CUSTOMER REPORT

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REPORT AND EXECUTIVE SUMMARY

Stage 2. Future options for the cellulosic fibre value chain in the Green Triangle, South Australia: strategic technology roadmaps, business cases and policy recommendations

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Report's title	
Stage 2. Future options for the cellulosic fibre value chain in the Green Triangle, South Australia: strategic technology roadmaps, business cases and policy recommendations	
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Summary

The forest and wood products industry and associated value chain, along with many other Australian manufacturing industries, have experienced a very difficult decade, peaking in recent times from the exceptional circumstances created by the global financial crisis and increased globalisation. Coupled with internal factors such as a lack of re-investment, aging equipment and poor management decisions have resulted in a significant reduction in industry profitability and a loss of employment opportunities that have combined to create an atmosphere of doom and gloom in the crisis situation that exists today.

Regional Development Australia Limestone Coast has met this challenging situation by pursuing an agenda of economic diversification to broaden the economic base of the South East through the initiative of The Limestone Coast Economic Diversification Forum. In turn, the South Australian government have felt compelled to act and sought the assistance of VTT, as experts in the forest product value chain, to develop grounded pathways for the renewal of the industry, both in the short (3–5 years), medium (5–10 years) and long-term (greater than 10 years), through a roadmap exercise. The work undertaken forms the basis of this report.

The study followed a rigid and proven process, involving local players and overseas experts, as well as the substantial internal resources of VTT. The process has resulted in the development of altogether three pathways with a 3 to 5 year time horizon, four more concise pathways beyond a time horizon of 5 years, and three generic policy-oriented recommendations to support all the pathways. These are covered in detail in the body of the report.

Whilst it is a promising beginning, the process undertaken to date is not complete. To implement all of the recommendations arising from the study at the same time is simply not possible for logistical reasons and cost considerations. Clearly, these will have to be prioritised in a manner that will require input from all the key regional players in the value chain, including potential equipment vendors. However, based on our assessment the following 6 options would appear to offer particular promise:

1. *X-ray scanning*. Expenditure of A$ 2-4 million has the potential to increase yield volume by 5%, equivalent to an extra annual sales revenue of A$ 70 million for large sawmills.
2. *Cross-laminated timber (CLT)*. A plant with a capacity of 60,000 m^3 per annum would cost approximately A$ 40 million and have a payback period of 3-5 years. This would reduce the export of chips/logs of low value, help create regional employment and also provide construction materials to increase urbanisation.
3. *Glued-laminated timber (Gluelam)*. A typical plant with a capacity of 40,000 m^3 per annum would cost approximately A$ 20-30 million and have a payback period of 3-5 years. This would also reduce export of chips/logs of low value and put the Green Triangle on the map as an eco-friendly construction material manufacturing site.
4. *Biocomposites, in particular wood plastic composites (WPC)*. Biocomposites may contain up to 80% of wood and could also utilise some of the lower quality uncommitted waste biomass. The WPC biocomposite industry and markets are expected to grow significantly in the next 5 years. The Green Triangle region currently does not have a polymeric resin supplier, but could be the manufacturing site of WPC pellets for further processing at existing or new biocomposite sites and increase ties to composite users such as the car industry.
5. *Energy biorefinery - bio-oil by fast pyrolysis*. This technology is readily available and cost competitive and an investment of A$ 50-60 million plant would make bio-oil production by fast pyrolysis a serious option. Such pyrolysis plants could be realised in Green Triangle in the next

3–5 years, supplying energy first to the sawmill boilers and kilns and later to external customers. Significant parts of the unused forest residues available in Green Triangle would be converted to a more usable energy form with profitable outcome for the region.

6. *Bio-char by torrefaction*. The energy sector and mining and metal industry in South Australia uses millions of tonnes thermal coal annually and they could use co-fire biocoal in their power plants. Available biomass in Green Triangle for torrefaction includes excess pulpwood, forest biomass and chips produced at sawmills, and the production of bio-char could be considered. Torrefied biomass and bio-char would have a significant market for soil enrichment.

The next steps have yet to be finalised, but a series of workshops leading to detailed technology development projects with VTT assistance, government representatives at all levels and research providers is suggested as a good way forward.

The Green Triangle has the opportunity to host a strong, innovative and high-value forest and wood products industry that is simultaneously locally oriented and globally connected, and part of a vibrant national economy. This will result in a stronger overall South Australian economy with potentially high growth prospects that capitalises on the dynamism of the national economy. This will take time because the outlook for forest sector manufacturing remains negative in the short-term.

Our vision for the Green Triangle region is the following: Green Triangle has a thriving forest and wood products industry that provides a sustainable contribution to the economy of South Australia in the long term, contributing to community, wellbeing, sustainability, and quality of life.

Espoo 19.9.2013

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Preface

This report has been prepared with considerable local, national and international input at a time when it is widely recognised that the Fibre Value Chain will be significantly different in the future compared to the past. This report is part of a broader program of delivering sustainable prosperity for South Australia.

VTT has collaborated closely with the State Government of South Australia, Commonwealth Govt DIICCSRTE, the Department for Manufacturing, Innovation, Trade, Resources and Energy (DMITRE), Regional Development Australia Limestone Coast Inc, and PIRSA

VTT would like to acknowledge the contribution of the following representatives /organisations for their participation in the Steering Committee meetings, constructive feedback and one-on-one discussions:

Steering Committee

- Chair, Prof Göran Roos, AMC
- Len Piro, DMITRE
- Stuart West, PIRSA
- Mike Ryan, RDA
- Prof Gil Garnier, Monash University
- Trevor Smith, South Australian Forest Industry Advisory Board
- Laurie Hein, Green Triangle Forest Products
- Brad Coates, CFMEU
- Allan O'Conner, University of Adelaide

Non Steering Committee Members

- Dermot Cussen, DMITRE
- Noel Richards, PIRSA
- Peta Crew, PIRSA
- Steve Chapple, RDA
- Jennifer Kelly, AusIndustry
- Andrew Trainer, DIICCSRTE
- Mark McShane, SELGA

The work has benefited by discussions with many other organisations including, FWPA, Parsonson & Parsonson and their views are touched upon in this report.

The following companies and stakeholders participated in the first round of interviews. Their constructive comments and valuable time has been greatly appreciated by VTT.

- NF McDonnell & Sons
- Timberlink
- Whitehead Timber Sales
- Green Triangle Forest Products
- Geddes Management
- Whiteheads
- Round Wood Solutions
- Hancock Victorian Plantations Pty Ltd
- LV Dohnt
- International Timber Solutions Pty Ltd
- Green Triangle Bark & Mulch
- South East Pine
- Tabeel Trading
- KC & MR Boult
- SERIC
- Badenoch Integrated Logging
- Biogro
- Blackbird Industries

- Kimberley-Clark Australia
- Southern Tree Breeding Association
- Banner
- Forestry SA

1. Executive summary

The forest and wood products industry and associated value chain, along with many other Australian manufacturing industries, have experienced a very difficult decade, peaking in recent times from the exceptional circumstances created by the global financial crisis and increased globalisation. Coupled with internal factors such as a lack of re-investment, aging equipment and poor management decisions have resulted in a significant reduction in industry profitability and a loss of employment opportunities that have combined to create an atmosphere of gloom and doom.

Faced with this predicament, the South Australian government felt compelled to act and sought the assistance of VTT, as experts in the forest product value chain, to develop grounded pathways for the renewal of the industry, both in the short (3-5 years), medium (5-10 years) and long-term (greater than 10 years), through a roadmap exercise (see Roos 2012a; DMITRE 2012). The work undertaken forms the basis of this report.

Our vision for the Green Triangle region is the following: Green Triangle has a thriving forest and wood products industry that provides a sustainable contribution to the economy of South Australia in the long term, contributing to community, wellbeing, sustainability, and quality of life.

The study followed a rigid and proven process, involving local players and overseas experts, as well as the substantial internal resources of VTT. The process has resulted in the development of three pathways with a 3 to 5 year time horizon, four more concise pathways beyond 5 years time horizon, and three generic policy-oriented recommendations to support all the pathways. In the following, the executive summary summarises these recommendations.

Summing up the pathways with 3 to 5 year time horizon

Pathway 1: New wood products from underutilised Green Triangle log supplies

- **Recommendation 1: Oriented Strandboard (OSB) manufacturing**

  OSB is a structural panel product produced from low-cost pulpwood grade logs. The Green Triangle region has a surplus of SWD and HWD pulpwood. This is being exported as chip and as logs at low prices. Experience from several markets demonstrates that OSB has reasonable potential when priced competitively.

  The technology is mature and an efficient factory investment of A$130 million is required to develop a plant of 200,000 m^3/a scale. This might require foreign investors/partners.

  To progress this initiative forest owners, local councils and the State Government should work together to define the biomass opportunity, favourable factory location and investment hosting inducements. This will result in value-added uses for pulpwood and supplies of locally-produced OSB that will significantly reduce Australia's wood product imports, thereby reducing its balance of payments deficit.

- **Recommendation 2: Veneer-based Engineered Wood Products (EWP)**

  EWP products can potentially be produced from the region's underutilised pulpwood-grade logs. A proportion of these logs will meet the quality requirements for peeling to produce veneers as furnish for EWP such as LVL (Laminated Veneer Lumber). This type of mill requires relatively high cost large peeler logs. For example, the Wespine investment in Western Australia was of approximately A$ 110 million for a nameplate output of 90,000 m^3.

  To progress this initiative, there needs to be an evaluation of the proportion of pulpwood logs that would meet the requirements for EWP to scope out the scale of opportunity. Such an opportunity would generate another value-add use for pulpwood and would increase the returns to forest growers.

- **Recommendation 3: Improved sorting and better yields by X-ray scanning**

  X-ray scanning of logs to be processed is a not a new technology and has been used for at least 10 years in several sawmills in Scandinavia. The simple advantage is that being able to "see" inside a pine log, better and more efficient sawing is possible, e.g. splitting the round wood to sawn timber pieces of highest possible quantity and quality. The logs with inner defects can be sorted to different sawing patterns before sawing and thus the end products are of the best possible quality and volume.

  Investment of X-ray scanners is quite modest, A$ 2-4 million, but may also require investment in additional ICT and sometimes to extra log sorting and mill layout. Payback time is very short, usually within 1-2 years. The best result can be reached through stem terminal, but this needs higher investment costs and can be utilized beneficially only in large sawmills.

  The next step would be to contact X-ray technology suppliers and establish what yield improvement is achievable through real time measurement on local radiata pine logs at one of the larger mill sites with good log sorting facilities. Labour safety regulations concerning the installation and use of scanners must to be checked. The value yield increase can be best verified through use of equipment in local mills.

  Ultimately the stem terminal solution can be adjusted and verified during this process, but this needs more research work for logistics etc. Only then can the value of the yield increase be estimated, not only for the sawmill, but for the total forest biomass.

- **Recommendation 4: Specialised sawmilling (using smaller logs for sawmills)**

  Since the use of small size pine logs and pulpwood in the region is diminishing rapidly due to the closure of the pulp mill at Tantanoola, the raw material is exported as logs or chips, or simply unused.

  The small logs could and should be processed locally. Existing mills in the region are constructed in the main to use larger and longer logs with the use of smaller logs primarily for roundwood products. Higher value can be achieved through specialised sawmilling for short and small timber products, either in separate mills or in a new line in an existing mill. Investment in such a facility would be of the order of A$ 30 million. With low priced small logs and modern equipment, the payback time can be reasonably short, while also offering new employment possibilities. Investment is even more attractive if integrated into an existing sawmill, particularly if at a larger site. The resulting timber pieces are estimated at having a value four times higher than chips from currently unused pulpwood.

  To progress this initiative, the availability and logistics of good quality small logs and pulpwood is required, preferably after final felling. An optimum location for small log sawmill, or alternatively a small log line in an existing mill, needs to be chosen and a seasoned small log machinery supplier consulted.

Pathway 2: Opportunities in construction industry using existing outputs

- **Recommendation 5: Cross-laminated timber (CLT) and high storey houses**

  Cross-laminated timber (CLT) is an innovative-engineered wood product that is not currently produced in the Green Triangle. Imports of CLT are growing and the national and international market is predicted to grow. CLT is presently rapidly growing in Europe, but has still only a very low share of the construction material market. It can be expected that the same trend will be replicated in Australia and hence a good business case can be made for increasing the production of CLT. There is enough material for a new CLT plant that should be co-located with one of the existing sawmills. The investment for a 60,000 m^3 capacity plant is approximately A$ 30 million with a payback of 3 to 5 years.

  The next step would be to consider in detail the recent experiences in Europe and initiate contact with CLT equipment and adhesive suppliers. It would be necessary to work with FWPA, South Australia Government and other groups to modify relevant building codes to permit use of CLT in a range of applications including in the construction of high-rise CLT buildings. Training programs to build competence in wooden building skills and encourage use of CLT in public construction projects would need to be initatiated. The value chain of building code authorities, sawmill, CLT site, construction companies and eco-marketing companies needs to be developed. As a consequence tall wood buildings will be part of the next generation of high-performance sustainable buildings. This is a trend that South Australia should not miss, but could if locally produced CLT is not available. Beyond the potential profitability of construction with CLT, South Australia will produce a safe, carbon-neutral and sustainable alternative to the conventional structural materials of the increasingly urban world.

- **Recommendation 6: Glued-laminated timber (Gluelam)**

Gluelam is well known engineered wood product already in Australia. Its use in Europe for most large constructions like sport halls, industrial buildings, malls and larger open constructions is very common. However, in Australia building with environmentally much lower performance materials such as concrete and steel are traditionally used.

Investment in gluelam equipment even for large-scale beams is quite modest at A$ 10−20 million and would be best utilized together with big sawmills.

The next steps are to consider in detail the vast experience in Europe and follow the seasoned practices. As with CLT, the building codes should be modified to permit and promote the use of gluelam products in large constructions e.g. municipal buildings. An initiative for an investment into a large scale gluelam site integrated into one of the bigger sawmills is needed. As a consequence, raw material input in gluelam can be of lower quality, thus increasing the value yield of local sawmilling.

- **Recommendation 7: Wooden bridges**

Wooden framed bridges are currently widely used in several countries in the world. Norway and Sweden are the leaders in this field, but examples can also be found in USA, Finland and Chile.

The advantages of lightweight constructions bring along with it the possibility to assemble bridges without any disturbance over existing roads and with simple “one-lift” operation over railroads, rivers and other obstacles. It offers an effective low-cost option as such structures can be manufactured in factories and delivered by trucks.

Investment in wooden bridge equipment even for large scale bridges is very modest (around A$ 1 million) when made from gluelam production. To progress this initiative, consideration should be given to the experience in northern Europe and to follow their seasoned practices and building models. The building codes should be modified to permit and promote the use of wooden bridges and discussions initiated with the appropriate bodies to achieve this outcome. Coating and preservation needs to extend lifetime and prevent termite damage should be assessed with local experts from CSIRO and other academic institutions. The consequence of all this is that local and sustainable raw-material can be used instead of concrete and steel and this in turn creates more employment and increases the valuable use of gluelam from local underutilised pine plantations.

- **Recommendation 8: Biocomposites**

Biocomposites, in particular wood plastic composites (WPC) are synthetic, thermoplastic resin/wood/additives that contain up to 80% wood and could utilise the lower quality uncommitted waste biomass. The WPC biocomposite industry is predicted to grow to 4.6 million tonnes globally by 2016. The price of composite materials ranges from A$ 1500 to 5000 per tonne. The Green Triangle region does not have a polymeric resin supplier, but could be the manufacturing site of WPC pellets for further processing at existing or new biocomposite sites, for example APR or similar companies (http://www.advancedplasticrecycling.com.au/). WPC may also be of interest to advanced technology flooring companies for example 3RT. Another application could be along the lines of a composite development by Puustelli Group Oy, a leading kitchen furniture manufacture in Finland that was realised in co-operation with VTT.

The next steps to consider would be to evaluate if an existing MDF mill could be retro-fitted using the same front end and providing an alternative product and market stream. The logistics of the supply of suitable polymer is absolutely crucial. Forest owners, local councils and the State Government will need to work together to better define the biomass opportunity, and investment possibilities. A national/international investor search canvassing biocomposite producers, as one of a range of possible end-uses for the underutilised pulpwood logs would also be needed. As a consequence there may be an opportunity to generate composites from sawdust, pulp logs, wood chips and shavings and thereby add value to these biomass residuals. There is the potential to generate new forest-based value chains, more employment and add value to underutilised biomass in the Green Triangle region.

Pathway 3: Biorefinery - opportunities for underutilised wood fibre and residues

- **Recommendation 9: Bio-oil by fast pyrolysis**

Fast pyrolysis to heating oils is commercial ready technology. It is capable of converting different biomass resources including industrial and forest residues into liquid fuel that can replace heavy fuel oil used in boilers and kilns. The investment for a 60,000 – 90,000 m^3/a bio-oil facility is relatively low, in the region of A$ 30 million, and would generate about A$ 60 million worth of annual sales.

The next steps to consider would be to identify suitable sawmills for a pyrolysis plant implementation based on feedstock availability and potential bio-oil users in the region, to establish conditions and regulations for bio-oil market development, to carefully assess potential “crude” bio-oil and upgraded bio-oil users, to develop bio-oil supply infrastructure and to follow the bio-oil upgrading technology development. As a consequence, first plants could be realised in Green Triangle in next 3–5 years, supplying energy first to the sawmill boilers and kilns and later to external customers. Significant parts of the unused forest residues available in Green Triangle will be converted to a more usable energy form with profitable outcome for the region.

- **Recommendation 10: Bio-char by torrefaction**

The energy, mining and metal industries in South Australia, which uses millions of tonnes of thermal coal annually, could co-fire biocoal in their power plants. In addition, biochar can be used as a soil conditioner and biogenic carbon sink. Biomass in the Green Triangle available for torrrefaction includes excess pulpwood, forest biomass and chips produced at sawmills. Production volume of torrefied pellets, as part of overall energy biorefinery platform, could be in the range of 100,000 to 200,000 bdt/a with annual sales value of about A$15-30 million (excluding potential soil conditioning and biogenic carbon sink application revenues). Investment requirement is also relatively small ranging from A$ 20 to A$ 40 million.

The next steps to consider would be to develop incentives and regulations for biomass use in heat and power production, to identify potential biochar customers, to establish the connections between the different value chains (forestry, power, mining,and metal, etc.), to identify suitable torrefaction plant location and to commence biochar logistics design and planning. As a consequence of the regulations, demand of solid biofuel increases in the energy sector, enabling investments into torrefaction.

- **Recommendation 11 and 12 combined: Power, heat and biofuels by gasification**

Gasification is a key future energy biorefinery technology that has many different application areas. Gasification of forest residues has been demonstrated at an industrial scale. Large amounts of unused wood and forest biomass in the Green Triangle is a potential raw material base for electricity and, in the future, for conversion of syngas into transportation fuels or chemicals. Revenues of over A$ 100 million are possible for a facility processing 1,000,000 m^3/a biomass when FT-diesel is produced.

The next steps to consider would be to identify most suitable incentive or capital investment subsidy programmes for supporting first implementations of liquid transportation fuels production and for motivating bio-based electricity production, to develop contacts and co-operation with fuel producers and distributors, to establish well-operating low cost biomass supply chain for supporting the large biomass demand of gasification based biofuels production, and to identify by-product heat integration possibilities. A successful progression could see the first gasification based heat and power plants being realised in 3-5 years and a major part of unused forest biomass valorized.

Summing up the pathways with beyond 5 years time horizon

Pathway 4: Development of adsorbents and membranes for local opportunities

Manufacture of wood plastic composites from sawmill residuals could be extended to utilise waste fibre sources by the generic innovative utilisation of side-streams to generate biobased monomers and corresponding polymers for amongst other things improved bioplastics, and high quality lignin plastics. Two more distant and unconventional ideas are a paper bottle or transparent cellulose based packaging materials.

Pathway 5: Cellulose fibres in textiles

The use of cellulose fibres for textiles to replace cotton has high future business impact and, as such, is a topic of significant research effort worldwide. The subsequent demand will transform the bulk cellulose business to one that focuses on the premium design applications of cellulose. However this would currently necessitate the location of a pulp mill in the region which, as already mentioned, is considered most unlikely in the current circumstance. However, a recent development on small-scale pulping using an organic solvent is showing some promise (Lignofibre technologies), and if successfully scaled could be transformational and make this opportunity even more attractive.

Pathway 6: Bio-based chemicals and polymers

Biobased chemicals and polymers are part of the development of next generation cellulose products. The Green Triangle region, with its abundance of unused biomass, should retain an interest and in particular the development of added value products from hemicellulose and lignin. Hemicelluloses and celluloses are the most abundant of the natural polymers, and their availability practically outranges the current volumes of plastic production. There are opportunities for the use of xylan and cellulose derivatives. Routes to chemicals and materials useful for coating and packaging, including films, barrier materials and coating binders. The key state-of-the-art solutions that should also be considered are bio-based platform chemicals and polymers that have more than one application, such as natural polymers modified like starch and biobased materials like polylactic acid PLA which have established a position in the biodegradable plastic market. A key tendency is also from proven biopolymers towards composites, and the development of business and market development in the field of biopolymers and composites.

Pathway 7: Opportunities in nanocellulose

Nanocellulose has been shown to have the potential to be very useful for a number of future technical applications. The key to understanding how nanocellulose will behave in different applications is to have a thorough understanding of how the structure and interactions of nanocellulose affect its function and hence its suitability for different applications. One large cost of producing nanocellulose comes from the energy input required for defibrillation of the starting materials. The rapid pace of development will see significant advances that should be watched very closely.

While a promising beginning, the process undertaken to date is not complete. To implement all of the recommendations arising from the study at the same time is simply not possible for logistical reasons and cost considerations. Clearly, these will have to be prioritised in a manner that will require input from all the key regional players in the value chain. How this is best implemented has yet to be finalised, but a series of workshops with VTT assistance involving representatives from the various interest groups, government representatives at all levels and research providers is suggested as a good way forward.

In most of the world there are on-going research programs related to the development of intelligent and resource-efficient processes, future biorefineries and bioenergy solutions which may be templates for South Australia. For example, the Finnish Bioeconomy Cluster (FIBIC; http://fibic.fi/), is one of six Strategic Centres for science, technology and innovation in Finland (SHOK; http://www.shok.fi/en/) that aim to turn science and technology into sustainable bio-based solutions. They have experience in offering businesses and research organizations a new way of engaging in close, long-term cooperation and leveraging the best competences and resources. FIBIC combines research and companies for innovative solutions. FIBIC are accelerating Finland to become a pioneer in the sustainable bioeconomy and VTT, universities and global businesses are partnering in the development of a more innovative, resource-efficient and competitive society.

2. Setting the scene

South Australia's forest and wood products industry is being significantly challenged as production levels fall due to declining export competitiveness and accordingly means for improving the industry's competitiveness are being sought. DMITRE has invited VTT Technical Research Centre of Finland experts to undertake a study that identifies potential routes by which increased competitiveness can be achieved.

It cannot be overstated that the forest and wood products industry in the Green Triangle region is currently highly challenged and even, according to some, in a state of crisis. Several company closures and the transforming situation in the forest resource have left the region in an uncertain state. This is why something needs to be done and with a matter of urgency. The forest sector thus needs actions to boost and renew the industry to a new level. The objective of this roadmapping exercise is to provide the region with the information that would allow such a transition to take place.

Achieving world class productivity in existing businesses combined with the development of higher value-add products are keys to creating a sustainable future for the forestry industry. The study is a prime initiative of the State Government's Manufacturing Works strategy, and is also one of the key actions identified in the Limestone Coast Economic Diversification report.

The South Australian Cellulosic Value Chain Technology Roadmap project aims at developing the full potential of the forestry resources in the Limestone Coast region of South Australia. The project is funded by Department of Manufacturing, Innovation, Trade, Resources and Energy (DMITRE) and led by VTT Technical Research Centre of Finland.[1]

The project has two objectives. The first objective is to provide the South Australian government with a roadmap describing how current processes can be made more efficient using existing or commercial ready technological advancements (efficiency gains) and, to potentially diversify into other new and high value products (effectiveness gains) using the raw materials available in the region, while taking into account relevant local issues. The second objective of the roadmapping exercise is to identify suitable companies that would consider locating in the region with VTT as their local and global research provider and supporter in accessing global value chains. The overall goal is to identify new business opportunities for the region as well as raising technology levels to meet the requirements of a competitive modern fibre-based industry.

As stated in the stage 1 report (Ahlqvist et al. 2013), the project will create grounded paths for the future development of the region that outline practical steps for competitive, revived, and future-oriented forest and wood products industry.

This report presents the key results from the second stage of Cellulosic Value Chain Study for the Limestone Coast, South Australia. The stage 2 report focuses on strategic technology roadmaps for the region. The following aspects are covered:

- Four roadmaps in four lenses: mass, energy, molecular and atomic lenses that cover opportunities in the short, medium and long-term
- Assessment of a short term (0−3 years) portfolio of options for the Green Triangle region
- Assessment of business potentials of prioritised technologies
- Outlook on the state-of-the-art R&D for the mid (5 years) and longer term (10 years)
- Business case reviews
- Market analysis, including market potentials in the fibre-based industry, differentiated according to solution areas and geographical regions
- Patent and intellectual property analysis
- Global industry consultation, with an emphasis on companies and institutions in Northern Europe
- Policy recommendations that outline strategic options, builds a draft agenda for joint strategic R&D, and sets out policy recommendations to the SA government

[1] VTT is a leading multi-technological research organisation in Northern Europe, with world-class R&D competencies in forest-based industries, including biorefinery, bioenergy, biochemicals, nanocellulose, sawmilling, and wood-based construction as well as conventional pulp, paper and packaging.

The stage two roadmapping also includes:

- Complete outline of the roadmapping process
- Analysis of the roadmap contents
- Roadmap narratives
- Roadmap visualisations
- Outline and results of the complete roadmapping process

The work outcome is structured in two reports. The first (Report and executive summary) covers the major aspects of the study and comprises seven chapters including the executive summary, introduction, summary roadmaps, the roadmap in four lenses and conclusions. The second (Appendices) contains the contributing information in the form of twelve appendices that includes literature reviews, best practice cases in biorefineries, market analysis, process for constructing strategic technology roadmaps, patent analysis, business cases and techno-economic evaluations, portfolio options for the Green Triangle forest and wood products industry, policy options and recommendations, biorefinery summary tables, and biofuel mandates around the world.

Need for the study:

The Green Triangle, incorporating South Australia's Limestone Coast region and adjacent parts of Western Victoria is Australia's premier wood production region. The Green Triangle hosts approximately 355,000 ha of plantations, half softwood (SWD) Pinus radiata, and the balance hardwood (HWD) Eucalyptus globulus.

The SWD plantations yield 3.2 million m^3 of logs annually, approximately two-thirds sawlogs and one-third pulplogs (Figure 1). A well-established forest and wood products industry cluster developed to grow, harvest and transport, and process these logs. However manufacturing capacity is declining with notable facility closures in the last several years. Chronic underinvestment for most facilities has left the majority of the remaining industry relatively uncompetitive versus state-of-the-art domestic or international competitors. This sector has experienced poor markets for key products, especially low-grade sawnwood, residual chips and surplus roundwood. Consequently, the whole value chain has struggled to generate adequate returns. Increasing SWD log exports are an outcome, as growers seek to re-balance log demands with the log mix produced from their forests.

Figure 1. A softwood plantation (Pinus radiata) in Green Triangle (Authors).

The HWD plantations produce mainly pulpwood logs (Figure 2). The plantations were developed by ad-hoc planting during the last decade by Managed Investment Scheme (MIS) promoters, many of which have gone into receivership. The estimated volume of logs to be yielded from these plantations will exceed 4 million green metric tonnes (GMT)/year by the middle of this decade. Significant volumes of HWD pulpwood supplies will be available for the following 10 years. Aside from chipping, there is no domestic processing of these logs. Chips are currently exported from Portland destined for Asian pulp mills. Export of HWD roundwood logs is a recent and growing phenomenon (Figure 3). At present, the

Port of Portland's dock facility capacity represents a (potential) constraint on chip exports. Infrastructure will limit HWD chip exports to approximately 3.4 million GMT/a.

Figure 2. A hardwood plantation (Eucalyptus globulus) in Green Triangle (Authors).

Asian markets are currently oversupplied with HWD chip and pricing is well below the level required to deliver adequate returns to growers. Consequently, industry observers expect around half of Australia's current HWD plantation estate will not be re-planted. This will include plantations in the Green Triangle. The area replanted will affect the HWD pulpwood volumes available beyond 2025.

In addition to the supply of SWD and HWD logs, the region can also generate an estimated 500,000 m^3/a of woody biomass. This material comprises the tops and branches of trees left after harvesting.

Figure 3. Logs waiting to be exported in the Portland dock (Authors).

The situations outlined above for the cellulosic value chain requires urgent actions. The Stage 1 study found that few of the current players had initiatives in place to address either the fundamental problems in the existing sector, or to capture the region's unique opportunities. Government grants have underpinned investments that are planned. However, as far as we can determine not all of the grants have been deployed in ways that have enhanced the region's competitiveness. Consequently, the South Australian Government commissioned this study to stimulate new ideas for pathways to grow the Limestone Coast forest-based industry cluster.

The current SWD industry can benefit from investments to improve its competitiveness, and to develop value added uses for currently underutilized components of the log and residuals supplies available. On the positive side, the quality of the region's logs, proximity to key markets and the potential to achieve world competitive scale facilities means this is a unique opportunity in Australia.

The HWD pulpwood supplies yielded from the region represent a globally significant volume of high quality, certified fibre. The current owners of these plantations are actively looking to diversify uses away from the current low paying export chip markets. In addition, Australia is the only region with a long term surplus of cellulose.

In the Green Triangle, a more strategic perspective to the cellulosic value chain is needed. This perspective would be particularly crucial for forest owners and sawmillers. Rethinking the industry would in the best case scenario result in more capital to invest in the region’s processing assets. Renewing the technologies employed and diversifying into new sectors have long term positive effects across the cellulosic value chain.

The Stage 1 Study results, and experience to date, indicate that the investments needed are not, with some notable exceptions, on the horizon. Consequently, the South Australian Government is seeking to challenge and to stimulate thinking around these issues and opportunities. This stage of the study was specifically tasked to identify new, but commercially viable, technologies and product ideas that could be implemented in the Limestone Coast Region. The study findings will also expose these opportunities to a wider audience of potential investors, thereby increasing the likelihood of attracting the needed investments.

Approach to the study:

This report is based on a number of concurrent activities carried out over a period of several months:

- Interviews conducted in Stage 1 of this study with most of the local plantation owners, sawmills and selected fibre chain companies
- The assumption was given that there will not be a pulp mill in the region (Figure 4)
- Workshops by VTT experts to develop the in-depth roadmaps, business case examples and policy aspects for the future of the fibre value chain in the Limestone Coast region
- VTT’s simulations and assessments for assessing the future of the region
- Pöyry’s independent assessment of the situation in Green Triangle
- An extensive literature review

Figure 4. Parts of the deconstructed Tantanoola pulp milll. The pulp mill was shut down in December 2010 (Authors).

Study findings structure:

The following three pathways with 3 to 5 year horizon have been identified:

- Pathway 1: New wood products from underutilised Green Triangle log supplies
- Pathway 2: Value-adding opportunities for construction industry using existing outputs
- Pathway 3: Biorefinery – value adding opportunities for underutilised wood fibre and residues

The study also defined four pathways that have the temporal horizon beyond 5 years. Because the report's emphasis is on 3 to 5 year pathways, these more long term options are described only briefly:

- Pathway 4: Adsorbents and membranes for local opportunities
- Pathway 5: Cellulose fibres in textiles
- Pathway 6: Bio-based chemicals and polymers
- Pathway 7: Opportunities in nanocellulose

Trends in relevant industry clusters shaping the study focus:

The traditional sawn timber production industry must continuously improve and develop to ensure world-class productivity, but in an emerging bioeconomy this is not enough. The new opportunities presented by bioenergy, biochemicals and biomaterials must be captured, in addition to further developing opportunities in more traditional but evolving areas like construction elements, wood residue laminates, wood plastic composite products, and value added packaging materials etc. This could mean, for example, that in addition to the focus on developing the existing industry through productivity improvements and product extensions, next-generation biorefineries could be established in the region, utilising side streams or under utilised raw material streams from the forest and wood products industry as input for the production of bioenergy, biochemicals and biomaterials. The goal is to identify new business opportunities suitable for local companies as well as raising the technological level of the region's industry to meet the requirements of a competitive modern fibre-based industry. The vision is to make the Limestone Coast a significant player on the global integrated biorefinery stage and to raise the employment and skills level in the region.

The Cellulosic Value Chain Technology Roadmap study also covers the production of biofuels, bioenergy, biochemicals and biomaterials from a biorefinery. Biofuels and bioenergy are seen as lowest value per volume of the co-products from a biorefinery but are important, as supplementary sources to existing fuels assuming sufficient levels and mandates are available. However, it is clear from recent reports by Parrat & Associates and CSIRO in 2011 that the petroleum and petrochemical industry refineries need higher value co-products to make them economically viable (e.g. 80–90% of the profit from crude oil processing comes from the 10–20% of materials produced as chemicals and downstream products). This study includes an analysis of the bioenergy opportunities, together with the production of chemicals and plastics from biomass, even though the authors are concerned that there are no obvious related industries in the area. The biofuel opportunity could well be impacted by a recent study (Cook et al 2013) indicating that Australia's shale gas deposits are far more abundant than previously expected, though their remote location could make extraction a costly prospect except where infrastructure already exist like in the Cooper Basin. How this plays out in the longer term could well be critical.

This study also investigates the "low hanging fruit" or more immediate opportunities for the forest and wood products industry. In the Limestone Coast Region this sector has declined in recent years. Member companies, and the sector as a whole, urgently need to improve their efficiency and effectiveness leading to new business opportunities. To help address these issues, the report proposes the development of a woody biomass-based value chain facilitated by the clustering and cooperation of the existing industry and supported by applied (primarily process and equipment) research, development and engineering in the region to explore selected product opportunities relevant to these existing businesses.

Another focus of this study is to evaluate the commercial and technical feasibility of suggested biorefinery options under the proposed carbon price. The rapid pace of development in the bioeconomy sector worldwide coupled with the significant changes in the global agricultural and manufacturing environments must also be kept in mind, particularly what is happening in Asia, North and South America and the European Union (EU).

The Green Triangle region currently exports wood chips and logs to Asian markets. This source material could be used just as profitably in the region with the right investment, mandates and legislation in place. Indications are that in the Limestone Coast region, the lignocellulosic material (woody biomass from radiata pine and/or Eucalyptus) is available in sufficient quantity and reliability of supply to warrant future investment in integrated biorefineries. However, it is clearly understood that the establishment of a biorefinery based on forestry biomass would need to compete directly for access to the resource at a competitively stable price, volume and supply at least equivalent to alternative uses such as mulch or particleboard.

The current situation in the Green Triangle SWD processing sector

The Green Triangle's potential harvest and end uses are summarised in Table 1. Of this total supply, the region's industry currently processes just under 2.5 million m^3 annually, with additional resource exported from the region as logs. In addition, there are substantial volumes of residues produced by the primary processing sector. These include sawmill chips, shavings, sawdust and bark.

The region has two (operating) large (>500,000 m^3/a) sawmills, and three small (< 100,000 m^3/a) sawmills. In addition, the region supports two particleboard mills (300,000 m^3/a), and pole and roundwood timber preservation plants processing (<100,000 m^3/a). Softwood chips and softwood logs are also exported from the Port of Portland.

Table 1. Resource availability, current uses and opportunities in the Green Triangle.

Product	Quantity (000 tonnes/year)	Current uses (000)	Opportunities
SWD Sawlog	2,400	Structural timber (400 m^3/a) Non-structural product (150 m^3/a) Log exports (500 m^3/a)	Increase recovery of structural product Increase domestic sawing Higher value yield from logs Add value to non-structural product
SWD Pulplog	825	Pole and treated post (100 m^3/a) Particleboard furnish (120 m^3/a) Log export (400 m^3/a) Chip export (200 GMT/a)	OSB Small log sawmilling Bioenergy Biofuels/biorefinery
SWD sawmill residues	475	Particleboard furnish (180 GMT/a) Export Chips (125 GMT/a) Boiler fuel (50 GMT/a) Animal bedding (20 GMT/a) Landscape (bark) (100 GMT/a	Bioenergy Biofuels/biorefinery
HWD Logs	4,000	HWD Chip Exports (1,800 GMT/a) HWD Log Exports (200 JAS m^3/a)	Engineered wood products Bioenergy Biofuels/biorefinery
Biomass (HWD & SWD)	500	Unused	Bioenergy Biofuels/biorefinery

The Green Triangle Region enjoyed significant investments during the period between the 1970s and the mid 1990s. The major assets, including the two largest sawmills and the particleboard plants, were state-of-the-art when built. However, the lack of investments, particularly since 2000 means the region's sawmills have lost competitiveness relative to domestic and international competitors. The existing sawmills' internal layouts reflect the operating requirements of the day.However, these layouts now constrain efforts to update these mills to take advantage of new technologies such as in-line scanners to improve recoveries and lower the costs. The region's sawmills produce a range of products, primarily structural timber sold into the domestic construction sector. The region also produces a large array of non-structural products including boards, pallet and landscape timbers and millwork (Text box 1).

TEXT BOX 1.
Bombala Sawmill, New South Wales
$74 MILLION BOMBALA SAWMILL

- Dongwha Timbers has expanded its softwood sawmill in Bombala, New South Wales at a cost of A$ 74 million
- The expansion project was called Project "Namu", Korean for "tree", and incorporated the construction of new green mill, planer, and timber treatment plant with an associated infrastructure including boilers, 3 kilns, wastewater management system, new site access, new office and car park
- The saw system is based on novel technologies, for example:
  - The process line allows optimisation of wood for different uses
  - The sawing line at 150 metres of sawn timber per minute is exceptionally fast
  - Machine-tooling kit is coordinated with RFID (radio frequency identification) technology
- Regional Development Australia announced A$ 4.7 million of funding for Bombala Timber Precinct Infrastructure Project on 07/06/12 and this was followed by and award of A$ 8.2 million for Clean Technology on 23 November 2012
- The expansion will enable Dongwha Timbers, to increase softwood log input from 106,000 to 300,000 tonnes per annum and sawn timber output from 31,800 tonnes to 150,000 tonnes. By 2016 production is expected to be 270,000 tonnes per annum
- It can be assessed that the productivity of this saw will be about 10% higher (taking into account labour, energy and maintenance costs) compared to the regular sawmill technology

The region's sawmilling industry has been challenged by the combination of the slow domestic housing markets and competition from imported structural timber. This has kept timber prices relatively low, while costs, especially labour and electricity, have increased. The region's sawmills' lack of investment has meant the mills have relatively higher labour and power costs versus state-of-the-art competitors.

The sawmills' dated technology also produces higher levels of non-structural sawn products that typically attract relatively lower prices. In addition, the current market for sawmill chips is limited and prices are low. This combined has impacted adversely on the financial performance of the region's sawmills.

The typical outputs for Green Triangle's large and small sawmills are contrasted with a hypothetical Australian best practice mill sawing the same logs (as available to the large sawmills) (Table 2). The hypothetical mill employs curve or shape sawing technologies and state-of-the-art scanning technologies that allow such sawmills to generate higher yields of product and a higher proportion of structural product than either of the typical mill types in Green Triangle. The best practice mills typically have lower labour and energy costs per unit quantity of timber produced. The present average labour use in large sawmills is 800 m^3/a per person. In the new Bombala mill, the average labour use will be 1200 m^3/a per person.

Table 2. The typical large and small Green Triangle sawmills benchmarked against hypothetical Australian best practice.

Output Component	**A typical Large Green Triangle sawmill** (>500,000 m^3 log input/a) Av **42.0**% dry dressed recovery	**Hypothetical Australian best practice large softwood sawmill** (>500,000 m^3 log input/a) Av **47.0**% dry dressed recovery	**A typical Small Green Triangle sawmill** (<100,000 m^3 log input/a) Av **48.0**% green sawn Recovery = <40% dry dressed recovery
Structural grades (MGP 10 or better)	29%	35%	5%
Non-structural boards	7%	6%	26%
Non-structural core wood	6%	6%	17%
Woodchips	28%	25%	28%
Shavings/dockings	18%	17%	10%
Sawdust	11%	11%	15%
TOTAL	100%	100%	100%
Bark	7%	7%	7%

Consequently, the key challenges facing the Green Triangle region's sawmills include improving the recovery of higher value products. The large Green Triangle sawmills could potentially lift recovery of structural grade product by up to 5% by investing in curve sawing and advanced scanning technologies. Additional opportunities exist to improve prices achieved for fall down products, and to reduce key input costs.

The South Australian Government's A$ 27 million South East Forestry Partnerships Program is providing direct grants to the existing sawmill operators. At the time of writing, the program has earmarked A$ 17 million in grants, with A$ 10 million remaining which may be partially used to support new initiatives.

The Timberlinks Tarpeena sawmill is one of the large Green Triangle sawmills and was last upgraded in any major way about 30 years ago. Timberlinks and the South Australian Government have announced planned investments at the mill. The State Government has committed a A$ 7.8 million grant to be matched dollar for dollar by the company. The new investment is expected to increase sawlog processing volume from 460,000 to 575,000 m^3 annually (two shift basis). It is understood that Timberlink are considering installing a Quad Reducer Bandsaw as the primary machine centre, while at the same time undertaking a major upgrade of the sawmill waste handling system. The benefits anticipated include improved productivity, and lower manufacturing costs. Investments will also be made in the, drying kilns, and drymill.

As is typical for sawmills built during the 1980s, there is very limited space between the machine centres in the mill. This limits the ability of the owners to implement the latest in-line scanning and related technologies. In the specific case of the Tarpeena sawmill, the low initial investment made by the current owners (New Forests) coupled with the generally good quality of the logs processed by the mill means that the benefits accruing from a major reconstruction and reinvestment are unlikely to justify the significant additional investment costs needed to bring the sawmill up to the best practice standards.

Timberlinks has identified another potential initiative for the Tarpeena site. The company is in the early stages of assessing the potential to develop a combined heat and power (CHP) facility at the Tarpeena location. Such a facility would take the residues from the sawmill, plus additional biomass and wood waste from other sources, as fuel.

CHH operates the Green Triangle's second large sawmill (Jubilee Highway) and has a partially mothballed sawmill at Lakeside. The company also operates two particleboard mills in the region at Lakeside and White Avenue. The Jubilee Highway sawmill facility benefits from its supply of arguably Australia's best quality sawlogs as measured by average diameter, sweep and knot size. The sawmill equipment was upgraded in 1994/95 and is among the largest (by throughput) sawmills in Australia.

As previously noted above, the prevailing sawmill configured in the 1990s and earlier have constrained the current owners in terms of their ability to incorporate the latest in-line technologies. As with the Tarpeena sawmill, this disadvantage is partly offset by the consistent high quality of the sawlogs processed by the Jubilee Highway sawmill. Consequently, while the product recovery and costs achieved by this mill are not up to best practice standards, the likely investments needed to achieve these benchmarks may not be justified on the basis of the improved returns generated.

The small Green Triangle sawmills are typically family-owned and operated. These enterprises are capital constrained, and have developed sawing systems that are robust, flexible and with relatively lower (capital) cost. The businesses have adapted their processing equipment to allow them to process the log mix available, and to meet often niche markets not serviced by the larger operators.

3. Where to next? Potential pathways for Green Triangle

3.1 Introduction to the pathways with 3 to 5 year time horizon

This section presents the next steps as outlined in the roadmapping process. Three pathways have been developed that collectively capture the opportunities for expanding the local forest and wood products industry. The opportunities were selected from among the very wide array of possible products and processes by applying the following selection criteria:

- Be practically implementable within a 3 to 5 year timeframe
- Add value to wood resources available within the region where such resources are not currently being used by domestic manufacturers
- Be of sufficient scale to make a difference at a regional level
- Raise the competence levels of regional forest and wood products industry
- Create opportunities for long term investments and new jobs in the region
- Renew the industry and raise its competitiveness

The Table 3 presents central pathways and recommended next steps. It must be mentioned that the next steps are not in any particular order of preference, but are presented as options to be compared and explored further.

The section also includes four more future-oriented pathways that are covered in section 3.3 in less details because the recommendations emphasise targets that could be realised in the 3 to 5 year timeframe. The section ends with identification of more policy-related recommendations and suggestions for Green Triangle and South Australia (Section 3.4). The synthesis of the recommendations is presented at the end of the executive summary.

Table 3. Three main pathways in a nutshell: the time span is 3–5 years.

Recommended next steps in no particular order	**RECOMMENDED NEXT STEPS IN THE PATHWAYS**			
PATHWAY 1: *New wood products from underutilised Green Triangle log supplies*	1.1 Oriented Strand Board (OSB)	1.2 Veneer based engineered wood products (EWP)	1.3 Improved sorting and better yields by X-ray scanning	1.4 Specialised sawmilling by using smaller and shorter logs
PATHWAY 2: *Value-adding opportunities for construction industry using existing outputs*	2.1 Cross-laminated timber (CLT) and high storey houses	2.2 Glued Laminated Timber (gluelam)	2.3 Wooden bridges	2.4 Bio-composites
PATHWAY 3: *Biorefinery - opportunities for underutilised wood fibre and residues*	3.1 Bio-oil by fast pyrolysis	3.2 Biochar by torrefaction	3.3 Power and heat by gasification	3.4 Biofuels and biochemicals

Before detailing the specific recommendations in each pathway, it is important to note that the pathways for growth are often interrelated. All opportunities identified have to be capable of contributing positively to the overall success, especially financial, of the value chain. Consequently, the recommended pathway elements are focused on the relatively low paying end-uses and products, and processing inefficiencies identified previously. Sawmills play critical roles in the regional SWD value chain and this will continue. Based on European experience, large-scale sawmills and large-scale biorefineries will be crucial for the future success of Green Triangle forest and wood products industry.

Large-scale sawmills generate the quantities of residues and can host new generation value-adding uses. In the example in Table 4, operation of a very large sawmill plus supplementary resources as needed, can be expanded to an energy biorefinery concept by adding a biorefinery producing bio-oil and a power plant utilising the available chips and/or bark. This will require a modification of the existing business model to maximise the benefits inherent in the concept.

Table 4. The energy biorefinery scenario (Kivimaa & Karlsson 2013).

	Biorefinery	Power plant that uses bark*
Input	Chips: 400,000 m^3	Bark: 90,000 m^3
Output	Pyrolysis oil: 100,000 tonnes	Energy
Greenfield investment	50 million € (semi-final bio oil, pyrolysis oil; needs to be refined in a big refinery)	4-5 million € + (12–15 MW)

** Depending on the set-up of biorefinery, it could be possible to partly use the excess heat of the drying processes instead of building a separate power plant*

Thus, sawmills can become the backbone of the bioeconomy by securing the raw material supply and integrating it into an existing sawmill network. The energy biorefinery could form the basis of a future profitable business for private sawmills by making total use of forest biomass to generate maximum returns so as to strengthen the local economy. Ideally, it should be located near the source of the raw-material, possibly utilising an existing site, thus minimising process and logistical costs.

In order to be successful the backing of all stakeholders in the value chain will be needed; be they private large and medium-sized sawmills, forest owners, timber harvesting and logistics developers, biochemical value chain producers and customers, energy business operators and equipment engineering companies.

The key success factor for implementation is that the basic sawmill operation would be supported by a new business of value added biofuels, biochemicals or biomaterials. In the case of the Green Triangle, the residues from several sawmills may be combined to ensure adequate volume. The forest owners also need to be involved to ensure the potential biomass residues can be collected from harvested areas. Ultimately, the bio sawmill business model can work assuming profitable uses are found for the total forest resource such that each part goes to its highest and best use. Thus, sawlogs should not be used for energy or bio products, but rather as structural timber for construction.

3.1.1 Pathway 1: New wood products from underutilised Green Triangle log supplies

The basic starting point for the pathway 1 is that the Green Triangle produces large volumes of logs that are currently underutilised in the region. These logs include both SWD pulplogs and some small-sized sawlogs, and HWD pulplogs. Together there are approximately 4.6 to 4.8 million tonnes of logs potentially available that are surplus to domestic uses. When considering the new wood products in South Australia, the question of termites should be given particular attention (see Text Box 2).

TEXT BOX 2.
Termites and wood products – protection against termites in new wood products

When constructing new buildings, certain procedures and preventative measures must be followed in Australia [1]. These include physical barriers (metal shields, stainless steel mesh or granite chip barriers), chemical barriers with varying modes of action (e.g. termiticide-treated layer of soil surrounding and under the building), chemical baits, and construction design (under-floor ventilation, easy to inspect structures and structures enabling re-application of chemical barriers).

Wood products industry treats timber and other products with termiticides for termite damage prevention. These include creosote, Chromated Copper Arsenate (CCA), Alkaline Copper Quaternary (ACQ), Copper Boron Azole (CBA), and different borates. E.g. CCA contains arsenic and its use in residential use wood products is questionable. Other methods that wood product producers have are pressure treatment and providing plastic-wood composite products to replace traditional timber products.

[1] The Australian Standards relating to termite management are: AS 3660.1

Pathway 1, recommendation 1: Oriented Strand Board (OSB) manufacturing

Oriented Strand Board (OSB) is a structural panel product that shares many of the performance characteristics of plywood. OSB's main advantage over plywood is that it can be manufactured from pulpwood-grade roundwood logs. Such logs are typically significantly lower in cost than the peeler quality logs required for plywood production. OSB can be produced from SWD or HWD pulpwood, although most Northern Hemisphere OSB is produced using softwood pulpwood. OSB is produced by flaking the logs to produce strips of wood. The flakes (or strands) are dried, combined with resins, formed into a mat and pressed to produce a panel. The resin types typically used include Phenol formaldehyde (PF), melamine fortified Urea Formaldehyde (MUF) or isocyanate (PMDI), all of which are moisture resistant binders. Presses are either multi-daylight or state-of-the-art continuous presses. The latter are more flexible and capable of making high-grade product. European producers favour continuous hot presses, while the multi-daylight press is more common in North America. Products range from commodity panels that are used for wall and roof sheathing, to more demanding products including water-resistant flooring, siding and other specialty end-use applications. OSB mills benefit from scale with capacities ranging from 250,000 m^3 output up to 800,000 m^3. Investments are typically in the order of A$ 90–160 million (250,000–800,000 m^3).

Biomass requirements: The biomass requirement for a small-scale plant in international standards (producing 200,000 m^3/a) would be approximately 400,000 m^3 of SWD or HWD pulpwood logs.

Potential customers and markets: The potential customers are the Australian construction sector, and, potentially, Asian OSB markets. The Australian market for OSB is currently just over 20,000 m^3/year, and is met entirely by imports. Most imports are from Germany and North America. However, the market for plywood is much larger. Imports from New Zealand alone exceed 300,000 m^3. Imported OSB prices range between A$ 320 to 430 per m^3, and prices for imported plywood range from A$ 480 to 980 per m^3 – depending on the quality and origin. Another potential market exists as a substitute for particleboard flooring panels used in Australia. OSB has captured the majority of wood-based panel flooring in North America. The product's structural performance makes it the preferred choice in this application.

Potential revenue streams in 3–5 years: In 3–5 years time, the biggest revenue streams come from adding value to pulpwood logs currently exported either as chips or as logs. Given the relatively low prices for both logs and chips are in part due to current excess supplies versus market demands, then any application that removes supply of these products could only have a beneficial effect on prices for these commodities. Assuming the quality of OSB produced in the Green Triangle matches the product currently supplied into the Australian and wider Asian markets then the local product will have the potential to pay more for these pulpwood logs than is currently being paid.

Required capabilities and competencies*:* The concept would be more than likely developed by a company from outside of the region, and potentially a foreign-owned company. The manufacturing skills required are likely present in the Green Triangle as the product is similar to particleboard in the fundamental principles of manufacturing. A bigger gap is likely to be in the arena of market development and product development.

Key enabling technologies: There is no particular need for really new technology, because OSB manufacturing is a well established process. There may be adaptations of resin formulations required to process HWD, while SWD is better understood.

Business cases: There have been several examples where OSB has been introduced into markets successfully. Louisiana Pacific entered into a partnership to produce OSB in Chile and built a business from a scratch in a market previously dominated by masonry house construction. A second example is introduction of OSB manufacturing in the UK by Norbord. Again, this helped to build a strong presence for the product in a market previously serviced by imports from North America and Ireland. The investment level for a green-field factory is around A$ 100 milion.

Required infrastructure and ecosystem: This recommendation would not require any specific changes in the existing infrastructure.

Companies in the field: There are several specialised press manufacturers, and many companies operating as producers. Press producers are Dieffenbacher and Siempelkamp. Significant OSB producers include (from North America) Louisiana Pacific (LP; http://www.lpcorp.com/), Georgia Pacific (GP; http://www.gp.com/index.html) and Norbord (http://www.norbord.com/). The latter is also a European (UK) producer, with Kronospan the largest European player.

Pathway 1, recommendation 2: Veneer-based Engineered Wood Products (EWP)

The substantial volumes of underutilised pulpwood grade logs in the Green Triangle presents opportunities to add further value than the current practices of either chipping the logs, or exporting them as logs. These products can be produced from pulpwood logs meeting certain diameter, length and straightness criteria. The region’s plantations can yield logs suitable for use as a feedstock for laminated veneer lumber (LVL) and other veneer-based EWPs. Fast-grown, lower density eucalypts generally present no major difficulties with respect to adhesion; any of the adhesive systems conventionally used by the EWP industry could in all likelihood be used by Australian EWP manufacturers to produce fit-for-purpose products from plantation eucalypt resources with air-dry densities less than 650 kg/m^3 (Hague 2013).

Arguments for plausibility: The region previously produced LVL product at CHH’s Nangwarry plant. LVL production at the Nangwarry plant ceased due to competition from other domestic and international suppliers. That facility was very high cost and employed old technology, with high staffing and log costs. The new concept is based on using peripheral drive lathes that allow use of smaller diameter, and much cheaper, logs. Eucalyptus and pine logs are currently being exported to China where at least a proportion of these logs are being peeled to produce veneer-based products.

Biomass requirements: A propotion of bigger size pulpwood logs would be diverted from export markets to service a new domestic processing facility. This facility would produce waste veneer and cores that would be available to other residue-based manufacturing processes.

Potential customers and markets: The products yielded would be sold primarily into the construction sector. Wesbeam is Australia’s sole LVL plant. CHH imports significant volumes from its NZ-based Marsden Point plant.

Potential revenue streams in 3–5 years: Veneer-based products have the potential to generate significantly higher levels of value adding versus alternative uses of pulpwood-grade logs. The volumes contemplated for such a plant would not preclude existing uses (export logs and woodchips). The value of the veneer-based product is roughly ten times higher than exported logs.

Required capabilities and competencies: The required capabilities existed in the region when the Nangwarry plant was operating.

Key enabling technologies: The key enabling technologies will include those to assist in the selection and segregation of the bigger and better quality logs to be redirected from the pulpwood stream to the proposed end use. While there are now large numbers of equipment manufacturers in this arena, care will be required in selection of appropriate lathes for peeling veneers from plantation-grown E. globulus. In addition, further work is required to identify which specific resin, and its application guidelines, will give reliable bonds of the strength required for a structural product such as LVL. Finally, a suitable hot press technology would be selected from those available to meet the scale and throughput parameters of the new plant.

Business cases: The current Australian producer invested A$ 100–115 million for a plant with a rated capacity of 90,000 m^3/a. However, current output is estimated at less than 65 000 m^3/a. The facility uses Pinus pinaster peeler logs, with supplementary logs potentially available from Pinus radiata plantations. The plant is also contemplating peeling HWD logs. Today the investment would be about A$ 130 million.

Required infrastructure and ecosystem: Existing log supply systems and businesses will continue to produce logs, with a proportion selected and diverted to this use.

Companies in the field: There are a large number of companies producing the lathes and presses needed to produce this product. An example would be Raute PLC from Finland.

Pathway 1, recommendation 3: Improved sorting and better yields by X-ray scanning

The third recommendation for pathway 1 is improved sorting by X-ray scanning that forms part of new forestry methods called ‘‘precision forestry’’ (Chiorescu & Grönlund 2004). This aims at applying new technologies and information know-how to make the forest and wood products industry more effective by streamlining log diagnostics, logistics, and supply chain management. The purpose of the installation is to get higher value yield from existing feedstock.

X-ray scanning is a promising, but not yet widely used, method for examining and sorting logs. The idea is to monitor and analyse the inner structure of timber, like knots, fractures, extent of heartwood, extent of sapwood, holes and the like. Sawmills can utilise this technology to diversify the use of wood, get better yields, and for quality control purposes. The price range of X-ray equipment starts from A$ 2 million. Computer tomography (CT) is another technology to achieve 3D models of wood. At this point, its value is doubtful since it generates approximately the same benefits as X-ray at approximately twice the cost. The log tomography system can include the following components: sensors (like infrared, shadow scanner, laser scanning, color scanning, X-ray imaging, radio and microwave technology, computer tomography), control technologies, software, and applications.

As an example, X-ray scanning technology has been used extensively, with positive outcomes, since 2003–2004 by Stora Enso and UPM sawmills. The payback time of the investment was found to be 1−2 years.

However, the alignment of this opportunity with the present Green Triangle region sawmills could be quite challenging in that the layout of the sawmills might not allow an easy fit of the technologies. A further potential complication is the old age of the existing sawing equipment in the region, which as an initial step should be renewed to maximise the return on this investment.

Once X-ray scanning is in operation the next step for the region could be to progress to a Stem Terminal, which is a sawmill system that uses 18–20 m stems. The price range of a Stem Terminal, including X-ray technology, is A$ 8 to A$ 10 million. It is based on the principle that when the wood is harvested, the log is not cut to length, but transported to the stem terminal for thorough and accurate X-ray and 3D scanning. The idea is that wood is cut as late as possible in the process, and only after detailed examination of the stem properties. In the terminal, the wood is then cut to different needs according to its inner geometrical properties and consideration for the sawn timber qualities. Stem Terminal also enables the monitoring of the defects and changes in the properties of the wood. Stem Terminal is best located in the yard of a major sawmill.

It is estimated that a Stem Terminal system can result in up to 10% better value in the use of wood resources. The estimate takes into account the rise in production value and the impacts of residue control. If applied widely in Finnish sawmills, the system has the potential to return some A$ 290 million per year. The payback time of Stem Terminal is approximately 2 to 3 years. Its potential for the Green Triangle requires further work to quantify.

However, the implementation of a Stem Terminal requires changes in the established harvesting and haulage systems, and also changes in the way sawmills are organised. This is clearly not a simple step to be made and would involve changes throughout the value chain: changes that would be costly and may be resisted.

Arguments for plausibility: The X-ray scanning will enable better value yields, that is, less wood material for the same timber quantity. Value recovery increases of up to 15% have been reported. Better control of the sawing pattern will increase the amount of high grade boards and planks recovered It will also enable identification of right timber for the correct purpose and therefore lead to better quality timber. By these means it will lower raw material costs per ready products.

Biomass requirements: Biomass requirements will remain the same. The X-ray scanning does not affect the consumption of wood, but enables an optimised value generation from the logs.

Potential customers and markets: The market would remain the same, with the exception of shifting towards high-end customers.

Potential revenue streams in 3–5 years: Payback time for the x-ray scanning, in the best case scenario, is one year. Initial investment for X-ray equipment is in the range of A$ 2–4 million and for the Stem Terminal A$ 8−10 million, depending on scale and level of technology. More accurate scanning enables better optimisation but requires more X-ray views per log.

Required capabilities and competencies: Basic ICT competencies, especially ways to find the best algorithms for local pine, are required. The system including software and algorithms are commercially available. Improving the optimisation and automatic detection of flaws requires higher programming skills. Additional skills could be supply chain management (right hardware and software), ERP (enterprise resource planning) system knowledge and market knowledge. It should be noted that there are high levels of competence and skill in ICT and sensor technology related domains in South Australian Universities, PRO's and firms.

Key enabling technologies: Enabling technologies are ICT, measuring technology, X-ray technology and scanning technology.

Business cases: In Finland there are about 10 sawmills using X-ray scanning and improved sorting. Technology is used to some extent also elsewhere in Scandinavia but less so in the rest of Europe

Required infrastructure and ecosystem: Basically, no new infrastructure is required. Outside the sawmills, the key operators would be providers of technologies and software. At the sawmill, increased sorting capacity, more effective wood yard operations and space might be necessary.

Companies in the field: Key companies in the field are Bintec (Fin; http://www.bintec.fi/fi), Inray (Fin; http://www.inray.fi/), Microtec (It; http://www.microtec.eu/en), FinScan (Fin; http://www.finscan.fi/), Limab (Swe; http://www.limab.com/) and RemaControl (Swe; http://www.remacontrol.se/start_se.asp).

Pathway success factors: The market for higher grade boards needs to exist. If the demand is for the cheaper grades, optimisation of sawing pattern will not increase the sales prices or improve process economics.

Pathway 1, recommendation 4: Specialised sawmilling by using smaller and shorter logs

The last recommendation in this pathway is specialised sawmilling, which refers particularly to the use of smaller and shorter logs in sawmills. Traditionally sawmills have used a minimum of 15–17 cm wood for sawing. However due to lower raw wood prices and the closure of the only pulp mill in the Green Triangle, there is raw material available that is under 15–17 cm diameter. When using modern sawmilling technologies, logs down to 10 cm in diameter can be utilised. Furthermore, the product range in smaller dimensions would allow even wood less than 10 cm in diameter to be considered.

Specialised sawmilling is based on the need to gain faster feed-speeds. It is also possible to invest in simpler and small-scale sorting facilities. In this way the equipment will be affordable but still enable high productivity for specialised sawing. The small log sawing machines use very rapid feed-speeds, some 200 m/min being normal, thus productivity per person and per invested dollar is high. Such machinery is already used both in Scandinavia and in Eastern Canada. For example, in Piteå in Northern Sweden, an old traditional sawmill that was shut recently will be soon re-opened as a specialised small log sawmill.

In all cases using small logs as raw material to make sawn products is more profitable than using it for chips. Thus yield even in the 30−35% range is profitable. Also, the quality of the thinner "top logs" is favourable for many end-uses due to small and sound knots, and there is a possibility to use short lengths (down to some 3 meters) in many applications. Thus the traditional pulpwood could be utilised, making green-field investments simpler and cheaper.

A major advantage of this technology from the Australian perspective is the opportunity for enhanced and more effective utilisation of the radiata pine raw material: instead of just exporting low priced chips, part of this same raw material could be upgraded to sawn timber. Also, there are definite opportunities to integrate specialised small log operations into the traditionally equipped sawmills. This would lower the required investments and would make the other operations related to sawmilling, (like using forklifts, warehouses, and eventually the kilning capacity) significantly more effective.

Arguments for plausibility: The specialised sawmilling is plausible because using smaller logs is cheaper and as a consequence generates affordable raw material. The specialised sawmilling also enables biorefining. It is basically about making a value-added product from local small logs and achieving more revenue from the raw material than from just chipping it. Consequently, it would be an alternative to exporting. Specialised sawmilling would create new jobs, since the opportunities of the sawmills would be broadened and attract new participants/investment. In addition, after closure of the pulp mill in the Green Triangle there is an excess of raw material looking for a more profitable use of the wood.

Biomass requirements: The biomass requirement would be basically the same as for larger logs. However, the timber would be used much more effectively with more timber products generated from the same amount of forest raw material and less export of chips. This scenario would also mean higher value gain capture. Most proper feedstock comes from final fellings and partly from second thinnings.

Potential customers and markets: The potential customers are sawmills. In particular, small logs can be used in door frames, panelling and in small gluelam products. The advantage of small logs is that it also has small and sound knots. The markets have not been favouring small logs. Building operative markets for the small logs requires rethinking and change in perception of how wood is be used.

Potential revenue streams in 3–5 years: The greatest revenue streams come from adding new value to timber. Additionally, as Green Triangle export moves up the value chain towards higher value products, renenues will rise. For example, it can be estimated that the timber is roughly twice as valuable as chips.

Required capabilities and competencies*:* Basically, the required capabilities would most revolve around the readiness of the local companies to adopt this new production concept. The realisation of the recommendation would require capabilities in handling small log machinery and fast sawing machine lines.

Key enabling technologies: There is no particular need for new technology, just adjustments for the existing machinery. Obviously, modernised process technology would help in raising the yields and making the processes more effective.

Business cases: There are a few specialised sawmills in Nordic countries, some even on a large scale. In Green Triangle, the supply of the unused pulplogs exceeds the demand.

Required infrastructure and ecosystem: Apart from finding potential markets for the small log products, this recommendation would not require any major changes in the existing technical infrastructure.

Companies in the field: There are several specialised machine manufacturers in Scandinavian countries, including Veisto (Fin; http://www.hewsaw.com/fi), Jartek (Fin; http://www.jartek.fi/main-page), and Heinolan Sahakoneet (Fin; http://www.heinolasm.fi/en/) and Comtec (Can).

3.1.2 Pathway 2: Opportunities in construction industry using existing outputs

The second pathway presents four recommendations for moving the traditional forest and wood products industry towards producing value-added goods for the construction industry. This pathway is focussed on upgrading the value of the outputs from the sawmills. As noted in the preamble, the SWD value chain suffers from relatively low prices for the fall-down products and lower rated structural timber. The following processes are opportunities to upgrade these outputs.

There is a growing recognition of the value of wood as a construction material as it meets more of the criteria increasingly applied to materials selection. Wood is logistically a credible efficient solution, as it weighs less than steel, and can be pre-fabricated. Wooden houses also have the capacity to embody significant quantities of carbon dioxide (CO_2), particularly compared with the emissions arising from the production of cement. In addition, modern engineered wood products can be used to create very eco-efficient buildings and thus be effective sequesters of carbon.

Pathway 2, recommendation 1: Cross-laminated timber (CLT) and high storey houses

Cross-laminated timber (CLT) is an innovative-engineered wood product developed in Europe [Austria and Germany], which is used in residential and non-residential applications in several countries. Cross-laminated timber (CLT) is best described as a prefabricated solid engineered wood product made of at least 3 and (up to 7) orthogonally bonded layers of solid-sawn timber or structural composite timber. This product is created, by bonding with structural adhesives, alternate longitudinal and transverse laminations. The result is a solid rectangular-shaped panel intended for roof, floor or wall applications. Thickness of individual laminating boards may vary from 10 mm to 50 mm and the width may vary from about 60 mm to 240 mm. Panel sizes vary by manufacturers; typical widths are 0.6 m, 1.2 m, and 3 m and can be up to 4~5 m in particular cases, while lengths can be up to 18 m and the thickness can be up to 400 mm. The panel dimensions are more accurate than those of panels formed from concrete. Transportation regulations may impose limitations to CLT panel size. The boards are either rated by visual means or by machine stress, and are kiln dried. In general, the composition of CLT is such that dimensional seasoned softwood timber is used for the interior layers and higher structural grades for the outer layers. In Australia this could be achieved using lower grade timber products of radiata pine.

The key to a successful CLT manufacturing process is consistency in the timber quality and control of the parameters that impact on the quality of the adhesive bond. Stringent in-plant quality control tests are required to ensure that the final CLT products will fit for the intended applications. CLT panels used for prefabricated wall and floor structures offer many advantages. The cross-laminating process provides improved dimensional stability to the product, which allows for prefabrication of wide and long floor slabs and single storey long walls. Additionally, cross-laminating provides high in-plane and out-of-plane strength and stiffness properties in all three dimensions of the product, giving it a two-way action capability similar to a reinforced concrete slab. The ‘reinforcement’ effect provided by the cross lamination in CLT also considerably increases the splitting resistance of CLT for certain types of connection systems (Figure 5).

Figure 5. Cross-laminated timber (CLT).

The prevailing tendency in Europe when establishing a cross-laminated timber production facility has been to locate the plant adjacent to an existing sawmill, thereby reducing distance and time lag between timber processing and engineered timber production. Often the existing sawmill is a family owned operation that has diversified into cross-laminated timber production.

CLT is considered a complete building system allowing a company to build a multi-story building. It is in commercial use in several European countries, including Austria, Germany and the UK, and is beginning to be produced in North America. Two plants are operating in Canada and three under construction in the United States

DMITRE have advised the authors that there are no Australian standards or codes that cover CLT manufacturing or installation. There is an American standard that covers the manufacturing, qualification and quality assurance requirements for CLT in USA. In Europe, CLT manufacturers go through an approval process that includes preparation of a European Technical Approval Guideline. In Australia, as CLT is not covered in documents such as the BCA standard guidance, all designs (for buildings 3 storeys or higher) have been required to go through an alternate approval path (i.e., show by design that building design standards will be met). This may be compared with North America where changes to the building codes and development of proper standards and design values were required to enable market penetration. In Finland, new laws now permit high-rise houses up to 8 storeys with CLT as a construction component. It could be suggested that especially a small scale trial CLT plant in the Green Triangle could be considered as a test bed for the Australian market and that the regulatory environment is changed to open up for the use of this material.

Arguments for plausibility: CLT is a value added timber product and it can be used in the production of mass timber products (like FFTT, acronym for: Finding the Forest Through the Trees[2]), a construction model for building high-rise apartment buildings from wood). CLT is light and easy to transport. Also, production of wooden bridges, as well as CLT plant, can be integrated to an already existing sawmill with quite modest investments (around A$ 30-40 million).

Biomass requirements: The CLT plant would be integrated with existing sawmill sawn timber outputs and raise its value. As noted in Table 2, the existing sawmills produce between 30% and 80% non-structural sawn timber outputs. For example, 60,000 m^3 sized plant uses about 80,000 m^3 of timber. Each of the large regional sawmills would have the output to sustain a plant of this size. Normally a reasonable proportion (one-third) of the sawn timber raw material (inner parts) can be of lower quality.

Potential customers and markets: The markets are in a construction industry and building companies. Two of the great challenges of our time are climate change and urbanisation. Protection of the forests is essential to the health of the planet as wood sequesters carbon until it rots or burns. Using wood responsibly in buildings is an excellent way to reduce carbon dioxide emissions and to

[2] The detailed report can be found from: http://wecbc.smallboxcms.com/database/rte/files/Tall%20Wood.pdf (accessed 13 September 2013).

store carbon for a long time. As 40% of dry weight wood is carbon, 1 m^3 of harvested wood results in approximately 100 kg of carbon being tied up in timber.

Tall wood buildings will be part of the next generation of high-performance sustainable buildings in a trend that is already emerging in Europe. The light weight of the construction enables long haulage to the customer.

Currently 70-90% of the Green House Gases (GHG) and energy footprint of developed world buildings is related to the heating, cooling and electrical operations of those structures. The energy codes are evolving to modify the operational side but a larger percentage of the overall GHG comes from materials used such as concrete and steel.

The authors have established a dialogue with a company called MG architects (http://mg-architecture.ca/) in Vancouver to learn more about their study entitled “The case for tall wood buildings: How mass timber offers a safe, economical, and environmentally friendly alternative for tall building structures”. The report introduces a new structural system using wood that represents a real challenge to concrete and steel structures in tall building design. This is a safe, carbon-neutral and sustainable alternative to the conventional structural materials of the urban world. The potential market for these ideas is quite simply enormous. The proposed solutions have the potential to revolutionize the construction industry as well as addressing the major challenges of climate change, urbanization, and sustainable development and to significantly contribute to world housing needs.

Funding for the ‘Case Study’ project was provided to the Canadian Wood Council (CWC; http://www.cwc.ca/index.php/en/) on behalf of the Wood Enterprise Coalition (WEC; http://canadiantimberstructures.com/) by Forestry Innovation Investment (FII; http://www.bcfii.ca/). In the report they refer to a FFTT concept that was originated by architect Michael Green and structural engineer Eric Karsh; mgb architecture + design (http://www.mgb-architecture.ca/), Equilibrium Consulting (http://www.eqcanada.com/), LMDG Ltd (http://www.lmdg.com/), and BTY Group (http://www.bty.com/). Their findings are inspiring, especially when viewed from a South Australian perspective.

The report defines Mass Timber as solid panels of wood engineered for strength through laminations of different layers. The panels vary in size but can range upwards of 20 m x 2,4m and in the case of CLT can be of any thickness from a few inches to 40 cm and above. Ultimately these are very large, very dense solid panels of wood. Mass Timber products offer significant benefits over light wood frame techniques in terms of fire, acoustic performance, and structural performance, scale, material stability and construction efficiency. Their use in regional Australia, particularly in high fire-prone locations, should be investigated.

The structural details of FFTT as a “strong column – weak beam” balloon-frame approach using large format Mass Timber Panels as vertical structure, lateral shear walls and floor slabs is described in their report. The “weak beam” component is made of steel beams bolted to the Mass Timber panels to provide ductility in the system. Concrete is used for the foundations up to grade. No further concrete is necessary in the system unless selected for architectural reasons. Mass Timber buildings are definitely changing the scale of what is possible to be built in wood around the world. Different systems will continue to evolve but their proposed FFTT system can efficiently achieve heights of 30 storeys in a predominantly wood solution (with steel beams). The CREE system in Austria has also shown that a 30 storey hybrid wood and concrete structure is possible. The FFTT system is a predominantly wood system with a solid wood central elevator (and stair) core and wood floor slabs. Steel beams are used to provide ductility in the system to address wind and earthquake forces. Concrete has been used for the below grade areas of the structure. Wall thicknesses of Mass Timber are comparable or thinner than concrete walls due to the dramatic difference in the fundamental weight of the building. This means that there is no floor area penalty to a developer interested in a FFTT building. The FFTT system allows for open plans that will accommodate both office and residential uses.

The current building height limit for wood buildings in South Australia is 3 storeys. This height limit was probably established with light wood-frame (wood-stud) structures in mind. Mass Timber buildings are significantly different from light wood-frame buildings in their fire performance due to the solid nature of the timber panels and their inherent ability to resist fire without the addition of protective membrane barriers. Fire history and recent fire testing in Europe and Canada has demonstrated that solid wood structural elements can be designed to perform to a 2-hour fire-resistance rating as required for high buildings. The conclusion is that the building regulations need to be modified to accommodate new technology.

Appropriately-designed Mass Timber buildings will not create the arrangement and volume of combustible concealed spaces that are a possibility with light wood-frame construction. This is because the solid wood panels form a key part in the fire-rated assemblies between compartments of the building according to (Green 2012). Wood shaft systems can be protected with non-combustible lining materials and sprinkler systems to resolve issues associated with vertical flame spread. In addition to the typical ‘active’ fire protection systems (automatic sprinkler systems, fire alarm and detection systems) are possible.

The use of Mass Timber in South Australia and elsewhere in Australia will require a reassessment of building codes. The initiation of such discussions with the responsible government and/or building authorities is strongly recommended.

Potential revenue streams in 3–5 years: Total global demand of CLT is currently 700,000 m^3 pa. The majority of this is within Europe, but the US and Asia is also expanding. Total usage is expected to reach 1 million m^3 pa over the next two years. Two significant buildings are being developed in Melbourne and have created a lot of interest in the cost, construction time, and utility in service. Significant further growth is expected globally with several major wood promoting agencies working hard to increase market penetration into the non-residential sector. This is dependent on the building codes and regulation. Government can have significant effects on these matters by, for example, granting incentives to wooden constructions. The local administration could also endorse the use of CLT by, for example, subsidising its use in municipal buildings.

CLT presents a strong growth opportunity in the Green Triangle region, however exports will be a key to longer term success, as will developing the acceptance of CLT within the State and national Australian building codes. European and North American suppliers have significant scale, and the Green Triangle will have to ensure it is competitive against those overseas suppliers, especially if the future business case calls for export of the product.

A UK report that looked at the feasibility for setting up a facility capable of 70,000 m^3 of CLT production had estimated set up costs being in the region of A$ 35-42 million (this figure is similar to Stora Enso’s second CLT plant in Austria in 2011, production capacity of 63,500 m^3 and set up cost of A$ 33 million (Hague 2013).

This same UK report looked at viable European models where annual production of cross-laminated timber is around 10000m^3 pa and investment costs in the range of A$ 7–9 million. In one particular example (Egoin, based near Bilbao, Spain) the company has capacity to manufacture 9000m^3 of cross laminated timber pa from locally grown timber and has developed a range of volumetric solutions from its basic panel production that it now exports to France. From a standing start, development of Egoin’s plant and the subsequent securing of all necessary European approvals for its products took around four years at a total investment cost of around €5m. (http://www.cicstart.org/userfiles/file/FS-52-REPORT-PUBLIC.PDF).

European examples

- KLH (Austria, UK, Sweden): 71,000 m^3 (http://www.klhuk.com/)
- Stora Enso (Austria): 60,000 m^3 (http://www.storaenso.com/products/wood-products/products/clt-cross-laminated-timber/Pages/cross-laminated-timber-clt.aspx)
- Binderholz (Austria): 25,000 m^3 (http://www.binderholz.com/en/)
- Martinsons (Sweden): 5,000 m^3 (http://www.martinsongroup.com/construction-wood)
- Moelven (Norway): 4,000 m^3 (http://www.moelven.com/#)
- Thoma Holz GmbH (Austria; http://www.thoma.at/)
- FinnForest Merk (Germany/UKM; http://www.metsawood.co.uk/Pages/Default.aspx)
- HMS (Germany; http://www.hms-holz.com/)

Required capabilities and competencies: The competencies required are architects, and designers, construction engineers and builders who are trained in the use of wood. Education can either be done by new programmes or by re-training existing construction engineers in specific requirements of wood construction. The training could be organised quite easily through different programmes, but real hindrances are the changes in the building codes.

Key enabling technologies: The key enabling technologies, in addition to more traditional technologies used in forestry and sawmilling, are gluing technologies, construction design, and information models.

Business cases: Stora Enso (London) this eco building had extra storeys due to the use of CLT rather than concrete and steel. The light weight of CLT is one advantage but the use of this material also reduced the cost of the project considerably.

Stora Enso Building and Living division is further developing its Building Solutions business with the delivery of its first CLT (cross-laminated timber) shipment from Europe to Australia. The Docklands Library and Community Centre in Melbourne, built by Lend Lease, one of the world's leading property and infrastructure providers, will be the first public building in Australia to use CLT as a construction material. The major structural components of the three-storey library are made from more than 500 m^3 of CLT, which was produced at Stora Enso's Ybbs and Bad St. Leonhard units in Austria and shipped to Australia at the beginning of February. Deliveries of the CLT elements to the site commenced in mid-April and the estimated erection time is 6–8 weeks. The centre is scheduled to be completed by the end of 2013 and to open its doors to the public by March 2014. It was designed by Clare Design and Hayball architects, an award-winning architectural team.

In a recent press release, Stora Enso has stated that "…this building will be a great start for CLT construction in Australia and a natural extension to our business in Australia, where Stora Enso has been operating for more than ten years through four distribution centres around the country…."

Required infrastructure and ecosystem: The production infrastructure can be integrated with existing sawmills. There should also be logistics for moving CLT from the integrated sites. The weight of CLT is only about 20% of concrete element.

Companies in the field: The following companies are the main global players: Stora Enso (Finland), Thoma Holz (Austria; www.thoma.at), Binderholz (Germany; http://www.binderholz.com/en/), and Finnforest Merk (Finland/Germany; http://www.metsawood.com/Pages/Default.aspx). Stora Enso currently has plans to increase their activities within Australia.

Pathway 2, recommendation 2: Glued Laminated Timber (Gluelam)

Glued Laminated Timber (Gluelam) is a structural timber product made up of a number of layers of dimensioned timber bonded together with durable, moisture-resistant structural adhesives. Like CLT it is a valued-added engineered wood product. The process of laminating removes a number of problematic natural features that reduce the strength of timber, such as knots, sloping grain and gum vein and produces a structural member with known properties of less variability than solid timber. Lam stock (wood sized and dried appropriately) is face laminated together in different combinations depending on the final strength characteristics needed. The final product may be planed and coated depending on customer specifications. Gluelam is typically used as vertical columns, horizontal beams or curved/arched spans as it can span long distances with minimal deflection unlike steel and concrete structures. Gluelam may be used in almost any type of buildings and bridges due to its strength, stability, and chemical and fire resistance (Figure 6).

Figure 6. Gluelam structure in the Portland Building, University of Portsmouth, United Kingdom (Wikipedia).

It is estimated that the total global market for laminated timber exceeds 5 million m^3 pa. The market for standard grades of Gluelam continues to expand, as end users demand known performance and quality. This market is expected to continue to expand but at very narrow profit margins.

Traditionally one of the largest users is the Japanese building trade, using large volumes of small size laminated products. Gluelam also presents a growth opportunity in the Green Triangle region but an important key to this will be the continued development of products within this category to fully utilise the properties of radiata pine.

Arguments for plausibility: Gluelam is a value added timber product and it can be used in the production of mass timber products (like CLT in the above mentioned FFTT, system for building high-rise apartment buildings from wood). In terms of weight for strength, gluelam is an efficient product and easy to transport. Also, production of wooden bridges, as well as gluelam plant, can be integrated to an already existing sawmill with quite modest investments (around A$10–30 million). In addition, smaller gluelam products could be profitably exported, for example, to Japanese markets. Small houses in Japan are built from standardized gluelam beams because of their ability to withstand earthquakes. There has been substantial research in gluelam properties, timber adhesives used in the laminating process, lamination joints and gluelam behaviour in both in-service environments and long term, over the past three decades and gluelam is now accepted world-wide as a structural material of known behavioural properties.

Biomass requirements: The gluelam plant would basically use existing sawmill biomass and raise its value. 10,000 m^3 would be a reasonable size for a plant, and this sized plant would utilise some 20,000 m^3 timber. Small products could be produced in 2–4 times bigger units because of standardised nature of products. Normally about one third of the sawn timber raw material can be of lower quality.

Potential customers and markets: The markets are in construction industry. Gluelam is suitable for large constructions, like sports halls, industrial buildings, warehouses, and malls. A significant opportunity would be exports of small size gluelam to Japan.

Potential revenue streams in 3–5 years: This is dependent on the building codes and regulation. Government can have significant effects on these matters by, for example, granting incentives to wooden constructions. The local administration could also endorse the use of gluelam by subsidising its use in municipal buildings and shopping centres as an example.

Required capabilities and competencies: The competencies required are architects, designers, construction engineers and builders who are trained in the use of wood. It can be assessed that education can be achieved either by new programmes or by transformation training, for example, re-training already graduated construction engineers towards wood construction. The training could be organised quite easily through different programmes, but real hindrances are the changes in the building codes.

Key enabling technologies: The key enabling technologies, in addition to more traditional technologies used in forestry and sawmilling, are gluing technologies, construction designing, and information models.

Business cases: In Australia, depending on location, the species used in the manufacturing process differs from producer to producer. In the west, the predominant species for the production of timber is jarrah, in the South East, Tasmanian Oak and radiata pine and in the north east, Spotted Gum, Slash Pine and other mixed hardwoods, such as Blackbutt, Iron Bark, Sydney Blue Gum. There are thousands of examples from big buildings in Europe. In Japan there are several examples of house timber frames made from gluelam products in small dimensions. However, the gluelam is currently under-utilised in Australia.

Required infrastructure and ecosystem: The production infrastructure can be integrated with existing sawmills. There should also be logistics for moving gluelam from the integrated sites. The manufacturing process produces large and long length gluelam members and also results in increased strength when compared with that of the individual timber bits. This also means that much larger pieces of timber can be produced than would otherwise be possible with traditional solid sawn timber. Gluelam is consistently stronger than solid timber and comparable to concrete and steel. This is due to the lamination which reduces the occurance of natural defects and allows much bigger dimensions compared with solid timber. The weight of gluelam is significantly lower (about 20–30%) when compared with steel and concrete products.

Companies in the field: VersoWood (Finland; http://www.versowood.fi/), Stora Enso (Finland; http://www.storaenso.com/), MetsäWood (Finland; http://www.metsawood.com/Pages/Default.aspx), Keitele Group (Finland; http://www.keitelegroup.fi/). Others include: Australian Sustainable Hardwoods (Victoria; http://www.vicash.com.au), Austim (WA; http://www.austim.com.au), Tilling Timber (Victoria, regional office in SA; http://www.tilling.com.au), AKD Softwoods (Victoria; http://www.akd.com.au), Le Messurier (South Australia; http://www.lemessurier.com.au/timber), Big River Group (NSW; http://www.bigrivergroup.com.au), Hyne (Qld; http://www.hyne.com.au/), Dindas Australia (Victoria, office and major distribution in SA; http://www.dindas.com.au/) and Laminated Timber Supplies (Victoria; http://www.lamtim.com.au).

Pathway 2, recommendation 3: Wooden bridges

The use of wood in bridge construction is not widely practised in the Australian or the SE Asian market. In Sweden and Norway there are several very effective wooden bridge constructions that have provided competitive business options. The building of bridges is usually a matter of public administration: ministries and agencies responsible for logistics and roads. Wider use of wood-based construction in the society is mainly blocked by building codes and related legislation. Therefore, it is important to have policy incentives for creating operating markets and an environment in which these constructions can be realised. Additionally, it would be necessary to form a standardised, modular and simple structure especially for light weight traffic that enables cheaper prices and larger production volumes (Figure 7).

Figure 7. Wooden bridge in Montmorency River, Quebec, Canada (Wikipedia Creative Commons).

A big advantage for wooden bridges is that the product can be manufactured inside a factory and set into its place in one lift-up. It means that wooden bridges could be assembled in their places almost without disturbing other traffic. The structure of the wooden bridges could be based on simple modules and construction of a standard and detailed typical bridge from these modules. The development work would contain similar elements as the development of high-rise wooden apartment houses, but it is still simpler. Most likely the trickiest solutions would consider the coating of the bridge cover and the structural protection of the skeletal material. Thus, the planning of the wooden bridges would firstly require the creation of the BIM (building information model) concept of the actual bridge, and secondly the planning of the manufacturing of the wooden modules. The more long term perspective would be to develop automatic system for monitoring the structural stability of the bridge and potential moisture damages before they become dangerous.

Therefore, we recommend that wooden bridges could be third direction Green Triangle forest and wood products industry could push towards in the construction industry pathway. It would promote the use of wood across the Australian society, and would be a “follow-up” of the development of building legislation and architectural regulation. Different possibilities for extending the understanding of wood utilisation should be considered through appropriate education programs. When considering the implementation of wooden bridges in Australia, the question of termite control would need to be addressed.

Arguments for plausibility: The wooden bridges would be a plausible because the bridges are value added timber products that can use the mass timber concept (like FFTT). The bridges are light and easy to transport. Also, production of wooden bridges can be integrated to an existing sawmill and gluelam plant with quite modest investments, basically just putting up an assembly plant. The investment would be roughly A$1 million.

Biomass requirements: The plant could utilise existing sawmill biomass and raise its value. It can be argued that a plant of 5,000–10,000 m^3 in size would be a reasonable sized operation. A plant of this scale would use 10,000–20,000 m^3 of timber. A single bridge consumes timber from 50 to 1000 m^3 depending on size.

Potential customers and markets: The potential customers are construction industry, municipalities for the light traffic bridges and ministry of roads and railroads for roads outside the cities.

Potential revenue streams in 3–5 years: This depends primarily on the building codes and regulation. Government can have significant effects on these matters by granting incentives to wooden constructions.

Required capabilities and competencies: The competencies required are architects, designers, construction engineers and builders who are trained in the use of wood. It can be assessed that education can be either done by new programmes or by transformation training, for example, re-training already graduated construction engineers towards wood construction. The training could be organised quite easily through different programmes, but real hindrances are the changes in the building codes.

Key enabling technologies: The key enabling technologies are in gluing, construction design, information models and simulation technologies, in addition to more traditional technologies used in forestry and sawmilling.

Business cases: Many cases exist in Norway and in Sweden. Today in Norway there are over 300 public wooden bridges constructed since 1995, with another 400 wooden bridges currently in the planning phase. Most of the Norwegian bridges cross roads and rivers. There are also some wooden bridges in Chile, and some small-scale ones in Finland.

Required infrastructure and ecosystem: The production infrastructure can be integrated with existing sawmills. There should also be logistics for moving bridges from the integrated sites.

Companies in the field: VersoWood (Fin; http://www.versowood.fi/), Late (Fin), Martinsons (Sweden; http://www.martinsongroup.com/home).

Pathway 2, recommendation 4: Biocomposites

Biocomposites are materials consisting of bioplastics, natural fibres and/or fillers and additives, which are also preferred to be biomass-based. There is no universal definition or standard for biocomposites (Nättila 2013), but synonyms for biocomposites, like bio-based composites, green composites and natural composites, do exist. The utilisation of non-food resources will be one of the main issues and drivers in material development. The variety of biomaterials, the number of material combinations, processing technologies and potential applications offer extensive opportunities but there are many challenges that must be overcome during the development of biocomposites and bioplastics. It is common knowledge that the interaction between fibres and matrix determine the properties of a composite. Many research and development activities have been and are being carried out with the aim of improving performance of natural fibre composites (NFC), wood plastic composites (WPC) and biocomposites. These activities include improvements of the properties of natural fibres: optimal fibre length and aspect ratio, and distinct fibre treatments. In addition, new biomass- based additives, such as impact modifiers, fire retardants and biocides are globally under development. The type and treatment of wood particles or fibres are the main contributing factors on composite performance, while the development of new bioplastics is crucial for the properties and future of biocomposites.

The most common variations of biocomposites are wood plastic composites (WPCs, synthetic resin/wood/additives), natural fibre composites (NPCs, synthetic resin/natural fibre/additives), biocomposites (biopolymer/natural fibre/additives) and naturally reinforced plastic composites (NRPCs, synthetic resin/wood/ natural fibres/additives). Thus, there is a need for standardisation of terminology and definitions, but also in the production processes, like composition, performance and testing. The next generation of biomaterials are being developed around the world through the use of advanced processing techniques and nanotechnology principles. However, it is already currently possible to make injection molded, plastic-like composite by integrating lignin and cellulose (Figure 8).

Figure 8. Injection molded, plastic-like composite by integrating lignin and cellulose.

Today, the production of biocomposites is based on processes of common plastics and composites (Nättilä 2013). Future enhancements will require material development in conjunction with processing technologies, new ways of thinking and designing of composites, adapted processing technologies for the reinforcement of fibres, and modification of process equipments such as feeders, screw geometries, and dies. Wood plastic composite (WPC) is a thermoplastic biocomposite that contains up to 80% wood in its components. The process for producing WPC requires compounding prior to moulding to raise the quality of materials that are suitable for processing by injection moulding and extrusion. WPC has definite benefits when compared with polymers derived from petrochemical sources: being both more cost competitive and environmentally friendly. Some feasible targets for future research and development are low-cost, medium sized composite solutions for pallets and packaging boxes, and high-quality and high-performance WPCs for cleats, frames and injection moulded furniture systems (Nättilä 2013).

Natural fibres have found their way into the composite market as reinforcements or fillers, mainly in polyolefin-based WPC products. Currently, bio-based materials are widely researched with the aim of replacing polyolefins and other oilbased plastics. Applied fibre length and its compatibility to the matrix are the major contributors to expected mechanical properties. The current 'bulk' bio-plastic polylactic acid (PLA) is being accompanied by other commercial bio-polymers such as starch-based polymers (Figure 9).

Figure 9. Examples of PLA in packaging (http://www.european-bioplastics.org).

The total wood-based biocomposite production in 2009 was 1.5 million tonnes and growth rates have been significant. From 2000–2005, the markets grew by 40% in USA, 100% in Europe and 13% in

Japan. The market forecasts for biocomposites also show significant potential. For example, BCC Research has estimated that the market for wood plastic composites, cellulosic plastics, plastic timber and natural fiber composites was about 2.4 million tonnes in 2011. By 2016, the market is estimated to be nearly 4.6 million tonnes, and expanding well above 10% annually. The biggest and fastest growing market segment is the building and construction sector (BCC Research 2011).

Legislation, changes in raw material resources and prices, consumer demand, land filling, innovations, global warming and the ‘green image’ are all driving the market of biomass-based products, namely bioplastics and biocomposites. The oil/petroleum-derived plastics industry is faced with on-going issues such as increase and continuous fluctuations in petroleum prices, which have resulted in price volatility. Furthermore, the sources for synthetic plastics (fossil fuel reserves) are diminishing and the demand for renewable materials is increasing. However, the raw materials used for bioplastics are agricultural resources that are renewable and present in abundance, thereby establishing bioplastics as a sustainable industry.

Improved properties, the increase in the number of producers, the growing variety of different types of bioplastics, the depreciating prices of bioplastics and availability are all factors that will increase the usage of bioplastics and open up new possibilities and application areas for bioplastics, biofoams and biocomposites (see Figure 10). For example, in 2009 Coca-Cola launched its “PlantBottle” concept with a bottle design of 30% PET biocontent. In the future, the company plans make to bottles that are fully made of bio-based materials (Figure 11)

Figure 10. On the left, biofoam made out of cellulose fibres. On the right, ultra-light weight cellulose-based material.

Figure 11. The “PlantBottle” concept of Coca-Cola.

The production range of biocomposites is huge. In America, the products include floorings, panels, roofs, window features, and deck structures. Some key producers in North America are Andersen, Trex, EnviroShake, Choice Dek, Dexx Corporation, and TimberTech. In Asia, the production focuses on panels, floorings, furniture, and terraces. The main producers in Asian markets are EinWood, PlussPolymers, Eidai Kako Company, Nanjing Youerda Logistics, and Perth. In Europe, the production focus is on panels, floorings, furniture, and terraces, but there are also different products like utensils, noise barriers and even musical instruments such as guitars. Some of the producers are B.T. Innovation, Fa. Rödel, Polyplank, Kareline, IKEA, Moeller, and PPI. Wood plastic composites can be widely applied, for example in extrusion for building industry and in injection moulding for automotive components, furniture, and auxiliaries.

Arguments for plausibility: There is an opportunity to generate composites from sawdust, wood chips and shavings and thereby add value to these biomass residuals. There is the potential to add some characteristics that wood currently does not exhibit. In the Green Triangle region there is potential to generate wood fibre plastic composite as a wood fibre pellet (WFP) which is used as a feedstock in the plastics industry. The initial processing would be similar when making fibre for MDF. Chemicals are added to the fibre, formed into a low density mat and then diced into pellets which are used to provide polymer reinforcement to polyolefin compounds as moulded resin plastics. The technology is new but is now licensed and developed for commercial use. The process can be retro-fitted to an existing MDF mill using the same front end and providing an alternative product and market stream.

