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SUSTAINABILITY AND OPERATIONAL ASPECTS OF FOREST BIOMASS HARVESTING FOR ENERGY IN SCANDINAVIA

JORGE RAMOS

2009 GOTTSTEIN FELLOWSHIP REPORT

Joseph William Gottstein Memorial Trust Fund

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are:

1. Fellowships and Awards - each year applications are invited from eligible candidates to submit a study programme in an area considered of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their programme. These are then distributed to industry if appropriate. Skill Advancement Awards recognise the potential of persons working in the industry to improve their work skills and so advance their career prospects. It takes the form of a monetary grant.

2. Seminars - the information gained by Fellows is often best disseminated by seminars as well as through the written reports.

3. Wood Science Courses - at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.

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EXECUTIVE SUMMARY

This report documents a 5 week study tour in Sweden, Finland and Denmark on sustainability and operational aspects of forest biomass harvesting for energy generation. It describes partnerships between forest owners and local governments, sustainable criteria for forest residue harvesting, planning procedures and chain supply recommendations.

The information was gathered from field visits to harvesting sites, visits to bioenergy plants, personal communication with foresters, environmentalists and researchers, attendance at the Elmia Wood Slash Conference, and participation in a Sustainable Bioenergy Production workshop. This workshop, which was part of the Baltic Bioenergy Project organised by the Swedish Forestry Agency, provided valuable information about the process of setting potential indicators, which can be used to monitor sustainable harvesting of forest biomass. In addition, a visit to the Finnish office of the Programme for the Endorsement of Forest Certification (PEFC), and field visits to Southern Finland and Denmark, provided an insight into technical and environmental aspects of harvesting, including stump removal and thinning of young stands.

As in Australia, Nordic countries have developed guidelines for sustainable harvesting of sawlogs, pulp and to some extent forest residues. However, the view of experts involved in forest management and sustainability in Scandinavia is that intensification of forest residue harvesting warrants specific operational guidelines. These guidelines are aimed at reducing the risk of environmental damage as well as ensuring that future forest growth is not compromised. This is a work in progress, as gaps in knowledge about the long term effects of intensified forest biomass harvesting, including stump harvesting and whole tree harvesting, are yet to be filled.

The focus in Scandinavia is on the assertion that use of forest biomass for energy generation should result in less greenhouse gas (GHG) emissions than the fossil fuel energy systems that they are replacing. The challenge is the production efficiency of bioenergy systems and the energy consumed producing, procuring and delivering the biofuel. The idea is that reductions in GHG emissions can be further achieved through innovation and efficient use of energy and resources throughout the whole production chain. The use of life cycle assessments is seen as one of the best tools to monitor progress in this area.

The report also makes reference to governmental instruments supporting silvicultural management coupled with renewable energy production. The Finnish Act on Financing Sustainable Forestry is a good example of measures that favour harvesting of energy wood and tending of young forest stands.

The main recommendations from this study make reference to harvesting of residues from Australian planted forests. These are:

- The creation of a forest biomass energy working group spearheaded by the forest industry
- The assessment of potential partnerships between forest owners, energy generators and local councils.
- Use of life cycle assessments or a carbon footprint to monitor GHG emissions from land use change and whole supply chain of forest biomass harvesting.
- The introduction of sustainability criteria specific to forest biomass harvesting and the establishment of site specific volume thresholds recommended for harvesting.

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UNITS OF MEASUREMENT

Distance and Area
m = metre
km = kilometre (1,000m)
m^2 = square metre
m^3 = cubic metre
ha = hectare (10,000m^2)

Weight
kg = kilogram
t = tonne (1,000 kg)

Energy
W = watt
kW = Kilowatt (1,000 watts)
MW = Megawatt (1,000,000 watts)
GW = Gigawatt (10^9 watts)
TW = Terawatt (10^{12} watts)
Wh = Watt hour
J = Joule (3,600 Wh)
PJ = Petajoule (10^{15} Joules)

Greenhouse Gases
CO_2 = Carbon dioxide
SO_2 = Sulphur dioxide
NOx = Nitrogen oxide

Currency Abbreviations
€ = Euro
SEK = Swedish Kronor
DKK = Danish Kroner
A$ = Australian Dollars

1. INTRODUCTION

The new binding target of the European Union (EU) is a 20% share of renewable energy source in energy consumption and a 10% minimum for biofuel use in transport by 2020. With large forested areas, the greatest potential for Nordic countries to increase renewable energy production and achieve these goals lies in forest biomass.

As in Australia; Scandinavian countries face two major challenges from intensified harvesting of forest biomass: a) The need to reduce cost on delivery of biomass at final destination and b) The need to ensure environmental aspects resulting from biomass harvesting are protected and long term forest productivity is not negatively impacted. To address these concerns, resources have been allocated to the development of cost efficient harvesting systems, planning tools, the creation of business partnerships between forest owners and municipalities and the design of policies and legislation that promote use of low value timber for energy generation while promoting sound silvicultural management.

From a sustainability point of view the focus has been the introduction of instruments such as harvesting guidelines, best management practices for biomass harvesting and modifications to existing certification standards. Besides soil, biodiversity and water protection, proposed new criteria on biomass use incorporates targets on reductions of net GHG emissions from fossil fuel substitution in energy generation. There are also provisions for monitoring of emissions from land use change. A number of initiatives aim to develop criteria on general biomass use; some at international level such as the Sustainable Bioenergy Production in the Baltic Region. Others are directed at forest sustainability and are country specific; such as PEFC in Finland, where the recently revised certification standard now includes a criteria on energy from forest biomass.

The number of wood energy related activities in Australia is on the rise. Examples of this include new co-generation plants in Northern NSW, a new pellet manufacturing plant in WA and plans for installation of similar manufacturing plants in the green triangle in Victoria and South Australia.

Residues from harvesting of plantations in Australia are significant. It is estimated 2 million tonnes of residues a year result from harvesting operations (NAFI. 2008), with the potential to generate up to 220 MW. This would signify a reduction in CO_2 emissions in the order of 1.5 million tonnes per year.

Currently, forest residues must be managed at the harvesting site, through expensive silvicultural treatments such as rough stacking and burning to allow for re-establishment and reduce fire risk. Alternatively, some of this material could be used for energy generation thus contributing to national and state targets for renewable energy production, while simultaneously reducing costs of plantation re-establishment. However, as in Nordic countries there is a pressing need to ensure that intensified harvesting operations do not result in increased carbon emissions, losses of nutrients or soil damage that are likely to impact future forest growth.

2. SWEDEN

2.1 Forestry Synopsis

The current annual timber growth of Swedish forests is more than 106 million m^3 with annual harvesting of about 90 million m^3. With an estimated potential of 45 million m^3 of wood for energy generation, it does not come as a surprise that 20% of all energy consumed in Sweden comes from fire wood (the total energy consumption from all renewable sources is 26%). With a net use of 6.2 million m^3 of wood per year, Sweden's approach to energy production is varied in size. One example of larger plants is the new combined heat and power (CHP) plant at Igelsta in Södertälje, which will commence operations in 2010, supplying the grid with 200 MW of heat and 85 MW of electricity, and consuming 200,000 tonnes of biomass per year. On the other side of the spectrum are small plants (0.5 MW to 2 MW) scattered across the country under the umbrella of municipal programs such as the "Heating Kronoberg" project in the Kronoberg and Kalmar regions.

One significant characteristic of Swedish forestry is the large proportion of private forests owned by the public (about 50%) with a strong presence of associations such as Södra. With its origins dating back to 1938, this association became one of the largest of its kind in Scandinavia, with more than 50,000 members owning 2.5 million ha of forest. The primary role upon its creation was to organise cooperation among its members and provide them with advice on forest management. Today the association is one of the largest industry owners in Sweden. In all there are 350,000 private forest owners in Sweden with holdings averaging 50 ha while the government owns only 18% of the productive forests. The role of the forest associations is to rationalise the use of the forest, facilitate forest management, improve forest owners' knowledge, and above all protect the financial interest of its members.

The government's forest management policies are administered by the Swedish National Board of Forestry (Skogsstyrelsen). The goal is to promote the multiple use of the forest through recreation, hunting, gathering of berries and mushrooms and sustainable timber production. In the past, less sound practices have been used in Sweden. In the late 20s, silvicultural management encompassed selective harvesting, which created large areas of middle age stands with poor growth. Clear cutting took place in the 40s and 50s and large replanting programs in the 70s.

The 70s also saw a heated debate on use of herbicides and insecticides in forestry activities, which caused major disagreements between foresters and environmentalists. The situation improved through a series of discussions between the two sides, which resulted in some changes to the criticised practices, including the replacement of herbicides for mechanical weed control. This measure, although expensive to the forestry sector had a positive effect on public opinion and public relations (Hamilton. 2004). Nowadays however; environmental organisations such as the World Wildlife Fund (WWF) question whether current measures in place have the scope to address the environmental impact of intensified biomass harvesting activities.

2.2 Biomass Harvesting

The main harvesting activities observed during the Swedish leg of the trip were harvesting of stumps, residues collection and thinning of small diameter trees in younger stands.

2.2.1 Residues Harvesting

In Sweden, tops and branches are harvested in an integrated manner with sawlogs. Other woodfuel harvested includes decaying and un-merchantable timber. Non-integrated harvesting of residues is rare in Sweden, as is whole tree harvesting.

Primary harvesting systems used in Sweden include:

1. Piling on site and bundling. The residues are baled using a bundler (Figures 19 and 20 show a 828 Combi Pinox 100) and then transported to road side for haulage and delivery to the customer. The bundling system eliminates comminution on site or at road side as chipping is done at the terminal or energy plant.
2. Extraction at road side
3. Pilling on cut over site

The process for these two systems is:

- ***Planning:*** Information on available residual volumes, costing, environmental and cultural restrictions, operational licences, and land future management is compiled and processed.
- ***Harvesting:*** Trees are harvested and de-limbed. Logs, branches and tops are accumulated in separate piles at both sides of the operating strip.
- ***Piling and Seasonal drying:*** This is done at the logging site which is the preferred option, as the drying time is shorter than at road-side because of the larger piles required and the limitations with space. Residues forwarded for road side drying are gathered in a continuous pile of 5m in height by 4m wide covered with a mat that prevents excessive humidity absorption. The drying time ranges from 3 to 18 months. In sites where integrated harvesting of pulp and energy wood takes place, the operator decides where to pile up the material ensuring differentiation of the two products (pulp and energy wood) by using diameter as the main factor.
- ***Wood-chipping:*** Ideally, wood chips will be deposited on a mat for truck collection using a loader. This procedure provides some flexibility on timing of material collection. Another alternative is to woodchip and deposit the material in woodchip containers (Figure 8), that will be collected by a truck. This option will require extreme coordination between loaders and trucks and might result in time wasted if the truck is late or the containers are not available. Even more desirable is the use of a truck with an integrated woodchipper and container (Ms. Å Ohman. Pers. comm. Enköping. 5/06/09).

