J. W. Gottstein Memorial Trust Fund

The National Educational Trust of the Australian Forest Products Industries

GOTTSTEIN
TRUST

FOREST BIOFUEL HARVESTING TECHNOLOGIES IN SCANDINAVIA AND AMERICA

ROSS ANDREWARTHA

2002 GOTTSTEIN FELLOWSHIP REPORT

Ross Andrewartha currently works as the Southern Regional Harvesting Superintendent for Forestry Tasmania, a government business enterprise. He is responsible for harvesting contractor management and timely delivery of a wide range of forest products to customers throughout Tasmania and Asia.

He is currently involved with the Southwood Resources (Huon) Project, a $A110 million initiative to develop downstream processing and value-adding industries within Tasmania. This project includes the construction of a wood-fired power station along with other timber processing facilities and a log-merchandising yard.

Ross has worked in a variety of operational roles within Tasmanian, NSW and overseas public and private forestry organisations, including a 4 year secondment with the Tasmanian Forest Industries Training Board as the Training and Development Officer.

Ross's overseas experience includes 7 years in the South Pacific, most recently in Vanuatu, as the Training Adviser on the successful Vanuatu Sustainable Forest Utilisation Project. During this period he completed a number of short-term consultancies within SE Asia and the Pacific.

Ross has recently graduated with a Masters Degree in Forestry at the University of Queensland.

Joseph William Gottstein Memorial Trust Fund

The Joseph William Gottstein Memorial Trust, established in 1971 after Bill Gottstein's untimely death in Papua-New Guinea, aims to create opportunities for persons from Australia's forest and forest products industries to enhance their knowledge and competencies.

The Trust's annual activities include offering:

- Short term fellowships to assist staff within Australian forest industries to further their experience, education or training either within or outside Australia. Proposals are accepted from any area of the industries with an emphasis on value-adding. There is no formal minimum educational requirement for Fellowship applicants.
- 12 month research fellowship at the World Forest Institute (WFI) at Portland Oregon jointly funded by the Gottstein Trust, the Forest and Wood Products Research and Development Corporation and by the WFI. The minimum educational requirement is a bachelor's degree in forestry or forest products, or its equivalent.
- Skill advancement awards are offered to assist any person involved in the Australian forest industry, at whatever level, to improve their work skills. No formal qualifications are required. These types of awards are for smaller activities than the Fellowships and take the form of a monetary grant.

FURTHER INFORMATION:

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Executive Summary

Global economic growth patterns and the subsequent accompanying energy demand is forecast to average 3 % per year for the next 20 years. Bioenergy is a rapidly increasing source of energy worldwide and is designed to meet some of the expected demands in a more environmentally-acceptable manner. IN addition to being renewable, biomass as a fuel source has numerous benefits including meeting government regulatory targets and mitigating the effects of greenhouse gas emissions from other forms of energy generation.

Scandinavian countries in particular are now placing increased importance in developing sources of renewable energy. Finland and Sweden have set ambitious targets to increase the usage of forest biofuels over the next decade in accordance with climate-related international and European Union protocols. Also Denmark, despite having a relatively small forest estate, is developing pro-active forest biofuel programs, primarily for district heating plants. America, by contrast, has adopted a free-market approach to energy producers, with a deregulated and very competitive energy sector in most states.

Conventional Australian harvesting operations in natural forests primarily concentrate on the removal of 'stem wood' for various traditional products. Significant suitable post-harvesting biofuel volumes consisting of dead standing material, stumps, limb wood, bark and understorey material exist within Australian forests. Tasmanian State Forest’s residual volumes alone are conservatively estimated to be approximately 2.5-5.0 million green tonnes per annum. On a heat basis, this is approximately equivalent to 1-2 million tonnes of black steaming coal.

Presently these residues remaining after Tasmanian forestry operations are burnt, in late summer in order to simulate the natural fire regime that is essential for the regeneration of Tasmania's eucalyptus forests. Much of these residues could potentially be diverted to renewable energy production providing dual benefits of

reducing the impact of coupe regeneration burning and act as a substitute for non-renewable, less expensive fuel sources, presently used in Australian energy production.

A wide range of biofuel harvesting and processing options are available. Numerous Scandinavian systems would be applicable in Australian softwood conditions on reasonable terrain, whereas American 'whole-tree' systems and 'logging residue processing' systems, which tend to be more robust in construction, would be more appropriate for Australian hardwood operations. This recommendation is based on the variability of piece size, form and terrain encountered in typical Australian and American hardwood logging operations.

Suggested Australian transportation methods, based on overseas systems would be in 'chip-form' either in 'dedicated chip-vans' (USA) or in modular 'containers' (Scandinavia). Efficient logistical arrangements and excellent infrastructure facilities designed to deliver competitively priced processed biofuels to a myriad of customers typify Scandinavian biofuel operations. Careful consideration must be given to the complete supply chain if Australian forestry agencies are contemplating biofuel harvesting, processing and supply.

In addition and prior to the establishment of a wood-fired power station the following should occur;

- quantification of the actual available fuel resource and its characteristics ie piece size dimensions;
- determination of the plant's output, location and biofuel specification in relation to fuel moisture content;
- negotiation of a long term supply agreement;

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Glossary

BDT	Bone Dry Tonne
CFB	Circulating Fluidised Bed
CHP	Combined heating and power plant, co-generation of heat and power
CO_2	Carbon Dioxide
CRL	Composite Residue Log
DHP	District Heating Plant
EU	European Union
HLPS	Honey Lake Power Station
m^3	cubic metres
MW	Megawatt
MWe	Megawatt (electricity)
MWth	Megawatt (thermal)
NEPOOL	New England Power Pool
Nordic	Nordic countries including Finland, Sweden, Norway and Denmark
PJ	Pentajoule
SED	Small end diameter
TEKES	National Technology Agency (Finland)
TJ	Terajoule
TW	Terawatt
USA, US	United States of America
VTT	Technical Research Centre of Finland
Yr	Year

Units

Area

Cm	Centimetre
D	Diameter
ha	Hectare
km	Kilometre
km^2	Square kilometres
m	Metre
m^2/ha	Square metres per ha
m^3	Cubic metre
m^3/ha	Cubic metres per hectare

Energy

°	Degree
BTU	British Thermal Unit
C	Celsius
Cal.	Calorie
J	Joule
Mtoe	Million tonnes of oil equivalent
Toe	Tonnes of oil equivalent
Wh	Watt-hour

Prefixes of SI-units

k	kilo	10^3	= 1 000
M	mega	10^6	= 1 000 000
G	giga	10^9	= 1 000 000 000
T	tera	10^{12}	= 1 000 000 000 000

Conversion factors for energy units

1 kilojoule (kJ) = 1000 J
1 megajoule (MJ) = 1000 kJ
1 gigajoule (GJ) = 1000 MJ
1 terajoule (TJ) = 1000 GJ
1 petajoule (PJ) = 1000 TJ

1 kWh (kilowatt-hour) = 3.6 MJ
1 MWh (megawatt-hour) = 3.6 GJ
1 GWh (gigawatt-hour) = 3.6 TJ
T TWh (terawatt-hour) = 3.6 PJ

Conversion table

	TJ	Gcal	Mtoe	MBtu	GWh
TJ	1	239	$23.9 * 10^{-6}$	948	0.278
Gcal	$4.19 * 10^{-3}$	1	10^{-7}	3.97	$1.16 * 10^{-3}$
Mtoe	$4.19 * 10^{3}$	10^{7}	1	$39.7 * 10^{6}$	$11.6 * 10^{3}$
Mbtu	$1.06 * 10^{-3}$	0.252	$25.2 * 10^{-9}$	1	$293 * 10^{-6}$
GWh	3.6	$0.860 * 10^{3}$	$86.0 * 10^{-6}$	$3.41 * 10^{3}$	1

