Analysis of Biomass Supply Chain in Scotland – opportunities for biorefining

Scottish Enterprise

optimat
strategies for success

Executive Summary

April 2016

J2840

Executive Summary

There are a number of existing wood-based biorefineries in Europe and these are typically located in Scandinavian countries. For example, Domsjo Fabriker, in Sweden, is located at a converted pulp and paper mill. Using softwood inputs a range of products are produced including cellulose for textiles, hemicellulose converted to ethanol, lignin into lignosulfinate and bark to biomethanol. Other plants, such as UPM Lappeerntanta in Finland, produce biodiesel from forest residues. The Borregaard biorefinery demonstration plant in Sapsborg, Norway is targeting the production of second generation bioethanol and advanced biochemical.

The Domsjo Biorefinery Cluster is a collaboration of local and regional actors, encompassing 21 companies representing forest, chemical and energy industries. The Domsjo Fabriker facility is one of the worlds most advanced biorefineries. It is a traditional pulp and paper mill that has been converted into a wood-based biorefinery where softwood (both Swedish and imported) is converted into a range of products: speciality cellulose, ethanol, lignosulfonate, biomethanol and bioDME. The process from log to cellulose bale takes around 40hours. The cluster is a privately owned enterprise with a turnover of 2-3 billion SEK.

UPM Lappeernranta Biorefinery is the world's first to produce wood-based biodiesel from forest residue. The biorefinery is located at the same site as UPM's pulp and paper mill in Finland. The facility is the first of its kind, certainly in terms of scale with industrial investment of €150 – 175 million. The main product is renewable diesel. Crude tall oil, a residue of the pulp making process, is used as a raw material. The renewable raw material originates from forests that are managed sustainably. The company is aiming at 100,000 tonnes of biodiesel per annum.

Solander Science Park, Pitea, Sweden is home to Smurfit Kappa mill. They are working in partnership with Sun Pine, a Swedish technology company to make biodiesel from tall oil. Another Swedish oil company, Preem, has joined the partnership and will take the high-sulphur, tall-oil based crude and further refine it, including desulphurisation, in an existing petroleum refinery. The site also includes work on gasification to form BioDME.

Fortum, Joensuu, in Finland. Fortum is an energy company, specialising in district CHP plants. The activities focuses on the production of bio-oil to replace heavy and light fuel oil (integrated into the company's CHP plant). This is an example of industrial scale demonstration of fast (catalytic) pyrolysis technology. Fortum are in partnership with UPM and Valmet for this project. There is also the potential to convert the bio-oil into chemicals and transport fuel.

The Borregaard biorefinery demonstration plant in Sarpsborg, Norway – the plant will produce green chemicals and sugars based on biomass from wood and agricultural and forestry waste. The demonstration plant, called Biorefinery Demo, started preliminary operations in summer 2012, followed by normal operations in the 1st quarter of 2013. The plant relies on Borregaard's proprietary BALI technology, which involves converting the cellulose fibres in biomass to sugars that can be used for the production of second generation bioethanol, while other components of the biomass (lignin) are targeted to produce an advanced biochemical.

Outside of Europe, there are a number of wood-based biorefinery operations. An example of Canadian activity is that of the Alberta Pacific Forest Industries Kraft pulp mill, the largest such mill in North America, which has just begun to produce commercial grade biomethanol. Conventional Kraft pulp mill processes generate a waste gas stream from the digester which contains as much as 70% methanol. However, this gas stream also contains turpentine and other components which prevent the separation of methanol for higher value use. Traditionally, the gas stream is burned in the lime kiln. A new process for extracting and purifying bio-methanol has been developed by Canadian engineering firm A.H. Lundberg to produce bio-methanol. This process will collect the methanol produced by the digester, distil it, remove impurities and use it in its pulp bleaching operations. The liquid bio-methanol is easily stored and transported, allowing excess quantities to be sold for use in other industrial processes and products

In the US, the Department of Energy has funded a number of small-scale biorefining projects. This includes the Flambeau River Biofuels demonstration-scale biorefinery. This is planned as an integrated biorefinery for the production of bio-diesel at an existing pulp and paper mill. The biorefinery will gasify forest biomass to syngas. The syngas will be cleaned and converted to liquid fuels or products through a Fischer-Tropsch conversion process. Unconverted syngas will be burned for heat for use in the biorefinery and to offset some of the existing mill energy needs.