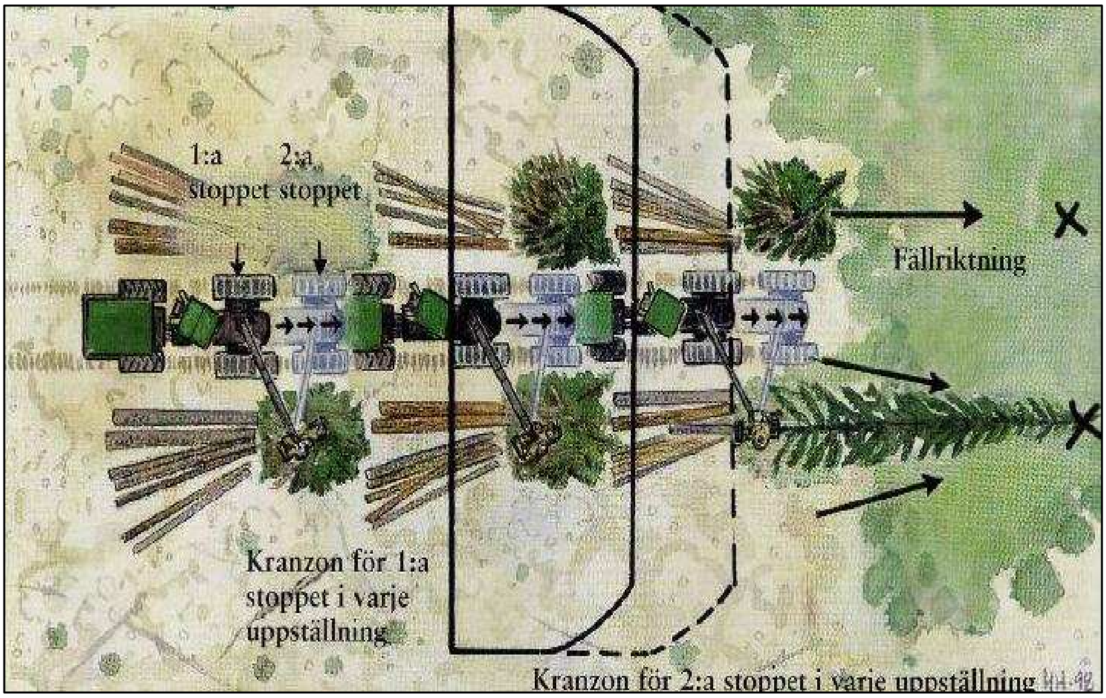

Figure 1.Example of integration of sawlog and forests residues harvesting in Sweden. (Source: Johannesson. 2009. Skogsfork)

Characteristics of integration:

- Felling direction of trees in the direction of the harvester rather that in perpendicular direction to the machine
- 1-3 stops at each heap
- Logs and residues in separate heaps

2.2.2 Stump Harvesting

Sweden has seen a reduction in sawlog and pulp demand as a result of the financial downturn. By contrast markets for forest fuels are increasing. During the first quarter of 2009 the prices of pulpwood fell by 6% compared to the previous quarter, with an increase in demand for residual material and pulp diverted to energy generation (Wood News. June 09). Increased demand on forest fuels, as well as cost benefits in site preparation and the availability of the resource has stimulated harvesting of stumps. It is estimated averages of 50 tonnes of stumps/ha (approximately 150 m^3/ha) with diameters of up to 60 cm are being harvested. It is expected that the area harvested for stumps will increase from 1,500 ha in 2008, up to 20,000 ha in 2 years. This volume will be reviewed in 2013 (Swedish Forests Agency 2009 -1).

Harvesting of stumps is an activity usually associated with regeneration activities and/or site preparation for replanting (Figure 2.) -as observed in Laxa, where 150 ha where being harvested by Sveaskog. The process consists of uprooting and splitting the stump using the head harvesting systems described below. The stumps are then piled into small heaps where wind, sun and rain wash away soil particles. Once the seasonal drying is completed the stumps are forwarded to the roadside and then transported to the plant – typically a large CHP plant with the capacity to use different fuel sizes - where comminution takes place. The harvesting of stumps eliminates the need of ripping during site preparation. The new seedlings can instead be planted by hand on the edge of the area where the tree once stood (Mr. M Karlsson. Pers. comm. Laxa 8/06/09).

2.2.2.1 Types of Stump Harvesters

As the interest in stump harvesting increases, new harvesting heads are being developed with special emphasis on increased yield productivity and reduction of soil disturbance. Some of the modifications observed included:

- The extractor finger type (Figure 3.): This system consists of 2 parallel curved metal pieces and a curved opposite blade used to split the stumps if required. The stump is pulled from the ground and then through vibration, soil is released from roots. In addition the head has a tool that can be used to facilitate site preparation for new plantings. Appropriate machines to mount the heads are excavators of 18 to 25 tonnes.

- Combination of axe and extractor (Figure 4): This head consists of a grapple with shaped fingers or teeth that allows for easier splitting of stumps. This system allows for a cleaner extraction, and also the harvesting head has a vibration absorption system that makes its operation smoother when shaking excess soil from the root system.

- Rotary stump cutter prototype: The stump cutter is a cylinder of 70 cm in diameter with cutter teeth incorporated in its lower edge. With this technique the wood core of the stump is cut and lifted out of the ground. One drawback is the extreme friction of the cylinder against soil and the lower yield that can be harvested when compared to the other 2 systems. However, the impact on soil disturbance is less extreme than with the other 2 systems (Hofsten and Norden. 2007). It might be the less soil disruptive of all.

Figure 2. Stump Harvesting in Laxa, Sweden.

Figure 3. Detail of Stump Lifting Head

Figure 4.Combination Axe and Extractor Stump Lifter

2.2.2.2 Stump Harvesting Sustainability Aspects

The benefits of stump harvesting are represented by saving factors on regeneration where scarification is needed, soil preparation, and the financial benefits derived from good quality fuel (apparently less water is absorbed in stumps than in logging residues during the seasonal drying process). There are also additional advantages from stump harvesting through prevention of tree diseases spreading from stump rot in the next rotation (Mr. M Karlson. Pers. comm Laxa 8/06/09).

On the other hand, stump harvesting is an activity likely to cause significant soil disturbance effects. Of concern are impacts on water courses, biodiversity, physical soil properties, mobility of toxic substances including heavy metals, soil nutrients, soil erosion and carbon losses. Good practice recommendations on stump harvesting have been drafted by the Swedish Forestry Agency – some of them still subject to future revision pending research being conducted.

These recommendations include:

- Species: Only conifers are to be harvested
- Material left on site: 15-25% of stumps/ha should be left on site to reduce productivity losses
- Topography: No harvesting on slopes greater than 20 degrees
- Soil types: Operation on soils with high humidity content should be avoided. Harvesting in soils with low fertility is likely to be even further affected, especially those where needles and tops have also been harvested.
- Soil carbon losses: The expectation is that soils rich in organic matter might have higher decomposition rates and therefore greater carbon losses.

2.3 Ash Recycling

In Sweden about 300,000 tonnes of ashes from CHP operations are generated every year; and from this quantity 50,000 tonnes are processed and dispersed in forest soils. The remaining volume goes to landfill (Dr. G Thelin. Pers. Comm. Jonköping.1/06/09).

An increasingly common activity in forest management in Sweden is compensation of nutrient exports resulting from harvesting operations. Nutrient balance is achieved by spreading ashes from combustion of wood chips combined with nitrogen when required. Although voluntary, this activity is recommended by Skogsstyrelsen. Ash recycling is conducted in areas where tops and branches have been harvested or where needle shed is prevented or large quantities of biomass are exported, as is the case in integrated logging residues and stump harvesting.

2.3.1. Ash Processing and Application

Askungen Vital AB is a company based in the Jonköping area; specialising in management of ashes resulting from biomass combustion. The process was explained as follows during a field visit to one of its operations (Mr. B Pederson. Pers. Comm. Jonköping 1/06/09): The company signs an agreement with energy generators to take care of the material at one of Askungen's landfills, where ashes are stored for about 3 months to harden and reduce their alkalinity.

Once the ashes are hardened, they are crushed and sieved to an optimum particle size (Figure 6). Prior to its transportation and application, the ashes are tested to ensure they meet the standards set by Skogsstyrelsen (see below). Once the test is performed and compliance confirmed, the ashes are transported to the forests and dispersion takes place using an ash spreader (F9 Rottne) which is a forwarder specially modified with a couple of rotational disks to allow effective distribution (Figure 5). The typical amount of ashes applied is 3-4 tonnes/ha.

Figure 5 Modified Rottne Forwarder Used for Ash Application. Jonköping, Sweden.

2.3.2 Environmental Aspects of Ash Recycling

According to Skogsstyrelsen; nutrient compensation is not required in post thinning operations as there is likely to be enough branches and needles to still ensure acceptable nutrient levels. There is also the risk of damage to the remaining trees. However, for clearfells, ashes are required or at least recommended. Some best practice guidelines have been drafted by this organisation on the following:

- Origin: Ashes must be from forest fuel and not treated timber
- Pre treatment: Ashes need to be treated to prevent mechanical damage to trees, soil and vegetation. The use of a hardening process and mechanical treatments (sieving) will result in a particle size that will dissolve gradually.
- Stability: Only stabilised (physically and chemically) ashes that take a long time to dissolve are to be used. Stabilised ashes are considered those in pellet form or self hardened ashes (Figure 6). Ashes that dissolve rapidly (more unstable) should not be applied 5 years prior to a clearfell or 5 years after the clearfell has taken place.
- Spreading: Even dispersion of ashes in the field should be favored.
- Chemical concentrations: The quantity of heavy metals, micronutrients and trace elements returned during a rotation should not exceed the quantity removed during the same period. Acceptable limits on concentrations have been established in accordance with the previous dominant species. It is evident that some of these recommendations are not prescriptive measures and that its implementation will depend upon the characteristics of the area where the ashes are being returned.

Figure 6. Close up of Ash Pellet used in Compensation Fertilisation

2.4 WWF's Position on Intensified Biomass Harvesting

WWF does not oppose the use of forest biomass for energy generation, on the contrary it sees this activity as part of a solution to a more GHG neutral Swedish society. However, the position of this organisation is that more needs to be done to manage the impacts of activities that involve more than just sawlog and residue harvesting.

Perhaps the most contentious harvesting activity in WWF's view is regeneration felling with extraction of harvest residues followed by stump extraction. This type of harvesting involves all of the following activities at a given site:

- Tree felling with harvester
- Extraction of timber with forwarder
- Extraction of harvest residues with forwarder
- Stump extraction with excavator
- Stump removal with forwarder
- Mechanical site preparation (where required)
- Possible protective ditching

According to WWF the potential soil damage and sedimentation resulting from multiple "passes" of machinery to harvest timber at different stages has been underestimated by the forest industry. There are also concerns about the long term landscape impact resulting from intensified operations, carbon emissions from harvesting of stumps and habitat losses for some rare species of insects and fungi that live in decomposing stumps.