Conversion factors of power units

1 kilowatt (kW)	= 1000 W
1 megawatt (MW)	= 1000 kW
1 gigawatt (GW)	= 1000 MW
1 megajoule per second (MJ/s)	= 1 MW
1 horsepower (HP)	= 0.735 kW

Conversion factors relating to quantities of woodchips, energy and calorific value

Cubic content/ weight:

1 cubic metre of solid wood chipped takes up approx. 2.8 cubic metres

1 cubic metre of wood chips contains approx. 0.35 cubic metres of solid wood

1 cubic metre of wood chips weighs approx. 250 kg*

1 cubic metre of solid wood chipped weighs approx. 700 kg*

1 tonne of wood chips fills approx. 4.0 cubic metres*

1 tonne of wood chips contains approx. 1.4 cubic metre of solid wood*

Calorific value:

Calorific value in 1 cubic metre of wood chips = 2.6 GJ*

Calorific value in 1 cubic metre of solid content wood chips = 7.3 GJ*

Calorific value in 1 tonne of wood chips = 10.4 GJ*

1 megatonne (Mt.) (1 million tonnes of oil equivalent, crude oil) = 41.868 PJ

1 tonne of fuel oil = 42.7 GJ

1000 litres of fuel oil = 36.0 GJ

1 litre of fuel oil = 36.0 MJ = 10kWh

* The calculations are based on wood chips of Norway Spruce, a common biomass fuel in Scandinavia. Norway spruce has a specific gravity (solid matter content) of 400 kg per cubic metre and wood chips with a moisture content of approx. 40% which is equal to the moisture content of storage-dry wood chips. Source (Danish Centre for Biomass Technology 1999).

1. Background

1.1 Purpose of Study

Forestry Tasmania, as the organisation responsible for the management of Tasmania's State Forests, is currently investigating the potential of using forest residue biomass for renewable energy production, a common practice in other regions of the world.

Conventional Australian harvesting operations primarily concentrate on the removal of 'stem wood' for various products including material suitable for solid timber products or pulpwood for paper or reconstituted board products. A substantial volume of the timber on a coupe is either too defective or unsuitable for any of the previously mentioned products. These 'residues' consist of dead standing material, stumps, limb wood, bark and understorey material. Available residual biomass volumes are conservatively estimated to be around 2.5-5.0 million green tonnes per annum from planned Tasmanian State Forest operations. On a heat basis, this is approximately equivalent to 1-2 million tonnes of black steaming coal.

Current regeneration techniques in Tasmanian wet sclerophyll forests include conducting 'high intensity' burns in late summer to remove the post-harvesting residues and provide a 'seedbed' for subsequent eucalypt regeneration. A proportion of these residues could be used for bio-energy production, thereby obviating the need for high intensity regeneration burning. Tasmanian regeneration burning practices are increasingly attracting general public criticism and due to their timing, have potentially negative impacts on the peak periods of the Tasmanian wine & tourist industry. Also they can be perceived to be contrary to the promotion of Tasmania's 'clean, green image', currently an essential international marketing tool.

The use of forest residues as an energy source has been demonstrated elsewhere in the world as a sensible, economical & efficient use of a previously wasted resource. Usage of renewable biomass as a fuel source has numerous benefits including meeting government regulatory targets and mitigating the effects of greenhouse gas emissions from other forms of energy generation.

From an economic perspective, biomass recovery (ie the harvesting of additional volumes per hectare) may reduce the overall harvesting costs of conventional solid-wood & pulpwood products due to greater machinery productivity and volume 'throughput per year'. Such cost-savings are vital in an increasingly competitive international market for Australian forest product exports (particularly woodchips) where Australia directly competes with countries with cheaper wage structures and/or lower environmental standards.

The areas of investigation during the study focussed primarily on:

- Biofuel harvesting technologies, work methods (whole-tree, short-wood or long-wood systems) and machinery developments (in relation to felling, skidding, forwarding and biofuel accumulation);

- Biofuel processing methods (chipping, hogging and grinding) at various sites (in forest, at roadside, at power plant site);

- Biofuel transportation methods (whole stem, chipped etc).

2. Introduction

2.1 Economic Growth and Global Demand

Global economic growth patterns and the consequent energy demand is forecast to average 3 % per year for the next 20 years (International Energy Agency 2000). To fulfil this expected demand and simultaneously meet reduced greenhouse gas emission targets, renewable biomass will become increasingly important as an energy source, in particular for developed and developing countries which are traditionally reliant on fossil fuels for energy production.

Numerous international and regional initiatives have been introduced over the past decade to promote bioenergy usage. The European Commission has been very pro-active in this area. A recently released Green Paper, 'Towards a European strategy for the security of energy supply' highlighted the importance of renewable energy sources. The current European Union (EU) directive sets targets to increase the use of renewable energy by 2010 to 22.1% up from the 1997 target of 12 % (TEKES 2002).

Finland is an excellent example of a country attempting to fulfil this commitment. It recently adopted a target to increase the use of biomass fuels as an energy source from 1 million tonnes in 2003 to 7 million tonnes in 2010 (Prof. Pentii Hakkila, pers. comm. June 02). Other Scandinavian countries, without significant fossil fuel resources are also demonstrating strong commitment to the current EU targets. Sweden and Denmark both have pro-active approaches to bioenergy as a fuel source.

3. Finland

3.1 Forestry Overview

Finland with a relatively small population of 5.2 million, has extensive forest resources, with an estimated 23.0 million hectares covering 75% of the land area. Predominant species are Norwegian Spruce, Scots Pine and birch with a combined total standing volume estimated to exceed 19 x 10^8 cubic metres.

With such abundant resources, Finland has an extensive forest industry producing paper, pulp, sawn and plywood products and the highest value per capita in the world of an estimated $USD2000 (VTT Energy 2001). Annual felling volumes are approximately 60 million m^3, of which 90% is used in conventional industries and the balance as bioenergy fuels. These wood-fuels[1] make a significant contribution to the diverse and decentralised Finnish energy system. 70-90% of the paper and sawn products are exported, predominantly to Europe. Figure 1 shows the industrial wood usage in 2000, including imports totalling 13 million m^3, mainly from Russia.

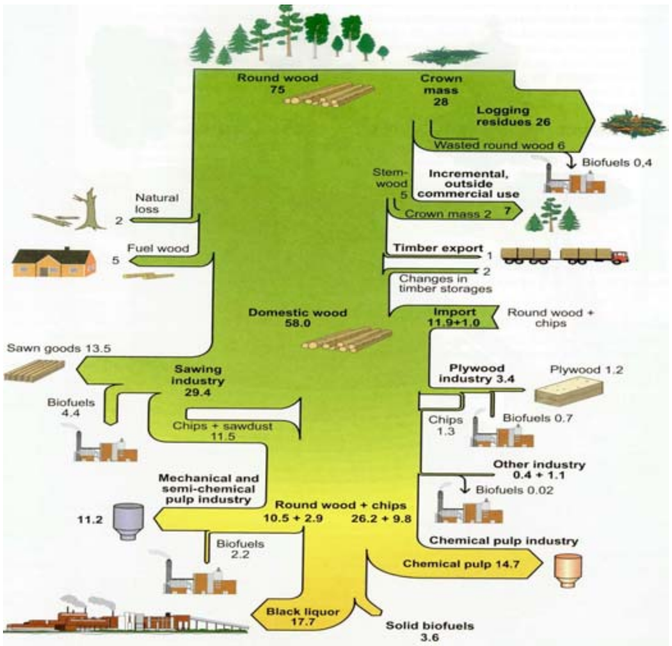

Figure 1: Industrial Wood Usage in Finland in 2000 (Mm^3)

[1] Wood fuel: fuel originating from biological material (biofuel), the origin of which was trees or parts of trees. The term 'bioenergy' is superordinate to the terms 'biofuel' and 'wood fuel'. Wood fuel includes stem wood, branches, tops and by-products from the forest product processing industry.

