12-2010

Export Potential of U.S. - Produced Switchgrass and Wood Pellets for the EU Market

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To the Graduate Council:

I am submitting herewith a thesis written by Mladen Grbovic entitled "Export Potential of U.S. - Produced Switchgrass and Wood Pellets for the EU Market." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

Burton English, Major Professor

We have read this thesis and recommend its acceptance:

Kimberly Jensen, Daniel G. De La Torre Ugarte, Tun-Hsiang Yu

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Thesis Presented for
the Master of Science
Degree
The University of Tennessee, Knoxville

Mladen Grbovic
December 2010

DEDICATION

To my mother

Dragica Grbovic (1946-1985),

my father

Milan Grbovic (1946-2003)

my step-mother

Nada Filipovic (1948-2008)

and my brother

Dragoslav Grbovic

ACKNOWLEDGEMENTS

I thank you - Dr. English, Dr. Jensen, Dr. Ugarte and Dr. Yu -for all of your support and help during my stay in Tennessee.

Thanks to my brother Dragoslav Grbovic, UT alumni and currently a Professor at Naval Postgraduate School in Monterey, CA for giving me limitless support in my life and for convincing me to come to the University of Tennessee.

I would also like to thank:

Baird, J. Marketing Executive at Logistec USA,
Camp, C. Manager of Logistics, Alabama State Port Authority,
Frey, B. Operations Manager at Bienergy Group,
Grason, B. BM&M Manufacturing,
Gruss, T. Assistant Regional Manager at Morbark Inc.,
Hanna, M. National Sales Manager at Schutte-Buffalo Hammermill LLC,
Jackson, S. Vice President for Feedstock Operations at Genera Energy,
Locke, J. Applications Coordinator at Bliss Industries LLC,
Luppold, W. Project Leader at USDA Forest Service Princeton West Virginia Forestry Sciences Laboratory,
Moran, W. Owner of the Coastal Equipment Sales Inc,
Rafter, F. Market Manager at Buhler-Aeroglide,
Rockey, R. Biofuels Representative at Andritz Inc,
Schroeder, D. President and Owner of Baker-Rullman Manufacturing Inc,
Tuffano, A. Process Equipment Sales at Aaron Equipment Company,

For providing me necessary information for my research, suggestions, contacts and useful insights in pellet production process and pellet market.

ABSTRACT

European Union's (EU) dependence on fossil fuel imports strongly affects its energy supply and economic and national stability. In order to reduce its dependence and maintain the leadership position in GHG emissions reductions and renewable energy consumption, EU has set ambitious targets of reducing GHG emissions by at least 20% compared with 1990, raising the share of renewable energy to 20% and increasing the levels of biofuels in transport fuels to 10% by 2020. While some of the countries, due to their large renewable potential, have already reached set targets, some are still far behind. Biomass, with 69.8% share in gross inland consumption of renewables, has the greatest potential. Since some EU members have low availability of biomass, and are scarce in other renewable sources, they have become biomass importers. As some studies have shown, imports of biomass reduce cost of achieving targets for renewable electricity and increase electricity production from biomass. Wood pellets, currently the most tradable solid biomass commodity, already reached significant shares in imports and consumption of biomass in some EU countries. Pellets were traditionally imported from Canada; however, last year US became the EU's largest importing partner with 534,000 tons of industrial pellets exported mainly to Belgium and Netherlands. The EU's increasing demand for wood pellets was a major driver for substantial increase in the wood pellet production capacity in US, with many plants being constructed for export to EU. This thesis evaluates the possibility of producing wood and switchgrass pellets in East Tennessee, assuming three feedstock scenarios, and their export to EU. Results from the base-case model showed that production costs of pellets would be $155, $164 and $170 per ton, while price of pellets on the EU market will have to be $207, $216 and $222 per ton in the 100% mill residue, 40/60 blend and 100% switchgrass scenarios, respectively, for the project to breakeven. Sensitivity analysis showed a strong impact of feedstock price, moisture and exchange ratio on project’s return on investment.

TABLE OF CONTENTS

ABBREVIATIONS

Btu	British Thermal Unit
CIF ARA	cost, insurance and freight (Amsterdam, Rotterdam and Antwerp)
dt	dry ton
EC	European Commission
st	short ton
CHP	Combined Heat and Power
GJ	Giga Joule
EEA	European Environment Agency
EU15	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom
EU25	Austria, Belgium, Czech Republic, Cyprus, Denmark, Estonia, Finland, France,Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom.
EU	EU25 + (Bulgaria and Romania)
GHG	green house gas
IEA	International Energy Agency
kWe	kilowatt electricity
kWh	kilowatt hour
MBP	Mixed Biomass Pellets
Mtoe	million tons of oil equivalent (toe)
NCV	Net Calorific Value
OECD Europe	includes Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey and the United Kingdom (IEA 2009)
RED	Renewable Energy Directive
RES – E	electricity produced from renewable energy sources

CONVERSION TABLES

Conversion Tables for Energy

To:	**TJ**	**Mtoe**	**Mbtu**	**GWh**
From:		multiply by:		
TJ	1	2.388×10^{-5}	947.8	0.2778
Mtoe	4.1868×10^{4}	1	3.968×10^{7}	11630
Mbtu	1.0551×10^{-3}	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	8.6×10^{-5}	3412	1

Source: IEA

Coversion Tables for Mass

To:	**kg**	**T**	**lt**	**St**	**lb**
From:			multiply by:		
kilogram (kg)	1	0.001	9.84×10^{-4}	1.102×10^{-3}	2.2046
ton (t)	1000	1	0.984	1.1023	2204.6
long ton (lt)	1016	1.016	1	1.12	2240
short ton (st)	907.2	0.9072	0.893	1	2000
pound (lb)	0.454	4.54×10^{-4}	4.46×10^{-4}	5.0×10^{-4}	1

Source: IEA

Chapter 1: Introduction

Recent energy crisis in 2008 caused by the litigation between Russia and Ukraine about Ukrainian's natural gas debt, demonstrated Europe's dependence on imported energy resources. Imports from Russia constitute 40.8% of all natural gas imports (EC 2010). Given the current level of energy consumption, EU's dependence on imported gas is expected to increase from 57% in 2007 to 84% by 2030 (EC 2007a). Oil imports are expected to increase from 82% to 93% of total energy consumption in 2030 (EC 2007a). The challenges of climate change, increasing dependence on import and higher energy prices are faced by all EU members (EC 2007a).

Nuclear energy comprises the largest share of total energy production (28%), followed by solid fuels (22%), gas (20%), renewables (16%) and oil (14%). Table 1 lists the distribution of the energy produced and consumed in the EU.

Table 1. Energy production, gross inland consumption and imports from Russia (given as a share of consumption) in EU (in 2007)

	Production		Consumption		Imports from Russia
Energy type	Mtoe[1]	%	Mtoe	%	%
Nuclear	241.26	28.07	241.26	13.35	-
Solid	187.78	21.85	331.23	18.34	26.2% (coal)
Gas	167.36	19.47	432.41	23.94	40.8%
Oil	121.62	14.15	656.93	36.34	34%
Renewables	138.83	16.15	141.03	7.81	-
Other	2.6	0.30	3.51	0.20	
Total	859.45	100	1,806.38	100	-

Source: EC, Directorate-General for Energy and Transport (2010)

In 1997, the EC published a White Paper with a target for the share of Renewable Energy Sources (RES) in total energy consumption to 12% for 2010 (European Renewable Energy Council 2004) while in directive (2001/77/EC) from 2001 Commission set indicative target of 22.1% for electricity to be produced from renewables in 2010 (EC 2001). With the 2004 enlargement, the EU's overall objective became 21%. Based on current trends, with 7.8% share of renewables in EU gross inland energy consumption (EC 2007a) and 15.6% of electricity produced from renewables, Europe is still likely to fail to meet its renewable energy targets for 2010 despite the legislation, the recommendations, the exhortations and even legal proceedings against some Member States (EC 2009b). In 2007, Commission proposed new legislation (RED) covering all renewables and set new targets for 2020 to ensure a sTable regulatory framework for the decade ahead (EC 2009). The following targets were endorsed in this directive: reducing GHG emissions by at least 20% compared with 1990, improving energy efficiency by 20%, raising the share of renewable energy to 20% and increasing the levels of biofuels in transport fuels to 10%.

Energy–related emissions accounts for 80% of all GHG emissions in the EU (European Environment Agency 2008), and contribution of renewables is expected to grow as a result of a strong EU commitment to achieve its targets regarding these emissions (EC 2008b). One limitation to achieving these RES target shares could be the limited availability of biomass in Europe. Europe is not considered a region with a high ratio of biomass production potential to expected energy demand, and biomass imports are likely to make an important contribution in the EU renewable energy consumption (EC 2007c).

Currently, the EU meets about 98.4Mtoe of its energy needs from biomass or 5.4% of total gross inland energy consumption, while at the same time its primary production of biomass and waste was 96.2 (Figure 1). For the most part, biomass is used in the heating sector which accounts for 50% of the total EU energy consumption. Solid biomass, with 52% share in total heat produced from renewables in 2007 (OECD Europe countries), followed by the municipal waste with 35.6 %, is the most important renewable energy source for heat production (Figure 2). In electricity sector, solid biomass accounted for 6.9% of total electricity produced from renewables in OECD Europe in 2007 (IEA 2009). Wood pellets, as currently one of the largest solid biomass traded commodity (Heinimo and Junginger 2009) are expected to contribute significantly to the reaching the 2020 targets, especially for their use in electricity and heat production.

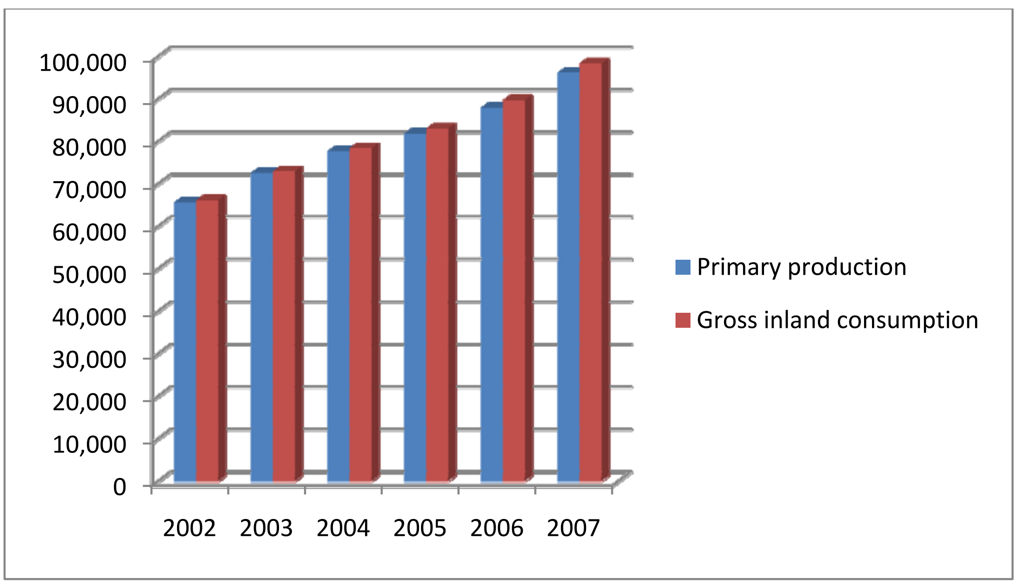

Figure 1. Gross inland production and consumption of biomass and waste in EU (in Ktoe). Source: Eurostat

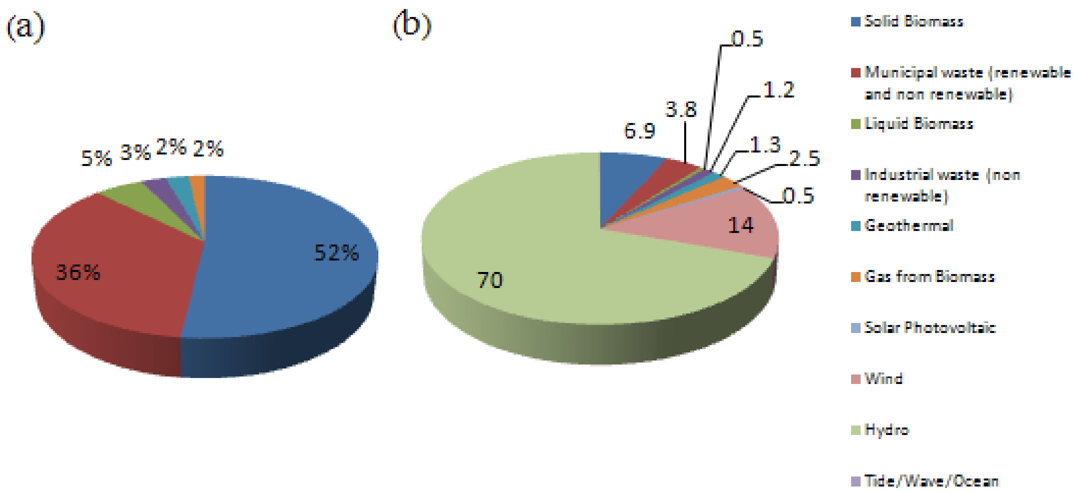

Figure 2. Distribution of different renewable and waste sources in gross heat (a) and electricity (b) produced from renewables and waste in OECD Europe in 2007. Source: IEA 2009

The wood pellet market in Europe has significantly increased during the past few years. Initially, wood pellet production in Europe started in Sweden during the 1980s as a result of a second oil crisis, but real development of Swedish market began as a result of fossil fuel taxation in 1992. This fiscal measure made wood pellets competitive with other fuels, especially in years with high oil prices (Dicken 2008).

Production, consumption and prices of wood pellets differ across EU member states, as well as their usage (industry, municipality buildings, residential and district heating and co-firing with coal in electric power utilities). Most differences among countries originate from differences in raw material availability, market development, and the energy content to price ratio between wood pellets and other fuels. While some of the EU countries are largely self-sufficient (Germany and Austria) others like Belgium, Netherlands, Italy, Denmark and Sweden depend on imports of wood pellets (Sikkema at al. 2009).

World's largest producers, United States, Germany, Canada and Sweden, produced around 1,800,000, 1,460,000, 1,405,000 and 1,400,000 tones of wood pellets in 2008, respectively (Spelter and Toth 2009, Sikkema et al. 2009). Canada used to be a major exporter to the European market exporting around 90% of its production in 2008, mainly to EU (Spelter and Toth 2009). Recently, U.S. also became an exporter of wood pellets (Figure 3) with 20% of total production shipped to the EU (Canada shipped 90%) in 2008 and surpassing Canada's export in 2009.The U.S. was mainly producing and importing wood pellets from Canada for domestic consumption until 2007, before construction of couple of big export-oriented pellet mills (mostly in the Southern US). This significantly increased U.S. production capacity and made it the largest exporter of wood pellets to EU in 2009 with 534,000 tons, followed by Canada with 520,000 tons and Russia with 377,000 tons (Appendix, Table A1). The US exports of sawdust, wood waste and scrap to EU (whether or not agglomerated in logs, briquettes, pellets or similar forms) increased from 7.5 thousand tons in 2007 to around 500,000 in 2009 with Belgium and Netherlands importing 97% (Table 2).

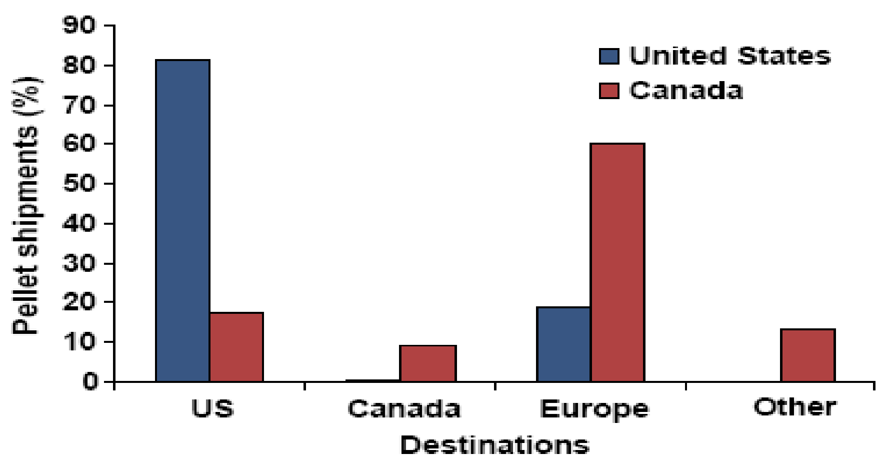

Figure 3. Destinations of pellets shipments by region in 2008.
Source: Spelther and Toth (2009)

Table 2. U.S. exports of sawdust and wood waste and scrap to EU (whether or not agglomerated in logs, briquettes, pellets or similar forms)

	2007	2008	2009
Belgium	19,000	121,122	259,030
Netherlands		49,782	235,222
Other	7,633	4,283	1,375
Total	26,633	175,187	495,627

Source: U.S. International Trade Commission (2010)

The U.S. wood pellets are exported mostly through ports of Panama City, Florida and Brunswick, Georgia in Panamax or Handymax vessels, with average overseas shipments between 20,000 – 30,000 tons according to Sikemma et al. (2009). Currently the biggest pellet mill in the world in Cottondale, FL (500,000 tons capacity) transports its wood pellets (mainly from yellow pine and sawdust) 100 km to the south to Panama City with bottom-unloaded wagons, where they are stored in a large hall with 35,000 tons capacity before they are shipped to EU (Junginger, Sikkema and Faaij, 2009; Sénéchal and Grassi 2009). The main destination for exported wood pellets to EU is the port of Rotterdam. It is expected that with increasing amounts of imported wood pellets from North America and with raw materials becoming scarce in North-Western Europe, Rotterdam could become a major hub where wood pellets would be transferred from large ocean ships to smaller river barges and vessels (Hiegl and Janssen 2009).

The production and use of wood pellets as fuel has begun in Canada and the United States during the first oil crisis in the 1970s (Dicken 2008). At that time, they were used mainly as a heat source in industrial, commercial and institutional sectors (Peksa-Blanchard et al. 2007). The creation of residential wood pellets market in USA started with sales of the first wood pellet stoves in 1983 (Peksa-Blanchard et al. 2007). Today, around 800,000 homes in USA use wood pellets for heat in freestanding stoves, fireplace inserts and furnaces (PFI 2009). With about 110 pellet plants in operation, North American pellet producers increased their production capacity from 1.1 million tons in 2003 to expected 6.2 million tones in 2009 (Spelter and Toth 2009). The South has the largest share of U.S. capacity with 46% followed by the Northeast, the West and the Midwest with 24%, 16% and 14%, respectively (Figure 4). U.S. wood pellet mills produced around 1.8 million tons in 2008 (Figure 5), with 66% of total capacity use, while Canada produced 1.4 million tons or about 81% of capacity (Spelther and Toth 2009). This represents a significant increase from 800,000 tons produced in around 60 pellet mills in 2006, according to Wood Pellets Association of Canada. Junginger, Sikkema and Faaij estimated that US consumed around 2.3 million tons of wood pellets in 2008 (Appendix, Figure B1).

The strong development of Canadian wood pellet industry and recent increase in U.S. production-capacity is mainly driven by a growing demand in EU member states as a result of strong commitments for GHG emission reductions and renewable targets set for 2020. These trends are largely dependent on many factors but especially on: pellet prices in EU, supply from other regions, change in climate policies in the U.S. and ocean freight rates (Junginger, Sikkema and Faaij, 2009).

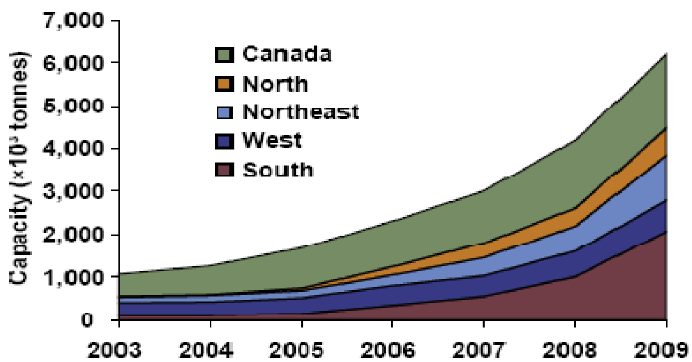

Figure 4. Wood pellets production capacity in North America
Source: Spelther and Toth (2009)

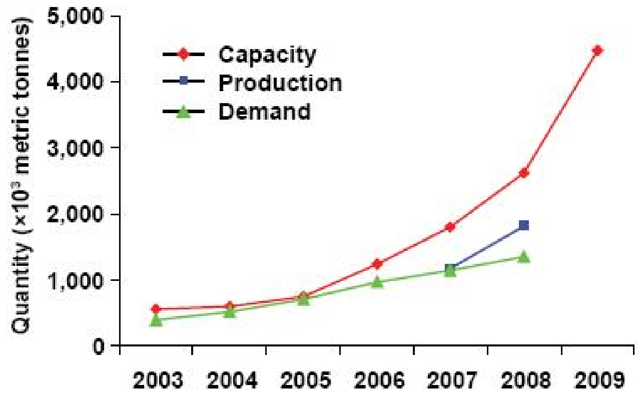

Figure 5. Total capacity, production and consumption of wood pellets in the US.
Source: Spelther and Toth (2009)

However, the Canadian wood pellets market is still weak due to a lack of favorable energy policies for biomass, and domestic consumption is not expected to increase without their implementation (Junginger, Sikkema and Faaij, 2009). Two primary markets for pellets exist in USA: retail market for residential heating and industrial and institutional and utility sector. Around 95% of U.S. wood pellet production is consumed in residential heating sector as Premium pellets, while the rest is being consumed as utility grade pellets in school boilers, commercial office buildings and industrial plants (BBI 2009).

The Pellets Fuel Institute (PFI), a trade association of wood pellet manufacturers, industry suppliers, appliance manufacturers and retailers, proposed new pellet standards to the industry that are supposed to replace its original set of standards from1995 (BBI 2009). The new classification scheme is shown in Appendix Table A2 and it specifies requirements for four different pellet grades. With present technologies for pelletizing, only pellets made from clean, white wood can meet ash limit criteria for residential use, both in USA and Europe (BBI 2009). Due to their higher ash content, it is most likely that pellets made from agricultural biomass and dedicated energy crops, will be classified as utility grade. The European pellet standards are shown in Appendix Table A3 for comparison.

Data for utility grade pellets is scarce, because contracts are usually made on individual basis between pellet manufacturer and utility. Pellet Fuels Institute (PFI) estimates that utility-grade pellet market is quite a bit larger than the 100,000 tons of pellets per year. According to the IEA Biomass Division, there were 40 ongoing and experimental projects for co-combustion of biomass with coal in USA (as of 2005) (Appendix, Table A4). Only one plant, located in Missouri used pellets for co-firing. Demand for utility grade wood pellets in USA would increase significantly if certain policies, like those related to renewable targets and GHG emissions reduction in EU would be enacted.

Although pellets can be produced from round wood they are usually made from cheaper residues from wood processing industry like sawdust, shavings or grounded wood chips. Both softwood and hardwood residues may be used. Around 69% of the raw materials used for pellet manufacturing comes from sawmill residues, 14% from furniture and millwork residues, 16% from pulpwood and logging residues and only about 1% comes from urban wood (Spelther and Toth 2009). The pellet production process includes compression of raw material under high pressure and temperature into wood pellets, and usually includes: reception of raw material, screening, grinding, drying, pelletizing, cooling, sifting and packaging (Peksa-Blanchard et al. 2007).

Recent crisis in the U.S. housing market caused less building of wooden houses, therefore decreasing the lumber production and its byproducts sawdust and shavings (Junginger, Sikkema and Faaij, 2009). The main consumers of wood waste are historically: particle board, medium fiberboard and pulp production sector (Spelther and Toth 2009). Figure 6 shows the balances between demand and supply for sawdust, shavings and sunder dust over the past decade. Significant decrease in supply and narrowing of the gap between supply and demand is a result of crisis in the housing market and shows drawbacks of pellet industry's reliance on residues availability (Spelther and Toth 2009). The result was a reduced supply of raw materials to pellet producers, especially in 2008 and 2009. However, increased demand for wood pellets and competition for raw materials with other industries can create possible raw material shortage and increase wood pellets prices. This will, together with technology improvement for production and combustion, possibly create a market for MBP pellets, including switchgrass.

Contracts for utility-grade pellets are done on an individual basis directly between a pellet manufacturer and an end user (BBI 2009). Premium residential pellets, with their larger market, are often sent to distribution centers before eventually ending up at retailers around the country. The PFI also offers a Table that is updated weekly where pellet mills can let it be known that they have fuel inventory ready to ship.

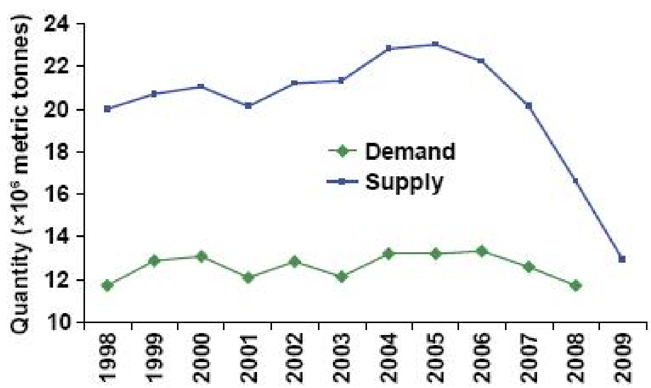

Figure 6. North American wood residue supply (softwood lumber, hardwood lumber and pulp wood) and demand (pellets, medium density fiberboard, pulp and particleboard). Source: Spelther and Toth 2009.

As of early 2009, the average price for premium pellets (sold in 40 lb bags) in the U.S. is $296/ton (BBI 2009). The price has risen considerably in the past few years, corresponding to an exponential rise in the use of pellet-burning appliances that has led to supply shortages of pellets. Publically-available data does not exist for industrial grade pellets in the U.S. In Europe, industry trade group Pellet Atlas reports that MBP currently sell for €164/ton, or $218/ton (BBI 2009).

With the Kyoto protocol's commitments and renewables fiscal incentives, tax and duty exemptions and subsidies in all GHG emitting sectors, developed countries have an incentive to import wood pellets. Little is known about whether the price and quality of US wood and switchgrass pellets would be competitive in the EU, but US pellet producers have an opportunity to penetrate the fast-growing EU market. To be competitive, export-oriented US producers would have to synchronize their production processes with EU standards regarding energy-related emissions and ash contents of pellets, and acquire information about possible trade barriers. Rapidly expanding EU demand might also provide an opportunity for US switchgrass pellet producers to penetrate the EU market, because of the greatly reduced CO_2 emissions from switchgrass pellets compared to those of fossil fuels (Jannasch et al. 2001).

Few studies with focus on wood pellet markets have been conducted on the global level (Peksa-Blanchard et al. 2007). Fewer studies have evaluated the European wood pellet industry and market, and more specifically no research has been found estimating the future demand for imports of wood pellets and how U.S. may supply a portion of these pellets.

Research Objectives

The objectives of this research are:

1) To determine the demand in the EU for imported wood pellets in 2020 based on different technology and policy settings

2) Evaluate the feasibility for US wood and switchgrass pellets to enter the EU pellet market, given the current pellet industry in the EU.

This thesis will be divided into two major sections: one which examines EU demand for wood pellets and a second which assesses the ability of the U.S. to supply potential EU wood pellet needs.

Chapter 2: Literature review

In 2007 a project began to develop and promote transparency in the European pellet market. Its purpose was to induce trade and remove market barriers (European Pellets Center 2008). Several reports were created as outcome of this project: Hiegl and Janssen (2009) gave an overview of European pellet market with special attention on two main markets for wood pellets: for residential heating and for industrial use; Sikkema et al. (2009) described national wood pellet markets, pellet flows and price development, in their final report on producers, traders and consumers of wood pellets; Capaccioli and Vivarelli (2009) gave projections for future trends in production and consumption of both wood pellets and MBP pellets till 2020 in their paper "Projections on Future Development of European Pellet Market and Policy Recommendation". Capaccioli and Vivarelli assumed the following periods for wood pellets market: strong development (up to 2011), normalization (2011-2013), difficult (2013-2015) and stabilization (2013-2020) and assigned different yearly increase rates for production and consumption for each of them (Appendix, Table A5). The results show that imports of wood pellets will be a necessity, reaching more than 7 million tons in 2020. In their second paper they classified pellet markets by consumption into (Appendix, Table A6): developed, emerging and new ones and analyzed them (Capaccioli and Vivarelli 2009a). Applying different constant increase rates for production on different types of the markets (5%, 7% and 1% for developed, emerging and new markets, respectively), projected production in 2020 would be 14.7 million tons (Capaccioli and Vivarelli 2009). In the same study they estimated production levels for MBP on 2.5 million tons in 2020.

The statistical pocket book publication (EC 2010) contains a section with data on energy consumption, production, prices and taxation, which makes it a good source for comparing energy sources among countries. The IEA "Renewables Information" publication for 2009 and IEA database includes data on energy balances of all renewable sources for 1990 – 2007 (IEA 2009). It also contains data on use of different biomass sources for heat and electricity production for the same period. Statistical database of European Union (Eurostat) is a valuable source of information on biomass production, consumption and imports including the imports of wood pellets since January 2009.

Dicken (2008) presents the parameters for the present European pellet standards for small domestic stoves and boilers. Alakangas et al. (2006) described common European standard for classification and specification (CEN/TS 14961). This standard classifies solid biofuels by their origin and source in following subcategories: woody biomass (Appendix, Figure B2), herbaceous biomass (Appendix, Figure B3), fruit biomass and blends and mixtures. This enables traceability of fuel production back over the whole chain. The equivalent standard in the US and Canada is

ASTME 870 (standard test method for analysis of wood fuel) for premium grade, which means that only pellets of this characteristic can be exported into EU for residential use (Dicken 2008). In his paper, Pichler (2009) gives an overview of European pellet – related standards development, pellet quality issues in different countries and new pellet certification scheme.

According to the study of Hilring (2006) Europe accounted for only 5.9% of total World's production of wood fuel in 2002, while at the same time share of Europe in World's imports of forestry products was 45.1%. The study from Skytte, Meibom and Henriksen (2006) showed that increased imports of biomass in the future will increase electricity produced from biomass (Figure 7), significantly reduce the cost for reaching the renewables targets, but will cause a decline in utilization of energy crops and decrease in use of agricultural residues within EU (Appendix, Table A7).

The same study concludes that countries with the largest biomass resources and developed energy system for biomass utilization are expected to be the major importers of biomass from outside the EU. For some countries like Belgium, Netherlands, Italy, Spain and Portugal it would be cheaper to import certain amounts of renewable electricity to achieve their targets than to use domestic sources solely (Uyterlinde et al. 2003).

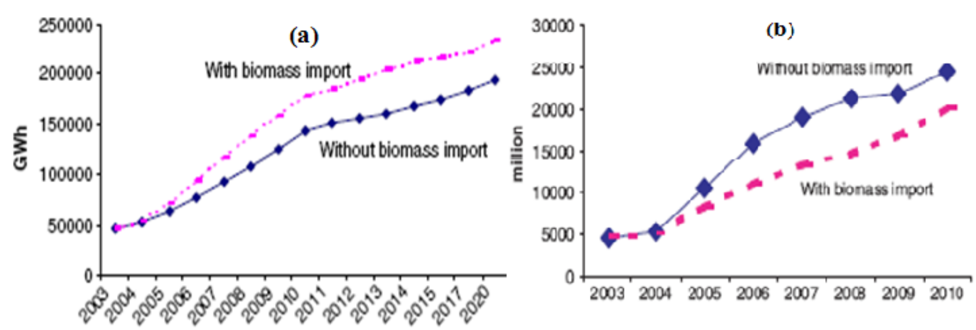

Figure 7. Total electricity generation from biomass-fired plants (a) and total cost (in euros) of target compliance (b) in EU15 with and without biomass imports. Source: Skytte, Meibom and Henriksen (2006)

An overview of biomass potential for production of densified biofuels (Parikka 2004), shows that the total sustainable world's biomass energy potential is about 100EJ/a, with woody biomass contributing 41.6 EJ/a, which represents 12.5% share in total global energy consumption today. Berndes et al. (2003) reviewed 17 different studies on the contribution of biomass in future energy demand. The projected contribution of biomass in these studies differs from $100EJy^{-1}$ to $400EJy^{-1}$ in 2050.

Hoogwijk et al. (2003) identified following factors that determine biomass availability for energy: *(1) The future demand for food, determined by the population growth and the future diet; (2) The type of food production systems that can be adopted world-wide over the next 50 years; (3) Productivity of forest and energy crops; (4) The (increased) use of bio-materials; (5) Availability of degraded land; (6) Competing land use types, e.g. surplus agricultural land used for reforestation.*

The EUBIONETIII project funded by the EU's Intelligent Energy for Europe program, has the main objective to increase biomass-based fuels use in the EU by finding ways to: overcome the market barriers, promote international trade and secure the raw material at reasonable price. Analysis of abovementioned is included in the final report of EUBIONETIII project by Junginger and Alakangas (2010) and also includes individual country reports with an overview of: biomass use in new industries, current potential and use of solid biomass and international bioenergy trade in selected countries.

In their study, Siemons et al. (2004) used an equilibrium model (SAFIRE) to provide estimates for bioenergy's contribution to the EU energy market by 2010 and 2020 while taking into consideration various policy instruments. The SAFIRE model simulates the energy market in two steps: with technical potential given as input and with determination of market potential and penetration by simulation of economic decision making.

The ADMIRE REBUS project team used dynamic market simulation model (ADMIRE REBUS model) to analyze the market barriers, support policies and potentials for renewable energy production in Europe (Uyterlinde et al. 2003). In this model, national renewable energy electricity supply curves are matched with policy–based demand curves (Figure 8). The model showed that biomass use will increase if policy ambition level increases, with significant increase in biomass for CHP and biomass co-firing, with establishment of a common Tradable Green Certificate (TGC) scheme, compared to continuation of current policies (Figure 9). The strong projected increase in use of CHP and co-firing technologies is result of their larger competitiveness in comparison with other biomass and renewable technologies in general (Uyterlinde et. al 2003).

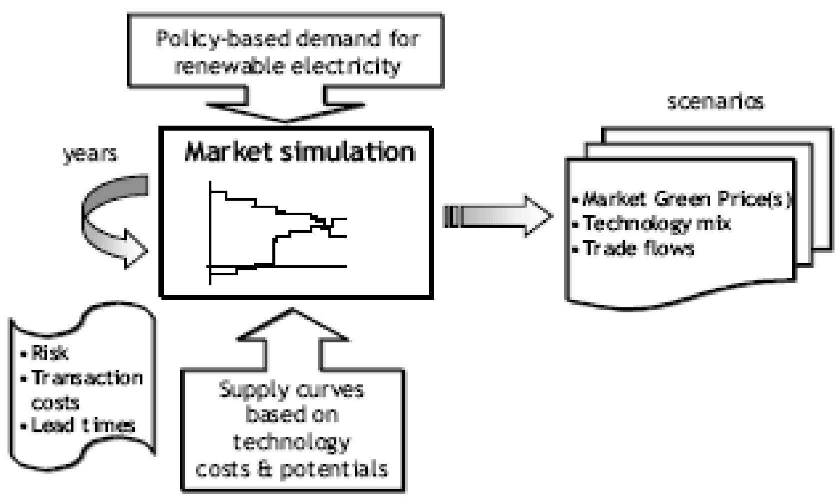

Figure 8. The ADMIRE REBUS model scheme
Source: Uyterlinde et al. (2003)

Co-firing is not largely supported under specific policies like feed-in tariffs, but within TGC it becomes one of the cheapest options (Uyterlinde et. al 2003). The biomass-fired CHP's and co-fired facilities will benefit more from the TGC scheme introduction than other biomass technologies, such as gasification, anaerobic digestion (biogas) and ordinary biomass combustion (Uyterlinde et. al 2003). Dornburg (2008) showed that co-firing with coal has the lowest investment cost (€/kWe) compared to other biomass combustion technologies. The study also shows that cost of electricity produced in co-fired plants is the lowest compared to other biomass conversion technologies. Co-gasification and co-firing are expected to have the lowest cost of production in 2020 (Appendix, Figure B4).

In his overview of European renewable policy development, Blok (2006) concludes that support schemes on national level like feed-in tariffs and tax exemptions are still needed, until development of the renewable energy market enables the support system to evolve to European support system based on renewable energy obligations and tradable green certificates.

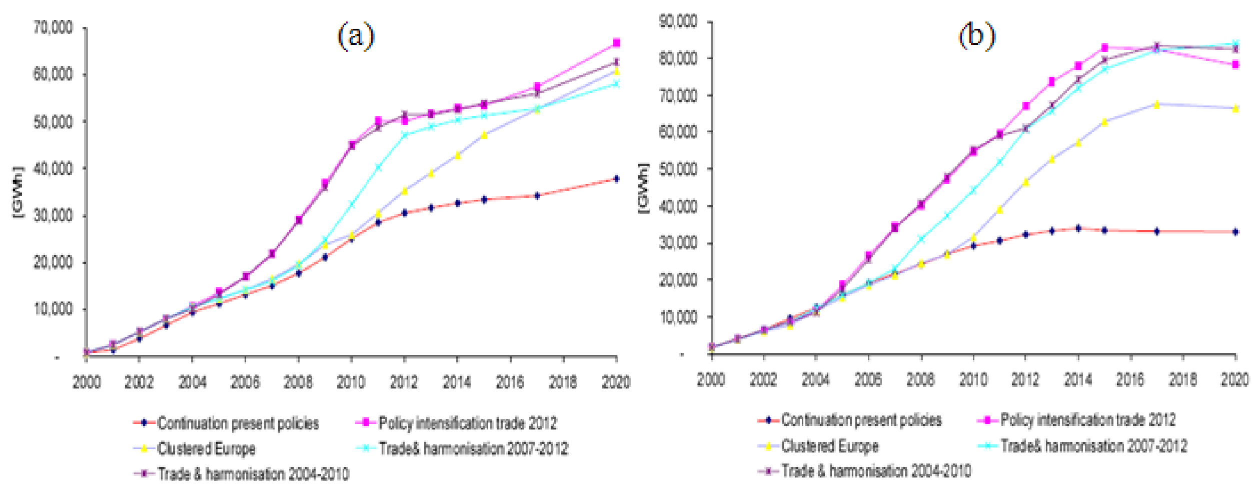

Figure 9. Biomass CHP (a) and co-firing (b) development under different policy scenarios. Source: Uyterlinde et al. (2003)

One study (Malisius et al. 2000) has analyzed the market potential, technical and non–technical obstacles and strategies for wood pellets. The study describes production process, applications and combustion technology for wood pellets. The same study also describes pellet distribution systems, storage and market characteristics with strategies for market penetration. Their study included Sweden, Austria and Germany as the only countries in Europe with developed pellet markets in 2000, and Norway for its raw material potential.

Thek and Obernberger (2004) investigated, calculated and compared production cost loco factory for different framework conditions in Austria and Sweden using data from already realized plants and questionnaire survey of pellet producers. Study showed that an economic production of wood pellets requires at least three shifts per day and 5 days per week operation, with optimum of 7 days per week and 85-90% of plant availability. According to the same study, raw material and drying cost can contribute up to one third of total cost. The lower price for electricity and larger plant capacities resulted in lower cost for wood pellets in Sweden.

Mani et al. (2006) performed an engineering economic analysis of a biomass pelleting process for North American conditions, with estimates for several plant capacities. They reported $51/t production cost, with raw material cost being the largest cost element. The increase in raw material price, substantially increased production cost. An increase in plant capacity significantly decreases pellet production cost (Mani et al. 2006; Thek and Obernberger, 2004). Figure 10 shows changes in pellet production cost with changes in pellet production rate and raw material cost. Mani et al. (2006) also showed that use of different fuels for drying process has a substantial impact on the final cost of pellets, with wet sawdust and coal producing the lowest cost.

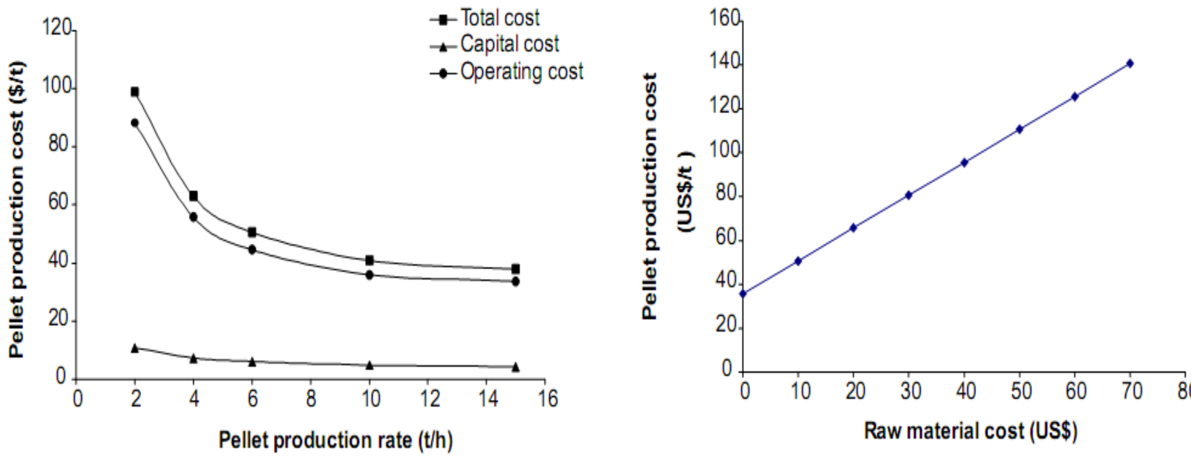

Figure 10. Change in pellet production cost with change in production capacity and raw material cost. Source: Mani et al. (2006)

Pastre (2002) analyzed technical obstacles related to the transformation of agricultural residues (mainly straw) into fuel pellets and problems with their utilization. The importance of raw material availability and production cost was also emphasized. According to the same study, the main difference between wood and agri-pellets is the higher friability and the slightly lower energy content of agricultural pellets. The study concluded that agri-pellets should be used mainly in large heat and power plants with sophisticated combustion-control systems and flue gas cleaning system, due to their environmental impact and ash, nitrogen, sulphur, chlorine and potassium content (increased by the use of fertilizers and chemicals in agriculture).

A commercial-scale pelletizing trial (with switchgrass as feedstock) conducted by REAP – Canada in Ste. Marthe, Quebec in 2001 pelletized 9 tons of baled switchgrass with 14,5% moisture (Jannasch, Quan, and Samson, 2001). Results showed that switchgrass can be pelletized without drying (cost reduction by $8-12 per tonne) and pellet throughput was 2 tonnes/h rate similar to that of wood. The percent yield of 91% on a dry matter basis was achieved after the loss of fines during the pelletizing, cooling and temporary storage stages. If pellet fines were returned to the pellet mill, the yield would probably be increased to 95%. Other pilot plant studies on switchgrass pelleting were performed with the support of the Natural Resources Canada and were performed by California Pellet Mill-CL type 5 lab model pelleter and a 25HP (9.3MJ/h) CPM Master mill (Samson et al. 2000).

In the final report of their market study, Jannasch et al. (2001b) presented some advantages of switcghrass as a pelleted biofuel, like lower carbon dioxide emissions (8,17kg CO_2/GJ compared to 62.13, 89.67, and 57.32 kg CO_2/GJ for natural gas, heating oil and electricity, respectively). Thus, heating with switchgrass pellets reduces carbon dioxide emissions between 86 and 91% compared to conventional energy sources (Jannasch et al. 2001a). Jannasch et al. (2001) also found that the annual cost of heating a 2000 ft^2 home with switchgrass pellets in Dell Point Technology's 34,000-BTU space heater is $1213, compared to $2,234, $1,664, $882 and $2,302 for electricity, heating oil, natural gas and propane, respectively.

Switchgrass behaved similarly to alfa-alfa during pelleting and was significantly easier to pellet than hardwood/softwood raw material (Samson et al. 2000). The conditions like fine length of chop (use of hammermill with a 7/64 or 2.8mm screen), high temperature steam treatment of >110°C (250F) (to release natural binders and lubricants) and adequate die selection (length/diameter in the 9-10 range) are necessary for switchgrass pellets to achieve high throughput and good durability (Samson et al. 2000).

Hu et al. (2010) reported similar chemical bulk properties for four different populations of switchgrass (Alamo, Kanlow, GA993 and GA992) with the most significant differences in ash and lignin content (Table 3). The time of harvest, influence the ash content of switchgrass, with values for spring harvested roughly 0.5-1% lower than one harvested in fall (Samson et al. 2000). Spring harvest also enables nutrients leaching during the winter, thus reducing potassium and chlorine concentrations to 0.06% and 0.02%, respectively, significantly lower than recommended values (Samson et al. 2000). The lower ash content of switchgrass allows for higher energy content of 18.2MBtu/t for spring harvested material and 18.5MBtu/t for fall harvested material, which is just slightly lower than that from wood (18.8MBtu/t) (Samson et al. 2000).

Study from Colley et al. (2006) showed that moisture content significantly affects physical properties of switchgrass pellets. Increased moisture content increased the diameter of pellets by 8% (varied from 4.85 to 5.25mm) while decreasing the length by 17% (Appendix, Figure B5). A maximum durability of 95.91% was obtained with pellets moisture of 8.6%. Already mentioned laboratory-scale model CL5 from California Pellet Mill Co was used for the study

Luppold and Bumgardner (2009) examined changes in sawmill concentration and hardwood lumber mill production in Tennessee in 1979-2005 period. Results showed that large mills (>10 MMBF) share in total annual production of lumber in East Tennessee reached 61% in 2005, a significant change from 0% in 1979 (Table 4). According to Luppold and Bumgardner (2009) increase in saw mills concentration in East Tennessee has been facilitated by relatively low delivered-log prices and improved highway system.

Table 3. Lignin and ash content in switchgrass (based on oven-dried weight)

Switchgrass population	Lignin (%)	Ash (%)
Alamo	21.2	3.8
Kanlow	22	3.5
GA993	22.6	4
GA992 (W)	22.4	3.6

Source: Hu et al. (2010)

. Table 4. Percent share of different-size East Tennessee hardwood sawmills in total annual production for 1979-2005

Eastern region					
Year	Very small (<0.99MMBF)	Small (1 to 2.9MMBF)	Medium (3 to 4.9MMBF)	Large (5 to 9.9MMBF)	Very large (>10MMBF)
1979	28	49	17	6	0
1984	21	50	24	5	0
1989	15	36	27	11	12
1999	8	9	8	20	55
2005	6	8	10	14	61

Source: Luppold and Bumgardner (2009)

Jensen et al. (2007) conducted analysis of Tennessee's farmers' willingness to supply switchgrass to the energy market. Although results showed that many farmers, at the time the study was conducted, had never heard about switchgrass, almost 30% were willing to grow it if it would be profiTable. They were concerned that market was not developed yet and that they would need technical assistance for the production of switchgrass. Study showed that those farmers with higher off-farm income were more willing to convert their land than those with higher net farm income, reflecting the opportunity cost of converting land out of its current use.

While desire to provide wild habitat, market development, use of contracts and potential harvest limitations under CRP influenced land share farmers would be willing to convert to switchgrass, others like: role in reducing atmospheric emissions, need for subsidies use and government payments to grow switchgrass did not influence farmers' willingness to convert. Researchers from Center for Agricultural Development at Iowa State University concluded (in 2007) that farmers would consider growing switchgrass instead of corn for any of the following scenarios: 8.96 tons/ha yield and $121 price/ton or 13.4 tons/ha and $90/ton (Campbell 2007).

Allison et al. (2009) estimate that average and maximum yields of switchgrass as biofuels feedstock in Tennessee will be 6.7 and 14.5t/ha, respectively, using Environmental Policy Integrated Climate process-level agroecosystem model from over 7,700 30-year simulations (Figure 11).

Biomass utilization study for Aitkin County in Minnesota (BBI 2009) explored the opportunity to utilize biomass resources for renewable electricity generation. Four different scenarios with different quantities of feedstock processed (50,000 tons and 100,000 tons) and different end uses (pellets and CHP energy) were evaluated. The study showed that 100,000 tons of feedstock – biomass pellet scenario produced the greatest annual average return on investment (26.8%) and internal rate of return (24.1%) compared to other scenarios. Table also shows that investment in a pellet-plant is considerably lower than if the plant also produces energy. The larger-scale scenarios produced better financial yields as a result of economies of scale. The feedstock and pellet-price variability are the main factors influencing financial result after servicing construction debt (BBI 2009).

