Low Cost, Long Distance Biomass Supply Chains

(Revised in April 2014)

IEA Bioenergy

Task 40: Sustainable International Bioenergy Trade

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Executive summary

Aim and scope

This report focuses on long-distance biomass supply chains, including ground-based supply of raw biomass to densification plants, and transportation of densified biomass to ports in other continents.

It aims to:

- provide an overview of the characteristics of three densified biomass forms; solid wood pellets, solid torrefied wood and liquid pyrolysis oil; for these;
- outline existing and future markets and specific supply chains for these products and explore large sources of biomass worldwide, some well-established and already being developed either for local use or trade, some only identified as a possible future potential source;
- highlight the importance of the costs of logistics in biomass supply chains;
- illustrate current cost structures of existing long-distance biomass supply chains, and
- explore how the cost of current and future long-distance supply chains of wood pellets, torrefied pellets and pyrolysis oil could be lowered, and what this would require form the stakeholders involved.

The study encompasses three biomass products; wood pellets, torrefied wood, and pyrolysis oil. Each of these biomass products increases the volumetric and energy density of the original biomass feedstock to improve biomass uniformity and reduce transportation cost. Wood pellets are currently the only commercially viable product and the only product already traded in significant volumes. Not covered in this study are other solid biomass types such wood chips or untreated agricultural residues, and liquid transport fuels such as ethanol and biodiesel. Russia is a growing biomass exporter, and main expected supply is to the EU, i.e. a relatively short-distance trade route. Exports from Russia have thus not been covered in this report.

Where possible supply chain costs are examined. Costs are displayed fully loaded, containing project returns to debt and equity holders. All costs are expressed in US$.

To eliminate the difficulties of publishing sensitive cost data by company or by plant, all costs are expressed as a percentage of the highest cost supply chain, which in this study is a 50,000 tonne pellet plant in Northern Ontario, Canada, exporting pellets to Europe. The numbers in this report are indicative and subject to change. The recent Rentech/Drax deal shows that it's apparently commercially feasible to export wood pellets from Ontario to the UK.

Results

Between wood pellets, torrefied pellets and pyrolysis oil, wood pellets are by far the only active product being traded over long distance. Wood pellets have been traded for over 20 years, with a total traded volume reaching 3.2 million metric tonnes (MT) between North America and the EU in 2012 (see **Fig.** ES-1), and the supply chain is mature (Lamers et al., 2013).

Several torrefied wood technologies are now coming on stream but as of May 2013 only one company, New Biomass Energy in the US, is capable of producing at the commercial level and is now exporting small volumes by ship. Torrefied pellets are 40% more dense on a volume basis than wood pellets and thus should have a transportation advantage.

Pyrolysis oil has been produced commercially for 23 years, but in small volumes. Most production has been exported by truck-throughout North America with only test volumes transported by ship, and in containers rather than in bulk. Pyrolysis oil is twice as energy dense as wood pellets, and may become a preferred medium for long distance transport of biomass, especially in new bio-chemicals markets.

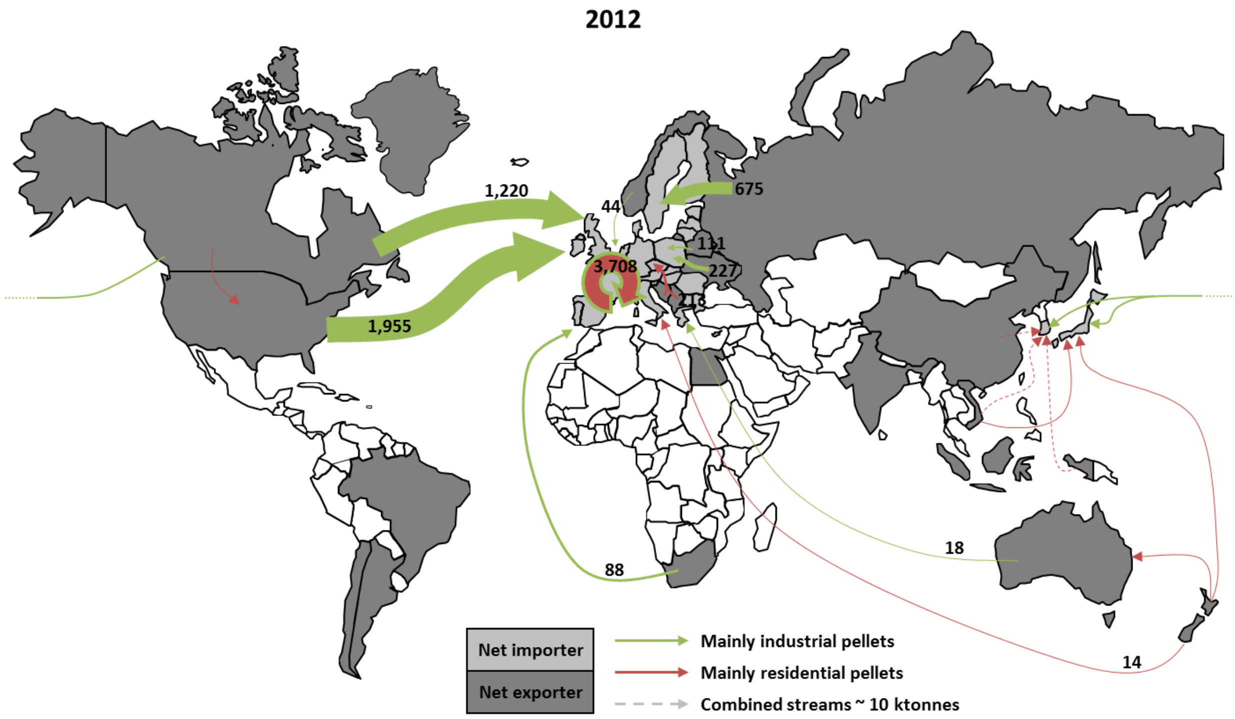

Fig. ES-1 Global wood pellet trade flows 2012 (Lamers et al., 2013)[1]

Europe has legally binding targets for renewable energy by 2020, and a considerable amount of this energy will be from biomass, much of it imported. In 2011, Korea too established renewable energy targets up to the year 2020, and post-Fukushima Japan has decided to wind down its nuclear industry in favour of renewable energy, thus creating a new market for biomass. Pellet market growth is projected to be substantial, necessitating an increase in world trade in biomass. Approximately 60% of wood pellets traded overseas go to large power plants and district heating systems while 40% is for the small community heat segment. Torrefied pellets may gradually take some of the growth in the large power market. Pyrolysis oil has been fired in large boilers. If pyrolysis oil can be manufactured in large volumes and low-cost bulk shipping is proved it is likely to be traded long distances in the same manner as pellets are being sold into the power market. A 2012 USDOE study showed pyrolysis oil to be the lowest cost route to renewable transportations fuels,

[1] Lamers P, Marchal D, Heinimö J, Steierer F (forthcoming) Chapter 3: Global woody biomass trade for energy. In: Juninger, M, Goh, C.S., and Faaij , A. (eds.): International Bioenergy Trade: History, status & outlook on securing sustainable bioenergy supply, demand and markets. Springer, Dordrecht.

such as gasoline, diesel and jet fuels. Should this path succeed, pyrolysis oil could also be shipped to conventional petroleum refineries as a feedstock for upgrading into these lucrative markets.

Logistics costs of long-distance supply chains are typically more than half of the cost of traded biomass. Yet when planning and evaluating bioenergy projects the focus tends to be on the operational performance of the mill and on raw material supply. Logistics is often of secondary interest, and regarded as difficult to influence. In future, while manufacturing efficiencies will be sought, optimizing supply chains may be a major source of cost reductions as well. Most important factors identified to reduce supply chain costs are:

- make use of the existing infrastructure more efficiently
- achieving economies of scale in rail and ship transport, e.g. using specialized rail cars and larger ships,
- joining forces with other producers to be able to achieve these economies of scale, e.g. by collectively bargaining for freight rates etc.
- bringing technical and organizational aspects of supply into one fully integrated supply chain under the control of one stakeholder. For the long-term viability of bioenergy trade, a system with independent logistics service providers in competition should be able to achieve cost efficiencies by integration with other businesses locally or parallel along the supply chain.
- convincing external stakeholders that long distance and long term export of bio-energy would be viable and sound

In the short term (3-4 years) biomass sources will continue to be regions where large amounts of biomass are available and accessible, and where supply chain infrastructures for trade are in place or easily added, such as BC Canada, US South, and increasingly Eastern Canada. Gradually, new sources may be added that will require new, game-changing supply chains, including Malaysia, Indonesia, Brazil, and finally the Caribbean and stable countries in Southern Africa.

British Columbia, Canada, is 8,000 km by sea to Korea and 16,000 km To Europe. As such, pellets from BC may increasingly be diverted from the ports of Vancouver and Prince Rupert to ports in Korea, Japan, and China. BC is meeting the challenge with major investments in port facilities to reduce costs. Europe is expected to see volumes ramping up from the US South initially, and increasingly from Eastern Canada, notably Quebec. Northern Ontario is not yet competitive in pellets, with long supply chains and expensive wood. However Quebec and Ontario sawmill industries are rebounding from a 2008-12 industry downturn and more low-cost feedstock is likely to come available.

Costs can be reduced further with innovative solutions, such as piggybacking on existing mature supply chains. For example, wood pellets commonly are shipped on 35,000 tonne Handymax ships, and on occasion 70,000 tonne Panamax ships. If and when torrefied pellets are traded long distances, they will be shipped in small volumes in some holds of small ships as pellets were initially. Coal, a major commodity, is shipped from modern terminals on Panamax and Capesize ships. Major coal exporters Australia, Indonesia, US, Columbia and Western Canada also have considerable available biomass. It is envisioned that torrefied pellets can be manufactured near coal terminals, and subsequently be loaded into holds adjacent to coal on large ships, thereby getting the cost advantage of large vessels.

A similar option is possible with pyrolysis oil. Two of the world's leading pyrolysis oil companies, Ensyn and Dynamotive, have successfully demonstrated processing of palm oil extraction residues into pyrolysis oil. In Malaysia and Indonesia alone there are 50 million tonnes of fruit bunches available annually. The palm oil supply chain is already mature; truck or rail to ports, efficient storage and handling, and sufficient volume to warrant Panamax ships. Pyrolysis oil plants could be built near a palm plantation using the ready feedstock and with minor modifications use the existing ground supply chain to port.

Essentially, meeting the expected increase in biomass required to achieve the EU 2020 renewable energy targets will require opening up new sources of previously stranded biomass, and the adoption of innovative logistics concepts to get the biomass competitively where it is needed. As shown in chapter 6 of this report, increasing the scale and optimizing supply chains can lead to significant reduction of costs for all three technologies investigated – depending on the exact supply chain, between 20-45% cost reduction compared to a current base case may typically be achievable. However, this will require actions from different market parties directly in the supply chain, but also support from policy makers, banks and other external stakeholders.

1. Transportable Biomass Characteristics

Wood pellets, torrefied wood and pyrolysis all have different characteristics. **Table** 1.1 compares these differences against properties of wood and competing fossil fuels such as coal and heavy fuel oil. Wood pellets, by far the most prevalent of the densified biomass fuels, have calorific value of 16-18 GJ/tonne and energy density of 9.6-12.2 GJ/m^3. Torrefied biomass has energy content of 19-23 GJ/t, and energy density of 13-18 GJ/m^3, 50% more energy dense than wood pellets. Pyrolysis oil has about the same heat value as pellets by weight- 16-19 GJ/t, but on a volume basis it is twice as energy dense as pellets- 19.2-22.8 GJ/$m^{3.}$ This is a major advantage in transportation.

Table 1.1- Properties of Transportable Biomass and Competing Fossil Fuels[2].

	Fresh Wood	Wood Pellets	Torrefied Pellets	Pyrolysis Oil	Coal	HFO
Moisture (%)	35-50	7-10	1-5	20-25	10-15	<.5
Calorific Value (GJ/T)	9-12	16-18	19-23	16-19	23-28	42.5
Bulk Density (T/m3)	.2-.25	.6-.68	.65-.75	1.2	.8-.85	.99
Energy Density (GJ/m3)	2-3	9.6-12.2	12.4-17.3	19.2-22.8	18.4-23.8	42
Acidity (pH)				2-3		
Ash (% by wt.)		0.4-2	0.4-2.5	<0.25	9.7-20.2	.08

1.1 Wood Pellets

Wood pellets are generally made from compressed sawdust or other residuals from sawmilling and manufacturing other wood products, though an increasing proportion of raw material for pellets now comes from round wood thinnings and harvest residues. Pellets are manufactured in several types and grades as fuels for electric power plants, homes, and other applications[3]. Pellets are dense and can be produced with a low moisture content (below 10%) that allows them to be burned with a very high combustion efficiency[4]. Pellets are produced in different sizes, normally between 6-10 mm in diameter. Smaller diameter pellets have a larger surface area per ton and are therefore suitable for direct burning. Pellets that are larger in diameter are cheaper to produce and are normally ground before combustion and are therefore burnt primarily in larger boilers. Different sizes of pellets have the same bulk density.

The regular geometry and small size of pellets allow automatic feeding with very fine calibration. They can be fed into a burner by auger feeding or by pneumatic conveying. Their high density also permits compact storage and rational transport over long distance. Provided application of state-of-the-art technology, pellets can be moved conveniently from a bulk vessel to a storage bunker or silo on a customer's premises[5].

[2] Possible Effect of Torrefaction on Biomass IEA
[3] Research on Off-Gassing and Self-Heating in Wood Pellets During Bulk Storage- S. Melin, WPAC Nov 2011
[4] Global Wood Pellet Industry Market and Trade Study- IEA Bioenergy Dec 2011
[5] Ibid 3.

As wood from conifer trees is rather homogeneous with good properties for pelletizing, conifer pellets are not differentiated with regard to wood species. In contrast, properties of hardwood species vary greatly, effecting both the pelletizing process and properties for combustion. Some pellet manufacturers use binders to achieve good stability values and to avoid dust. However, some quality standards do not accept binders for pellets in their highest quality class. Hardwood pellet users like to separate the fuel into quality classes, for example by species such as eucalyptus, aspen, mixed hardwoods, to allow users to improve the combustion efficiency of boilers.

Handling and transporting pellets can be dangerous, with risks similar to those of other biotic material (grain, wood chips, lumber, etc.). Under the IMO (International Maritime Organization), rules for safety and risk reduction have been established. In spite of these rules, some serious and accidents have occurred in wood pellet transportation. Though pellets have been used for years, users continue to develop and apply new procedures to minimize risk, including safety initiatives by different industry associations. It should be noted that accidents have occurred for many energy forms including coal, oil and natural gas.

1.2 Torrefied Wood

Wood pellet feedstock is restricted to sawmill and pulp mill residues with some harvest residue possible, but with a large proportion of white wood. Torrefied wood can accommodate a broader feedstock base and has a lower sensitivity in homogeneity of the input material. Torrefaction is a thermo-chemical process whereby biomass, such as wood, is heated under an inert or nitrogen atmosphere within a temperature range of 230-300^{o} C, similar to roasting coffee beans. This process results in decomposition of hemi-cellulose, lignin and cellulose. The roasting causes evaporation of some volatile components of the biomass resulting in 20-40% mass reduction accompanied by energy content losses of 10-20%. Improved ease of pulverization, increased water resistance and cleaner burning are significant advantages over the biomass feedstock. Torrefied biomass is lightweight causing plenty of fines and dust if transported, therefore mechanical compacting of torrefied biomass is necessary to make it transportable. Pelletizing and briquetting are processes employed today. If done well, a bulk density of 650-750kg/m^3 can be achieved, even as high as 800kg/m^3 as reported by Netherlands research organisation ECN. Torrefied biomass, although completely dried, will be traded at moisture contents typically at 5-8% as water is typically added in quenching after torrefaction and/or prior to compacting.

All solid biomass can be torrefied, however, the mass and energy balance of product and its mineral components will vary and reflect composition of feedstock. Once biomass is torrefied it becomes hydrophobic. Water absorption by torrefied biomass, even if exposed to wet conditions, will be significantly reduced. Water normally sticks only on the surface of particles, like sand. However, torrefied biomass in pellet or briquette form will not necessarily be waterproof and the quality of the compacting process will determine how long the products can withstand the eventual entrance of water into cracks and rifts in the surface of the product. Water encroachment does not necessarily result in complete decomposition of a torrefied pellet as it would with wood pellets, but it still weakens the physical strength of torrefied products and its grindability in coal power plants.

Compacted torrefied biomass is currently considered to be a non-hazardous good. Once cooled no increases in temperature have been reported to date when stored or shipped in bulk carriers. Off-gassing is similar to or less than that seen from wood pellets. Torrefied product traded today is transported and stored under special licences, as there is insufficient experience with the material. Registration such as REACH (Registration, Evaluation, Authorization & restriction of Chemicals) and licensing is now being assessed.

1.3 Pyrolysis Oil

Pyrolysis Oil is a dark-brown, free-flowing liquid made from plant material by a thermo-chemical process called fast pyrolysis, whereby biomass particles are rapidly heated in the absence of oxygen (typically to 500C in less than 1 second), vapourized, and the vapours then quenched into the Pyrolysis Oil liquid, also known as bio-oil. The process typically yields 65-72% liquid (dry feed basis), 15-20% char (a black charcoal-like powder) and 12-18% non-condensable gases, depending on the type of feedstock and other factors in the manufacturing process. Pyrolysis oil is not an "oil", like a vegetable oil or petroleum oil, because it is composed of hundreds of different chemicals including acids and contains about 25% water. Pyrolysis oil is immiscible with conventional fossil-derived oils but can be readily mixed with water. The fast pyrolysis process has no waste since both pyrolysis oil and char have significant commercial application and value, while non-condensable gases are recycled and produce approximately 75% of the energy required for the process itself. The product oil has a density of approximately 1.2 t/m^3, and heating a value of 16-19 GJ/t, approximately 55% of the heating value of diesel by volume basis and 45% on a weight basis. Pyrolysis Oil contains only traces of sulfur and therefore does not produce significant SO_2 (sulfur dioxide) emissions during combustion, and usually produces approximately half the NO_x (nitrogen oxide) emissions in comparison with fossil fuels

Pyrolysis oil can be stored, pumped and transported like petroleum products. However, pyrolysis oil has a pH of 2-3, about the same acidity as household vinegar. The acidic and thus corrosive nature of pyrolysis oil means that modifications are required for storage and transportation, but these are not onerous. Storage vessels and piping should be stainless steel, PVC, Teflon or similar corrosion-resistant materials. Segregation/settling of pyrolysis oil is not an issue for short-term transportation and storage. Neither trucks, nor rail, nor shipping are required to have mixing capability. Mixing capability in customer storage tanks is easily arranged with existing tanks.

Pyrolysis oil can be combusted directly in boilers and potentially in engines (slow to medium speed diesels) and gas turbines for heat and power although the latter applications are unproven beyond short-term testing using "enhanced" pyrolysis oil.. For boiler applications ASTM Technical Standard D-7544 limits ash content to <0.25% and although they are under development, no standards exist for engine applications.

Trans-ocean transportation of Pyrolysis oil is not subject to the same issues as petroleum oils. Petroleum spills can spread as a micro thin layer over a wide area, often hundreds of square kilometres with major environmental consequences. Pyrolysis oil does not spread, but separates into a very heavy organic fraction that will sink and is largely inert[6], and an aqueous fraction that will be diluted and is very bio-degradable. Initial toxicology tests show that liquid produced from fast pyrolysis processes is non-toxic[7].

The by-product char is the remains of solid biomass that has been incompletely combusted, similar to charcoal. Char is 65-76% carbon by weight, 5-12% ash, and less than 2% moisture. It has heat value of 28-30GJ/t. It is a charcoal powder with particle size less than 1 mm, and has bulk density of 0.25-3 t/m^3. Since char is very fine and has low bulk density, around 250-350kg/m^3. As it can be difficult to handle in powder form, pelletizing char is recommended if transported any great distance. Pelletized char can be added directly to the coal feed without limitation.

[6] Dr. Tony Bridgwater, Aston University, Birmingham
[7] Blin J, Volle G et al, Biodegradability of Fast Pyrolysis Oil", CIRAD Forestry Dept, International Research Center for Agricultural Development, France

2. Markets, Markets Issues and Readiness

2.1 Wood Pellets

In 2010, global capacity for wood pellets was estimated to be 28 million tonnes, of which over 60% was in the top five countries, shown in **Table** 2.1. Pellet production reached 14.3 MT, while consumption was 13.5 MT[8]. The EU is the main market for wood pellets consuming 11.4 MT in 2010, 84% of world consumption. Overall in 2010, about 9.2 MT was produced in the EU, and 2.2 MT was imported to meet demand. By 2012, the volume imported from outside the EU has risen to more than 4.2 MT. The prospects for growth in demand are high in the EU, but are dependent on continued policy support. **Table** 2.2 projects wood pellet demand in Western Europe to more than double from 10.8 MT in 2010 to 22.8 MT in 2020.