3.2 Bioenergy Sector Overview

Finland is a world leader in the utilisation of bioenergy and associated combustion technologies. Renewable energy sources, equivalent to 31.2 Mtoe accounted for 25% of the total energy consumption in Finland in 2000 (TEKES 2002).

Finland recently launched its 'National Climate Strategy', which outlines the Kyoto Protocol commitments to reduce greenhouse gases to a level of 76.5 million tonnes of carbon dioxide. The Finnish Action Plan for Renewable Energy Sources (launched in 1999) has the objective by 2025 of doubling the utilisation of renewable energy sources from 6.1 Mtoe in 1995 to 12.3 Mtoe. In response to this aim, usage of forest woodchips will rise from 1 million tonnes in 2002 to 5 million tonnes in 2010 (TEKES 2002).

Wood-fired 'district heating plants[2]' (DHP's) or 'combined heat and power' (CHP) plants have been energy suppliers in rural and regional Finland for many years. Currently 108 plants with annual outputs of 2015 MWth and 860 MWe are strategically located throughout the country and in close proximity to urban centres (see Figure 2-4). Plants range in size from 5 MW to 550 MW and use a diverse range of wood based fuels. An estimated 35 million m^3 is used annually and is derived from liquid and solid industrial wood residues. Forest chips make a modest but increasingly important contribution to this annual figure as previously indicated (7 million tonnes by 2010).

In 1996 the Finnish Government deregulated the energy industry. This action created many challenges for CHP (renewable) energy producers, with strong competition from fossil and nuclear power producers. To offset this effect a tax subsidy has been introduced, particularly for smaller CHP plant operators.

[2] District heating is a public heating system intended to supply heat in networks to residential and industrial users. Heat is supplied in the form of hot water boiler plants, known as district heating plants (DHP's) or from the more efficient 'combined heat and power' plants (CHP's), which simultaneously generate heat and electricity.

Figure 2 **Example of Combined Heat and Power (CHP) Plant. Annual output 48 MW of heat and 17 MW of electricity**

Figure 3 **Rauhalahti CHP in the central Finnish city of Jyvasklya (pop. 80,000). Annual output: 140 MW of heat and 87 MW of electricity**

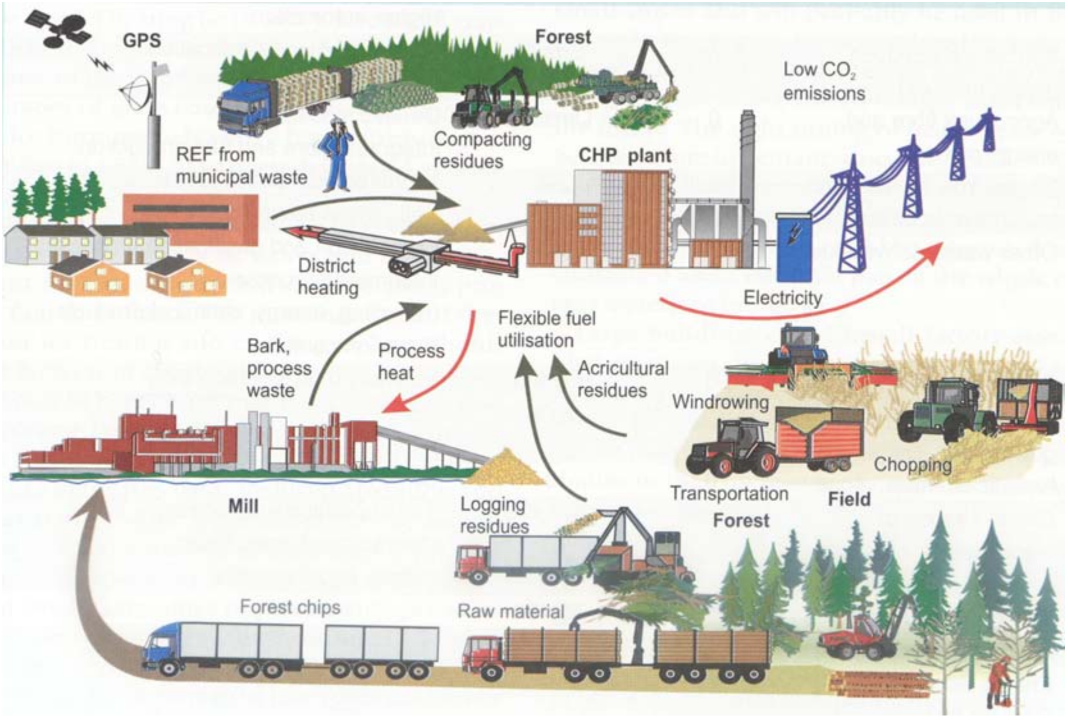

Figure 4 Typical Fuel Supply Chain for a Multi-fuel CHP Plant

3.3 Forest Biofuel Harvesting Methods

3.3.1 'VTT Energy' Research Activities

The research group, VTT (Technical Research Centre of Finland) has several major research facilities throughout Finland, focussing on all aspects of renewable energy sources. 620 researchers and support staff throughout Finland are employed in six major areas including energy production, pulp and paper industry, nuclear energy, new energy technologies (including renewable energy), systems and models, and emission controls. Within the 127-person energy group, located at Jyvaskyla, research is centred on biofuels, combustion technologies (fluidised beds, pyrolysis and gasification), CHP and micro-power plants.

VTT has an annual turnover of Euro$57 million and funding is derived from various sources including private energy companies (45% - inclusive of domestic (36%) & foreign (11%) organisations), direct government grants (26%) and 27% from TEKES, the National Technology Agency (Mr Ari Ekkila pers. comm June 02). It collaborates with private and public sector partners in research and development, provides information to government in support of the national energy strategy, contributes data to EU projects and recently completed a nationwide survey of the liberalised electricity market.

3.3.2 Conventional Forest Harvesting Methods

Conventional forest harvesting (i.e. solid stem material) in Finland is characterised by:

- Intensive stand management, including pre-commercial and commercial thinning
- Dispersed cutting on small clearfelling sites (<5ha in size)
- High level of utilisation & optimisation
- Totally mechanised harvesting and processing methods
- Independent contractors, specialised in each facet of the supply chain ie felling, forwarding, processing and transportation

- Sophisticated logistical arrangements
- Transport distances on average >100 km
- Excellent roading infrastructure (both in-forest and on-highway)

3.3.3 Conventional Forest Biofuel Harvesting Methods

Typically the Finnish forest industry uses the stem wood section of a tree to a SED of 5-9 cm. The remaining tree sections (ie tree top, limbs and stump) are available as forest biofuels (TEKES 2002). The percentage of standing volume available for biofuels varies between species (Figure 5), stand age and site quality. Across Finland this typically varies from 15-55% of the standing biomass and equates to residues of up to approximately 100 tonnes/ha.