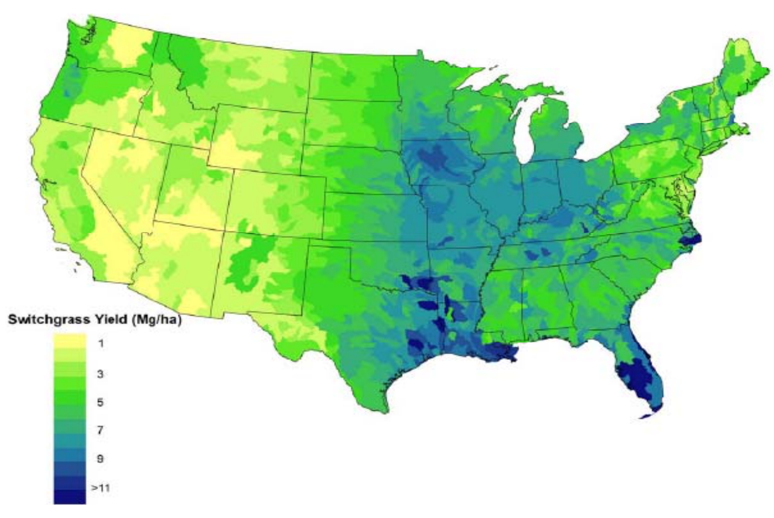

Figure 11. Simulated potential for 30-year average switchgrass yield for lowland and upland ecotype, with one harvest per year. Source: Allison et al. (2007)

The feasibility-study for an agricultural biomass pellet company from Agriculture Utilization Research Institute – AURI (Campbell 2007) contains: technical and financial information, cost estimates and industry data for two alternative scenarios: retail and utility fuel production business models for different plant sizes (2, 4, 8 and 14 tons of pellets per hour). The study's main objective was to serve as a guide for an enterprise whose primary business would be production and marketing of agricultural biomass fuel pellets (blend of corn stover, soybean straw and damaged hay and grasses).The analysis has shown that capital cost per ton of produced pellets decrease with an increase in plant size, for both scenarios. The estimated capital budget savings for utility business model with production of 14 TPH (around 100,000 tons of feedstock) compared to retail business model was $1,870,000 mainly because bagging and palleting systems are not needed in that case. Feedstock costs contribute substantially in total production cost with more than 50% share for 8 and 14 TPH scenarios. For the utility grade pellet price of $120/ton return on initial equity is 13%, -44%, -17% and 15% for 2, 4, 8 and 14 TPH, respectively.

Dornburg (2008) studied bioenergy chain consisted of biomass production, transportation and energy conversion. The study included a number of representative options for each part of the chain and two different levels of technological development: current and future one in the next decade. It also presented general parameters that characterize the cost of these chains including formulas for their calculation.

In his assessment of cost and energy consumption for various biomass energy transport chains, Suurs (2002) developed a model to create the possibility of obtaining an insight in the most important factors influencing transport systems. Different production systems, pretreatment operations, and transport options were taken into account with various transport chains being subjected to a sensitivity analysis, with respect to variables like distance, fuel prices and equipment operation time. Among all analyzed scenarios, transport chain of wood logs and pellets showed as the most attractive, while transportation of chips should be avoided due their low energy density and high production cost. The study showed that high energy costs for pelletization are being compensated by energy savings from more efficient transport operations.

Study from Siemons et al. (2004) finds that charcoal, wood pellets and bio-oil are the most attractive biofuels for import to Europe with cost for imported wood pellets between €3.8 and €5.3/GJ. They assumed that if delivered price at conversion plant for imported pellets reaches a value of €6/GJ including local transport from port to the plant, substantial imports would be realized.

Hamelinck, Suurs, and Faaij (2005) developed a tool to compare the possible bioenergy supply chains and evaluate the influence of key parameters such as distance, timing and scale on their performance. The wide range of different bioenergy chains was envisioned, including: different biomass production systems, pretreatment and conversion operations, transport of either raw or refined solid biomass, or liquid biofuels. While the study showed that European biomass residues and crops can be delivered at $110 and $87/dt when shipped as pellets, South American crops are produced for a much lower price, thus enabling for delivered cost in importing port to be as low as $50/dt despite the long-distance transport. The study also showed that feedstock cost account for between 25-40% of delivered cost and that biomass production area is restricted by expensive truck transport, thus making high yields of biomass per hectare necessity for large scale production. Truck transport should be applied only for distances less than 100km (~60 miles) when flexibility is required and when train or ship transport is not available (Hamelinck, Suurs, and Faaij 2005).

The paper from Magelli et al. (2009) analyzed the fuel consumption and emissions associated with wood pellet production in British Columbia and their export to Sweden, starting from tree harvesting and shipping from Vancouver to Stockholm. The results showed that about 39% (7.2 GJ) of the total energy content of the one tonne of wood pellets is consumed during their production and shipping to Europe with 2.6GJ associated with ocean transportation. The fossil fuel content in one tonne of Canadian wood pellets sold at European market was 19% if wood residues are used for drying and 35% for natural gas.

The study from Wang, Larson and English (2009) evaluated cost of various baling and on-farm storage systems by simulating final delivered cost to the biorefinery under two representative soil types in Tennessee and also the least-cost delivery schedule for switchgrass to a biorefinery from the processor's perspective, considering bale types and storage methods. Results showed that costs are minimized if rectangular bales are processed immediately after harvest, while round bales minimize cost if switchgrass is stored without protection for 200 days before being transported to the biorefinery. They used a mixed integer programming model to optimize the year-round switchgrass delivery schedule within 50 miles of the biorefinery in East Tennessee from the processor's perspective. Larsson et al. (2009) applied the capital budgeting and GIS to analyze the cost of three logistics methods of acquiring switchgrass feedstock for a 25 million per year refinery (Table 5). The round-bale technology without any protection produced the lowest cost ($74.38/dry st or $82/dry mt) assuming one-third of switchgrass production being delivered immediately after harvest (November to February) and two-thirds uniformly delivered from March through October. Study also showed that when the industrial compactor/baler/wrapper was used, weighted average delivered cost were only $60/dt.

The annual Renewable Energy Technical Assessment Guide (TAG – RE) provides a consistent basis to evaluate the feasibility for different renewable technologies, including biomass (EPRI 2006). It contains detailed economic data for renewable technologies which is of a great value to system planners creating long-term strategies and sustainable generation portfolios. Technical report created by NREL (Aden et al. 2002) shows lingo-cellulosic biomass to ethanol process design and economics utilizing corn stover, including: processing design and cost estimates, process economics and sensitivity analysis for parameters that are likely to vary and how they could be controlled to a definable range.

Table 5. Delivered cost of switchgrass to refinery by harvest method and storage type ($/dry st)

	Round Bale						Rectangular Bale		
Days	None	Tarp+ Pallet	Tarp+ Gravel	Tarp	Pallet	Gravel	None	Tarp+ Pallet	Tarp+ Gravel
0	70.19	NA	NA	NA	NA	NA	60.86	NA	NA
30	71.91	78.66	89.03	75.71	76.42	86.53	NA	70.72	76.33
60	73.34	79.29	89.75	76.3	77.96	88.3	NA	74.43	80.39
90	74.51	79.89	90.45	76.88	79.22	89.77	NA	77.68	83.94
120	75.48	80.47	91.12	77.44	80.26	90.96	NA	80.48	87
150	76.26	81.04	91.78	77.98	81.1	91.93	NA	82.85	89.58
180	76.89	81.59	92.42	78.5	81.78	92.72	NA	84.82	91.74
210	77.4	82.12	93.03	79.01	82.32	93.35	NA	86.45	93.52
240	77.8	82.64	93.63	79.51	82.76	93.86	NA	87.79	94.98
270	78.13	83.14	94.2	79.98	83.11	94.26	NA	88.87	96.16
300	78.39	83.62	94.76	80.44	83.39	94.58	NA	89.74	97.11
330	78.59	84.08	95.3	80.89	83.61	94.84	NA	90.44	97.87
360	78.75	84.53	95.82	81.32	83.78	95.04	NA	91	98.48
Average[a]	74.38	77.75	84.96	75.7	77.62	84.87	NA	76.09	80.64

a) Average cost weighted by the volume delivered to biorefinery each month over a year

Source: Larsson et al. (2009)

Kentucky Extension service developed decision tool for comparison of profitability of switchgrass for biofuel/bioenergy production to hay production. The tool includes establishment of a switchgrass stand and compares net revenues for biofuel production to hay production for 10-30 year time periods.

Chapter 3: Conceptual framework and methodology

The future role of biomass (including pellets), currently mainly used renewable energy source in Europe, is determined by the supply/demand of biomass and biomass derived fuels and characteristics of the conversion technologies (Siemons et al. 2004). Given the targets for renewables share in total energy consumption in 2020 and current levels of wood pellet imports in EU, its market is assumed to be dependent of imported pellets in the future. It is also assumed that US pellet producers' goal is to maximize profit.

Thus, their motivation to produce pellets intended for export depends on the potential annual profit:

$$\mathbf{PNR = PR - TC,}$$

where PNR is net revenue from pellets sold in EU; PR is price of pellets in EU and TC is total cost (including raw material cost, pelletizing cost and transportation cost). Figure 12 illustrates the relationship between major impacts on total net revenue of pellet exports from the US to the EU.

Demand for the product in a market is an important factor in making a decision of whether to produce for that market or not. It is assumed that wood pellet demand is dependent on prices of electricity, prices of fossil fuels and government subsidies for consumers or producers.

EU’s feed-in tariffs and quota obligation system on consumers or producers coupled with ambitious GHG emission reduction targets is a major driver for increased demand for biomass and its use in large-scale utilities. The policies supporting solid biomass and policies in favor of other renewables can both have significant impact on pellets demand. Investment subsidies for utilities combusting wood pellets are also an important factor.

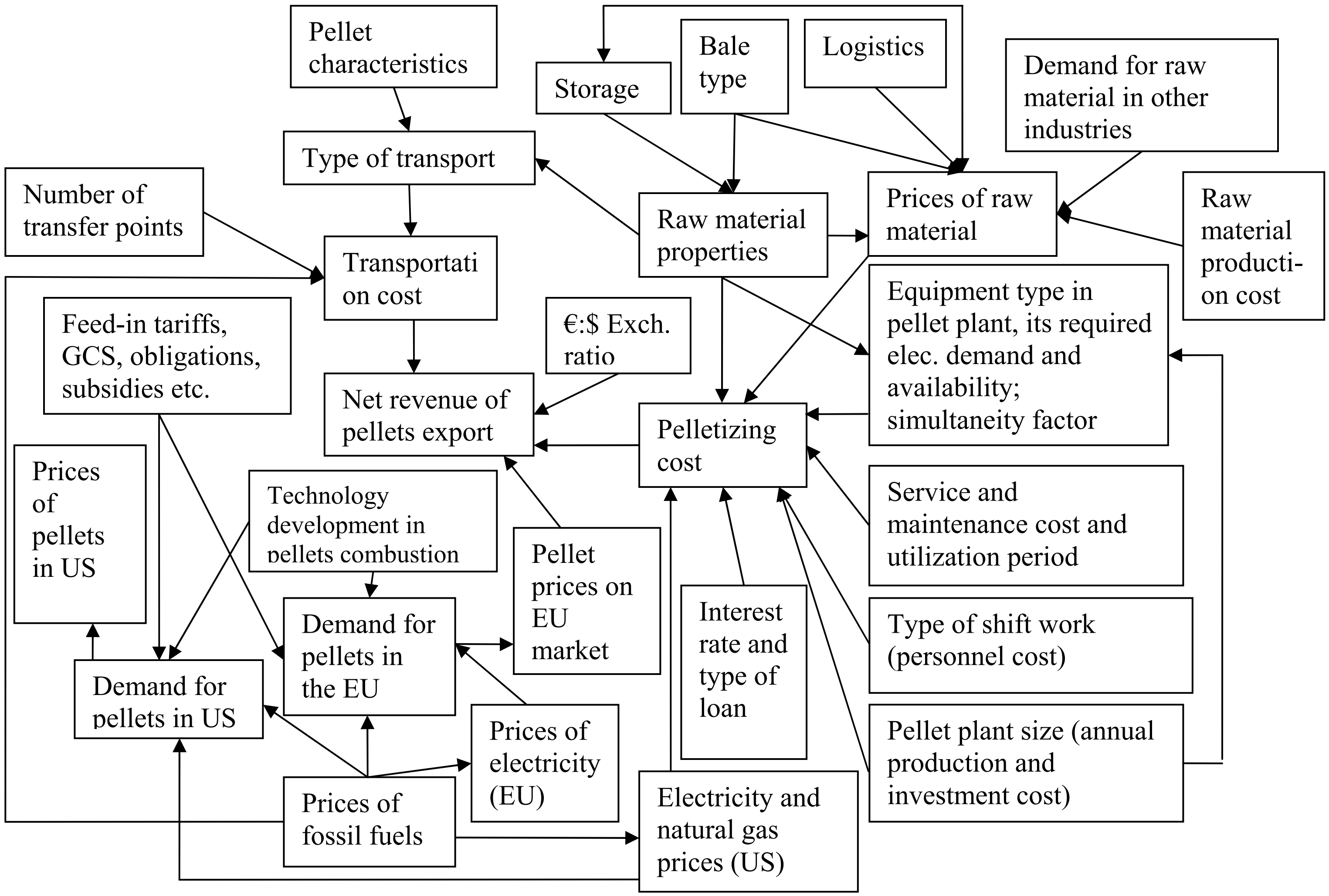

Figure 12. Relationship between factors that influence net revenue from pellet exports

Changes in demand for wood pellets cause changes in the wood-pellet price and vice versa. High electricity prices and unsecured gas supply in EU make wood pellets competitive for use in heating installations. The change in fossil fuel prices can influence both transportation and production cost of pellets. The logistic to collect the raw material might limit its amount for pellet producers, thus increasing their price. The limited weight capacities of some roads, together with lack of rail or waterway transportation close to the production plant, might increase pellets cost significantly (Alakangas and Junginger 2010).

The net revenue from pellet production is dependent on feedstock, transportation and pelletizing cost. Transportation costs depend on the number of transfer points and type of transport included in international supply chain. It usually includes transport of biomass from the field to the pellet plant, transport to the exporting port, ocean transport and transport from importing port to the final consumer in EU. Local transport to the pellet plant is performed usually by truck, while long-distance transport requires use of train or ship. If pellet plant does not have on-site access to the rail, truck transport is required to loading location. Transportation cost depend on fixed and variable cost related to distance and can be split into cost of loading/unloading, energy cost during transportation and other specific management cost (Dornburg 2008).

Feedstock can be delivered to the pellet plant in various forms: bales, chips, sawdust, shavings, bark, logs etc. Depending on its size, it may require sizing, grinding and drying operations in order to be suiTable for densification. Densification of biomass to pellets increases its density and improves its properties regarding long-distance transportation, thus making it cheaper for transport. Larger feedstock and pellet storage is required for larger pellet manufacturing facilities in order to secure feedstock supply and preserve pellet quality intended for export. Sometimes, pellets have to be stored in exporting terminal prior to shipment which also increases the total cost.

Pelletizing cost depend on: whether a plant uses its own raw materials or buys them on the market; raw material cost and properties; investment cost of the equipment used in the pellet production process (and its availability) as well as construction, offices and data processing; maintenance cost and utilization period for all equipment and facilities; number of working days and shifts (personnel cost); plant size (annual production); the price and type of fuel used in drying and heat demand; required electricity demand for all installations, simultaneity factor (assumption that not all electrical installations operate at the full load at the same time) and electricity prices; interest rate; equipment availability; characteristics of pellets (bulk density and moisture). The raw material properties (dry or with different levels of moisture, bulk density) influence the level of transportation losses, dryer type, heating level and raw material prices. The competition for raw materials with other industries (particleboard, fiberboard and pulp sector) together with raw materials availability indirectly affects the demand for wood pellets through their price. The demand for pellets in the US and EU with corresponding price levels impacts the manufacturer's decision about export of their products. Favorable exchange ratio euro/$ (stronger euro) also makes imported wood pellets cheaper and competitive on the EU market. European standards for pellets which determine types of pellets that can be used for different applications also influence export decision.

With the estimated increase in demand for pellets in EU and with net revenue for pellets sold on EU market bigger than if they were sold in US, pellets export will be profiTable.

Methodology

The wood pellets market analysis includes 27 EU countries, with special focus on countries with: developed markets, traditional biomass and wood and wood waste imports and those importing pellets for use in large heat and power utilities. The later is important because overseas trade for premium grade pellets currently does not exist and most likely will not in the close future, so this paper will focus on import possibilities for industrial pellets. However, current support schemes favor pellets use in electricity generation to their use in residential heating.

Initially, the available biomass resources in EU by type and use will be given, followed by the comparison of available potential and current use. The estimated biomass energy potentials up to 2040 will be presented to determine availability of different biomass resources for energy production in the future.

Historical data for wood and wood waste imports for 1990-2007 will be used to analyze the countries already dependent on such a trade and trends in their import levels. The share of wood pellets in imported wood and wood waste for 1990-2007 for countries with developed pellets markets, to show the increase of wood pellets imports over other woody biomass products will be calculated with following formula:

$$(1)\ \mathbf{WPIS} = \frac{\mathbf{WPI} * \mathbf{16.5}}{\mathbf{WWI} * \mathbf{3,968} * \mathbf{10^4}},$$

where: WPIS is the share of imported wood pellets in total wood and wood waste imports (in %); WPI is wood pellets import (in Mtoe) and WWI is total imports of wood and wood waste (in Mtoe). The energy value for wood pellets is 16.5Mbtu per ton (Campbell 2007), while imported wood and wood waste is converted from Mtoe to Btu's using $3{,}968*10^4$ Mbtu for 1Mtoe conversion factor (same conversion factors used for formulas 2,3 and 4).

The share of wood pellets consumption in total consumption of wood and wood waste will be calculated to show growing significance of wood pellets use as solid biomass resource. The calculation will be done using the following formula:

$$(2)\ \mathbf{WPCS} = \frac{\mathbf{WPC} * \mathbf{16.5}}{\mathbf{WWC} * \mathbf{3,968} * \mathbf{10^4}},$$

where: WPCS is share of wood pellets consumption in total wood and wood waste consumption (in %); WPC is wood pellets consumption (in Mtoe) and WWC is total consumption of wood and wood waste (in Mtoe).

The data on the imported amounts of wood pellets for 2009 will illustrate the current monthly trade flows of pellets to EU and to its biggest importers. The historical use of solid biomass in heat and electricity production will be provided for traditional importers of wood and wood waste to show the trends in different end use. The 2020 projections from IEA for solid biomass use in heat and electricity generation in selected countries will help to determine future increasing/decreasing trends in these sectors. This will help to identify the countries which are most likely to increase their future use in large heat and power utilities and possibly import industrial pellets, currently the largest traded solid biomass commodity.

The detailed description of wood pellets market with capacity, production and consumption in each of the EU members for 2008 (including the number of pellet manufacturers, the number of large consumers and imported quantities) will be used to represent the current situation in pellets market for each of EU's member-states.

Following the classification of Capaciolli and Vivarelli (2009) all EU countries will be classified in three market types for wood pellets: developed, emerging and new. They defined developed pellet markets as follows: "*Countries where the pellet market is mature, well developed, with a good historical series of data about consumption, production, importation of pellets, with already developed national standards for pellet production; also countries that export their product due to a surplus of production can be considered as developed"*. Pellet consumption and use in different sectors in developed markets will be presented to identify the countries mostly using pellets for large heat and power generation.

Then, the share of wood pellets in total imports of biomass and waste will be calculated for selected countries using the following formula:

$$(3)\ \mathbf{WPS} = \frac{\mathbf{WPI} * \mathbf{16.5}}{\mathbf{IB} * \mathbf{3,968} * \mathbf{10^4}},$$

where: WPS is the share of wood pellets import in total biomass and waste import (in %); WPI is wood pellets import (in tons) and IB as imported biomass and waste (in Mtoe).

Detailed market description for the biggest consumers and importers of industrial wood pellets will be given, with their: biomass potential, wood and MBP pellets market situation and policies and measures supporting biomass use.

Description of the SAFIRE model with its different scenarios, together with projected biomass consumption and imports in 2020 for all EU members will be given. The following two scenarios to calculate imported wood pellets in 2020 for selected countries (using projections from SAFIRE model) will be assumed:

- Same share of wood pellets in imported biomass in 2020 as in 2008 for countries traditional importers of wood pellets.
- Assumed different shares of wood pellets imports in imported biomass in 2020 (sensitivity analysis). This analysis will be performed for all countries with projected significant biomass imports.

Calculated and assumed shares will be used to estimate the volumes of imported wood pellets in 2020 in those countries, using the following formula:

$$(4)\ \mathbf{IWP} = \frac{\mathbf{IB} * \mathbf{WPS} * \mathbf{3,968} * \mathbf{10^4}}{\mathbf{16.5}},$$

where: IWP is wood pellets import; IB is imported biomass and waste (in Mtoe); WPS is estimated wood pellets share in imported biomass&waste (in %);

The possibility of producing industrial pellets in East Tennessee and their export to EU will be evaluated for location at industrial park in Vonore City (Monroe County) since it has a large number of farmers producing switchgrass under the contract in 50 miles radius and large mill residue potential. Three different feedstock scenarios will be evaluated for the plant with capacity of 100,000 tones of pellets per year: 100% switchgrass as feedstock, 100% sawdust as feedstock and blend switchgrass/sawdust with 40:60 feedstock ratio.

The study assumes that most of the potential acres planted under switchgrass would come from acres currently under hay production. The acres currently used for hay in selected counties will be presented to show total number of acres that can be converted to switchgrass production. Decision tool from Kentucky's extension service was used to calculate the price for switchgrass which creates larger NPV then if growing hay, thus motivating farmer to switch their production to switchgrass. The data from University of Tennessee Extension budgets for switchgrass were entered into the decision tool for necessary calculations.

The cost of pellets delivered to the EU market will be determined by summing: delivered cost of mill residues and/or switchgrass to the pellet plant; pellets production cost (including storage at the plant) and transportation cost (including wharfage, handling and storage at port) from pellet plant to Europe.

Data for pellets transportation cost calculations (management, energy and loading/unloading cost) were obtained from Dornburg (2008). Since the study gives these cost in euro values, they were converted to U.S. dollars using the exchange ratios from European Central Bank for the last day of 2008. The assumed pellet plant location in the industrial park has a rail line in a close proximity; thus we assumed the cost of rail construction from plant to the railroad in our budgets under site development cost. The transportation chain consists of: 1) transport from raw material production site to the pellet plant and it is being performed by truck (already included in delivered cost of switchgrass and mill residues and thus will not be calculated); 2) train transport from industrial park to exporting terminal; 3) ocean transport by ship from exporting to importing terminal (port); 4) transport from import terminal to European consumer (since we will use CIF Rotterdam price for our calculations they will not be calculated here). Only ports on the US East Coast and Mexican gulf will be considered for transportation to the EU. Although currently, only ports of Brunswick and Panama City are involved in pellet export (Camp 2010; Baird 2010) we will consider ports of Savannah, Charleston, Mobile and Jacksonville for our calculations as well, assuming that increased demand for wood pellets in EU will soon make this ports exporting terminals too.

Following formula will be used:

$$\textbf{(5) CIFR=PPC + TC,}$$

where CIFR is delivered cost of pellets in Rotterdam port; PPC is pellets production cost, and TC is transportation cost.

The cost of transportation will be calculated as follows (Dornburg 2008):

$$\textbf{(6) } TC= \sum d_i * stc_i,$$

where TC is transportation cost of pellets ($/ton); d_i is distance in transportation (km); stc specific transport cost - $stc_i= (ec_i + mc_i) + lc_i/d_i$; ec_i is specific energy cost of transport mode ($/Mgod/km); mc_i is management cost of transport mode used in step i ($/Mgod/km); and lc_i is specific loading/unloading cost of transport mode ($/Mgod).

Pellet production costs were calculated with following formula:

$$\textbf{(7) } PPC = MR + SG_{b,s} + ACC_{ic,i,n} + OC,$$

where PPC is pellets production cost ($/ton); MR is delivered cost of mill residues; SG delivered cost of switchgrass; ACC annualized capital cost ($/ton); and OC operating cost ($/ton); and *b* is bale type, *s* storage type, *ic* installed cost of equipment, *i* interest and *n* utilization period.

Operating costs were calculated using the following formula:

$$\mathbf{(8)\ OC = Dc_{m,de,n,gp} + Ec_{au,sf,ep,er} + Ps_{wd,w,sh,nw} + I_{np,i} + Sm_{ic} + Wl_{au,d} + Pt + Ovc_{ic}}$$

Where OC is operating cost ($/ton); Dc drying cost ($/ton); Ec electricity cost ($/ton); Ps personnel cost; I interest cost ($/ton); Sm service and maintenance cost ($/ton); Wl wheel loader operating cost ($/ton); Pt property tax ($/ton); Ovc other variable cost ($/ton); and *m* is moisture content; *de* is dryer efficiency (kg of evaporated water/Btu); *n* utilization period for dryer (years); *gp* natural gas prices (in $/therm); *au* annual use (hours); *sf* simultaneity factor (%); *ep* electricity price ($/kWh); *er* energy requirement of equipment (in HP); *wd* working days (days/week) *w* wage ($/hour); *sh* number of shifts; *nw* number of workers; *np* number of loan payments (years); *i* interes rate (%); *ic* installed cost of equipment; *d* diesel price ($/gallon);

Annualized capital costs were calculated using the Capital recovery method (Thek, and Obernberger 2004) with a capital recovery factor of:

$$\mathbf{(9)\ CRF = (1+i^{n})*i/(1+i^{n}) - 1),}$$

where i stands for interest rate in % and n for utilization period. Salvage value is assumed to be zero at the end of the useful life of the equipment. The general parameters used for the calculations of transportation and production cost of pellets in the base case model are summarized in Table 6.

Description of pelletizing process with budget estimates and assumptions made for the equipment (including site preparation and development), together with delivery to the European market is described in Appendix D.

Table 6. Parameters used in base-case calculations

Base case model parameters	Description	Value
General information		
Interest rate	%	8
Loan duration	years	10
Loan payment schedule	constant annual payments of principal and interest	
Estimated useful life of the project	years	50
Plant production capacity	tons of pellets per year	100,000
Production capacity per hour	tons of pellet per hour (TPH)	14
Total annual production hours	hours	7,443
Freight cost (% of purchased price)	%	4
Mechanical installation (% of purchased price)	%	32
Electrical installation (% of purchased price)	%	20
Contingency (% of total capital investment)	%	3
Electricity prices	$/kWh	0.05361
Demand charge	$/per month	140
First 1000kW of billing demand	$/kW	13.97
Excess over 1000kW	$/kW	16.1
Additional fee for every kW over 2,500kW	$/kW	16.1
Natural gas prices (for <250 therms)	$/therm	1.1395
Natural gas prices (for >250 therms)	$/therm	1.0308
Simultaneity factor	%	85
Euro: dollar exchange ratio		1.3984
Number of shifts		3
Feedstock information		
Mill residues moisture	%	50%
Switchgrass moisture	%	15%
Switchgrass bale size (large round bale)	ft x ft	5x4
Switchgrass bale size (large rectangular bale)	ft x ft	4x8
Mill residue price	$/ton	30
Switchgrass price	$/ton	82
General construction (building, office, site development)		
Utilization period	years	50
Service and maintenance	% (of total investment)	0.01
Other variable cost (% of total installed cost of equipment)	%	0.05
Primary grinder (wood hog)		
Energy requirements	HP	950
Utilization period	years	10
Service and maintenance	%	18
Other variable cost (% of total installed cost of equipment)	%	0.05

Table 6. Continued

Base case model parameters	Description	Value
Drying		
Dryer type	type	rotary drum dryer
Energy requirements (including connected equipment)	HP	430
Energy required to evaporate one lb of water	Btu	1,500
Utilization period	years	15
Service and maintenance	%	2.5
Other variable cost (% of total installed cost of equipment)	%	0.05
Grinding		
Hammermill's energy requirement	HP	610
Utilization period	year	10
Service and maintenance	%	18
Other variable cost (% of total installed cost of equipment)	%	0.05
Milling		
Number of pellet mills		4
Energy requirements per pellet mill	HP	520
Utilization period	year	10
Service and maintenance	%	10
Other variable cost (% of total installed cost of equipment)	%	0.05
Cooling/screening		
Screeners energy requirements	HP	15
Cooler energy requirements	HP	2
Utilization period - cooler	year	15
Utilization period - screener	year	10
Service and maintenance	%	2
Other variable cost (% of total installed cost of equipment)	%	0.05
Other equipment		
Energy requirements (total)	HP	530
Wheel loader utilization period	year	10
Annual use of wheel loader at full load	hours	2,000
Wheel loader’s fuel consumption	Gallons/hour (at full load)	4.1
Price of diesel	$/gallon	3
Utilization period conveying/airvey/pneumatic system	year	10
Service and maintenance	%	2
Storage		
Mill residues storage	type	warehouse
Switchgrass bales storage	type	bale lot
Bale lot size	square feet	120,000
Pellet storage	type	silo
Pellet storage capacity	tons	24,000

Table 6. Continued

Base case model parameters	Description	Value
Transportation		
Assumed export terminal	port	Savannah
Distance to export terminal	km	~692
Assumed import terminal in EU	port	Rotterdam
Distance to import terminal	km	~7,290
Assumed number of days of storage at port	days	60
Type of ocean ship assumed		Panamax/Handymax
Ocean ship capacity	tons	25,000-60,000
Pellets characteristics		
Moisture content	%	7
Ash content	%	based on the buyers' requirements
Chlorine content	%	based on the buyers' requirements
Bulk density	kg/m3	550-650
Diameter	mm	6.35-7.25
CIF ARA price	euro/ton	131

Numerous pellet manufacturers' representatives, engineers and contractors currently involved in pelletizing projects were contacted to obtain data for the equipment budgets estimates. One of the manufacturer's representatives (Locke 2010) provided us with pellet plant layout with optimal size for three feedstock scenarios we provided. It also included a pellet plant operations flow with necessary equipments': layout, size and energy requirements. The most of the manufacturer's representatives agreed that the same equipment specified in the layout could be used for pelletizing switchgrass and mill residues since switchgrass has similar throughput rates to those of hardwood, with minor corrections.

They were all asked to give the optimal type, size and energy requirements for their equipment including estimated budgets for the following plant characteristics:

1. The plant would operate **7days/week, 24h/day**

2. Pellet production of **14t of pellets/hour**

3. Raw materials used:

-**First scenario**: 100% sawdust (50% moisture)

-**Second scenario**: 100% switchgrass (15% moisture)

-**Third scenario**: 40% sawdust and 60% switchgrass blend

4. Bulk density of feedstock: Sawdust 200kg/m3

Switchgrass 130kg/m3

Chopped Switchgrass 50kg/m3

5. The fiber length of chopped switchgrass is between 2, 5- 10cm

For sawdust particle size is between 2-10 mm

6. Final product: utility grade pellets (bulk) with 0.250-0.285 inches (6.35-7.25mm) diametter and <10% moisture

General investment costs were calculated to show the initial investment that has to be made in order to put the pellet plant of this size in operation. Rough estimates from different equipment manufacturer's representatives for total investment necessary for plant of this size ranged $9 to $17 million. The feasibility studies from Campbell (2007) and BBI (2009) estimated total investment cost for a biomass pellet plant of 14TPH production capacity to be $9.13 and $22.5 million, respectively. Sam Jackson (Genera Energy) estimates that construction of pellet plant that would use 100,000 tons of switchgrass as feedstock would cost $21 million.

Financial analysis for the second year of production (assuming that full production is achieved) was conducted to determine return on investment-ROI (pre-tax return on equity) for each feedstock scenario and base-case model parameters. Sensitivity analysis was performed to determine the parameters which mostly influence pellet production cost and return on investment, like: feedstock moisture and cost, pellet price, interest rate and euro-dollar exchange ratio.

Estimated pellet production cost and transportation cost, coupled with sensitivity analysis, will provide different price scenarios for U.S. pellets when they reach the EU market. Net income and return on investment will be calculated using current CIF ARA price for industrial wood pellets created by ENDEX (energy exchange for wholesale market participants) located in Amsterdam, Netherlands. The pricing panels consist of producers, distributors and brokers who provide ENDEX with quotes for up to five years ahead and reference prices are then being used by wholesalers and large end-users to negotiate commercial contract terms (ENDEX). The prices for industrial wood pellets are formed on a weekly basis, and are published on ENDEX's website free of charge. The minimum price for industrial pellets that will create positive financial result for export-oriented US producers will be determined. Thus, profitability and the competitiveness of U.S. pellets on the EU market will be estimated.

Chapter 4: Overview of EU's production, consumption and transformation of biomass with focus on wood pellets and necessity of imports for meeting future demand

The European biomass market and its potential in the EU

Currently, EU is largely dependent on fossil fuel imports (Appendix, Table A8) with 41.2%, 82.6% and 60.3% import dependence on solid fuels, oil and gas, respectively, with majority of EU member states dependent more than 90% on imports in at least one of the fossil fuels (EC 2010). In order to reduce its dependence on imports and reach the 20% target of renewable energy from final energy consumption (Appendix, Table A9) the development of all renewables and their use in sectors of heating and cooling, electricity and biofuels are needed (EREC 2008). Biomass, with 5.4% share of 7.8% of energy produced from all renewables in EU's gross inland energy consumption (Appendix, Table A10) has the largest contribution potential for reaching EU's renewables targets in consumption (Eurostat 2009) as well in GHG emission reduction (biomass for energy production is considered CO_2 neutral). Appendix Table A11 shows increase in biomass share in total renewables energy consumption from 61% in 1990 to 69.8% in 2007, with 8.6Mtoe increase from 2006 to 2007. At the same time, increase in consumption of all other renewables together was 2.5Mtoe. It is expected that 120Mtoe of biomass will be used for heat production by EU member states in 2020 comparing to 60Mtoe in 2006 while targets for electricity are being set to 250TWh from biomass in 2020 compared to 89.9TWh in 2006 (EREC 2008).

The EU consumed 98.4Mtoe of biomass in 2007 or 5.4% of total energy consumption with most of it being used in heating sector (Appendix, Figure B6). Countries with heavy subsidies and tax incentives have the greatest biomass consumption (Wright 2006). Germany and

France were both the EU's biggest biomass consumers and producers, with consumption of 22.1Mtoe and 13.4Mtoe and production of 22.1Mtoe and 13.1Mtoe, respectively (Figure 13).

The strong incentive for development of renewables market in EU was the result of the Kyoto Protocol's Annex I countries' obligations to reduce their GHG emissions by certain quantity (Siemons et al. 2004). The GHG reductions cannot be achieved without strong European policy support like tax exemptions on renewables, emission caps, Green Certificate Scheme and both domestically and internationally traded GHG emission allowances through Joint Implementation (JI) and Clean Development Mechanism (CDM) (Siemons et al. 2004).

These policy measures were applied through following of EU's documents and directives: White Paper on "Energy for the future" in 1997, directive on the promotion of electricity produced from renewable energy sources in the internal electricity market (2001), directive on the promotion of biofuels for road transportation (2003) and directive on the promotion of the use of energy from renewable energy sources (2009). Appendix Table C1 presents policy framework development of RES in EU.

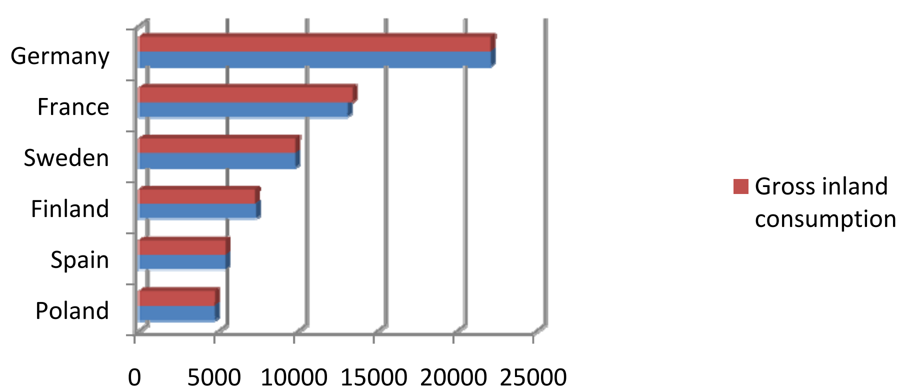

Figure 13. EU's biggest biomass and waste producers and consumers in 2007 (in Ktoe)
Source: Eurostat

Despite EU's ambition to create a strong common renewable energy policy since the adoption of the White Paper, it is still mainly nationally oriented (Blok 2006), resulting in different levels of market development. The common policy mainly consisted of three elements: R&D support, setting short and long-term targets and providing framework conditions (Blok 2006). Currently, each EU member state has its own national support scheme, usually a combination of measures such as investment subsidies or soft loans as an addition to feed-in tariffs or quota obligations (EC 2008b). While the majority of member states use feed-in tariff, others opted for quota obligation schemes with both continuously trying to improve adopted policy performance (EC 2008b) (Appendix, Figure B7). In its communication with European Parliament from 2004, EC concluded: the share of hydropower in electricity from renewables is nearly static; biomass is growing slowly and wind power is growing rapidly; targets from directive will not be met unless use of biomass starts to grow at a higher pace (EC 2005) (Figure 14).

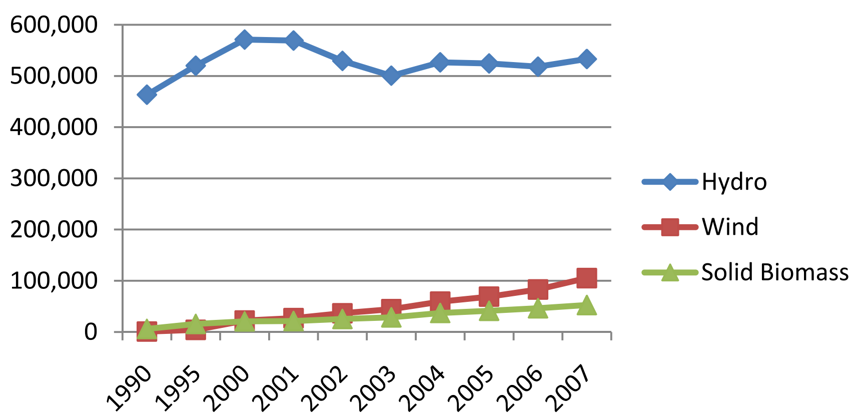

Figure 14. Electricity produced from hydro, wind and solid biomass (without industrial and municipal waste) in OECD Europe (in GWh). Source: IEA

In September 2005, European Parliament called for an ambitious mandatory target of 35% share for electricity from renewables in gross inland energy consumption by 2020 (Verhaegen et al. 2007).

Increase of efficiency, reliability and competitiveness in biomass production and conversion technologies resulted in diversified use of biomass in: small and large scale combustion, co-firing with coal, incineration of municipal solid waste, biogas generation, district and individual household heating and transportation fuels like ethanol and biodiesel (EREC 2008). Electricity from biomass can be produced by pellets, dedicated energy crops, agricultural residues, municipal and industrial waste or through biogas in combined heat and power plants, while wood chips or wood pellets are mostly used for heat production in boilers and single stoves (EREC 2004). In EU, around 36,6Mtoe of biomass and wastes is used in transformation sector, with 55%, 34% and 9% being combusted in public thermal power plants, auto producer thermal power stations and district heating, respectively (Figure 15). Large part of biomass and wastes being used as transformation input comes from wood and wood-waste (17.4Mtoe) with 87.1% being used in conventional thermal power stations (public thermal power plants, auto producer thermal power stations) and 12.9% in district heating plants.

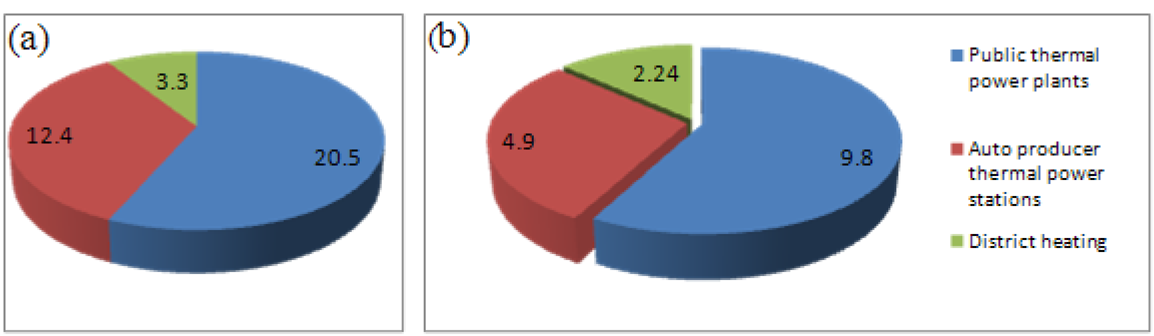

Figure 15. Biomass (a) and wood and wood waste (b) use in transformation sector in 2007 (Mtoe). Source: Eurostat

Forestry byproducts and refined wood fuels, solid industrial and agricultural residues and solid energy crops are already increasingly relevant biomass resources in the EU (Siemons et al. 2004). Thanks to the favorable policies and increased prices of fossil fuels in the past decade industrial use of wood for energy production has increased significantly (Hillring 2006). Among wood fuels, wood pellets have the largest increase in demand in the last decade due to their advantages in both heat and electricity production. Its increased use in these two sectors can contribute significantly in reaching the EU targets for 2020.

The great potential of pellets lies in the fact that technologies for production and consumption are fully developed while there is still lack of public awareness for both potential and opportunities associated with pellets use (AEBIOM 2009). Development of adequate technologies could also enable wood pellets use as a feedstock for the second-generation biofuels production (Sikkema et al. 2009).

Although biofuels were traditionally used in their production region, in the last couple of years some countries, mostly from Northern Europe started with biomass import from long distances for industrial use (Hillring 2004). Some analyses have shown that the international trade is the most cost-effective way of achieving targets from renewable energy sources (Uyterlinde et al. 2003, Skytte et al. 2006). Countries like Sweden, Netherlands, Belgium and Denmark have a growing interest in international trade, because such trade can provide biofuels at lower prices, better quality and secured feedstock supply (Hillring 2006). Currently, EU imports 4.16Mtoe of biomass and waste (Figure 16) with Italy, Austria, Netherlands, Belgium, Denmark and United Kingdom contributing more than 80%. At the same time, imports of wood and wood waste in EU reached 2.85Mtoe with the same countries as major importers (Eurostat).

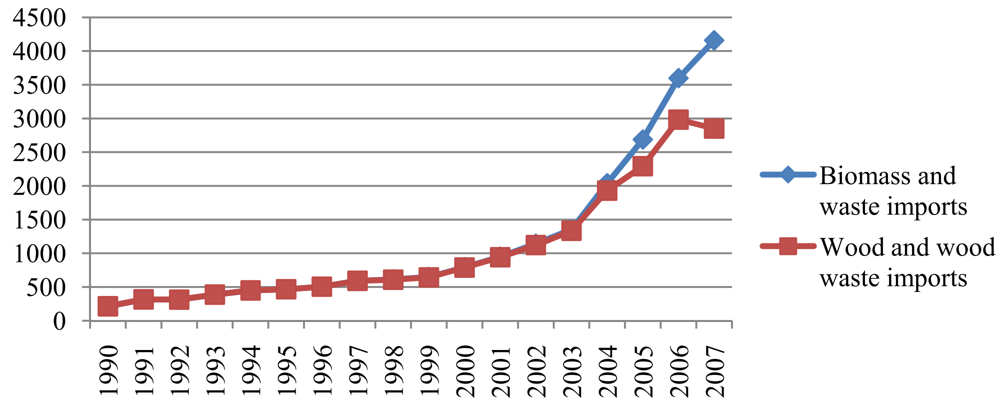

Figure 16. Total biomass and waste and wood and wood waste imports in EU (ktoe)
Source: Eurostat

Appendix Figure B8 shows import quantities in 2007 for all EU countries currently importing wood and wood waste. It was estimated that international trade of solid and liquid biofuels in 2006 was $0.9EJy^{-1}$, with $0.3EJy^{-1}$ coming through direct trade of ethanol, wood pellets and palm oil (Heinimo and Junginger 2009). From 2004-2006, indirect trade remained almost constant while direct trade increased 60% with wood pellets probably being the largest traded solid biomass commodity (Heinimo and Junginger2009). International biomass trade consist mostly of refined wood fuels such as wood pellets or briquettes, due to higher energy density and various regulations regarding pests and disease control related with import of untreated wood products (Skytte et al. 2006).

Compared to the negligible international trade of high quality pellets, international trade of industrial pellets has already reached remarkable levels with the highest use of imported pellets for large-scale consumption in countries with low pellet production (Hiegl and Janssen 2009). While some markets like Germany and Austria are largely self-sufficient, countries like Denmark, Netherlands and Belgium are dependent on wood pellets import with 925,700t, 793,500t and 595,000t imported in 2008, respectively (Pellets@tlas). The EU mainly imported wood pellets from USA (534,679t), Canada (520,197t) and Russia (377,156t) in 2009 (Eurostat 2009a) (Appendix, Table A1). In 2008, the Netherlands used 85% and Belgium 96% of its total consumption of wood pellets in large – scale utilities, mainly for electricity production (Pellets@tlas).

Since biomass is expected to contribute significantly in achieving renewable targets in 2020 it is important to make an assessment of its availability for energy production in the future. Biomass availability will have a great impact on future cost of biomass resources, thus influencing its competitiveness with other renewables.

The most of the biomass resources are located outside Europe (Appendix, Table A12) which has the lowest total biomass potential compared with other regions. Since North America, Latin America and former USSR have larger annual potential and uses smaller portion of available resources; the EU countries will most likely have to import biomass from countries located in those regions (Skytte et al. 2006).

Total available annual biomass potential (Junginger and Alakangas 2010) in EU24 and Norway is 6,577PJ (Appendix, Table A13) with forest residues and herbaceous and fruit biomass together having the greatest potential (46%). These data do not include solid municipal and industrial waste and if about 50% of the waste production would be used for energy, total biomass and biodegradable waste potential would increase to 7,347PJ (Junginger and Alakangas 2010).

Siemons et al. (2004) estimated 183Mtoe and 210Mtoe of bio-energy available for energy production in 2010 and 2020, respectively (Appendix, Table A14). According to their study, the most of the biomass resources in 2020 will come from forestry byproducts and refined wood fuels (51.6Mtoe) with significant increase in share of biodegradable municipal waste (33.7Mtoe in 2020 compared to 7.2Mtoe in year 2000). EEA (2006) estimates that environmentally compatible biomass potential in 2020 will be 228Mtoe with 43Mtoe, 100Mtoe and 85Mtoe coming from wood directly from forest, wastes and residues and energy crops, respectively.

The forest residues potential is closely related to the utilization of roundwood in forest industry (Appendix, Table A15) while industry by-products and residues like bark, sawdust, cutter chips etc. are already well exploited in energy production and in pellets or briquettes production (Junginger and Alakangas 2010). The energy potential from forestry residues and energy crops is important in order to determine availability of these resources for production of pellets. The potential from forestry residues is assessed as the potential for electricity production (De Noord et al. 2004) assuming 35% of total annual roundwood production left as forestry residues and 35% of fuelwood production being used for electricity production. The EU15 countries with estimated lowest availability of forestry byproducts per-year in 2020 are (Siemons et al. 2004): Greece (52ktoe), Ireland (67ktoe), Netherlands (136ktoe), Belgium (216ktoe), and Denmark (321ktoe) (Appendix, Table A16). Appendix Table A17 shows estimated availability of refined wood fuels (including pellets and briquettes) with Belgium having the lowest estimated availability for 2020 with 9ktoe per year, followed by Slovakia, Ireland, Czech Republic and Slovenia with 47, 99, 157 and 160ktoe per year, respectively. The availability of agricultural and industrial residues in 2020 for EU members is shown in Appendix Table A18. The competition between other purposes and the cost of the agricultural land has a substantial impact on the agricultural land availability (De Noord et al. 2004). The countries with estimated lowest agricultural residues potential (availability factor of 30% was used) for 2020 are: Estonia (28ktoe), Slovenia (30ktoe) and Latvia (38ktoe). France (12,007ktoe) and Italy (4,759ktoe) have the largest potential in this resource. Estimated availability of industrial residues (including sawdust) for 2020 is lowest for: Bulgaria, Slovenia, Slovakia and Netherlands with 37, 48, 85 and 99ktoe/year, respectively.

If the available potential from energy crops, forestry residues and agricultural residues (Appendix, Tables A19, A20 and A21) is compared with the projected maximum biomass co-firing fuel input for 2011-2020 period (Appendix, Table A22) it is most likely that countries like Germany, Netherlands and United Kingdom will have to import additional quantities of biomass for this purpose. If it is assumed that not all of the available potential will be used for co-firing but also for direct combustion, gasification and in CHP plants, then Belgium and Denmark will most likely have to import certain amounts of biomass for co-firing as well.