To address the associated risk of intensified harvesting in Sweden WWF suggests the following:

- Gaps in knowledge regarding the accumulated effects of intensified harvesting operations at landscape level need to be filled. Also, lack of knowledge on compensatory measures need to be addressed. The forestry sector, together with researchers and other interested parties, should coordinate their activities in order to obtain more information about the environmental effects of forestry and stump extraction at stand and landscape level.
- Emissions of GHG need to be established. A full LCA needs to be conducted for stump harvesting activities. There is not enough information on how much of the stump wood is transformed to soil carbon.
- WWF considers that it is necessary to have reinforced environmental considerations close to watercourses in connection with stump extraction, and sees the need for clear regulations for this.
- The limit of the diameter of stumps which is relevant from an economic perspective as regards stump extraction is stated to be 15-20 cm. There are concerns that harvesting of smaller diameters will occur if higher prices make it profitable to extract smaller stumps. A clear delimitation is needed in respect to what stumps can be extracted and where they may be harvested from, based on what the environment and the biological diversity can tolerate. (Mr. P. Roberntz. Pers. Comm. 24/09/09)

2.5 Recent Developments in Biomass Harvesting

There is approximately 1 million ha of forest in Sweden, with stocking of up to 10,000 stems/ha and maximum volume of 0.05 m^3/tree. These areas – or "conflict stands" as they are referred to - have an annual energy potential of 10 TWh/year (Iwarsson. 2009). As a result of the low prices for pulp, the need to manage dense stands, and increased demand of wood for energy, first thinning harvesting is becoming an important source of feedstock. Increased markets for wood energy have provided forest owners with the possibility of conducting pre-commercial thinnings with revenues of up to SEK 350/m^3 (A$ 58/m^3).

- The need to improve harvesting times and reduce handling costs of stems has seen the introduction of a "bouquet system" which enables collection of up to 7 small trees at once or a single tree of up to 30 cm in diameter. The multi stem handling harvesting machine observed in Laxa, the 560 C Ecolog harvester (Figure 7), is fitted with a small head harvester and a 12m arm that can yield up to 45m^3/day or 1 ha/day (Mr. M Karlson. Pers. comm Laxa 8/06/09). This development is seen as a major efficiency improvement when compared to previous systems that were able to hold only 1 harvested tree at a time. Typically the new harvesting heads consist of a cutting equipment guillotine, circular saw blades or saw swords. The next phase of development in harvesting machines is likely to involve the development of harvesters that facilitate continuous harvest and accumulation of stems in the harvester (Iwarsson. 2009).

Figure 7. Multi Stem Harvester 560 C Ecolog Used in Thinning of Young Stands.

Figure 8. Road side chipping: Container being filled for Collection.

2.6 Regional Bioenergy Initiatives

A number of actions aimed to reduce reliance on fossil fuels have been implemented in Southern Sweden since the early 1980s. The strategy used is a combination of strategies on changed behaviour, energy and transport efficiency and increased use of renewable energy. In this region for instance, heating from oil and electricity is being replaced by district heating based on biofuels with significant consumption of wood energy. A couple of examples are included below.

2.6.1 The City of Växjö Experience

Contrary to fossil fuel energy generation where the idea of large plants dominates; bioenergy systems and the optimum size of energy plants depends on the availability of resources. Moreover, rather than setting large plants, bioenergy systems should be based on a number of small plants strategically located in accordance to the available resource (Pr. B Zethraeus, Pers. comm. Växjö 28/05/09).

One such example is the fossil fuel free program "The Heating Kronoberg" (NHK), established in 1996 in the regions of Kronoberg and Kalmar. This program covers 20 municipalities and more than 35 small CHP Plants, totaling about 130MW in a region with a population of 420,000 inhabitants. The goal of the project is to reach a maximum $C0_2$ footprint per capita of 3 tonnes (2.3 tonnes/person in Växjö). To put this into context, $C0_2$ emissions per capita in Australia are in the order of 20 tonnes (Maplecroft. 2009).

Similarly, a fossil fuel free program has now been set up in the city of Växjö. It seemed that all the factors to make the project a successful venture came together: Policy and local initiative through a carbon target which is driven by a government carbon tax, the “know-how” provided by the University of Växjö, and the financial input from the private industry and government which invested €45,000,000 in this project.

The initiative was spearheaded by the creation of a consortium of 7 companies, which included Södra (Sweden’s largest forest owner’s association) and Växjö Energy. This consortium in turn appointed a technical committee; the “Bioenergy Group”, coordinated by the University of Växjö. The role of the Bioenergy Group was -and still is- to provide technical advice and identify and prioritise bioenergy R&D projects.

Another factor which contributed to the success of this project was the need for energy (heat in this case), and also the significant availability of biomass. The forest cover in the region is 60%, which provides about 300,000 m^3 of green wood that is used every year to generate power. Typically the plants generate between 0.75 MW and 3.5 MW each using a combination of woodchips; briquettes and pellets.

The plant visited in Ingelstad (Figures 9 and 10) generates 1 MW of thermal output from woodchips and is remotely operated. It is estimated that the project creates 1 job/2000 MWh/year (from pellets) and 1 job/3000 MWh/year (from woodchips) (Energykontor.nd). At this stage no consideration is given to energy crops due to the abundance of wood material, and also partly in response to the debate on land use change, and resistance to reduction of the availability of arable land for food production.

Figure 9. Ingelstad Plant, Storage Section.

Figure 10. Ingelstad 1 MW Thermal Output Plant near Växjö.

2.6.2 The Enköping Plant (Energi AB)

Another good example of collaborative arrangements between forestry entrepreneurs, farmers, energy generators, local councils and communities was observed in a visit to Energi AB (ENA), in the city of Enköping.

The CHP ENA biomass plant (Figure 11) has an output of 250 GWh of heat and 100 GWh of electricity serving 12,000 households throughout a 100 km pipe distribution network. A fuel mix of about 400,000 m^3 of wood residues including saw dust (15%), branches (15%), tops (50%) and bark (20%) procured by Naturbränsle (distinctive roles of the participants are summarised in Table 1).

In contrast to the NHK project where energy crops are not included, 15% of the total fuel used by ENA comes from 2000 ha of *Salix* planted within the municipality. These plantations provide the required feedstock on a 4 to 5 year crop rotation basis with productions of up to 5 tonnes/ha/year.

Organisation	Role	Responsibilty
ENA Energy	Energy Generator	Ash treatment and analysis
Agroenergi Cooperative	Farmers cooperative	Salix cultivation, ash transport and dispersal
Mellanskog	Forest owners association	Provision of forest residues
Naturbränsle (25% owned by Mellanskog)	Forestry contractor	Forest residues procurement and salix chip production
Swedish University of Agricultural Sciences (SLU)	Researcher	Soil analysis in respect to ash application
Enköping municipality	Local Government	Sludge treatment and irrigation

Table 1. Energy Cycle Model - Enköping Participants.

Figure 11. ENA Co-generation Heat and Power Plant, Enköping.

2.6.2.1 The Bio-cycle

The model used by ENA is based on a clean production "cycle concept" where forest residues and *Salix* chips are harvested as fuels (Figure 12). To compensate for nutrient losses, the fly-ash generated at the plant is dispersed in the forest where the wood is harvested and the bottom ash is mixed with the city's sludge-water and applied to the energy crops (Figure 13).

The requirements for crop fertilisation, and the need to eliminate the deposition of nitrogen and phosphorous from waste water into the Enköping River and Lake Mälaren, opened the door for a collaboration between the Enköping Council, ENA and Agroenergi cooperative through a program called the "Nynas Project". The project started with 150 ha of *Salix* and is expanding (Figure 14.). Crops are located next to the city's waste water treatment plant which comprises 3 sludge ponds and a 350 km irrigation system. The production process allows application of 300 kilos of nitrogen /ha/ year.

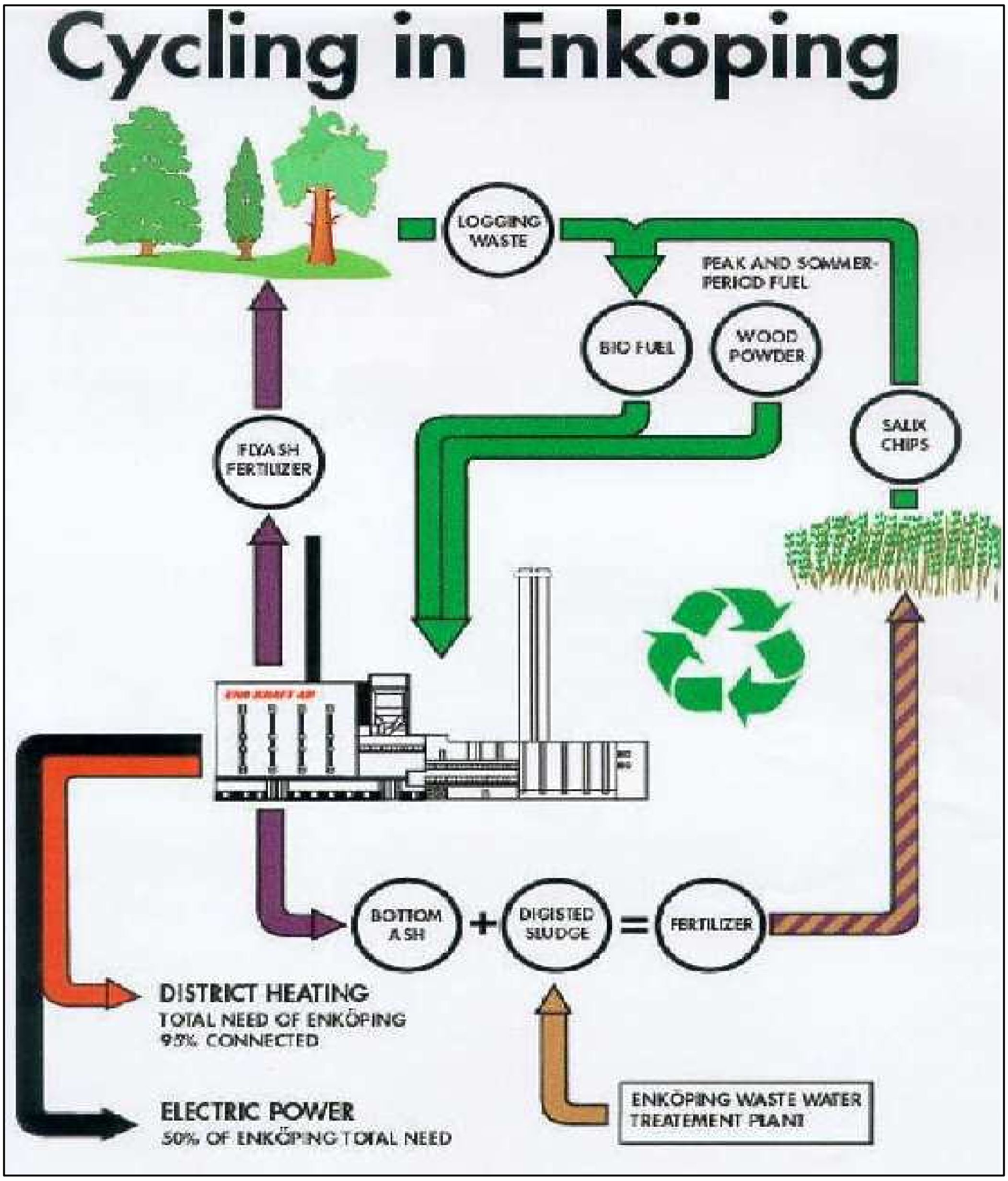

Figure 12. Energy Cycle in Enköping (ENA 2009).