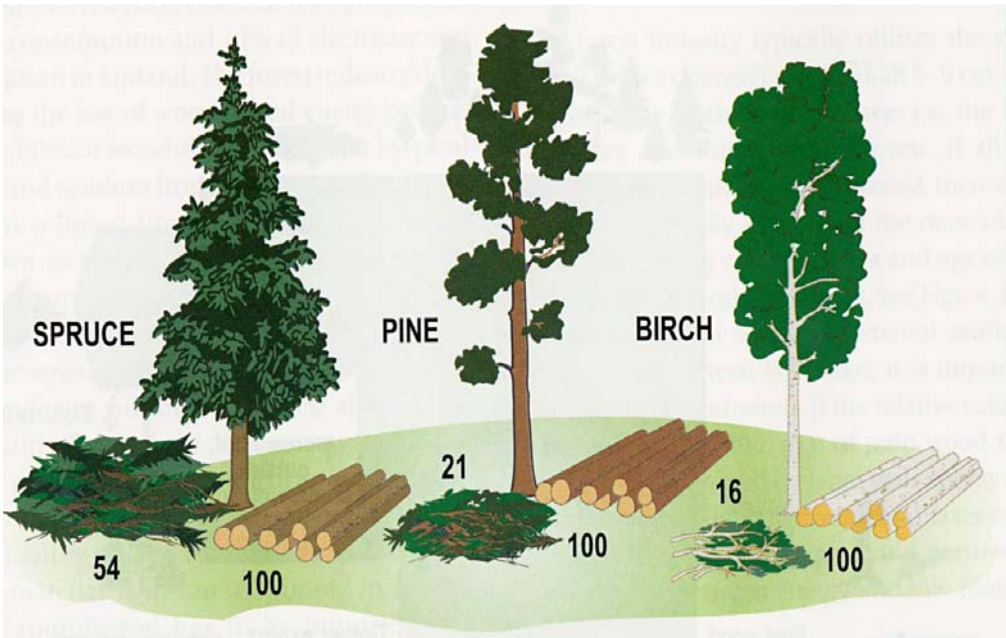

Figure 5 Foliage versus stem mass in predominant Finnish tree species

A wide range of sophisticated biofuel harvesting machinery is currently operating in Finland, with the predominant method being 'roadside chipping' Figure 6 provides a pictorial view of the wide range of biofuel production systems currently being used in Finland.

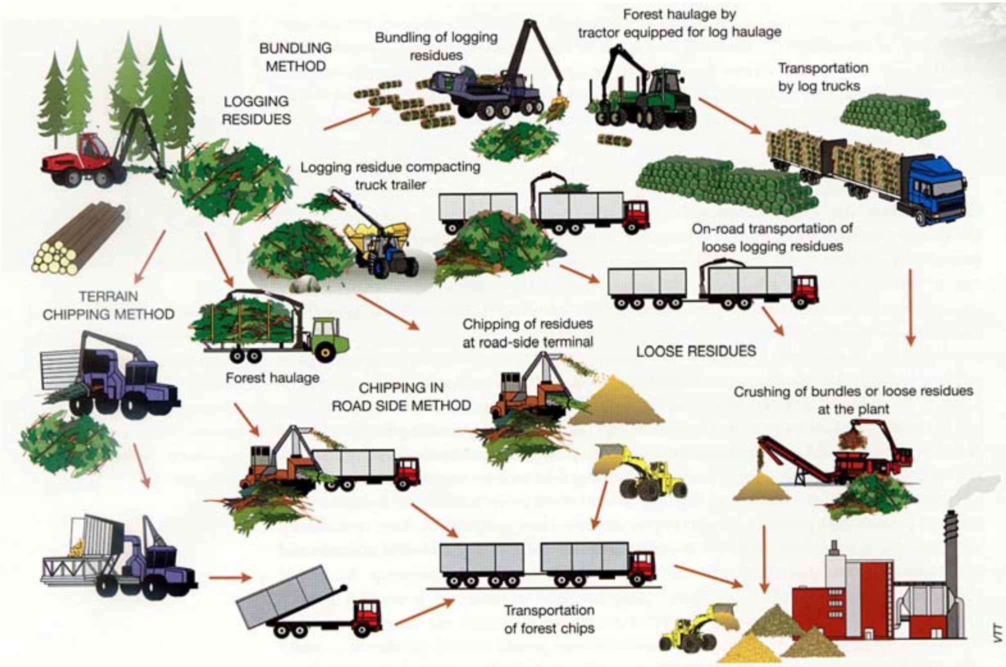

Figure 6 Forest biofuel production systems in Finland

Roadside chipping, the most common biofuel production system, is detailed below:

- Windrowing of 'limb' & head material during felling & log processing phase (see Figure 7);
- Forwarding the post-logging residues to roadside during favourable conditions using modified machinery (see Figure 8);
- Stacking & covering of the residues to allow maximum air-drying (see Figure 9);
- Processing, using truck-mounted chippers (either disc or drum) (See Figure 10);
- Transportation of processed material (60 tonne payloads) either to storage terminal or directly to a customer (60 tonne payloads)

Figure 7 Windrowed logging residues and processed logs awaiting extraction

Figure 8 Modified forwarder (for greater payloads) used for logging residue extraction

Figure 9 Seasoning stockpiled material awaiting processing

Figure 10 Roadside processing using a truck-mounted drum chipper

Figure 11 is an example of a post-harvesting site, with the biofuel removed and is awaiting reforestation.

Figure 11 Example of a post-harvesting site (solid wood and biofuel removed and awaiting reforestation)

3.3.4 Recent Biofuel Harvesting Innovations

Timberjack recently purchased the design rights to a 'biomass bundling system' originally developed in Sweden. This innovative method has been developed as the primary forest biofuel harvesting method for the Alhomens Kraft CHP plant in Pietersaari, a western coastal town in Finland. This plant, the largest biofuel plant in the world, with a thermal capacity of 550 MWth, uses a diverse range of fuels (see Figure 12), including industrial waste wood and bark residues (35%), forest residues (10%) and peat (45%) as its primary fuel sources. Heavy fuel oil or coal (10%) is used as a 'secondary' or reserve fuel. The plant aims to use 200,000 solid m³ (1,440 TJ) of logging residues annually, which due to the scale necessarily requires sophisticated logistical arrangements. The plant produces steam for the adjacent UPM-Kymene Pulp and Paper mill and for a local electricity generating utility.

This innovative harvesting system ‘bundles’ spruce limb material into ‘composite residue logs’ (CRL’s), which are then treated in a similar fashion to solid logs (see Figures 13-15). Composite Residue Logs (CRL’s) can be moved to roadside by existing forwarders (see Figure 16), transported by conventional log trucks fitted with extendable stanchions and processed or stored at central processing terminals (see Figures 17-18).

Figure 12 Alhomens Kraft CHP plant, Pietarsaari (550 MWth capacity)

Figure 13 Timberjack Bundling System

Figure 14 Close-up view of bundler (mounted on a forwarder chassis)

Figure 15 Processed bundles (3.2 m x 70-80 cm diameter, vol. 0.5 m³)

Figure 16 Forwarding CRLs' to roadside

Figure 17 Transportation of CRL's using conventional log trucks

Figure 18 Terminal Processing at Alhomens Kraft CHP plant

4. Sweden

4.1 Forestry Overview

The Swedish forest estate covers 21.2 million hectares (approximately 50% of the landmass) with the following primary species, spruce (45%), pine (39%) and hardwood (16%). The forest estate supports an annual harvesting rate of some 66 million m^3, with the majority of industry output (pulp, paper and sawnboard) being exported. Forest products account for 17% of the total value of exports.