Table 2.1 Wood Pellet Capacity- Million tonnes per Year (Data in 2010)[9]

	Capacity (MT)	Utilization rate (%)	Production (MT)
US	6.0	33%	2.0
Germany	3.2	56%	1.8
Russia	3.1	32%	1.0
Canada	2.5	72%	1.8
Sweden	2.3	70%	1.6
Other	10.9	56%	6.1
	28.0		14.3

Japan, Korea and China were minor users of pellets in 2010, but their consumption is projected to exceed that of Western Europe by 2020. In 2011, Korea committed to 30% reduction in GHGs by 2020, and a renewable portfolio standard of 2% of power generation from renewable sources by 2012 with annual increases to reach 10% by 2022. Though pellet demand is projected at 5 MT by 2020[9], Korea has not yet begun to import pellets. It lacks pellet import infrastructure and Korea is pursuing extremely low pricing. In Japan, following the 2011 earthquake-caused meltdown at the Fukushima power plant, the government decided to phase out nuclear power in favour of renewable energy. Biomass is seen as one of the contributors to renewable energy[10]. Biomass imports to Japan may reach 8.5 MT by 2020[11].

Another major consumer of pellets is the US. This market, at 3.4 MT, is driven primarily by the residential heating market in the NE States that are not on a natural gas pipeline. The domestic market appears to have peaked, and any new pellet production will be directed at Europe. In Canada pellet production capacity reached 3.8 MT in 2012 with another 440,000 tonnes under construction, but the domestic market is small at about 250,000 tonnes[12]. The domestic market is growing slowly owing to the infrastructure for domestically produced oil and gas, and also barriers to utilization including the requirement for ASME (not ISO) certification, and obsolete steam engineer legislation.

[8] Global Wood Pellet Industry Market and Trade Study- IEA Bioenergy Dec 2011
[9] Presentation Vancouver Nov 2012- Biomass Demand in Korea- Hyoung Woo Lee, Drying Engineering Inc
[10] Ibid 2
[11] Presentation Vancouver Nov 2012- FIT and Biomass Demand in Japan - Hidetoshi Iguchi, Mitsibishi
[12] Canada Report on Bioenergy 2012- CanBio (to be published in spring of 2013)

In Canada, in late 2012 OPG shut down its Atikokan power plant and began the conversion to a 100% biomass plant. This plant will use only 45,000 tonnes from each of two local plants, so excess pellet production will have to be exported.

Table 2.2 Major Consumers of Wood Pellets[13]

Major Consumers of Wood Pellets- Million Tonnes			
	2010	2015	2020
Western Europe	10.8	16.4	22.8
Japan/Korea	0.2	3.8	13.5
China	0.6	3	10
North America	3.4	4.3	5.6

There are three main markets for wood pellets; co-firing in large coal-fueled power plants, industrial pellets for CHP and district heating, and small residential heating. The large increase in demand for industrial pellets for co-firing, in countries such as the Netherlands, Belgium, Denmark and the UK, were driven by feed-in-tariffs or similar incentives, and increasingly will be driven by EU Renewable Energy targets. In the Netherlands 94% of pellet consumption is co-firing in power plants[14], in Belgium 88%, UK 77% and Denmark 55%. Several large power producers are planning for large 100% biomass plants. Implementation is now taking place in the UK. Similar developments are under way in CHP. In Sweden, Denmark and Germany pellets tend to be used in medium to large CHP plants. In Sweden in 2009, 40% of pellet consumption was in large district heating plants[15].

In the residential heating market, the main drivers for market expansion are often indirect policy support measures for the installation of pellet stoves and boilers, as well as cost competitiveness of wood pellets compared to heat pumps, natural gas and heating oil. A broad range of pellet stoves, central heating furnaces, and other heating appliances have been developed and marketed since 1999. In Europe, Italy, Austria, Denmark and Germany are the main countries in this segment, both in bulk delivery and in bag delivery. It goes without saying that the demand in the heating market is very much related to weather and climate conditions.

2.2 Torrefied Wood

The technological development for biomass upgrading through torrefaction is clearly focusing on large scale coal power plants as the main consumers. This segment is looking for a biomass commodity similar to coal that allows an easy integration into existing conversion plants and logistical systems. Neither wood chips nor wood/agro pellets fulfil these criteria satisfactorily, and they only allow limited co-firing ratios or complete conversion of the plant. In most cases pellets can be co-fired only up to 10% before physical limitations come in to play, such as gumming up coal grinders. Some instances report up to 30% depending on the grade of adaptation of the feeding

[13] Industrial Wood Pellets Report- Laborelec Mar 2012
[14] Poyry- Presentation at Biomasspotenziale und Torrefaktion- Graz 2011
[15] PelletAlas Country Report 2009

system, coal mills and boilers. De-rating of the power plant is also an issue. Plants are designed for a certain volume of throughput, and if fuels that are fed in have a lower calorific value than coal, the power output is reduced according to a linear function. In laboratory scale, torrefied biomass has proven that 100% firing regimes are possible with minimum adjustments to the coal power plant's combustion unit and at significantly reduced de-rating compared to wood pellets.

Increased energy density, easier handling through hydrophobic character and better water resistance are expected to result in significant reduction in transportation costs. Improved brittleness is expected to result in the possibility for co-milling and combustion characteristics almost superior to those of coal and should allow easy substitution in co-firing or complete conversion at lower costs.

All parties along the value chain, including raw-material owner/providers, processors, transporters, stevedores, shippers, and consumers, should experience benefits from torrefied biomass compared to wood or agro pellets. However, power plants remain unconvinced.

There was a lot of manufacturing "hype" in 2011, but very little torrefied biomass was actually produced. There were a number of test burns of torrefied pellets in European power plants, some of which worked well, and some tests were not convincing. In some cases, the torrefied pellets did not mill well at all with the coal. The differences in appearance and characteristics combined with the sometimes delayed performance of suppliers caused the impression in power plants that developers still needed some time and European power plants are showing preference to making infrastructure investments needed to combust wood pellets rather than go with a product that isn't being produced yet at commercial levels.

This does not necessarily mean that this power plants will not switch to torrefied product once on the market, but there will be no incentive to pay premiums for torrefied product.

Most of coal in power production is consumed outside Europe. Though not directly cost competitive with steam coal at coal and CO_2 market conditions of 2013, the uptake of torrefied biomass in regions of extreme growth in coal demand – China, India - may be driven strongly by the need to increase security of supply. A second leg in supplies provided by torrefied biomass might be very welcome by strategic departments of power utilities. That torrefied biomass will ship from different ports and may also utilise different vessel classes, might contribute to higher price stability of torrefied biomass in respect to coal. Wood pellets have proven in the past decade to have lower volatility in pricing.

As of early 2013, the market for torrefied biomass has not started in earnest due to a chicken and egg problem. Both manufacturers and buyers are risk averse, typical for new technologies. Both are waiting for the other side to move first. Producers are willing to implement torrefaction technology and produce torrefied biomass, but before investing in a full size commercial plant they need long term off take contracts from bankable customers. Buyers are not un-willing to buy, but first they need to prove that promises concerning torrefied biomass use are met, including quality and volume guarantees, and on operational issues. To do this suppliers have to provide burn samples and large volumes for testing at the power plants, more than can be produced in small existing demo plants. One producer, New Biomass Energy, is now shipping burn sample volumes from Mississippi to

Europe, but one producer is insufficient to build a market. In particular, European power plants undergoing conversion from coal to biomass within the next few years need reliable specifications of fuel to be burned to evaluate and properly design needed technology adjustments. If specs and supply security are not provided soon, the conversion will be implemented on basis of wood pellets, which, as said above, may not rule out combustion of torrefied products in the future, but will cause power plants to put in capital that would not be required for torrefied pellets eliminating the opportunity for premium pricing

In recent years more and more potential applications of torrefied biomass both in energy and processing are being evaluated, for example heat production applications in mid to larger scale heat plants in industrial units as well as in district heating systems, possible application in steel industry, in food processing plants and other industrial processes. Furthermore, it seems that torrefied biomass could help decisively to overcome technical problems in biomass gasification, another market for mid to small scale applications.

Torrefied wood will be manufactured where biomass is found, and in many cases there may be large local markets that would take precedence over long-haul shipping to offshore markets. For example, there are 15 cement plants producing a total of 15 MT cement in Canada that could use torrefied material in co-firing. Tests have been done with great success. Similarly asphalt plants use natural gas, heavy fuel oil and light fuel oil that could be replaced by torrefied material, technically.

2.3 Pyrolysis Oil

2.3.1 Industrial Market

Only two companies have built large (100 – 200 tonnes per day feed rate (dry basis)) pyrolysis oil plants; Ensyn (Ottawa, Canada) and Dynamotive (Vancouver, Canada). Early energy uses for pyrolysis oil were to replace heavy oil and light oil in small stationary engines in many applications. Both Dynamotive and Ensyn plan to use pyrolysis oil as a feedstock for drop-in transportation fuels.

Ensyn has been producing pyrolysis oil (Ensyn refers to it as RTP renewable liquid fuel) steadily since 1989, and to date plants built by Ensyn have produced over 65 million litres of pyrolysis oil[16] although the primary use has been to extract food flavouring and the energy utilization has only been secondary lower-value heat. Ensyn production comes from 6 plants: Ensyn's commercial plant in Renfrew, Ontario, Canada with a nominal capacity of 100 tonnes per day built in 2005; four plants designed and built by Ensyn now owned by Red Arrow, Wisconsin; and one feedstock test facility in Texas. Red Arrow produces RTP oil primarily for BBQ-sauce type flavouring in food products and for process heat in its plants. Production at the Renfrew plant routinely exceeds it nominal capacity and has demonstrated production levels at 120 tpd (based on feed input – dry basis). The Renfrew facility has the principal RTP unit as well as smaller testing RTP facilities, handling facilities and chemical processing units. Production is primarily exported to Red Arrow in the US, but is also used in Canada for research in new markets.

[16] Ensyn website

Dynamotive demonstrated 100 tpd wood waste pyrolysis from an adjacent furniture factory in West Lorne, Ontario, Canada although the facility has subsequently gone into receivership and been dismantled. In 2007 Dynamotive announced construction of a 200-tpd plant in Guelph, Ontario, Canada and its current status is uncertain.

BTG Biomass to Liquids, Netherlands, has started construction on a 5 tph plant in Hengelo that when completed will produce 22,500 tonnes pyrolysis oil. The University of Twente plans on producing half of its electricity using pyrolysis oil from this plant[17]. In Finland Metso will deliver a turnkey pyrolysis oil plant to Fortum Power and Heat at the Fortum plant in Joensuu. The plant will use 225,000 solid m^3 forest residue and other biomass to make 50,000 tonnes of pyrolysis oil annually[18]. The pyrolysis oil will be used initially to replace HFO at the Fortum plant, but eventually may be used as feedstock in the chemicals industry and in biodiesel production.

While pyrolysis oil has many potential applications, because of the small production volume it is almost an unknown product. In boilers, Pyrolysis oil can be substituted directly for heavy fuel oil (HFO), light fuel oil (LFO) or natural gas. When significant volumes are available applications could include pulp mill lime kilns, large power plants and district heating plants. Additional applications that have been tested include heating in greenhouses, sawmill dry kilns and industrial boilers. However, because of the small volumes, there are no widespread distribution systems to enable these markets to flourish. It is anticipated that new plants will be built near to a biomass source that is also near to markets. An example is in the province of Quebec in Canada where there is no natural gas pipeline and expensive fuel oil is used for heating buildings. However, to make such projects happen requires long term contracts for feedstock supply, bank financing for a large plant using technology not known to banks, stainless steel storage systems, establishing distribution systems etc.

Ensyn is now in final stages of testing the use of pyrolysis oil in small stationary diesel engines for power. Ensyn has announced the first of multiple 400 tpd projects in Malaysia and Indonesia that will use oil palm residues as feedstock to produce heat and power[19]. It has also announced that it will build a 150 tpd plant in Colle di Val d'Elsa Italy to make pyrolysis oil and fuel a diesel engine for power. Dynamotive plans to build 200-tpd modular plants, Ensyn plans 400-tpd plants.

Both Ensyn and Dynamotive are working on upgrading pyrolysis oil to make "drop in" transportation fuels which petroleum refineries can make into fuels such as gasoline, diesel and aircraft fuel, that are indistinguishable from their petroleum-based counterparts. Ensyn has teamed up with UOP, a Honeywell company, in a joint venture called Envergent Technologies to develop commercial scale processes to produce transportation fuels from RTP liquids. UOP was awarded a $25 million US DOE grant to build a commercial facility that is now under construction in Hawaii. Dynamotive has partnered with IFPen and their commercial arm Axens to further develop the upgrading process. In 2012 Airbus joined an Australian consortium (Virgin Australia, Renewable Oil Corp, Future Farm Industries, and Dynamotive) to study production of aviation fuel from mallee trees using Fast Pyrolysis.

[17] BTG Website - http://www.btg-btl.com/news_bu.php
[18] Metso website
[19] Ensyn website

A US Department of Energy Study illustrated the costs of economically viable technology routes to produce hydrocarbon biofuels[20]. Fig 2.1 below compares cost of manufacturing biofuels using the Fischer-Tropsch process, methanol-to-gasoline, and pyrolysis, including the capital cost, operating and maintenance costs, and feedstock cost. Pyrolysis oil is easily the lowest cost option at $2/gallon. The study notes that costs for pyrolysis oil production are projected to decline substantially through research, $4.55/gal to $2.32/gal[21].

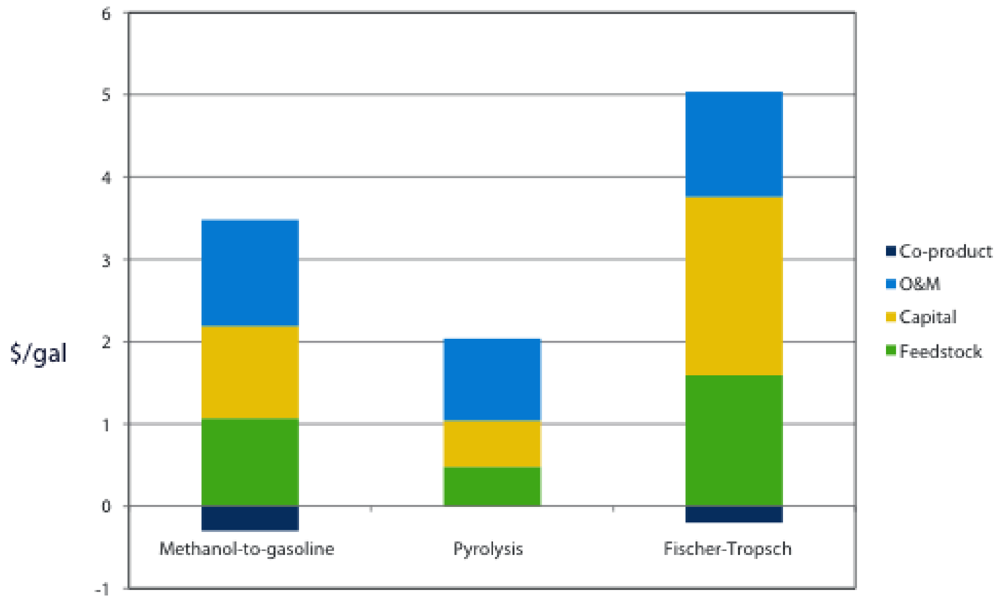

Fig. 2.1 Costs for the nth Bio-refinery plant

2.3.2 Household Market

Biomass is being used an energy source in home heating applications[22]. However, the use of chipped or shredded raw biomass and even processed solid fuels such as wood pellets can require significant capital investments to convert the biomass to usable home heat. District heating with raw and pellet biomass fuels has been proven cost effective when centralized heating plants with all of the necessary biomass handling and processing infrastructure are available to convert many forms and types of biomass to heat for distribution to nearby homes.[23,24] With increasing concern about energy security, energy cost, and the impact of energy systems on the global climate, many countries have adopted energy policies to use biomass like wood pellets for combined heat and power generation

[20] Biofuels Design Cases- April 12, 2012- Zia Haq- US DOE
[21] US DOE Study 2012- http://www.usbiomassboard.gov/pdfs/tac_design_case_haq.pdf
[22] Goh CS, Junginger M, Cocchi M, Marchal D, Thran D, Hennig C, Heinimo J, Nikolaisen L, Schouwenberg P, Bradley D, Hess JR, Jacobson J, Ovard L, Deutmeyer M (2012) Wood pellet market and trade: a global perspective. Biofuels Bioproducts and Biorefining 7: 24-42.
[23] Arctic Energy Alliance (AEA) (2010) NWT Community wood pellet district heating study. Prepared by: Arctic Energy Alliance for GNWR Environment and Natural Resources
[24] Kallio M (XXXX) "Best practice examples" for the combustion of alternative and mixed biomass pellets. Intelligent Energy Europe. IEE/09/758/S12.558286 – MixBioPells WP 3 / D 3.3.

applications.[25] However, when district heating infrastructure is not available, or homes and business are spread over large areas, the capital investment for centralized heating facilities and the associated heat distribution network becomes logistically and economically impractical [26]. Equipping individual homes to use solid biomass fuels is no less challenging. An estimated $15,000US is required to convert a single home in the Northeastern United States from heating oil to an in-home wood pellet furnace[27]. As such, even when the economics of using solid biomass versus more expensive petroleum heating oil for home heating is favorable, the "in-home" capital investment and amortization time required for switching to solid biomass fuels (e.g., pellets) is too great for most home owners. To overcome these capital investment barriers associated with using solid biomass fuels, the biomass must be processed and converted into an infrastructure-compatible form. For home heating oil applications in the Northeastern United States, converting solid biomass to pyrolysis oil could potentially allow biomass to become a tradable alternative and/or blend stock for the home heating oil market[28].

Transforming biomass from its raw and highly variable state into forms that have similar performance and infrastructure compatibility as existing fossil based energy products is essential to increase biomass trade and utilization. However, considering just the home heating oil market, the challenges with transforming raw biomass to a heating oil compatible product include biomass specifications and variability; emergent pyrolysis conversion technologies and processes to produce stable and compatible bio-oils, infrastructure compatibility issues associated with corrosion, combustion, and fouling; bio-oil/heating oil blending and compatibility issues, and finally market acceptance and regulatory compliance. However, raw bio-oil has high challenges, which precludes its direct utilization in existing heating oil infrastructure. Challenges of corrosion, viscosity and stratification can be overcome by hardening the existing infrastructure with corrosion resistant tanks, pump systems and modified high volume burners, but such bio-oil distribution and in-home modifications are estimated to be about the same as converting to solid biomass fuels.

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[25] Gustavsson L, Holmberg J, Dornburg V, Sathre R, Eggers T, Mahapatra K, Marland G (2007) Using biomass for climate change mitigation and oil use reduction. Energy Policy 35: 5671-5691.
[26] Vallios I, Tsoutsos T (2009) Design of biomass district heating systems. Biomass and Bioenergy 33: 659-678. http://hrt.msu.edu/Energy/Notebook/pdf/Sec4/Biomass_Heating_Project_Analysis_from_NR_Canada.pdf
[27] Jacobson J (2012) [Modeled costs of conversion from heating oil to an in-home wood pellet furnace (residential)] Unpublished raw data. Idaho National Laboratory.
[28] U.S. Department of Energy (DOE) (2012) Technical information exchange on pyrolysis oil: potential for a renewable heating oil substitution fuel in New England. May 9-10, 2012, Manchester, New Hampshire. http://www1.eere.energy.gov/biomass/pdfs/pyrolysis_workshop_report.pdf

3. Current and Future Supply Sources

3.1 Canada

In 2004, sawmill and pulp mill operations produced the equivalent of 21.5 m ODt[29] of bark and sawdust annually, while 19.4 m ODt were utilized leaving an annual surplus of 2.1 m ODt. In 2007-08, the sub-prime loan crisis in the US caused the US housing market to collapse, builders drastically reduced home building, and Canadian sawmill production fell by 50%. Mill residue production was insufficient to meet demand. The US housing market is recovering in 2013, and importantly BC sawmills have found new lumber markets in Asia. In 2009-11 mill residue production increased from 11.5 m ODt to 13.6 m ODt, but much of this production was taken by bioenergy plants that either had shut down or were forced to use higher price biomass. As lumber markets continue to grow, it is projected that by 2014, 3 m ODt of new mill residue will be available, as shown in **Table** 3.1.

Table 3.1 Annual Biomass Availability- 000 ODt[30]

	000 Odt	$/Odt
Mill Residues	2,900	35
Hog Fuel Piles	2,150	10
Harvest Residues	8,800	50
Sub-total	13,850	
Unused AAC	39,400	80
Unmerchantable Timber	2,700	80
Urban	8,500	60
Total Annual	64,450	

In the Western provinces sawmills were required to incinerate excess mill residues, but Eastern mills were not allowed to incinerate so that mills built up massive piles of hog fuel. There are over 70 such piles identified in 6 provinces holding 21.5 m ODt of residues that are dry enough and uncontaminated enough to be used economically for bioenergy, or 2.15 m ODt annually if mined over a 10-year period. Some piles in Quebec are being mined now. Hog fuel cannot be used to make wood pellets, but it can be used for torrefied wood and pyrolysis oil.