The data from EUBIONET III project showed that countries with the lowest biomass potential are (Junginger and Alakangas 2010): Denmark (34PJ), Bulgaria (47PJ), Lithuania (47PJ), Estonia (48PJ), Belgium (50PJ), Slovenia (53PJ), Slovak Republic (72PJ), Greece (74PJ) and Netherlands (77PJ). Germany, Sweden, Spain, France and Italy are considered countries with the highest potential in biomass resources with 1,080PJ, 841PJ, 588PJ, 574PJ, 484PJ and 428PJ, respectively (Junginger and Alakangas 2010).

Junginger and Alakangas (2010) gave a summary of different studies regarding biomass energy potentials (Appendix, Table A23) analyzed in Biomass Energy Europe (BEE) project. The summary shows a wide range for both total and specific sectors potentials mainly because of the lack of the harmonization and comparability (Junginger and Alakangas 2010).

Nearly 80% of 10 million km^2 forest area in Europe and more than three quarters of 100 billion m^3 timber volume is located in Russian Federation (Capaccioli and Vivarelli 2009) which makes it possible large exporter of wood pellets in the future. Using the estimated average annual production of wood in the forest of 18.5 dt/ha they calculated potential annually available wood of 9,250,000 dt/year. Assuming that 20% of wood will be left on the fields and that 15% will not be feasible to collect, they estimated 6,012,500 dt/year of wood available for pellet sector. About two thirds of forests in north-western member states are privately owned while 90-100% of forests are publicly owned in Southeastern and Eastern European countries (Capaccioli and Vivarelli 2009).

Total available set-aside land in the EU in 2000 was estimated at 7,903,000 ha (Siemons et al. 2004) with Slovenia, Netherlands and Belgium having only 10,000, 16,000 and 24,000 ha, respectively (Appendix, Table A24). Maximum allowable portion of set-aside land area was assumed to be available for dedicated energy crops. According to the EEA report No 7/2006 (Appendix, Table A25) the total available arable land (plantation as cereals, oilseed and other arable crops) for dedicated energy crop in 2020 will be 16.2 million ha (EEA 2006). Capaccioli and Vivarelli (2009) used this number to calculate the potential annually available agricultural residues in EU for MBP sector (around 132 million, dt/year). They used 15dt as average annual yield for agricultural residues and assumed that 20% of available residues will be left on the fields while 30% will not be useful for energy scopes.

According to EUBIONET III partners, the total use of biomass in 2006 was 3,178PJ (Appendix, Table A13) with firewood being the most used resource (29%) followed by solid industrial wood residues and by-products (25%) and liquors (15%) (Junginger and Alakangas

2010). The spent liquor is currently the most exploited solid biomass resource with all potential being used, followed by solid industrial wood residues with 90% and firewood with 77%. Appendix Figures B9, B10 show solid biomass resources potential and use in 2006 for EU24 countries and Norway. The Appendix Figure B11. shows that Belgium and Denmark already use biomass resources above their potential, while Netherlands, Portugal and Slovakia use almost all of their biomass resource potentials for energy use.

Appendix Table A26 compares biomass consumption in 2007 with EEA's estimated environmentally compatible biomass potential for 2010. The comparison shows that some countries have very high potential of unused biomass while others like Denmark and Netherlands have the negative values as net importers of biomass.

Imports of wood and wood waste

Currently around 13 countries import wood and wood waste with Austria, Belgium, Denmark, Italy, Netherlands and United Kingdom as the only countries importing it continuously since 1990 (Figure 17).

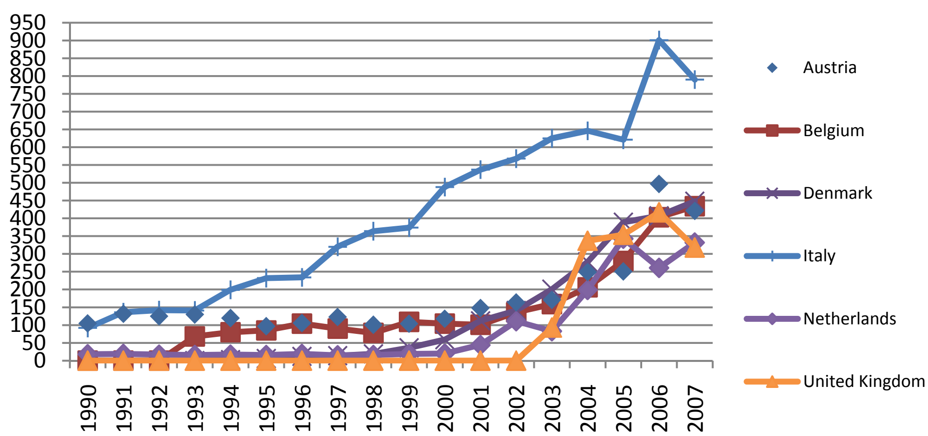

Figure 17. EU's biggest importers of wood and wood waste (in ktoe)
Source: Eurostat

The same countries are also the biggest wood and wood waste importers as well. Italy is the major importer of wood and wood waste since 1990, with 901Mtoe imported in 2006. It also has the strongest increase in imports since 1993, while for Austria, Belgium, Denmark, Netherlands, and United Kingdom the increasing trend started in 2000's as a result of favorable policies for biomass use in energy production. Since the most traded wood and wood waste resource is wood pellets, it is most likely that they account for the most of the imported quantities. Although Sweden is traditional importer of woody biomass, no trade is being reported neither in Eurostat or IEA database.

Table 7 shows shares of imported wood pellets in imports of wood and wood waste in countries with developed pellets market. Austria, Finland, and Germany are not listed since they export wood pellets. Since Sweden does not report any trade volumes it will not be included in this Table. The first reported amount of wood pellets import for the UK was in 2008 and since data for wood and wood waste imports goes up to 2007, the UK is not included either. Denmark has the highest share of wood pellets imports in total imports of wood and wood waste with average share higher than 70% since 2001.

Table 7. Share of pellets imports in total imports of wood and wood waste (%)

	2001	2002	2003	2004	2005	2006	2007
Belgium	-	-	-	-	-	-	49.34
Denmark	87.51	83.50	79.83	81.31	67.45	77.14	78.30
Italy	-	-	3.32	2.06	3.35	3.69	5.69
Netherlands	-	18.69	50.00	26.16	45.74	59.98	74.79

Source: Eurostat, Pelletsatlas

The Netherland's share of wood pellets increased significantly since 2002, from 18% to almost 75% in 2007, mostly due increased consumption of pellets in large power plants as a result of feed-in tariff. Belgium, which started using pellets recently, has already reached almost 50% of wood pellets imports in total imports, thanks to the GCS and minimum price. On the other hand, Italy had shares between 2-5% showing that other solid biomass sources are largely imported. Countries with the highest share of wood pellet consumption in total wood and wood waste consumption (Figure 18) are Netherlands (35.93%), Belgium (28.03%), Denmark (21.86%), Italy (10.5%), and Sweden (8.45%). Again, a sharp increase in wood pellets share in Belgium, Denmark, and the Netherlands can be explained by the increased demand from large-scale utilities for electricity and heat production.

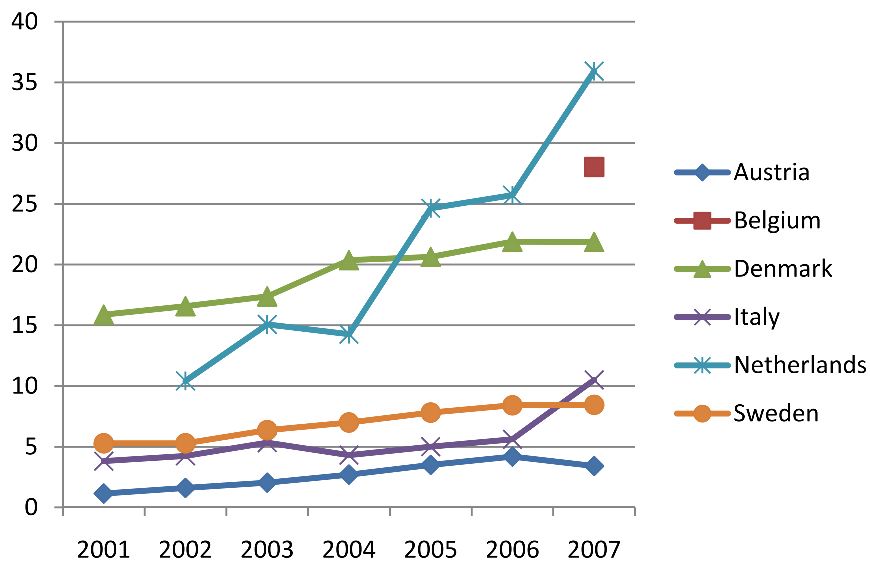

Figure 18. Share of wood pellets consumption in wood and wood waste consumption (%)
Source: Eurostat, Pellets@tlas

Biomass demand

Use of solid biomass in heat and power production in the largest wood and wood waste importers in EU

Appendix Table A27 represents production of heat and power from renewables and wastes in countries the biggest importers of wood and wood waste (solid biomass). Sweden is the largest producer of both heat (120,825TJ) and electricity (78,824GWh) from renewables and wastes (IEA 2009). It is also the biggest consumer of solid biomass in heat production amongst selected countries with 88,070TJ, followed by Austria (20,899TJ) and Denmark (19,491TJ) (Figure 19). The lack of stronger policy support for biomass use in heat production, results in low biomass use in this sector in most of the EU's countries. The share of solid biomass in electricity produced from renewables and waste is biggest in Belgium (31.2%) followed by Netherlands (21.5%) and Denmark (16.5%). If the heat produced from geothermal and solar thermal energy is excluded, share of solid biomass in heat generated from combustible renewables and waste is highest for: Austria (79.5%), Sweden (72.9%), Denmark (43%) and Italy (34.7%).

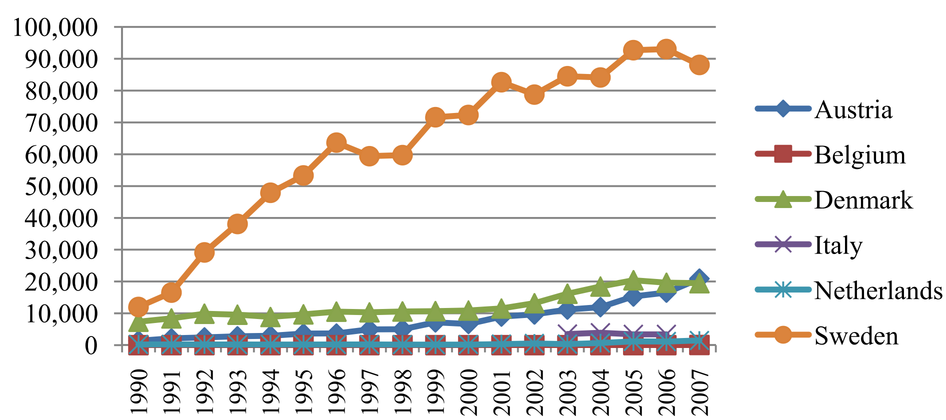

Figure 19. Heat generated using solid biomass (in TJ)
Source: IEA

The countries with the highest shares of electricity from solid biomass in electricity generated from combustible renewables and waste (excluding electricity from hydro, geothermal, solar, tide, wave and ocean and wind energy) are: Sweden (79.7%), Austria (76.7%), Belgium (49.9%) and Denmark (47.4%) (Figure 20). While most of the selected countries produced renewable electricity in electricity-only plants, some, like Netherlands and Denmark, produced more than half in the CHP plants. The Netherlands is the only country producing more heat from renewables and waste in heat-only plants than in CHP.

The information about CHP plants in EU is still scarce, but Center for Renewable Energy Sources surveyed and analyzed 122 CHP plants with solid biomass in 14 European countries through Biomass cogeneration Network in 2003 (CRES 2003). 67% of analyzed plants had commercial use, 14% was demonstration plant, 7% pilot and 6% testing plant for collection of experience with new CHP technologies. 35% of the plants had an electric power less than $1MW_{el}$, 24% from 1 to $5MW_{el}$ and 20% from 5 to $20MW_{el}$. Only 15% were above $20MW_{el}$. More than 62% of solid biomass was coming from woodchips, with 38% from forest residues and 24% from saw mill residues (Figure 21).

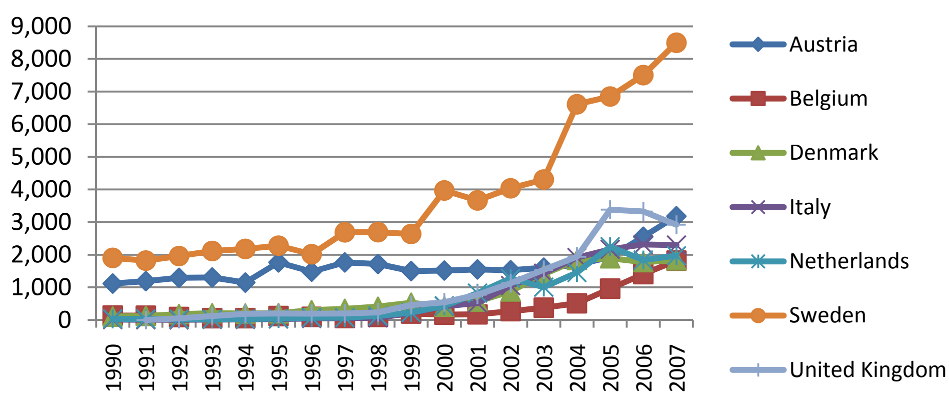

Figure 20. Electricity production from solid biomass (in GWh)
Source: IEA

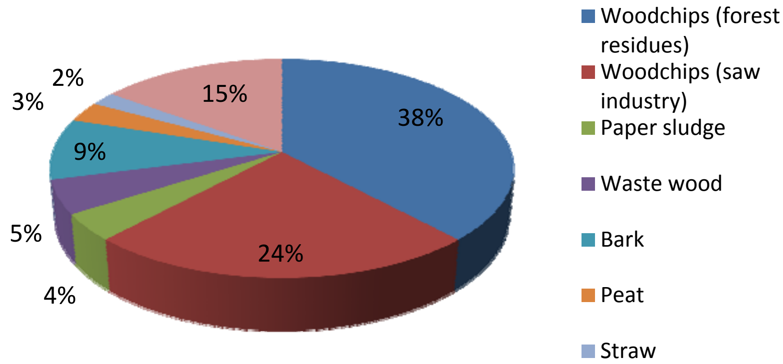

Figure 21. Type of solid biomass used in CHP plants
Source: CRES (2003)

Woodchips are the most important solid biomass resource for CHP plants in all selected countries except Turkey (Appendix, Figure B12) whereas bark, paper sludge and wood waste are also relevant. Pellets are included in “Other” category. The only country using straw in some of the surveyed plants is Denmark with more than 20% share in total solid biomass used whereas Finland is the only country using peat (about 20%). Since wood pellets have many advantages compared to all of these resources and can be easily used in CHP plants, the only barrier might be their availability and price.

The IEA projections for combustible and renewables use in 2020 (projections provided by each country individually) project significant increase in their use in heat production in Belgium and Sweden whereas they project the decrease for Austria (Table 8). The largest increase in electricity production from combustible renewables and waste is expected in Netherlands and United Kingdom.

Table 8. Heat and electricity production in largest solid biomass importers 2007 with projections for 2020

	Austria	Belgium	Denmark	Italy	Netherlands	Sweden	UK
Total ren. heat from combustible renewables and waste in 2007 (TJ)	26,286	236	45,283	9,776	9,689	120,825	
Total projected ren. heat from combustible renewables and waste in 2020 (TJ)	24,200	27,524	54,427	11,000	12,110	141,582	n/a
Total ren. electricity from combustible renewables and waste in 2007 (GWh)	4,150	3,641	3,859	6,954	5,566	10,656	11,395
Total projected ren. electricity from combustible renewables and waste in 2020(GWh)	7,000	7.148	5.395	10,000	16,800	14,452	20,155

Source: IEA database - projections (2009)

Biofuel consumption projections for 2010 and 2020

The objectives of the study from Siemons et al. (2004) were to provide reliable and accurate data on contribution by bioenergy to the EU energy market by 2010 and 2020, taking various policy instruments into the consideration and to indentify new approaches for promoting a positive public perception of bioenergy. They used SAFIRE model to properly reflect the following functions in different scenarios: demand function (the demand for renewable energy in general and biomass in particular); supply function (the supply of biomass and biomass derived fuels) and technology development function (the characteristics of biomass fuelled energy conversion technologies).

They used sector covenant and large-scale market approaches to analyze the demand function. According to sector covenant approach, political decision is made and individual industries or sectors are obliged to produce or use specific quantity of renewables. The large-scale market approach introduced a new value component of renewable energy, a component of sustainability (tax exemptions, traded avoided GHG emissions, traded GHG emission allowances and emissions connected with electricity, etc) with market forces being left for its implementation. The Kyoto Protocol allows countries to reduce their GHG emissions with emission caps or trading in GHG emissions within country but also outside their country, through Joint Implementation (JI) and Clean Development Mechanism (CDM) programs. These measures and programs make GHG neutrality a tradable good, thus introducing a new value component (value of sustainability) for renewable energy: a component of emission neutrality, expressed either in monetary units per ton of CO_2 avoided or per energy unit (€/kWh or GJ). This programs are being executed by the European Trading Scheme (ETS) ensued from the directive 2003/87/EC (EC 2003).

The study classified bio-fuels into non-tradables and tradables. The non-tradable bio-fuels are under direct influence of various regulations and policies (the Directive on the incineration of waste 2000/76/EC, the Directive on the limitation of emissions of certain pollutants into the air from large combustion plants 2001/80/EC and the Directive on the landfill of waste 1999/31/EC) and cannot be offered on the more general bio-fuel market. They include: manure, waste from pulp and paper production, slaughter house waste and biodegradable municipal waste and sewage sludge. According to their study, those bio-fuels will play an important role in the future. On the other hand, impact of policies on tradables' market is less direct as a result of more distant effect of the relevant policies: the Directive on RES electricity 2001/77/EC, the Directive on biofuels or other renewable fuels for transport 2003/30/EC, the Directive on the GHG trade scheme 2003/87/EC and the Kyoto Protocols flexible instruments (CDM and JI). The effects of these policies were analyzed and given as input data to the SAFIRE model. In contrast to previous studies their study also assumed the possibility of international trade which significantly influences shift in the biomass supply function. In its Green Paper from 1997, EC proposed international trade as an option for reduction of dependency on oil imports.

Currently, large research and development programs for biomass-fuelled electricity generation technologies are being carried out while research in biomass-fuelled CHP and heat generation is funded to a much lesser extent. While the objective in electricity generation, is to achieve higher energy conversion efficiencies, in CHP and heat generation focus is on lower emission levels and user convenience. Both of these types of research and development were relevant for the study of Siemons et al. 2004. The study also attempted to make a realistic estimate for cost and conversion efficiencies for different technology options for bio-transportation fuels.

The SAFIRE model used different scenarios to test the impact of different hypotheses, concerning: the capital cost of applications, the biomass fuel cost and the value of sustainability premium. While biomass fuel prices for tradeables were estimated by analyzing supply and demand functions of biomass, acquisition cost for non-tradeables were taken as zero (the owners would have to dispose of them anyway). Any negative value attached to non-tradeables was considered to balance operating and capital cost of waste removal, while the cost for their processing to heat or electricity was considered additional. The average supply costs of tradable biomass and crops for transport fuels used to construct supply curves are given in the Appendix Table A28 and are not necessarily equal to ones occurring at market equilibrium. What was specific for the study was that biomass fuel prices were assessed in a dynamic model and that assessment is made explicit. Since bio-transport fuels are directly affected by different policies, their production costs were taken as an input and sustainability premium required to meet the targets was determined.

The SAFIRE model simulates economic investment behavior within a future that is defined by a set of external parameters, and for their study Siemons et al. used a base case scenario with a number of variants that were used to analyze the influence of certain parameters. The effects of changes to: the value of sustainability premium, the presence or absence of subsidies on investments in biomass fuel conversion technologies and the failure to succeed in introduction of more efficient biomass technologies were tested using the scenarios variation.

Although policies and subsidies (their existence usually referred to sustainability) vary in different countries and are usually restricted to specific users and technologies, Siemons et al. focused on clear and simple set of scenarios creating single-policy measures uniform across the countries investigated. The role of bioenergy was then analyzed given the absence or presence of thus generated policies. They expressed sustainability in terms of avoided CO_2 emissions in tons, as the single indicator for all values related to use of biofuels like: environmental protection, reduced import dependency, regional development, job creation and creation of business opportunities for EU industry in other countries. This indicator is measurable and values can be found on the market for avoided GHG emissions. They removed all taxes and subsidies related to the sustainability of energy systems and applied uniform add-on to consumer electricity and heat prices that is equivalent to the avoided GHG emissions. This resulted in higher fossil fuel prices and preference of end users toward sustainable alternatives. The values from the Table 9 were selected for the sustainability premium.

Table 9. Different values for the sustainability premium, for different scenarios

	2010	2020
0-value sustainability premium scenario	0€ /t CO2-eq	0€ /t CO2-eq
Low-value sustainability premium scenario	25€ /t CO2-eq	50€ /t CO2-eq
High-value sustainability premium scenario	50€ /t CO2-eq	100€ /t CO2-eq

Source: Siemons et al. 2004

Technology development related scenario analysis included the effect of capital subsidies intended to stimulate technology developments and effect of eventual failure of biomass-fuelled GCC technology introduction. Two scenarios were distinguished: one with capital subvention for certain type of power plants (the highly efficient, large-scale, typically 100 MW_e stand-alone, biomass-fuelled plants were investigated during their introduction into the market) and one without the capital subvention. Appendix Table A29 shows different scenarios for an electricity-only plant with specific investment cost (€/kWe) and NCV efficiency (%) for 2000, 2010 and 2020. The scenario with the associated biomass-fuelled gasifier coupled to combined cycle technology (GCC) not being successfully introduced, was tested too.

Three different technology scenarios were analyzed: existing technology, non-subsidized innovative and subsidized innovative (Figure 22). The sustainability premium scenarios are being discussed within each of the technology scenarios. The model's base-year (2000) is characterized by actually installed power capacities, fuel consumption and with a number of existing capital subsidies, CO_2 taxes, tax exemptions and other stimulating measures for renewables consumption. The zero-sustainability premium scenario excludes all of those supportive measures for new bio-energy capacity but maintaining it for existing one. The model also assumed that the capacity that had been installed in 2000 will not cease to be operational in 2010 and 2020.

		Technology		
		existing	non-subsidized innovative	subsidized innovative
Sustainability premium	0			
	low			
	high			
	variable (to meet biofuel transport target)			

Figure 22. Matrix for different technology and sustainability premium scenarios
Source: Siemons et al. (2004)

Market assessment

Overview of EU's wood pellets market

The importance of wood pellets in heat and electricity generation in Europe is constantly increasing, especially because they can contribute significantly in reaching RED targets (Hiegl and Janssen 2009). While the pellet market growth in countries with developed markets is still very strong, additional markets are emerging as well (Hiegl and Janssen 2009). Based on a different end use the pellet markets can be classified into (AEBIOM 2008): i) small-scale residential users: with demand less than 10 tons of pellets per year; used for individual heating in pellet stoves or for water heating in pellet boilers; delivery can be organized in small bags (pellet stoves) or in bulk (in a storage room or container, usually for one year); ii) medium-scale users with demand between 10 and 1,000 tons per year (companies, hotels, service sector and large residential units); iii) large-scale users with demand above 1,000 tons per year (power plants, industries and big district heating companies). The Appendix Figure B13 shows the overview of major characteristics of European pellet market types.

Table (Appendix, Table A30) represents the different use of wood pellets in developed markets in residential and large heat and power sectors. Wood pellets consumption has been increasing in all developed market countries since 2001 except Belgium and United Kingdom, where substantial consumption started in 2007 and 2008 respectively (Figure 23). Austria, Germany and Italy use wood pellets almost exclusively for residential heating, while Belgium, Netherlands and United Kingdom use them mainly for power generation. Denmark and Sweden have both sectors well established. While Denmark uses most of industrial wood pellets for co-firing with coal in power plants, in Sweden they are mostly used for district heating.

There are currently more than 500 pellets producers in EU with more than 13 million tons of production capacity (Pellets@tlas). Total production in EU reached around 7.5 million tons in the 2008 while at the same time its members consumed 7.8 million tons (Appendix A31). Around 60% of produced pellets were of premium grade quality while 40% were lower quality or industrial grade pellets (Hiegl and Janssen 2009). Austria has the most developed market for residential heating with wood pellets (Hiegl and Janssen 2009).

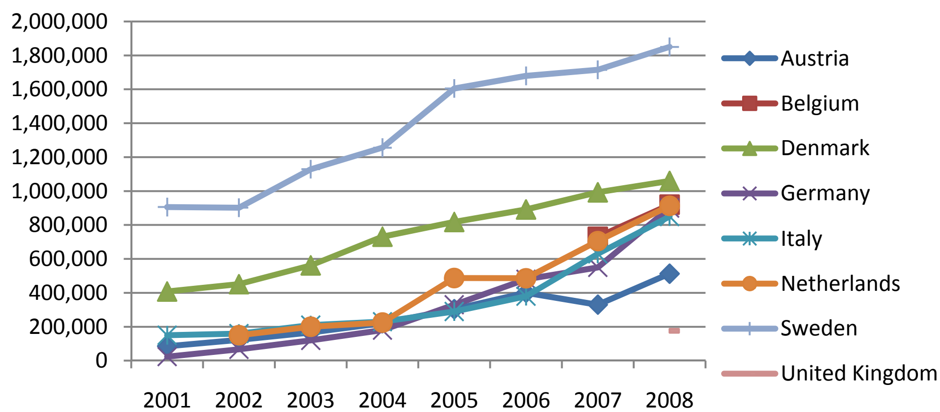

Figure 23. Total consumption of wood pellets in developed market countries
Source: Pelletsatlas

Sweden has the largest number of pellets manufacturers (94) followed by Italy (75), France (54) and Germany (50). As a country with the most developed wood pellet market, Sweden had the biggest production capacity until 2007 when Germany surpassed it and became a major producer of wood pellets with 1,460,000 tons in 2008 (pellets@tlas 2009). Despite large increase in both capacity and production in Germany, Sweden remained the largest consumer in the EU thus far, with consumption of 1,850,000 tons of wood pellets in 2008.

Wood pellets utilization per capita (Appendix, Figure B14) is the largest in Sweden with 201.5 kg followed by Denmark and Belgium with 193.4kg and 89.3kg, respectively. More than 35% of total EU wood pellet consumption in 2008 has been used for large heat and power production in Sweden, Denmark, Belgium, Netherlands and United Kingdom (Pellets@tlas). Possible shortage of woody raw materials for pellet production (caused by competition with other industries and increasing demand for wood pellets) in countries such as Sweden and Denmark, and the low forestry residues potential in southern European Countries could result in pellet producers having to switch to other biomass sources like agricultural residues and dedicated energy crops (Pastre 2002). For example, the supply of sawdust, shavings and sander dust in Canada and USA dropped to 16.6 million tons in 2008 compared to 21 million tons in normal year, mainly due to recession effects on the housing market (Spelther and Toth 2009).

The scenario with woody raw materials shortage creates a great potential for mixed biomass pellets (MBP) energy conversion, but the lack of: standards, market for MBP fuels and their combustion characteristics restricts their full utilization at the moment (Bastian and Wach 2009). Current production capacity of MBP in EU in 2008 was 809,000 tones, while real production was 351,700 tones (Capaciolli and Vivarelli 2009). Because the emissions of critical elements (NOx, SOx, HCl, polychlorinated dibenzo-p-dioxins and fly ash) from pellets containing bark, agricultural residues and dedicated energy crops can cause slagging, corrosion and interference with process control in small scale combustion (Pichler 2009) they should be used in large scale combustion plants equipped with sophisticated combustion control systems and flue gas cleaning systems (Pastre 2002).

Since quality is a critical issue for further development of pellet markets, a set of European standards related to solid fuels is under preparation with classification based on their origin, source and traceable production chain (Alakangas, Valtanen and Levlin 2006). Existing official national standards for wood pellets (Appendix, Table A3): ONORM M 7315 (Austria), DIN 51731 (Germany) and SS 187120 (Sweden) which contributed to development of national markets, are not widely accepted across EU (Pichler 2009). The most commonly used certification label (DINplus), currently in use in EU, is the combination of the Austrian and German standards, including external controls and strict quality requirements (Pichler 2009). The Technical Committee 335 of the European Committee for Standardization (CEN) is developing the following pellet standards: EN 14961-1 for general use which includes all kind of biomass pellets (already published); EN 14961-2 for wood pellets for non-industrial use and EN 14961-2 for non-woody pellets for non industrial use (Alakangas 2009). The introduction of common European standard and certification scheme should promote further development and unification of European pellets market and international pellets trade.

The prices of pellets in the EU differ significantly for different market types (Sikkema et al. 2009): prices of industrial pellets for power production fluctuated between €112 – 128 from 2007 until July 2009, peaking at €141 in March 2009 (Appendix, Figure B15); prices of bulk pellets for district heating were €140 during the second half of 2008 while prices for residential pellets fluctuated between €125 – 300 for loose pellets (including delivery and VAT) and between €150 – 250 for bagged pellets (<25 kg excluding transportation and including VAT) (Appendix, Appendix Figure B16). For comparison, in March 2009, fuel cost for residential heating with pellets in Austria (Rachos 2009) were 4.21 €cent/KWh which is lower compared to natural gas (6.80€cent), heating oil (5.47€cent), propane (9.66€cent) or electricity (18.10€cent).

Prices for industrial wood pellets (CIF ARA) are formed by ENDEX (energy exchange for wholesale market participants) located in Amsterdam, Netherlands (APX-ENDEX). The pricing panels consist of producers, distributors and brokers who provide ENDEX with quotes up to five years ahead and reference prices are then being used by wholesalers and large end-users to negotiate commercial contract terms (ENDEX). The prices for industrial wood pellets are formed on a weekly basis, and are published on ENDEX's website free of charge. Prices of industrial wood pellets for power production are strongly influenced by shipping cost with Baltic Dry Index (BDI) being used as a key independent barometer for forming the prices of dry bulk commodities (Sikkema et al. 2009). The BDI is composed of professional ship broker assessments of four types of vessels (Sikkema et al. 2009). Although the shipping cost for dry bulk commodities (BDI) have dropped significantly due to economic crisis, it did not have immediate effect on shipping cost of wood pellets, because their final price is closely linked with size and the length of the contract (Sikkema et al. 2009). Hawkins Wright Ltd developed Biomass Co-firing Index (BCI) to track the competitiveness of co-firing biomass, relative to burning coal in a typical electricity generating plant which represents price the plant will be willing to pay for biomass. On April 30th, 2009 BCI was $14/MWh CIF ARA and comprised of:

the spot price of coal, the price of emissions allowances necessary to cover the CO_2 emitted by coal combustion and combustion efficiency adjustment (Hawkins Wright 2009). The subtraction of this amount from the price of wood pellets on the same month ($36.52/MWh, assuming calorific value of 4.72MWh/t of wood pellets) gives BCI spread of $22.5/MWh which has to be compensated by policy instruments in order for biomass to be competitive with coal (Hawkins Wright 2009). In 2009, the specialized forest industry index provider (FOEX Indexes Ltd, Finland) started two projects to develop biomass price indexes based on the calorific value of biomass and reported in euro per tonne: Pelletsbio on industrial wood pellets and Forestbio on other forest biomass (Hawkins Wright 2009). The main goal of Pelletsbio is to form a pan-European index based on regional pellet price indices (Hawkins Wright 2009). It focuses especially on wood pellets for industrial end use (FOEX Indexes ltd).

Estimated imports of wood pellets in 2009 were more than 3.6 million tons with more than half of it being intra trade (Sikkema et al. 2009). The EU countries imported more than 1.6 million tons of wood pellets in 2009 from countries outside EU with 1.43 millions being imported from USA, Canada and Russia (Appendix, Table A32). Two former Soviet Union countries Belarus and Ukraine exported together around 105,000 tons of wood pellets to EU in the same period, while all other countries exported together less than 70,000 tons. According to these data average monthly imports of wood pellets from outside EU in 2009 were 133,000 tons with maximum of 171,000 tons being imported in May. The wood pellets export reached 2.7 million tons, mainly as EU intra trade (Sykemma et al. 2009). The Eurostat started publishing official import/export statistics for wood pellets since January, 1st 2009 under the product code 44.01.3020 defined as "sawdust and wood waste and scrap, agglomerated in pellets" which is expected to be embedded in the World trade statistics not earlier than 2012 (Sykemma et al. 2009). The Rotterdam is one of the major importing ports for wood pellets, while St. Petersburg and Riga are being used for their export. The most of the shipments arriving in Rotterdam port are being performed by large vessels from North America with average load between 20,000-30,000 tons per shipment, while shipments from mentioned exporting ports have average loads from 4,000-6,000 tons mostly to Scandinavia (Sykemma et al. 2009).

Since this paper is focused on projections of pellets import growth into future and exporting possibilities for U.S. industrial pellets, the pellet market for large-scale users will be its main area of interest. The main source of pellets for EU large-scale users is international traders supplying pellets with large (Panamax or Handymax) vessels to a few large, usually internationally operating, electricity companies (Appendix, Figure B14). Industrial pellets can be stored either in a port (up to 200,000 tons) or at a plant site (up to 10,000 tons) and are supplied under long term contracts (up to 3 years) and through spot markets (Sykemma et al. 2009). Latter is the case in the situation with low market prices when large consumers, although they have long-term contracts with suppliers, create strategic storage facilities at a port for their own use or for re-export to the other countries (Sykemma et al. 2009).

The rising feedstock prices were pointed as the main barrier for international pellet trade by pellet traders, large-scale users and scientist participating at the workshop held in Utrecht in June 2008 (Junginger et al. 2009). Fluctuation in policies supporting co-firing with coal was mentioned as the second most important, while competition with fossil fuels and sustainability criteria were expected to be the minor barriers. They saw increasing oil prices as the main driver for the international pellet trade, followed by the policies for both large scale electricity and heat production. Increasing CO_2 prices were seen only as a minor driver. Although logistical barriers were not selected as a major barrier, the development of dedicated pellet terminals at major ports and pretreatment options such as torrefication were mentioned as challenges to be overcome. All of the participating experts expected that Canada, USA, Russia, Belarus and Ukraine will become the most important producers and exporters of wood pellets in recent future.

Market potential for industrial pellets (Belgium, Denmark, Netherlands, Sweden and UK)

Belgium, Denmark, Netherlands, Sweden and United Kingdom are currently the largest importers and consumers of industrial wood pellets. The proximity of large-end consumers to ports or their accessibility to ports through inland waterways in these countries make them attractive for industrial pellets imports from overseas. More detailed information on biomass potential, wood pellet markets and renewables policies for these countries will be presented here.

Belgium

Belgium's target of national action plan based on RED is set to 13% of gross energy consumption in 2020 produced from renewable energy sources based on 2005 consumptions (Pieret 2009). According to IEA (2005) Belgium is currently not on target to meet its Kyoto commitments, and some modeling results even show that energy-related CO_2 emissions will surpass 1990 emissions by 8.3% in 2012 under one scenario. The phase-out of nuclear power (currently supplying around 55% of Belgium's total electricity) between 2015 and 2050, passed in legislation in 2003, will make it more difficult to achieve further GHG emissions reductions (IEA 2005). Biomass is indentified as a major biomass resource and its use for energy production is being supported by the following main incentives: Green certificate scheme (GCS), financial grants and voluntary agreements (Pieret 2009).

Belgium has a limited resource potential, thus being highly dependent on energy imports (Pieret 2009). Appendix Table A33 shows techno-economical potential and energy use of solid biomass resources. The use of forest residues, spent liquors, other biomass and refined biomass fuels in 2006 largely exceeds Belgium's production levels.

Currently, there are 10 pellet producers in Belgium, producing around 325,000 tons of wood pellets, with production capacity of 450,000 tones (Pelletsatlas). Due to a large continuous demand, especially from large scale users (currently two) that consumed 800,000 tons in 2008, Belgium imports significant amounts of wood pellets (595,000 tons). Those large consumers are owned by Electrabel Company and both are CHP plants (Awirs and Rodenhuize) located in cities of Flemalle and Gendt, repectively (Sikkema et al. 2009). Large amounts of wood pellets are being used in Les Awirs (80 MW, 100 % biomass) and its four co-firing facilities (Hiegl and Janssen 2009). Electrabel used 1 million tones of wood pellets in 2009 and expects to increase it to 3 million until 2014 (Hiegl and Janssen 2009). Wood pellets are being used mostly in electricity or heat production, with insignificant market for residential heating (only 1,000 boilers and 9,000 pellet stoves in 2008). The supply network is developing, with 50 providers and 5 bulk trucks registered in Wallonia (Pieret 2009).

According to Eurostat, Belgium's major importing partners for wood pellets in 2009, were USA (185,000tons), Canada (87,000tons) and Russia (45,000tons). At the same time, around 127,000 tons came from EU intra-trade (mainly Germany).

According to Hiegl and Janssen (2009) Electrabel signed a three year contract for pellet supply (worth €39 million) with an Australian company in 2009 (Hiegl and Janssen 2009). At the moment there is no distinction between pellets for industrial or for residential use, and no certification system or quality controls are implemented; the norms from other countries are being used: two producers are DINplus certified and some traders import only DINplus pellets (Sikkema et al. 2009).

There is little information about Belgian MBP market and according to Belgian biomass association (VALBIOM) it is most likely that it does not exist (Wach and Bastian 2009).

The GCS has been qualified as a public service obligation. The GCS in Flanders started in 2001 with penalty of 7.5ct/kWh being set for producers for not reaching RES-E targets, and increasing to 10ct/kWh in 2004 (Uyterlinde et al. 2003). The other region, Wallonia established GCS in 2003 with obligation on the supplier including 3% quota in 2003 with progressive increase to 12% in 2010 (CHP included in this obligation). The penalty has been set to 10ct/kWh (Uyterlinde et al. 2003). Investment subsidies also exist in both regions. Appendix Table C1 lists all existing policies and measures regarding renewable energy in Belgium since 1990 (IEA).

Denmark

Although Denmark lacks in hydro energy and does not have long tradition in biomass use like other Scandinavian countries, due to the favorable policies it became a country with one of the most developed renewable energy sectors (IEA 2006a). Its energy intensity, being 35% below the IEA average and the lowest in the EU gives Denmark a pioneering role in energy efficiency (IEA 2006a). Use of renewables contributed to the reductions of CO_2 emissions by 6.5 million tones in 2004, or about 10% of that year's emissions which is very important for Denmark which faces challenging Kyoto target (IEA 2006a).

In 2008, total consumption of wood pellets reached 1,060,000 tons, with 355,000 tons being used in large-scale consumption and rest in residential heating. More than half of the residential heating demand is supplied through District Heating (Capaccioli and Vivarelli 2009). Currently, twelve companies produce wood pellets in Denmark. With total production capacity of 313,000 tons and real production of 134,000 tons, Denmark has become the largest wood pellets importer at the moment with more than 900,000 tons of imports in 2008. In 2009, wood pellets were imported mainly from other EU countries (600,000 tons) and Russia (86,000tons) (Eurostat) to cover the increasing demand for residential small-scale, medium scale (district heating) and large scale (CHP and power plant) consumption (Junginger and Alakangas 2010). Two large pellet users operate in Denmark: Dong Energy (Fredericia) and Vattenfall (Kobenhavn) both for electricity production (Sikkema et al. 2009). The Danish wood pellet market is also considered one of the most developed in all aspects such as: trade, logistics and availability of historical data (Sikkema et al. 2009).

Denmark is the only country in the EU using significant quantities of straw for electricity production, with power plants arranging tenders for straw producers (Junginger and Alakangas 2010). The utility company Vattenfall, produces between 80,000 – 100,000 tonnes of straw pellets in its factory in Koge and use it for electricity production at the own plant Amagervarket in Copenhagen (Wach and Bastian 2009). While the plant used 80,000 tonnes in an old block in 2008, it is assumed that newly refurbished block burned 100,000 tonnes of both straw and wood pellets in 2009 (Wach and Bastian 2009).

Denmark uses premium feed-in tariffs and tender schemes (for wind offshore) with support duration from 10 to 20 years depending on the technology and scheme applied (EC 2008b). The payments are recovered from electricity customers as a component of the Public Service Obligation (PSO), a levy placed on every kilowatt-hour of electricity sold in Denmark

(IEA 2006a). Tariffs vary from about 5 – 8.1 €ct per kWh, but depend on electricity prices (Loo and Koppejan 2008). Appendix Table A34 lists feed-in tariff scheme in Denmark as of 2007. The tariff level is lover compared to previously used high feed-in tariffs (EC 2008b). Thanks to the government policies, Denmark is the world leader in wind turbine manufacturing and Danish Energy Authority has calculated that all-in cost of onshore wind turbines dropped from 10 eurocents per kWh in the 1980's to 4.9 eurocents in 2004 (IEA 2006a). It is expected that those prices will further drop by 2020. However the government's renewable support policies cost Danish customers around 0.2 % of the country's GDP in 2004 or DKK390 per person (IEA 2006a). Appendix Table C2 lists all existing policies and measures regarding renewable energy in Denmark since 1990 (IEA).

The Netherlands

The RED sets the 14% target for Netherlands for RES energy share in total energy consumption in 2020 (Junginger 2009). In February 2009, the Dutch Government set the following targets under its Clean and Efficient programme and its Energy Report 2008 strategy: 2% annual energy efficiency improvements, 30% reduction of GHG from 1990 levels and 20% of renewable energy in the energy mix in 2020 (IEA 2009a). The Dutch Government explicitly mentioned biomass as one option to reduce GHG emissions by the utility sector with ambitious target for agriculture sector to utilize 200PJ of biomass (only 0.4PJ estimated for 2004) for energy purposes by 2020 (Junginger 2009). Given the prices for land and labor and the availability of cheaper biomass from import, it is unlikely that woody or herbaceous biomass crop plantations will be established in the near future in the Netherlands (Junginger 2009). Since feedstock potential to produce refined solid biofuels is limited and is largely utilized, the

Netherlands became significant importer (mostly wood pellets). Appendix Table A33.1 summarizes techno-economical potential and use of solid biomass in 2006.

The Netherlands consumed 914,000 tons of wood pellets in 2008, with 95% being used in industrial sector and only 5% for residential use. The large availability of domestically produced cheap natural gas and lack of policies for residential pellet boilers hinders development of residential pellet market (Hiegl and Janssen 2009). With only 350,000ha of land under forests, and forest industry strongly dependent on large timber imports, the Netherlands is unlikely to have more wood pellet producers (at the moment only two) in the future, due to the lack of raw material (Capaccioli and Vivarelli 2009). The lack of raw material, partially caused by its dedicated use in Belgium particle industry and the extensive Dutch dairy sector is the main reason for low production levels of wood pellets in the Netherlands (Hiegl and Janssen 2009). The current production capacity of 130,000 tons and production of 120,000 tons (mainly DIN51731 standard) cannot meet growing demand, which together with ambitious Dutch renewable targets (20% of renewable electricity till the end of 2020) makes the Netherlands largely dependent on imports.

The Netherlands' imports of wood pellets originate mainly from Canada (412,770 tons) and USA (313,361 tons) while 104,000 tons came from EU intra-trade (Eurostat). The Dutch ports of Amsterdam, Flushing and especially Rotterdam are being used for re-export of wood pellets from North America to Germany, the UK and Denmark (Junginger and Alakangas 2010). Typically, they are imported through Rotterdam and Amsterdam ports by large dry bulk carriers and then transported by smaller river barges to the large consumers, mostly large coal plants

(Hiegl and Janssen 2009). The Rotterdam port is currently considered the biggest hub for wood pellets in EU.

The use of wood pellets for co-firing started in late 1990's with intensified use after the year of 2000 as a result of covenant between electricity producers and Dutch Government (2002) and policy support schemes (Hiegl and Janssen 2009). Five large consumers of wood pellets operate in the Netherlands mostly for the electricity production (Sikkema et al. 2009): Delta Energie (Middelburg), Electrabel Nederland (Zwolle), EoN Benelux BV (Rotterdam), Essent (Arnhem) and NUON (Amsterdam). They consumed 850,000 tons of wood pellets in 2008 (Pelletsatlas). The wood pellets substitute between 1 – 20% of total input in electricity generation with an average of 2.8% of coal being substituted in 2008 (Hiegl and Janssen 2009). The contribution of wood pellets in total electricity generation in the Netherlands (119,000GWh) in 2008, was 1,700GWh (Hiegl and Janssen 2009). The Essent also started a pilot project with the use of MBP made from coffee husks (from Brasil) for co-firing in their Amer coal plant with initial intention to reach annual imports of 250,000 tonnes (Wach and Bastian 2009). Due to a lack of policy support for MBP use, they decided to stop the project until adequate subsidies for their use are put in place (Wach and Bastian 2009). Some other large utilities used 15,000 tonnes of soy husks pellets from Netherlands and 10,000 tonnes of imported agro-pellets for co-firing in 2006 and 2007 (Wach and Bastian 2009).

The Netherlands had a premium payments system (MEP feed-in premium) from July 2003 with a Green Certificate (GO) received from the issuing body for each MWh of renewable electricity generated. The premiums were guaranteed for 10 years and were paid for each submitted GO (EC 2008). This measure provided a subsidy of 6-7 €ct per kWh for electricity produced from clean woody biomass (Capaccioli and Vivarelli 2009). The government abolished all payments in August 2006 believing that the renewable electricity target would be achieved in advance of 2010 (EC 2008). Soon the Netherlands aimed to introduce a new support scheme as early as possible in 2008 with preferred policy option being improved premium payments (EC 2008). Since most of the contracts were signed for full period of ten years, it is expected that current levels of consumption and imports of wood pellets will remain stable until 2012 when first contracts from 2003 will be terminated (Hiegl and Janssen 2009). It is most likely that new policy scheme will be implemented, given the large share of co-firing in renewable electricity generation (Hiegl and Janssen 2009). The Netherlands also uses fiscal incentives for investments in RES. Appendix Table C3 lists all existing policies and measures regarding renewable energy in the Netherlands since 1990 (IEA).

Sweden

Sweden has the lowest level of CO_2 emissions per GDP and the second-lowest per capita of all IEA member countries (IEA 2008). Although it is most likely that Sweden will reach the targets under Kyoto Protocol, it is still putting effort to improve energy efficiency and increase the use of renewable energy, already at a high level (IEA 2008). Since electricity use per capita in Sweden is one of the highest in the world, investments in the new capacities will be needed in order to maintain the security of supply (IEA 2008).

Sweden is also considered a large importer of biofuels since 1990's with most of the import consisting of refined and unrefined wood fuels for district heating and CHP plants, many of them being located close to the port facilities (Stahl and Wikstrom 2009). This enabled them to use lower cost bioenergy imported from longer distances, like North America. The target of

Sweden's national action plan in general, based on RED, aims for 50% of energy consumption from renewables in 2020 (39.8% in 2005) which is one percent higher than the target set by RED (Olsson, Hillring and Cardoso 2009). At the same time, target calls for 10% of all transportation fuels to be renewable and assumes no fossil fuels used for heating. Bioenergy use doubled from 60 TWh in 1984 to 120 TWh in 2007, with increase in primary energy supply from 11.6 % to 19.2 % for the same period (Olsson, Hillring and Cardoso 2009). Bioenergy is used primarily in the forest industry, district heating and CHP plants (Olsson, Hillring and Cardoso 2009). It is expected that future growth in bioenergy use will come from increased use of forest residues (tops, branches, small trees and stumps) and from agriculture (straw and agricultural residues) (Olsson, Hillring and Cardoso 2009). Appendix Table A33.2 shows techno-economical potential and use of bioenergy in Sweden in 2006.

Sweden has one of the most developed markets for wood pellets in the world with total consumption of 1,850,000 tons in 2008 (Hiegl and Janssen 2009). At the moment 1.5 million of wood pellets are being produced in about 94 plants, with total production capacity of around 2.2 million in 2008, with production mainly based on residues from wood processing industries (Hiegl and Janssen 2009). Sweden had 33 % increase in use of wood pellets for household heating between 2004 and 2006 (Stahl and Wikstrom 2009). The small-scale (households) and medium-scale (apartment buildings) users form the major category of customers since 2004 (Stahl and Wikstrom 2009). There were around 120,000 households using pellet boilers in 2008 and 20,000 with pellet stoves (Hiegl and Janssen 2009). At the same time around 4,000 medium-sized boilers were in use too (Hiegl and Janssen 2009).