The market for wood plastic composites, and therefore WFP, is expected to grow globally. Use of this material is predicted to expand rapidly over the next five years in North America, Europe and Asia, with some development in Australia. The WFP is added to moulded resin plastics to add strength and is a substitute for short fibre glass re-enforcing. Pricing is yet to be fully established due to the newness of the product, but as a material substitute it will be largely driven by the price of glass fibre; being the established incumbent product.

Biomass requirements: Low quality biomass such as bark is sufficient, while kraft pulp may also be used depending on technical requirements. Wood based materials are considered to be at risk due to deterioration caused by termites.

Potential customers and markets: Automotive industry, furniture industry (as an example Finnish company Puustelli uses UPM developed Formi material in kitchen cabinet frames replacing particle board), infrastructures (outdoor terraces etc.; one Australian company already has products under the brand ModWood (http://www.modwood.com.au/). The Green Triangle does not have a polymeric resin supplier, but the region could be the manufacturing site of WPC pellets for further processing at existing or new biocomposite sites for example APR or similar companies (http://www.advancedplasticrecycling.com.au/). WPC may also be of interest to advanced technology flooring companies for example SMR. Another application could be along the lines of a composite development by Puustelli Group Oy (http://www.puustelli.com), a leading kitchen furniture manufacture in Finland.

Potential revenue streams in 3–5 years: According to a market source, the volume of current market composite products such as wood plastic composites (WPCs), cellulosic plastics, plastic timber and natural fibre composites was estimated at 2.4 million tonnes in 2011. The market is forecast to grow to 4.6 million tonnes by 2016. The price range for composite materials is from A$ 1500 to A$ 5000 per tonne.

Required capabilities and competencies: Material science / engineering; regular forestry competences; knowledge of plastics as a material and an understanding of how woody biomass needs to be refined or modified for mixing with plastics.

Key enabling technologies: Conventional plastics production techniques such as injection moulding and extrusion, or where special requirement of the material, such as fibre length reduction is important. Compatibility of the fibres can be improved by means of chemical agents. The biomass can be made more termite resistant by thermal treatment or acetylation, which also improves durability for outdoor applications.

Business cases: Composite products are used widely in different applications, product areas and manufacturing industries. Forest-based companies such as UPM, Weyerhaeuser and others have their own products.

Puustelli Group Oy is a leading kitchen furniture manufacture in Finland with over 90 years of proficient woodworking history. Puustelli is growing internationally with exports to Russia, Sweden and the Baltics. Puustelli's eco-kitchen is a ground-breaking innovation and its concept features biocomposites in the furniture framework. UPM manufactures the composite material and Puustelli manufactures the units. The new material is lighter by almost one-third, yet still significantly stronger than chipboard. The new biocomposite reduces raw material consumption by 30% and the carbon footprint of the furniture by almost 50%, while end users appreciate the lower discharge of formaldehyde from the product. This is in keeping with the Puustelli mantra of minimal environmental impact and low carbon footprint. VTT and Desigence were cooperating with Puustelli in the development of an eco-friendly biocomposite material for the furniture framework. This is considered a generational shift in furnish products, involving revolutionary manufacturing techniques and design (Figure 12).

Figure 12. Puustelli composite kitchen frames (http://www.upm.com/formi/Pages/default.aspx).

A company named Zeoform (http://www.zeoform.com/) will launch a new type of cellulose based composite September 2013 in Sydney. The company has patented a glue-free process for making durable building material from cellulose and water. The process applies hydroxyl bonding. The resulting material is called Zeoform. Zeoform can be sprayed, molded or shaped into different products (Figure 13).

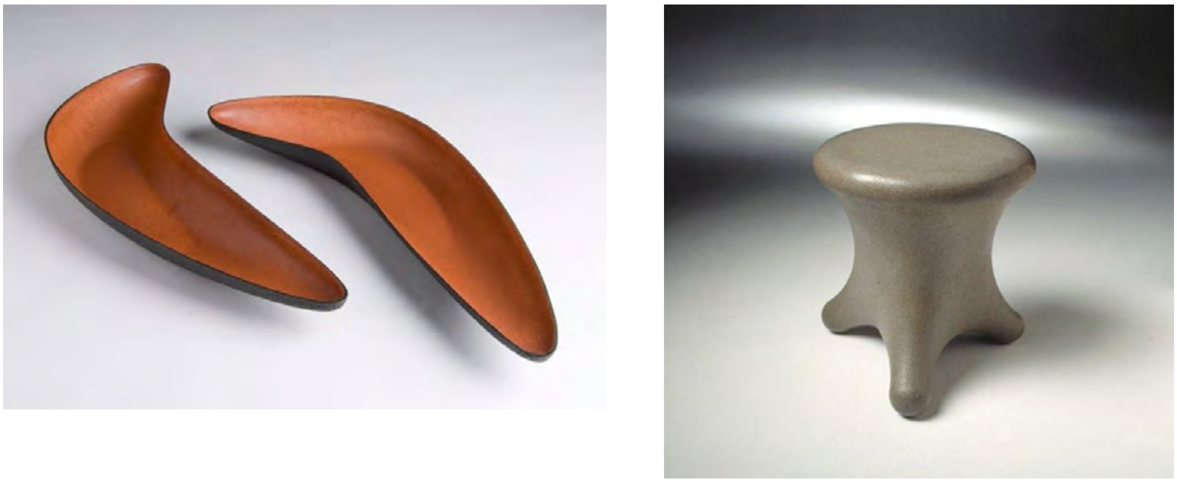

Figure 13. Examples of prodcuts made of Zeoform (Gizmag).

The exemplary companies in biocomposites are Puustelli (UPM manufactures, Puustelli assembles), Modwood, Lunacomp (also Thermowood; http://www.lunacomp.fi/en/), and Struktol (http://www.struktol.com/).

Required infrastructure and ecosystem: When conventional plastics are used together with woody material or chemical pulp, plastics can be sourced through normal channels. Composites should be introduced and marketed to industries and companies in Australia with the potential for material replacement. This would lead to the creation of regional and commercial interest for R&D in bioplastics and composites

Companies in the field: UPM, Modwood, Lunacomp, Struktol, and plastics industry companies in general.

Pathway Success factor: Production of composites doesn't require cutting edge technology but success needs to be created at the marketplace where composites can be used. Partnering with potential composite users and identification of suitable application areas for Green Triangle biomass are key to any concrete investment in composite production and development of profitable business case. Composites are already widely on the market, which means that cost competitiveness is a necessity.

ThermoWood™

Thermal modification of sawn timber is a process designed to add durability to the wood without the addition of chemicals. The process is done at temperatures above those used during drying, but in a controlled atmosphere to eliminate the risk of combustion and reduce the production of pyrolysis products. Thermowood™ is a thermal modification process using steam and high heat treatment to increase the durability of wood. The process takes between 48 and 96 hours depending on timber species, width and initial moisture content. Thermowood is made primarily to improve certain properties of softwood.

Thermowood™ process can be divided into 3 parts; high temperature drying, heat treatment and cooling. As a result of the high temperature applied to the wood, the substances which reduce the lifecycle of the wood, such as glucose, citric acid and resin that exist at the inner part of the wood are removed and the rest is crystallized. The product is more decay resistant, less likely to absorb water and may have some colour change (darkening). The process is seen as being more environmentally friendly as it does not use chemicals, while the wood is easier to dispose of at the end of its life.

In principle the heat treatment process can be applied to all wood species and the market for non-chemical, untreated but durable wood is already large and seen as having green credentials and encouraging ongoing expansion. This treatment will expand market options for radiata pine timber as untreated radiata has low durability, especially where it is exposed to moisture. Also, thermowood radiata has a hard surface and thus it is highly applicable in floorings as an example. The current targeted end-uses include decking, garden applications, joinery and flooring but also different infrastructure applications. Current supply is in the range of 150–200,000 m^3 pa and is predicted to increase as various leading global timber companies may choose to invest in this technology.

3.1.3 Pathway 3: Biorefinery – opportunities for underutilised wood fibre and residues

Early in this study it became very evident that there was no likelihood for a new pulp mill in the Limestone Coast region due to the high level of investment required. For pulp mills to be most profitable they need to be located close to the raw material source, as for example is the case in Brazil where mills producing approximately 1.5 million tonnes of pulp from hardwood require an investment in excess of A$ 2 billion. This scale of pulp mill is not feasible for the Limestone Coast region, although the location would have high potential for a "simplified pulp mill concept" when this development become commercially viable.

Matters that affect commercial viability of bioenergy plants include quality of available feedstocks, issues of collection and logistics as well as existing energy costs with which it must compete. The existing energy costs clearly provide more incentives for development of alternatives to the traditional sources of energy. In Australia, however, there exists relatively low cost coal power stations and it would be difficult to compete with these directly without suitable mandates for alternatives such as greenhouse gas reduction incentives. An opportunity exists to significantly increase bioenergy as a means for Australia to achieve its target of 20% of national power obtained from renewable energy by the year 2020. Currently, solar and wind dominate this landscape, with opportunities for biomass far less developed despite some clear advantages.

In this report a number of energy biorefinery routes have been considered (see Table 5 and Appendix 6 for details) using the following assumptions regarding the feedstock costs: cost of chips A$ 138 per bone dry tonne (bdt), sawdust 68 A$/bdt, bark 68 A$/bdt, and forest biomass 80 A$/bdt.

Production costs of these routes using different raw materials are shown in Figure 14.

Table 5. Summary of selected energy biorefinery routes.

Route	Time to market	Feedstock[#]	Scale [*]	Yield (main product)[+]	Main Product[^]	End-use
Bio CHP	Present	Forest residues, sawmill residues, HW, SW	small/large	20% (HHV basis)	Electricity, heat	Sawmill electricity and heat (drying), grid
Extended Bio CHP	Medium / long term	Forest residues, sawmill residues, HW, SW	small	20% (HHV basis)	Electricity, heat, ethanol	Sawmill electricity and heat (drying), grid, transportation fuel
Hydrolysis I	Present	HW, HW forest residues, HW sawmill residues	large	24% (mass basis)	Ethanol	Transportation fuel
Hydrolysis II	Medium/long term	Forest residues, sawmill residues, HW, SW	large	32% (mass basis)	Ethanol, lignin	Transportation fuel, lignin markets
Pyrolysis	Present	Forest residues, sawmill residues, HW, SW	small	65% (mass basis)	Bio-oil, char	Boiler fuel
Pyrolysis with oil upgrading	Medium/long term	Forest residues, sawmill residues, HW, SW	small	32% (mass basis)	Upgraded bio-oil (diesel, naphtha), char	Transportation fuel, boiler fuels
Small scale gasification	Present	Forest residues, sawdust, bark, HW, SW	very small (15% of sawmill residues)	24% (HHV basis)	Electricity	Sawmill electricity and grid
Gasification with FTL synthesis	Medium term	Forest residues, sawdust, bark, HW, SW	large	18% (mass basis)	FT-diesel	Transportation fuel
Gasification with SNG production	Medium term	Forest residues, sawdust, bark, HW, SW	large	60% (HHV basis)	SNG	Natural gas replacement (pipeline)
Pelleting	Present	Forest residues, sawdust, bark, HW, SW	small	97% (LHV basis, excl. drying)	Pellets	Boiler fuel, residential heating, export
Torrefaction with pelleting	Present	Chips (HW, SW, Forest biomass or sawmill chips)	small	77% (mass basis)	Torrefied pellets	Coal replacement in power plants
Hot water extraction prior to pelleting	Medium/long term	Forest residues, sawdust, bark, HW, SW	small	78% (LHV basis, excl. heat generation)	Pellets, ethanol	Boiler fuel, residential heating, export, transportation fuel

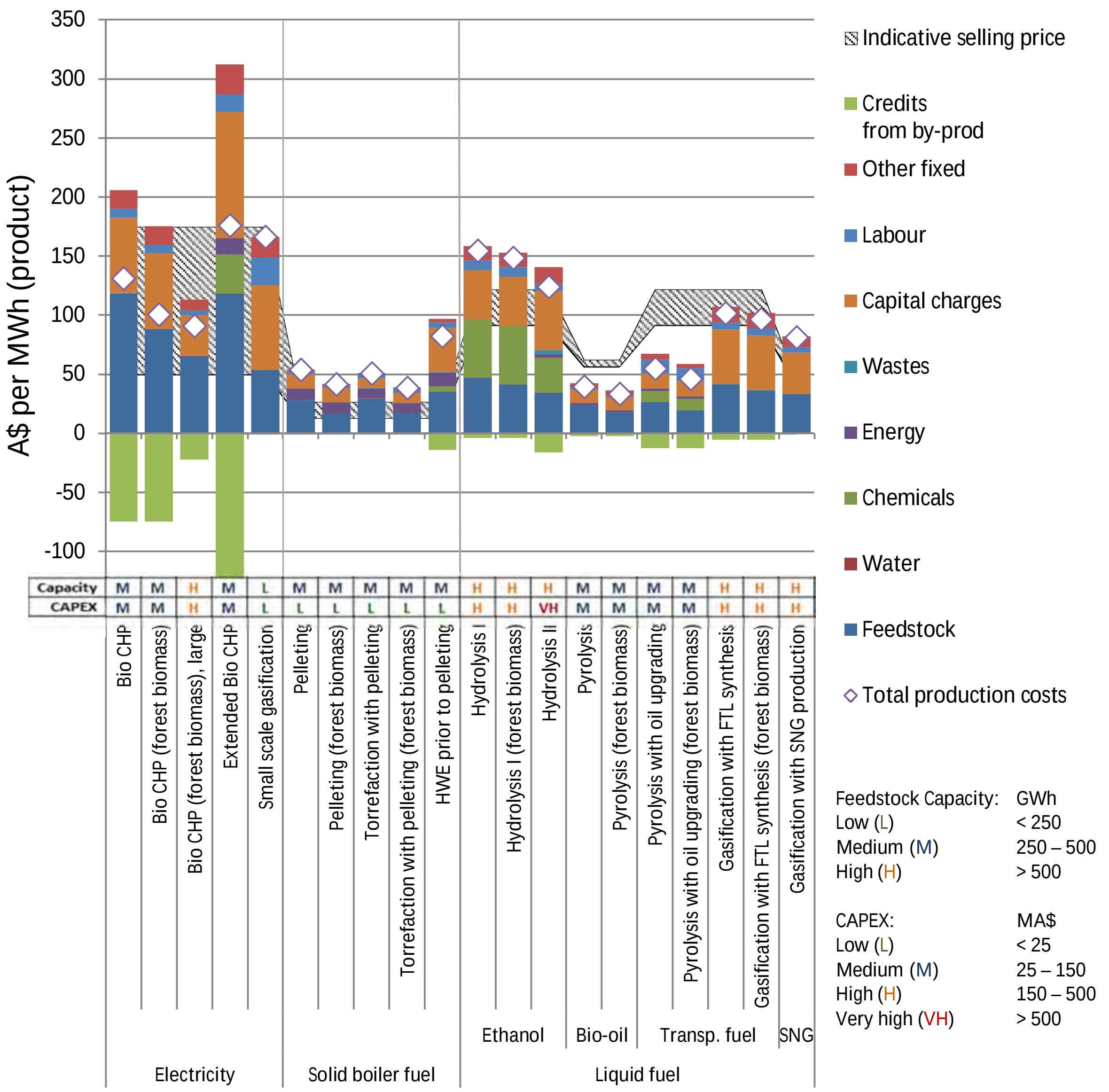

Figure 14. Production costs in energy biorefinery routes selected for this study. Costs are shown as positive A$/MWh and by-product credits as negative A$/MWh, main cost categories are shown with different coloured bars in the histogram. Total production costs assigned to the main product are shown with white diamond. NOTE: The routes produce different end products and the costs are therefore not comparable, instead all routes should be compared against their products' respective sales price range (indicated with the shaded area). The design biomass capacity and magnitude of capital expenditure are presented as low (L), medium (M), high (H) and very high (VH)

There is suitable quality and quantity of available feedstock in the Limestone Coast region. The current price level for typical feedstocks can however be a challenge for some biorefinery routes. If typical sawmill chips with price of about A$ 140 per bone dry tonne (bdt) (70 A$/$m^3$) are the feedstock then biorefinery processes do not look particularly attractive. However, the residual forest biomass with price of 80 A$/bdt (40 A$/m^3) or below improves the economics of the energy biorefinery significantly. Furthermore, long term guaranteed feedstock supply is important, ideally 10–20 years to ensure reasonable lifetime and profitable operation of the bioenergy facility.

In the implementation of any biorefinery, the focus should initially be on the most industrially advanced technologies, such as pyrolysis or torrefation, while at the same time keeping options open for more diversified product portfolio. A diversified biorefinery produces several products, such as bioenergy and biochemicals to mitigate risks and maximise returns. A more diversified industry would enable the development of regional cluster structures for local bioenergy and biochemical production. The target products could include precursors for plastics and chemical industries; wood-based chemicals, such as fuels, pharmaceuticals, oils, water purification chemicals, and flocculants; and biochemicals and converted products.

For example, on 22 August 2013, Kauppalehti (the Finnish equivalent for Financial Times) reported that biorefinery projects based on such mature technologies are in an acceleration phase in Finland (Semkina 2013) with investments expected to increase by hundreds of millions of Euros in the coming years. This flow of investment is not only a result of the long lasting product development but also a favourable regulatory environment. The key policy instruments for endorsing biorefineries in Finland are distribution obligation to the liquid transportation fuels and tax incentives. In Finland there is currently legal obligation to mix renewable components in gasoline and diesel to at least 6% rising to 20% by 2020 as a result of European Union policies. Today, there are nine active biorefineries in Finland, another eight under construction and a further eight in the planning phase. The biggest Finnish facility is UPM's biorefinery in Lappeenranta, Finland, that utilises tall oil. Its production capability is 1200 GWh at an investment cost of A$ 245 million and is due to be completed in 2014.

If chips at price of 70 A$/m^3 or higher had to be used then costs in many energy biorefineries would be too high but if side streams or residual forest biomass was utilised at price of 40 A$/m^3 or less then there would be the potential for profitable production of value add bio-products. Should the biomass price would be even lower than the forest residue price then clear benefits are seen: Solid biofuel production routes become promising (pelleting and torrefaction with pelleting), and pyrolysis becomes even more attractive, assuming that heavy fuel oil users have suitable technology for replacing their fuel with the bio-oil. The production costs of other liquid biofuels also decrease with lower feedstock costs, especially in the case of Fischer Tropsch liquids production for diesel replacement. It would be advisable to design the plant for low cost biomass feedstocks only, thus wood chips are clearly too expensive at the moment. In the case where forest biomass is the only feedstock of a larger combined heat and power (CHP) plant using grate furnace, then electricity production cost is also clearly lower due to a higher power-to-heat ratio. Furthermore, these processes could benefit from integration into an existing or extended sawmill platform.

Therefore, VTT suggests that an energy biorefinery could be set up in the Green Triangle region, with a collaborative partnership between the major local players. The biorefinery could be developed either as a stand-alone unit or as an integrated unit with a sawmill. According to the analysis, the first and the most promising option would be to produce pyrolysis oil for use in boilers and kilns. This is due to the ready availability of commercial scale technology and its relatively competitive production costs. The second potential energy biorefinery option would be for the production of torrefied pellets. Torrefaction is technologically feasible, but in order to produce solid energy products one would require regulations and incentives for fossil-based fuel replacement. The third potential energy biorefinery option would be heat, power and liquid fuels by gasification. As with torrefaction, gasification based systems would require incentives and/or regulations to guarantee the long term feasibility, due to the high capital costs requirement of gasification needed to achieve cost-competitive production scale. In addition, the technological readiness level of gasification is somewhat behind fast pyrolysis and torrefaction. The fourth potential energy biorefinery option would be combined heat and power (CHP) based on combustion. The economic feasibility of this alternative is, however, highly dependent on the availability and fluctuations of electricity prices. The scale of the energy biorefinery operation and the cost and type of input biomass will influence profitability, and thus should be a subject for further analysis.

Pathway 3, recommendation 1: Bio-oil by fast pyrolysis

In general terms, pyrolysis is a thermal conversion process where the raw material is treated in an inert atmosphere in the absence of air or oxygen with final temperatures of ca. 500–600 °C (e.g. Demirbas 2008, Vamvuka 2011). The main pyrolysis processes may be slow (conventional) or fast pyrolysis. The conventional slow pyrolysis has been applied for thousands of years and has been mainly used for the production of charcoal. Related processes have also been important sources for tar and many biochemicals, such as acetic acid and methanol.

Fast pyrolysis applies very short residence times (few seconds to a fraction of a second) at a typical temperature of (500–550 °C), to result in high yields of bio-oil (up to 70%). Fast pyrolysis is further characterized by high heating rates and rapid quenching of the liquid products, to terminate the secondary conversion of the products. The main use for the resulting bio-oil is the production of heat and/or power in plants currently using heavy fuel oil (HFO). In addition, it can be used in various types of HFO fired industrial kilns, such as cement and lime kilns. Australian mining companies are among potential users.

In a biorefinery setting, the fast pyrolysis route converts ground biomass into a crude-oil, called bio-oil that can be used as boiler fuel to replace fossil oil (Wright et al. 2010; McKeough et al. 2005). In this concept, the biomass is dried to 10% dry content using flue gas before being fed to the pyrolyser. The product oil is separated and purified from the solids and non-condensable gases before storage. The char formed as a by-product is combusted in a separate unit to generate steam/flue gases for drying and pyrolysis (fluidizing agent), with any excess char sold as a horticultural product.

Licella is an Australian company very active in this field. The company uses non-food, sustainable plant material, including forest residues such as sawdust, as the input source. It is mixed with water to form slurry and injected into a continuous flow, catalytic hydrothermal reactor (Cat-HTR) where application of heat and high pressure rapidly transforms the feedstock into refinery ready, “drop-in” biocrude oil (Figure 15). Licella has been the recipient of state and federal government funding to advance its technology, and is currently seeking to progress from the pilot plant to the pre-commercial phase. This represents an opportunity for the Green Triangle region which in the opinion of the authors should be actively pursued.

Figure 15. Licella commercial demonstration plant (http://www.licella.com.au/about-us/commercial-demonstration-plant.html).

Arguments for plausibility**:** Based on the analysis depicted schematically in Figure 14, pyrolysis of the forest biomass to bio-oil without further upgrading of the oil is the most cost-effective bioenergy route in terms of indicative selling price and investment costs. Feedstock requirements and investment cost are relatively moderate. It should, however, be taken into account that this technology (without oil upgrading) is just entering the industrial demonstration phase. There are still many uncertainties concerning the technologies and costs of the oil upgrading to transportation fuels.

Biomass requirements**:** The pyrolysis processes can be used for whole wood, debarked wood, and different harvesting residues and other industrial wood residues. Typically, clean debarked wood can yield bio-oil of up to 70% yield, although lower yields of 60% are more typical when residues are processed. Final product yield is high and the size of the plant depends, among other things, on the availability of biomass. In the plants being build or designed in Finland, the annual production capacity (as bio-oil) ranges from 50,000 to 90,000 m^3. Pyrolysis requires wood drying to below 10% moisture and milling to fine particle size.

Potential customers and markets**:** As summarised by Lehto et al. (2013), there are globally several fast pyrolysis plants under construction or in the planning phase. For example, in Finland there will be several plants with production scales of 50,000 to 70,000 m3, requiring approximately 90,000–165,000 tonnes of raw material (dry matter). From the perspective of the raw materials, certain similarities between Finland and South Australia can readily be recognised, as in both areas the harvesting residues would form the bulk of the feedstock.

Potential revenue streams in 3–5 years**:** Pyrolysis oil production technology to transportation fuels is at a pre-commercial phase and both plant design and construction require substantially more development before commercial production can begin. For these reasons, no revenues can be expected in 3–5 years time. Pyrolysis technology to heating oils is at commercial scale, and first plants could be realised in next 3–5 years, including in Australia. In South Australia, the value of annual pyrolysis oil sales could reach A$ 20 million. Furthermore, potential longer term customers (5–10 years) could include oil refineries capable of converting bio-oil to biochemicals in existing or re-engineered oil refineries. As a recent example, Shell was one of the main partners in the large EU-funded project “BIOCOUP” (www.biocoup.com), coordinated by VTT, that developed technologies for bio-oil refining in conventional oil refineries. The lack of refining facilities close to the Green Triangle region is a complicating factor.

Required capabilities and competencies**:** Several companies are currently offering pyrolysis technology for the production of bio-oil, and thus “normal” chemical engineering and maintenance knowledge is sufficient. It is noteworthy that transportable pyrolysis plants of different capacities are available or under development, for example by ABRI-Tech Inc., Canada. The introduction of new technology and pyrolysis oil as a product to potential consumers will be a challenge.

Key enabling technologies and required infrastructure**:** The successful realisation of a wood pyrolysis industry in the region will require well-organised working systems for the collection and handling of wood residues and other suitable input materials, the handling, storage and delivery of products in addition to the erection of the pyrolysis plants. Other enabling technologies include bio-oil quality and stability improvement and upgrading technologies.

Business cases**:** As mentioned previously (cf. Lehto et al. 2013), numerous plants are currently either under construction or planned in countries including Finland, Sweden, USA, Canada, and Malaysia.

Companies in the field**:** Examples of major companies include Fortum, Metso, Green Fuel Nordic; UOP (Honeywell), and Australian mining companies.

Pathway success factors: Integrated pyrolysis oil production at a sawmill is already close to being financially sustainable. What is required to drive the development is identification of potential bio oil users in Australia or export markets, investment support from government or public bodies and/or reduction of wood cost from the current level of 55 A\$/m^3 to 40–45 A\$/m^3 or lower.

Figure 16 presents the bio-oil (fast pyrolysis) production costs as function of capacity for different feedstock prices. In the figure, the diamond represents the base case scenario for the pyrolysis (forest biomass) route. The maximum equipment sizes currently available in the market are in the range of 50,000 to 90,000 m^3 bio-oil/a.

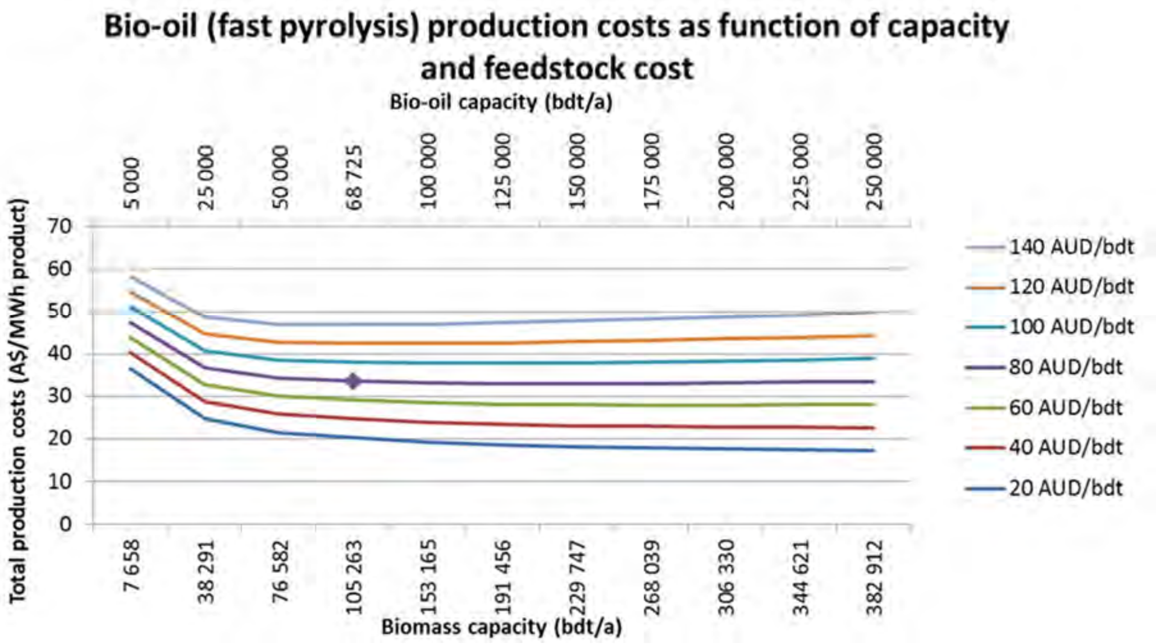

Figure 16. Bio-oil (fast pyrolysis) production costs as function of capacity and feedstock cost.

Pathway 3, recommendation 2: Biochar by torrefaction

Torrefaction is the second recommendation for the bioenergy route. In torrefaction, relatively large dried wood particles (chips) are heated to 200–300 °C at atmospheric pressure and in the absence of oxygen. All volatile compounds of the biomass are evaporated but no combustion reactions take place in the process. About 90% of the biomass energy content is obtained in the torrefied biomass, which is often pelletized because of its very low bulk density.

TOP-process (combined torrefaction and pelletisation) (Bergman et al 2005), is considered in this analysis. In this route, the feedstock needs to be of larger particle size compared with pyrolysis and gasification and for this reason sawdust and bark cannot be used. If necessary, the chips (sawmill or forest based) are first converted to a uniform size, dried using burner flue gases, and then torrefied. The flue gases are also used as heat for the torrefaction reactor. The torrefied material is further milled or ground to smaller size following the same principles as for pelletising. A lower overall yield compared with pelleting is achieved because part of the biomass is combusted in the process. Additionally, fuel is needed.

Based on the assessment shown in Figure 14, torrefaction of forest biomass with pelleting appears as a promising option. This was also confirmed by the Pöyry assessment (Appendix 7, section 7.3) which indicated torrefaction to be a plausible bioenergy route for a large sawmill, provided appropriate policy incentives are applied. In addition, it is a well developed and inexpensive route.

Arguments for plausibility**:** The argument for torrefaction in South Australia is its potential for coal replacement in power plants and the metal industry with a sustainable fuel (biocoal with higher energy value than normal pellets). There is also a possibility to use available and underutilized forest residues such as tops and branches. Moreover, biochar can be used as a soil conditioner and biogenic carbon sink.

Biomass requirements**:** Torrefaction can utilize sawmill residues, forest/harvesting residues and whole wood chips. Sawdust or bark cannot be used. The final product yield is in the range 50–77% depending on process design and technology selection. Minimum feedstock requirement for feasible operation is around 150,000 m^3 of wood chips annually.

Potential customers and markets**:** Power plants, particularly those utilising pulverized coal, can co-fire torrefied biomass. In the metal industry, torrefied biomass can replace fossil coking coal in steel mill blast furnaces.

***Potential revenue streams in the time span of 3–5 years*:** The value of annual torrefied biomass product sales depends on production scale, but using a 50,000 t/a plant as a test case the sales value is of the order of A$ 10–15 million.

***Required capabilities and competencies*:** Basic engineering skills needed are in woody biomass handling and drying, as well as knowledge on thermal processes and process safety due to explosion risks associated with torrefaction technology.

***Key enabling technologies*:** Biomass drying technology, torrefaction technology and technology for pelleting or briquetting are the key enabling technologies.

***Business cases*:** Several development projects and demonstration plants are at various stages of construction and pre-commercial operation. However, currently there are no fully commercial industrial scale plants in operation.

***Required infrastructure and ecosystem*:** Connections between metal and forest industries should be established, while transportation could be realised through existing coal transport routes. If harvesting residues are used as feedstock, collection and transportation chains should be developed and built. Final product logistics for domestic consumption or export opportunities will need to be established.

***Companies in the field*:** Power and mining companies operate in the region and are potential end users. Long term domestic or export contracts would be needed as currently there is no existing local market for torrefied biomass. Potential technology vendors for collaboration include Andritz, Topell, Arba Flame, and Areva.

***Pathway success factors*:** Based on a preliminary analysis, the production of torrefied biomass product for energy markets is not financially sustainable at current wood and biomass (pellet) prices. In order to create a profitable business case for torrefied biomass in South Australia, significant incentives for biomass use in heat and power production will need to be created. A dramatic increase in the demand for biomass in energy production in the Asia Pacific region would have a positive impact on the price of biomass products.

Figure 17 presents the torrefied pellet production cost as function of capacity with different feedstock prices. In the Figure, the diamond represents the base case scenario for the torrefaction with pelleting (forest biomass) route. Similar trends are seen as for pyrolysis route, while equipment sizes planned for this pathway are in the same range.

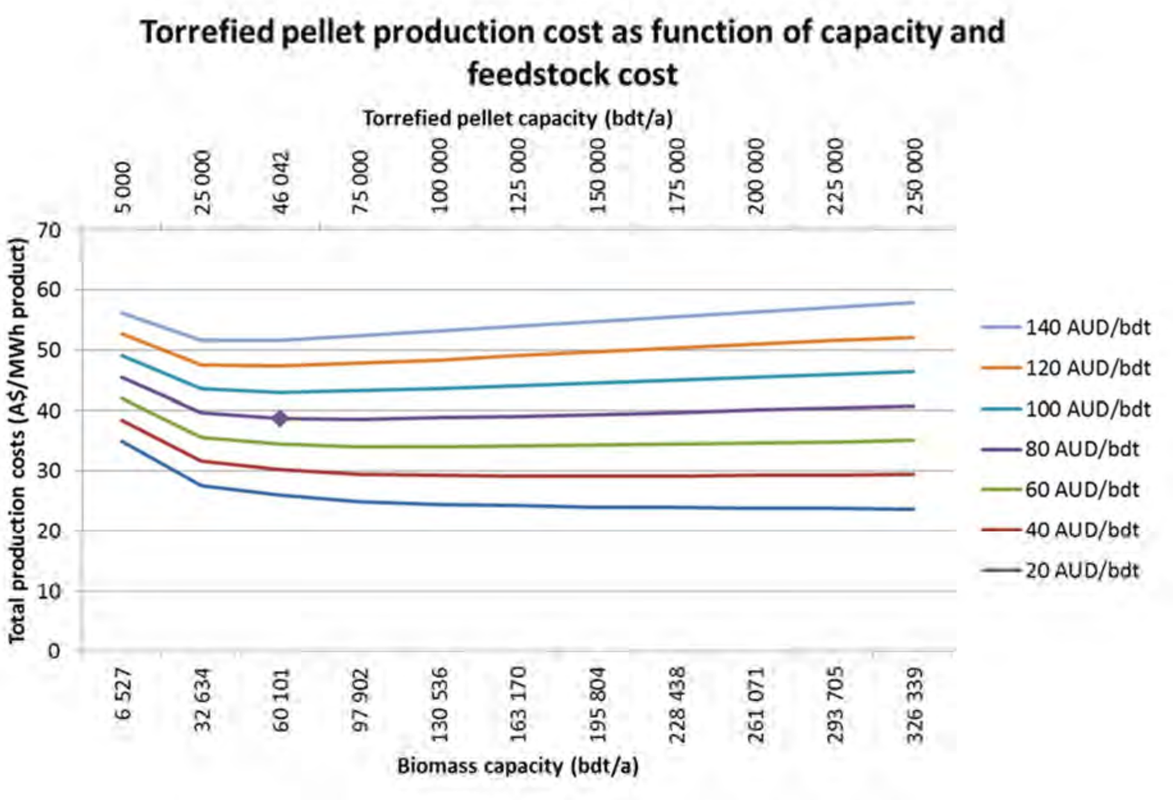

Figure 17. Torrefied pellet production cost as function of capacity for different feedstock prices.

Pathway 3, recommendations 3 (and 4): Power, heat and biofuels by gasification

Gasification is a high temperature (>700 °C) conversion of solid, carbonaceous fuels into combustible product gas which is used commercially in heat, power and CHP production. The gas made in this process is cleaned and processed to form a so-called syngas, the composition of which can be controlled.

Depending on the final goal, gasification processes can be used either for the direct production of heat and/or power, hydrogen, synthetic methane or liquid transportation fuels and/or chemicals by chemical synthesis after very effective syngas purification. Transportation fuels may be FT-diesel, methanol, dimethyl ether (DME) or gasoline. Various chemicals can also be produced from syngas, including ammonia, olefins and aromatics.

Alternative gasification technologies have been used for different biomass feedstocks and different applications. High-pressure, oxygen-blown entrained-flow gasifiers originally developed for coal and oil gasification are also being developed for biomass-based syngas production. Major industrial developments are ongoing; in Germany using solid wood fuels and in Sweden using black liquor from the pulping industry. Raw pyrolysis oil can also be used as the feedstock.

The other main gasification alternative is fluidised-bed technology, which can be either oxygen-blown direct gasification or indirectly-heated steam gasification. These gasifiers usually require less feedstock pre-treatment than entrained flow gasifiers but produce more tars and light hydrocarbon gases, which need more complicated gas purification systems. These technologies are presently being developed by two industrial groups in Finland, as well as other players elsewhere.

Arguments for plausibility: This is a key technology that has many different application areas ranging from simple fossil fuel replacement in energy production to production of synthetic transportation fuels and chemicals. Progress in gasification technology is directly related to the renewal of the forest and wood products industry. Simple and low-cost gasification systems can be used to replace fossil fuels in industrial kilns and power plants, while the production of syngas for transportation fuels or green chemicals require more complicated process concepts. A recent VTT technology study has shown that product price for gasification based transportation fuels to be quite competitive especially if the biomass cost would be of the order of 30–40 A$/bdt, which is one-third of the average Finnish price for forest residues (Hannula & Kurkela 2013).

Biomass requirements**:** Fluidised-bed gasifiers are very fuel-flexible and can utilise the same raw material as pyrolysis but with lower level of feedstock pretreatments. However, if the production of transport fuels or chemicals is pursued then the quantities will be larger than in pyrolysis. FB-Gasifiers do not require wood milling but simple crushing to below 50 mm particle size is sufficient. As an example, the forest company UPM's planned facility in France would produce around 100,000 tonnes of biodiesel and consume close to 1 million m^3 of woody biomass as feedstock.

Potential customers and markets**:** Main customers are synthetic fuels and chemicals markets. Gasification is also suitable for oil and chemical companies.

Potential revenue streams in 3–5 years**:** Gasification of forest residues for syngas applications has been demonstrated on an industrial scale and the technology is ready for commercial realization. However, the required large plant size and high capital costs create challenges for commercialisation. First industrial plants could be realised in 3-5 years time-frame in Australia, but is unlikely. Best economics would be achieved at sites where by-product heat can also be utilised more effectively than by steam turbine cycles. In addition to renewable diesel production, methanol is an interesting end-product which opens routes for the production of gasoline and olefins for green packaging materials.

Required capabilities and competencies**:** Chemical and energy industry engineering; chemistry skills; demanding process development work and experience in operating high temperature and pressure processes.

Key enabling technologies**:** The key enabling technologies are biomass gasification, gas cleaning, gas to liquid synthesis, and different final product conversions, such as hydro treatment to diesel, methanol to gasoline (MTG) and methanol to olefins (MTO).

Business cases**:** For synthetic biofuel or chemical production, there are no commercial plants in operation. Fluidised-bed gasifiers have been in commercial use in Finland from the 1980's.

Required infrastructure and ecosystem**:** For synthetic biofuel or chemical production, the plant resource usage should be in the magnitude of 1 million m^3 of wood annually. Also, it would require well-operating and optimised raw material sourcing network. The investment cost would be high at hundreds of million of dollars (A$). Co-operation with major transportation fuel producers and distributors will be a necessity.

Companies in the field**:** Technology suppliers and development partners, such as Linde, Uhde, Foster Wheeler, Metso, Andritz, Technip.

Pathway success factors**:** Production of transportaion fuels via gasification is a long-term option. The availability of competitively priced, sustainable long-term feedstock supply is a key requirement. First steps in gasification technology could be taken by identifying fossil fuel replacement targets in heat and power production applications and in industrial fuel consuming processes.

Figure 18 presents FT-liquid production costs as function of capacity for different feedstock prices. In the figure, the diamond represents the base case scenario for the gasification with FTL synthesis (forest biomass) route. As was noted above, gasification plants requiring up-to 1,000,000 m^3/a of biomass have been proposed. Moreover, operating FT-synthesis plants (using stranded natural gas) have capacities of over 1.1 million m^3 FT-liquids per year, and proposed projects with three times higher capacities using coal as feedstock are being evaluated.

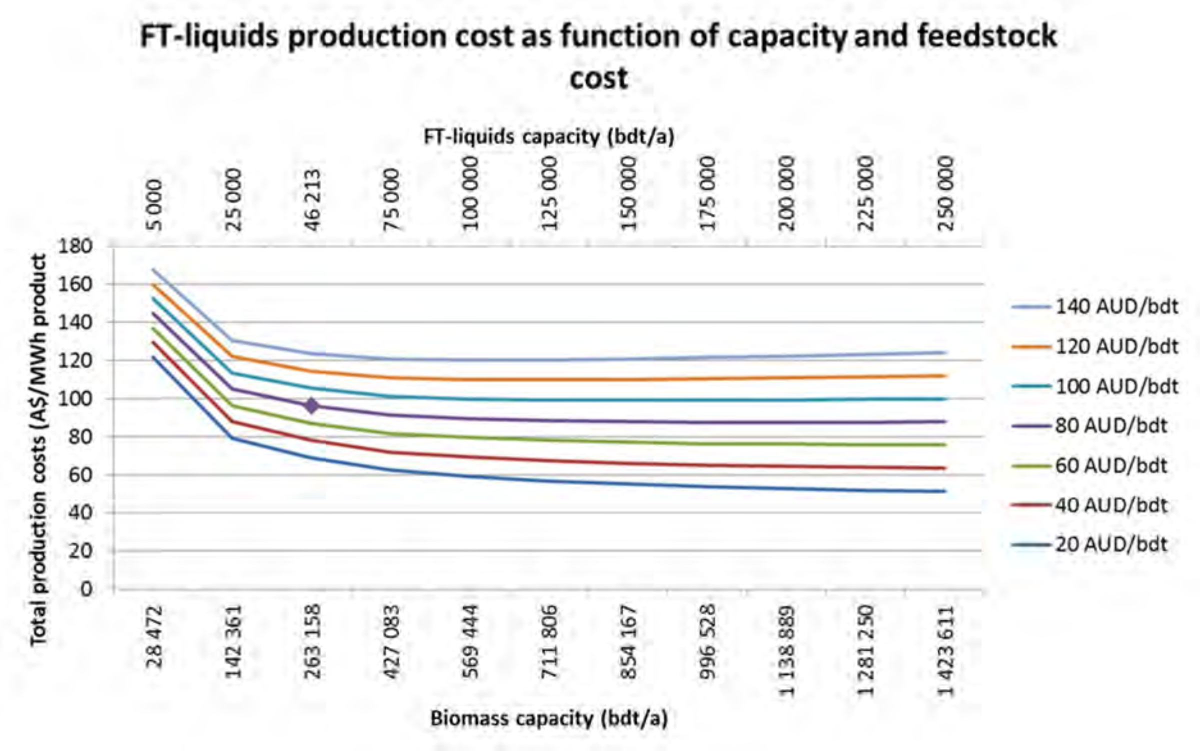

Figure 18. FT-liquids production cost as function of capacity with different feedstock prices.

3.2 Summary of the pathways with 3 to 5 year time horizon

This section presents two summary illustrations that consider the main recommendations in the three pathways advocated in the preceding section.

The Figure 19 presents a synthesising assessment, made by VTT's key technology experts in the project, of the key recommendations in the three pathways. The assessment is realised on a simple two-axis matrix; "Value-adding component" on the y-axis, with only two measures: "lower" or "higher", and "Connection to the present industrial structure of the Green Triangle" on the x-axis and also with two measures: either "somewhat compatible with the present structure" or "requires modications to the present structure". The idea is to show in a simplified manner how the recommended next steps would fit with the present structure of forest and wood products industry in the Green Triangle. It needs to be emphasised that this assessment is a comparative visualisation of the various options to assist with policy discussions and should not be taken as a strict scientific assessment. It is an interpretation of the pathways when set in a simplified structure.

As can be seen from the data in Figure 19, the recommendations are positioned, with minor exceptions, in the upper right corner of the matrix. Some recommendations require more changes to the industrial structure, but their value-added component would also improve. Some recommendations require less change in the industrial structure, but their expected value-add would diminish and be more uncertain.

The two key take home messages are:

1. All the recommendations have the potential to raise the value-adding component in the regional industry
2. All the recommendations would require modifications to the present industrial structure in the Green Triangle in order to be effective

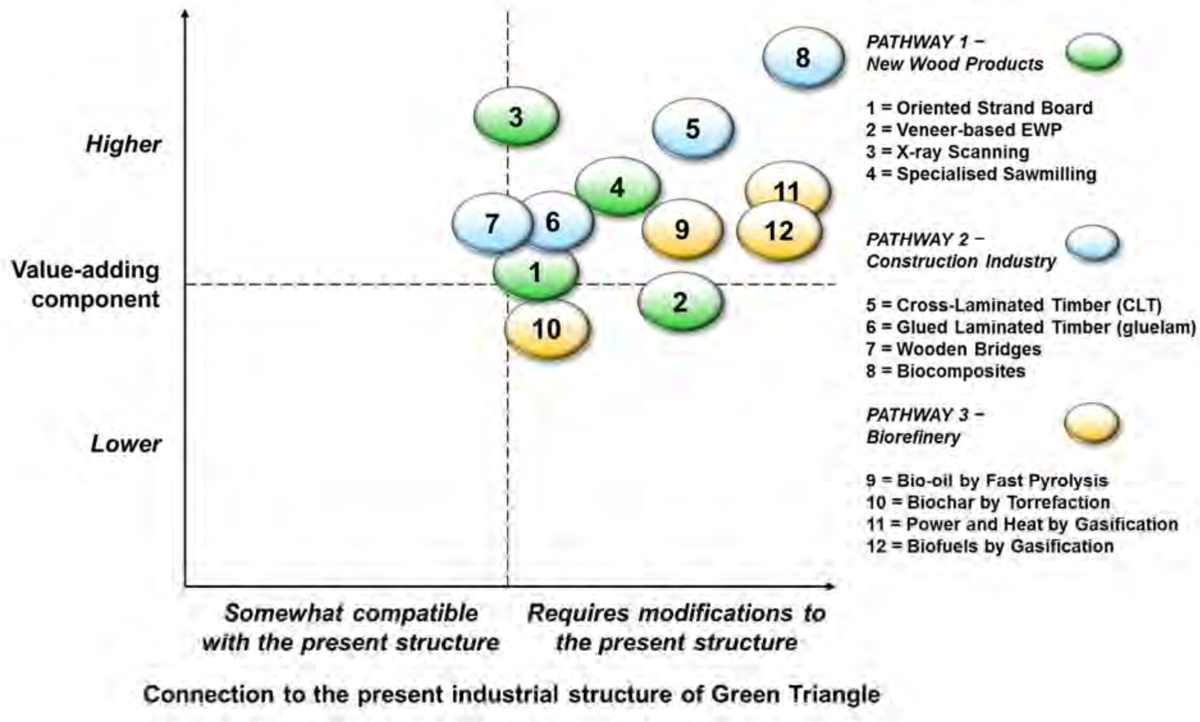

Figure 19. Key recommendations in a matrix.

The Figure 20 and 21 present stylised depictions of the potential performance improvements in the three main pathways. The key idea behind the visualisation is that by implementing some of the next step options, there is a possibility to catch the next generation of technology, and leap from a declining S-curve towards a new and still emerging technological S-curve. In other words, the different products advance the possibility to transform from the traditional forest and wood products industry towards a more advanced biomass and cellulose-based industrial path.

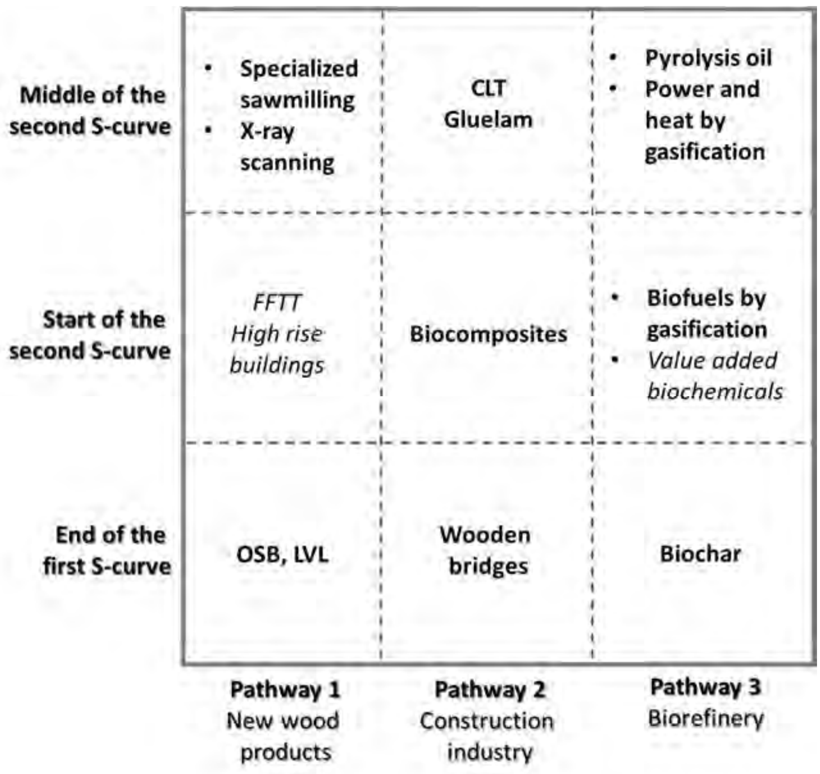

Figure 20. Performance improvements in the pathways.

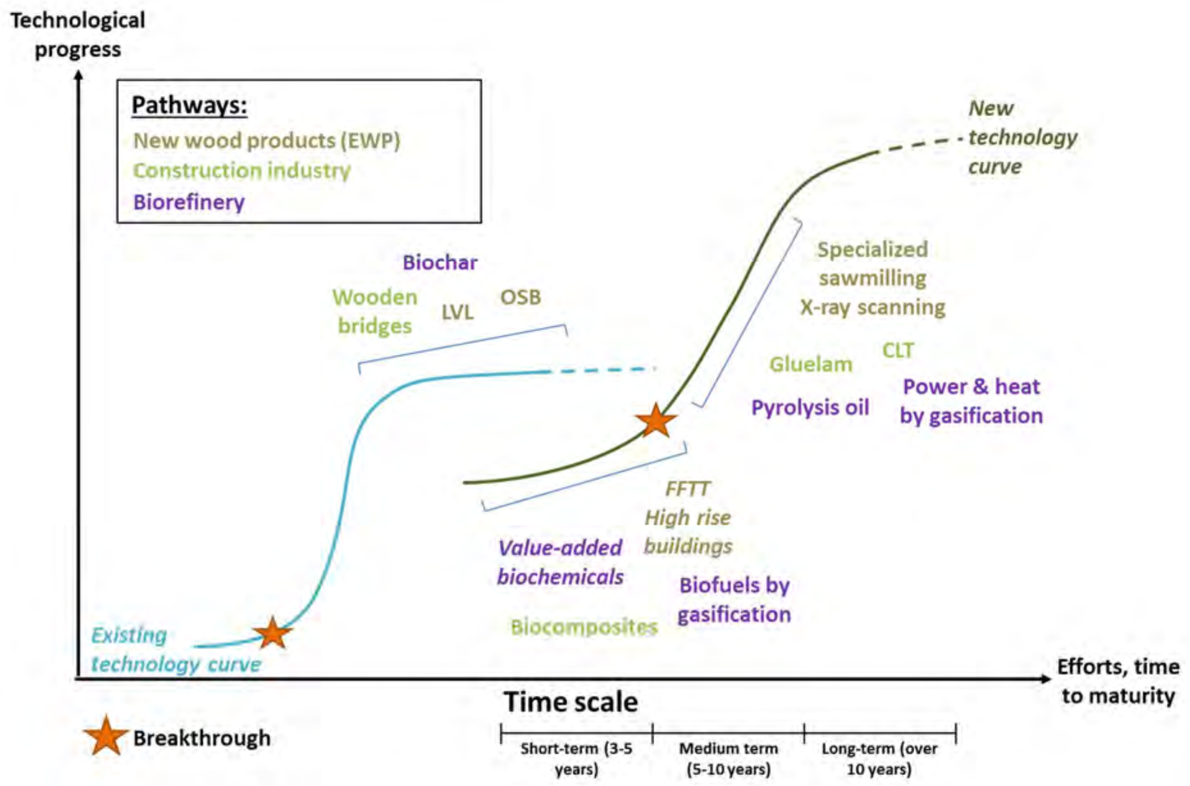

Figure 21. Technology evolution in the three suggested pathways. Position of each technology on the curve describes its current technological progress level and the time scale presents the estimated time needed until breakthrough is achieved or the technology is matured.

3.3 Introduction to the pathways beyond 5 year time horizon

This section presents recommendations that are beyond the 3 to 5 year time frame, but according to our evaluations, could hold potential as future options for Green Triangle forest and wood products industry, particularly should a fledging biorefinery industry have commenced in the region in the interim. Therefore, these ideas should be viewed not as medium term options for the Green Triangle region, but rather as opportunities for a more diversified biomass based industry going forward. In assessing the options, consideration has been given to unique Australian aspects such as the local biomass and scarcity of water, which may well mean that solutions found as being suitable in North America, Europe or Scandinavia may not necessarily be applicable here without substantial modification. In fact, it may well be that technologies observed as highly effective elsewhere may have a limited future under Australian conditions. For this reason alone, South Australia (and more generally Australia), needs to maintain or develop a suitable forest-based capability to take advantage of any opportunities.

3.3.1 Pathway 4: Adsorbents and membranes for local opportunities

Cellulose based materials, especially nanocellulose, may be designed, developed and optimised into novel bio-based foams/filters/membranes/adsorbent materials with high and specific selectivity using nanocellulose and combinations thereof for decentralized industrial and domestic water treatment. Stable membranes/ filters that withstand the flux and pressure during the purification process without compromising on the perm selectivity may be developed by methodologies including control of pore size, orientation of pores, layered multiple functionality, atomic layer deposition (ALD) treatment of the porous surface of cellulose materials.

Functional external stimuli sensitive filter surfaces for reduced bio fouling and enhanced filter cleaning or intelligent design of membrane modules from tailored cellulose materials allowing self cleaning, antifouling and increase the service-life of the membranes are futuristic but work is already underway (EU Project Nanoselect; http://nanoselect.eu/). NanoSelect focuses on the design, development and testing of membrane based prototypes in collaboration with industry with specific focus on the removal of toxic chemicals, heavy metal ions, pesticides, fertilizers etc. from contaminated industrial water and portable modules with high selectivity towards bacteria for drinking water. In addition, the membranes will be evaluated for disposal by composting and its impact on environment at the end-of-life. These bio-based functional membranes provide a highly energy efficient but cheaper, biodegradable, non-toxic and green substrate for water treatment. This should be of particular interest to South Australia as the driest state in the driest continent in the world and where water salinity is a real and ongoing concern, both in both drinking water and for industrial applications.

Another line of research has led to the development of superadsorbent hydrogels that are chemically or physically cross-linked networks which are water-insoluble but capable of absorbing large amounts of water, saline or physiological solutions compared with general absorbing materials. Hydro-gels based on naturally occurring products are of interest not only for their renewable character and nontoxic nature but also because they may offer biocompatibility and biodegradability. Superadsorbent and hydrogels possess a degree of flexibility due to their significant water uptake properties (up to 20-400 g of water/g of an adsorbent material) and they are potential material candidates, for example, in tissue engineering, controlled drug release and hygiene products. All are extremely high value added materials (see Pohjanlehto et al. 2011).

Smart, intelligent, stimuli-sensitive or -responsive, environmentally sensitive, functional materials react to stimuli such as temperature, pH, solvent content, ions and light by yielding a response that is usually reversible, e.g. a phase transition, collapse-swelling, colour change, or conductivity change.

VTT, amongst many other research organisations are actively working on these fibre derived carbohydrate-based materials such as hydrogels and membranes.

Another related and equally important development is foam forming technology which gives exciting opportunities to develop new recyclable and light weight wood fibre products. It also gives a possibility to decrease raw material usage and production costs remarkably compared with existing technology. With foam forming technology it is possible to improve paper properties and/or to manufacture high porosity, smooth and light weight products (e.g. hygiene products, insulation materials and filters). There is also an opportunity for it to be a cost effective solution for various printed intelligence, nano- or microcellulose applications.

3.3.2 Pathway 5: Cellulose fibres in textiles

The use of cellulose fibres for textiles in order to replace cotton has been the topic of significant levels of research worldwide, and is currently estimated to have a potentially high future business impact. The subsequent demand will transform the bulk cellulose business to one that focuses on the premium design applications of cellulose. Effectively this will be equivalent to the “Eiffel Tower moment” that affected the possible height limits of buildings for the cellulose industry. All that will be needed is the 21st century version of the Spinning Jenny to revolutionise the industry and create a totally new business ecosystems in Australia.

This type of design will evolve from and be implemented by an integration of expertises of chemistry, manufacturing and machine technology, as well as improved sustainability and business development for the new value chain concepts for cellulose products.

However this would currently necessitate the location of a pulp mill in the region which, as already mentioned, is most unlikely. However, a recent development on small-scale pulping using an organic solvent is showing some promise (Lignofibre technologies), and if successfully scaled could be transformational and make this opportunity even more attractive.

Lignofibre (LGF) organosolv pulping method is based on cooking wood and non-wood materials with organic solvents, such as ethanol or acetic acid, in the presence of phosphinic acid (H_3PO_2), and has been developed recently at VTT. The LGF process aims at separation and recovery of all lignocellulosic components, i.e. cellulose, lignin and hemicelluloses, at high yield. The properties of cellulose fibres produced in the LGF process depend on the choice of solvent. For example, when cooking with ethanol, suitable material for enzymatic hydrolysis is obtained and further fermentation of the monomeric sugars into bioethanol looks promising. However, when acetic acid is used as the cooking solvent, production of bioethanol is not a viable alternative, since acetylation of cellulose is known to take place, leading to inhibition of enzymatic hydrolysis. One high potential application is in dissolving pulps and the various cellulose-based products derived from them. In fact, the general suitability of organosolv pulps for dissolving pulps has already been established. As the demand for regenerated cellulose, and thus for dissolving pulps, is estimated to increase during the next decades, organosolv processes could offer a feasible alternative for the production of these pulps.

3.3.3 Pathway 6: Bio-based chemicals and polymers

Biobased chemicals and polymers (Figure 22) are part of the development of next generation cellulose products and in particular the development of added value products from hemicellulose and lignin. This should be of interest to the Green Triangle region as a net producer of biomass.

Hemicelluloses and celluloses are the most abundant of the natural polymers, and their availability practically outranges the current volumes of plastic production. There are opportunities for the use of xylan and cellulose derivatives. Routes to chemicals and materials useful for coating and packaging include films, barrier materials and coating binders.

Figure 22. A transparent and flexible film obtained from a butylated and allylated xylan.

The key state-of-the-art solutions that should also be considered are bio-based platform chemicals and polymers that have more than one application, e.g. natural polymers modified like starch and biobased materials like polylactic acid PLA have established a position in the biodegradable plastic market. A key tendency is also from proven biopolymers towards composites, and the development of business and market development in the field of biopolymers and composites. Gums, latexes, resins, essential oils, bioactives are also being increasingly produced by current industries using components from all parts of the tree. Moreover, the potential uses of these chemicals and their derivatives in the food industry should not be underestimated. In the near future shale gas may lower the price of PE and make novel and cheap bioplastics even more attractive. These suggestions for bioplastics are thus interesting, but they still include high risk when it comes to challenging proven technology.

Activities in Australia on bio-based chemicals is limited, but the Melbourne based Circa Group (http://circagroup.com.au/) is actively pursuing the conversion of lignocellulosic waste and other residues into value-added renewable chemical products using proprietary technology. Their breakthrough process produces levoglucosenone, a high-value chemical intermediate that has considerable potential for the manufacture of pharmaceutical ingredients, agrochemicals, polymers and speciality chemicals. Encouraging such companies to locate their operations in the Green Triangle region is something that should be actively pursued.

It is highly probable that there will be a wider use of bio-based raw materials in various packaging applications and product segments in the future. The Green Triangle underutilised fibre could play a significant role in this value chain.

New plant based foods to meet dietary, flavour and sustainability requirements of food are being developed from plant-derived fibre, and represent another opportunity where a watching brief needs to be maintained.

3.3.4 Pathway 7: Opportunities in nanocellulose

Nanocellulose has been shown to have the potential to be very useful for a number of future technical applications. The key to understanding how nanocellulose will behave in different applications is to have a thorough understanding of how the structure and interactions of nanocellulose affect its function and hence its suitability for different applications. One large cost of producing nanocellulose comes from the energy input required for defibrillation of the starting materials. The processing energetics comes from understanding the fundamental thermodynamics of the system as well as the most energy-efficient route towards it (Figures 23 and 24).

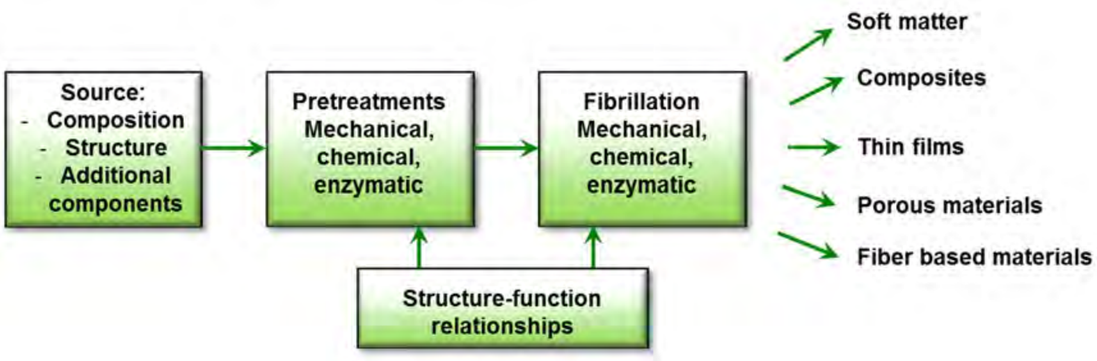

Figure 23. Nanocellulose processing: the flows of material and process steps. A strong link in understanding the whole chain, especially how the starting points affect applications, gives versatile and competitive expertise for developing applications and technology.

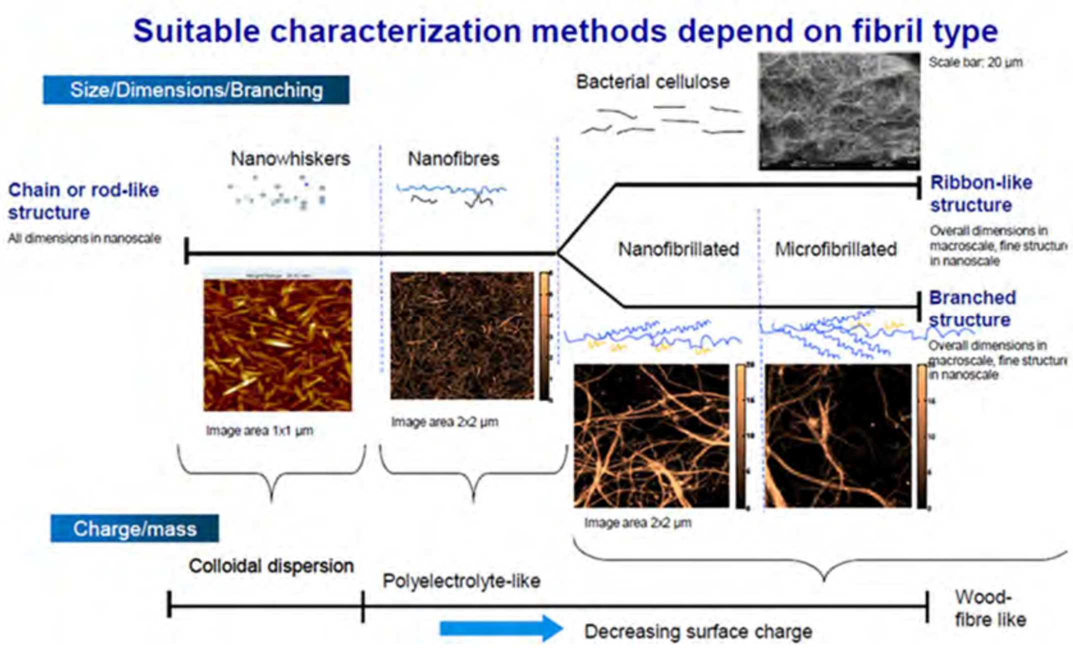

Figure 24. The typical sizes of nanocellulose and tailoring the surfaces to different needs.

Nanocellulose research is underway in many locations around the world and one of the leading players is VTT (Figure 25). The rapid pace of development will see significant advances that should be watched very closely.

Figure 25. On the left, nanocellulose foam. On the right, printed film of nanocellulose manufactured in pilot scale through controlled adhesion, spreading and drying of NFC without any wiremarkings (VTT).

3.4 Recommended policy actions to support all pathways

The evidence gathered during the roadmap process invariably points to the following conclusion: the advanced biomass based industry is unlikely to achieve a successful outcome or be severely hindered without the right policies and incentives in place, as has been the case in North America, Europe and elsewhere. Therefore, the technologies and processes identified and prioritised in this report as being attractive for the Limestone Coast should be supported with sets of well-planned policies. This could be challenging in the Australian context where for the biomass industries there exists currently regulatory and legislative uncertainty and even fragmentation between different jurisdictions and government departments. Clearly, where duplication or confusion exists, every effort should be made to alleviate or eliminate the complexity. Rather than being active drivers in the creation of future environments for the local industries, policies on biomass utilisation in Australia have tended to lag and be reactionary. Several policy oriented recommendations follow.

Policy action 1: Promote and increase the use of wood in the society

Wood and wood fibre should be encouraged as a generic option for industries. There are many arguments to endorse the use of wood. For example, wood is a logistically credible solution as it can be sourced locally and weighs less than steel. Wood is a green, renewable and a sustainable material. Wooden constructions are good containers of carbon dioxide and the construction can also be unequalled in energy efficiency.

Promoting wood across the society should be encouraged through different pathways, with the prime consideration to affect building legislation and building codes that will enable the use wood in construction options such as house construction, public buildings, bridges, high-raise apartment buildings and the like. This can be enhanced through networking and collaboration within and between industries (forest, wine and mining), policy makers, research units (CSIRO, universities and appropriate international organisations) and non-government bodies.

Any program should aim to build on the momentum created by the Wood: Naturally Better™ campaign initiated by Forest & Wood Products Australia (FWPA; http://www.fwpa.com.au/). Launched in 2008, this industry initiative, together with associated programs, has actively promoted, with considerable success, the many benefits of wood to working professionals as well as the general community.

The collaboration can take place in workshops aimed at training and raising awareness, cross-industry workshops, creative projects between like-minded industries that are biomass based (such as the forest and wine industries) that share best practice philosophies and by developing supplier development measures. Another approach would be to create networks between producers, consumers and other potential partners, including forest owners, harvesters and hauliers, integrated sawmill operators, biorefinery owners, ship owners and the mining industry. There are good examples of such collaboration in Finland, with the SHOK system; national strategic centres of excellence and especially the bioeconomy shok being the prime example. Additionally, different public-private partnership structures, such as European initiatives SPIRE (Sustainable Process Industry through Resource and Energy Efficiency; http://www.spire2030.eu/) or BRIDGE (Biobased and Renewable Industries for Development and Growth in Europe; http://bridge2020.eu/), can be used as potential benchmarks.

The longer term target for Green Triangle should be the creation of cross-industrial collaboration groups as, for example, between the forest, wine, agricultural and mining industries, and possibly other value-chain sectors centred on cellulose-based products and utilising virtual concepts. The Finnish Centre of Nanocellulosic Technologies is based on such a system and is a good example to evaluate.

Policy action 2: Build education strategies for cellulose based industries

The key for the entire Limestone Coast is to build capabilities and skills commensurate with the needs of both the existing and proposed new industries. The education system should pay attention to the training of architects and construction engineers able to plan and build facilities from wood. It should also be capable of training engineers with a specific focus on biomass-based industries via new education programmes in the universities, exchange schemes for workers in forest and products industry, and transformation programmes for engineers currently employed in related fields and wishing to be re-trained. Realising these demanding targets will require communication and interaction between universities, industry across the full value-chain, industry associations and policy-makers. Successful relationships can be found in Europe, notably in Finland, Sweden and Austria.

The starting point from the perspective of Green Triangle is that whatever the focus of the education and training programmes, they should be modular and allow distance education. To organise the training, one should consider setting up a national training network in cellulosic industries - composed of companies, universities and government actors - that would aim towards modular programmes through systematic identification of educational gaps.

Buy-in from the union movement, and particularly those intimately associated with the forest-product and allied value chains, is a necessary pre-requisite for success. Unions in Australia (South Australia included) are strong advocates of skill improvement for its members and any programs they have should be modified to reflect the new opportunities identified in this report.

State government has a role to play as an initiator of training programmes in co-operation with universities, research organisations and companies. The programmes could be distributed through industry organisations to ensure a more business focus. In order to realise the education target, there should be strong links with like-minded international research bodies and appropriate visiting programs for industrial practitioners and academics at all levels. The European Union provides a good example of where different programmes, such as COST actions, stimulate the exchange of ideas and co-operation across Europe. Many research projects funded by the European Union require collaboration across the jurisdictions as a necessary pre-requisite. Another good example is the Finnish Distinguished Professor Program (FiDiPro) that enables distinguished researchers, both overseas and local, to team up with the best and so make a difference.

At the very least, the education strategy needs to reverse the disastrous trend of the last few years that has seen a significant reduction in the forestry and forest product scientific research capacity in Australia across all the major players; private companies, universities, CSIRO and state governments. The impact of this change has been well documented in a position paper recently prepared by the Australian Forest Products Association (AFPA; http://www.ausfpa.com.au/site/). Their proposal for government to commit $50 million over 4 years to create a National Institute for Forest Products Innovation (NIFPI) and to better organise/enhance current capacity is worthy of serious consideration and debate, as would other suggestions that have been advocated from time to time i.e. the recommendation from the Pulp & Paper Industry Strategy Group to fund a Biorefinery Research Institute or the advocacy by others for a Biorefinery CRC.

The proposal described in AFPA policy paper includes two possible structures for the NIFPI based around a central organisation coordinating the research activities at a number of sites and institutions.

Whether such an arrangement best meets the requirements for the Green Triangle region is questionable but, at the very least, the idea is worthy of further consideration and debate.

Policy action 3: Create targeted government policies and policy instruments

When considering targeted public policy measures to influence industrial development, all policy measures should be carefully selected to match with the maturity of technology and product life cycle, identified entry barriers for new products in the marketplace, and capacity of local firms to take advantage of new opportunities. Optimally, the policy measures should aim at influencing both supply for and demand of new products based on novel technologies. In the following, policy measures are outlined for each potential industrial transformation pathway.

The policy actions discussed here are based on the presumption that sawmill process improvements and technology ugrading, presented in the previous sections, are already being implemented in some form. Available policy should aim to build industrial capacity by subsidizing training programmes, initiating awareness raising campaigns together with relevant industrial associations, and promoting international benchmarking of best available technologies. Financial policy instruments can be used to facilitate large investments associated with any technology upgrade. The government can also support research and education institutions to build technical competencies and develop relevant technical services to industrial firms (see also Roos 2012b).

Creating incentives for the local industry to diversify to value-added products for construction sector along the second pathway can be supported by various policy measures lowering entry barriers of new products to the marketplace thus promoting their demand. The main object of the policy should be to reduce risks associated with adopting new wood material components in construction industry where buildings have a very long life cycle. Building codes and other regulation impacting use of new wood-based products can be revised by implementing performance-based norms in construction. Performance-based norms regulate functional properties of building materials (e.g. durability, fire resistance) but are neutral with regard to technical properties of materials used. This will create room for alternative materials such as wood-based building components meeting these functional requirements. Government may also facilitate new product entry by ensuring availability of technical testing and verification services and promotion of product standards. Collaboration with bodies granting certificates for green building ratings systems should promote recognition of environmental credentials of wood-based products. Direct demand for wood-based construction materials can be stimulated by public procurement when investing in municipal buildings (schools, health care facilities) and infrastructure (bridges). Awareness raising campaigns can be used to influence perceptions among professionals and the public at large about benefits and safety of wooden-based constructions. Finally, as large markets for some of the added-value construction products are found overseas (e.g. Japan), export promotion measures should be also considered when the industry is ready to introduce new products.

As for the third pathway, the primary target of policy measures encouraging industry to move towards value-added products for bioenergy should be twofold. First, policy should support industry to build technical skills and production capacity in biorefinery technologies. As implementation of biorefinery concepts at industrial scale requires sizable investments the government can share some of the risk in building the technical capability by co-financing demonstration sites and industrial pilots. These pilots can be also used as training facilities for professional capacity building purposes with local educational institutions. Second, policy should facilitate emergence of a market for bioenergy products. The most intensive policy measures include environmental obligations and fiscal measures such as tax incentives. Communication campaigns can be also considered to assure the public that risks associated with adoption of new technologies with potential hazards (e.g. explosion risks) are minimized. Finally, as some of the potential biorefinery technologies, most notably pyrolysis, has potential applications also in metal industry, government can provide support to building cross-industry capabilities through knowledge transfer programmes.

Policy recommendations concerning the fourth pathway towards advanced biorefinery build on the assumption that a second generation biorefinery industry has taken off in the region. The principal target of policy is to support building technical capacity in the industry and supporting institutions to shift into next generation biorefinery concepts along the maturation of technologies. Knowledge base can be strengthened with support to research and development, education, and testing and piloting facilities. Institutional environment can be strengthened by promoting standardisation of biorefinery products based on wood fibre such as biocomposites. Regulatory environment should be also revised not to maintain any unnecessary barriers to advanced sustainable biorefinery products such as biocomposites in comparison with conventional products based on fossil resources.

3.5 Summary: cumulative outcomes of the proposed actions and roadmaps

This final section of the “where to next” summarises the pathways and key recommendations. It also takes a more forward-looking perspective to the future potential of the Green Triangle. The cumulative outcomes of the three main pathways can be summarised as depicted in the Figures 26 and 27.

Figure 26 provides a synthesis of the proposed actions and roadmaps. It wraps up the key messages emphasised in this project:

- Engaging the three pathways, and the presented next steps, will raise the value-adding component of the industry
- The three pathways can be implemented in parallel: the upgrading of the industry could start with process improvements, then move toward value-added products for the construction industry and then towards energy biorefinery
- The transformation of the regional industry is a long-term process that should have a strategic perspective of over 10 years or longer
- It would be beneficial for the strategic perspective to be jointly constructed and shared by the regional operators
- Visionary long-term targets for the region could be a full-scale diversified biorefinery with multiple value adding products as in shown schematically in the Figure 27

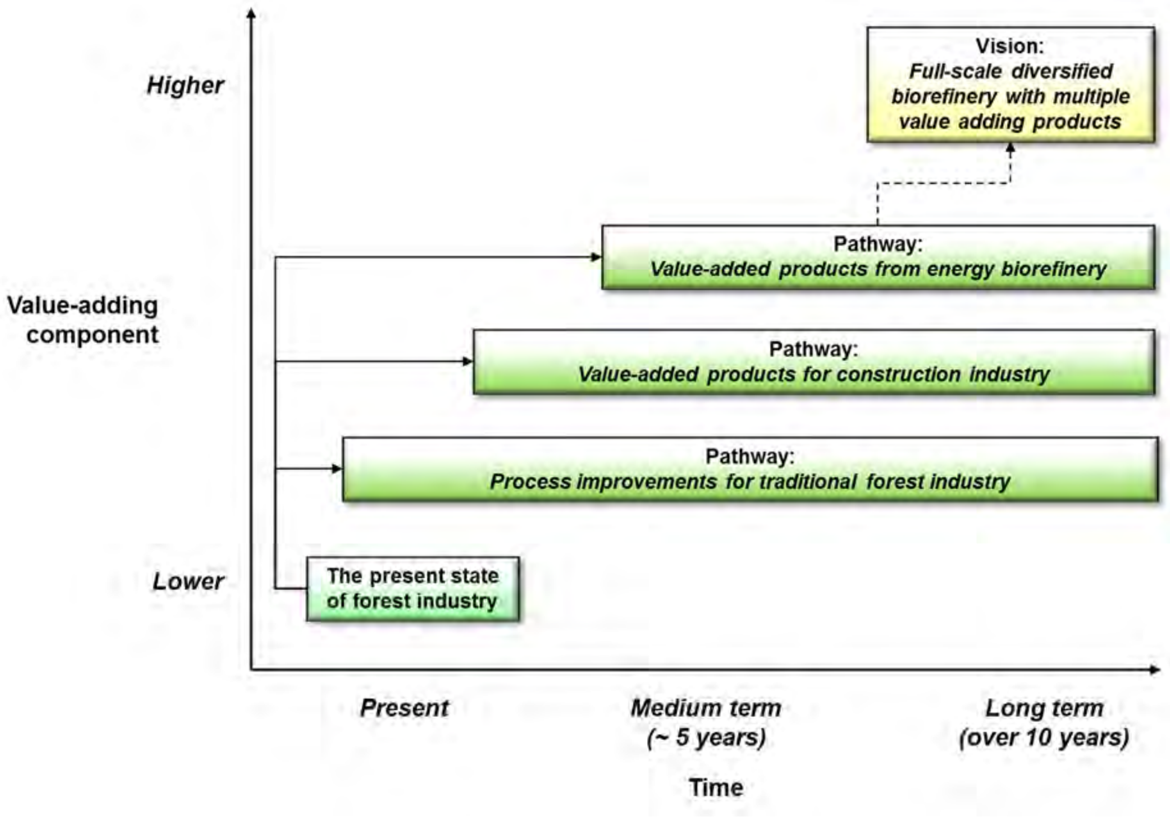

Figure 26. Synthesis of the proposed actions and roadmaps.

The future sawmills need to become more diversified and specialised. Some sawmills would retain their current core business, but would be under heavy pressure to modernise their processes and technologies. Some sawmills would specialise towards more value-adding high-end products, like building materials, wood products and different processed fibres for making cellulose and chemicals. Some sawmills could move towards the biorefinery space, and produce advanced raw material such as biofuels, biochemicals and biomaterials. In this space, some sawmills could specialise as processors of residual materials from the forests.

The concept shown in Figure 26 envisages different sawmill types; traditional sawmills with modernised and more effective process technologies, sawmills that are specialised more towards value-added high-end products, and sawmills with activities in the biorefinery space. However, in this more future-oriented value network, there is also the possibility for sawmill functions to be radically altered. One foreseeable direction is the changing roles of the traditional sawmills towards more generic integrated processors of wood-based biomass, or so-called ‘biomass flow regulators’. These future ‘sawmills’ would be more like process factories that provide several biomass-based products, just-in-time and for different purposes.

The Figure 27 presents a prospect of creating an energy biorefinery platform based on the integrated functions of conventional sawmilling and the emerging technological pathways. The first component of the biorefinery platform would be the conventional sawmilling. In addition, there would be three new value-added components in this energy biorefinery: engineered wood products, biomaterials and bio-oil. Engineered wood products would focus on cross-laminated timber (CLT), laminated veneer lumber (LVL) and oriented strand board (OSB). The production of biomaterials would, in the first stage, consist of production of biochar, and the next steps could be biocomposites and biochemicals. The production of bio-oil would start with implementation of pyrolysis technologies and the next step, when the need to up-scale the production emerges, would be gasification. The energy biorefinery platform could also interact with a traditional pulp mill and a mill producing bleached chemithermomechanical pulp (BCTMP). However, the pulp mill would not be part of the integrated energy biorfinery platform.

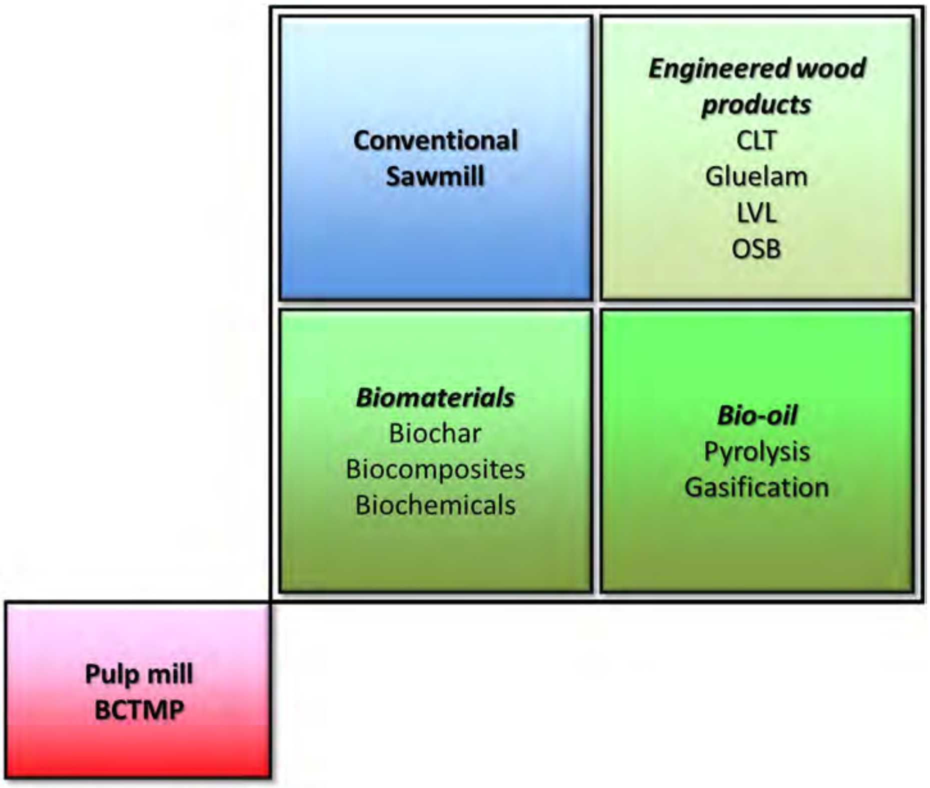

Figure 27. Energy biorefinery platform.

Figures 28 and 29 illustrate the differences between the hypothetical, fully developed energy biorefinery platform and current forest and wood products industry in Green Triangle at higher level of detail.

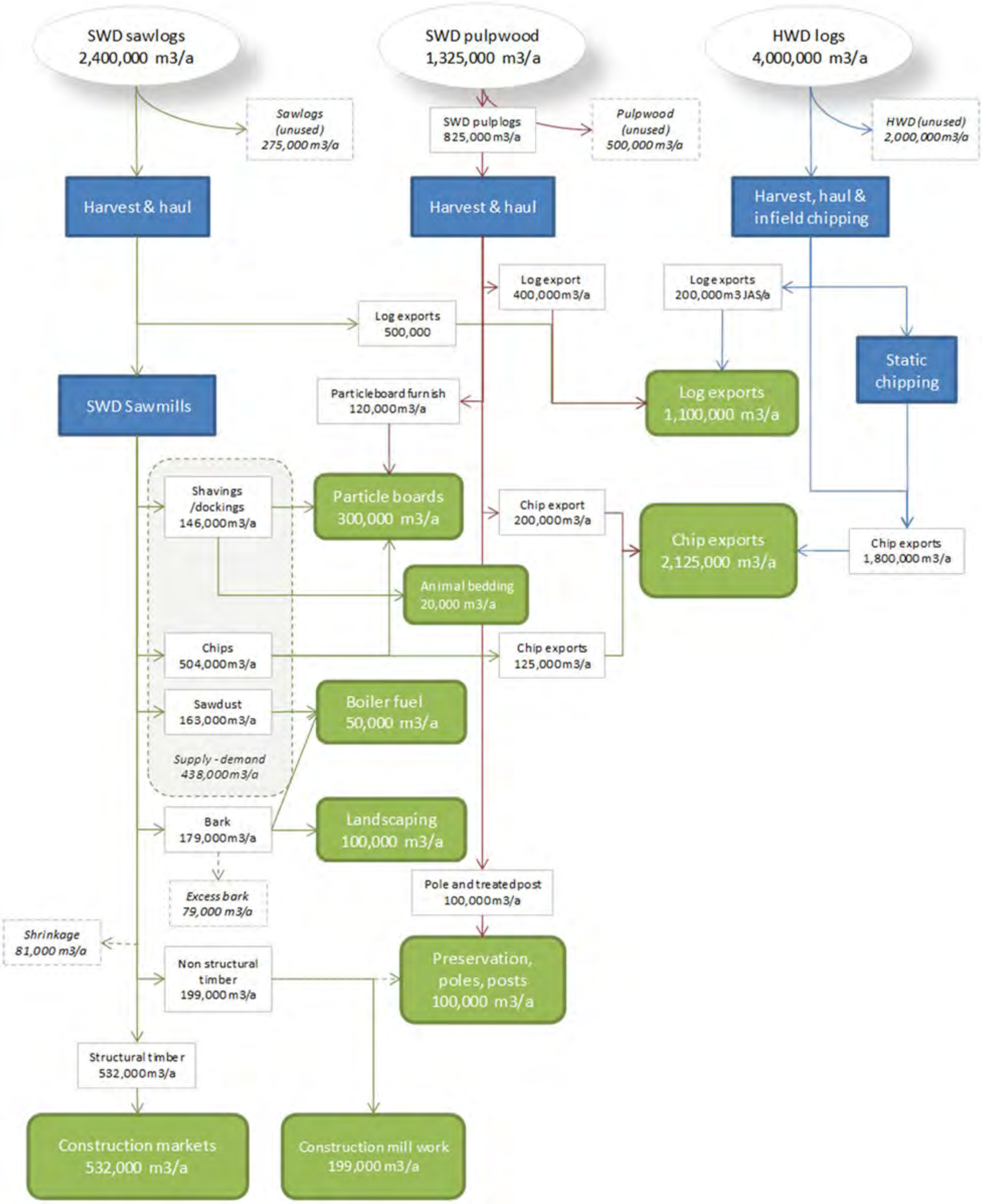

Figure 28. Wood and forest products flows in Green Triangle – current situation. Flows are presented in m³/a. White ellipses – feedstocks, Blue boxes – processing, Green rounded box – applications/demand, dashed boxes – balance/loss. Quantity of available raw materials is listed in Table 1.

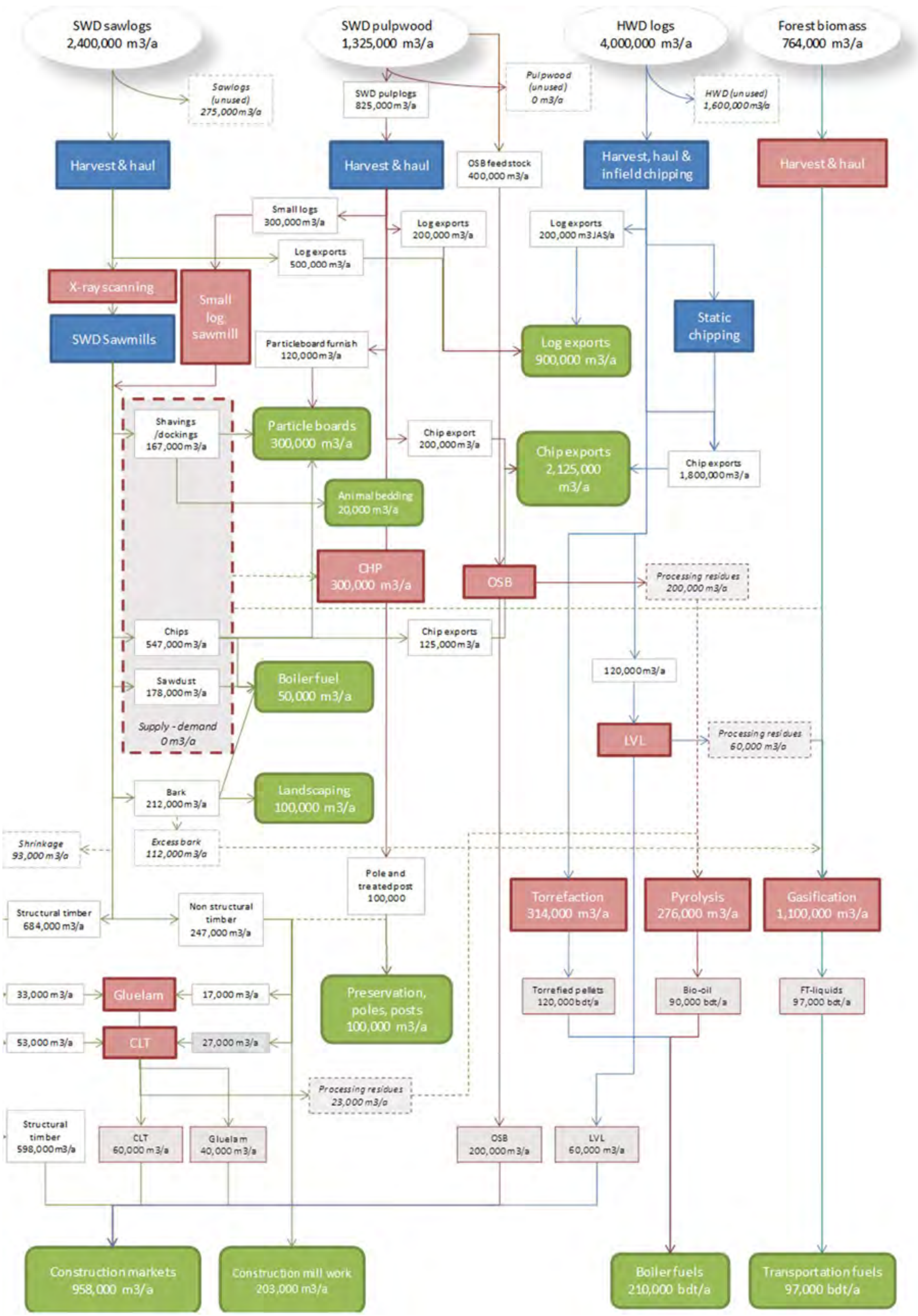

Figure 29. Wood and forest products flows in Green Triangle – hypothetical *future scenario. White ellipses – feedstocks, Blue boxes – processing, Green rounded box – applications, dashed boxes – balance, Pink – new processes/product flows. X-ray scanning, small log sawmills, CLT, Gluelam, OSB,* LVL, *pyrolysis, torrefaction with pelleting and gasification plants implemented. HWD logs used for LVL production and SWD pulpwood for OSB production. All processing residues, excess SWD pulpwood, HWD logs and forest biomass used as feedstock to the energy biorefinery processes,*

totalling 2,000,000 m^3/a biomass used in all biorefineries. Part of timber products is used for CLT and Gluelam production.

The major improvements are better utilisation of the sawlogs and biomass (both logs and processing residues), and a more diversified product portfolio. A comparison of sawmill efficiencies and timber yield is shown in Table 6 (for more details refer to appendix 6 in the associated report). Table 7 illustrates further the potential revenues resulting from the full implementation of the hypothetical energy biorefinery platform shown in Figure 29, together with the investment requirement.

Table 6. Sawmill yields for current scenario sawmill, hypothetical future scenario sawmill and small log sawmill.

	Current scenario	Future scenario	Small log sawmill
Structural timber	33%	38%	22%
Non-structural timber	12%	13%	12%
Chips	31%	25%	47%
Sawdust	10%	10%	8%
Shavings & dockings	9%	9%	7%
Shrinkage	5%	5%	4%
TOTAL	100%	100%	100%
Bark	10%	10%	10%

Table 7. Revenue increase from the forest products, total investment cost requirement of the implementation of the hypothetical future energy biorefinery platform and the feedstock costs. Production costs (variable and fixed costs) not included.

Process	Product	Prod. rate	Units	Price (A$/m^3)	Revenue (MA$/a)	Investment cost range* (MA$)	Feedstock cost** (A$/m^3 or MWh)
Sawmill (increase)	Structural timber	66,000	m^3/a	400	26	40 – 50	130
	Non-structural timber	4,000	m^3/a	180	1		
CLT	CLT	60,000	m^3/a	650	39	35 – 50	440
Gluelam	Gluelam	40,000	m^3/a	650	26	20 – 30	410
OSB	OSB	200,000	m^3/a	270	54	90 – 120	140
EWP	LVL	60,000	m^3/a	700	42	120 – 140	140
CHP	Power	136,000	MWh/a	50	7	114 – 190	90
Pyrolysis	Bio-oil	90,000	bdt/a	680	61	32 – 50	120
Torrefaction	Torrefied pellets	120,000	bdt/a	100	12	27 – 50	100
Gasification	FTL	97,000	bdt/a	1140	111	636 – 1070	460
Export	SWD pulplogs	200,000	m^3/a	70	-14	-	-
Total increase in revenues from the forest					365		
Investment requirement						1100 - 1700	

* Investment cost depends on the number of installations; for many technologies the hypothetical scenario total capacity would be possible to achieve only with one plant, except in the case of torrefaction
** Feedstock for the processes are illustrated in the hypothetical scenario (Figure 29); feedstock costs are fully allocated to the product of the technology and credits from by-products and all other costs not included

In the hypothetical future scenario, eight new products are produced and the total increase in sales value is estimated at about 365 MA$ annually, of which half comes from traditional and new wood products and the rest from the energy opportunities. Payback times for the lower capital cost options (small scale wood product and pyrolysis processes) are estimated at between 3–5 years. Payback time for the higher capital cost energy biorefinery option is more difficult to quantify as it depends on regulations and subsidies.

In the longer term i.e. beyond 10 years, the Green Triangle forest and wood products industry should develop the capacity for intensive collaboration with other industries. Firstly, the construction of a joint regional strategy is of crucial importance for the continuous renewal of the future forest and wood products industry in the region. The joint regional strategy should stress the formation of cross-industry cluster structures, and also align specific investment plans. The key idea of a joint strategy springs from the key principle of cluster theory: the concept of simultaneous co-operation and competition. It is possible that two companies might co-operate in some function, while competing in others. Both types of linkages also signal the same necessity; needs to open more information channels in the forest and wood products industry system of Green Triangle, and thus achieve greater information flow. Although the opening of these channels may be challenging initially, it is necessary in order to renew the industry and to raise the activity levels to achieve a creative ‘buzz’. This is the necessary baseline for more value-added industry structures.