Sweden and Finland have been using harvest residues (tops and branches from the limbs) for decades for bioenergy. Now Canada is also using harvest residues, primarily in BC and Quebec. There are an estimated 8.8 m ODt of such residues available annually.

Provinces carefully assess the forest resources and estimate what proportion of the managed forest companies may harvest annually to ensure sustainability, called the Annual Allowable Cut (AAC). Partly due to the decline in lumber markets, companies are harvesting far less than the AAC, leaving a considerable amount of timber potentially available for bioenergy, estimated at 39.4 m ODt p.a. Provinces also have unmerchantable timber that is not usable for paper or pulp. Ontario has stated

[29] m ODT = million oven dry tonnes, i.e. 0% moisture

[30] Mill residue, hog fuel and harvest residue estimates- Climate Change Solutions, Ottawa. Unused AAC and Unmerchantable Timber- Province of Ontario, Urban Wood- Canadian Forest Service.

that 2.7 m ODt of unmerchantable timber is available for bioenergy. There are 8.5 m ODt of urban biomass available for bioenergy, approximately 50% tree and bush trimmings and 50% post industrial wood. Urban wood is relatively expensive and would be considered for only a part of a feedstock mix for bioenergy. Supply chains for urban wood are immature, and it is an unlikely feedstock for pellets.

Depending on local supply and demand, mill residues may cost $35/ODt and hog fuel $10/ODt. The cost of harvest residues varies greatly depending on m^3 per hectare and distance to a mill. FP Innovations estimate the cost at $55-60/ODt, however these costs could come down with experience and use of efficient equipment.

While most Canadian pellets are exported from the West coast, Eastern Canada is a major potential source of biomass, where the shipping distance to the EU is on average only 5,000 km. There are 19 pellet plants with combined capacity of 1 million tonnes, yet only 270,000 tonnes are sold (120,000 to Europe, 150,000 to the US, and 100,000 domestically). There is a surplus of 630,000 tonnes[31]. In many cases the plants lack low cost fibre due to the struggling sawmill industry, making the pellets uncompetitive at 2012 EU pellet prices. In the case of Ontario, current inland supply chains are too long. Producers do not to cooperate and thus have poor economies of scale for storage and shipping. Recent growth in sawmill production and improved supply chains may make this a valuable source.

3.2 United States

The US South, covering the South Eastern and the Gulf States, is one of the main forestry regions in the world with potentials for export and long-distance supply of bio-energy. That development is already emerging in practice in the form of large-scale pellet plants, and more projects are in the planning stage. The main base for these ventures is the biomass resource in existing forests that totals 8.7 million tonnes, shown in **Table** 3.2 below. The annual harvest of all forest products is recorded to be around 109 million tonnes, and the annual growth around 163 million tonnes. Thus, the biomass base would be enough to support the growth and development of large-scale bio-energy export. The key question would be if biomass could be made available in sufficient quantities and at competitive prices.

In contrast to Canada, where 90% of forests are publically owned, in the US South 61% of the forests are owned by private individuals or families, as shown in **Table** 3.3. Few regard wood and timber production as the main reason for forest ownership. One study[32] found that timber production is very low in the priority list for forest owners, below amenity, hunting/fishing, etc. As a result, large portions of the forestland and therefore biomass potential would not be made available. Most of the softwood plantations are found in the private corporate sector, including forest companies and institutional owners. These forests are managed for wood and timber production. In recent years,

[31] Development of an Efficient Wood Pellet Supply Cain from Eastern Canada to Europe- Gordon Murray presentation Berlin Oct 2012

[32] US Dept of Agriculture

there has been a declining demand for pulpwood from the pulp industry in the region and the bio-energy plants have been able to acquire raw material from that surplus to reasonable prices.

Table 3.2 Biomass Available- US South

	000 ODt
Roundwood	5,976
Tops & Branches	1,401
Other	1,296
Total Biomass	8,673

Table 3.3 Forest Ownership- US South

	Mil Ha.	%
Private	53	61%
Private- corporate	23	26%
Public	11	13%
Total	87	

In order to support the increased utilization of biomass, the federal government has introduced a support program, BCAP (Biomass Crop Assistance Program) with public money. This program has contributed to the present development of the export oriented bio-energy projects in the region. A recent summit[33] suggested that pellet exports from the US South would grow from 1.2 MT in 2011 to 5.6 MT by 2015. Further, it was projected that by 2015 there would be 720,000 tonnes of torrefied wood from 6 plants, all exported, growing to 5.7 MT by 2020 from 10 plants. RISI's North American Bioenergy 5-Year forecast projects the USA will export 2 MT tonnes of pellets in 2012, a figure which is forecasted to grow to 5.6 MT in 2017.

Based on other Task 40 work, Hoefnagels et al. (2013)[34] has described several wood pellets supply chains (and their costs) from the US SE to Rotterdam. Feedstock supply chains of herbaceous and woody biomass, produced in the U.S. Midwest and southeast respectively and shipped to Europe for conversion to Fischer-Tropsch diesel are analyzed to evaluate the implications of international shipping in context of a total biofuel production system.

3.3 Australia-New Zealand

In Australia, there are 163 million hectares of forest. Most industrial forest management occurs on the 45.6 million hectare "Open Forest", while almost none occurs in public tropical rain forest or

[33] Biomass Trade and Transport Summit- July 2012, Charlotte, North Carolina
[34] Hoefnagels R, Searcy E, Cafferty K, Cornelissen T, Junginger M, Jacobson J, Faaij A (2013) Lignocellulosic feedstock supply systems with intermodal and overseas transportation: Fischer-Tropsch diesel production from internationally sourced biomass. For submission to Biofuels, Bioproducts and Biorefining.

private native forests. **Table** 3.4[35] summarizes fibre that is economically available for pellet manufacture. There are 24 MT of agricultural grain residues and 9 MT of sugar cane bagasse and trash, primarily in Queensland, that is targeted mostly for direct combustion, gasification or pyrolysis. There are 2.1 MT of urban construction and demolition waste annually; 0.44 MT is recycled, leaving 1.63 MT for energy. It is a secure source, but the challenge is to consolidate sufficient volume from several municipalities. All pulp mill residue is currently used to make power. There are 2.8 MT in sawmill residues, and 6 MT of forest residues; 2.2 MT from native forests and 3.8 from plantations. Plantation sources are projected to grow by 75,000 ha annually to reach 3 million ha by 2020. An increasing amount in addition to this is likely to be sourced from short rotation eucalypt coppice and as residues from integrated farm forestry.

Table 3.4 Economic Biomass Availability Australia

	MT
Agricultural Residues, Grain Crops	24
Sugar Cane Bagasse	5
Sugar Cane Trash	4
Urban wood	1.6
Forest Residues- Native Forests	2.2
Forest Residues-Plantation Wood	3.8
Sawmill Residues	2.8
	43.4

In New Zealand, essentially all harvesting (99.94%) is on plantations. In 2010, 10,000 m^3 of natural forest was harvested compared with 20.5 million m^3 from plantations. As shown in **Table** 3.5, 30.1% of plantation forests, or 527,000 ha, are in Central North Island, with the largest concentration of pulp mills and sawmills centred around Rotorua. Of this, 16.2% are on the East side of North Island, 11.2% are in the far north and 92% of plantations are privately owned. The largest holder is Hancock at 257,000 ha, or 15% of total plantation area. There are 16 owners with more than 10,000 ha, but fully 38% of plantations are owned by holders with less than 10,000 ha, many planted by farmers for retirement income. 92% of plantations are in Radiata Pine, 1% in Eucalypt.

Table 3.5 Plantations in New Zealand[36]

	Hectares	%
Central North Island	527.4	30%
East Coast & Hawke's Bay	282.8	16%
Northland	195.7	11%
Southland	208.4	12%
Other	536.7	31%

[35] Biomass Resource Appraisal, Bioenergy Australia. http://www.cleanenergycouncil.org.au/technologies/bioenergy.html
[36] New Zealand Facts & Figures 2010- New Zealand Forest Industry Association

	1751.0	

Establishment of plantations peaked at 100,000 ha annually in 1994, declining to only 2-3,000 ha planted in 2010. A major increase in harvesting of Radiata Pine began in 2005, with 43,500 ha harvested in 2010. As shown in **Table** 3.6, of 22.5 million m^3 harvested in 2010, 9.5 million m^3 was exported as logs, primarily to China and Australia, and 13 million m^3 was processed in New Zealand, 63% as sawlogs and 26% to pulp mills. Sawmills and plywood mills together produced 4-6 million m^3 mill residues.

Table 3.6 Harvest in New Zealand 2010

	000 m3	
Sawmills	7,020	
Plywood	1,149	
Sawlogs	8,169	63%
Pulp	3,385	26%
Other	1,452	11%
Processed	13,006	100%
Log Exports	9,567	
	22,573	

3.4 Africa - Namibia, Mozambique, others

Biomass supply from Eastern Africa has to be based on sustainable and certified biomass sources, and such sources are still hard to find. Forestry companies like Global Woods, Green Resources, New Forests, etc. are active in establishing sustainably managed wood plantations, as are governments and small tree growing associations. The total area covered by all East African countries is about 700 million ha (Mozambique-80, Tanzania-95, Uganda-24, Kenya-58, Somalia 64, Rwanda-2.5, Burundi-2.7, South Sudan-64, Sudan 190, Ethiopia-110, Eritrea-12).

Sustainably managed forests in those countries represent less than 1% of the available forest lands of about 250 million ha. Mozambique, in East Africa, has 30 million hectares of forest, but has only a very small wood-processing sector producing just 38,000 m^3 of sawn wood annually. With high annual rainfalls and fertile lands in large parts of the country, Mozambique is endowed with perfect conditions to become an important biomass producer. There are 38,000 hectares of planted forests, and on these there are thousands of hectares of palm tree plantations that are suffering from yellowing disease. These plantations alone provide a significant source of energy biomass. Other important sources of biomass could be generated through the reforestation of highly degraded natural forests (60,000 ha in 2010), and the use of sugar cane bagasse (>3.4 MT sugarcane were milled in 2011) for energy. Batidzirai & van Hilst wrote, " By 2030, 6.4-16.5 million hectares of land could be made available in Mozambique for the production of bioenergy feedstock, while taking into account sustainability aspects". Vegetation zones in Mozambique are shown in **Fig.** 3.1.

In West Africa, in Namibia there are more than 20 million hectares of prime agricultural land infested by invasive Acacia thorn bush especially in the northern areas. Because of high bush density, the potential for cattle grazing is much lower and productivity of the land decreases. The government is trying to reverse this encroachment and restore wild life habitat and ranch land productivity. Each infested hectare has 10-11 tons of standing Acacia, therefore there is a technical potential of over 200 million tons of Acacia wood that can be used as biomass feedstock. Local cement plants such as Ohorongo Cement in Otjozondjupa Region have already started to harvest these invader bushes as biomass fuels for their cement kilns. In a radius of 75 km, they expect to source a more than 6 million tonnes of woody biomass over the next few years. The exact economical potential is difficult to assess, but there is sufficient biomass to secure enough feedstock for several biomass preconditioning plants, especially in addition with other local biomass sources from agricultural operations. The production of clean charcoal, torrefied pellets and pyrolysis oil, especially in combination with adapted diesel generators, seems to be an interesting option to serve both national and international energy markets.

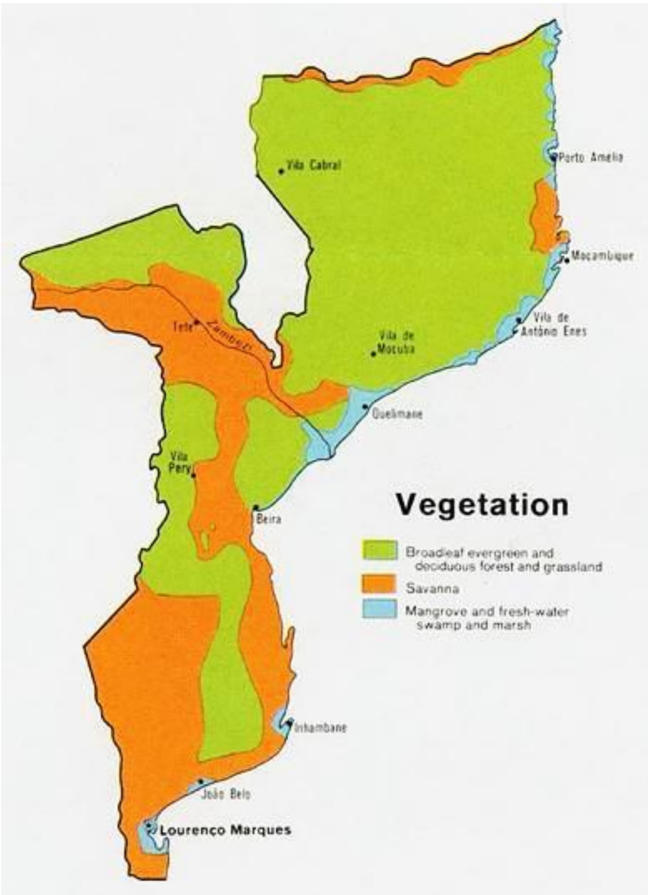

Fig. 3.1 Mozambique Vegetation Zones

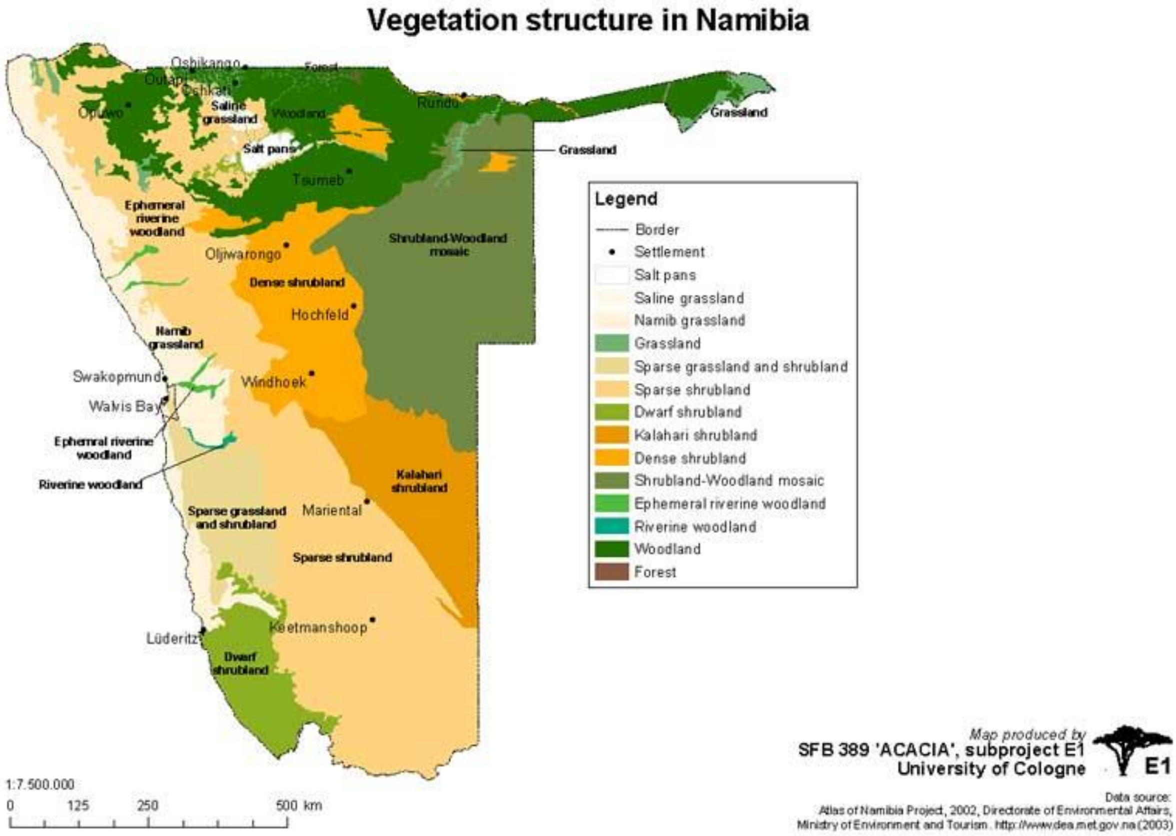

Fig. 3.2 Namibia Vegetation Zones

3.5 South America- Brazil, Argentina

Brazil is a major producer of forest products and sugar cane. In 2008, Brazil produced 219 MT of cane and 19.5 million litres ethanol. Most sugar cane bagasse is burned inefficiently in sugar and ethanol plants for heat, however steam saving actions, minor investments and new cane production can yield 25 m ODt of surplus bagasse at 50% moisture. There is 31 m ODt of leaves and stalks available in the field. The forest industry had an estimated 70 million ODt of surplus biomass in 2010, however much of this biomass is hundreds of kilometres from sea ports and logistics for export might be challenging.

There are 2,300 companies in forest industry manufacturing in Argentina. 700 sawmills are in Misiones province and 300 in Corrientes province[37]. The sawmill industry in **Argentina** produces about 2.8 MT of waste per year, 60% of the raw material used[38]. Of this amount about 50% can still be used in pulp, plates, etc., while 50% is wasted. Argentina produces around 50,000 tons of wood pellets annually, most of which is being exported. A recent study conducted by the INTI Wood and Furniture Centre looked into the wood waste from seven municipalities of Buenos Aires involving

[37] http://encyclopediaofforestry.org/index.php/Argentina
[38] Argentina Forestal/Renewable Energy Magazine- Instituto Nacional de Technologia- Mar 2011

approximately 700 companies in the wood and furniture sector. This biomass could become feedstock for wood pellet production.

3.6 Caribbean

The Caribbean has been identified as having significant volume of agricultural biomass, but biomass supply is extremely fragmented, there is no creditworthy supplier, and no known quality control[39]. An installation would have to be done from scratch and at great risk.

3.7 South-East Asia

South-East Asia was been identified as a major source of biomass from forests, plantations, and processing facilities. **Table** 3.5 projects residues available in 2010 as projected in 1997. The lowest cost feedstock is residues from palm oil and other processing plants, most prominent in **Indonesia** and **Thailand.** Wilmar estimated in 2012 that there are 50 million tonnes of fruit bunches available annually from its palm oil production business. A higher cost but abundant source is agro-residues, with Indonesia and Thailand having the greatest potential.

Table 3.5 Residual Potential Asian Countries (PJ)[40]

	Indonesia	Malaysia	Philippines	Thailand
Woodfuels from Forest Land	2,359	320	119	137
Woodfuels from Agriculture	1,272	336	588	467
Woodfuels from Other Wooded Lands	61			284
Waste Woodfuels from Deforestation	2,232	811	361	-
Total Woodfuels	5,924	1,467	1,068	888
50% of Crop Residues	457	49	198	317
Total Potential	6,381	1,516	1,266	1,205

[39] Thomas Meth, Intrinergy LLC presentation
[40] FAO Regional Wood Energy Development Program in Asia 1999. Available at: http://ces.iisc.ernet.in/energy/HC270799/RWEDP/acrobat/fd50.pdf

4. The Importance of Logistics in Total Costs

4.1 Cost Structure

It is recognized that to efficiently transport biomass long distances for energy, biomass must be densified to reduce transportation costs. Section 1 outlined the characteristics of three densified biomass forms; solid pellets, solid torrefied wood (pellets or briquettes) which are approximately 50% more energy dense than pellets by volume, and liquid pyrolysis oil, which is approximately twice as energy dense as pellets by volume. Section 2 outlined existing and future markets for these products. Pellet markets for trade are primarily Europe, Korea and Japan. Torrefied markets are expected to be large power plants in Europe, Korea and Japan. Pyrolysis markets are expected to be initially replacement of fossil fuels for energy, and in the longer term as feedstock for biorefineries, and thus candidates for long distance trade. Section 3 outlined large sources of biomass worldwide, some well-established and already being developed either for local use or trade, some only identified as a possible future potential source. The outcome of these analyses is that there is not enough biomass near to key markets, and thus large amounts of biomass will have to be traded long distances to meet demand.

There is a wide variance in cost structure between bio-energy projects aimed at long distance supply. Despite this variance, one important aspect in cost structure is the dominance of logistics in the total supply system. It may be easier to focus cost reduction not on production efficiency but on logistics efficiency. A related aspect is the effects of economy of scale, which in most cases is essential for the viability of the venture. A typical range of cost structure for pellets is shown below on **Table** 4.1, where logistics costs are 34-77% of full costs.