Sweden's carbon taxation system favors renewable energy sources which resulted in increased large scale consumption of wood pellets in district heating and CHP plants. Many district heating plants switched from oil combustion to coal prior to 1991 and CO_2 taxation, when they started switching from coal to biofuels (Hiegl and Janssen 2009). While in Swedish previous tax system heat generation was CO_2 taxed, this was not case with electricity (Sikkema et al. 2009). Current taxation system (since 2009) makes no difference between heat and electricity production anymore (Sikkema et al. 2009). Currently about 40% of pellets (800,000 tons) are being used by large scale users (Capaccioli and Vivarelli 2009). The most pellets consumed in district heating plants are supplied through long-term contracts (up to 3 years) while power plants buy most of the pellets on spot markets (Sikkema et al. 2009). The prices of wood pellets used in district heating are slightly higher than those for industrial pellets (reaching 140 euros in 2008). The intermediate storage facilities in Sweden are well organized with one organization coordinating pellet purchases for district heating and having storage facilities in Swedish ports for more heating plants (Sikkema et al. 2009).

The first recorded long-distance transport of wood pellets in the world was in 1998 from Canada to Sweden (Sikkema et al. 2009). Sweden is traditional importer of wood pellets and chips from Baltic States, wood pellets from Canada and recovered wood from some European countries (Stahl and Wikstrom 2009). In last couple of years Sweden imported between 300,000 and 400,000 tons of pellets annually with some of the companies also exporting them, mainly to Denmark and United Kingdom (Hiegl and Janssen 2009). In 2009, Sweden imported more than 320,000 tons of wood pellets from other EU countries, while the main importing partner from outside EU was Russia with around 160,000 tons followed by USA with 30,000 tons (Eurostat).

In 2003, Sweden implemented quota obligation system on electricity consumers based on TGCs (EC 2008b) which replaced feed-in tariff system. TGCs apply to wind, solar, geothermal, hydroelectric, wave and biofuel power with purchase obligation on consumers raising from 6.4% in 2003 to 15.3% in 2010 (Uyterlinde et al. 2003). Electricity producers were protected with guaranteed price of 6.5 €cent in 2004 with decrease over transition period, reaching zero in 2008 (Uyterlinde et al. 2003). Not fulfilling the obligation entailed penalty of 150% of the volume weighted average of the certificate price during the 12 month period, with maximum penalty of 2.2 ct/kWh (Uyterlinde et al. 2003). Appendix Table C4 lists all existing policies and measures regarding renewable energy in the Sweden since 1990 (IEA).

The United Kingdom (UK)

The UK Renewables Obligation scheme (RO) requires that 15% of electricity comes from renewable sources by the year 2016 (Panoutsou and Perry 2009). In 2007, 5% of electricity came from renewables with 4% coming from bioenergy (mostly biogas, waste wood and other residual feedstocks) (Panoutsou and Perry 2009). The UK has very ambitious GHG emission reduction targets under RED (15% of renewables in final energy consumption in 2020) and even more ambitious targets for electricity produced from renewables (30-35% by 2020) (Hawkins Wright 2009). The fact that current shares of renewables in final energy consumption and electricity generation are only 1.3% and 5.3%, respectively, significant investments in renewable power capacity will be necessary (Hawkins Wright 2009). Biomass contributed less than 1% in total heat consumption, mostly as domestic and industrial use of wood (Panoutsou and Perry 2009). Appendix Table A33.3 lists current technical potential of solid biomass in UK. Recent UK policy reports estimate land use for energy crops between 350,000 – 1,000,000 ha by 2020, although currently less than 15,000 ha of land is planted with willow and miscanthus combined (Panoutsou 2009).

Although production of pellets in UK started in 1990's its market is still considered emerging but with a very fast growth in the last couple of years, and it is expected to reach the developed stage soon (Capaccioli and Vivarelli 2009). The pellet market in UK supported by different support schemes, began its strong development from 2006 onwards (Hiegl and Janssen 2009). Currently, 15 pellet manufacturers produce around 125,000 tons per year, mainly from: sawdust, clean waste wood, energy crops and forest thinning (Capaccioli and Vivarelli 2009). The production capacity was estimated at 218,000 tons in 2008, but this number is probably higher due to a number of new plants being open. Although some industry representatives have estimated total consumption of wood pellets in 2008 of 750,000 tonnes (Hiegl and Janssen 2009) the proven amount is 176,000 tons of wood pellets consumption in 2008, with 51,000 tons coming from imports (Pelletsatlas). Four large consumers used 166,000 tons of wood pellets in 2008: Drax Power Station (Selby, Yorkshire), Scottish & Southern Energy plc, EON UK plc and Lynemouth power station (Ashington). The consumption of high quality residential pellets is very low, thus making certain amounts available for export, mainly to Ireland and Italy (Hiegl and Janssen 2009).

The UK electricity sector is dominated by: coal, gas and nuclear energy, with 38%, 36% and 18% of electricity being supplied from these sources, respectively (Perry and Rosillo-Calle 2008). At the same time 4.6% of electricity generation came from renewable sources (Perry and Rosillo-Calle 2008). In 2006, co-firing of biomass with coal accounted for 13.9% of electricity generated from renewable energy sources (Perry and Rosillo-Calle 2008). Co-firing of biomass with coal on a commercial scale started in 2002 with establishment of RO, and soon became third largest source of renewable energy electricity (behind hydro and landfill gas) reaching 2.5TWh in 2005 (Panoutsou and Perry 2009). There were 19 dedicated biomass plants in the UK in 2007, with total installed generating capacity of 226MWe and different biomass sources (Perry and Rosillo-Calle 2008). The two largest dedicated biomass plants (commissioned in 2007) use short rotation coppice and woodfuel as a source (Perry and Rosillo-Calle 2008). At the same time, there are 14 coal-fired power plants with a stated capacity over 1GWe (Perry and Rosillo-Calle 2008). Tests conducted at some facilities demonstrated that up to 20% of biomass, by thermal input, can successfully be co-fired (Perry and Rosillo-Calle 2008).

In the last couple of years, ten biomass power production projects (mainly located close to the ports) were announced with total capacity of 2.7GW_e and if they would be completed, the UK will become the biggest importer of biomass (Hawking Wright 2009). Since the annual feedstock requirement for this capacity which is estimated to be 206 million GJ (equates to about 12 million t/year of pellets and 20 million t/year of wood chips) greatly exceeds the availability of woody biomass in the UK, great amounts of biomass will have to be imported (Hawkins Wright 2009).

The UK currently imports significant amounts of biomass, mainly for co-firing in coal-fired power stations (Junginger and Alakangas 2010). Over 1.4 million tones of biomass was cofired in 2005, with more than 1 million coming from palm (450,000t) and olive residues (283,000t), tall oil (120,000t) and wood pellets (164,000t) (Perry and Rosillo-Calle 2008). It is estimated that UK imported around 0.76 million tonnes (54% of total 1.4 million) of biomass for co-firing for electricity production (Panoutsou and Perry 2009). Imported biomass is usually purchased on spot markets and consumers have the ability to switch between different suppliers and feed-stocks to get the best value for their money (Hiegl and Janssen 2009). Pellets are currently being imported as EU intra-trade and possibly from North America (Hiegl and Janssen 2009). The market for MBP is small with only two producers producing straw pellets, mainly for co-firing with coal (Wach and Bastian 2009).

The UK uses quota obligation system (ROC's based on TGS) with obligation put on electricity suppliers and with obligation target increasing to 2015 with the same level guaranteed until 2027 (EC 2008b). One ROC (Renewable Obligation Credit) is awarded for each MWh electricity generated from eligible renewable sources (Perry and Rosillo-Calle 2008). The percentage of co-fired ROCs that suppliers can include in their ROC claim was capped at 25% with decrease to 10% in 2006 (Perry and Rosillo-Calle 2008). The cap resulted in two different ROC markets: one for co-firing and other for all other ROCs (Perry and Rosillo-Calle 2008). In 2007, limitations on the proportions of ROCs that could be claimed from co-firing together with uncertainties about co-firing long-term status within the RO resulted in decrease in electricity produced from co-firing (Panoutsou and Perry 2009). The average auction price for standard ROCs in July, 2007 was €69 while for ROCs from co-firing it was €65 (Perry and Rosillo-Calle 2008). The structure of the RO changed in 2009, allowing permanent and unlimited role for co-firing within the RO, but with greater support for dedicated biomass power plants than for co-firing (Junginger and Alakangas 2010). Suppliers which do not comply with the obligation have to pay buy-out penalty, with collected fund being returned to the suppliers in proportion to the number of ROC's they hold (EC 2008b). A tax exemption for electricity generated from RES is also available (Levy Exemption Certificate). Appendix Table C5 lists all existing policies and measures regarding renewable energy in the UK since 1990 (IEA).

SAFIRE Model results

The model results for all scenarios are given in Appendix Tables A35, A36 and A37. The availability and use of biomass in 2010 and 2020 for different sustainability premiums are shown in Appendix Figures B17, B18 for technology base case scenario.

For all technology scenarios, prices of tradables remain modest in 2010-2020 period, ranging between 2.1 and 4.2 €/GJ without sustainability premium, while for the low and high sustainability premiums they range between 2.8 and 5.5 €/GJ and 3.7 – 6 €/GJ, respectively. Total bio-energy consumption increases significantly from 49.6 to 100.3Mtoe/yr (2000 – 2020) in the technology base case scenario without sustainability premium, while in low and high sustainability premium scenarios it raises to 157.5 and 225.3Mtoe/yr, respectively. In the case of non-subsidized and subsidized technologies this increase is even more significant with around 180 and 250Mtoe/yr for low and high sustainability premium scenarios in 2020, respectively. The most of this increase should come from tradables in all scenarios, which benefit the most from the sustainability premium. Although levels of non-tradables increase with sustainability premiums, their total levels do not exceed 40Mtoe/yr in 2020 in none of the scenarios with more than 70% coming from organic waste.

The agricultural residues consumption has strong increase from 1.3 in base-year to around 20Mtoe/yr without and to around 32Mtoe/yr with sustainability premium included, in 2020 for all technology scenarios. The consumption of transport fuels remains bellow 15Mtoe/yr even with high sustainability premiums and study concluded that EU target of 5.75% share of biofuels will not be met in any case. The model calculated necessary sustainability premium of

219 €/ton CO_2 for this target to be met. Solid industrial residues consumption doubles with maximum of around 17Mtoe/yr in 2020, for all technology and sustainability premium scenarios. The use of solid energy crops increases to 3.8Mtoe/yr under technology base case and to about 5.8Mtoe/yr in both innovative technologies scenarios in 2020 without sustainability premium, while the consumption reaches between 11.5 – 19.4Mtoe/yr with both low and high premiums included (for all technology scenarios). Forestry byproducts and refined wood fuels remain the most important tradable in all years and scenarios, excluding imported biomass. The consumption of this products increase from 21.9Mtoe/yr in base year to between 31.9-34.5Mtoe/yr in 2020 for no sustainability premium in all technology scenarios, and to around 43Mtoe/yr for sustainability premium included.

The study showed that consumption growth in high sustainability scenario is mainly driven by strong increase in biomass imports. The share of imported biomass in total consumption of biomass, in technology base case scenario, rises to 12 and 28%, for low and high sustainability premium included, respectively. Appendix Figure B19 shows that technology subsidies influence mostly imported biomass levels and to some extent solid energy crops (study assumed that 50% of set-aside area is available for solid energy crops and 25% each for bio-ethanol and bio-diesel). Technology subsidies have a very small influence on organic waste and wet manure consumption, while low and high sustainability premiums increase it significantly. The model showed that biomass imports might reach between 6.1-7.7Mtoe/yr, 19.5-35Mtoe/yr and 64-85.9Mtoe/yr in the case of zero, low and high sustainability premium, respectively, in different technology scenarios.

Appendix Table A38 shows the projected levels of imported biomass for EU countries in 2020 for all technology and sustainability premium scenarios from SAFIRE model. Since CO_2 futures emission prices (for 2014) fluctuated between €15-20/t CO_2 in 2009 and beginning of the 2010, we assume that most likely they will not reach €100/t CO_2 in 2020 as in high sustainability scenario. Therefore, we assume a low sustainability scenario with non subsidized innovative technologies as the most realistic scenario in SAFIRE model.

Model results from low sustainability-non subsidized innovative technologies scenario show that Germany, UK, Czech Republic, Poland and Ireland are expected to be the largest importers of biomass in 2020, although UK is the only significant importer at the moment. It also shows that introduction of sustainability premium caused significant increase in imports in all countries. This is especially characteristic for Greece, Ireland, Netherlands and UK where absence of premium gives negligible import levels. On the other hand, Poland, Czech Republic, Germany and Belgium are the only countries whit significant import levels even with exclusion of sustainability premium. Italy, Austria and Sweden, the three biggest biomass importers in EU are expected to import negligible levels in the most likely scenario. Inclusion of high sustainability premium in Italy and Sweden would induce imports. Low predicted levels of imported biomass for Denmark are probably resulting from favorable policies for wind electricity generation which already made it world leader in this sector.

It is difficult to predict the future pellets share (both wood and MBP) in imported biomass because it largely depends on future policy development and support to one or another renewable source. Although SAFIRE model results estimate that Germany will be the largest importer of biomass, at the moment, Germany is the biggest exporter of wood pellets in EU with the largest production capacity (over million tons in excess of production levels in 2008) and uses of wood pellets almost exclusively for residential heating. Similarly, other expected large biomass importers like Czech Republic, Ireland and Greece consumed together less than 60,000 tons of wood pellets (mostly for residential heating) in 2008. At the same time Poland and Czech Republic are considered wood pellets exporters with 153,000 and 220,000 tones of wood pellets being exported in 2008, respectively, with low levels of consumption. Only Poland used pellets in large heat and power units to a larger extent. Even if they become importers of wood pellets, the proximity of Russia, Ukraine and Belarus, countries with high biomass potentials and already significant exports of wood pellets, will probably make them cheaper source of wood pellets.

Appendix Table A39 shows projected quantities of imported biomass and pellets in 2020 (for different technology scenarios and different levels of sustainability premium) for all of the EU's traditional importers of wood pellets. First, we assumed share of wood pellets in total biomass imports in 2020 to be the same as in 2007. Without sustainability premium, quantity of imported pellets would be lower than in 2007 for each technology scenario. With low sustainability premium included, Netherlands and Belgium would import 1,636,281 and 1,387,962 tons in the base case and 2,570,547 and 1,611,890 tones in both innovative technologies scenarios, respectively. Denmark, currently the largest wood pellet importer and the importer with the largest share of wood pellets imports in imported biomass is expected to import about 570,000 tons of pellets in low sustainability premium scenario (for both technology scenarios). Inclusion of a high sustainability premium would increase import levels to about 2,000,000 tons. Although United Kingdom's shares of wood pellets in total biomass import will most likely grow in the future due to favorable RO schemes and announced numerous co-firing utilities, applying current share of 5.5% gives imported levels for low and high sustainability scenarios between 700,000 – 1,300,000 tons. With the same share as in 2007, Italy would have very low levels of pellets import (less than 35,000) in low sustainability and between 450,000 and 500,000 tons in high sustainability premium scenario.

It is most likely that wood pellets share in imports of biomass will change significantly for each country with changes in their renewable policies and their compliance with RED targets, so we conducted a sensitivity analysis by varying values of shares of imported pellets in projected biomass imports for 2020. This enables estimation of imported pellets for EU (Figure 24) assuming that at least some part of biomass imports would come from pellets. Since only several countries currently import wood pellets (shares vary from 5.5 – 77.3%) and assuming lower shares for other countries becoming importers in upcoming years, it is most likely that shares of pellets import in biomass imports in 2020 will be between 10-15% on EU level, or between 7.9 and 12 million tons of pellets.

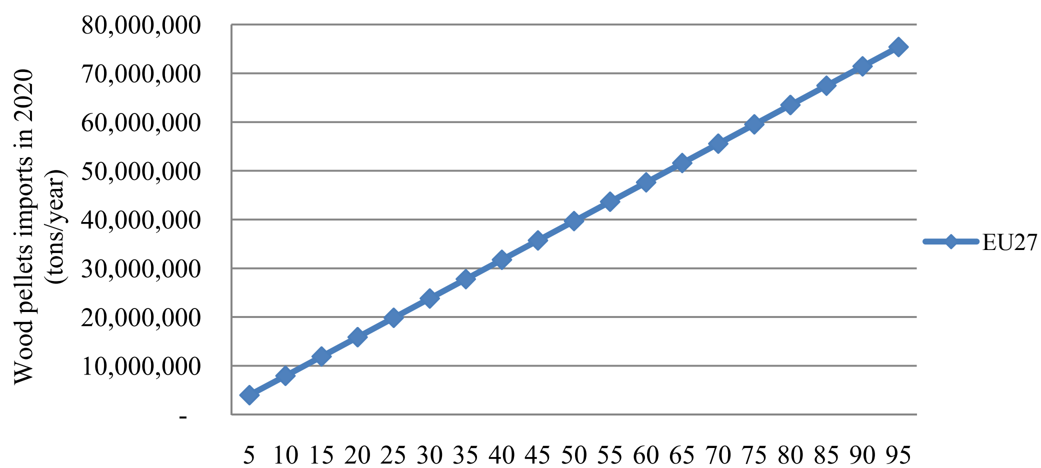

Figure 24. Wood pellets imports (tons) in 2020 for different shares in biomass imports

We expect that Belgium, Netherlands and United Kingdom (Figure 25) are going to stay amongst the largest industrial pellets importers according to their: current and projected consumption of solid biomass in heat and electricity generation, consumption of pellets in large heat and power utilities, production capacity and current consumption of wood pellets, imports of pellets, policies in power regarding heat and electricity generation, set targets and compliance with them, projected biomass imports and biomass potential. Figure26 shows the estimated imports of pellets for all other countries having projected biomass imports of more than 800Ktoe/year. As some of the largest consumers of coal for electricity generation in EU (Appendix, Table A40): Germany (300TWh), Poland (145TWh), Czech Republic (54TWh) and Greece (35TWh) are most likely to become industrial pellet importers with adequate policies supporting combustion of biomass for electricity generation. Especially because co-firing of biomass with coal is thus far the cheapest technology for biomass combustion, with the similar being expected for 2020 (only co-gasification is expected to have lower cost) (Dornburg 2008). Poland recently enacted policy measures that induced consumption of wood pellets in large scale utilities. Spain, which consumes significant amounts of coal for electricity generation (73TWh) will need high sustainability premiums according to Siemons et al. (2004) to become significant importer of biomass and therefore is not included in the Figure.

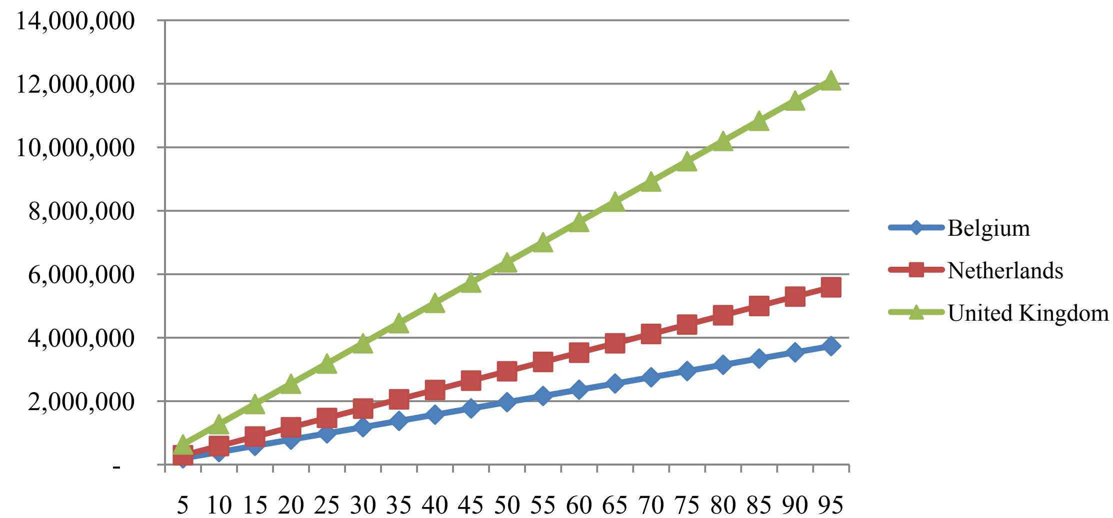

Figure 25. Wood pellets imports (tons) in 2020 (with different shares of wood pellets import in biomass imports) in expected major industrial pellets importers

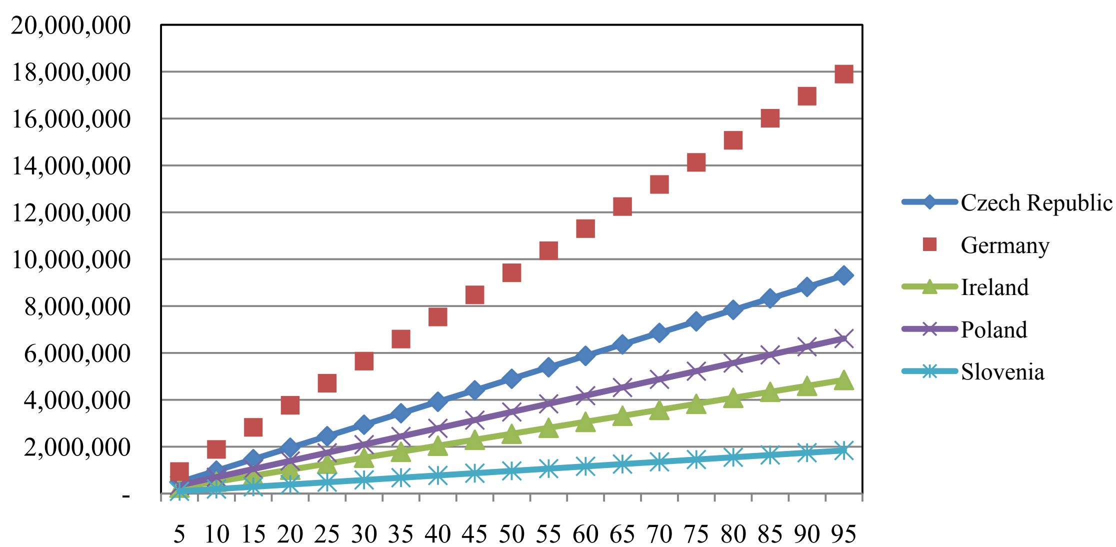

Figure 26. Wood pellets imports (tons) in 2020 (with different shares of wood pellets import in biomass imports) in other projected major biomass importers

Chapter 5: Feasibility study for pellets production in East Tennessee and their competitiveness on EU market

Switchgrass and mill residues availability

Since feedstock cost contribute significantly to the pellets production cost, its availability in proximity to the pellet plant is of great importance. With feedstock source closer to the plant, its delivered cost decrease due to the lower transportation cost. Many studies use 50 miles (~80km) as a maximum economically feasible distance for biomass transportation by truck to the processing facility. Appendix Table A41 shows necessary quantities of mill residues and switchgrass to produce 100,000 tons of pellets per year, including different blend mixes.

Switchgrass

Currently, there is approximately 2,000 acres of switchgrass planted in the 50 miles radius from the assumed plant location. Those acres are planted under contracts between farmers and the University of Tennessee, with about 45 farmers currently participating in the program. Assuming a 5t yield per acre, current production is around 10,000 tons of switchgrass which will be mostly used as a feedstock in recently built ethanol plant in Vonore. We assume that adequate price will motivate farmers to produce switchgrass under contract with pellet plant as well. From March to October, switchgrass will be uniformly delivered while from November to February it will be delivered to the pellet plant directly after the harvest (Larson 2009).

In order to successfully run, pellet plant with capacity of 100,000 tons using 100% switchgrass as feedstock will need between 14,000 – 17,000 acres of land planted under switchgrass (with yields between 5 and 6 tons per acre). We assumed that farmers will most likely switch their acres, currently under hay (other hay), to switchgrass production in case of favorable price for switchgrass comparing to that of hay. Appendix Table A42 lists number of farms growing other hay, harvested acres in 2002 and 2007, and average yield for 2003-2008. We included only acres for other hay because hay from alpha-alpha is more expensive and it will be harder to motivate farmers to change it to switchgrass production. Appendix Table A40 shows prices for other hay in the last 8 years.

Appendix Table A43 shows NPV farmers will receive for different prices of switchgrass and hay. Already mentioned decision tool from University of Kentucky was used for calculations. In order to supply enough feedstock to the pellet plant, and depending on the switchgrass-mill residues ratio, between 2-8% of total acreage under other hay in observed region will have to be converted to switchgrass production.

Mill residues

East Tennessee is mostly covered by interior forest classification of land which covers almost 40% of total land (Appendix, Figures B20 and B21). Hardwood is dominating forest type in Tennessee, which makes a basis for good feedstock quality supply for premium grade wood pellets (Appendix, Figures B22 and B23). The Monroe County is located in an area covered with hardwood forest as well.

According to the US Department of Agriculture's Forest Service, Tennessee is a state with the highest quantity of unused mill residues (187,500t) which represents 14,48% of total unused mill residues in US (1,295,560t) and 9.33% of total mill residues production in Tennessee (2,009, 600) (Figure 27). As it can be seen from the Figure, site location (Industrial Park in Monroe County) falls into the category with the highest level of unused mill residues (dark green). Five counties in 50 miles range from site location (Hamilton, Bradley, Rhea, Roane and Blount) fall into the same category (4,700-100,000t) of unused mill residues).

Figure 28 shows Primary Mill Residues distribution in US per county (include wood materials (coarse and fine) and bark generated at manufacturing plants (primary wood-using mills) when round wood products are processed into primary wood products, such as slabs, edgings, trimmings, sawdust, veneer clippings and cores, and pulp screenings. The Monroe County produces between 10,000-25,000 dt of primary mill residues per year.

Appendix Figure B24 shows that in 50 miles radius from the plant location operate 22 wood-processing mills with 0-5 million and 4 sawmills with 5-20 million board feet of timber processed annually, one veneer production site, two pulpmill and one composite panel production location. Appendix Table A45 shows southern pellet mills' capacities currently in operation. The only pellet mill in close proximity to the selected plant location is one in North Carolina with production capacity of 21,000 tons per year.

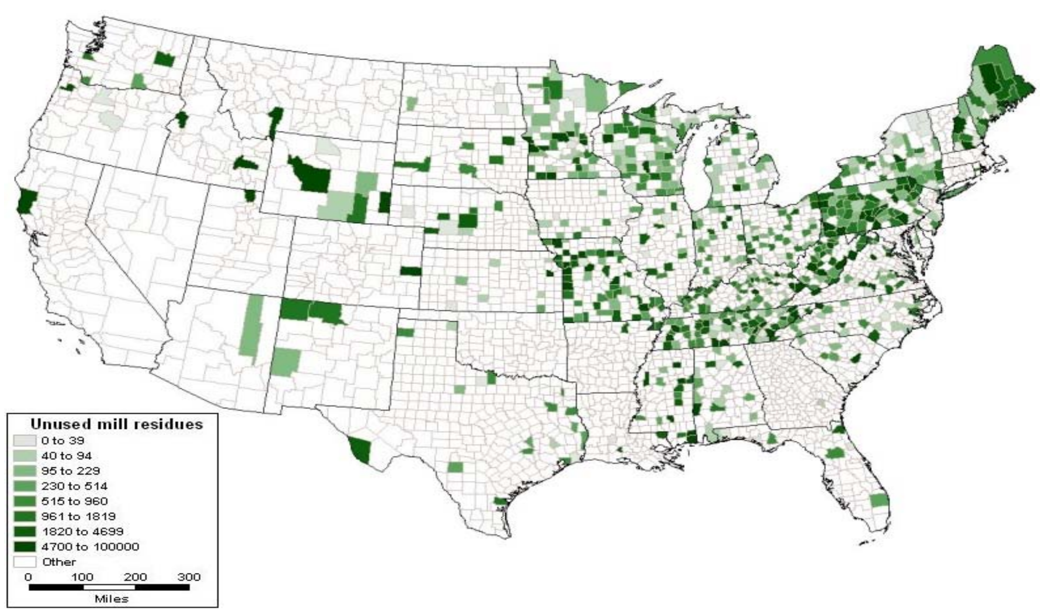

Figure 27. Unused mill residues per county
Source: USDA, Forest Service's Timber Product Output database, 2007

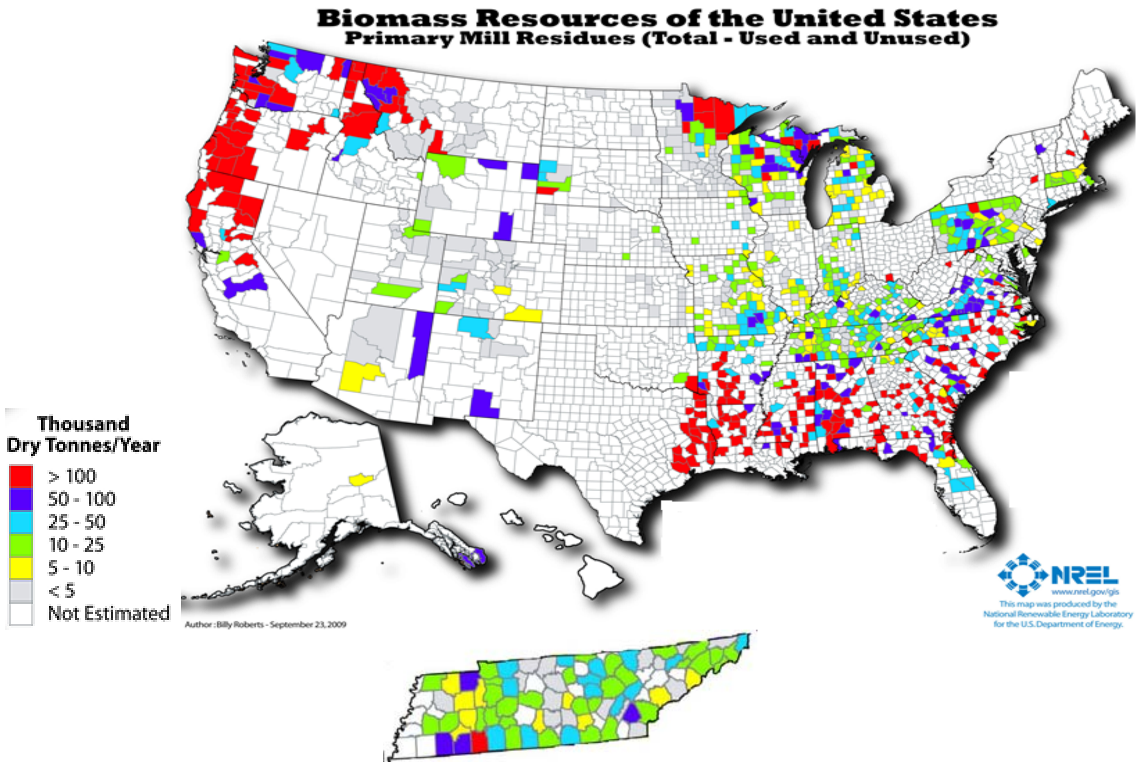

Figure 28. Primary Mill Residues per county
Source: USDA, Forest Service's Timber Product Output database, 2007

The mill residues supply curves for counties in 50 miles radius from the plant (Appendix, Table A46) show estimated supply of raw material for different price levels. For the prices for mill residues higher than $25, it is expected there would be enough feedstock to operate 100,000 tpy pellet plant, because at the moment no significant consumers of mill residues exist in the area. It could also be expected that for a higher than $25 price, feedstock of a better quality and less moisture could be obtained.

In the first quarter of 2009, bark-free, in-wood pine chips, excluding transport cost, were quoted in the range of $31–$39 per green tone (Spelther and Toth 2009). According to Timber Mart-South, delivered pulpwood prices in the U.S. south in 2008, averaged $30/green tone (Spelther and Toth 2009) main feedstock used in nearly all pellet plants exporting to Europe according to Luppold (southern pine pulpwood). Spelther and Toth (2009) also reported $42/green ton for fiber residues for South US.

Investment and pellets production cost

Investment cost

Include cost of: project and construction management and support, site development, feedstock storage (bale lot, warehouse) plant construction including offices, field expenses (consumables, small tool equipment rental, field services, temporary construction facilities, and field construction supervision), proreatable cost (this includes fringe benefits, burdens, and insurance of the construction contractor) processing and other equipment (including freight, mechanical and electrical installation) and other cost. Other cost include: start-up and commissioning cost; land, rights-of-way, permits, surveys, and fees; piling, soil compaction/dewatering, unusual foundations; sales, use, and other taxes; freight, insurance in transit and import duties on equipment, piping, steel, instrumentation, etc; overtime pay during construction; field insurance; project team; transportation equipment, bulk shipping containers, plant vehicles, etc; escalation or inflation of cost over time; interest on construction loan (Aden et al. 2002). Since all of the abovementioned cost except processing equipment and feedstock storage can vary significantly for different situations (i.e type of a deal with contractors for engineering and construction, land quality and site condition etc) we calculated them with factors based on industry standards used for lignocellulosic biomass to ethanol process design from Aden et al. 2002 (Table A47, Appendix).

Investment costs for the equipment were obtained from surveyed manufacturers for their equipment and machinery. Mechanical and electrical installation cost for the equipment were calculated as a percentage of total installed cost of processing equipment using industry standard (32% for mechanical and 20% for electrical installation) used in a biomass pellet plant feasibility study created by Campbell (2007) and then assigned to each piece of equipment according to its purchase cost share in total equipment purchase cost. Mani et al. (2006) reported total installation cost between 40-75% of purchased price. The freight costs were calculated the same way as installation cost and were calculated as 4% from equipment purchased price (Campbell 2007). Some representatives also suggested 2% for calculations of freight cost but we will use larger number for the accuracy. Appendix Table A48 shows total installed equipment cost and Appendix Table A49 lists total project investment cost for 100,000TPH pellet plant.

Raw material cost (MR, SG)

Have a big share in total cost and will be adopted from Larsson (2010) (Table 5) as delivered cost for switchgrass and from supply curves (Appendix, Table A46) developed by Marie Walsh, for mill residues (English et al. 2006). Calculated delivered cost for switchgrass includes: contracts with individual farmers and pays for opportunity cost of land, switchgrass establishment, annual maintenance, harvest and storage. The price of $82/ton will be used for base-case model assuming round bale stored on the ground without tarp, pallet or gravel. The wood pellets raw material cost (mill residues) will be adopted from the mentioned supply curves (mil residues per county for different prices). Since for prices lower than $30 per ton of mill residues, supply will not be enough to operate the pellet plant, only cost equal or higher than $30 will be used in the analysis.

Annual capital cost (ACC)

Recent studies assumed interest rate between 6.5-8 % (Mani 6%, Thek and Obernberger 7%, Urbanowski 7%, Campbell 8.5%, BBI 8%, Jackson 6.5%) for pellet plant construction, while study for lignocellulosic biomass to ethanol plant (Aden et al. 2002) and Renewable Energy Assessment Guide from EPRI (2006) assumed 7.5% and 8%, respectively. For the accuracy we will assume higher interest rate (8%) for this study. Utilization period for different equipment is given in Table 6.

Operating cost (OC)

Comprise of: maintenance, electricity and personnel cost, heating cost for drying, interest rate, property tax, wheel loader operating cost and other variable cost. Required electric power depends on the type of technology of production used. We assumed simultaneity factor for electricity demand of 85% (electric power needed on average/nominal electric power of all units*100) since equipment is not always run on a full load, based on the experience from Austrian and Swedish pellet plant operators (Thek and Obernberger, 2004). Rates for the electricity and natural gas were obtained from the official web site of Knoxville Utility Board (KUB).

Electricity cost (Ec)

Niles Ferry Industrial park has a good access to natural gas and electrical services. We used energy demand for each piece of equipment, provided by the manufacturer's representatives and from already mentioned pellet plant layout (for equipment like conveyors, dumpers and air exhaust) sum it with expected usage and then applied local utilities electric rates. With assumed throughput rate of 14TPH we assume that annual energy use would be 7,443 hours (608 hours per month) to produce 100,000 tons of pellets. This number includes allowance for 300 idle hours (when equipment is warming up, shutting down or otherwise running without production) (Campbell 2007). Currently, average electricity price for industrial users in Tennessee is $0.0531 (EIA 2009). Since billing demand is expected to be greater than 1000kW per month in 12 months period, following charges apply for KUB general power rate customers: $140 customer charge per delivery point per month; first 1,000 kW of billing demand per month, at $13.97 per kW. Excess over 1,000 kW of billing demand per month, at $16.1 per kW, plus an additional 16.1 per kW per month for each kW, if any, of the amount by which the customer's billing demand exceeds the higher of 2,500 kW or its contract demand; energy charge of 5.361¢ per kWh per month. Appendix Table A50 lists electricity requirements and cost estimates for 14TPH pellet plant.

Drying cost (Dc)

Heat for drying and related cost depends on a dryer type and moisture of raw material. The amount of heat used to evaporate one pound of water ranges from 1,400 – 1,550 (Schroeder 2010; Thek and Obenberger, 2004; Campbell, 2007). In their study, Thek and Obernberger (2004) used 1000kWh/ton of evaporated water, which is equal to 1,550BTU/pound. For this study we used 1.500 BTU/lb of evaporated water and assuming natural gas as the only source for drying process. Although use of other sources may change the final price of produced pellets (Mani et al. 2006) they are not going to be considered here. We assume that KUB will be the supplier of natural gas for the plant. Since pellet plant is expected to have more than twenty seven therms or more of natural gas consumption per month it will be paying following service fee under rate schedule G-4: customer charge of $5.3; $1.14 per therm for the first 250 therms; plus $1.03 per therm for the excess over 250 therms.

Appendix Table A51 shows estimated cost of natural gas usage and cost for all scenarios. In order to be pelletized, optimal moisture of feedstock before entering the pellet press should be between 8-12% on the wet basis (Van Loo and Koppejan, 2008; Urbanowski, 2005). Pastre (2002), Mani et al. (2006), Magelli et al. (2009) and Campbell (2007) suggest moisture level prior to pellet press of 10%. Pelletizing equipment operates the most efficiently and produces the most consistently density pellets with moisture content of 12% according to BBI (2009). Depending on the feedstock usage we assume drying of raw material from 50 to 12% for mill residues and from 15 to 12% for switchgrass in our calculations.

Service and maintenance cost (Sm)

For all processes will be calculated as a percentage of total investment cost per year (Thek and Obernberger, 2004). Table 6 lists factors used in calculations of service and maintenance cost for each facility or piece of equipment.

Personnel cost (Pc)

Depend on the number of personnel in the production process and the number of plant working days and shifts. The number of personnel depends on the automation of the plant processes. Campbell (2007) uses 6 laborers per shift in his study (shift supervisor, four machinery/equipment operators, one bagging/forklift operator and one maintenance worker on call). He also assumes that pellet plant of 8TPH and 14TPH will need general and financial manager, marketer and administration assistant. BBI (2009) uses total number of employees for 14TPH plant to be 10 (one plant manager, two shift leaders, two shift operators, three yard/commodities labor, one maintenance manager and one maintenance operator) but do not specify the number of shifts or number of worker per shift. Jackson (personal communication) uses number of 14 employees per shift in his pelleting budgets. Appendix Table A52 shows number of shifts, personnel and estimated cost used for calculations in this study.

Project financing and interest rate (I)

Campbell (2007), BBI (2009), Urbanowski (2005) and Mani et al. (2006) assumed 40% and 60% debt financing with 8.5%, 8%, 7% and 6% interest rate, respectively, amortized over ten years. Campbell (2007) assumed interest only payments for the construction period and first years of operation, common values experienced in industry according to BBI (2009). Renewable Energy Assessment Guide also assumes 60-40% debt-equity ratio with 8% interest rate for merchant plants. For this study we will use this debt-equity ratio and 8% interest rate. No subsidies from government are assumed for the construction of the pellet plant. We assumed that loan returns the payment on the principal for 10 years for the investment based on periodic, constant payments and a constant interest rate. Appendix Table A53 shows annual loan payments.

Property tax (Pt)

Property tax for commercial and industrial property for Vonore, Monroe County is $1.58/100 dollars on 40% of assessed value (Tennessee Comptroller of the Treasury). Assessments are based on a percentage of fair market value of the property as of each Jan. 1. We assume total investment cost as the market value of the pellet plant.

Other variable cost (Ovc)

Include insurance rates, overall dues, taxes and administration cost and will be calculated as a percentage of: total installed cost of the equipment, total cost of buildings and offices and feedstock storage cost. We assumed other variable cost as 0.05% of mentioned cost, number used in study from Thek and Obernberger (2004).

Total production cost of pellets (PPC)

Appendix Table A54 represents total production cost of pellets. The largest share in total production cost comes from feedstock cost followed by the drying cost (if mill residues are used as the only feedstock) and annualized capital cost. Assumed large raw material moisture content (50%) incures high drying costs for mill residues scenario and together with feedstock cost contribute close to the 49% in total production cost. Use of switchgrass as the only feedstock reduces drying cost significantly (from $22.74/t in 100% mill residues scenario to $1.12/t). The share of feedstock cost in total production cost of pellets is 34% for 100% mill residue scenario while 52% and 47% for 100% switchgrass and 40/60 blend scenarios, respectively. Annualized capital cost have the highest shares in production cost after feedstock cost for 100% switchgrass and blend scenarios, with 13.2% and 12.5% respectively. Electricity, personnel and interest costs have around 10-11% share for all scenarios. Figure 28 shows shares of different cost in total production cost of pellets for all feedstock scenarios.

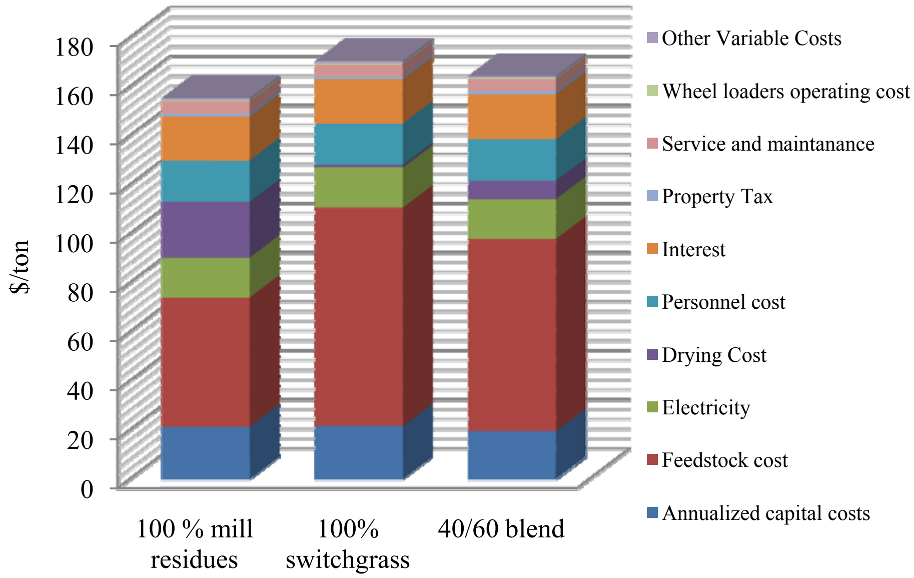

Figure 29. Share of different cost in total production cost of pellets for different feedstock scenarios

Shipping cost (TC)

Pellet plant location will have access to the railroad and necessary on-site equipment for loading pellets on to the railcars, thus eliminating need for truck transport. We assume that pellets will be shipped 2-4 times a year, or between 25,000-50,000 tons per shipment. Using formula (6) we calculated freight rates for train and ocean transport assuming that different ports might be used for export (Table A55, Appendix). The map (with main line railroad service distances) from Rand MC Nally & CO was used to approximate travel distances between Knoxville and Port Terminals, while world ports distances calculator was used for distance between U.S. ports and Rotterdam (assumed as import terminal). Since calculated ocean freight rates do not include port's storage and handling cost, tariff rates from Panama City port were used as the only port (to the best knowledge of authors) listing tariffs for wood pellets. Costs at port include wharfage, handling and storage cost (Panama City port authorities). Since handling and storage rates for bulky material can be quoted only upon request, we used rates for scrap wood pulp we assumed to be the most similar to those of wood pellets.

Financial analysis

Profitability of the pellet plant will be expressed as a pre-tax net income and as a return on investment (return on equity). Since many assumptions would have to be made in order to appropriately estimate model parameter changes for the longer period, profitability is calculated for the second year of production, assuming no escalation of current cost of input or prices of output. The second year production picture assumes full production of the pellet plant and already developed market for its product. No federal or state income taxes are being subtracted from net income. Calculations are based on base-case model parameters for all feedstock scenarios (Table 6). Figure 30 represents cost structure for delivered pellets at Rotterdam for different feedstock scenarios.

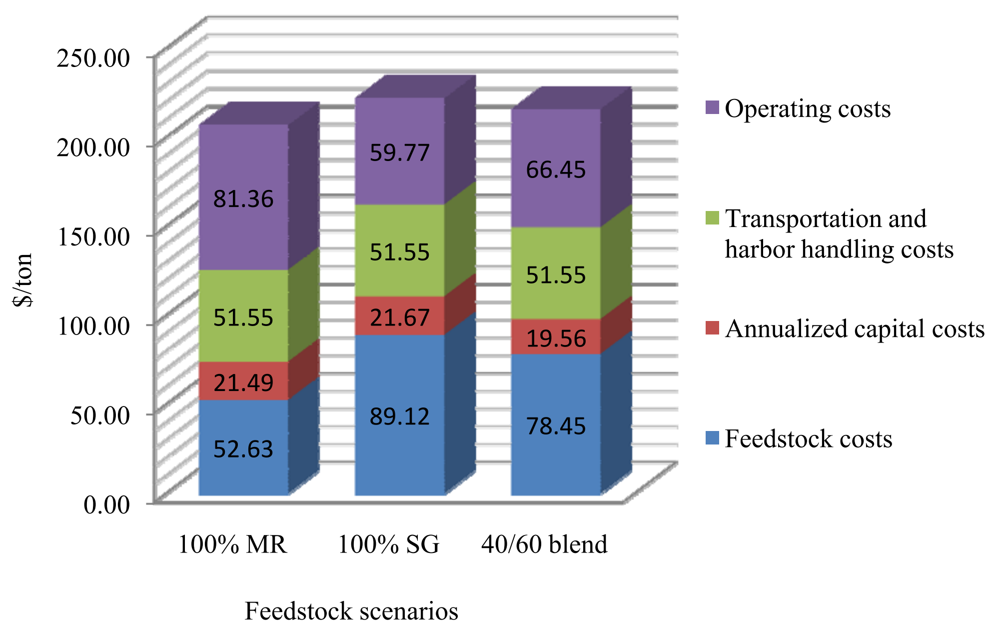

Figure 30. Cost structure for delivered pellets at the port of Rotterdam (CIF)

Income statement for the base-case model parameters is given in Appendix Table A56. All feedstock scenarios produce negative ROI. The scenario with mill residues as the only feedstock produces the least negative ROI of (4.63%) followed by the 40/60 blend and 100% switchgrass scenarios with (6.52%) and (7.78%) respectively. 100% mill residues scenario produced $24 loss per ton, while 40/60 and 100% switchgrass scenarios produced $33 and $39 loss per ton, respectively.

Appendix Table A56 and Figure 30 show that feedstock costs have the largest portion in total CIF ARA cost with 40% and 36% of share for 100% switchgrass and 40/60 blend scenario, respectively. The share of feedstock cost for 100% mill residue scenario is second largest with 25% while operating cost have the largest portion (due to the high drying cost) with 40%. Transportation costs comprise significant share of total delivered pellets cost in Rotterdam as well and have a share of about 24% for all scenarios.

Feedstock price, raw material moisture and loan terms (different interest rate and numbers of annual payments) are the parameters with the largest impact on production cost of pellets. On the other hand, pellets price, exchange ratio and transportation costs have a significant impact on final delivered cost of pellets and their competitiveness in the EU market.

Corresponding tables and figures in Appendix show impact of various parameters variations on cost of production, gross income and return on investment.

Appendix Tables A57, A58, and A59 and Figures B25, B26 and B27 represent changes in ROI for all feedstock scenarios by varying the feedstock and pellets prices, keeping general parameters constant. Pellet prices of $207/ton and $222/ton in EU will be necessary for project with 100% mill residues and 100% switchgrass to breakeven, respectively, assuming all other parameters from the base case model constant. For the prices of mill residues larger than $50, breakeven price increases to more than $240/ton for 100% mill residues scenario. With $50/ton price for switchgrass, breakeven price falls to $188/ton, while price of $95/ton of switchgrass increases it to $237/ton. Appendix Table A60 shows that if mill residues with 30% moisture will be used, project would breakeven with mill residues prices of $30, $40, $50 and $60/ton, with around $175, $195, $205 and $215/ton price for wood pellets on the EU market, respectively. Prices of pellets will have to be around $30/ton higher for project to breakeven if mill residues with the same price and moisture of 50% are used in production.