Secondly, the construction of joint regional strategy should be complemented with improved planning and development activities, including different consultancy services, product planning and design services, forest management and planning services, solutions for precision forestry, and ICT (information and communication technologies) based services for forestry and process engineering. These would include different CAD/CAM/information model solutions.

Thirdly, it is important for the Green Triangle to build a strategy for enhancing its research and development (R&D) capabilities, in process and product development. The region should build organic links to world-class universities and public research organisations (PROs) that are active in these domains. Naturally, universities are primarily focused on research whereas firms are primarily focused on innovation, while PRO’s such as VTT are focused on both. One of the key underpinnings of successful regional industrial economic value-creation is a well-functioning innovation system of which universities and PRO’s are an integral part (Roos 2012).

These public research organisations (PRO’s), for example VTT operate with an innovation model that involves:

- Exploratory research to develop an area of capability or a technology platform.; this area is normally interdisciplinary or trans-disciplinary in nature; a good example is VTT’s development of leadership in biorefinery, an area that requires integration of material science, biotechnology, chemical engineering and fibre value chain know-how
- Further work to refine and exploit that knowledge in relatively non-standardised ways, often in collaborative projects with industry, or through the use of a dedicated production facility
- More routinised exploitation of the knowledge, including consulting services, licensing or spin-off company formation.

The Figure 30 presents VTT’s version of this approach. In principle, the core funding of a research and technology organisation is primarily intended to pay for the first or exploratory stage of the innovation process, where the knowledge and capabilities needed to support its industrial customers are developed. On a narrower definition, this is the key element that distinguishes a research and technology organisation from a technical consultancy. The public money is used to create the capabilities the institute needs to take companies ‘one step beyond’ what they could otherwise do, thereby providing social returns by reducing the risk of innovation.

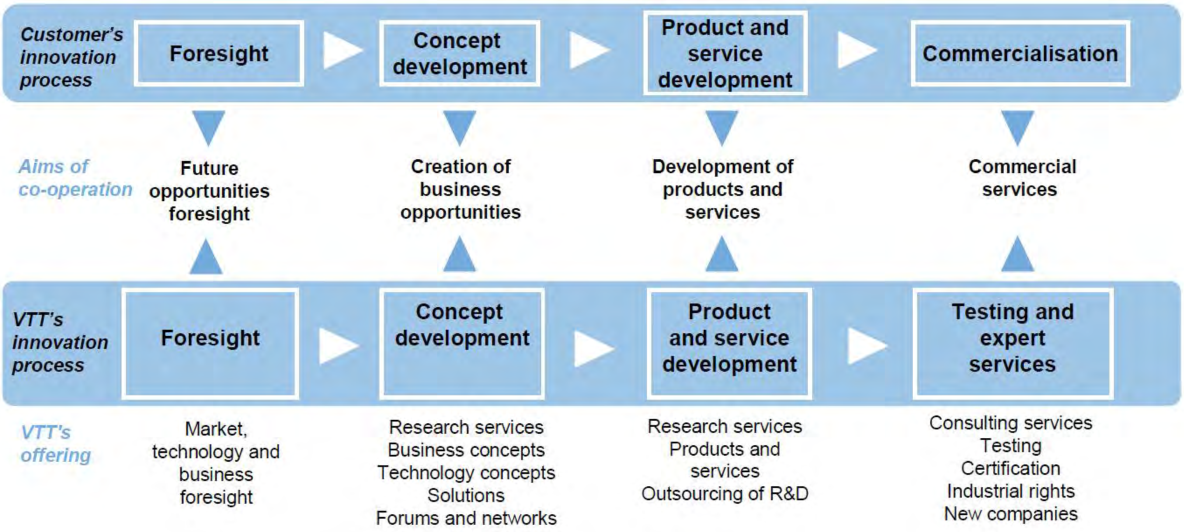

Figure 30. The linkages between customer's and VTT's innovation processes.

From the firm perspective it is clear that there are many dimensions to innovation, such as technology-based, design-based, business-model based, efficiency-driven and effectiveness-driven innovations. On the firm level these are usually executed in an integrated way. In the Green Triangle, in such an SME economy, the importance of research and technology organisations tends to increase, since they can live up to the requirement of having both insight into the firm's reality and insight into the research result space. The future the forest and wood products industry, in general and in the Green Triangle in particular, is heading towards what can be called an advanced biomass-based process industry, which will be increasingly reliant on more advanced R&D competencies than the traditional forest and wood products industry. Advanced biomass-based process industry will have significant emphasis on continuous product development. The industry will be formed partly on the basis of existing forest-based companies transitioning their product portfolios to include energy, materials and even food. This new industrial structure may also include other large companies and actors that are currently not engaged in activities involving wood fibres such as petrochemical companies as an example, or even players with no previous association with forestry or forest products.

4. Summary of the roadmaps

Mass lens: more efficient traditional forest and wood products industry

The key present drivers for the increased use of wood are resource scarcity, sustainability and emission policies. In the medium term new policy incentives could emerge at the federal and state level to favour wood as a raw material in different industrial settings. Also, the need for an affordable, safe and comfortable societal environment is rising. In the long term a new driver will be energy efficient buildings.

Presently, large scale markets exist for wood-based construction and high-rise housing in the US and Europe, coupled with an increasing need to attain low cost timber of premium quality. In the medium term, the uses of the wood in the construction industry will develop and vary. For example, wood could be used in building bridges. There is also a rising need for construction materials that enable industrial production of prefabricated components. In the long term, advanced zero energy and easy-to-modify buildings with specific parameters will emerge. There will be specific needs to control acoustics in wooden constructions.

It would be important to start a state-wide PR (public relations) process for marketing wood as widely applicable and sustainable resource. For Green Triangle, the critical issue is to form a joint regional strategy among the key players in the region. The key players from the regional perspective are the saw mill owners as well as technology providers. In the medium term, it is important to continue the state-wide PR process. Also, the Green Triangle joint strategy development should be continued and intensified. In the long term, it can be envisioned that Green Triangle will have a new industry cluster specialising in value added fibre-based production.

To realise the new value-added fibre-based production, the key present objective is to develop value added products from raw materials and side streams. The following processes, applied in Scandinavian sawmills, could be transferred to Green Triangle: specialisation also in small logs, applying moder equipment like oriented strand board, veneer based engineered wood products, X-ray scanning and geometring scanning, using improved sorting, using thinner blades, practicising outsourcing, and developing new grades. In the medium term, the creation of value added products from raw materials and side streams is emphasised. Innovative construction technologies and solutions for public premises and housing are rising in importance. There is also an increasing emphasis for the diversification of wood production. In the long term, new products such as materials to control microclimate in buildings and wood-based easy-to-use technologies for modifying structures on site will emerge. In the construction sector, new foam-fibres will be used as insulation, and these will be related to the development of wood components. Also, 3D-manufacturing of building components will gain prominence together with new fibre board technologies.

The present state-of-the-art enabling technologies apply modular thinking that could be key perspectives, along with enhanced process efficiency, when forming a joint regional strategy in Green Triangle. A key state-of-the-art enabling technology is the vision recognition of timber, which should be integrated with new planning systems and integrated information system models. Other state-of-the-art enablers in this category are X-ray scanning combined with artificial intelligence. In the medium term, new enabling technologies that aim for the production of cross-laminated wood and massive glued beams will grow, while the utilisation of ICTs (information and communication technologies) will intensify. In the long term, the new enablers will be novel wood composite materials and emerging bio-based protective treatments for wood products.

Energy lens: industry renewal through energy biorefinery

The key present driver is a resource scarcity that widely affects societies and industries. It will push the industrial system towards the efficient use of raw materials; to use raw materials sustainably throughout the entirety of the lifecycle. The active CO_2 market is the secondary driver. Climate agreements and the related policy incentives to lessen the dependence on fossil fuels act as critical drivers in the energy lens. In the medium term, the drivers such as resource scarcity, CO_2 market, climate agreements together with related policy incentives, and development of fuel standards will collectively increase in impact. In addition, new drivers such as competition for biofuels will play a more important role. In the long term, the competitiveness of biofuel will become a key driver, as biofuel production reaches maturity.

Markets and consumer needs are currently regulated by the need for electricity. Today, it is important to fulfil biofuel requirements in safe way i.e. biofuels should be compatible to or complementary with existing fuels. In the medium term, new affordable biobased fuels in some form will be available in the market. Second generation biofuels are emerging rapidly. As these enter the market, there will be increasing competition between land for food and land for fuel production. In the long term, the question of biofuel pricing and pricing mechanism will rise in importance, coinciding with enhanced competition among the players.

International agreements currently set the standards in the field. The key players in the present and medium term are grid owners and utility companies. The forest and wood products industry, with logistics of biomass, will become an increasingly important player and sawmills will also play a key role. Already, the mining industry is a key user of biofuels in their fleets. In the medium term, the question of fuel blends, and community acceptance of biofuels as a local solution will be crucial. In the long term, and provided the question of blending is resolved, the mining industry will be the major beneficiary of local biofuel capacities. New players will enter the field, such as energy and biofuel companies.

The state-of-the-art present solutions include solid biofuels, made from sawmill side-streams towards simple products, like fuel for CHP (combined heat and power), pellets, and charcoal. However, production is still at an early stage and the scale is small. In the medium term, the liquid biofuels, mainly pyrolysis oil to boilers, emerge as state-of-the-art solution. In the medium term, gaseous biofuels can also be produced, for example, by gasifying fuel gas to CHP. The field of gaseous biofuels will develop and solutions to convert syngas to SNG (synthetic natural gas) will emerge. In the long term, solid biofuels will move from torrefied wood to the use of lignin for energy purposes. In order to achieve this, the lignin will be separated from the bioethanol process. The liquid biofuels consist mainly of hydro-treated pyrolysis oil, low cost biomass to ethanol, DME (dimethyl ether), and FT-liquids. More advanced liquid biofuel technologies are emerging, such as biomass fractionation to yield ethanol and other products from the hemicelluloses and lignin components. In the case of gaseous biofuels, the main process will be converting syngas to SNG (synthetic natural gas). In the long term, the biofuel production will be integrated with petrochemical production.

Current enabling technologies include methods for harvesting the biomass on site, with drying technologies for pyrolysis and gasification being particularly important. The enabling technologies focus on first generation bioethanol and biodiesel, and on the second generation biodiesel through thermochemical or biochemical routes. In the medium term, new enabling technologies will emerge. Initially, enzymatic processes will develop further, and progressively novel separation/fractionation technologies will emerge, together with technologies that enable methanol to be converted to gasoline. In the long term, the advanced enzymatic processes will emerge. Other interesting technological opportunities include the possibility of making ethanol by total hydrolysis and combining it with the fermentations from sawmill waste. Several new catalytic and biotechnical processes may also be industrially implementable.

Molecular lens: radical industry renewal through new biorefineries

The key present drivers are biomass/biofuels regulations and directives. The second driver is the benefit of using renewable resources that minimizes the dependency on fossil fuels. The third driver is the emergence of new business opportunities that are based on nature's chemistry. In the medium term there will be regional and national bioeconomy strategies. New business models via partnering and joint ventures will increasingly act as drivers. Replacement of oil based plastic materials with renewable ones will be a crucial driver, as will be the developing performance chemicals. In the long term, the bioeconomy will be increasingly regulated and standardised. The availability of cheaper energy has the potential to be a significant driver.

The markets and consumer needs currently emphasise the business models of partnering and joint ventures. The biodegradable plastic market is focusing on packaging. In the medium term there will be more products that are based on current biochemicals, bioplastics and high performance products. There will also be service businesses related to these. In the long term, the demographic changes in the South-East Asia will increase demand of materials.

Presently, large enterprises and SMEs are particularly active in the field. Brand owners currently use "green" for differentiation purposes. There are also new players in the field, like food and agricultural companies, seeking added value for their side streams. There is the requirement in the longer term for better coordination between government, academia and industry at the R&D, pre-commercial (pilot-scale providers) and commercial level. In the medium term, there will be increasing joint ventures between the forest and wood products, biofuels and chemical industries. SMEs will have an important role to play in specialty technologies and niche products. Large chemical companies will enter the market with biopolymer and material solutions. In the long term, the impact of technical development will be significant and will require the involvement of both industry and academia. Coordinating these alliances will become increasingly important to achieve positive outcomes.

The key state-of-the-art solutions are bio-based platform chemicals and polymers. Another solution is bioethanol from wood hydrolysis that could potentially be used in lignin fractionation. New products and derivatives, such as those from organosolv pulping and fractionation processes, are entering markets. In the medium term, new isolation and conversion technologies will be applied. Simultaneously, bio-based drop-in replacements, like green-PE and bio-PET will offer new market opportunities. All fractions should be utilised, for example thermo-mouldable lignin, cellulose fibres, and fibres suitable for food productions. In the long term, the range of biobased products will increase. New fully bio-based chemicals, materials and other products will emerge. Combinations of fibre materials and new biopolymers will find emerging markets, particularly in packaging applications. Organosolv pulping and fractionation processes will be commercialised and various by-products isolated, for example sulphur-free lignin for polymers. In the long term, the advanced processes, like catalytic pyrolysis, will emerge.

The present enabling technologies emphasise chemical and enzymatic technologies with strong process control. These technology platforms are currently advancing at a significant pace, as are existing biorefineries with improved fractionation and separation technologies. In addition, raw material handling, sorting and compacting has improved significantly and are being realised through fully optimised logistics. In the medium term, the enabling technologies will focus on complementary biofuel production through side streams. New and emerging enzyme technologies to transfer cellulose to starch will emerge. A new generation of thermal processes will be developed on a major scale. There will also be novel cascade concepts and zero-waste biorefining technologies. In the long term, new enzyme technologies for transforming cellulose to starch will emerge. New generation of thermal processes will be developed on a major scale. In the long term, a more radical vision could be to remove biomass and utilise CO2 from the air. Combinations of synthetic biotechnology with chemical engineering and polymer science will have a market impact.

Atomic lens: radical industry renewal through new biomass-based production

The key drivers of the atomic lens can be linked to generic drivers affecting the global economy, like climate change and energy policy, the rising demand for renewables and the transition towards a bio-economy. In the medium term, there will be new potential drivers, such as the emergence of regional and national bioeconomy strategies, and the potential for bio-premiums. New business models, partnering and joint ventures will increasingly act as drivers. In the long term, the development towards performance chemicals could be a significant driver for the industry in the medium term, as well the need to replace of starch-based products with cellulose equivalents.

There is a strong potential for cellulose and fibre-based products and highly increasing interest in developing numerous novel cellulose-based technical and life-science related products. There are established and increasing markets for wood plastic composites (ca. 3 Mt 2012), and novel applications are constantly being explored. In the medium and long term, it is expected that global demand for textile fibres will increase by 80% by 2030, while stagnation in cotton production may increase the potential for cellulosic textiles by 15 Mt.

The key present actors include forest and wood products industry and chemical industry. Also, various actors in other industrial sectors, such as textiles, cosmetics, food, electronics, and construction are part of the value chain. However, there is still intensive research and development needed before the new value chains are in full operation. For this purpose, research co-operation is paramount. In the medium term, there will be evolving new value chains, with various opportunities for new companies, including SMEs. These novel value chains will cover the complete spectrum from raw material (biomass) production to end-use development, testing and marketing, and require active collaboration between research providers and industries. In the long term, a key development could be the emergence of global virtual research centres with expertise in cellulose-based products.

Currently, nanocellulose production has commenced, but is still in its infancy. Another solution is in wood plastic composites (WPC) that can be used in multiple ways, including as extrusion for building industry, for injection moulding in the car industry, and in furniture and auxiliaries. Currently, there are different packaging solutions based on wood and cellulose fibres, and for coating and barrier materials. Different wood treatments, such as chemical and thermal treatments are currently available. In medium term, there will be an increased demand for cellulose particularly in the textile industry, but also for other applications. This demand will generate new cellulose processes that will result in new cellulose-based products for use in agriculture, soil conditioning, water purification, tissue engineering, and insulation applications. In the medium term, numerous solutions for nanocellulose will emerge. Wood plastic composites (WPC) will continue to grow in importance. Different packaging solutions based on wood and cellulose fibres for coating and barrier materials will be high on the agenda. Functional packaging will advance and result in multiple product categories. In the long term, new products will emerge at the convergence of nanocellulose with printed intelligence, and nanocellulose with photovoltaics. There is a possibility of developing optical photovoltaics, and combining nanocellulose and pharmaceuticals. Additionally, different water related solutions will become more common.

Presently, the key enabling technologies focus on advanced, but existing, pulping and other processes that are suitable for different raw materials. Further enabling technologies include applications of material sciences, chemistry and biotechnology. In the medium to long term, the key enabling technologies will be novel pulping and fractionation processes, for example hot water systems and use of ionic liquids. These will enable optimal separation and uses of all biomass constituents. A further enabling technology is for new polymer and fibre blends, and for composites.

5. Roadmaps in four lenses: mass, energy, molecular, atomic

5.1 The current value network in Green Triangle

This section presents the roadmaps constructed by the VTT experts in two workshops held on 25 April 2013 and 16 May 2013, and in the several iteration rounds following the workshops.

The bases were laid out in the stage 1 report (see Figure 31). To reiterate, the key functions of the present value network can be divided into the activities of forest owners and supporting actors, notably that of breeding and genetics, machine suppliers, and data analysis providers. All these actors provide inputs for utilisation and renewal of the resource base in the region, mainly formed of pine and eucalyptus plantations. This set of activities forms the first loop of the value network.

The first loop acts as an input to the second loop, that is from hauling and harvesting to the downstream sawmills. The key present products of Green Triangle sawmills are sawlogs, pulp logs, roundwoods, woodchips, sawmill and wood residues, and barks. Important external inputs for this second loop are skilled labour and cost-related factors such as electricity and fuel.

In the third loop, the sawmills act as the providers to different customer industries, the first of which is the direct exports of woody materials such as logs and woodchips that are mainly to Asia and some of which are imported back to Australia as value-added products. The second is the traditional pulp and paper industry that has been in decline in the region. The pulp and paper industry uses mainly pulp logs and wood chips as material for the production of cellulosic pulp, and, subsequently, paper products. The third customer industry is the construction and building industry which utilises sawn timber, panels, engineered wood products, posts and treated timber. Downstream the industry can produce furniture, fencing and other products. There are also residual products, like mulch and potting mix, but these do not contribute significantly to the present value networks. On the basis of our analysis, the side streams are currently under-utilised and, as a consequence, provide an opportunity.

In the current value network, the functions of the four company groups studied can be summarised as follows. The core business of forest owners is to take care of the renewal of the basic resources, production of timber (softwood and hardwood), and the core functions related to this. The hauliers and harvesters persevere with their core business of hauling, harvesting and transport. The sawmills produce processed timber, generally at low levels of added value. The specialised suppliers provide services and products that are different, both business-to-business and business-to-customer. There are currently services, for example, in breeding and genetics, machine supply, data analysis and geoinformatics, but their potential in the forest and wood products industry system is not fully realised because there is a lack of advanced demand and/or demanding customers.

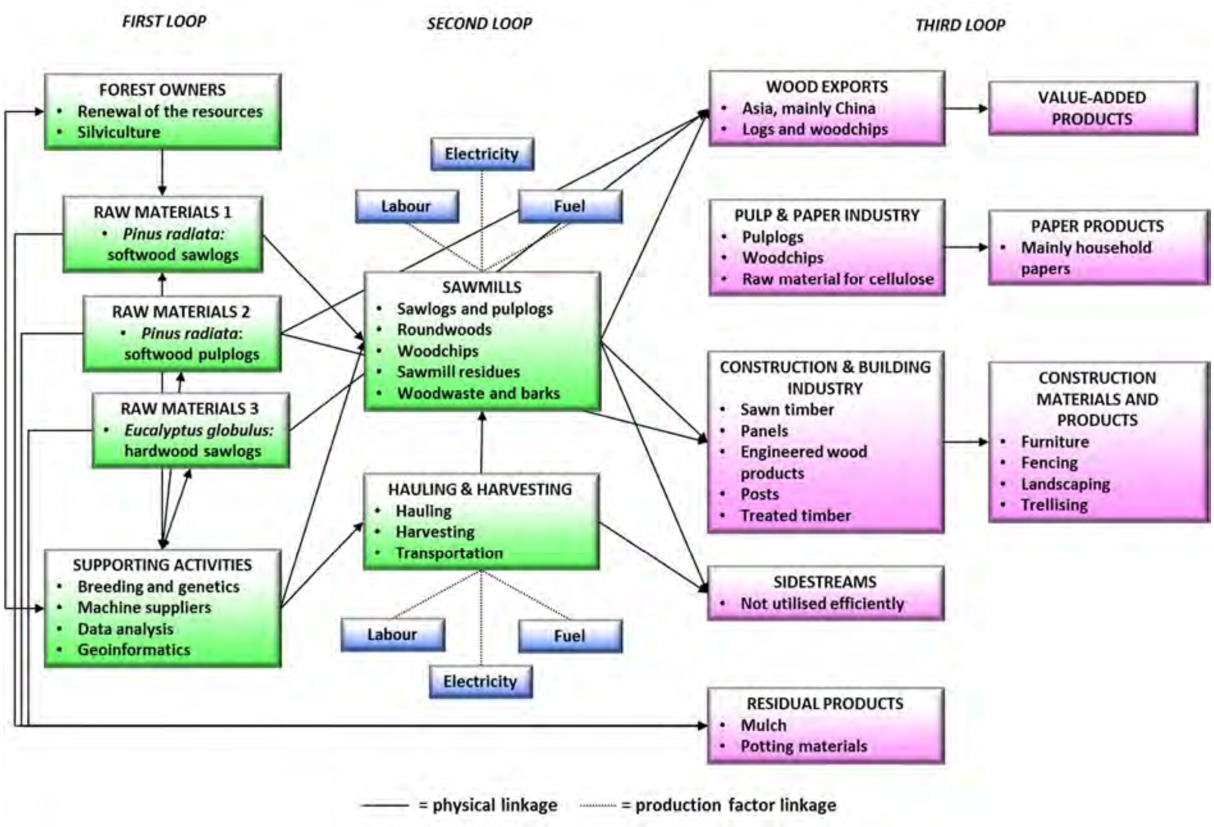

Figure 31. Representation of the forest and wood products industry value network in the Green Triangle region. The shaded green colour depicts the key functions in the value network, the shaded purple depicts key output directions, and shaded blue colour designates key external inputs.

5.2 Mass lens: more efficient traditional forest and wood products industry

Vision statement for the mass lens
A modern and globally competitive mechanical forest and wood products industry that provides high value added products for different industries and customers such as the furniture and construction industries.

Present (state-of-the-art)

Drivers

Presently, there are a number of drivers for the mass lens (Figure 32). The first driver is resource scarcity that will widely affect societies and industries. It will push the industrial system for the efficient use of raw materials; to use raw materials sustainably throughout the entire lifecycle. The second driver is also connected to the issue of sustainability: the LCA (life cycle analysis) of wood is very favourable compared with concrete and steel and this makes wood a sustainable building material. The third driver is the emission policies, and especially the carbon tax in Australia. This could prove to be an important driver for the use of wood. Already the use of wood, and more widely fibre-based biomass, as a basic resource for industries and the economy is increasing.

Markets and consumer needs

Today, large scale markets exist for wood-based construction and high-rise housing in the US and Europe, together with an increasing need to attain low cost timber of premium quality, across the different markets.

Actors and actions

It is important to start a state-wide PR (public relations) process for marketing wood as widely applicable and sustainable resource for, as an example, in the building industry (a possible slogan might be “wood feels good”). For Green Triangle, the critical issue is to form a joint regional strategy among the key players in the region, as well as finding key funders at the state level (see stage 1 report section 7). The first steps in the regional strategy would be to identify key markets, develop a product portfolio and identify the enabling technologies. The key players from the regional perspective are the saw mill owners as well as technology providers.

Solutions

The key objective here is to create value added products from the raw materials and side streams. There are also important developments in measurement techniques and the automatation of saw mills. The following bullets presents potential opportunities based on the tenets operating Scandinavian sawmills:

- Specialisation as in a Scandinavian mill. In Finland, advanced sawmills limit the log size (30–35 cm diameter) and would operate either two mills or two separate lines in one mill. Key to this is that small saw logs (less than 20 cm) do not maximise the utilisation of equipment in large sawmills.
- X-ray scanning. In Finland there are already 10 mills utilizing X-ray scanning equipment to obtain yield increases. This development has enabled better sorting especially in mills using pine.
- Oriented strand boad (OSB). OSB is a structural panel product that shares many of the performance characteristics of plywood. OSB’s main advantage over plywood is that it can be manufactured from pulpwood-grade roundwood logs.
- Veneer-based engineered wood products (EWPs). Veneer-based products, like laminated veneer lumber (LVL), have the potential to generate significantly higher levels of value adding versus alternative uses of pulpwood-grade logs.
- Geometric scanning. Improves productivity by better taking into account geometrical defects in shape (longitudinal and conical).
- Improved sorting. In Finland mills have a feedback arrangement to better match the expected outcome from the log class. By adjusting sorting and log class rules for the logs improved yields of up to 5% have been achieved.
- Thinner blades. Big savings have been achieved with thinner saw blades as a result of less generation of sawdust (15+%).
- Outsourcing as practised in Scandinavia: Big integrated and small sawmills in Scandinavia have outsourced forklift work and internal logistics to third parties to free up capital. Such machines can be maintained during shuts or serviced during night shifts.
- Small logs. The demand for small logs 8–15 cm has greatly diminished with the closure of Tantanoola. This has led to an increase in chip exports at low margins. There are technologies available in Scandinavia and Canada that enable a higher value from this material than just chipping and exporting them
- New Grades. The new CITES (Convention on International Trade of Endangered Species of fauna and flora) agreement will limit the trade of various plant and animal species, including 100 species of tropical hardwood. The Max Planck Inst, Germany, has developed technology that inserts flavonoids into cell walls and improves dimensional stability of the wood considerably.

Additionally, from the perspective of better wood utilisation, the Green Triangle region should consider a mill to handle only small logs.

There are also important new solutions for consideration, the most critical of which is to find new uses for low-value components of fibre and to develop capacities for adding value to the raw materials. The value-adding practices could be realised through a variety of ways, like development of wood components for construction, production of coal for pig iron (intermediate product of smelting iron ore with a high-carbon fuel) production, or developing capacities for making fibre boards and packages, like fibre board produced with TMP-type (thermomechanical pulping) process.

Enabling technologies

The present state-of-the-art enabling technologies apply modular thinking in technology development that in the case of Green Triangle should be integrated in the formulation of joint regional strategy. A further dimension to be included is the technology transfer for production efficiency. A key state-of-the-art enabling technology in the mass lens is the vision recognition of timber, which should be integrated with new planning systems such as WoodCIM software developed at VTT or the like, and new integrated information system models. Other state-of-the-art enablers in this category are X-ray scanning and long X-rays that are combined with artificial intelligence. The use of thinner blades is also an important enabling technology, as well as developing different protective treatments for wood products.

Medium term

Drivers

The medium term drivers are essentially the same as for the present. However, one could assert that new policy incentives could emerge at the federal and state level to favour wood as a raw material in different industrial settings. Also, in the western economies there is an increasing need for governments at all levels to provide an affordable, safe and comfortable environment for its citizens, and wood could be an ideal solution to respond to this societal driver.

Markets and consumer needs

In the medium term, the uses of the wood in the construction industry will develop and vary. For example, wood could be used in bridge building, since the solutions would enable fast assembly without disturbing traffic. There is also the potential for an increase in “do it yourself” assembly kits. The forest and wood products industry could encourage new product categories to assist the trend such as the next generation of wood products. There is also a rising need for construction materials that enable industrial production of prefabricated components. The markets and consumer needs, combined with the societal driver of sustainability, will possibly lead to fine-tuned targets and recommendations for how to use renewable raw materials in different local settings.

Actors and actions

In the medium term, it would also be important to continue the state-wide PR (public relations) process for marketing wood as a usable and sustainable resource for building industry as an example. Also, the Green Triangle joint strategy development should be continued and intensified. This could include two activities that aim, firstly, towards clustering of industry through simultaneous co-operation and competition and, secondly, by identifying specific competitive advantages of small production units in this region.

Solutions

In the medium term, the creation of value added products from raw materials and side streams is emphasised. In addition, innovative construction technologies and solutions for public premises and housing are rising in importance. This line of development should emphasise building code and land use target setting. The forest and wood products industry players should be co-operating extensively with construction companies. Additionally, trajectories that have been identified as present state-of-the-art solutions, like geometric scanning to handle small logs and developing new grades by inserting flavonoids into cell walls of wood, will gain prominence. There is also an increasing emphasis for the diversification of wood production such as wood components for construction and fibre board produced with a TMP-type process connection that generate thermowood type of products

Enabling technologies

Enabling technologies that exist presently, such as modular thinking, vision recognition, X-ray scanning, thinner blades and protective treatments for wood products, will continue to grow and flourish. New enabling technologies that aim for the production of cross-laminated wood and massive glued beams will grow, while the utilisation of ICTs (information and communication technologies) will surely intensify in the medium term. Another enabling technology could be the building of TMP-plant utilizing eucalyptus.

Long term

Drivers

The drivers are the same as for the present and medium terms. A new driver is energy efficient buildings, particularly those leading to higher energy savings and CO_2 reductions.

Markets and consumer needs

Here, it is to be expected that the “do it yourself” market will continue to increase. In the long term, new markets and needs will emerge. It will commence with the demand for healthy air in low and zero energy buildings, continue with the need to control acoustics in wooden constructions, and finally trend towards easy-to-modify buildings. In addition, the requirement for sustainability will be emphasised through the visible reuse of construction materials.

Actors and actions

In the long term, it can be envisioned that Green Triangle will have a new industry cluster specialising in value added fibre-based production. This structure is an evolving outcome of joint regional strategy and clustering. In this cluster, renewed sawmills (see the next sections in this report) will act as biomass regulators together with new actors who will grow in number. These are real estate and regional development companies. Communities and organisations involved in building code legislation will also play a role in the future fibre-based industry.

Solutions

In the long term, the creation of value added products from raw materials and side streams is even more emphasised than in the medium term. Developments such as geometric scanning, a mill to handle small logs and new grades by inserting flavonoids into cell walls of wood will become more pivotal. The increasing emphasis on diversification of the wood production will continue as will the use of wood components for construction and fibre board produced with TMP-type treatments. In addition, new solutions will emerge. These will include materials to control microclimate in buildings and wood-based easy-to-use technologies for modifying structures on site. In the building and construction field, new foam-fibres will be used as insulation, and the development of these will be connected to development of wood components. Also, 3D-manufacturing of building components will gain prominence together with new fibre board technologies. In this scenario, CTMP (chemithermomechanical pulping) will develop both for hardwood and softwood paperboards. In the long term, the fibre board technologies and production can be linked also to biorefinery developments.

Enabling technologies

Enabling technologies will continue along the same path already seen in the present, such as modular thinking, vision recognition and X-ray scanning. In the long term, the utilisation of ICTs (information and communication technologies) will intensify even further. Another enabling technology will be the building of TMP-plant utilizing eucalyptus. New enablers, in the long term, will be novel wood composite materials and emerging bio-based protective treatments for wood products.

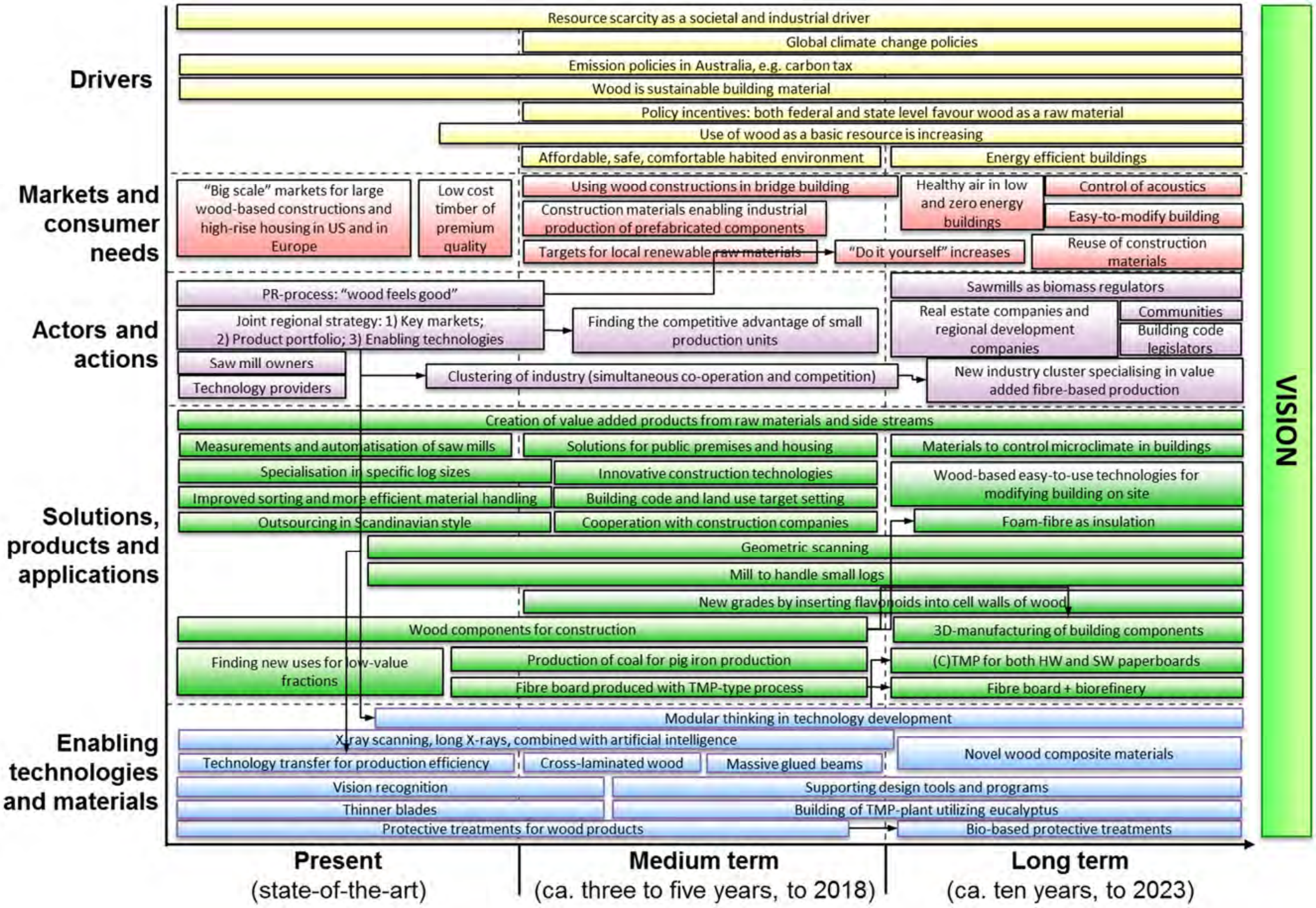

Figure 32. Roadmap 1 – Mass lens: more efficient traditional forest industry.

5.3 Energy lens: industry renewal through energy biorefinery

Vision statement for the energy lens
Energy lens focuses on a modern biorefinery facility that produces energy and other value adding products. The biorefinery utilizes Green Triangle's biomass, and complements the globally competitive mechanical forest and wood products industry that provides high value added products for different industries and customers, e.g. furniture industry and construction industry.

Present (state-of-the-art)

Drivers

The key driver in the energy lens presently is a resource scarcity that widely affects societies and industries (Figure 33). It will push the industrial system towards the efficient use of raw materials; to use raw materials sustainably throughout the entirety of the lifecycle. The active CO_2 market is the secondary driver. Climate agreements and the related policy incentives to lessen the dependence on fossil fuels act as critical drivers in the energy lens. The construction of wide-ranging fuel standards will be a driver throughout the period from the present to the long term.

Markets and consumer needs

These are regulated presently by community and industry needs for electricity. Today, it is important to fulfil biofuel requirements in safe way i.e. biofuels should be compatible to or complementary with existing fuels. In Australia, there is an increasing requirement to provide affordable biobased fuels for transportation, e.g. for trucks in the mining, forest and products, and other industries.

Actors and actions

International agreements currently set the standards in the field. The key players in the present and medium term are grid owners and utility companies that can put renewable electricity into the grid. There should be increasing support for the transformation of regional infrastructures. This includes building up road network for the collection of the biomass and also the creation of energy infrastructure for the transfer of energy as examples. The forest and wood products industry, with logistics of biomass, will become an increasingly important player, utilising and feeding these new infrastructures, while sawmills will also play a key role. Already, the mining industry is a key user of biofuels in their fleets, a trend that is likely to continue going forward.

Solutions

The state-of-the-art include solid biofuels, made from sawmill side-streams towards simple products, like fuel for CHP (combined heat and power), pellets, and charcoal. However, production is still at an early stage and the scale small. Additionally, liquid biofuels, mainly pyrolysis oil for boilers, can be listed as a state-of-the-art solution. Presently, gaseous biofuels can also be produced by gasifying fuel gas to CHP to use one example. Increasingly, the agriculture industry is moving towards bioethanol, but the emphasis for the forest and wood products industry is on power production through electricity/heat combined production and integration.

Enabling technologies

Current enabling technologies include methods for harvesting the biomass on site, with drying technologies for pyrolysis and gasification being particularly important. The state-of-the-art enabling technologies focus on first generation bioethanol and biodiesel, built on fatty acid esters. It consists of the intensified development of FT (Fischer-Tropsch) and second generation biodiesel through thermochemical (gasification, pyrolysis or torrefaction) or biochemical (fermentation or anaerobic digestion) routes. Other state-of-the-art technologies include gas cleaning for synthesis gas, mechanical or chemical pre-treatment and different enzymatic processes for constructing biofuels, like enzymatic transesterification (Fjerbaek et al. 2009).

Medium term

Drivers

In the medium term, the drivers such as resource scarcity, CO_2 market, climate agreements together with related policy incentives, and development of fuel standards will collectively increase in impact. In addition, new drivers such as competition for biofuels will play a more important role as global R&D activities increase and emerging actors and investors interested in entering the bioenergy domain start to mushroom. Another driver in the medium term will be an increased demand for second generation biofuels, as these mature.

Markets and consumer needs

Needs are still regulated by community and industry requirements for electricity. New affordable biobased fuels in some form will be available in the market. Second generation biofuels are emerging rapidly. As these enter the market, there will be increasing competition between land for food and land for fuel production, leading to vigorous debates amongst the protagonists. This juxtaposition will manifest itself at the legislation level. There will also be increasing evidence on what are the economically feasible and environmentally friendly ways to produce biodiesel.

Actors and actions

In the medium term, the international agreements will still set the standards in the field. The key players are the grid owners and utility companies. The forest and wood products industry with its logistic capabilities for handling and transporting biomass, will become an increasingly important player utilising and feeding these new infrastructures, while sawmills, as uses of energy through biorefineries, will also play a key role. The key user of biofuels will be the mining industry in their vehicle fleets. In the medium term, the question of fuel blends, and community acceptance of biofuels as a local solution will be crucial.

Solutions

The state-of-the-art solutions include solid biofuels made from sawmill side-streams towards simple products such as fuel for CHP (combined heat and power), pellets, and charcoal. However, the production is small but growing. Additionally, liquid biofuels, mainly pyrolysis oil to boilers, can be listed as a state-of-the-art solution. In the medium term, gaseous biofuels can also be produced, for example, by gasifying fuel gas to CHP. The field of gaseous biofuels will develop and solutions to convert syngas to SNG (synthetic natural gas) will emerge.

Enabling technologies

In the medium term, new enabling technologies will emerge. Initially, enzymatic processes will develop further, and progressively novel separation / fractionation technologies will emerge, together with technologies that enable methanol to be converted to gasoline. There will be new solutions for using Fischer Tropsch to produce power solutions. Further enablers will include hydrodeoxygenation of extractives and pre-treatments that, combine mechanical, chemical and enzymatic processes.

Long term

Drivers

In the long term, the impact of drivers such as resource scarcity, CO_2 market, climate agreements together with related policy incentives, and development of fuel standards will intensify further. The competition for biofuels will become even more intense as a result of increasing global R&D activities, and mushrooming actors and investors interested in entering the field of bioenergy. The increase for second generation biofuels will also deepen. In the long term, biofuel competitiveness will become a key driver, as biofuel production reaches maturity.

Markets and consumer needs

Needs are still regulated by the community and industry requirements for electricity. New affordable biobased fuels are becoming competitive in global markets. In the long term, the question of biofuel pricing and pricing mechanism will rise in importance, coinciding with enhanced competition among the players.

Actors and actions

In the long term and provided the question of blending is resolved, the mining industry will be the major beneficiary of local biofuel capacities. New players will enter the field, such as energy and biofuel companies. The emergence of these new operators will reshape the industry by providing a competitive market environment on the global scale.

Solutions

In the long term, solid biofuels will move from torrefied wood to the use of lignin for energy purposes. In order to achieve this, the lignin will be separated from the bioethanol process. The liquid biofuels consist mainly of hydro-treated pyrolysis oil, low cost biomass to ethanol, DME (dimethyl ether), and FT-liquids. More advanced liquid biofuel technologies are emerging, such as biomass fractionation to yield ethanol and other products from the hemicelluloses and lignin component of the biomass. In the case of gaseous biofuels, the main process will be transforming syngas to SNG (synthetic natural gas). In the long term, the biofuel production will be integrated with petrochemical production, like currently is the case in oil refineries. Raw material usage is intensified even further, and regulation at the global scale could be required to resolve the land for food or fuel issue.

Enabling technologies

In the long term, the separation / fractionation technologies are among the key enablers, as are the advanced enzymatic processes. Other interesting technological opportunities are likely to emerge; including the possibility of making ethanol by total hydrolysis and combining it with the fermentations from sawmill waste. Several new catalytic and biotechnical processes may materialize that could change the structure of biofuel production which as it becomes more industrialised will enter the stage of integration and consolidation. This means that biorefineries are increasingly using close loop solutions and integrated energy and material / chemical solutions in production. Furthermore, agility and overall optimization will have significant impacts on the structures of bioenergy production in the long term.

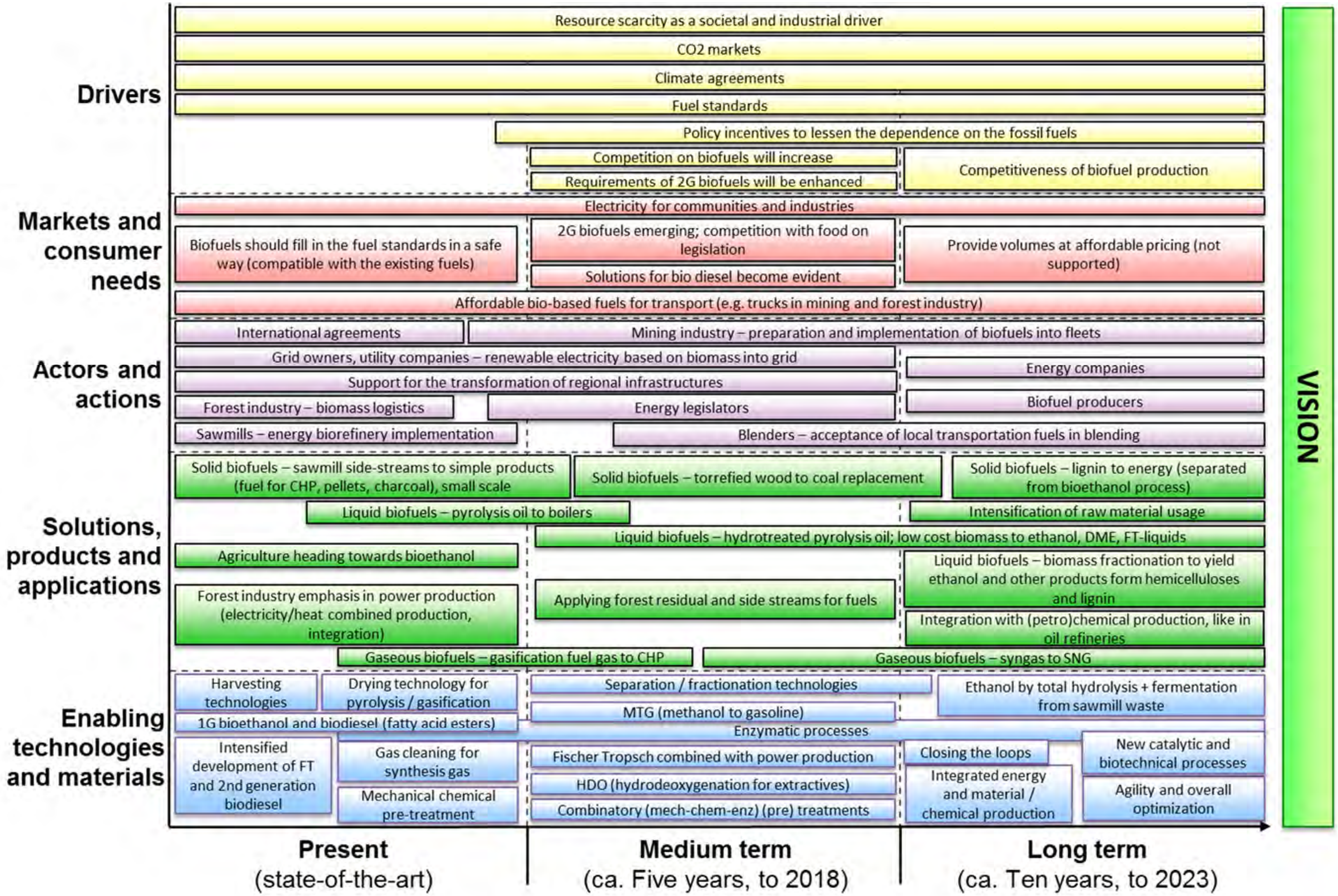

Figure 33. Roadmap 2 – Energy lens: industry renewal through energy biorefinery.

5.4 Molecular lens: radical industry renewal through new biorefineries

Vision statement for the molecular lens
A diversified second and third generation biorefinery facility that utilizes state-of-the-art technological solutions. The facility provides diverse set of green chemicals, and different side-streams.

Present (state-of-the-art)

Drivers

The key present drivers are biomass/biofuels regulations and directives (Figure 34). A second driver is the benefit of using renewable resources that minimizes the dependency on fossil fuels, benefiting both CO_2 emissions and oil price instability. The third driver is the emergence of new business opportunities that are based on nature's chemistry, and the possibility for creating new value chains with new players.

Markets and consumer needs

The markets and consumer needs currently emphasise the business models of partnering and joint ventures. Markets are developing for nature's chemicals and materials that are "bio" based, and this will result almost certainly in more biochemicals and bioplastics. The biodegradable plastic market is focusing on packaging.

Actors and actions

Presently, large enterprises and SMEs are particularly active in the field with the entrance of many new joint ventures between chemical and biotech companies. Brand owners currently use "green" for differentiation purposes, but whether this will continue in the coming years is questionable. Everyone from brand owners to retailers are facing increasing demands from consumers for improved social responsibility and sustainability guarantees. There are also new players in the field, like food and agricultural companies who seek added value for their side streams. There is the requirement in the longer term for better coordination between government, academia and industry at the R&D, pre-commercial (pilot-scale providers) and commercial level. Coordinating these alliances for successful outcomes will become increasingly important going forward. There are currently an increasing numbers of equipment suppliers that offer new solutions critical for the development of biorefineries.

Solutions

The key state-of-the-art solutions are bio-based platform chemicals and polymers that have several possible applications, e.g. natural polymers modified to perform like starch and biobased materials such as polylactic acid PLA that have established their position in the biodegradable plastic market. A key tendency is for proven biopolymers to migrate towards composites, and for business and market developments in the field of biopolymers and composites. The key state-of-the-art solutions are bio-based platform chemicals and polymers, including lignin from wood hydrolysis. Gums, latexes, resins, essential oils, and bioactives are currently isolated from many parts of the trees and increasingly used by the current industries. Presently, some 3 Mt of chemicals are also isolated or manufactured as by-products of pulp mills. There are also new products and derivatives entering markets such as those originating from organosolv pulping and fractionation processes. Various products are being manufactured from sulphur-free lignin while different pyrolytic processes for bio-oil and charcoal, bio-oil for energy and organic farming are currently being developed.

Enabling technologies

The present enabling technologies emphasise chemical and enzymatic technologies with strong process control. These technology platforms are currently advancing at a significant pace, as are existing biorefineries with improved fractionation and separation technologies. In addition, raw material handling, sorting and compacting has improved significantly and are being realised through fully optimised logistics.

Medium term

Drivers

In the medium term there will be regional and national bioeconomy strategies that could include different incentives for bio-based products. New business models via partnering and joint ventures will increasingly act as drivers, as will emerging opportunities based on nature's chemistry and the possibility for creating new value chains with new players. Replacement of oil based plastic materials will act as a crucial driver in the medium term. The development will be towards performance chemicals that could be significant drivers for the industry moving forward.

Markets and consumer needs

In the medium term there will be more products that are based on current biochemicals, bioplastics and high performance products. There will be increased service businesses based on each of these different products. The impacts of potentially strong "green" brands will be significant. There will be an increase in market volumes because consumers will demand sustainability. Brand owners will take a more active role, while drop-in bio-plastics will more than double the biopolymer market.

Actors and actions

In the medium term, there will be increasing joint ventures between the forest, biofuels and chemical industries. SMEs will have an important role to play in specialty technologies and niche products (by volumes). Large chemical companies will enter the market with biopolymer and material solutions. Consortia between chemical and agribiomass players will become more common. Chemical forest industry companies will widen their offerings and reorient their business models. A longer term requirement will be the need for improved coordination between the key players at all levels in the value chain. Coordinating these alliances to successful outcomes will become increasingly important in the future, as will taking advantage of new solutions offered by equipment suppliers in developing biorefinery processes.

Solutions

The range of biobased products will increase, and new isolation and conversion technologies applied. Simultaneously, bio-based drop-in replacements, like green-PE and bio-PET will offer new market opportunities. This means increased utilization of sugar based ethanol and other precursors for chemicals, and the possibility for affordable hydrolysed sugars in the food production chain. All fractions should be utilised, for example thermo-mouldable lignin, cellulose fibres, and fibres suitable for food productions. A product example is CMC (carboxymethyl cellulose), or cellulose gum, is a cellulose derivative with well-established global markets. Another example is insoluble fibers that can be used as a dietary ingredient to aid digestion in humans. The key question is how to fractionate such that the valuable fractions are obtained at the right time. Another solution is bioethanol from wood hydrolysis. It could potentially be usable in lignin fractionation. Gums, latexes, resins, essential oils and bioactives, derived from all parts of the tree, are also increasingly used in many applications by the current industry. New products and derivatives are being commercialised originating from organosolv pulping and fractionation processes. In the medium term, advanced processes for refining bio-oil to biochemicals will emerge, possibly via catalytic pyrolysis.

Enabling technologies

In the medium term, the enabling technologies focus on complementary biofuel production through side streams. New and emerging enzyme technologies to transfer cellulose to starch will emerge. A new generation of thermal processes will be developed on a major scale. There will also be novel cascade concepts, e.g. sugar/polysaccharide extractions from wood residues, sawdust and other materials, including strands for board/panel industry. Zero-waste biorefining technologies for wood and bark and other residues will become more common in medium term.

Long term

Drivers

In the long term, the bioeconomy will be increasingly regulated and standardised. The availability of cheaper energy has the potential to be a significant driver. There may be instabilities in the petrochemical industry from shale gas. Better materials with improved performance are needed to reduce overuse and drive commodity products to premium quality.

Markets and consumer needs

In the long term, there will be more products that are based on current biochemicals, bioplastics and high performance products. Service businesses based on biochemicals, bioplastics and high performance products will increase. The impacts of potentially strong “green” brands will be significant as consumers demand sustainability. The demographic changes in South-East Asia will increase material demand.

Actors and actions

In the long term, there will be increasing joint ventures in the forest and products, biofuels and chemical industries. SMEs will have important roles to play in specialty technologies and niche products (by volumes). Another requirement will be the need for successful coordination between academic and industrial R&D, pilot-scale providers, and industry. The impact of technical development will be significant and will require the involvement of both industry and academia. Coordinating these alliances will become increasingly important to achieve positive outcomes. Advantage should be taken of equipment suppliers and their offer of new solutions to better develop biorefinery processes. New companies will evolve from the oil-based chemical companies.

Solutions

In the long term, the range of biobased products will increase and new isolation and conversion technologies applied. New fully bio-based chemicals, materials and other products will emerge such as biopolymers, bioplastics, and packages. Novel biopolymers developed in laboratories will be introduced after successful scale-up attempts. Combinations of fibre materials and new biopolymers will find emerging markets, particularly in packaging applications. An interesting long-term solution could be a more rapidly growing forest, if genetic modification studies presently underway are successful. Furthermore, pine branch extracts and other valuable products may offer other interesting solutions. In addition, fermentable products from biomass-based sugars are emerging. A further solution is a biorefinery that utilises tree barks, foliage and other residuals for adhesives, metal removal for mine waters, nutraceutical or drugs. Organosolv pulping and fractionation processes will be commercialised and various by-products isolated, for example sulphur-free lignin for polymers. Synthetic biotechnology will be in use. In the long term, the advanced processes, bio-oil for refining to biochemicals will emerge perhaps via catalytic pyrolysis.

Enabling technologies

In the long term the enabling technologies focus on complementary biofuel production through side streams. New enzyme technologies for transferring cellulose to starch will emerge. New generation of thermal processes will be developed on a major scale. There will also be novel cascade concepts such as sugar/polysaccharide extractions from wood residues, sawdust and other materials (including strands for board/panel industry). Zero-waste biorefining technologies for wood and bark and other residues will become increasingly common. In the long term, a more radical vision could be to remove biomass and utilise CO_2 from the air. Combinations of synthetic biotechnology with chemical engineering and polymer science will have a market impact.

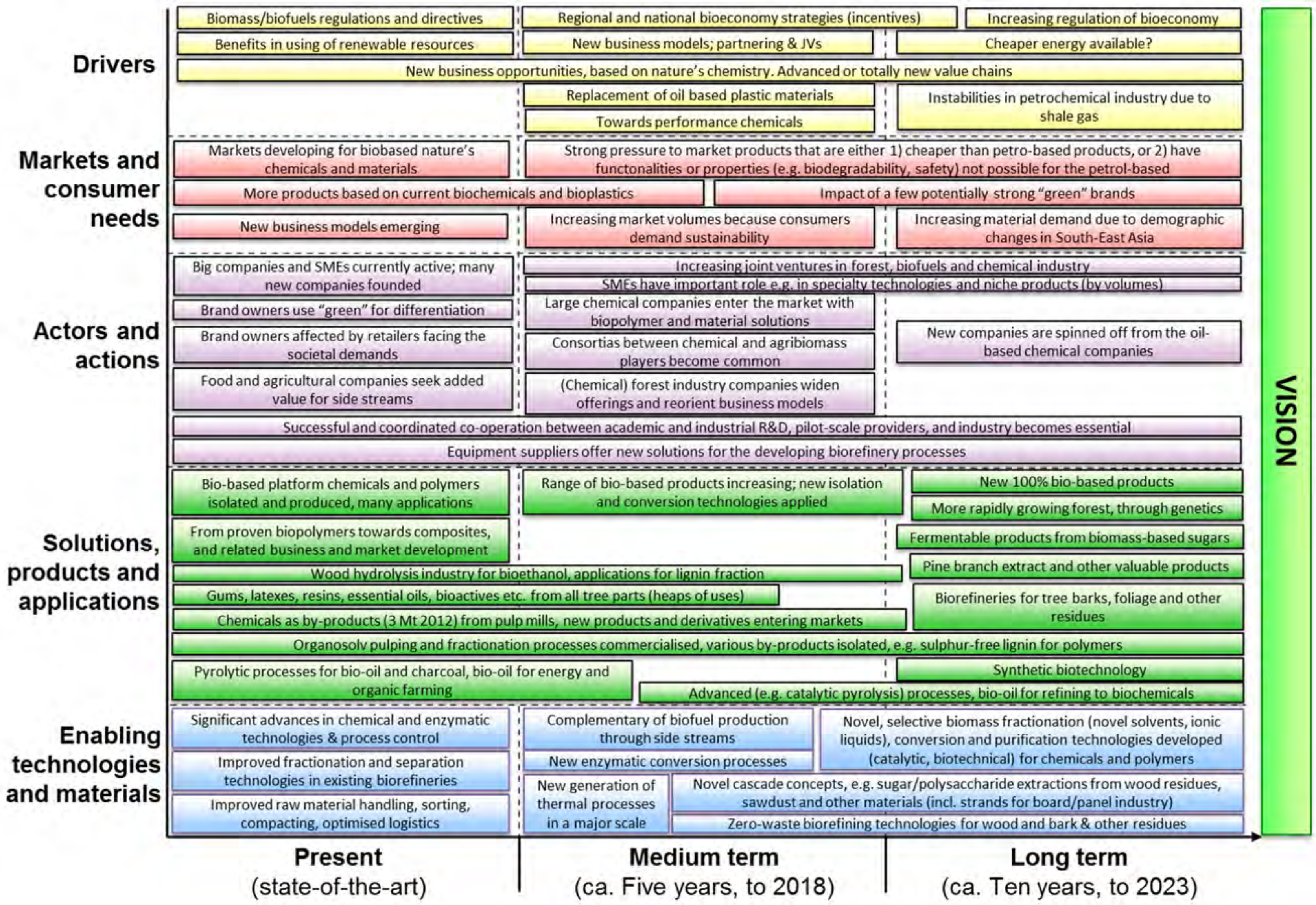

Figure 34. Roadmap 3 – Molecular lens: radical industry renewal through diversified second and third generation biorefineries.

5.5 Atomic lens: radical industry renewal through new biomass-based production

Vision statement for atomic lens
A novel form of biomass and fibre-based industry producing high value added nanomaterials, packaging solutions, bioplastics, and chemicals. The industry uses a mix of first, second and third generation biorefinery technologies.

Present (state-of-the-art)

Drivers

The key drivers of the atomic lens can be linked to industrial drivers (the need to innovate and redefine business models; shift from timber and pulp processing towards energy production and bio-based products), cultural drivers (the need to respond to climate change; perceiving forests as sources of wellbeing), environmental drivers (changes in climate and demographics), financial drivers (from "US-centric to more multipolar global economy; the increasing economic power of China; the price of energy and fuel) and regulation drivers (climate and energy policy; the rising demand for renewables; the transition towards a bio-economy) (Figure 35). The more specific drivers would be biomass/biofuels regulations and directives, and the generic benefits of using of renewable resources. In addition, new business opportunities and totally new value chains could be considered as drivers that are currently emerging.

Markets and consumer needs

It is expected that global demand for textile fibres will increase by 80% by 2030. Additionally, and due to stagnation in cotton production, the potential for cellulosic textiles may increase by 15 Mt. There is thus a strong potential for cellulose and fibre-based products and highly increasing interest in developing numerous novel cellulose-based technical and life-science related products. There are established and increasing markets for wood plastic composites (ca. 3 Mt 2012), and novel applications are constantly being explored.

Actors and actions

The key actors include forest and wood products industry and chemical industry. Also, various actors in other industrial sectors, such as textiles, cosmetics, food, electronics, and construction are part of the value chain. However, there is still intensive research and development needed before the new value chains are in full operation. For this purpose, research co-operation is important. For the forest and wood products industry in Green Triangle region, one option could be to engage in open exchange with the wine industry on aspects of co-operation, networking and clustering.

Solutions

The global pulp production is about 200 Mt, of which 6 Mt is dissolving pulp used in the textile and chemical industries. Currently, nanocellulose production has commenced, but is still in its infancy. Another solution is in wood plastic composites (WPC) that can be used in multiple ways, including as extrusion for the building industry, for injection moulding in the car industry, and in furniture and auxiliaries. Currently, there are different packaging solutions based on wood and cellulose fibres, and for coating and barrier materials. Different wood treatments, such as chemical and thermal treatments are currently available. An interesting option to consider is the use of Australian radiata pine as a source of extractives and in a future move towards the production of cellulose or hemi-cellulose based chemicals.

Enabling technologies

Presently, the key enabling technologies focus on advanced, but existing, pulping and other processes that are suitable for different raw materials. Further enabling technologies include applications of material sciences, chemistry and biotechnology for the modification of cellulose and fibres for improved novel products. Rapid progress is expected to result in numerous new innovations and applications. A further enabling technology is for new polymer and fibre blends, and for composites.

Medium term

Drivers

The key drivers in the medium term of the atomic lens can also be linked to industrial drivers (need to innovate and redefine business models; shift from timber and pulp processing towards energy production and bio-based products), cultural drivers (need to respond to climate change; perceiving forests as sources of wellbeing), environmental drivers (changes in climate and demographics), financial drivers (from “US-centric” to more multipolar global economy; the increasing economic power of China; the price of energy and fuel) and regulation drivers (climate and energy policy; the rising demand for renewables; the transition towards bio-economy). There are also new potential drivers, such as the emergence of regional and national bioeconomy strategies, and the potential bio-premiums that could be included in these strategies. New business models, partnering and joint ventures will increasingly act as drivers, as will new business opportunities based on nature’s chemistry, and the possibilities for creating value chains with new players. Replacement of oil based plastic materials with “green” equivalents will act as a crucial driver in the medium term. The development towards performance chemicals could be a significant driver for the industry in the medium term. A further driver is a need to replace of starch-based products with cellulose equivalents that leave starch to be used for food and feed.

Markets and consumer needs

In the medium term, the global demand for textile fibres is continuously rising due to the introduction of new solution areas. Also, the stagnating cotton production will drive the textile fibres. Life sciences are breaking through as a market for novel cellulose-based products. The wood plastic composites and biocomposites will be widely utilised in different industries.

Actors and actions

In the medium term, there will be evolving new value chains, with various opportunities for new companies, including SMEs. These novel value chains will cover the complete spectrum from raw material (biomass) production to end application development, testing and marketing, requiring more active collaboration between groups such as research providers, mining, wine and forest industries, agriculture, and other industrial sectors.

Solutions

There will be an increased demand for cellulose particularly in the textile industry, but also for other applications. This demand will generate new cellulose processes that will result in new cellulose-based products for use in agriculture, soil conditioning, water purification, tissue engineering, and insulation applications. In the medium term, numerous solutions for nanocellulose will emerge based on its graphene-like properties. Wood plastic composites (WPC) will continue to grow in importance due to its multiplicity of uses e.g. as extrusion for building industry, for injection moulding in car industry, and in furniture and auxiliaries. Different packaging solutions based on wood and cellulose fibres for coating and barrier materials will be high on the agenda. In the medium term, more WPCs could be made from sawmilling and other residues such as scrapped plastics. New WPCs with novel functionalities will emerge and an option to consider will be fibre-plastic composites made from waste streams. Functional packaging will advance and this will result in softer and more tender toilet/hygiene/paper products, and novel barrier coatings (grease and oxygen) based on cellulose and hemicellulose.

Enabling technologies

In the medium term, the key enabling technologies will be novel pulping and fractionation processes, for example hot water systems and use of ionic liquids. These will enable optimal separation and uses of all biomass constituents. Further enabling technologies include applications of material sciences, chemistry and biotechnology for modification of cellulose and fibres for improved and novel products. Rapid progress is expected to result in numerous new innovations and applications, new polymer and fibre blends, and also composites.

Long term

Drivers

In the long term, the key drivers of the atomic lens will remain the industrial drivers (need to innovate and redefine business models; shift from timber and pulp processing towards energy production and bio-based products), cultural drivers (need to respond to climate change; perceiving forests as sources of wellbeing), environmental drivers (changes in climate and demographics), financial drivers (from "US-centric" to more multipolar global economy; the increasing economic power of China; the price of energy and fuel) and regulation drivers (climate and energy policy; the rising demand for renewables; the transition towards bio-economy). There are also new potential drivers, such as emergence of regional and national bioeconomy strategies, and the potential bio-premiums that could be included in these strategies. New business models, like partnering and joint ventures, will increasingly drive the development. Same will apply generically to the emerging opportunities based on nature's chemistry and the possibilities for creating new value chains with new players. Replacement of oil based plastic materials will act as a crucial driver in the long term. The development towards performance chemicals could be a significant driver for the industry in the long term. In the long term, a need to replace of starch-based products with cellulose, and thus leave starch to be used for food and feed, will also be a driver.

Markets and consumer needs

The market trends that were on the rise in the medium term will continue. The key trend is the widening of the application areas for novel cellulose-based products. The demand for textile fibres continues to soar, and novel cellulose-based products will be widely used in medicine and life sciences. The new composites will be applied in the different industries for making light and durable structures.

Actors and actions

In the long term, new value chains will evolve, with numerous opportunities for new companies, including SMEs. These novel value chains will cover the complete spectrum from raw material (biomass) production to end-use development, testing and marketing. A key development could be the emergence of global virtual research centres with expertise in cellulose-based products. A prototype for these centres is in evolution in Finland and given the name: the Finnish centre of nanocellulosic technologies.

Solutions

There will be an increased demand for cellulose, particularly in the textile industry, but also for other applications. This demand will generate new cellulose processes that will result in new cellulose-based products in agriculture, soil conditioning, water purification, tissue engineering, and insulation applications. Numerous solutions for nanocellulose will emerge based on its graphene-like properties. Wood plastic composites (WPC) will gain in importance due to its use flexibility as extrusion material in the building industry, for injection moulding in the car industry, and in furniture and auxiliaries. Coated wood and cellulose fibres with barrier properties will find application in different packaging. New WPCs with novel functionalities will be established, and an option to consider could be fibre-plastic composites made from various waste streams. In the long term, functional packaging will continue to advance and new products will emerge at the convergence of nanocellulose with printed intelligence, and nanocellulose with photovoltaics. There is a possibility of developing optical photovoltaics, and combining nanocellulose and pharmaceuticals. Additionally, different water related solutions will become more common such as collecting moisture with nanocellulose and producing fresh water from nanocellulose applications.

Enabling technologies

Key enabling technologies will be novel pulping and fractionation processes, for example hot water systems and the use of ionic liquids. These will enable optimal separation and use of all biomass constituents. Further enabling technologies include applications of material sciences, chemistry and biotechnology for modification of cellulose and fibres to improve products and develop new ones. Rapid progress in technology is expected to result in numerous new innovations and applications such as new polymer and fibre blends, and composites.

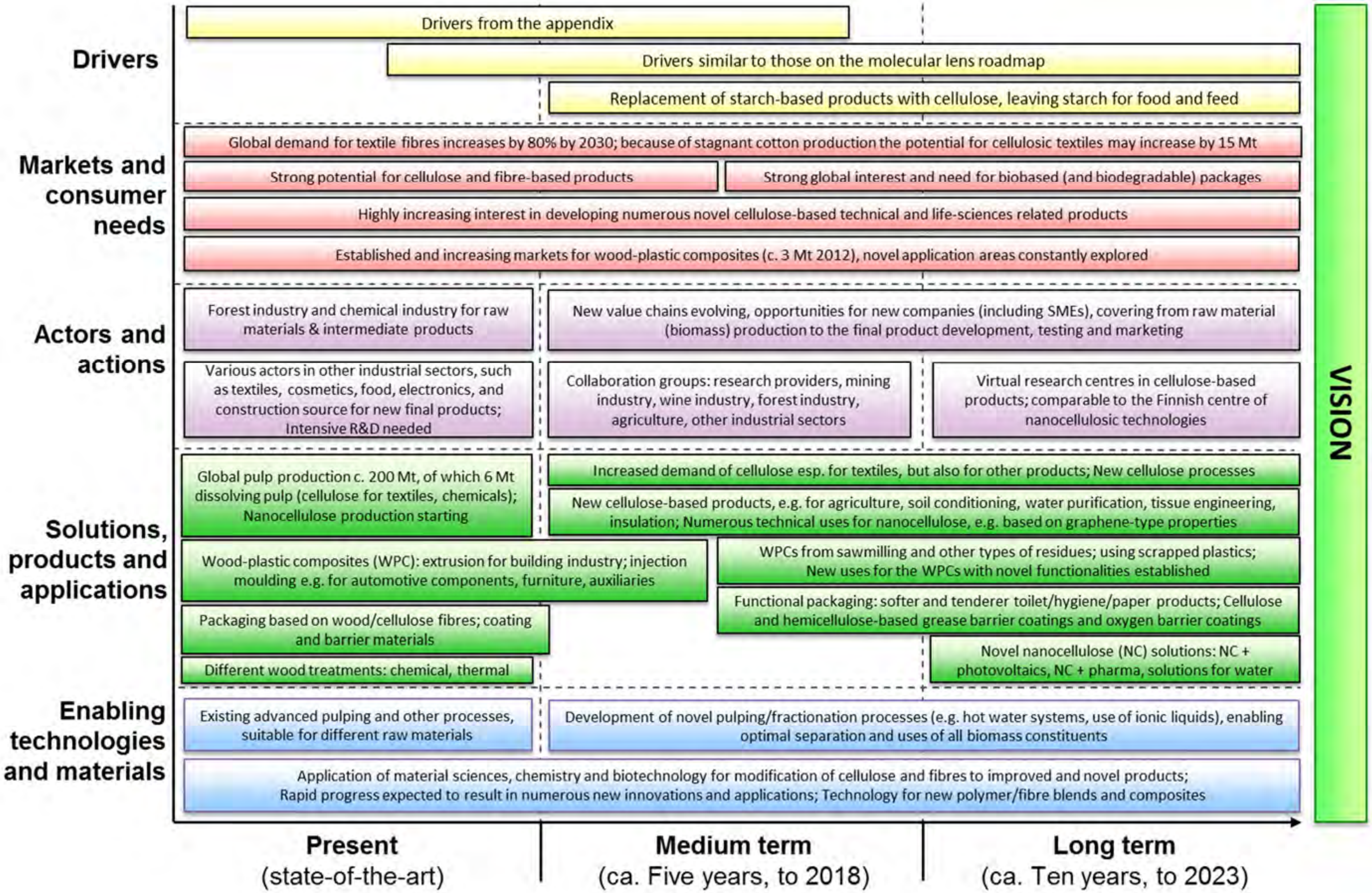

Figure 35. Roadmap 4 – Atomic lens: radical industry renewal through new biomass and fibre-based production.

6. Recommendations

The forest and wood products industry and associated value chain, along with many other Australian manufacturing industries, have experienced a very difficult decade, peaking in recent times from the exceptional circumstances created by the global financial crisis and increased globalisation. Coupled with internal factors such as a lack of re-investment, aging equipment and poor management decisions have resulted in a significant reduction in industry profitability and a loss of employment opportunities that have combined to create an atmosphere of gloom and doom.

Faced with this predicament, the South Australian government felt compelled to act and sought the assistance of VTT, as experts in the forest product value chain, to develop grounded pathways for the renewal of the industry, both in the short (3–5 years), medium (5–10 years) and long-term (greater than 10 years), through a roadmap exercise (see Roos 2012a; DMITRE 2012). The work undertaken forms the basis of this report.

Our vision for the Green Triangle region is the following: Green Triangle has a thriving forest and wood products industry that provides a sustainable contribution to the economy of South Australia in the long term, contributing to community, wellbeing, sustainability, and quality of life.

The study followed a rigid and proven process, involving local players and overseas experts, as well as the substantial internal resources of VTT. The process has resulted in the development of altogether three pathways with 3 to 5 year time horizon, four more concise pathways beyond 5 years time horizon, and three generic policy-oriented recommendations to support all the pathways. The following section summarises the recommendations in terms of why they are considered as prime candidates for the region, what the next steps should be and what would be the benefit.

Pathway 1, recommendation 1: Oriented Strand Board (OSB)

Why this recommendation?

OSB is a structural panel product produced from low-cost pulpwood grade logs. The Green Triangle region has a surplus of SWD and HWD pulpwood. This is being exported as chip and as logs at low prices.

OSB substitutes plywood in many applications. Australia is a net importer of structural panels. More than 300,000 m^3 of plywood is imported annually from New Zealand alone. This provides an excellent advantage for a locally made OSB product. Lack of domestic product has limited local demand. Experience from several markets demonstrates that OSB has reasonable potential when priced competitively.

The technology is mature and an efficient factory investment of A$ 130 million is required to develop a plant of 200,000 m^3/a scale. This might require foreign investors/partners.

What are the next steps?

- Forest owners, regional councils and the State Government work together to define the biomass opportunity, favourable factory location and investment hosting inducements.
- Initiate a national/international investor search process canvassing OSB producers as one of a range of possible end-uses for the underutilised pulpwood logs.

What are the consequences of the steps?

Value-added uses for pulpwood are an essential requirement for increasing the returns to forest growers.

Access to lower-cost structural panel products will assist SA and Australia to increase use of wood in all forms of construction.

Supplies of locally-produced OSB will also significantly reduce Australia's wood product imports, thereby reducing its balance of payments deficit.

Pathway 1, recommendation 2: Veneer-based Engineered Wood Products (EWP)

Why this recommendation?

Engineered Wood Products can potentially be produced from the Green Triangle underutilised HWD and SWD pulpwood-grade logs. A proportion of these logs will meet the quality requirements for peeling to produce veneers and further to higher value products such as LVL (Laminated Veneer Lumber).

Logs being exported to China are already being used for this purpose. The domestic market was growing at 8–12% until the recent slowing down in construction. Australia's sole producer is based in WA.

LVL requires relatively large size logs. Green-field investment of approximately A$ 130 million can produce easily 60,000 m^3 and with low further investment double the quantity when the market justifies. The basis for the investment would be good raw-material supply and advantageous mill site in the Green Triangle area.

What are the next steps?

- Evaluate the proportion of HWD pulpwood logs that would meet the requirements for LVL
- Forest owners and SA regional and State Governments work together to define the biomass opportunity, favourable factory location and investment hosting inducements.
- Initiate a national/international investor search process canvassing LVL producers as one of a range of possible end-uses for the underutilised HVD pulpwood logs.

What are the consequences of the steps?

Value-added uses for pulpwood are an essential requirement for increasing the returns to forest growers.

Access to high valued engineered wood products will help to increase use of wood in construction.

Producing high value LVL products efficiently with modern equipment from low cost raw-material would enable the export of standardised products

Pathway 1, recommendation 3: Improved sorting and better yields by X-ray scanning

Why this recommendation

X-ray scanning of logs to be processed is a not a new technology and has been used for at least 10 years use in several sawmills in Scandinavia. The simple advantage is that being able to "see" inside a pine log allows better and more efficient sawing by splitting the round wood to sawn timber pieces of the highest possible quantity and quality. The logs with their inner defects can be sorted to different sawing patterns before processing and thus the end products are of the best possible quality and volume.

Investment in X-ray scanners is quite modest at A$ 2–4 million, but may also require additional investment in IT and sometimes extra log sorting and the mill layout. Payback time is usually within 1-2 years. The best result can be reached through stem terminal, but this needs higher investment and is best utilized in large sawmills.

What are the next steps?

- Evaluate X-ray technology suppliers and establish how much yield can be reached, through real material tests on local radiata pine logs
- Check the labour safety regulations concerning the installation and use of scanners
- First installation of X-ray equipment should be at one of the larger mills with good log-sorting facilities

What are the consequences of the steps?

The supplier of the equipment can adjust the algorithms to best suit the local Radiata Pine after the initial testing period

The value yield increase can be verified through use of equipment in a local mill

The stem terminal solution can be adjusted and verified during this process, but more development is needed in logistics etc. before the ultimate value of the yield improvement can be estimated, not only for the sawmill, but for the total forest biomass.

Pathway 1, recommendation 4: Specialised sawmilling by using smaller and shorter logs

Why this recommendation?

The use of small size pine logs and pulpwood in the region is diminishing rapidly as a result of the closure of the only pulp mill, resulting in the unused raw material being exported as logs or chips.

The small size pine logs could and should be processed in the region. The existing mills are configured largely to process bigger and longer logs, with the small logs directed to roundwood products predominantly. Higher values are possible by treating the short and small timber in separate mills with specialised sawmilling equipment or by installing a new line in an existing mill.

Investment in a green-field site to utilise small logs would be of the order of A$ 30 million. With a low priced raw material processed in a modern production site, the payback time can be reasonably short and offer new employment possibilities. If it is integrated with an existing large sawmill, the investment would be less.

What are the next steps?

- Examine the availability and logistics of good quality small logs and pulpwood, preferably after final felling
- Decide the optimum location for a small log sawmill or alternatively a new small log line in an existing mill
- Initiate discussions with a seasoned small log machinery supplier to install the first equipment at a chosen site

What are the consequences of the steps?

The timber pieces from the small logs will have four times higher value than chips from the currently under-utilised pulpwood, as well as the potential to generate new jobs in the region.

The sawn timber from small logs could widen the possibilities for exporting pine products such as small size gluelam to Japan and other Far-East markets.

Pathway 2, recommendation 1: Cross-laminated timber (CLT) and high storey houses

Why this recommendation?

Cross-laminated timber (CLT) is an innovative-engineered wood product that is not currently produced in the Green Triangle. Imports of CLT are growing and the national and international market is predicted to grow. CLT is presently rapidly growing in Europe, but has still only a very low share of the construction material market. It can be expected that the same trend will be replicated in Australia and hence a good business case can be made for increasing the production of CLT.

There is enough material for a new CLT plant that should be co-located with one of the existing sawmills. The investment for a 60,000 m^3 capacity plant is approximately A$ 30 million with a payback of 3–5 years.

What are the next steps?

- Consider in detail the recent experiences in Europe and initiate contact with CLT equipment and adhesive suppliers.
- Work with FWPA, South Australia Government and other groups to modify relevant building codes to permit use of CLT in a range of applications including in the construction of high-rise CLT buildings
- Initiate training programs to build competence in wooden building skills and encourage use of CLT in public construction projects
- Promote wooden buildings, including CLT, with architects and building developers, and have initiatives for building construction out of CLT
- The value chain of building code authorities, sawmill, CLT site, construction company and eco-marketing company needs to be developed

What are the consequences of the steps?

Tall wood buildings will be part of the next generation of high-performance sustainable buildings. This is a trend that South Australia should not miss, but likely will if locally produced CLT is not available.

Part of the raw material used in gluelam can be of lower quality, thus increasing the value yield of local sawmilling.

Beyond the potential profitability of construction with CLT, South Australia will produce, safe, carbon-neutral and sustainable alternative to the conventional structural materials in an increasingly urban world.

Pathway 2, recommendation 2: Glued Laminated Timber (Gluelam)

Why this recommendation?

Gluelam is a well known engineered wood product already in Australia. The use of gluelam products in Europe for all bigger constructions like sport halls, industrial buildings, malls and larger open constructions is very common. However, in Australia construction practices with much lower performance environmentally, such as concrete and steel are traditionally used.

Japanese small houses are consuming approximately 1,000,000 m^3 of glued timber in constructions, which are favourable for earthquakes and can be handled without special expertise. This model will probably be followed in other Far-Eastern developing countries with limited wood resources of their own.

Investment of gluelam equipment, even for large scale beams, is quite modest at A$ 10-20 million and would be best utilized together with big sawmills.

What are the next steps?

- Consider in detail the vast experience in Europe and follow the seasoned practices
- The building codes should be modified to permit and promote the use of gluelam products in large constructions such as municipal buildings
- An initiative for an investment into a large scale gluelam site integrated into one of the larger sawmills

- Research the acceptability of radiate pine pulpwood based gluelam products to the Japanese market

What are the consequences of the steps?

Part of the raw material used in gluelam can be of lower quality, thus increasing the value yield of local sawmilling.

Due to the light weight of glued timber, the possibility to deliver larger constructions over longer distances would give the Green Triangle region an advantageous position in nationwide market.

Pathway 2, recommendation 3: Wooden bridges

Why this recommendation?

Wooden framed bridges are currently widely used in several countries in the world. Norway and Sweden are leaders in this domain, and there are also some examples in USA, Finland and Chile.

The advantages of light weight constructions bring along with it the possibility to assemble bridges over existing roads without any disturbance and with simple "one-lift" operation over railroads, rivers and other obstructions. It offers an effective low cost option for bridges by allowing manufacture in factories and delivery by trucks.

Investment of wooden bridge equipment, even on a large scale, is very modest at around 1 million A$ when made with a gluelam producer.

What are the next steps?

- Consider in detail the experience in northern Europe and follow the seasoned practices and building models
- The building codes should be modified to permit and promote the use of wooden bridges
- Research the local coating and preservation needs with local expertise to extend lifetime and prevent termite damage.

What are the consequences of the steps?

The use of a local and sustainable raw material instead of concrete and steel creates more employment opportunities and increases the valuable use of gluelam as an outlet for underutilised pine plantations.

Due to the light weight nature of glued timber there is a possibility to deliver larger constructions over longer distances and this gives the Green Triangle region an advantageous position in nationwide market.

Pathway 2, recommendation 4: Biocomposites

Why this recommendation?

Biocomposites, in particular wood plastic composites (WPC) are synthetic, thermoplastic resin/wood/additives that contain up to 80% wood and could utilise the lower quality uncommitted waste biomass.

The WPC biocomposite industry is predicted to grow to 4.6 million tonnes globally by 2016. The composite materials price range from A$ 1500-5000 per tonne.

The Green Triangle does not have a polymeric resin supplier, but the region could be the manufacturing site of WPC pellets for further processing at existing or new biocomposite sites as, for example, APR or similar companies (http://www.advancedplasticrecycling.com.au/). WPC may also be of interest to advanced technology flooring companies such as 3RT. Another application could be along the lines of a composite development by Puustelli Group Oy, a leading kitchen furniture manufacture in Finland.

What are the next steps?

- Assess the possibility to retro-fit an existing MDF mill, using the same front end to provide an alternative product and market stream.
- The logistics of the supply of suitable polymer is crucial
- Forest owners, regional councils and the State Government work together to better define the biomass opportunity, and investment possibilities.
- Initiate a national/international investor search process canvassing biocomposite producers as one of a range of possible end-uses for the underutilised pulpwood logs.

What are the consequences of the steps?

There is an opportunity to generate composites from sawdust, pulp logs, wood chips and shavings and thereby add value to these biomass residuals. There is the potential to generate new forest-based value chains, more employment and add value to underutilised biomass in the Green Triangle region.

Pathway 3, recommendation 1: Bio-oil by fast pyrolysis

Why this recommendation?

Fast pyrolysis technology to convert biomass to heating oils is commercial ready. Moreover, this energy biorefinery technology is capable of converting different biomass resources, including industrial and forest residues, into liquid fuel that can replace heavy fuel oil used in boilers and kilns. The investment for a 60,000–90,000 m^3/a bio-oil facility of some A$ 30 million is relatively low and would generate about A$ 60 million worth of annual sales.

What are the next steps?

- Identification of suitable sawmills for installation of pyrolysis plant based on feedstock availability and potential bio-oil users in the region
- Establishing conditions and regulations for bio-oil market development
- Assessment of potential “crude” bio-oil and upgraded bio-oil users and the development of a bio-oil supply infrastructure
- Follow the bio-oil upgrading technology development

What are the consequences of the steps?

First plants could be realised in Green Triangle in a 3–5 year time-frame, supplying energy first to operators of sawmill boilers and kilns and later to external customers. A significant part of the unused forest residues available in Green Triangle will be converted to a more usable energy form.

Pathway 3, recommendation 2: Biochar by torrefaction

Why this recommendation?

The energy, mining and metal industries in South Australia use millions of tonnes thermal coal annually. Equally, they could co-fire biocoal in their power plants. In addition, biochar can be used as a soil conditioner and biogenic carbon sink. Available biomass in the Green Triangle for torrrefaction includes excess pulpwood, forest residuals and chips produced at sawmills. Production volume of torrefied pellets in the region, as part of overall energy biorefinery platform, could be in the range of 100,000 to 200,000 bdt/a, with an annual sales value of about A$ 15–30 million. Investment requirement is a relatively small and estimated at A$ 20 to A$ 40 million.

What are the next steps?

- Development of incentives and regulation for biomass use in heat and power production
- Identification of potential biochar customers and establishing the appropriate value chain connections (e.g. forestry, power,mining and metal industries)
- Identification of suitable torrefaction plant location and biochar logistics design and planning

What are the consequences of the steps?

Demand of solid biofuels increases due to regulations.

Pathway 3, recommendation 3 and 4 combined: Power, heat and biofuels by gasification

Why this recommendation?

Gasification is a key future energy biorefinery technology that has many different application areas. Gasification of forest residues has been demonstrated at an industrial scale. Large amounts of unused wood and forest biomass in the Green Triangle is a potential raw material base for electricity and in the future, the syngas can be converted into transportation fuels or chemicals. Revenues of over A$ 100 million are possible for a facility processing 1,000,000 m^3/a biomass when FT-diesel is produced.

What are the next steps?

- Incentives or capital investment subsidy for liquid transportation fuels production; feed-in tariffs for bio-based electricity production
- Development of contacts and co-operation with fuel producers and distributors
- Due to large capacity requirement for economic production of gasification based biofuels, establishing a well-operating low cost biomass supply chain
- Identification of by-product heat integration possibilities

What are the consequences of the steps?

Under a favourable feedstock cost level and with incentive systems in place, first gasification based heat and power plants could be realised in 3–5 years. Major part of unused forest biomass will be valorized.

While a promising beginning, the process undertaken to date is not complete. To implement all of the recommendations arising from the study at the same time is simply not possible for logistical reasons and cost considerations. Clearly, these will have to be prioritised in a manner that will require input from all the key regional players in the value chain. How this is best implemented has yet to be finalised, but a series of workshops with VTT assistance involving representatives from the various interest groups, government representatives at all levels and research providers is suggested as a good way forward.

In most of the world there are on-going research programs related to the development of intelligent and resource-efficient processes, future biorefineries and bioenergy solutions which may be templates for South Australia. For example, the Finnish Bioeconomy Cluster (FIBIC; http://fibic.fi/), is one of six Strategic Centres for science, technology and innovation in Finland (SHOK; http://www.shok.fi/en/) that aim to turn science and technology into sustainable bio-based solutions. They have experience in offering businesses and research organizations a new way of engaging in close, long-term cooperation and leveraging the best competences and resources that combines research and companies for innovative solutions. FIBIC are accelerating Finland to become a pioneer in the sustainable bioeconomy and VTT, universities and global businesses are partnering in the development of a more innovative, resource-efficient and competitive society.

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APPENDICES

Stage 2. Future options for the cellulosic fibre value chain in the Green Triangle, South Australia: strategic technology roadmaps, business cases and policy recommendations

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Confidentiality: Public

Contents

1. APPENDIX 1: Abbreviations used in the reports

2G	second generation
3D	three-dimensional
3G	third generation
a	annum / year
ACOLA	Australian Council of Learned Academies
ADEME	French Environment and Energy Management Agency (France)
AFPA	Australian Forest Products Association
ALD	atomic layer deposition
ANR	French National Research Agency (France)
APR	aqueous phase reforming technology
ARENA	Australian Renewable Energy Agency
ASU	air separation unit
ATSCH	ambient temperature starch/ cellulose hydrolysis
AUD	Australian dollar
BC	bacterial cellulose
BCTMP	bleached chemithermomechanical pulp
bdt	bone dry tonne
BFT	The Bionic Fuel Technologies Group
BIM	building information model
BioDME	biodimethyl ether
BLG	black liquor gasification
BMBF	Federal Ministry of Education and Research (Germany)
BMELV	Federal Ministry of Food, Agriculture and Consumer Protection (Germany)
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Germany)
BRIDGE	Biobased and Renewable Industries for Development and Growth in Europe; EU project
BtL	biomass to liquid
C5	5-carbon sugars
C6	6-carbon sugars
CAD/CAM	Computer-aided design/computer-aided manufacturing
CAGR	compound annual growth rate
CAPEX	capital expenditure
Cat-HTR	catalytic hydrothermal reactor
CBIN	Canadian Biomass Innovation Network
CBP	consolidated bioprocessing
CEA	Atomic Energy Commission (France)
CEPCI	chemical engineering plant cost index
CFB gasification	circulating fluidized bed gasification
CHP	combined heat and power
CITES	Convention on International Trade of Endangered Species of fauna and flora
CLT	cross-laminated timber
CMC	carboxymethyl cellulose
CNC	computer numerical control
CNG	compressed natural gas
CNRS	National Center for Scientific Research (France)
CO	carbon monoxide
CO_2	carbon dioxide
COST	European Cooperation in Science and Technology

CPRS	Carbon Pollution Reduction Scheme
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CT	computer tomography
CTMP	chemithermomechanical pulp
CWC	Canadian Wood Council
DC	dry content
DME	Dimethyl ether
DMITRE	Department of Manufacturing, Innovation, Trade, Resources and Energy
DNA	Deoxyribonucleic acid
DOE	US Department of Energy
EESA	The Electric Energy Society of Australia
EESI	Environmental and Energy Study Institute (USA)
EPA	Environmental Protection Agency (USA)
ESL	engineered strand lumber
EU	European Union
EVOH	ethylene vinyl alcohol copolymer
EWP	engineered wood product
eWPC	enhanced wood plastic composite
FB gasifier	fluidised-bed gasifier
FDA	Food and Drug Administration (USA)
FFTT	Finding Forest Through the Trees; a building concept for wooden tall buildings
FIBIC	Finnish Bioeconomy Cluster
FiDiPro	Finnish Distinguished Professor Program
FII	Forestry Innovation Invesment
FOB	free on board
FP7	Framework Program 7; a generational portfolio of EU projects
FT	Fischer Tropsch
FTL	Fischer Tropsch liquid
FWPA	Forest and Wood Products Australia
GDP	gross domestic product
GHG	green-house gases
Gluelam	glued laminated timber
GMT	green metric tonne
GWh	gigawatt hour
H_2	hydrogen
HDS	hydrodesulphurization
HFO	heavy fuel oil
H-gas	hydrogen gas
HHV	higher heating value
HP	high pressure
HTC	hydrothermal carbonization
HWD	hardwood
HWE	hot water extraction
ICT	information and communication technology
IFP	Institut Français du Pétrole (France)
INSA	Institut National des Sciences Appliquées (France)
IPC	Immaterial Property Classification
KCL	Central Laboratory (Oy Keskuslaboratorio - Centrallaboratorium Ab); a Finnish forest industry research centre that was jointly funded by the industry; the centre was merged into VTT 2009
LCA	life-cycle assessment
LCFS	low carbon fuel standard

LGF	lignofibre
LHV	lower heating value
LP	low pressure
LSL	laminated strand lumber
LVL	laminated veneer lumber
m^3	cubic meter
MCC	microcrystalline cellulose
MDF	medium-density fibreboard
MeOH	methanol
MFC	microfibrillated cellulose
MGP	machine graded pine
MIS	Managed Investment Scheme
MSW	municipal solid waste
Mt	megatonne
MTG	methanol to gasoline
MTO	methanol to olefins
MWh	megawatt hour
NCC	nanocrystalline cellulose
NER 300	one of the largest funding programmes in the world for low-carbon energy demonstration projects
NFC	natural fibre composite
NFC	nanofibrillar cellulose
NGO	non-governmental organisation
NIFPI	National Institute for Forest Products Innovation
NRPC	naturally reinforced plastic composite
NWBC	Nordic Wood Biorefinery Conference
NZ	New Zealand
OSB	oriented strand board
PATSTAT	Patent Statistical Database
PDU	pilot and demonstration unit
PE	polyethylene
PET	polyethylene terephthalate
PFI	Paper and Fibre Research Institute (Norway)
PG	product gas
PGA	polyglycolic acid
PHA	polyhydroxyalkanoate
PLA	polylactic acid
PPP	public-private partnership
PR	public relations
PRO	public research organisation
PSL	parallel strand lumber
R&D	research and development
RED	Renewable Energy Directive
RFID	radio frequency identification
RME	rape methyl ester
S&T	science and technology
SARDI	South Australian Research and Development Institute
SCL	structural composite lumber
SEK	Swedish crown
SHOK	Strategic Centres for science, technology and innovation in Finland
SHS	self-propagating high-temperature synthesis
SME	small and medium sized enterprise
SNG	synthetic natural gas

SOL	solution
SPIRE	Sustainable Process Industry through Resource and Energy Efficiency; European public-private partnership
SSL	sulphite spent liquor
SWD	softwood
TAPPI	Technical Association of the Pulp and Paper Industry
TECH	technology
Tekes	Finnish Funding Agency for Technology and Innovation
TMP	thermomechanical pulp
TOP process	combined torrefaction and palletisation
tpa	tonnes per annum
UK	United Kingdom
USD	US dollar
USDA	United States Department of Agriculture
USPTO	United States Patent and Trademark Office
WA	Western Australia
WFP	wood fibre pellet
WGS	water gas shift
WoodCIM	modelling and simulation software for sawmills, developed by VTT
WPC	wood plastic composites

2. APPENDIX 2: Literature review: reflections from the perspective industry renewal

2.1 Key drivers affecting the forest and wood products industry

There are a number of key drivers that impact the forest and wood products industry, and these are discussed in turn.

Industrial drivers. Worldwide, the forest and wood products industry is in a state of transition. The wood and pulp and paper industries in Scandinavia and North America cannot compete with the emerging economies of Latin America and Asia, which have modern plants and wood and labour costs advantages. There is a need to innovate and redefine business models and culture and shift from timber and pulp processing towards energy production and bio-based products (Näyhä 2012a). The global demand for forest products such as paper and timber is expected to grow, but this is mainly fuelled by the growth in China, India, Brazil and other developing countries (Jonsson 2011). In Europe and North America, the digitalization of media has decreased the need for paper, but in the developing countries the demand is expected to grow along with the GDP (Hujala & Hilmola 2009). However, the growth in 'traditional' product domains is modest compared to new applications. According to the Forest Products Association of Canada (2011) the market potential for new bio-products and biomass based energy is predicted to grow from $500 billion USD to $1300 billion USD by the year 2030, whereas the growth in traditional forestry products is expected to be more modest from $500 billion USD to $550 billion USD.

Cultural drivers. The main changes in cultural values are related to the responses to climate change and the perception of forests as a source of wellbeing and ecotourism (Niinistö et al. 2012). The change in values will affect the way forests are used. Pelli and den Herder (2013) present different possibilities in the use of forests for health and wellbeing as well as to green infrastructure: recreation and therapeutic experience, forest spas, source for chemical components such as enzymes, food additives, vitamins etc., shelter beds for fresh water, reducing pollution and noise and carbon storage.