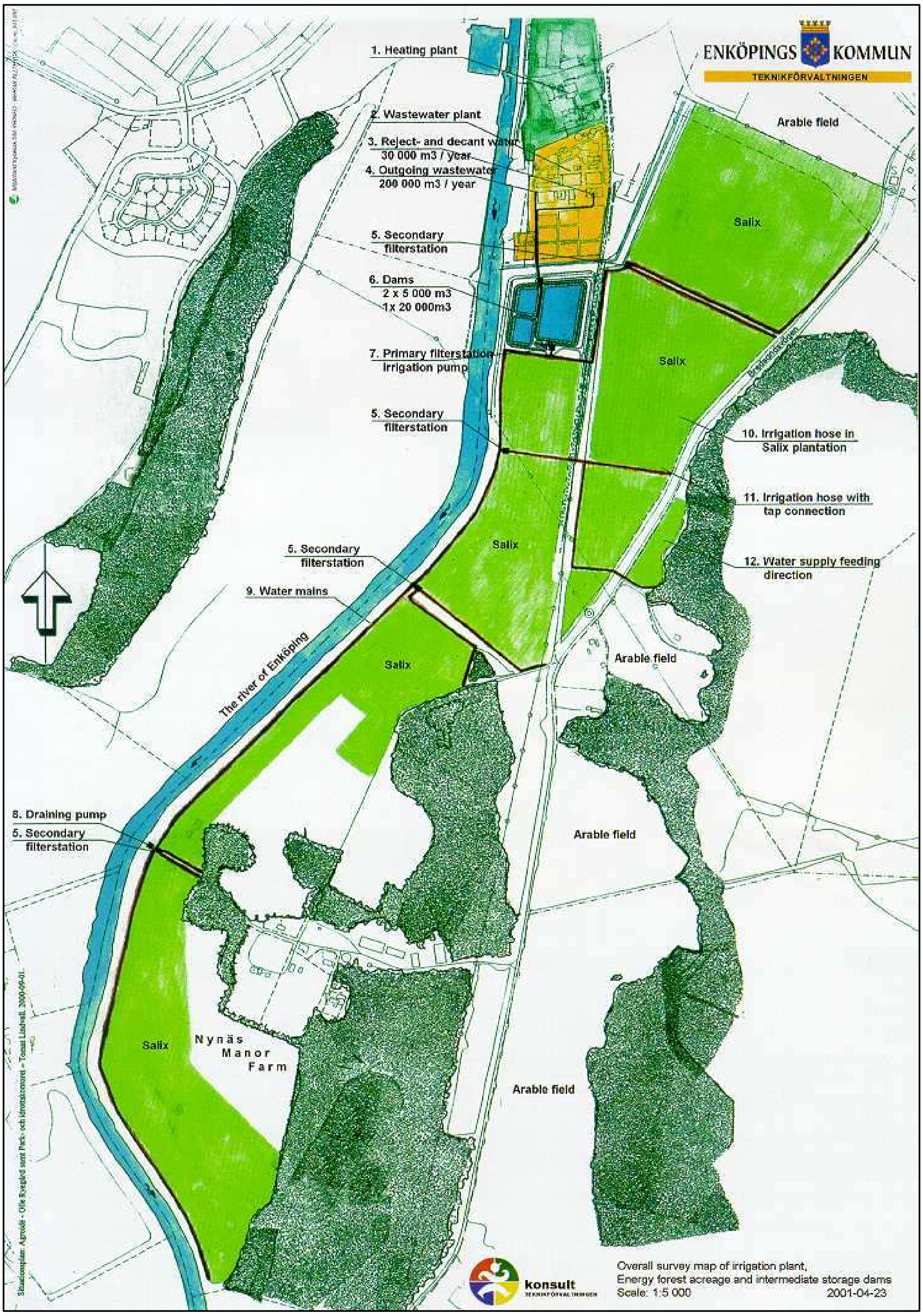

Figure 13. Layout of Salix plantations and sludge treatment system –Nynäs Project (ENA 2009).

Figure 14. Energy Crop “Nynas Project” Enköping.

2.7 Sustainability Criteria for Bioenergy Systems

In spite of the significant role of forest biomass in energy generation in Scandinavian countries, there is still strong interest to further increase the use of wood for energy generation. The view of regional experts with regard to biomass procurement is that there is a need to analyse and distribute information about the various characteristics that define sustainable bioenergy production systems. The idea behind this initiative is that such work will contribute to increasing acceptance of energy from biomass sourced from forestry and agriculture.

During the Swedish leg of the trip there was an opportunity to attend a workshop of the Baltic Sea Region project on “Sustainable Bioenergy Production from Agriculture and Forestry”. The main objective of the workshop was to set the basis and identify criteria for sustainable bioenergy, make recommendations in the area of bioenergy systems and set the foundation for a bioenergy certification scheme. Of special note was the opportunity to attend the sessions where potential criteria and indicators were discussed. It was a general consensus among the participants that a major outcome of the project should be the “establishment of a common market in the region for bioenergy produced in a sustainable way, with a competitive advantage, compared to less environmental or climate effective alternatives”.

The first part of the workshop focused on systems that were most likely to dominate the market for bioenergy, including first thinning biomass from young stands and short rotation energy crops. The second part identified issues critical to climate change mitigation efficiency, intensification of harvesting operations, land use change, and the need to develop energy efficient production systems. Pressure on arable land and food production, conflicts between feedstock’s volume requirements for energy generation, and environmental services provided by forests were also included. The third part dealt with limits to the criteria and potential indicators. The following is a compilation of principles proposed during the workshop:

I. ***Ensuring a minimum net GHG saving in energy production:*** This refers to targets of up to 80% in GHG savings by 2017 with reference to fossil fuel replaced in all activities related to bioenergy generation. For instance, if an energy system generates 100 tonnes of GHG using coal, then the replacement of this fuel by biomass should generate a maximum of only 20 tonnes of GHG, as a result of production activities including planting, fertilizing, harvesting, transportation, production, etc. The key point here is innovation, leading to efficient use of energy and resources throughout the whole production chain.

The same principle applies to land use change scenarios. The emissions savings from replaced land use should be at least 70% of the emissions that would be generated by using fossil fuel to generate the same amount of energy for a given period of time (50 years was suggested as a reference). An example would be an energy crop replacing a forest. If the new energy crop replaces 100 tonnes of CO_2 emitted by burning fossil fuel, the emission from input of energy in production (losses in carbon soil, planting, fertilizing, etc) and land use change should be less than 30 tonnes of CO_2. Life Cycle Assessments (LCAs) will be used to quantify emissions from planting to final use for both production and land use change.

II. ***Conversion of High Carbon Stocked land:*** No biomass is to be harvested or procured from land with high carbon stocks, nor energy crops to be established in these areas. CO_2 emissions caused by land use change should be avoided. Emissions from land use change will be included in the biofuel life cycle as mentioned above. As an incentive; it was suggested that GHG "bonuses" should be granted to forest managers and operators rehabilitating degraded or marginal lands.

III. ***Prevention of loss of biodiversity:*** No harvesting of primary forests should be allowed, but harvesting in areas with low biodiversity value could be allowed. Harvesting of protected areas will be allowed only if operations are compatible with environmental safeguards specific to the regions. No use of highly biodiverse grasslands should be allowed. Nutrients compensation, application of recycled ash and preservation of habitats will be required.

IV. ***Ensuring social and environmental standards are maintained:*** Cross compliance with the rules of the common agriculture policy of the European Union (CAP EU) on environmental and social aspects is required. A series of reporting obligations for operators on soil, water and air protection are yet to be defined. Bioenergy should contribute to promote economic activity of rural areas without endangering the conservation of cultural and heritage values of local communities and cultures.

The discussion on basic principles for sustainable bioenergy systems drew a few interesting comments; for instance:

- With regard to sustainability criteria; it is not possible to qualify bioenergy systems as "good or bad", it all depends on the structure of the individual systems and local conditions where the systems are developed. It was acknowledged that a certification scheme is unlikely to have the scope to address important issues that may arise such as economic development problems and population displacement in developing countries.

- Long term productivity usually increases when carbon stocks increase and vice versa, hence the importance of quantifying soil carbon stocks prior to land use changes. With regard to water pollution and eutrophication, it was argued that the problem tends to be less significant whenever perennial crops are planted instead of annual crops.

- With regard to biodiversity, positive or negative effects are dependent on the initial biodiversity value where the bioenergy system is being established.

A compilation of potential criteria is included in Appendix 1.

3. FINLAND

3.1 Forestry Synopsis

Finland is one of the most forested countries in the world with a total forest cover of 23 million ha and an annual growth of 100 million m^3. The domestic industrial consumption is 60 million m^3 (Kainulainen.2009). There are about 30 indigenous species of trees. The most common species are: Scots Pine (*Pinus silvestris*) 47%, Norway Spruce (*Picea abies*) 34 % and broadleaved trees (mainly Birch, *Betula pendula*) 19 %.

Forest management is compartment based; meaning that management is directed at homogenous parts of the forest. The average size of a compartment is 2 ha. The structure of the forest is even aged with rotations between 50 to 120 years depending on species, site conditions and geographical location (PEFC. 2009).

Family forestry is the cornerstone of forestry in Finland. There are 920,000 forest owners in Finland with 633,000 of them belonging to one of 112 Forest Management Associations (FMA), which in turn are divided across the country in 13 Regional Forest Centres (RFC). The area privately owned in Finland is about 13 million ha (60% of the country's total) with an average area of 24 ha/holding (MTK, 2009).

3.1.1 Contribution of the Forestry Sector to Energy Generation

Currently 27% of the energy consumed in Finland comes from renewable sources (Statistics Finland.2008). The goal is that by 2020, 38% of the total energy will be sourced from renewable energy. In 2008 the Finnish energy sector consumed 14.3 million m^3 of wood products in the generation of 27 TWh of energy using solid wood derived products (Figures 15 16 and 17). Wood chips from forest operations, including residual harvesting, stump removal and thinning of young stands; totaled 4 million m^3 in 2008 (Kärhä. 2009). The 2020 target means an increase to 12 million m^3/year from wood chips.