According to Appendix Figures B25 and B26 and with all other parameters held constant, greater ROI can be achieved by 100% switchgrass scenario with $50/ton paid for switchgrass, than with 100% mill residues with the same price for feedstock. 40/60 blend scenario with prices of raw materials of: $30/ton mill residues - $50/ton switchgrass, $40/ton mill residues - $50/ton switchgrass and $50/ton mill residues - $50/ton switchgrass requires pellet prices of around $180, $190 and $195 per ton to breakeven. All other price combinations shown on Appendix Figure B28 require larger prices for project to breakeven.

Appendix Figure B28. shows impact of mill residues' price change on production cost of pellets (in 100% mill residues scenario) for different moisture levels of raw material. Increase in mill residue prices significantly increases pellet production cost. Reduction of feedstock moisture decreases production cost substantially, with larger cost reduction with higher feedstock prices. Mill residues price of $30/ton with moisture of 20% reduces production cost to $117/ton.If pellet mill could buy mill residues of 30% moisture for $30/ton, breakeven price will be $180/ton and ROI could reach 14.27% with $250/ton pellet price (Appendix, Figure B29). The mill residues price of $50/ton (30% moisture) creates almost the same ROI as price of $30/ton for feedstock of 50% moisture, for all pellet price levels. Mill residues moisture content does not influence production cost significantly in 40/60 blend scenario as in 100% mill residue scenario (Appendix, Figure B30). However, change in the price of switchgrass impacts production cost substantially for 100% switchgrass and 40/60 blend scenarios (Figures B30, B31).

Appendix Figure B32 shows that with exchange rate euro-dollar higher than 1.6 project will earn positive ROI for the 100% mill residue scenario, while ratio of 1.7 will generate positive ROI for the other two scenarios (keeping all other model parameters constant). Appendix Table A61 shows euro:dollar conversion matrix for different exchange ratios.

One percent change in interest rate does not substantially influence the change in production cost (Appendix, Figures B33 and B34). The change in number of annual loan payments from 10 to 20 years with same interest rate does not have a large impact on production cost either (decrease of $6/ton).

With transportation costs to the port of Rotterdam of $40, $50 and $60 per ton, pellet prices of $195, $205 and $215 per ton are needed, respectively, for a project with 100% mill residues to break even (Appendix, Figure B35). The 100% switchgrass scenario will need pellet prices of $210, $220 and $230 per ton to breakeven with abovementioned transportation cost levels, respectively, while 40/60 blend scenario will breakeven with $205, $215 and $225 per ton (Appendix, Figure B36, B37).

In an optimistic scenario with: 20% mill residues moisture, 6% interest rate with 20 year payment period, 1.5 euro: dollar exchange ratio, $50/ton price for switchgrass and €140/ton price for pellets in EU, project would create 9.96%, 6.66% and 8.35% ROI for 100% mill residues, 100%switchgrass and 40/60 blend scenarios, respectively (Appendix, Tables A62, and A63). Production costs would be \$107, \$125 and \$116 per ton for 100% mill residues, 100% switchgrass and 40/60 blend scenarios, respectively.

Chapter 6: Summary and conclusions

The EU's increasing demand for wood pellets provided a major drive for substantial increase in the wood pellet production capacity in the USA in the last couple of years, with many pellet plants commissioned recently for the export to EU. Some of them are already closed and some of them operate and export successfully. However, many companies consider pelletizing projects at the U.S. South intended for export as very profitable at the moment. With raw material costs and its properties having the largest influence on pellet production cost, together with shipping costs to EU consumers, mills closer to cheaper sources of biomass and ports will be more competitive.

SAFIRE model showed the necessity of biomass imports in 2020, with countries currently the biggest producers of electricity from coal expected to be among major importers. With estimated imports of 1.8 and 2.3 million tons of wood pellets in 2020, Belgium and Netherlands are expected to remain the most important partners for U.S. The UK, with ambitious plans for biomass use in electricity production in recent future, will require a feedstock equivalent to 12 million tons of wood pellets. Since the demand would greatly exceed the available biomass potential, UK will have to import it. There is an opportunity for U.S. pellet producers to take a portion of UK pellet market since it is developing rapidly. Estimated demand for pellet imports from these three countries is equivalent to the production capacity of about 150 plants producing 100,000ton of pellets per year.

SAFIRE model estimated that with the price of $8.4-9/GJ for imported biomass (assuming 1.4-1.5 euro:dollar exchange ratio) or around $168-180 for a ton of wood pellets in 2020, import levels will be significant. In order to be competitive in the EU market, pellet producers in the East Tennessee will have to deliver their product with pellet price in this range. Cheap mill residues with low moisture content (around 20-30%) together with lower price for switchgrass ($50/ton or less) will be necessary for profitable operation. U.S. exporters will also have to protect themselves with long-term contracts to avoid negative impact of pellet prices decrease or unfavorable exchange ratio.

Financial analysis for the three different feedstock scenarios showed that assuming: 50% moisture of mill residues; prices of $30/ton for mill residues and $82/ton for switchgrass; and exchange ratio euro:dollar of 1.39, all three feedstock scenarios produce negative ROI. Base-case model parameters calculated the production costs of $155, $174 and $165 per ton for 100% mill residues, 100% switchgrass and 40/60 blend scenarios, respectively. Addition of shipping costs calculated CIF prices for exported pellets of $207, $222 and $214 per ton for 100% mill residues, 100% switchgrass and 40/60 blend scenarios, respectively. With current CIF prices for industrial pellets on EU's exchange market of $170/ton, pellet production and shipping costs will have to be reduced in order for project to breakeven. Use of cheaper raw material in an optimistic scenario with moisture content of around 20-30% and the price of switchgrass of $50/ton, reduced production costs significantly, and created a positive return on investment of 9.96%, 6.66% and 4.12% for 100% mill residues, 100% switchgrass and 40/60 blend scenarios, respectively.

Recent substantial increase in Russian production capacity and export, especially to Scandinavian countries, promoted Russia to the biggest competitor for Canadian and U.S. pellets exporters. Its large woody biomass potential creates possibility for lower production cost of pellets. Further research in production capacity, production and consumption of pellets in Russia, together with estimation of pellet production costs, is necessary in order to more properly assess possibility for U.S. pellets export in EU in the future.

The limitations of this study are that it was not able to distinguish mill residues by their type and moisture content, thus using relatively high value of 50%. It also did not include possible investment grants for projects of this type and did not evaluate the possibility of transporting pellets from plant to the ports in the Mexican Gulf by river barges which might be a cheaper option. Proper consideration of these parameters, together with possibility of using the biomass as a fuel for drying, may influence the final production and CIF costs of pellets.

Production of industrial pellets for Tennessee's utility sector should also be considered as an option if favorable policies like mandatory co-firing with coal are enacted in the near future. In that case, transportation cost will be significantly lower, reducing distance to the consumers and excluding ocean shipping. Also, the option of using low moisture mill residues with higher quality (like sawdust) for Premium pellets will possibly create much higher ROI, but will probably incur additional cost for marketing and market positioning of product.

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APPENDIX A

TABLES

Table A1. World's major importers and exporters of wood pellets in 2009

	Importers				
Exporting partners	Belgium	Denmark	Netherlands	Sweden	EU
USA	185,249	-	313,361	30,138	534,679
Canada	87,078	17,878	412,770	-	520,197
Russia	45,458	86,535	19,352	162,953	377,156
Belarus	340	12,976	149	622	74,846
South Africa	7,222	-	34,560	-	41,782
Ukraine	276	7,546	-	-	30,363
Intra EU	127,688	603,269	104,756	326,083	2,056,043
Total	453,311	728,204	884,948	519,796	

Source: Eurostat

Table A2. U.S. residential/commercial densified fuel standards for pellet fuel

Fuel property	PFI Super Premium	PFI Premium	PFI Standard	PFI Utility
Bulk density, lb/cubic foot	40 - 46	40 – 46	38 - 46	38 - 46
Diameter, inches	0.250 - 0.285	0.250 - 0.285	0.250 - 0.285	0.250 - 0.285
Diameter, mm	6.35 - 7.25	6.35 - 7.25	6.35 - 7.25	6.35 - 7.25
Pellet durability index	≥ 97.5	≥ 97.5	≥ 95	≥ 95
Fines, % (at the mill gate)	≤ 0.5	≤ 0.5	≤ 0.5	≤ 0.5
Inorganic Ash, %	≤ 0.5	≤ 1	≤ 2	≤ 6
Length, % greater than 1.50 inches	≤ 1	≤ 1	≤ 1	≤ 1
Moisture, %	≤ 6	≤ 8	≤ 8	≤ 10
Chloride, ppm	≤ 300	≤ 300	≤ 300	≤ 300
Ash fusion	NA	NA	NA	NA
Heating value	As - Rec ± 2SD	As - Rec ± 2SD	As - Rec ± 2SD	As - Rec ± 2SD

Source: Pellets Fuel Institute

Table A3. Existing national standards for wood pellets in EU

Specification	Austria ÖNORM 7135		Sweden SS 18 71 20			Germany DIN 51731/DIN plus			Italy CTI - R 04/5				British BioGen/UK Code of good practice	
	Holzpresslinge	Rindenpresslinge	Group 1	Group 2	Group 3	5 length classes (cm)			4 categories according origin and with/without pressing aids (A no additives, A with additives, B and C)				Premium fuel pellets	recovered fuel pellets
Size	Pellets: 4-20 mm Ø	Brikkets: 20-120 mm Ø	max 4mm Ø**	max 5mm Ø	max 6mm Ø		Length	Ø	6 mm, 8mm	6 mm, 8mm	6 mm, 8mm	10-25mm	<4mm-20mm	>10mm<20mm
	max 100 mm lg.	max 400 mm lg.				HP1	>30	>10						
						HP2	15-30	6-10						
						HP3	10-15	3-7						
						HP4	<10	1-4						
						HP5	<5	0.4-1						
Bulk Density			≥600kg/m3**	≥500kg/m3	≥500kg/m3				620-720 kg/m3	620-720 kg/m3	620-720 kg/m3	≥550 kg/m3	>600 kg/m3**	>500 kg/m3**
Fines in % <3mm			≤0.8	≤1.5	≤1.5								≤0.5	≤0.5
Unit density	≥ 1.0 kg/dm3	≥ 1.0 kg/dm3				1-1.4 cm/dm3								0.527 kg/dm3
Moisture content	≤12 %	≤18 %	≤10 %	≤10 %	≤12 %	≤12 %			≤10 %	≤10 %	≤10 %	≤15 %	≤10 %	≤10 %
Ash content	≤0.5*	≤6%*	≤0.7 %	≤1.5 %	>1.5 %	<1.5 %			≤0.7 %	≤0.7 %	≤1.5 %	tbs	<1%, <3% or 6	<1%, <3% or 6
Calorific value	≥18 MJ/kg*	≥18 MJ/kg*	≥16.9 MJ/kg (4.7 kWh/kg)	≥16.9 MJ/kg (4.7 kWh/kg)	≥16.9 MJ/kg (4.7 kWh/kg)	17.5-19.5 MJ/kg***			≥16.9 MJ/kg	≥16.9 MJ/kg	≥16.2 MJ/kg	tbs	>4.7 kWh/kg	>4.2 kWh/kg
Sulphur	≤0.04 %*	≤0.08 %*	≤0.08 %	≤0.08 %	anges	<0.08 %			≤0.05 %	≤0.05 %	≤0.05 %	tbs	<300ppm	<300ppm
Nitrogen	≤0.3 %*	≤0.6 %*				<0.3 %			≤0.3 %	≤0.3 %	≤0.3 %	tbs		
Chlorine	≤0.02 %*	≤0.04 %*	≤0.03 %	≤0.03 %	anges	<0.03 %			≤0.03 %	≤0.03 %	tbs	tbs	<800ppm	<800ppm
Arsenic						<0.8 mg/kg								
Cadmium						<0.5 mg/kg								
Chromium						<8 mg/kg								

Table A3. Continued

Specification	Austria ÖNORM 7135		Sweden SS 18 71 20			Germany DIN 51731/DIN plus	Italy CTI - R 04/5				British BioGen/UK Code of good practice	
	Holzpresslinge	Rindenpresslinge	Group 1	Group 2	Group 3	5 length classes (cm)	4 categories according origin and with/without pressing aids (A no additives, A with additives, B and C)				Premium fuel pellets	recovered fuel pellets
Copper						<5 mg/kg						
Mercury						<0.05 mg/kg						
Lead						<10 mg/kg						
Zinc						<100 mg/kg						
EOX						<3 mg/kg	≤1 %	≤1 %	≤1 %	tbs		
Fines, before delivery to costumer	max 1%					max. 1%						
Additives	max. 2% only natural		to be stated				none	tbs	tbs	tbs		
Ash melting point			temperatur to be stated									
Durability							≥97.7%	≥97.7%	≥95%	≥90%		

Source: Pichler (2009)

Table A4. Ongoing and experimental projects for co-combustion of biomass with coal in USA (as of 2005)

Location	Location	Plant name	Owner	Output (MWe)	% heat	Cofired fuel(s)	Status
Stillwater	MN	King (AllenS.) Generating Station #1	Northern States Power	560	5% wt	Kilndriedwood/pet.coke/PRBblend	2years(In commercial operation)
Sibley	MO	Siblye Generating Station	Kansas City (MO) Pwer and Light	840	5% wt	Pellets	12 months test phase
Gadsden	AL	Gadsden Steam Plant #2	Southern Company/Alabama Power Company	60	12% wt	Switchgrass	3-4 weeks
Lakeland	FL	Lakeland Electric #3	Lakeland Electric	350	2% heat	RDF	
Tampa	FL	Gannon (F.J.) Generating Station #3	Tampa Electric Company (TECO)	165	5% wt	Paper Pellets	21 days (over 60 days period)
Dublin	GA		Southeast paper	65		Sludge	
Milledgeville, Atlanta	GA	Harlee Branch Generating Station	Southern Company/Georgia Power Company	250, 319, 480, 49	1% heat	Sunder dust	Continuous (several years)
Port Wentworth	GA	Kraft /Riverside Plants #2	Southern Company/Savannah Electric and Power Company	46	36% heat	Sawdust from pallets	11 tests, 8-10 hours a day
Oakwood	IL	Vermilion Power Station #1	Illinois Power Company	75	25% heat	Railroad ties	3 hours
Lake Michigan	IL	Michigan City Generating Station #12	Northern Indiana Public Service Company (NIPSCO)	469	20% wt	Urban wood waste/Shoshone coal/PRB blend	6 tests over 5 days
Marshalltown	IA	Ottumwa Generating Station #1	IES Utilities Inc.	650	2.5% heat	Switchgrass	ongoing
Rumford	ME	Rumford Cogen Co.	Rumford Cogen Co.	76		Oil wood	
Prewitt	NM	Escalante Generating Station #1	Tri-State Generating&Transmission Association Inc.	250	1% wt	Waste paper sludge	2 years
Dresden	NY	Dunkirk Steam Station #1	Niagara Mohawk Power Corp	90	20% heat	Wood residue and willow	Long-term (six months planned)
Dresden	NY	Greenidge Generating Station #6	New York State Electric and Gas (NYSEG)	108	30% wt	Wood chips	16 hrs a day
Johnstown	PA	Shawville Generating Station #2	Reliant Energy	138	3% wt	Various ground wood	7 days, 3-4 hours
Johnstown	PA	Shawville Generating Station #3	Reliant Energy	190	3% wt	Various ground wood	7 days, 3-4 hours
Pitsburgh	PA	National Institute of Occupational Safety and Health (NIOSH)	National Institute of Occupational Safety and Health (NIOSH)		40% wt	Wood chips	5 burns
Pitsburgh	PA	Pittsburgh Brewing Company	Pittsburgh Brewing Company		40% wt	Wood chips	16 burns of 4-16 hrs, one 72 hour burn

Table A4. Continued

Location	Location	Plant name	Owner	Output (MWe)	% heat	Cofired fuel(s)	Status
Pitsburgh	PA	Seward Generating Station #12	Reliant Energy	32	12% wt	Sawdust	ongoing
Spring Grove	PA	Spring Grove Paper Mill	P.H. Glatfelter Co.			Anthracite, wood, oil	
Moncks Corner	SC	Jefferies Generating Station #3 and #4	Santee Cooper	165	20% wt	Wood chips	6 months
Pelzer	SC	Lee (W.S) Steam Station #3	Duke Pwer Company	170	5% wt	Shredded railroad ties	2 days
Milbank	SD	Big Stone Plant #1	Otter Tail Pwer Co.	450	1% heat	Seed corn and soy beans	Continuous (several years)
Memphis	TN	Allen (T.H) Fossil Plant	TVA	272	20% wt	Sawdust	10-24 tets, 3-6 hours each
Oak Ridge	TN	Kingston Fossil Plant #5	TVA	180	5% wt	Hardwood sawdust	9 tests, 3-4 hours each
Tacoma	WA	City of Tacoma Steam Plant #2	Tacoma Public Utilities	18	80% heat	Wood, refuse-derived fuel (RFD)	ongoing
Ashland	WI	Bay Front Station	Norther States Power Co.	44	100% wt	Wood, shredded rubber, railroad ties	Continuous
Madison	WI	Blount Street	Madison Gas and Electric Company	2x50	15% wt	Switchgrass	Unkown
Tuscumbia	AL	Colbert Fossil Plant #1	TVA	182	5% wt	Sawdust	Up to 24 hrs tests (ongoing)
Coosa	GA	Hammond Generating Station #1	Southern Company/Georgia Power Company	100	13% wt	Sawdust and tree trim	3 days
Hammond	GA	Georgia Power		100		Waste wood	
Chesterton	IN	Bailey Generating Station #7	NIPSCO	160	10% wt	Urban wood waste, petroleum coke	57 tests, 300 hrs total
Thomas Hill Reservoir	MO	Thomas Hill Energy Center #2	Associated Electric Cooperative, Inc.	175	7% wt	Railroad ties	1 week
Bismark	ND	North Dakota State Penitentiary	North Dakota Dept. of Corrections and Rehabilitation			Wood waste	not yet finished
Burlington	VT	Mc Neil Generating Station	Future Energy Resources	50	15% heat	Wood chips	Since 1998
England		BL Station #1	Northern States Pwer Company	120	12% wt	Shredded pallet wood chips	2 months, 2 days with TDF, wood and coal
Fort Drum			Black River Partners			Anthracite, wood	
Niagara Falls			UDG Niagara Goodyear			Tyres	
Savannah		SEPCO		54		Waste wood	

Source: BBI (2009)

Table A5. Projections for wood pellets production and consumption up to 2020

	Production (tons)	Yearly increase rate %	Consumption (tons)	Yearly increase rate %
2006	4,615,340	0.28	4,749,000	0.23
2007	5,942,827	0.25	5,866,800	0.37
2008	7,429,440	0.2	8,060,650	0.25
2009	8,915,328	0,20	10,075,813	0,25
2010	10,252,627	0,15	12,090,975	0,2
2011	11,277,890	0,10	13,904,621	0,15
2012	12,292,900	0,09	15,712,222	0,13
2013	13,276,332	0,08	17,597,689	0,12
2014	13,674,622	0,03	18,829,527	0,07
2015	14,358,353	0,05	19,771,003	0,05
2016	15,076,271	0,05	20,759,553	0,05
2017	15,980,847	0,06	22,005,127	0,06
2018	16,939,698	0,06	23,325,434	0,06
2019	17,956,080	0,06	24,724,960	0,06
2020	19,033,444	0,06	26,208,458	0,06

Source: Capaccioli and Vivarelli 2009

Table A6. Classification of wood pellet markets in EU with consumption levels in 2008 by country and type of pellet market

Market Type	Country Name	Consumption (tons)
Developed	Austria	513,000
	Belgium	920,000
	Denmark	1,060,000
	Finland	150,000
	Germany	900,000
	Italy	850,000
	Netherlands	913,500
	Sweden	1,850,000
	Total	7,156,500
Emerging	Estonia	3,000
	France	200,000
	Poland	120,000
	Romania	25,000
	Slovakia	17,500
	Spain	10,000
	Slovenia	112,000
	Latvia	39,000
	UK	176,000
	Total	526,500
New	Bulgaria	3,000
	Cyprus	0
	Czech Republic	17,000
	Greece	11,100
	Hungary	1,000
	Ireland	30,000
	Lithuania	20,000
	Luxembourg	0
	Malta	0
	Portugal	10,000
	Total	82,100

Source: Pellets@tlas, Capaccioli and Vivarelli (2009)

Table A7. Estimated electricity production in 2010 from different biomass resources

	Without Import		With Import	
	GWh	Share	GWh	Share
Energy crops	27,395	19%	13,228	7%
Forestry residues	38,309	27%	94,008	53%
Municipal solid waste	12,798	9%	12,798	7%
Agricultural residues	40,942	29%	34,761	19%
Others	23,873	17%	23,870	13%
Total	143,317		178,665	

Source: Skytte, Meibom and Henriksen (2006)

Table A8. Import dependency on fossil fuels of EU countries in 2007 (%)

Country	All fuels	Solid fuels	Oil	Gas
Belgium	77.2	95.8	97.4	99.8
Bulgaria	51.9	39.4	100.8	91.5
Czech Republic	25.1	-14.8	96.2	93.7
Denmark	-25.4	100.4	-67.9	-99.7
Germany	58.9	37.2	94.3	80.6
Estonia	29.7	0.9	99	100
Ireland	88.3	65.1	97	91.4
Greece	67.3	3.3	100.9	99.6
Spain	79.5	66.6	99.7	98.9
France	50.4	92.5	98.7	96.5
Italy	85.3	99.2	92.5	87
Cyprus	95.9	68	98.6	
Latvia	61.5	88	98.1	96.8
Lithuania	62.3	87.2	93.3	102.9
Luxembourg	97.5	100	98.8	100
Hungary	61.4	44	82.7	79.9
Malta	100	100		
Netherlands	38.6	105.3	92.8	-64.3
Austria	69.1	105.1	92.6	81
Poland	25.5	-15.5	102.2	66.7
Portugal	82	100.5	98.9	98.7
Romania	32	34.8	53.7	29.8
Slovenia	52.5	21	98.9	99.7
Slovakia	69	95.4	91.3	97.9
Finland	53.8	62.8	97.8	100
Sweden	36.1	93.8	96.7	100
United Kingdom	20.1	69.5	0.9	20.3
EU27	53.1	41.2	82.6	60.3
EU25	53.6	41.4	82.9	61

Source: Eurostat, May 2009
Definition: Import Dependency = Net Imports / (Bunkers + Gross Inland Consumption). Negative numbers indicate that the country is a net exporter. Values over 100 % are possible due to changes in stocks.

Table A9. Share of renewable energy in gross final energy consumption, up to 2020 (%)

Country	Indicative Trajectory by year Share of renewable energy in gross final energy consumption %					Mandatory Target for share of energy from renewables in final consumption of energy%
	2005	2011/2012 average	2013/2014 average	2015/2016 average	2017/2018 average	2020
Austria	23.3	25.4	26.5	28.1	30.3	34
Belgium	2.2	4.4	5.4	7.1	9.2	13
Bulgaria	9.4	10.7	11.4	12.4	13.7	16
Czech Republic	6.1	7.5	8.2	9.2	10.6	13
Cyprus	2.9	4.9	5.9	7.4	9.5	13
Denmark	17	19.6	20.9	22.9	25.5	30
Estonia	18	19.4	20.1	21.2	22.6	25
Finland	28.5	30.4	31.4	32.8	34.7	38
France	10.3	12.8	14.1	16.0	18.6	23
Germany	5.8	8.2	9.5	11.3	13.7	18
Greece	6.9	9.1	10.2	11.9	14.1	18
Hungary	4.3	6.0	6.9	8.2	10.0	13
Italy	5.2	7.6	8.7	10.5	12.9	17
Ireland	3.1	5.7	7.0	8.9	11.5	16
Latvia	32.6	34.5	35.4	36.8	38.7	42
Lithuania	15	16.6	17.4	18.6	20.2	23
Luxembourg	0.9	2.9	3.9	5.4	7.5	11
Malta	0	2.0	3.0	4.5	6.5	10
Netherlands	2.4	4.7	5.9	7.6	9.9	14
Poland	7.2	8.8	9.5	10.7	12.3	15
Portugal	20.5	22.6	23.7	25.2	27.3	31
Romania	17.8	19.0	19.7	20.6	21.8	24
Slovakia	6.7	8.2	8.9	10.0	11.4	14
Slovenia	16	17.8	18.7	20.1	21.9	25
Spain	8.7	11.0	12.1	13.8	16.0	20
Sweden	39.8	41.6	42.6	43.9	45.8	49
United Kingdom	1.3	4.0	5.4	7.5	10.2	15
EU - 27	6.7	9.4	10.7	12.7	15.3	20

Source: EC (2001)

Table A10. Share of renewables in Gross inland consumption in 2007

	Hydro	Wind	Solar	Biomass& Wastes	Gheotermal	Total
Country				%		
Austria	9.2	0.5	0.3	13.7	0.1	23.8
Belgium	0.1	0.1	0	3	0	3.1
Bulgaria	1.2	0	0	3.3	0.2	4.7
Czech Republic	0.4	0	0	4.3	0	4.7
Cyprus	0	0	2	0.5	0	2.4
Denmark	0	3	0.1	14.2	0.1	17.3
Estonia	0	0.1	0	9.8	0	10
Finland	3.2	0	0	19.3	0	22.6
France	1.9	0.1	0	5	0	7
Germany	0.5	1	0.2	6.5	0.1	8.3
Greece	0.7	0.5	0.5	3.4	0	5
Hungary	0.1	0	0	4.8	0.3	5.3
Italy	0.4	0.2	0	2.4	2.7	6.9
Ireland	1.5	1.1	0	1.5	0	2.9
Latvia	4.9	0.1	0	24.6	0	29.7
Lithuania	0.4	0.1	0	8.4	0	8.9
Luxembourg	0.2	0.1	0	2.1	0	2.5
Malta	0	:	:	:	:	0
Netherlands	0	0.4	0	3.2	0	3.6
Poland	0.2	0	0	4.8	0	5.1
Portugal	3.3	1.3	0.1	12.1	0.7	17.6
Romania	3.4	0	0	8.4	0	11.9
Slovakia	2.1	0	0	3.3	0.1	5.5
Slovenia	3.8	0	0	6.2	0	10
Spain	1.6	1.6	0.1	3.7	0	7
Sweden	11.3	0.2	0	19.4	0	30.9
United Kingdom	0.2	0.2	0	1.7	0	2.1
EU27 (in aggregate)	1.5	0.5	0.1	5.4	0.3	7.8

Source: Eurostat (2009)

Table A11. EU-27's Gross inland energy consumption of different renewable sources (1990-2007)

	Renewables	Biomass and waste	Solar	Geothermal	Hydro Power	Wind Energy	Biomass share
Year				(mtoe)			%
1990	73.1	44.6	0.2	3.2	25.1	0.1	61
1995	85.5	53.4	0.3	3.4	28.1	0.4	62.4
2000	99.6	63.5	0.4	3.4	30.4	1.9	63.7
2001	102.4	63.9	0.5	3.6	32	2.3	62.4
2002	100.9	66.2	0.6	4	27.1	3.1	65.6
2003	109	72.9	0.6	5.3	26.3	3.8	66.9
2004	117.4	78.4	0.7	5.4	27.8	5.1	66.8
2005	121.6	83	0.9	5.3	26.4	6.1	68.3
2006	129.9	89.7	1.2	5.6	26.6	7.1	69.1
2007	141	98.4	1.6	5.8	26.7	9	69.8

Source: AEBIOM (2009)

Table A12. Biomass potential and use - distribution between regions

Biomass source	North America	Latin America	Asia	Africa	Europe	Middle East	Former USSR	World
				10^3 PJ/year				
Woody biomass	12.8	5.9	7.7	5.4	4	0.4	5.4	41.6
Energy crops	4.1	12.1	1.1	13.9	2.6	0	3.6	37.4
Straw	2.2	1.7	9.9	0.9	1.6	0.2	0.7	17.2
Other	0.8	1.8	2.9	1.2	0.7	0.1	0.3	7.6
Total potential	19.9	21.5	22	21.4	8.9	0.7	10	103.8
Use	3.1	2.6	23	8.3	2	0	0.5	39.7
Use/potential (%)	16	12	107	39	22	7	5	38

Source: Skytte et al. 2006

Table A13. Annual potential and use of different solid biomass resources in 2006 in EU24 and Norway

Biomass source	Annual biomass resources		Share	Use in 2006		Share	Use of resources
	PJ	Mtoe	%	PJ	Mtoe	%	%
Forest residues	1,461	35	22	340	8	11	23
Firewood	1,224	29	19	937	22	29	77
Solid industrial wood residues and by-products*	901	22	14	809	19	25	90
Spent liquor	482	12	7	482	12	15	100
Used wood	368	9	6	183	4	6	50
Woody biomass total	4,436	106	67	2,742	66	86	62
Herbaceous&fruit biomass	1,582	38	24	232	6	7	15
Other biomass	559	13	8	193	5	6	35
Total	6,577	157	100	3,178	76	100	48

**includes raw material used for pellet production*
Source: Junginger and Alakangas 2010 (Data from EUBIONET III project)

Table A14. Availability of bio-energy in EU in 2000, 2010 and 2020

	2000	2010	2020
	Mtoe/year		
Tradables	107	115	125
Forestry byproducts & refined wood fuels	41.9	46.7	51.6
Solid agricultural residues	32.3	36.1	39.9
Solid industrial residues	13.1	14.4	15.6
Solid energy crops	19.2	19.2	19.2
Non-tradeables	47.1	62.4	79
Wet manure	14.4	15.8	17.2
Organic waste			
Biodegradable municipal waste	7.2	19.5	33.7
Demolition wood	5.9	6.4	7.1
Dry manure	2.3	2.4	2.8
Black liquor	10.6	11.8	12.9
Sewage gas	2.1	2.3	2.6
Landfill gas	5.1	4.7	2.5
Transport fuels	**5.7**	5.7	5.7
Bio-ethanol	4.2	4.2	4.2
Bio-diesel	1.5	1.5	1.5
Total bio-energy	159	183	210

**50% of set-aside area is assumed to be available for solid energy crops and 25% each for bio-ethanol and bio-diesel.* Source: Siemons et al. (2004)

Table A15. Total roundwood production in EU

Year	2002	2003	2004	2005	2006	2007
Country			1000m³*			
Austria	14,846	17,055	16,483	16,471	19,135	21,317
Belgium	4,500	4,765	4,850	4,950	4,230	4,945
Bulgaria	4,833	4,833	4,833	5,862	5,992	5,696
Cyprus	15	12	10	10	7	20
Czech Republic	14,541	15,140	15,601	15,510	17,678	18,508
Denmark	1,446	1,627	1,627	2,962	2,358	2,566
Estonia	10,500	10,500	6,800	5,500	5,400	5,900
Finland	53,011	53,778	53,800	52,250	50,812	56,870
France	35,449	32,828	33,647	63,171	61,790	62,759
Germany	42,380	51,182	54,504	56,946	62,290	76,728
Greece	1,591	1,673	1,526	1,523	1,523	1,743
Hungary	5,836	5,785	5,660	5,940	5,913	5,640
Ireland	2,646	2,683	2,562	2,648	2,672	2,710
Italy	7,511	8,219	8,697	8,691	8,618	8,124
Latvia	13,466	12,916	12,754	12,843	12,845	12,173
Lithuania	6,115	6,275	6,120	6,045	5,870	5,855
Luxembourg	257	257	277	249	268	291
Malta	-	-	-	-	-	-
Netherlands	839	1,044	1,026	1,110	1,107	1,022
Poland	27,137	30,836	37,733	31,945	32,384	35,935
Portugal	8,742	9,673	11,553	10,746	10,805	10,805
Romania	15,154	15,440	15,777	14,501	13,970	15,341
Slovak Republic	5,782	6,355	7,240	9,302	7,869	8,875
Slovenia	2,283	2,591	2,551	2,733	3,179	2,882
Spain	15,839	16,105	16,290	15,531	15,716	14,528
Sweden	66,600	67,100	67,300	64,600	64,600	77,200
United Kingdom	7,802	8,075	8,281	8,417	8,417	9,018
EU-27	369,121	386,747	392,502	454,120	425,448	467,449

**Includes all quantities of wood removed from the forest and other wooded land or other fueling sites during a certain period of time.* Source: AEBIOM (2009)

Table A16. Forestry by-products availability in 2002 and future potential in EU15

	Available quantity	2000	2010	2020
Country	ktones/year			
Austria	8,333	3,583	3,958	4,372
Belgium	411	177	195	216
Denmark	611	263	290	321
Finland	5,333	2,293	2,533	2,798
France	2,111	908	1,003	1,107
Germany	7,900	3,396	3,752	4,144
Greece	99	43	47	52
Ireland	128	55	61	67
Italy	860	370	408	451
Luxembourg	-	-	-	-
Netherlands	260	112	123	136
Portugal	1,173	504	557	615
Spain	3,250	1,397	1,543	1,705
Sweden	9,333	4,013	4,432	4,896
United Kingdom	889	382	422	466
Total EU15	40,691	17,496	19,324	21,346

Source: Siemons et al. (2004)

Table A17. Refined wood fuels availability in 2002 and future potential in EU15

	Available quantity	2000	2010	2020
Country	ktones/year			
Austria	2,389	1,027	1,134	1,253
Belgium	18	8	8	9
Denmark	389	167	185	204
Finland	2,778	1,194	1,319	1,457
France	14,333	6,162	6,807	7,519
Germany	4,722	2,030	2,243	2,477
Greece	1,100	473	522	577
Ireland	189	81	90	99
Italy	4,611	1,982	2,190	2,419
Luxembourg				
Netherlands	639	275	303	335
Portugal	1,522	654	723	799
Spain	672	289	319	353
Sweden	3,961	1,703	1,881	2,078
United Kingdom	1,500	645	712	787
Total EU15	38,823	16,690	18,436	20,366

Source: Siemons et al. (2004)

Table A18. Agricultural and industrial residues potential in EU

Country	Energy potential (Ktoe/year)					
	Agricultural residues			Industrial residues		
	2000	2010	2020	2000	2010	2020
Austria	215	237	262	1,194	1319	1457
Belgium	163	180	199	301	332	367
Bulgaria	1153	1,273	1,406	30	33	37
Czech Republic	342	378	417	327	361	399
Cyprus	-	-	-	-	-	-
Denmark	690	762	842	119	132	146
Estonia	23	26	28	150	166	184
Finland	233	257	284	1,123	1240	1370
France	9840	10,870	12,007	1,003	1108	1224
Germany	3105	3,430	3,789	955	1055	1166
Greece	1648	1,820	2,011	254	280	310
Hungary	619	683	755	162	179	198
Italy	3900	4,308	4,759	860	950	1049
Ireland	50	55	61	112	123	136
Latvia	31	34	38	287	317	350
Lithuania	146	161	178	179	198	218
Luxembourg	-	-	-	-	-	-
Malta	-	-	-	-	-	-
Netherlands	267	294	325	81	90	99
Poland	2979	3,291	3,635	347	383	423
Portugal	616	681	752	645	712	787
Romania	1775	1,960	2,165	549	607	670
Slovakia	220	243	269	69	77	85
Slovenia	24	27	30	40	44	48
Spain	3012	3,327	3,675	2,085	2303	2544
Sweden	131	144	159	1,783	1970	2176
United Kingdom	1548	1,710	1,889	287	317	350
EU	32730	36151	39935	12942	14296	15793

Source: Siemons et al. (2004)

Table A19. Energy potential from energy crops in EU15

Country	Agricultural area* (1000ha)	Available area (1000ha)	Yield/harvest (ton ODM/ha)	Potential (PJ/year)
Austria	3,470	160	7	31
Belgium	1,360	63	8.2	14
Denmark	2,689	124	6.7	23
Finland	2,259	104	5.3	15
France	29,972	1,380	7.3	278
Germany	17,279	796	8.5	185
Greece	9,038	1,703	3.9	182
Ireland	4,399	203	6.8	38
Italy	15,556	2,930	5.2	423
Luxembourg	117	5	8.2	1
Netherlands	1,970	123	8.1	3
Portugal	3,830	721	2.9	58
Spain	29,971	5,646	3.1	482
Sweden	3,272	151	7.4	30
United Kingdom	17,439	803	7	154
Total	145,276	14,921		1,939

**It is agricultural area according to the definition of FAO (2002) with averages from 1994 – 1999. Since the overall growth rate of the agricultural area for the listed countries is around 0.6 ‰ it is assumed that there will be no major changes in future area availability (De Noord et al. 2004)*

Source: De Noord et al. (2004)

Table A20. Roundwood and fuelwood production and potential in EU15

	Annual Production	Potential
Country	(mln m3)	(PJ)
Austria	17.7	48.4
Belgium	2	5.5
Denmark	2.7	7.3
Finland	56	152.8
France	50.7	138.4
Germany	42.8	116.8
Greece	3.3	8.9
Ireland	2.5	6.7
Italy	15.3	41.6
Luxembourg	0.1	0.3
Netherlands	1.2	3.2
Portugal	9.6	26.1
Spain	17.4	47.6
Sweden	64.6	176.3
United Kingdom	7.6	20.7
Total	309	843.3

Source: De Noord et al. (2004)

The available amount of energy in PJ can be calculated using (De Noord et al. 2004):
Specific mass: 0.52 ton ODM/m3
Specific energy: 15 GJ/ton ODM
ODM – Oven dry matter

The amount of wood available for energy production is based on the average production from 1997 – 2001 (FAO 2002 database). The study from De Noord et al. assumed that exploitation of production forests in the EU is sustainable thus assuming equal availability for 2030 as it is given in the Table.

Table A21. Average area and energy potential of barley, maize, oil crops, rapeseed and wheat residues

Country	Barley		Maize		Oilcrops		Rapeseed		Wheat residues	
	Area (Km^2)	Energy (PJ)	Area (Km^2)	Energy (PJ)	Area (Km^2)	Energy (PJ)	Area (Km^2)	Energy (PJ)	Area (Km^2)	Energy (PJ)
Austria	2,423	5.5	1,082	3.2	2,733	8.2	566	1.3	1,839	6.6
Belgium	582	1.3	199	0.6	1,983	6	97	0.2	277	1
Denmark	7,250	16.3	1,188	3.6	6,549	19.6	1,165	2.6	0	0
Finland	5,696	12.8	627	1.9	1,348	4	627	1.4	0	0
France	16,123	36.3	21,195	63.6	50,976	152.9	11,515	25.9	18,112	65.2
Germany	21,742	48.9	12,281	36.8	28,005	84	10,674	24	3,678	13.2
Greece	1,272	1.9	11,969	18	8,526	12.8	0	0	2,089	3.8
Ireland	1,870	4.2	37	0.1	828	2.5	37	0.1	0	0
Italy	3,523	5.3	16,811	25.2	23,432	35.1	496	0.6	10,568	19
Luxembourg	31	0.1	10	0	104	0.3	5	0	15	0.1
Netherlands	508	1.1	57	0.2	1,281	3.8	10	0	156	0.6
Portugal	241	0.4	3,886	5.8	2,134	3.2	0	0	1,712	3.1
Spain	33,249	49.9	33,275	49.9	21,969	33	435	0.5	4,544	8.2
Sweden	4,421	9.9	718	2.2	3,640	10.9	572	1.3	0	0
United Kingdom	12,332	27.7	5,784	17.4	19,298	57.9	4,794	10.8	0	0

50% of available residues is assumed to be available for energy purposes (25% for maize) because of their use for other purposes (fertilizing, fodder and soil conditioner). Source: De Noord et al. 2004

Table A22. Projected maximum biomass fuel input for co-firing with different co-firing shares

Period	2000	2001-2005	2006-2010	2011-2020
Co-firing share	10%	10%	15%	20%
Country			PJ	
Austria	13.5	10.9	16.4	20.6
Belgium	14.8	8.6	12.9	14.4
Denmark	38.2	24.7	32.4	43.2
Finland	36.3	36.3	45.2	33
France	88.8	84.7	77	102.6
Germany	347	412.5	625.1	833.4
Greece	32.2	33.8	50.6	67.5
Ireland	9	12.5	18.8	25
Italy	47.5	73.2	201.4	298.4
Luxembourg	0	0	0	0
Netherlands	23.3	23.3	35	56.7
Portugal	12.6	12.6	19	17.1
Spain	81.4	81.4	121.6	141.3
Sweden	7.1	6.9	10.3	13.4
United Kingdom	238	422.1	560.4	636.8
Total	989	1,244	1,826.90	2304.4

Source: De Noord et al. 2004

Table A23. Summary of biomass energy potentials in EU

		Unit	2000	2010	2020	2030	2040
Energy crops on agricultural and marginal land	Min	PJ	700	800	800	6,000	6,100
		Mtoe	17	19	19	143	146
	Max	PJ	1,400	6,100	12,000	8,000	22,000
		Mtoe	33	146	287	191	525
Forestry and forest residues	Min	PJ	1,000	1,000	900	900	2,400
		Mtoe	24	24	21	21	57
	Max	PJ	3,900	3,200	3,900	2,400	
		Mtoe	93	76	93	57	
Agricultural residues and organic waste	Min	PJ	2,000	2,900	1,500	3,100	n.a
		Mtoe	28	69	36	74	
	Max	PJ	2,800	3,900	4,300	3,100	
		Mtoe	67	93	103	74	
Total	Min	PJ	3,700	4,700	3,200	10,000	n.a
		Mtoe	88	112	76	239	
	Max	PJ	8,100	13,000	20,000	14,000	
		Mtoe	195	310	478	334	

Source: Junginger and Alakangas 2010

Table A24. Arable and set-aside land in EU in 2000

Country	Arable land	Set-aside land	Set-aside share
	(000ha)		%
Austria	1,399	107	8
Belgium	815	24	3
Bulgaria	3,524	293	8
Czech Republic	3,082	70	2
Denmark	11,804	1,137	10
Estonia	1,128	220	20
Finland	2,187	177	8
France	18,440	1,489	8
Germany	2,281	213	9
Greece	2,741	30	1
Hungary	4,902	215	4
Ireland	1,050	29	3
Italy	7,984	231	3
Latvia	2,946	443	15
Lithuania	2,946	300	10
Netherlands	909	16	2
Poland	14,071	130	1
Portugal	1,990	80	4
Romania	9,906	500	5
Slovakia	1,450	29	2
Slovenia	173	10	6
Spain	13,317	1,329	10
Sweden	2,706	264	10
United Kingdom	5,876	567	10
EU	117,627	7,903	7

Source: Siemons et al. (2004)

Table A25. Available arable land for dedicated energy crops

Year	2010	2020	2030
Country		million ha	
Austria	204	266	298
Belgium	0	0	0
Czech Republic	303	314	301
Denmark	74	0	0
Estonia	88	154	159
Finland	486	299	174
France	536	1,000	2,000
Germany	1,000	2,000	3,000
Greece	356	298	266
Hungary	413	512	547
Ireland	0	0	0
Italy	1,074	1,786	2,165
Latvia	83	144	183
Lithuania	525	882	1,055
Netherlands	0	0	0
Poland	3,823	4,321	4,525
Portugal	250	169	125
Slovakia	81	140	213
Slovenia	3	16	36
Spain	2,706	2,582	2,459
Sweden	135	168	178
United Kingdom	824	1,118	1,584
New Member States	7,646	9,686	12,249
EU-22	12,965	16,170	19,267

Source: EEA 2006

Table A26. Comparison between current biomass use and potential for 2010 in the EU

	Biomas consumption in 2007	Biomass Potential (EEA for 2010)	Unused potential
Country	mtoe	mtoe	%
Austria	4,63	6,9	48
Belgium	1,71	2,3	26
Bulgaria	0,68		
Cyprus	0,01	0,3	97
Czech Republic	1,99	3,8	48
Denmark	2,92	2,8	-4
Estonia	0,59	1,5	61
Finland	7,28	9,6	24
France	13,39	31,4	57
Germany	22,1	26,2	16
Greece	1,13	1,6	29
Hungary	1,3	3,6	64
Ireland	0,24	1,1	78
Italy	4,46	16,2	72
Latvia	1,17	1,3	10
Lithuania	0,77	4,1	81
Luxembourg	0,1	-	-
Malta	-	-	-
Netherlands	2,7	2,6	-4
Poland	4,74	23,8	80
Portugal	3,15	3,6	13
Romania	3,36	-	-
Slovak Republic	0,6	2,2	73
Slovenia	0,45	1,8	75
Spain	5,39	16,5	67
Sweden	9,82	11,7	16
United Kingdom	3,71	13,5	73
EU	98,39	187,9	48

Source: AEBIOM (2009)

Table A27. Production of heat and electricity from renewables, solid biomass and combustible renewables and wastes

Country		1990	1995	2000	2003	2004	2005	2006	2007
Austria	**Total Heat from renewables and wastes (TJ)**	3,939	7,644	10,463	15,271	16,514	19,811	22,094	26,803
	From CHP	2,094	3,041	2,366	3,615	3,505	5,368	9,872	14,173
	Heat only plants	1,845	4,603	8,097	11,656	13,009	14,443	12,222	12,630
	Total from solid biomass	1,404	3,645	6,664	11,192	11,954	15,295	16,510	20,899
	% of total heat generated from solid biomass	35.6	47.7	63.7	73.3	72.4	77.2	74.7	78.0
	Total ren. Heat from Combustible renewables and waste (TJ)	3,939	7,612	10,085	15,859	17,755	19,249	21,532	26,286
	% of solid biomass in heat generated from combustible and waste	35.6	47.9	66.1	70.6	67.3	79.5	76.7	79.5
	Total Electricity from renewable and waste sources (GWh)	33,687	40,386	45,298	37,694	42,262	42,538	42,857	44,670
	From CHP	647	1,159	1,153	1,132	1,390	1,555	1,816	2,135
	Electricity only plant	33,040	39,227	44,145	36,562	40,872	40,983	41,041	42,535
	Total from solid biomass	1,116	1,766	1,517	1,604	1,693	1,930	2,553	3,182
	% of total electricity generated from solid biomass	3.3	4.4	3.3	4.3	4.0	4.5	6.0	7.1
	Total from Combustible renewables and waste (GWh)	1,180	1,907	1,730	2,022	2,359	2,582	3,423	4,150
	% of solid biomass in elec. generated from combustible and waste	94.6	92.6	87.7	79.3	71.8	74.7	74.6	76.7
Belgium	**Total Heat from renewables and wastes (TJ)**	411	241	885	1,905	2,349	3,607	2,660	297
	From CHP	0	0	389	1,689	2,237	3,429	2,485	236
	Heat only plants	411	241	496	216	112	178	175	61
	Total from solid biomass	0	0	0	0	0	0	4	56
	% of total heat generated from solid biomass	0	0	0	0	0	0	0.2	18.9
	Total ren. Heat from Combustible renewables and waste (TJ)	368	188	832	1,905	2,349	3,556	2,586	236
	% of solid biomass in heat generated from combustible and waste	0	0	0	0	0	0	0.2	23.7
	Total Electricity from renewable and waste sources (GWh)	1,627	2,281	3,051	3,027	3,697	4,082	5,101	5,821
	From CHP	0	0	518	618	811	683	805	676
	Electricity only plant	1,627	2,281	2,533	2,409	2,886	3,399	4,296	5,145
	Total from solid biomass	135	121	164	377	512	960	1,406	1,818
	% of total electricity generated from solid biomass	8.3	5.3	5.4	12.5	13.8	23.5	27.6	31.2
	Total from Combustible renewables and waste	723	1,042	1,336	1,623	1,948	2,250	3,105	3,641
	% of solid biomass in elec. generated from combustible and waste	18.7	11.6	12.3	23.2	26.3	42.7	45.3	49.9