An example of a small-scale development that would be highly relevant to the Scottish setting is that of the Placer County (California) demonstration to convert forest thinning into biomethane to be used as a transportation fuel in the County run bus services. The initiative will use a proprietary PydroCatalytic hydrogenation process developed by a Canadian company called G4 Insights. A small commercial plant, consuming approximately 2 logging trucks worth of wood per day is projected to produce around 400 GJ/day output of biomethane. The process is particularly well suited to small forest operations.

Biorefining technology development has received significant funding via the European Commission. One area of focus has been on pre-treatment technologies to break down wood fibre into constituent parts. Approaches to this have included steam explosion, torrefaction and the use of ionic liquids and other new solvents to open up the cellulose matrix. Example projects include:

- AFORE: The project, which was completed in August 2013, has demonstrated to pilot and industrial scales a prioritised selection on separation, extraction and upgrading techniques, aimed at developing higher value added products from forestry resides and side stream from the pulp and paper process used in Kraft mills. The techniques included the separation and fractionation of birch bark, supercritical CO2 extraction of valuable components from eucalyptus and birch bark, and catalytic pyrolysis of lignin.
- BIOSONIC: A novel ultrasonically-enhanced separation process was developed in this project, which completed in December 2015, to cleanly separate wood into its main constituent parts much faster than traditional processes. A pilot plant (50kg/h, 300tonnes/annum) is now operating at PERA, Melton Mowbray. The technique uses organic acid, water, organosolv and ultrasonic energy to separate cellulose,

hemicellulose in the form of C5 and C6 sugars, and lignin from surplus/waste lignocellulosic biomass.

- 2G BIOPIC: The project aims to scale up to demonstration (1 tonne biomass/hour) a biochemical process for the production of bioethanol from agricultural residues and wood that was previously proved at pilot scale (50kg/hour) in the FP7 BIOCORE project. The process is based on technology known as organosolv which is said to cleanly deconstruct lignocellulose biomass
- US4GREENCHEM: The project aims to combine mechanical pre-treatment of lignocellulose with ultrasound and subsequent enzyme recovery of sugars to valorise by-products. CO2 technologies will also be used to maximise release of sugars as well as the development of purification and conversion strategies for lignin-based products. The project commenced in July 2015 and will complete in July 2019
- COSEPA: This project, titled "Controlled Separation and Conversion Processes for Wood Hemicelluloses" aims to develop novel alternative ways to separate and fractionate wood hemicellulose.

Improved process design has also been the focus of much research. This has included developments in both thermochemical and biochemical routes, specifically to improve pyrolysis and gasification techniques and to develop new yeast strains and enzymes for fermentation of biomass. Other areas of developments include novel reactors, size reduction of reactors, coupled systems and improved catalysis. Selected examples include:

- BIOREFINE-2G: The project is looking to develop new (genetically engineered) industrial yeast strains to convert side streams from bioethanol production into value added products such as dicarboxylic acids which can then be used as precursors for biodegradable polymer production. The project recognises the greater challenges associated with converting second generation biomass (lignocellulose) into profitable products and hopes to support this goal by developing commercially higher value options for (pentose-rich) side stream that are currently utilised for biogas and energy production. Importantly, the project consortium includes the Borregaard biorefinery.
- CRACKING of LIGNIN: The aim of this project is to convert lignin to bio-fuel and chemicals using water at high pressure and high temperature (near-critical water). The work involves the development of novel laboratory reactors to better understand the process. The project commenced in October 2012 and will complete in September 2016.
- BIOGO: The project aims to advance the nanocatalysts used in the synthesis of biofuels and to develop innovative reactor technology. BIOGO will develop and demonstrate a mini-plant (containerised plant) including all reaction, separation and purification steps from bio-feedstock to hydrocarbon fuel and chemicals.

Examples of technology developments by companies include:

- G4 Insights (Canadian) is developing and commercialising a proprietary PyroCatalytic Hydrogenation (PCH) process to produce a renewable drop-in replacement for fossil natural gas. It is a lignocellulose thermochemical process. The G4 process coverts pyrolyzed biomass directly into methane and water. This unique process eliminates the generation of polyaromatics and minimizes tar formation. Current development of the technology is in the process demonstration phase. The company has a demonstration unit.

- Developed by Swedish R&D company, Innventia, LignoBoost is a unique technology for extracting high quality lignin from a Kraft pulp mill. The LignoBoost process makes it possible to expand the capacity of a pulp mill at a lower cost. Since 2008, the LignoBoost technology is owned and commercialized by Valmet. Two commercial plants (Domtar, USA and Stora Enso, Finland) are presently running with the technology. Innventia also offer:
    - High-temperature membrane separation of e.g. hemicelluloses from process liquids.
    - Leaching of inorganic and/or organic compounds from wood chips.
    - Upgrading of hemicelluloses through precipitation and washing processes to high purities.
    - Separation of suberin and betulin from hardwood bark using a water-based method (patent pending).