Environmental drivers. Here the major drivers are changes in climate and demographics. Climate change will impact all biological production in the following decades and massive forest loss is one serious threat (Lindahl & Westholm 2011). On the other hand, reforestation is one key part of climate change mitigation strategies. However, because of increasing population and demand for more food production, there will be competition for arable land.

Financial drivers. The global economy is changing from "US-centric" to a more multipolar international one as the emerging markets account for the majority of economic growth (World Bank 2011). The increasing economic power of China will change the global economic landscape, as China invests in technology and the African market (Donner-Amnell et al. 2011). In the pulp and paper industry, global prices will decrease as the production capacity increases in China, South America, Russia and Central Eastern Europe (Uronen 2010). The price of energy and fuel is expected to continue to increase, which will have major impacts in global logistics and material flows (Donner-Amnell et al. 2011). This may lead to more regional industrial systems operating in an optimal radius for the given product.

Regulation drivers. Climate and energy policy are the main regulation drivers related to the forest and wood products industry. They are intertwined in that energy policy is a key part in mitigating climate change. The main drivers that benefit forest-based bio-energy are concerns for energy security and the rising demand for renewables (Lindahl & Westholm 2011). Developed nations do not want to be dependent on imported oil and coal in the future and bio-mass based energy is one attractive solution. According to UNECE (2009) there is already structural change in the forest and wood products industry due to demand for bio-energy. In order to respond to the increase in energy demand, the investments to bio-energy will need to increase markedly (Donner-Amnell et al. 2011). From the viewpoint of climate policy, forests have a larger role than being mere substitutes for fossil-based energy. Forest biomass can be used in bioplastics, substituting the use of fossil-based products while forests act as sources and sinks of carbon dioxide (Lindahl & Westholm 2011). Sustainable forest management and prevention of deforestation are important actions to mitigate climate change. The transition towards bio-economy brings with it debates on land use, especially in countries where arable land is sparse (Lindahl & Westholm 2011). The land required by forests increases when the role of forests as a source for fuel, energy, wood, paper and new cellulose based products increases. The limited availability of land may complicate meeting this demand (Nilsson 2007).

Research and development drivers. The report “Australia’s forest industry in the year 2020” (DAFF 2007: 58–62) outlines sets of emerging technologies for the forest and wood products industry. The first group of these is engineered wood products, which includes Medium Density Fibreboard (MDF), Laminated Strand Lumber (LSL) and Engineered Strand Lumber (ESL). Engineered wood products contain also wood-plastic composites. The second group of emerging technologies is bioenergy and biofuels. The wood-based energy production is based on different technologies, like direct combustion, co-firing, gasification, pyrolysis and fermentation (DAFF 2007: 60). Bioenergy is an emerging direction that is highly conditioned by the development of regulation. The report also assesses that the wood-based energy production has been steadily rising, and especially the European Union’s (EU) regulation which has driven the use of wood-based bioenergy. Even though the report is few years old, there is nothing to indicate that this circumstance has changed and it is safe to conclude that Australia still lags considerably behind the EU in regulation incentives.

2.2 Emerging technologies

The emerging technologies in this report focus on three wider clusters of the technologies relevant for the forest and wood products industry in Green Triangle: 1) biorefineries, 2) integrated process technologies and concepts, and 3) new bio-based materials.

As Vlosky et al. 2012 noted that there are new and different sources for competitive advantage in sawmill processing. These include softwood timber and process improvements in chipping technology, thinner kerf saws, curve sawing, and computerized scanning and “optimization” technology (Meil at al. 2007). There are also novel 3-D scanning technologies that evaluate log and check contour, presence of knots and surface irregularities or defects. Also, new laser-based and computer optimized downstream processing solutions enable different automated solutions for sawing, edging, planing, sanding, and sorting processes. Another example is CNC-based (computer numerical control) instruments, such as drills and lathes. These tools give greater precision and repeatability in production. Further applications are in the field of robotics, for example in the furniture industry, where robotics can be applied to produce simulated distressing, like worm holes and dents to give the products an aged look.

New product categories, like engineered wood products (EWPs), have also been emerging in the “renewed sawmill space”. EWPs are products that are designed by engineering methods and built from different sets of smaller components and can be perceived as flexible alternatives to traditional sawn timber. Several kinds of products are already in the markets, like I-joists, trusses, and Structural Composite Lumber (SCL) that includes Laminated Veneer Lumber (LVL), Parallel Strand Lumber (PSL), and Laminated Strand Lumber (LSL) (Vlosky et al. 2012). Other related options close to market already are wood-plastic composites that are made from recycled plastic and wood residues. These can be utilised in several applications, such as outdoor deck floors, fences, benches, window and door frames (Vlosky et al. 2012). Other examples are green nanocomposites that have several applications, such as packaging, electronics, energy, and defence (Vlosky et al. 2012).

In addition to more traditional sawmilling, there are whole new alternatives for using biomass as raw material. According to the results of BioRefine – New Biomass Products Programme 2007–2012, funded by the Finnish Funding Agency for Technology and Innovation (Tekes), there are several development paths for the future utilisation of biomass; namely (Tekes 2012):

- Forest-based biofuels by gasification
- Refined biofuels and bio-oil from forest residues
- Alcohols and chemicals from non-food biomass
- Wood-based biomaterials
- Distributed biorefinery concepts
- Research openings: algae technology, cyanobacteria in energy production
- Sustainability of biomass utilisation

There are several emerging possibilities in the biorefinery space. Näyhä (2012b: 63) concludes that the biorefinery value chain “will provide business opportunities for new actors, particularly for small companies”. However, entering into the biorefinery domain is not just a matter of applying new technology, but it will require changes in the value chain structures and in collaboration. It will also call for new strategies and leadership. As Näyhä (2012) further continues, the lack of R&D expertise in the fibre value chain might pose problems in the adoption of biorefinery concepts.

The future biorefinery was a wide research programme funded by Finnish Technology and Innovation Agency Tekes (Kokko 2012). Future Biorefinery programme is one of the three strategic focus areas of Forestcluster Ltd, founded in 2007, to aid in the implementation of the National Research Strategy of the Finnish forest-based sector. Forestcluster is one of the six Strategic Centres for Science, Technology and Innovation in Finland (Kokko 2012: 18). Future biorefinery consists of several development paths for the forest industry: namely regenerated fibre and chemicals, structural composites, novel packaging and filtration materials, health-promoting products, wood preservatives and glues, and polymers, resins and chemicals. All of these development paths include new potential emerging technologies for the forest and wood products industry.

Another option for biorefinery technology is a biorefinery pulp mill, as studied by Mielonen (2012). This concept is based on "prehydrolysis of wood chips and acid hydrolysis of logging residue for the production of bioethanol" (Mielonen 2012: 66). Another aim is to separate the lignin for the production of biodiesel. The strength of this concept is that it brings new opportunities for the forest and wood products industry, yet keeps the focus on the main product from the pulp mill, the chemical pulp. The process structure is shown in Figure 1. There are many other ways to modify current pulp mills to more advanced pulp mill biorefineries, using different prehydrolysis or pre-extraction techniques, as recently reviewed by Engelberth and van Walsum (2012).

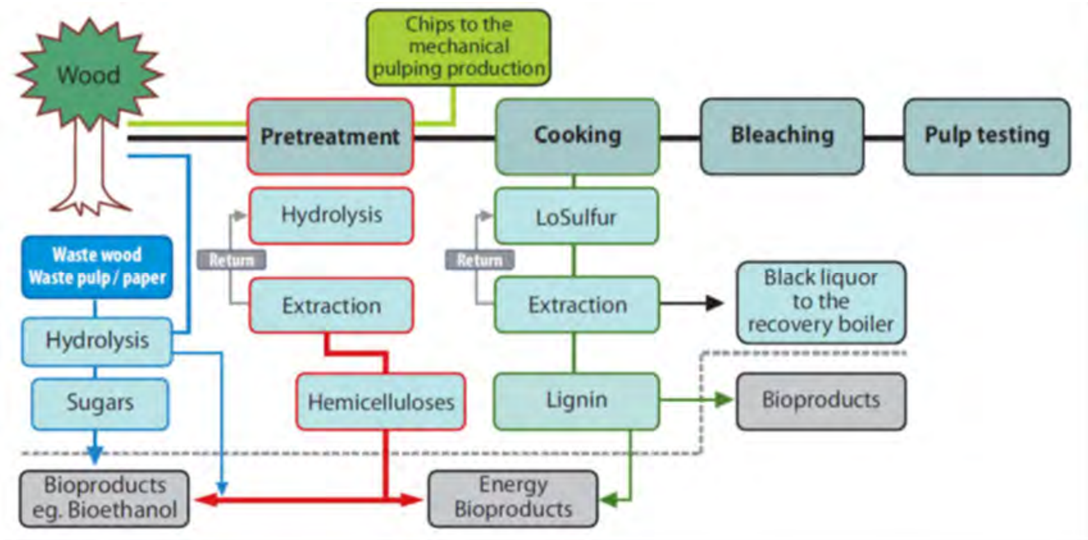


Figure 1. Biorefinery Pulp Mill concept as a block diagram.

Another approach for more advanced pulp mill biorefineries can be based on organosolv processing that apply different (either acidic or alkaline) organic chemical systems for the separation of cellulose, lignin and hemicellulose fractions. One of the pioneering processes, ethanol-based Alcell process was operated in a demonstration scale in Canada from 1989 to 1996; the pulping capacity was 30 tons of hardwood pulp per day. As a by-product, more than 5 tons of Alcell lignin was produced daily. The lignin was fully dried, bagged, and sold on a commercial basis. Evaporated stillage, consisting of syrups mostly of water-soluble hemicellulose saccharides and low-molecular weight lignin fragments, was also produced. Furfural, another significant by-product of the process, was recovered and sold on a routine basis. Altogether, 3,700 tons of Alcell lignin was produced and marketed.

The Alcell technology was acquired by Lignol (Vancouver, Canada) in 1997, and is currently being commercialised as a biorefinery technology. In its current form (as the Lignol process), however, cellulose will be used for the production of ethanol (Arato et al. 2005).

Acidic organosolv processes are currently commercialised by two European companies, CIMV from France and Chempolis from Finland, mainly for the processing of straw and other non-wood materials. Both of the processes also aim at isolating lignin and sugars (also furfural) as important marketable by-products, and various process modifications have been tested to achieve different desired product portfolios.

VTT is currently developing another type of organosolv process, based on the use of acetic and phosphinic acids as the main chemicals (Figure 2). This process has been shown to work both with hardwood and softwood raw materials, thus demonstrating wide applications areas. Furthermore, the resulting cellulose fraction can relatively easily be refined to dissolving pulp (Kangas et al. 2013), for textile and chemical (also nanocellulose) uses. Thus, there might be some potential for this type of hardwood processing plant in the study area in SA.

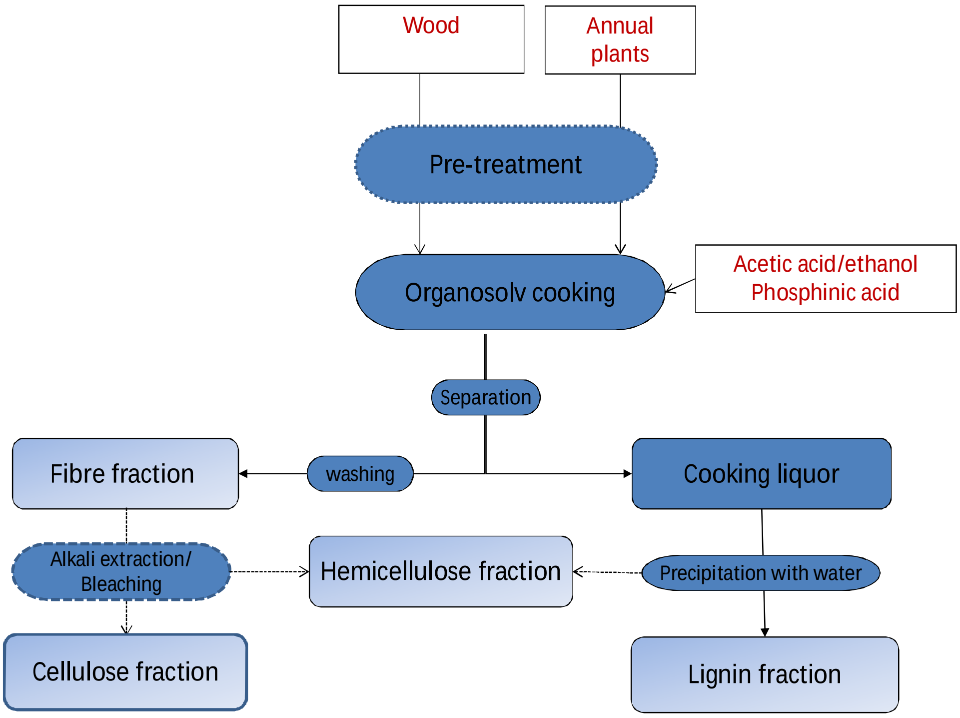


Figure 2. Scheme of the Lignofibre organosolv process developed at VTT.

The second group of emerging technologies are the integrated modern process technologies and concepts. Figure 3 shows a new planning system for sawmills developed at VTT (Kivimaa 2013) called WoodCIM software that enables one to design and optimise plans for harvesting, production and marketing operation within a certain time-frame and in a specific regional context. It provides an integrated monitoring system for a future value network of forest and wood products industry.

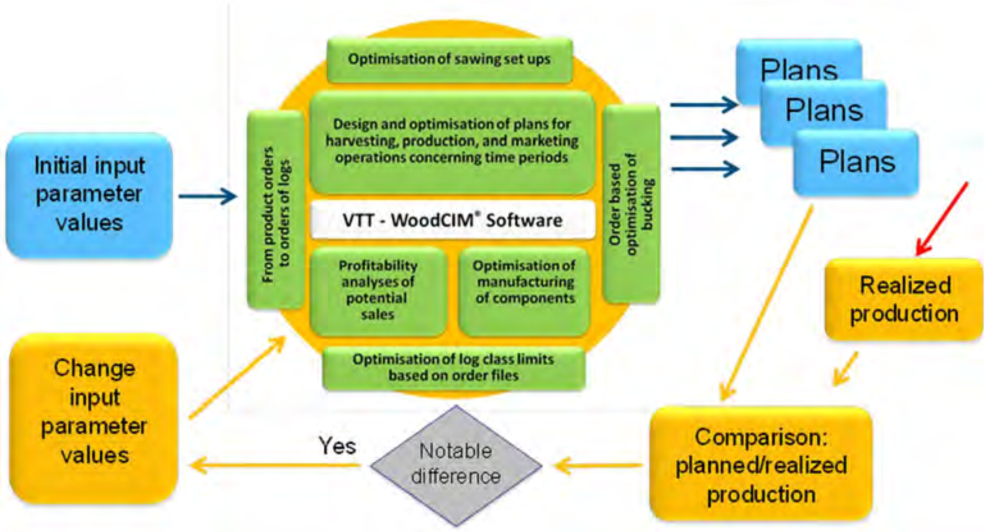


Figure 3. New planning system for sawmills – VTT WoodCIM Software (Kivimaa 2013).

Figure 4 presents another integrated information system model for sawmills that enables new analytical processes, and enriches the knowledge base, in the value chain.

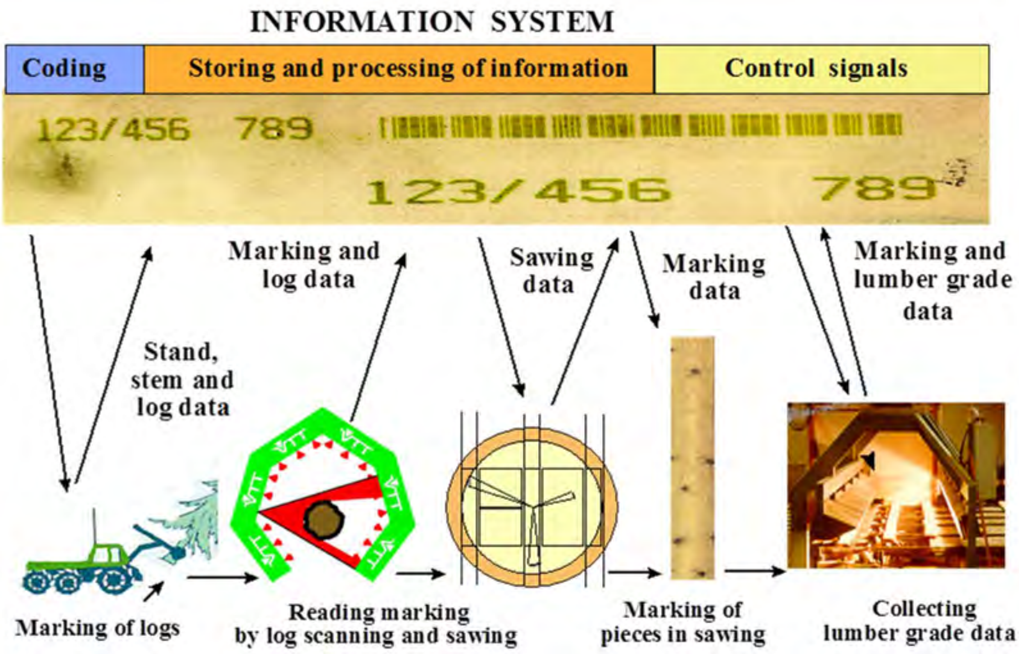


Figure 4. Information system for sawmills (Kivimaa 2013).

New bio-based materials are the third group of emerging technologies. Harlin et al. (2009) have summarised the most important future technology options for biomaterials. The first emerging technology is biomass-based precursors. These have an important role in the development of performance polymers and materials through new matrix opening and fractionation methods, novel biochemical tools and chemical synthetic routes. The second technology option is applied biopolymers, based on modified cellulose and hemicellulose. The group includes novel latexes, adhesives and coating formulations. The third option is the natural composite fibre or nanofibres. These can be utilised to “modify material properties and thus create products that better match future market needs” (Harlin et al. 2009). Combining the nanofibres with other natural fibres, selected polymers and plastics processing technologies bring new emerging possibilities. The fourth option involves converting technologies. These include new thermoplastic compounds, elastomers and processing methods. In-situ converting, reactive compounding and short series conversion technologies have been especially developed. A fifth option is different materials in applications, such as in the fields of packaging, building, vehicles and appliances. The renewable bio-based materials bring new and exciting opportunities in new industrial sectors. For example, bio-based composites can be used in developing passive building concepts.

2.3 Technological opportunities

Biopathways (FPAC 2011), a project initiated by Forest Products Association of Canada (FPAC), FPInnovations and Natural Resources Canada, has envisioned the following opportunities for products from the forest and wood products industry:

- Clothing: textiles from wood, compatible with rayon; competing with traditional synthetic textile fibres; alternative to the shrinking global cotton supply
- Aerospace: fibre-based nanocrystalline cellulose composites to be used in aerospace to replace heavier non-renewable materials; lower fuel costs and emissions
- Bio-plastics and biodegradable forest products; plastics from renewable biomass; replacement of the petroleum-based plastics
- Tires can be made out of lignin instead of petroleum-based carbon black that is currently used to manufacture rubber
- Producing bio-oils from wood fibres, especially from side streams and residuals
- Bio-active paper and packaging: different smart technologies, like sensors, integrated in the forest products; application in health, hygiene and consumer industries
- Bio-pharmaceuticals from wood components; new drugs

Green chemistry programmes have developed new bio-based coating solutions for different surfaces. For example, the Swedish GreenChem programme developed “a wide variety of different waxes and components for lacquers, as well as cyclic carbonates to be used in polyurethanes, utilizing biotechnology-based methods and/or renewable raw materials” (GreenChem 2011: 11).

There are further development opportunities in construction materials, like thermal wood products, composites and sandwich structures, like light-weight sandwich panels made out of variety of face and core materials, for example Kraft paper (Sam-Brew 2010).

Parratt et al. (2011: 9) explored the potential of new value fibre-based value chain in regional Victoria, from “value chain from woody biomass (forestry, pulp and paper waste) through to candidate products for the chemicals and plastics (manufacturing) sector”. The report asserts that regional Victoria already has the key factors to drive the biorefinery transition: an educated population, research centres of excellence, biomass resources, infrastructure, a necessary manufacturing base, industries seeking opportunities and governments willing to support the shift.

Goroyias (2013) suggests that potential for biorefineries in Australia could be in the following directions:

- Biocomposites: wood plastic composites for the car industry as an example
- Biofuels: depending on government policies
- Biochemicals: Chemicals and intermediates from wood resources; also novel chemicals in new areas such as xylitol and synthetic vanillin
- Biomaterials: biopolymers, like PLA
- Biopellets; simple and low value products, depending on the regulation
- New products with new opportunities, like nanocellulose

Painting with a broad brush, the key technological opportunities in the cellulosic fibre value chain can be summarised in the Table 1 below.

Table 1. Summary of technological opportunities in the cellulosic fibre value chain.

Opportunities	***Examples***
Sawmill space	• Softwood timber and process improvements • X-ray and 3-D scanning technologies • New planning systems for sawmills • Information systems for sawmills • CNC-based tools • Robotics • Engineered wood products • Wood-plastic composites • Nanocomposites
Biomaterials	• Biomass-based precursors • Biopolymers • Nanofibres • Converting technologies • Packaging, building and vehicles/appliances
Biofuels	• Bioethanol etc.
Biochemicals	• New chemicals from wood • Platform chemicals
Construction industry	• Engineered wood products • Construction materials • Wood plastic composites
Textiles	• New textile fibres • Mixed textiles, e.g. with rayon

2.4 Innovation activities

As Stendahl and Roos (2008: 663) contend in a theoretical review of the forest and wood products industry the antecedents of the innovation processes can be crystallised into the following issues: a diverse range of skills; organizational slack; a management team that encourages exploration and tolerates mistakes; a structured product development process; market orientation and organizational size. Also, they highlight what they call innovation barriers:

> *"potential company-external barriers are difficulties in obtaining raw materials, lack of demand for innovations, and government regulations or policies. Some examples of potential company-internal barriers are lack of competence, resistance to change among the personnel, lack of management time, and lack of technical or financial resources. Also, uncertainties, i.e., factors that are difficult to determine beforehand, influence the perceived risks with product development and can therefore act as barriers to product development." (Stendahl & Roos 2008: 664)*

They (Stendahl & Roos 2008: 674–675) identified a specific set of factors that companies in forest and wood products industry categorise as barriers to innovation practices. These are: lack of competence (emphasises particularly the lack of knowledge about wood material, processing technology and customers' needs); deprioritising innovation (innovation is given a low priority in the daily operations and in investment decisions); raw material problems (using the variability in raw material supply and quality as scapegoats for non-innovation); 'no need to innovate' (the industry-specific view that there is no need for innovation activities); innovation seen as too risky activity (fear of imitation and problems in finding external financing); and the general reluctance to change (especially among the personnel).

Forest biomass has multiple uses that enable different kinds of products and innovation activities, as indicated schematically in Figure 5.

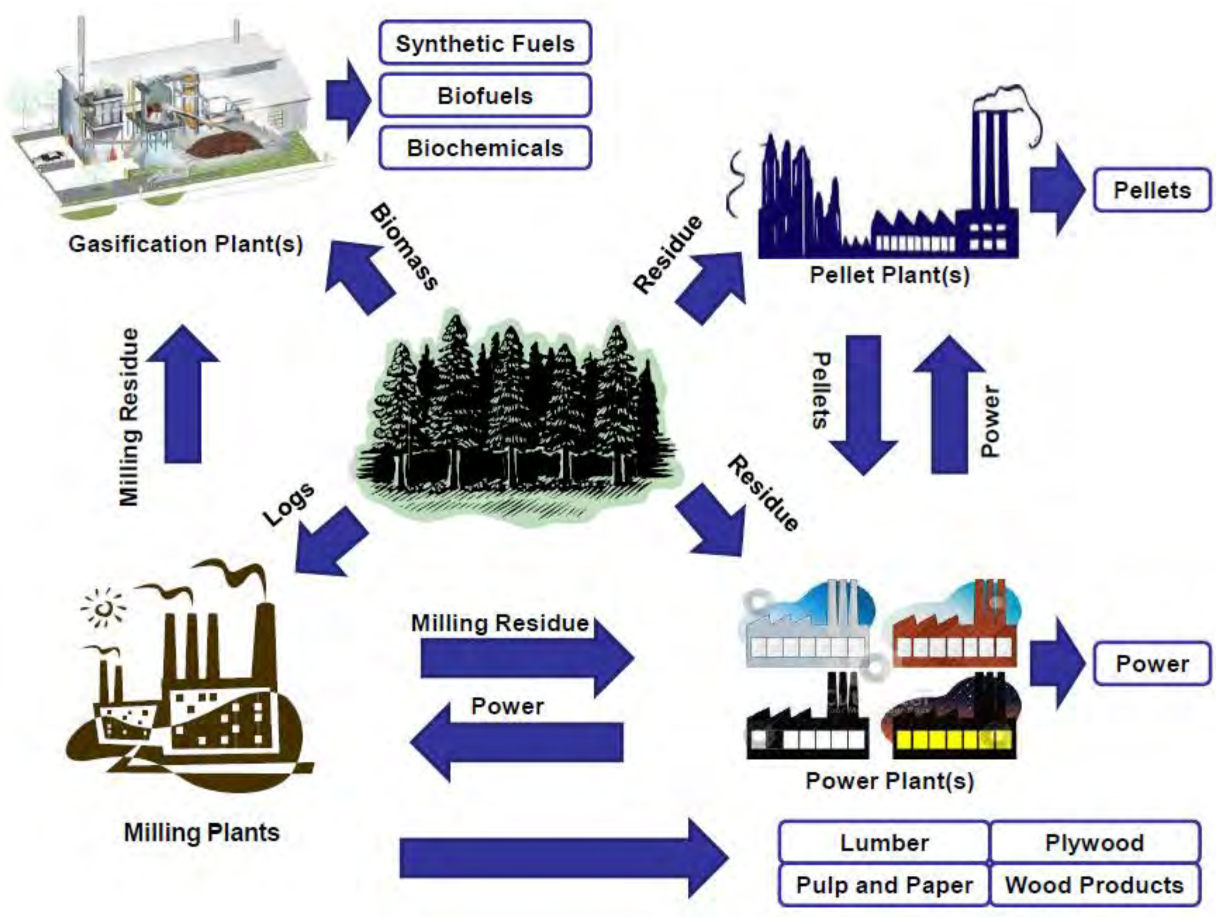


Figure 5. Multiple uses for forest biomass (Vlosky et al. 2012).

Parratt et al. (2011) have studied the drivers and bottlenecks of the biorefineries in the Victorian region. They emphasise especially drivers in the operating environment and government regulation. These aspects have obvious relevance for the case of Green Triangle. They (2011) identify the following drivers for the biorefineries: transport issues; renewable energy policies, particularly the Carbon Pollution Reduction Scheme (CPRS); government regulation about the amount of waste to be left in the forests; the value chain profitability issues, like how forest production and regional processing are linked; and how the electrical power is organised for the production sites. They identified also the following bottlenecks: uncertainties about the consequences of the CPRS; capital costs of investments when compared with the existing petrochemical production; availability of feedstock across the entire value chain; and general market issues for bio-based materials.

2.5 Other issues – Shale gas in Australia

An unrelated study released during the course of this work has indicated that Australia's shale gas deposits are far more abundant than previously thought, though their remote location could make extraction a costly prospect. A report issued on 4th June 2013 by the Australian Council of Learned Academies (ACOLA) entitled "Securing Australia's Future" says Australia's undiscovered shale gas reserves could be more than double prior estimates and that the frequently cited estimate of 396 trillion cubic feet of gas only examined four basins, neglecting other potential deposits (Cook et al. 2013).

The ACOLA report suggests that the success of an Australian shale gas industry depends on "effective regulation – and the right rocks". The report makes 51 key findings and provides Australia with an opportunity to fully assess its shale gas resources and reserves and to consider the potential social, economic and environmental impacts while exploration is still at an early stage. It is clear that there is a significant potential, but a rapid development of a shale gas industry in Australia is not expected as extraction will be more costly than in the USA and it will require great skill, capital and careful management of any impacts on ecosystems and natural resources. The report also found that the increased use of gas, including shale gas, in place of coal for electricity generation could significantly "decrease Australia's greenhouse gas provided 'green completion schemes' and associated codes of best practice are adopted to minimise the greenhouse gas emissions associated with shale gas production".

2.6 Other issues − The carbon tax in Australia

The Australian Parliament implemented a Clean Energy Act and concomitant legislation on 8 November 2011. The act seeks to diminish the green gas emissions in Australia by 5% in 2020 and ca. 80% in 2050 when compared with 2000to levels (KPMG 2012). Technically, the entities that emit more than 25 000 tonnes of carbon dioxide equivalents need to have permits for their emissions.

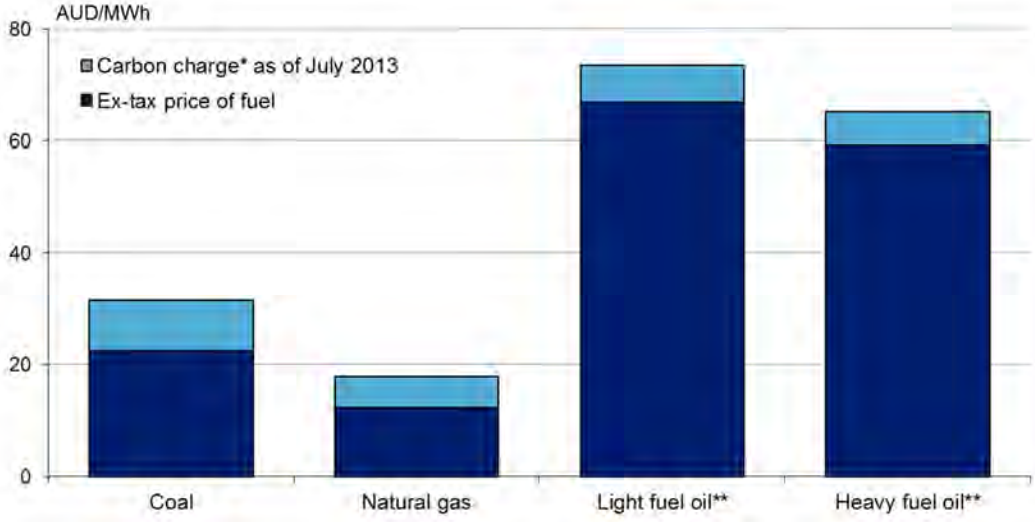
As put in the Pöyry (2013) document Australian fuel taxation has been consisting of excise duties and fuel tax credits. From the 1 June 2012 it has also included a carbon charge. The goods under the tax include alcohol, petroleum, tobacco and coal. Majority of off-road activities have been eligible for fuel tax credits that have a rate rate which depends on the end-use industry.

Fuel ethanol and biodiesel have no effective fuel tax. In addition, carbon charge does not apply to liquid and transport gaseous fuels in e.g. specified agriculture, fishing or forestry activities, nor renewable fuels such as biodiesel or fuel ethanol.

Carbon charge is an amount equal to the price of carbon emissions from the use of fuels. This charge varies for the different fuels depending on their carbon emissions.

The carbon charge is usually realised through (1) a reduction in fuel tax credit entitlements; (2) an increase in the amount of excise duty payable on domestic aviation fuels (aviation kerosene and aviation gasoline; and (3) a reduction in the automatic remission of excise on LNG and LPG intended for non-transport use.

The estimation of the effects of carbon tax on the fuel costs in Australia is shown in the Figure 6.



* From July 2012 onwards, off-road activities of coal, natural gas and fuel oils have been exempted from excise tax and included in the carbon tax scheme. ** Based on New Zealand ex-tax price for light fuel oil and high sulphur heavy fuel oil, respectively.

Figure 6. The effects of carbon tax on the fuel costs in Australia (Pöyry 2013).

The general consequences of carbon tax are hard to predict, particularly from the perspective of the new cellulosic fibre value chain. As the KPMG (2012: 13) report suggests, the legislation created new risks for organisations in terms of non-compliant legislation, lack of accurate data, the format of permits, impairment of assets, unclear reporting requirements, and non-transparent links between the data and political decision-making. However, the scheme also creates new opportunities for investments, through several government programmes linked to it.

Different sectoral studies suggest general uncertainty about the effects of carbon tax (e.g. CIE 2011). For example, in the construction industry the responses have been categorised as: the uncertainty about the short and long term effects of the carbon price; the trajectory that emission prices will follow; the options to abate the costs; and the uncertainty about the timing and form of abatement actions when compared with other countries (CIE 2011). A survey among representatives of Australian business community showed that 47% of the respondents assessed the carbon tax to have either moderately or extremely negative impacts on their organisations. Furthermore, 59% of the respondents evaluated that the carbon tax would raise their organisations' operational costs (AIM 2012: 6–7). In addition, other reports assessed that the impacts for the SME's to be a rise in operational costs (Castalia Ltd 2011). However, John Humphreys, an Australian libertarian politician, contended that "the strongest argument for a carbon tax over a carbon trading scheme is that the revenue raised from a carbon tax can be used to reduce or remove other taxes" (Humphreys 2007: 3). He also assessed that the carbon tax to be a better option than a carbon trading scheme, because "under a carbon trading system […] the payments of polluters are used as subsidies" (ibid.).

The Government of Western Australia's report entitled "Preliminary Assessment of the Impact of the Proposed Carbon Tax on Western Australia" (GWA 2011) has evaluated the impacts of the carbon tax on the state expenditures. The report contends that the increases will be reflected in the price of consumables with "carbon-intensive building materials, such as concrete, steel and asphalt, likely to become more expensive" (GWA 2011: 11).

Siriwardana et al. (2011) presented an economic analysis based on a general equilibrium model on the effects of carbon tax. Their simulation revealed that the short term impacts based on a carbon tax of $23 per tonne was a decline in the real GDP of Australia of 0.68 percent, a rise in the consumer price index of 0.75 percent and a potential rise in electricity prices of 26%. However, emissions would be cut significantly by 12% in the first year of operation.

Recent changes in the political landscape has seen a renewed debate on the carbon tax that has resulted in the decision to move to an emission trading scheme to commence on 1 July 2014 or 12 months earlier than previously announced.

2.7 Other issues – Biofuel mandates around the world

In 2012 some 65% of EU vegetable oil, 50% of Brazilian sugarcane, and about 40% of US corn production was being used as feedstock for biofuel production. Today, it would be inconceivable to prepare an agricultural projection without taking biofuels into account.

The OECD reported that world ethanol prices increased strongly in 2011 well above the levels of the 2007/08 highs in a context of strong energy prices, although the commodity prices of ethanol feedstock, mainly sugar and maize, decreased from their peaks in 2010. The two major factors behind this increase were the stagnating ethanol supply in the United States and a reduction in Brazilian sugarcane production. Additionally, ethanol production was also significantly below expectations in developing countries having implemented mandates or ambitious targets for the use of biofuels.

World biodiesel prices also increased in 2011. Contrary to the global ethanol market, production did not stagnate in 2011; the four major biodiesel producing regions (the European Union, the United States, Argentina, and Brazil) increased their supply compared with 2010. This increase was moderated by a decreasing biodiesel production in Malaysia from about 1 bbl in 2010 to near zero in 2011.

Biofuels Digest reported in 2012 that Brazil, India, the US, China and the EU will represent a 60 billion gallon biofuels market by 2022. In November 2012, an annual review of biofuels mandates and targets around the world was released (refer Appendix 5) for 52 countries.

The bulk of mandates is from the EU-27, where the Renewable Energy Directive (RED) specifies a 10 percent renewables content by 2020 that continues to be plagued by the food versus fuel debate and land use concerns. However, 13 countries in the Americas have mandates or targets in place, 12 in Asia-Pac, and 8 in Africa. Besides the EU, the major blending mandates that will drive global demand are those set in the US, China and Brazil, each of which has set targets or, in the case of Brazil, is already there at levels in the 15–20 percent range by 2020–2022. India's fast-growing economy also has a 20 percent ethanol mandate in place for 2017, but the country up to now has a shaky record of implementing mandates.

Over the projection period to 2022, ethanol and biodiesel prices are expected to remain supported by high crude oil prices and by the implementation and continuation of policies promoting biofuel use. Changes in the implementation of biofuel policies can strongly affect biofuel markets.

Global ethanol and biodiesel production are projected to expand but at a slower pace than in the past. Ethanol markets are dominated by the United States, Brazil and to a smaller extent the European Union. Biodiesel markets will likely remain dominated by the European Union followed by the United States, Argentina and Brazil.

Biofuel trade is anticipated to grow significantly, driven by differential policies among major producing and consuming countries. The United States, Brazil and the European Union policies all "score" fuels differently for meeting their respective policies. This differentiation is likely to lead to additional renewable fuel trade as product is moved to its highest value market, resulting in potential cross trade of ethanol and biodiesel.

3. APPENDIX 3: Review of best practice cases in biorefineries

3.1 Forest and wood products industry moves towards biorefining

During the past 10–15 years, Nordic, European and global interest in the advanced use of wood and other lignocellulosic raw materials as a source of chemicals, materials, and energy products has grown tremendously. At the same time, biorefining has become a widely used term to illustrate a range of means to process biomass materials to different products, often emphasising the role of biofuels. Forest biorefining, as an example, typically refers to a zero-waste use of the whole wood biomass for the sustainable manufacture of a variety of marketable products and energy. In case of using wood and other lignocellulosic raw materials, the main product types include fibres (for papermaking or chemical cellulose uses), chemicals, materials, biofuels and other energy products.

The current and foreseen forest biorefinery products include both traditional wood-derived products and numerous new ones. The new wood-products have previously been available only from other sources (e.g. from other biomass materials or oil), or in many cases, they may represent totally new types of materials or chemicals. The more advanced, sustainable use of wood for the manufacture of different products opens new opportunities to reach the biobased economy, for which the European Horizon 2020 strategy is currently in preparation. Number of pulp and paper companies are co-operating with chemical companies to explore a new, integrated biorefinery model which would connect pulp mills to chemicals manufacturers. It is proposed that the pulp mills gasify biomass materials (wood chips, agricultural waste, etc.) to create synthesis gas, which then could be converted into different green fuels and chemical feedstock like acetic acid, methanol and methyl acetate. Additionally, the waste heat from the syngas process can be tapped for energy, thus reducing the need of pulp and paper mills to purchase natural gas and electricity. With this model new value streams can be created for pulp and paper companies. The biomass gasification strategy ideally requires the pulp and paper plant and chemical plant to be sited next to or close to each other, which makes economic sense as pulp and paper mills are already large customers of chemical companies.

When producing a chemical pulp, less than half of the wood is converted to fibre. The remainder of the wood material, comprising a mixture of carbohydrates, lignin, suberin and resin, is usually utilised as fuel at the mill, although much ends up as low-value heat with no practical use. Within a “pulp mill biorefineries” platform, a spectrum of valuable chemicals would be expected to be processed from the streams in addition to conventional products from a pulp mill.

Many current or planned forest biorefinery operations are integrated into the existing pulping and papermaking processes, although different types of stand-alone processes and concepts are also being designed and constructed. The integration of the biorefinery processes into the existing pulp and papermaking processes usually aims at the efficient use of different side-streams or wastes, in addition to strengthening or optimising the current main products. The stand-alone processes typically use different thermal, thermochemical, chemical and biotechnical systems for the manufacture of biofuels, biochemicals, and biomaterials (others than pulp and paper). Different new or overlooked chemicals can be isolated (or otherwise prepared) from pulping spent liquors and other internal process streams, from wastewater treatment systems, from bark and different harvesting residues, and from additional sources (such as pre-extraction of chips before pulping). There are several areas that have recently attracted considerable interest, including the isolation of hemicelluloses and lignin for different applications, isolation of bio active compounds and other chemicals from bark, use of gasification and other thermal processes for the manufacture of biofuels, pyrolysis of different waste wood materials for bio-oil, and manufacture of ethanol from different suitable sources. Many of these processes are likely to be commercialised in the near future, as there are already various demonstration plants in operation.

According to Sipilä (2005) several options exist for bio-energy co-products from Forest-Products-Platforms (BIOPOL; Sipilä 2005).

- Firstly, it is possible to substitute fossil fuel by biofuels (biofuel gasification for lime-kiln fuel and fluid bed boilers).

- The second option is to increase the back-pressure power from biofuels. This can be reached for example by energy production with higher power-to-heat ratios in steam turbines or by biomass gasification Integrated Combined Cycle (black liquor and solid residues).
- The third option is to export biofuels or produce and export upgraded biofuels. For example, it is possible to produce methanol via gasification or ethanol from wastepaper and export it. Additionally, it would be possible to produce pyrolysis-based bio crude oil and pellets as well as synthesis gases and synfuels.
- The fourth option mentioned by Sipilä is to substitute paper-components and produce bioenergy, making it possible to substitute (industrial and municipal waste-derived) fibre and produce bio-energy (CHP, combined heat and power). Another possibility is to integrate agrofibre, CHP and synfuels production.

On the 22 August 2013, Kauppalehti (the Finnish equivalent for Financial Times) reported that biorefinery projects are in an acceleration phase in Finland (Semkina 2013) with investments expected to increase by hundreds of millions of euros in the coming years. This flow of investment is a result of long lasting product development and favourable regulatory environment. The key policy instruments for endorsing biorefineries in Finland are distribution obligation to the liquid transportation fuels and tax incentives. In Finland there is an obligation to add renewable components, like bio oil or biodiesel, in gasoline and diesel to at least 6% rising to 20% by 2020 as a result of European Union policies. Today, there are nine active biorefineries in Finland, another eight under construction and a further eight in the planning phase. The biggest Finnish facility is UPM's biorefinery in Lappeenranta, Finland, that utilises pine oil. Its production capability is 1200 GWh at an investment cost of 150 million Euros and is due to be completed in 2014 (Table 2).

Table 2. The current biorefinery projects in Finland – organised according to capacity size (Adapted from Semkina 2013).

Location (FIN)	Company	Product	Capacity (GWh)	Investment (million €)	Stage
Porvoo	Neste Oil	Biodiesel	4,654		In operation
Kemi	Vapo	Bionaphtha, biodiesel	1,633	700	Investment decision in 2014
Joutseno	Gasum, Metsä Fibre, Helsingin Energia	Synthetic natural gas	1,600		Planning stage, investment decision in 2014
Lappeenranta	UPM	Biodiesel	1,200	150	Ready in 2014
Kotka	Stora Enso	Lignin	340	32	Ready in 2015
Kajaani	St1	Bioethanol, lignin	148	40	Investment decision in the end of 2013
Iisalmi	Green Fuel Nordic	Bio oil	500	50	Ready in 2014
Lieksa	Green Fuel Nordic	Bio oil	500	50	Planning stage
Savonlinna	Green Fuel Nordic	Bio oil	500	50	Ready in 2015
Joensuu	Fortum	Bio oil	220	28	Ready in 2013
Jokioinen	St1	Bioethanol	58		In operation
Lahti	Gasum, local companies	Biogas	50	17	Ready in 2014
Espoo (Ämmässuo)	Gasum	Biogas	40		Planning stage
Kuopio	Taaleritehdas	Biogas	34	10	Ready in 2014
Honkajoki	Taaleritehdas	Biogas	34	9	Permission to start building
Huittinen	Taaleritehdas	Biogas	30		In operation
Espoo (Suomenoja)	Gasum	Biogas	20		In operation
Hämeenlinna	St1	Biogas, bioethanol	20		In operation
Kouvola	Gasum	Biogas	15		In operation

Location (FIN)	Company	Product	Capacity (GWh)	Investment (million €)	Stage
Espoo (Mankkaa)	Gasum	Biogas	14		Planning stage
Oulu	Taaleritehdas	Biogas	14	8	Ready in 2014
Lahti	St1	Bioethanol	6		In operation
Vantaa	St1	Bioethanol	6		In operation
Hamina	St1	Bioethanol	6		In operation

International conferences devoted to wood and forest biorefineries

During the past 10–15 years, the research work in the area of wood-based biorefining has remarkably increased. In turn, this resulted in the need to establish an international wood and pulp mill biorefinery forum where researchers, industry representatives and policy makers could meet for the exchange of information and ideas. To fulfil this need, Innventia from Sweden and VTT from Finland initiated in 2008 an international conference series entitled “Nordic Wood Biorefinery Conference, NWBC”. Since the beginning, these events have been organised every 18 months. The Proceedings book (Niemelä 2012) from the 4th event (Helsinki, 2012) is freely available. The 5th NWBC event will be held in Stockholm in March 2014.

Other regular events also address many sides of forest and wood based biorefining, including TAPPI’s International Bioenergy and Bioproducts Conference, International Symposium on Wood, Fibre and Pulping Chemistry, European Workshop for Lignocellulose and Pulp, and International Forest Biorefinery Symposium (organised by Paptac in Canada).

3.2 Examples of commercial biorefineries

A selection of examples of commercial biorefineries has been described in deliverable “D2.3 Preliminary report on the global mapping of research projects and industrial biorefinery initiatives. Task 2.3.3 Commercial biorefineries in Europe” of Project no.: 241535 – FP7, Star-COLIBRI. Some of the most important examples from the perspective of Green Triangle are summarised below:

Domsjö Fabriker pulp mill (Processum Technology Park, Sweden). The Domsjö pulp mill is located on the outskirts of Örnsköldsvik, in the northern part of the Swedish east coast. The company has 340 employees in Sweden and 25 in the Baltic countries. The annual revenue is in the order of SEK 1.5 billion (ca. €150 million). Today, Domsjö has three business areas: specialty cellulose, ethanol and lignosulfonate. The main product is specialty cellulose which is delivered in dry form in bales to be used for as diverse activities as the production of textile fibres for food binding agents (www.domsjoe.com).

However, Domsjö Fabriker is no longer identifying itself as a pulp mill but as “a biorefinery“. The Company utilizes the components of the woody raw material as much as possible, while taking the greatest possible environmental care. The Domsjö process is unique globally, being a sulfite process using sodium as the base. The raw material is softwood only, Swedish and imported, and the cellulose bleach is based on hydrogen peroxide with full recovery of all filtrates. The whole process from log to cellulose bale takes about 40 hours. The log is chipped and the wood chips cooked to dissolve lignin and hemicellulose while leaving the pure cellulose fibres. The dissolved components are separated from the fibre and the hemicellulose is then fermented to ethanol. Part of the lignin is sold as lignosulfonate (Domsjö Fabriker has sold lignosulphonate in solutions for a long time and as a dried product since the first quarter of 2009) while the remaining black liquor is incinerated in the soda recovery boilers or, in the near future, gasified and turned into renewable motor fuels.

In September 2009, Domsjö and Chemrec were awarded an investment grant of SEK 500 million (€48 million) to build an industrial-scale demonstration plant for gasification of the Domsjö black liquor and the production of renewable engine fuels. Discussions with possible investors or partners representing oil, chemical and forest companies are progressing

With the geographic location in Domsjö’s industrial area, the conditions exist for introducing full-scale gasification technology. The extensive mill area has been formed by a hundred years of industrial history since the mill was first established in 1903. Now the area is a hotbed of development where a range of companies are cooperatively very actively. Processum Technology Park, the regional cluster collaboration, offers a strong development-oriented infrastructure with significant research and development resources (Biorefinery Euroview; www.processum.se).

The member companies operate within a range of industries; manufacturing, consultancy, research and development, the pulp, paper, chemical and energy. Processum's task is to coordinate new business and product development concepts, research and development work and marketing activities within the process industry in Örnsköldsvik. The vision of "The Biorefinery of the Future" envisages an increasing number of products being produced from renewable forestry feedstock. The companies are integrated not only through the product flow and their competence but also by common utilities including energy and water supply, and waste water biological treatment (www.processum.se). In May 2013, the SP Group (RTO) of Sweden purchased a 60% share of the company.

BLG Program. Two Black Liquor Gasification (BLG) processes exist in Sweden: the ABB process and the Chemrec process. The Chemrec´s black liquor gasification development plant (DP-1) has been in operation since 2005. In the 3 MW gasifier, 1% or 20 tonnes dry solids per day of the black liquor is gasified (Biorefinery Euroview; www.chemrec.se). The BioDME and SunPine projects will see construction of two separate plants for biofuel production in Piteå, one for the manufacturing of DME(di-methyl ether) from black liquor and the other for the manufacture of green diesel from tall oil.

BioDME project. The Swedish truck manufacturer Volvo coordinates the BioDME project, a collaborative project involving the automotive industry as well as fuel producers and distributors. The project, which demonstrates the entire technology chain from biomass to trucks powered by DME fuel and including fuel distribution and filling stations, has partners from all industrial sectors necessary to introduce a new fuel. The Swedish company Chemrec, which holds the gasification technology patents, is constructing the plant together with the Norwegian company Haldor Topsøe. Volvo will demonstrate the DME technology in 14 trucks and Preem will build filling stations in four Swedish cities. The project is co-financed by the consortium partners EU's Seventh Framework Program (FP7) and the Swedish Energy Agency (Biorefinery Euroview; www.biodme.eu).

SUNPINE project. (www.chemrec.se/SunPine_producing_tall_oil_diesel.aspx). The company SunPine, a partnership between forest owners Sveaskog and Södra Skogsägarna, the refinery company Preem and Lars Stigsson, the inventor of the SunPine technology, began construction of its pine diesel factory in Piteå in the fall of 2008. Planned for a capacity of 100,000 m^3, the factory did start production in 2010, establishing Sweden as the first country in the world to produce green diesel from wood raw material on an industrial scale (Biorefinery Euroview). Crude tall oil will be supplied from a number of paper mills (initially the tall oil will come from pulp mills in Sweden and in the longer term also from neighbouring countries). SunPine has contracted a large portion of the tall oil to satisfy the capacity of the crude tall oil diesel plant (the production will first use crude tall oil from a Smurfit-Kappa mill).

SunPine takes all its feedstock as by-product from the forest and wood products industry. During the pulping process resinous substances in the wood are dissolved and form calcium soaps. This soap is skimmed from the black liquor and subsequently washed and acidified to form crude tall oil, which in turn is esterified with methanol and sulphuric acid. The mixture produced will be distilled to crude tall diesel and bio-oil. The yield of tall oil diesel from the crude tall oil is high at 65–70%. The remaining 30–35% becomes pitch fuel, a renewable fuel oil which is returned to the pulp mill, as are other residual products such as sodium and sulfur.

Following shipment by boat, the raw tall diesel will be refined in a second process at Preem's petroleum refinery in Göteborg, where a plant capable of refining renewable raw material is under construction. This new plant is also a first of its kind. The SunPine fuel will be used to create a bio-diesel with almost 30 percent share of renewable energy source and will primarily be distributed to corporate customers with their own filling stations. The project represents a €50 million total investment: €25 million in SunPine plant in Piteå and €25 million in biorefinery in Göteborg.

This report has benefited from the findings of ***Cost Action FP0901: Analytical techniques for Biorefineries***. The main objective of COST Action FP0901 is to develop new and evaluate existing analytical methods related to forest-based and agro-industrial Biorefineries. Thus, the Action covers the analytical methods for the Biorefinery feed material and for processed biochemicals, biomaterials, and process residues. In particular analytical pre-treatments will be evaluated. The primary duties of the task force include a survey of the pilot plants, to publish a short description about each operating plant in Europe, and to establish a first contact with the pilot plants. The aim of the task force is to create connections between scientists within the cost action for all listed pilot plants during the COST action period. The Coordinator of the COST action is Mehrdad Arshadi, Associate Professor in Technology/Chemistry, Unit of Biomass Technology & Chemistry, Swedish University of Agricultural Sciences, Umeå, Sweden, (www.btk.slu.se) who gave permission to use their data. The results of their excellent work can be found in Appendix 4.

From the information listed in Appendix 12 it can be seen that a multitude of different forest biorefinery R&D projects have commenced over the past 15 years, and many more are in the planning phase. They vary from small university projects and medium-sized multi-partner international projects to very large industrial demonstration projects with budgets up to 100’s million €, and encompassing varying degrees of complexity and confidentiality. A comprehensive project discussion even for one country is difficult and perhaps best addressed here by using some carefully selected examples of the recent and current R&D activities in different countries and continents.

3.3 Forest biorefinery R&D in North America

3.3.1 Canada

During the past ten years, a lot of efforts have been focussed in Canada to more efficient utilisation of forest resources. For that purpose, for example, a technology roadmap for Canadian forest biorefineries was published in 2007 (Browne et al. 2007; cf. Towers et al. 2007). Also, the two-phase Bio-Pathways project was recently conducted, to find opportunities to produce a wide range of wood-based products. The first phase of the study examined the economic, social and environmental benefits of integrating these new bio-technologies within the traditional forest and wood products industry. The second phase (FPAC 2011) examined the global market potential of emerging bio-energy, bio-chemical and bio-products, and it explored new approaches to managing value and building partnerships in this critical area.

An overview of the ongoing forest biorefinery activities in Canada was recently given by Browne (2012). One of the key elements to boost studies on innovative forest products is the web of seven Forest Sector Univresity R&D Networks. The networks, led by several Canadian universities, include ForValueNet Network, Value Chain Optimization Network, Bioconversion Network, Lignoworks, Innovative Green Wood Fibre Products Network, Sentinel Bioactive Paper Network and NEWBuildS. There is an eighth R&D network called ArboraNano, the Canadian NanoProducts Network, a business-led centre of excellence. As a whole, funding of $34M over 5 years has been granted to these networks, involving over 100 senior academic staff across the country in research of relevance to the development of novel products from wood. In many cases, these researchers and their teams are new to forestry, bringing new viewpoints and knowledge of industries not usually associated with forestry. The networks are linked by FIBRE, an overarching organisation designed to build synergies in partnerhip with FPInnovations, NRCan, NSERC and the Forest Products Association of Canada (FPAC).

As an example, the Lignoworks network (www.lignoworks.ca) aims to create technology platforms for novel materials and chemicals based on lignin, to replace fossil-fuel based chemicals and products (Schmidt and Kadla 2012). The 16 running research projects represent the following main themes: polymeric lignin products, thermochemical processing of lignin, and catalytic processing of lignin.

The Canadian forest and wood products industry has facilitated from the support by several technologies programmes, such as Investments in Forest Industry Transformation Programme, the Pulp and Paper Green Transformation Programme, and Transformative Technologies Programme. For example, under the Transformative Technologies Programme, Natural Resources Canada launched the Pilot Scale Demonstration programme. Examples of the programme’s key results include construction of a small scale plant (at Domtar’s pulp and paper mill in Windsor, Quebec) for the production of nanocrystalline cellulose, and construction of a plant (at the Structurlam facility in Okanagan Falls, BC) to manufacture panels of cross-laminated timber (CLT). This product, made of layers of timber glued together under pressure, is already a popular construction material in Europe. Unusual about the Structurlam CLT project, however, is its plan to use beetle-killed pine and other softwood species (such as hemlock and balsam fir) that are generally little used.

The Canadian Biomass Innovation Network (CBIN) is a network of federal researchers, program managers, policy makers, and expert advisors partnered with industry, academia, non-governmental organizations, other government levels and the international community. The Network's goal is to continually ensure the availability of knowledge, technology and enabling policy required to support the development of a sustainable Canadian bio-economy. CBIN is supported by a federal inter-departmental committee which coordinates activities related to the development of the bio-economy. A sub-set of the CBIN interdepartmental committee, the Science and Technology (S&T) Portfolio Committee, focuses on developing and advancing next generation technologies for bioenergy, biofuels and industrial bioproducts. The S&T Portfolio Committee co-ordinates, plans and manages bioenergy, bioproducts and sustainability energy-related research, development and demonstration across the Federal Government.

3.3.2 USA

In the US, the Department of Energy (DOE) has significantly contributed to biorefinery development and commercialisation, by funding to numerous biofuel and biochemical projects. The main goal is to accelerate the construction and operation of pilot, demonstration, and commercial scale facilities. This way, the projects help lay the foundation for full commercial-scale development of a biomass industry in the United States. In addition, the United States Department of Agriculture (USDA) has a specific program, Biorefinery Assistance Program, to provide loan guarantees for the development, construction and retrofitting of commercial-scale biorefineries.

Thorp et al. (2011) has recently critically reviewed cellulosic biofuels and biochemicals projects in the US. The compiled lists include 32 sugar platform projects, 20 thermochemical platform projects, and 11 so-called natural platform facilities. For each of the project, company, location, capacity (pilot, demo, or commercial), and product type are given, together with some additional data.

According to the compiled data, there were (in 2011) in the cellulosic sugar platform 22 pilot plants running or in progress, 9 demonstration plants running or in progress, and 6 commercial plants in progress. In most cases, bioethanol and other biofuels were the main products. In several cases, the separation and application of lignin is also considered, but not yet taken to the pilot scales.

Several sugar platform projects also aim to produce sugar-based chemicals, instead of (or in addition to) biofuels. These include Alpena Biorefinery that uses sugar-rich stream from wood panels industry, to produce potassium acetate and ethanol. The Myrant project is targeted to produce succinic acid, and The Old Town Fuel and Fiber project is scheduled to extract hemicellulose from wood chips prior to pulping and convert them to n-butanol and other chemicals, such as furfural or acetic acid. Segetis is developing cellulosic-based levulinic acid derivatives.

The thermochemical platform projects aim to produce predominantly Fischer-Tropsch (FT) liquids and diesel. In 2011, there were 14 pilots running or in progress, 4 demonstration plants running or in progress, and 7 commercial facilities in progress.

The main natural products include tall oil (raw material for fatty and resin acids and for phytosterols) and turpentine, but at least one plant is isolating and refining kraft lignin for various chemical and material applications. Other types of natural products processes include conversion of sawdust activated carbon, by MeadWestvaco.

In 2010, the US wood and paper products companies, industry suppliers, government agencies, universities, and other organizations created The 2010 Forest Products Industry Technology Roadmap (available at www.agenda2020.com). In this Roadmap, advancing forest biorefinery development also has a strong role. The related identified key areas include, for example, evolving existing pulp mills to flexible biorefineries, development of more advanced processes for the fractionation of wood to its main components, and their further valorisation into different value-added products.

The USDA BioPreferred® program is to promote the increased purchase and use of biobased products. The program is expected to promote economic development, creating new jobs and providing new markets for farm commodities. To the extent that the BioPreferred program achieves its purpose, the increased purchase of biobased products will also be expected to reduce petroleum consumption, increase the use of renewable resources, better manage the carbon cycle, and may contribute to reducing adverse environmental and health impacts. (http://www.biopreferred.gov/). The BioPreferred® program was created by the Farm Security and Rural Investment Act of 2002 (2002 Farm Bill), and expanded by the Food, Conservation, and Energy Act of 2008 (2008 Farm Bill). The purpose is to increase the purchase and use of biobased products. The program is managed by United States Department of Agriculture.

3.4 Forest biorefinery R&D in Europe

In this Section, the role of multi-partner EU projects in the biorefinery-related R&D work is illustrated by a number of current or recent examples, with clear focus on wood- or forest-based biorefinery concepts and products. In addition, national research programmes and other initiatives from selected countries, each having strong forest and wood products industry, are briefly summarised.

3.4.1 EU

Three EU projects (coordination and networking activities) have recently been completed, related to mapping and surveying of the European biorefinery projects. One aim is to increase cooperation and avoid overlapping research tasks. The completed projects are Biopol, Biorefinery Euroview, and Star-Colibri.

The overall goal of BIOPOL was to assess the status (technical, social, environmental, political, and implementation) of innovative biorefinery concepts and the implications for agricultural and forestry policy.

Biopol produced the following public reports (all available at www.biorefinery.nl/biopol):

- Description of the general biorefinery concept.
- Technical, economic and ecological system assessments and market perspectives of biorefinery systems and platform chemicals.
- Note on literature review concerning market introduction and development of biorefinery concepts and related products.
- Report of market acceptance of biorefinery concepts and note with results questionnaire and interviews market acceptance for the biorefinery concepts amongst industry.
- Report of market acceptance of biorefinery concepts amongst consumers.
- Report with the assessment results concerning the impact of biorefineries on rural development, employment and environment.
- Note with results of EU assessment of the political legitimacy of biorefineries.
- Analysis of broad scenarios concerning the implications of renewable policy, forestry policy and agricultural policy for biorefinery viability.
- Report with results targeted scenario analysis concerning the implications of renewable policy, forestry policy, and agricultural policy for biorefinery viability.
- Note with results identification, classification and mapping of existing EU biorefineries.
- Prospects for further demonstration.
- A final project wide workshop to present the biorefinery assessments and recommendations to European Stakeholders and policy makers.

The Biorefinery Euroview (www.biorefinery-euroview.eu) was also designed to support European policy (agriculture, forestry, energy and research policies in particular) and to strengthen the European Research Area, in order to increase the competitiveness of European territorial systems in the biorefinery field. It focused on:

1. Studying existing or planned European biorefineries;
2. Identifying socio-economic factors and regulatory aspects which improve or slow down the development of biorefineries;
3. Building a range of forecasting scenarios for biorefinery development; and
4. Selecting the concepts and the operational policies for the future development of biorefineries.

The Star-Colibri project (www.star-colibri.eu), where VTT was a partner, aimed at overcoming fragmentation and promoting cross-fertilization in the area of biorefineries research. The project supported innovations by speeding up and facilitating industrial exploitation of research results in the biorefinery field, as well as promoting coordination in the field of future R&D funding and facilitates the creation of Public-Private Partnerships. The Star-Colibri project undertook comprehensive studies on European and global biorefinery activities, and has opened specific, public Star-Colibri wiki pages (www.star-colibri.net) where national and international biorefinery projects can be presented. There are currently c. 360 project presentations. The project has also delivered an important 68-page document, the European Biorefinery Joint Strategic Research Road Map for 2020 (available at the project's website)

A large number of recent or current biorefinery EU projects deal with lignocellulosic ethanol. These include:

- Babilafuente. Project for the production of 200 million litres of bioethanol in Babilafuente (Salamanca, Spain) from cereals and lignocellulose. The plant is operated by Abengoa Bioenergy that also has a pilot plant in the US.
- Biolyfe (www.biolyfe.eu). Demonstrating large-scale bioethanol production from lignocellulosic feedstocks. The main objective is the construction of an efficient 2nd generation industrial demonstration unit with an annual output of some 40,000 tonnes of lignocellulosic bioethanol, which can then be used for process optimisation testing.
- FibreEtOH. Bioethanol from paper fibres separated from municipal solid waste (MSW).
- Hype (high efficiency consolidated bioprocess technology for lignocellulose ethanol, blogs.helsinki.fi/hype-project). An efficient hydrothermal pre-treatment technology was applied to obtain a high consistency raw material stream, further prehydrolyzed (liquefied) at high temperature by thermostable enzymes.
- LED (Lignocellulosic Ethanol Demonstration, www.ledproject.eu). Industrial solutions from a global bioethanol player.
- Kacelle Kalundborg Cellulosic Ethanol Project (www.inbicon.com/Projects/KACELLE). The aim is to bring the patented Inbicon Core Technology from pre-commercial to near-commercial status, and making the technology available in the market and attractive to investors.
- Nemo (nemo.vtt.fi). Novel high performance enzymes and micro-organisms for conversion of lignocellulosic biomass to bioethanol.
- Nile. New improvements for lignocellulosic ethanol.
- Renewall (www.renewall.eu). Optimised plant cell walls for biofuels applications, by making them more readily converted into ethanol.

The FibreEtOH project will run from 2010 to 2013 with €8.65 million support under FP7. The project is coordinated by UPM. Other partners include AB Enzymes GMBH, Skandinavisk Kemiinformation AB, Poyry Forest Industry, Lassila & Tikanoja, ST1 Biofuels, Roal and VTT.

The innovative focus in the FibreEtOH project is to demonstrate globally for the first time on a commercial scale, a cost efficient paper fibre based ethanol production with high (greater than 70%) overall energy efficiency and high (greater than 50%) greenhouse gas reduction. The 2nd generation ethanol production technology has been developed using mainly corn stover, straw or saw dust as the raw material. Up to now, reliable and cost efficient hydrolysis technology has been the bottleneck for large scale commercial success.

By using paper fibres separated from commercial and municipal solid waste or de-inking sludge at paper mills, the hydrolysis process will be simplified as no pretreatment and special fractionation is needed. It is estimated that such raw material is available in quantities to produce more than one million t/a of ethanol at a production cost that is highly attractive due to the low price of the waste based raw material and distillation steam costs compared with typical straw and wood ethanol production plants. The proposed demonstration plant with 20,000 m^3/a ethanol production capacity will be build using 250,000 t/a of waste from the Helsinki metropolitan area in Finland. Biogas, district heat and electricity will be produced from the by-products.

The site and environmental permits have already been granted. The ethanol will be used in Finland in dedicated E5–E85 blends, optimising the ethanol fuels to cold climate conditions and tail pipe emissions reduction.

Three current large biorefinery EU projects, all originating from the FP7 *Sustainable biorefineries* will form flagship projects where only a limited number of large projects (all with some demonstration activities) were funded.

The **Suprabio** project (www.suprabio.eu) will take into account environmental sensitivities and will not compete with agricultural land best used for food crops or compete with food products. The project will use bio-resources (renewable raw materials) such as straw, seed oil, algae and waste water. The bio-resources will be improved and converted (through microbial, fungal, enzymatic and chemical processes) to make products for consumers and industry e.g. healthcare products, cosmetics, pharmaceutical intermediates, bio-fuels, and materials such as polymers.

The results from the project's research will lead to five demonstration units being built in Norway, Denmark, Sweden, the Netherlands and the United Kingdom. Finance to build these units will come from the project's corporate partners that include the International Lignin Institute and Borregaard. The coordinator is the University of Oxford.

The **EuroBioRef** project (eurobioref.org) will develop a new highly integrated and diversified concept, including multiple feedstocks (nonedible), multiple processes (chemical, biochemical, thermochemical), and multiple products (aviation fuels and chemicals). The project has a specific aim to overcome the fragmentation in the biomass industry. As efficiency is the key to bio-refinery processes, this implies to take decisive actions to facilitate better networking, coordination and cooperation among a wide variety of participants.

New synergies, cost efficiencies and improved methods will be achieved by involving the stakeholders at all levels: large and small (bio)chemical industries, academics and researchers from the whole biomass value chain, as well as European organisations.

The overall efficiency of this approach will be a vast improvement in the existing situation, and will ensure the production of aviation fuels and multiple chemical products in a flexible and optimized way. It will also take advantage of the differences in biomass components and intermediates. The target is also to improve cost efficiency by as much as 30% through improved reaction and separation effectiveness, reduced capital investments, improved plant and feedstock flexibility, and reduction of production time and logistics. Further, reduction in energy use and zero waste are expected. Raw material management will also mean that a reduction of feedstock consumption will be possible to the tune of at least 10%.

The EuroBioRef concept achieves integration across the whole system from feedstock to product diversification and adapts to regional conditions, integrating into existing infrastructures and minimizing risks to investors. The flexible approach means widening bio-refinery implementation anywhere in Europe, and offers opportunities to export bio-refinery technology packages to more local markets and feedstock hotspots. The project is coordinated by Université Lille Nord de France. The partners include, among others, Haldor Topsoe and Borregaard.

The **Biocore** project (www.biocore-europe.org) is coordinated by INRA (France) and there is also a partner (VTT) from Finland. Several European chemical companies are also involved.

The first challenge for Biocore will be to show how a biorefinery can use a mixed biomass feedstock. To do this, analyses will be performed in order to establish how a biorefinery can be supplied with a stable mixture of cereal by-products (straws etc.), forestry residues and short rotation woody crops. Several scenarios will be generated that will take into account harvest seasonality, transport and storage for biorefineries located in different regions of Europe and Asia.

From a technical viewpoint, Biocore will develop and optimize processes that will allow maximum use of the biomass resource. The first step will involve the extraction of each of the principle biomass components (cellulose, hemicelluloses and lignins). To achieve this, patented technology, which uses organic solvents to solubilise the lignin components, will be employed.

Thereafter, Biocore will combine the development of biotechnologies and chemical processes in order to create smart transformation itineraries that will allow for the production of 2nd generation biofuel, resins, polymers (and their intermediates), surfactants and food/feed ingredients.

In Biocore, the biomass feedstock will be used as a source of energetic molecules, but special emphasis will be placed on the use of biomass as a source of renewable carbon for the manufacture of chemicals that will substitute for petro-chemicals. The ultimate aim of Biocore is to supply a range of products to vastly different markets. Notably, through the production of a series of polymer building blocks, Biocore will cover 70% of the polymer families that constitute the current world plastics market.

Through pilot scale testing of selected technologies, Biocore will be able to demonstrate the industrial feasibility of biorefining in conditions that are close to the market. Pilot tested processes will be modelled and optimized both from technical and economic standpoints in order to demonstrate the relevance of a certain value chains.

Several additional, recent or ongoing EU projects, all with strong links to wood and other lignocellulosic biorefineries, are briefly listed below. All demonstrate the current strong research focus in the sustainable use of forest biomass for materials, chemicals and biofuels.

- **Afore** (www.eu-afore.fi/), coordinated by VTT, aimed at generating sustainable, flexible and techno-economically feasible forest biorefinery concepts for the production of added value chemicals, polymers and fibres from wood and forest process side streams. The project ran for four years (2009-2013) and it also included small-scale demonstration of several process concepts.
- **Biocoup** (www.biocoup.com) aimed at developing a chain of process steps which would effectively allow biomass feedstock to be co-fed to a conventional oil refinery with energy and oxygenated chemicals as co-products. The project was coordinated by VTT. There are numerous publications available on the project's website.
- **Bioref-Integ** (www.bioref-integ.eu) aimed at developing advanced biorefinery schemes to be integrated into existing fuel producing complexes. Several biomass processing sectors were considered within the project: sugar/starch (bioethanol), biodiesel, pulp and paper, conventional oil refineries, power production, the food industry and the agrosector.
- **Biorenew** was based on the biotechnological biorefinery concepts (use of bio-catalysts) for a more complete utilization of the lignocellulosic resources by the wood-based chemical industries.
- **Biostruct** (www.biostructproject.eu) project aimed to developing the next generation of wood and cellulose-reinforced composites – so-called "enhanced wood-plastic composites" or eWPCs – for complex structural and multifunctional components. Material development was accompanied by parallel process development to optimise the potential of the new composites. The newly developed materials and processes will be implemented in four different industrial sectors: automotive, construction, electronics and packaging.
- **Biosynergy** (www.biosynergy.eu) contributed to the cost-effective use of biomass, especially lignocellulose and residues, by sound techno-economic process development of integrated production of value-added chemicals, transportation fuels and energy by process development from lab-scale to demonstration at pilot-scale. Biosynergy had great potential impact as it also set up pilot plants of the most promising technologies for a bioethanol side-streams biorefinery. This happened in close collaboration with the lignocellulose-to-bioethanol pilot-plant of Abengoa Bioenergía Nuevas Tecnologías in Spain.
- **Dibanet** (www.dibanet.org) developed technologies to help towards eliminating the need for fossil diesel imports in the EU & Latin America, by advancing the art in the production of ethyl-levulinate from organic wastes and residues. Ethyl levulinate is a novel diesel miscible biofuel (produced by esterifying ethanol with levulinic acid.
- **Flexpakrenew** (www.flexpakrenew.eu) aimed at designing and developing an innovative ecoefficient low-substrate flexible paper for packaging from renewable resources to reduce the packaging industry's reliance on barrier films derived from petroleum.
- **Forbioplast** (Forest Resource Sustainability through Bio-Based-Composite Development) focused on the valorisation of forest resources for the production of bio-based products with the additional contribution to solve the problems related to materials produced by petro-derived resource, to waste disposal, to the use of energy consumption and polluting chemical pathways and to the use of hazardous substances. One topic of the research activity was the use of wood and paper mill by-products as raw materials for the production of polyurethane foams by an innovative sustainable synthetic process with reduced energy consumption. Efforts were also devoted to the promotion of the use of wood derived fibres to replace glass fibres and mineral fillers, in automotive interior and exterior parts, and as a component in composites materials with biodegradable polymeric matrices for application in packaging (cardboard, containers, etc.) and agriculture sector (mulching, greenhouse, tomato clips, pots etc.).
- **Forestspecs** (forestspecs.eu) aimed at developing sustainable, environmentally responsible, and economically attractive management of natural resources based on side products from the forest and forest-based industries. The target of the project was to replace certain large-

volume, oil-based chemical materials with bio-renewable and innovative products based on wood-related residues and humic substances. The aim was to find feasible ways to produce high value added, bioactive compounds such as pharmaceuticals and biological plant protection products, as well as to develop new environmentally benign industrial chemicals and polymers. Furthermore, one of the main targets was to create economically attractive options for the total usage of processed wood and peat residues either as a whole, or after extraction of the main bioactive fractions, for example in soil remediation.

- **Lignodeco** (www.lignodeco.com.br) was based on two Brazilian lignocellulosic raw materials, high-productivity and fast-growing clonal Eucalyptus and elephant grass. Combinations of enzymatic, chemical and/or mechanical pre-treatments for cell-wall deconstruction were evaluated for sustainable production of biofuels, specialty grade pulps and chemicals (including pulp additives). Production side streams and effluents were processed for energy recovery (including biogas) and minimized water consumption. In-depth chemical characterisation of the different lignocellulose (structural and non-structural) constituents in raw materials and their modifications in products and effluents were crucial for developing knowledge-based deconstruction pre-treatments. The project is coordinated by Federal University of Viçosa, Brazil with VTT as a partner.
- **Optfuel** (www.optfuel.eu/) aimed at the demonstration of the production chain of synthetic fuels from biomass (BtL) and the potential of pollutant emissions reduction in vehicle applications. Starting with the plantation of 200 ha of fast growing trees and ending with testing of the fuel in vehicles, the project paved the way for a large scale BtL production. There are several other biofuels-focused EU projects at various stages of completion.
- **Sustaincomp** (www.sustaincomp.eu) aimed at developing new types of sustainable composite materials for a wide range of applications and had the ambition to integrate today's large enterprises on the raw material and end-use sides. (e.g. pulp mills and packaging manufacturers) and small and medium sized enterprises on the composite processing side (e.g. compounders and composite manufacturers).
- **Wacheup** aimed at upgrading low-value residual products from pulp and cork manufacture into value-added bio-based chemicals, with methods that can be efficiently integrated with the pulp/cork mill.
- **Woody** (www.woodyproject.eu) aimed at developing new composite structures from renewable materials; namely wood derived cellulose fibres and resins obtained from natural raw materials. The related manufacturing processes for advanced composite components such as nanomaterials were also explored both as reinforcing fibres and as additives to bring new functionalities to structural composites.

COST Actions are important, typically 4-year networking activities which often result in new EU project proposals and other joint R&D activities. The following on-going or recently ended COST actions are examples of initiatives relevant for biorefinery research and industry:

COST Action CM0903, Utilisation of biomass for sustainable fuels & chemicals (Ubiochem) is aimed at coordinating scientific innovations within Europe in order to improve existing methods or develop new ones for utilisation of biomass to produce biofuels, platform and specialty chemicals in accordance with safety and environmental requirements. Special emphasis will be placed on the utilisation of lignocellulose biomass, algae and non-edible crops, which do not compete with food. It will involve the use of green catalytic methodologies (homogeneous, heterogeneous, enzymatic and photocatalysis) and novel reaction media. Moreover, alternative biomass-based products that are safer and have a reduced environmental footprint, (e.g. biodegradable polymers) will be explored. The Action is also linked to extended biorefinery concepts in the wood and pulp industry and to greener and more economic energy utilization between plants and communities. Success will require the cooperation of scientists and R&D workers in universities, research institutes and industry. The action is chaired by Roger Sheldon from Delft University of Technology.

COST Action FP0602, Biotechnology for lignocellulose biorefineries aims at developing innovative biosciences and technologies required to build and implement advanced lignocellulose biorefineries. The primary objective is to develop environmentally sound and cost-effective biotechnical tools and production technologies to be exploited in the production of fibres, chemicals and bioenergy. The Action will strengthen the position of Europe in the areas of white biotechnology and lignocellulose-based biorefineries. The participating experts are active in a broad range of scientific fields (enzymology, genetics, biochemical engineering, polymer chemistry, fibre technologies). The Action will contribute to the development and implementation of biorefineries, thereby assisting the member countries to achieve the targets set by the European Commission for sustainable energy supply and bio-based economy. The action, chaired by Prof. Liisa Viikari from University of Helsinki, ended in 2011.

COST Action FP0901, Analytical techniques for biorefineries, aims at developing new and evaluate existing sufficient analytical methods related to forest-based and agroindustrial biorefineries that eventually will be applied within novel and existing sustainable biorefining processes and for products, as well as in state-of-the-art academic research and innovations. The Action will end in October 2012.

COST Action FP1205, Innovative applications of regenerated wood cellulose fibres, is a recently (2013) started actions that aims to develop the sustainable emerging technologies in the areas of textile fibre production, cellulosic fibres, and the various forms of nanocellulose derived solely from wood. This advancement needs to be undertaken within a COST framework not only to provide a means of information sharing, but to educate and train scientists in new areas of development. Through a programme of collaboration and knowledge exchange and training, this Action will develop a pan-European leap in capabilities, product and processes. This will lead to an improvement in the environmental credentials of advanced cellulose-based materials, strengthening R&D and innovative material production across Europe.

3.4.2 France

France is highly active in the field of biorefinery research with in excess of 80 active research projects identified in the mapping phase of the previously mentioned Star-Colibri project. Six of these are large projects with budgets in the range of €21.4–112 million.

Biorefinery research is carried out in several universities and research institutes, such as CNRS (the French National Center for Scientific Research), CEA (the French Atomic Energy Commission), INSA (Institut National des Sciences Appliquées) and IFP (Institut Français du Pétrole). National public funding agencies involved in biorefinery research funding in France are OSEO Innovation, ADEME (the French Environment and Energy Management Agency) and ANR (the French National Research Agency).

Biorefinery research in France does not focus on evaluating and developing only one specific biorefinery concept or utilizing only a certain type of biomass as feedstock. Instead, there are several research areas covering the exploitation of a variety of biomass types. These include the production of biofuels and/or value-added products (such as cosmetic extracts and fertilizers) from algae, biomass gasification and gas cleaning as well as further conversion to biofuels or SNG and the production of biofuels and biochemicals from lignocellulosic biomass. One of the current examples is INRA's lignocellulose biorefinery programme that studies biomass and transformation processes to obtain molecules and products to replace those made from petroleum.

3.4.3 Germany

Biorefineries have become a core topic in Germany and the strategic development for the implementation of biorefinery concepts has well and truly commenced. The main drivers for the development are climate protection, energy efficiency and resource efficiency. The research and development in the area of biorefineries is currently strongly supported by national public funding. The primary sources are the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) which provide support through several programmes related to biorefineries. Recently, the German Federal Government published Biorefineries Roadmap, as part of the German Federal Government action plans for the material and energetic utilisation of renewable raw materials.

First pilot and demonstration plants already exist in agricultural and chemical locations in Germany. Most of the operating biorefineries are integrated to already existing biomass conversion sites, such as an oil mill, sugar/starch mill or a pulp and paper plant. For example in Freiberg, a demonstration plant following the synthesis biorefinery concept uses wood in the production of 2nd generation biofuel among other end products. There are also some projected or already existing pilot plants with connected research projects covering different processes and approaches, such as Lignocellulosic Biorefineries (based on wood or straw), a Synthesis Biorefinery based on straw and a Green

Biorefinery based on grass. As part of a two-phase project “Lignocellulose Feedstock Biorefinery (2007-2013), it could be shown (Michels and Wagemann 2011) that it should be possible under certain circumstances to run an organosolv-type lignocellulose feedstock biorefinery in Germany with a capacity of about 400,000 t/a dry wood in an economical and environmental sound way. It has also recently been possible to study thus process on pilot-scale (Leschinsky et al. 2012), using the facilities of recently opened Fraunhofer-Center for Chemical-Biotechnological Processes at Leuna.

3.5 Forest biorefinery R&D in Scandinavia

3.5.1 Norway

In Norway, the main research organizations involved in the field of biorefineries include the Paper and Fibre Research Institute (PFI), the Norwegian University of Life Sciences, SINTEF Materials and Chemistry and the Norwegian University of Science and Technology. On a national level, biorefinery research is primarily funded by the Research Council of Norway. Additionally, Norway participates in joint regional biorefinery activities that are supported by the Nordic funding institution, the Nordic Energy Research. Norway is also represented in several EU funded projects.

Based on the biorefinery projects mapped by the Star-Colibri project, biorefinery research and development in Norway is focused on the utilization of lignocellulosic biomass, especially wood, in different biorefinery concepts. Several projects aim at converting wood-based biomass into 2nd generation biofuels, such as biodiesel or bioethanol, with a simultaneous production of high value-added products. Borregaard has an operating biorefinery unit in Norway which uses spruce to produce specialty cellulose, lignin, biovanillin, yeast and bioethanol.

A national lignocellulose project “LignoRef” was conducted in Norway 2009-2012. In collaboration of several R&D and industrial partners (Øyaas et al. 2012). Its overall objective was to establish fundamental knowledge about central processes involved in the conversion of lignocellulosic biomass to second generation biofuels and value-added products. The studied central processes included biomass pretreatment and separation, enzymatic hydrolysis, fermentation and thermochemical conversion of biomass and process by-products. A further objective of the project has been to join central national players in the biorefinery area in order to promote national progress in this field.

3.5.2 Sweden

Important wood-based biorefinery players in Sweden include the Processum Biorefinery Initiative (www.processum.se) that represents the leading process industry companies in the Örnsköldsvik area. The companies operate in manufacturing, consultancy, and research and development within the pulp, paper, chemical and energy industries. Processum is also host for the regional growth initiative The Biorefinery of the Future. A large number of completed and ongoing R&D projects are listed on their website at www.bioraffinaderi.se.

Another local, strong network is Solander Science Park, a pulp mill based biorefinery cluster in Piteå. The research is focused on accelerating the transition of pulp mills into biorefineries by solving crucial problems in several areas, such as black liquor gasification, hemicellulose extraction, tall oil refinery and lignin fuel for lime kiln.

Funding to collaborative research projects in the area of biorefineries is mainly carried out by three funding agencies: the Swedish Energy Agency, Vinnova, and Formas. In 2009, the Swedish Energy Agency granted significant funds to full scale biorefinery demonstration facilities; €50 million to demonstration of the Chemrec Technology at Domsjö Fabriker; €22 million to the GoBiGas, phase 1 facility, and €9 million to Södra Cell for a full scale demonstration of the LignoBoost (kraft lignin separation) technology.

The research environment Bio4Energy aims to create a highly efficient and environmentally-sound biorefinery processes that uses biomass sourced from forests or organic waste as raw material. Bio4Energy's Environmental and Process Integration Platforms are cooperating with other organisations to check the methods and tools being developed by its process platforms for effectiveness and environmental impacts. These are platforms focused on thermal chemistry, biological chemistry, pretreatment and fractionation of biomass-based materials, catalysis and separation, as well as the design and "improvement" of feedstock. The network is coordinated by the University of Umeå.

In Sweden, there have been three national bioethanol programmes (1993-2011), focussing on the use of lignocellulosic raw materials. The fourth ethanol programme (2011-2015) has been started by the Swedish Energy Agency, to address a number of further questions, e.g. those related to the production of other products in biorefineries, in addition to ethanol.

Of the Swedish research institutes, Innventia has actively developed wood-based pulp mill biorefinery concepts. There has recently been strong focus for example on the separation of lignin and hemicelluloses, and finding various applications for them. Innventia also organises the international conference, Nordic Wood Biorefinery Conference, together with VTT.

3.5.3 Finland

A number of recent or ongoing national programmes have been devoted to development and commercialisation of different types of biorefinery processes in Finland. The Finnish biorefinery research is mainly focused on developing concepts that utilize forest biomass. Efforts in biorefinery research are placed on studying the potential materials and chemicals derived from wood and on developing technologies that use forest biomass in the production of biofuels.

Recently (2007-2012) Tekes (the Finnish Funding Agency for Technology and Innovation) had a large programme called “BioRefine – New Biomass Products”. This programme was devoted to developing innovative new products, technologies and services based on biomass refining. The final report of this €200 million programme can be downloaded at the programme’s website (www.tekes.fi/programmes/BioRefine), together with some data on all the funded projects.

Studies on advanced utilisation of forest biomass have especially been recently managed by Finnish Bioeconomy Cluster FIBIC (previously known as ForestCluster Ltd.). FIBIC (fibic.fi) is one of six Strategic Centers for science, technology and innovation in Finland (SHOK). The aim of FIBIC is to turn science and technology into sustainable bio-based solutions. Examples of the research programmes include EffFibre, FuBio, and Cellulose. Of these, the EffFibre programme focuses on improving availability and supply of high-quality raw material from Finnish forests and developing new production technologies for chemical pulping. The FuBio programme aims to establish in Finland globally competitive knowledge platforms within the field of wood biorefinery R&D for the renewal of the forest and wood products industry and creation of new business. FuBio is focused on development of novel value chains, in which wood is refined into especially materials and chemicals. The Cellulose programme focuses on promoting selected novel value chains starting from wood derived cellulose. The specific target of the program is to develop novel sustainable processes for production of staple fibres, new cellulose based materials and water treatment chemicals. The Cellulose programme is part of the 5-year FuBio programme. More information on the main contents and outcome of these industry-driven programmes can be found at http://fibic.fi.

The FIBIC research programmes are executed by research organisations (such as VTT and Finnish Forest Research Institute Metla) and universities, in close cooperation with the forest and wood products industry and other cluster companies. Due to the public nature of the studies, there is also a lot of academic outcome, for example in the form of numerous Ph.D. theses.

The Finnish Academy is the prime source of funding for basic research in Finland. Biorefinery-related research receives funding through the following Finnish Academy programmes: the Sustainable Energy Research Programme (SusEn, 2008–2011) and the Research Programme on Sustainable Production and Products (Ketju, 2006–2010). The biorefinery projects funded by the Finnish Academy are more or less small projects which concentrate on a few aspects of bio-refineries, such as the catalytic decomposition of wood rather than developing a whole concept.

Current industrial biorefinery projects, focusing on commercial-scale biofuel projects, have previously been described in Appendix 2.

3.6 Biorefinery R&D in other countries

In **Asia**, and especially in China, development of biorefineries is driven mainly by the energy demand of an expanding manufacturing sector and the increasing cost of fossil fuels (Tan et al. 2010, Tao et al. 2011). Renewable energy made up 7% of the energy mix in China in 2007, with a target of 16% renewable energy use by 2020. Biofuels are expected to meet 15% of China's transportation energy needs by 2020. As a result, there are numerous projects on bioethanol (and also biobutanol) and biodiesel production in China. In addition, the fragmented industry uses various biomass raw materials for the manufacture of a wide variety of sugar-based chemicals, pharmaceuticals, flavourants and prebiotics. Straws and other non-wood lignocellulose raw materials are mainly used. For example, China is the world leader in the production of furfural from xylose. As an example of wood-based chemicals,

China is the most important source for gum rosin and gum turpentine, isolated by traditional tapping methods. Some pulping by-products (such as soda lignin and lignosulfonates) are being isolated at pulp mills, although the main raw materials are typically of non-wood nature.

In **India**, biorefinery projects have typically dealt with bioethanol, biodiesel (traditional and algae-derived) and other biofuels (e.g. Mohantu et al. 2011, Sankar et al. 2013). For bioethanol, lignocellulosic raw materials have received a lot attention, as the main biomass types include agricultural by-products such as crop residues and gathered wood. Other Indian biorefinery research areas include production of lactic acid and other sugar-derived chemicals, production of polyhydroxyalkanoates, and utilisation of hydrolysis lignin. Small-scale isolation of lignin and other pulping by-products also takes place, both from wood-based and straw-based processes.

In **Japan**, one of the leading forest-based biorefineries is Nippon Paper that produces several different bioproducts (lignosulfonates, yeast, ribonucleic acids) as sulfite pulping by-products. Outside the pulping industry, the Japanese research organisations have been more focused on other lignocellulose-derived chemicals and materials, such as bioplastics. There have recently been several lignocellulose-based biorefinery projects, including the use of ionic liquids and utilisation of lignin from various processes. For example, the use of specific lignin materials for the car manufacture has successfully been tested by Toyota (Funaoka 2010). Supercritical methanol and water processes are also studied for cellulose processing, for example for the manufacture of levoglucosan. Thermochemical and gasification systems are also being investigated and developed.

In **Australia**, there is biobased products research and development activity led by CSIRO. Generally, Australian industry lags behind other developed countries in terms of innovation and product range, and has mostly centred around biobased food packaging products (such as novel biodegradable polymers). The research and development covers the full range of activities from investigation of agronomic characteristics, of activities from investigation of agronomic characteristics of new industrial crops, examination of value chains for bio-based materials and development of novel materials from agricultural by-products and high value products from existing plants and genetically engineered varieties. These have very much been motivated by the Australian Crop Biofactories Initiative. As a result, there is now a 3-stage, 12-year R&D and commercialisation program to build a versatile and sustainable Crop Biofactories Industry in Australia. There are also several projects (including demonstration projects) on lignocellulosic pyrolysis to bio-oil and on other biofuels at QUT amongst other places.

Generally, Australia lags behind other developed countries in terms of innovation and product range when it comes to biorefineries, although there are pockets of activity driven partly by government policy (allocation of funds to assist in the transition to a clean energy future) and partly by necessity (struggling businesses looking for new opportunities).

Some relevant Australian Government initiatives include:

- Funding of $12.6M A$ under the Second Generation Biofuels Research and Development program allocated to six projects over three years from 2009-12.
    - The University of Melbourne ($1.24M) to research biofuel from micro algae involving efficient separation, processing and utilisation of algal biomass
    - Algal Fuels Consortium ($2.7M); a consortium to develop a pilot-scale second generation Biorefinery for sustainable micro algal biofuels and value added products. The participants were the South Australian Research and Development Institute

(SARDI), Flinders University and CSIRO, with project located at Torrens Island, South Australia
    - Curtin University of Technology ($2.5M) to investigate the sustainable production of high quality second generation transport biofuels from mallee biomass by pyrolysis and utilising the Biorefinery concept. The project was supported by Spitfire Oil Pty Ltd and located in Perth, Western Australia
    - Bureau of Sugar Experimental Stations (BSES) Limited ($1.3M) to develop an optimised and sustainable sugarcane biomass input system for the production of second generation biofuels, located at Indooroopilly, Queensland, with CSIRO as a supporting partner
    - Microbiogen Pty Ltd ((2.5M) to produce commercial volumes of ethanol from baggasse using patented yeast strains. The project was located at Lane Cove, NSW
- Licella Pty Ltd (2.3M) for the commercial demonstration of lignocellulosics to a stable bio-crude at Somersby, NSW; Australian Renewable Energy Agency (ARENA); a new independent statutory authority established on 1July 2012 that consolidated the administration of $3.2B in government support for renewable energy technology innovation. ARENA currently provides financial assistance to a broad portfolio of projects and measures for each of the renewable energy technology types (bioenergy, geothermal, hybrid/enabling, hydropower, ocean and solar) and across the various stages of renewable energy technology innovation. The bioenergy projects, additional to the ones listed above, are:
    - James Cook University ($5.0M) to support a high energy algal fuels project investigating the research, development and demonstration of biofuels from microalgal feedstock
    - Almond Board of Australia ($32K) to assess the technical and economic feasibility for bioenergy generation from almond waste
    - Renergi Pty Ltd ($3.6M) to demonstrate an advanced biomass gasification technology
    - Licella Pty Ltd ($5.4M for the construction of its first pre-commercial biofuels plant
    - Muradel Pty Ltd ($4.4M) to prove its marine algal production and harvesting technology to produce sustainable biofuel from marine microalgae
    - Qantas Airways Ltd (0.5M) to look at the conditions under which the sustainable manufacture of alternative aviation fuel can be achieved in Australia

It is clear from the information above that majority of activities on Biorefinery research in Australia is on biofuels, with little activity in the related areas of biochemicals and biomaterials. We are aware of one company, Circa Pty Ltd located in Melbourne, Victoria that is developing a low capital cost thermo-mechanical process to convert cellulosic waste and residues into value-added renewable chemical products utilising two proprietary processes: Furacell™ for the production of levoglucosenone, a valuable chiral molecule used in the production of pharmaceutical drugs, and Furafuel™ for the production of value-added chemicals, water and char.

There is biobased products research and development activity led by CSIRO on innovative biobased food packaging products such as novel biodegradable polymers. The research and development covers the full range of activities from investigation of agronomic characteristics of new industrial crops, examination of value chains for bio-based materials and development of novel materials from agricultural by-products and high value products from existing plants and genetically engineered varieties. These have very much been motivated by the Australian Crop Biofactories Initiative. As a result, there is now a 3-stage, 12-year R&D and commercialisation program to build a versatile and sustainable Crop Biofactories Industry in Australia.

4. APPENDIX 4: Market analysis

The market analysis of the fibre-based value chain is split into the lens approach used in other sections of this report

- Mass Lens
  - Wood-based construction industry
  - Fibre-based packaging and paper products
- Energy and Molecular Lens
  - Biorefineries for energy and biochemicals
- Atomic Lens
  - Nanomaterials

While the basic material has been collected by VTT's Knowledge Solutions experts, the reflections are those of the authors.

4.1 Mass Lens: Wood-based construction industry

Traditionally the construction sector has been a primary catalyst for the demand of wood-based materials. Unfortunately, this sector is suffering particularly in the western world due to the economic downturn caused by the global financial crisis that has lowered the demand for wood-based materials in construction. However, global trade continues to flourish as demand in Chinese markets remains strong. In addition, there is a high demand for wood products in the Asian-Pacific rim. (UNECE/FAO 2012). In Australia an upturn in the construction industry is predicted.

4.1.1 Sawnwood

The global consumption of sawnwood has increased steadily since 2009 (see Figure 7) with CAGR of 6.1% to 402 million m^3 for softwoods and CAGR of 5.6% to 117 million m^3 hardwoods in 2011

However, in Australia both production and consumption of sawnwood have decreased during the recent years (FAO 2013).