Table 4.1 Importance of Logistics in Total Costs[41]

Cost item		**Cost in percent of price at end user**	**of which allocated to logistics**
Feed stock		1 to 25	
	if mill residues		1
	if road side or standing		10 to 25
Mill		8 to 15	
Finance		6 to 10	
Transport to port		5 to 10	5 to 10
Storage, load/unload		5 to 12	5 to 12
Ocean shipping		12 to 20	12 to 20
Transport to end user		2 to 10	2 to 10
Risk and profit		20+	
		59 to 122*	34 to 77*
* in these cases, the projects would not be viable			

[41] Bo Hektor analyses and interviews with industry, forestry and shipping experts

Table 4.1 is primarily applicable to pellet projects, but logistics costs are valid for other long-distance biomass supply projects. In typical cases, logistics costs are more than half of total costs. Many biomass projects purchase logistics services from within an existing structure. Logging and hauling work is acquired from forest contractors, rail or barge transport from existing transport companies etc. In the initial phases, this has meant that bioenergy companies had to adjust to existing structures and technologies from logistics providers that were uncertain of future requirements for bioenergy. The best solution is to bring technical and organizational aspects of supply into one fully integrated supply chain under the control of one stakeholder, as is currently happening with a few big projects in the US. Such a situation provides opportunities for considerable cost reductions. Barring this option, for the long-term viability of bioenergy trade, a system with independent logistics service providers in competition should be able to achieve cost efficiencies by integration with other businesses locally or parallel along the supply chain.

Economy of scale is normally essential for reducing the logistics costs. Ocean shipping in Panamax, Handymax, etc. sized vessels costs considerably less than shipping in smaller ships. In particular this is true for conditions where the vessel can be loaded and unloaded efficiently with a full load at one single visit. Thus, suitable berths, effective loading devices and adequate storage capacity would be needed.

Also in rail transport, economy of scale would lower logistics costs. The use of unit trains or other forms of scheduled traffic plans would be more efficient than using single wagons. The development of specific optimized wagons could also contribute to cost reductions. In some cases purchasing dedicated rail cars is a viable option to reduce costs and to confirm rail availability. However, such measures must be integrated in the development of scheduled logistics plans.

According to the background interviews for **Table** 4.1 above, conclusions can be drawn that improved logistics can reduce the costs in the supply chain by an amount of the same order of magnitude as to total costs in the production plant. Still, when planning and evaluating bio-energy projects, the focus tends to be on the operational performance of the mill, and on raw material supply. Logistics is often of secondary interest, and regarded as difficult to influence.

The scale needed to stimulate development of efficient and economic logistics is a product flow in the order of magnitude of 1 million tons p.a. Few bio-energy projects reach that unit size, as the raw material supply normally limits the size. Therefore, the effects of economy of scale normally must be accomplished by joint efforts by co-operation with other producers, negotiations with transport companies and port managers. Also political support and financing from public funding should be explored. However, a key aspect would be to be to succeed in convincing external stake holders that long distance and long term export of bio-energy would be viable and sound. Policy measures like the EU 20/20 policy and international consensus reports like the IEA Technology Roadmap provide support in that respect, but still in many cases the long term prospects of bio-energy are not fully and generally recognized which sometimes makes it difficult to mobilize external support for improvement of logistics for the export of bioenergy.

Logistics aspects are important for all types of long distance trade of biomass. In certain conditions logistics could be regarded to be the single most important factor for success. In Russia, for example, where waterways are closed and blocked by ice half of the year, storage and transport issues are of utmost importance. The problem is relevant both for raw material transport to big plants close to an export port and for inland plants with local raw material base.

Future bio-energy projects for long distance trade are expected to be developed in tropical/subtropical areas based on plantations. Some early plantation projects are already established, others are in the planning stage. It is a clear tendency, that plantations are located in areas of good biomass growth potential aiming at low raw-material costs. The final performance of the project would certainly be more successful if the planning of the logistics also would be integrated in the project planning.

4.2 Volatility in Shipping Costs

Wood pellets are shipped by dry bulk carrier vessels, and torrefied pellets will be also. Compared to other dry bulk cargoes such as coal, ore and grain, biomass will be (at least for the next decade) a tiny product group in terms of quantity, and as a result will have no influence on shipping rates which are driven by employment in the global fleet and the global economy. Shipping costs are mostly composed of two factors, the daily charter (rent per day) and the bunker costs (fuel consumed over the journey). Both are very volatile. Biomass transporters are pure price takers in shipping. As of the beginning of 2013, freight rates of the shipping market can be characterized as being extremely low. Some shipping costs stated in this report reflect today´s daily rates for vessels and bunker costs, while other published rates are several months old and thus relative shipping costs are more important. Careful planning in supply and purchase agreements are of paramount importance, illustrated by the volatile cost of wood pellets transport from Western Canada to ARAG or UK in Panamax vessels, **Fig.** 4.1.

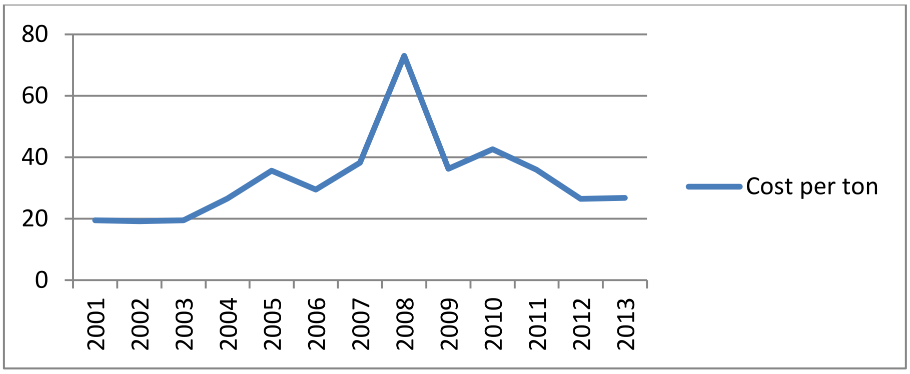

Fig. 4.1 Cost of wood pellets transport from Western Canada to ARAG or UK. Panamax vessels[42]

[42] Based on data from SS&Y, Platou, and Baltic bulk index

5. Current Supply Chains

5.1 Wood Pellets

In 2012, the EU imported more than 4.2 MT of wood pellets. The two biggest suppliers by far were Canada at about 1.2 MT and the US South at about 2.0 MT, shown in **Fig.** 5.1, making up about 76% of EU imports by ship. Russia and other East Europe countries have exported about 1.0 MT to the EU, but these are not shown on the table as long distance shipping. South Africa exported about 88 ktonnes to the EU, while Australia and New Zealand exports have reached 32 ktonnes. While Canada exported primarily to Europe, it also exported to Japan from BC, with minor amounts sold domestically and to the US.

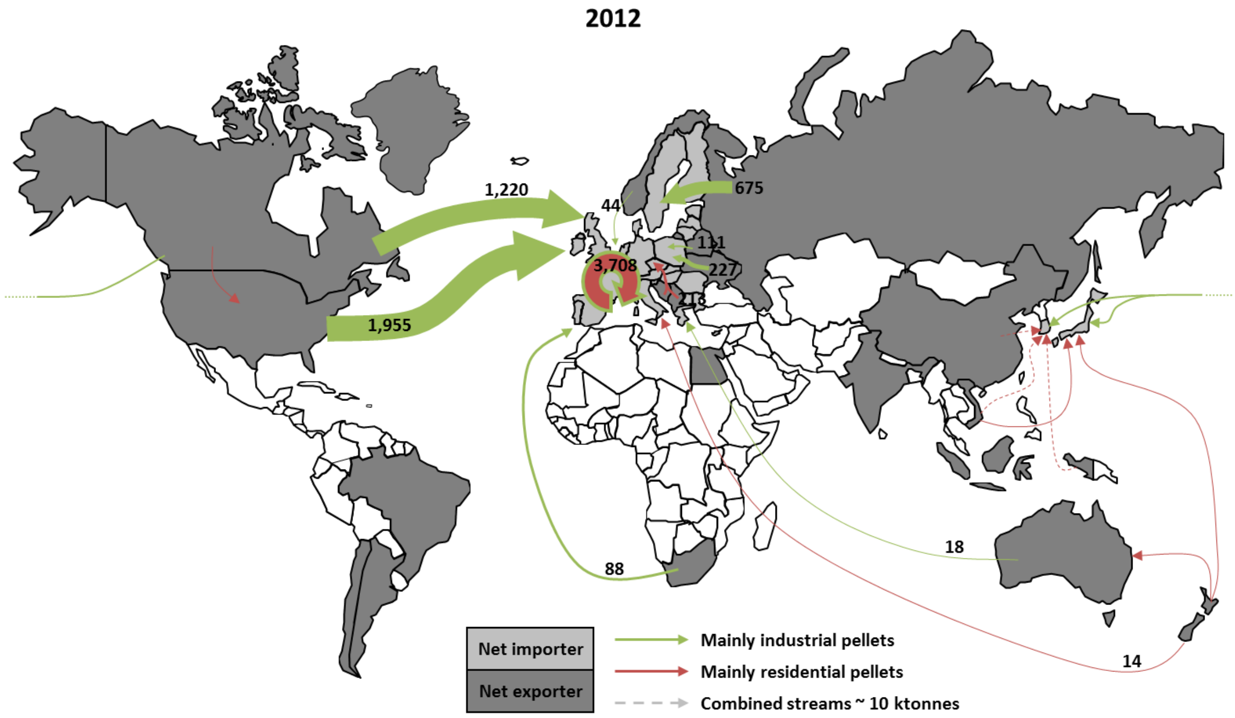

Fig. 5.1 Global wood pellet trade flows 2012 (Lamers et al., 2013)[43]

5.1.1 Canada West

Most of Canada's pellets are produced in central British Columbia, and shipped by rail either to the Port of Vancouver in the south or Prince Rupert in the north for export, as shown in Fig 5.2 below.

[43] Lamers P, Marchal D, Heinimö J, Steierer F (2013) Chapter 3: Global woody biomass trade for energy. In: International Bioenergy Trade: History, status & outlook on securing sustainable bioenergy supply, demand and markets. Springer, Dodrecht.

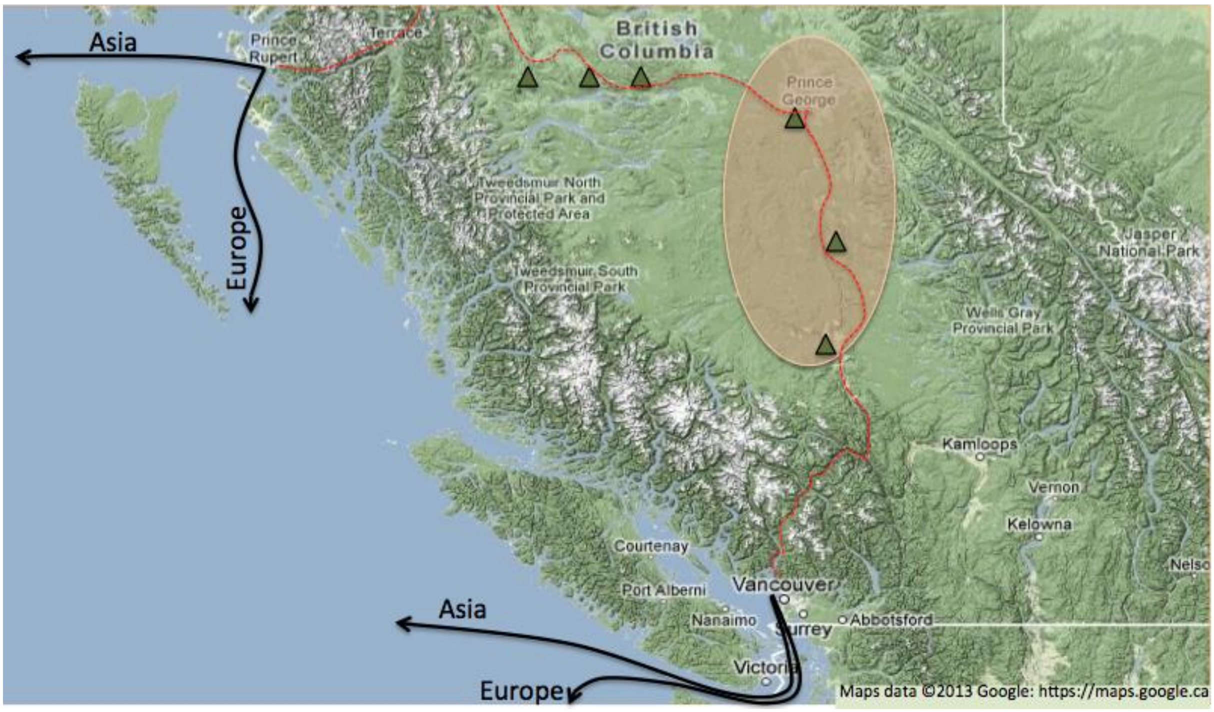

Fig. 5.2 BC Canada Existing Pellet Supply Chains

Supply chains have change considerably since the first exports in 1998. In the beginning, small 40-60,000 tonne plants owned by entrepreneurs without a secure wood supply or off-take agreements manufactured pellets and shipped in 5,000 tonne quantities in small ships. In contrast, in 2012, plants owned by corporations have capacities of 4-600,000 tonnes, have secured wood supply, and ship 50,000 tonnes at a time under pre-sold contracts[44]. Pellets from Vancouver are currently shipped in Handymax or Panamax ships 16,000 km through the Panama Canal to Europe, including the UK, Netherlands, Belgium, Sweden, and Italy. BC has just opened up the supply chain to Asia with shipments to Japan, a market that took several years to build.

In 2010, exports of pellets from BC were shipped primarily from the Kinder Morgan Terminal at Vancouver, with a smaller amount using the Ridley terminal at Prince Rupert. Kinder Morgan was primarily a grain terminal with limited pellet storage, Ridley essentially a coal terminal with one 14,000 tonne storage silo for pellets. In 2010, competing Vancouver terminal Fibreco invested $millions in the construction of storage and loading equipment. Rather than building old-style silos, Fibreco added a tension fabric facility that holds 18,000 tonnes of pellets raising storage to 45,000 tonnes, sufficient to fill an entire Handymax ship. Fibreco installed tripper-style conveyors with full-length enclosure so that pellets can be either forwarded to storage silos via inbound conveyors or hot-fed directly to ships. The loading rate is a minimum of 800 tonnes per hour. Fibreco now handles all pellet exports in south BC from 12 mills, and is the largest pellet export terminal in the world. Future plans include increasing storage to 62,000 tonnes, enough to fill a Panamax ship, and moving the company head office to another location to free up space for dedicated torrefied wood storage and handling equipment[45].

[44] Wood Pellet Association, as below.
[45] Presentation at CanBio conference in Vancouver- Grant Watkins CEO Fibreco

Fig 5.2 Port of Vancouver- Fibreco Pellet Terminal, and Neptune and Westshore Coal Terminals

At Prince Rupert, with coal exports increasingly taking over the Ridley terminal, a new terminal was needed for pellets. In October 2012 construction began on a $42 million wood pellet terminal. The Westview Terminal project will be operated by Pinnacle Renewable Energy, the largest pellet manufacturer in Canada, which has 6 pellet plants in British Columbia, 5 of which are located adjacent to the rail line to Prince Rupert. Facilities for shipping, storage and receiving will be designed specifically to receive wood pellets brought in by rail from production facilities, to be stored in silos and loaded onto bulk cargo vessels bound for overseas markets. Up to 7 silos will provide storage for pellets unloaded by the new conveyor and ship loading system. The terminal will be able to unload 8 rail cars per hour and will have a storing capacity for 60,000 tonnes after the first phase. The port will accommodate Panamax class vessels of up to 75,000 deadweight tonnes with a loading rate of 2,000 tonnes per hour[46], and will ship up to 2 million tonnes a year of wood pellets. The Westview terminal is depicted in **Fig**. 5.3.

[46] http://investnorthwestbc.ca/major-projects-and-investment-opportunities/map-view/prince-rupert/westview-pellet-terminal

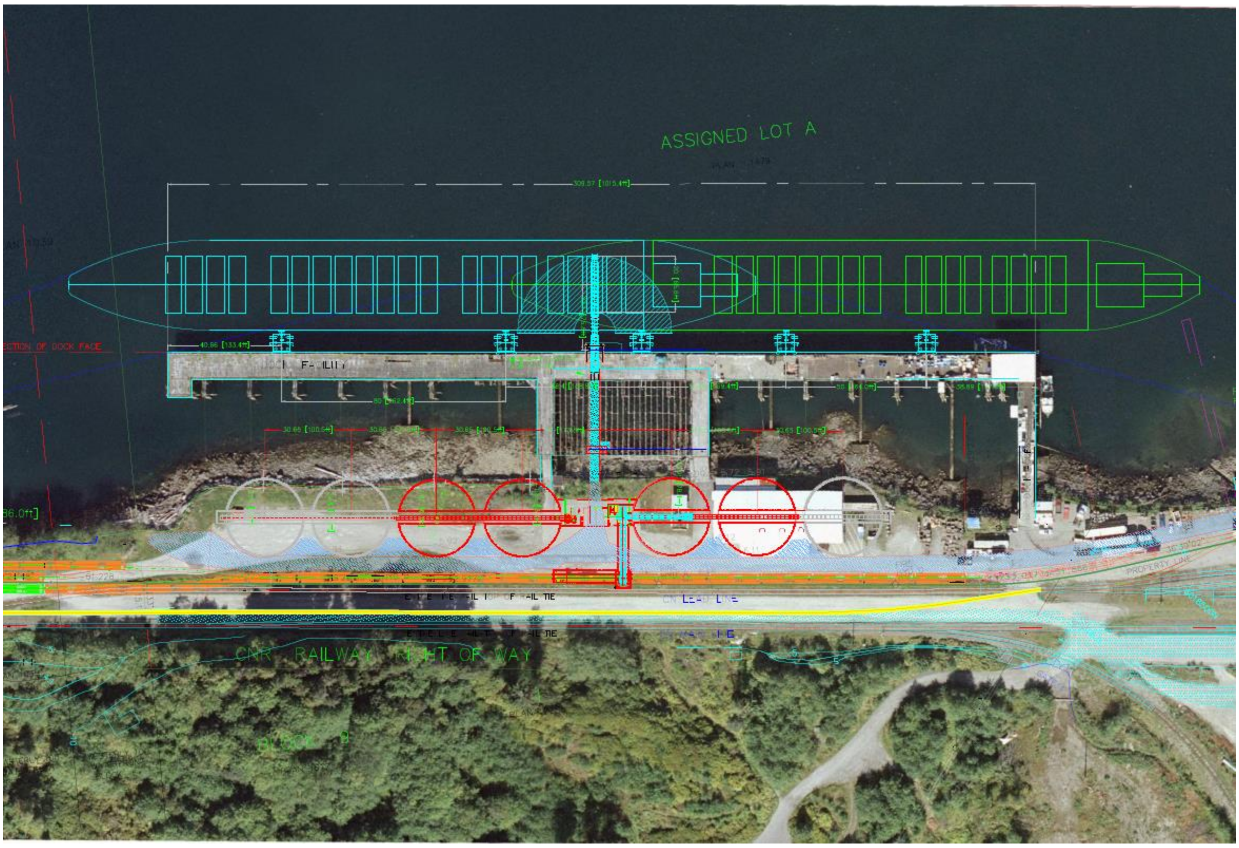

Fig. 5.3 Depiction of Westview Terminal, Prince Rupert, BC

Prince Rupert Port Authority reported a $90 million road and rail utility corridor initiative on Ridley Island, now used for coal exports only. This project will include construction on new access roads, a rail loop, utilities, onshore terminal infrastructure and marine components; each part of the Ridley Island Industrial Park development. It will provide greater rail access to new prospective users providing three inbound and two outbound tracks for coal and other bulk terminal developments[47]. By 2014, upgrades will have doubled the terminal's capacity from the initial 12 Mt/yr.

5.1.2 Canada East

Eastern Canada is a minor player in pellet exports compared to BC; however it has huge potential for development, with considerable wood resources and proximity to Europe. There are 9 ports, shown in **Table** 5.2, and 19 pellets plants, shown in **Table** 5.3. Fig 5.4 illustrates existing supply chains. Two pellet plants are operating in New Brunswick and are exporting to Europe via the Port of Belledune. Of 9 plants in Quebec, only 2 are operating at or near capacity, 2 are shut down and 5 are operating below capacity owing to market conditions. Small amounts were exported before 2011. There is potential for export from Newfoundland. There is potential for pellet manufacture in forested areas

[47] http://investnorthwestbc.ca/major-projects-and-investment-opportunities/map-view/prince-rupert/ridley-island-rail-and-utility-cooridor

in Abitibi-Témiscaming, Quebec, and northern Ontario, exporting through the Great Lakes and St. Lawrence River.