Table A27. Continued

Country		1990	1995	2000	2003	2004	2005	2006
Denmark	**Total Heat from renewables and wastes (TJ)**	19,518	25,273	40,135	43,047	45,501	44,832	45,620
	From CHP	882	8,659	24,324	27,034	31,507	30,851	32,069
	Heat only plants	18,636	16,614	15,811	16,013	13,994	13,981	13,551
	Total from solid biomass	7,373	9,693	16,196	18,438	20,417	19,636	19,491
	% of total heat generated from solid biomass	37.8	38.4	40.4	42.8	44.9	43.8	42.7
	Total ren. Heat from Combustible renewables and waste (TJ)	19,464	25,220	39,909	42,758	45,382	44,518	45,283
	% of solid biomass in heat generated from combustible and waste	37.9	38.4	40.6	43.1	45.0	44.1	43.0
	Total Electricity from renewable and waste sources (GWh)	848	2,117	8,746	10,174	10,627	10,012	11,062
	From CHP	210	900	3,160	3,560	3,986	3,877	3,857
	Electricity only plant	638	1,217	5,586	6,614	6,641	6,135	7,205
	Total from solid biomass	108	208	1,401	1,840	1,894	1,777	1,828
	% of total electricity generated from solid biomass	12.7	9.8	16.0	18.1	17.8	17.7	16.5
	Total from Combustible renewables and waste	210	910	3,147	3,545	3,988	3,879	3,859
	% of solid biomass in elec. generated from combustible and waste	51.4	22.9	44.5	51.9	47.5	45.8	47.4
Italy	**Total Heat from renewables and wastes (TJ)**	na	na	na	6,888	11,078	13,338	9,776
	From CHP	na	na	na	6,888	11,078	13,338	9,776
	Heat only plants	na	na	na	0	0	0	0
	Total from solid biomass	na	na	na	3,491	3,888	3,384	3,390
	% of total heat generated from solid biomass	na	na	na	50.7	35.1	25.4	34.7
	Total ren. Heat from Combustible renewables and waste (TJ)	na	na	na	na	11,078	13,338	9,776
	% of solid biomass in heat generated from combustible and waste	na	na	na	na	35.1	25.4	34.7
	Total Electricity from renewable and waste sources (GWh)	38,410	45,754	46,866	53,872	56,778	58,702	55,077
	From CHP	32	185	1,310	1,993	3,280	3,042	2,945
	Electricity only plant	38,378	45,569	45,556	51,879	53,498	55,660	52,132
	Total from solid biomass	12	30	1,434	1,912	2,166	2,313	2,298
	% of total electricity generated from solid biomass	0.03	0.07	3.06	3.55	3.81	3.94	4.17
	Total from Combustible renewables and waste	103	389	4,492		6,152	6,744	6,954
	% of solid biomass in elec. generated from combustible and waste	11.7	7.7	31.9		35.2	34.3	33.0

Table A27. Continued

Country		1990	1995	2003	2004	2005	2006	2007
Netherlands	**Total Heat from renewables and wastes (TJ)**	3,377	2,927	7,581	8,154	8,853	9,356	9,689
	From CHP	3,377	2,822	2,874	3,047	3,760	4,005	4,352
	Heat only plants	0	105	4,707	5,107	5,093	5,351	5,337
	Total from solid biomass	233	248	335	661	1,171	1,128	1,471
	% of total heat generated from solid biomass	6.9	8.5	4.4	8.1	13.2	12.1	15.2
	Total ren. Heat from Combustible renewables and waste (TJ)	3,377	2,927	7,581	8,154	8,853	9,356	9,689
	% of solid biomass in heat generated from combustible and waste	6.9	8.5	4.4	8.1	13.2	12.1	15.2
	Total Electricity from renewable and waste sources (GWh)	1,195	2,002	5,349	6,672	8,916	9,512	9,146
	From CHP	1,054	704	1,403	1,729	2,469	3,361	3,632
	Electricity only plant	141	1,298	3,946	4,943	6,447	6,151	5,514
	Total from solid biomass	34	41	1,007	1,458	2,246	1,840	1,970
	% of total electricity generated from solid biomass	2.8	2.0	18.8	21.9	25.2	19.3	21.5
	Total from Combustible renewables and waste	1,054	1,596	3,929	4,677	6,727	6,638	5,566
	% of solid biomass in elec. generated from combustible and waste	3.2	2.6	25.6	31.2	33.4	27.7	35.4
Sweden*	**Total Heat from renewables and wastes (TJ)**	24,534	68,448	106,652	104,305	118,879	120,952	120,825
	From CHP	8,518	40,923	69,600	69,124	77,421	75,599	78,822
	Heat only plants	16,016	27,525	37,052	35,181	41,458	45,353	42,003
	Total from solid biomass	11,986	53,340	84,518	84,131	92,685	93,059	88,070
	% of total heat generated from solid biomass	48.9	77.9	79.2	80.7	78.0	76.9	72.9
	Total ren. Heat from Combustible renewables and waste (TJ)	24,534	68,448	121,133	118,626	118,879	120,952	120,825
	% of solid biomass in heat generated from combustible and waste	48.9	77.9	69.8	70.9	78.0	76.9	72.9
	Total Electricity from renewable and waste sources (GWh)	75,044	70,683	59,113	69,028	82,167	72,080	78,274
	From CHP	2005	2,424	4,836	8,000	8,357	9,355	10,656
	Electricity only plant	73,039	68,259	54,277	61,028	73,810	62,725	67,618
	Total from solid biomass	1,902	2,278	4,305	6,611	6,848	7,503	8,496
	% of total electricity generated from solid biomass	2.5	3.2	7.3	9.6	8.3	10.4	10.9
	Total from Combustible renewables and waste	2,005	2,424	4,836	8,000	8,357	9,355	10,656
	% of solid biomass in elec. generated from combustible and waste	94.9	94.0	89.0	82.6	81.9	80.2	79.7

Table A27. Continued

Country		1990	1995	2000	2002	2003	2004	2005	2006	2007
UK	**Total Heat from renewables and wastes(TJ)**									
	From CHP	-	-	-	-	-	-	-	-	-
	Heat only plants	-	-	-	-	-	-	-	-	-
	Total from solid biomass	-	-	-	-	-	-	-	-	-
	% of total heat generated from solid biomass	-	-	-	-	-	-	-	-	-
	Total Electricity from renewable and waste sources (GWh)	7,876	8,835	13,183	14,269	13,932	17,398	22,427	24,335	25,628
	From CHP	316	410	422	2,385	2,215	1,637	1,735	1,655	1,748
	Electricity only plant	7,560	8,425	12,761	11,884	11,717	15,761	20,692	22,680	23,880
	Total from solid biomass	n/a	199	541	1,128	1,538	1,942	3,382	3,324	2,920
	% of total electricity generated from solid biomass	n/a	2.3	4.1	7.9	11.0	11.2	15.1	13.7	11.4
	Total from Combustible renewables and waste	678	2,054	4,455	5,571	6,682	7,880	11,663	11,653	11,395
	% of solid biomass in elec. generated from combustible and waste		9.7	12.1	20.2	23.0	24.6	29.0	28.5	25.6

Source: IEA

Table A28. Average supply cost of tradable biomass and crops for transport fuels (€/GJ)

	EU15	Accession States, plus Bulgaria and Romania
Tradeables		
Forestry byproducts	2.4	2.1
Wood fuels	4.3	2.7
Dry agricultural residues	3	2.1
Solid industrial residues	1.6	2.5
Solid energy crops	5.4	4.4
Imported biofuels	6	6
Transport fuels		
Bio-diesel	23	23
Bio-ethanol	29	29

Source: Siemons et al. 2004

Table A29. Technology cost related scenarios (electricity only plant, typically 100 MW_e)

	2000		2010		2020	
	Specific investment (/kWh)	NCV efficiency (%)	Specific investment (/kWh)	NCV efficiency (%)	Specific investment (/kWh)	NCV efficiency (%)
Base case technology scenario						
Solid clean fuels- all sectors	1,628 CS	34	1,628 CS	34	1,628 CS	34
Solid dirty fuels - all sectors	2,556 CS	18	2,556 CS	18	2,556 CS	18
Liquid dirty fuels (biogas) - all sectors	3,250	25	3,250	25	3,250	25
Bio-oil	1,628 CS	34	1,628 CS	34	1,628 CS	34
Non-subsidized innovative technology scenario						
Solid clean fuels- all sectors	1,628 CS	34	2,491 Introduction of GCC	44	1,343	44
Solid dirty fuels - all sectors	2,556 CS	18	2,556 Continued use of CS	18	1,343 Introduction of GCC	27
Liquid dirty fuels (biogas) - all sectors	3,250	25	3,250	38	2,680	38
Bio-oil	1,628 CS	34	927 Introduction of CC	52	927	52
Subsidized innovative technology scenario						
Solid clean fuels- all sectors	1,628 CS	34	1,343 Introduction of GCC	44	1,343	44
Solid dirty fuels - all sectors	2,556 CS	18	2,108 Introduction of GCC	27	2,108	27
Liquid dirty fuels (biogas) - all sectors	3,250	25	3,250	38	2,680	38
Bio-oil	1,628 CS	34	927 Introduction of CC	52	927	52

Source: Siemons et al. (2004)

Table A30. Pellet consumption in different sectors for selected countries

		2001	2002	2003	2004	2005	2006	2007	2008
		tons/year							
Austria	Residential	85,348	122,450	166,410	220,882	303,402	400,000	330,000	513,000
	Large Heat&Power								
	Other								
	Total	85,348	122,450	166,410	220,882	303,402	400,000	330,000	513,000
Belgium	Residential							30,000	120,000
	Large Heat&Power							700,000	800,000
	Other								
	Total							730,000	920,000
Denmark	Residential	223,000	253,000	283,000	295,000	309,000	469,000	505,000	471,000
	Large Heat&Power	114,000	126,000	206,000	362,000	432,000	289,000	344,000	355,000
	Other	71,000	72,000	73,000	74,000	77,000	134,000	144,000	234,000
	Total	408,000	451,000	562,000	731,000	818,000	892,000	993,000	1,060,000
Germany	Residential	24,000	67,000	120,000	180,000	330,000	480,000	550,000	900,000
	Large Heat&Power								
	Other								
	Total	24,000	67,000	120,000	180,000	330,000	480,000	550,000	900,000
Italy	Residential	150,000	160,000	190,000	210,000	270,000	340,000	567,000	850,000
	Large Heat&Power								
	Other			20,000	20,000	20,000	40,000	63,000	
	Total	150,000	160,000	210,000	230,000	290,000	380,000	630,000	850,000
Netherlands	Residential					36,000	37,000	40,000	38,000
	Large Heat&Power		150,000	200,000	225,000	451,000	449,000	665,000	875,500
	Total		150,000	200,000	225,000	487,000	486,000	705,000	913,500
Sweden	Residential	150,000	235,000	395,000	440,000	590,000	609,000	635,000	700,000
	Large Heat&Power	756,000	667,000	734,000	816,000	815,000	820,000	800,000	800,000
	Other					200,000	250,000	280,000	350,000
	Total	906,000	902,000	1,129,000	1,256,000	1,605,000	1,679,000	1,715,000	1,850,000
United Kingdom	Residential							6,178	10,000
	Large Heat&Power								166,000
	Other								
	Total								176,000

Source: Pellets@tlas

Table A31. Overview of wood pellet market in EU member states

	Number of producers	Production Capacity	Production	Consumption	Export/import	Large heat&power consumption	Number of large consumers
		tons/year					
Austria	25	1,006,000	626,000	513,000	113,000		
Belgium	10	450,000	325,000	920,000	-595,000	800,000	2
Bulgaria	17	62,300	27,000	3,000	24,000		
Czech Republic	14	260,000	170,000	17,000	153,000		
Cyprus	0	0	0	0	0		
Denmark	12	313,000	134,300	1,060,000	-925,700	355,000	2
Estonia	6	485,000	338,000	3,000	335,000		
Finland	19	680,000	373,000	150,000	223,000		
France	54	1,391,800	240,000	200,000	40,000		
Germany	50	2,400,000	1,460,000	900,000	560,000		
Greece	5	87,000	27,800	11,100	16,700		
Hungary	7	5,000	5,000	1,000	4,000		
Italy	75	750,000	650,000	850,000	-200,000		
Ireland	2	77,500	17,000	30,000	-13,000		
Latvia	15	743,600	379,200	39,000	340,200		
Lithuania	6	152,600	120,000	20,000	100,000		
Luxembourg	0	0	0	0	0		
Malta	0	0	0	0	0		
Netherlands	2	130,000	120,000	913,500	-793,500	875,500	5
Poland	21	674,200	340,200	120,000	220,200	150,000**	5
Portugal*	6	100,000	100,000	10,000	90,000		
Romania	21	260,000	114,000	25,000	89,000		
Slovakia	14	142,000	117,000	17,550	99,450		
Slovenia	4	185,000	154,000	112,000	42,000		
Spain	17	250,000	100,000	10,000	90,000		
Sweden	94	2,200,000	1,405,000	1,850,000	-445,000		
United Kingdom	15	218,000	125,000	176,000	-51,000	800,000	5
EU 27	511	13,023,000	7,467,500	7,951,150	-483,650		

**Due to lack of data, for Portugal we assume the same production capacity as production level*
***data for 2009*
Source: Pellets@tlas, Sikkema et al. (2009)

Table A32. Monthly imports of wood pellets in EU 27 (in 2009)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan-Dec
	tons												
USA	50,178	39,120	57,523	54,737	73,228	49,147	52,859	60,112	34,883	30,994	29,229	2,669	534,679
Canada	52,639	14,983	46,920	28,866	57,461	29,389	53,489	41,619	58,170	20,647	73,400	42,615	520,197
Russia	12,278	30,616	34,660	34,858	23,313	28,757	34,323	34,974	27,533	36,425	41,833	37,580	377,152
Belorussia	6,212	3,378	6,383	5,433	5,354	8,735	7,604	5,563	3,770	10,663	5,091	6,659	74,846
South Africa	4,015	4,980	3,724	189	8,728	234	165	11,146	3,975	136	116	4,375	41,782
Ukraine	732	1,585	1,804	1,468	1,661	1,860	1,912	2,807	4,058	4,181	4,222	4,074	30,363
Norway	2,510	1,742	1,745	552	681	1,679	253	183	130	66	242	426	10,209
Argentina	132	338	622	702	521	541	675	390	1,225	1,664	1,479	1,205	9,493
Switzerland	1,050	481	92	276	747	881	925	347	324	299	188	276	5,886
Brazil					0						279		279
China				17		156	2		41		5		221
Turkey											107		107
Chile								25		26			51
Total	129,746	97,223	153,473	127,081	171,694	121,223	152,205	157,141	134,068	105,075	155,800	99,879	1,605,265

Source: Eurostat

Table A33. Techno-economical potential and energy use of solid biomass resources in Belgium (in 2006)

	Forest residues	Solid industrial wood residues	Firewood	Used wood	Herbaceous and fruit biomass	Spent liquors	Peat	Other biomass	Refined biomass fuels	Total
Techno-economical potential (PJ/a)	5.7	11.4	6.1	5.7	1.14	1.7	0	11.9	6.1	43.7
Energy use (PJ/a)	7.4	11.4	6.1	5.7	included in other biomass	8.4	3.4	28.5	12.7	83.5

Source: Pieret (2009)

Table A33.1. Techno-economical potential and energy use of solid biomass resources in the Netherlands (in 2006)

	Forest residues	Solid industrial wood residues	Firewood	Used wood	Herbaceous and fruit biomass	Spent liquors	Peat	Other biomass	Refined biomass fuels	Total
Techno-economical potential (PJ/a)	9.3	9.5	3.6	19.1	6.9	0	0	26.6	1.9	75
Energy use (PJ/a)	3.6	4.7	9.3	2.3	0	0	0	28.3	8.5	56.7

Source: Junginger (2009)

Table A33.2. Techno-economical potential and energy use of solid biomass resources in the Sweden (in 2006)

	Forest residues	Solid industrial wood residues	Firewood	Used wood	Herbaceous&fruit biomass	Spent liquors	Peat	Other biomass	Refined biomass fuels	Total
Techno-economical potential (PJ/a)	250	96.5	43.6	15.9	140	160	43.2	140	30	889.2
Energy use (PJ/a)	61	78	29	6	5	139	7	43	34	397

Source: Olsson, Hillring and Cardoso (2009)

Table A33.3. Availability of existing UK's biomass resources and its potential for energy generation

Biomass resource	Available dt	Energy Potential Mtoe	Energy Potential TJ
Sawmill conversion products and aboricultural arisings	1,312,000	0.57 - 0.66	23,616 - 27,552
Energy crops (short rotation coppice and miscanthus)	155,463 - 222,787	0.07 - 0.09	2,757 - 3,955
Cereal straw	3,000,000	0.97 - 1.19	40,500 - 49,500
Paper and card	3,132,000	0.31 - 0.82	12,950 - 34,450
Garden/plant waste	3,429,000	0.34	14,400
Waste wood	5,563,000	2.21	93,000
Sewage sludge (dry solids)	340,000	0.12 - 0.16	5,134 - 6,800
Poultry manure - Meat birds (60% DM)	1,098,000	0.37	15,385
Total	18,030,363 - 18,097,687	4.96 - 5.84	207,742 - 245,042

Source: Panoutsou and Perry (2009)

Table A34. Feed-in-tariff scheme in Denmark

	Requirement	Feed-in-tariff	Premium
Denmark	Biomass-fired plants connected to the grid before April 2004	The subsidy and the market price ensure a tariff of DK 0.60/kWh (USD 0.102) for 20 years	n.a
	Biomass-fired plants connected to the grid after April 2004	n.a	DK 0.10/kWh (USD 0.017) for 20 years
	Biogas plants connected to the grid between 22 April 2004 and 31 December 2008	The subsidy and the market price ensure a tariff of DK 0.60/kWh (USD 0.102) for 10 years and DK 0.40 (USD 0.068) for the following 10 years	n.a
	Plants which use RE in combination with other fuels (if annual RE utilization is between 10% and 94% of the combustible value of total fuels) before 21 April 2004	n.a	DK 0.26/kWh (USD 0.044) for 20 years and for at least 15 years as from 1 January 2004
	Plants which use RE in combination with other fuels (if annual RE utilization is between 10% and 94% of the combustible value of total fuels) after 21 April 2004	n.a	RE-based production is eligible for a premium of DKK 0.26/kWh (USD 0.044) for the first 10 and DKK 0.06/kWh (USD 0.01) for the following 10 years
	Plants using biogas connected to the grid 22 April 2004 – 31 December 2008 in combination with other fuels (if annual RE utilization is between 10% and 94% of the combustible value of total fuels)	n.a	Biogas-based production is eligible for a premium of DKK 0.26/kWh (USD 0.044) for the first 10 and DKK 0.06/kWh (USD 0.01) for the following 10 years

Source: Pons (2007)

Theexchange rate used: euro/dollar 1:1.25 (2006)

Table A35. EU, Technology Base Case: Biofuel consumption (primary energy)

	Base year	No Sustain. Premium		Low Sustain. Premium		High Sustain. Premium	
	2000	2010	2020	2010	2020	2010	2020
Bioenergy source	mtoe/year						
Bio Electricity and Heat (tradeable, dedicated plant)	33	44	60	54	100	66	146
Bio Electricity (tradeable, co-combustion)	-	6.4	17.4	10.6	21.5	14.9	32.3
Bio Electricity and Heat (non-tradeable)	15.1	15.3	17.6	17.3	27.5	20.7	33.5
Bio Transport Fuels	1.5	3.4	5.3	3.8	8.5	4.1	13.5
Total bio-energy	49.6	69.1	100.3	85.7	157.5	105.7	225.3
Other renewables	37.2	50.6	55.9	55.9	74.8	62.3	87
Total renewables	86.8	119.7	156.2	141.6	232.3	168	312.3
Details bio-energy							
Tradeables*							
Forestry byproducts and refined wood fuels	21.9	24.3	31.9	27.8	40.6	31.8	43.6
Solid agricultural residues	1.3	14.4	20	18.4	32	23.2	32
Solid industrial residues	8.9	11.3	15	13.5	17.2	15	17.2
Solid energy crops	0.1	0.3	3.8	2.5	11.5	6.3	19.4
Imported biomass	0	0.2	6.1	1.6	19.5	4.9	64
Non-tradeables:							
Wet manure	0.1	0.3	0.7	0.5	2.2	0.8	4.6
Organic waste**	13	13	14	14.8	21.9	17	24
Sewage gas	0.8	0.8	0.9	0.9	1.1	1	1.4
Landfill gas	1.1	1.3	1.4	1.6	2.5	2.3	3.5
Transport fuels:							
Bioethanol	0.8	2.2	3	2.3	5.6	2.8	9.9
Biodiesel	0.7	1.2	2.3	1.4	3	1.5	3.7
Total bio-energy	49.6	69.1	100.3	85.7	157.5	105.7	225.3
*At an average equilibrium price of €/GJ for EU15:		3.2	3.7	3.7	4.9	4	6
and average equilibrium price of €/GJ for other EU members:		2.1	4.1	2.9	5.4	4	6

**Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.
Source: Siemons et al. (2004)

Table A36. EU, Non-subsidised Innovative Technology: Biofuel consumption (primary energy)

	Base year	No Sustain. Premium		Low Sustain. Premium		High Sustain. Premium	
	2000	2010	2020	2010	2020	2010	2020
Bioenergy resource	mtoe/year						
Bio Electricity and Heat (tradeable, dedicated plant)	33		69	58.8	118.7	69.5	162.4
Bio Electricity (tradeable, co-combustion)	-		17	10.6	21.2	14.9	31.8
Bio Electricity and Heat (non-tradeable)	15.1		17.9	18.5	33.5	21.8	39.4
Bio Transport Fuels	1.6		5.7	4.2	8.9	4.5	14.6
Total bio-energy	49.7		109.6	92.1	182.3	110.7	248.2
Other renewables	37.2		55.9	56	75.8	63.4	87.5
Total renewables	86.9		165.5	148.1	258.1	174.1	335.7
Details bio-energy							
Tradeables*							
Forestry byproducts and refined wood fuels	21.9		34.2	29.4	42.6	32.7	43.6
Solid agricultural residues	1.3		23.2	20.1	32	23.2	33
Solid industrial residues	8.9		16.1	14.5	17.2	15.7	17.2
Solid energy crops	0.1		5.7	2.8	15	6.6	19.4
Imported biomass	0		7	2.1	33.4	6.9	81.4
Non-tradeables							
Wet manure	0.1		0.9	0.4	3	0.8	5.3
Organic waste**	13		14.1	15	26.2	17.1	28.3
Sewage gas	0.8		0.9	0.9	1.2	0.9	1.5
Landfill gas	1.1		1.5	1.7	3.7	2.6	4.5
Transport fuels:							
Bioethanol	0.9		3.1	2.3	5.6	2.8	10.3
Biodiesel	0.7		2.6	1.7	3.3	1.9	4.2
Total bio-energy	49.7		109.6	92.1	182.3	110.7	248.2
*At an average equilibrium price of €/GJ for EU15:			3.9	3.7	5.2	4.3	6
And and average equilibrium price of €/GJ for other EU members:			4.2	2.8	5.4	3.7	6

**Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor
Source: Siemons et al. (2004)

Table A37. EU, Subsidised Innovative Technology: Biofuel consumption (primary energy)

	Base year	No Sustain. Premium		Low Sustain. Premium		High Sustain. Premium	
	2000	2010	2020	2010	2020	2010	2020
Bioenergy resource	mtoe/year						
Bio Electricity and Heat (tradeable, dedicated plant)	32.7	46.6	70.6	60.6	121.4	72.1	167.2
Bio Electricity (tradeable, co-combustion)	-	6.4	17	10.6	21.2	14.9	31.8
Bio Electricity and Heat (non-tradeable)	15.2	15.7	17.6	18	33.7	21.7	39.8
Bio Transport Fuels	1.5	3.4	5.3	3.8	8.5	3.8	8.5
Total bio-energy	49.4	68.7	110.5	93	184.8	112.5	247.3
Other renewables	37.7	50.1	56	55.5	75.3	62.8	87.2
Total renewables	87.1	118.8	166.5	148.5	260.1	175.3	334.5
Details bio-energy							
Tradeables*							
Forestry byproducts and refined wood fuels	22.2	25.3	34.5	31.1	42.3	33.2	43.9
Solid agricultural residues	1.3	15.1	23.4	20.2	32.1	23.9	32.5
Solid industrial residues	8.9	11.9	16.2	14.5	17.3	15.4	17.4
Solid energy crops	0.1	0.3	5.8	3	15.8	7.1	19.3
Imported biomass	0	0.4	7.7	2.4	35	7.5	85.9
Non-tradeables							
Wet manure	0.1	0.3	0.9	0.5	3	0.8	5.4
Organic waste**	13.1	13.1	14.2	15	25.9	17.4	28.5
Sewage gas	0.8	0.8	0.9	0.9	1.2	0.9	1.5
Landfill gas	1.1	1.3	1.5	1.7	3.7	2.5	4.5
Transport fuels							
Bioethanol	0.8	2.2	3	2.3	5.6	2.3	5.6
Biodiesel	0.7	1.2	2.3	1.4	3	1.4	3
Total bio-energy	49.4	68.7	110.5	93	184.8	112.5	247.3
*At an average equilibrium price of €/GJ for EU15:		3.2	4	3.7	5.2	4.5	6
and average equilibrium price of €/GJ for other EU members:		2.1	4.2	2.9	5.5	3.8	6

**Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor
Source: Siemons et al. (2004)

Table A38. Biomass import projections for 2020 (from SAFIRE model)

Unit	**Ktoe/year**	**No S-Premium**	**Low S-Premium**	**High S-Premium**
Country	Scenario	2020	2020	2020
Austria	Base Case	2	7	83
	Non Subsidised Innovative Technologies	2	7	126
	Subsidised Innovative Technologies	2	7	156
Bulgaria	Base Case	1	233	1,483
	Non Subsidised Innovative Technologies	1	693	2,153
	Subsidised Innovative Technologies	1	733	2,073
Belgium	Base Case	544	1,407	2,275
	Non Subsidised Innovative Technologies	911	1,634	3,512
	Subsidised Innovative Technologies	911	1,634	3,532
Czech Republic	Base Case	1,213	3,233	4,789
	Non Subsidised Innovative Technologies	1,553	4,074	6,232
	Subsidised Innovative Technologies	1,573	4,084	6,222
Denmark	Base Case	83	204	737
	Non Subsidised Innovative Technologies	112	307	1,067
	Subsidised Innovative Technologies	112	307	1,097
Estonia	Base Case	419	459	669
	Non Subsidised Innovative Technologies	509	559	869
	Subsidised Innovative Technologies	509	569	879
Finland	Base Case	1	2	79
	Non Subsidised Innovative Technologies	2	164	1,819
	Subsidised Innovative Technologies	2	164	2,019
France	Base Case	26	376	3,446
	Non Subsidised Innovative Technologies	39	411	3,336
	Subsidised Innovative Technologies	52	411	4,726
Germany	Base Case	1,613	7,080	17,289
	Non Subsidised Innovative Technologies	1,007	7,835	18,975
	Subsidised Innovative Technologies	1,146	8,325	18,828
Greece	Base Case	92	530	2,780
	Non Subsidised Innovative Technologies	92	1,810	3,354
	Subsidised Innovative Technologies	92	1,860	3,436
Hungary	Base Case	0	75	531
	Non Subsidised Innovative Technologies	8	75	1,061
	Subsidised Innovative Technologies	8	21	1,361
Italy	Base Case	1	236	3,289
	Non Subsidised Innovative Technologies	2	239	3,557
	Subsidised Innovative Technologies	2	239	3,701
Ireland	Base Case	41	804	2,304
	Non Subsidised Innovative Technologies	254	2,124	3,303
	Subsidised Innovative Technologies	254	2,134	3,313

Table A38. Continued

Unit	Ktoe/year	No S-Premium	Low S-Premium	High S-Premium
Country	Scenario	2020	2020	2020
	Non Subsidised Innovative Technologies	0	50	420
	Subsidised Innovative Technologies	0	50	490
Latvia	Base Case	0	9	170
	Non Subsidised Innovative Technologies	0	50	420
	Subsidised Innovative Technologies	0	50	490
Lithuania	Base Case	0	28	38
	Non Subsidised Innovative Technologies	1	28	178
	Subsidised Innovative Technologies	1	28	218
Poland	Base Case	1,806	1,716	6,209
	Non Subsidised Innovative Technologies	2,036	2,896	5,989
	Subsidised Innovative Technologies	2,036	2,976	6,478
Portugal	Base Case	3	14	2,018
	Non Subsidised Innovative Technologies	5	793	2,547
	Subsidised Innovative Technologies	502	932	2,597
Romania	Base Case	0	137	2,684
	Non Subsidised Innovative Technologies	0	137	2,930
	Subsidised Innovative Technologies	0	137	3,019
Slovakia	Base Case	1	25	659
	Non Subsidised Innovative Technologies	3	99	569
	Subsidised Innovative Technologies	3	129	659
Slovenia	Base Case	24	606	836
	Non Subsidised Innovative Technologies	46	806	1,036
	Subsidised Innovative Technologies	46	816	1,066
Spain	Base Case	1	21	973
	Non Subsidised Innovative Technologies	1	335	3,413
	Subsidised Innovative Technologies	1	335	4,253
Netherlands	Base Case	87	1,557	2,814
	Non Subsidised Innovative Technologies	157	2,446	4,122
	Subsidised Innovative Technologies	157	2,446	4,142
Sweden	Base Case	15	62	708
	Non Subsidised Innovative Technologies	19	92	1,288
	Subsidised Innovative Technologies	30	1,129	1,848
UK	Base Case	110	882	7,697
	Non Subsidised Innovative Technologies	208	5,302	9,575
	Subsidised Innovative Technologies	216	5,579	9,733
EU	Base Case	6,100	20,000	65,000
	Non Subsidised Innovative Technologies	700	33,000	81,000
	Subsidised Innovative Technologies	7,700	35,000	86,000

Source: Siemons et al. (2004)

Table A39. Estimated imports of wood pellets for all scenarios with the same shares* of wood pellets imports in biomass imports in 2020 as in 2007

Unit	Ktoe/year	No S-Premium		Low S-Premium		High S-Premium	
Country	Scenario	2020		2020		2020	
		Imported Biomass	Imported Pellets	Imported Biomass	Imported Pellets	Imported Biomass	Imported Pellets
Belgium	Base Case	544	597,157	1,407	1,544,486	2,275	2,497,303
	Non Subsidised Innovative Technologies	911	1,000,019	1,634	1,793,667	3,512	3,855,178
	Subsidised Innovative Technologies	911	1,000,019	1,634	1,793,667	3,532	3,877,132
Denmark	Base Case	83	141,749	204	348,396	737	1,258,666
	Non Subsidised Innovative Technologies	112	191,276	307	524,302	1,067	1,822,248
	Subsidised Innovative Technologies	112	191,276	307	524,302	1,097	1,873,483
Italy	Base Case	1	236	236	55,591	3,289	774,744
	Non Subsidised Innovative Technologies	2	471	239	56,298	3,557	837,873
	Subsidised Innovative Technologies	2	471	239	56,298	3,701	871,793
Netherlands	Base Case	87	82,375	1,557	1,474,225	2,814	2,664,399
	Non Subsidised Innovative Technologies	157	148,653	2,446	2,315,963	4,122	3,902,861
	Subsidised Innovative Technologies	157	148,653	2,446	2,315,963	4,142	3,921,798
United Kingdom*	Base Case	110	6,544	882	52,470	7,697	457,893
	Non Subsidised Innovative Technologies	208	12,374	5,302	315,415	9,575	569,615
	Subsidised Innovative Technologies	216	12,850	5,579	331,894	9,733	579,015

Current shares: Belgium 45,65%; Denmark 71.02%; Italy 9.8%; The Netherlands 39.4%; United Kingdom 2.5%
**Share of imported wood pellets in imported biomass in UK is probably bigger, but reported levels of import by Pellets atlas were used for calculations*

Table A40. EU countries with highest electricity generation from coal, in 2007

Country	TWh
Germany	299.79
Poland	145.57
United Kingdom	136.69
Spain	73.1
Czech Republic	53.8
Italy	44.11
Greece	34.68
Romania	25.1
Netherlands	24.92
France	24.45
Bulgaria	22.37
Finland	21.37

Source (Eurostat 2010)

Table A41. Feedstock quantity (in metric tons) for different scenarios

Switchgrass	%	100	90	80	70	60	50	40	30	20	10	0
Mill residues	0	108,696										
	10		112,994									
	20			117,647								
	30				122,699							
	40					128,205						
	50						134,228					
	60							140,845				
	70								148,148			
	80									156,250		
	90										165,289	
	100											175,439
Mill residues		-	11,299	23,529	36,810	51,282	67,114	84,507	103,704	125,000	148,760	175,439
Switchgrass		108,696	101,695	94,118	85,890	76,923	67,114	56,338	44,444	31,250	16,529	-

**assumed moisture of: switchgrass, mill residues and produced pellets 15%, 50% and 7% respectively).*

Table A42. Number of farms, acres harvested and average yield st/acre for other hay in selected counties (tons, dry)

County name	**Farms**	**Acres Harvested**		**yield tons/acre**					
	(number)	2002	2007	2003	2004	2005	2006	2007	2008
Anderson	273	10,198	8,140	2.2	2.2	2	2.4	2.2	2.5
Bledsoe	339	19,831	19,915	2.3	2.8	2.5	2.5	2.3	2.1
Blount	599	27,502	23,848	2.4	2.5	2.3	2.5	2.4	2.4
Bradley	404	18,243	16,970	2.3	2.6	2.4	2.3	2.6	2.25
Cumberand	404	23,850	22,663	2.3	3.3	2.8	2.2	2.3	1.95
Hamilton	273	12,497	10,578	2.2	2.2	2.1	2.4	2.2	2.1
Knox	546	22 ,535	19,459	2.2	2.1	2	2.3	2.2	1.85
Loudon	406	21,528	17,967	2.3	2.9	2.6	2.2	2.3	2.05
McMinn	591	28,126	25,148	2.4	2.5	2.3	2.6	2.4	2.35
Meigs	189	9,739	10,001	2.4	2.5	2.3	2.6	2.4	2.25
Monroe	453	21,401	18,659	2.4	2.9	2.7	2.5	2.4	1.85
Morgan	222	11,254	11,370	2.3	2.5	2.3	2.4	2.3	2
Polk	129	5,988	5,695	2.3	2.3	2.1	2.2	2.3	n/a
Rhea	228	12,675	9,387	2.5	2.7	2.5	2.3	2.5	2.4
Roane	270	13,908	10,232	2.4	2.2	2.1	2.2	2.4	2.3
Sevier	340	14,974	11,999	2.6	2.9	2.5	2.3	2.6	2.15
Total	**5,666**	**251,714**	**242,031**	**2.34**	**2.57**	**2.34**	**2.37**	**2.36**	**2.17**

Source (National Agricultural Statistics Service, Crop data per County. Census 2007)

Table A43. Net present value (NPV) advantage* for switchgrass (per acre)

		Price for switchgrass ($/ton)						
		40	50	60	70	80	90	100
Price for hay ($/ton)	40	$357	$713	$1,068	$1,423	$1,778	$2,133	$2,488
	50	$190	$545	$900	$1,255	$1,610	$1,965	$2,321
	60	$22	$377	$733	$1,088	$1,443	$1,798	$2,153
	70	($145)	$210	$565	$920	$1,275	$1,630	$1,985
	80	($313)	$42	$397	$753	$1,108	$1,463	$1,818
	90	($480)	($125)	$230	$585	$940	$1,295	$1,650
	100	($648)	($293)	$62	$417	$773	$1,128	$1,483

Source: Halich and Smith (2010)

* NPV for switchgrass production minus NPV for hay production for 10 years. Positive number favors switchgrass production and negative number favors hay production.

Main assumptions: harvest of switchgrass once a year as round bale, and 3 cuttings for hay; yield 6t/acre switchgrass, 2.2t/acre for hay; one way miles to delivery point: 37 for switchgrass, 10 for hay; trucking cost $11/ton for switchgrass, $7/ton for hay; storage costs assumed to be zero; no storage losses;discount rate 5%; mowing/raking increased cost factor for switchgrass 33% (e.g if yield per acre doubles per cutting then these costs increase by 33%);

Table A44. Annual Prices Received for Other Hay

Commodity	Year	Price per Unit $/dt
Hay Other (Dry)	2002	55
Hay Other (Dry)	2003	54
Hay Other (Dry)	2004	51
Hay Other (Dry)	2005	54
Hay Other (Dry)	2006	57
Hay Other (Dry)	2007	91
Hay Other (Dry)	2008	99
Hay Other (Dry)	2009	75

Source (National Agricultural Statistics Service, Crop data per County)

Table A45. Pellet plants currently in operation at South Eastern US

			Capacity (x103 tonnes)							
Company name	Town	State	2003	2004	2005	2006	2007	2008	2009	Comments
					Closed mills					
FutureFuel Chemical Co	Balesville	AR			27	36	36			Open in 2005, now down
					Operating mills					
Lee Energy Solutions	Crosville	AL								2009 or 10, 75k tons
Nature's Earth Pellet Energy	Reform	AL				5	5	6	6	100/tons/week in 2006
New Gas Concepts	Jackson	AL								2010? Eventually 600 stons
New Gas Concepts	Selma	AL						45	454	Eventually 500 stons
Barnes Bros Hardwood Flooring	Hamburg	AR					9	9	9	
Fiber Resources	Pine Bluff	AR	67	67	67	90	90	112	112	
Green Circle Bioenergy	Cottondale	FL						227	454	Open May 2008
Big Heat Wood Pellets	Sylvania	GA	9	9	9	9	9	9	9	Since 2001
Fram Renewable Fuels	Baxley	GA						42	132	Started plant 3/2008
Rock Wood Prod	The Rock	GA					14	18	18	
Woodlands Alternative Fuels	Meigs	GA							68	June 2009, 300 in 2010
Anderson Hardwood Pellets	Louisville	KY					18	18	18	Started in 2006
S Kentucky Hardwood Flooring	Gamaliel	KY				18	18	18	18	Available in 2006
Somerset Pellet Fuel	Somerset	KY				46	46	46	46	
Bayou Wood Pellets	West Monroe	LA						54	54	Started Jan 08
CKS Energy	Amory	MS				23	44	45	45	Since 2007
Indeck Magnolia BioFuel Center	Magnolia	MS								2010?

Table A45. Continued

			Capacity (x10^3 tonnes)							
Company name	Town	State	2003	2004	2005	2006	2007	2008	2009	Comments
Piney Woods Pellets	Wiggins	MS							19	up in July 2009, 50k tons
Carolina Wood Pellets	Franklin	NC							62	Expected start Q1 2009
Hassel & Hughes Lumber	Collinwood	TN					18	18	18	Started Jan 2007
Good Times Wood Prod	Rusk	TX			9	23	23	23	23	
Northcutt Woodworks	Crockett	TX				14	14	14	14	Since 2006
Patterson Wood Prod	Nacogdoches	TX					18	18	18	At least since 2007
American Wood Fibers	Marion	VA								Plant will start in 2009
Big Heat Wood Pellets	Chester	VA	9	9	9	9	9	9	9	
Lignetics Lunenburg		VA						45	45	
O'Malley Lum Co	Tappahannock	VA						32	32	Since Sep 2008
Potomac Supply	Kinsale	VA							18	Started 2/2009
Turman Hardwood Flooring	Galax	VA					14	14	14	Started in 2005
Hammer Pellet Fuel	Kenova	WV				36	41	41	41	
Hammer Pellet Fuel	Garden Grounds	WV					41	41	41	
Lignetics	Glenville	WV	36	36	36	36	36	59	59	
			2003	2004	2005	2006	2007	2008	2009	
Estimated Capacity			122	122	158	344	502	964	1,855	
Estimated 2008 Production								592		

Source: Spelther and Toth (2009)

Table A46. Availability of mill residues in 2015 for different price for counties in 50 miles range from plant location

	$/ton								
County	20	25	30	35	40	45	50	55	60
Anderson	0	0	0	0	0	0	0	0	0
Bledsoe	82	82	1,310	1,310	1,790	1,790	1,790	1,790	1,790
Blount	370	4,745	5,870	5,870	5,870	14,807	14,807	14,807	14,807
Bradley	661	661	661	661	661	661	661	661	661
Cumberland	0	9,804	10,690	10,690	11,286	17,086	17,086	17,086	17,086
Hamilton	159	20,233	20,277	20,277	20,298	25,234	25,234	25,234	25,234
Loudon	0	0	0	0	0	0	0	0	0
McMinn	963	963	120,489	120,489	120,858	120,858	120,858	120,858	120,858
Meigs	219	219	541	541	698	698	698	698	698
Monroe	596	9,254	16,175	16,175	16,361	17,199	17,199	17,199	17,199
Morgan	1,033	8,279	8,357	8,357	8,528	12,157	12,157	12,157	12,157
Polk	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245
Rhea	148	185	12,911	12,911	12,911	43,693	43,693	43,693	43,693
Roane	112	10,062	10,415	10,415	12,001	17,796	17,796	17,796	17,796
Total	9,588	69,732	212,942	212,942	216,507	277,224	277,224	277,224	277,224

Source: English et al. (2006)

Table A47. Factors for investment cost calculations based on industry standards used for lignocellulosic biomass to ethanol process design

Item	Description	Amount
Warehouse		1.5% of Total installed equipment cost
Site development	Includes fencing, curbing, parking lot, roads, well drainage, rail system, soil borings and general paving. This factor allows for minimum site development assuming a clear site, with no unusual problems such a right-of-way, difficult land clearing, or unusual environmental problems.	9% of installed cost of processing equipment
Prorateable cost	Includes fringe benefits, burdens, and insurance of the construction contractor	10% of total installed cost
Field expenses	Consumables, small tool equipment, rental, field services, temporary construction facilities and field construction supervision	10% of total installed cost
Home office and construction	Engineering plus incidentals, purchasing and construction	25% of total installed cost
Project contingency	Small because of the detail used in project design	3% of total installed cost
Other cost	Start-up and commissioning cost; land, rights-of-way, surveys, permit and fees; piling, soil compaction/dewatering, unusual foundations; sales, use and other taxes; freight, insurance in transit and import duties on equipment, piping, steel, instrumentation etc; overtime pay during construction; field insurance; project team; transportation equipment, bulk shipping containers, plant vehicles etc; escalation or inflation of cost over time; interest on construction loan.	