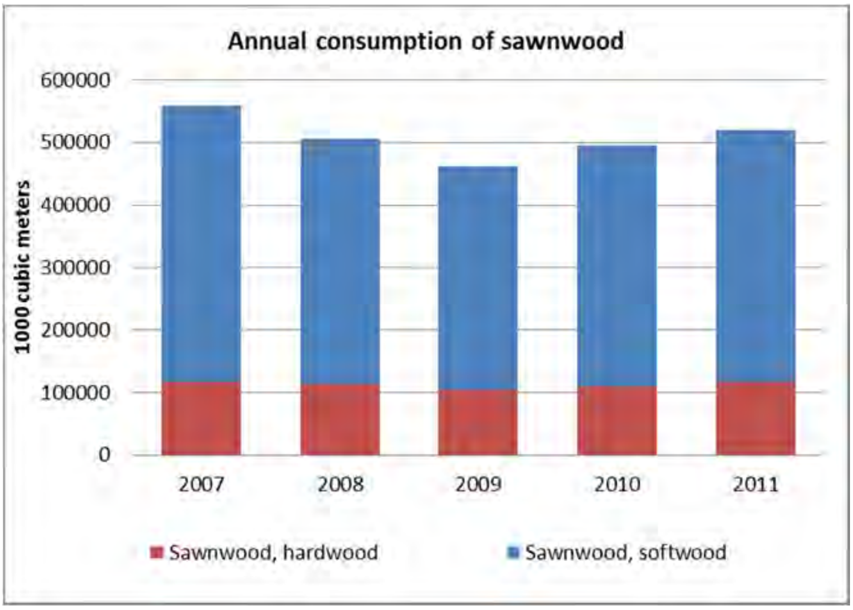


Figure 7. Annual global consumption of sawnwood. (FAO 2013).

Drivers

- Sustainability
  - o There is growing awareness and tighter regulations supporting the use of wood from sustainably managed sources. (Taylor et al. 2012)

- o Government policies and Green building Council Australia, are actively promoting sustainability in construction business (GBCA 2013)
- o Sustainability accreditation programs (eg. LEED and Green Star in Australia) are in use. (GBCA 2013)
- o Need to reduce greenhouse gas emissions
- o Timber material is a sequesterant for CO_2 for a long time in constructions
- o Availability of raw material in Australia

Restraints

- Since demand in Europe is not increasing, European sawmillers are focusing on export markets, including Australia. At the same time, non-European sawn softwood suppliers have has a difficult time competing in the European market, where there is intense competition, long-established relationships, timely deliveries, and high-quality wood manufactured into high-quality products (Taylor et al. 2012).
- Also North American producers are heavily focusing the sawn softwood export activities towards China, Japan, the Middle East, Asia and Oceania. (Taylor et al. 2012, see Figure 8)

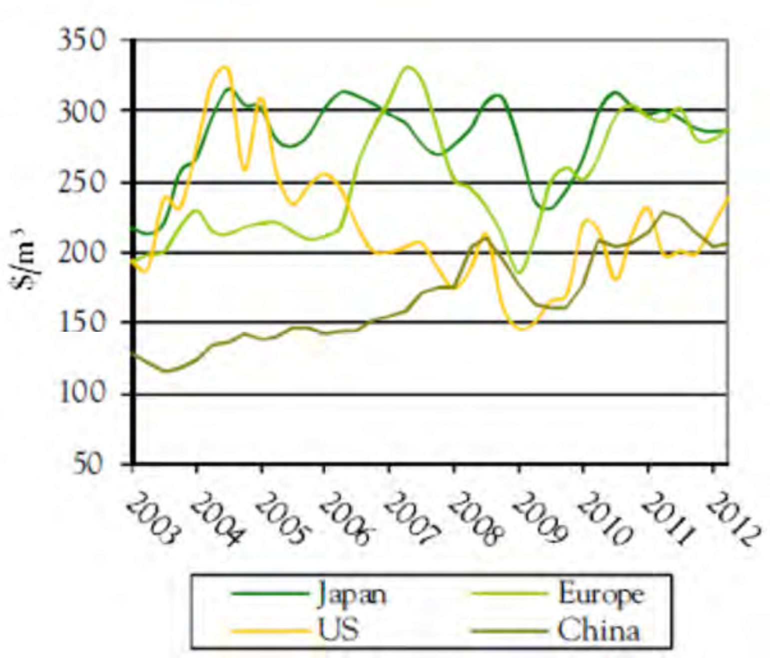


Figure 8. Softwood quarterly prices in Japan, Europe, US and China 2003–2012 (Taylor et al. 2012 / Wood Markets Monthly international report and China bulletin, 2012).

4.1.2 Value-added wood products

Value-added wood products, which are also known as secondary-processed products, are products that have been processed into furniture, builders' joinery and carpentry products, profiled wood and engineered wood products (Pahkasalo et al. 2012). The latter are basically materials for structural and industrial applications. The main segments in structural applications are structural panels (i.e. oriented strand board (OSB) and plywood), structural composite lumber (SCL) (i.e. laminated veneer lumber LVL, laminated strand lumber LSL, parallel strand lumber PSL and oriented strand lumber OSL), glue-laminated timber (gluelam), and I-joist (see Figure 9). The three main product segments in industrial applications are particleboard, high density fibreboard (hardboard), and medium density fibreboard (MDF) (Frost & Sullivan 2011, Strategic analysis of the North American and European engineered wood markets in construction and buildings).

Builders' joinery and carpentry markets are recovering, although levels prior to the GFC have yet to be reached. Due to the economic turndown many producers of value-added wood products such as builder joiners, carpenters, and wood profilers, have either gone to out of business or changed to other products and markets. This has been compounded by the mountain pine beetle infestation causing severe supply problems from eastern Canada.

It is expected that remodelling activity will increase, and such signs are already visible in the United States. However, the higher demand for value-added wood products for remodelling has not compensated for the lower demand of value-added wood products for new housing construction. Profiled wood demand is increasingly more focused on painted mouldings. Therefore the price advantage of clear knot free pine is decreasing. Profiled wood for painted mouldings is also facing competition from finger-jointed products and medium-density fibreboard (MDF) (Pahkasalo et al. 2012).

In addition, the engineered wood market is highly correlated with the housing and furniture industries. Market development depends on the product types. According to Frost and Sullivan (2011) the market for engineered wood products is expected to grow in Europe and North America at a CAGR of 10.9% and reach 55,6964 US$ million by 2016.

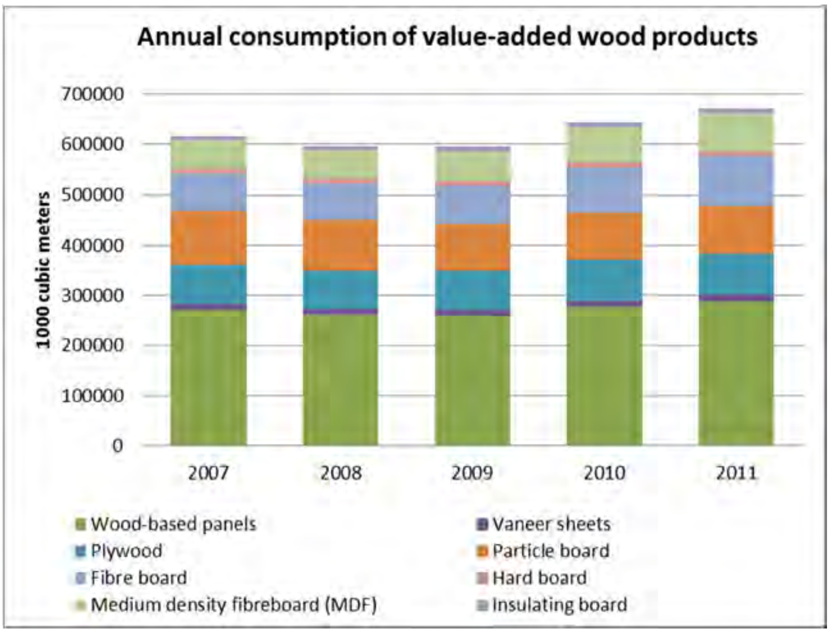


Figure 9. Annual consumption of wood-based construction materials (FAO 2013).

There are several positive **drivers** affecting the engineered wood products market, such as

- Sustainability trend in the construction industry. For example, in Australia
    - Government policies and Green building Council Australia, are actively promoting sustainability in construction business (GBCA 2013)
    - Australia is currently a leading player in the green building arena (GRESB 2012)
    - Sustainability accreditation programs (e.g. LEED and Green Star) are in use. (GBCA 2013)
    - The need to reduce greenhouse gas emissions
    - Repair and remodeling of existing homes drive the demand for engineered wood products (Frost & Sullivan 2011)
    - Recovery in new residential construction

It is noteworthy that uses of engineered wood products increase structural panel utilization in construction e.g. cross laminated timber for the construction of high structural load bearing applications, such as high-rise multi-family dwellings and municipal buildings like libraries and office buildings (Frost & Sullivan 2011, Pahkasalo et al. 2012). There is also growth in the furniture and kitchen industries especially in North America and Europe (Frost & Sullivan 2011). Also, engineered wood products have higher durability and precision than timber products. In additional EW products shrink less and are more consistent. Australia has the possibility to increase gluelam and LVL products in sports facilities, and large scale constructions, industry buildings and warehouses, as the proportion is small compared with that of European or North-American usage. However, there are also **restraints** and challenges for the market growth (Frost & Sullivan 2011) which include:

- economic recession that reduces investments in infrastructure and construction;
- high capital costs that hinder installation of new facilities and lead to capacity reductions;

- the use of wood for bioenergy has been restricted the supply of wood raw material to the engineered wood market and has increased the price of the raw material, and
- building codes to promote wood usage in construction as elsewhere in the world e.g. Europe.

4.1.3 New biobased materials for construction

In addition to the traditional sawnwood and engineered wood products use of other wood-based biomaterials has increased. One example of advanced biobased construction material is wood plastic composites.

Global demand for wood plastic composites was about 2.6 billion euro in 2009. By 2011 decking applications had become the largest end use, accounting for 44% of demand. Currently, global WPC production is estimated to be 900,000 tonnes, including thermoplastics filled with other natural fibres (Clark et al. 2012).

There are promising drivers for the new bio-based construction materials. For examples, for wood plastic composites (WPCs) the maintenance requirements are low in decking and railing applications (Frost & Sullivan 2012, Clark et al. 2012); the WPCs are sustainable; the WPCs have a lot of emerging application opportunities e.g. in roofing, fencing, doors, and windows; and WPCs have a growing end market (Frost & Sullivan 2008). The restraints for the bio-based construction materials are connected to a still negative perception of performance and the lack of implemented standards (Frost & Sullivan 2008).

In addition to WPCs, other innovative wood-based products for construction include thermally modified wood (thermowood), and new applications in insulation, e.g. wood-based insulation wool, wood-fibre insulation boards and bio-based foams. Despite the fact that cellulose-based insulation producers are small companies and competition is large, the products are achieving successful market penetration (Clark et al. 2012).

4.2 Mass Lens: Traditional fibre and paper products

According to Pöyry (2011) the combined world paperboard production in 2010 was 390 million tonne, representing a rise on some 22 million tonnes from the previous year, but still slightly below the peak reached in 2007 when production was 393 million tonnes. Asia is the biggest producing region, representing some 43% of all paper and paperboard production, followed by Europe (27%) and North America (23%). The biggest consuming regions are Asia with 45%, Europe 24% and North America 21% (Pöyry 2011). The prospects for paper and paperboard products are shown in Figure 10, and reveal growth in packaging and tissue, a slight increase in printing and writing papers, and a continual reduction in newsprint.

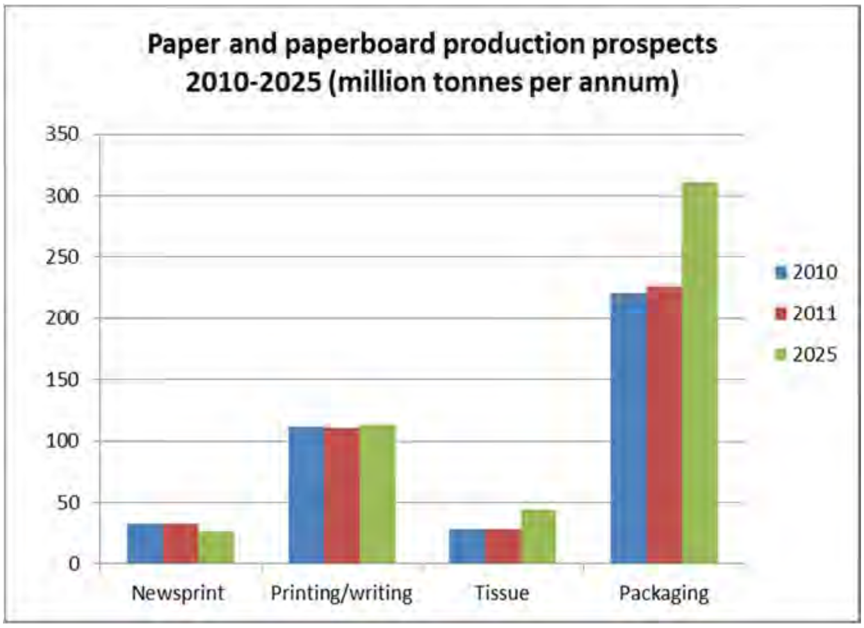


Figure 10. Paper and paperboard production prospects 2010‒2025 (Pöyry 2011).

Frost & Sullivan's (2012b) definition of "flexible packaging" covers packaging materials including plastic films, paper, and metal foils. The idea is that materials can be flexed or folded around objects. Considering the North American market, the report (Frost & Sullivan 2012b) assesses that converted flexible packaging market is growing but close to maturity. In North America the growth prospects are thus moderate. The growth focuses on end applications in the food, medical, pharmaceuticals, and consumer packaged goods, and where the food and beverage industries represent the most important applications. Potential new applications in this domain will also drive the growth in these sectors. The generic overall trend in the packaging industry is sustainability and biodegradability. The major drivers are changing consumer lifestyles, and the rise in the use of processed, packed, and pre-cooked food.

The most important chemical components of flexible packaging are the following (Frost & Sullivan 2012b): polyethylene, polypropylene, polyvinyl chloride, polyethylene terephthalate (PET), polyamide, ethylene vinyl alcohol copolymer (EVOH), biodegradable resins.

The key research focus areas in biodegradable food packaging are nanotechnology, edible films and coatings, starch-based packaging, polylactic acid (PLA)-based packaging, cellulose- based packaging, and polyhydroxyalkanoate (PHA)-based packaging (Frost & Sullivan 2011a). The key R&D regions are in North America and Europe with the former emphasing biodegradable products and the latter highlighting compostability. The industry has common operational practices such as building and expanding the technology and product portfolio, building new market creation and outsourcing of research activities. Regulation and voluntary standards play key roles in new product development.

Figure 11 presents a typology for food packaging materials.

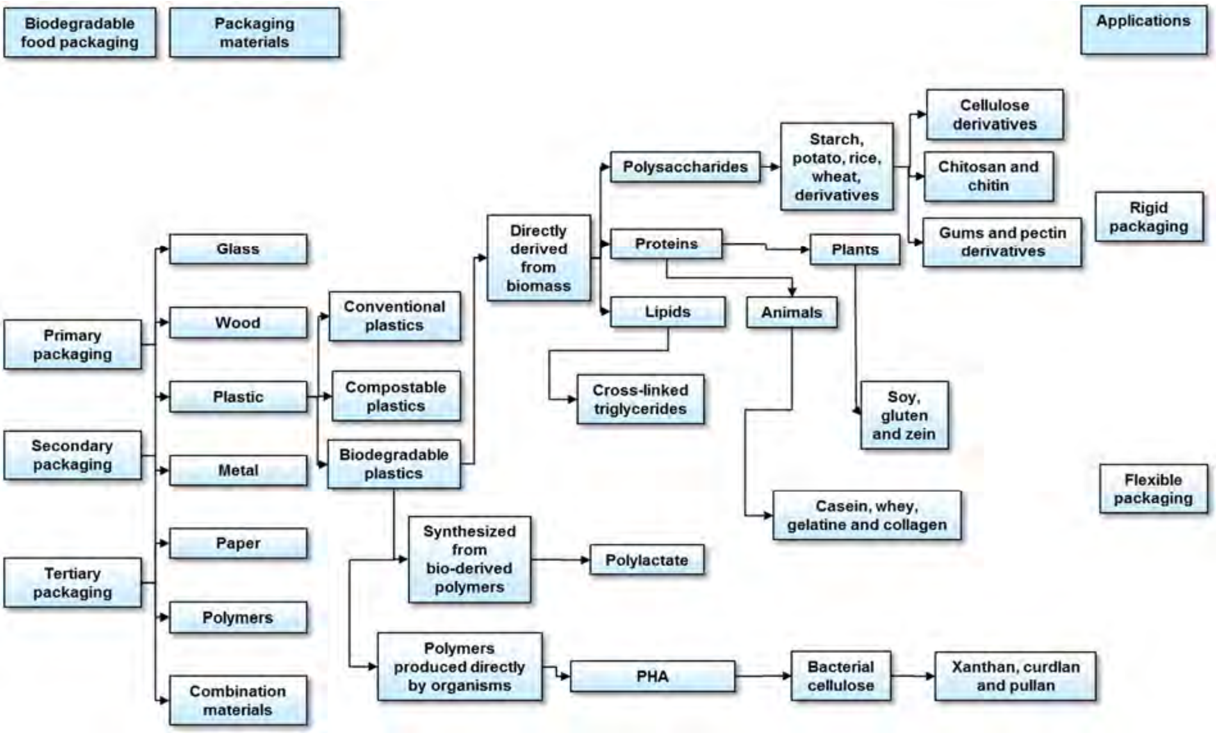


Figure 11. Food packaging materials typology (Frost & Sullivan 2011a).

Table 3 presents examples of new biodragadable packaging products.

The companies highlighted as industry stakeholders in this table have little or no presence in Australia, nor is their strategy for introducing new technologies into Australian known.

Table 3. Examples of new biodragadable packaging products (Frost & Sullivan 2011a).

Product	***Description***	***Benefits and Application***	***Industry Stakeholders***
Ultigreen	Fully biodegradable and home compostable printed film laminates.	They can biodegrade in commercial and domestic compost bins and are suitable to package fresh foods and meat products.	Ultimate Packaging, UK; in collaboration with Innovia Films and Sun Chemical
PLA-lined BagasseWare containers	Clamshell containers and other food serviceware products obtained from bagasse and lined with PLA	PLA lining enhances the performance of the products and they can be used to carry hot and moist foods.	Excellent Packaging & Supply, USA
Bio-Flex	PLA and co-polymer blend	Offers superior barrier properties and a wide processability window.	FKuR GmbH, Germany
Bio-based window cartons	Cellulose diacetate films	It allows moisture to escape the packaging without misting. It does not exhibit stress whitening.	Clarifoil, UK
Terraloy blends	A blend of natural resin and thermoplastic starch	They are cost-competitive, possess excellent strength characteristics.	Cerestech, USA
Freshlife Bio	A range of breathable bio-packaging films made of PLA and cellulose.	These films are biodegradable as well as compostable, have good barrier properties, high seal-strength, and low-sealing temperatures.	Paragon Flexibles, UK
Biodegradable food serviceware	Food service products such as cutlery, clamshells, bags, bowls, cups. Plates and trays	These are economical, light weight yet strong, heat-resistant, microwaveable, and do not leach any toxic materials.	Trellis Earth Products Inc., USA

4.2.1 Hygiene and tissue products

The disposable product market comprises a tissue sector that is mainly soft paper based and hygienic sector that includes a wide variety of materials such as nonwoven, fluff, super absorbent and plastic films. Tissue products have traditionally been pulp based whereas hygienic products relied initially on synthetics but is gradually targeting more sustainable and renewable materials.

Tissue markets: This segment consists of several product categories, including toilet papers, napkins / serviettes, kitchen towels, folded hand towels, industrials wipers and washroom towelling rolls.

As the data in Figure 12 shows, global tissue consumption has been growing steadily despite the negative effect of the global economic recession in 2009. In general, the tissue sector is less impacted by economic fluctuations than other paper grades such as magazine paper. The annual growth of tissue consumption is around 4% (Uutela 2011a).

While China has been the main driver for growth in the global tissue business, Latin America has also expanded greatly with demand growth now exceeding that of North America (see Figure 13). According to a RISI (2012) report, the large emerging markets of Brazil, Turkey and Russia will increasingly offer tissue companies new business opportunities over the next few years.

Between years 2010 and 2016, the growth in the global tissue market should be able to absorb global capacity additions of up to 1.3 million tonnes per year without having a negative effect on demand and supply, although the risk of overcapacity still exists. If demand and supply do not balance, restructuring measures will be needed with China and North America likely to play the main roles. Mill closures are also expected in other regions, including Europe and Latin America. (Uutela 2011a)

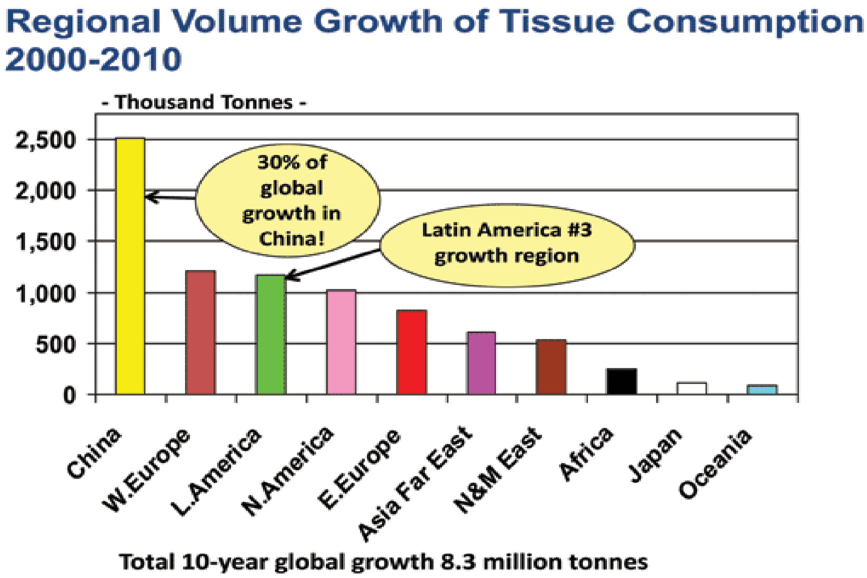


Figure 12. Regional volume growth of tissue consumption (RISI 2012).

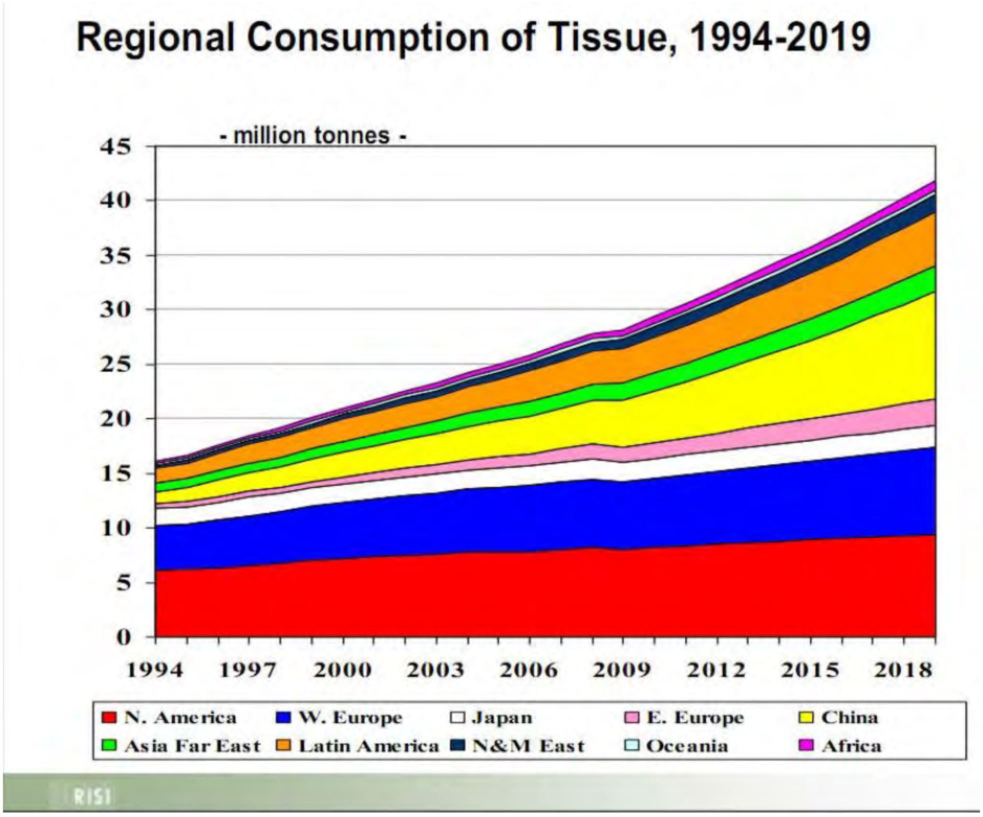


Figure 13. Regional consumption of Tissue 1994–2019 (European tissue / RISI).

The key trends and drivers in tissue sector are intensive growth in the emerging and developing markets due to rising incomes, and the shift towards higher quality and multi-ply products, while the restraints are risk of overcapacity (Uutela 2011b) and import/export limitations due to the bulky nature of the tissues which necessitates that production be close to the end markets

Hygiene market: The main product categories of hygiene, or personal care, products are baby diapers, incontinence products, and feminine care products. All these sectors are showing steady growth; diapers at 6% CAGR (SCA 2012), incontinence products at 5% CAGR (SCA 2012), and feminine care products at 4% CAGR (SCA 2012, Research and markets 2013). According to SCA (2012) the sizes of the market are baby diapers (USD 27,8 billion), incontinence products (USD 10,8 billion and feminine care products (USD 15,5 billion).

The highest growth rates are in the emerging markets where the current penetration is significantly lower than in mature markets. For example, the diaper consumption per capita in Asia is only about 10% of that in Western Europe. In mature markets, market penetration for incontinence remains relatively low. (SCA 2012)

In this *sector, the main drivers are* global population growth, intensive growth in the emerging and developing markets due to rising incomes, the aging population in western world driving the need for more incontinence products and the sustainability trend. Balancing these drivers are a number of restrictions including the declining birth rates in Western world, cultural differences in the use of baby diapers (e.g. traditionally in China, babies and toddlers do not use diapers) and a hardening attitude towards the use of disposable diapers in the western world. The sustainability trend is pushing new bio-based alternatives into the market; namely such products as cellulose-based non-wovens (lyocell) (Weyerhaeuser 2008), polysaccharide-based (i.e. cellulose, starch, chitin, and natural gums) super-absorbent polymers used in hygiene products (GIA 2010), and bio-plastics, like PLA and starch-based films

4.3 Energy and Molecular Lens: Biorefinery

4.3.1 Biorefineries

There are several arguments why biorefineries can be thought of as an industry of the future. This is because biorefineries are largely about improving and developing what already exists in nature (Penttilä 2010). The development aspects should be directed primarily to versatile product and technology options and on questions of how to combine various integrated technologies required in a future biorefinery as depicted in Figure 14.

The US organisation, Environmental and Energy Study Institute (EESI), discusses the biofuel policy options that can be implemented by the US states (EESI 2010) as well as engaging in a series of case reflections. As a conclusion, EESI report makes a following list of potential policy actions for encouraging a biofuels industry:

- Inventory of local bioenergy resources and markets, and developing long term plans
- Development of sustainable feedstock production guidelines that ensure the sustainability from the perspectives of ecosystems and biodiversity
- Researching and developing locally appropriate feedstocks and conversion technologies; basically this involves local demand as well as local technological solutions
- Creating programs for sustainable feedstock production; financial incentives for local producers to develop cellulosic feedstocks
- Establishing minimum renewable fuel standards to ensure an effective local market
- Enacting a low carbon fuel standard (LCFS); the report suggests that this policy action should be planned and implemented on a state level
- Co-operation among agencies and states to coordinate the transition
- Tax incentives for producers and retail distributors
- Leveraging state resources to promote federal and private partnerships

The list of policy actions provided by the EESI report emphasises an important point from the perspective of effective biofuels policy: the policy actions should be set firstly into the local context (the building of technological solutions that fit the existing local industry; promoting local advanced demand for the products) and then the necessary incentives created by the government.

Penttilä emphasises the role of governmental initiatives and policy regulation as drivers for biofuels (Penttilä 2010). The key regulatory incentives for biorefineries have been:

- Biofuels directives
- USA Chemistry industry roadmap ~ 25% of chemical compounds and materials will be produced from renewable resources 2030 (now 7%)
- EU Technology Platform for Sustainable Chemistry Visions
- National and international research programs

The biofuels can be divided into three generations (Table 4).

Table 4. The biofuel generations (Penttilä 2010).

The 1st generation biofuel production	**2nd generation (bioethanol, biobutanol)**	**3rd generation (biodiesel)**
• Traditional ethanol process based on grain/corn starch (or sugar cane) • Technology ready • C6 (glucose, sucrose) fermenting yeast • Grain/corn ethanol not energy efficient, high CO_2 emissions	• Lignocellulosic raw materials & waste • Technologies under vigorous development worldwide • C6 and C5 (pentoses xylose & arabinose) fermentation • Sustainable	• Algal production from sun light and CO_2

The steps towards biorefinery can be characterised as in the Figure 14.

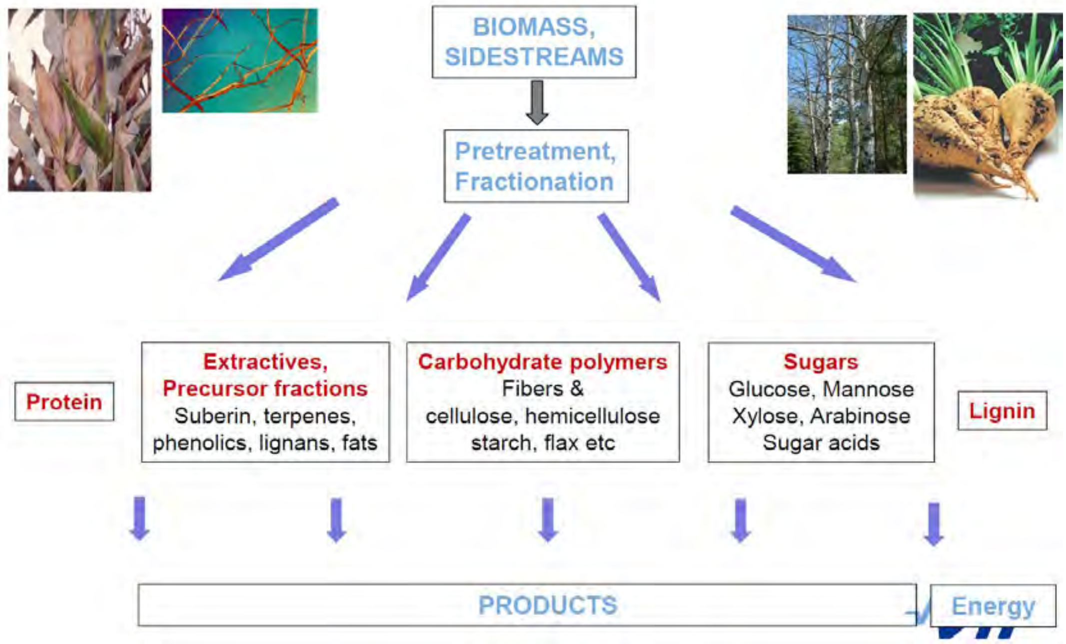


Figure 14. Steps towards biorefinery? (Penttilä 2010).

In an article on the future outlook for Australia in bioenergy (BI 2011) the following was written:

> "*The growth of Australia's biomass power market is subject to the willingness of state governments to provide incentives to generate electricity, and the availability and access to biomass feedstock, factors allowing biomass power generation costs to be economical to the end users of electricity. Yet in Australia, biomass power technology applications still have to compete with coal and gas on a price basis, indicating potential opportunities for utilities to introduce cost effective additional biomass power capacity. Australia's vast geographic expanse makes full national electricity interconnectivity from coast to coast challenging, as there are limited number of High Voltage Direct Current solutions available."*

The Australia's government is encouraging a R&D effort in the development and demonstration of new biofuel technologies and feedstock, indicating that the national government is targeting the use of feedstock for the purpose of producing biofuels, instead of aggressively promoting generation of electricity from available feedstock" (refer Figures 15 and 16).

The same report, biomass market future insight (BI 2011) makes the additional relevant points, both as general statements and specific to Australia:

- An increasing population drives demand for additional installed electricity capacity
- Globally, the renewable power market will become increasingly competitive.
- The scale of government support for additional renewable power capacity will grow backed by government support
- Countries including the US, Brazil, and China will continue to encourage the blending of transportation fuel with first generation fuels, by having regulatory programs and incentives.
- Globally, countries will continue with the adoption of additional biomass power capacity.
- The existing coal-fired power plants are responsible for emitting around 50% of the current greenhouse gas emissions in Australia.
- Australia's net biomass and waste power net generation contributed to less than 1% of Australia's total electricity supply in 2009.
- Within Australia, only Victoria provides a Feed-in Tariff for installing biomass power technology for a period of 15 years. Within Australia, state governments play an active role in driving the growth of the biomass power market by initiating Feed-in Tariff mechanism.
- Although Australia's biomass power market lacks a national level Feed-in Tariff mechanism, the government provides a grant for biomass power installation technology.

- According to a study published by the University of Newcastle, the most prominent feedstock resources found in Australia include agricultural-related wastes, energy crops, landfill gas, sugarcane, and wood-related wastes.
- The abundance of coal suggests the attractive venue of using technologies including biomass gasifier to convert the solid biomass into a fuel gas, which can be incinerated in the coal boiler furnace to generate power in Australia.

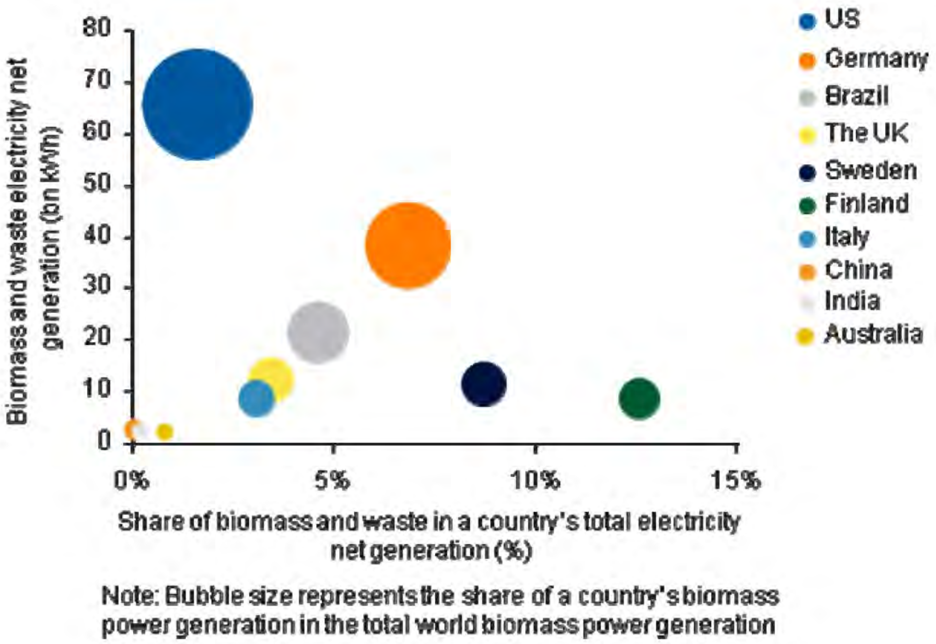


Figure 15. The share of biomass and waste in country's total electricity net generation (BI 2011).

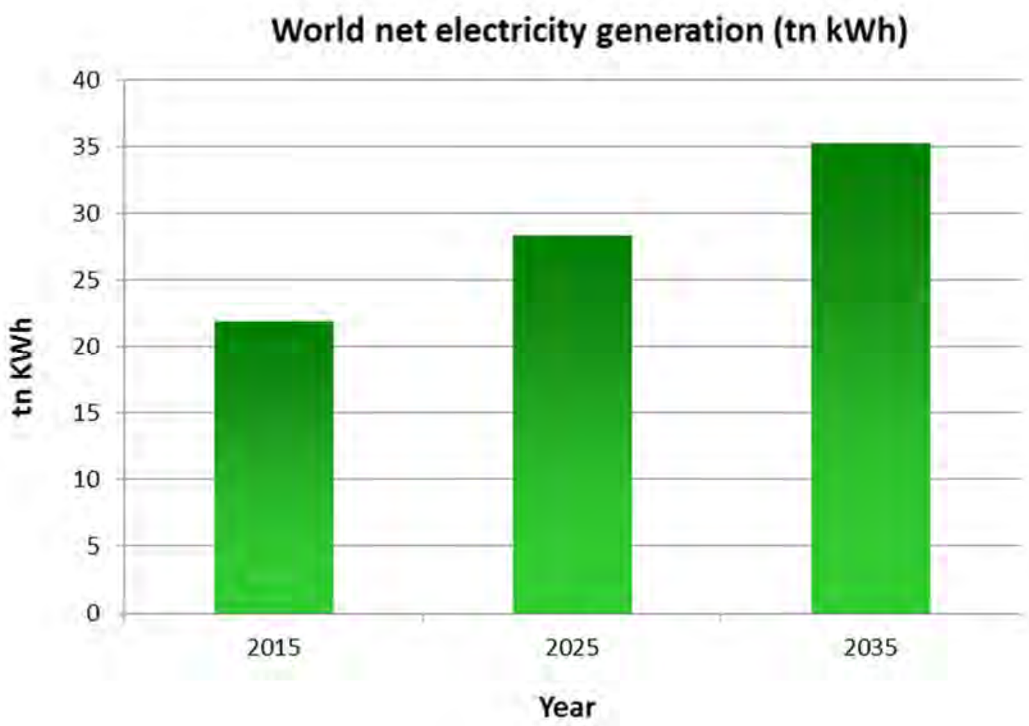


Figure 16. The world net energy generation (BI 2011).

According to Frost & Sullivan (2012c), the total market for biodiesel in SE Asia is expected to double between 2013 and 2017. The biggest markets are in Philippines and Indonesia.

According to Frost & Sullivan (2012d), biomass-based energy for residential and commercial applications has the following challenges:

- low biomass calorific value,
- continuous supply of feedstock,
- fuel proximity and transportation costs, and
- production costs,

Whilst the drivers are:

- waste management,
- incentives from regulatory bodies,
- government subsidies,
- off grid power generation and
- reducing landfills.

4.3.2 Markets of pyrolysis oil in Australia

Pöyry (2013) has made an analysis for VTT about pyrolysis and biocoal markets in Australia. The central insights of Pöyry's analysis are provided in this and the subsequent chapters.

Currently there is no active market for pyrolysis oil: it is not yet produced in significant amount and there is thus no active demand for the product. Basically, the market could be found in replacing the existing market of heavy fuel oil. Pyrolysis oil could technically replave oil in boilers and combustors.

The Figure 17 shows consumption of heavy fuel oil in Australia in 2010. In Australia, total heavy fuel oil consumption was nearly 1.1 million tonnes in 2010. It was utilised by mainly by three activities: non-ferrous metals industry (64%), domestic navigation (14%), and electricity plants (12%).

The value of pyrolysis oil can be assumed to be equal to the cost of heavy fuel oil use in different end-use application when taking into account all the relevant fuel taxes and CO_2 components."

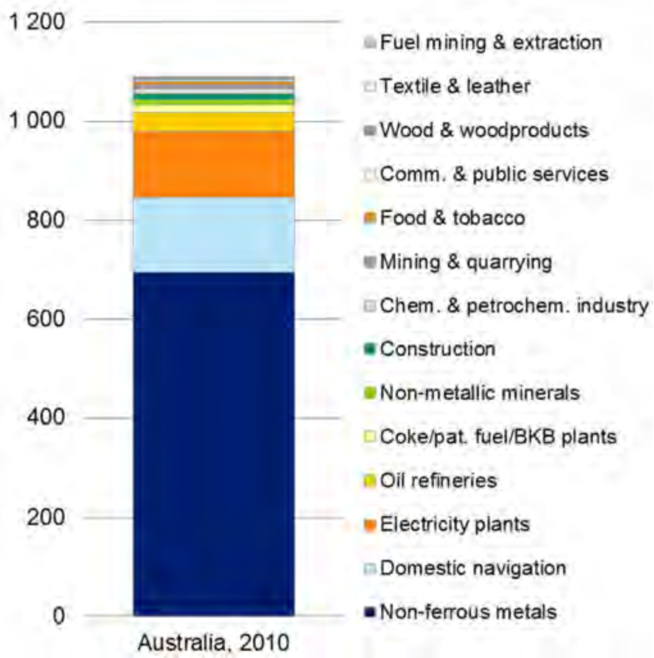


Figure 17. Consumption of heavy fuel oil in Australia (Pöyry 2013 adapting International Energy Agency).

Pyrolysis oil could be in replacing heavy fuel oil in industrial boilers and power plants with oil combustion capabilities. Pöyry (2013) estimates that taking into account the present qualities of pyrolysis oil "it is not possible to use the oil in stationary engines without significant further processing". When compared to heavy fuel oil the key challenges of pyrolysis oil are the acidity, lower heating value, solids content and higher water content.

Pöyry (2013) has estimated that there are limited amount of power plants in Australia that use heavy fuel oil in steam turbine units. Majority of these are in Northern and Western parts of the country. Also, there are several non-ferrous metal smelters that could offer a potential end use market for the oil, that is, in copper smelters (Figure 18).

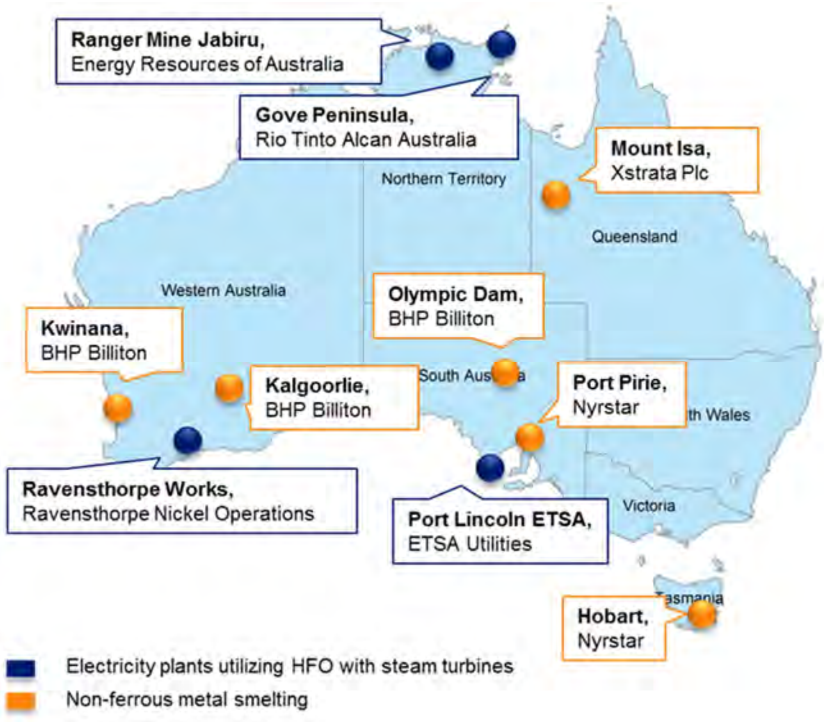


Figure 18. Potential users of pyrolysis oil Australia (Pöyry 2013).

4.3.3 Markets of biocoal in Australia

As with pyrolysis oil, there is no well-defined market for torrefied pellets. The closest thing is the present thermal coal market. The torrefied pellets could be co-fired with conventional coal at over 50% fuel shares.

In 2010, total thermal coal consumption in Australia was approximately 136 million tonnes. 93% of it was for electricity production. Other end-users include CHP plants and metals & mining industry.

The value of biocoal can be assumed to equal the cost of thermal coal, taking into account the tax incentives (Figure 19).

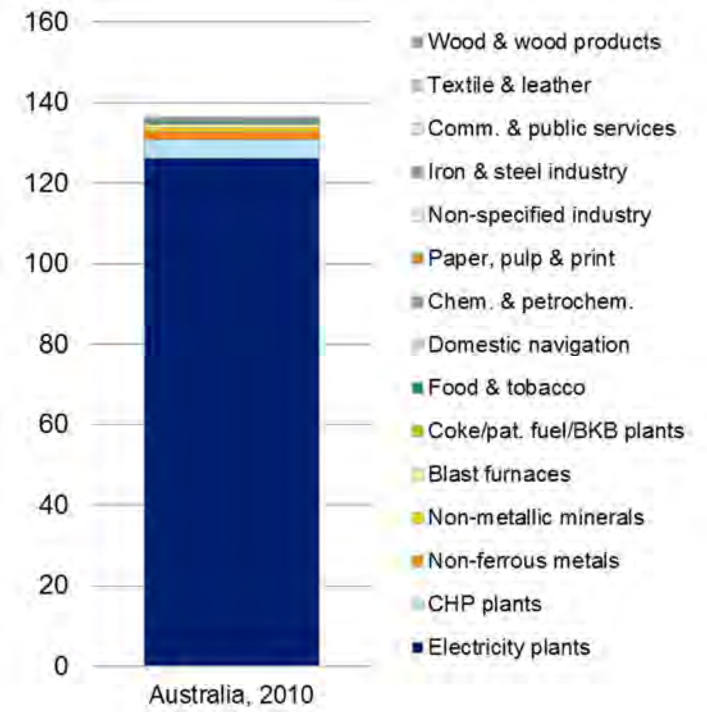


Figure 19. Consumption of thermal coal in Australia (Pöyry 2013).

There are several of coal fired power plants in South Australia and neighbouring regions that could utilise biocoal. The closest units are North of Adelaide and in the Melbourne region. However, the technical potential of the coal fired power plants out-scale the the planned production of biocoal. Much of the coal fired power capacity is located next to coal mines. Some potential end users could be small units in Whyalla Works, SA (Figure 20).

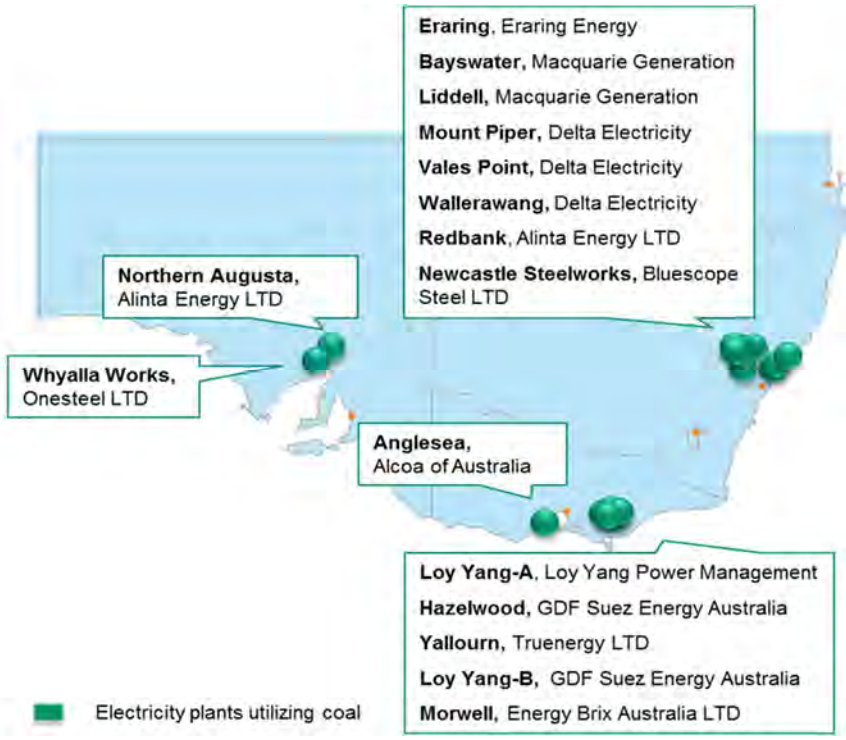


Figure 20. Potential users of biocoal in the vicinity of South Australia (Pöyry 2013).

The key points underpinning the production of both pyrolysis oil and biocoal from the perspective of Green Triangle region are the following (Pöyry 2013):

- The potential end users of pyrolysis oil and biocoal are located relatively far from the Green Triangle region
- The potential users of pyrolysis oil are located at least 500 km but most likely more than 1 000 km away from the production plant. This increases the delivery cost of fairly low energy content fuel oil that requires dedicated trucks for transport.
- Potential end users of biocoal are located 500-600 km away from Mt Gambier which increases the delivered cost. The local coal fired power plants are also partly located next to coal mines that could decrease their interest towards bio coal.
- The low taxation of fossil fuels and lack of support mechanisms for renewable fuels does not make the domestic market very attractive for fossil fuel replacement
- The export markets would require large quantities to the selected ports to enable ocean freight with large vessels to reach European and potentially Asian markets

4.3.4 Potential export markets for pyrolysis oil and biocoal

As put by Pöyry report (2013), the most important international markets for the Green Triangle bioenergy could be the Asia Pacific, especially Japan and South Korea. The field will be primarily power production. The power production will be heavily affected by emerging regulation considering renewable energy.

The export opportunities for torrefied pellets and pyrolysis oil seem quite challenging. The primary challenge is the high wood cost combined with higher personnel and sea freight costs as compared to competing regions, for example, in Far East Russia and Western Canada. There are also some cost advantages in Indonesia, Thailand or Vietnam when compared to Australia.

In the near future, as there are no support schemes for replacing heavy fuel oil with pyrolysis oils, the price levels in the Asia Pacific will be like in Australia. However, many countries in the Asia Pacific region have adopted liberal market approaches to support international bioenergy carrier trade. These include a liberalised power market, renewable energy incentives and a significant coal- and oil-fuelled power fleet.

Pöyry (2013) expects wood pellets to be the major bioenergy carrier for the short to medium term market in Asia Pacific. This is because the demand in co-firing is increasing and the commercial demonstration of solutions with multiple products, like torrefied pellets or pyrolysis oil, is becoming shorter.

Japan and South Korea are expected to become important markets in the bioenergy field, because both of the countries have implemented incentives for renewable energy generation. Also Thailand, the Philippines and Malaysia could potentially use bioenergy, but their energy demand is quite low and biomass can be sources domestically. Japan is expected to increase their pellet demand from current 0.2 million tons to 6 million tons by 2020. Also, market in South Korea is expected increase to 1.8 million tons by 2020.

Pöyry (2013) assessed that based on current cost estimation, Australian pellet or torrefied pellet production is not likelyu will not be competitive in Asia Pacific due to high wood, personnel and freight costs compared to competing region. In the case of pyrolysis oil the exportation as such will be challenging due to the more demanding transportation of low pH oil in small quantities.

4.3.5 Biomaterials

According to the definition of Frost & Sullivan's (2012a), biorenewable materials refer to the bioplastics that are biodegradable (compostable) and derived from renewable sources, and include such products as PLA, polyhydroxyalkanoates (PHAs), and starch-based polymers. An outlook on the growth of biobased materials is given in Figure 21.

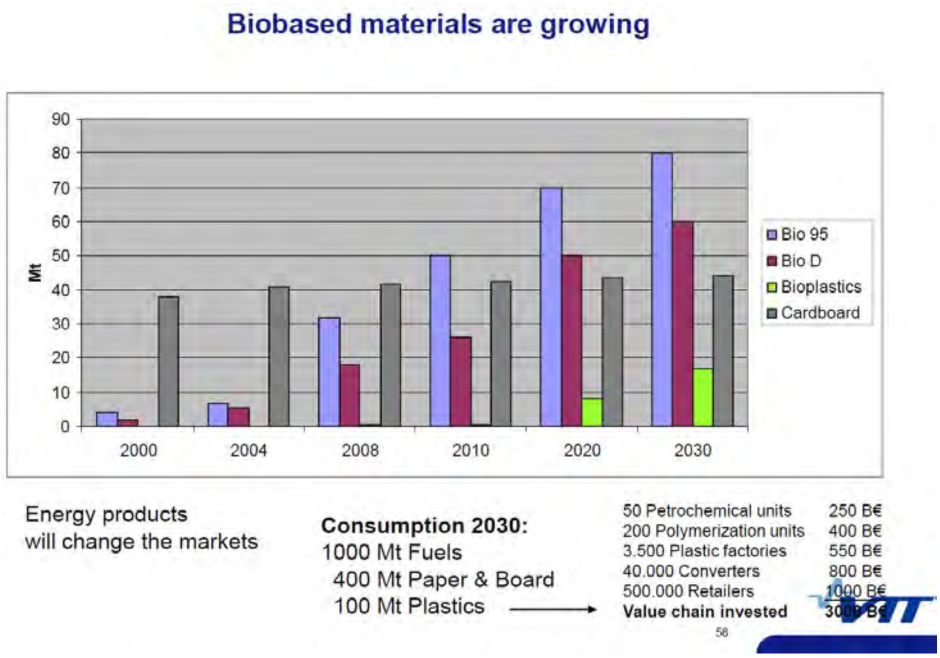


Figure 21. A view to a growth of biobased material markets (Penttilä 2010).

Key R&D players in replacing plastics with biobased materials include DuPont, BrasChem, Coca-Cola, K-Smart, Amcor, DSM/Roquettem, Danisco, PepsiCo and GoodYear.

Frost & Sullivan (2012a: 113) have made three predictions impacting the biorenewables markets:

- “Starch-based polymers are expected to dominate the bioplastics market in Asia-Pacific followed by PLA; however, PLA is expected to exhibit the highest growth rate among all bioplastics.
- Chinese manufacturers will have significant bargaining power as pilot plants become commercialised and capacity increases, which will further intensify competition and could lead to consolidation.
- Thailand and Malaysia are set to be the largest biorenewable material hubs in the Asia-Pacific rim, supported by wide availability of feedstock, favourable government mandates, and low production costs

Further views expressed by Frost & Sullivan 2012a are that bioplastics are expected to grow significantly in Asia-Pacific during 2011–2018, starch-based polymers will lead the demand for bioplastics, and that Thailand, Australia and Malaysia are expected to remain the largest markets in Asia-Pacific.

The Asia-Pacific market for biorenewable materials is still small compared to Europe and the United States, but there is high growth expectations with polylactic acid (PLA) expected to have the highest CAGR in the period 2011–2018. The key production hubs will be Thailand and Malaysia, with Australia and Singapore the main markets.

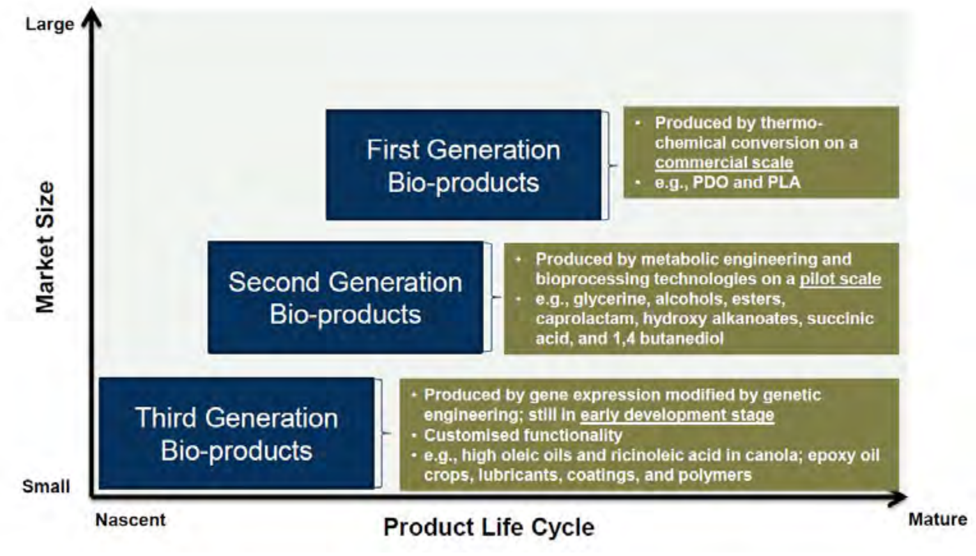


Figure 22. The evolution of technology platforms in biorenewable materials (Frost & Sullivan 2012a: 21).

According to Frost & Sullivan (2012a), there has been rising investment interests “from foreign companies to establish manufacturing units for the production of biochemicals and biomaterials” in the Asia Pacific Rim. This has been due to availability of feedstock, various government incentives, waste management and eco-labelling policies, and a low cost production environment. The key issue in the Asian Pacific operational environment is that the average price of bioplastics will reduce in the future because of increased capacity and the availability of feedstock (Frost & Sullivan 2012a: 44). Australia with its large population and Singapore are mentioned particularly as potential locations of high growth for the bioplastics market (Frost & Sullivan 2012a: 50). The top five players in the biorenewable materials market are: Natureworks LLC (PLA), Biotec (starch-based polymers), Purac (PLA monomers), Novamont (starch-based polymers) and PSM Co. Ltd (starch-based polymers). These players had 71.7% market share in the 2012, demonstrating that only a few players dominate the majority of the market.

The three market areas are starch-based polymers segment, PLA segment, and PHA segment (Frost & Sullivan 2012a).

The starch-based polymers segment is the largest of the biorenewable materials in the Asia-Pacific region. This is mainly because of packaging applications and new capacity addition. Its growth is fuelled by greenhouse gas emission reductions, good biodegradability, and good processability with regard to food packaging applications. It is also the most established bioplastic at a moderate price. The growth could be hindered by:

- competing materials,
- low heat distortion temperature,
- excess moisture absorption capacity and
- low mechanical strength.

The PLA segment is the second largest of the biorenewable materials market in the Asia-Pacific region. There are good growth expectations with Thailand and Australia forecasted to have the highest CAGR for the period 2011–2018. Basically, PLA has the same qualities enabling growth as with starch-based polymers. Growth is fuelled by new capacity additions, which will cater to the robust demand for PLA because of its good optical qualities, low price and its well-established position as a bioplastic. The key disablers are competing materials, low heat distortion temperature and sub-optimised oxygen barrier property that limits its use in carbonated drinks bottles.

PHA is the smallest of the three segments in Asia-Pacific region. Its’ advantages are good solvent-resistant properties, biodegradability features and its ability to be customised for specific applications. It also has good durability and ability to be processed. However, it has the highest price and a slow adoption rate. Thailand and Australia are forecasted to have the highest CAGR in the period 2011–2018.

In Australia, the market projection for biorenewable materials is the following (Frost & Sullivan 2012a: 96):

- 2011: Starch-based Polymers 53.6%; PLA 35.7%; PHAs 10.7%; Volume: 2.9 kT
- 2018 (forecast): Starch-based Polymers 48.0%; PLA 41.6%; PHAs 10.4%; Volume: 12.5 kT

The potential market application of biomaterials in the medium and long term is considerable. One emerging area is material light weighting in the automotive industry. Generally, the key drivers for the use of biomaterials in light weighting are low CO_2 emissions, recyclability and relative carbon neutrality (Frost & Sullivan 2013a). This aligns well with the sustainability trend of these materials. Material recyclability is of special interest in this context. The companies Faurecia, Bio Amber and Mitsubishi developed a series bioplastics in a collaborative project named BioMat to mass produced automotive interiors with a full palette range expected to rise between the years 2015–2020 (Frost & Sullivan 2013a). Another potential direction is the light weighting of car doors with biocomposites as exemplified by the “Kestrel” car produced by Motive Industries. This car weighs 2500 pounds and sells at around $25 000 (Frost & Sullivan 2013a).

Other interesting application area for biomaterials is marine composites. Frost & Sullivan (2013c) have analysed the key drivers in marine composites to be light weighting, fuel efficiency, worker safety, health legislations, and eco-friendliness. This opens up interesting application possibilities for biomaterials, such as bio-resins, natural fibre reinforcements, low-emission marine polyester/vinyl ester resins and gel-coats, tooling pastes and resins, 3D woven fabric and infusion-centric glass mats, and carbon nanotube reinforcements. Most potential biomaterials such as bio-resins enhance the recyclability and renewability of materials. Two producers in this area are EcoTek who make green resins from AOC Resins, and Envirez who manufacture bio-based polyester from Ashland. Another option for biomaterials is in natural fibre reinforcements in the boat industry for better handling and eco-aspects. An example is Biotex who makes flax fabric from composites (Frost & Sullivan 2013c: 31).

An interesting possibility is in wood plastic composites where combining fibres and resin materials could lead to novel solutions in high speed rails (Frost & Sullivan 2013d). Additionally, nanocellulose could be used for building composite structures (Spence et al. 2011).

4.3.6 Biochemicals

Key market sectors for biochemicals are food, drugs and cosmetics (Frost & Sullivan 2011b):

- Food – Biotechnological example: Biosynthesised nootkatone; Chemical transformation example: Nature-identical vitamins; Natural Extract/Derivative: Natural nootkatone; Natural Product: Gelatine
- Drugs – Biotechnological example: Biopharmaceuticals; Chemical transformation example: Codiene via morphine methylation; Natural Extract/Derivative: Galantamine; Natural Product: Nutraceuticals
- Cosmetics – Biotechnological example: Natural moisturising factors; Chemical transformation example: Surfactants from natural oils; Natural Extract/Derivative: Natural fragrance ingredients; Natural Product: Olive oil

The core market change for biochemicals is coming from the so-called “product push” in which the marketers emphasise green aspects and sustainability in the products, thus creating opportunities for biochemicals to replace petro-chemical products (Frost & Sullivan 2011b).

Frost & Sullivan (2011b) identifies four megatrends in the chemical industry that have specific relevance also for biochemicals. These are (1) low carbon economy, (2) functionality and performance, (3) health and wellness, and (4) globalisation. The general overall direction is towards sustainability. This can be achieved via two routes: by using bio-based feedstocks and emphasising “downstream sustainability” as, for example, energy efficiency in construction industry (see table 5).

Key developers in the use of lignocellulosic feedstock are Chemtex, Gevo, Purac and Genesis Research in New Zealand (Frost & Sullivan 2011b).

Biochemicals have also increasing opportunities in the transportation sector. For example, they can be used as engine coolants, antifreeze, lubricants, thermoplastics, thermoset resins for composites, tyre rubber, composites and resins, and additives for paint (Frost & Sullivan 2011b). Car producers can also use biobased chemicals in several ways: bio-based polyols for polyurethane foam in seating, and fibres for reinforcements in door liners.

Table 5. Impact of top six challenges on the bio-based chemical market in the future (Frost & Sullivan 2011b).

Challenge	1-2 years	3-5 years	6-9 years
Combating price volatility	High	High	Medium
Continuing dominance of fuel as a primary product	Medium	High	High
Overcoming end users' lack of knowledge about bio-based chemicals	High	Medium	Low
Competing against petrochemical technologies that also offer safety and environmental benefits	Medium	Medium	Medium
Competing for attention with other sustainability factors	Medium	Medium	Medium
Investment is critical to the industry's development	Low	Low	Low

Green feedstock market development could provide important information when reflecting against potential biomass residues. Frost & Sullivan (2011c) define green feedstock as follows: "green feedstocks are materials sourced from agricultural products, their wastes, or naturally occurring materials that are used as raw materials in the manufacturing of various chemicals and materials. This includes a vast range of agricultural products such as corn, soybean, sugarcane, cassava, potato, paddy, maize, and others."

According to Frost & Sullivan (2011c), the future drivers of the green feedstock market (especially in, palm oil, coconut oil, sugarcane, cassava) in South-East Asia are population growth, increasing demand for green chemicals and the drive toward towards biofuels, while the key bottlenecks are high price, a decrease in biofuel production, and competition from second generation and third generation feedstock.

4.4 Atomic lens: Nanomaterials

Nanotechnology refers to the technology that is used in developing products on a nanometer scale. Such materials are available in a wide variety of forms including nanoparticles, nanocomposites, nanotubes, nanocatalysts and nanocrystals. The total value of products using nanotechnology is expected to reach $2.9–3.2 trillion by 2015, though in the absence of labelling laws it is difficult to accurately define the size of the market (Barnett 2011).

On 18 October 2011, the European Commission adopted the following definition of a nanomaterial (Nanomaterials. European Commission. Last updated 18 October 2011):

> *"A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm. In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50% may be replaced by a threshold between 1 and 50%."*

Nanomaterials are under vigorous research and development in applied materials. While improvements may be only in basic mechanical and physical properties, added functionalities are being actively targeted. There are two types of nanomaterials; namely active and passive. Most of the materials developed are passive where nanoparticles are added to a base material enhancing the material properties such as adding nanoclay for improved barrier properties. Active nanomaterials, like quantum dots, have specific properties due their nano scale. Another example of unexpected functionality is nanocellulose, where the properties of cellulose are extended towards engineering materials and chemicals.

Nanotechnology is emerging in the packaging sector, with four main types of materials; nanoclays, carbon nanoparticles/nanotubes, nanoscale metals and oxides, and bio-based nanocomposites.

Currently, the main application of nanotechnology in packaging is in standard plastic packaging. However, coatings for fibre-based packaging (mainly board) have been one of the fastest evolving areas for nanotechnology in the packaging sector. Nanocoatings improve the barrier properties, strength and flexibility allowing paperboard to better compete with plastics. (Barnett 2011)

Barrier properties are vital in food and drinks packaging, and therefore many of the nanotechnology applications have the aim to improve barrier properties. Ultrathin coatings of metals and oxides to improve barrier protection are estimated to make up 44% of the global market for nanotechnology, although the main application sectors have been in electronics, storage, and optics. In addition, nanocomposites comprising a mixture of fillers, such as nanoclays or fibers, nanocellulose or nanosilica with polymers (bio- or petroleum-based) are being increasingly used as barrier materials (Barnett 2011).

Other active nanotechnology applications in food packaging include absorbing applications and antimicrobial materials. Currently oxygen-scavenging and moisture absorbing applications have approximately 80% market share. Antimicrobials, such as zinc oxides and silver, account for 40% of the controlled release packaging market. (Barnett 2011).

The main drivers fostering nanotechnology in packaging industry are enhanced product properties (barrier properties, strength, antimicrobial properties, etc.) and lightweighting of packaging to reduce costs and CO_2 emissions (Barnett 2011):

There are significant challenges holding back market growth including nanotechnology in packaging being considered unproven technology, consumers distrust of nano-ingredients, missing regulation specific to nanomaterials, long lead times from R&D to market and high costs (Barnett 2011)

One of the most promising nanomaterials derived from forest biomass is ***nanocellulose*** (refer Figure 23). There are three main types of nanocellulose; these being nanocrystalline cellulose (NCC), nanofibrillar cellulose (NFC) and bacterial cellulose (BC). On occasions, microcrystalline cellulose (MCC) and microfibrillated cellulose (MFC) are included in the category of nanocelluloses whose production is still at a very early stage, but it is estimated to increase sharply. Currently nanofibrillar cellulose accounts for 66% of production while the share of nanocrystalline cellulose is 34%. Bacterial cellulose has a low market share (<1%). Based on an estimate provided by FP Innovations, the market in North America will be worth $250 million by 2020 (Future markets 2012).

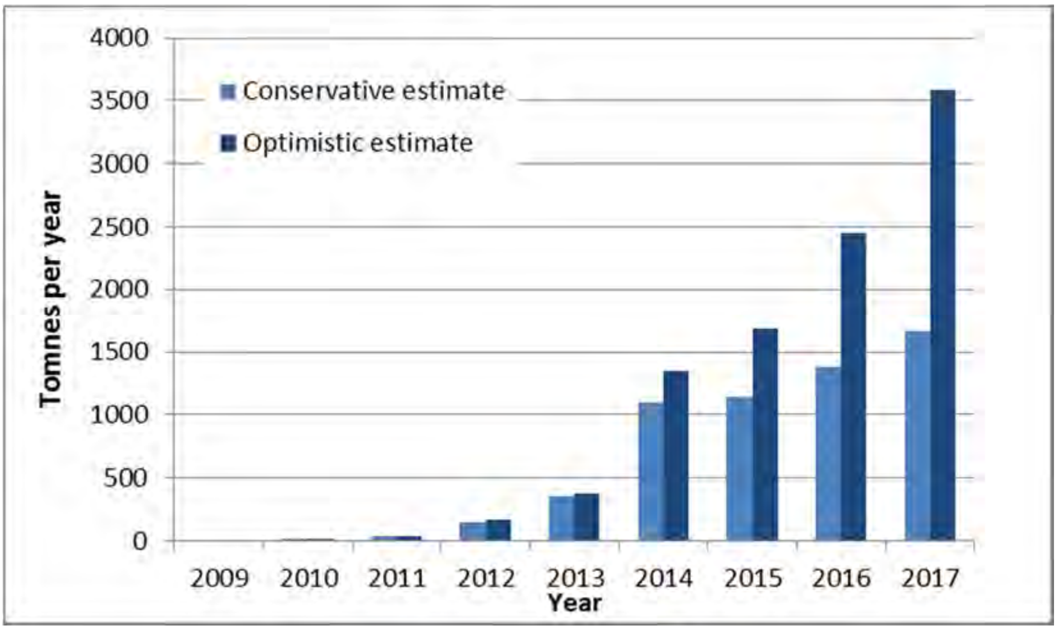


Figure 23. Nanocellulose (NCC, MFC/NFC, and BC) production volumes, forecast to 2017 (Future Markets 2012).

Nanocellulose based materials are useful in several current and potential applications; namely bio-nanocomposites (bio-based nanocomposites for example, nanocomposites from renewable nanoparticles and petroleum–derived polymers), automotive components, construction materials, paper and board, porous materials, functional surfaces and films, additives for inks, paints, and coatings, etc. (refer Figure 24). (Future Markets 2012).

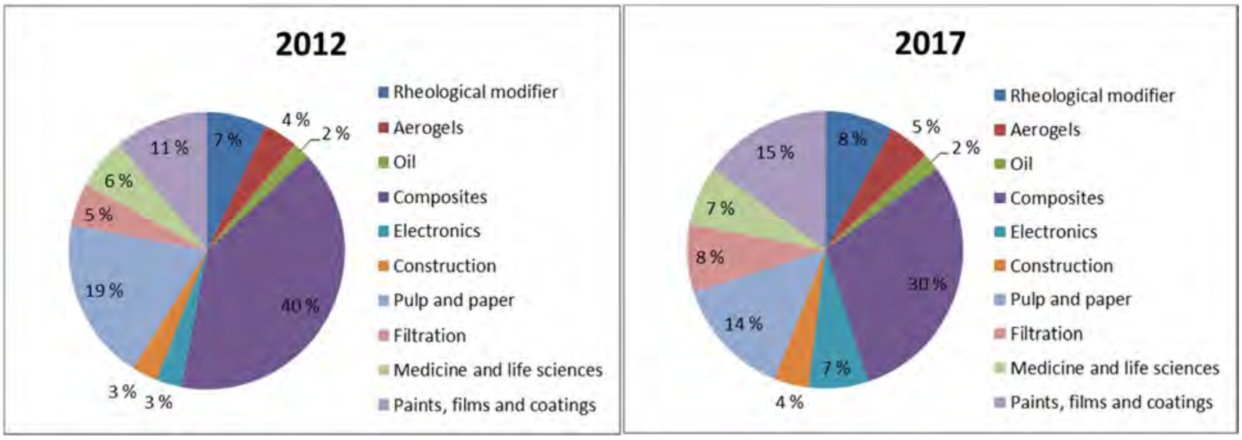


Figure 24. Demand for nanocellulose by end user segment in 2012 and estimated demand in 2017 (Future Markets 2012).

The dominant players in this market include both incumbent commercial scale nanocellulose producers (e.g. Borregaard, Nippon Paper, Stora-Enso, UPM-Kymmene, Daicel and J. Rettenmaier & Sohne, Akzo Nobel, BASF, Domtar), small and medium sized pilot scale producers (e.g. Celluforce, Bio Vision Technologies, Innventia) as well as laboratory pilot scale producers or public research organisations (e.g. US Forest Service Labs, Alberta Innovates, FP Innovations and VTT).

The growing trend for sustainability is also driving the market growth of nanocellulose as is the need for novel packaging materials with enhanced properties such as enhanced antibacterial/microbial characteristics, dimensional and thermal stabilities, strength, and improved barrier properties. Other significant drivers include the widespread availability of cellulose in nature, its renewability, biodegradability and biocompatibility, unique optical, mechanical and surface properties (high strength and modulus, and thermal stability), cost and non-toxicity (Future markets 2012)

In spite of its promising properties, the use of nanocellulose so far has been in niche applications. The main market challenges are related to production scale-up to industrial quantities, high moisture sensitivity, and high energy consumption that have hindered competition with bulk products such as plastics (Future markets 2012).

In common with other nanomaterials, there are occupational health and safety concerns with nanocellulose that are under standardization in ISO TC 229. Simultaneously, REACH Implementation Project on Nanomaterials (RIPoN) is nearing its final reporting stage (RIPON2 and RIPON3). [http://ec.europa.eu/environment/chemicals/nanotech/]. In the USA, the Food and Drug Administration (FDA) has published guidance for food and food packaging industry, which deals with the assessment of the effects of significant manufacturing process changes as well as the safety and regulatory status of food ingredients and food contact substances. In addition, Guidance for Industry on the safety of nanomaterials in cosmetic products has been published by FDA /2/. As of March 2013 both guidance are in draft form and available for commenting, but not ready for implementation. (http://www.fda.gov/ScienceResearch/SpecialTopics/Nanotechnology/ucm301093.htm; http://www.fda.gov/Cosmetics/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/ucm300886.htm).

Research needs have been made for safety, environmental performance and regulatory issues of nanofibrillated cellulose (NFC) by GLEEN in Finland. [http://www.ymparisto.fi/download.asp?contentid=139228&lan=fi]. As can be inferred by the discussion above, the OH&S aspects of producing and using nanomaterials is a subject receiving considerable attention in many jurisdictions around the world, and is likely to remain a hot topic for some time yet.

5. APPENDIX 5: Process for constructing strategic technology roadmaps

5.1 On roadmapping methodology

Our framework derives from the view that roadmapping can be considered both as a line of strategic thought and as a process methodology. There are also three crucial tenets on which our argument is based.

The first of these is the classic theory of dynamic capabilities, as defined by Teece et al. (1997). In the seminal paper they defined a ‘dynamic capability’ as: ‘the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments’ (Teece et al. 1997: 516). Extremely important is the notion that dynamic capabilities are linked to the managerial processes, strategic position and organisational path. Thus, it provides a theoretical basis for organisational transformation that connects the transition to contextual historical understanding.

The second tenet is the literature on strategic foresight. It has been suggested that in the context of strategic management, foresight contributes to different value creation forms (Rohrbeck 2012: 441). Here again in the context of innovation management, foresight can have different roles, such as the initiator, the strategist and the opponent (Rohrbeck 2012: 442). Strategic foresight can also be deployed to develop new business fields for companies (e.g. Heger & Rohrbeck 2012).

The third tenet is the organisational strategy crafting (e.g. Whittington & Cailluet 2008; Heracleous & Jacobs 2008), which argues that strategies should not be viewed as locked-in paths to some pre-determined goals, but rather as organic schemes that are always partially open and available for alternative options, multiple instruments and ‘side-schemes’.

On this basis, roadmapping can be utilised as a nexus for building a continuous and dynamic foresight practice for organisations. Roadmapping combines different modes of knowledge with specific activity layers (Kostoff & Schaller 2001, Phaal et al. 2004). Roadmaps are tools for the combination of organisational knowledge that may be ‘unlinkable’ with other strategic methods (see e.g. Petrick & Echols 2004; Phaal et al. 2006). It is possible to make a distinction between two roadmapping cultures. First is the culture of technology in which the roadmapping is approached as a normative instrument to identify relevant emerging technologies and to align them with explicit product plans and related action steps (see e.g. Phaal et al. 2001). Second is the emerging culture of strategy roadmapping which is perceived as a more dynamic and iterative process that produces weighed crystallisations, usually in a visual form, of an organisation’s long-term vision, and short- to medium-term strategies to realise this vision. This methodology is called process-based roadmapping. It is based on an idea that roadmaps are like visual narratives describing the most critical paths of future developments (Phaal & Muller 2009). This visual emphasis enables the use of roadmaps as crystallised strategy charts that open simultaneous perspectives both on macro-level currents and micro-level developments (see Blackwell et al. 2008).

Roadmapping, especially in its strategic form, is an adaptive process-based methodology well suited for systemic contexts (see Ahlqvist et al. 2012): its visual format enables the transparent formulation of visions with explicit linkages across the temporal spectrum (present, medium term, and long term) and roadmap layers (such as drivers, markets, and enabling technologies). In the systemic context, roadmapping refers to a continuous and transparent process, not a single exercise, which produces a hermetic chart of the future with a sealed vision. Therefore, the vision should be understood as a temporarily locked target that is systematically verified and re-formulated, either based on an organisation’s strategy clock or when a critical need emerges such as a change in the environment.

In the project, the policy recommendations aim towards forward-looking policy design. In our usage, policy design refers to an adaptive and experimental approach in which a selected variety of policy instruments are applied either simultaneously or successively. What these instruments are and how their sequential flow is organized depends on the characteristics of the system under policy intervention. These system characteristics are, for example: actor assemblages, enabling technologies and related infrastructures, a temporal scope of the system (e.g. what is short-term, what is long-term) and spatial scales of the system (e.g. local, regional and national). In policy design, multiple policy instruments are adapted and tested in parallel. Thus policy design aims to increase the resilience of the policy practices in the systemic contexts by allowing space for policy experimentation. In our approach, foresight has a specific role in forward-looking policy design.

5.2 The roadmapping process and workshops

Strategic technology roadmapping is a methodology that is strongly influenced by the quality of experts participating in the process. There are two basic principles in choosing the right mix of experts to take part in any roadmapping workshop.

The first principle is variety of expertise. To the extent possible the mix should include experts covering the most important technology fields foreseen as important for the topic under scrutiny. Obviously, it is not always possible to get the optimal mix of personnel at the workshop, but the process should be structured in such a way that potential gaps in the expert mix can be covered as widely as possible.

The second principle is of having sufficient experts with a future or long-term focus. This means that the review group should include sufficient technology experts with two key capabilities; namely excellent knowledge and the capability of strategic reflection on the potential direction of his/her technology branch. One needs visionaries in the roadmapping workshop that can think “outside the square” and vigorously debate alternate perspectives on the topic under scrutiny. Thus, it is not quantity that counts in roadmapping process, but rather quality and the right competent mix. The roadmapping in this project aimed at fulfilling both these two principles to the greatest extent possible.

5.3 Workshop I

Workshop 1 process

The aim of the workshop was to produce 4 roadmaps for the South Australian government and that would aid the industries in the Green Triangle region.

The roadmaps were defined as generic technology roadmaps that describe key drivers, markets, products, solutions and enabling technologies in a specific focus area (“lenses”).

Roadmap lenses

- **Mass lens**: increasing efficiency of production, modernising equipment, using better business strategies, yet focusing on the traditional end product (“basically making the same product as before, but with more modern equipment and more efficiently”)
- **Energy lens**: changing the emphasis of forest and wood products industry towards energy and fuel production through biorefineries and the use of sidestreams
- **Molecular lens**: highlights the potential of second and third generation biorefineries that could have the potential of producing specific chemicals, and even replace plastics (bioplastics)
- **Atomic lens**: emphasises the manipulation of nanoscale properties of wood fibres that open up new opportunities e.g. nanocellulose and different materials

The process applies the generic VTT roadmapping structure presented in Figure 25.

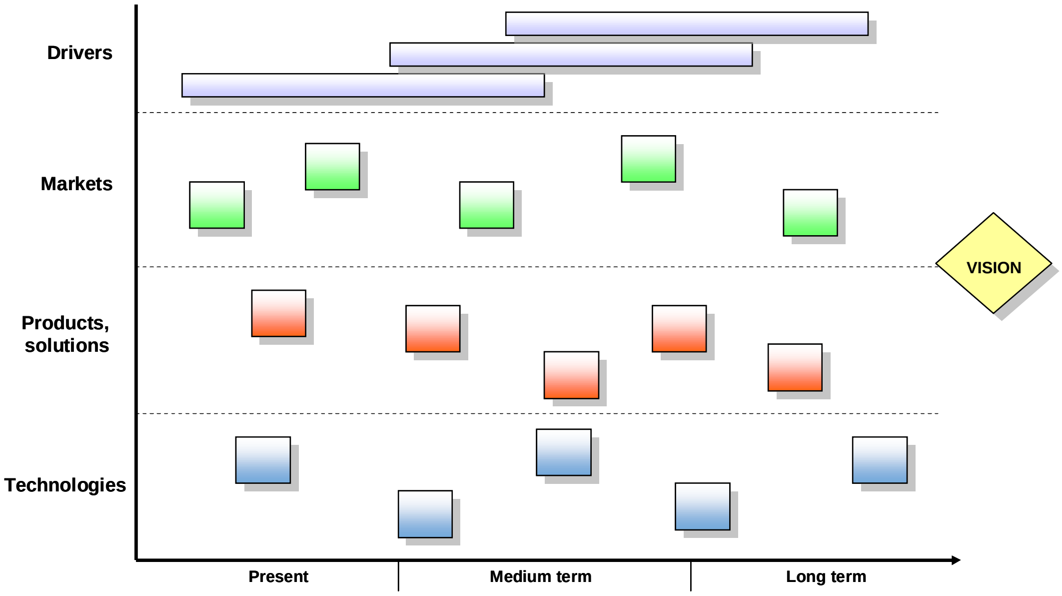


Figure 25. The generic roadmap structure utilised at VTT.

To structure the roadmapping process, four strategic developments paths were formed based on the "lenses" described in Figure 26, and detailed materials provided to the VTT experts participating in the workshops. These included information on the general drivers affecting the fibre-based industry from a 10 year perspective, collection of most important solutions and enabling technologies as identified from a literature review, and presentation of key aspects from stage 1 report.

The lenses crafted for this exercise can be summarised as follows:

- ***A mass lens*** – working title in the workshop: More efficient traditional forest and wood products industry
  - Core question: how much useful raw material can be obtained?
  - This is the lens that underpins the present traditional logging, wood chip and timber sector in Australia
  - Opportunities to add value in these industries
  - This is the lowest level of value adding and is significantly challenged and vulnerable in a high operating-cost environment
- ***An energy lens*** – working title in the workshop: Industry renewal through energy biorefinery
  - Core question: How much energy can be obtained from combusting the waste?
  - This is the lens that underpins the existing and emerging industries that focus on heat and energy generation, as well as ethanol and biodiesel production (normally via a first generation bio-refinery)
  - There are pockets of high value opportunities such as biodiesel, bioethanol and aviation fuel
- ***A molecular lens*** – working title in the workshop: Radical industry renewal through diversified second and third generation biorefineries
  - Core question: what can be made from the molecules?
  - This is the lens that shows emerging opportunities based around second and third-generation bio-refineries that have the potential to replace existing chemical production based industries
  - This could include specialty chemicals that are recyclable such as bioplastics for soft drinks bottles
- ***An atomic lens*** – working title in the workshop: Radical industry renewal through new biomass and fibre-based production
  - Core question: what nano-scale modifications can be made to create valuable outcomes?
  - This is the lens that enables the production of a wide range of new or modified materials such as biodegradable lightweight cellulose nano-crystals (CNCs) with a tensile strength exceeding that of steel
  - Cellulose foams as insulators for the construction industry, transparent paper replacing petroleum-based materials, like plastics

- This lens is high value-added and requires exceptional technological understanding and know-how

Roadmapping is a future-oriented exercise and it is helpful to assign vision statements that can act as a “future beacon”. For the purpose of the process, four generic vision statements were prepared:

- ***Vision statement for the path I***: A modern and globally competitive mechanical forest and wood products industry that provides high value added products for different industries and customers, e.g. furniture industry and construction industry.
- ***Vision statement for the path II:*** A modern biorefinery facility that produces energy and other value adding products. The biorefinery utilizes Green Triangle’s biomass, and complements the globally competitive mechanical forest and wood products industry that provides high value added products for different industries and customers.
- ***Vision statement for the path III***: A diversified second and third generation biorefinery facility that utilizes state-of-the-art technology-based solutions. The facility provides a diverse set of green chemicals, and different side-streams.
- ***Vision statement for path IV***: A novel form of biomass and fibre-based industry that produces high value added nanomaterials, packaging solutions, bioplastics chemicals. Uses a mix of first, second and third generation biorefinery technologies.

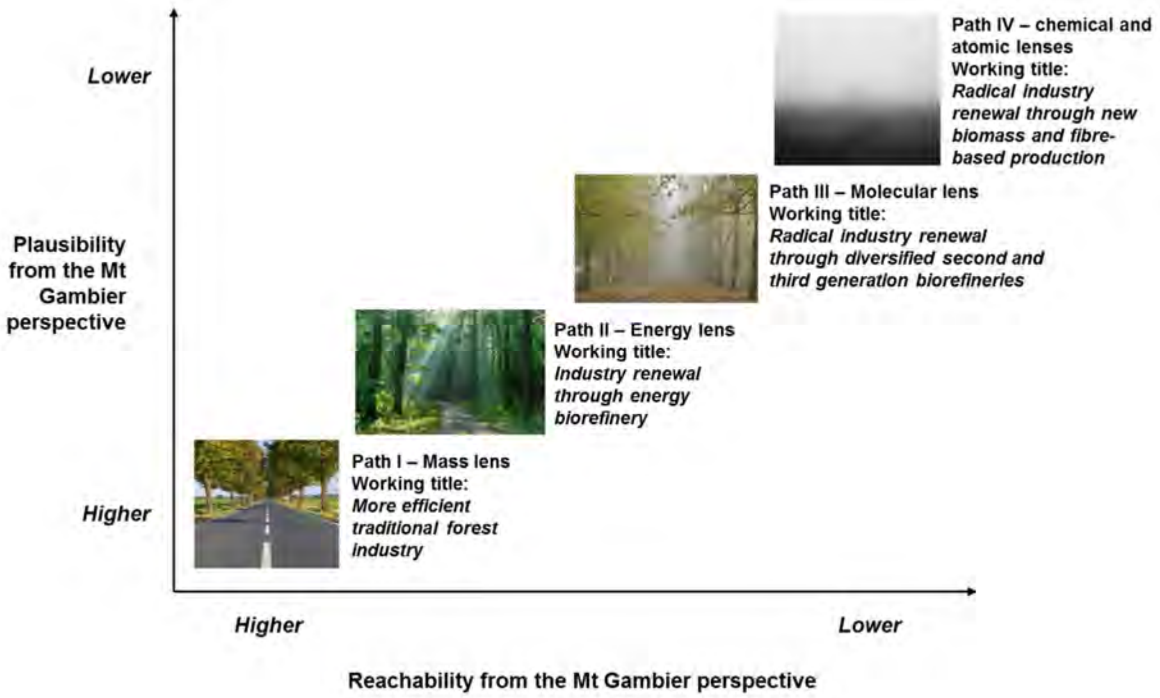


Figure 26. The strategic development paths for the Green Triangle region, and their positioning on the plausibility-reachability matrix.

The roadmapping process was realised in three phases that were structured through different facilitation methods. The experts were divided into four groups based on the strategic development paths and aimed at three goals:

1. Every expert to provide high quality input to the process
2. A satisfactory amount of information to be produced
3. Each group of experts to make collaborative strategic choices

The Figure 27 shows the modified roadmapping template that was used to collect the inputs from the experts in workshop 1.

	Topic:		
	PRESENT (state-of-the-art)	MEDIUM TERM (ca. five years, to 2018)	LONG TERM (ca. ten years, to 2023)
WHY? Drivers / Bottlenecks			
WHY? Markets and consumer needs			
WHO? Key actors Companies and organisations			
WHAT? Solutions Products, applications, services, business concepts			
HOW? Enabling technologies and materials			

Figure 27. The modified roadmapping template.

5.4 Workshop II

The first objective of workshop II was to review the roadmap templates produced in the first workshop. The second aim was to further assess the business dimensions of the technologies and solutions that were prioritised in the first workshop. The third objective was to create and assess potential policy options on the basis of the solutions and enabling technologies identified in the first workshop.

A specific definition for policy option was applied: Any kind of action or activity that policy actors can engage in to support fibre-based industry, whether it can be direct subsidies, investments to biorefineries, setting up new training programmes, endorsing global research collaboration, crafting regional strategies etc.

In the first part of the workshop, draft roadmaps of the four lenses were assessed:

- Mass lens: increasing efficiency of production, modernising equipment, using better business strategies, yet focusing on the traditional end product ("basically making the same product as before, but with more modern equipment and more efficiently")
- Energy lens: changing the emphasis of forest and wod products industry towards energy and fuel production through biorefineries and the use of sidestreams
- Molecular lens: highlights the potential of second and third generation biorefineries that could have the potential of producing specific chemicals, and even replace the plastics (bioplastics)
- Atomic lens: emphasises the manipulation of nanoscale properties of wood fibres, that could open up new opportunities such as nanocellulose and novel materials

In the second part of the workshop II, the experts split into three groups to make assessments of business potentials of the prioritised solutions and enabling technologies. The groupings were the following:

Group 1 − Revival of forest and wood products industry through proactive product, process and business development

- Emphasis on the product, process and business development with a wide focus
- Includes both traditional forest and wood products industry (e.g. sawmills, pulp) and more future-oriented aspects of the industry, such as new service concepts and biorefineries

Group 2 – Industry renewal through energy biorefinery

- Focus mainly on biorefineries through the energy lens, but can also include aspects related to biochemicals and biomaterials

Group 3 – Radical industry renewal through new biomass and fibre-based production, including diversified second and third generation biorefineries

- Focus mainly on the second and third generation biorefineries and the more radical options for the fibre-based industry

The Figure 28 presents the measurement frames used in the evaluations.

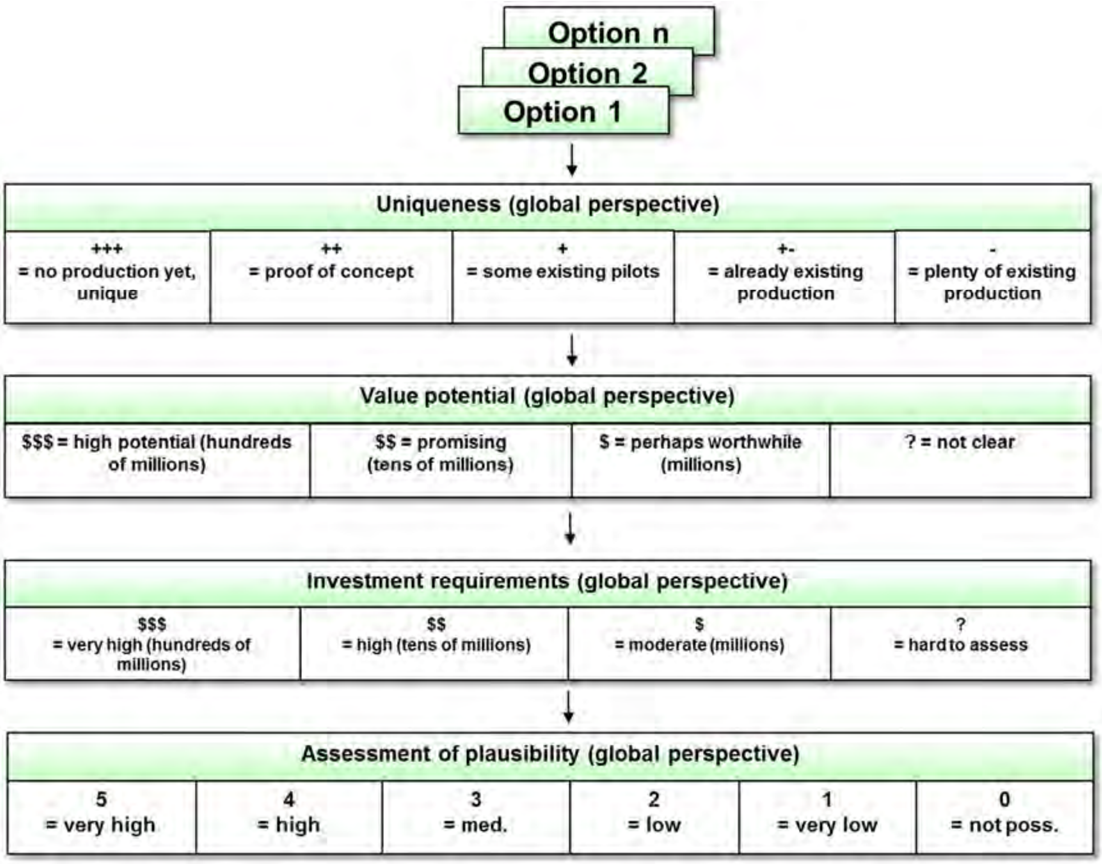


Figure 28. Assessment of business potentials: the measurement scales.

In the third aspect of the workshop, an assessment of the policy options was made using a crafting matrix shown in Figure 29.

Group:				
Option (name)	**Key actors**	**Enabling factors**	**Bottlenecks**	**Existing business cases / competitors**
1:				
2:				
3:				
4:				
5:				

Figure 29. Policy option matrix.

6. APPENDIX 6: Patent analysis of the selected technology groups

6.1 Summary

The search was carried out with a rather narrow scope of selected keywords and yielded a relatively low number of patents. The observation of few patents in the areas of bioplastics and biorefinery patents is noteworthy. Clear and expected sub-networks were formed based on Immaterial Property Classification (IPC) classes and several large networks holding the majority of inventions identified and labelled. Highlighted patents give examples of the type of immaterial property rights patented, but do not serve as an exhaustive list of content. However, the type of content is arguably captured due to the relatively low volume of patents.

Analysis of three selected companies (UPM Kymmene Oyj, Stora Enso Oyj and Borregaard Industries Limited), chosen for their leadership role in biomass processing, led to several application areas of core technologies being identified, such as cosmetics, biofuels, and agriculture. The patent study was limited to a small number of companies in order to keep the study at a practical length. The companies studied were selected based on three criteria, namely that (1) companies have patents in the first place, (2) relevant patents could be distinguished with a reasonable effort (excludes large multi-technology corporations) and that (3) the selected companies would represent different approaches in the industry.