Table 5.2 Ports in Eastern Canada

Port	Gateway
Thunder Bay	Great Lakes
Prescott	St Lawrence River
Montreal	St Lawrence River
Trois Rivières	St Lawrence River
Quebec	St Lawrence River
Saguenay	Saguenay River
Belledune	Atlantic
Halifax	Atlantic
Roddickton	Atlantic

Table 5.3 Port Capacity Eastern Canada (000MT)

	Plants	Ports	Capacity	Constr.
Ontario	1	2	30	195
Quebec	9	4	582	
New Brunswick	5	1	220	
Nova Scotia	2	1	160	
Newfoundland	2	1	67	
Total	19	9	1,059	

Fig. 5.4 Eastern Canada Existing Supply Chains

The Port of Belledune, New Brunswick, shipped 120,000 tonnes pellets[48]in 2012. The Shaw Group, an Eastern Canadian pellet producer, prompted the Port of Belledune to construct a new dry bulk

[48] Wood Pellet Association of Canada- Canadian Wood Pellet Industry Perspectives, G. Murray, Mar 19 2012

handling facility and a new warehouse in 2007 to meet the necessary requirements for pellets storage destined for Europe. A 4,220m^2 (45,500 sq. ft) multi-purpose, weather-sensitive wood pellet warehouse was constructed to accommodate the storage and export of wood pellets. It is operated by Shaw. This facility created a new revenue stream for the Port and 50% of the costs, $2.4 million, were covered by a grant from the Provincial Government. The Port of Belledune, shown in **Fig.** 5.5, has a 10 m draft and can handle up to Handymax 50,000 DWT.

Fig. 5.5 Port of Belledune, New Brunswick, Canada

Other ports in Atlantic Canada include the Port of Halifax that formerly served the 100,000 tonne Enligna pellet plant in western Nova Scotia. This plant has now been reopened as Scotia Atlantic, under Viridis Energy ownership. In Newfoundland Holson Forest Products built a 55,000 tonne plant on the expectation of exporting. It's shipping facilities are unsatisfactory and Holson hopes that someone will invest in the Port of Roddickton. There is a 12,000 tonne plant in Summerford owned by Cottle Island Lumber.

Quebec exported 120,000 tonnes to Europe. The province is served by 4 ports, all open 12 months per year; Saguenay, Quebec City, Trois Rivières, and Montreal. Trebio, a large Quebec pellet producer near Ottawa 180 km west of Montreal, ships bagged pellets by truck to the container terminals at the Port of Montreal and these are shipped by direct liner services to Italy. Currently, Trebio is trucking 50% of its pellet production from Montreal as it is cheaper to truck to Montreal than rail pellets for export to the Port of Trois Rivières[49]. Another Quebec pellet producer, Granules L.G. Inc., is projected to export 30,000 tonnes of its pellets from the Montreal Port in 2013.

The Port of Trois Rivières Quebec was used for pellet export in 2011-12, but none are exported currently. Volumes were low and supply chains were not well organized. Some pellet plants do not have a rail siding, and trucking is generally expensive. Trebio has a 430km direct rail link to the port and has exported in bulk up to 80% of its production to Europe via the Port of Trois Rivières. Bagged pellets were placed in maritime containers and bulk pellets were stored in silos prior to being loaded onboard cargo ships bound for Europe[50]. Discussion are taking place with CN rail to maintain other rail links. At the port Somavrac invested $250,000 in an unloading station for railway cars and trucks

[49] Louis Campeau of Trebio, 2013
[50] http://www.trebio.ca/about-trebio-woodpellets/

for the reception of the wood pellets[51]. The Port plans to spend $4-8 million in updated receiving and storage facilities as pellet volumes increase, which will reduce port costs by 40%, or $18-20/tonne. The port has four sheds, two of which can hold 8,000t of pellets each, but the port has in mind a new storage facility that will hold 25-50,000 tonnes. The port has a depth of 10.7m and can receive ships of 50-55,000 tonnes, a "small" Panamax[52]. The port of Saguenay on the Saguenay River has for years been the key port for the Quebec pulp and paper industry in the Lac St Jean region, It will serve the bioenergy industry equally well.

The port of Thunder Bay, Ontario, is the largest outbound port on the Great Lakes St. Lawrence Seaway System[53]. Its Keefer Terminal features dockside rail, heavy lift capabilities, an intermodal yard and storage facilities. The port has an unused 173,000 tonne grain elevator available for wood pellets and biofuels and 12 ha available for development. It has 2,000 tonne-per-hour loading and a 61 metre dock at Seaway depth[54]. All St Lawrence Seaway/Great Lakes ports have to meet a 24' (7.3 m) draft. All ports upstream from Montreal are closed for 2-3 months per year due to ice.

5.1.3 US South and South East

The wood pellet export market in the US South and Southeast has continued its rapid expansion. It has become clear that the pellet export industry has transitioned from a speculative start-up industry to one with strong established players. Based on European import statistics and RISI projections, pellet export volumes for the first half of 2012 are up 138% from the first half of 2011. Through the second quarter, the US exported more than 900,000 tonnes of wood pellets to the EU. There are just a handful of players currently exporting from the US South, with several other prospectors of varying validity lining up to join the party. Ports located on the east coast have a significant advantage for export to Europe compared to Gulf ports as the distance is approximately half. Going around the Florida peninsula adds about one week of shipping time.

US South export ports, pellet plants and supply chains are illustrated on **Fig.** 4.3. Enviva ships pellets from its Amory and Wiggins facilities in Mississippi through Port of Mobile, Alabama, and thence to Belgium. The company also ships out of its flagship port facility in Chesapeake, Virginia, just outside of Norfolk, which handles volumes from its Ahoskie plant in North Carolina. The port will also handle production from two more facilities under development in the area. The largest wood pellet facility in North America, Georgia Biomass, was running at full capacity as of early 2013. It ships pellets from the port of Savannah, Georgia, to supply its partner RWE in the UK. The longest established US pellet exporter, Green Circle, ships from Panama City, Florida, primarily to the Netherlands and the UK. Fram Renewable Fuels, ships from Brunswick, Georgia, to various European markets including Sweden, Denmark and Belgium. Lee Energy Solutions keeps showing up on the radar with shipments in the 30,000 tonne range from New Orleans destined for the Netherlands. General Biofuel has published plans for a 400 000 tpy pellet plant in Sandersville, Georgia. Production has been

[51] http://www.porttr.com/fichiers/docs/rapport-annuel-2011-anglais-final.pdf
[52] Jacques Pacquin, Port of Trois Rivières
[53] http://www.portofthunderbay.com
[54] http://www.portofthunderbay.com/article/intercity-site-231.asp

announced to start in the spring of 2014. Pellets will be transported by rail to Savannah port and shipped to a European utility. Baton Rouge is 100 km upstream from the Mississippi delta. The port authority has invested in pellet storage facilities able to hold 80,000, supporting two pellet plants, one in Mississippi and one in Louisiana. The port can take Panamax ships, unless there is a drought that lowers the level of the Mississippi River[55]. The present pellet export activities from New Orleans on the Mississippi delta are likely to be moved to the dedicated port facilities in Baton Rouge[56].

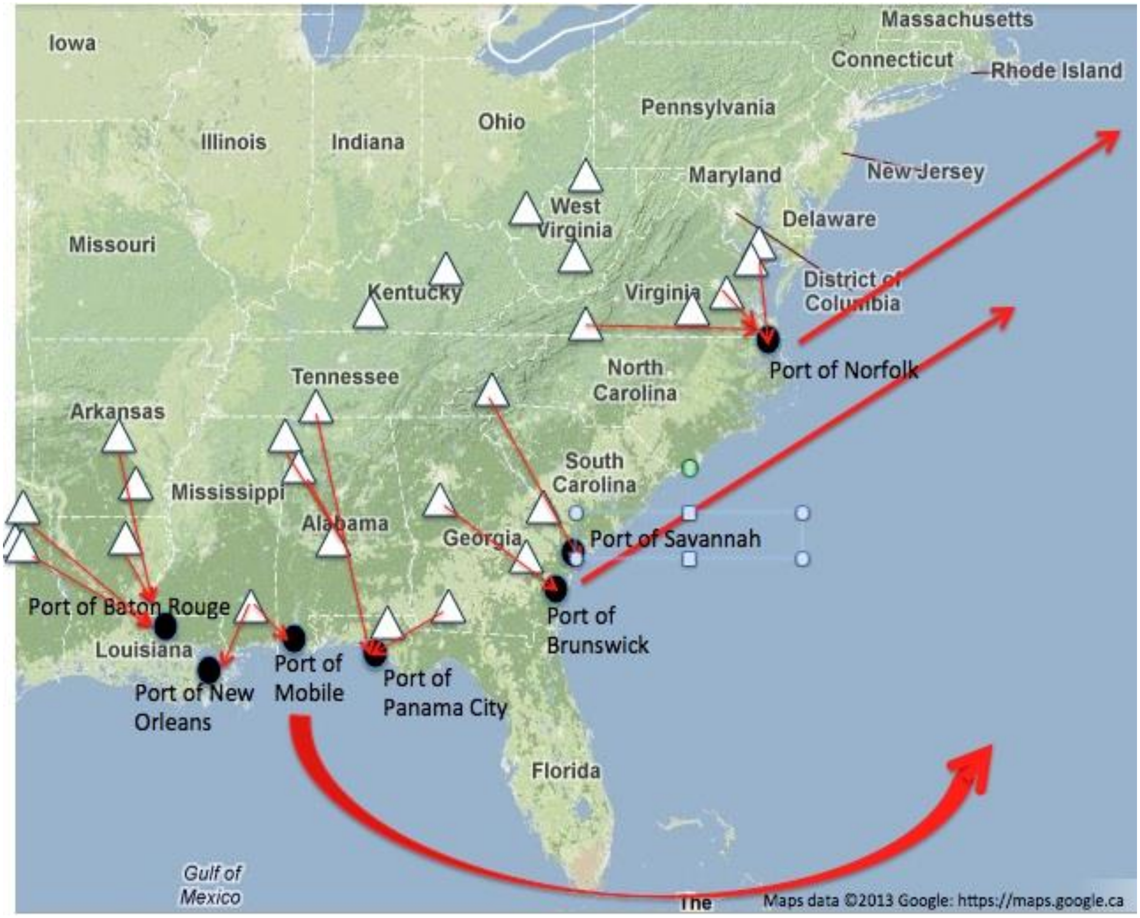

Fig. 4.3 US South Pellet Plants, Ports and Supply Chains

5.1.4 Australia

In 2010 93% of European imports came from Canada or the US, but several countries were beginning to enter the market. In 2009, one of Australia's largest wood pellet producers, Plantation Energy Australia (PEA), had set its sights high and expected to export up to 250,000 tonnes of pellets annually. A $50 million project, significant investments were also put into the port of Albany in order to properly store pellets and ensure the necessary export infrastructure. The port of Albany in Australia is a major exporter of wood-chips and the 2009 annual report expressed its excitement in

[55] Bo Hektor
[56] Ibid 54

seeing the start of a new trade of biomass fuel pellets[57], and on being the first port in Australia to handle biomass fuels pellets. It had done extensive due diligence work in equipping the Port to handle the pellets. Albany trade statistics charted the exports of pellets in 2010 at 26,531 MT, 76,782 MT in 2011 and 43,138 MT in 2012. The 2012 annual report noted that the pellet exporting business had ceased trade as of February 2012 due to ongoing problems with the biomass, a strong Australian currency, production problems and higher costs. PEA had made supply deals with a Belgian utility (Electrabel), a Dutch utility (Essent), and with a Japanese trading house (Mitsui). It has been suggested that the actual Albany plant had operating difficulties before the Australian dollar rose. The problem may have been a result of the feedstock containing fibrous bluegum bark that was very hard to reduce to a form for pelletizing and the amount of sand coming in with bark and leaves chopped up the press[58]. Within the last year, the primary owner has been seeking out potential buyers for the presses and associated machinery.

In 2013, two companies are entering the market and are expected to begin producing: Australian Renewable Energy in Geelong Australia with a capacity of approximately 20,000 tonnes of industrial pellets, and Altus Renewables based in SE Queensland, with a production facility being designed to produce 100,000 metric tonnes of pellets intended for both domestic and export markets. Several smaller pellets producers are based in Tasmania, SE New South Wales and possibly two plants near the centre of South Australia's major pine milling industry. Current projections for pellet capacity in place in Australia for year-end of 2013 are around 80-100,000 tonnes[59].

5.1.5 New Zealand

In 2010, there were 10 pellet producers in New Zealand, with all but one company primarily focused on domestic markets. The largest producer, Nature's Flame, had 3 plants; Christchurch on the South Island, and Rotorua and Taupo located in the heart of the timber industry on North Island. Since 2010, Nature's Flame has closed the original Rolleston plant in Christchurch and merged the mobile Rotorua plant into the Taupo plant, reported as producing approximately 30,000 tpa in 2012, it has a regional supply of up to 200,000 tonnes although they are they are facing the risk of diminishing feedstock sources[60]. Natures Flame has a major export focus and is located within easy driving distance of the international ports of Tauranga and Napier. Currently, their exports are going to Europe and Asian markets.

5.1.6 South Africa

Current information on South African pellets producers is limited, however four suppliers have been reported. EC Biomass (Pty) is the largest wood pellet plant in South Africa and is likely the only one

[57] http://www.albanyport.com.au/images/annrpt10.pdf
[58] Andrew Lang, WBA Board member
[59] Ibid 57
[60] Ibid 36

of the four currently in operation. EC Biomass began operation in 2008 with an annual capacity of 100,000 tonnes. It is located in the Coega Industrial Development Zone just outside Port Elizabeth of Eastern Cape, which is likely the primary port utilized in the export of pellets. As of June 2012, pellets were being exported to the power generating industry for co-firing in coal based power plants[61]. EC Biomass plans on supplying central heating companies and at the moment is focused on export markets. However, it is part of a strategic initiative of the South African Government's Industrial Policy Action Plan (IPAP) to shift the focus to supplying developing local markets and the green energy sector. Currently, EC Biomass is producing an annual capacity of 50,000 tons of pellets[62].

5.1.7 Argentina

Despite the large amount of wood residue available as biomass in Argentina, very little is converted into pellets. Production of wood pellets and briquettes is evolving and as of 2011 the annual production was approximately 50,000 tons of pellets, most of which was destined for export markets. Buenos Aires is Argentina's most important port as it receives ocean and river vessels and is the arrival and departure base for a large part of the country's trade.

Fig. 4.4 Argentina Existing Supply Chains

5.2 Torrefied Wood

New Biomass Energy, which (to the authors knowledge, as of summer 2013) operates the world's only large-scale industrial scale torrefied wood plant at Quitman Mississippi, shipped 1,200 tonnes of pellets to Europe in February 2012 in a small chartered vessel. The product was successfully tested in a large power plant in Europe, and additional shipments are taking place. Quitman is 200 km from the Gulf of Mexico, and although the plant has a rail siding, the excellent road infrastructure makes trucking more economic. Pellets are trucked to the port of Mobile Alabama. A shipment of 3,500 tonnes was loaded onto a Handymax ship in October 2012 and shipped to a European customer with

[61] CEO Mohammed Soolima. http://www.ecbiomass.co.za/biomass/
[62] http://www.ecbiomass.co.za/south-africa-biomass/

another 4,000 tonnes shipped in early 2013. New Biomass Energy is now undergoing an expansion, with additional larger reactors to be installed in the second quarter of 2013 to bring annual output up to 150,000 tonnes per year which will also include a second line of 5 pelletizers. New Biomass Energy has also been experimenting with briquettes and other options that will maximize bulk density of torrefied wood shipments, such as working with a variety of sizes.

In parallel to torrefaction, the company Zilkha Biomass continues to ship test samples of black pellets from its 40,000 tonne per year steam explosion facility in Beaumont, TX. Zilkha is working on commissioning a 275,000 tonne wood pellets plant into a flagship facility that is expected to begin operations in 2014.

To date it is not clear if the market will differentiate much between torrefied and steam exploded biomass and pellets. Steam explosion produces almost water resistant dark pellets as well but neither calorific value nor grindability will be enhanced as is possible by torrefaction.

5.3 Pyrolysis Oil

Internationally, Dynamotive and Ensyn have shipped containers (usually containing one tonne plastic totes) to the port of Montreal for testing in large power plants in Europe, and also shipped test volumes to Japan, Australia, Taiwan and South America.

Fig. 4.5 Pyrolysis Oil Supply Chains- Dynamotive and Ensyn

Ensyn has made regular shipments of its pyrolysis oil hundreds of kilometres by truck to customers in Wisconsin and Manitoba. The company also shipped pyrolysis oil by rail in containers 300 km to the port of Montreal where they were loaded onto a tanker and shipped to Europe for testing in a large utility. This method sufficed for testing, but in order to take advantage of the higher energy density of pyrolysis oil over pellets, it would have to be shipped in bulk in large holds in a chemical tanker.

6. Potential Future Supply Chains

The authors envision several potential supply chains to 2020, some of which are new, and some are in their infancy but show promise for growth. This is not an all inclusive list, but it reflects potential supply from areas of surplus, stranded, or expensive biomass that have potential to become economic through investment in plant and efficient supply chains, driven by demand in new regions and old.

Wood Pellets:

East Canada	to Europe
Mozambique	to Europe
Brazil, Argentina	to Europe

Torrefied Biomass: for power

Australia, New Zealand	to Japan, China, Korea, Europe
Indonesia, Philippines (SE Asia)	to Japan, China, Korea, Europe
BC Canada	to Japan, China, Korea , Europe
US South	to Europe
Africa	to Europe

Pyrolysis Oil: initially for small heat and power, large power, then as a feedstock for biorefineries

Malaysia, Indonesia	to Japan, China, Korea
Malaysia, Indonesia	to Europe
BC Canada	to Japan, China, Korea
Eastern Canada	to Europe

Biocoal: for large power stations (controversial concept)

Indonesia, Australia	to Japan, China, Korea
BC, Columbia	to Japan, China, Korea
US South, South Africa	to Europe

Section 6 compares costs of biomass delivered ARA (Amsterdam-Rotterdam-Antwerp) and delivered Shanghai, but it is recognized that cost structure of companies is generally confidential. So as not to have this data disrupt price negotiations between buyer and seller, the report compares manufacturing and delivery costs as a percent of the most expensive source, in this report pellets in Northern Ontario, Canada. BC exports competitively to Europe, with the feedstock being primarily lower cost mill residues from large sawmills. Eastern Canada is much closer to Europe but many of its sawmills shut down in 2007-12 leaving mill residues in short supply. As of 2012, Northern Ontario in particular suffered from expensive fibre (primarily non-merchantable standing timber), and long inefficient supply chains.

6.1 Wood Pellets

6.1.1 Eastern Canada

Pellet exports from Eastern Canada are currently served by the port of Belledune for New Brunswick plants, and the ports of Montreal, Trois Rivières and Quebec City for Quebec pellet plants close to the St. Lawrence River. There is a major forest products industry in the Abitibi-Témiscaming region in West Quebec 450 km west of Montreal, shown on **Fig.** 6.1. Rail supply chains to this region have been built up for the sawmill and pulp industries which once transported high value products like lumber and pulp to ports of Quebec and Montreal. For pellets, the combined impacts of low EU pellet prices, high wood costs owing to the cyclical low in sawmill residue production, and long supply chains have hindered this being a viable supply chain. However, the sawmilling industry is now recovering and this supply chain could prove extremely fruitful, exporting through the ports of Quebec, Trois Rivières and Montreal. Similarly a large forest industry exists in the Lac St. Jean region, with lumber and pulp formerly shipped out of the port of Saguenay. This region can also become a major pellet manufacturing region.

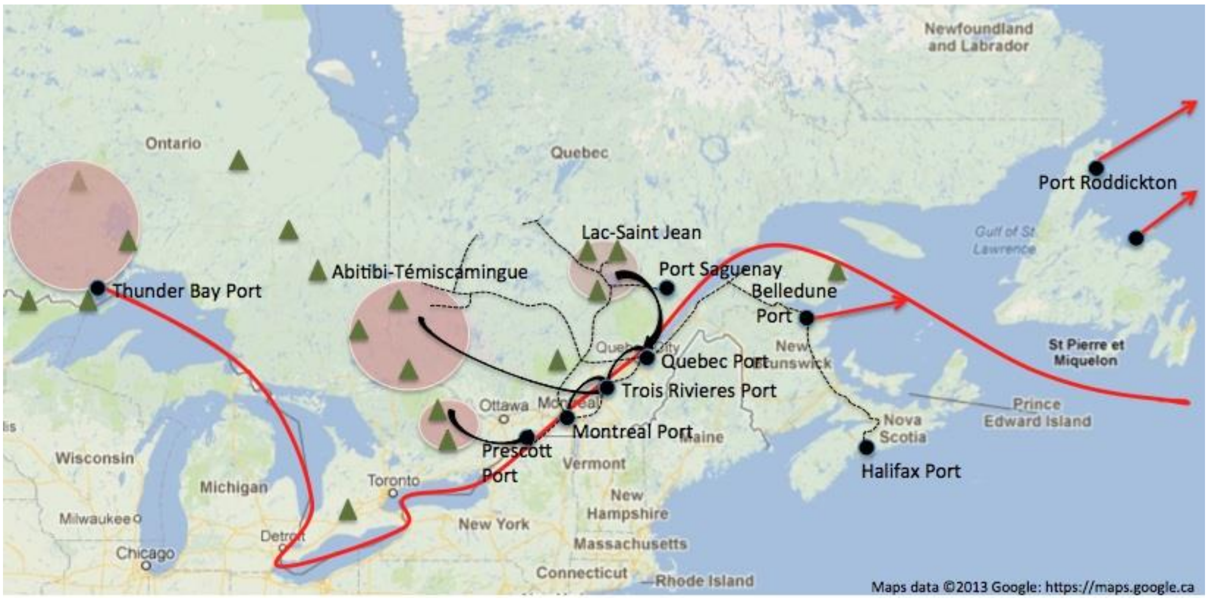

Fig. 6.1 Eastern Canada Supply Chains

Eastern Ontario has a major sawmill region 150 km west of Prescott that has aspirations of becoming a major pellet producer. Pellets or other bio-products could be exported from the port of Prescott on the St Lawrence River for 10 months, and Montreal for 2-3 winter months.