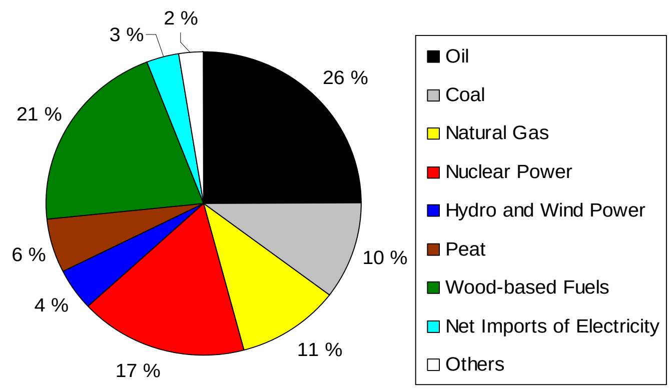

Figure 15. Total Energy Consumption (389 TWh = 33.5 Million Tonnes) Finland 2008. (Source: Metsäteho 2009)

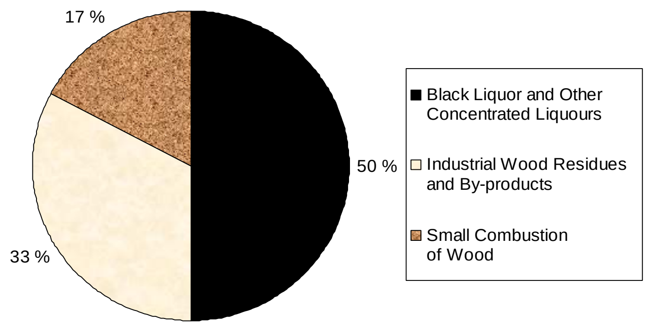

Figure 16. Total Wood Based Consumption in Energy Generation (82 TWh = 7.1 mill. tonnes). Finland 2008. (Source: Metsäteho 2009)

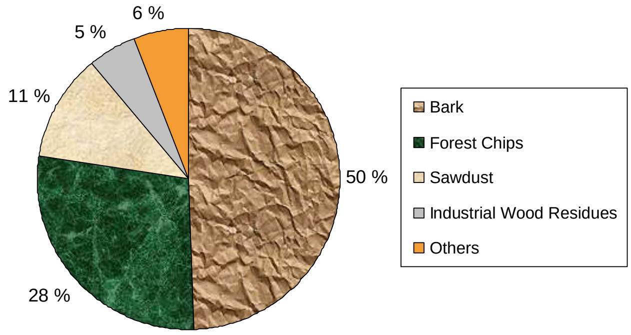

Figure 17. Solid Wood Based Consumption in Energy Generation (27 TWh = 14 million m^3) Finland 2008. (Source: Metsäteho 2009)

3.1.2. Policy and Legislative Framework

One of the most important instruments contributing to the development of the Finnish forest industry in recent years has been the National Forest Program (NFP). This program, launched in 1999, was a mechanism designed to include all Finnish forest stakeholders in a decision-making process aimed at promoting the use of timber, increasing the use of wood for energy, ensuring competitive conditions for the forest industry and identifying technology and development projects. The NFP involved 35 experts and was discussed in 50 national forums with almost 3000 participants (Boreal Forests. 2009).

The next phase of this program is the NFP 2015 which will be implemented by the Regional Forest Centers and coordinated by the Ministry for Agriculture and Forestry. The objective now is to expand the forest sector by € 700 million a year, including an increase in stumpage and energy wood by € 500 million a year, up to the year 2015. The number of direct new jobs the program will create will be about 5000. It is expected these goals will be achieved by improving forest management through financial incentives (Kemera Law) and the development of planning tools to produce up to date information for forest owners on volumes and opportunities for their growing stock. A revamped rail and road system will also contribute to achieve the objectives of the NFP (Finnish Ministry of Agriculture and Forestry.2009).

Carbon sequestration and energy feature heavily in the program by increasing the use of timber in construction - the target will be 1.2 m^3 of sawlog per person per year from the current 0.94 m^3. On the energy front, the goal is to increase as above mentioned to 12 million m^3 of wood-chips/year (Finnish Ministry of Agriculture and Forestry.2009). Arguably the most significant piece of legislation addressing undesirable high stocking of stands is the Act on the Financing of Sustainable Forestry. This legislation, enacted in 1996, aimed to provide private forest owners with financial incentives in forest regeneration activities, forest remedial fertilisation and prescribed burning. Its significance in the development of the wood energy business is the incentive provided to forest owners who conduct thinning and pruning of young stands and harvesting of energy wood (section 3.3).

3.2 Biomass Harvesting

The different arrangements used to produce wood chips and the size of the plants where the material is used, are in essence the factors that define Finnish biomass harvesting systems.

3.2.1 Small to Medium size Plants

Small to medium size plants are typically plants installed in homes, schools, farms and municipalities with energy outputs ranging of less than 2 MW. These plants require high quality material (e.g. clean, consistent sizes) usually chipped from de-limbed trees. The rule of thumb is that the smaller the plant, the higher the quality requirement of the wood chips used.

The process in this type of arrangement starts with an accumulating head harvester used for pre-commercial and first thinnings, and seasonal drying of piled wood on site to allow the drop off of needles to reduce nutrient losses and increase value of the timber. Once the wood is dried, the material is transported to the roadside and chipped (terrain chipping is rare in Finland) using a farm tractor with chipper attached, with a productivity of approximately 60 m^3/hour. Depending on the distance to the plant, which is usually no more than 50 km, haulage of fuel is done using tractors.

Procurement of small volumes of woodchips is usually done by a local farmer. In Finland it is not uncommon that a farmer signs a contract with a local council or municipality to conduct all practical operations including procurement of wood chips and operation and maintenance of small plants.

In Finland, as in other Scandinavian countries, payment for wood chips is made based on energy content. The truck transporting the material is weighed at the plant, and 6 samples per truck are taken to determine the moisture content of the wood chips. At the beginning of a contract arrangement, single samples from a given contractor are combined on a daily basis to profile each provider. The idea is that with time this “profile” or characterisation will contribute to reduce the frequency of samples that need to be collected for each contractor.

3.2.2 Medium to Large size Plants

Plants with an output power greater than 2 MW fall in this category. Medium size plants use a broader and varied range of materials including forest residues, barks and stumps, in some instances mixed with peat, pellets and sawdust, while large CHP Plants use multi-fuel boilers that enable co-firing with coal.

3.2.2.1 Comminution Arrangements

The different arrangements used to produce woodchips are dependant upon the size of the operation and customer requirements, while productivity depends on haulage distance, terrain, load capacity of the machinery and available volume. The summary provided below was gathered during field visits to Joensuu and Jyväskylä and personal communication with senior researchers from Metsäteho in Helsinki.

Primary arrangements for wood chipping include:

1. Road side chipping

Material is accumulated along side strip roads rather than in front of the harvester to avoid contamination by dirt. The material is then transported to road side for chipping. An integrated chipper-truck is ideal for this type of arrangement but separate truck and chipper seems more common, perhaps because of its lower cost.

Advantages

- Easy estimation of volumes
- Good quality chips and no needles when using de-limbed trees
- Easy accumulation of material
- Collection and haulage cost is relatively low

Disadvantages

- Well synchronised transportation and wood chipping operations are a must. An empty transport unit is required for loading to avoid productivity losses.
- Not much space for integration with conventional forestry practices when harvesting small trees

2. Integrated chipper-truck (Road Train type of truck)

Advantages

- No time losses between haulage and chipping
- The possibility of distributing chips to several small plants

Disadvantages

- The size of the material to be chipped needs to be reasonably small
- Long distance transportation costs
- Large loading area required
- Potential impact on soil conditions at loading site

3. Separate Chipper – Truck:

Advantages

- Depending on the chipper, no restrictions on size of material
- Wide range of available machinery in the market in both Finland and Australia
- Experience using this type of machinery in both Finland and Australia

Disadvantages

- High transportation costs
- Large loading area required
- Potential productivity losses from interruptions between transportation and chipping
- Potential impact on soil conditions at loading site

4.Chipping at terminal

Residues are transported and chipped in a stockyard or depot (Figure 18). This system is seen as a mean to control procurement and distribution processes. Material at the terminal is stored un-comminuted and then chipped and transported to plants when the demand is higher.

Advantages
- Chipping and haulage operations independent from each other
- Effective chipping resulting in high quality material
- Easy distribution to several plants
- Security of chip deliveries

Disadvantages
- Establishment cost is high
- Identification of strategic location of terminal is critical
- Extra handling times and cost
- High risk of fire from spontaneous combustion

Figure 18. Biomass Chipping at Terminal

5. Chipping at plant

As in chipping at terminal, residual material is transported and then chipped. The critical issue with these two systems is the low bulk density of the material transported. One solution has been the use of bundles (Figures 19 and 20) and the development of compacting logging residues trucks. The operational and technical capability of the machinery becomes more evident with this system; the higher the energy output of the plant, the more cost effective the method is. Mobile chippers are replaced with stationary crushers capable of processing stumps, trees with limbs, bundles and recycled wood. Due to its high cost, this arrangement is only adopted by larger plants.

Advantages

- Potential for large scale energy production
- Chipping and haulage operations independent from each other
- Identified as the most cost effective supply system

Disadvantages

- Large areas for wood chipping as well as large roadside storage space required
- High transportation cost as the volumes required are very high

Figure 19. Forests Residue Bundler

Figure 20. Bundled Forest Residues Ready for Collection

3.3 Recent Developments in Biomass Harvesting

Thinning of young stands in Finland is a major activity in great part thanks to a government subsidy of €7/m^3 for timber harvested and destined for energy generation. This stimuli is part of the Act on Financing Sustainable Forestry better known as the "'Kemera law". To be eligible, the area selected for thinning must be greater than 1 ha. Typically, thinnings in young stands are conducted where the harvestable round wood estimated volume is >20 m^3/ha and the tree top height is somewhere between 8 m and 14 m. The intensity of the thinning will be around 30 % of the stocking (Siren & Tanttu. 2004).

The subsidy also covers bunching and haulage of timber destined for energy generation and procured from management of young stands. The subsidy is also paid for reporting implementation of management activities, such as weed control for seedlings and trees between 3-5 m in height (which attracts a subsidy of € 180/ha) and the possibility of a 50 % rebate on application of fertilisers. The actual cost of harvesting 1 m^3 of timber is 15.9 €, which makes the subsidy imperative.

3.3.1 Thinning Innovations

Finnish machinery developments have focused on reducing operational costs through efficiency of feedstock transportation and harvesting of whole trees. One example in this area is the integration of a multi-stem harvester head fitted with a pulse feeder and a bundler –Fixteri P2 manufactured by Biotukki - attached to the harvester (Figures 21 and 22). This is arguably one step further than the multi stem harvesting machines observed in Sweden.