6.2 Data

The data source for the patent analysis is EPO Worldwide Patent Statistical Database (PATSTAT). The query was limited to four topics of particular interest; namely (1) biofuels, (2) bioplastics and biomaterials, (3) biorefiney, and (4) biochemicals derived from cellulose fibre. The database query included patent searches in the United States Patent and Trademark Office (USPTO) since 2001 and for each focus item a specific query was used as listed below:

- Biofuels in total 534 patents
- Query= biofuel OR bioethanol OR biomass-to-liquids OR biomethane
- Bioplastics, biomaterials in total 40 patents
- Query = cellulose AND (bioplastic OR biomonomer OR biopolymer)
- Biochemicals from cellulose fibre in total 281 patents
- Query = cellulose AND (lignin OR bioaromatics OR terpenes)
- Biorefinery in total 8 patents
- Query = biorefinery

The topic biorefinery has been left out of any further network analysis due to the low number of patents retrieved. For the three larger queries, the patent application data, including metadata, was imported to VantagePoint 7.1 software for cleaning and manipulation of the data using R 3.0.0 statistical software and Gephi 0.8.2 beta visualization software.

The raw data was manipulated by dividing the IPC (Immaterial Property Classification) class fields into a relational structure where a patent has one or several individual IPC classes. The IPC system divides patents to eight major classes:

Section A – Human Necessities

Section B – Performing Operations; Transporting

Section C – Chemistry; Metallurgy

Section D – Textiles; Paper

Section E – Fixed Constructions

Section F – Mechanical Engineering; Lighting; Heating; Weapons; Blasting

Section G – Physics

Section H – Electricity

and subsequent subclasses that narrow down the invention, such as C12N 1/21 where the first letter C stands for chemistry major class and the following characters narrow the invention to biochemistry (12), microorganisms (N) and modified introduction to genetic material (1/21). The results are, for the reader's convenience, summarized with an assigned label. However, the IPC classes are also provided with the event the reader wishes to look up the actual class.

Subsequent analysis provides network diagrams of patent clusters based on the IPC class assigned to individual patents. The structure is further analysed by deriving sub-networks by algorithmic solutions. These sub-networks draw out any latent topics within the data. Finally, the type of immaterial property in each sub-network is highlighted showing the content of patents selected as examples.

6.3 Structure of the Immaterial Property Classifications (IPCs)

6.3.1 Biofuels

By definition, biofuel is a fuel produced from living organisms with biomass conversion. Consequently, sub-networks biofuel related immaterial property rights would be expected to focus on raw materials (biomass) or production of fuel (biomass conversion). Analysing the immaterial property classification network and the algorithm produced sub-networks, confirming this assumption. Altogether, the algorithm produced 62 sub-networks, of which five clearly dominate as seen by the data in Figure 30. These five sub-networks, further identified in Table 9, show two raw material sub-networks (coloured purple and brown) and three sub-networks focusing on the preparation of or structure of fuels.

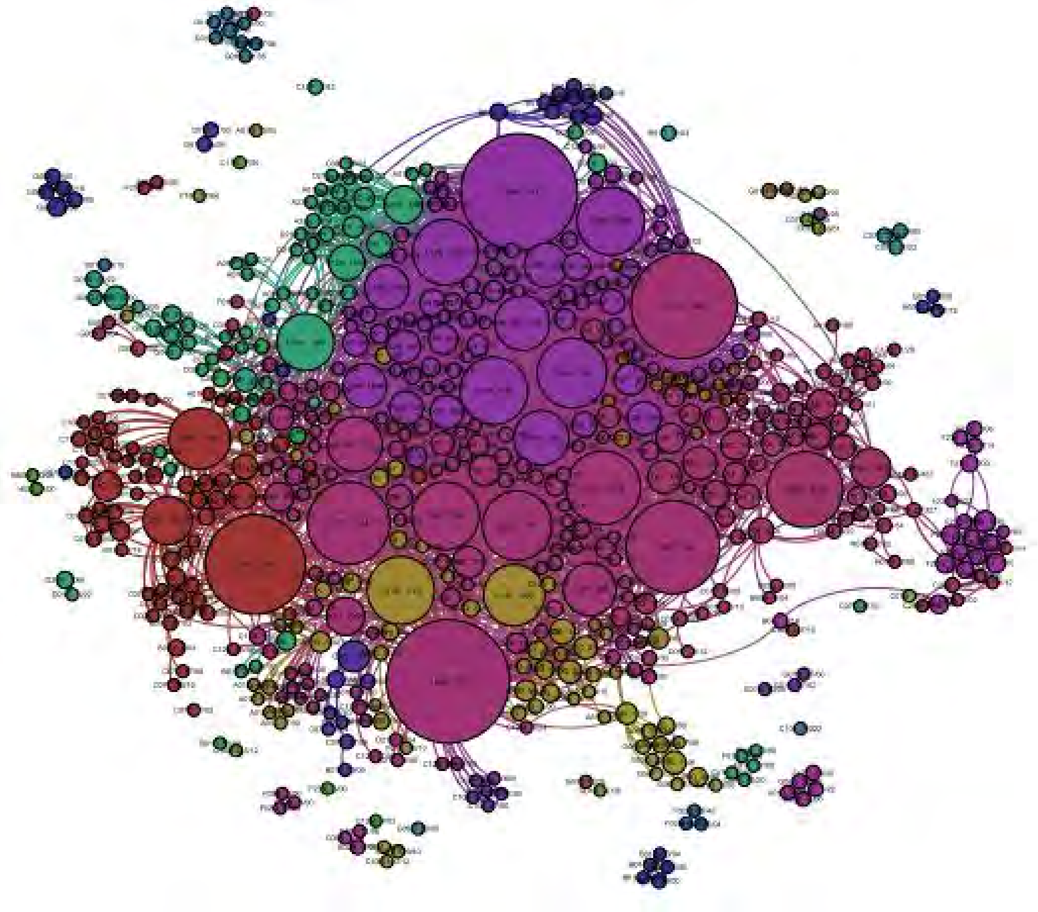


Figure 30. IPC patent network of biofuels clustered with a modularity function to 62 sub-networks.

The analysis raised a sub-network focusing on bacteria and fungi, and a sub-network focused on conventional biofuels produced by the action of micro-organisms or enzymes from sugars, starches or cellulose (lilac coloured sub-network). This suggests that the majority of immaterial property rights focus on the production of first generation biofuels. The brown sub-network, however, has IPC classes that warrant further study to uncover possible second generation biofuel immaterial property rights that appear largely algae based.

Table 6. Five major sub-networks identified by the modularity algorithm for biofuels.

Sub-network Color	Major IPC classes	Assigned label(s)
Purple	C12N 1/21; C12N 1/19; C12N 1/20; C12N 15/63; C07H 21/04	Bacteria, Fungi modified by introduction of foreign genetic material; Compounds containing two or more mononucleotide units having separate phosphate or polyphosphate groups linked by saccharide radicals of nucleoside groups
Lilac	C12P 1/00; C12P 7/06; C12P 7/64; C12M 1/00; H01M 8/16	Preparation of compounds or compositions containing Ethanol, Fats, using micro-organisms or enzymes; Biochemical fuel cells, i.e. cells in which micro-organisms function as catalysts
Red	C10L 1/18; C10L 1/19; C10L 1/02	Liquid carbonaceous fuels based on components consisting of carbon, hydrogen, and oxygen only / containing additives oxygen or esters
Green	C10L 1/00; C12N 15/82; A01H 5/00	Liquid carbonaceous fuels; genetic engineering for plant cells; Flowering plants, i.e. angiosperms
Brown	C12N 1/12; C12P 5/00	Micro-organisms, Unicellular algae; Preparation of hydrocarbons

Table 7 provides an explanation of the different patents clustered in various sub-networks. Although the sub-networks are broad, this gives an insight of the immaterial property right embedded in the biofuel immaterial property rights.

Table 7. Highlighted patents with IPC classes in the different sub-networks in Figure 30.

Sub-network	Title	Abstract	Assignee	Filing year
Purple	Fungal Endoglucanases , Their Production and Use	Novel fungal endoglucanases with substantial performance at low temperatures are disclosed. The endoglucanases are conveniently produced by recombinant technology, and means for their production are described. The endoglucanases are used for treating cellulosic material, especially in textile industry, e.g. in biofinishing or biostoning. They may also be used in detergents, in animal feed and/or in pulp and paper industry or bioethanol production.	Ab Enzymes Oy	2009
Lilac	Biomass treatment process and system	The present invention provides processes and systems for treating biomass and, e.g., making biofuels, such as bioethanol, from the biomass. More particularly, one process according to the present invention includes (a) inducing at least a first portion of a composition containing biomass and a working fluid to flow into a passage of a fluid processing apparatus, (b) injecting a high velocity transport fluid into the composition through a nozzle communicating with the passage of the fluid processing apparatus, whereby the transport fluid applies a shear force to the composition such that the working fluid is atomised and a vapour and droplet flow regime is formed downstream of the nozzle, (c) condensing the vapour and droplet flow regime, (d) transferring the composition to a first holding vessel, and (e) holding the composition in the first holding vessel at a first predetermined temperature for a first predetermined period of time, wherein a liquefaction enzyme is added to the composition prior to or during the process. Thereafter, the composition may be further processed to form a biofuel, such as, e.g., bioethanol.	Pursuit Dynamics Plc	2008
Red	Demulsifiers for mixtures of middle distillates with fuel oils of vegetable or animal origin and water	The invention provides fuel oils comprising a major proportion of a mixture of A) a middle distillate fuel oil and B) a biofuel oil, and also a minor proportion C) of an oil-soluble, crosslinked block copolymer composed of C2- to C4-alkylene oxides.	Clariant Produkte (Deutschland) Gmbh	2005

Focusing specifically on identified terms of interest, the patent dataset includes several patents of potential interest. These are embedded in the larger sub-networks illustrated before and selected based on identified key terms that could highlight significant future technologies. Three groups of patents are explicitly mentioned: 1) Fisher-Tropsch, 2) wood, forest, forestry and 3) algae, algal or cyanobacteria.

The Fisher-Tropsch process was identified in seven patents in the dataset. These are understandably process patents describing the system and method for producing transportation fuels from biomass. The relatively low number of patent included applications from UPM-Kymmene Oyj with a patent on the method and apparatus for producing biofuel from solid biomass (priority year 2007), Chevron U.S.A. Inc. with a patent on feed-tolerant biofuel production method (priority year 2007) and individuals Petri Kukkonen, Pekka Knuuttila and Pekka Jokela, previously given as the inventors and co-applicants in an UPM patent, titled “Waste Water Treatment From A Biomass-To-Liquid Process Comprising Synthesis Gas Production and Integrated Factory Facility” (priority 2007).

The number of patents that explicitly mention wood or forestry in the abstract is relatively low and 9 in total. Different publication numbers were retrieved, mostly focusing on production of biomass or pre-treatment of biomass. The patents included, for example, immaterial property rights owned by Katal I Sverige Ab on biofuel from a biomass of vegetable origin, Borregaard Industries Limited on second generation biofuels, and Aphios Corporation on the pre-treatment of cellulosic biomass.

By far the largest group (79 in total) involved algae and cyanobacteria related immaterial property rights with publication titles ranging from algae production, harvesting and processing to process and systems for production of biofuels using algae. Examples of these patents include Aquatic Energy llc patent on the materials and methods of culture production, harvesting and processing of algae (priority year 2008), Genifuel Corporations patent on "Integrated Processes and Systems for Production of Biofuels Using Algae" (priority year 2006) and Heliae Development, Llc patent on the methods and system of production of algae based biofuel.

6.3.2 Bioplastics

The volume of patents related to bioplastics altogether is relatively low, even when searched more broadly.. Extending the search to patents not published in the USPTO, raised the number of patents only slightly. This low number of patents might be the result of the narrow search algorithm, but can be viewed as identifying specific patents that are at the core of the topic. In addition, it should be noted that the data set contains several divisional applications[1]. Although all of the applications contain a new invention, the number of totally different immaterial property rights is significantly lower and closer to 20 than the 40 previously mentioned. The largest divisional applications in the set are "Gelled biopolymer based foam" by Andersen Peder O, Olav Gaserod and Rolf Myrvold with 8 patents and "Biodegradable biopolymers, method for their preparation and functional materials constituted by these biopolymers" by National Institute Of Agrobiological Sciences with 7 patents.

Using the visualization tools and the modularity algorithm, the search led to an IPC class network which is divided into two large sub-networks with a number of smaller sub-networks as illustrated in Figure 31. For the two dominating networks, the light blue network focuses on human necessities, specifically related to medical and veterinary science. The lime coloured network is more diversely divided into human necessities, operations, and chemistry. This suggests somewhat that the application specific patents are included into the light blue network, while the lime coloured includes materials technology and methods. On the other hand, the light green network is specifically focused on displays, signs and labels. These classifications are described more fully in Table 8.

Table 8. Three sub-networks identified by the modularity algorithm for bioplastics.

Sub-network Color	Major IPC classes	Assigned label(s)
Light blue	A61L 26/00; A61Q 11/00; A23L 1/00; A61Q 17/00	Chemical aspects of, or use of materials for, liquid bandages; Preparations for care of the teeth; Foods or foodstuffs; Barrier preparations
Lime	A61K 9/14; C09K 3/00; C12N 5/00; B01D 15/00 C08J 3/00	Medicinal preparations of particulate form; Undifferentiated cells; Separating processes; Processes of treating or compounding macromolecular substances
Light green	G09F 3/00; G09F 3/10; C09J 7/02	Labels, tag tickets with an adhesive layer; Adhesives in the form of films or foils on carriers

When looking at Figure 31 or Table 8, it should be noted that in the case of the light green sub-network the number of patents is extremely low, while the smaller isolate networks in the figure consist of one or two patents. Thus, Figure 51 should be interpreted with caution and the focus should be on the two larger networks.

Table 9 lists the different patents clustered in various sub-networks, focusing on those mentioned in Table 8 and indicates the difference between the two large networks. The Light blue focuses on biopolymer materials in human necessities and the Lime network focuses on materials and their production. Reverting to Table 9, the difference can also be seen in the Major IPC classes, where in the Light blue network the classes commence with A – Human Necessities and in the Lime network most of the class start with C – Chemistry; Metallurgy. The small light green sub-network clearly focuses on the application bioplastics to labels.

[1] Patent applications that contain matter from a previously filed application (so-called parent application).

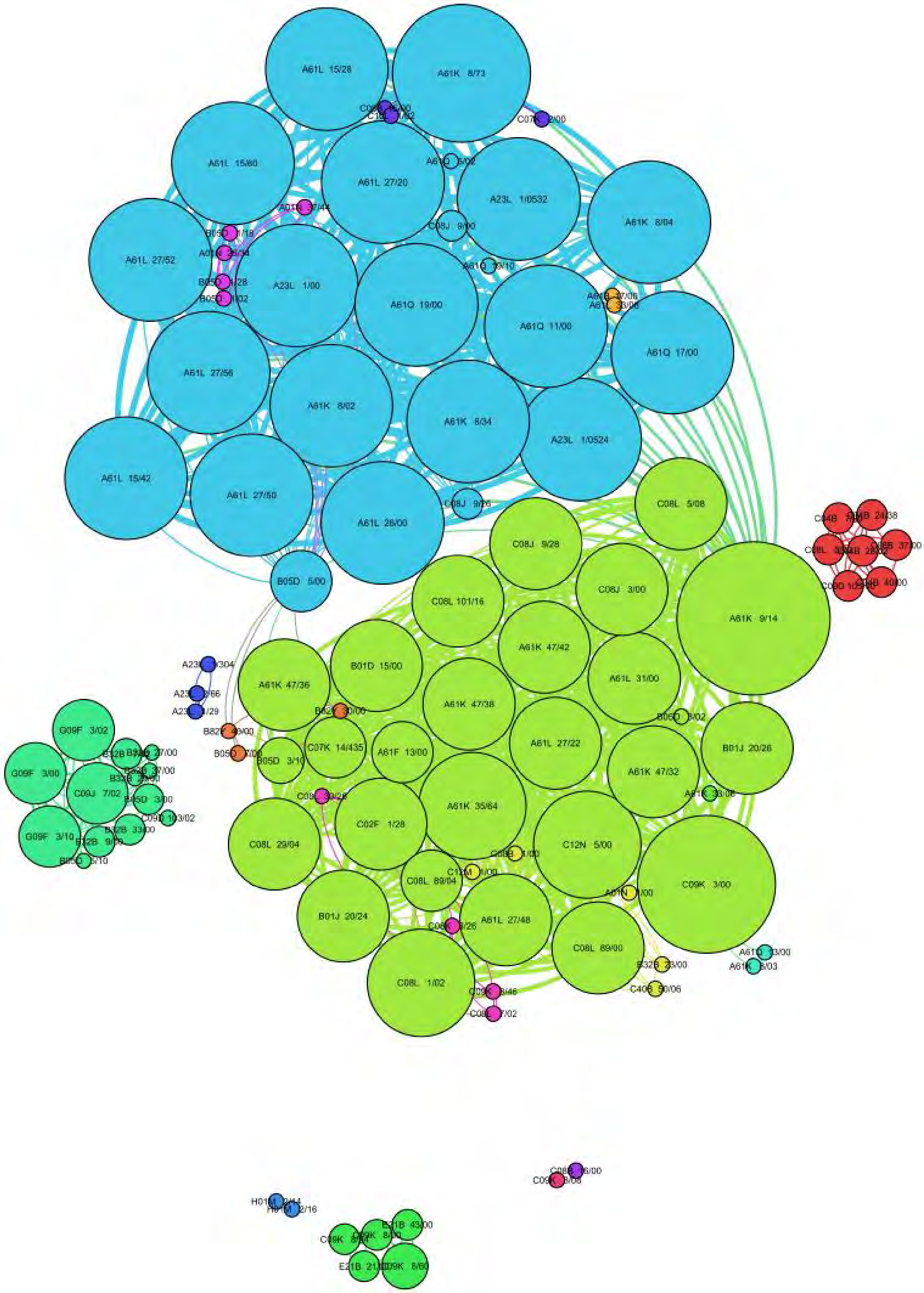


Figure 31. IPC patent network of bioplastics clustered with a modularity function to 17 sub-networks.

Table 9. Highlighted patents with IPC classes in the different sub-networks in Figure 31.

Sub-Network	Title	Abstract	Assignee	Year
Light blue	Gelled biopolymer based foam	Gelled biopolymer based foams are disclosed. The gelled foams comprise a cross-linked biopolymer, preferably alginate; optionally, a foaming agent such as hydroxy propyl methyl cellulose; and a plasticizer, preferably glycerin sorbitol, or a mixture thereof, that forms the predominant portion of the gelled foam. The foams are soft and pliable and have high absorbency. They are used as wound dressing materials, controlled release delivery systems, cell culture, barrier media for preventing tissue adherence, and bioabsorbable implants. They also have various personal care applications, especially in oral hygiene, and can be used in food applications.	Fmc Biopolymer As	2006
Lime	Biodegradable biopolymers, method for their preparation and functional materials constituted by these biopolymers	A biodegradable biopolymer material consists of silk fibroin from domesticated silkworm; silk fibroin from wild silkworm; a composite material comprising silk fibroin from domesticated silkworm and silk fibroin from wild silkworm; or a composite material comprising either silk fibroin from domesticated silkworm or silk fibroin from wild silkworm and at least one secondary substance selected from the group consisting of cellulose, chitin, chitosan, chitosan derivatives, keratin from wool and polyvinyl alcohol. The material may be prepared by, for instance, casting an aqueous solution of domesticated silkworm silk fibroin on the surface of a substrate and then cast drying the applied solution. The biodegradable biopolymer material is effectively used as, for instance, a metal ion-adsorbing material, a sustained release substrate for a useful substance such as a medicine, a biological cell-growth substrate and a biodegradable water-absorbing material.	National Institute Of Agrobiological Sciences	2010
Light green	Labels	Labels (preferably cellulose (e.g. regenerated cellulose), Labels (preferably cellulose (e.g. regenerated cellulose), cellulose acetate and/or PLA) said sheet being substantially transparent to visible light when uncoated characterised in that the sheet comprises) said sheet being substantially transparent to visible light when uncoated characterised in that the sheet comprises: (a) a first coating on at least one surface thereof to aid printability thereon; (b) a second coating comprising an adhesive dispersible in an aqueous medium; and (c) optionally a third coating to modify water permeability through the sheet. The labels are to be applied to articles such as glass containers. Preferred labels are wet glue cellulose labels for example where the first coating also comprises a copolymer of vinyl chloride and vinyl acetate to aid water permeability and hence rapid drying of the label on an article.	Ucb, S.A.	2004

The dataset on applications, selected from the whole data set, includes several patents of potential interest. Pohl et al. have patented the structure of “Antimicrobial films, sponges and sponge cloths” based on biopolymers specifically cellulose and/or protein or uncoated or coated textile material. Another interesting application is the biopolymer based, specifically cellulose ester, telecommunication cable patented by Nexans. Cellulose based biopolymers also have application in the medical field as seen from the patent by Sofradim Production titled “Medical implant including a 3D mesh of oxidized cellulose and a collagen sponge”, wherein the 3D mesh is based on microbial cellulose.

6.3.3 Biochemicals from cellulose fibre

Immaterial property rights for biochemicals made from cellulose fibre were searched by coupling the term cellulose and with one of the following; lignin, bioaromatics or terpenes appearing in the patent abstract. This resulted in a total of 281 hits.

Using the Gephi visualisation tool and the modularity algorithm, the patent IPC classes were divided into a network with sub-networks that totalled 47 in number and included three significant nodes (IPC classes). These sub-networks can be visually seen in Figure 32 as purple, lilac and brown circles.

Looking more closely at the content of the sub-networks, the purple and lilac network consists mostly of IPC classes under the general category of chemistry. The significant difference in the sub-networks is that the lilac network has large nodes under the heading “organic macromolecular compounds”, while the purple network focuses specifically on biochemistry and particularly on micro-organisms or enzymes and fermentation. The brown network, on the other hand, focuses on the major category of textiles and paper, and specifically on the “production of cellulose by removing non-cellulose substances from cellulose”.

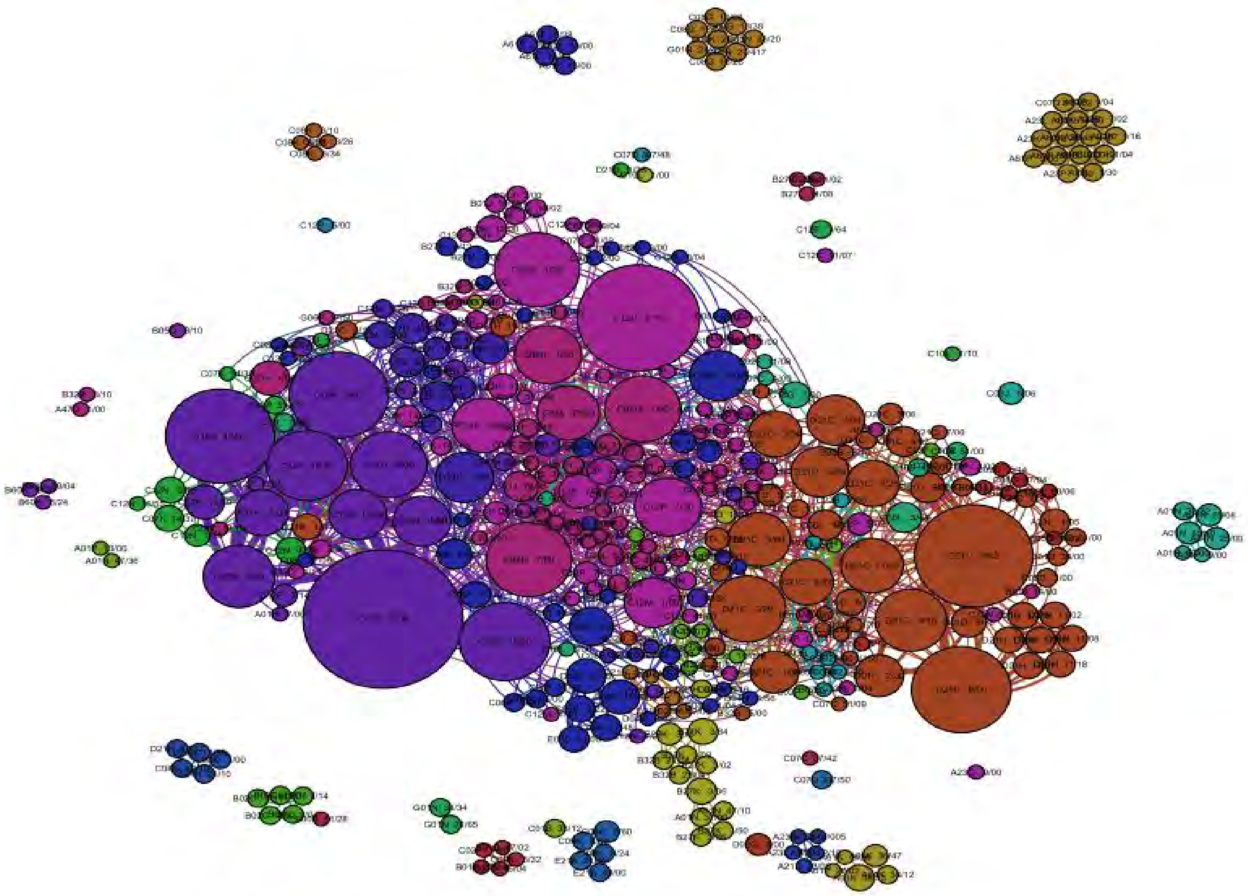


Figure 32. IPC patent network cellulose and lignine clustered with a modularity function to 47 sub-networks.

Table 10. Three major sub-networks identified by the modularity algorithm for Cellulose (lignine).

Sub-network Color	Major IPC classes	Assigned label(s)
Purple	C12P 7/06; C12N 15/82; C12N 9/42; C12P 19/00	Preparation of compounds containing saccharide radicals; Preparation of oxygen-containing organic compounds containing ethanol; Enzymes, hydrolases acting on beta-1, 4-glucosidic bonds, e.g. cellulase
Lilac	C12P 7/10; C08H 7/00; C08L 97/00; C08B 1/00; C12P 1/00	Preparatory treatment of cellulose for making derivatives; Preparation of compounds or compositions using micro-organisms or enzymes; Compositions of lignin; Preparation of oxygen-containing organic compounds
Brown	D21C 3/02; D21C 9/00; D21C 3/20	Pulping cellulose-containing materials with inorganic bases or alkaline reacting compounds, e.g. sulfate processes and organic solvents; After-treatment of cellulose pulp

The patents listed in Table 11 demonstrate the content of the sub-networks. In the purple network, the patent entitled “Transgenic plants containing ligninase and cellulase which degrade lignin and cellulose to fermentable sugars” has the focus of reducing the cost by taking advantage of cellulose in the production of fermentable sugars. The inventors specifically refer to the unused potential of “leaves and stalks” in energy production, which would be greatly helped with the development of transgenic plants.

Table 11. Highlighted patents with IPC classes in the different sub-networks in Figure 33.

Sub-network	Title	Abstract	Assignee	Filing Year
Purple	Transgenic plants containing ligninase and cellulase which degrade lignin and cellulose to fermentable sugars	The present invention provides transgenic plants which after harvest degrade the lignin and cellulose therein to fermentable sugars which can further be fermented to ethanol or other products. In particular, the transgenic plants comprise ligninase and cellulase genes from microbes operably linked to a DNA encoding a signal peptide which targets the fusion polypeptide produced therefrom to an organelle of the plant, in particular the chloroplasts. When the transgenic plants are harvested, the plants are ground to release the ligninase and cellulase which then degrade the lignin and cellulose of the transgenic plants to produce the fermentable sugars.	Board Of Trustees Of Michigan State University	2007
Lilac	Processes for Producing Fermentation Products	The present invention provides a process of producing a fermentation product comprises the steps of i) pre-treating lignocellulosic material to release or separate cellulose, hemi-cellulose and/or lignin, ii) subjecting the pre-treated material to a cellulase, iii) fermenting in the presence of a fermenting organism, wherein xylose isomerase is added in step ii) and/or step iii).	Guillerma Coward-Kelly, Keith Alan Mccall, Novozymes North America, Inc, Mads Peter Torry Smith	2006
Brown	Method of making a modified unbleached pulp for lyocell products	In accordance with the present invention, lyocell products can be made with unbleached pulps resulting in products with high amounts of hemicellulose and high amounts of lignin as compared to conventional lyocell products. The lyocell products of the present invention are advantageously less expensive to produce but retain the desirable strength of conventional lyocell products.	Weyerhaeuser Company	2003

The patent in the lilac sub-network, focusing on the biomass, is concerned with a process “…producing a fermentation product, especially ethanol, from lignocellulosic material”. The intention of the inventors is to improve the possibilities for producing fermentation products from lignocellulosic material. The example in the brown sub-network does not focus on biomass and energy production, but rather the production of Lyocell, a regenerated cellulose fibre made from bleached wood pulp, and used everyday in fabrics. The patent presents a method for reducing the production cost of the material.

Although not an exhaustive list, the examples above show the variability of the patents found in the search. Of the 281 patents, 77 have a reference to biomass and 42 reference ethanol which, to some extent, gives an indication of patents with energy focus. When viewed from possible end-use applications, the IPC classes that belong to the major class A (Human necessities) focus on agriculture (A01), baking (A21), foods or foodstuff (A23), furniture and domestic appliances (A47) and medical or veterinary science (A61).

6.4 Data for company based search

The company based search has been carried out from the online terminal of the European Patent Office. The query was limited to three companies of interest UPM Kymmene Oyj, Stora Enso Oyj and Borregaard. The database query included patents applied for in any of over 80 countries that are signatories to the European Patent Office database. The queries were carried out with the assignee field including the name of the company; UPM in the case of UPM Kymmene Oyj, Storaenso or Stora Enso in the case of Stora Enso Oyj and Borregaard in the case of Borregaard.

The patent application data for the three companies, including metadata, was imported to VantagePoint 7.1 software for cleaning and manipulated data further analysed using R 3.0.0 statistical software, Excel, Notepad++ and Gephi 0.8.2 beta visualization software.

The raw data was manipulated with the following processes prior to analysis: (1) merging and cleaning the downloaded csv-files prior to importation into VantagePoint, (2) dividing the IPC classes fields to relational structure where a patent has one or several individual IPC classes, (3) extracting the assignee from the data and (4) merging assignee names that have been misspelled, inclusion of special characters, varying the use of small and large capitals in names or by correcting assignees that clearly are the same entity to one unique identifier. The thesaurus used is not perfect, but improves the quality of the results significantly. The thesaurus can be provided for evaluation if of interest to the reader.

The subsequent analysis provides network diagrams of patent clusters based on the IPC class given to individual patents. The structure is further analysed by deriving sub-networks by algorithmic solutions. These sub-networks draw out any latent topics within the data. Finally, we highlight the type of immaterial property in each sub-network by showing the content of patents selected as examples.

6.5 Structure of companies and Immaterial Property Classifications (IPCs)

In total, the dataset contains 1057 records, of which 542 include the company name UPM, 442 Stora Enso and 26 Borregaard. UPM and Stora Enso have 17 common records, but Borregaard does not have patents in common with either of the other two. As seen from the data in Figure 33, the network is largely divided into two by UPM and Stora Enso, which suggest that the two companies have different sub-network structures. Although the two companies have several shared IPC categories, the companies' sub-network structure has significant differences. The majority of the patents included in the whole dataset of 1057 records belong to classes such as “Containers for storage”, “Layered products” and “Pulp compositions”, which is an indication that the majority of the immaterial property rights belong to the “mainstream” of the industry.

A careful look at the data shows a sub-network containing biomass and biofuel related patents as indicated in Figure 33 by the red highlighted area. This network is fairly small with both UPM and Stora Enso having links to the network; although the majority of biomass and biofuel related patents are assigned to UPM. These patents included, for example “Method and apparatus for producing liquid biofuel from solid biomass”, “Integrated biorefinery plant for the production of biofuel”, and “A method and a system for producing liquid fuel from biomass”, which have all been patented by UPM or its subsidiaries. In the same network, under IPC classes C07J53/00 and C07J63/00, Stora Enso has patented “a method for preparation of betulinic acid from betulin”. This patent suggests that the “Suitability of betulin and the derivatives thereof for medical and cosmetic applications and for industrial chemical applications”is known to some extent. Use of betulinic acid in cosmetic applications as a promoter of growth and as components in skin creams is known. Although, not related to biofuels, this shows an interesting application of bark.

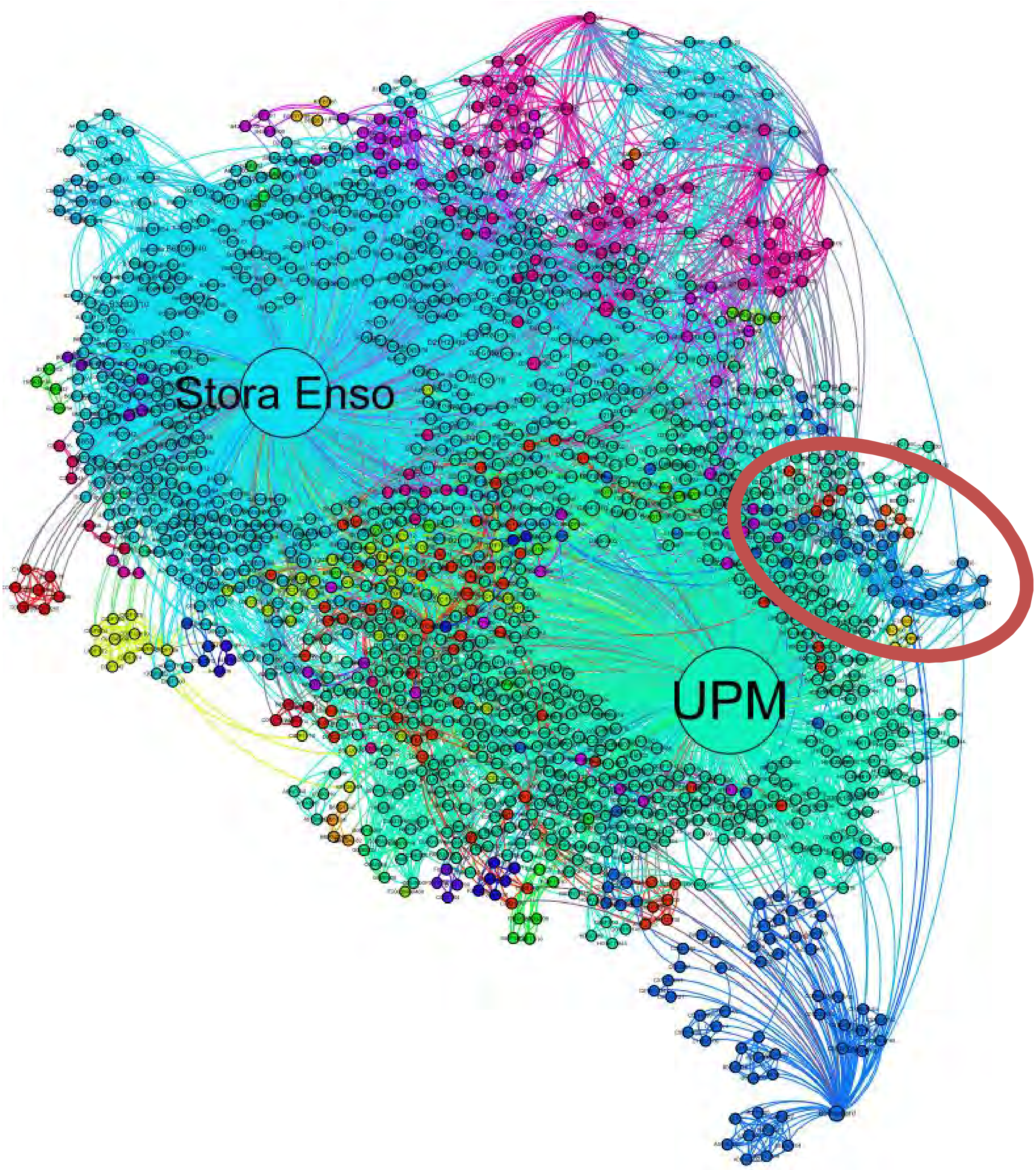


Figure 33. Company and IPC classification network. Highlighted in red is a patent sub-network containing classes including biofuel and biomass patents.

Borregaard has a different and distinct patent profile in comparison with UPM and Stora Enso. The company states that it "…produces advanced and environmentally friendly biochemicals, biomaterials and bioethanol that can replace oil-based products. Borregaard also holds strong positions in ingredients and fine chemicals, as reflected by a portfolio of 26 patents. The patents include titles such as "Lignocellulosic biomass conversion", "Method for producing microfibrillated cellulose" and "Enzymatic hydrolysis of cellulose". These patents do not include those from the previous owners ORKLA ASA, which may have been assigned to Borregaard.

As seen from the data in Figure 34, the Borregaard patent portfolio consists of three sub-networks, the most significant of which is the dark blue network. The majority of IPC classes are under C07 "inorganic chemistry", and C08 "organic macromolecular compounds". In addition, Borregaard has immaterial property rights under human necessities A23 "Foods or foodstuffs".

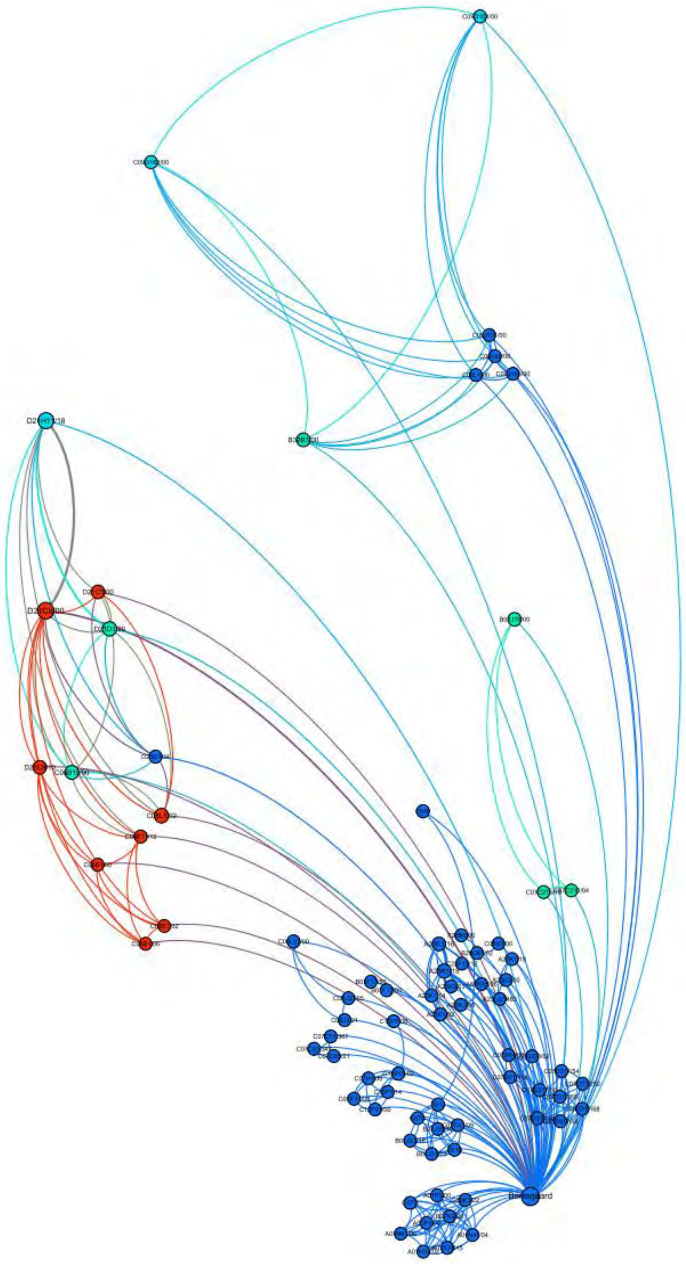


Figure 34. Borregaard and IPC classification network.

Under the category of human necessities class, there are a number of application oriented patents including "growth enhancers" for pigs, "sacrificial antioxidants" that "concerns the use of lignosulfonates as a sacrificial agent in combination with other antioxidants" and "Use of a composition comprising acid and lingo-sulphonate for addition to litter" that "…reduces the amount of unfavourable bacteria and mould in the litter".

From the data it would appear that Borregaard has two different immaterial property rights, one clearly on core technology development and the other on application of the core technologies developed by the company, although it needs to be stated that the interpretation is based on a relatively low number of total patents at 26.

7. APPENDIX 7: Business cases and techno-economic evaluations

This section outlines three business case and techno-economic evaluations. The first (section 11.1) evaluates options in the mass lens for sawmills of capacities ranging in size from small to moderate, the second (section 11.2) presents evaluations for different energy biorefinery concepts and the third (section 11.3) a number of specific bioenergy options based on an evaluation carried out by Pöyry as a subcontract

7.1 Mass lens

The view through the mass lens shows the possibilities for increasing the efficiency of current production through equipment modernisation, and the better use of business strategies.

To help visualise this, three scale options for Scandinavian sawmills and their associated costs are shown in Table 12. The process units considered for each option include; log yard and material intake, log sorting, sawmill intake including debarking, sawmill lines, green sorting and stacking, kiln driers, final sorting and packaging, further processing (for example glue-lam factory, planning line, etc.), storages and shipping, and power plant and offices.

Table 12. Sawmill scenarios: two 'regular' sawmills and a new small log sawmill (Kivimaa 2013).

	Sawmill 1 **Log length 3 - 6 m** **Diameter > 15 cm**	**Sawmill 2** **Log length 3 - 6 m** **Diameter > 15 cm**	**New small log sawmill** **Log length 3 m** **Diameter 8 – 17 cm**
Description	Small Scandinavian sawmill 1	Average Scandinavian sawmill 2	New small log sawmill
Input	Radiata logs: 200,000 m^3 per annum	Radiata logs: 600,000 m^3 per annum	Radiata logs: 320,000 m^3 per annum
Output	Timber: 100,000 m^3 Sawdust: 20,000 m^3 Chips: 80,000 m^3	Timber: 300,000 m^3 Sawdust: 60,000 m^3 Chips: 240,000 m^3	Timber: 120,000 m^3 Sawdust: 15,000 m^3 Chips: 185,000 m^3
Greenfield investment	25 million + power plant 2million € Staff 40 + office	50-55 million € Staff ca. 100 + office	18-20 million € Staff ca. 20 + office

Sawmills in Finland are characterised by approximately 28–30 million m^3 per annum of timber being processed of which roughly 60% is spruce and 40% pine. Products are being increasingly exported to China largely because of Canada's diminishing ability to supply timber as a result of its mountain pine beetle infestation. The importance of Japan as an export market is increasing, while India shows promise as an export market from a longer term perspective. Capital rotation is of the order of 1.5–2 months.

The operation of the sawmill can be expanded in some cases to an energy biorefinery concept by adding to the sawmill line a "biorefinery" producing bio-oil and a power plant utilising the available chips and/or bark as shown in Table 13.

Table 13. The energy biorefinery scenario (Kivimaa & Karlsson 2013).

	Biorefinery	Power plant that uses bark*
Input	Chips: 400,000 m^3	Bark: 90,000 m^3
Output	Pyrolysis oil: 100,000 tons	Energy
Greenfield investment	50 million € (semi-final bio oil, pyrolysis oil; needs to be refined in a big refinery if target product is diesel)	4-5 million € + (12–15 MW)

* Depending on the set-up of biorefinery, it could be possible to partly use the excess heat of the drying processes instead of building a separate power plant

Thus, sawmills can become the backbone of the bioeconomy by securing the raw material supply and integrating it into an existing sawmill network. The energy biorefinery could form the platform of a future profitable business for private sawmills by making total use of forest biomass to generate maximum profit so as to strengthen the local economy. Ideally, it should be located near the source of the raw-material, possibly utilising an existing site, thus minimising process and logistical costs.

In order to be successful the backing of all stakeholders will be needed, be they private large and medium-sized sawmills, forest owners, timber harvesting and logistics developers (”able to provide the whole stem to sawmill site”), biochemical value chain producers and customers, energy business operators and equipment engineering companies.

The key success factor for implementation is that the basic sawmill operation would be supported by a new business of value added products, but several sawmills would need to combine their efforts to ensure adequate volume, while the forest owners would also need to be involved. The novelty of the bio sawmill business model is found in the use and availability of renewable biofuel and the better utilization of total forest resource such that the most valuable parts of wood is not used for energy or bio products but for the sawn timber for construction.

In 2013, the Finnish sawmiller’s trade journal Puumies reported that the Finnish company Veisto delivered the most modern sawmill in Australia to Bombala, New South Wales, 2013 (Varis 2013). The concept of running the saw is new and the saw system uses mainly unsorted radiata timber as the feed wood. System flexibility allows the production of all timber dimensions currently used in Australia, mainly timber for frameworks and coatings to be used by construction industry and basic round logs. The process line allows optimisation of wood for different uses. The sawing line at 150 metres of sawn timber per minute is exceptionally fast. Modern technologies are also utilised in machine-tooling kit, in which different parts of machine are marked with RFID (radio frequency identification) tags. The productivity of this “state-of-the-art” mill will be higher than the largest corresponding operation in the Green Triangle. The exact figures can be given only after the first full year of operation, but it can be assessed that the productivity of this saw will be about 10% higher (taking into account labour, energy and maintenance costs) compared to the regular sawmill technology used in Australia today.

7.2 Energy lens: evaluation of energy biorefinery concepts

7.2.1 Overall business case evaluation procedure

The procedure to select business cases for evaluation was done in three steps:

Step 1: Alternative strategies for industry renewal were identified in the roadmapping process using the four lens approach

Step 2: The strategies from the mass and energy lenses were selected for conceptual economic analysis based on the capability of the strategies to answer the current challenges for enhancing the economics of the core business through efficiency increases and additional energy products from available resources. The analysis is done using a combination of information available in the public domain and from in-house VTT expertise

Step 3: A number of the promising strategies were selected for more detailed assessment encompassing specific evaluation of the process and product feasibility

This section covers a techno-economic assessment of twelve selected energy-biorefinery routes at a conceptual level. Some of those are at early stages of development whereas others are ready for implementation. The performances and costs of the selected routes were evaluated based on efficiency assumptions for similar process concepts and price information available in the public domain. Thus, the results only illustrate general performance of the options without taking into account any site specific opportunities or constraints such as access to additional low cost raw material, process integration or local bioenergy carrier markets. Moreover, feedstock comparison has not been conducted and therefore product yield and quality differences between feedstocks not considered. The evaluated routes are summarised in Table 14.

Table 14. Summary of energy biorefinery routes.

Route	Time to market	Feedstock#	Scale *	Yield (main product)+	Main Product^	End-use
Bio CHP	Present	Forest residues, sawmill residues, HW, SW	small	20% (HHV basis)	Electricity, heat	Sawmill electricity and heat (drying), grid
Extended Bio CHP	Medium / long term	Forest residues, sawmill residues, HW, SW	small	20% (HHV basis)	Electricity, heat, ethanol	Sawmill electricity and heat (drying), grid, transportation fuel
Hydrolysis I	Present	HW, HW forest residues, HW sawmill residues	large	24% (mass basis)	Ethanol	Transportation fuel
Hydrolysis II	Medium/long term	Forest residues, sawmill residues, HW, SW	large	32% (mass basis)	Ethanol, lignin	Transportation fuel, lignin markets
Pyrolysis	Present	Forest residues, sawmill residues, HW, SW	small/large	65% (mass basis)	Bio-oil, char	Boiler fuel
Pyrolysis with oil upgrading	Medium/long term	Forest residues, sawmill residues, HW, SW	small	32% (mass basis)	Upgraded bio-oil (diesel, naphtha), char	Transportation fuel, boiler fuels
Small scale gasification	Present	Forest residues, sawdust, bark, HW, SW	very small (15% of sawmill residues)	24% (HHV basis)	Electricity	Sawmill electricity and grid
Gasification with FTL synthesis	Medium term	Forest residues, sawdust, bark, HW, SW	large	18% (mass basis)	FT-diesel	Transportation fuel
Gasification with SNG production	Medium term	Forest residues, sawdust, bark, HW, SW	large	60% (HHV basis)	SNG	Natural gas replacement (pipeline)
Pelleting	Present	Forest residues, sawdust, bark, HW, SW	small	97% (LHV basis, excl. drying)	Pellets	Boiler fuel, residential heating, export
Torrefaction with pelleting	Present	Chips (HW, SW, Forest biomass or sawmill chips)	small	77% (mass basis)	Torrefied pellets	Coal replacement in power plants
Hot water extraction prior to pelleting	Medium/long term	Forest residues, sawdust, bark, HW, SW	small	78% (LHV basis, excl. heat generation)	Pellets, ethanol	Boiler fuel, residential heating, export, transportation fuel

Notes:
Hardwood (HW), softwood (SW)
* Small 200,000 tonnes per annum (tpa), large 500,000 tpa, 50% DC
+ Higher heating value (HHV), lower heating value (LHV)
^ Main product is underlined

7.2.2 Description of the evaluated routes

In this section all routes are described using block-flow diagrams and the key process parameters such as product yields, consumption of energy and other raw materials listed.

Feedstock and product properties used in the calculations are shown in Table 15.

Table 15. General assumptions used in conversions between volume, mass and energy units.

Feedstock • dry matter content • dry content • LHV (lower heating value) • HHV (higher heating value)	380 kg/m3s 50% 8,2 MJ/kg 19 MJ/kg	Average values used for all types and grades of feedstock
Liquid fuels (HHV) • Ethanol • pyrolysis oil (bio-oil) • Upgraded pyrolysis oil • Fischer Tropsch (FT) diesel	29,7 MJ/kg 25 MJ/kg 46 MJ/kg 45 MJ/kg	Diesel, naphtha
Solid fuels (HHV) • pellet • torrefied pellet	18 MJ/kg 22 MJ/kg	
SNG (HHV)	54 MJ/kg	

General design bases

The feedstocks listed in Table 14 indicate the range of raw materials that can be used in the chosen route. Generally, energy-biorefineries are not sensitive to the feedstock, except in the case of the hydrolysis route where softwood is not the preferred biomass of choice due to its difficulty to hydrolyse without proper pre-treatment (the route designated Hydrolysis II should be used in such cases). The process scale has been fitted to the average sawmill operations in the Mount Gambier region; namely the amount of available sawmill residues is assumed to be 200 000 tonne wet biomass per year (dry content (DC) 50%), distributed into chips (57%), sawdust (19%) and bark (24%). For large scale operations with feedstock capacity of 500 000 ton wet biomass per year, the gap between amounts of available sawmill residues and the plant capacity is from untaken forest biomass. In addition, the routes were evaluated using forest residues as single feedstock.

Many of the route designs include a boiler and steam turbine, which obviously increases capital cost. However, in these designs process electricity and heat demand are met by these systems lowering the variable production costs. Excess heat is only available from the routes that have electricity as their main product and is dependent on design details resulting from case specific definitions such as waste heat recovery from flue gases and heat integration between sawmill operations and the energy-biorefinery.

Bio CHP

In the Bio CHP route, sawmill residues are combusted in a grate furnace, and in the boiler high pressure superheated steam is generated to be converted to electricity using a steam turbine. Sawmill heat demand is supplied as low pressure steam. All system parts employ existing technologies (Figure 35).

For this option the following assumptions are used: The CHP plant is based on a steam turbine process and the generated heat is utilised to the maximum extent in sawmill drying chambers. The heat demand of the sawmill is assumed to be 100 GWh/a and any remaining heat is considered as lost. The main process parameters of the design (Obernberger & Thek 2004) for heat and power production are 278 GWh_{th}, 93 GWh_{el}, 80% total efficiency, 20% electricity efficiency, of which 100 GWh_{th} is used at the sawmill.

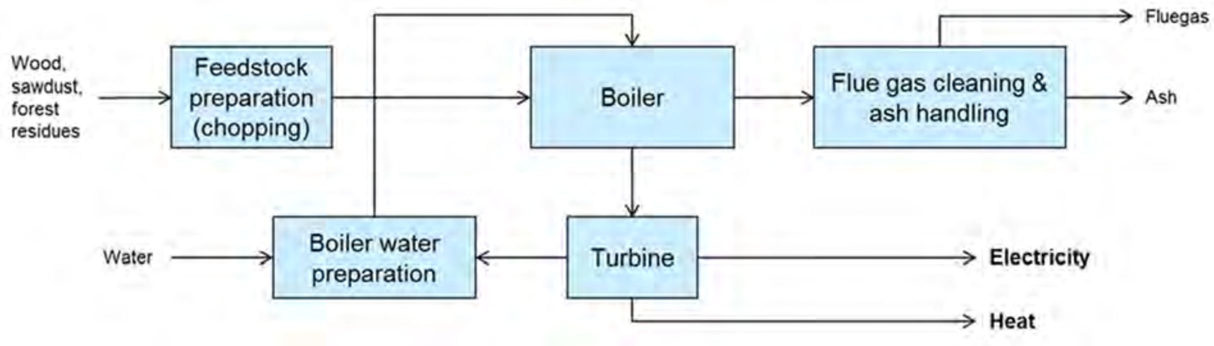


Figure 35. Block-flow diagram of Bio CHP -route.

Extended Bio CHP

The extended Bio CHP route consists of the same boiler-steam turbine system as the bio CHP route which is extended with a hot water extraction of hemicelluloses from the feedstock followed by conversion of the hemicelluloses into ethanol. The extract which is rich in hemicelluloses is treated and converted into sugars using enzymes and the sugars then converted into ethanol. The major technologies required are available already, but as demonstration is still needed this route is considered as a potential solution in the medium to long term (Figure 36).

The main process considerations and assumptions are:

- The impact of the heating value change due to the removal of low value components has not been considered
- An extracted yield of 20% on biomass (Pu 2011; Mesfun 2010)
- The extracted hemicelluloses converted to ethanol through enzymatic hydrolysis of hemicelluloses (mainly 5-carbon sugars (C5) in case of hardwoods or 6-carbon sugars (C6) in case of softwoods)
- Enzyme cost of 0.26 A$ per liter of ethanol, and an ethanol yield of 6% on biomass
- The increased process steam demand supplied by the CHP
- In extraction of hardwoods, acetic acid is formed as an interesting by-product in almost equal proportions as ethanol

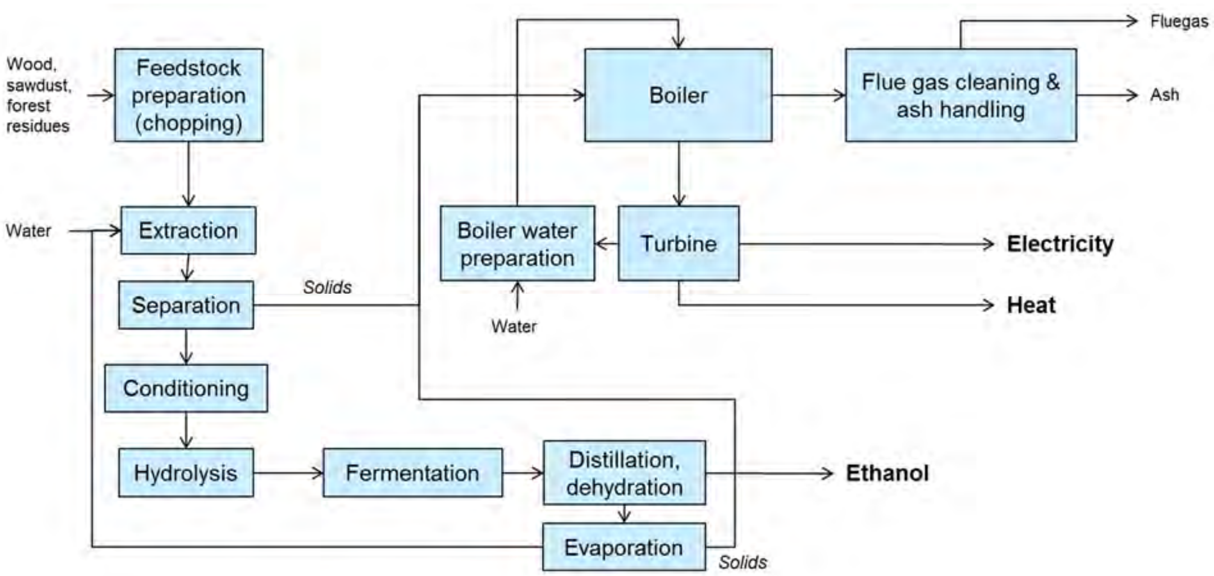


Figure 36. Block-flow diagram of Extended Bio CHP -route.

Hydrolysis I

This route represents the state-of-the-art ethanol production from lignocellulosic as the raw material (Humbird et al. 2011). All utilities and waste management are included in the facility, thus making it a stand-alone plant. Large biomass capacity is considered for the route. The process consists of dilute acid pre-treatment, followed by enzymatic hydrolysis (enzyme cost assumed at 0.26 A$ per litre ethanol), fermentation of C6 sugars (mainly cellulose -based) into ethanol, distillation and dehydration of the product, and processing of the side streams (e.g. solids handling in the boiler to produce steam). The system is energy self-sufficient, producing small amount of excess electricity to be sold into the grid (Figure 37).

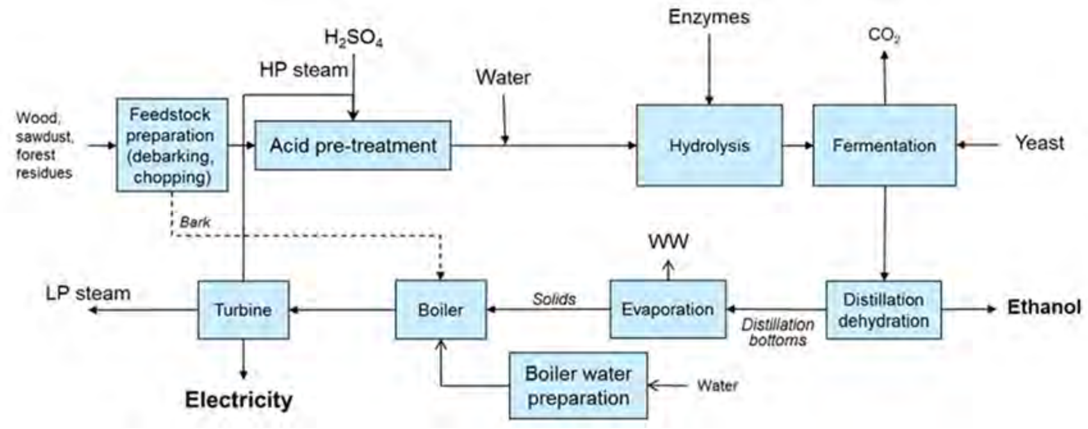


Figure 37. Block-flow diagram of Hydrolysis I –route. HP – high pressure (steam), LP – low pressure (steam), WW – waste water.

Hydrolysis II

This route differs from Hydrolysis I in many ways even though the main product is identical (ethanol). A chemical pre-treatment (alkaline oxidation) removes the lignin from the lignocellulosic material, thus enabling its isolation as a by-product. Additionally, the chemical used in the pre-treatment is recycled. The route has not been demonstrated or piloted and is therefore a medium to long term proposition. This will allow the accommodation of any new developments, including efficient fermentation of C6 and C5 sugars into ethanol or other products (Figure 38).

The main process considerations and assumptions (Kallioinen et al. 2011) are:

- Alkaline pre-treatment of biomass to facilitate lignin separation, followed by enzymatic hydrolysis
- Both C6 and C5 sugars are converted to ethanol
- Enzyme cost of 0.13 A$ per litre of ethanol
- Alkali is recycled with 95% efficiency
- Oxygen is purchased over the fence
- Excess electricity is sold to the grid
- Lignin by-product is sold into lignosulfonate markets

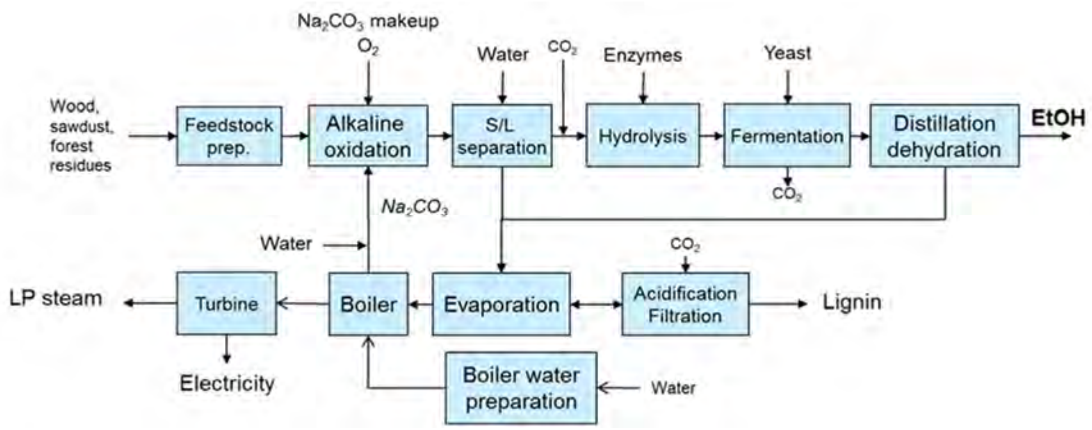


Figure 38. Block-flow diagram of Hydrolysis II –route. S/L – solid/liquid, LP – low pressure (steam).

Pyrolysis

Fast pyrolysis route converts biomass into crude-oil also called bio-oil that can be used as boiler fuel to replace fossil oil (Wright et al. 2010; McKeough et al. 2005). In this concept, the biomass is sub-divided in two steps and the target dry content of 10% in the pyrolyser feed obtained with flue gas. The oil is separated and purified from the solids and non-condensable gases before storage. Part of the char formed as a by-product is combusted in a separate unit to generate steam/flue gases for drying pyrolysis (fluidizing agent), with any excess char sold as a horticultural product (Figure 39)

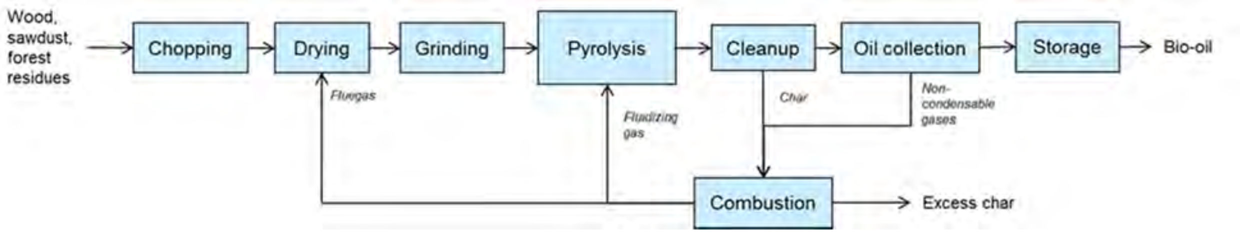


Figure 39. Block-flow diagram of Pyrolysis -route.

Pyrolysis with oil upgrading

This route is the same as fast pyrolysis with upgrading of the bio-oil to diesel and naphtha (Wright et al. 2010), but with lower overall yield. Hydrogen used in the hydrotreatment unit is purchased to maximize product yield. The major product is sold to diesel and gasoline markets at a higher price and the by-product gas as a natural gas replacement (Figure 40)

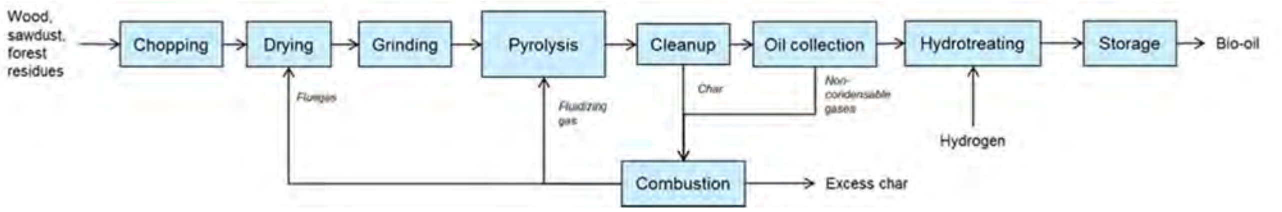


Figure 40. Block-flow diagram of Pyrolysis with bio-oil upgrading -route.

Small scale gasification

The assessed Small scale gasification route is a modular gasifier-gas engine system generating electricity for internal use or for selling to the grid (Stassen and Knoef 1993). The process requires a dry and small size feed in the case of bark, gasification at low temperatures (~700 °C) and solids and tar removal before combustion in a gas engine(Figure 41).

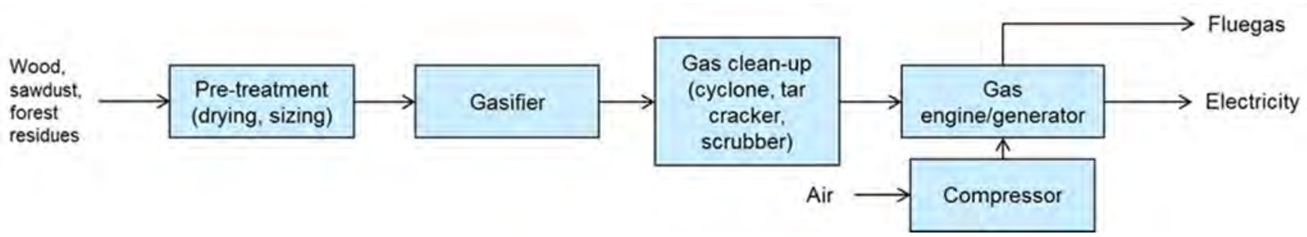


Figure 41. Block-flow diagram of Small scale gasification -route.

Gasification with FTL (Fischer Tropsch liquids) synthesis

The assessed Fischer-Tropsch liquids production from synthesis gas is based on a state-of-the-art system design (Hannula & Kurkela 2013). The system consists of oxygen blown gasifier (5 bar and 850 °C), with oxygen produced in an air separation unit, followed by gas cleaning and conditioning to obtain the required H_2/CO ratio for the synthesis. Any side-streams from the process are combusted in a boiler to produce steam and electricity, with any surplus electricity sold to the grid (Figure 42).

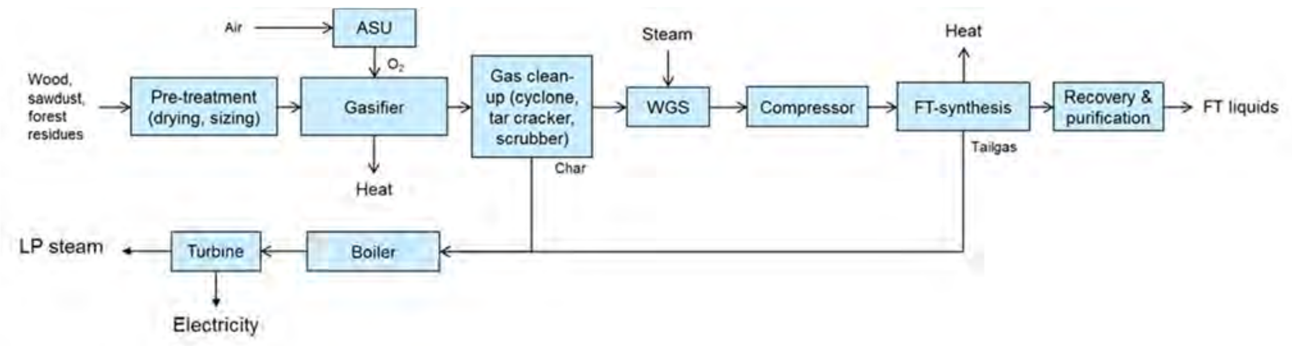


Figure 42. Block-flow diagram of Gasification with FTL synthesis -route. WGS – water gas shift reactor, ASU – air separation unit.

Gasification with SNG (synthetic natural gas) production

This path utilises the same gasification configuration as for the FT-liquids route (Hannula & Kurkela 2013). SNG is produced via an exothermic methanation system (Larson et al. 2012; Haldor Topsøe 2009) and where the methanation heat recovery is very high at 85%, resulting in steam generation of 3 kg/Nm^3 SNG that could be used at the sawmill as a heat source(Figure 43).

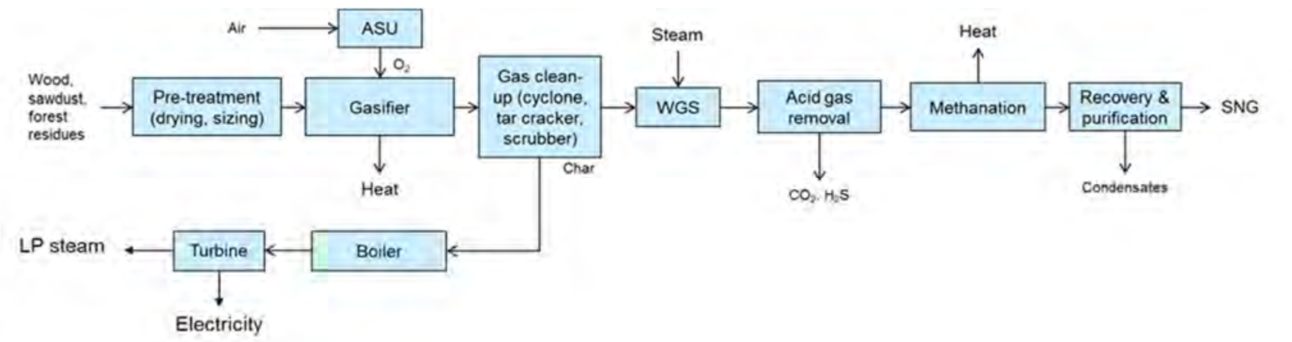


Figure 43. Block-flow diagram of Gasification with SNG production -route. WGS – water gas shit reactor, ASU – air separation unit.

Pelleting

For this process, the feedstock needs to be treated to uniform size and dryness. This can be achieved using equipment similar as for pyrolysis; that is chopping and grinding combined with drying. Due to the high energy demand for drying (70% of the total used in process), only chips from the saw mill are best used as feedstock. For the drying step, sawmill sawdust and bark are best utilised as fuel. After their formation, the pellets need to be cooled and screened. Very high yields on an energy basis can be obtained at a dry content of 90% (Pirraglia 2010, McKeough et al. 2005) (Figure 44).

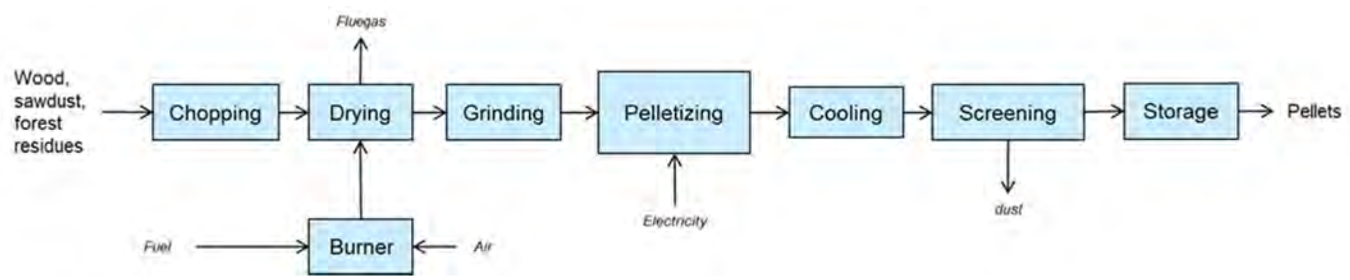


Figure 44. Block-flow diagram of pelleting -route.

Torrefaction with pelleting

Torrefaction can be combined with pelleting to obtain a char for use as fuel. Combined torrefaction and pelleting TOP-process (Bergman et al. 2005), is considered in this analysis. In this route, the feedstock needs to have a larger particle size compared with pyrolysis and gasification and, for this reason, sawdust and bark cannot be used. If necessary, the chips (sawmill or forest based) are first converted to a uniform size, dried using burner flue gases, and then torrefied. The flue gases are also used as heat for the torrefaction reactor. The torrefied material is further milled or ground to smaller size following the same principles as for pelleting. A lower overall yield compared with pelleting is achieved because part of the biomass is combusted in the process and additional fuel is needed (Figure 45).

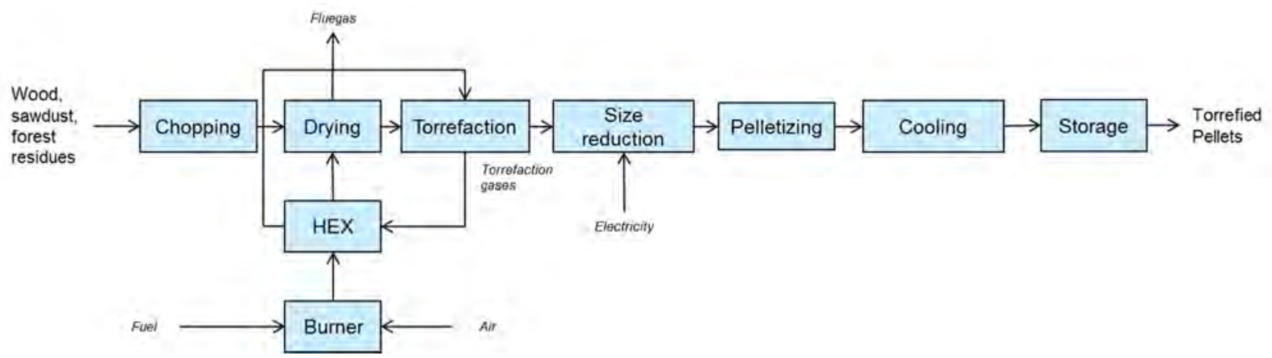


Figure 45. Block-flow diagram of Torrefaction with pelleting -route.

Hot water extraction (HWE) – HWE prior to pelleting

In this process, the wood used is pre-treated to obtain a hemicellulose-rich stream (Amidon and Wood 2013). This fraction of the wood component has a lower heat value than lignin and its removal does not affect the heating value of the pellet adversely (Figure 46).

The same process parameters as for pelleting are used; namely sawmill chips only are used for pelleting and the energy demand for both processes, extraction (including extract down-stream processing) and pelleting are assumed to be met by the sawdust and bark available at the sawmill.

In extraction of hardwoods, acetic acid is formed in almost equal proportions as ethanol and is an interesting by-product, but requiring further purification. The use of the hot water extracted solids in other applications has been proposed in Oriented Strandboard (OSB) and manufacturing (Paredes Heller 2009).

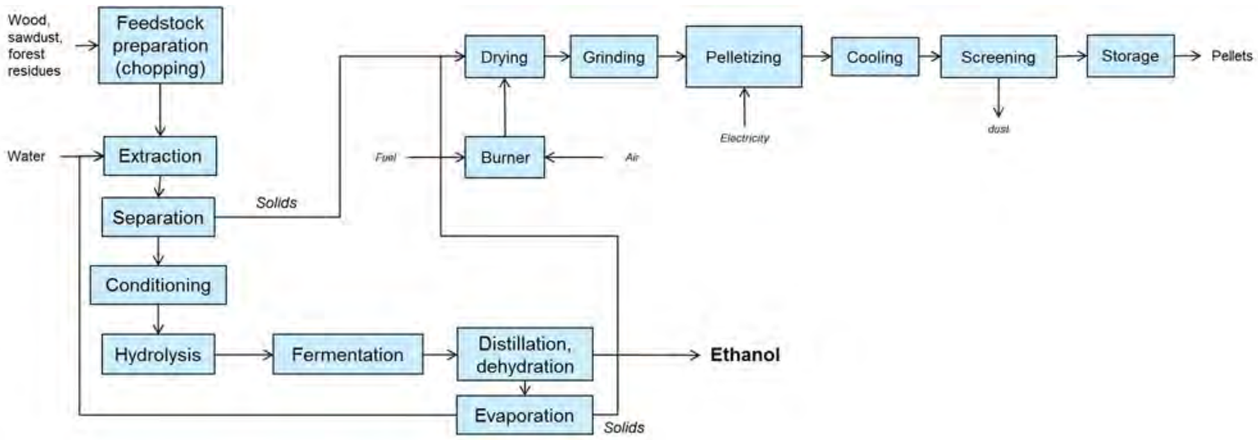


Figure 46. Block-flow diagram of HWE prior to pelleting –route.

7.2.3 Evaluation of business cases – production costs

Evaluation methods

Input-output mass and energy balance models of the selected routes described above are used as the basis of cost evaluation. Variable production costs consist of feedstock costs (excluding feedstock transportation), chemical costs (includes main chemicals and biochemical), energy costs (heat and electricity), and waste disposal costs (ash and waste water). The listed prices in Table 17 are from public sources.

Capital costs are scaled from published design studies (using chemical engineering plant cost index (CEPCI), scaling exponent of 0.65, exchange rates of August 2013 1.09 A$/US$, 1.44 A$/EUR), while the fixed costs are estimated using factors shown in Table 16. Credits from by-products are subtracted from the production costs to obtain the total costs. Costs for delivering the products to the end-user or port are not included.

Table 16. Assumptions used in financial assessment.

Annual capital charge	7% 20%	of capital costs (medium to high capital investment) of capital costs (low capital investment)
Labour cost per person	70 000 A$ per year	assumed average for all (employees and other staff)
Maintenance costs	1.5%	of total capital cost
Other fixed costs	3%	of sales

Sawmill residues (sawdust, chips) are purchased from sawmills that have the possibility to sell to the highest bidder. Similarly all energy products are sold to the markets. Sawmills need to purchase their electricity and heat from the biorefinery. A list of prices is given in Table 17.

Table 17. Prices at the biorefinery gate.

		Price	Unit	Notes
Feedstock	bark	68	A$/bdt	Energy value, scaled from coal price, no transportation costs included
	sawdust	68	A$/bdt	
	sawmill chips	138	A$/bdt	
	forest residues (chips)	80	A$/bdt	Values ranging from 60 to 120 A$/bdt (excl. transportation costs) reported (Parratt & Associates 2010)
Energy	heat	68	A$/MWh	Based on bark and sawdust
	biomass (fuel)	68	A$/bdt	Based on bark and sawdust
	Electricity	50	A$/MWh	Spot between 50 and 175 A$/MWh in South Australia (http://www.euaa.com.au/spot-market-prices/)
Chemicals	H_2SO_4	70	A$/t	
	Lime	216	A$/t	
	Na_2CO_3	84	A$/t	
	O_2	100	A$/t	
	H_2	1436	A$/t	
	NaOH	518	A$/t	
Products	EtOH	92	A$/MWh	Pre-tax petrol price (http://www.aip.com.au/pricing/internationalprices.htm)
	Bio-oil	57	A$/MWh	670 A$/t heavy fuel oil and heating value 43 MJ/kg
	Transportation fuel	92	A$/MWh	upgraded bio-oil, FT-liquids; Pre-tax diesel price between 0.95 and 1.3 A$/liter (http://www.aip.com.au/pricing/internationalprices.htm)
	Pellets	13	A$/MWh	
	Torrefied pellets	13	A$/MWh	Thermal coal price 100 A$/t and heating value 28 MJ/kg; coking coal price about 220 A$/t
	SNG	40	A$/MWh	Natural gas price
By-products	Char	100	A$/t	Thermal coal price
	Lignin	500	A$/bdt	Lignosulfonate prices range from 100-1000 USD/t

7.2.4 Techno-economic analysis results

The capital cost estimates for the assessed routes are given in Table 18. The estimates are scaled from the capital cost values presented in the references using scaling exponent of 0.65.

Table 18. Capital cost estimates for the selected routes at defined production capacities.

Route (reference)	Feedstock capacity (t/a)	Production capacity (MWh)	Capital cost estimate (MA$)
Bio CHP (Obernberger & Thek 2004)	200,000	91,000	90
Bio CHP - forest biomass (Obernberger & Thek 2004)	200,000	91,000	90
Bio CHP - forest biomass (large) (Obernberger & Thek 2004)	500,000	307,000	170
Extended Bio CHP (Obernberger & Thek 2004, Humbird et al. 2011)	200,000	91,000	150
Hydrolysis I (Humbird et a. 2011)	500,000	486,000	320
Hydrolysis I - forest biomass (Humbird et al. 2011)	500,000	486,000	320
Hydrolysis II (Kallioinen et al. 2011)	500,000	666,000	530
Pyrolysis (McKeough et al. 2005)	200,000	453,000	30
Pyrolysis - forest biomass (McKeough et al. 2005)	200,000	453,000	30
Pyrolysis + oil upgrading (Wright et al. 2010)	200,000	406,000	80
Pyrolysis + oil upgrading - forest biomass	200,000	406,000	80
Small scale gasification (Stassen & Knoef 1993)	27,000	15,000	20
Gasification + FT/MeOH (Hannula & Kurkela 2013)	500,000	549,000	400
Gasification + FT - forest biomass (Hannula & Kurkela 2013)	500,000	549,000	400
Gasification + SNG (Hannula & Kurkela 2013; Haldor Topsøe 2009)	500,000	685,000	380
Pelleting (McKeough et al. 2005)	114,000	252,000	20
Pelleting - forest biomass (McKeough et al. 2005)	114,000	252,000	20
Torrefaction + pelleting (Bergman et al. 2005)	114,000	255,000	10
Torrefaction + pelleting - forest biomass (Bergman et al. 2005)	114,000	255,000	10
Hot water extraction prior to pelleting (Humbird et al. 2011, McKeough et al. 2005)	114,000	202,000	40

It is important to understand and emphasise that the evaluated routes have different feedstock and production capacities. This results in significantly different investment requirements, even for the same feedstock capacity. In addition, the references differ: while some represent detailed evaluations of installed facilities or existing commercial technologies, most of the references are engineering studies. The scope of the studies also differ, especially the torrefaction with pelleting route which requires a more detailed cost estimate to verify the relatively low capital cost compared with the pelleting route. Moreover, the final project cost depends on many factors that have not been considered here. For example, equipment from different equipment vendors can differ substantially for the same process, existing assets in different locations can decrease the costs significantly (for example boiler, turbine and water treatment), installation costs can vary between regions, or a company capabilities in engineering and project execution can differ markedly. Thus, all the capital cost values presented here should be regarded as order of magnitude estimates that will require further refinement in the event of their serious consideration.

The production costs per MWh of main product are shown in Figure 47.

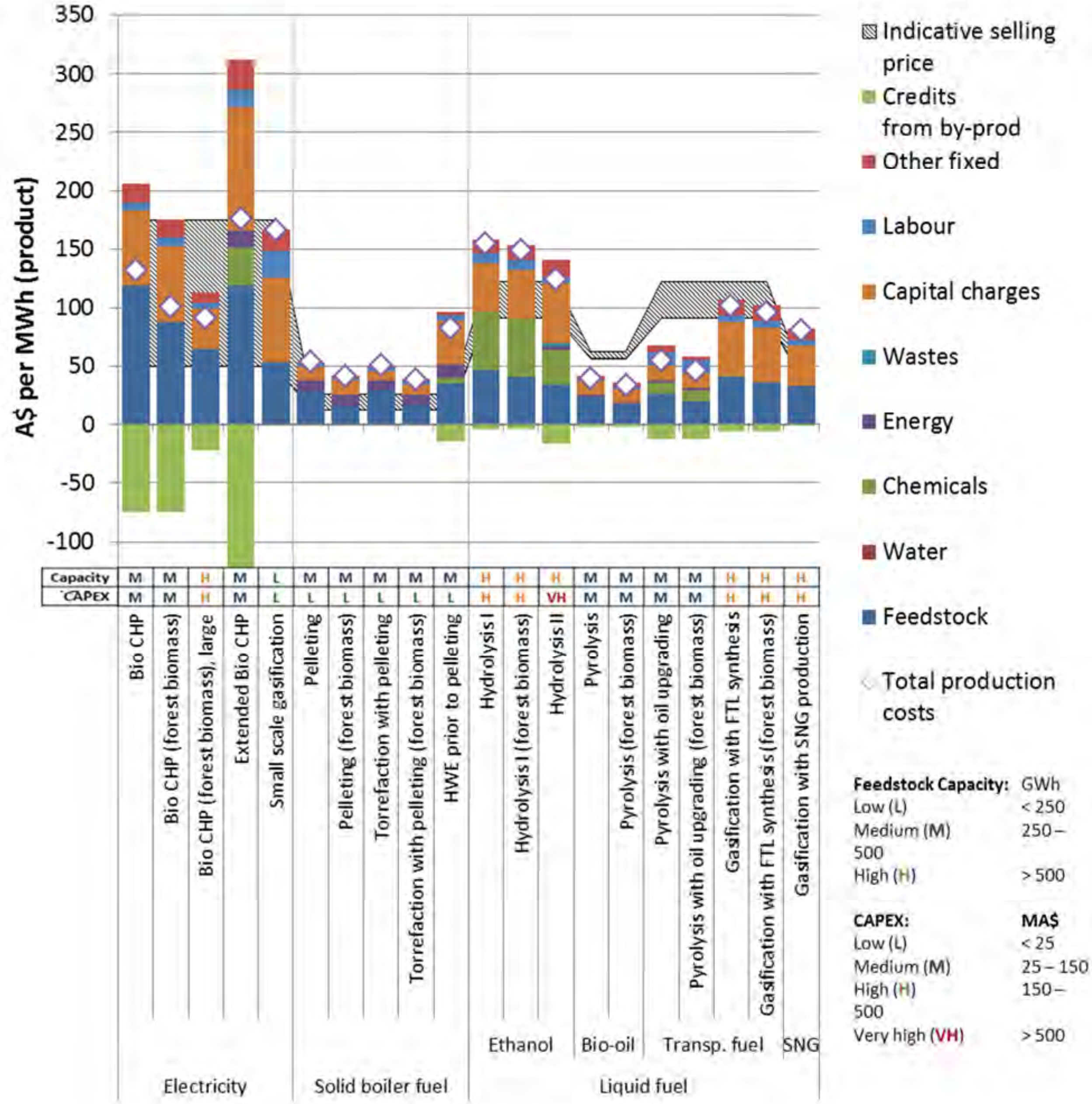


Figure 47. Production costs in selected routes. Costs are shown as positive A$/MWh and by-product credits as negative A$/MWh, main categories are shown with different coloured bars in the histogram. Total production costs assigned to the main product are shown with white diamond.NOTE: The routes produce different end products and the costs are therefore not comparable, instead all routes should be compared against their products' respective sales price range (indicated with the shaded area). The design biomass capacity and magnitude of capital expenditure are presented as low (L), medium (M), high (H) and very high (VH).

In general, feedstock and capital costs dominate the total costs. For the Hydrolysis routes, enzyme costs are a major contributor to the cost of the chemical. Fixed costs are also significant for all routes, especially when production capacity is very small and labour costs become more significant. Energy costs are separately observed in the pelleting, torrefaction with pelleting and the pyrolysis routes. These routes purchase electricity and use part of the feedstock as a source of heat (sawdust or bark, or forest residues). By-product revenues are significant in CHP routes and for routes with high value by-product (HWE prior to pelleting, by-product is ethanol; Hydrolysis II, by-product is lignin; pyrolysis with oil upgrading, by-product is gas).

For electricity generation as the main product of the energy biorefinery, a stand-alone CHP would appear not to be a potential solution if the electricity sales price is lower than 100 A$/MWh. This is mainly due to the high feedstock costs (sawmill residue chips, sawdust and bark). When a feedstock of lower cost is available and plant capacity increased, CHP becomes more attractive. The assessed small scale CHP by gasification shows the least promising economics (even with low cost bark as the feedstock). Examples of small scale CHP plants in Finland, Denmark and Sweden, some of them integrated into sawmills, are reported for example by Kirjavainen et al. (Kirjavainen et al. 2004). Small scale gasification route for electricity production is in the proper scale for sawmill bark, however the capital costs per MWh electricity are high resulting in poorest performance of the electricity producing energy biorefinery routes evaluated.

Solid fuels production has the lowest product value per MWh and even with relatively high yield the feedstock costs represent about half of total costs. With lower cost forest residues as feedstock, better economic performance is achived. Energy costs are also an important cost factor for these routes. Pre-extraction of hemicelluloses for ethanol production does not enhance the economics due to the high associated costs. Additional revenues from acetic acid, for example, could make this case more attractive.

The liquid fuel routes perform differently depending on the end-product. Ethanol production has three key cost categories (feedstock, enzymes and capital) that all are affected by the relatively low yield on biomass. Pyrolysis to produce bio-oil and pyrolysis with oil upgrading to naphtha/diesel quality show both positive economic performance, whereas FT-liquids and SNG production perform worse due to lower yield and higher capital costs per MWh of the product.

7.2.5 Impact of biomass cost

Feedstock cost is the dominant cost factor for all the options assessed. Three routes, pyrolysis, torrefaction with pelleting and gasification with FTL synthesis from forest biomass, represent logical alternatives for the region: potential users for the liquid biofuel (bio-oil or FT-diesel) and torrefied pellet for replacing coal exist. These three routes were selected to illustrate the impacts of feedstock price and production capacity on the total production costs, and the results of this assessment shown infigures 48 to 5a0.

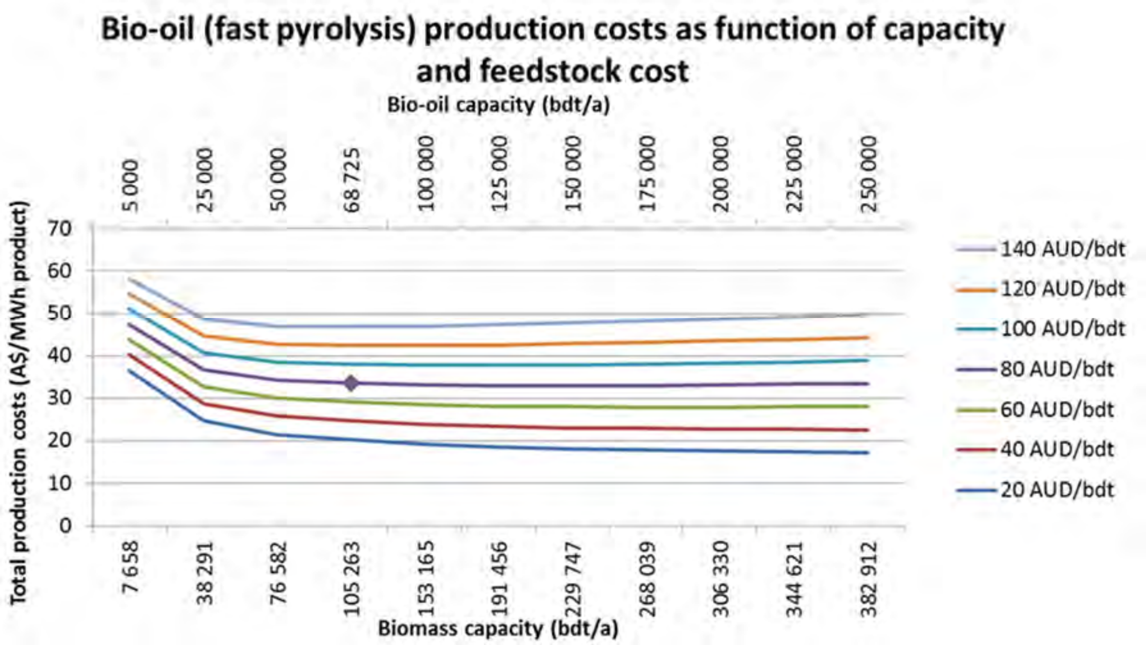


Figure 48. Production costs of bio-oil with different biomass costs as function of capacity. Diamond indicates the base case route.

Production costs with biomass at prices of between 20 and 140 A$/bdt (at the mill gate) are shown. The fixed costs (biomass growing, harvesting, loading/unloading) for the base case capacity is with 75% assigned to the biomass and the remaining 25% to transportation. The fixed cost part remains constant whereas the transportation cost changes as a function of capacity. All other variable and fixed production costs are also constant with respect to capacity. Indicative selling price of the bio-oil is higher with all considered biomass prices.

Capital cost is scaled up/down from the base case estimate using an exponent of 0.65, and capital recovery factor of 0.2 was used (full depreciation in 5 years) because the capital investment requirement is relatively low (~30 MA$).

Maximum equipment sizes currently available in the market for fast pyrolysis are in the range of 60 000–90 000 m^3 bio-oil per year. Larger facilities would require two or more parallel production lines, leading to a “saw-toothed” cost curve illustrated in Figure 49. This curve is dependent on the equipment selection. However, the total cost curve shown in Figure 50 depicts an overall reduction in costs with increasing capacity, or economies of scale, provided the feedstock price is at a reasonable level.

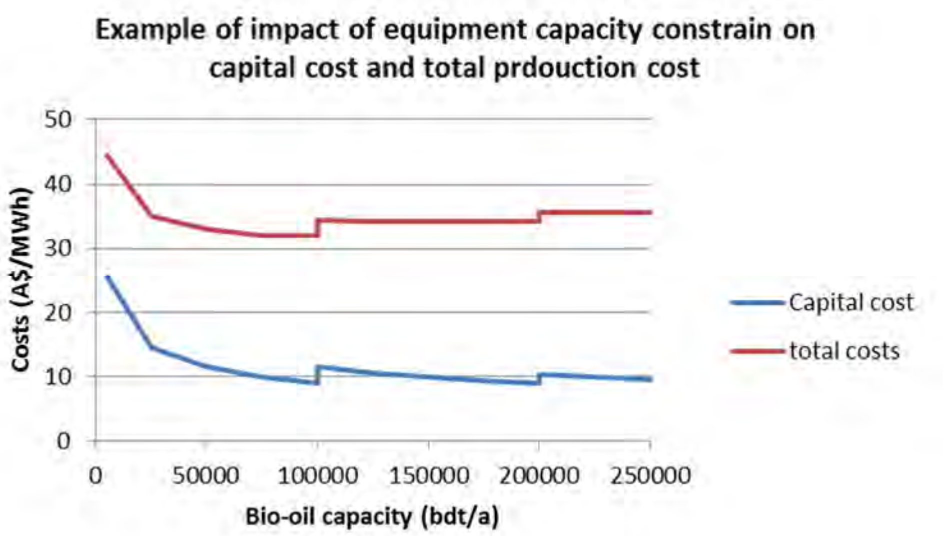


Figure 49. Impact of equipment size constraint on cost curve, example of fast pyrolysis system with hypothetic maximum production rate of 100 000 bdt/a per production line.