Contrasting with Australia, where natural forests are predominantly publicly owned, there is a high level of private forest ownership in Sweden;

- Private forest growers 50%
- Forest companies 37%
- Public forests 13%

4.2 Bioenergy Sector Overview

Bioenergy has been a long established energy form in Sweden. Wood-based fuels make a 16% contribution towards meeting the annual Swedish demand of 440 TW hours.

Sweden uses several different policy instruments to promote the use of bioenergy, including energy taxation, emission control legislation and investment support (Hillring 2000). The 1997 energy policy is based on limiting the use of fossil fuels and developing efficient sustainable 'renewable energy sources'. A 7-year research and development program, commenced in 1998 is presently developing alternatives to fossil & nuclear fuels. High levels of taxation (energy tax, CO_2 & sulphur emission tax), introduced in the early 1990's are applied at the various energy production phases to assist in making biofuels more competitive with fossil fuels. This has favoured the untaxed biofuels (mainly wood fuels) in the district heating sector where the market has grown rapidly during the 1990's (Hillring 2000).

CHP plants are common in regional and rural areas and their primary fuel sources are as follows:

- Sawmilling by-products (sawdust) 33%
- Bark 17%
- Sawmill chips 17%
- Forest residues (chips, bundles) 33%

Figure 19 shows the increased supply to heating plants over the past two decades, which utilise sawmilling residues, forest residues and imported recycled material.

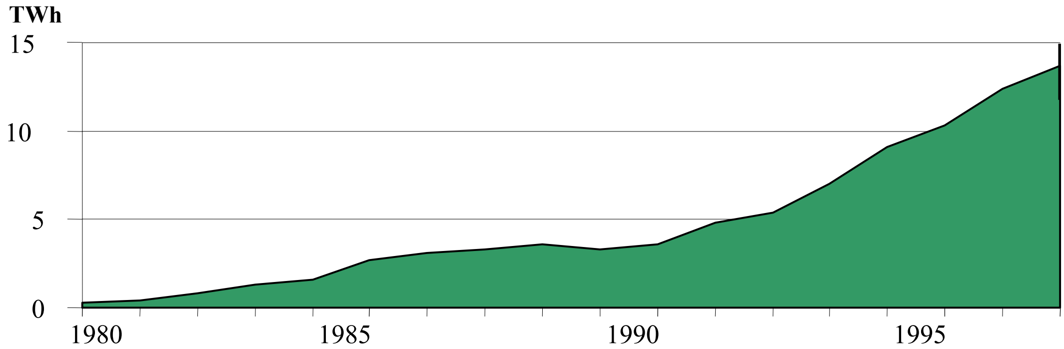

Figure 19 Forest fuels to Swedish heating plants (including imports)

A 1996-7 SkogForsk survey indicated primary forest fuels were used to generate 6 TWhr, consisting of 4.4 TWhrs from final felling operations, 1 TWhr from stem material unsuitable for pulping or sawing (due to rot) and 0.7 TWhr from thinning operations (Mr. Magnus Thor, SkogForsk pers. comm. June 02)

Approximately 40 companies (of varying size) in Sweden are involved in supplying biomass fuels to various small and large-scale customers. Sydved Energi, Naturbransle and SCA Skog are the dominant companies and supply bark and chips from sawmilling operations, forest chips from logging operations residues and clean ‘recycled wooden material’. Payments are based on ‘energy content’ (calorific value).

4.3 Forest Biofuel Harvesting Methods

Swedish biofuel harvesting has a summer seasonal bias, with forest residues extracted, covered and stored at roadside during drier periods. These residues are then processed during higher demand periods in winter, after a period of natural 'seasoning', which lowers the overall moisture content of the recovered residues and therefore increases the calorific content.

Harvesting activities are generally concentrated in two main regions namely:

- central Sweden, where the lower calorific value softwood residues are harvested;
- southern Sweden where hardwood species are predominant (see Figure 20). Such species are the preferred types for forest fuel chips, due to their higher calorific value.

Figure 20 Swedish hardwood (beech) forest thinning operation

All operations are totally mechanised and typified by innovative harvesting, processing and transport contractors. The average processing operation is 250-

400 m³ loose per work-site of mostly seasoned (dry) material. The processing methods (by %) are as follows:

- roadside chipping (80%)
- terrain (in-forest) 10%
- terminal (centralised) 10%.

Fully integrated harvesting systems have been developed to incorporate logging residue recovery methods in association with stem harvesting. Figure 21 shows the conventional harvesting methods and the newer residue recovery work patterns, where residues are placed in discrete piles or windrows.

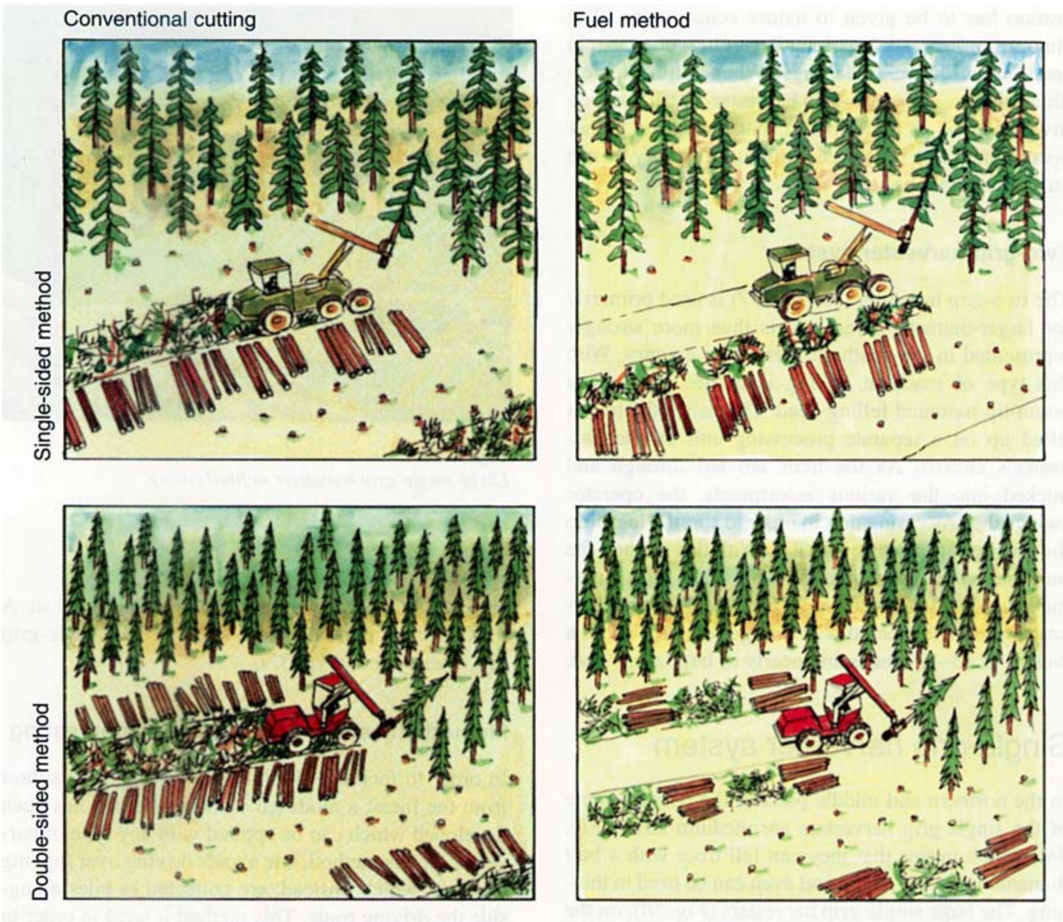

Figure 21 Conventional stem harvesting & integrated biofuel methods

After harvesting and removal of stemwood (logs), the residues are either extracted to roadside or processed at the stump. Figures 22-35 show examples of various Swedish biofuel harvesting methods.