Some of the innovations of this new machine include the possibility of continuous bundling of whole trees without resorting to longitudinal cuttings. The stems are fed into the bundler, cutting the logs to the desired length (approx. 3 m) and then the material is compressed into rolls using a wrapping system. Once the bale is completed, the chamber opens and the bundle is dropped on the side of the strip road.

Prototypes of this machine have been tested in stands where harvesting for pulp and wood for energy are integrated. The bundles mix the two products and separation takes place at the debarking drum at the pulp mill. Characteristics of the system include cleaner material, increased productivity of 20-30 % when compared to the harvesting of one stem at a time, and flexibility to switch from energy to pulp and vice versa according to diameter demands. The system is limited to the harvesting of trees >10 cm in diameter and has a productivity of 20 bundles/hour for stem diameters of 14 cm on average.

Figure 21. Fixteri Bundler with Multi-stem Harvester used in Early Thinnings (Kärhä et al, 2008)

Figure 22. Detail of Fixteri Bundling Chamber (Kärhä et al, 2008)

3.3.2 Planning of Harvesting Operations for Biomass

A major challenge in optimisation of fuel procurement in Finland is the availability of residues, site characteristics, variability in age classes, dispersion of stands, and long term management expectations. With operating units of 0.5-2 ha the possibilities for effective biomass harvesting are challenging.

To facilitate decision making processes on selection of harvesting systems and the "when and where" to conduct cost effective harvesting operations, the Finnish Forest Research Institute (METLA) in Joensuu has developed a methodology to conduct feasibility analysis for logging of residues, stumps and whole tree harvesting chipping (thinning of young stands). The analysis incorporates inventory data at plot and tree level, biomass estimations, variations in time and space, road network and environmental and logistic constraints. The goal of the analysis is to present a comparison of cost estimations under different stand selection criteria or through a combination of these.

This planning tool incorporates financial analysis and tactical and strategic planning using a simulation process driven by different management alternatives, and an optimisation tool. The ultimate objective of the simulation process is to derive a 5 year optimal forest management plan. Although under different conditions to those of Australia, this methodology is a good example of how key information on fuel location, volume availability, production costs, and management alternatives can be procured and utilised.

A methodology resembling the one described below has the potential to provide forest managers with readily available information on residue location, application of environmental constraints in harvesting operations and transportation costs. This information is likely to facilitate selection of harvesting systems, contribute to fine tuning chain supply aspects and facilitate policy design.

3.3.2.1 Methodology for Selection of Biomass Harvesting Sites

The methodology described below was developed by METLA (Mustonen & Anttila.2009) and illustrates the process used to locate potential clearfall and early thinning stands for biomass harvesting, by segmenting available Earth Observation data (spatial information).

1. Creation of thematic maps

First, the measured sample plot data is generalised to all raster cells with a k-NN[1] estimation (K- nearest neighbour). Next, the forest inventory data is combined with advanced tree height and crown ratio models. These model predictions are used as an input to tree-level biomass equations, which make it possible to obtain biomass estimates for each sample plot. Plot-level biomass estimates are used in combination with satellite images and digital maps (base maps, soil maps and digital elevation models) in order to produce thematic maps of the forest biomass over the area of interest.

2. Segmentation of Earth Observation (EO) data

In order to locate the stands of different standing forest stocks (and tree species), EO data (satellite images) are segmented for the area of interest. In the segmentation, a forest area is stratified into homogeneous stands based on the features of the EO data. For effective stratification of the forest area, remote sensing data should have the best available resolution.

3. Excluding protected areas

Before the segmentation process takes place different kinds of masks[2] can be used to include only forest available for wood supply. The analysis excludes all conservation areas and areas under environmental law and/or regulations where harvesting is not allowed. Therefore, all areas where harvesting is not allowed are set to zero in the thematic maps. For this analysis the PEFC criteria is used (95 % of all forests in Finland are certified under PEFC).

4. Forest characteristics for the segments

After the stands are segmented they are coupled to stand data. This is done by overlaying the stands on raster maps of stand attributes and calculating stand-level statistics. Information on Stand attributes is sourced from inventory information which includes: Administrative information, location, site index, growing stock (mean variables for each tree species and canopy layer), cutting strategies and silvicultural treatment proposals (5 years), biodiversity, heritage value and tree mortality.

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[1] K-NN refers to a nearest neighbor analysis where a raster cell is assigned the value of the nearest plot. The plot contains information on volume, basal area, mean height, site type and biomass.

[2] A mask is a geographic information system (GIS) application that conceals areas not included in a spatial analysis.

5. Environmental criteria and technical constraints for wood harvesting

This part of the process uses constraints, which are country specific and are highly dependant on harvesting conditions. Biomass thresholds are used as guidelines for biomass estimations. The basic constraints are slope, maximum and minimum residual recoverable volumes and minimum stand size. In addition to these constraints, existing road connections from each stand to each power plant are included. This enables the calculation of distances between forest stands and plants. For those stands selected for biomass harvesting the forwarding distance to road side is also established. The distance that is deemed financially sound is highly dependant on harvesting costs and harvesting conditions.

In Finland, the average forwarding distance is about 250 m. From a financial point of view the distance from the edge of the stand to the road side should be less than 500 m. In order to apply sustainability criterion and economical feasibility of harvesting, the minimum biomass removal and minimum size are defined for each stand. Finnish foresters have concluded that the residual biomass yield for each stand should be more than 30 m^3/ha and the minimum size 1 ha. Also, below-ground forest residue harvesting (stump and roots) is restricted around the water bodies because of the high probability of nutrient leaching. The buffer size around the water bodies should be at least 10 m.

6. Harvesting level scenario

As the actual availability of primary forest products and residues depends on the level of harvesting of industrial roundwood, a baseline ("business as usual") is established using historic harvesting records of mean annual sawlogs and pulp. This information applies to both clear fells (CF) and thinning of young stands (TH).

7. Technical potential

The estimation of technical potential starts by locating the stands by age classes. The stands are selected iteratively from the groups of all CF and TH stands until the harvesting areas of the scenario "business as usual" is fulfilled. The stand selection order is based on stem volume: the stands with the most growing stock are harvested first. The estimate of the fuel wood removal (in m^3 or MWh) for CF stands is a sum of the stands logging residues and stumps. The fuel wood removal for TH stands is estimated using thinning models. The models predict the amount of biomass, which will be removed from the stand according to the sustainable forest management regime (Tapio, 2007).

3.4 Sustainability Criteria and Harvesting Guidelines

PEFC Finland has modified its forest certification criteria to address increasing biomass harvesting activity. At the time of the visit a criterion on “sustainable methods used in energy wood”, was being finalised. The indicators used to ensure compliance with this criterion are based on a set of guidelines compiled by the Forestry Development Centre (TAPIO).

The guidelines, which focus on early thinnings and residual material harvested from clearfalls, are prescriptive and were developed as a response to increasing interest in Finland’s commitments to increase its renewable energy supply by 2020. In the absence of a specific set of guidelines, an extract of recommendations that could have application in Australian conditions follows.

3.4.1 Energy Wood from Thinnings

Advantages

- Silvicultural management improvements in dense young stands
- Movement in the forest is facilitated
- Increased growth of retained trees
- Additional revenue for forest owners from sales of roundwood material and energy wood
- Cost reductions conducting pre-clearing for mature clearfalls.

Disadvantages

- Risk of damage to retained tress
- Risk of nutrient reductions as a result of whole tree harvesting

1. Harvesting quality

- Material mixed with dirt should be placed on a mat to allow soil material to wash away. The use of harvesting mats are recommended both on the ground and on top of piles to prevent dirt contamination and humidity absorption.
- Clearing of underground as required prior to harvesting will prevent damage to retained trees
- Whenever possible trees should be de-limbed on site
- The minimum volume per tree that is cost effective to harvest is well identified in Finland: as a rule of thumb trees smaller than 0.02 m^3 in volume are cut and left on site.

2.. Storage

- To accelerate the drying process, piling in sunny and windy areas is recommended
- The stack of timber should be as high as possible to prevent humidity absorption
- The piling area should be as flat as possible and should be clear of rocks, stones and other material that might affect the chipping process. As aforementioned, the use of mats are recommended (Figure 23).
- If necessary, branches and logs should be used as a piling base to reinforce the soil’s bearing capacity.

3. Nutrient deficit management

- In Finland, the top 2 m of each tree are recommended to be cut and left on site. The same applies to trees with a DBH smaller than 5 cm, these should also be cut and left on site.
- Trees should be left on site to dry and allow needles to fall
- Nutrient compensation is recommended whenever whole tree harvesting occurs. Ash recycling might an option.

4. Late Thinning

- To ensure growth is not affected by nutrient deficit; whole tree harvesting should not be conducted in secondary thinnings.
- Thinning below the recommended stem target or basal area should not be conducted, unless the stand is of very poor quality and an intended heavy thinning is likely to improve growth of retained trees.

3.4.2 Harvesting of Residues from Clearfalls

Advantages

- Cost savings in site preparation and regeneration activities
- Faster ploughing and mounding activities
- Facilitates cultivation specially where mechanical planting is used
- Improvements on seedling survival
- Facilitates movement in the forest

Disadvantages

- Reduces the formation of humus which might affect water retention in drier areas
- Reduces habitat formation
- Reduces the amount of nutrients
- Increases the chances of weed invasion

1. Storage

- Piling should occur in large, dry, open spaces. 6-7 m of storage area is required for every 100 m^3 of sawlog harvested.
- The pile should have a slope at both ends, and ideally should be 5 m in height and 6 m in width.

2. Landscape Appearance

- It is recommended that at least 30 % of residual material should be left un-harvested. This material should be spread as evenly as possible over the harvested area.
- Logging residues used to reinforce the base of piles should not be harvested.
- It is estimated that for every ha of stumps harvested 40 m of storage area is required.
- No machinery should circulate over piles to avoid contamination
- Decomposing stumps should not be harvested
- Stumps under a minimum set diameter should be left un-harvested (In Finland stumps smaller than 15 cm are not removed) and also a minimum number of 25 stumps/ha are to be left on site.

Figure 23. Road side Chipping and Logging Residues with Brush Mat Protection.

4. DENMARK

4.1 Forestry Synopsis

Forestry in Denmark is a relatively minor activity when compared to the scale of operations in Sweden and Finland. The total forested area is about 400,000 ha with a remaining native forest area of only 1000 ha scattered across the country. 70 % of all forest residues are used for energy generation, which corresponds to 5.1 PJ (FAO. 2008). The pulp industry does not exist in Denmark and all forestry products are destined for sawlog, greenery and bioenergy. The annual forest increment is estimated to be 5.45 million m^3, while harvesting is 2.2 million m^3 (Nordic Family Forestry. 2009).