Source: Aden et al. (2002)

Table A48. Total installed cost of equipment

Processing equipment	Number of units	Total installed cost ($)
Receiving and scale	1	130,000
Wood hog (for both bales and mill residues)	1	708,884
Grinding receiving belt with magnet and screen	1	174,139
Air-vey system to dryer feed	1	69,347
Dryer (Furnace, rotary drum dryer and fan)	1	1,386,947
Pre pellet storage bin 2700 CU FT	2	215,747
Dry material screener	1	58,560
Milled material conveying system	1	69,347
Explosion Detection	1	69,347
Hammermill	1	154,105
Pellet-mill steam system	1	53,937
Pellet-mill	3	1,386,947
Air-vey system to pellet cooler	3	138,695
Pellet cooler (with air system)	1	92,463
Pellet shaker/screener	1	29,280
Dust collection system and piping	1	77,053
Wheel loaders	2	339,032
Total processing equipment cost		5,153,832
Other equipment		
Control center, automation, interduction, lab equipment		770,526
Consumable and spare parts		77,053
Storage (silo storage)		5,547,789
Total installed equipment cost		11,549,200

Table A49. Total project investment cost for different feedstock scenarios (in $)

	100% mill residues	100% switchgrass	40/60 blend
Total installed equipment cost	11,549,200	11,549,200	11,549,200
Warehouse for mill residues	280,000	-	280,000
Bale storage lot	-	360,000	360,000
Site development	463,845	463,845	463,845
Total installed cost	12,293,045	12,373,045	12,653,045
Indirect Cost			
Field expenses + ProreaTable expenses	2,458,609	2,474,609	2,530,609
Home office and construction fee	3,073,261	3,093,261	3,163,261
Project Contingency	368,791	371,191	379,591
Total capital investment	18,193,706	18,312,106	18,726,506
Other cost	1,819,370	1,831,210	1,872,650
Total project investment	20,013,076	20,143,316	20,599,156

Table A50. Electricity cost for the base case scenario

Equipment type	HP	kW	Simultaneity factor[1]	kWh (monthly)	kWh (annualy)	$/kWh	$/kW	Total ($)	$/ton
Wood hog grinder	950	709	85.00%	373,763	4,485,155	0.05361		240,449.14	2.4
Dryer (furnace, rotary drum dryer and fan)	430	321	85.00%	169,177	2,030,123	0.05361		108,834.87	1.09
Hammermill	610	455	85.00%	239,995	2,879,941	0.05361		154,393.66	1.54
Pellet Mill (3)	1,560	1,164	85.00%	613,758	7,365,096	0.05361		394,842.79	3.95
Pellet Cooler (with air system)	2	1	85.00%	787	9,442	0.05361		506.21	0.01
Air system/pneumatic conveying	400	299	85.00%	157,374	1,888,486	0.05361		101,241.74	1.01
Pellet shaker/screener (2)	15	11	85.00%	5,902	70,818	0.05361		3,796.57	0.04
Convey, tanks, other fixed equip	130	97	85.00%	51,146	613,758	0.05361		32,903.57	0.33
Demand charge ($140 per month)								1,200.00	0.01
First 1000kW of billing demand ($ per kW)							13.97	167,640.00	1.68
Excess over 1000kw ($ per kW)							16.1	289,800.00	2.9
Additional fee for every kW over 2,500kW							16.1	182,674.93	1.83
Total electricity cost	4,097	3,057	85.00%	1,611,902	19,342,819			1,628,620.77	16.29

[1]Simultaeinity factor: 85%; Scenarios with switchgrass include electricity cost for boiler (100HP) used for switchgrass conditioning and increase final cost by $0.25/ton

Table A51. Drying cost for base case scenario

	100% mill residues	100% switchgrass	40/60 blend
Annual pellet production	100,000	100,000	100,000
Btu to evaporate LB of water	1,500	1,500	1,500
LB to evaporate from ton of feedstock	838	66	375
Btu/ton of feedstock	1,256,635	99,208	562,179
Tons of feedstock per year	175,439	108,696	128,205
MMBtu/Year	220,462	10,783	72,074
Therms/year	2,204,623	107,835	720,742
Customer charge ($)	105	105	105
Annual Natural Gas cost	2,273,812	112,443	744,228
Cost per ton of pellet	22.74	1.12	7.44

Table A52. Personnel cost

Required personnel per shift	Horly rate (Mean)[1]	Total number of hours	Annual salary per worker	Salary with Labor benefits (30% above salary)	Number of shifts	Number of workers per shift	Total annual cost
Shift supervisor	22.66	2,620	59,369	77,180	3	1	231,540
Maintenance and repair workers	17.13	2,620	44,881	58,345	3	2	350,069
Plant and system operators	23.37	2,620	61,229	79,598	3	2	477,589
Material moving workers	15.05	2,620	39,431	51,260	3	2	307,562
						7	1,366,760
Management and administration personnel							
Management labor			107,320	139,516	1	2	279,032
Bookkeeping, Accounting, and Auditing Clerks	15.2	2,000	30,400	39,520	1	1	39,520
							318,552
Total labor cost							1,685,312
Cost per ton of pellet							16.85

[1] Occupational employment statistics for Tennessee (Bureau of labor statistics, Accessed July, 2010)

Shift supervisor, maintenance, operators and moving	7days*8hours*52weeks
Book keepers	5days*8hours*52weeks
Laborers are paid for the vacation	yes

Table A53. Project financing cost

	100%MR	100%SG	40/60 blend
Investment cost	20,013,077	20,143,317	20,599,157
Equity	8,005,231	8,057,327	8,239,663
Principal 60% debt	12,007,846	12,085,990	12,359,494
Interest First year	480,314	483,440	494,380
interest Second year	960,628	966,879	988,760
Interest rate	0.08	0.08	0.08
Number of payments	10	10	10
Principal First year	($828,895.48)	($834,289.72)	($853,169.57)
Annual payment	$1,789,523	$1,801,169	$1,841,929

Table A54. Production cost for 14TPH pellet plant for different feedstock scenarios (100,000 tons of pellets annually)

Production cost	100 % mill residues	$/ton	%	100% switchgrass	$/ton	%	40/60 blend	$/ton	%
Annualized capital cost	2,148,759	21.49	13.82	2,167,121	21.67	12.71	1,955,809	19.56	11.89
Feedstock cost	5,263,158	52.63	33.85	8,911,947	89.12	52.25	7,845,378	78.45	47.70
Electricity	1,628,621	16.29	10.48	1,628,621	16.29	9.55	1,628,621	16.29	9.90
Drying cost	2,273,812	22.74	14.63	112,443	1.12	0.66	744,228	7.44	4.52
Interest on long-term debt	1,789,523	17.9	11.51	1,801,169	18.01	10.56	1,841,929	18.42	11.20
Property Tax	126,483	1.26	0.81	115,733	1.16	0.68	130,187	1.3	0.79
Personnel cost	1,685,312	16.85	10.84	1,685,312	16.85	9.88	1,685,312	16.85	10.25
Service and maintanance	494,251	4.94	3.18	494,465	4.94	2.90	488,994	4.89	2.97
Wheel loaders operation cost	49,200	0.49	0.32	49,200	0.49	0.29	49,200	0.49	0.30
Other Variable Cost	89,125	0.89	0.57	89,705	0.9	0.53	76,998	0.77	0.47
Total production cost	**15,548,243**	**155.5**	**100**	**17,055,715**	**171**	**100**	**16,446,655**	**164.5**	**100**

Table A55. Transportation cost for the base case scenario

	Unit	Train	Ocean ship (Panamax)	∑
Energy cost of transport mode[1]	\$/ton/km[4]	0.025	0.0014	
Management cost of tranport mode[2]	\$/ton/km	0.0084	0.00028	
Specific loading/unloading cost[3]	\$/ton	0.53	2.56	
Distance (Knoxville - Savannah)	miles	430		
Distance (Knoxville - Savannah)	km	692		
Distance (Savannah - Rotterdam)	miles		4,530	
Distance (Savannah - Rotterdam)	km		7,290	
Specific transport cost of transport mode used	\$/ton	23.64	14.74	38.38
Warfage[5]	\$/ton			1.05
Handling[6]	\$/ton			5.51
Storage[7]	\$/per day/ton			6.61
Days in storage at port				60
Total transportation cost	\$/ton			51.55

[1,2,3] Dornburg (2008)
[4] Exchange ratio €:\$ from 12/31/2008 (1:1.3917) used for conversion to 2008 dollars (European Central Bank's database)
[5,6,7] Panama City Port Authorities

Table A56. Income statement for the base case scenario for different feedstock scenarios

	100% MR	$/ton	100% SG	$/ton	40/60 blend	$/ton
Gross Income	**18,319,040**	**183.19**	**18,319,040**	**183.2**	**18,319,040**	**183.2**
Pellet price (set price for 2011 by ENDEX)	183.19		183.19		183.19	
Pellets produced	100,000		100,000		100,000	
Total pellets production cost	**15,548,243**	**155.48**	**17,055,715**	**170.6**	**16,446,655**	**164.5**
Feedstock cost	**5,263,158**	**52.63**	**8,911,947**	**89.12**	**7,845,378**	**78.45**
Switchgrass	0	0	8,911,947	89.12	-	-
Mill residues	5,263,158	52.63	0	0	7,845,378	78.45
Annualized capital cost	**2,148,759**	**21.49**	**2,167,121**	**21.67**	**1,955,809**	**19.56**
Operating cost	**8,136,326**	**81.36**	**5,976,647**	**59.77**	**6,645,468**	**66.45**
Electricity cost	1,628,621	16.29	1,628,621	16.29	1,628,621	16.29
Drying cost	2,273,812	22.74	112,443	1.12	744,228	7.44
Labor cost	1,685,312	16.85	1,685,312	16.85	1,685,312	16.85
Maintenance	494,251	4.94	494,465	4.94	488,994	4.89
Wheel loader operation cost	49,200	0.49	49,200	0.49	49,200	0.49
Other variable cost	89,125	0.89	89,705	0.9	76,998	0.77
Interest on long-term debt	1,789,523	17.9	1,801,169	18.01	1,841,929	18.42
Property taxes	126,483	1.26	115,733	1.16	130,187	1.3
Transportation and port handling cost	**5,155,129**	**51.55**	**5,155,129**	**51.55**	**5,155,129**	**51.55**
Train freight	2,364,280	23.64	2,364,280	23.64	2,364,280	23.64
Ocean freight	1,473,587	14.74	1,473,587	14.74	1,473,587	14.74
Wharfage	104,720	1.05	104,720	1.05	104,720	1.05
Handling	551,156	5.51	551,156	5.51	551,156	5.51
Storage	661,387	6.61	661,387	6.61	661,387	6.61
Total expenditures	**20,703,372**	**207.03**	**22,210,843**	**222.1**	**21,601,784**	**216**
Net earnings (loss)	**(2,384,332)**	**(23.84)**	**(3,891,803)**	**(38.9)**	**(3,282,744)**	**(32.8)**
Pre-tax return on Investment (ROI)	**(4.63)**		**(7.78)**		**(6.52)**	

[1]Assumed exchange ratio €:$ is 1:1.3984 (European Central Bank, average exchange ratio for 2009)

Table A57. ROI for 100% mill residue scenario for different feedstock and pellet prices (all other parameters constant)

100% Mill residues		Pellet price ($/metric ton)											
		140	150	160	170	180	190	200	210	220	230	240	250
Mill residues price $/metric ton	30	(13.40)	(11.40)	(9.40)	(7.40)	(5.40)	(3.40)	(1.41)	0.59	2.59	4.59	6.59	8.59
	40	(16.90)	(14.91)	(12.91)	(10.91)	(8.91)	(6.91)	(4.91)	(2.91)	(0.91)	1.08	3.08	5.08
	50	(20.41)	(18.41)	(16.41)	(14.41)	(12.42)	(10.42)	(8.42)	(6.42)	(4.42)	(2.42)	(0.42)	1.57
	60	(23.92)	(21.92)	(19.92)	(17.92)	(15.92)	(13.92)	(11.93)	(9.93)	(7.93)	(5.93)	(3.93)	(1.93)
	70	(27.42)	(25.43)	(23.43)	(21.43)	(19.43)	(17.43)	(15.43)	(13.43)	(11.43)	(9.44)	(7.44)	(5.44)
	80	(30.93)	(28.93)	(26.93)	(24.93)	(22.94)	(20.94)	(18.94)	(16.94)	(14.94)	(12.94)	(10.94)	(8.94)
	90	(34.44)	(32.44)	(30.44)	(28.44)	(26.44)	(24.44)	(22.44)	(20.45)	(18.45)	(16.45)	(14.45)	(12.45)
	100	(37.94)	(35.94)	(33.95)	(31.95)	(29.95)	(27.95)	(25.95)	(23.95)	(21.95)	(19.96)	(17.96)	(15.96)

Table A58. ROI for 100% switchgrass scenario for different feedstock and pellet prices (all other parameters constant)

100% Switchgrass		Pellet price ($/metric ton)											
		140	150	160	170	180	190	200	210	220	230	240	250
Switchgrass price $/metric ton	50	(9.40)	(7.41)	(5.43)	(3.44)	(1.46)	0.53	2.51	4.50	6.49	8.47	10.46	12.44
	60	(11.56)	(9.57)	(7.59)	(5.60)	(3.62)	(1.63)	0.36	2.34	4.33	6.31	8.30	10.29
	70	(13.72)	(11.73)	(9.75)	(7.76)	(5.77)	(3.79)	(1.80)	0.18	2.17	4.16	6.14	8.13
	75	(14.80)	(12.81)	(10.82)	(8.84)	(6.85)	(4.87)	(2.88)	(0.90)	1.09	3.08	5.06	7.05
	80	(15.88)	(13.89)	(11.90)	(9.92)	(7.93)	(5.95)	(3.96)	(1.97)	0.01	2.00	3.98	5.97
	85	(16.95)	(14.97)	(12.98)	(11.00)	(9.01)	(7.03)	(5.04)	(3.05)	(1.07)	0.92	2.90	4.89
	90	(18.03)	(16.05)	(14.06)	(12.08)	(10.09)	(8.10)	(6.12)	(4.13)	(2.15)	(0.16)	1.82	3.81
	95	(19.11)	(17.13)	(15.14)	(13.16)	(11.17)	(9.18)	(7.20)	(5.21)	(3.23)	(1.24)	0.74	2.73

Table A59. ROI for 40/60 blend scenario for different feedstock and pellet prices (all other parameters constant)

Mill residues price	Switchgrass price	Pellet price ($/metric ton)											
$/metric ton		140	150	160	170	180	190	200	210	220	230	240	250
30	50	(9.98)	(8.04)	(6.10)	(4.16)	(2.22)	(0.27)	1.67	3.61	5.55	7.49	9.44	11.38
	75	(13.72)	(11.78)	(9.83)	(7.89)	(5.95)	(4.01)	(2.07)	(0.12)	1.82	3.76	5.70	7.64
	100	(17.45)	(15.51)	(13.57)	(11.63)	(9.68)	(7.74)	(5.80)	(3.86)	(1.92)	0.02	1.97	3.91
40	50	(10.98)	(9.04)	(7.10)	(5.15)	(3.21)	(1.27)	0.67	2.61	4.56	6.50	8.44	10.38
	75	(14.71)	(12.77)	(10.83)	(8.89)	(6.95)	(5.00)	(3.06)	(1.12)	0.82	2.76	4.71	6.65
	100	(18.45)	(16.51)	(14.56)	(12.62)	(10.68)	(8.74)	(6.80)	(4.85)	(2.91)	(0.97)	0.97	2.91
50	50	(11.97)	(10.03)	(8.09)	(6.15)	(4.21)	(2.27)	(0.32)	1.62	3.56	5.50	7.44	9.39
	75	(15.71)	(13.77)	(11.83)	(9.88)	(7.94)	(6.00)	(4.06)	(2.12)	(0.17)	1.77	3.71	5.65
	100	(19.44)	(17.50)	(15.56)	(13.62)	(11.68)	(9.73)	(7.79)	(5.85)	(3.91)	(1.97)	(0.02)	1.92

Table A60. ROI for 100% mill residues scenario for different feedstock and pellet prices (assumed moisture content 30%)

100% Mill residues		Pellet price ($/metric ton)											
		140	150	160	170	180	190	200	210	220	230	240	250
Mill residues price	$/metric ton 30	(7.72)	(5.72)	(3.72)	(1.72)	0.28	2.28	4.28	6.27	8.27	10.27	12.27	14.27
	40	(10.31)	(8.31)	(6.31)	(4.32)	(2.32)	(0.32)	1.68	3.68	5.68	7.68	9.67	11.67
	50	(12.91)	(10.91)	(8.91)	(6.91)	(4.91)	(2.91)	(0.92)	1.08	3.08	5.08	7.08	9.08
	60	(15.50)	(13.50)	(11.51)	(9.51)	(7.51)	(5.51)	(3.51)	(1.51)	0.49	2.48	4.48	6.48
	70	(18.10)	(16.10)	(14.10)	(12.10)	(10.10)	(8.11)	(6.11)	(4.11)	(2.11)	(0.11)	1.89	3.89
	80	(20.69)	(18.70)	(16.70)	(14.70)	(12.70)	(10.70)	(8.70)	(6.70)	(4.71)	(2.71)	(0.71)	1.29
	90	(23.29)	(21.29)	(19.29)	(17.29)	(15.30)	(13.30)	(11.30)	(9.30)	(7.30)	(5.30)	(3.30)	(1.30)
	100	(25.89)	(23.89)	(21.89)	(19.89)	(17.89)	(15.89)	(13.89)	(11.90)	(9.90)	(7.90)	(5.90)	(3.90)

Table A61. Euro:dollar conversion matrix for different exchange ratios

	Exchange ratio euro/dollar	value in euros															
		100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
value in dollars	1.1	110	115.5	121	126.5	132	137.5	143	148.5	154	159.5	165	170.5	176	181.5	187	192.5
	1.15	115	120.75	126.5	132.25	138	143.75	149.5	155.25	161	166.75	172.5	178.25	184	189.75	195.5	201.25
	1.2	120	126	132	138	144	150	156	162	168	174	180	186	192	198	204	210
	1.25	125	131.25	137.5	143.75	150	156.25	162.5	168.75	175	181.25	187.5	193.75	200	206.25	212.5	218.75
	1.3	130	136.5	143	149.5	156	162.5	169*	175.5	182	188.5	195	201.5	208	214.5	221	227.5
	1.35	135	141.75	148.5	155.25	162	168.75	175.5	182.25	189	195.75	202.5	209.25	216	222.75	229.5	236.25
	1.4	140	147	154	161	168	175	182	189	196	203	210	217	224	231	238	245
	1.45	203	213.15	223.3	233.45	243.6	253.75	263.9	274.05	284.2	294.35	304.5	314.65	324.8	334.95	345.1	355.25
	1.5	150	157.5	165	172.5	180	187.5	195	202.5	210	217.5	225	232.5	240	247.5	255	262.5
	1.55	155	162.75	170.5	178.25	186	193.75	201.5	209.25	217	224.75	232.5	240.25	248	255.75	263.5	271.25
	1.6	160	168	176	184	192	200	208	216	224	232	240	248	256	264	272	280
	1.65	165	173.25	181.5	189.75	198	206.25	214.5	222.75	231	239.25	247.5	255.75	264	272.25	280.5	288.75
	1.7	170	178.5	187	195.5	204	212.5	221	229.5	238	246.5	255	263.5	272	280.5	289	297.5
	1.75	175	183.75	192.5	201.25	210	218.75	227.5	236.25	245	253.75	262.5	271.25	280	288.75	297.5	306.25
	1.8	180	189	198	207	216	225	234	243	252	261	270	279	288	297	306	315
	1.85	185	194.25	203.5	212.75	222	231.25	240.5	249.75	259	268.25	277.5	286.75	296	305.25	314.5	323.75
	1.9	190	199.5	209	218.5	228	237.5	247	256.5	266	275.5	285	294.5	304	313.5	323	332.5
	2	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350

*Current price for industrial pellets in $/ton

Table A62. ROI for optimistic* scenario for 100% mill residue scenario

100% Mill residues		Pellet price ($/metric ton)											
		140	150	160	170	180	190	200	210	220	230	240	250
Mill residues price	$/metric ton 30	(3.74)	(1.74)	0.26	2.26	4.26	6.26	8.25	10.25	12.25	14.25	16.25	18.25
	40	(6.04)	(4.04)	(2.04)	(0.04)	1.96	3.96	5.96	7.96	9.95	11.95	13.95	15.95
	50	(8.33)	(6.33)	(4.34)	(2.34)	(0.34)	1.66	3.66	5.66	7.66	9.66	11.65	13.65
	60	(10.63)	(8.63)	(6.63)	(4.63)	(2.64)	(0.64)	1.36	3.36	5.36	7.36	9.36	11.36
	70	(12.93)	(10.93)	(8.93)	(6.93)	(4.93)	(2.93)	(0.93)	1.06	3.06	5.06	7.06	9.06
	80	(15.22)	(13.23)	(11.23)	(9.23)	(7.23)	(5.23)	(3.23)	(1.23)	0.77	2.76	4.76	6.76
	90	(17.52)	(15.52)	(13.52)	(11.53)	(9.53)	(7.53)	(5.53)	(3.53)	(1.53)	0.47	2.47	4.46
	100	(19.82)	(17.82)	(15.82)	(13.82)	(11.82)	(9.83)	(7.83)	(5.83)	(3.83)	(1.83)	0.17	2.17

*20% mill residues moisture, 6% interest rate with 20 year payment period, 1.5 euro: dollar exchange ratio, $50/ton switchgrass price and €140/ton price for pellets in EU

Table A63. ROI for optimistic* scenario for 100% switchgrass scenario

100% Switchgrass		Pellet price ($/metric ton)											
		140	150	160	170	180	190	200	210	220	230	240	250
Switchgrass price	$/metric ton 50	(7.28)	(5.29)	(3.31)	(1.32)	0.66	2.65	4.63	6.62	8.61	10.59	12.58	14.56
	60	(9.44)	(7.45)	(5.47)	(3.48)	(1.50)	0.49	2.48	4.46	6.45	8.43	10.42	12.41
	70	(11.60)	(9.61)	(7.63)	(5.64)	(3.65)	(1.67)	0.32	2.30	4.29	6.28	8.26	10.25
	75	(12.68)	(10.69)	(8.70)	(6.72)	(4.73)	(2.75)	(0.76)	1.22	3.21	5.20	7.18	9.17
	80	(13.76)	(11.77)	(9.78)	(7.80)	(5.81)	(3.83)	(1.84)	0.15	2.13	4.12	6.10	8.09
	85	(14.83)	(12.85)	(10.86)	(8.88)	(6.89)	(4.91)	(2.92)	(0.93)	1.05	3.04	5.02	7.01
	90	(15.91)	(13.93)	(11.94)	(9.96)	(7.97)	(5.98)	(4.00)	(2.01)	(0.03)	1.96	3.94	5.93
	95	(16.99)	(15.01)	(13.02)	(11.04)	(9.05)	(7.06)	(5.08)	(3.09)	(1.11)	0.88	2.86	4.85

20% mill residues moisture, 6% interest rate with 20 year payment period, 1.5 euro: dollar exchange ratio, $50/ton switchgrass price and €140/ton price for pellets in EU

APPENDIX B

FIGURES

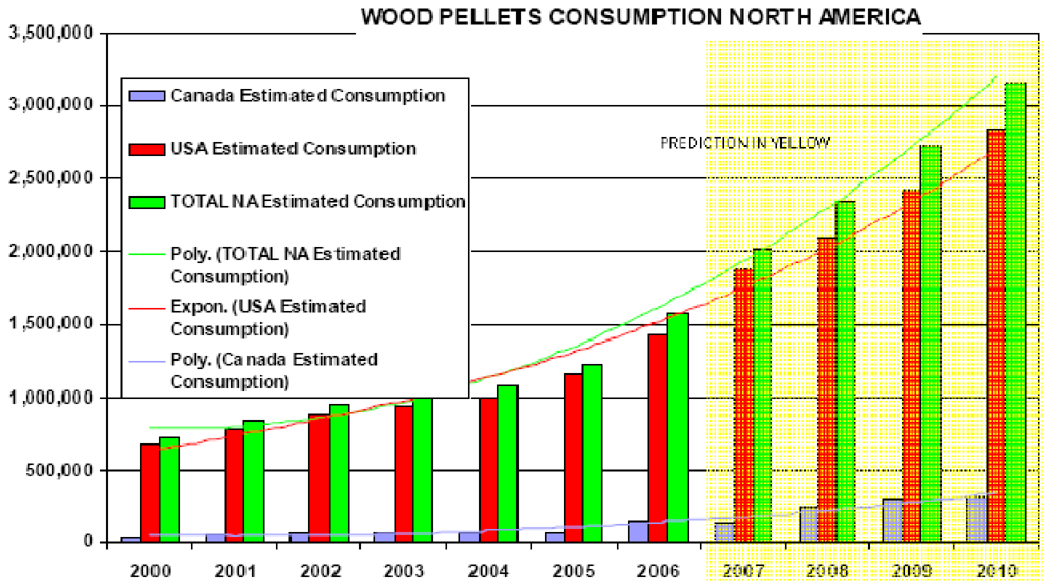

Figure B1. Wood pellets consumption in North America up to 2007 (numbers from 2007-2010 are estimates)
Source: (Junginger, Sikkema and Faaij, 2009)

1.1 Forest plantation and other virgin wood	1.1.1 Whole trees without roots	1.1.1.1 Deciduous
		1.1.1.2 Coniferous
		1.1.1.3 Short rotation coppice
		1.1.1.4 Bushes
		1.1.1.5 Blends and mixtures
	1.1.2 Whole trees with roots	1.1.2.1 Deciduous
		1.1.2.2 Coniferous
		1.1.2.3 Short rotation coppice
		1.1.2.4 Bushes
		1.1.2.5 Blends and mixtures
	1.1.3 Stemwood	1.1.3.1 Deciduous
		1.1.3.2 Coniferous
		1.1.3.3 Blends and mixtures
	1.1.4 Logging residues	1.1.4.1 Fresh/Green, Deciduous (incl. leaves)
		1.1.4.2 Fresh/Green, Coniferous (incl. leaves)
		1.1.4.3 Stored, Deciduous
		1.1.4.4 Stored, Coniferous
		1.1.4.5 Blends and mixtures
	1.1.5 Stumps/roots	1.1.5.1 Deciduous
		1.1.5.2 Coniferous
		1.1.5.3 Short rotation coppice
		1.1.5.4 Bushes
		1.1.5.5 Blends and mixtures
	1.1.6 Bark (from forestry operations)	
	1.1.7 Segregated wood from gardens, parks, roadside maintenance, vineyards and fruit orchards	
	1.1.8 Blends and mixtures	
1.2 By-products and residues from wood processing industry	1.2.1 Chemically untreated wood residues	1.2.1.1 Without bark, Deciduous
		1.2.1.2 Without bark, Coniferous
		1.2.1.3 With bark, Deciduous
		1.2.1.4 With bark, Coniferous
		1.2.1.5 Bark (from industry operations)
	1.2.2 Chemically treated wood residues, fibres and wood constituents	1.2.2.1 Without bark
		1.2.2.2 With bark
		1.2.2.3 Bark (from industry operations)
		1.2.2.4 Fibres and wood constituents
	1.2.3 Blends and mixtures	
1.3 Used wood	1.3.1 Chemically untreated wood	1.3.1.1 Without bark
		1.3.1.2 With bark
		1.3.1.3 Bark
	1.3.2 Chemically treated wood	1.3.2.1 Without bark
		1.3.2.1 With bark
		1.3.2.3 Bark
	1.3.3 Blends and mixtures	
1.4 Blends and mixtures		

Figure B2. Classification of woody biomass (EN 14961-1)
Source: EUBIONET

2.1 Herbaceous Biomass from agriculture and horticulture	2.1.1 Cereal crops	2.1.1.1 Whole plant
		2.1.1.2 Straw parts
		2.1.1.3 Grains or seeds
		2.1.1.4 Husks or shells
		2.1.1.5 Blends and mixtures
	2.1.2 Grasses	2.1.2.1 Whole plant
		2.1.2.2 Straw parts
		2.1.2.3 Seeds
		2.1.2.4 Shells
		2.1.2.5 Blends and mixtures
	2.1.3 Oil seed crops	2.1.3.1 Whole plant
		2.1.3.2 Stalk and leaves
		2.1.3.3 Seeds
		2.1.3.4 Husks or shells
		2.1.3.5 Blends and mixtures
	2.1.4 Root crops	2.1.4.1 Whole plant
		2.1.4.2 Stalk and leaves
		2.1.4.3 Roots
		2.1.4.4 Blends and mixtures
	2.1.5 Legume crops	2.1.5.1 Whole plant
		2.1.5.2 Stalk and leaves
		2.1.5.3 Fruit
		2.1.5.4 Pods
		2.1.5.5 Blends and mixtures
	2.1.6 Flowers	2.1.6.1 Whole plant
		2.1.6.2 Stalk and leaves
		2.1.6.3 Seeds
		2.1.6.4 Blends and mixtures
	2.1.7 Segregated herbaceous biomass from gardens, parks, roadside maintenance, vineyards and fruit orchards	
	2.1.8 Blends and mixtures	
2.2 By products and residues from herbaceous processing industry	2.2.1 Chemically untreated herbaceous residues	2.2.1.1 Cereal crops and grasses
		2.2.1.2 Oil seed crops
		2.2.1.3 Root crops
		2.2.1.4 Legume crops
		2.2.1.5 Flowers
		2.2.1.6 Blends and mixtures
	2.2.2 Chemically treated herbaceous residues	2.2.2.1 Cereal crops and grasses
		2.2.2.2 Oil seed crops
		2.2.2.3 Root crops
		2.2.2.4 Legume crops
		2.2.2.5 Flowers
		2.2.2.6 Blends and mixtures
	2.2.3 Blends and mixtures	
2.2.3 Blends and mixtures		

Figure B3. Classification of herbaceous biomass (EN 14961-1)
Source: EUBIONET

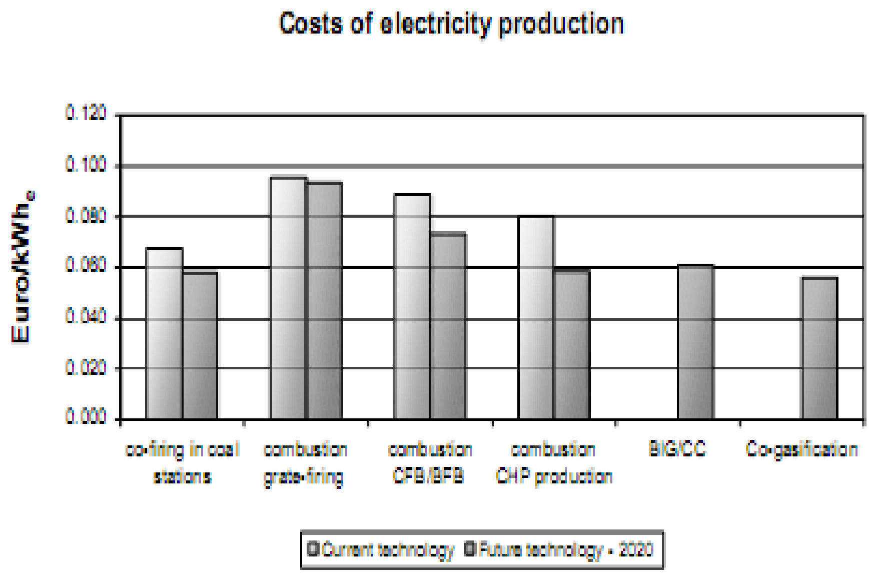

Figure B4. Cost of electricity production from biomass using different technologies with fuel cost of 5€/GJ_{lhv} (including transportation) with basic assumed heat prices of 0.011€/MJ[6], heat load of 2,500 h/yr, lifetime of 20 years and interest rate of 6%
Source: Dornburg (2008)

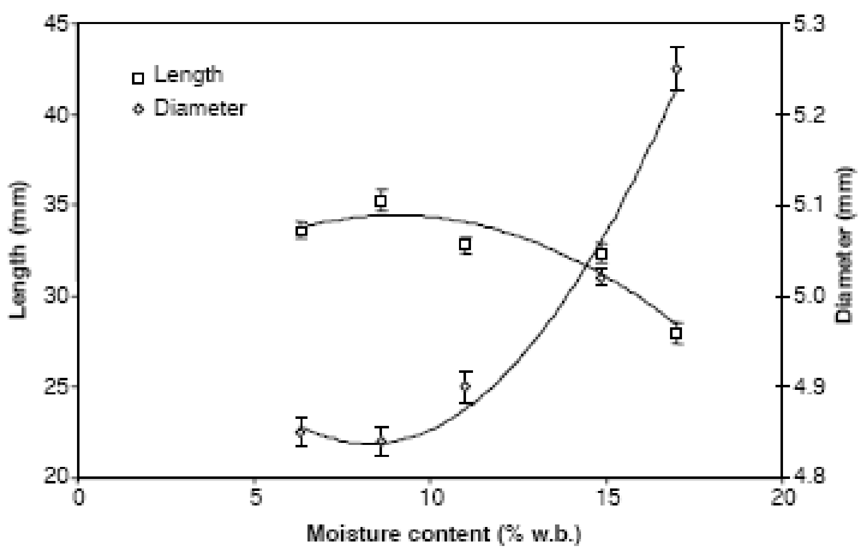

Figure B5. Effect of moisture on length and diameter of pellets (Error bands are standard deviations from experimental results). Source: Colley et al. (2006)

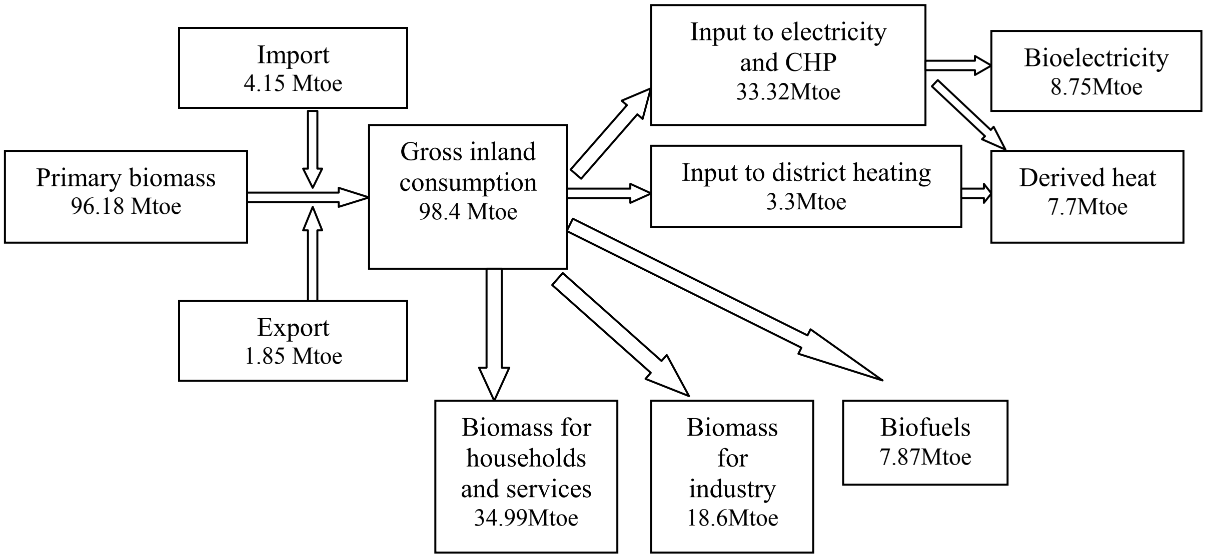

Figure B6. EU's Bioenergy balance in 2007
Source: AEBIOM (2009)

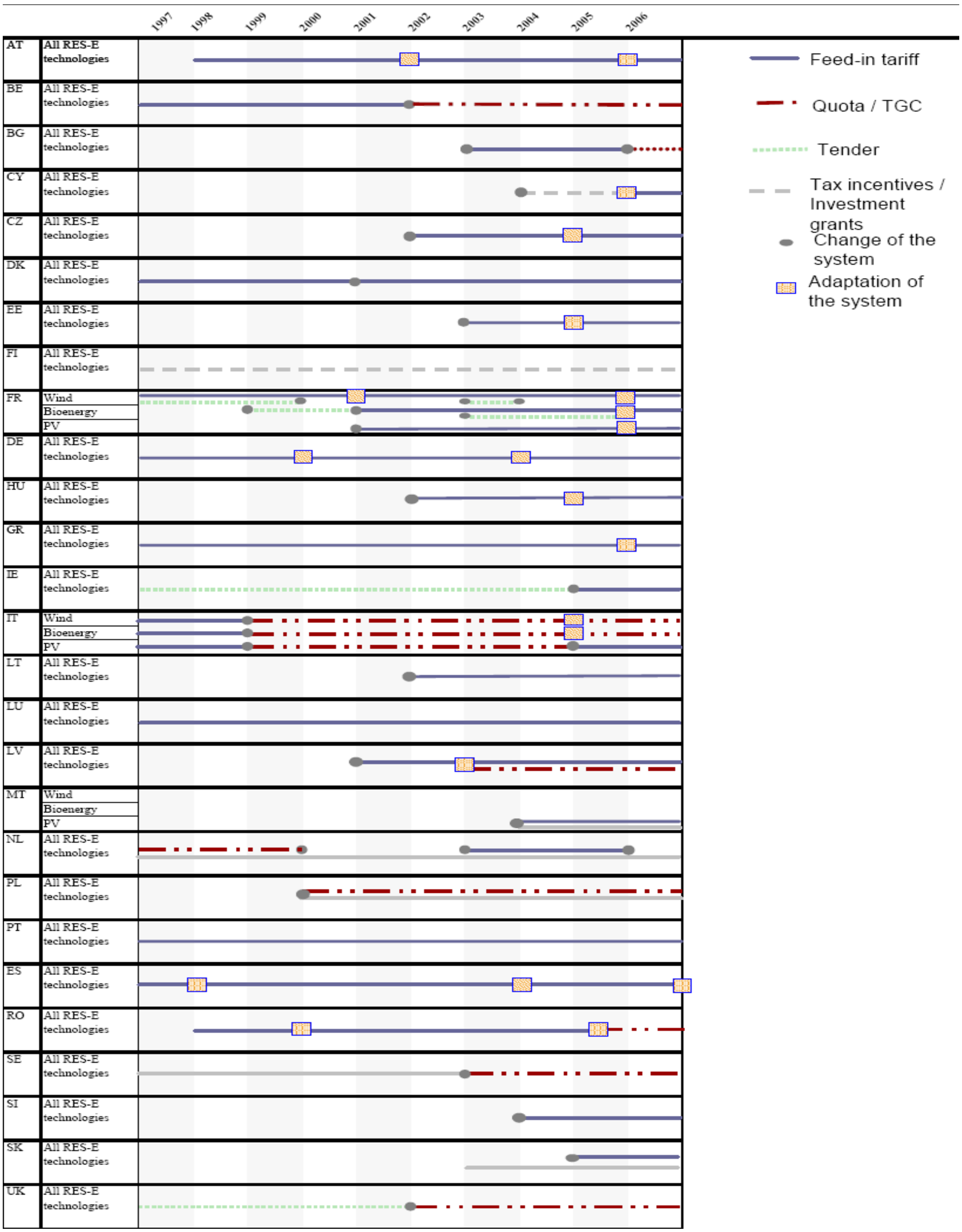

Figure B7. Support schemes for renewables in the EU
Source: EC 2008.

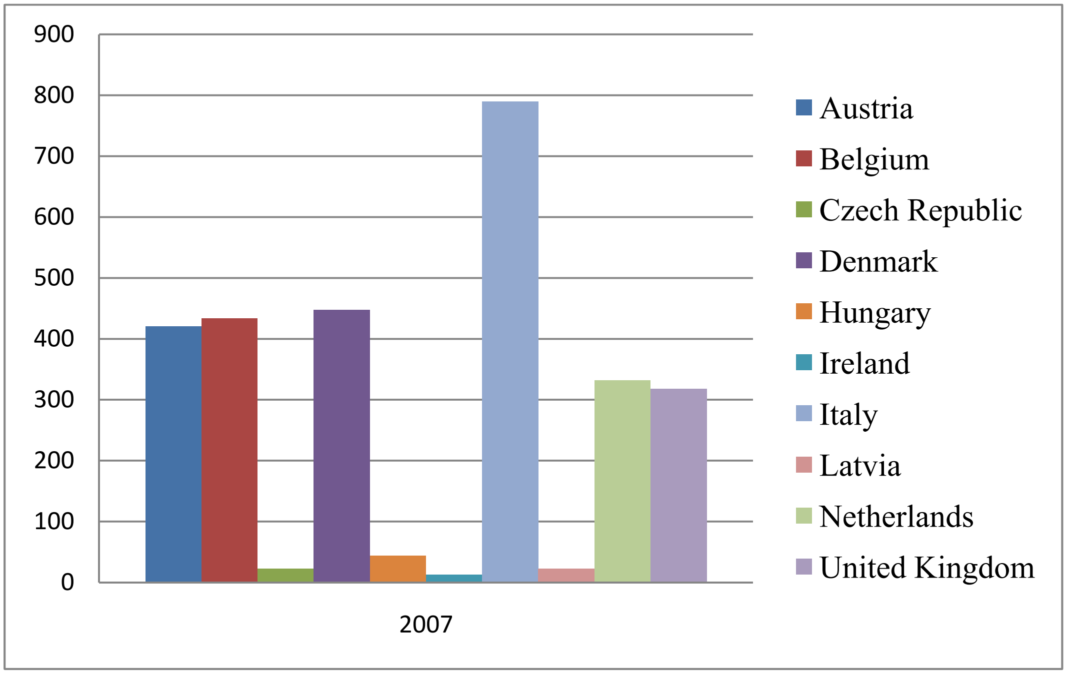

Figure B8. Wood and wood waste importers in 2007 (ktoe)
Source: Eurostat

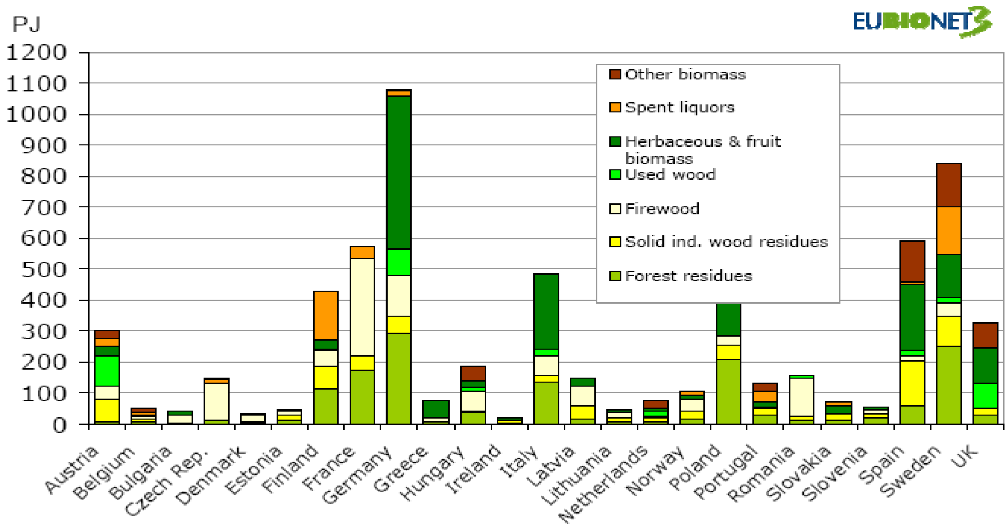

Figure B9. Solid biomass potential in 2006 in EU24 and Norway
Source: Junginger and Alakangas 2010

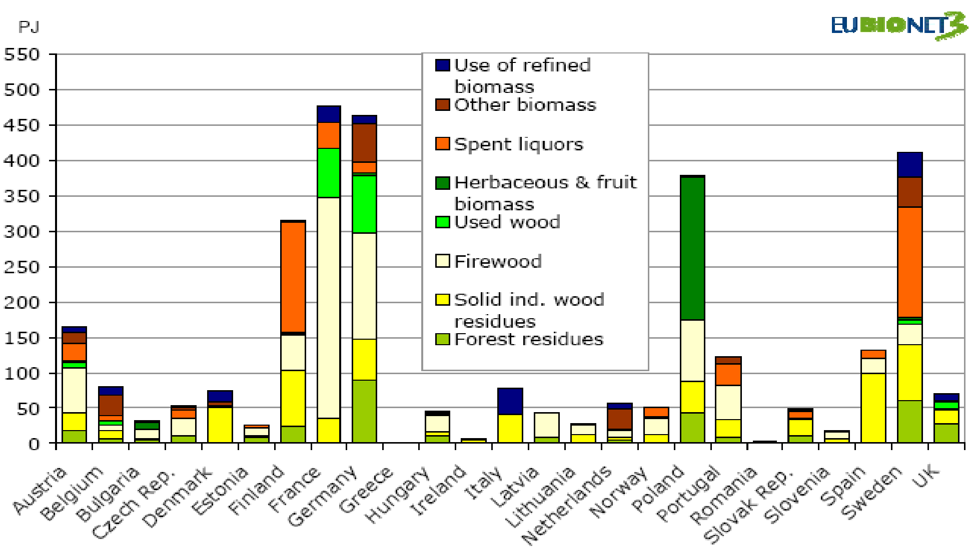

Figure B10. Solid biomass use in 2006 in EU24 and Norway
Source: Junginger and Alakangas 2010

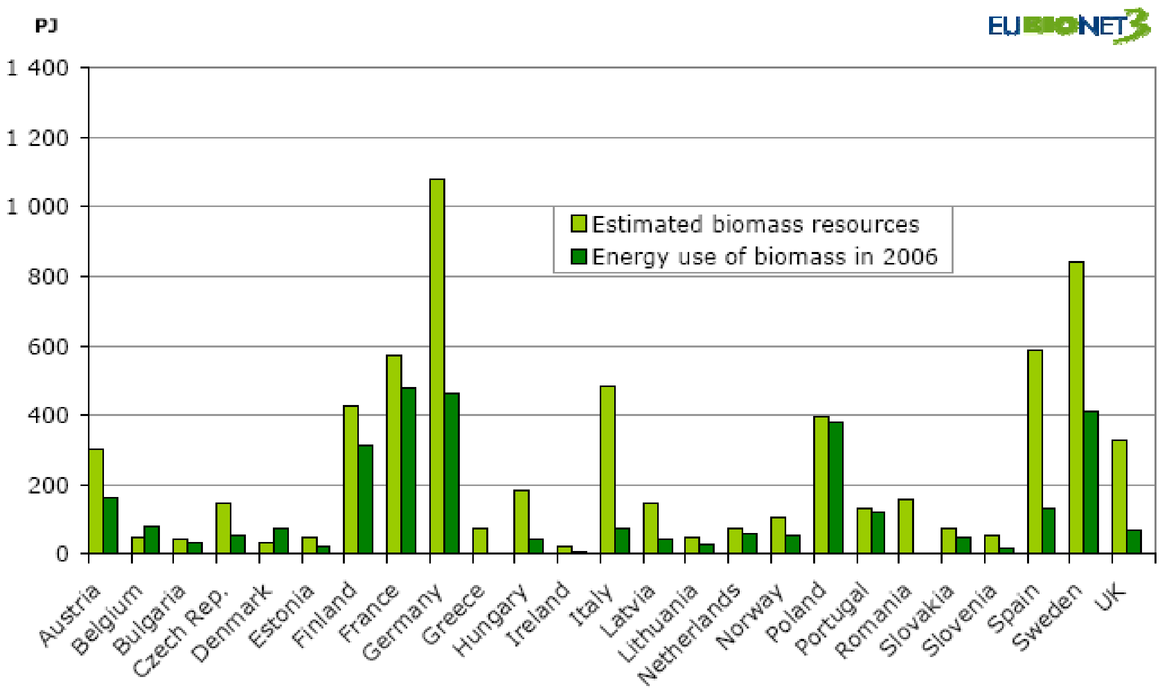

Figure B11. Biomass use compared to resources in different countries
Source: Junginger and Alakangas 2010

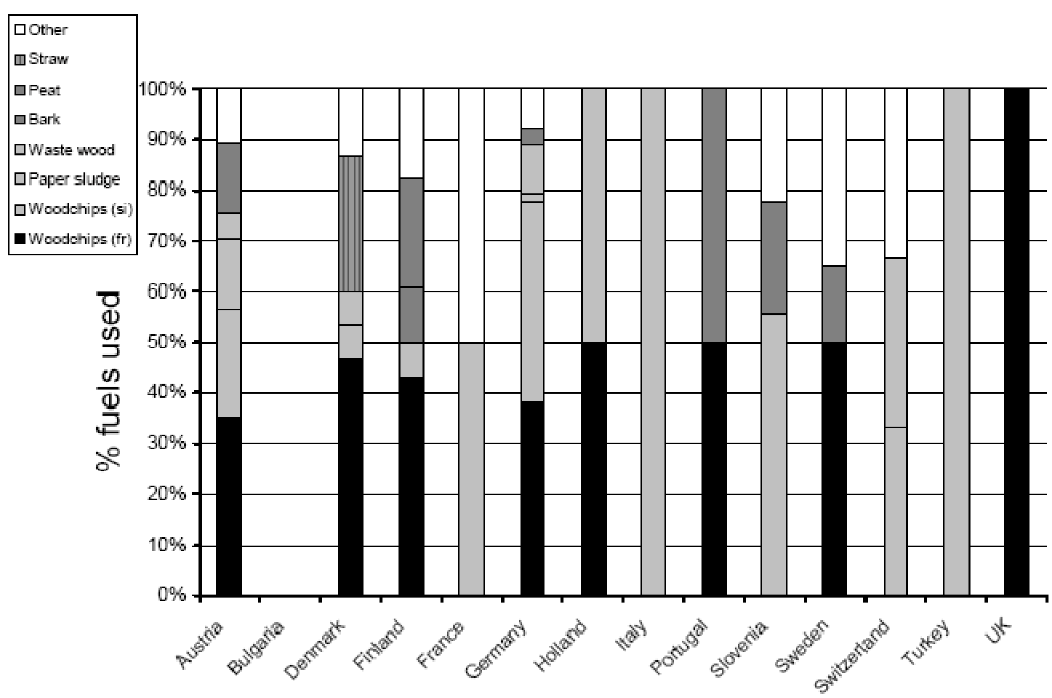

Figure B12. Share of solid biomass fuels in CHP plants
Source: CRES (2003)

	Large scale users (bulk)	Medium scale users (bulk)	Small scale users (bulk)	Small scale users (small bags)
Number of demand players per country	Few, internationally operating electricity companies (e.g. Netherlands 4 power companies having six cofiring units)	E.g. Sweden about 100 district heating plants	Many consumers: E.g. 63,000 boilers in Austria	Many households: E.g. about 700,000 pellet stoves in Italy
Actual storage at end users	Both at harbour (up to 200,000 tonnes) and on-site (up to 10,000 tonnes per plant).	Storage in harbours could be large, up to 10,000 tonnes, like in Sweden. One organization coordinates all pellet purchase. On site less stock volumes needed: up to 500 tonnes	Average annual use for boilers in Austria and Germany is about 6.5 tonnes and storage capacity may range from 1.5 to 15 tonnes	Low, due to contents of small bags (15 to 25 kg) and continual purchase of these bags
Intermediate companies	International traders	Predominantly domestic traders	Domestic traders	Retailers
Suppliers	International pellet production plants	European pellet production plants	Domestic production plants	Domestic production plants
Actual storage at pellet plants	Average 2,500 to 5,000 tonnes per plant			
Typical way of transport	(Inter-) continental shipping (in Panamax or Handymax vessels, freights: 10,000 to 100,000 tonnes)	European sea shipping or lorry transport (delivery rates of 40 tonnes)	Lorry transport (delivery of 1 to 6 tonnes per household per year)	Both lorry transport to retailers and private cars to households
Contracts	Both long term contracts (up to 3 years) and purchase from spotmarkets	Predominantly long term contracts (up to 3 years), plus spotmarkets	Annual deliveries upon request	Infrequent purchase at retailers (15 to 25 kg bags)
Quality requirements	General criteria; company specific	Detailed, strict criteria; country specific standards, like ŐNORM M 7135 and Umweltzeichen 38 (Austria), SS 187120 (Sweden), DINplus (Germany). Critaeria according EN 14961-2 as well as ENplus certificate are about to be implemented		

Figure B13. Overview of major characteristics of European pellet market types
Source: Sikkema et al. (2009)

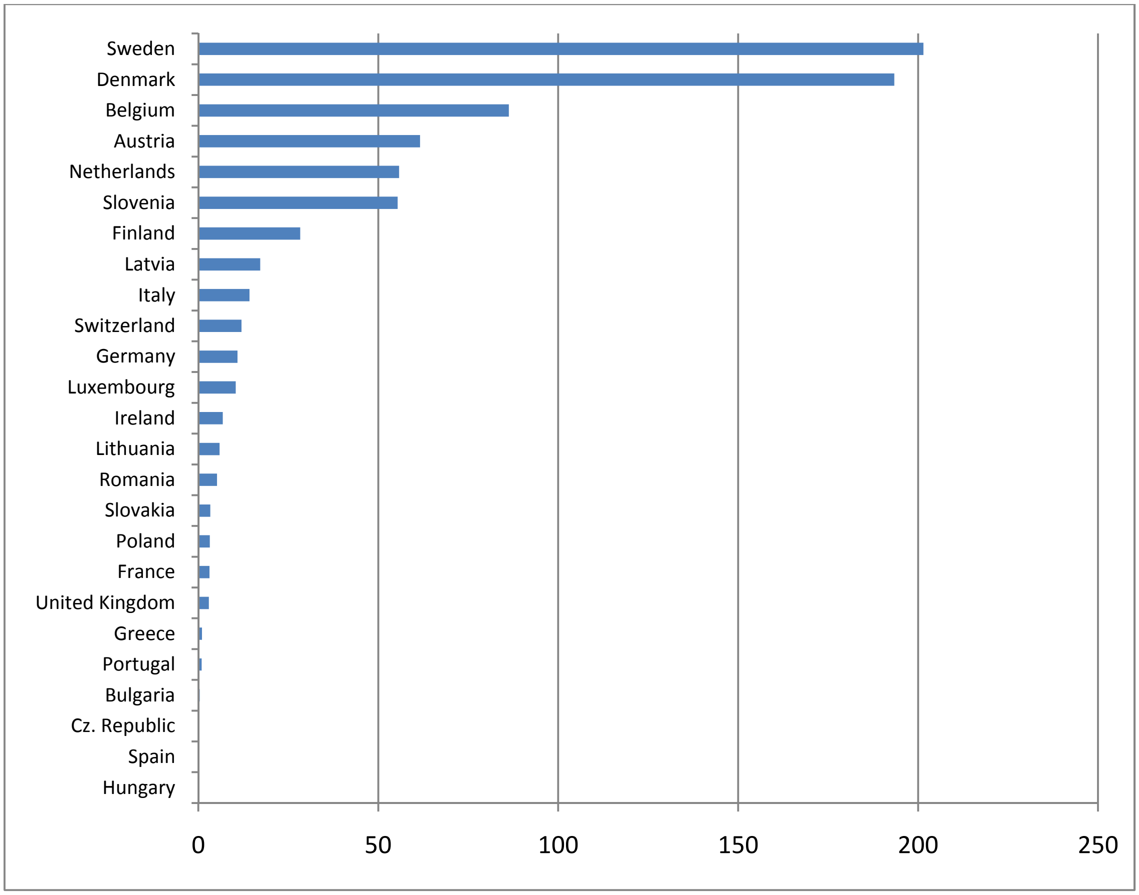

Figure B14. Procapita utilization of pellets in EU (in kg)
Source: Capaccioli and Vivarelli (2009)