Figure 22 Biofuel material prepared for extraction

Figure 23 Sydved Energi AB contractor extracting logging residue

Figure 24 In-forest chipping using Bruks 804 CT model chipper

Figure 25 Side view of Bruks 804 CT in-forest chipper

Figure 26 In-forest chipping of seasoned logging residue (Bruks 804 CT mounted on Timberjack 1410B forwarder)

Figure 27 Bruks chipper unloading material into pre-positioned bins

Figure 28 Southern Sweden beech (hardwood) forest thinning site

Figure 29 Hardwood tree-head material awaiting roadside processing

Figure 30 Purpose built chipper with 180º rotating cabin (mounted on a turntable) & rear storage bin

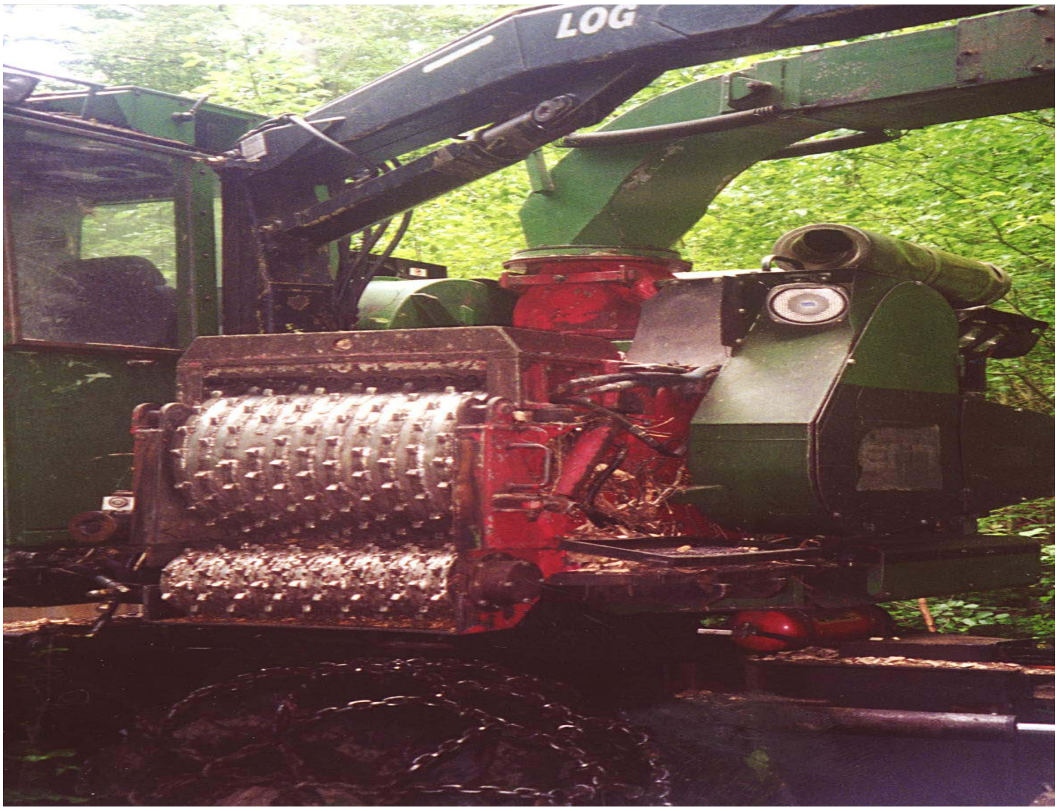

Figure 31 Close-up view of in-feed roller and drum chipper

Figure 32 Purpose-built chip bin forwarder (25 m³ capacity) with self-levelling capability

Figure 33 Demonstration of the capabilities of the self-levelling forwarder (bogies have a 130 cm travel range) (NB uphill wheels)

Figure 34 Roadside processing directly into chip bins using a remote controlled stationary chipper.

Figure 35 Close-up view of drum chipper powered by 500 HP motor

5. Denmark

5.1 Forestry Overview

Denmark has had a long and active reafforestation program, which has seen the forest area double in area over the past 100 years to 450,000 hectares (11% of the land mass) (Danish Centre for Biomass Technology 1999). A further two-fold increase is planned in the next century. There are approximately 20,000 forest properties throughout Denmark, of which 90% are less than 20 hectares in size. Private individuals own the majority of these properties (46%). The remainder are either state-owned (31%) or owned by foundation / associations (23%). Some 130 properties are larger than 500 ha and constitute 50% of the forested area. This fragmented ownership creates logistical challenges and requires very mobile harvesting and processing equipment.

No significant forest industry ownership occurs in Denmark, unlike Sweden or Finland and there are no pulp or paper mills. The sawmilling sector is well developed. However there is a limited capacity for conversion of lower grade or smaller stem material, thereby making the wood energy market an important outlet for material generated from silvicultural thinnings or storm salvage operations.

One third of the forest area consists of broad-leaved hardwoods and two-thirds are coniferous. The annual harvest volume is approximately 2 million m^3 of round logs (1/3 hardwood and 2/3 softwood).

5.2 Bioenergy Sector Overview

Denmark has developed a series of specific energy policies over the past three decades, originally in response to the 1970's oil crisis. The broad policy aims are:

- increased supply security by diversification of fuel types;
- increased emphasis on renewable fuels (biofuels, wind and solar);
- reduced consumption and environmental impact by co-generation, improved building insulation and cleaner fuels.

The current plan, 'Energy 21' has a stated target of increasing the use of biomass as an energy source from the current 60 Pentajoules (PJ) to 145 PJ in 2030. The increased use of forest chips and straw at centralised power plants will assist in progressing towards the stated goal (Danish Centre for Biomass Technology 1999).

Government intervention measures to assist achievement of this target include:

- 'central economy directives' which compels electricity utilities and district heating plants to use biofuels
- taxes on non-preferred fuels (i.e. fossil fuels)

5.3 Forest Biofuel Harvesting Methods

As mentioned, the fragmented nature of the Danish forest resources necessitates having highly organised and mobile harvesting, processing and transport contractors. The flat terrain and ground conditions favour 'in-forest / at stump' chipping. The average chipping operation is 500 m^3 loose. Work planning and production scheduling is critical to ensure peak efficiency.

Fuel woodchips are derived from the following sources;

- First and second thinning operations
- Conversion of over-mature stands or under-performing stands
- Storm or insect damaged stand harvesting
- Clearfelling residues (limbs and tree tops)

Woodchip moisture content must be reduced from 55% to approximately 40%, which improves calorific value. To achieve this reduction in moisture, trees are felled during summer to dry and allowed to dry prior to chipping in the following winter. ‘Needle-shed’, also occurs during the drying period, which allows nutrients to remain on-site. Payment for forest chips is based on ‘calorific value’ that is sampled upon delivery to the customer.

Two pre-dominant systems are used in Denmark namely 'in-forest' chipping (70%) and 'roadside' chipping (30%). Roadside chipping operations typically process clear-cutting logging residues and material generated from degraded or under-performing sites during forest re-establishment operations. Their configuration is similar to previously described operations.