An important aspect of forest management in Denmark is the protection of cultural and recreational values of the forest. Testimony to this policy is the promotion of mixed species plantings driven by the "Close to Nature" program which started in 2002. The use of well adapted species; mainly native trees, permanent forest cover through avoidance of large clear-cuttings, use of natural regeneration, development of diverse forest structures and single tree management are key principles to the "Close to nature" forestry program.

4.2 Incentives and Strategies for the Use of Biomass Resources in Denmark

In order to gain some understanding of the importance of forest residues and renewable energy in Denmark, it is necessary to revisit the mid 1970´s during the first oil crises, when the Danish government enacted new laws to prevent future crises in energy supply. The aim of these new laws and policies were:

1. Reduce the energy consumption by 15 %
2. Increase the consumption of natural gas by 170 %
3. Increase the consumption of renewable energy by 100 %
4. Reduce the consumption of coal by 45 %
5. Reduce the consumption of oil by 40 %
6. Reduce CO_2 emissions by at least 20 %
7. Reduce SO_2 (Sulphur Dioxide) emissions by 60 %
8. Reduce NOx (Nitrogen Oxide) emissions by 50 %

(Frisk.2001).

The goals of these measures are being achieved through a wide range of activities: Energy savings, tax on CO_2 emissions, conversion to the use of environmentally desirable fuels in central CHP plants, subsidised construction and operating of district heating systems, and subsidised establishment of biofuel boilers.

The use of biomass has been further stimulated by exemption on taxes for both energy and CO_2 (Figure 24.).

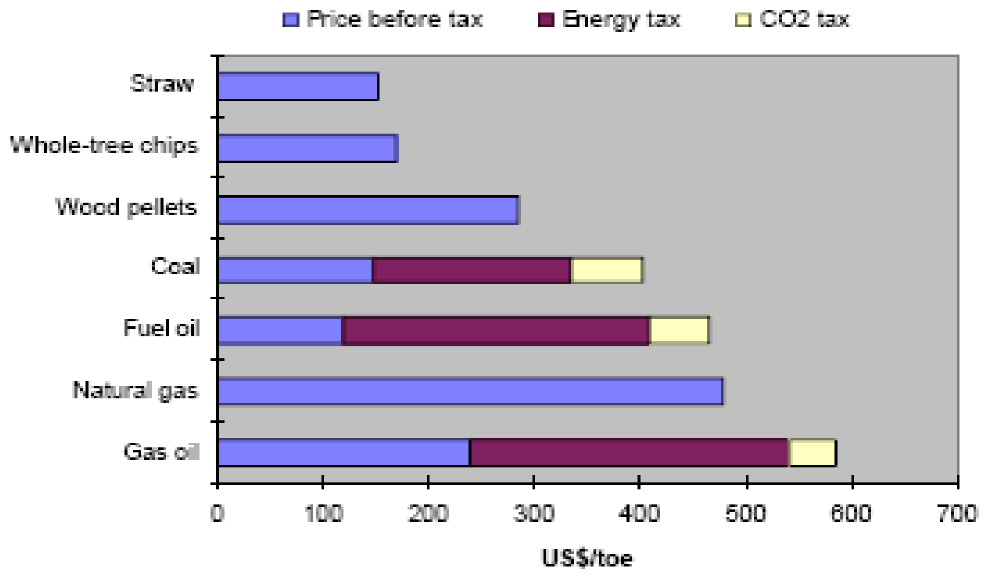

Figure 24. Total price of fuels after energy and CO_2 taxes in Denmark.

Source: Asean-Scandinavia FAO 2008.

Other factors contributing to increased energy production is an incentive of DKK 0.27/kWh for achieving 80% in efficiency production from straw and wood energy. One of the results of the government's policy is increased utilisation of forest chips for fuel, and today it represents a production of great importance to forestry in Denmark. About 48 % of biomass used originates from forestry comprising chips, pellets and firewood (Pöyry, 2008).

4.3 Future Energy Goals

The Danish government is implementing further initiatives to reduce fossil fuel dependency including:

- Taxes: An increase of the 2008 Carbon Tax and a new NOx Tax from 2010 onwards
- Energy savings: An ambitious plan of reduction of energy consumption by 2 % by 2011 and by 4 % by 2020, compared to 2006 levels.
- Increase of renewable energy usage: An increase of 20 % by 2011 and by 30% by 2020 (Danish government 2008).

4.4 The role of Forest Owners Associations

It is difficult to talk about forestry in Scandinavian countries without referring to the major role that private forest owner associations play in this industry. 69 % of the total forest area in Denmark is privately owned.

With its beginnings dating back to 1904, the Danish Forest Owners Association comprises 7 independent local regional units under the umbrella of the Danish Forestry Extension (DEF). With a membership of 20,000 owners; totaling 80,000 ha the land holding areas range from 1 ha to 800 ha. The relevance of the forest associations in the biomass business is quite Significant as 2/3 of their wood products (1.1 million tonnes or approx. €60 mil) go to energy generation.

4.4.1 Structure of the Associations and their Purpose

The Regional Unit structure consists of a General Assembly formed by the owners, a Board of Directors elected by its members, a Chief Forester appointed by the board and 3 or 4 Foresters or Forest Rangers (Figure 25). By a way of example the unit visited (Holstebro) has 450 members and manages 15,000 ha with 9 foresters.

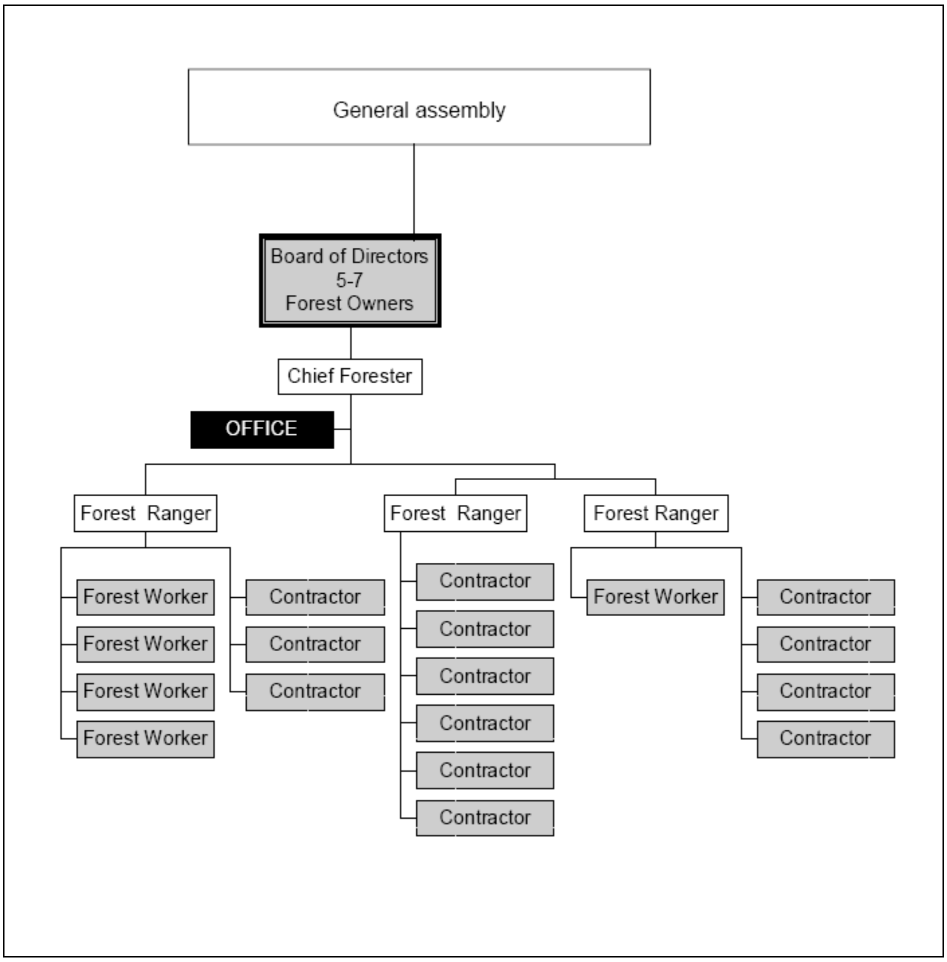

Figure 25. Local Units Administrative Organisation (source: Danish Forestry Extension. 2009)

The purpose of the DFE is to:

- Assist Regional Units with technical training
- Protect the economic and political interest of forest owners
- Secure a sustainable production of wood products
- Represent forest owners to the state and other relevant organisations within the forest and environment sector.

The main role of these associations is to provide its members with:

- A pool of foresters directly employed by the association to provide technical advice on contracting, plantation establishment, silvicultural management, harvesting and operations planning for roundwood and biomass for energy generation. As mentioned before the pulpwood industry is non-existent in Denmark.
- Sale of seedlings at preferential prices
- Improvement of access to markets and financial rationalisation (exclusion of the “middle man”)

4.5 Biomass Harvesting

Biomass for energy generation in Denmark is mostly procured from first and second thinnings. Unlike Sweden and Finland, terrain chipping is common. Trees are felled during winter and chipped in the terrain after at least one summer, ensuring that the needles remain in the forest and that the moisture content has been reduced from the initial 55 % to somewhere between 30 % and 40 %. Logging residues from clear fell areas are also harvested. The material comes from de-limbed trees, which is placed aside in separate rows to be used as assortments.

Most of the small forest owners are members of forest owner associations and have handed over their forest management to cooperatives, who will hire contractors to conduct harvesting operations (Mr. P Kofman, pers. comm.19/05/09).

There was an opportunity to visit Thilsted in North West Denmark and observe harvesting operations: The process consisted of a first thinning (by chainsaw) and then selective thinning using a harvester and integrated woodchipper – the Silvatec 878 HC (Figures 26 and 27) - which is a self propelled chipper and crane mounted in the front of the machine with a production capacity of 50 m^3/hour and a tipping container (15m^3) in the rear. The woodchips collected by the Silvatec are then uploaded in a chip shuttle which is a modified forwarder (Figure 28). The shuttle transports the chips to road side where 20 m^3 containers are loaded and transported by truck (Figures 29 and 30).

Other systems observed included the use of Fendt agricultural tractors -936 model- (Figure 31) which is well suited to thinning of young stands. The advantage of this system compared to the Silvatec is its lower production cost and mobility with a production capacity of 40 m^3/hour. The tractor system does not use a chip shuttle, instead woodchips are directly transported and loaded into containers by the road side.

Figure 26. Harvester and Integrated Woodchipper. Silvatec 878 CH. Denmark.

Figure 27. The Silvatec 878 CH Uploading a Chip Shuttle

Figure 28. Chip Shuttle Uploading Containers

Figure 29. Containers Ready for Collection

Figure 30. Containers Being Transported (2 x Truck)

Figure 31. Fendt 936 Tractor Adapted for Woodchipping

4.6 Sustainability Aspects

Long rotations are typical of Scandinavian forest and Denmark is no exception; up to 50 years for pines and 80 years for Norway Spruce (*Abies grandis*). The length of these rotations gives a semi-natural or semi-planted characteristic to Danish forest, with stands strongly dominated by Norway Spruce (19%), Beech (*Fagus sp*.), Pine (12%) and Oak (9%).