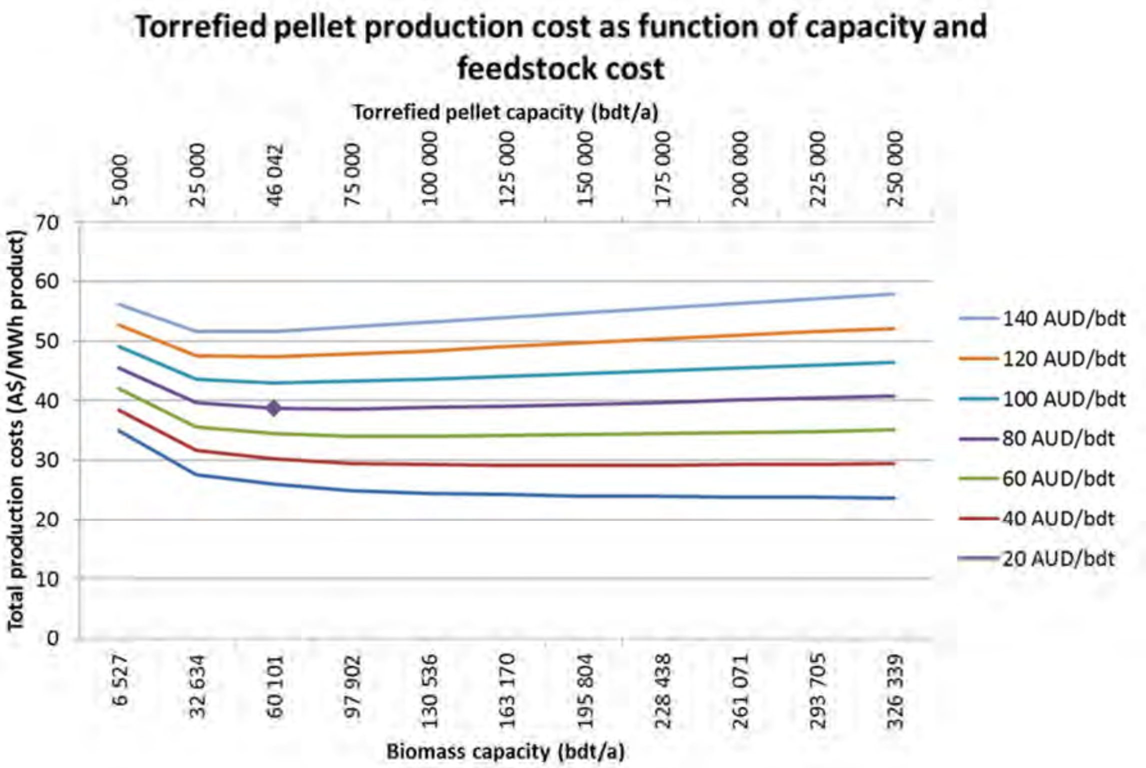


Figure 50. Production costs of torrefied pellets with different biomass costs as function of capacity.

A similar cost trend exists for torrefaction as does for pyrolysis. In addtion, the available equipment sizes are in the same range as for pyrolysis. On the other hand, even a very low biomass price is not enough to bring the costs below the indicative selling price of pellets (~13 A$/MWh).

A capital recovery factor of 0.2 has been applied (full depreciation in 5 years) because the capital investment requirement for torrefaction and pelleting is low (~10 MA$).

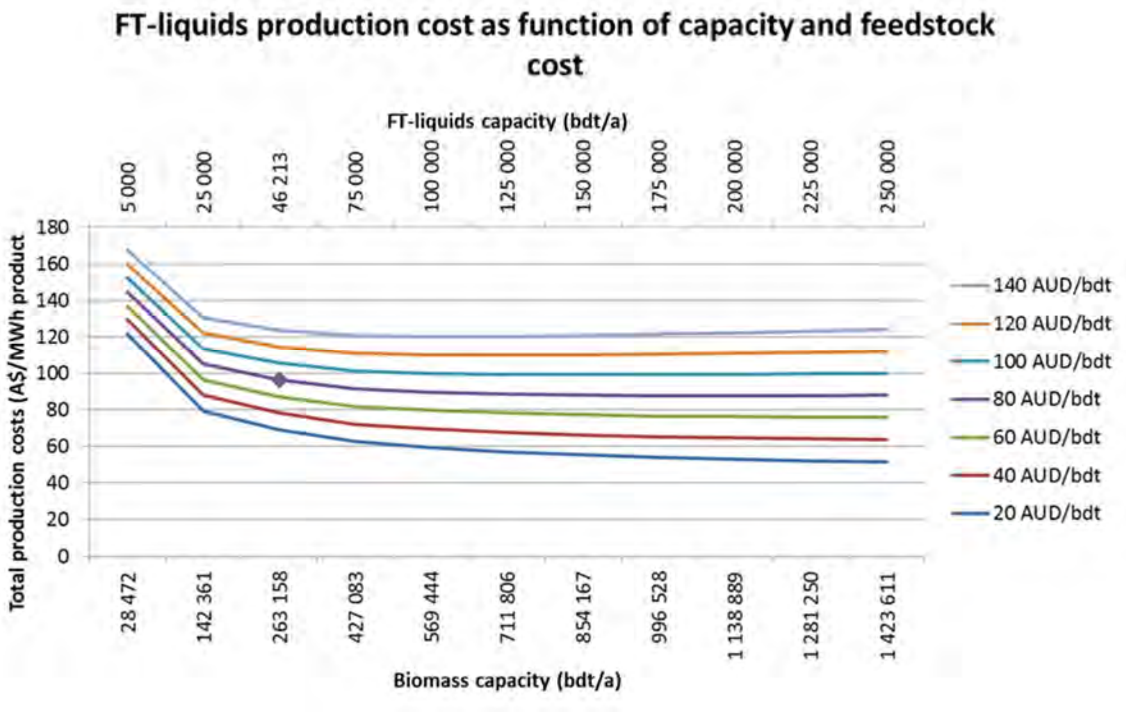


Figure 51. Production costs of FT-diesel with different biomass costs as function of capacity.

Equipment sizes of up to 1 000 000 bdt/a biomass have been proposed for gasification and the largest CFB gasification plant in operation in Vaasa, Finland has biomass capacity of 140 MW; FT-synthesis systems are even larger. The forest residue availability (500,000–1,000,000 m^3/a) was used to define the capacity of the base case (500,000 t wet/a, 50% dry content, dry density of about 400 kg/m^3). Larger facilities would need to use mixed raw material.

A capital recovery factor of 0.1 was used (full depreciation in 10 years) for this route because capital investment requirement is relatively high (~400 MA$). With an even longer depreciation plan this route would become more promising, If more biomass could be collected at a low cost, the total production costs would be lower than the indicative selling price of approximately 77 A$/MWh of FT-diesel.

7.2.6 Summary

Based on the conceptual level assessment of the selected energy biorefinery routes, bio-oil production shows clear promise. Solid fuel production could offer an alternative for replacing thermal or other types of coal. FT-liquids with significantly higher investment cost do not appear profitable, at current biomass prices.Thus, product and feedstock selection play an important role in determining the best strategy for industry renewal through energy biorefinery route. The analysis would suggest that electricity and ethanol production are not promising options, unless the electricity is generated from forest residues on a large scale.

The assessment was made using publicly available data on process performance, prices and costs. CHP, pelleting, small scale gasification, torrefaction and pyrolysis are relatively mature technologies, with only minor challenges remaining in some of the processing steps. Synthesis and catalytic upgrading of bio-oil from various feedstocks are under development and is evolving at a rapid pace. The hydrolysis route from lignocellulosic feedstocks has been the focus of numerous R&D activities over the last decades and significant progress has been achieved in cost reduction. There are existing commercial scale facilities currently operating producing ethanol from woody biomass, although first plants using agricultural waste have been operating for some time. Further improvements can be expected, especially in the field of valorisation of by-products, while developments in the more mature routes are likely to lead to further cost reductions.

As capital costs play such a key role in many of the routes described, a more detailed case-by-case analysis should be conducted in order to achieve more accurate estimates.

7.3 Summary of Pöyry evaluations

In May-June 2013, VTT contracted Pöyry Management Consulting Oy to carry out an economic analysis on the production of torrefied pellets and pyrolysis oil as two of the more promising bioenergy options for the Green Triangle region. The assessment consists of analysis of available feedstocks, description of key technologies, overview of the biocoal and pyrolysis markets in Australia, techno-economic evaluation of selected fast pyrolysis and torrefaction systems integrated into a sawmill, and an analysis of the business opportunities for bioenergy carriers. This section provides the key findings from this evaluation. In the Pöyry study, sawmill residue and price levels were obtained from the ABARE 2011 report (ABARE 2011) and it is possible that the price figures and market dynamics have changed somewhat since then.

Summary of feedstock availability in the Green Triangle region

The Pöyry evaluation was based on an assumption that the sawmill residue potential in the Green Triangle area is about 500,000 m^3 per year and concentrated on two large sawmills in the Green Triangle region. The residues are 75% softwood chips and 25% sawdust. Bark was left out of the analysis on grounds that it is usually utilised as fuel for the drying kilns. The focus of the analysis was on the two largest sawmills in Mt Gambier and Tarpeena, since they represent almost 90% of the capacity in the region. The sawmills have similar capacity and they are located near each other, raising the possibility for a stand alone biorefinery that could be located somewhere nearby and utilising the residues from both mills. The feedstock study indicates that there is a balanced supply and demand situation for particleboard production in the Greent Triangle where roughly the same amount of chips and sawdust are consumed that the sawmills produce. However, part of the sawmill residues are exported and the particleboard producers use forest biomass chips. The fact that large volumes of softwood pulpwood are currently being exported through the Portland port was also seen as a potential opportunity for bioenergy production.

Assessed process concepts: pyrolysis and torrefaction

The Pöyry evaluation focused on pyrolysis oil production and torrefaction technologies that are two options for wood based energy production offering products for fossil fuel replacement. Fast pyrolysis technology is at near commercialisation with a first plant due to be commissioned in Finland at the end of 2013. Currently, there are no commercial torrefaction plants, but the technology has advanced to the demonstration level and is maturing at a rapid pace as recognised pulp and paper technology suppliers enter the field. The reason why Pöyry focused their evaluation on these two technologies is that sawmills with a steady flow of side products and heat demand for kiln drying offer very good integration options for both technologies, as Pöyry asserts “by combining the heat production of the two processes significant integration benefits can be achieved, as well as utilisation of existing infrastructure and utilities of operated sawmills”.

Techno-economic evaluation of selected sawmill integrates

The starting point for the techno-economic evaluation is based on the production estimates made with Pöyry’s cost models that have been partly co-developed with VTT. The assessed capital costs are based on announced project or technology costs, database prices for known parts of the process and cost estimates for new technologies. They are based on North European cost levels converted to Australian currency. Unit costs are derived from Pöyry’s database for Australia or, where appropriate, estimated on European cost levels. In the evaluation, unit consumptions and process efficiencies have been assumed to equal European standards. The task of the Pöyry evaluation is stated as: “the main objective of the techno-economic analysis is to find the high level cost levels that bioenergy carriers have in Australia”, while taking into account the different elements that affect the development of the technologies and result in cost differences.

The assumptions used in this techno-economic evaluation are presented in the Table 19 for both the torrefaction and pyrolysis options.

Table 19. Selected sawmill and stand-alone cases (Pöyry 2013).

Concepts	Sawmill torrefaction			Sawmill pyrolysis		
Location	Large sawmill 1	Large sawmill 2	Stand alone	Large sawmill 1	Large sawmill 2	Stand alone
Production capacity	60 300 t/a	55 800 t/a	200 000 t/a	362 000 MWh	335 000 MWh	388 000 MWh
Annual wood consumption	173 300 m3s/a of wood chips, All bark and 60% of sawdust used for energy	160 100 m3s/a of wood chips, all bark and 60% of sawdust	730 000 m3s/a of softwood chips	231 000 m3s/a of softwood chips and sawdust	213 000 m3s/a of softwood chips and sawdust	277 000 m3s/a of woodchips
Energy integration	New boiler is designed to produce required drying energy for sawmill and torrefied pellet plant	New boiler is designed to produce required drying energy for sawmill and torrefied pellet plant	Hot gas generator used for drying wood before torrefaction	New boiler is designed to produce required drying energy for sawmill and pyrolysis plant	New boiler is designed to produce required drying energy for sawmill and pyrolysis plant	Pyrolysis side products are combusted in separate reheater and flue gases are used for drying

The related investment cost estimates are presented in the Table 20.

Table 20. Investment cost estimates (Pöyry 2013).

Concepts	Sawmill torrefaction			Sawmill pyrolysis		
Investment costs, MAUD	**Large sawmill 1**	**Large sawmill 2**	**Stand alone**	**Large sawmill 1**	**Large sawmill 2**	**Stand alone**
Boiler	10	9	12	12	11	70
Dryer	3	3		4	4	
Torrefaction/Pyrolysis	19	18	56	23	21	
Pelletisation/Size reduction	6	5	20	2	2	
Total investment	**37**	**35**	**88**	**40**	**38**	

Key assumptions for the economic evaluation

The key assumptions used by Pöyry (2013) in their calculations are given in Table 21. The wood cost at mill is based on the softwood chip FOB price, excluding costs of loading and transport from mill to port. The chip cost was 55 A$/m^3 in the case of Mt Gambier and 54 A$/m^3 in the case of Tarpeena. The economic evaluation assumes a 10% interest rate for capital costs and a payback period of 15 years. The delivery costs of final products are based on prices to Portland, while other prices and costs are based on European cost levels.

Table 21. Key price assumptions (Pöyry 2013).

Item	Value	Unit	Based on
Annual operation hours	7500 h/a		Typical for this type of new technologies
Softwood chips price at port	68 AUD/m3s		Portland FOB price excluding loading
Sawdust price	27 AUD/MWh		Estimated based on chip price and use in particleboard production
Bark price	15 AUD/MWh		Estimated based on local fuel prices
Pyrolysis oil price	59 AUD/MWh		Estimated cost of HFO used in Australia
Torrefied pellet price	31 AUD/MWh		Estimated cost of coal in power plants 2012
Electricity price	50 AUD/MWh		Electricity price in South Australia Oct 2012, EESA
Heat price	17 AUD/MWh		Price estimated based on bark price
Personnel cost	82 250 AUD/person		Estimated personnel cost including all social costs
Transport cost / 100 km	11 AUD/m3s		Cost of truck transport in Australia

The economic evaluation of sawmills energy carriers is shown in the Table 22.

Table 22. Economic evaluation of sawmill energy carriers (Pöyry 2013).

Concepts	Sawmill torrefaction			Sawmill pyrolysis		
Production costs, AUD/MWh	Large sawmill 1	Large sawmill 2	Stand alone	Large sawmill 1	Large sawmill 2	Stand alone
Wood	26,5	26,5	33,2	34,8	34,0	39,0
Electricity	1,3	1,3	1,5	2,3	2,3	3,9
Heat	-0,5	-0,5	0,5	-3,7	-3,7	0,0
Delivery	2,6	3,0	2,8	4,9	5,6	5,2
Other variable	1,5	1,5	0,3	0,0	0,0	0,0
Personnel (incl. all social costs)	3,8	3,8	3,4	2,3	2,5	4,2
Maintenance	2,6	2,6	0,8	3,7	3,8	3,6
Insurance	0,3	0,3	0,2	0,3	0,3	0,5
Other fixed costs	0,9	0,9	0,9	1,7	1,7	1,6
Capital costs (10%,15a)	13,6	13,9	9,6	16,1	16,5	23,9
Total production costs	**52,6**	**53,4**	**53,2**	**62,4**	**62,9**	**81,9**

The results of the analysis

The results of the analysis are presented in the Figure 52.

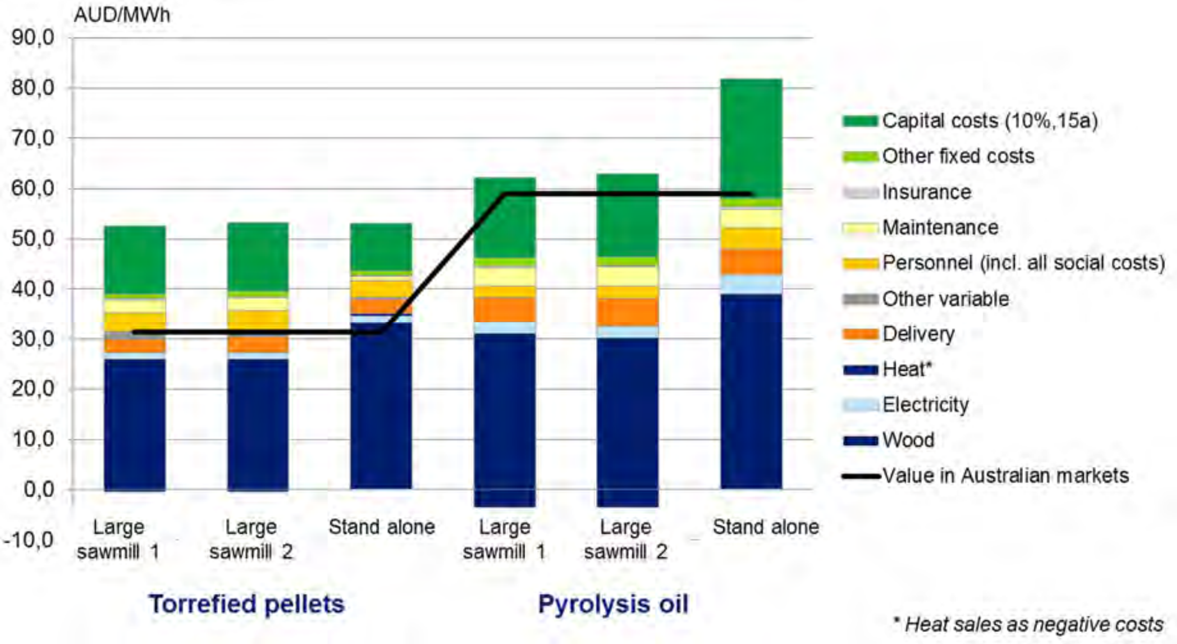


Figure 52. Economic evaluation of sawmill bioenergy carriers.

Based on their analyses, Pöyry made five key conclusions, and these are quoted here (Pöyry 2013):

- Based on the techno-economic assessment, bioenergy carriers do not offer attractive business economics for sawmill residue processing with current price levels. The current export price levels of softwood chips and low prices of fossil fuel make the investment equations challenging.
- Pyrolysis oil was seen as the most promising option for sawmill integration with positive return for the investment. Pyrolysis market is though very challenging due to long distances from Green Triangle to the nearest potential end users and the modification required by the end users.
- Torrefied pellet production costs are estimated to be in line with the European production cost estimates. The challenge is the lack of national support schemes for coal replacement and the

long transport distance to high paying European markets. It is likely that the production of torrefied pellets from softwood residues will remain as not competitive for short to medium term in South Australia.

- Pyrolysis oil production needs to get a long term off-take agreement with prices above 60 A$/MWh to make the investment in new technology viable. Most potential clients could be non-ferrous metal smelters that use low grade oils in their processes, i.e. copper smelters.
- Investment grants in range of 20–40% would also enhance the profitability of the new investments, but they don't decrease the evident market risks related to renewable fuels that require reliable longterm support schemes. (Pöyry 2013)

8. APPENDIX 8: Identifying a portfolio of options for the forest and wood products industry in Green Triangle: workshop results

8.1 Summary

This section aims at identifying a portfolio of options for the Green Triangle forest and wood products industry, based on the strategic technology roadmaps as ascertained in the four lenses (mass, energy, molecular, atomic).

8.2 Roadmap paths as evolving, layered structures

In order to assess the immediate opportunities (sometimes referred to as “low hanging fruit” (LHF)), an “evolutionary” depiction was created of how the different lenses are related to one another as a function of time (refer Figure 53). The idea is that the industrial development should be viewed as evolutionary and layered, instead of sharply disruptive. Thus, the first layer depicts existing sawmills operations and represents the base case scenario. The next two layers 2 represent modernising the traditional forest and wood products industry by implementing strategies of low (“low hanging fruit”) or moderate (“traditional plus”) cost i.e. developments identified in the mass lens roadmap. In the case of layers 2, 3 and 4, the roadmap paths include the potential opportunities identified in the energy, molecular and atomic lenses respectively. It depicts an industry that is being transformed progressively with positive impacts. It should be stressed that in this representation, the traditional forest and wood products industry remains as the backbone and its transformation is about a steady growth in diversity with commensurate improvement in industry sustainability and profitability.

To emphasise, Figure 53 visualises the roadmap paths as evolutionary structures that develop as a function of time. Advancing up the value network (mass-energy-molecular-atomic) ladder, changes the functional structure of the forest and wood products industry, leading to positive outcomes on its profitability and sustainability. The roadmap paths are layered structures that do not replace, but build on, existing industrial operations in the region. In principle existing sawmills could form the basic backbone of the forest and wood products industry, both now and in the future, depending on their adaptability and desire to partake in future-oriented activities.

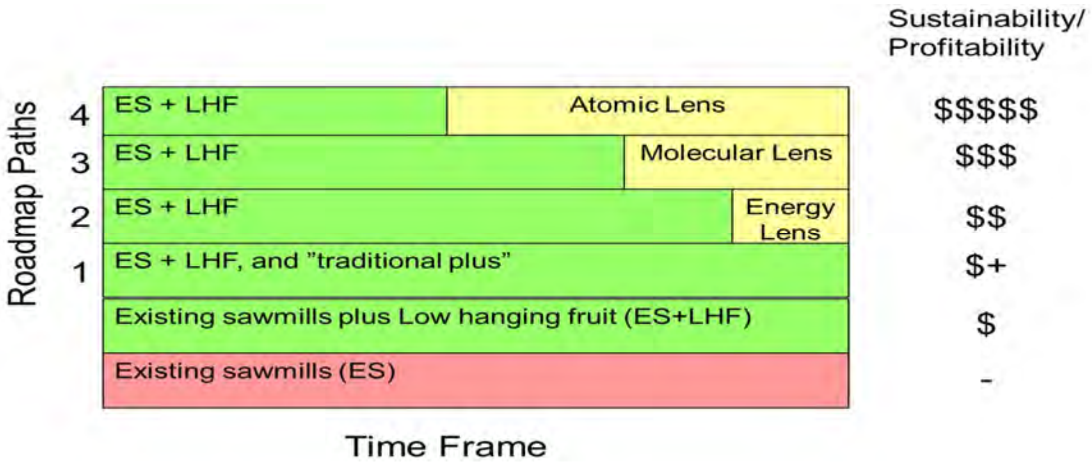


Figure 53. Roadmap paths as evolving, layered structures.

8.3 Business impact-technological feasibility matrices

The portfolio of options was identified during the workshop process by using so-called business impact-technological feasibility matrices. After building roadmaps in four strategic development paths, the task was to make a first iteration of the options in the cellulosic fibre-based value chain. For this purpose, facilitated group work was utilised and the results documented in the business impact-technological feasibility matrices. As part of the process, a portfolio of options, consisting of 10–15 solutions, was identified, reviewed and positioned on the business impact-technology feasibility matrix that is presented in Figure 54.

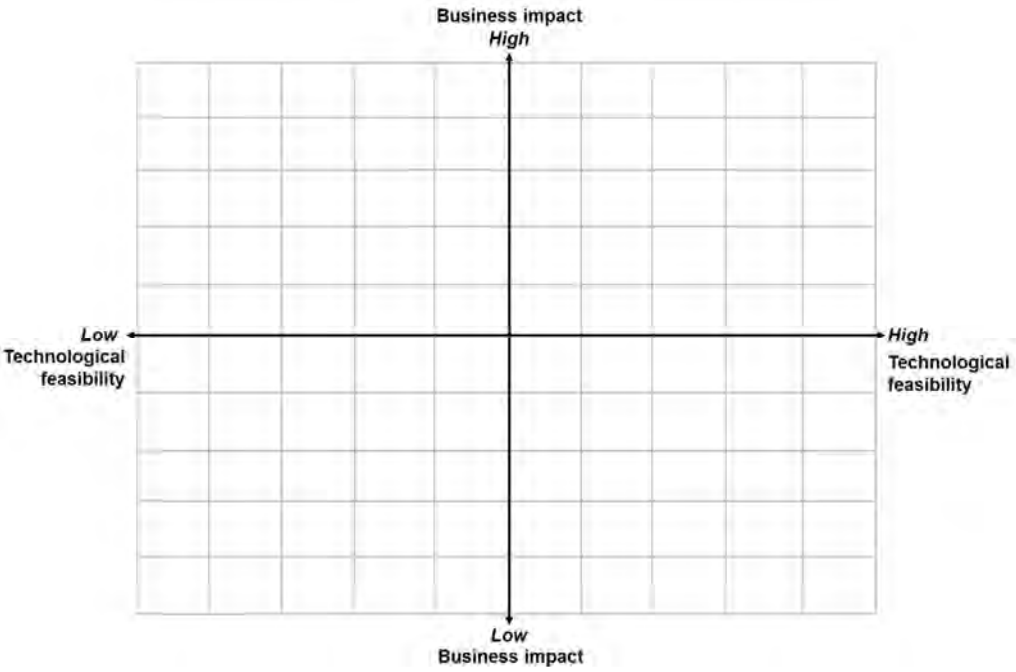


Figure 54. Business impact-technological feasibility matrix.

8.4 Portfolio of options in mass lens

In Table 23, a number of immediate or short-term opportunities identified are presented for the mass lens scenario with a working title "more efficient traditional forest and prodcuts industry".

Table 23. Near term options in mass lens, emphasis on sawmills.

Low hanging fruit	Considerations	Suggestion	Business case
1. Specialisation	• In Finland, advanced sawmills limit the log size (30–35 cm diameter) and would operate either two mills or two separate lines in one mill • Small saw logs (less than 20 cm) do not maximise the utilisation of equipment in large sawmills.	• Use large logs in big mills and smaller logs in "niche" small mills to improve productivity (will require cooperation between large and small sawmills)	• Being evaluated
2. X-ray scanning	• In Finland at least 10 mills are utilizing X-ray scanning to obtain yield increases • This development has made sorting possible for medium sized mills	• Utilise X-ray scanning to detect inner knots and other defects thus permitting better log classification	• Approx.1M Euros with payback estimated to be less than one year
3. Geometric scanning	• Improve productivity by taking into better account geometrical defects in shape (longitudinal and conical)	• Consider fine tuning the log class limits e.g. instead of say 17 cm, simply to go to 16.8 cm	• Equipment cost is less than X-ray scanning • Capital cost to increase the number of "pockets" due to the need of different sawing pattern / log sorts
4. Improved sorting	• In Finland mills have a feedback arrangement to better match the expected	• Consider installation of a simulator system	• Cost up to 200 k€ which

Low hanging fruit	Considerations	Suggestion	Business case
	outcome from the log class • By adjusting sorting rules for the logs improved yields of 5% have been achieved	together with dynamic log sorting	includes training
5. Thinner blades	• Big savings have been achieved with thinner saw blades through less sawdust generation 15+ % less	• Consider trialling thinner blades obtainable from Europe (Finnish/German TTT Oy)	• Cost to be determined locally
6. Outsourcing	• Big integrated and small sawmills in Scandinavia have outsourced forklift work to third parties to free up capital • Such machines can be maintained during shuts or serviced during night shifts	• Consider copying Scandinavian experience	• Best costed locally
7. Small logs	• The demand for small logs 8–15 cm has greatly diminished with the closure of Tantanoola • This has led to an increase in chip exports with low margins	• Design a mill to handle small logs (7–8 cm to 12–15 cm) to produce short logs(up to 3.0 meters only) • These logs could be converted partly to sawn timber (small dimensions) and not only to chips	• Not completed
8. New Grades	• The new CITES agreement will limit the trade of various plant and animal species, including 100 species of tropical hardwood • The Max Planck Inst, Germany, has developed technology that inserts flavonoids into cell walls and improves dimensional stability of the wood considerably	• Consider applying this or other technologies (Thermowood) to Pinus Radiata to develop better and stronger grades	• Not appropriate at this stage – needs to be evaluated

In the longer term, and beyond the more immediate options, one could talk about renewed sawmill (Figure 55). The renewed sawmill is functionally wider than the current sawmill.and it is more like a biomass regulation system than a traditional sawmill. The renewed sawmill is based on the idea that the sawmill coordinates different production directions.l. The first step is the coordinated raw material procurement from several mills. The timber is delivered to the sawmill as long stems, and after accurate X-ray and 3D scanning, they are cut to different lengths and for different purposes. Firstly, the renewed sawmill produces two sorts of chips: chips for export and chips for the energy use. Secondly, the saw mill produces high quality sawn timber to be used e.g. for value added construction materials, like CLT or glulam, or in flooring or decoration panel. Thirdly, the sawmill also contains a more advanced product route for making bio-based raw materials to be processed with different techniques. The products could include biomaterials, biopolymers, wood-plastic composites, and biochemicals. These products have several application fields, like foodstuffs and health.

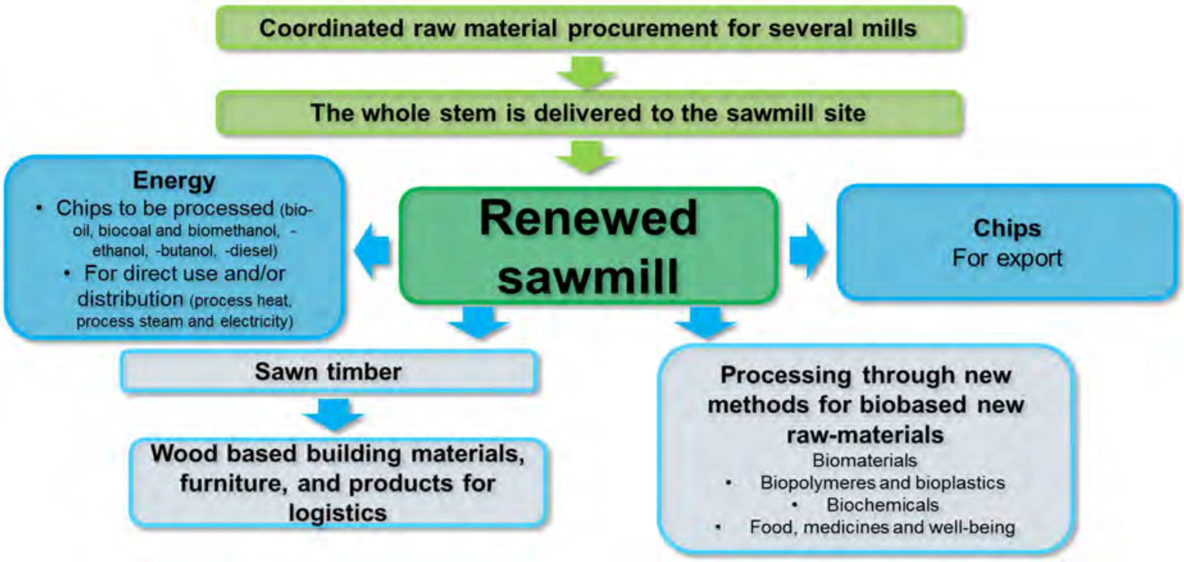


Figure 55. The renewed sawmill: key flows.

Figure 56 advances the view of renewed sawmills as biomass regulators. In this case, the "biomass regulation" is about holistic and integrated planning and use of the forest biomass for different purposes. It includes the tradition uses of timber, as well as the systematic introduction of forest side steams, such as chips, sawdust and bark. The side streams could be used in many ways: chips sold for the production of pulp and paper, the making of first tier energy products like bio-oil and bio-coal, and for providing bioenergy for CHP plants through biorefinery solutions. Bioenergy could also be produced from wet chips or simply from combustion of the wood. The renewed saw mill process also includes the fractionation of the raw materials (timber and side streams) to be directed towards raw materials for more advanced bioproducts.

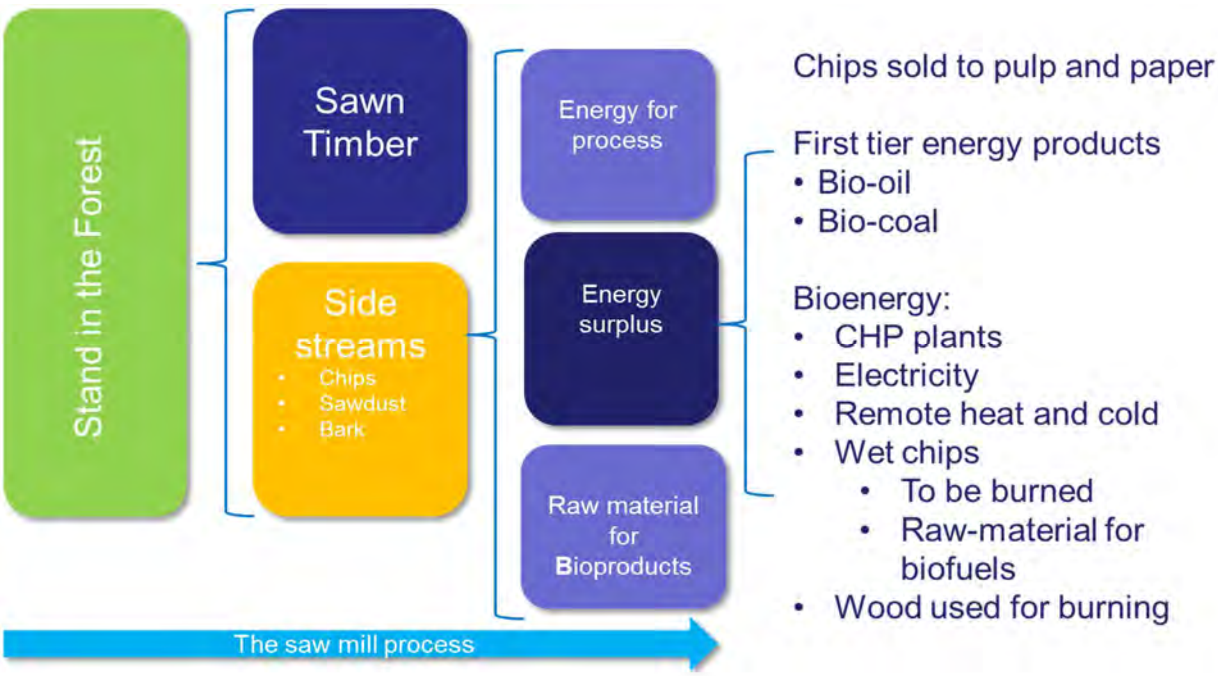


Figure 56. The renewed sawmill: sawmills as biomass regulators.

8.5 Portfolio of options in energy lens

For the energy lens, the following energy technology paths were identified in the roadmapping workshops (Figure 57).

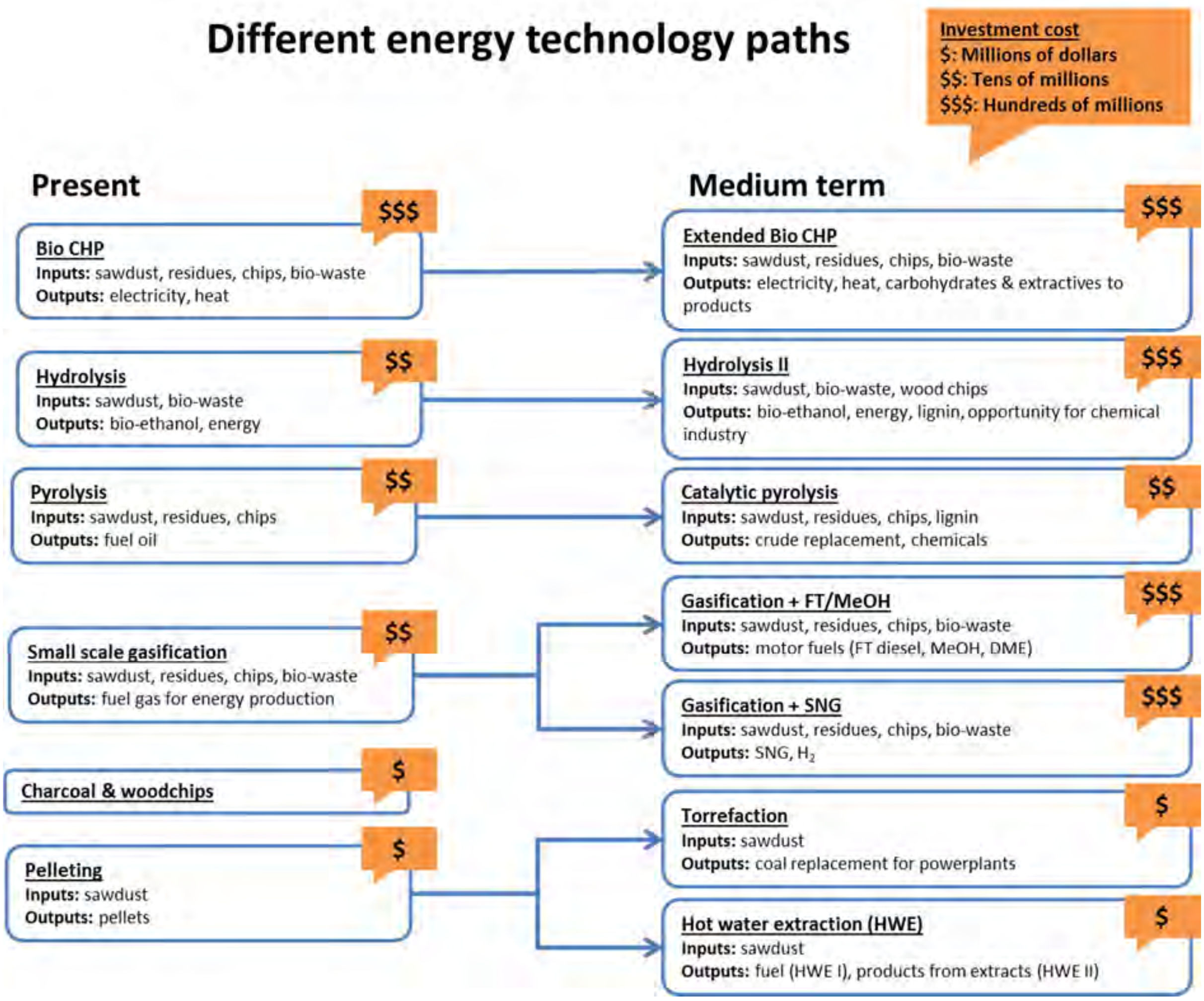


Figure 57. Energy lens – energy technology paths.

Figure 58 presents the business impact-technological feasibility matrix for opportunities identified in the energy lens. An advanced version of hydrolysis (termed “Hydrolysis II”) has the highest estimated business impact and the lowest estimated technological feasibility, implying a certain level of uncertainty. “Catalytic hydrolysis” has an improved technological feasibility but mediocre business impact. Both these two options are relatively unattractive as they lie in the top left hand side of the matrix. For the same reason, Gasification SNG, pyrolysis and charcoal are not particularly attractive, largely as a result of their low business impact. The more interesting technology options lie in the top right hand quadrant in Figure 58, where there are eight technology options in two sets of four; “HWE II”, “Extended Bio CHP”, “Gasification FT/MeOH” and “Hydrolysis that exhibit both moderate technical feasibility and business impact, and “HWE I”, “Pellets”, “Bio CHP” and “Small scale gasification” that has moderate business impact but high technical feasibility.

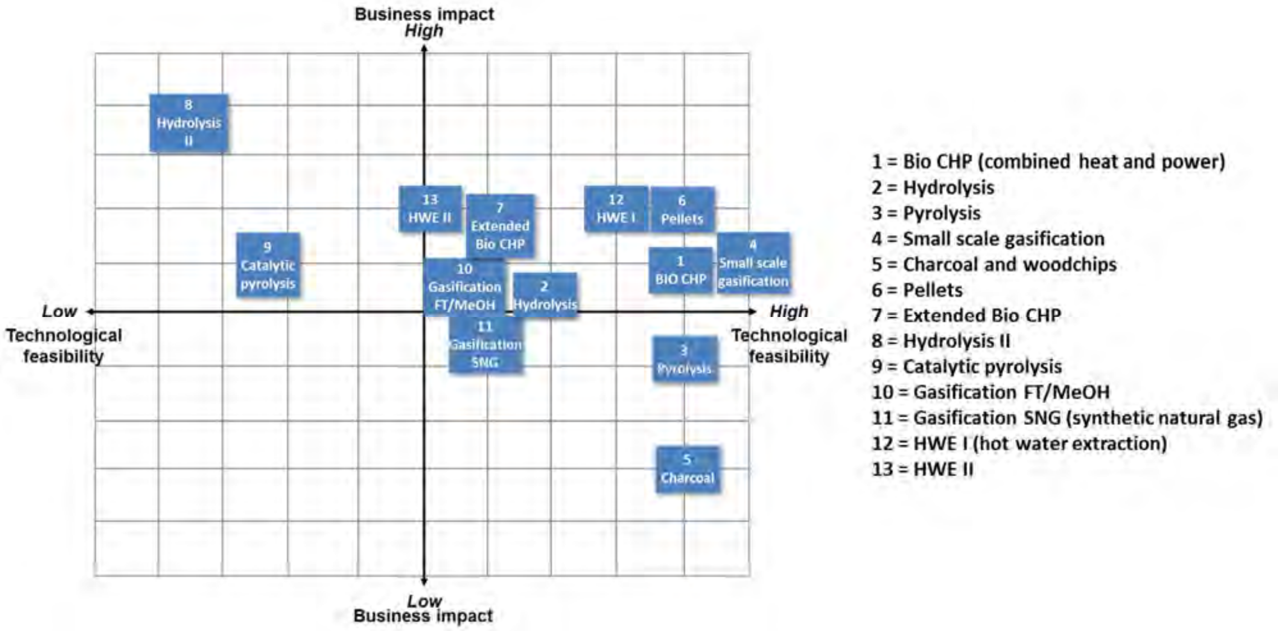


Figure 58. Energy lens in a business impact-technological feasibility matrix. For explanations, see previous Figure 57.

8.6 Portfolio of options in molecular lens

The portfolio of solutions (SOL) identified in the workshops for the molecular lens, are presented in Figure 59.

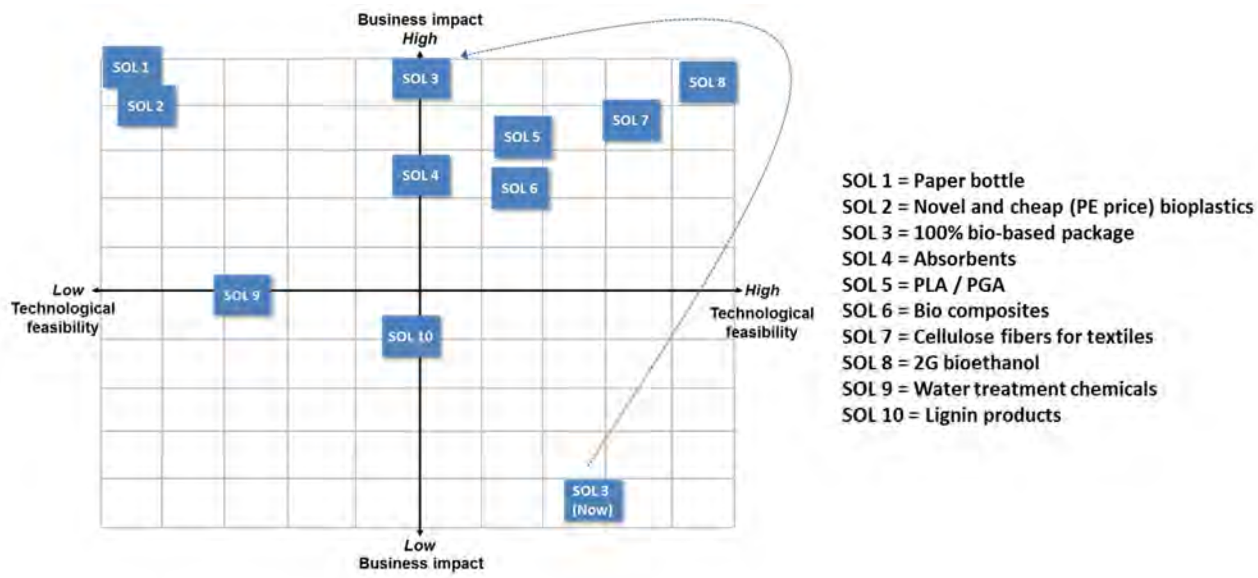


Figure 59. Molecular lens in a business impact-technological feasibility matrix.

As the most attractive solutions are those with high business impact and technical feasibility (top right hand quadrant), those assigned with numbers 1 (paper bottle), 2 (bioplastics), 9 (water treatment chemicals), 10 (lignin) and 3 Now (bio-based packaging) can be disregarded on the basis of their assigned relatively poor business impact or low stage of technical development, meaning there is considerable associated risk. Bio-based packaging (SOL 3) is interesting in that its business impact is estimated to rise significantly in the future as depicted by the arrow in the Figure 59. The solutions (SOL) numbered 4 (absorbents), 5 PLA (polylactic acid) / PGA (polyglycolic acid), 6 (bio-composites), 7 (cellulose fibres for textiles) and 8 (second generation [2G] bioethanol offer the most promising opportunities based on our analysis, particularly the latter two options (SOL 7 and SOL 8).

8.7 Portfolio of options in atomic lens

The portfolio of solutions (SOL) and technologies (TECH) identified in the workshops for the molecular lens is shown diagrammatically in Figure 60.

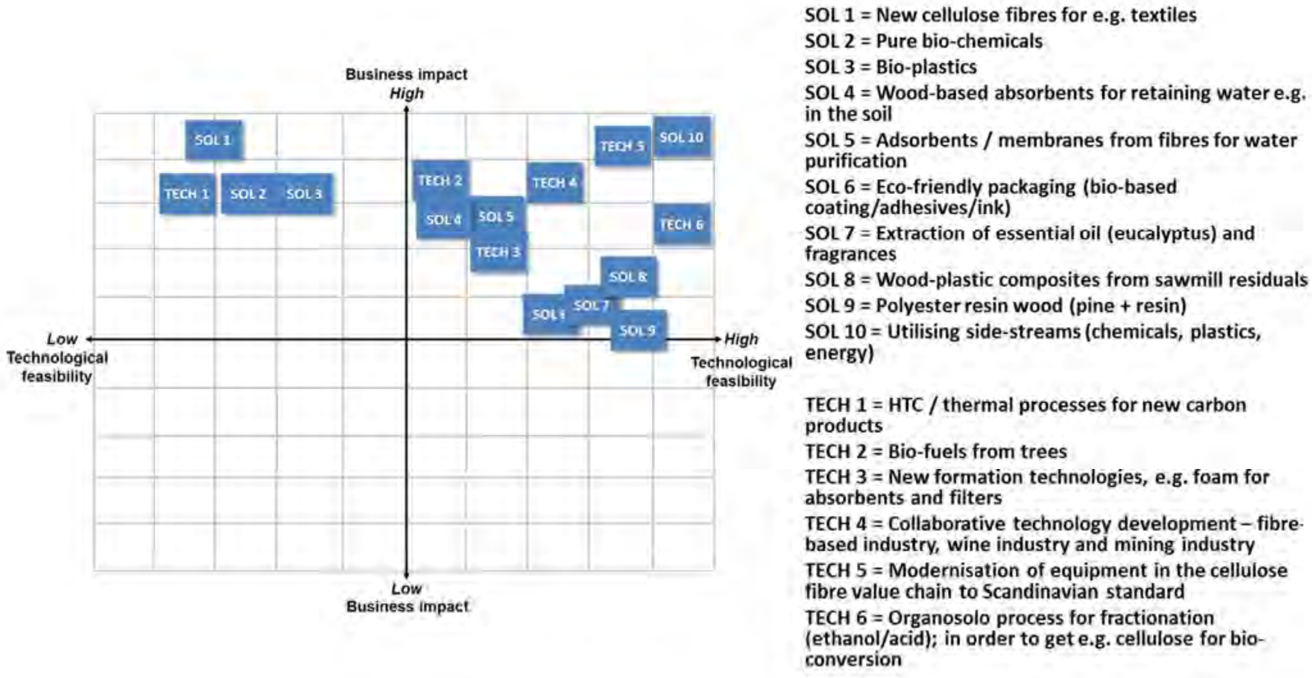


Figure 60. Atomic lens in a business impact-technological feasibility matrix (draft).

The solution and technology options identified for the atomic lens fall loosely into four groups; namely

Group 1 that includes new cellulose fibres for textiles with emerging technology (SOL 1), pure bio-chemicals (SOL 2), bio-plastics (SOL 3) and HTC / thermal processes for new carbon products (TECH 1) that is characterised by high business impact, but low to moderate technical feasibility

Group 2 comprising wood-based absorbents with water retention properties ((SOL 4), adsorbents / membranes from fibres for water purification water (SOL 5), bio-fuels from trees (TECH 2) and new formation technologies such as foam for absorbents and filters (TECH 3) which have high business impact and low to moderate technical feasibility.

Group 3 consisting of eco-friendly packaging as for example bio-based coating/adhesives/ink **(**SOL 6), extraction of essential oil (eucalyptus) and fragrances (SOL 7), wood-plastic composites from sawmill residuals (SOL 8) and polyester resin wood (SOL 9) has moderate to high technical feasibility but moderate business impact.

The solutions and technologies considered as the most promising both from the perspective of business impact and technical feasibility form the final group and include collaborative technology development for the fibre-based, wine and mining industries (TECH 4), modernisation of equipment in the cellulose fibre value chain to Scandinavian standard (TECH 5), organosolv process for fractionation (ethanol/acid) in order to isolate cellulose for bio-conversion (TECH 6) and utilising side-streams for chemicals, plastics and energy (SOL 10).

8.8 Assessing the business aspects in the lenses

This section presents the business assessments for the solutions prioritised in the four lenses as determined by a specific group of VTT experts.

There are two sets of assessments. The first set includes expected value potential, uniqueness and investment requirements, while the second set incorporates three cross-tabulated scatter plots: namely uniqueness versus value potential, uniqueness versus investment requirements, and value potential versus investment requirements. The order of the solutions presented in the Figures 61–68 follows the assessed value potential scores.

8.8.1 Mass lens

In the mass lens, the solutions were prioritised as follows, in descending order:

1 = Foam fibre as insulation
2 = Using wood frame in high-rise apartment housing and in large constructions
3 = Thinner blades
4 = Small logs (bio sawmill)
5 = X-ray scanning
6 = Fork lift outsourcing
7 = Service concepts
8 = Specialisation
9 = Improved sorting
10 = Geometric scanning
11 = Novel treatments and / or thermowood type products
12 = Biobased protective treatments
13 = Protective treatments for wood
14 = Acoustic testing
15 = Composites from low value production

As can be seen from the data in the Figure 61, there are ten solutions in the list assessed to have a specific value potential; five (items 1, 2, 3, 4, and 5) in the category of “high potential”, two (items 6 and 7) as “promising”, and three (items 8, 9 and 10) as “worthwhile”. There were five technologies (items 11, 12, 13, 14, and 15) assessed as “unclear” with respect to value potential.

All the solutions in the mass lens were assessed as moving between “proof of concept” and “existing production” for “uniqueness”.

Investment requirements were harder to prioritize, but solutions 1, 3, 4, 5, 8, 9 and 10 were assessed to require only moderate expenditures.

Based on the results from the scatter plot analyses (Figure 62), the most promising solutions in the mass lens are: thinner blades, bio sawmills utilising small logs, and foam fibre as insulation, while X-ray scanning, improved sorting and specialisation also appear promising. The opportunities for Green Triangle are dicussed in the main report.

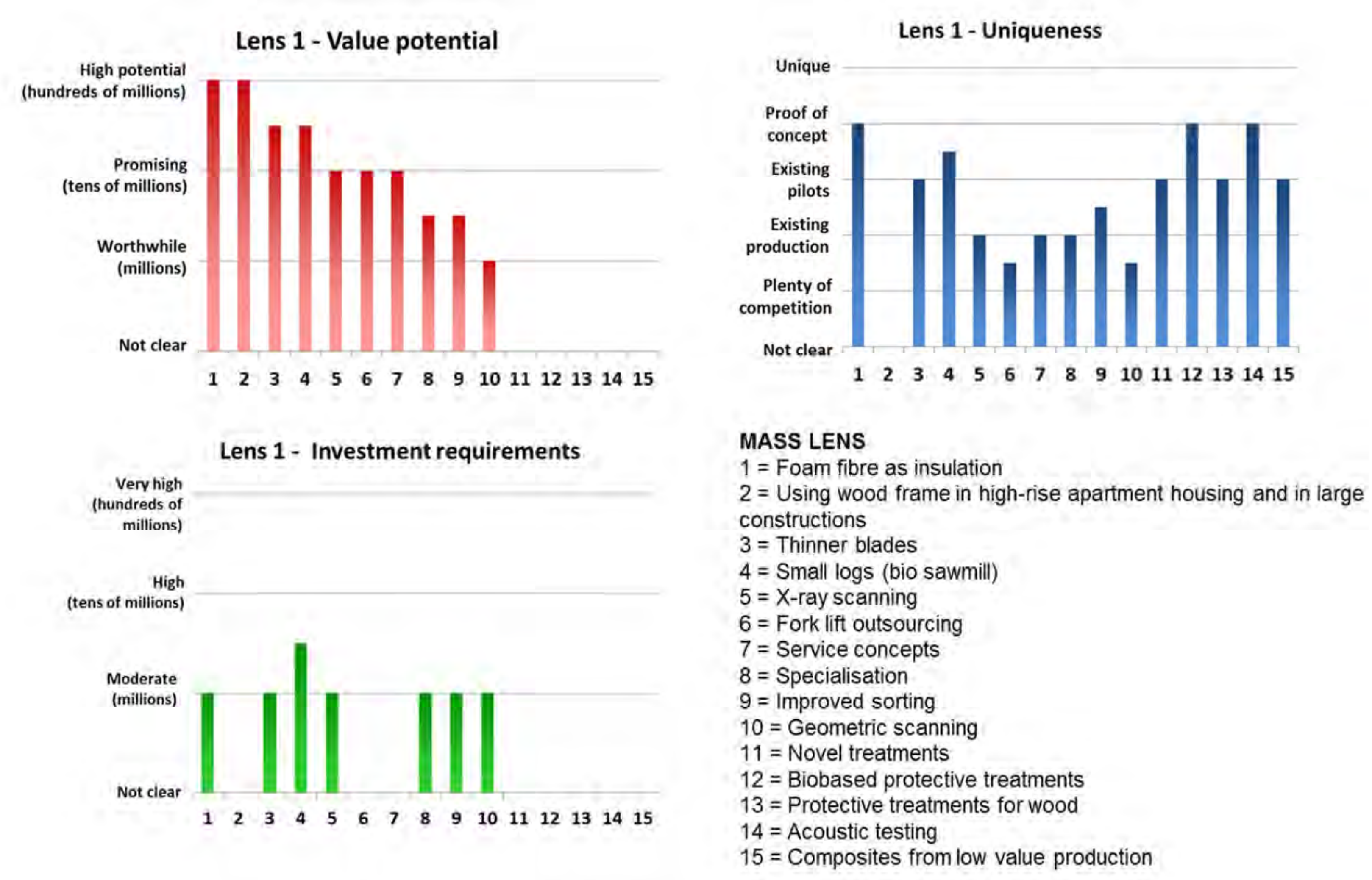
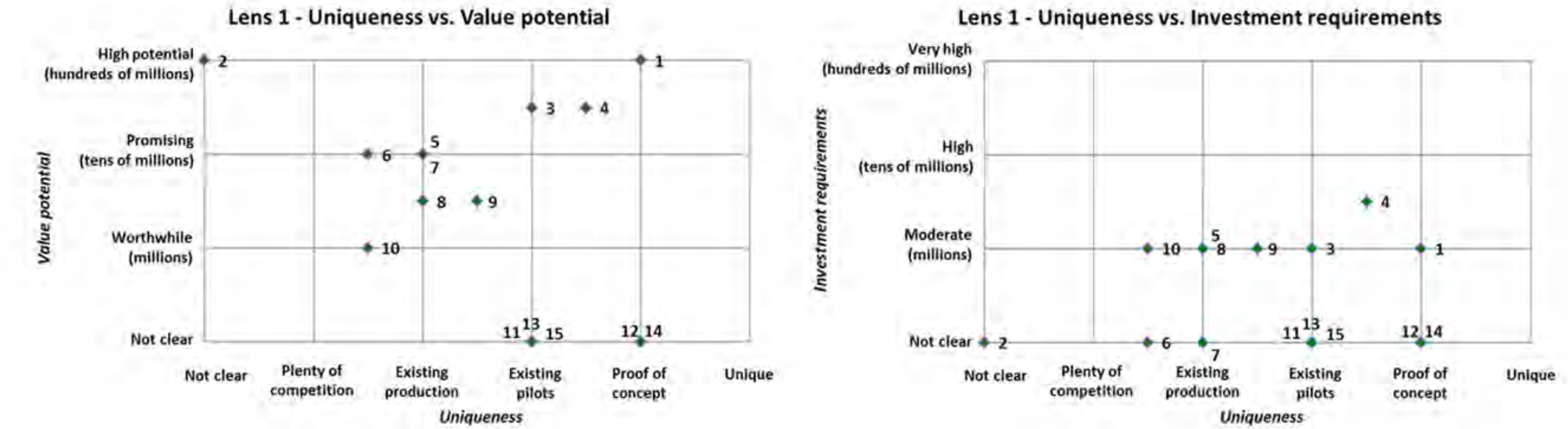
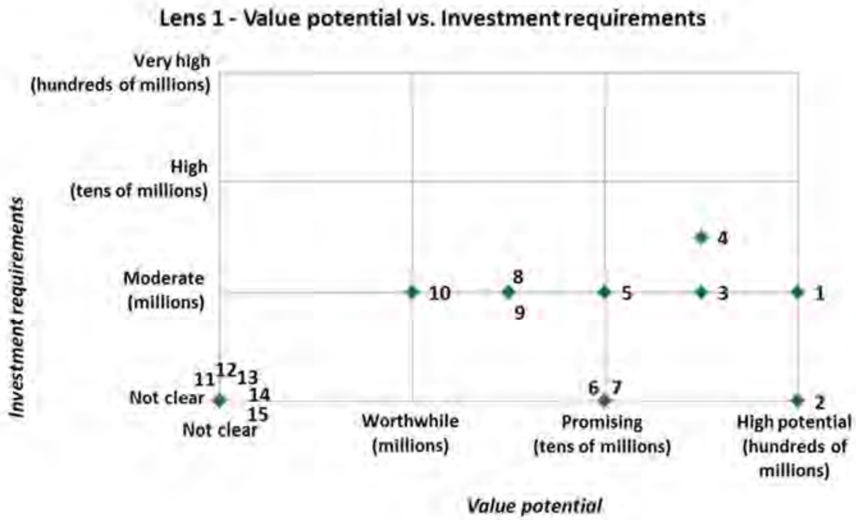


Figure 61. Mass lens – value potential, investment requirements and uniqueness.





MASS LENS

1 = Foam fibre as insulation
2 = Using wood frame in high-rise apartment housing and in large constructions
3 = Thinner blades
4 = Small logs (bio sawmill)
5 = X-ray scanning
6 = Fork lift outsourcing
7 = Service concepts
8 = Specialisation
9 = Improved sorting
10 = Geometric scanning
11 = Novel treatments
12 = Biobased protective treatments
13 = Protective treatments for wood
14 = Acoustic testing
15 = Composites from low value production

Figure 62. Mass lens – scatter plots: uniqueness vs. value potential, uniqueness vs. investment requirements, value potential vs. investment requirements.

8.8.2 Energy lens

In the energy lens, the prioritised solutions were the following, in descending order::

1 = Gasification + FT/MeOH (Fischer Tropsch/Methanol)
2 = Extended Bio CHP (combined heat and power)
3 = Hydrolysis II
4 = Gasification + SNG (synthetic natural gas)
5 = Bio CHP (combined heat and power)
6= Hydrolysis
7 = Pyrolysis
8 = Catalytic pyrolysis
9 = Small scale gasification
10 = Charcoal & woodchips
11 = Pelleting
12 = Torrefaction
13 = Hot water extraction (HWE)

From the data shown in Figure 63, twelve solutions in the list were assessed as having a specific value potential; one (item1) of “high potential”, three (items 2, 3 and 4) as “promising”, and eight (items 5, 6, 7, 8, 9, 10, 11 and 12) as slightly less “promising”. Item 13 or hot water extraction was the one solution that was difficult to quantify.

For the assessment of “uniqueness”, six solutions were in the category “not clear”. Bio CHP, small scale gasification, charcoal and woodchips and pelleting were assessed as technologies where strong competition exists, while for hydrolysis there are existing pilot amenities, and for pyrolysis and torrefaction the presence of actual production facilities.

Investment requirements were assessed as very high or high for solutions 1 to 9, and moderate for the remaining four (solutions10 to 13).

Based on the data in the scatter plots (Figure 64), the most promising solutions in energy lens are: torrefaction, pyrolysis, charcoal and woodchips, and pelleting.

The opportunities for Green Triangle are discussed in the main report.

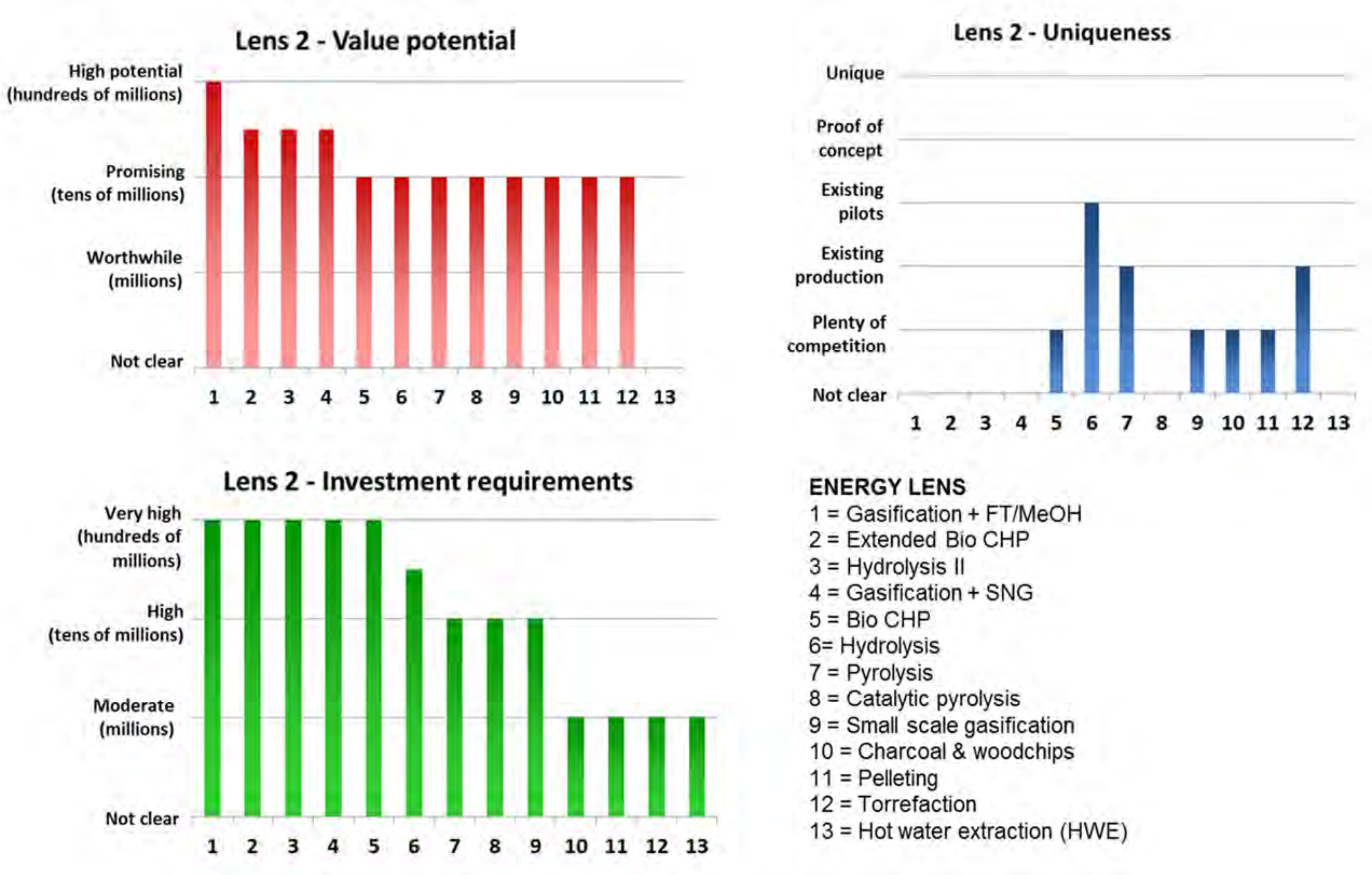


Figure 63. Energy Lens – value potential, investment requirements and uniqueness.

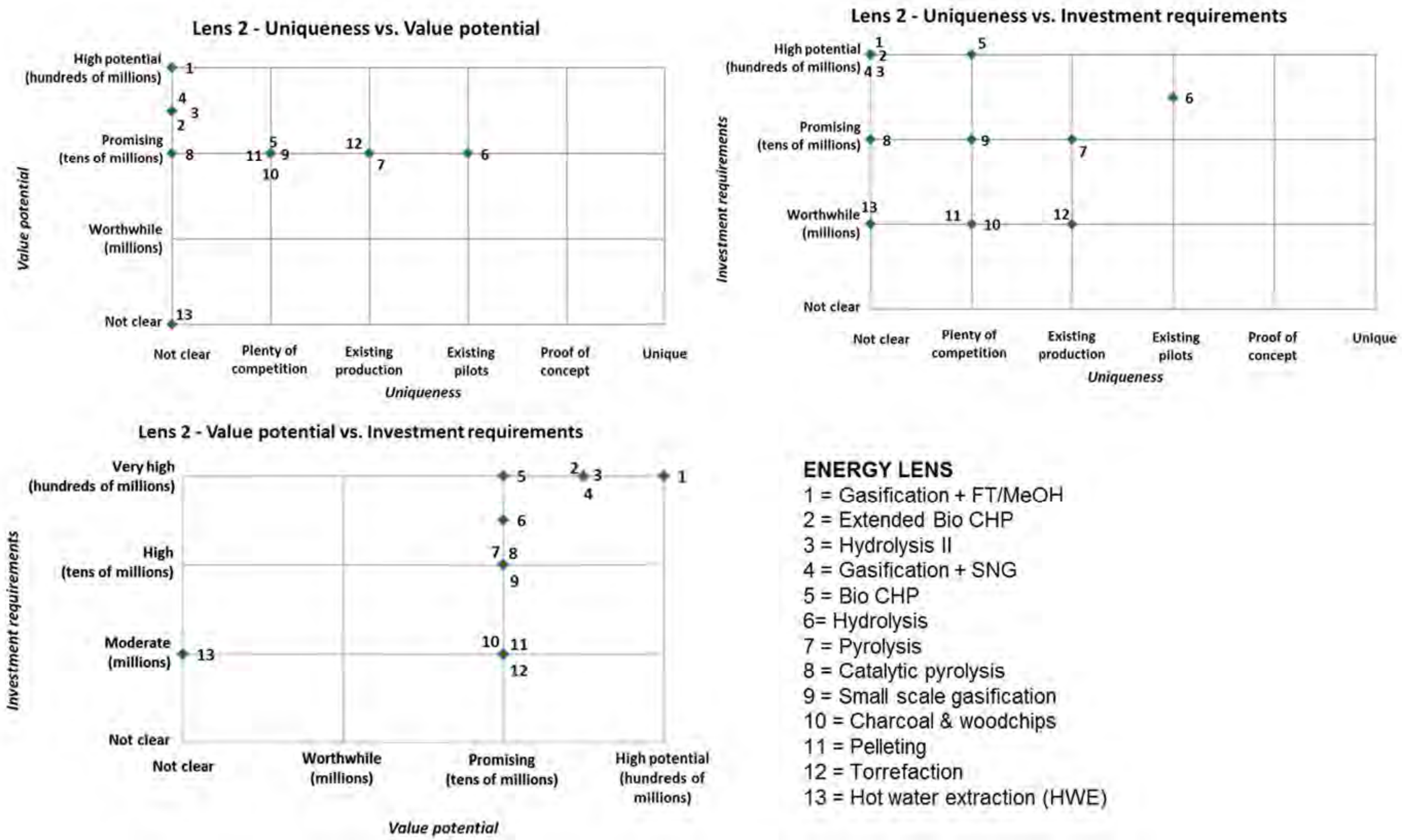


Figure 64. Energy lens – scatter plots: uniqueness vs. value potential, uniqueness vs. investment requirements, value potential vs. investment requirements.

8.8.3 Molecular lens

In the molecular lens, the prioritised solutions were the following, in the descending order:

1 = Paper bottle
2 = Novel and cheap (PE price) bioplastics
3 = Improved bioplastics
4 = Biobased monomers & corresponding polymers
5 = High quality lignin plastics
6 = 100% bio-based package
7 = PLA (polylactic acid) / PGA (polyglycolic acid)
8 = Cellulose fibers for textiles
9 = Water treatment chemicals
10 = Ultra high consistency processing
11 = Absorbents
12 = Biocomposites
13 = 2G bioethanol
14 = Second generation biofuels
15 = Thermo mouldable lignin
16 = Lignin products
17 = Organic acids

In all, seventeen solutions were assessed for value potential in this scenario as shown by the data in Figure 65. The first three (items 1, 2 and 3) were assessed as being of “high potential”, the next three (items 4, 5 and 6) in the same category but at a slightly lower level, the next four (items 7, 8, 9 and 10) as “promising” and the last seven (items 11 to 17) at between “promising” and “worthwhile”.

For the assessment of “uniqueness”, the solutions of high quality lignin plastics (item 5) and thermo mouldable lignin (item 15) were assessed as being “unique”. There were five solutions namely paper bottle (item 1), novel and cheap bioplastics (item 2), PLA (polylactic acid) / PGA (polyglycolic acid) (item 7), ultra high consistency processing (item 10) and thermo mouldable lignin (item 15) that were in the category of at or near “proof of concept”, while biobased monomers and corresponding polymers(item 4)), 100% bio-based package(item 6) and water treatment chemicals (item 9) were close to the “existing pilots” category. The rest of the solutions were grouped in the “existing production” category.

Investment requirements were assessed as high for solutions 1, 2, 7, 8, 12 and 13, moderate for solutions 4, 14, and 17, and intermediate between high and moderate for the remainder.

Based on the scatter plot analyses (Figure 66), the most promising solutions in the molecular lens are improved bioplastics, high quality lignin plastics, biobased monomers & corresponding polymers and paper bottles.

The possibilities from the perspective of Green Triangle are discussed in the main report.

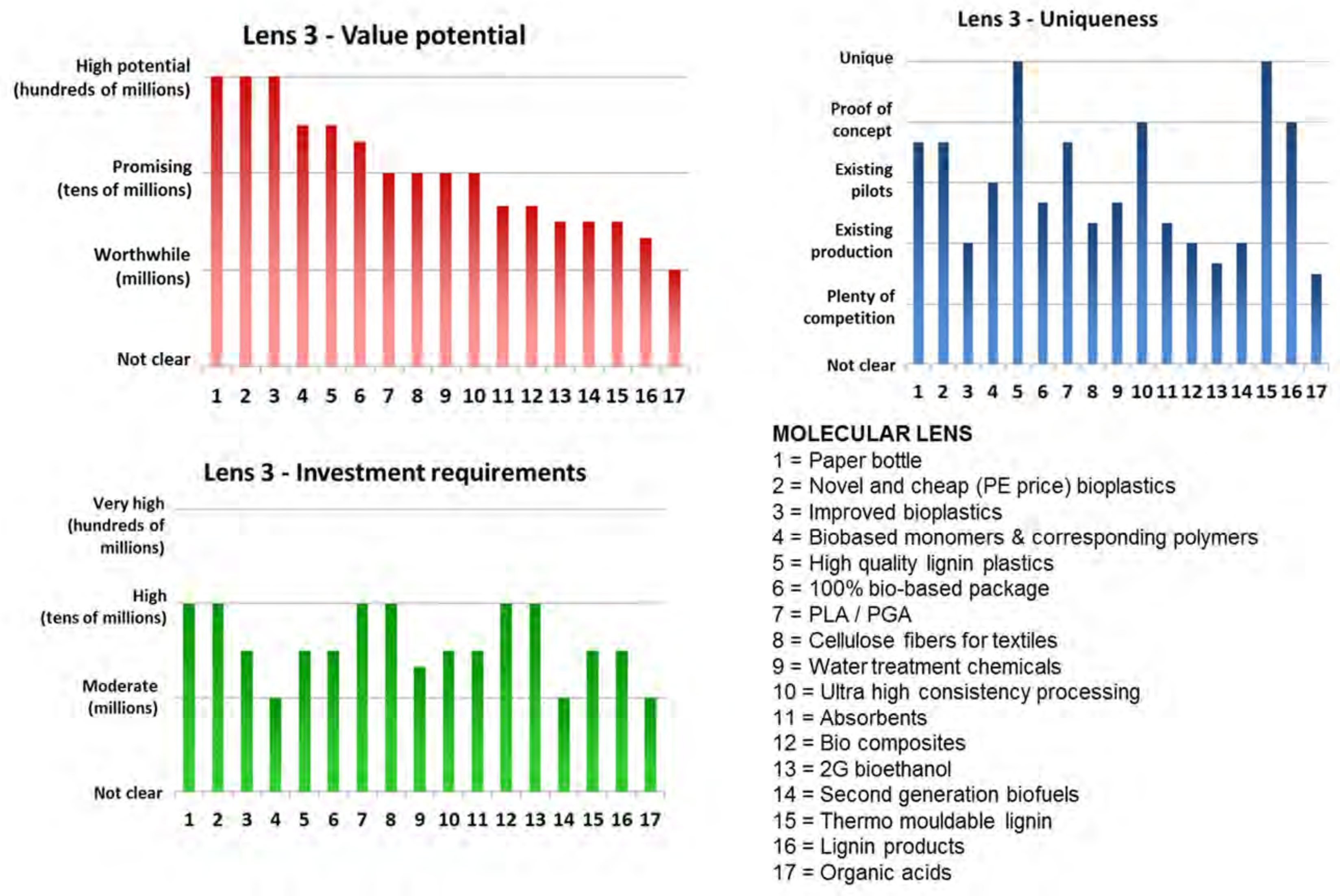
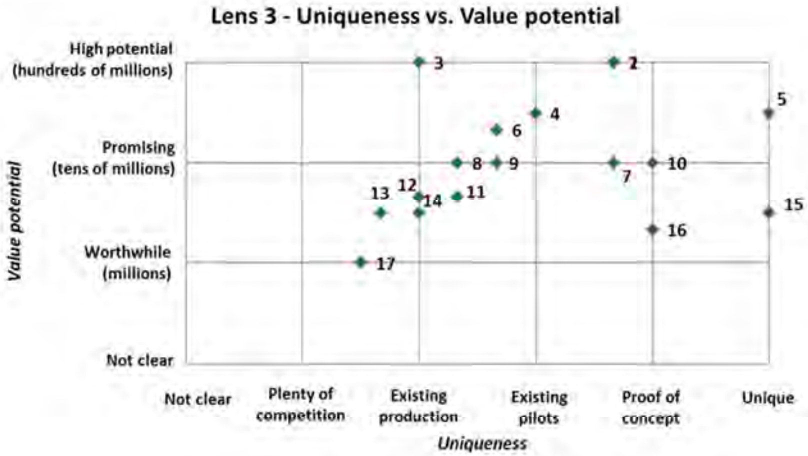
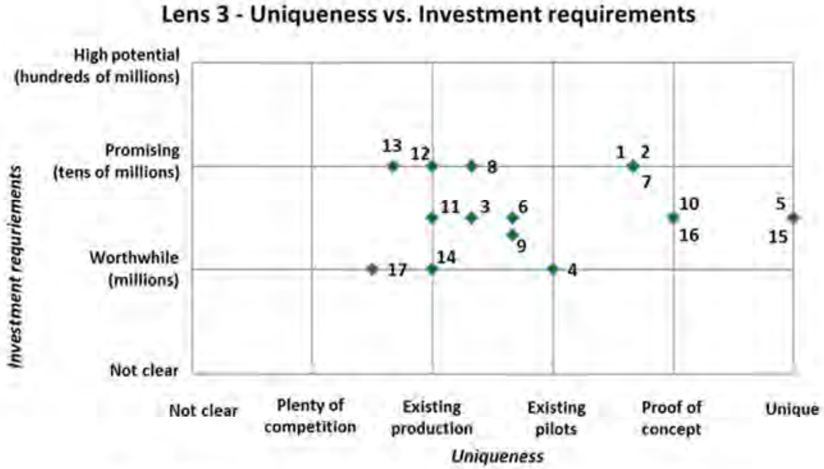
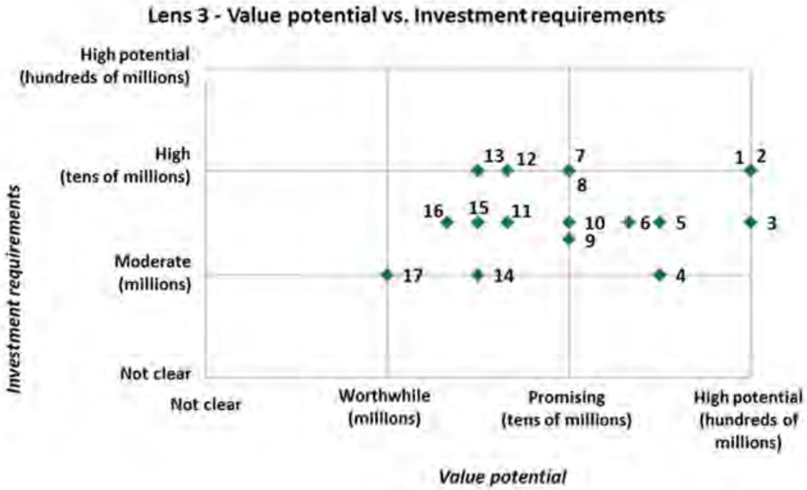


Figure 65. Molecular lens – value potential, investment requirements and uniqueness.







MOLECULAR LENS

1 = Paper bottle
2 = Novel and cheap (PE price) bioplastics
3 = Improved bioplastics
4 = Biobased monomers & corresponding polymers
5 = High quality lignin plastics
6 = 100% bio-based package
7 = PLA / PGA
8 = Cellulose fibers for textiles
9 = Water treatment chemicals
10 = Ultra high consistency processing
11 = Absorbents
12 = Bio composites
13 = 2G bioethanol
14 = Second generation biofuels
15 = Thermo mouldable lignin
16 = Lignin products
17 = Organic acids

Figure 66. Molecular lens – scatter plots: uniqueness vs. value potential, uniqueness vs. investment requirements, value potential vs. investment requirements.

8.8.4 Atomic lens

In the atomic lens, the prioritised solutions were the following, in the descending order:

1 = New cellulose fibres for e.g. textiles
2 = Utilising side-streams (chemicals, plastics, energy)
3 = HTC / thermal processes for new products e.g.active carbon
4 = Biofuels from wood fibres
5 = New formation technologies, e.g. foam for absorbents and filters
6 = Collaborative technology development – fibre-based industry, wine industry and mining industry
7 = Pure biochemicals
8 = Bioplastics
9 = Wood-based absorbents for retaining water e.g. in the soil
10 = Adsorbents / membranes from fibres for water purification
11 = Wood plastic composites from sawmill residuals
12 = Modernisation of equipment in the cellulose fibre value chain to Scandinavian standard
13 = Organosolo process for fractionation (ethanol/acid); in order to get e.g. cellulose for bio-conversion
14 = Eco-friendly packaging (bio-based coating/adhesives/ink)
15 = Extraction of essential oil (eucalyptus) and fragrances
16 = Polyester resin wood (pine + resin)

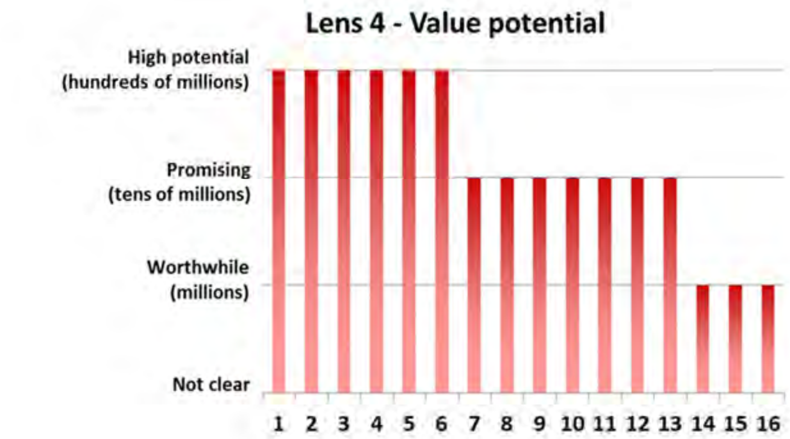
Based on the analysis presented in Figure 67, the solutions in the list above were assessed as being of “high potential” (items 1, 2, 3, 4, 5 and 6), as “promising” (items 7, 8, 9, 10, 11, 12 and 13) or “worthwhile” (items 14, 15 and 16).

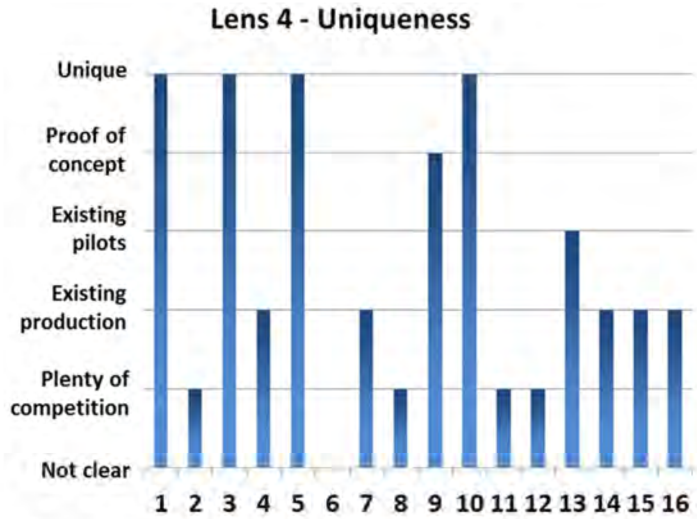
For the assessment of “uniqueness”, four solutions were assessed as being “unique”; namely: new cellulose fibres for textiles (item 1), HTC / thermal processes for new carbon products (item 3), new formation technologies such as foam for absorbents and filters (item 5) and adsorbents / membranes from fibres for water purification(item 10). Wood-based absorbents for retaining water as for example in soil (item 9) was assessed as being at the “proof concept” stage, while the organosolv process for fractionation in order to isolate cellulose for bio-conversion (item 13) was assigned as being at the “existing pilot” phase. All the other solutions were considered as being either in “existing production” or at “plenty of competition”.

The investment requirements were assessed as very high or high for solutions 1 to 5, 8, 9 and 12, moderate for solutions 10, 11, 14, 15, and 16, and “not clear” for solutions 6, 7 and 13.

The most promising solutions for the atomic lens based on the scatter plot data in Figure 68 are adsorbents / membranes from fibres for water purification, wood-plastic composites from sawmill residuals, new cellulose fibres for textiles) and utilising side-streams for chemicals, plastics, or energy.

As with preceding sections, the key opportunities for Green Triangle are discussed in the main report.

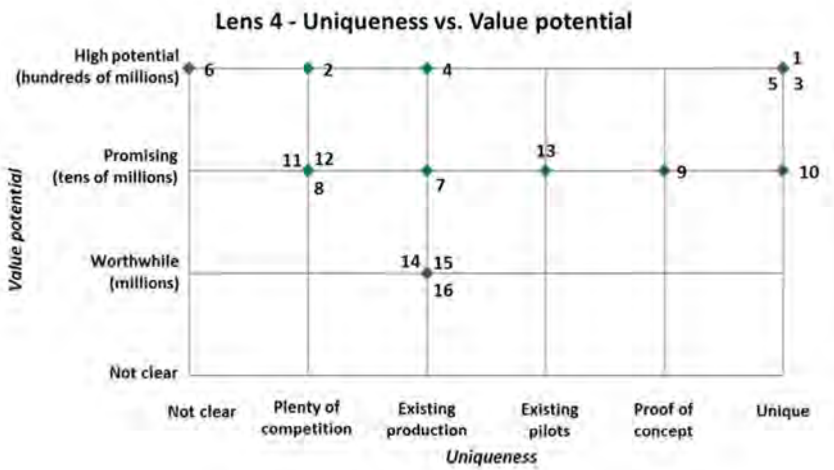


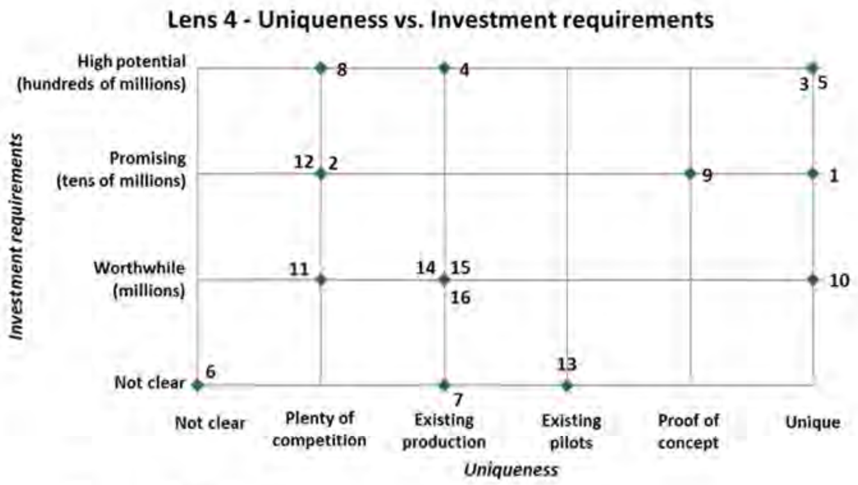


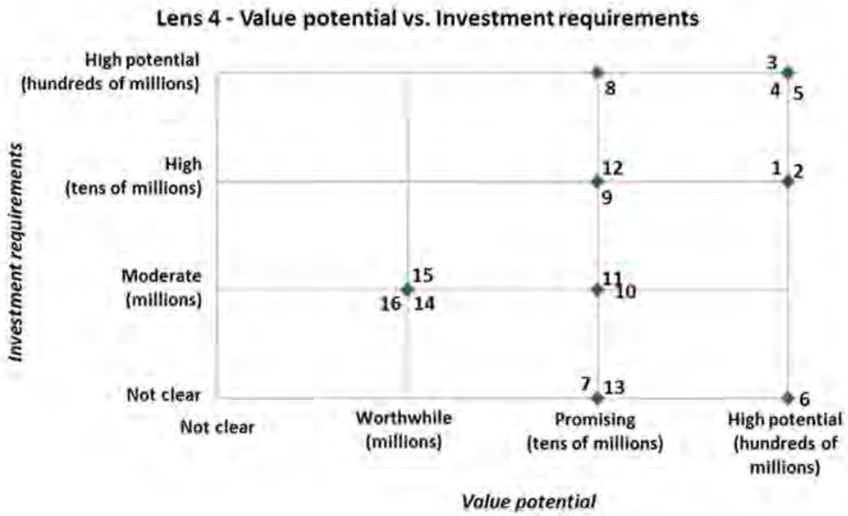
ATOMIC LENS

1 = New cellulose fibres for e.g. textiles
2 = Utilising side-streams (chemicals, plastics, energy)
3 = HTC / thermal processes for new carbon products
4 = Biofuels from wood fibres
5 = New formation technologies, e.g. foam for absorbents and filters
6 = Collaborative technology development – fibre-based industry, wine industry and mining industry
7 = Pure biochemicals
8 = Bioplastics
9 = Wood-based absorbents for retaining water e.g. in the soil
10 = Adsorbents / membranes from fibres for water purification
11 = Wood-plastic composites from sawmill residuals
12 = Modernisation of equipment in the cellulose fibre value chain to Scandinavian standard
13 = Organosolo process for fractionation (ethanol/acid); in order to get e.g. cellulose for bio-conversion
14 = Eco-friendly packaging (bio-based coating/adhesives/ink)
15 = Extraction of essential oil (eucalyptus) and fragrances
16 = Polyester resin wood (pine + resin)

Figure 67. Atomic lens – value potential, investment requirements and uniqueness.







ATOMIC LENS

1 = New cellulose fibres for e.g. textiles
2 = Utilising side-streams (chemicals, plastics, energy)
3 = HTC / thermal processes for new carbon products
4 = Biofuels from wood fibres
5 = New formation technologies, e.g. foam for absorbents and filters
6 = Collaborative technology development – fibre-based industry, wine industry and mining industry
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10 = Adsorbents / membranes from fibres for water purification
11 = Wood-plastic composites from sawmill residuals
12 = Modernisation of equipment in the cellulose fibre value chain to Scandinavian standard
13 = Organosolo process for fractionation (ethanol/acid); in order to get e.g. cellulose for bio-conversion
14 = Eco-friendly packaging (bio-based coating/adhesives/ink)
15 = Extraction of essential oil (eucalyptus) and fragrances
16 = Polyester resin wood (pine + resin)

Figure 68. Atomic lens – scatter plots: uniqueness vs. value potential, uniqueness vs. investment requirements, value potential vs. investment requirements.

9. APPENDIX 9: Policy options and recommendations: workshop results

9.1 Summary

This section sums up the the intermediate policy recommendations as formed in the VTT expert workshops. The workshop process is highlighted by two elements: firstly, the ideas that were created during the roadmapping process and seem to cut through the roadmaps lenses (mass, energy, molecular, atomic) and, secondly, the most critical differences between the lenses. This section seeks to outline the most plausible development options for Green Triangle that cross-cut the four lenses. In addition the interpretation attempts to identify some disruptive developments. The policy recommendations were constructed from the perspective of Green Triangle. The final and more detailed discussion on policy recommendations is located in the main report.

9.2 Assessing the policy options

A tailored definition of policy option was created for the workshop. As defined for this purpose, policy option was defined as:

> *Any kind of action or activity that policy actors can engage in to support fibre-based industry – it can be direct subsidies, investments to biorefineries, setting up new kinds of training programmes, endorsing global research collaboration, crafting regional strategies etc.*

The integrated methodological approach enables the production of detailed policy recommendations on a robust basis (so-called 'evidence-based policy approach'). In addition, in the course of project the possibilities to engage in so-called 'platform policies' (see e.g. Boschma et al. 2011, Cooke 2008a, 2008b, Lazarix et al. 2008) will be evaluated. It means at this stage that possibilities for increased co-operation and joint strategy process in the region will be, at least to some extent, mapped.

The key idea in structuring the policy options was to seek both so-called implementation strategies and adaptive strategies. Implementation strategies emphasise actions that could be plausibly introduced in the Green Triangle in order to produce new innovation dynamics in the fibre-based value chain, and novel production niches for the region. But when the implementation strategies, e.g. for strategic differentiation, are implausible, one should seek adaptive strategies. Adaptive strategies are strategic options emphasise the ways to tap in the existing global streams in forest and wood products industry. For example, one could seek "strategic holes" in the global streams, that is, local opportunities that could have the potential to go against the stream and be disruptive in the longer term.

Group 1 − Revival of forest and wood prodcuts industry through proactive product, process and business development (Table 24)

- Emphasis on the product, process and business development with a wide focus
- Includes both more traditional forest and wood products industry (e.g. sawmills, pulp), but also more future-oriented aspects, such as new service concepts and biorefineries

Table 24. Results from the group 1: Revival of forest and wood products industry through proactive product, process and business development.

Option (name)	*Key actors*	*Enabling factors*	*Bottlenecks*	*Existing business cases / competitors*
Priority 1: Raw material rationalisation • Small logs vs. large logs • Rational of logistics for logs • Local use of small size logs • Novel treatment • Side stream utilisation • Bio-crude	• Industry	• Better cluster mentality • Better utilization of raw material • High reform • Limited cost	• Lack of “cluster” mentality • New thinking required	• Scandinavian technology suppliers
Priority 2: Promoting the use of wood across the society • Building legislation • Architectural issues • Education programs • Extended understanding on the possibilities of wood	• Government • Universities • Industry • Building links between key players • Timber industry associations	• Lobbying • Political decisions • Common attitudes • Communication • Case studies	• Negative sentiments; “exploiters of forests”, better education • Other interest groups (mining car, etc.) are more powerful	• Finland • Sweden • Austria
Priority 3: Measurement technologies • Acoustic testing • X-ray scanning • Geometric scanning • Thinner blades	• Mill personnel • Bintec Oy • Microtec S.A	• Standards • Education • Case studies • Co-operation • Equipment suppliers	• Cost • Not enough experience	• Scandinavian technology suppliers
Priority 4: Common practices across the state borders • From Green Triangle towards an integrated Limestone Coast	• State government • Local government • Hauliers	• Common legislation • Study tours for world’s best practices	• Politics • Transportation, e.g. improve roads • Pricing of power & energy across states	• North America? • EU

Group 2 – Industry renewal through energy biorefinery (Table 25)

- Focus mainly on biorefineries through the energy lens
- Includes aspects related to biochemicals and biomaterials

Table 25. Results from the group 2: industry renewal through energy biorefinery.