Opportunities for adding value at the wood pellet manufacturing stage were also investigated. Three areas were identified including: supercritical CO_2 extraction involving removal of 80% of lipids and resin acids from sawdust prior to palletisation (with products potentially used as anti-foaming agents); microwave-assisted hydrothermal de-polymerisation of cellulose and; controlled separation and conversion processes for wood hemicelluloses. The latter area is the focus of a project involving numerous partners including Napier University, Balcas and Arbuthnott Wood Pellets and seeks to separate hemicellulose and purify it for use as a barrier film and conversion to platform chemicals.

There are various potential sources of wood fibre arising in Scotland that could potentially be used as inputs to a biorefining process. These include small roundwood (7-14cm diameter), poor quality stemwood, stumps, brash, non-timber sawmill product and arbocultural wood fibre. Each of these differs in the scale of arisings, geographical dispersion, current utilisation rates etc.

Small roundwood, together with poor quality stemwood, is referred to in the forestry sector as 'industrial roundwood'. In Scotland the annual arisings of industrial roundwood are just over 2 million green tonnes. This increases to over 2.25 million green tonnes if the North of England is included (industry feedback suggests Scotland and the North of England can be regarded as a single unit of supply and demand). At current market prices most of this material is recovered during forestry harvesting operations and it is all utilised in markets such as panel board manufacture, fencing and bioenergy. It has been identified that some 200,000 green tonnes of the total 2 million green tonnes of industrial roundwood is exported from Scotland to the rest of the UK and a further 200,000 green tonnes is exported from Scotland to markets outside of the UK.

There is estimated to be over 6.5 million green tonnes of stumps and brash arisings connected to annual softwood harvesting. However, due to a combination of environmental factors (e.g. need to retain nutrients in the soil for subsequent planting) and operational factors (e.g. site slopes being too steep for stump harvesting equipment) this can be reduced to 1.15 million green tonnes. In reality, however, virtually no stump harvesting takes place due to the high cost of extraction compared to the market price of other potential sources of wood fibre. Brash harvesting is also a marginal activity and is only feasible where there is a sufficiently close source of demand for bioenergy. In the case of both stumps and brash the energy value is poor compared to industrial roundwood and the ash content is higher. A potential alternative to stump harvesting was identified during the stakeholder interviews. This would involve increased recovery of stump material during the main harvesting operation by developing a new blade mechanism that would use a 'v' shaped cut rather than a horizontal cut. This will require some technical development work but could increase yield of wood fibre by over 21,000 green tonnes for each additional 10% of the stump recovered in this way (in Scotland).

Non-timber sawmill product includes woodchip, sawdust and bark which arises at the sawmill. It is estimate that there is over 1.5 million green tonnes of this material arising each year with most of it being located at one of the 20 large sawmills based in Scotland. Woodchip is used as an input to paper production, chipboard and medium density fibreboard production. Sawdust is used as an input to particleboard and bark is used in the horticulture sector as a mulch or composting material. Although all this material is fully utilised the value obtained for the bark is low and there may be potential to consider this as a target material for biorefining.

Arbocultural arisings are estimated to be between 0.3 million green tonnes and 0.5 million green tonnes. The majority of this is utilised for domestic firewood, etc. with the remaining 0.1 million green tonnes not currently utilised being very geographically dispersed and owned by a large number of fragmented arbocultural service providers. This is not viewed as a key source of wood fibre for biorefining.

In conclusion, this research has summarised a number of existing biorefining operations. These tend to be operating at a scale that is unlikely to be applicable in Scotland. There is a number of interesting research projects and emerging technologies focusing on pre-treatment and improved process design that offer smaller scale alternatives. Many of these are still at technical feasibility stage although there are some examples of pilot plants being operational. The scale of these is potentially more applicable to Scotland and opportunities may be present to establish pilot projects at sites where there is a concentration of arisings. This could include at sawmills, waste wood processing facilities (to address post-consumer MDF) and mobile units at harvesting locations.

business growth

economic development

technology commercialisation

Head Office

Optimat Ltd.

Torus Building, Rankine Avenue

Scottish Enterprise Technology Park

East Kilbride G75 0QF

tel: +44 (0)**1355 272 800**

fax: +44 (0)**1355 272 556**

web: **www.optimat.co.uk**

optimat