Although Ontario is a minor pellet producer with capacity only 30,000 tonnes, there are 195,000 tonnes under construction and a further 1.1 million tonnes planned in Northern Ontario. OPG (Ontario Power Generation) recently shut down its coal burning Atikokan power station near Thunder Bay and has started converting it to burn biomass only. It will require 90,000 tonnes of pellets annually. Most of excess pellet production would either be railed from Northern Ontario to the port of Montreal, or go through the port of Thunder Bay, formerly the world largest grain port, which serves ocean going ships and Lakers. Thunder Bay is 3,000 km from the ocean. The maximum ship size is Seawaymax at 28,500 DWT, and they must pass through 6 canals and 19 locks. A Seaway

Supply Chain Working Group is now looking at potential for efficiencies. From BC experience, WPAC recommends: rail transport to the pellet terminal on owned cars, fewer terminals handling large volumes, multiple producers co-mingling product at the terminal, and frequent 50,000 tonne shipments to reduce costs.

Table 6.1 shows estimated relative pellet delivered costs from Ontario North of Lake Superior and from Quebec, comparing 50,000 tonne and 150,000 tonne plants. Currently plants in Northern Ontario face feedstock costs of $80-110/ODt for standing timber, usually non-merchantable timber allocated by the Ontario government. Northern mills currently face unwelcome supply chain costs, for example $15/t to deliver to the Thunder Bay terminal, $24-28/t for a Laker (lake only ship) to deliver to Quebec City, plus tolls, trans-loading costs to an ocean going vessel, and ocean transport in small quantities. The delivered cost CIF ARA is uncompetitive at May 2013 pellets prices. Costs can be reduced by $5/t by putting pellets directly on an ocean going vessel in Thunder Bay, but lake traffic is only possible 9-10 months per year. Rail is possible, but often a 12 month contract is required. The delivered cost of a 50,000 tonne pellet plant that uses non-merchantable timber for feedstock is shown as 100%. In 2013 the US housing industry is recovering sharply and as northern sawmills reopen, feedstock costs can be reduced to 67% of Base costs by using a mix of 25% mill residue, 35% harvest residue, and 40% standing timber, reducing the delivered cost to 86% of Base. However, this is still uncompetitive. It will take a larger 150,000t pellet plant and specific supply chain improvements to make the Northern Ontario business model competitive for pellets. Fibre costs can be reduced by using more mill residue, and optimizing ground supply chains for harvest residues. Several pellet plants in the region could negotiate with the Great Lakes Seaway Authority and CN rail for better terms. Large pellet volumes from both Quebec and Ontario would warrant larger ships and lower shipping costs. An efficient Northern Ontario supply chain could deliver at 81% of Base costs, in the range of May 2013 levels of competitiveness.

Table 6.1 Estimated Delivery Costs Northern Ontario and Quebec vs North Ontario Base

% of Northern Ontario 2012	N Ont-50k t	N Ont-Low fibr	N Ont-150k t	NOnt Eff	Quebec-50k t	Quebec-150k t	Que Eff
Production (000 tonnes)	50	50	150	150	50	150	150
Costs $/t							
Fibre Cost	100%	67%	67%	50%	55%	55%	50%
Manufacturing	100%	100%	82%	82%	100%	82%	82%
Transport to Quebec Port	100%	100%	89%	73%	33%	33%	27%
Ship to EU	100%	100%	100%	82%	100%	71%	59%
Returns to Debt, Equity Taxes	100%	100%	105%	105%	100%	105%	100%
Delivered Cost EU $/t	100%	86%	81%	69%	69%	63%	57%

Quebec is closer to the St Lawrence River than most of Ontario, though the interior Abitibi-Témiscaming region is 450 km away. Assuming a similar manufacturing cost to Ontario but lower costs to transport to port , a 50,000 t plant in Quebec may have a delivered cost of 69% of the Base, but a 150,000 t plant with shorter and efficient supply chains would yield a delivered cost at 57% of Base.

6.1.2 Brazil-Argentina

In Argentina**,** 45,000 tonnes of wood pellets are produced annually most of which is exported, however there is still 700,000 ODt of mill residue from the sawmill industry that is unused. The largest potential for transportable bio-products is in Corrientes province, on the Parana River 800 upstream from Buenos Aires, and Misiones province, 1600 km upstream. The Parana river is a transport route and goods are shipped by barge right to ocean ports. Wood pellets could be barged to Buenos Aires, trans-loaded to Panamax ships, and transported to Europe, as shown in **Fig.** 6.2.

Fig. 6.2 Biomass Supply Chains Argentina, Brazil, Namibia, Mozambique, Caribbean

Brazil has 10 operating pellet plants with combined capacity of 320,000 tonnes per year[63]. It is believed that all of this productions is used domestically. However, Brazil has huge potential for pellet production from plantation wood. In 2011, Timber Creek announced that they would build a 90,000 t plant near Pien, all for export. In 2012, Suzano Energia Renovavel, a the Suzano pulp company unit, announced that it would spend $534 million in new forests and two pellet plants in the state of Maranhao that would produce 2 million tonnes pellets by 2014[64], all for export. Shipping costs from Brazil port to Europe have been estimated to be $44/t from Brazil compared with $22/t from the US South and $40/t from BC[65].

[63] Global Wood Pellet Industry Market and Trade Study- IEA Bioenergy Task 40- Dec 2011.
[64] http://www.bloomberg.com/news/2011-09-30/suzano-to-invest-534-million-in-brazil-wood-pellet-production.html
[65] Argus Biomass Markets- 2012

6.1.3 Africa- Mozambique

Countries such as Mozambique and Tanzania have favourable growing conditions, good access to deep sea water ports, and untapped and often degraded land resources for sustainable biomass production. These advantages may allow the region to become an important biomass basket for international trade. A prerequisite is a substantial increase in investment in sustainably managed forests and plantations, preconditioning technologies and adequate port infrastructure with efficient storage and loading.

Mozambique is uniquely equipped with a number of ocean ports such as Maputo, Beira and Nacala mostly serving international trade. Pemba and Quelimane mainly serving domestic trade. So far little biomass export is taking place and no refined solid biomass fuels are being produced for export. Transport of biomass to sea ports is mostly done by truck in Eastern Africa. Trucking costs are generally much higher than similar transportation services in Europe or Northern America due to the often bad quality of roads, less return freight, theft of fuel and goods, etc. Cost is about $2/km for a 40 tonne truck. Relatively high prices for electrical power of $100-150/MWh and unsecure power supply requiring costly back up power result in high preconditioning costs for energy biomass such as chipping, briquetting or pelletizing - all dependant on electrical power. Estimated delivered costs from Mozambique to Europe, shown in **Table** 6.2, are only 66% of the North Ontario Base, competitive with pellet prices in May 2013. Low biomass costs are offset by higher risk for investors and higher interest rates for loans. Sustainably grown biomass is being developed now in expectation of exporting.

Table 6.2 Wood Pellet Manufacturing Costs- Mozambique

	Base	Mozambique
Delivered biomass	100.0%	58.5%
Conversion	100.0%	109.1%
Transport to port (300 km)	100.0%	54.6%
Ocean shipping (22,000 km), handling	100.0%	90.3%
Returns to Capital	100.0%	included
	100.0%	66.0%

6.2 Torrefied Wood

6.2.1 General

Biomass supply chains tend to become longer and longer, reflecting the need to enlarge catchment areas for biomass. Western and Central Europe, the centre of gravity in biomass for energy, is importing from all other continents. Since the cost of transportation from processing site to final consumer is often half of total cost, reducing supply chain costs is critical. Torrefaction, by its increased energy density, yields significant cost reductions. Energy density is increased by (1) increased net calorific value (NCV)/kg of material as a result of torrefaction, and (2) further densification of torrefied material into pellets or briquettes. Although shipping rates in Fig 6.3 may be a few months out of date, the chart shows relative supply chain costs of torrefied wood and pellets.

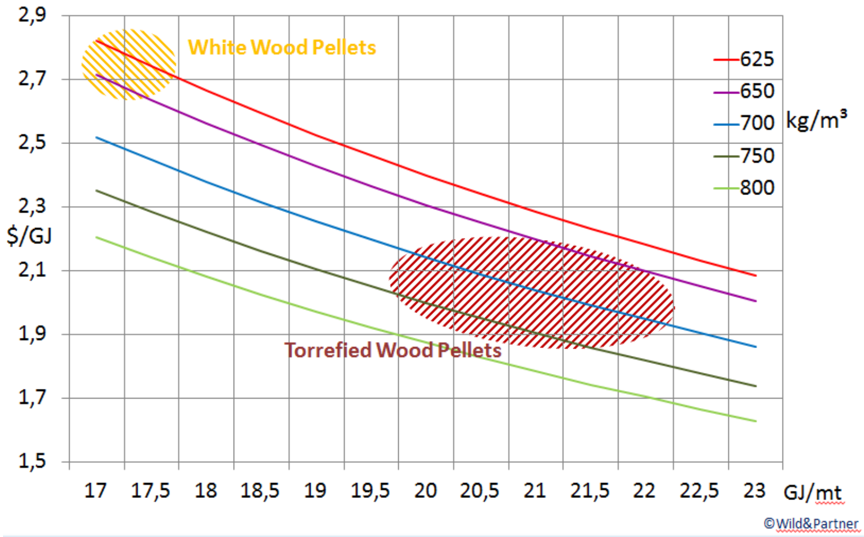

Fig. 6.3 Relative costs along supply chain-example US Gulf to ARA

As shown, manufacturing torrefied product at 21 GJ/tonne NCV and 700 kg/m³ bulk density results in a transportation cost of $2/GJ US Gulf to ARA. Wood pellets on the same route would be $2.70/GJ. Thus torrefied pellets yield a reduction of approximately $0.70US/GJ along the supply chain. The hope is to find ways to increase density further and reach the 800kg/m³ as promoted by research centres.

Hydrophobicity of torrefied biomass will help decrease storage and loading costs further, but producers cannot yet guarantee full water resistance over time for either pellets or briquettes. Generally the more costly a supply chain is, the more significant the positive impact of torrefaction. **Fig.** 6.4 below illustrates the reduced costs of torrefied pellets vs wood pellets by distance from port. Shipping torrefied pellets 200 km by train to port costs €6.10/GJ ($8.20/GJ), while shipping wood pellets costs €6.75/GJ ($9.10).

Undertaking a full cost comparison of torrefied versus non-torrefied, densified biomass is tempting but difficult. None of the technology suppliers has published pricelists for its torrefaction technology although some of the companies are quoting their equipment to potential customers. The few facilities in operation are careful not to release details on operations data and hence those can only be assumed. **Fig.** 6.5 below summarizes cost factors based on data for wood chip and white pellet supply chains and assumptions on torrefied chains based on best available data, not considering eventual higher mark-ups in capital costs. Results do show a clear advantage of torrefied product.

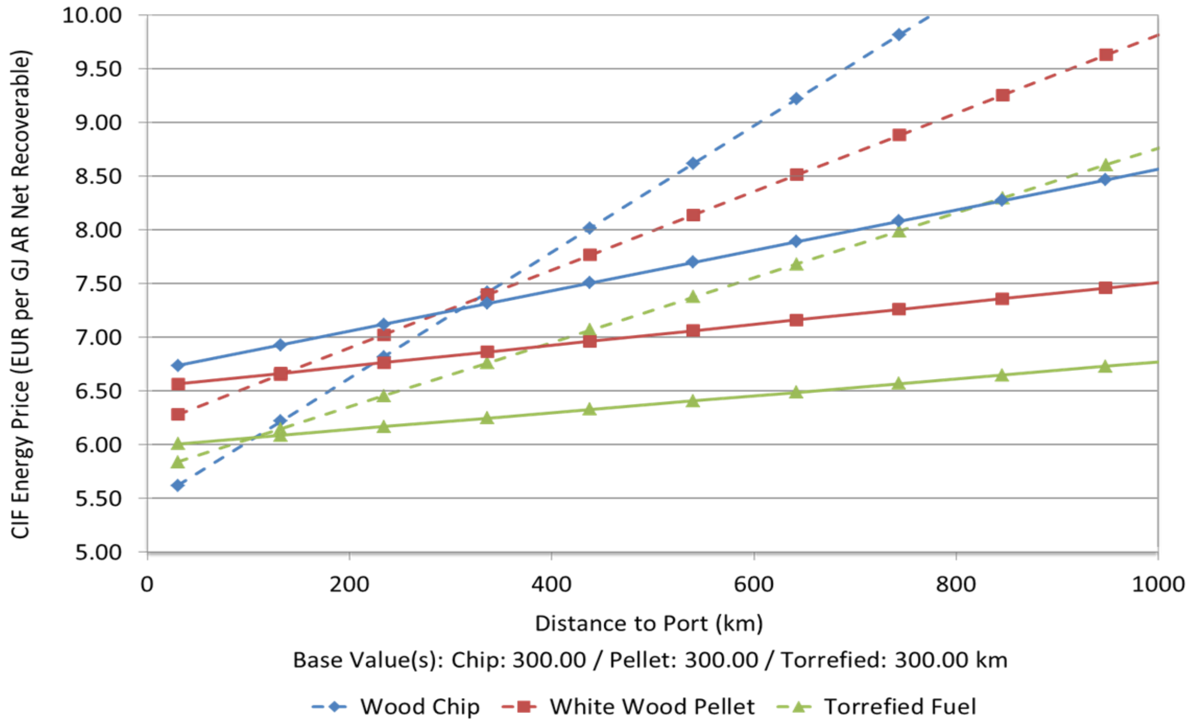

Fig. 6.4 Sensitivity of CIF fuel price to distance from processing facility to port (Truck – dashed line; Train – solid line)[66]

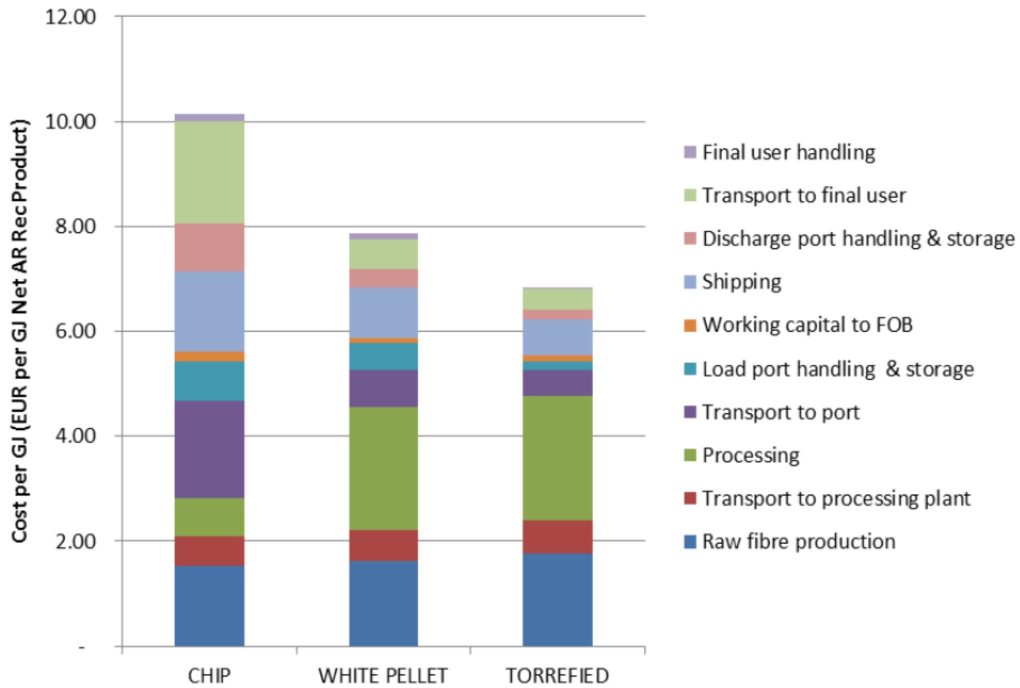

Fig. 6.5 Future cost breakdown with torrefied fuel shipped in Handy size vessels

Source: The supply chain economics of biomass torrefaction, Hawkins Wright

[66] The supply chain economics of biomass torrefaction, Hawkins Wright

6.2.2 US South

In 2013 no region on the globe can compete with the US South in number and size of biomass-for-energy processing plants in the pipeline, some already in implementation. Relatively low cost of fiber that is expected to fulfill sustainability criteria, combined with good infrastructure, economic stability, public support, skilled labour and direct links into major shipping routes, all very much favour the US South. Still transportation to EU customers from plants in the US South are projected to be in the range $55-80/tonne. Whether cost reductions by producing and shipping torrefied product instead of normal wood pellets can be achieved remain to be seen. An estimate of the full transportation costs and the savings potential to be achieved through torrefaction is given in **Table** 6.3. The table shows a potential for 29% savings by shipping torrefied pellets compared to wood pellets[67].

Table 6.3 Estimated Logistics Savings- Wood Pellets vs Torrefied Pellets

	trucking to port	storage	load	ship	Total CIF	unload	barge	unload	Total CPT
variation%	-20/+50	+/- 25	-25/+50	-15/+200		-25/+50	-25/+50	-25/+50	
US$/t wood pellets	15	2	5	30	57	5	15	2	74
$savings torrefied	3.53	0.47	1.18	9.91	16.26	1.18	4.95	0.47	21.69
savings %	24%	24%	24%	33%	29%	24%	33%	24%	29%

The only full-scale torrefaction plant in continuous operation is in the US South. New Biomass Energy of Mississippi is developing the first experience in bulk shipping across the Atlantic, but even this company has shipped only small volumes, so transportation savings are not yet proved. Agri-Tech LLC intends to become active in the Carolinas, and additional torrefied wood plants are seen in Tennessee, Georgia and Texas (steam explosion pellets). Andritz, Thermogen on Rotawaves technology, River Basin Energy, New Biomass Energy and others intend to roll out their technologies. Though their investment quotes differ, and it is not always clear what are the system boundaries of quotations, the increased capital expenditures and operating expenditures of torrefaction when compared to white pellets production seems be low enough to be compensated by savings along the logistical chain to customers.

Table 6.4 compares estimated costs of 100,000 tonne production plants in for US Gulf with the Northern Ontario pellet Base. The cost of delivered biomass to a US Gulf pellet plant is only 52% of the Northern Ontario Base, 44% for a torrefied wood plant. (Manufacturing costs appear higher for the US Gulf than the Base, but returns to investors are imbedded in manufacturing costs for the US.) Plant gate costs on a GJ basis for a US Gulf pellet plant are 67% of the Base, 70% for a torrefied wood plant. When ocean shipping on Handysize to Handymax vessels is included, landed cost is 70% of the base for US SouthGulf pellets, and 65% of Base for torrefied pellets. However, as shown on **Table** 6.3,

[67] Michael Wild

the remainder of the supply chain to pre-combustion processing gives torrefied pellets a further cost advantage.

Table 6.4 Coast of US Gulf Wood and Torrefied Pellets vs Base on a GJ basis[68]

	N Ont	Pellets	Torrefied
Fibre	100%	52%	44%
Manufacturing	100%	133%	164%
Returns to Debt/Eq	100%	included	included
Plant Gate	100%	67%	70%
To Port	100%	56%	36%
Ship to EU	100%	103%	83%
Delivered ARA	100%	70%	65%

A Columbia South Carolina company with an exclusive license for the torrefaction technology developed by the North Carolina State University (NCSU), and has designed a standard, 5 ton per hour torrefaction unit and run the prototype on NCSU's campus for several years. The company believes it has a more cost-effective and less complex torrefaction process than most of its competitors because it can process biomass at 40% moisture in a single step without pre-drying. This innovation may lower costs further.