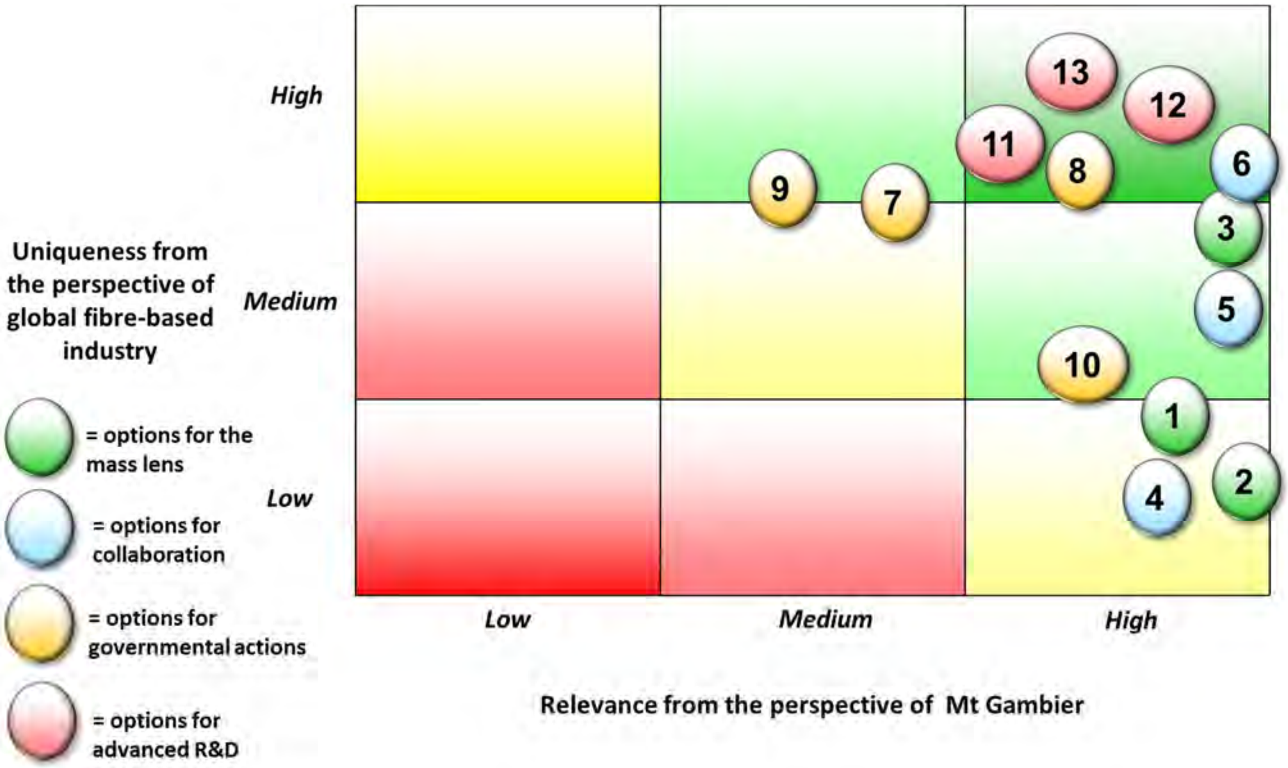
Option (name)	*Key actors*	*Enabling factors*	*Bottlenecks*	*Existing business cases / competitors*
1: Networking collaboration	• Industries • Policy makers, regulators • Research units (CSIRO, Universities) • NGO's	• Training workshops, awareness rising • Profitable value chain creation • Workshop with wine industry, Re: international business • Supplier development measures	• "Narrow" mindsets (cultural traditions) • Slow response of government • Late actions of SA government (in comparison to other Australian states)	• Wine industry experiences (e.g. confederation networking) • SHOKs in Finland, especially FIBIC • SPIRE PPP, BRIDGE PPP
2: Research, education & training	• Initiator: Governmental organisations • Actors: Research & education organisations • Companies (training programs to improve personnel's skills)	• Federations play role (ct. Wine industries) • International research cooperation (visiting professors & researchers) • Joint R&D centres	• Local resistance to change • Lack of promotion	• EU funding of projects & cooperation between countries • COST Actions • "KCL-model" • FiDiPro as financier of visiting professors
3: Government regulation	• Government • Consultants	• Follow lead market" approach (e.g. Californian regulation) • "Right" pricing according to scarcity	• Role of government vs. "hands-off" culture (Is this changing?)	• SPIRE PPP Zero-waste processes • Californian environmental regulation
4: Government sustainability policy	• Government • Consultants	• A well informed government aware of options available • Public procurement to demonstration of 2nd generation biofuels • Turning challenges into opportunities	• Attractiveness of mining industries (investments, skilled workforce etc.) • Shale gas competition	• EU directives • Biomass Action Plan • 2020-policy
5: Government incentives	• Government • Consultants	• Awareness of options available to local business • Government incentives for modernizing equipment, i.e. tax breaks • Government incentives for foreign investments (tax breaks etc.)	• Money	• NER 300 • US DOE investment programmes

Group 3 – Radical industry renewal through new biomass and fibre-based production, incl. diversified second and third generation biorefineries (Table 26)

- Focus mainly on the second and third generation biorefineries and more radical options in the fibre-based industry

Table 26. Results from the group 3: Radical industry renewal through new biomass and fibre-based production, incl. diversified second and third generation biorefineries.

Option (name)	*Key actors*	*Enabling factors*	*Bottlenecks*	*Existing business cases / competitors*
Water management • purification, desalinization • retaining water • adsorbents-> wine industry, mining industry **Absorbents** • Agriculture • Horticulture • Erosion control **Water purification**	Kemira Ahlström Metso Food industry	**Clean water** • Drinking water • Mining industry • Wine industry	Lack of technology Investors needed Resources and conversion	
Fibre production and converting • Fibre materials: packages, textiles, filters **Functional fibre-based materials** • Composites • Plastics • Films, membranes • Packaging -> electronics, organic photovoltaics	Forest and wood products industry Chemical industry Construction industry Film and membrane + textile producers Food industry	Sawmills are existing and harvesting Globally existing solutions	As above Pulp mill is needed	
Wood-based chemicals • Fuels • Pharmaceuticals • Oils • Water purification • Flocculants **Biochemical cluster** Precursors e.g. for plastics and chemical industries Biochemicals and converted products	UPM Daicel Neste Oil Naval stove industry Chemical companies	Abundant availability of eucalyptus oils and resins Existing solutions	Lack of biorefineries concept Energy efficiency: combustion vs upgrading/utilisation	



1. Raw material rationalisation
- Small logs vs. large logs
- Rational of logistics for logs
- Local use of small size logs
- Novel treatment
- Side stream usage
- Bio-crude

2. Promoting the use of wood across the society
- Building legislation
- Architectural issues
- Education programs
- Extended understanding on the possibilities of wood

3. Measurement technologies
- Acoustic testing
- X-ray scanning
- Geometric scanning
- Thinner blades

4. Common practices across the state borders
- From Green Triangle towards an integrated Limestone Coast

5. Networking/collaboration
- Create networks between producers and consumers (i.e. between energy biorefinery owner and ship owners / mining industry)
- Creation of link with mining + wine industry for fuels
- Demand for local production to minimize transportation
- Generate local + commercial interest in bioplastics / composites (i.e. education & promotion of idea)

6. Development of regional cluster structures in energy and in biochemical production
- Precursors e.g. for plastics and chemical industries
- Wood-based chemicals: fuels, pharmaceuticals, oils, water purification, flocculants
- Biochemicals and converted products

7. Research, education & training
- Different level of education available locally
- External R&D by bio-experts to fill local absence of scientific experts

8. Government regulation
- Environmental regulation & standardisation
- Waste minimization
- Zero-waste process required

9. Government sustainability policy
- National bio-directives (bioenergy, biofuels, biochemicals)
- Develop "demand" for heat (lots of excess heat generated in energy biorefinery process)

10. Government incentives
- Investment support, taxation etc.
- R&D funding
  - Piloting
  - Demonstration

11. Development of cellulose-based solutions for water management
- Water purification, desalinization, retaining water
- Adsorbents: wine industry, mining industry
- Absorbents: agriculture, horticulture, erosion control

12. Development of capacities for fibre production and converting
- Fibre materials: packages, textiles, filters

13. Development capacities for producing functional fibre-based materials
- Composites, plastics, films, membranes, packaging -> electronics, organic photovoltaics

Figure 69. Policy option grid: the prioritised intermediate policy options as assessed by VTT experts.

10. APPENDIX 9: References

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11. APPENDIX 11: Participants in the VTT workhops

Workshop 1, 26 April 2013

1 Jussi Manninen, VTT
2 John Kettle, VTT
3 Annaleena Kokko, VTT
4 Henna Sundqvist, VTT
5 Jaakko Hiltunen, VTT
6 Marjo Määttänen, VTT
7 Toni Ahlqvist, VTT
8 Sauli Vuoti, VTT
9 Anna Leinonen, VTT
10 Tiina Nakari-Setälä, VTT
11 Tarja Tamminen, VTT
12 Eemeli Hytönen, VTT
13 Antti Korpela, VTT
14 Jarmo Ropponen, VTT
15 John Kettle, VTT
16 Harri Setälä, VTT
17 Esa Torniainen, VTT
18 Ali Harlin, VTT
19 Christiane Laine, VTT
20 Kyösti Valta, VTT
21 Lauri Kuutti, VTT
22 Tekla Tammelin, VTT
23 Anna Suurnäkki, VTT
24 Mikko Dufva, VTT
25 Jouko Myllyoja, VTT

Workshop II, 16 May 2013

1 Toni Ahlqvist, VTT
2 Tekla Tammelin, VTT
3 Eemeli Hytönen, VTT
4 John Kettle, VTT
5 Jaakko Hiltunen, VTT
6 Nafty Vanderhoek, VTT
7 Jarmo Ropponen, VTT
8 Anna Leinonen, VTT
9 Tiina Nakari-Setälä, VTT
10 Sauli Vuoti, VTT
11 Jouko Myllyoja, VTT
12 Antti Korpela, VTT
13 Klaus Niemelä, VTT
14 Jaakko Hiltunen, VTT
15 Ville Valovirta, VTT
16 Torsti Loikkanen, VTT
17 Antti Kivimaa, VTT
18 David Thomas, VTT
19 Timo Pekkarinen, VTT

12. APPENDIX 12: The literature scan

This section includes a selected list of literature reviewed for this project, but not necessarily referred to in the actual report.

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13. APPENDIX 13: Biorefinery summary tables from EU initiative COST FP0901

Permission to reproduce the information in the attacted tables was given by Mehrdad Arshadi, Associate Professor, Swedish University of Agricultural Sciences, Department of Forest Biomaterials and Technology, Umeå, Sweden.

Table A.1. Biorefinery summary tables from EU initiative COST FP0901.

Project owner	Project name	Country	Technology	Raw material	Product	Facility Type	Status	Start-up year	Web	Technology brief
Aalborg University Copenhagen	BornBiofuels optimization	Denmark	biochemical conversion	lignocellulosics; wheat straw, cocksfoot grass	ethanol; biogas;	pilot	operational	2009	www.sustainablebiotechnology.aau.dk	BornBiofuels Optimization involves the further optimization of the 2nd generation bioethanol concept behind the BornBiofuels (EUDP) demo project of the company Biogasol. Optimization includes increasing the yield of bioethanol, biogas and hydrogen, reducing the input of energy and external enzymes, and improving the process robustness of the whole biorefinery scheme. Pilot testing will be performed on an optimized process integration including modified pretreatment and hydrolysis, on-site enzyme production, and with improved and adapted fermentation strains. New process configurations will be tested on potential biomass resources, relevant for the BornBiofuels project.
Abengoa Bioenergy Biomass of Kansas, LLC	Commercial	United States	biochemical conversion	lignocellulosics; corn stover, wheat traw, switch grass;	Ethanol;	commercial	under contruction	2013	www.abengoabioenergy.com	Steam explosion coupled with biomass fractionation, C5/C6 fermentation, distillation for ethanol recovery. Heat and power is provided by means of biomass gasification. Cogeneration of 18 MW gross electrical power.
Abengoa Bioenergy New Technologies	Pilot	United States	bioquemical conversion	lignocellulosics; corn stover	Ethanol;	pilot	operational	2007	www.abengoabioenergy.com	-
Abengoa Bioenergy, Biocarburantes Castilla y Leon, Ebro Puleva	Demo	Spain	biochemical conversion	lignocellulosics; cereal straw (mostly barley and wheat)	Ethanol;	demo	operational	2008	www.abengoabioenergy.com	Steam explosion, no fractionation, Enzymatic Hydrolysis (glucose)
Abengoa Bioenergy, S.A.	Abengoa Arance EC demonstration	France	biochemical conversion	lignocellulosics; agricultural and forest residues	ethanol;	demo	planned	2013	www.abengoabioenergy.com	Steam explosion , Saccharification, C6 sugars fermentation, Enzymes, Distillation, Anaerobic digestion process
Aemetis	Pilot	United States	biochemical conversion	lignocellulosics; switchgrass, grass seed, grass straw and corn stalks	Ethanol;	pilot	operational	2008	www.aebiofuels.com	ambient temperature starch/ cellulose hydrolysis (ATSCH)

Project owner	Project name	Country	Technology	Raw material	Product	Facility Type	Status	Start-up year	Web	Technology brief
AliphaJet Inc.	AliphaJet Pilot Plant	United States	chemical conversion	oils, fats; Oils from soy, beef tallow, waste veg. oil, and oil crops such as camelina, jatropha, pennycress, and pongamia	diesel; jet fuel;	pilot	planned	2013	www.aliphajet.com	AliphaJet's proprietary catalytic deoxygenation ("decarboxylation") technology converts any renewable oils and fats (such as waste vegetable oil, tallow, algal oil, and non-food oil crops like pennycress, camelina, jatropha, and pongamia), into true "drop-in" hydrocarbon fuels including diesel (F-76), jet fuel (Jet-A, JP-5, JP-8), and high-octane gasoline. It does this by catalytically removing the oxygen from the fatty acids contained in triglyceride oils, producing hydrocarbons and glycerine as the sole products
Amyris, Inc.	Amyris Antibioticos	Spain	biochemical conversion	fermentable sugars; sugar beet; dextrose	hydrocarbons	commercial	operational	2011	www.amyris.com	Conversion of fermentable sugars to a 15-carbon hydrocarbon, called beta-farnesene using genetically modified microorganisms in fermentation. Farnesene can be converted to render: a. Fuels (primarily diesel) b. Lubricants c. Polymers and Plastic Additives d. Cosmetics e. Consumer Products Ingredients f. Flavors and Fragancies
Amyris, Inc.	Amyris Biomin	Brazil	biochemical conversion	fermentable sugars; sugarcane	hydrocarbons	commercial	operational	2010	www.amyris.com	Conversion of fermentable sugars to a 15-carbon hydrocarbon, called beta-farnesene using genetically modified microorganisms in fermentation. Farnesene can be converted to render: a. Fuels (primarily diesel) b. Lubricants c. Polymers and Plastic Additives d. Cosmetics e. Consumer Products Ingredients f. Flavors and Fragancies
Amyris, Inc.	Amyris Paraiso	Brazil	biochemical conversion	fermentable sugars; sugarcane	hydrocarbons	commercial	planned	2012	www.amyris.com	Conversion of fermentable sugars to a 15-carbon hydrocarbon, called beta-farnesene using genetically modified microorganisms in fermentation. Farnesene can be converted to render: a. Fuels (primarily diesel) b. Lubricants c. Polymers and Plastic Additives d. Cosmetics e. Consumer Products Ingredients f. Flavors and Fragancies
Amyris, Inc.	Amyris Pilot & Demonstration Plant	Brazil	biochemical conversion	fermentable sugars; sugarcane	hydrocarbons	demo	operational	2009	www.amyris.com	Conversion of fermentable sugars to a 15-carbon hydrocarbon, called beta-farnesene using genetically modified microorganisms in fermentation. Farnesene can be converted to render: a. Fuels (primarily diesel) b. Lubricants c. Polymers and Plastic Additives d. Cosmetics e. Consumer Products Ingredients f. Flavors and Fragancies
Amyris, Inc.	Amyris Sao Martinho	Brazil	biochemical conversion	fermentable sugars; sugarcane	hydrocarbons	commercial	planned	2013	www.amyris.com	Conversion of fermentable sugars to a 15-carbon hydrocarbon, called beta-farnesene using genetically modified microorganisms in fermentation. Farnesene can be converted to render: a. Fuels (primarily diesel) b. Lubricants c. Polymers and Plastic Additives d. Cosmetics e. Consumer Products Ingredients f. Flavors and Fragancies
Amyris, Inc.	Amyris Tate & Lyle	United States	biochemical conversion	fermentable sugars; corn dextrose	hydrocarbons	commercial	operational	2011	www.amyris.com	Conversion of fermentable sugars to a 15-carbon hydrocarbon, called beta-farnesene using genetically modified microorganisms in fermentation. Farnesene can be converted to render: a. Fuels (primarily diesel) b. Lubricants c. Polymers and Plastic Additives d. Cosmetics e. Consumer Products Ingredients f. Flavors and Fragancies
Amyris, Inc.	Amyris USA	United States	biochemical conversion	fermentable sugars; sugarcane	hydrocarbons	pilot	operational	2008	www.amyris.com	Conversion of fermentable sugars to a 15-carbon hydrocarbon, called beta-farnesene using genetically modified microorganisms in fermentation. Farnesene can be converted to render: a. Fuels (primarily diesel) b. Lubricants c. Polymers and Plastic Additives d. Cosmetics e. Consumer Products Ingredients f. Flavors and Fragancies

Project owner	Project name	Country	Technology	Raw material	Product	Facility Type	Status	Start-up year	Web	Technology brief
BBI BioVentures LLC	Commercial	United States	biochemical conversion	lignocellulosics; pre-collected feegnocellulosics ; pre-collected feestocks that require little or no pretreatment-stocks that require little or no pretreatment	ethanol;	commercial	plans abandoned	2010	www.bbibioventures.com	-
Beta Renewables (joint venture of Mossi & Ghisolfi Chemtex division with TPG	Pilot	Italy	biochemical conversion	lignocellulosics; corn stover, straw, husk, energy crops (Giant Reed)woody biomass	ethanol; various chemicals;	pilot	operational	2009	www.betarenewables.com	Enzymatic conversion of selected Biomasses. Pretreatment, handling of pre-treated material and hydrolysis done in equipment specifically designed. Production of oher biochemicals will start in 2012/13.
Beta Renewables (joint venture of Mossi & Ghisolfi Chemtex division with TPG)	IBP - Italian Bio Fuel	Italy	biochemical conversion	lignocellulosics;	ethanol;	commercial	under construction	2012	www.betarenewables.com	Enzymatic conversion of selected Biomasses. Pretreatment, handling of pre-treated material and hydrolysis done in equipment specifically designed.
BFT Bionic Fuel Technologies AG	OFT Alyssa	Denmark	other innovative conversion	lignocellulosics; straw pellets	diesel; hydrocarbons	demo	stopped	2008	www.microfuel.eu	Bionic microfuel technology transforms biomass to lightoil using advanced microwave technology: The Bionic Fuel Technologies Group (BFT) has significantly enhanced a method for a catalytic low temperature depolymerization of hydrocarbons. The method itself and its chemo physical foundations have been well known for many decades and have proven their principal functionality on multiple occasions. The critical breakthrough for BFT came with the application of microwave technology as the primary source of reaction energy. With this approach it became not only possible to overcome all obstacles associated with earlier plant developments, but also additional beneficial effects could be achieved. During a pre processing phase, which, regarding its detailed lay out, depends strongly on the chosen feedstock, the input material is shredded initially to the required particle size. Subsequently it is mixed with a zeolite based catalyst and some additives and finally pelletized. The pellets are transferred to the main reactor where they are gradually heated up. The steam building up in the interior of the pellets first induces a partial hydrogenation of the carbohydrates contained, until they burst due to the rising pressure, while the remaining steam escapes. After more heating to close to 300 degrees Celsius through the application of microwaves the catalyst becomes active. It cracks the hydrocarbons present to a chain length of around C16, which instantly vaporize, escape from the reaction mass and get distilled as a diesel like

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										oil fraction. From the remaining reaction mass the reusable part gets separated and cycled back to the preprocessing for further use. The residues are extracted and have to be disposed of. In a follow up process the produced oil can be cleaned through an additional distillation if necessary and can be refined to standards conform heating oil or diesel through the necessary additives. For certain feedstock it may be required to add a desulphurization process.
Bioenergy 2020+	FT synthesis	Austria	thermochemical conversion		FT diesel, FT waxes	demo	planned	2014	www.bioenergy2020.eu	-
Bioenergy 2020+	Mixed alcohols	Austria	thermochemical conversion	wood chips	mixed alcohols	pilot	operational	2011	www.bioenergy2020.eu	-
BioGasol	BornBioFuel2	Denmark	biochemical conversion	lignocellulosics; straw, various grasses, garden waste.	ethanol; biogas; lignin; fertilizer	demo	planned	2016	www.biogasol.com	Integration of core BioGasol technologies into a complete plant; Reduce technical and financial risk for future full-scale plants; Demonstrate technical feasibility and feedstock flexibility; Test centre for technology developments at semi-industrial scal
BioGasol	BornBioFuel1	Denmark	biochemical conversion	lignocellulosics; flexible	ethanol; pretreated biomass;	pilot	operational	2008	www.biogasol.com	Process- and equipment design and development of core technologies (Pre-treatment and C5 fermentation) at pilot capacity scale; Maturation and up-scaling of core technology to industrial standards; Proof-of-technology to achieve commercially viable soluti
Biomassekraftwerk Guessing	SNG demo	Austria	thermochemical conversion	lignocellulosics; syngas from gasifier	SNG;	demo	operational	2008	www.eee-info.net	After lab testing in a scale of 10 kW during the last few years, the pilot and demonstration unit (PDU) with an output of 1 MW of SNG was inaugurated in June 2009. The plant uses a side stream of the existing Güssing gasifier. The syngas is further purifed before entering the catalysis reactor, where the conversion to methane takes place. The plant has been designed to work in a fairly wide pressure (1-10 bar) and temperature range (300-360°C) in order to optimize the efficiency of the system. SNG upgrading downstream of the reactor is focussed at reaching H-Gas quality in order to meet the feed in conditions for natural gas pipelines. Achieved peformance of the plant is above expectation and the CNG filling station has beed supplied with high quality H-gas. CNG cars have been run successfully with the gas produced.
BioMCN	BioMCN commercial	Netherlands	chemical conversion	glycerine; crude glycerine, others	methanol;	commercial	operational	2009	www.biomcn.eu	converting glycerine (a by-product from biodiesel production) into bio-methanol
Blue Sugars Corporation (formerly KL Energy)	Blue Sugars	United States	biochemical conversion	lignocellulosics; Sugarcane bagasse and other biomass	ethanol; lignin;	demo	operational	2008	www.bluesugars.com	-
Borregaard AS	BALI Biorefinery Demo	Norway	biochemical conversion	lignocellulosics; sugarcane bagasse, straw, wood, energy crops, other lignocellulosics	ethanol; biogas; lignin; hydrogen;	demo	operational	2012	www.borregaard.com	Chemical pretretment, saccharification with commercial enzymes, conventional fermentation of hexoses, aerobic fermentation or chemical conversion of pentoses, chemical modification of lignin

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Borregaard Industries LTD	ChemCell Ethanol	Norway	biochemical conversion	lignocellulosics; sulfite spent liquor (SSL, 33% dry content) from sprucewood pulping	ethanol;	commercial	operational	1938	www.borregaard.com	Pulp for the paper mill is produced by cooking spruce chips with acidic calcium bisulfite cooking liquor. Hemicellulose is hydrolyzed to various sugars during the cooking process. After concentration of the SSL, the sugars are fermented and ethanol is distilled off in several steps. A part of the 96% ethanol is dehydrated to get absolute ethanol.
BP Biofuels	Jennings Demonstration Facility	United States	biochemical conversion	lignocellulosics; dedicated energy crops	cellulosic ethanol;	demo	operational	2009	www.bp.com/biofuels	-
Butamax Advanced Biofuels LLC	Biobutanol demo	United Kingdom	other innovative conversion	other; various feedstocks	biobutanol	demo	planned	2010	www.butamax.com/	-
Chempolis Ltd.	Chempolis Biorefining Plant	Finland	biochemical conversion	lignocellulosics; non-wood and non-food lignocellulosic biomass such as straw, reed, empty fruit bunch, bagasse, corn stalks, as well as wood residues	ethanol; pulp;	demo	operational	2008	www.chempolis.com	Chempolis' core products are the two patented biorefining technologies: 1) formicobio™ for the production of cellulosic ethanol and biochemicals from non-food biomasses and 2) formicofib™ for the production of papermaking fibers (i.e. pulp) and biochemicals from non-wood biomasses. These two technologies share a common technology platform that enables selective fractionation of various biomasses with a novel biosolvent, full recovery of biosolvent and co-production of biochemicals. Chempolis' technologies enable highly profitable and environmentally sustainable biorefining deriving from higher revenues and reduced operating costs while CO_2 emissions and other pollution to atmosphere and waterways can be eliminated practically completely.
Chemrec	BioDME	Sweden	thermochemical conversion	Liquefied biomass - black liquor from forest raw material	DME	large pilot / demo	operational	2011	www.biodme.eu	The recovery boiler in the paper mill is replaced or supplemented by a gasification based fuel generating and pulp mill cooking chemicals recovery system. The BioDME pilot is an integrated part of heavy DME fuelled vehicle fleet trials.
CHOREN Fuel Freiberg GmbH & Co. KG	beta plant	Germany	thermochemical conversion	lignocellulosics; dry wood chips from recycled wood and residual forestry wood; additionally in the future fast growing wood from short-rotation crops	FT-liquids;	demo	stopped	Start up was originally planned for 2012	www.choren.com	-
CHOREN Industries GmbH	sigma plant	Germany	thermochemical conversion	lignocellulosics; dry wood chips from recycled wood; fast growing wood from short-rotation crops	FT-liquids;	commercial	stopped	2016	www.choren.com	-
Coskata	pilot	United States	biochemical conversion	lignocellulosics; various	ethanol;	pilot	operational	2003	www.coskata.com	-

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Coskata	Lighthouse	United States	biochemical conversion	lignocellulosics; wood chips, natural gas	ethanol;	demo	operational	2009	www.coskata.com	"The plant will employ the Plasma Center's gasifier to superheat raw materials at temperatures up to 1700 degrees Fahrenheit (1000°C), then release the resulting synthetic gas, or “syngas”, into a bioreactor, where it will become food for microorganisms that convert it into ethanol. Mr. Roe said Coskata's process will produce 100 gallons of ethanol from a ton of feedstock, compared with 67 gallons produced from the same amount of corn, and that the fuel will cost less than $1 a gallon to produce. Coskata is commercializing a proprietary process and related technologies for the conversion of a wide variety of input materials into ethanol. Coskata has an efficient, affordable, and flexible three-step conversion process: 1. Incoming material converted to synthesis gas (gasification) 2. Fermentation of synthesis gas into ethanol (bio-fermentation) 3. Separation and recovery of ethanol (separations) Ethanol can be manufactured using this cutting edge technology at a variable cost of under US$1.00 per gallon - the lowest cost of manufacture in the industry. During gasification, carbon-based input materials are converted into syngas using well-established gasification technologies. After the chemical bonds are broken using gasification, Coskata's proprietary microorganisms convert the resulting syngas into ethanol by consuming the carbon monoxide (CO) and hydrogen (H_2) in the gas stream. Once the gas-to-liquid conversion process has occurred, the resulting ethanol is recovered from the solution using “pervaporation technology”. Coskata's proprietary microorganisms eliminate the need for costly enzymatic pretreatments, and the bio-fermentation occurs at low pressures and temperatures, reducing operational costs. In addition, the Coskata process has the potential to yield over 100 gallons of ethanol per ton of dry carbonaceous input material, reducing both operational and capital costs. Coskata's exclusively licensed separation technology dramatically improves the separations and recovery component of ethanol production, reducing the required energy by as much as 50%. The entire process includes a gasifier, gas clean-up, fermentation, and separation (both distillation and membrane separation) similar to what is in the process illustration."
DuPont	DuPont Cellulosic Ethanol Demonstration plant	United States	biochemical conversion	lignocellulosics; corn stover, cobs and fibre; switchgrass	ethanol;	demo	operational	2010	www.dupont.com	enzymatic hydrolysis
Dynamic Fuels LLC	Geismar Project	United States	chemical conversion	oils, fats; hydrotreatment of animal fats, used cooking greases	diesel;	commercial	operational	2010	www.dynamicfuelsllc.com	Hydroprocessing of animal fats, used cooking greases and the like, into renewable synthetic diesel meeting teh US ASTM D975 diesel spec.
ECN	pilot	Netherlands	thermochemical conversion	lignocellulosics; clean wood and demolition wood	SNG; syngas;	pilot	operational	2008	www.ecn.nl	Production of Substitute Natural Gas from woody biomass using MILENA gasification, OLGA tar removal, gas cleaning, gas upgrading and methanation
ECN	demo	Netherlands	thermochemical conversion	lignocellulosics;	SNG; heat;	demo	planned	2013	www.ecn.nl	-

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Enerkem	Sherbrooke pilot plant and research center	Canada	thermochemical conversion	biomass /biomass coal blends; Municipal solid waste (MSW) from numerous municipalities and more than 25 different feedstocks, including wood chips, treated wood, sludge, petcoke, spent plastics, wheat straw. Feedstocks can be in solid, slurry or liquid form.	ethanol; methanol; power; syngas; acetates;	pilot	operational	2003	www.enerkem.com/en/facilities/innovation-centers/sherbrooke-quebec-canada.html	-
Enerkem	demo	Canada	thermochemical conversion	biomass /biomass coal blends; Treated wood (i.e. decommissioned electricity poles, and railway ties), wood waste and MSW	ethanol; methanol; hemicelluloses; power; syngas;	demo	operational	2009	www.enerkem.com/index.php?module=CMS&id=11&newlang=eng	Enerkem develops biofuels and chemicals from waste. With its proprietary thermochemical technology, Enerkem converts abundantly available municipal solid waste (mixed textiles, plastics, fibers, wood and other non-recyclable waste materials) into chemical-grade syngas, and then methanol, ethanol and other chemical intermediates that form everyday products.
Enerkem	Edmonton Waste-to-Biofuels Project	Canada	thermochemical conversion	biomass /biomass coal blends; Post-sorted municipal solid waste (MSW)	ethanol; methanol; syngas;	commercial	under construction	2013	www.enerkem.com/en/facilities/plants/westbury-quebec-canada.html	Enerkem develops biofuels and chemicals from waste. With its proprietary thermochemical technology, Enerkem converts abundantly available municipal solid waste (mixed textiles, plastics, fibers, wood and other non-recyclable waste materials) into chemical-grade syngas, and then methanol, ethanol and other chemical intermediates that form everyday products.
Enerkem - Varennes Cellulosic Ethanol L.P.	Varennes commercial facility	Canada	thermochemical conversion	biomass /biomass coal blends; Sorted industrial, commercial and institutional waste	ethanol; methanol; syngas;	commercial	planned		www.enerkem.com/en/facilities/plants/varennes-quebec-canada.html	Enerkem develops biofuels and chemicals from waste. With its proprietary thermochemical technology, Enerkem converts abundantly available municipal solid waste (mixed textiles, plastics, fibers, wood and other non-recyclable waste materials) into chemical-grade syngas, and then methanol, ethanol and other chemical intermediates that form everyday products.
Enerkem Mississippi Biofuels LLC	Enerkem Mississippi Biofuels	United States	thermochemical conversion	biomass /biomass coal blends; Sorted municipal solid waste and wood residues	ethanol; methanol; syngas;	commercial	planned	-	www.enerkem.com/en/facilities/plants/pontotoc-mississippi.html	Enerkem develops biofuels and chemicals from waste. With its proprietary thermochemical technology, Enerkem converts abundantly available municipal solid waste (mixed textiles, plastics, fibers, wood and other non-recyclable waste materials) into chemical-grade syngas, and then methanol, ethanol and other chemical intermediates that form everyday products.

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Fiberight LLC	Commercial Plant	United States	biochemical conversion	municipal solid waste;	ethanol; biogas; power; sugars;	commercial	under construction	2013	www.fiberight.com	Fiberight's innovative technology efficiently fractionates the organic components of MSW such as contaminated paper, food wastes, yard discards and other degradables for the production of cellulose and hemicellulose into fuel grade ethanol and other sugar platform biochemicals using enzymatic hydrolysis and fermentation. The plastic fraction and methane collected from Fiberight's processes may also used to create co-generation electricity to power its plant facilities for zero energy input. Fiberight's proprietary extraction, pulping and digestion processes have the potential to unlock over 5 billion gallons of renewable biofuel contained in the 175 million tons of non-recyclable Municipal Solid Waste (MSW) generated each year in the US.
Fiberight LLC	Integrated Demonstration Plant	United States	biochemical conversion	municipal solid waste;	ethanol; biogas; power; sugars;	demo	operational	2012	www.fiberight.com	-
Flambeau River Biofuels Inc.	Project Trixie	United States	thermochemical conversion	lignocellulosics; Forest residuals, non-merchantable wood	FT-liquids;	demo	plans abandoned	Start up would have been in 2013.	www.flambeauriverpapers.com	Thermochemical conversion of biomass using advanced gasification technologies followed by FT catalytic conversion into renewable liquid fuels and waxes. Currently pilot plant testing; start of construction anticipated for fall 2011.
Frontier Renewable Resources	Kinross Plant 1	United States	biochemical conversion	lignocellulosics; wood chip	ethanol; lignin;	commercial	planned	-	-	-
Göteborg Energi AB	GoBiGas Plant - Phase 1	Sweden	thermochemical conversion	lignocellulosics; Forest residues, wood pellets, branches and tree tops	biomethane;	demo	under construction	2013	www.gobigas.se	-
GraalBio	GraalBio plants	Brazil	biochemical conversion	sugarcane bagasse; Sugarcane bagasse and straw	ethanol;	commercial	planned	-	www.betarenewables.com	-
Greasoline GmbH	sts-plant	Germany	thermochemical conversion	oils, fats; bio-based oils and fats, residues of plant oil processing, free fatty acids, used bio-based oils and fats	diesel; hydrocarbons; gasoline type fuel;	pilot	operational	2011	www.greasoline.com	Catalytic cracking of bio-based oils + fats primarily produces diesel fuel-range hydrocarbons. Preferred catalysts are activated carbons. Variation in process conditions, catalysts and input material lead to alkenes, LPG, gasoline and drop-in jet fuels.
GTI Gas Technology Institute	Flex-Fuel and Advanced Gasification Test Facilities, Wood to Gasoline	United States	thermochemical conversion	lignocellulosics; Forest residues: tops, bark, hog fuel, stump material	FT-liquids;	pilot	Operational	2004	www.gastechnology.org	-

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GTI, Gas Technology Institute	IH2 â€“ 50 Continuous Pilot Plant	United States	thermochemical conversion	lignocellulosics; Wood, Corn-stover, Bagasse, Algae	FT-liquids; gasoline type fuel;	pilot	operational	2012	httpwww.gastechnology.org	The IH2 pilot plant contains a first stage fluidized bed catalytic hydropyrolysis reactor, and a second stage hydroconversion reactor. Hydrogen produced in the process is continuously recycled. The biomass is continuously fed while liquid, gas, and char products are continuously removed. The pilot plant operates 24 hours a day in test campaigns lasting 30 days or longer.
Inbicon (DONG Energy)	pilot 1	Denmark	biochemical conversion	lignocellulosics; straw	ethanol; c5 molasses; solid biofuel;	pilot	operational	2003	www.inbicon.com	hydrothermal pre-treatment, high gravity hydrolysis, yeast fermentation
Inbicon (DONG Energy)	pilot 2	Denmark	biochemical conversion	lignocellulosics;	ethanol; c5 molasses; solid biofuel;	pilot	operational	2005	www.inbicon.com	hydrothermal pre-treatment, high gravity hydrolysis, yeast fermentation
Inbicon (DONG Energy)	demo	Denmark	biochemical conversion	lignocellulosics; wheat straw	ethanol; c5 molasses; solid biofuel;	demo	operational	2009	www.inbicon.com	-
INEOS Bio	Indian River County Facility	United States	biochemical conversion	lignocellulosics; Vegetative Waste, Waste wood, Garden Waste	ethanol;	commercial	under construction	2012	www.ineosbio.com	-
Iogen Corporation	demo	Canada	biochemical conversion	lignocellulosics; wheat, barley and oat straw; corn stover, sugar cane bagasse and other agricultural residues	ethanol;	demo	operational	2004	www.iogen.ca	Iogen technology makes it economically feasible to convert biomass into cellulosic ethanol using a combination of thermal, chemical and biochemical techniques. The yield of cellulosic ethanol is more than 340 litres per tonne of fibre. The lignin in the plant fibre is used to drive the process by generating steam and electricity, thus eliminating the need for fossil CO_2 sources such as coal or natural gas. Pretreatment: Iogen developed an efficient pretreatment method to increase the surface area and "accessibility" of the plant fibre to enzymes. We achieve this through our modified steam explosion process. This improves ethanol yields, increases pretreatment efficiency, and reduces overall cost. Enzyme Production: Iogen has new, highly potent and efficient cellulase enzyme systems tailored to the specific pretreated feedstock. Iogen already has a worldwide business making enzymes for the pulp and paper, textiles and animal feed industries. Enzymatic Hydrolysis: Iogen developed reactor systems that feature high productivity and high conversion of cellulose to glucose. This is accomplished through separate hydrolysis and fermentation using a multi-stage hydrolysis process. Ethanol Fermentation: Iogen uses advanced microorganisms and fermentation systems that convert both C6 and C5 sugars into ethanol. The "beer" produced by fermentation is then distilled using conventional technology to produce cellulosic ethanol for fuel grade applications. Process Integration: Large-scale process designs include energy efficient heat integration, water recycling, and co-product production that make the overall process efficient and economical. Iogen has successfully validated these improvements within its demonstration scale cellulosic ethanol facility.

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Iowa State University	BioCentury Research Farm	United States	biochemical and thermochemical conversion	lignocellulosics; grains, oilseeds, vegetable oils, glycerin	ethanol; FT-liquids; biodiesel; pyrolysis oils;	pilot	operational	2009	www.biocenturyresearchfarm.iastate.edu	The Iowa State University BioCentury Research Farm is an integrated research and demonstration facility dedicated to biomass production and processing. Activities at the Farm include cultivar development and testing; biomass harvest, storage, and transportation; biomass processing; and byproduct disposal. The bioprocessing facility will offer three different lines for processing ground and pretreated biomass: a biochemical train, a thermochemical train, and a bioprocessing train (hybrid technologies). The products can be fuels and other biobased products. Byproduct recycling to the field shall be optimized.
Karlsruhe Institute of Technology (KIT)	bioliq	Germany	thermochemical conversion	lignocellulosics;	diesel; gasoline type fuel;	pilot	under construction	2013	www.bioliq.de	Fast pyrolysis, high pressure entrained flow gasification, hot gas cleaning, DME- and gasoline-synthesis Status: Fast pyrolysis: in operation; Gasification, DME- and gasoline synthesis under construction finished end of 2011
LanzaTech - Concord Enviro Systems PVT Ltd.	MSW Syngas to Electricity and Fuel	India	biochemical conversion	Any gas containing Carbon Monoxide; Municipal solid waste	ethanol;	demo	planned	2013	www.lanzatech.com	Facility using municipal solid waste-derived syngas.
LanzaTech (Beijing Shougang LanzaTech New Energy Technology Co., Ltd.)	Waste Gas to Fuel	China	biochemical conversion	Any gas containing Carbon Monoxide; Industrial off gas	ethanol;	demo	under construction	2013	www.lanzatech.com	-
LanzaTech BaoSteel New Energy Co., Ltd.	Waste Gas to Fuel	China	biochemical conversion	Any gas containing Carbon Monoxide; Industrial flue gasses	ethanol;	demo	operational	2012	www.lanzatech.com	Convertion of CO-rich gases from steel production facilities into fuels and chemicals.
LanzaTech New Zealand Ltd	waste gas to fuel	New Zealand	biochemical conversion	Any gas containing Carbon Monoxide; industrial flue gasses	ethanol;	pilot	operational	2008	www.lanzatech.com	waste gas to fuel conversion using proprietary microbial catalysts
LanzaTech, Inc.	LanzaTech Freedom Pines Biorefinery	United States	biochemical conversion	lignocellulosics; Biomass syngas	ethanol;	commercial	planned	2013	www.lanzatech.com	Gas fermentation process using biomass syngas derived from forestry residues
Licella	Commercial demonstration plant	Australia	thermochemical conversion	lignocellulosics; Radiata Pine, Banna Grass, Algae	bio-oil;	demo	operational	2008	www.licella.com.au	Using our proprietary Catalytic Hydrothermal Technology (Cat-HTR), Licella can use any form of lignocellulosic biomass feedstock to produce its Bio-Crude oil. Licella's process can in one step produce a high energy density (34-36 MJ//Kg) Bio-Crude within 30 minutes, that can be blended with traditional fossil crude and dropped in to existing refineries to make the same range of fuels e.g. petrol, diesel and jet and chemical feedstocks.

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Lignol Energy Corporation	pilot	Canada	biochemical conversion	lignocellulosics; hardwood & softwood residues	ethanol; cellulose; lignin; various chemicals; sugars;	pilot	operational	2009	www.lignol.ca	Lignol Innovations is commercializing its unique integrated cellulose to ethanol process technology for biorefining ethanol (fuel alcohol), pure lignin and other valuable co-products from renewable and readily available biomass. The technology is based on original 'Alcell' biorefining technology that was developed by General Electric and Repap Enterprises at a cost of over $100 million. The Lignol delignification process was first developed by General Electric Corp. in the early 1970s to produce ethanol and organosolv lignin to be used as a clean burning gas turbine fuel. The process was subsequently applied to the pulp and paper industry, commercialized by Repap Enterprises between 1987 and 1997 to generate wood pulp. Repap refocused the Alcell delignification process as a pulping process in which lignin (the natural glue in wood) was removed, and following bleaching, produced a 100% cellulose/hemicellulose wood pulp.
Lignol Energy Corporation	demo	United States	biochemical conversion	lignocellulosics; hardwood & softwood residues; agri - residues	ethanol; lignin;	demo	plans abandoned	originally planned to start 2012	www.lignol.ca	-
Mascoma Corporation	Demonstration Plant	United States	biochemical conversion	lignocellulosics; Wood Chips, Switchgrass and other raw materials	ethanol; lignin;	demo	operational	2003	www.mascoma.com	The unique technology developed by Mascoma Corporation uses yeast and bacteria that are engineered to produce large quantities of the enzymes necessary to break down the cellulose and ferment the resulting sugars into ethanol. Combining these two steps (enzymatic digestion and fermentation) significantly reduces costs by eliminating the need for enzyme produced in a separate refinery. This process, called Consolidated Bioprocessing or "CBP", will ultimately enable the conversion of the solar energy contained in plants to ethanol in just a few days.
Neste Oil	Porvoo 1	Finland	chemical conversion	oils, fats; hydrotreatment of palm oil, rapeseed oil and animal fat	biodiesel;	commercial	operational	2007	www.nesteoil.com	-
Neste Oil	Porvoo 2	Finland	chemical conversion	oils, fats; hydrotreatment of oils and fats	biodiesel;	commercial	operational	2009	www.nesteoil.com	-
Neste Oil	Rotterdam	Netherlands	chemical conversion	oils, fats; hydrotreatment of oils and fats	biodiesel;	commercial	operational	2011	www.nesteoil.com	-
Neste Oil	Singapore	Singapore	chemical conversion	oils, fats; hydrotreatment of oils and fats	biodiesel;	commercial	operational	2010	www.nesteoil.com	-

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New Energy and Industrial Technology Development Organization (NEDO)	Development of an Innovative and Comprehensive Production System for Cellulosic Bioethanol	Japan	biochemical conversion	lignocellulosics; wood chips	ethanol;	pilot	operational	2011	http://demoplants.bioenergy2020.eu/projects/info/497	Mechanochemical Pulping Process for conversion of cellulose to ethanol. The project's goal is to develop a coherent bioethanol production system from biomass plantation to ethanol production. The targeted cellulosic biomass in the project is wood from eucalyptus. The development includes basic studies on raw material production, pretreatment using pulping technology, simultaneous saccharification and fermentation using thermal and acid tolerant yeast, and saving energy technology with self-heat recuperation.
NREL (National Renewable Energy Laboratory)	Integrated Biorefinery Research Facility (IBRF)	United States	biochemical conversion	lignocellulosics;	ethanol;	pilot	operational	1994 (expansion completed 2011)	www.nrel.gov/biomass/	-
NREL (National Renewable Energy Laboratory)	Thermochemical Users Facility (TCUF)	United States	thermochemical conversion	lignocellulosics;	various chemicals; transport fuels;	pilot	operational	1985 (expansion in progress)	www.nrel.gov/biomass/	-
NSE Biofuels Oy, a Neste Oil and Stora Enso JV	demo	Finland	thermochemical conversion	lignocellulosics; forest residues	FT-liquids;	pilot	stopped	2009	www.nesteoil.com; www.storaenso.com	Fischer-Tropsch production of paraffins from biomass; fluid bed gasifier with tar reformer
NSE Biofuels Oy, a Neste Oil and Stora Enso JV	commercial reference plant	Finland	thermochemical conversion	lignocellulosics; forest residues	FT-liquids;	commercial	plans abandoned	-	-	Fischer-Tropsch production of paraffins from biomass; fluid bed gasifier with tar reformer
Pacific Ethanol	West Coast Biorefinery (WCB)	United States	biochemical conversion	lignocellulosics; wheat straw, corn stover, poplar residuals	ethanol; biogas; lignin;	demo	plans abandoned	Originally planned for start up in 2010	www.pacificethanol.net	-
Petrobras	Bioethanol second generation production	Brazil	biochemical conversion	sugarcane bagasse;	ethanol;	pilot	plans postponed	-	-	Acid hydrolysis as pretreatment and enzymatic hydrolysis to convert cellulose into glucose and fermentation with Saccharomyces cerevisae yeast. The sugars of five carbons from hemicellulose fraction are submitted to the fermentation process using Pichia stiptis yeast.
Petrobras	Pilot	Brazil	biochemical conversion	sugarcane bagasse;	ethanol;	pilot	operational	2007	-	Acid hydrolysis as pretreatment and enzymatic hydrolysis to convert cellulose into glucose and fermentation with Saccharomyces cerevisae yeast. The sugars of five carbons from hemicellulose fraction are submitted to the fermentation process using Pichia stiptis
Petrobras and Blue Sugars	Second generation ethanol demo plant	United States	biochemical conversion	sugarcane bagasse;	ethanol;	demo	operational	2011	-	Specific Petrobras test programm that has been running on Blue Sugars demo plant of which name plate capacity is described in the Blue Sugars fact sheet.
POET	Scotland	United States	biochemical conversion	lignocellulosics; corn fiber, corn cobs and corn stalks	ethanol;	pilot	operational	2008	www.poet.com	Enzymatic Hydrolysis
POET-DSM	Project Liberty	United	biochemical	lignocellulosics;	ethanol;	commercial	under	2013	www.project	Integrated technology package that converts corn crop residue to

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Advanced Biofuels		States	conversion	agricultural residues	biogas		construction		liberty.com	cellulosic bio-ethanol to third parties, as well as the other 26 existing corn ethanol plants in POET's network. The process makes use of corn stover that passes through the combine during harvest. We use approximately 25% of the material, leaving about 75% on the ground for erosion control, nutrient replacement and other important farm management practices.
PROCETHOL 2G	Futurol Project	France	biochemical conversion	lignocellulosics; flexible; woody and agricultural by-products, residues, energy crops	ethanol;	pilot	operational	2011	www.projet-futurol.com	-
Queensland University of Technology	Mackay Renewable Biocommodities Pilot Plant	Australia	biochemical conversion	lignocellulosics, sugarcane bagasse, trash, wood chip, sweet sorghum, energy grasses, stover	ethanol, lignin, chemicals	pilot	Operational	2010	www.ctcb.qut.edu.au/programs/pilot.jsp	Soda pulping and ionic liquid based pretreatments, lignin recovery, saccharification with commercial enzymes, conventional fermentation of hexoses
Range Fuels, Inc.	K2A Optimization Plant	United States	thermochemica conversion	lignocellulosics; Georgia pine and hardwoods and Colorado beetle kill pine	mixed alcohols;	pilot	Stoped	2008	www.rangefuels.com/	The thermochemical process employed by Range Fuels invovles two steps: Step 1: Solids to Gas: Biomass (all plant and plant-derived material) that cannot be used for food, such as agricultural waste, is fed into a converter. Using heat, pressure, and steam the feedstock is converted into synthesis gas (syngas), which is cleaned before entering the second step. Step 2: Gas to Liquids: The cleaned syngas is passed over our proprietary catalyst and transformed into mixed alcohols. These alcohols are then separated and processed to maximize the yield of ethanol of a quality suitable for use in blending with gasoline to fuel vehicles. A Simple Process: Because Range Fuels process utilizes a thermochemical process, it relies on the chemical reactions and conversions between forms that naturally occur when certain materials are mixed under specific combinations of temperature and pressure. Other conversion processes use enzymes, yeasts, and other biological means to convert between forms. Feedstock Flexibility: The Range Fuels process accommodates a wide range of organic feedstocks of various types, sizes, and moisture contents. This flexibility eliminates commercial problems related to fluctuations in feed material quality and ensures success in the real world, far from laboratory-controlled conditions. Tested and True Range Fuels technology has been tested and proven in bench and pilot-scale units for over eight years. Over 15,000 hours of testing has been completed on over 30 different non-food feedstocks with varying moisture contents and sizes, including wood waste, olive pits, and more. Range Fuels continues to optimize the conversion technology that will be used in our first commercial cellulosic ethanol plant near Soperton, Georgia using a 4th generation pilot plant in Denver, Colorado that we have been operating since the first quarter of 2008.
Range Fuels, Inc.	commercial	United States	thermochemical conversion	lignocellulosics; Wood and wood	ethanol; methanol;	commercial	plans abandoned	Start up would have	www.rangefuels.com/	Range Fuels is focused on commercially producing low-carbon biofuels, including cellulosic ethanol, and clean renewable power using renewable

Project owner	Project name	Country	Technology	Raw material	Product	Facility Type	Status	Start-up year	Web	Technology brief
				waste from nearby timber harvesting operations				been in 2010.		and sustainable supplies of biomass that cannot be used for food. The company uses an innovative, two-step thermo-chemical process to convert biomass, such as wood chips, switchgrass, corn stover, sugarcane bagasse and olive pits to clean renewable power and cellulosic biofuels. In the first step of the process heat, pressure and steam are used to convert the non-food biomass to a synthesis gas or syngas. Excess energy in this step is recovered and used to generate clean renewable power. In the second step the cleaned syngas is passed over a proprietary catalyst and transformed into cellulosic biofuels, which can then be separated and processed to yield a variety of low carbon biofuels, including cellulosic ethanol and methanol. This suite of products can be used to displace gasoline or diesel transportation fuels, generate clean renewable energy or be used as low carbon chemical building blocks; all of which can reduce the country's dependence on foreign oil, create immediate jobs, and dramatically reduce GHG emissions.
Research Triangle Institute	Synfuel production	United States	thermochemical conversion	lignocellulosics;	FT-liquids; mixed alcohols;	pilot	under construction	-	www.rti.org/ process	"Biomass-derived syngas will be generated in the University of Utah's pilot-scale gasification system from woody biomass and a combination of wood and lignin-rich hydrolysis residues generated at NCSU. RTI will integrate their dual fluidized bed reactor system called the "therminator" into the gasification process. The "therminator" which operates between 600–700ºC (1112–1292ºF) with a novel attrition-resistant triple function catalyst system, to simultaneously reform, crack, or remove tar, ammonia (NH_3), and hydrogen sulfide (H_2S) down to ppm levels. The catalyst is circulated between coupled fluidized-bed reactors to continuously regenerate the deactivated catalyst. The gas leaving the therminator will be cooled and filtered before it enters the second (polishing) stage, consisting of a fixed-bed of a mixed-metal oxide-sorbent catalyst, to further reduce the tar, NH_3, H_2S, and heavy metals to less than 100 ppb each so that the syngas can be directly used in a downstream process for synthesis of liquid transportation fuels. Once installed in the University of Utah gasification facility, therminator gas cleanup performance will be validated during for 300 hours of operation in Phase 1 of the project. The results from these Phase I trials will be used as input for gasification process models that will also be developed during Phase I. The results from the gasification trials, and the process and economic modeling will then be used to guide the Phase 2 work. In particular these results, in consultation from DOE and industry, will be used to direct the selection of the gas to liquids catalyst towards a Fischer-Tropsch catalyst system for hydrocarbon production or a molybdenum sulfide-based catalyst system for mixed alcohol synthesis. Phase 2 will follow the successful demonstration of the gas cleanup technology to produce a clean syngas that is suitable for a fuel synthesis process. The targeted tar, sulfur, chloride, and nitrogen impurity concentrations will meet or exceed the levels required for the projected 5-year operation of a Fischer-Tropsch catalyst system for hydrocarbon production or a molybdenum sulfide-based catalyst system for mixed alcohol synthesis. RTI will design and build a slurry bubble column reactor system to convert the clean syngas into a liquid transportation fuel. This unit operation will be installed in the

Project owner	Project name	Country	Technology	Raw material	Product	Facility Type	Status	Start-up year	Web	Technology brief
										University of Utah gasification facility downstream of the therminator and operated for 500 hours (at least 100 hours continuously) in an integrated biomass gasification/gas cleanup and conditioning/fuel synthesis process. RTI will be the prime contractor and will be responsible for the overall project. The project will be managed within the Center for Energy Technology (CET) and Dr. David C. Dayton will serve as the overall project manager. The NCSU team will be led by Dr. Steven Kelley and include four faculty, two from Wood and Paper Science and two from Chemical Engineering. Dr. Kevin Whitty will lead the University of Utah team in the Institute for Clean and Secure Energy that will be responsible for the operation of the gasification facility. Successful validation of these integrated gas cleanup and fuel synthesis operations will provide invaluable data and operating experience to reduce the risk of scale-up and commercialization of these technologies and contribute to the development of a robust biofuels industry."
Schweighofer Fiber Gmbh	biorefinery	Austria	biochemical conversion	lignocellulosics; sulfite spent liquor (SSL, 33% dry content) from spruce wood pulping	ethanol;	demo	plans postponed	-	www.schweighofer-fiber.at	Pulp for the paper mill is produced by cooking spruce chips with acidic magnesium bisulfite cooking liquor. After concentration of the sulfite spent liquor (SSL) in the evaporation plant it is incinerated in the combustion boiler to produce steam and electricity, whereas magnesium oxide and sulfur dioxide are recycled to produce new cooking liquor. The concept for the production of ethanol is to ferment the wood sugars from SSL and to distil off the ethanol in the distillation plant. Afterwards the 96% ethanol is dehydrated by molecular sieves to get water free absolute ethanol. The mash will be recycled as described above.
SEKAB	commercial plants	Sweden	biochemical conversion	lignocellulosics;	ethanol;	commercial	plans postponed	Start up was originally planned for 2016.	www.sekab.com	reference plant on best method
SEKAB	planned demo plant	Poland	biochemical conversion	lignocellulosics; Wheat straw and corn stover	ethanol;	demo	planned	2014	www.sekab.com	Enzymes with pretreatment of diluted acid in one step.
SEKAB Industrial Development AB	IDU	Sweden	biochemical conversion	lignocellulosics; flexible for wood chips and sugarcane bagasse	ethanol;	demo	plans abandoned	originally planned to start 2011	www.sekab.com	Enzymes with pretreatment of diluted acid in one step.
SEKAB/EPAP	demo plant	Sweden	biochemical conversion	lignocellulosics; primary wood chips; sugarcane bagasse, wheat, corn stover, energy grass, recycled waste etc have been tested.	ethanol;	pilot	Operational	2004	www.sekab.com	2 step diluted acid + enzyme hydrolysis
Southern Research	technology development	United States	thermochemical conversion	lignocellulosics; Cellullulosics,	FT-liquids; mixed	pilot	operational	2007	www.SouthernResearc	thermochemical conversion, catalytic liquids synthesis, hot and cold syngas cleaning

Project owner	Project name	Country	Technology	Raw material	Product	Facility Type	Status	Start-up year	Web	Technology brief
Institute	laboratory and pilot plant - thermochemical			Municipal wastes, syngas	alcohols; bio-char; power;				h.org	
Sued-Chemie AG	sunliquid	Germany	biochemical conversion	lignocellulosics; wheat straw	ethanol;	demo	operational	2012	www.sunliquid.com	biotechnological process for the conversion of lignocellulosic feedstock to cellulosic ethanol via enzymatc hydrolysis and fermantation; turn-key technology solution from pretreatment to separation: process-integrated enzyme production using a small amount of the pretreated feedstock, feedstock and process specific enzymes (patented), one-batch-fermentation of C5 and C6 sugar (50% higher production compared to a pure C6 fermentation), ethanol purification on the basis of an adsorption-desorption-process replacing the destillation (50% less energy consumption); all process heat comes from the use of residual materials incl. the lignin which is separated after saccharification
Technical University of Denmark (DTU)	Maxifuel	Denmark	biochemical conversion	lignocellulosics; wheat straw, corn fibre	ethanol; biogas; lignin;	pilot	stopped	2006	www.biogasol.com	-
Tembec Chemical Group	demo	Canada	thermochemical conversion	lignocellulosics; spent sulphite liquor feedstock	ethanol;	demo	operational	2003	www.tembec.com	-
Terrabon	Energy Independence I	United States	biochemical conversion	lignocellulosics; municipal solid waste, sewage sludge, manure, agricultural residues and non-edible energy crops	ethanol; mixed alcohols; various chemicals;	demo	operational	2009	www.terrabon.com/	The MixAlco® technology converts biomass to biofuel using carboxylic acid fermentation followed by conventional chemistry that processes the resulting carboxylic salts into valuable chemicals that can be further refined through separate, well-established processes in the chemical industry to produce renewable biofuels. The technology uses conventional non-sterile, anaerobic digestion with standard processing equipment, resulting in competitive capital and operating costs. Depending on the lignin content, the biomass can be pretreated before being fed to a mixed culture of acid-forming microorganisms derived from a saline environment. An organic acid broth is created, which is then converted to its corresponding organic salt with a buffer used to manage pH at the optimal biological conditions. The carboxylate salts are filtered, dewatered, concentrated, and then thermally converted to ketones. During ketonization, the salts decompose into mixed ketone vapors and carbonates. Conventional chemical process technology is used to convert the residual purified ketones into secondary alcohols through hydrogenation. The hydrogenated alcohols then undergo oligomerization and further conversion and purification to produce a drop-in fuel (conventional gasoline, diesel, and/or jet fuel).
TNO	Superheated steam pilot plant	Netherlands	biochemical conversion	lignocellulosics; Wheat straw, grass, corn stover, bagasse, wood chips	pretreated biomass ;	pilot	operational	2002	www.tno.nl	In a reactor a continuous flow of SHS passes through a heap of grass or straw, in contrast with the usual stagnant and saturated steam. By using SHS the heat is not transferred by condensation but by convection. The initial dry matter contents can be 20-45% w/w and probably higher. Such high dry matter content decreases the use of thermal energy since a lower amount of mass is heated. Moreover, as a result of lower water content less acid catalyst is required to reach the effective concentrations and by evaporation of water a desired increase in acid concentration can be created. High dry matter concentrations are important for the

Project owner	Project name	Country	Technology	Raw material	Product	Facility Type	Status	Start-up year	Web	Technology brief
										economy of fermentation and downstream processing, as higher substrate concentrations lead to higher product concentrations, which makes recovery more cost-effective. The fast temperature increase and decrease within a few seconds allows a better process control. By evaporation of water the final dry matter content can be increased to values between 30% and 60% w/w. The amount of water evaporation can be adjusted by the pressure in combination with the superheating temperature. Flexibility in acid concentration has been observed as well. The user can choose between less acid and longer reaction times or more acid and shorter times. In addition, the user can choose between various inorganic and organic acids. The process can be carried out within a few minutes and a temperature of 160°C already is effective, which can be placed within the fastest and coldest existing thermal mild acid pretreatment processes, which adds to a favourable economy of the process. After SHS pretreatment a conversion of more than 95% of cellulose and hemicellulose after enzymatic hydrolysis can be reached, which can be regarded as high. Samples have been successfully subjected to ethanol fermentation at 38% DM. The pretreatment step can be carried out in TNO'ssuperheated steam pilot plant. SHS dryers are already on the market at the sizes required for lignocellulose biorefineries / cellulosic ethanol production, although they should be adapted to shorter residence times and higher pressures.
TUBITAK	TRIJEN (Liquid Fuel Production From Biomass and Coal Blends)	Turkey	thermochemical conversion	biomass /biomass coal blends; combination of hazelnut shell, olive cake, wood chip and lignite blends	FT-liquids;	pilot	planned	2013	trijen.mam.gov.tr/	The aim of the project is to develop and demonstrate the technologies for liquid fuel production from biomass and/or biomass-coal blends at the laboratory and pilot scale systems. The technological areas within the scope of the project are gasification, gas clean-up, gas conditioning, CO_2 separation and liquid fuel production via Fischer-Tropsch (FT) synthesis. Activities related to the technological research areas consist of the pre-design of the units, laboratory tests, detailed design, engineering, manufacturing, commissioning and testing at pilot scale. In the gasification step, two types of gasifiers circulating fluidized bed gasifier and pressurised fluidized bed gasifier have been studied in laboratory scale (150 kWth). 1,1 MWth capacity pressurised fluidized bed gasifier have been designed for pilot scale. The aim of the gas cleaning step is to remove impurities from raw gas of gasifier. Both hot and cold gas clean-up technologies have been used in laboratory scale experiments. Hybride hot and cold gas clean-up pilot system has been designed. The third step of project is gas conditioning. The aim of this step is to adjust H_2/CO ratio in syngas and capture CO_2. H_2/CO ratio in syngas will be adjusted in a water gas shift (WGS) reactor and CO_2 will be captured by chemical absorption technique. One of the main work packages of the project is the production of liquid fuels via Fischer-Tropsch synthesis since the activities related to both FT catalyst development and fixed bed and slurry phase reactor applications have been performed in this work package. Low temperature FT process with multi tubular fixed bed reactor will be used to produce synthetic diesel in pilot plant. Iron based FT catalyst has been developed to convert syngas into hydrocarbon chains. All units of the pilot scale system are under construction

Project owner	Project name	Country	Technology	Raw material	Product	Facility Type	Status	Start-up year	Web	Technology brief
										currently.
Weyland AS	Weyland	Norway	biochemical conversion	lignocellulosics; various feedstocks, mostly spruce & pine	Ethanol; lignin; sugars;	pilot	operational	2010	www.weyland.no	-
Vienna, University of Technology	FT synthesis	Austria	thermochemical conversion	wood chips	FT diesel, FT waxes, FT kerosene	pilot	operational	2005	www.vt.tuwien.ac.at	"Aim of the work is to convert the product gas (PG) of the Biomass gasification plant with a Fischer-Tropsch (FT) process to liquid fuels, especially to diesel. A FT-PDU (process development unit) is operated, which converts about 7 Nm^3/h PG at 25bar in a Slurry reactor to FT-products. The gas cleaning of the raw PG consists of several steps. First a RME (rape methyl ester) -scrubber is used to dry the gas. After the compression step, chlorine is separated with a sodium aluminate fixed bed. Organic sulphur components are hydrated with a HDS-catalyst and the H2S is chemically separated with Zinc oxide. Both is realised in fixed bed reactors. In alternative to the HDS also activated carbon filter can be used for gas cleaning. As catalyst in the slurry reactor, iron and cobalt based catalyst are used. The results from a Cobalt catalysts give mainly an n-alkan distribution from C1 to compounds higher than C60 n-alkanes. The iron based catalysts give more alkenes and oxygenated compounds. The analyses of the diesel fraction from the distillation of the FT-raw product show that the obtained diesel from the Cobalt catalyst has cetan-numbers of about 80 and is free of sulphur and aromatics."
Virent, Inc.	Eagle Demonstration Plant	United States	thermochemical conversion	lignocellulosics; Cane sugar, beet sugar, corn syrup, hydrolysates from cellulosic biomass including pine residues, sugarcane bagasse and corn stover	various chemicals; gasoline type fuel; industrial sugars; lignin specialty chemicals;	demo	operational	2009	www.virent.com	Virent's BioFormingÂ® platform is based on a novel combination of Aqueous Phase Reforming (APR) technology with modified conventional catalytic processing. The APR technology was discovered at the University of Wisconsin in 2001 by Virent's co-founders. The BioForming platform expands the utility of the APR process by combining APR with catalysts and reactor systems similar to those found in standard petroleum oil refineries and petrochemical complexes. The BioForming process converts aqueous carbohydrate solutions into mixtures of drop-in hydrocarbons. The process has been demonstrated with conventional sugars obtained from existing sugar sources (corn wet mills, sugarcane mills, etc.) as well as a wide variety of cellulosic biomass from nonfood sources. A key advantage to the BioForming process is the ability to produce hydrogen in-situ from the carbohydrate feedstock or utilize other sources of hydrogen such as natural gas for higher yields and lower costs.
ZeaChem	Demonstration scale biorefinery	United States	biochemical conversion	lignocellulosics; poplar trees, wheat straw	ethanol; mixed alcohols; diesel; acetates; jet fuel;	demo	operational	2011	www.zeachem.com	The conversion process uses naturally-occurring organisms and proven, industrial equipment in order to reduce scale-up risk. Non-GMO bacteria ferment cellulosic sugars with nearly 100% carbon efficiency and the combination of biological and thermochemical processes deliver a 40% yield advantage compared to other processes. Like a petrochemical refinery, ZeaChem biorefineries can make multiple fuels and chemicals, shifting production to the highest margin products. Fuel products include ethanol, jet fuel, diesel and gasoline; chemical products include acetic acid, ethyl acetate, ethylene and propylene.
ZeaChem Inc.	Commercial	United	biochemical	lignocellulosics;	ethanol;	commercial	planned	2014	www.zeach	The conversion process uses naturally-occurring organisms and proven,

Project owner	Project name	Country	Technology	Raw material	Product	Facility Type	Status	Start-up year	Web	Technology brief
	scale biorefinery	States	conversion	poplar trees, wheat straw	acetates;				em.com	industrial equipment in order to reduce scale-up risk. Non-GMO bacteria ferment cellulosic sugars with nearly 100% carbon efficiency and the combination of biological and thermochemical processes deliver a 40% yield advantage compared to other processes. Like a petrochemical refinery, ZeaChem biorefineries can make multiple fuels and chemicals, shifting production to the highest margin products. Fuel products include ethanol; chemical products include acetic acid, and ethyl acetate.

Table A.2.

Project name	Project location	Input	Output capacity	Partners	Investment	Funding
BornBiofuels optimization	Bornholm	0.5 t/h	11 t/a; 40 l/d	Biogasol ApS	11692000 DKK	6814000 DKK
commercial	Hugoton, Kansas	320000 t/a	34 000 t/a; 11,3 mmgy	-	-	76 000 000 USD
Pilot	York, Nebraska	330 t/a	75 t/a; 0.02 mmgy	NREL, Auburn University	-	3550000 USD
Demo	Babilafuente, Salamanca	35000 t/a	4000 t/a; 5.0 Ml/a	CIEMAT, University of Lund	-	50000000 EUR
Abengoa Arance EC demonstration	Rocade Sud d'Arance, Plateforme Induslacq - Porte d'Abidos, Arance, 64300	-	40000 t/a; 50000 m^3/a	-	10466737,4 EUR	8632722 (EU funded; LED) EUR
Pilot	Butte, Montana	-	500 t/a; 0,16 mmgy	-	-	-
AliphaJet Pilot Plant	San Francisco	1 t/d	230 t/a; 0,08 mmgy	-	-	4500000 USD
Amyris Antibioticos	Avenida Antibioticos 59, Leon, 24009	-	farnesene; n.s. t/a;	Antibioticos S/A; toll manufacturing	-	-
Amyris Biomin	Estrada Prof. Messias Josa Baptista, 2007 - Bairro Itaper, Piracicaba, 13400-970, Sao Paulo	-	farnesene; n.s. t/a;	Biomin GmBH; toll manufacturing	-	-
Amyris Paraiso	Rodovia Brotas-Torrinha Km 7,5, Brotas, SP , Brotas, 17380-000, Sao Paulo	-	farnesene; n.s. t/a;	Paraiso Bioenergia S/A	-	-
Amyris Pilot & Demonstration Plant	Rua James Clerk Maxwell, 315 - Condomnio Techno Park, Campinas, 13069-380	-	farnesene; n.s. t/a;	-	-	-
Amyris Sao Martinho	Fazenda Sao Martinho s/n - Zona Rural, Pradopolis, 14850-000, Sao Paulo	-	farnesene; n.s. t/a;	Sao Martinho S/A	-	-
Amyris Tate & Lyle	Decatur	-	farnesene; n.s. t/a;	Tate & Lyle; toll manufacturing	-	-
Amyris USA	5885 Hollis Street, Emeryville, 94608, California	-	farnesene; n.s. t/a;	U.S. department of energy	-	-
commercial	Denver, Colorado	52 000 t/a	13 000 t/a; 4,5 mmgy	Fagen	32000000 fagen	-
pilot	Rivalta Scrivia	250 t/a	50 t/a;	-	-	Self-funded
IBP - Italian Bio Fuel	Crescentino (VC), 13044, Piedmont	270000 t/a	60000 t/a;	-	-	Self-funded
OFT Alyssa	Aarhus - odum	0.05 t/h	200 t/a; 0.025 t/h	OFT Aarhus	600000 EUR	-
FT synthesis	Güssing	50Nm³/h synthesis gas	0.5 barrel/day	Repotec, biomass CHP Güssing	-	-
mixed alcohols	Güssing	5Nm³/h synthesis gas	5kg/day	TU Vienna, Repotec, biomass CHP Güssing, Mondi	-	-
BornBioFuel2	Aakirkeby, Bornholm	2,5 t/h dry weight	4 000 t/a; 5.2 Ml/a	Siemens, Alfa Laval, Grundfos, Agro Tech	27500000 EUR	10400000 EUR
BornBioFuel1	Ballerup	0.05 and 1 resp. t/h	n.s. t/a;	Agrotech, Siemens, CKJ Steel A/S	57000000 DKK	127500000 DKK
SNG demo	Europastraße 1, Güssing, 7540	350 Nm^3/h	576 t/a; 100 Nm^3/h	Vienna University of Technology, Austria; Paul Scherrer Institute, Switzerland; Repotec, Austria	-	-
BioMCN commercial	Oosterhorn 10, Farmsum, 9936 HD, Groningen	-	200000 t/a;	Waterland, Teijin, NOM	-	-
Blue Sugars	Upton, 82730, Wyoming	1-2 t/h	2500 t/a; n.s.	Petrobras, other industrial partners and investors	-	-

Project name	Project location	Input	Output capacity	Partners	Investment	Funding
BALI Biorefinery Demo	Sarpsborg, 1701	1 t dry biomass/day	0,5 ton lignin specialty chemicals and 0,5 ton C5/C6 sugars/day	none	18 mill EUR	7,5 mill EUR
ChemCell Ethanol	Sarpsborg	400000 t/a	15800 t/a; 20 Ml/a	-	-	-
Jennings Demonstration Facility	1107 Campbell Wells Road, Jennings, LA	-	4200 t/a; 1.4 mmgy	-	79000000 USD	
Biobutanol demo	Hull	-	15 t/a; 0.005 mmgy	BP Biofuels, DuPont	-	-
Chempolis Biorefining Plant	Oulu	25000 t/a	5000 t/a;	-	20000000 EUR	-
BioDME	Piteå	20 t DS/d	4 t/d	Chemrec, Volvo Trucks, Haldor Topsoe, Preem, Total, ETC, Delphi	€20 million	Partners, EU FP7, Swedish Energy Agency
beta plant	Freiberg	-	13500 t/a; 18 Ml/a	-	100 000 000 EUR	-
sigma plant	Schwedt	-	200 000 t/a; 270 Ml/a	-	-	-
pilot	Warrenville, Illinois	-	n.s. t/a;	-	-	-
Lighthouse	Madison, Pennsylvania	-	120 t/a; 0,04 mmgy	-	-	-
DuPont Cellulosic Ethanol Demonstration plant	Vonore, Tennessee	-	750 t/a; 0.25 mmgy	Genera Energy, University of Tennessee	-	-
Geismar Project	Geismar, Louisiana	-	210000 t/a; 75 mmgy	50:50 Venture of Syntroleum Corporation and Tyson	138000000 USD	-
pilot	Petten	1 800 t/a	346 t/a; 60 Nm^3/h	-	-	-
demo	Alkmaar	-	11,6 MW;	Consortium Groen Gas 2.0 (ECN, HVC, Gasunie, Roya Dahlman, Province North-Holland)	-	-
Sherbrooke pilot plant and research center	Sherbrooke, Quebec	4,8 t/d	n.s. t/a; -	-	-	-
demo	Westbury, Quebec	48 t/d	4000 t/a; 1,3 mmgy	-	-	-
Edmonton Waste-to-Biofuels Project	Edmonton, Alberta	350 t/d	30000 t/a; 10 mmgy	Enerkem Inc., City of Edmonton via Alberta Innovates – Energy and Environmental Solutions, Alberta Energy, Waste Management Corporation of Canada, EB Investments ULC	-	-
Varennes commercial facility	Varennes, Quebec	350 t/d	30000 t/a; 10 mmgy	GreenField Ethanol	-	-
Enerkem Mississippi Biofuels	Pontotoc, Mississippi	350 t/d	30000 t/a; 10 mmgy	hree Rivers Solid Waste Management Authority, USDA, DOE	-	-
Commercial Plant	Blairstown, Iowa	500 t/d	18 t/a; 6 mmgy	-	-	Private equity, USDA Loan $25M, State Grant $2.9M
Integrated Demonstration Plant	Lawrenceville, Virginia	75 t/d	3 t/a; 1 mmgy	Fiberight's innovative technology efficiently fractionates the organic components of MSW such as contaminated paper, food wastes, yard discards and other degradable for the production of cellulose and hemicellulose into fu grade ethanol and other sugar platform biochemicals using enzymatic hydrolysis and fermentation. The plasti fraction and methane collected from Fiberight's processes may also used to create co-generation electricity to power its plant facilities for zero energy input. Fiberight's proprietary extraction, pulping and digestion processes have the potential to unlock over 5	-	Private equtiy

Project name	Project location	Input	Output capacity	Partners	Investment	Funding
				billion gallons of renewable biofuel contained in the 175 million tons of non-recyclable Municipal Solid Waste (MSW) generated each year in the US.		
Project Trixie	200 First Avenue North, Park Falls, 54552, Wisconsin	350000 t/a	51000 t/a; 17 mmgy	EPC: AMEC, Miron Construction; Engineer: AECOM (formerly Earthtech); Technology Suppliers: TRI, EFT	310000000 USD	-
Kinross Plant 1	Kincheloe, Michigan	700 t/d	60 000 t/a; 20 mmgy	Joint venture of Mascoma Corporation and J.M. Longyear	-	-
GoBiGas Plant - Phase 1	Göteborg	-	160000 MW;	-	150000000 EUR	Project Owner, partly funded by the Swedish Energy Agency
GraalBio plants	Nord Est, Alagoas	65000 t/a;	65000 t/a;	Beta Renewables and Chemtex	-	-
sts-plant	Oberhausen	3 kg/h	2 t/a;	Fraunhofer UMISCHT; Greasoline GmbH	3000000 EUR	-
Flex-Fuel and Advanced Gasification Test Facilities, Wood to Gasoline	Des Plaines, Illinois	21 t/d	880 t/a; 23 bbl/day	ANDRITZ Carbona and their client UPM-Kymmene	-	-
IH2 50 Continuous Pilot Plant	Des Plaines, Illinois	50 kg/d	4,1 from wood; 8 from algae t/a; 4,1 from wood; 7,9 from algae gal/d	-	-	-
pilot 1	Fredericia	0,1 t/h	-	-	5 000 000 EUR	2 500 000 EUR
pilot 2	Fredericia	1 t/h	-	-	15 000 000 EUR	5 000 000 EUR
demo	Kalundborg	30 000 t/a	4300 t/a; 5.4 Ml/a	-	53 000 000 EUR	10 000 000 EUR
Indian River County Facility	Vero Beach, Florida	-	24000 t/a; 8 mmgy	INEOS Bio; New Planet Energy	132000000 USD	DOE share 50000000; owner's share 83000000 USD
demo	Ottawa, Ontario	20-30 t/d	1600 t/a; 5000-6000 l/d	-	-	-
BioCentury Research Farm	Boone, Iowa	5 t/d	200 t/a; 5 t/d	-	18 000 000 USD	2 500 000 USD
bioliq	Karlsruhe	0.5 t/h	608 t/a; 100 l/h	Lurgi GmbH, Chemieanlagenbau Chemnitz (CAC), MUT Advanced Heating GmbH, MAT Mischanlagentechnik GmbH	-	-
MSW Syngas to Electricity and Fuel	Aurangabad	-	300 t/a;	LanzaTech has licensed its technology to Concord Enviro Systems.	-	-
Waste Gas to Fuel	Beijing	-	300 t/a;	Lanza Tech Inc., Capital Steel	-	-
Waste Gas to Fuel	Shangha	-	300 t/a;	Lanzatech, BaoSteel	-	-
waste gas to fuel	Auckland	-	90 t/a;	-	-	-
LanzaTech Freedom Pines Biorefinery	Soperton, Georgia	125 t/d	15000 t/a;	Lanza Tech Inc., Concord Enviro	-	-
Commercial demonstration plant	Somersby	1000 odt	350 t/a; 2500 bbl/a	Licella	10,000,000 AU$	Government and Private
pilot	Burnaby, British Columbia	1 t/d	n.s. t/a; Operates in campaigns 24 hours per day from several days to several weeks	-	20 000 000 CAD	-
demo	Grand Junction, Colorado	35000 t/a	7500 t/a; 2.5 mmgy	-	80000000 USD	-

Project name	Project location	Input	Output capacity	Partners	Investment	Funding
Demonstration Plant	Rome, NY	5 t/d	500 t/a; 0,125 mmgy	Marathon Oil Chevron Technology Ventures General Motors State of New York	-	-
Porvoo 1	Porvoo	-	190000 t/a;	-	-	-
Porvoo 2	Porvoo	-	190000 t/a;	-	-	-
Rotterdam	Rotterdam	-	800000 t/a;	-	-	-
Singapore	Singapore	-	800000 t/a;	-	550000000 EUR	-
Development of an Innovative and Comprehensive Production System for Cellulosic Bioethanol	Hiroshima	1 t/d	65 t/a; 50 l/d	Oji Paper, Nippon Steel Engineering, AIST	-	-
Integrated Biorefinery Research Facility (IBRF)	Golden, Colorado	0,5-1 t/d	100 t/a;	-	cumulative 50000000 USD	government and industry
Thermochemical Users Facility (TCUF)	Golden, Colorado	0,5 t/d	50 t/a;	-	cumulative 30000000 USD	government and industry
demo	Varkaus	-	656 t/a; slipstream from 12 MW thermal gasifier	Neste Oil / Neste jacobs, Stora Enso, Foster Wheeler, VTT	-	-
commercial reference plant	Porvoo or Imatra	-	100000 t/a;	Neste Oil / Neste jacobs, Stora Enso, Foster Wheeler, VTT	-	-
West Coast Biorefinery (WCB)	Boardman, Oregon	5,8 t/h	8 000 t/a; 2,7 mmgy	-	48 600 000 USD	24 300 000 USD
Bioethanol second generation production	Horacio Macedo Avenue, 950, Rio de Janeiro, 21941-915, Rio de Janeiro	1 t/d	-	-	-	-
Pilot	Horacio Macedo Avenue, 950, Rio de Janeiro, 21941-915, Rio de Janeiro	10 kg/d	270 l/t;	-	-	-
Second generation ethanol demo plant	Upton, Wyoming	60 t/d	700 t/a;	Petrobras	-	-
Scotland	Scotland, South Dakota	-	60 t/a; 0,02 mmgy	-	9 000 000 USD	-
Project Liberty	Emmetsburg, Iowa	-	75 000 t/a; 25 mmgy	POET and Royal DSM	250 000 000 USD	250000000 USD
Futurol Project	Route de Bazancourt, POMACLE, F-51110	-	2 700 t/a; 3,5 Ml/a	The members of the PROCETHOL 2G consortium : Agı industrie Recherches et Developpements (ARD), Confederation Generale des Betteraviers (CGB), VIVESCIA, Credit Agricole du Nord-Est, IFP New energies, Institut National de la Recherche Agronomiqu (INRA), Lesaffre, Office National des Forts (ONF), Tereos, Total and Unigrains.	76400000 EUR	-
Mackay Renewable Biocommodities Pilot Plant	Mackay, Queensland	0.02 t/h	3 L/h ethanol	Mackay Sugar Ltd, Syngenta	10000000 A$	-
K2A Optimization Plant	Denver, Colorado	-	-	-	-	-
commercial	Soperton, Georgia	-	300 000 t/a; 100 mmgy	Department of Energy, Merrick and Company, PRAJ Industries Ltd., Georgia Forestry Commission, The Stat of Georgia, Truetlen County Development Authority; BioConversion Technology; Khosla Ventures; CH2MHil	-	76 000 000 USD

Project name	Project location	Input	Output capacity	Partners	Investment	Funding
Synfuel production	3041 Cornwallis Road, Research Triangle Park, 27709, North Carolina	0,5 t/d	22 t/a; 0.0075 mmgy	North Carolina State University, University of Utah	3 000 000 USD	2 000 000 USD
biorefinery	Hallein, 5400	600000 t/a	12000 t/a; 15 Ml/a	-	-	-
commercial plants	Örnsköldsvik	-	120 000 t/a; 150 Ml/a	SEKAB will be a technology provider and the plant wou probably be owned by some other partner, maybe with minority ownership of SEKAB	-	-
planned demo plant	Goswinowice	225000 t/a	50000 t/a; 60 Ml/a	SEKAB will be a technology provider and the plant wou probably be owned by some other partner, maybe with minority ownership of SEKAB.	1500000000 SEK	-
IDU	Örnsköldsvik	-	4 500 t/a; 6 Ml/a	-	-	-
demo plant	Örnsköldsvik	2 (dry substance) t/d	160 t/a; 600 l/d	EPAP is owned by University of Umea, Technical University of Lulea, and SEKAB E-technology AB; SEKAB E-Technology runs the plant, and is responsible for the development as well.	2000000 SEK	-
technology development laboratory and pilot plant - thermochemical	International Drive, Durham, 27712, North Carolina	2-4 t/d	-	Commercial and US government clients	30000000+ USD in facility and infrastructure	20000000+ USD since inception
sunliquid	Budapester StraÃŸe 2, Straubing (MÃ¼nchen), 94315, Bavaria	4500 t/a	1000 t/a;	-	28000000 EUR	10000000 EUR
Maxifuel	Building 205, Kemitorvet, Technical University of Denmark, Lyngby, 2800, Copenhagen	0,06 t/h	10 t/a; 40 l/d	BioSystems, Cambi A/S, Novozymes	20 000 000 DKK	-
demo	Temiscaming, Quebec	-	13 000 t/a; 17 Ml/a	-	-	-
Energy Independence I	Mumford Road, Bryan, 77807, Texas	5 t/d	254 t/a; 0,09 mmgy	Waste Management; Valero Energy	3 000 000 USD	-
Superheated steam pilot plant	Zeist	13 kg/h	100 t/a; 0,05 t/h	TNO	-	-
TRIJEN (Liquid Fuel Production From Biomass and Coal Blends)	Gebze, Kocaeli	0.2 t/h	250 t/a;	As Project Executors: TUBITAK MAM, ITU, MU, HABAS,UMDE As Customer Institutions: TKI, EIE	-	8500000 EUR
Weyland	Fleslandsveien 205, Blomsterdalen, 5258	0.075 t/h	158 t/a; 0.2 Ml/a	-	-	6500000 EUR
FT synthesis	Güssing	5Nm³/h synthesis gas	10kg/day	Repotec, biomass CHP Güssing	-	-
Eagle Demonstration Plant	Madison, Winconsin	-	30 t/a;	Virent Inc.	-	-
Demonstration scale biorefinery	Boardman, Oregon	10 t/d	750 t/a; 0.25 mmgy	GreenWood Resources	-	-
Commercial scale biorefinery	Boardman, Oregon	625 t/d	75000 t/a; 25 mmgy	ZeaChem Inc., GreenWood Resources	232500000 $	conditional loan guarantee from U.S. Department of Agriculture

14. APPENDIX 14: Biofuel mandates around the world

Adapted from citation: Biofuels Mandates Around the World: 2012
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http://www.biofuelsdigest.com/bdigest/2012/11/22/biofuels-mandates-around-the-world-2012/

BX Mixture of biodiesel and petroleum diesel containing X volume percent biodiesel

EX Mixture of ethanol and gasoline containing X volume percent ethanol

Mandates in the Americas

Argentina
Has a B7 biodiesel mandate in place – increased in 2010 from B5. The government had previously been on a program to reach B10 biodiesel blending by October 2012, up from 7 percent in May 2012, but a report in Agra-Net suggests that high soybean oil prices are the causal factor in delays in B10, in addition to falling demand for diesel which is bringing down import pressures.

Also has an E5 ethanol mandate in place.

Brazil
Mandates a minimum ethanol content of 18-20 percent – reduced from 25 percent last year when ethanol supplies tightened on rising global prices for sugar.

On the biodiesel side, the Brazilian biodiesel industry is pushing for an intermediate blending rate of 7% for 2013 before the expected implementation of B10 in 2014 to help boost local demand for biodiesel. The country currently has a B5 policy but about 60% of the installed capacity is currently idled. In order to reach the B20 seen for 2020, the industry says it needs $14 billion in investment. has a B2 biodiesel mandate, scheduled to increase to B5 in 2013.

Canada
Canada has a Renewable Fuel Standard featuring E5 ethanol, and B2 biodiesel. Canada introduced the 2 percent biodiesel mandate as of July 2011, and the Canadian Renewable Fuels Association and the Canadian Truckers Alliance are locked in a tit-for-tat debate over it. The CTA is claiming that the mandate will push diesel prices higher and that biodiesel is bad for some engines. On the other hand, the CRFA claims price increases would be unnoticeable over a 25-year period and that engines have shown better performance under state testing than with fossil diesel. Four provinces have individual provincial mandates, up to E8.5.

Also, the national government released its final regulations last year for its 5 percent ethanol mandate. The Canadian Renewable Fuels Association said that an assessment conducted by econometric firm Doyletech Corporation concluded that, “the grand total of the annual positive economic impact of renewable fuels is $2.013 billion.”

Colombia
Has an E8 ethanol mandate in place since 2008, with discussions underway to increase the mandate to 10 percent.

Chile
Has an E5 ethanol and B5 biodiesel target in place, no mandates.

Costa Rica
Has an E7 ethanol and B20 biodiesel mandate in place.

Jamaica
Has an E10 ethanol mandate that took effect last year.

Mexico
Has an E2 ethanol mandate in place in Guadalajara, and will expand the blending mandate next year (2012) to Mexico City and Monterrey.

Panama
In Panama, the country is preparing to introduce an ethanol mandate beginning with 2% in April 2013, rising to 5% from April 2014, hitting 7% in April 2015 and reaching 10% by April 2016.

Paraguay
Has an E24 ethanol mandate and a B1 biodiesel mandate in place.

Peru
Has an E7.8 ethanol, and B2 biodiesel mandate in place. It is expected to move towards B5 biodiesel.

Uruguay
Has a B2 biodiesel policy in place, but not obligatory, and requires the use of domestic biodiesel. It is expected to move to E5 ethanol in 2015. A plan is underway to develop a biodiesel plant in Montevideo and an ethanol plant in Paysandú for a total investment of $130 million. The B5 policy should be obligatory by 2015.

Last winter in Uruguay, the government said it was hoping to implement a B5 policy this year but it will depend on the ability to boost domestic biodiesel production. Already a B2 policy exists,

USA
President Obama supports the preservation of the Renewable Fuel Standard (RFS), as a part of an “all of the above energy strategy”. However, there is fear that affordable private capital will not be available to support any major capacity building for advanced biofuels — putting the RFS itself, with its steep annual volumetric increases, in considerable jeopardy. The resulting lack of capacity and rewriting of mandates to support lower levels of capacity building — well, many US observers (including the heads of all the industry trade associations) take the view that the resulting market uncertainty will likely further reduce (or even zero out) investor interest in the sector.

The US Environmental Protection Agency EPA recently released 2013 biodiesel requirements under the Renewable Fuel Standard:

Biomass-based diesel (1.28 billion gallons – 1.13 percent)

Advanced biofuels (2.75 billion gallons ethanol-equivalent; 1.62 percent)
Cellulosic biofuels (6 million gallons; 0.004 percent)
Total renewable fuels (16.55 billion gallons; 9.74 percent)

Updated figures from: http://www.epa.gov/otaq/fuels/renewablefuels/documents/420f13042.pdf.

Overall, the US is moving towards a 36 billion gallon biofuels target by 2022.

Mandates in the EU

EU-27
In 2003. EU introduced the goal of a 5.75% share of renewable energy in the transport sector by 2010 by the non-mandatory directive. In 2009 this share was rised to a minimum (mandatory) 10% in every Member State in 2020. The European Commission proposed in 2012 to limit the use of food crop -based biofuels to 5 percent, introduce indirect land use change into calculations on acceptable feedstocks, phase out the use of certain arable crops altogether, and provide “multiple counting” benefits that they say will accelerate advanced biofuels adoption by providing huge incentives for their development.Concise information can be found for instance at http://www.biofuelstp.eu/legislation.html or http://ec.europa.eu/energy/renewables/biofuels/biofuels_en.htm.

Mandates in Asia-Pac

Australia
The states of New South Wales has an E4 ethanol blending mandate and a B2 biodiesel mandate in place. The Queensland E5 ethanol mandate was expected to take effect in Fall 2011, but was shelved after opposition from the Against Ethanol Mandates Alliance.

China
Overall, the country seeks to move to a 10 percent biofuels mandate by 2020, and currently has a 15 percent overall target for 2020. Nine Chinese provinces have required 10% ethanol blends to date, including – Heilongjian, Jilin, Liaoning, Anhui, and Henan.

Fiji
The government approved last year a voluntary blend of 5% biodiesel and 10% ethanol with an eye on a mandate by the end of 2012, but action on the mandate has not been forthcoming.

India
The country has an E5 ethanol mandate, scheduled to move to E10 as soon as production is in place, and ultimately has set a goal of 20 percent for all biofuels content by 2017 – it is highly doubtful that they will reach the target.

Indonesia
An on-and-off 2.5 percent biodiesel mandate, and an E3 ethanol mandate.

Malaysia
The country's B5 blending mandate kicked off in June 2011. The program begins in Putrajaya and will be phased in over time throughout the rest of the country. Biodiesel will be price controlled while the government has recently removed the subsidy on fossil diesel.

New Zealand
Back in May 2012, the Labour Party began pushing for the government to reinstate the biofuel obligation that the party had introduced in 2008 when it was in power.

The National party replaced the Labour party's Biofuels obligation with a biodiesel subsidy. Bioethanol enjoyed at the time and still does have an excise exemption. The subsidy scheme essentially levelled the playing field between the two biofuels. The biodiesel grants scheme was not extended beyond its original time frame of 30 June 2012.

The Philippines
Has an E10 ethanol and B2 biodiesel mandate, supporters are asking the biodiesel mandate to be increased to B5.

South Korea
Currently has a B2 biodiesel mandate in place. The introduction in 2012 of a B2.5 biodiesel mandate is expected to boost demand for imported Malaysian palm oil for use as fuel. Malaysian palm oil imports accounted for 32.2% of South Korea's oil imports during 2010. Palm oil is beginning to make in-roads in the Korean market for cooking as well.

Taiwan
Has a B1 biodiesel mandate in place since 2008; considering an E3 ethanol mandate.

Thailand
Has a B5 biodiesel mandate in place.

Vietnam
Has an E5 ethanol blending mandate.

In Thailand this month, the new policy mandating 5% blending of palm oil-based biodiesel came into effect on Nov 2012The move to B5 from B4, which requires additional supply of 200,000 liters per day, was delayed due to lack of availability of locally-produced palm oil due to poor weather conditions but the supply issue has since been resolved, making way for implementation of the higher blend.

http://www.biofuelsdigest.com/bdigest/2012/11/07/thailand-rolls-out-b5-mandate-as-palm-oil-supplies-increase/

In Vietnam, the government was developing a plan as of October 2012 to promote biofuels production and consumption. Submitted by the Ministry of Industry and Trade, the plan will include 5% mandatory biofuel use in some big cities. The plan includes increased production of ethanol and biodiesel to 1.8 million tons through 2015 with a vision to expand the plan to 2025.

In Taiwan, the Taiwan Institute of Economic Research released a report in October 2012 on the benefits of ethanol blending in Tainan. Just last year, the country began producing ethanol from agricultural waste products, and has been exploring the possibility of introducing a blending mandate with 95E3 ethanol, a blend of 3% ethanol. “Tainan has a vigorous sugar industry and a lot of fallow farmland,” noted Tainan Mayor Lai Ching-de. “Setting up a factory here would help revitalize the economy in rural areas and encourage young people to return home.”

http://www.biofuelsdigest.com/bdigest/2012/10/08/taiwan-looks-to-ethanol-blending-following-successful-ethanol-production/

In the Philippines this month, a government-owned corporation supporting more than 3 million Filipino coconut farmers, CIIF Oils Mills Group, has again asked the Department of Energy to increase the 2.0 percent minimum mandated biodiesel blend to 5.0 percent.

Mandates in Africa

Angola
Has an E10 ethanol blending mandate in place.

Ethiopia
Has an E5 ethanol blending mandate in place.

Kenya
Has an E10 mandate in place in Kisumu, the country’s third largest city.

Malawi
Has an E10 ethanol mandate in place, but depends on availability.

Mozambique
Has an E10 ethanol mandate in place.

Nigeria
Has an E10 ethanol target in place, no mandate.

South Africa
Implemented an E10 ethanol blend rate in August – enforcement expected to begin this December.

Sudan
Has an E5 ethanol mandate in place.

In South Africa this month, recent blending mandates that require minimum blending of 2% bioethanol have prompted a prominent law firm, Norton Rose, to release a warning that the requirements could lead to further price increases. According to the government, the policies aim to develop the local biofuels industry in an attempt to attract investment in rural areas and promote agricultural development.

In Zimbabwe, the Confederation of Zimbabwe Industries is pushing for mandatory E10 blending no later than December in line with the mandate put in place by South Africa on Aug. 23. South Africa doesn’t yet have commercial scale ethanol production but Zimbabwe’s own ethanol facility has been idle since February 2012 due to lack of a local market. If the government approves a 20% ethanol blending mandate, Green Fuel will need to raise about $40 million to fund an expansion that would allow it to satisfy increased demand. The roughly 2,000 employees who were put on half-time salaries in February 2012 when the plant shut down after reaching its maximum storage capacity are strongly urging the government to put a blending mandate in place