The production of forest chips typically takes place in connection with three different activities:

1. Thinning in immature softwood stands (the main source of material)
2. Silvicultural management
3. Harvesting of logging residues

(Frisk. 2001)

It was observed during the study tour that three strategies are recommended and applied to prevent nutrient losses: Pre-drying of whole trees in situ and ash recycling. Selective extraction of tree sections; the latter linked to site class classification has been suggested.
This practice achieved by the drying process where only stems and no branches are harvested.

The area visited in the South West of Denmark (Aarhus), which has some of the poorest soils in Denmark, commonly applies the first two recommendations in all but the intensively fertilised *Pinus sylvestris* plantations. The pre-dying process is a general practice applied across the country to allow the material to dry for about 4 to 6 months prior to chipping. The aim of this practice is not only to prevent significant nutrient losses but to allow a reduction of up to 50 % in moisture content.

Ash recycling, which has been practised for more than 10 years in Denmark, has been a contentious issue as there are concerns about presence of high heavy metal concentrations. Nevertheless, its application is used as a compensatory measure for losses of potassium and phosphorous. Legislation addressing ash application was enacted in 2006. It contains prescriptive limits on maximum concentrations in parts per million (ppm) allowed for minor elements and nutrients. Use of wood ash is limited to forestry and ash from straw is used in agriculture (Haglund. 2008).

Recommendations for forest biomass harvesting in Denmark were developed in the mid 80s, and have not yet been up dated. These recommendations refer to stands managed for production with an average increment of less than 9 m^3/year/ha:

- i) Wood chipping should only take place in stands that will be fertilised
- ii) Wood chipping should only take place in first and second thinnings, and second thinning only if pre-drying takes place in both thinnings,
- iii) Wood chipping of logging residues on clear cuts should be limited and only take place after pre-drying on the forest floor.
- iv) Burning of logging residues and forwarding to windrows should be avoided.

(Skovstyrelsen. 1985).

5. RECOMMENDATIONS

This report intends to provide a general view of some of the environmental and operational aspects of harvesting biomass in Scandinavia and does not suggest for obvious reasons that some of the prescriptive measures included have application in Australia. However, the development of sustainability criteria principles, as well as indicators, can be highly relevant to this country.

The main recommendations from this study in an Australian context are:

i. Partnerships between forest owners, local government and energy generators, as observed in southern Sweden where small energy plants are used to serve the energy requirements of small towns or large buildings, should be explored within the Australian context. A suggestion would be the creation of a forest biomass energy working group driven or coordinated by forest owners, forest agencies or forest managers.

The aim of the working group would be the promotion of residual timber from planted forest as a third major forest product in addition to sawlogs and pulp. An approach could comprise estimation of the resource at regional level (residual volumes available), identification of regional energy markets including heating, cooling and electricity, and the assessment of business models and technical options such as pyrolysis, gasification and direct combustion.

Under a new de-carbonised economy, forestry towns/communities could benefit from district heating or cooling systems where haulage distances of material would be short, therefore less onerous and with a smaller carbon footprint. It is estimated for instance that CHP arrangements might have the potential to reduce GHG emissions by 75% (NSW Parliament 2004).

ii. A strength of the forest industry in Scandinavia is the ability to publicise credible information on advantages of its forest management activities, particularly with regard to the debate on climate change. Until now this strategy has contributed to dispel doubts of the industry's environmental credentials and attract considerable political and public support.

Forestry agencies in Australia could improve their position by promoting their work on adaptation to climate change. In the absence of regulatory framework; one option supporting claims in this area is the use of indicators in carbon flows and GHG reductions. Examples are the use of residual material from planted forest for energy generation and substitution of construction materials such as steel and concrete for wood. It is likely the forest industry will have an additional incentive to manage forests in a sustainable and efficient way in the face of the negative effects of climate change, if the potential of wood products (including wood for energy) to offset carbon emissions is recognised and quantified.

iii. It might be necessary to give more relevance to life cycle analysis, not only from a planting, harvesting and haulage perspective, but also whenever land use change occurs. This might be the case when ex-pasture lands are converted to forest; even if the new land use is not eligible under a regulated carbon certification scheme.

iv. If harvesting of forest residues in Australia intensifies it would be necessary to create a set of criteria addressing nutrient management. These might include establishing upper limits for volumes of material that can be extracted and the need to balance nutrient extractions according to specific site conditions. This would have to be a regulatory measure initiated and implemented by the forest industry itself to ensure that forest growth of future rotations are not affected.

PEFC Finland revised its certification standards in May 2009, adding new criteria addressing harvesting of energy wood and the role of forest in carbon sequestration. In the future a new set of criteria in this regard might become a feature of national standards in countries where forest residues are intensively harvested. This might become the case in Australia.

v. The use of multi stem harvesters could have potential in thinning of young softwood plantations where retained trees need to be protected and in stands with poor site quality requiring heavy thinning or areas where markets for pulp are limited. With an efficiency increment of more than 30 % this type of harvesting machine could have a major role reducing the cost of harvesting low value wood.

vi. More research will be needed to understand the long term effect of biomass harvesting. The gap in knowledge could be closed by starting at regional level before decisions on a large commercial scale are made.

vii. Depending on the site and scale of the operation, road side chipping is probably the comminution system best suited to Australian conditions. This recommendation is based on the availability of machinery currently used in Australia. However, the criteria for selecting a system should be based on careful cost analysis and thorough planning. Aspects that might affect this selection are the available biomass volumes, stand characteristics, labour and machine costs and needs of the end user.

viii. Harvesting of forest residues is highly dependant on small but important details, that add value to the process. Examples include the use of brash mats on the top and base of piles to avoid contamination and reduce humidity, the arrangement of harvested material in well organised piles and the size of the pile prior to chipping. These are aspects that would need to be considered and tailored to Australian conditions.

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Appendix 1. Suggested Biomass Sustainability Criteria –Adapted from Workshop Discussion on Sustainable Bioenergy Production-, Baltic Sea Region Program 2007-2013.

Principle	Criteria	Potential Indicators
1. Biodiversity Biomass production shall not endanger biodiversity at landscape level. However, special considerations to threatened species shall be given at local level. Biomass production shall whenever possible, strengthen biodiversity and contribute to an increased variation in the landscape	1. Biomass production shall not result in depletion of biodiversity at landscape level 2. Whenever possible, biofuel harvesting should be conducted in relation to other management practices at landscape level 3. Biomass production or extraction shall not be performed in protected areas or areas with high conservation values unless it is part of a management plan aimed to protect biological value 4. Exotic species shall be cultivated under conditions of careful control and monitoring. 5. Biomass plantations shall, if possible, be located and designed in a manner that contributes to a varied landscape so as to sustain or enhance biodiversity, including the regional recovery and persistence of endangered species.	1. Number and abundance of species prior project initiation 2. Area affected and number of exotic species from uncontrolled propagation 3. Land use within the landscape
2. GHG savings Greenhouse gas emission savings (i.e. emissions of all important greenhouse gases in CO_2 equivalents) from the production and use of biomass as feedstock for heat, cooling and electricity production should be maximised.	1. The greenhouse gas emission reduction of the production chain from cultivation to conversion, including distribution, shall be calculated in relation to a reference scenario with fossil fuels. Both long and short term gains and losses shall be evaluated. The use of residues and by-products shall be encouraged and accounted for when calculating greenhouse gas savings 2. Special consideration shall be given to organogenic soils. For example, frequent tillage should be avoided on organogenic soil.	1.sTonnes of GHG replaced from equivalent energy generation processes from fossil fuels
3. Carbon stocks: Biomass production from crops and plantations shall not endanger above- or underground carbon sinks. Greenhouse gas emissions caused by land-use conversion shall be low in relation to the amount of greenhouse gas emissions that can be avoided within a certain time frame	Biomass production shall not take place in areas where there is a great risk for new or increased carbon losses from the soil unless they can be restored within a time period of 50 years.	1. Estimation of volumes of carbon losses through the life of the project 2. Carbon losses compensated for by biomass production within a stipulated time period

4. Energy efficiency For the production of sustainable bioenergy the energy balance should be positive. Resulting by-products and residues used for other purposes than energy shall be accounted for. Input energy shall therefore be distributed on all products (main and by-products) based on an average product value proportion basis.	1.For the production of heat and electricity, the energy input of biomass and fuel production should be at least 20 % of the energy output. 2.For the production of transport fuels the energy input should be less than 50 % of the energy output.	1. Energy balance: consumption v.s production
5. Environmental Impact Natural resources shall be used efficiently and biomass production shall not cause depletion of natural resources or damage to natural ecosystems.	1. Nutrients in waste products from food and feed processing and consumption, and ash originating from bioenergy production should be recycled 2. Residues and by-products should be used for energy or other applications in order to increase efficiency 3. Bioenergy production shall be conducted in a way that prevents further deterioration and protects (or enhances) the status of aquatic ecosystems. 4. Methods that cause a net depletion (after compensatory measures) of humus, nutrients and minerals in the soil below levels necessary for the maintenance of the long-term soil production capacity shall be avoided 5. Buffer zones between biomass production areas and waters and wetlands.	1. Volume of waste products recycled. 2. Use of residues 3. Water quality 4. Methods and compensatory measures implemented
6. Social and Cultural impact Bioenergy production should contribute to an increase in rural activity and contribute to the development of viable business and security in energy supply without endangering the conservation of cultural values, heritage and/or prosperity of local communities and cultures.	1. Local acceptance and the avoidance of conflicts should be reached through regional and local planning instruments 2. Development of local energy systems that enable combinations of different renewable energy sources shall be encouraged 3. Activities shall have generally positive effects on social welfare and be carried out with consideration to local communities and cultures	1. Documented information opportunities (all stakeholders that could be affected by a bioenergy installation should be given the opportunity to be a part of/comment on the project at planning stage). 2. Rural income estimation (from project additionality) 3.Migration, displaced population (The bioenergy producer should be responsible for the assessment of the values of

		the production area and also for the assessment of how the production may affect the local community)
7. Land use change Land as a resource shall be used efficiently and the production and use of biomass for energy shall not endanger food security or local production of biomass for other applications.	1. The use of the landscape and productivity should be optimised by locating, managing and designing the production in the best suitable way and where synergetic effects are at their best 2. Residues and by-products should be used to make the production system and the use of land more efficient 3. Practices that optimise productivity shall be used. 4. The production of biomass for energy shall only occur in places where it does not threaten local/regional food supply 5. Property rights and use shall not be violated.	1. All land use changes must be reported by area. 2. Management, design and crop rotation schemes are reported by area. 3. Number of owners consulted and community meetings should be documented.