6.2.3 BC Canada

BC already exports over 1 MT of pellets to Europe. Major supply chain improvements have been made including Pinnacle Pellet integrating with the supply chain by buying 300 rail cars, and the Fibreco Terminal adding sufficient storage to handle a full Handymax ship. **Table** 6.5 compares the fully loaded cost of wood pellets and torrefied pellets delivered EU based on a 100,000t plant. The feedstock cost for pellets is only 48% of the far more costly standing timber in the Northern Ontario 2012 Base. The cost at a European port is only 67% of the cost compared to the Base, and torrefied pellets are 74% of the Base on a $/GJ basis. As noted in 6.3, the advantages of torrefied wood occur in tertiary transport, storage at the power plant, and pre-combustion processing.

[68] 15-25% more biomass input is required to make a tonne of torrefied pellets than conventional wood pellets. However, in torrefaction recycled energy reduces costs of drying so that the net costs of biomass input between a torrefaction line and a pellet line is minimal, within 1-3%. Rather than showing higher cost for biomass and reduced operating costs, we have simply shown biomass costs/tonne to be the same.

Table 6.5 Delivered Cost from BC Canada on a GJ basis

	N Ont	Pellets	Torrefied
Fibre	100%	39%	31%
Manufacturing	100%	133%	140%
Returns to Debt/Eq	100%	included	included
Plant Gate	100%	71%	66%
To Port	100%	56%	45%
Ship to EU	100%	126%	102%
Delivered ARA	100%	76%	67%

6.3 Torrefied Biomass Options- Sharing Existing Efficient Supply Chains

One of the technology delays with torrefied wood technologies has been compacting torrefied wood by pelletizing or briquetting. Although this challenge has been mastered now by major companies in torrefaction, some companies have developed ideas of marketing non densified torrefied biomass. Torrcoal in NL/B producing densified and non densified torrefied biomass, the later shipping in nitrogenised containers to local clients. Although locally viable it is neither a cost competitive solution for a long distance supply chain, nor is it in bulk. In another approach, Global Bio-coal Energy in BC surmises saving the cost and trouble of pelletizing, and mixing the torrefied wood with coal at a port in a proportion that can be third party certified. It would accomplish many goals, including saving the time, money and trouble of pelletizing, allowing mixing at the outgoing port to customer specifications and certified so that the customer need not worry about mixing and certifying at the power plant, and allowing torrefied wood to be shipped at Panamax rates. This concept has not been implemented to date and it may remain so as the ban of bulk transport of charcoal by the IMSBC (International Solid Bulk Cargoes) code may create insurmountable barriers for bulk transport of non densified torrefied biomass. Another alternative to take advantage of Panamax rates is to mix torrefied pellets with coal, but incoming ports may not allow such mixed cargo. A likely solution is to load torrefied pellets in separate holds adjacent to the coal holds.

Table 6.6 below compares energy density of various products. Torrefied pellets are 21 GJ/t, 24% more energy dense on a weight basis than wood pellets at 17 GJ/t. However, the limiting factor on ships is often not weight but volume. Torrefied pellets have a higher bulk density at 700 kg/m^3 compared to 650 kg/m^3 for wood pellets. Thus torrefied pellets are 14.7 GJ/m^3, 31% more energy dense than pellets on a volume basis at 11.1 GJ/m^3. Furthermore, various methods of packing are being researched, such as packing pellets of various sizes together, that could enable an energy density of 987kg/ m^3 to be achieved, a 41% increase in energy compared with the normal 700 kg/ m^3, as shown in **Table** 6.6[69].

[69] Presentation Michael Wild, CanBio Annual National Conference, Nov 27-28 2012, Vancouver

Table 6.6 Energy Density of Fuels

		Coal	Torrefied Wood	Torrefied Pellets	Wood Pellets	Torrefied Dense
Energy Density	GJ/tonne	25.13	21	21	17	21
Bulk Density	kg/m^3	800	200	700	650	987.2
	GJ/m^3	20.1	4.2	14.7	11.1	20.7
	tonnes/m^3	0.8	0.2	0.7	0.65	0.99

Table 6.7 outlines shipping costs assuming 20 days of steaming and fuel cost of $700/tonne. Shipping coal on a 40,000t Handymax ship would be 87¢/GJ, but only 71¢/GJ on a 68,000t Panamax, a savings of 18%. Owing to the lower energy density of torrefied wood, filling an entire Handymax ship with torrefied pellets, even if it could be done, would result in a $1.18/GJ cost, 97¢/GJ by filling a Panamax and probably more if torrefied wood took only 1-2 holds. What would happen if torrefied wood, definitely available in smaller quantities only in the initial years, shared the coal supply chain? On a Panamax the cost of shipping 80% coal at 71¢/GJ – shipping for coal thus unchanged to coal only cargos - the shipping of 20% torrefied pellets would drop in costs to 0,974¢/GJ, almost what it would reach shipping in whole Panamax cargos on its own. If approximately the same volume of torrefied pellets would share for the same distance on a 120,000t Capesize ship with 90% coal and 10% torrefied pellets it would be a mere 87¢/GJ, a transport savings of 27% over a Handymax ship. Thus enabling significant cost savings and faster turnover.

Table 6.7 Shipping costs assuming 20 days of steaming and fuel cost of $700/tonne

					loading	Sailing + ballast	rental costs	Port	Fuel			
		tonnes x 1000	m^3 x 1000	GJ x 1000	t/wwd	days	$/day x 1000	$ x 1000	t/d	$ x 1000	$/GJ	$/t
Handymax	100% coal	40.0	50	1005.20	6000	20	10.5	100	25	420	0.87	21.75
Handymax	100% torr.	35.0	50	735.00	5250	20	10.5	100	25	420	1.18	24.86
Panamax	100% coal	68.0	85	1708.84	8000	20	12.5	150	38	602	0.71	17.86
Panamax	100% torr.	59.5	85	1249.50	7000	20	12.5	150	38	602	0.97	20.41
Panamax	80% coal	54.4	68	1367.07	8000	20	12.5	150	38	602	0.71	17.84
	20% torr.	11.9	17	249.90	7000	20					0.97	20.37
Capesize	100% coal	120.0	150	3015.60	10000	20	13.8	200	75	1120	0.64	16.06
Capesize	90% coal	108.0	135	2714.04	10000	20	13.8	200	75	1120	0.64	16.08
	10% torr.	10.5	15	220.50	8750	20					0.87	18.27
Handymax	100% WP.	32.5	50	552.50	4875	20	10.5	100	25	420	1.57	33.07

This supply chain concept may work where biomass is available and also where coal is exported. **Table** 6.8 lists the top coal exporters in 2010. Australia was the world's largest exporter, shipping 328 million tons, or 27.1% of the world total. Port Waratah Coal Services operates the world's largest and most efficient coal handing operations through its two terminals, Carrington and Kooragang, at the Port of Newcastle. Most of the coal arrives by train, some as long as 148 cars pulled by four locomotives, and it unloads into receiver hoppers under the track. Coal is then either loaded directly onboard a ship, or taken by conveyor to a stockpile. The system can also "blend" different coals, well suited to a torrefied wood fraction, and the coal is treated with a chemical agglomerate to bind the fine particles to prevent dust emission; well suited again to torrefied wood. Australia has tremendous plantation potential to make bio-coal, as do the US South and Indonesia. Canada has considerable potential from harvest residues from Mountain Pine Beetle Wood.

Table 6.8 World Coal Exports 2010

	Mil. Tons	%
Australia	328.1	27.1%
Indonesia	316.2	26.1%
Russia	122.1	10.1%
United States	83.2	6.9%
South Africa	76.7	6.3%
Colombia	76.4	6.3%
Canada	36.9	3.0%
Other	173.20	
Total	1,212.80	

Table 6.9 lists the top coal importers in 2010. Japan was the world's largest importer at 206.7 million tons, or 17.5% of the total, while China was the second largest importer at 195 Mt. In 2011, Australia shipped 115 Mt of coal (39% of its coal exports) to Japan, 42Mt to China, and 40.7 Mt to Korea. Korea has renewable energy targets to 2020 and Japan is beginning to wind down nuclear power in favour of renewable energy by co-firing. Both Japan and Korea could be interested in defined proportions of renewable torrefied wood in coal shipments. Key supply chains would be Australia to Japan and China.

Table 6.9 World Coal Imports 2010

	Mil. Tons	%
Japan	206.7	17.5%
China	195.1	16.6%
South Korea	125.8	10.7%
India	101.6	8.6%
Taiwan	71.1	6.0%
Germany	55.1	4.7%
Other	422.70	
Total	1,178.10	

Indonesia is the world's second largest coal exporter, with key customers China and India. It also has enormous wood resources and potential for biomass energy. Bio-coal would be an option, with supply chains to China, Japan and Korea. The US is the world's 4th largest exporter of coal. A major customer is Germany, which has legally binding RE targets to 2020, another potential bio-coal supply chain. Canada is the 7th largest coal exporter, shipping much from the Ridley terminal at Prince Rupert to China, Japan and Korea. With millions of tonnes of Mountain Pine Beetle wood, BC could become a major exporter of torrefied product to Asia and to Europe made competitive by piggybacking the coal supply chain.

In Indonesia, one of the main coal producing regions is Kalimantan. There are 5 ports that can take Panamax and larger ships; Tanjung Bara 200,000dwt, South Pulau Laut 200,000dwt, North Pulau Laut 150,000dwt, IBT 70,000dwt and Balikpapan 60,000dwt, shown on Fig 6.6.

Numerous Indonesian ports are equipped to handle Capesize ships capable of carrying 80,000-175,000 dwt, primarily in the regions containing the highest coal reserves , Sumatra and Kalimantan. Coal producers also use transshipment facilities in open seas to load coal from barges to bulk carriers. For example, PT Adaro Indonesia has four floating transshipment systems that can load vessels up to 25,000 tpd. In the Sulawesi Sea at Muara Pantai, PT Berau Coal has a facility that uses ship cranes to load coal directly from barges to ships with a loading rate of 12,000 tpd and also uses a Semi Submersible Trans-shipper to transfer coal to ships from barges by conveyors with loading rate of 15-18,000 tpd per day. Lastly, PT Bayan Resources Tbk operates the Kalimantan Floating Transfer Station to load coal onto Cape-size vessels and has the capacity to load coal to such vessels at a rate of 4,000 tonnes per hour[70].

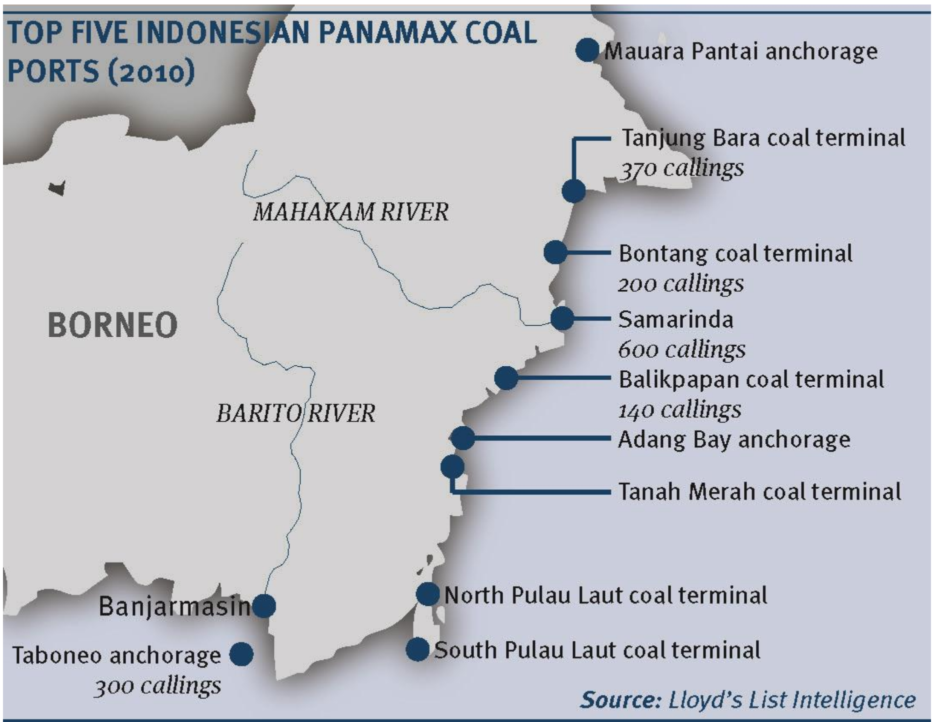

Fig. 6.6 Indonesian Coal Ports

Indonesia has built the world's 9th largest pulp industry with considerable production of pulp mill residue. Despite this growth there are some long-standing structural problems with the sector, for example, in 2010 producers Riau and Sumatra sourced half their wood supply from natural forests[71]. To counteract this sustainability issue the government established a Long Term Forestry Plan that envisions 14.5 million hectares of timber plantations by 2025. By 2011 plantation area reached 5

[70] http://www.censin.com/indonesia-coal-ports/
[71] ARD Learning Exchange 2012- Forests, Trees and Landscape- Synergy, Tradeoffs, Challenges, 6-11 May 2012.

million ha. Kalimantan has a large number of plantations and it also has the largest potential for additional plantations. All of this fibre source would only be of interest if it were proved to be from sustainable sources. A viable supply chain would be to produce torrefied pellets from plantation wood or residues from pulp operations, transport it to the coal ports, and ship it with coal to interested markets.

BC exports high-quality metallurgical coal, and BC ports are among a small number that can handle Capesize ships. West Shore Terminals and Neptune Bulk Terminals, Vancouver, invested $49 million and $51 million respectively in expansions. Ridley Terminal at Prince Rupert is undergoing expansion that will double coal handling capacity to 25 MT. Ridley can load at 9,000 t/hour and docks ships of 250,000 DWT. For environmental protection it has water-dampened coal storage to minimize coal dust, and closed loop drainage for complete recovery of coal fines. There are many sources of sustainably managed forests that can provide fibre for torrefaction facilities that can produce torrefied wood for export while piggybacking on the existing coal supply chain. One company, Global Bio-coal Energy, plans a 3-phase project to make torrefied wood and explore supply chains, beginning with an 80,000t facility. The company has confirmed up to 400,000t wood p.a., has signed off-take agreements with a UK broker. It estimates manufacturing costs of $180/t and transportation costs $40/t, shown in **Table** 6.10.

Table 6.10 Estimated Supply Chain Costs- Torrefied Wood BC to Rotterdam

	$/tonne
Manufacturing	180
Train	16
Load	7
Ship	17
Costs	220

As Ridley and Roberts Bank West Shore Terminals are handling only coal, Global Bio-coal looks to use Watson Island, a bulk terminal nearby that will take biomass. Potential supply chains are shown on **Fig.** 6.7: Indonesia, Australia, Columbia and BC to Korea, Japan and China; US South and South Africa to Europe.

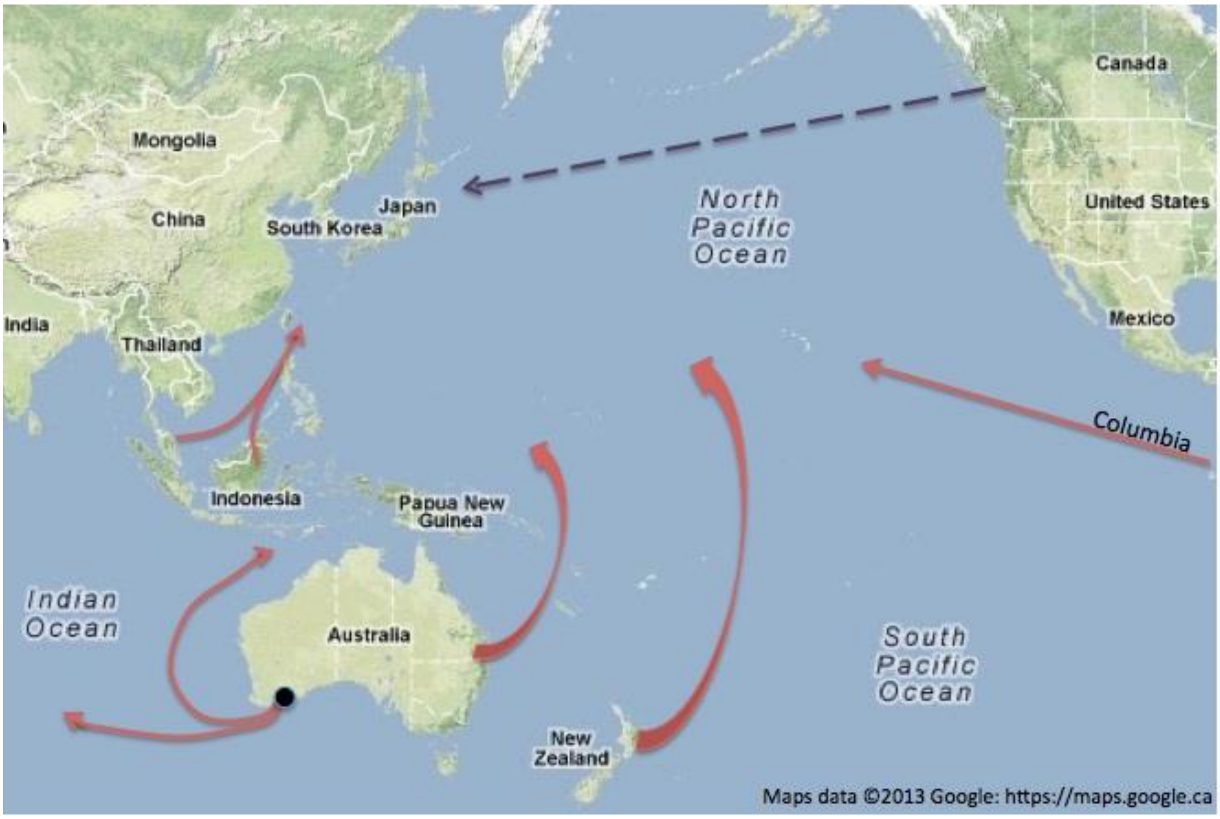

Fig. 6.7 Potential BioCoal Supply Chains

6.4 Pyrolysis Oil- Sharing Existing Efficient Supply Chains

6.4.1 Industrial

Ensyn has announced intentions to build a 400 tpd pyrolysis oil plant in Malaysia using fruit bunches as feedstock, which it will use either to generate electricity or sell to local plants to substitute for heavy fuel oil. A 400-tpd plant could sell all its production to one cement plant, shipped in trucks with stainless steel containers. Dynamotive is also active in Malaysia and Australia, where it is planning the development of multiple plants. Plants are in planning stages in Quebec, Canada, and the hope is that pyrolysis oil could be sold locally in the mining industry. It may be that local markets will be built slowly and that some production would have to be transported long distances. In Canada, trucking costs are approximately 10 times rail transport. The preferred supply chain is to have a pyrolysis oil plant adjacent to a rail siding so that product could be shipped at low cost to a port, stored in stainless steel tanks, and then loaded onto bulk chemical tanker to European ports. Costs would initially be high because of low volumes, but the expectation is that regions could support 4-5 400-tpd plants. Each would produce 98,000 tonnes pyrolysis oil, so that 4-5 plants could ship 20,000 tonnes to port every two weeks.

There are several difficulties with long distance shipping of pyrolysis oil, and developing infrastructure for a relatively new commodity with initially low utilization. Initially shipping rates would be high due to low volumes. Market rates for shipping have proved to be extremely volatile, evidenced by the sharp increase in shipping costs in 2008. Also ships may not be available when needed. For this reason, an integrated supply chain may offer the best option, for example, acquiring dedicated ships that operate only for the purpose of shipping pyrolysis oil from one or more plants, or making long term contracts to do the same. The notion of buying the supply chain has been employed by Wilmar, the largest manufacturer of palm oil in the world. Wilmar has a fleet of 200 ships to guarantee transportation of palm oil at known prices. Dynamotive proposes a model for long distance supply chains, shown in Fig 6.8, is similar to that of the oil industry.

In the oil industry, crude oil is pumped from the ground and subsequently either pumped long distances through pipelines or shipped on Capesize ships to refineries. The refineries make products such as gasoline, aircraft fuel, fuel oil and chemicals that are sold locally in end markets, For pyrolysis oil, the plants would be the same, built close to the biomass feedstock where raw pyrolysis oil would be manufactured, then transported long distances in bulk on large chemical ships to conventional petroleum refineries for upgrading or directly to bio-refineries that would convert the raw pyrolysis oil to bio-fuels and other bio-products.