A typical ‘in-forest’ Danish fuel woodchip production system is as follows:

- Selective thinning using a ‘feller-buncher’ that aligns the harvested stems to facilitate efficient chipping (production: 250 trees/hr)
- In-forest (at stump) chipping, using a self-propelled, front-fed disc chipper, equipped with a holding bin (approximate capacity: 15 m^3) (see Figure 36-37)
- Chip transfer (in the forest) to a specialised forwarder with a tipping container (See figure 38)
- Chip transfer (at roadside) to pre-positioned ‘truck containers’ (approximately 20 m^3 capacity) (See Figure 39)

The combined production of the chipper and forwarder is approximately 60-80 m^3 of chips/working hour. 90% of fuel woodchips are transported directly to the customers to avoid increased handling costs. Chip production is regulated on a seasonal basis i.e maximum production in winter during peak demand periods, minimal production during summer.

The productivity of biofuel chipping has been significantly improved over the past two decades from 40 man-minutes/tonne to 5 man-minutes/tonne due to the development of specialised machinery, operator training and delegation of responsibilities to the field operators (ie chipper operators and transport contractors) (Mr Ebbe Leer, Hededelskabet, pers comm. June 02)

At-stump cost allocation (in % terms) are felling (24%), chipping (24%), forwarding (14%), road transport (22%), stock costs (7%) and management (9%).

Figure 36 Terrain (in-forest) Silvatec CH 878 Disc Chipping Machine

Figure 37: Silvatec 878 processing fuel chips in a storm salvage operation

Figure 38 Chip transfer to forwarder for transportation to roadside

Figure 39 Flat-bed containers awaiting collection (normal truck payload: 60 m³, configuration 3 x 20 m³ bins)

6. United States of America

6.1 Bioenergy Sector Overview

In the USA today, the vast majority of biofuels produced are sourced predominantly from forestry operations that occur either on privately owned or federal forested land. Currently this section of the energy industry is under intense competition from the lower cost electricity generators whose fuel sources are based on fossil or nuclear fuels. The situation has been exacerbated in some instances by the uncertainty created by state deregulation particularly in California.

Despite the dominance of the traditional energy producers, interest in bioenergy continues to grow, driven in part by green advocacy groups. It is estimated that 3-5% of the currently generated electrical energy in the US could be derived from forest or forest product processing residues. In addition, potentially 7-20% of the US energy demand could be meet from biomass sources by the continued use of forest-based fuel sources and the expanded growth of specific agricultural ‘energy crops’ (Hughes 2000).

Many of the USA's bioenergy industries were established in response to the oil crisis in the 1970's. States with significant bioenergy capacity include Michigan, Vermont, Georgia, Alabama, North Carolina, Mississippi and California.

California’s bioenergy industry, despite being severely damaged by state policy decisions in the mid-1990’s, generates 600 MW/yr from some 30 plants state-wide and generates sufficient electricity for approximately 750,000 households (California Biomass Energy Alliance 1999). Fuel sources include urban waste (1.5 million t/yr), forest & processing residues (2.5 million t/yr) and agricultural waste, predominantly from orchards (1.0 million t/yr).

6.2 Forest Biofuel Harvesting Methods

6.2.1 Michigan Case Study: Lincoln Power Station

6.2.1.1 Plant Details

Located northwest of Saginaw, in the small rural town of Lincoln, this plant has operated since 1990 (see Figure 40). The plant owned by Tractebel Electricity & Gas International, annually produces 16.3 MWe (net), meeting the electricity demands of approximately 13,000 households. The plant classified as a 'base load' plant has a long term supply contract with a major Michigan electricity utility, Consumers Energy Company. Strict emission controls exist for the plant and a continuous emission monitoring system is designed to check emission levels on a continual basis. A three cell electrostatic precipitator is used to capture the by-product particulate matter.

Figure 40 Lincoln Power Station, Michigan (in operation at time of photo)

Average daily fuel consumption by the plant is 600 tons per day. The plant's primary fuel source is fuel woodchips, drawn from a 120-km radius supply zone. Secondary fuels include industrial wood waste (sawdust, edgings), recycled waste wood, hogged waste fuel, green urban waste and disused car tyres. Daily tyre chip usage is approximately 40 tonnes.

All delivered green material must average 44% moisture content, as determined by random sampling (which is conducted at the plant weighbridge). Payment is based on 'delivered green tons' and penalties are applied if the moisture content of the delivered chips exceed the required specification. Various other moisture specifications are required for the other secondary fuels such as sawmill residues hogged waste fuel, pelletised recycled paper and urban waste.

6.2.1.2 Harvesting Methods

The plant engages ninety contractors on various supply arrangements to meet the annual demands of the Lincoln plant and its sister plant located at McBain. Weekly supplies from these contractors range from 50 ton –1500 tons/week.

Currently, severe resource competition is occurring between pulp producers and biofuel users in this region due to a buoyant pulpwood market and limited supply zones. The major sources of fuel woodchips (both hardwood and softwood) are from 'tender' operations on private or state forests. These operations are 'fully-integrated', segregating sawlogs and producing chips suitable either for pulp production or for power station boiler firing.

Whole-tree chipping at roadside is the predominant processing method. Components for these systems include:

- Tree felling using a rubber-tyred 'feller-buncher', (eg HydroAx, John Deere 643D fitted with a 'hot saw') (see Figure 41).
- Tree-length grapple skidding using mid-sized skidders eg John Deere 748 (see Figure 42 for hardwood operations and Figure 43 for softwood operations);
- Roadside chip production using either Trelan 23L or Morbark machines, chipping directly into chip vans (See Figure 44-46)

Figure 41 Feller-buncher (John Deere 643) fitted with a 'hot saw'

Figure 42 Tree-length skidding using grapple skidders

Figure 43 Softwood 'tree-length' integrated harvesting (thinning operation)

Figure 44 Trelan 23L disc chipper, chipping directly into a chip bin

Figure 45 A close-up view showing angled chipper which assists 'log feed'

Figure 46 Logging residue awaiting processing after segregation of sawlog & pulpwood material

6.2.2 Vermont Case Study: McNeil Power Station

6.2.2.1 Plant Details

The McNeil Power Station in Burlington, Vermont, when built in 1984 for US$67 million, was the world's largest wood-fired plant and is still the largest U.S. wood-fired utility-owned facility (see Figure 46). The plant is jointly owned by the Burlington Electric Department (50%), the Central Vermont Public Service Authority (20%), the Vermont Power Supply Authority (19%) and the Green Mountain Power Corporation (11%).

The plant has a nominal capacity of 50 MWe and belongs to the New England Power Pool (NEPOOL). This membership limits the plant's operating capacity due to the NEPOOL's economic dispatch procedures, which requires all pool members to make electricity production price bids on a daily basis. Plants with a lower production cost (ie lower fuel costs) operate on a continuous basis, but McNeil's operation (which produces power in the mid-range of prices) is usually weather-dependent. This intermittent operating nature requires careful regulating of fuel supplies.

Figure 47 McNeil Power Station in operation, Burlington, Vermont

Whole-tree chips either from hardwood (60%) or softwood species (40%) provide 70% of the plant's fuel requirements. The chips are sourced from harvesting operations in low-quality secondary or storm damaged forests or derived from logging residues arising from integrated sawlog and pulpwood harvesting operations. Both federal and private lands are harvested. The remaining portion of the plant's wood requirements comes from sawmilling residues (sawdust, bark and chips) and processed urban waste.

6.2.2.2 Harvesting Methods

McNeil Power Station supply contractors mainly use whole-tree or logging residue chipping systems (see Figures 48-49). The supply zone is approximately a 100-km radius from the Swanton rail terminal, which is located 60 km north of Burlington. Operations occur in the states of Vermont and New York. Usage of the remote rail terminal at Swanton was a licence condition, imposed to reduce the amount of road transport movements within the city limits. The rail component of the freight system adds approximately 17% to the delivered fuel cost, due mostly to increased storage and handling costs. Delivered fuel costs typically range from $US 12-20 / tonne.

Burlington Electric Department employs four foresters to monitor the chipping operations to ensure compliance with state and federal forestry environmental regulations.

Figure 48 McNeil Power Station chipping contractor processing hardwood logging residues (predominantly tree limbs & tops)

Figure 49 Morbark stationary chipper, McNeil Power Station, Vermont

6.2.3 Californian Case Study: Honey Lake Power Station

6.2.3.1 Plant Details

Situated near Wendel, in the high desert region of northeastern California, the Honey Lake Power Station (HLPS) commenced operation in 1989 and produces 36 MWe per annum (see Figure 50). The plant uses heat from nearby subterranean geothermal wells and approximately 360,000 tonnes/yr of wood waste from forestry and sawmilling operations.

The plant produces steam from a travelling grate boiler and generates approximately 248,000 megawatt-hours of electricity annually. This is sold to the Pacific Gas and Electricity Company, one of the largest companies in the USA, under a 30-year contract.

Honey Lake Power Station has a deliberate policy of sourcing materials from a diverse range of suppliers to assist in obtaining competitive fuel prices. Sources include:

- Juniper thinnings (35%)
- Forest residues from thinning and logging operations (40%)
- Urban green waste (15%)
- Sawmilling residues (10%)

Figure 50 Honey Lake Power Station in full operation, NE California

6.2.3.2 Harvesting methods

Honey Lake Power Station fuel chips are generally processed at ‘roadside’ either from disc or drum chipping operations or tub grinding (the less preferred method due to poorer product quality and increased ash content). Examples of logging residue processing are shown in Figures 51-52. Fifty suppliers with various sized contracts and terms, supply material from an average supply zone of 70 kms.

Figure 51 Post-logging residues stockpiled for processing

Figure 52 Example of Trelan Disc Chipper in operation

Figure 53 shows a treated stand with the dead or dying material (termed ‘ladder fuels’ in reference to fire behaviour) and poorer formed stems removed. This type of silvicultural treatment is increasingly used on private lands (and potentially on government land) as a fire-mitigation strategy.

Figure 53 Example of a thinned stand, treated to remove poorer form stems and reduce fuel loadings

6.2.4 California Case Studies: Anderson Power Station

6.2.4.1 Plant Details

Anderson Power Station is located in the upper Sacramento Valley, 30 km south of the large regional centre of Redding. The plant commissioned in 1987 has a net output of 49 MWe/yr, produced from three independent boilers, fitted with travelling grate furnaces. The plant is part of the Wheelabrator Shasta Energy Company, an affiliate of the larger Wheelabrator Environmental Systems group.

Approximately 800,000 green tonnes (equivalent to 400,000 BDT) with an average moisture content of 50% are consumed annually, which equates to approximately 100 tonnes of fuel per operating hour. Fuel sources include sawmilling wastes (40%), orchard wastes from the nearby intensive horticultural industries (30%), forest chips (20%) and miscellaneous sources (10%), including urban waste and disused railway sleepers. The plant receives approximately 100-truck deliveries/day on a year-round basis. Figure 54 shows an aerial view of the plant and Figure 55 shows the twin-reclaim conveyors and fuel stockpiles.

Figure 54 Aerial view of Anderson Power Station (log yard in foreground)

Figure 55 View of the Anderson plant's fuel stockpile. Twin reclaim lines continuously overfeed the plant's 3 boilers

6.2.4.2 Harvesting Methods

Anderson Power Station has over 125 full-time contractors involved in harvesting, processing and transporting the biofuels. Its annual fuel purchasing budget exceeds $US20 million/year.

Forest biofuel harvesting methods are similar to those used by other Californian plants, include wheeled feller-bunchers, grapple skidders and dedicated disc or drum chippers. Most chipping is down at 'roadside' either of post-logging material or from silvicultural thinning operations, designed to reduce forest fuel loads and improve the stand quality (see Figures 56-59).

Figure 56 Purpose-built feller-buncher fitted with hot-saw (Wolverine).

Figure 57 Whole-tree chipping of poor-form pine on private land near Redding.

Figure 58 Close-up view of dedicated chipper in operation.

Figure 59 Whole tree chips are blown directly into chip bin for transport to Anderson Power Station.

Figures 60-61 show tub grinding of delivered urban waste, which contributes approximately 10% of the plant's intake. This waste although cheaper than fuel chips to produce, is considered an inferior product due to increased contaminates (dirt) and its higher ash content.

Figure 60 Tub grinding urban waste at Anderson Power Station

Figure 61 Loader feeding tub grinder. Material is fed onto secondary reclaim chain for delivery to the main stockpile.

7. Summary

7.1 Study Tour Outcomes

The study tour provided the opportunity to:

- inspect 'state to the art' harvesting, processing and transport systems, concentrating on those most applicable to Australian wet sclerophyll forests;
- discuss confidential financial and economical aspects of biofuel processing across a range of countries, sites and methods;
- create a valuable international ‘contact network' with key personnel within research organisations, forestry agencies, harvesting, processing and haulage contracting services and machinery manufacturers and suppliers.

A wide range of processing options were observed during the study tour with ‘roadside processing’ of smaller material appearing to be the most promising option for Tasmania, as used in Sweden and America, to take advantage of ‘natural seasoning' to reduce fuel moisture content.

Preferred transportation options were mainly in ‘chip-form’ either in ‘dedicated chip-vans’ (USA) or modular ‘containers’ (3 x 20 m^3 bins, throughout Scandinavia, where larger payloads were permitted). Delivery destinations varied from directly to customers (of varying sizes) or to storage terminals (located either at in-forest sites or away from urban areas, where power plants tend to have limited site storage capacities).

7.2 Recommendations

Following the inspections and discussions throughout Scandinavia and America the following recommendations are made:

- A wide range of Scandinavian biofuel harvesting systems would be suitable for harvesting softwood forest harvesting residues on reasonable terrain. Such applicable systems would include the efficient Danish ‘terrain chipping’ machinery, traditional Swedish ‘at roadside’ processing methods or the new sophisticated Finnish Timberjack bundling system. Detailed investigations would be necessary however to determine residual volumes on typical Australian softwood sites. Production rates would be similar due to the similar nature of the biofuel and cost-comparisons could be readily drawn to indicate the viability of such operations.

- American ‘whole-tree’ systems and ‘logging residue processing’ systems, which tend to be more robust in construction, would be appropriate for a wide range of Australian hardwood logging operations. This recommendation is based on the variability of piece size, form and terrain encountered on a typical Australian and American hardwood logging operation.
- Efficient transport logistics are essential where multiple chipping sites are operating and multiple customers are being supplied. Careful consideration must be given to the complete supply chain if forestry agencies are contemplating biomass harvesting.
- Based on anecdotal discussions with fuel supply managers at several power stations it is imperative to quantify and secure the available biofuel resource prior to establishing wood-fired power stations. Several stations that were visited during the fellowship, that were originally designed to be fuelled on forest-based chips on a long-term basis, were forced to find new fuel sources when supply and access circumstances altered.
- Siting of a wood-fired power station should be as close to fuel source as practically possible to optimise transport logistics and assist in economical aspects of biofuel delivery.
- The critical limits of fuel moisture content must be determined before entering into long term supply contracts as moisture content can be a significant ‘variable’, depending on the other fuels used, boiler design and the power plant's output.

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