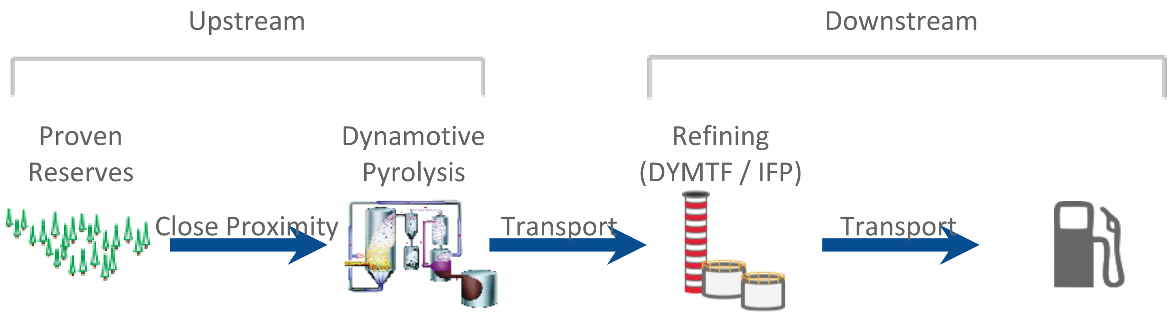

Fig. 6.8 Long Distance Pyrolysis Oil Supply Chains[72]

6.4.2 Malaysia-Indonesia

Malaysia and Indonesia have 656 PJ and 3,631 PJ of agricultural forest residues (Sec. 3.5). Wilmar, the world's largest manufacturer of palm oil, estimates annual availability of 50 MT p.a. of palm fruit bunches. Dynamotive and Ensyn both have tested palm fruit bunches for the production of pyrolysis oil. **Table** 6.11 shows the generic costs of manufacturing pyrolysis oil based on production of 250 tpd, or 82,000 tonnes annually[73]. An average price for pyrolysis oil and char of $220/t plus other net income less royalties yields revenue of $17.8 million. In this generic example, $22/t for biomass, $74/t for conversion and $11/t for local transportation yield a manufacturing cost of $106/t, and a margin of $10.8 million.

Table 6.11 Generic Pyrolysis Oil Manufacturing Costs[74]

	$000	$/t
Revenue- BioOil	18,040	220
Other, incl royalty	-240	
Net Revenue	17,800	
Cost- Biomass	1,763	22
Cost- Conversion	6,027	74
Cost- Transport	861	11
Adj	-1,651	-20
Cost	7,000	106
Margin	10,800	115

Table 6.12 estimates the delivered cost vs the Base of pyrolysis oil from Malaysian plants based on above conversion costs at local wage rates and costs of construction, and local biomass costs. Biomass in the form of palm fruit bunches, at $10/green tonne, is far less than the high-cost fibre in the Base. The cost per tonne pyrolysis oil at the plant gate (and also cost/GJ since both pellets and pyrolysis oil are 18GJ/t) is 59% of the Base. **Table** 6.10 also notes that a second plant built beside the first would cost 20% less capital than the first, and would also have far lower conversion costs since no extra labour would be required. Two plants would deliver GJ to the plant gate at 53% of the Base.

[72] Dynamotive presentation delivered by Douglas Bradley at CanBio Quebec conference Oct 2012
[73] Dynamotive Web Site
[74] Ibid 63

Table 6.12 Pyrolysis Oil Manufacturing Costs[75]

Pyrolysis Oil Production Costs vs Base- Malaysia			
	1st Plant	2nd Plant	Total
Capital $000	20,000	16,000	36,000
Costs:			
Biomass	16%	16%	16%
Conversion	91%	65%	78%
Tax+ equity/debt returns	194%	156%	175%
Plant Gate	59%	47%	53%

The cost to ship palm oil reached a 2-year high in January 2013 at $50/t Malaysia to Rotterdam on a 35-40,000t Handymax ship. As palm oil is 40GJ/t, the shipping cost would be $44.50/m^3, or $1.25/GJ, shown in **Table** 6.13.

Table 6.13 Shipping Cost of Pyrolysis Oil

Shipping Cost Pyrolysis Oil								
							Handymax	Panamax
Palm Oil Shipping	Km	t/m3	GJ/t	GJ/m3	$/ t	$/m3	Mkt $/GJ	Owned $/GJ
Malaysia-EU	11,397	0.89	40	35.6	50	44.50	1.25	0.63
Malaysia- Shanghai	4,415	0.89	40	35.6	19.37	17.24	0.48	0.24
BioOil Shipping								
Malaysia-EU	11,397	1.2	19.97	23.96	37.08	44.50	1.86	0.93
Malaysia- Shanghai	4,415	1.2	19.97	23.96	14.37	17.24	0.72	0.36

Malaysia to Rotterdam is 11,397 km, Malaysia to Shanghai 4,415 km. If one assumes a linear cost-distance relationship, the shipping cost of palm oil to Shanghai would be $0.48/GJ. Pyrolysis oil in this operation is 20 GJ/t and 24 GJ/m^3 compared with 40 GJ/t and 35.6 GJ/m^3 for palm oil. Assuming that volume is the determining factor in shipping, pyrolysis oil would cost $1.86/GJ to ship to Rotterdam, or $0.72/GJ to Shanghai. These shipping costs are based on a peak price. Mature supply chains would use Panamax ships, for a 15% saving. Wilmar Inc reduces costs and risk by buying the supply chain. It owns a fleet of 200 ships. A mature pyrolysis oil supply chain would do likewise, reducing the shipping cost to $0.93/GJ to Europe and $0.36/GJ to Shanghai. In the near term, pyrolysis oil project proponents might partner with Wilmar or similar companies in sharing plant-to-port supply chains and port-to-customer supply chains to garner low rates. The delivered cost to China is estimated in **Table** 6.14. In 2013 delivered cost for production from one plant on Handymax ships at today's peak shipping rates is $6.56/GJ. The product is assumed to be BioOil+, pure pyrolysis oil mixed with some char that is 30GJ/t to raise the energy value of the exported product. By 2020 two plants side by side shipping production on owned Panamax ships (or by partnering with a palm oil exporter) is $5.70 (in 2013 dollars). Similarly shipping to Europe today would be $7.69/GJ vs $6.27 in 2020. The cost to the EU is 56% of the Base on a GJ basis. The cost drops to 46% of the base when two plants are combined and product is exported on a Panamax ship.

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[75] Capital costs based on 20% lower capital costs than North America. Both Ensyn and Dynamotive have stated that labour is 4 per shift in a plant regardless of size. Assume 1 on feedstock per shift. 4 shifts. Labour and management rates from Malaysian Investment Development Authority.

Table 6.14 Delivered cost Pyrolysis Oil- Malaysia to Shanghai and EU- $/GJ

Delivered Cost $/GJ vs Base- Malaysia				
	To China	To China	To EU	To EU
	2013	2020	2013	2020
Mfg Cost	5.04	4.54	5.04	4.54
Transport to port	0.40	0.40	0.40	0.40
Load	0.40	0.40	0.40	0.40
Ship to Shanghai	0.72	0.36	1.86	0.93
Delivered Shanghai	6.56	5.70	7.69	6.27
			56%	46%

6.4.3 BC Canada

BC is a potential producer of pyrolysis oil. In BC the feedstock is wood, which has a 70% pyrolysis oil yield compared to 65% for fruit bunches in Malaysia. Despite the high yield, feedstock in BC is more expensive at ~$40/BDt (70% mill residue at $35/BDt and 30% harvest residues at $50/BDt) than Malaysia, but less costly than Northern Ontario. Labour costs are assumed to be almost triple that of Malaysia, and capital costs 20% higher. Fully loaded manufacturing cost is 83% of Base on a GJ basis, 74% of base if two plants are built side by side, as shown in **Table** 6.15.

Table 6.15 Estimated Pyrolysis Oil Manufacturing Costs US$

Pyrolysis Oil Production Costs- BC Canada			
	1st Plant	2nd Plant	Total
Capital $000	25,000	20,000	45,000
Production (t)	70,125	70,125	140,250
Production (GJ)	1,356,919	1,356,919	2,713,838
Costs:			
Biomass	36%	36%	36%
Manufacturing Cost	86%	54%	70%
Tax+equity/debt returns	295%	241%	268%
Loaded Manufacturing cost	83%	66%	74%

Delivered costs from BC are estimated in **Table** 6.16. The shipping distance Vancouver-Shanghai is 9,000 km. Using a shipping cost proportional to distance, the delivered cost on Handymax ships in 2013 is $11.38/GJ, which drops to $8.80 if two modular plants are built side by side and larger ships are used. The delivered cost Rotterdam is estimated at $12.91 in 2013, or $9.37 in 2020.

Table 6.16 Delivered Cost Pyrolysis Oil from Vancouver Canada- $/GJ

Delivered Cost $/GJ- Vancouver - China		
	2013	2020
Mfg Cost- loaded	8.91	7.07
Transport to port	0.50	0.50
Load	0.50	0.50
Ship to Shanghai	1.47	0.73
Delivered Shanghai	11.38	8.80
Delivered EU	12.51	9.37

6.4.4 Eastern Canada

Eastern Canada could become a major source of biomass supply. In 2012 much of the wood was high cost unmerchantable timber or harvest residues, and in many cases the source is a long way from ocean supply chains. For many areas the wood pellet business model will not work unless a number of factors line up; sawmills opening and reducing fibre cost, higher pellet prices, and sufficient pellet production volumes to lower supply chain costs. A pyrolysis oil model be more appropriate. **Table** 6.17 compares the two options. There is almost no market for pellets in the region. Under conditions of early 2013, pellets would have to be exported at a delivered cost of $217/tonne. In the region there IS a potential market for pyrolysis oil; pulp mill lime kilns, industrial boilers, and potentially diesel to power. In this model half of pyrolysis oil production is sold locally. Pyrolysis oil can use lower quality feedstock with more bark. A lower biomass cost would be offset by higher conversion costs. Considerable savings would be achieved on transportation. Half is sold locally. Pyrolysis oil contains much more energy per unit volume, so ocean shipping costs would be reduced. Pellets would be delivered EU at $12/GJ vs $9.50/GJ for pyrolysis oil.

Table 6.17 Pellets vs Pyrolysis Oil- Northern Ontario

Pellets vs Pyrolysis Oil- Northern Ontario				
$/tonne	Pellets	Pyrolysis	Domestic	EU
tonnes	150,000	57,750	28,875	28,875
raw material	80	71	71	71
Delivery	25	15	15	15
Biomass	105	86	86	86
processing	53	74	74	74
Plant Gate	158	160	160	160
transport	35	13.75	10	17.5
shipping	24	6	0	12
Delivered EU port	217	180	170	190
GJ/mt	18	20	20	20
$/GJ	12.06	9.01	8.52	9.50

Fig 6.9 Illustrates new Eastern Canada supply chains to the EU; train or ship transporting pellets, torrefied wood or pyrolysis oil from Thunder Bay or the Abitibi Témiscaming region of Quebec.

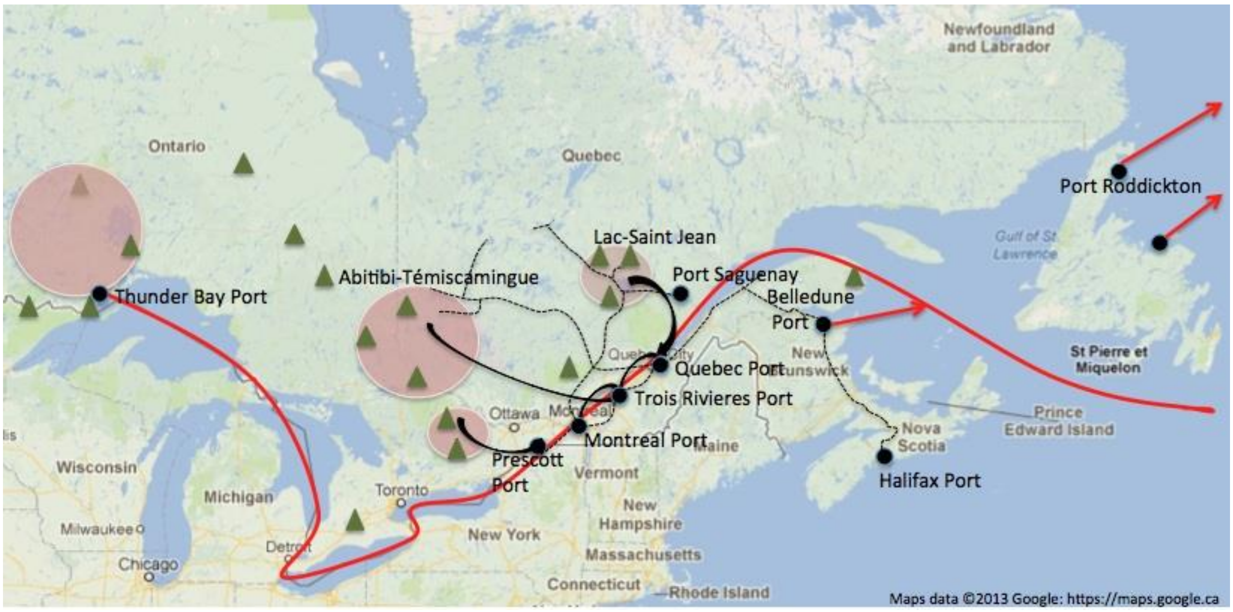

Fig. 6.9 New Eastern Canada Supply Chains

7. Discussion and conclusion

This report examines the supply chains of wood pellets, torrefied pellets and pyrolysis oil, including current and future cost and possible cost reductions. Currently, only wood pellets are traded over long distance in large volumes. In 2012, the total import volume of wood pellets by the EU was more than 4.2 MT. At the moment of writing, only one company is capable of producing torrefied pellets at commercial level. Both torrefied pellets and pyrolysis oil are only being traded at marginal volume, so analyses on torrefied pellets and pyrolysis oil in this report are only indications. In some markets torrefied pellets and pyrolysis oil are regarded as potential alternatives to wood pellets, and for long distance transport of biomass they may have transportation advantages owing to their energy density. Torrefied wood and pyrolysis oil will also be in markets different from wood pellets.

While logistics costs of long-distance supply chains typically contribute half or more of the total delivered cost to the end user, the logistics are often of secondary interest, and main attention is given to the operational performance of the mill and raw material supply. Regions where large amounts of biomass are available and accessible are usually located at a long distance from the main market, i.e. the EU, and also emerging markets like Japan and Korea. It is expected that regions with supply chain infrastructures for trade already in place or easily added, such as BC Canada and US South will remain as the main exporters of biomass. Gradually, new sources may emerge like Eastern Canada, Brazil, Indonesia, Malaysia, the Caribbean, Mozambique and other stable countries in Southern Africa. Northern Ontario is not yet competitive in pellets, with long supply chains and expensive wood. However Quebec and Ontario sawmill industries are rebounding from a 2008-12 industry downturn and more low-cost feedstock is becoming available. Brazil is a burgeoning exporter, but wood costs have climbed, and there is heavy competition for supply chains from the forestry regions to the coastal ports.

Current torrefied pellets and pyrolysis oil supply chains provide room for cost reduction in logistics with innovative solutions. As identified in chapter 4, the most important opportunities and preconditions to reduce cost in the supply chain are:

- **achieving economies of scale in shipping**. Ocean shipping in Panamax, Handymax, etc. sized vessels costs considerably less than shipping in smaller vessels. In particular this is true for conditions where the vessel can be loaded and unloaded efficiently with a full load at one single visit. Thus, suitable berths, effective loading equipment and adequate storage capacity are needed.
- **achieving economies of scale for rail transport**. The use of unit trains or other forms of scheduled traffic plans would be more efficient than using single wagons. The development of specific optimized wagons could also contribute to cost reductions. In some cases purchasing dedicated rail cars is an excellent option to reduce costs and to confirm rail availability. However, such measures must be integrated in the development of scheduled logistics plans.
- **utilizing existing infrastructure efficiently**. For example, for large coal power plants that face renewable energy targets torrefied pellets could be loaded into holds adjacent to coal on large ships for delivery to a single customer, thereby getting the cost advantage of large vessels.

- **joining forces**. The scale needed to stimulate development of efficient and economic logistics is a product flow in the order of magnitude of 1 million tons p.a. Due to feedstock supply limitations, few bio-energy projects reach that unit size. Joint efforts by co-operation with other producers and sharing transport and storage/harbor facilities will enhance negotiations with transport companies and port managers. Also political support and financing from public funding should be explored.
- **bringing technical and organizational aspects of supply into one fully integrated supply chain under the control of one stakeholder**, as is currently happening with a few big projects in the US. Barring this option, for the long-term viability of bioenergy trade, a system with independent logistics service providers in competition should be able to achieve cost efficiencies by integration with other businesses locally or parallel along the supply chain.
- **convincing external stakeholders that long distance and long term export of bio-energy is viable and sound**. Policy measures like the EU 20/20 policy and international consensus reports like the IEA Technology Roadmap provide support in that respect, but still in many cases the long term prospects of bio-energy are not fully and generally recognized which sometimes makes it difficult to mobilize external support for improvement of logistics for the export of bioenergy.

Based on these factors, it is estimated that the costs of logistics can typically be reduced as much as the costs of biomass production through technological advances, and should thus be considered as equally important.

To illustrate the possible cost reductions, the report attempted to compare delivered cost as a percentage of a base case, the highest cost alternative - 2012 costs per GJ for a 50,000 tonne Northern Ontario pellet plant delivered EU using existing supply chains. The cost data came from several different sources, often reflecting plants of different size, and usually with different mixes of feedstock. Although the data is not directly comparable, some interesting conclusions can be drawn. Based on the assumptions laid out in this report for capital and operating costs (assumptions based on projected costs from current 100 tpd plants), **Fig.** 7.1 provides an indication of the lowest cost of biomass delivered CIF ARA. Please note that this figure encompasses uncertainties in factors such as the development of pyrolysis and torrefaction technologies (and associated cost reductions), but also the cost of feedstock, assumed investments in logistic infrastructure and other factors. The figures shown should therefore only be as an indication of how far cost could be lowered compared to a typical current supply chain. Neither should it be seen as an identification of which pretreatment technology is the most (cost-)effective, as this depends on the specific logistic chain but also the requirements of the end-consumer.

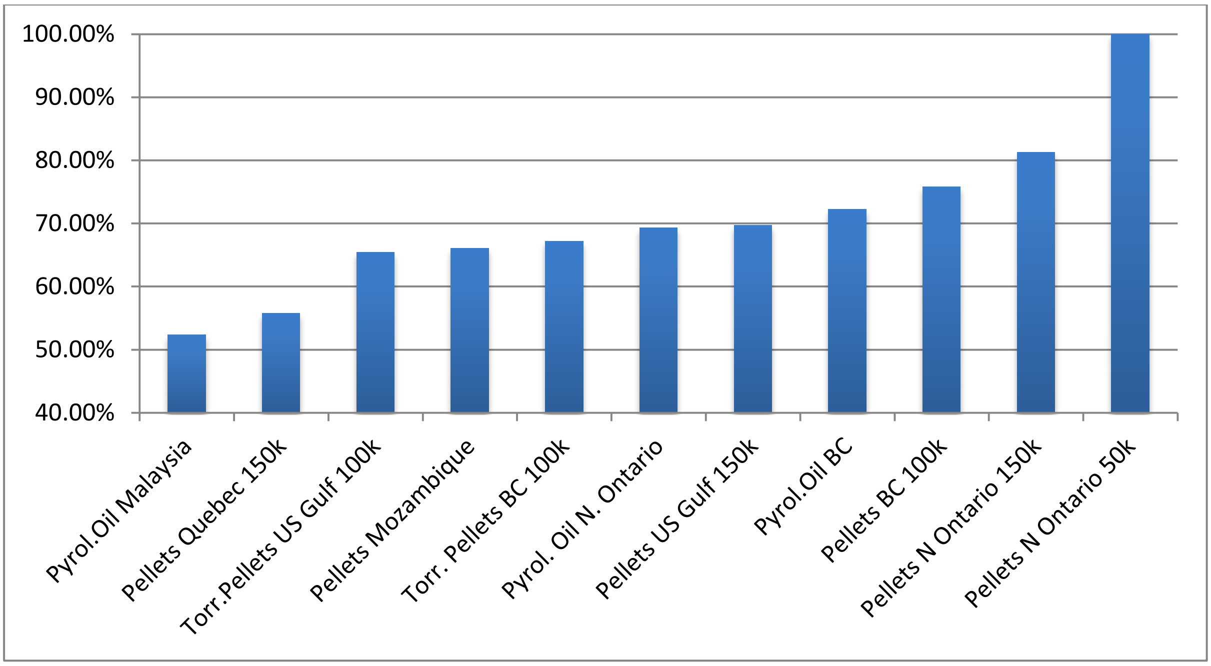

Fig. 7.1 Cost comparison of options, Delivered Cost of Biomass to Rotterdam

As shown in figure 7.1, pyrolysis oil manufactured from palm fruit bunches and transported by Handymax ship to ARA, may achieve a delivered cost of 52% of the assumed base case. By 2020, this product could possibly be delivered for 43% of the base case assuming tandem plants, higher volumes, and sharing existing supply chains using larger ships. The US Gulf is very competitive in pellets at 70% of base costs, and surprisingly Mozambique pellets data yields a cost 66% of the base. Other supply chains investigated typically achieve cost reductions between 20-30% compared to the base case.

Again, the cost reductions for specific supply chains should be seen as examples to illustrate that cost reductions could be substantial, also for chains using an already proven pretreatment technology (wood pellets). These cost reductions are crucial to enable the further growth of bioenergy, and ultimately to realize the bio-based economy. However, to achieve these cost reductions, different market actors will need to cooperate, but also the support of policy makers, banks and other external stakeholders is needed.