**Cyprus, Malta and Estonia have zero values*

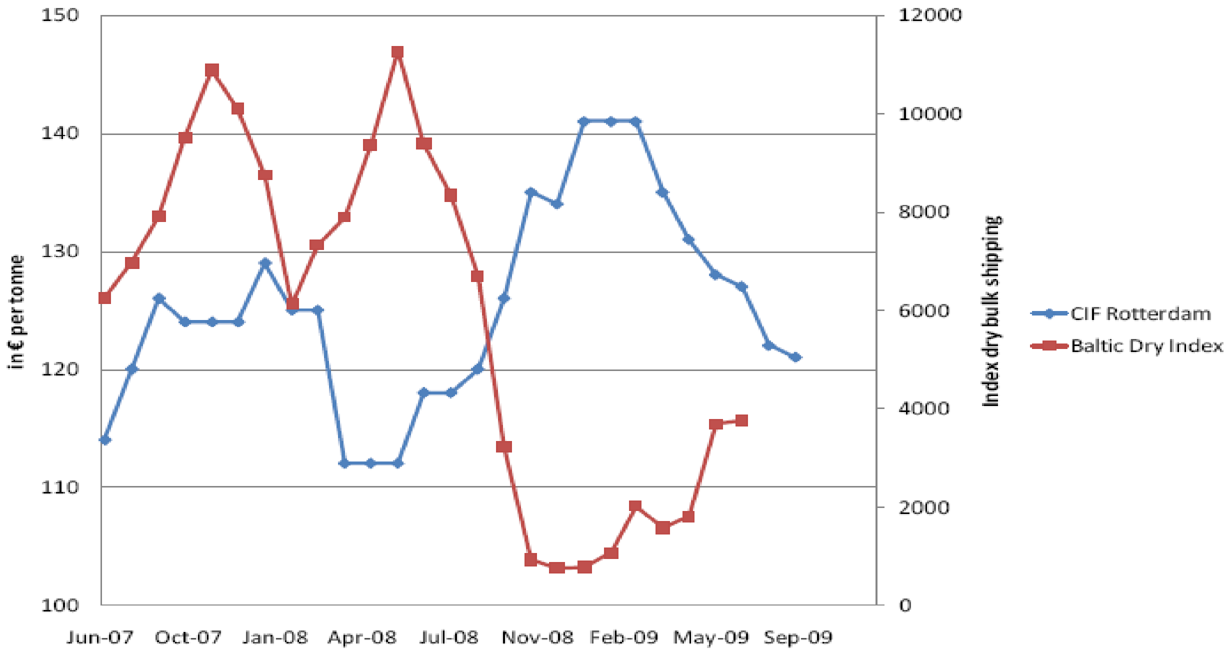

Figure B15. Prices of industrial pellets for power production in EU (CIF ARA, excluding VAT) and Baltic Dry Index for comparison (dry bulk shipping)

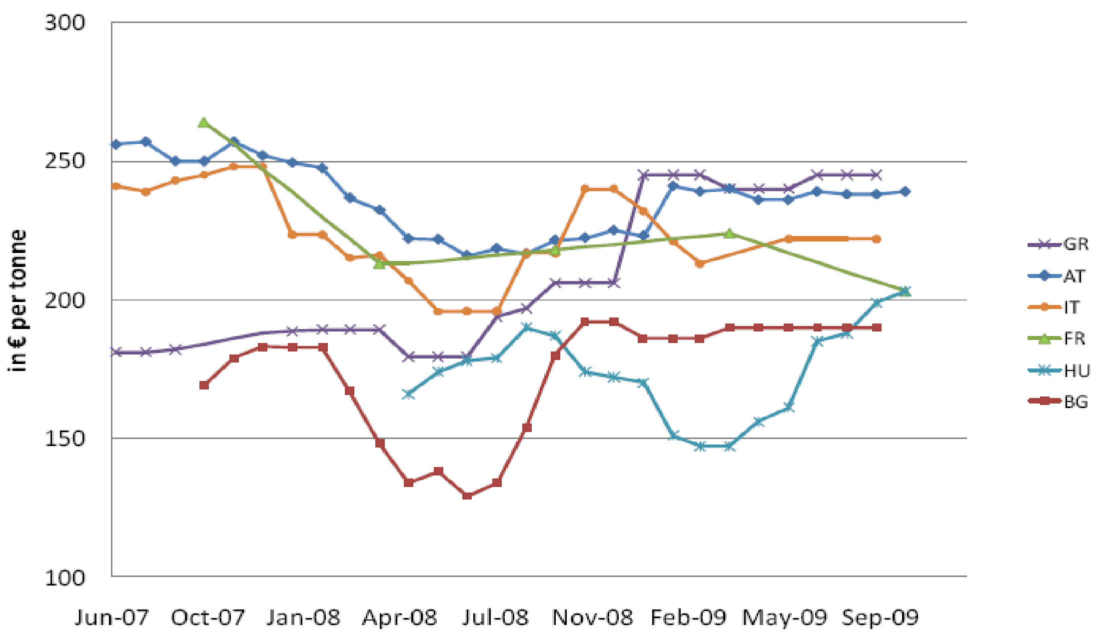

Figure B16. Prices of pellets in bags (<25kg) for residential heating (excluding transportation, including VAT)

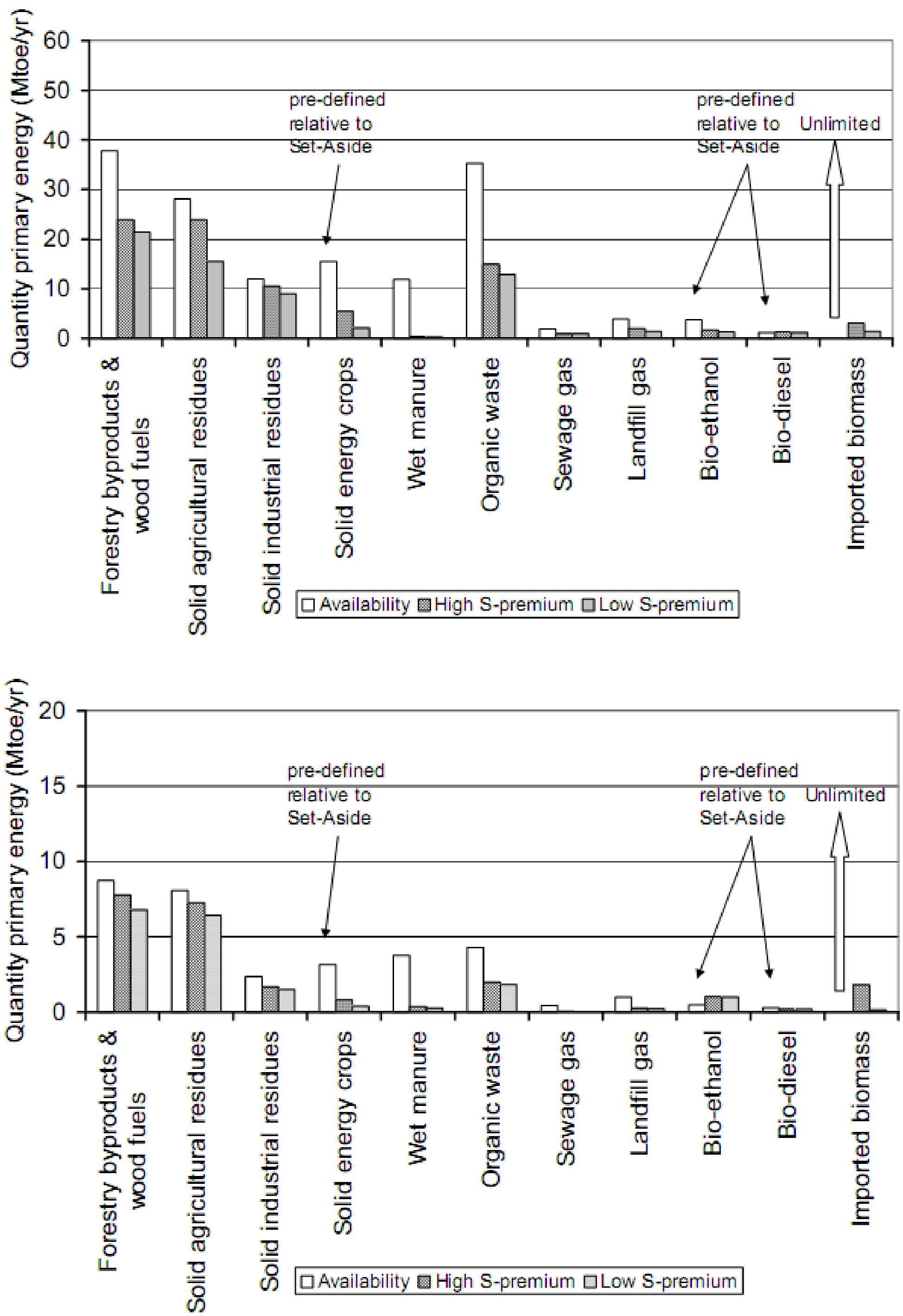

Figure B17. Availability and use of biomass in the EU15 (above) and other member states (below) in the Technology Base Case, in 2010. Source: Siemons et al. (2004)

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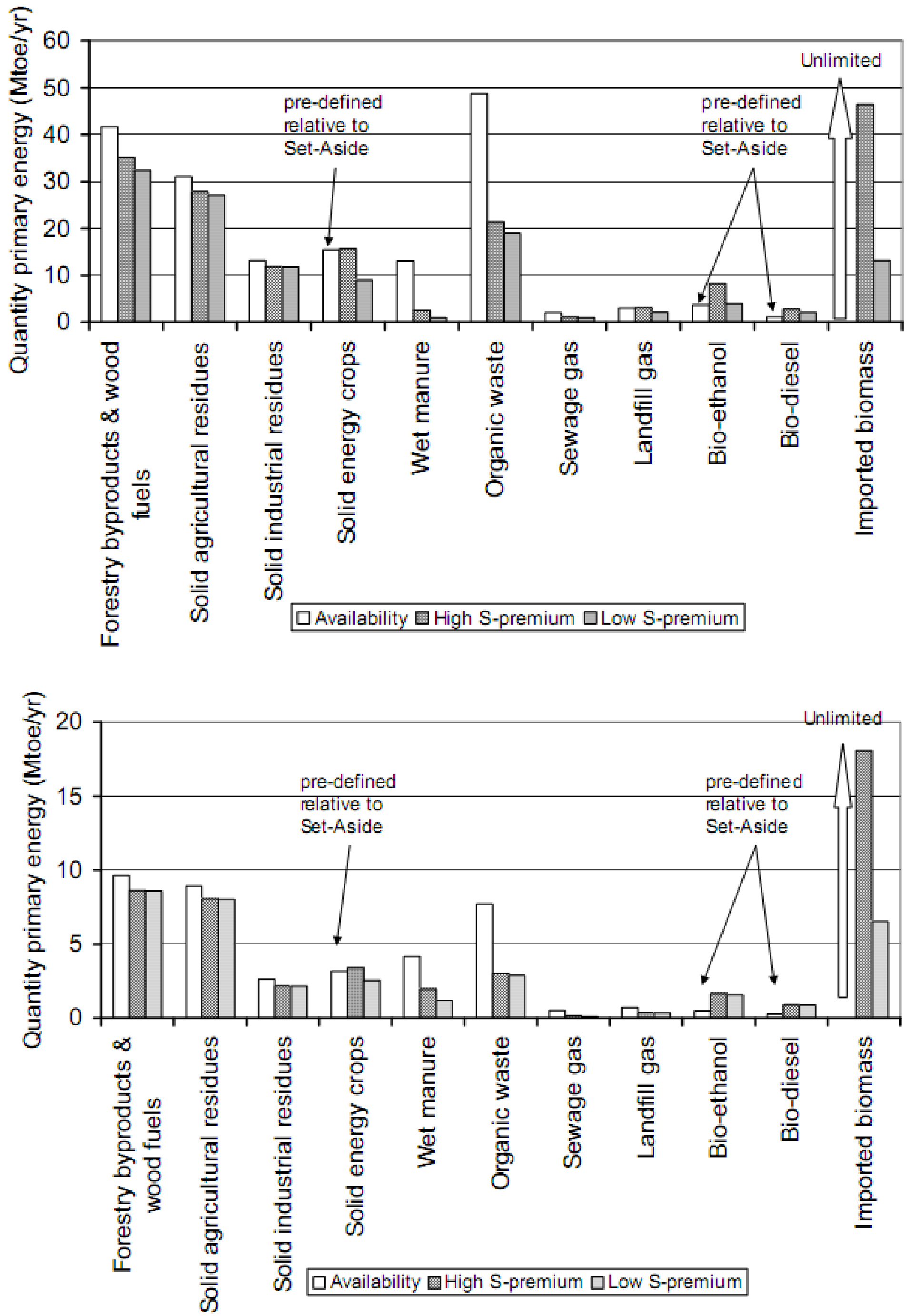

Figure B18. Availability and use of biomass in the EU15 (above) and other member states (below) in the Technology Base Case, in 2020. Source: Siemons et al. (2004)

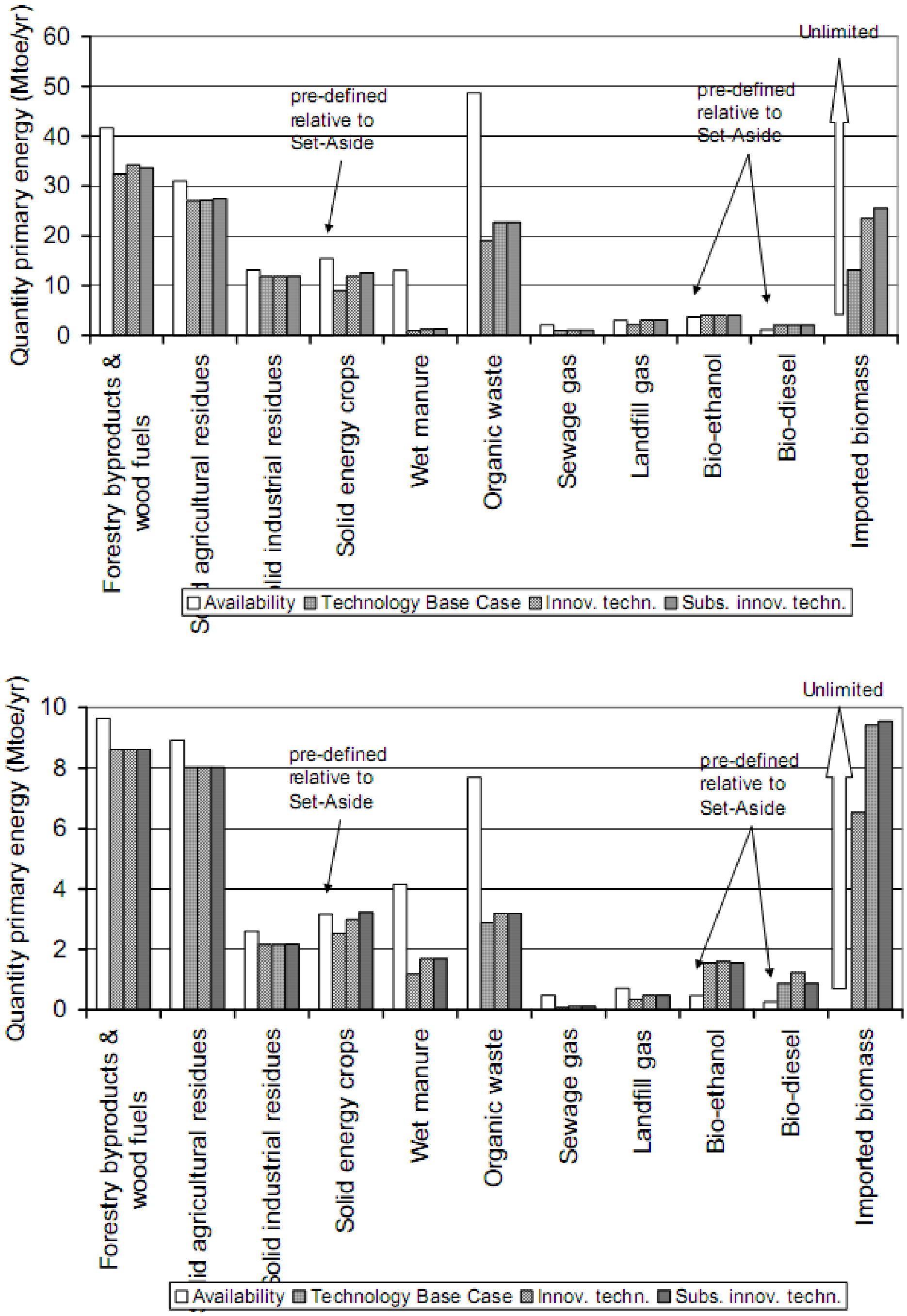

Figure B19. EU15's (above) and other EU members' (below) availability and use of biomass in 2020: Comparing the technology scenarios under the low sustainability premium scenario
Source: Siemons et al. (2004)

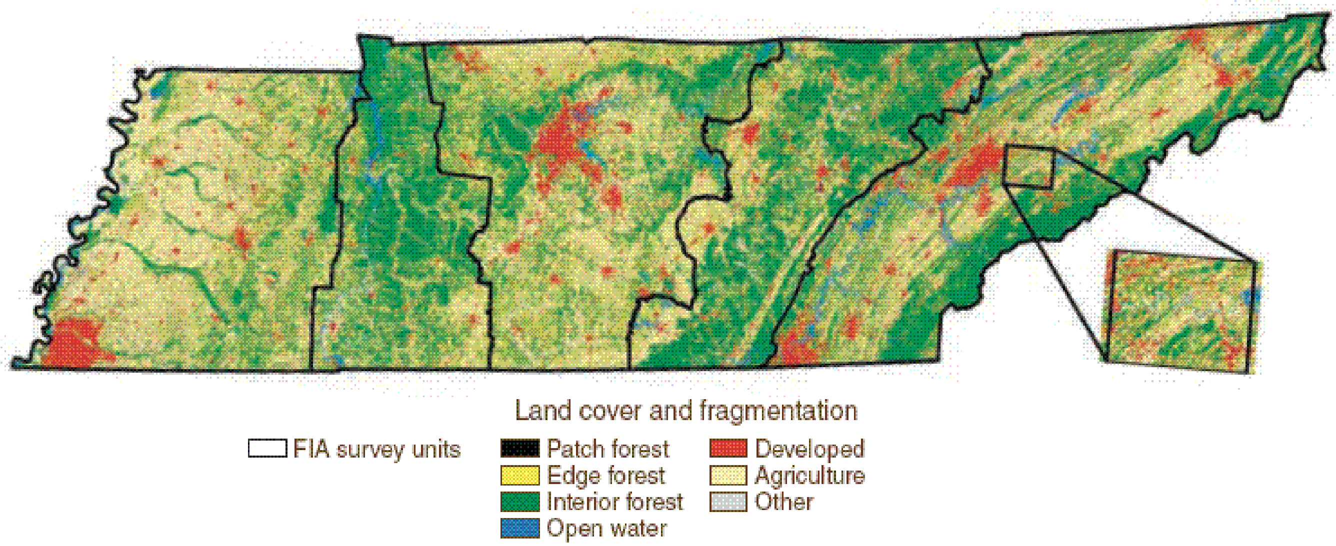

Figure —Landscape classification of land use in Tennessee according to seven land-use categories. Adapted from a moving window analysis (see Riitters and others 2002) of the 2001 National Land Cover Data.

Figure B20. Land cover in Tennessee
Oswalt, C.M. Tennessee's Forests 2004. United States Department of Agriculture. Forest Service (2005)

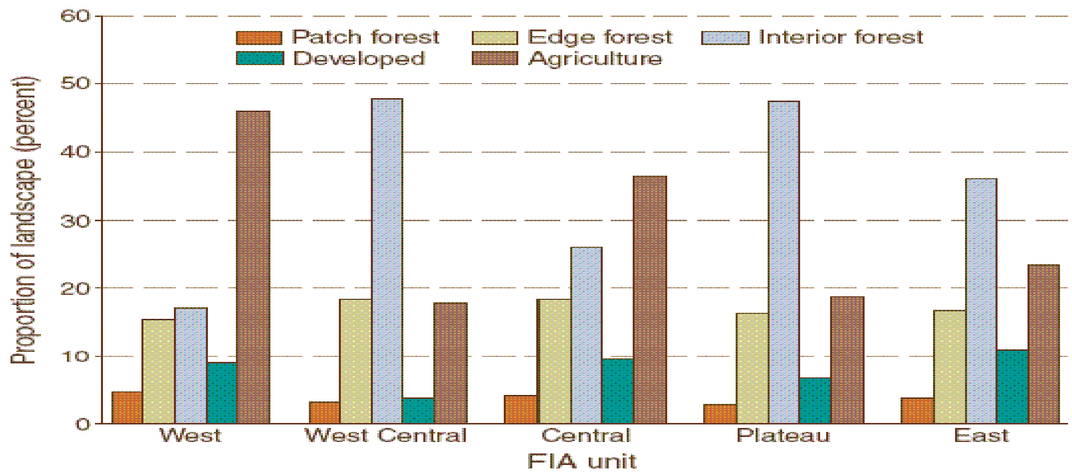

Figure B21. Landscape classification by land use in different parts of Tennessee
Source: Oswalt, C.M. Tennessee's Forests 2004. United States Department of Agriculture. Forest Service (2005)

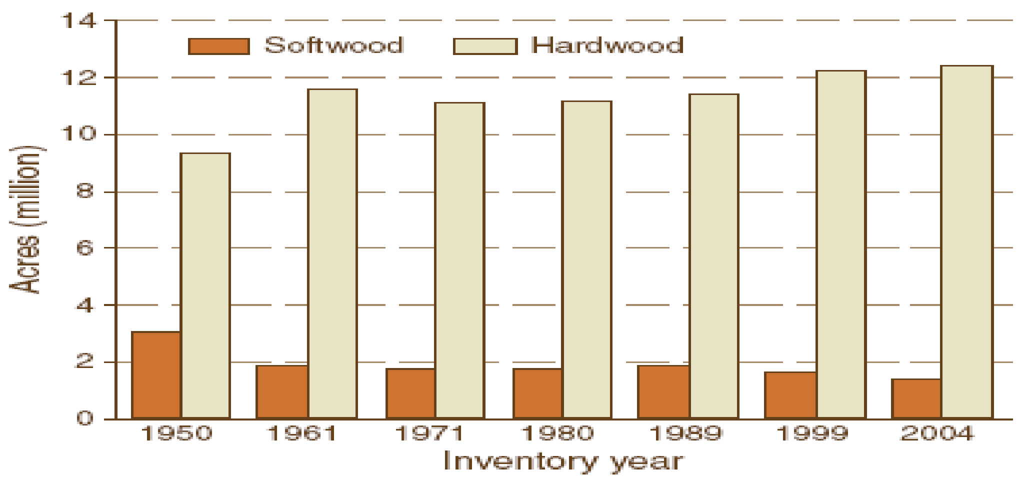

Figure B22. Major forest type groups for Tennessee (1950-2004)
Source: Oswalt, C.M. Tennessee's Forests 2004

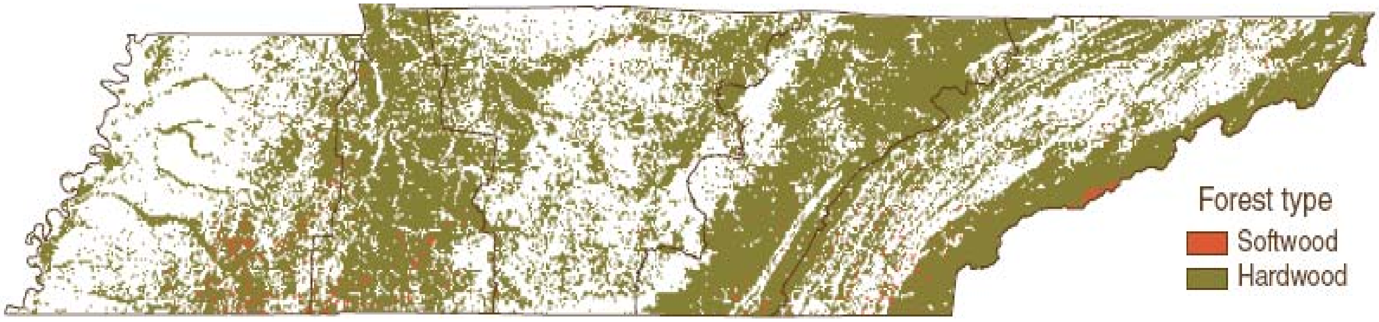

Figure B23. Distribution of hardwood and softwood forest types in Tennessee (Adopted from 2001 National land cover data)
Source: Oswalt, C.M. Tennessee's Forests 2004

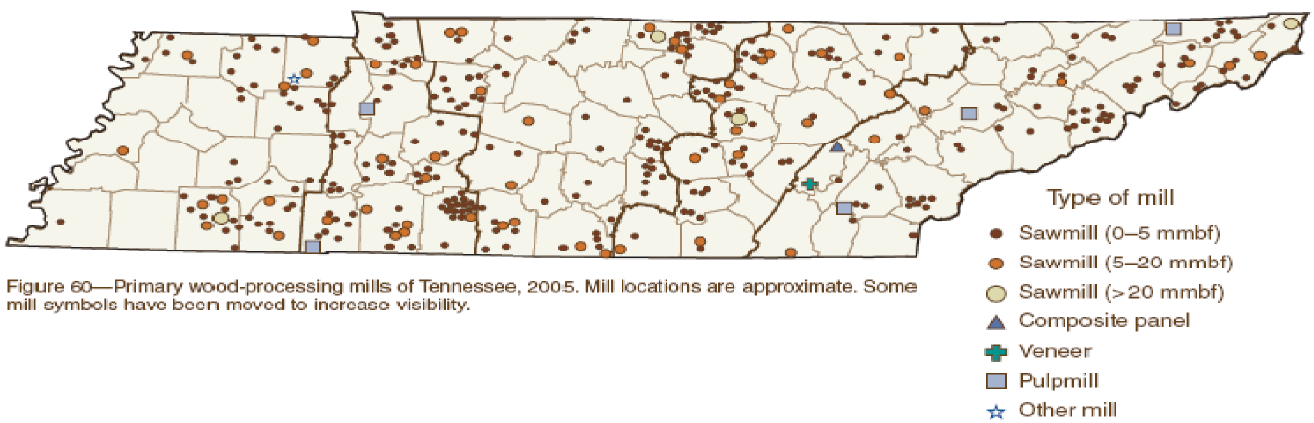

Figure B24. Primary wood-processing mills of Tennessee
Source: Oswalt, 2004.

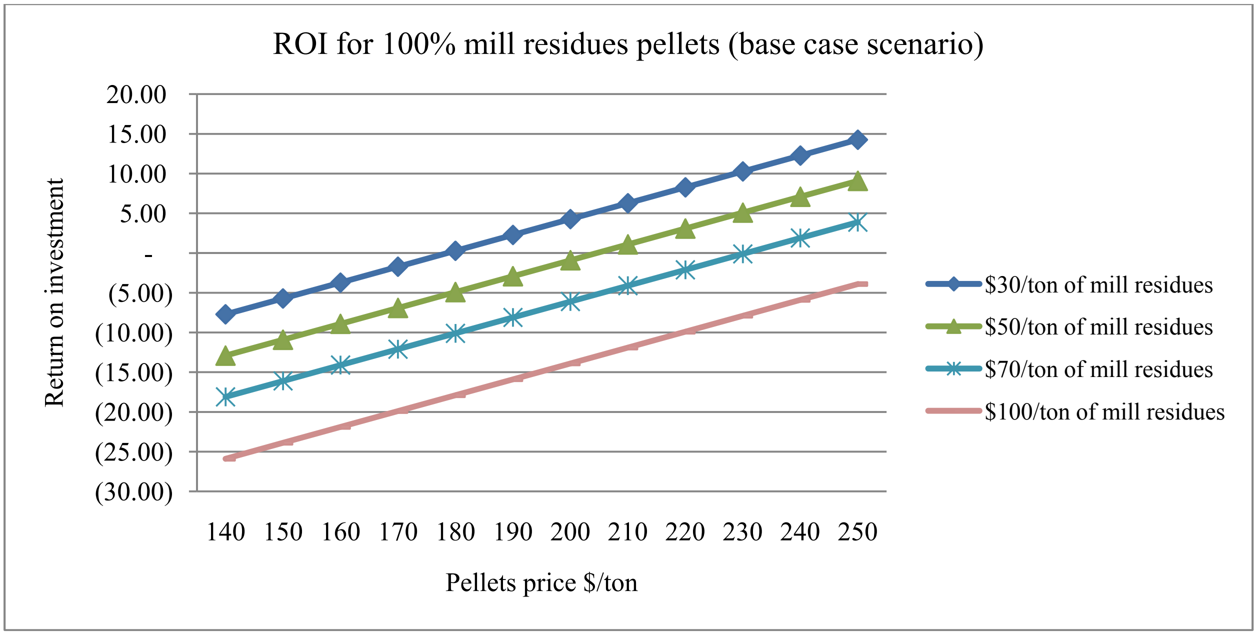

Figure B25. ROI for 100% mill residue scenario for different feedstock and pellet prices (all other parameters constant)

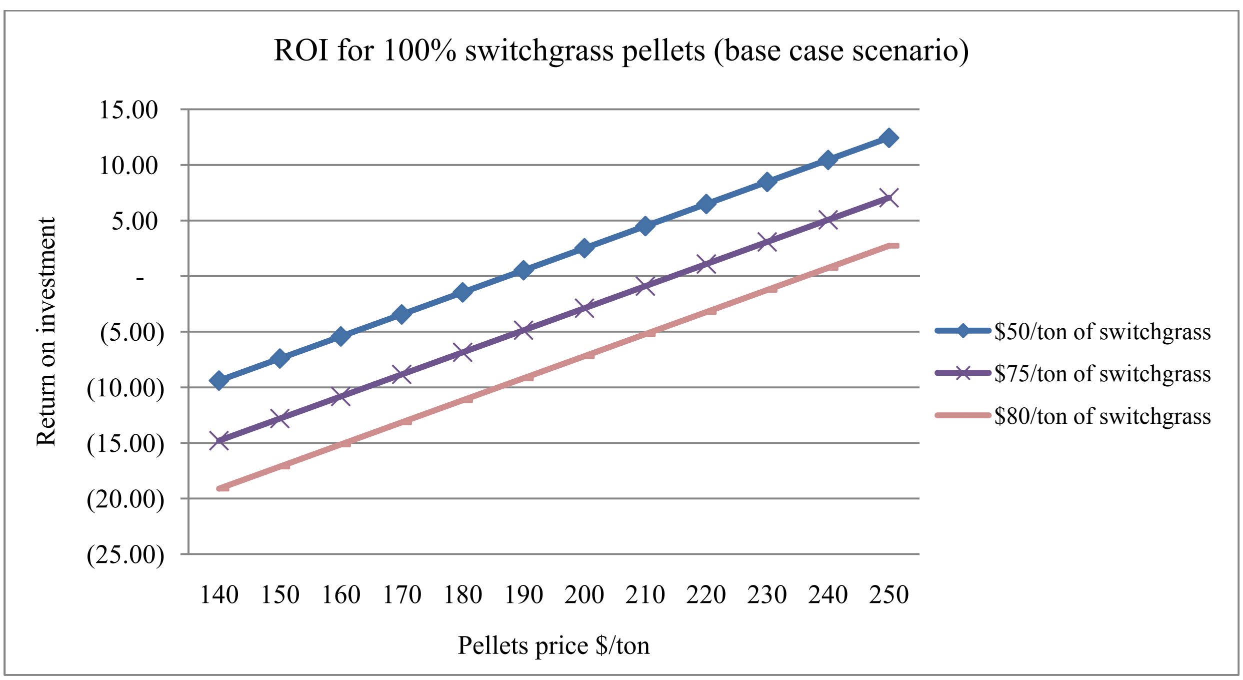

Figure B26. ROI for 100% switchgrass scenario for different feedstock and pellet prices (all other parameters constant)

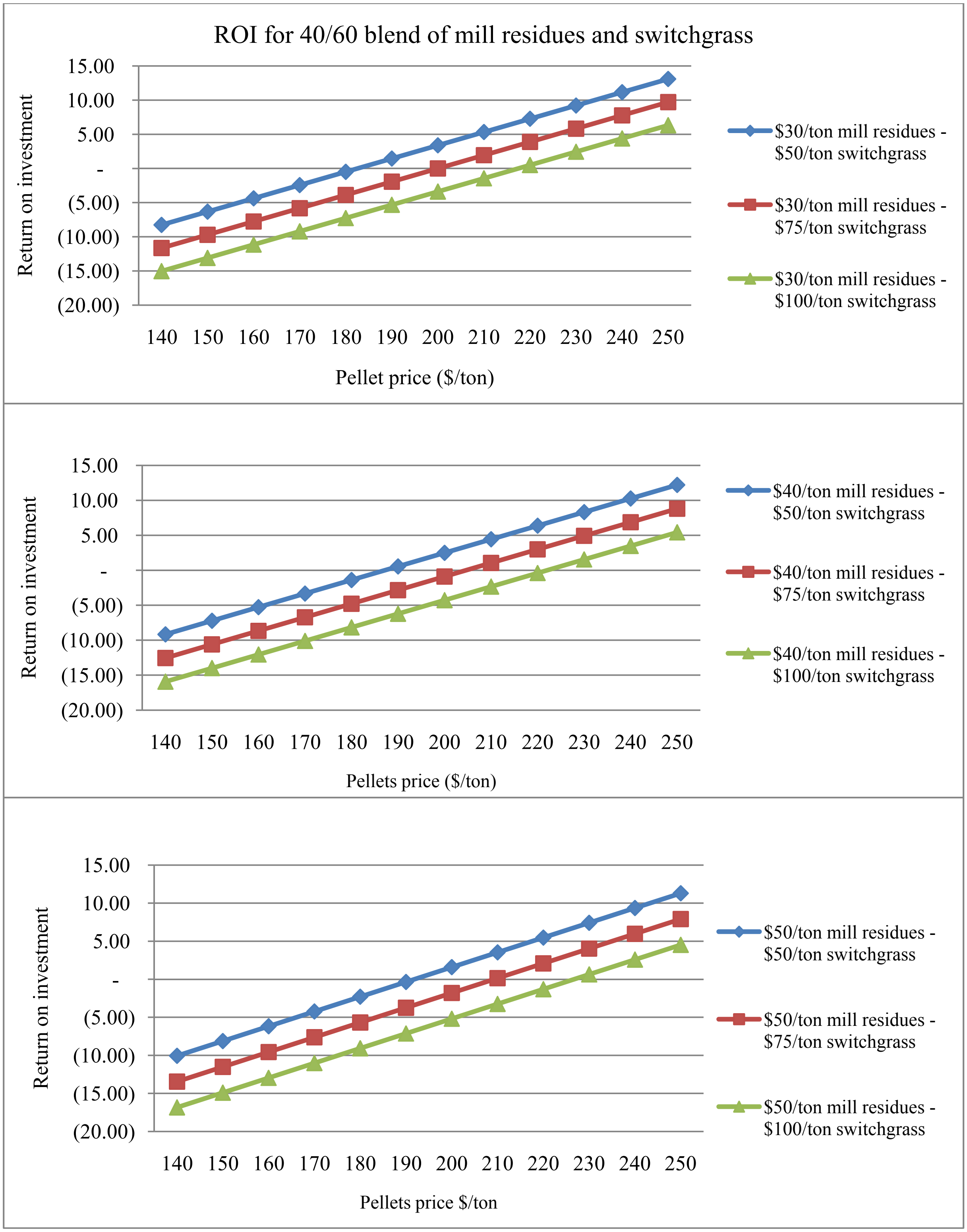

Figure B27. ROI for 40/60 blend scenario for different feedstock and pellet prices (all other parameters constant)

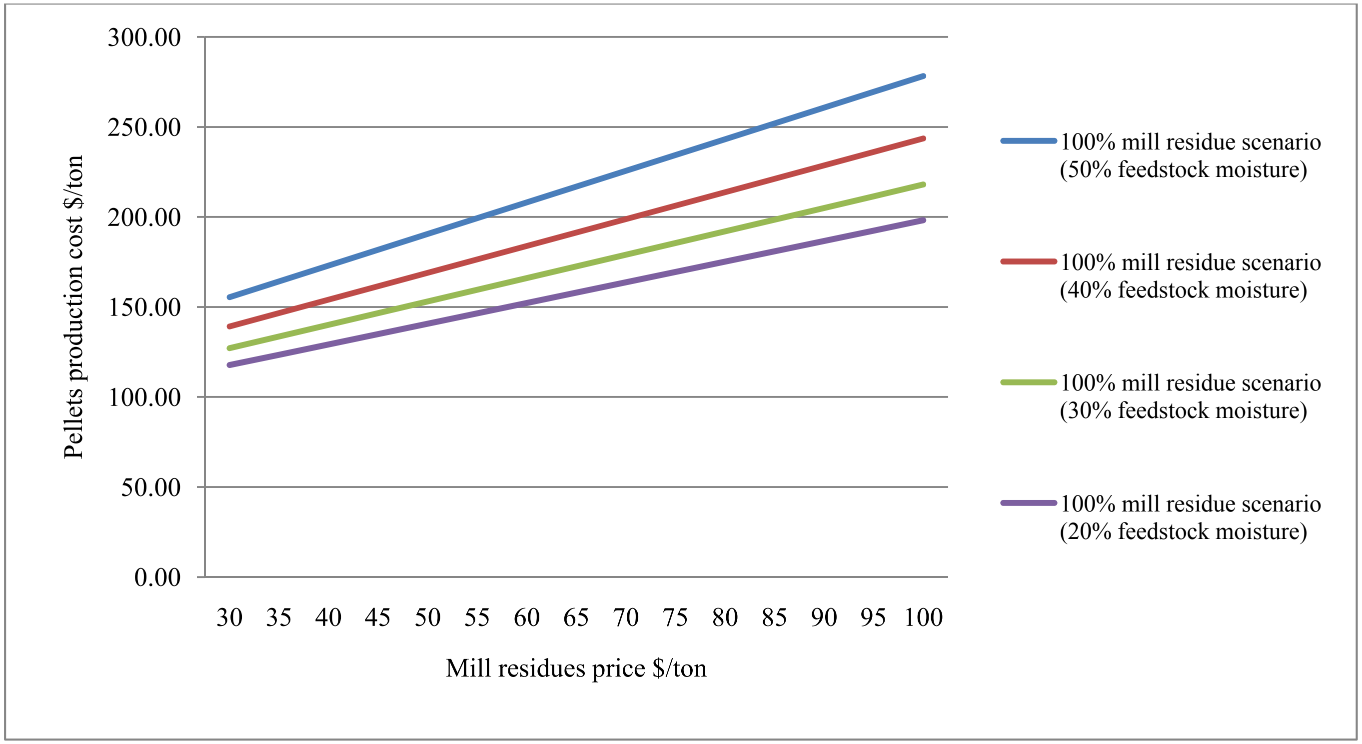

Figure B28. Impact of mill residues price change on pellets production cost for different feedstock moisture

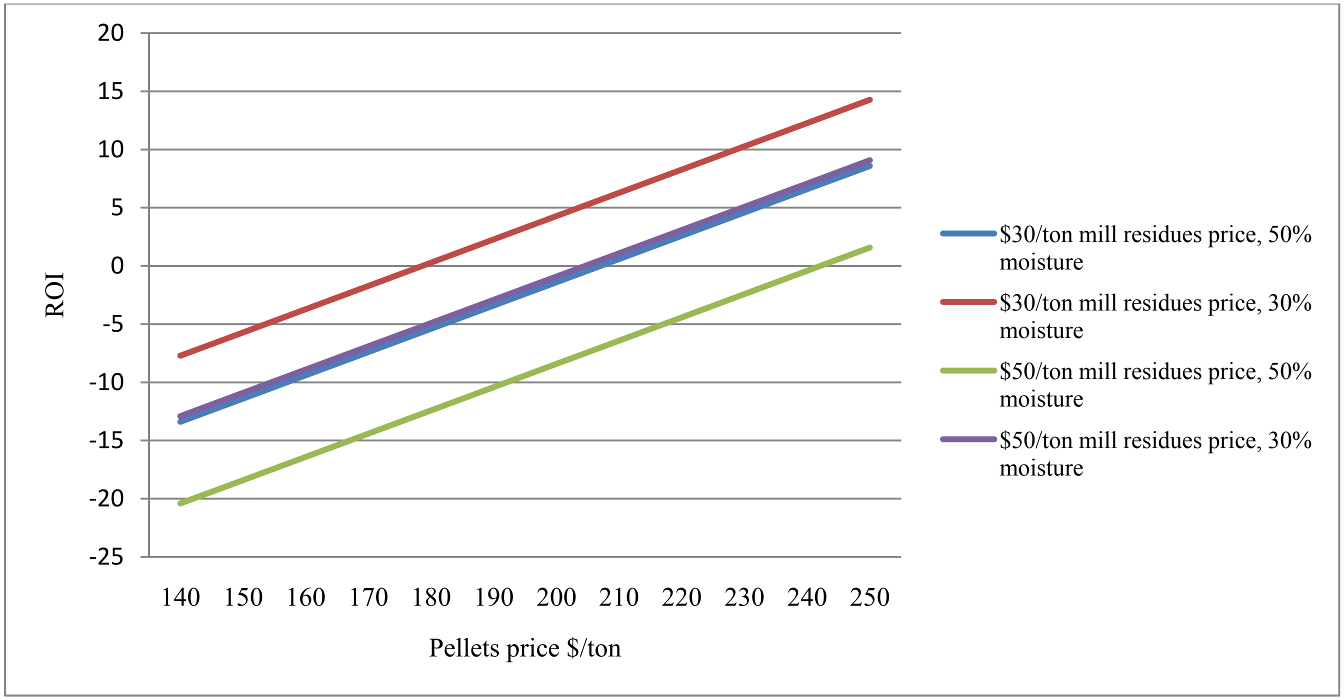

Figure B29. ROI for 100% mill residue scenario for different feedstock prices and moisture

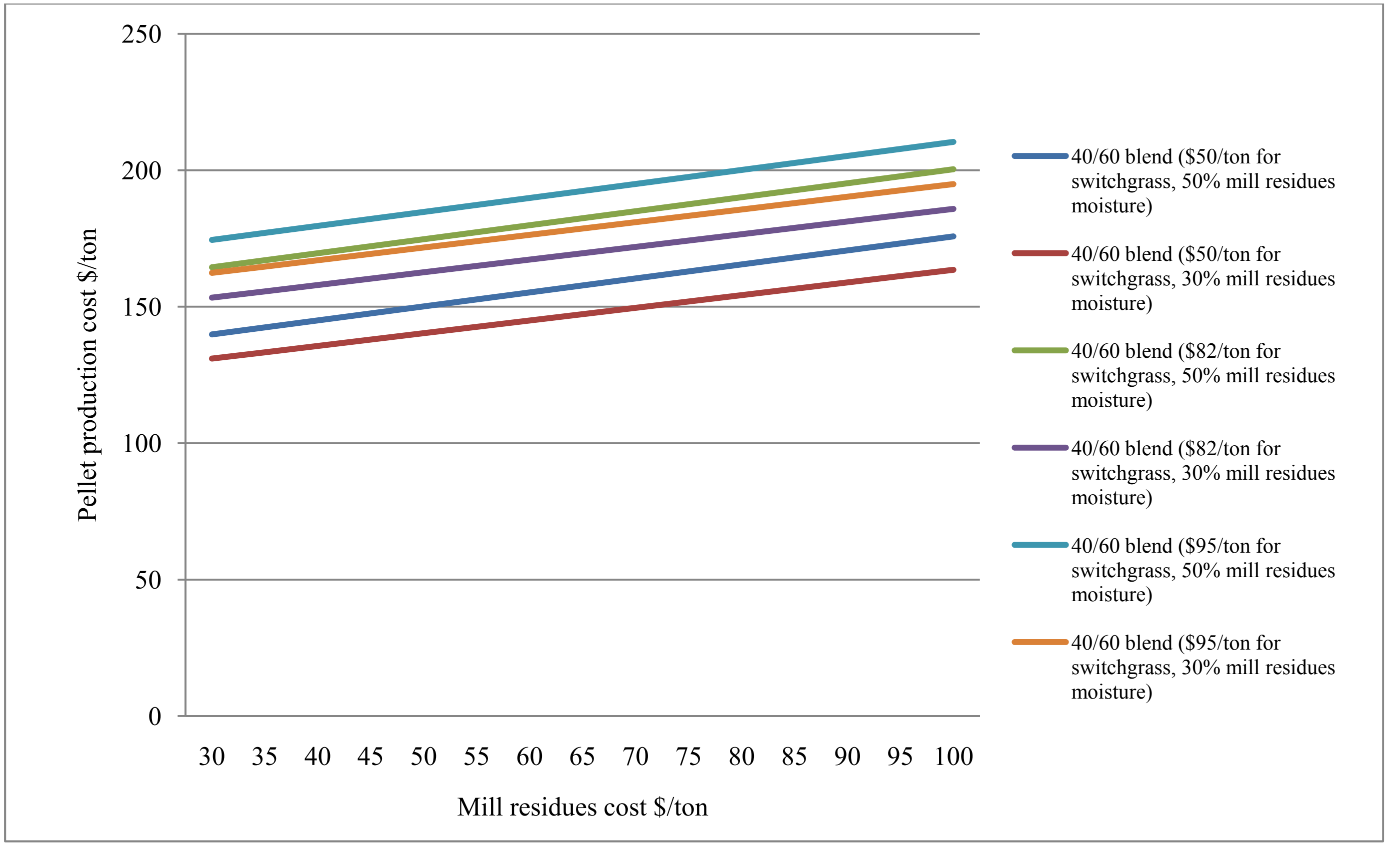

Figure B30. Impact of mill residues price change on pellets production cost in 40/60 blend scenario, for different switchgrass cost and mill residues' moisture levels

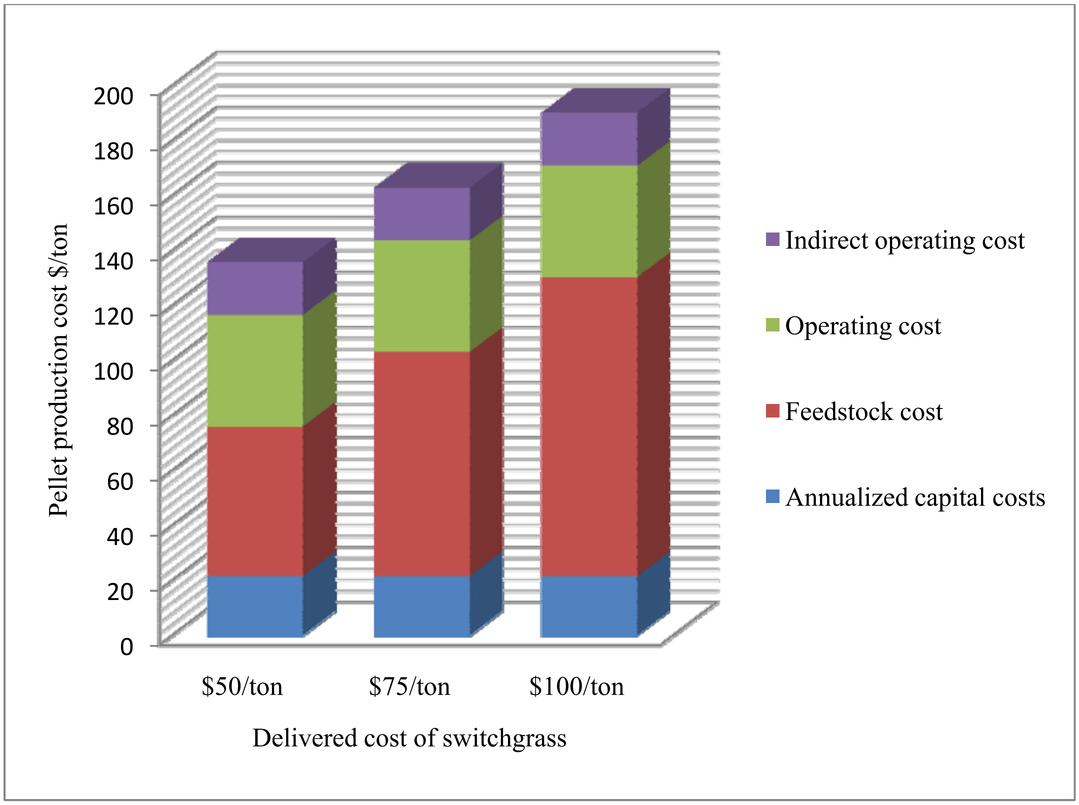

Figure B31. Impact of switchgrass' price change on production cost of pellets

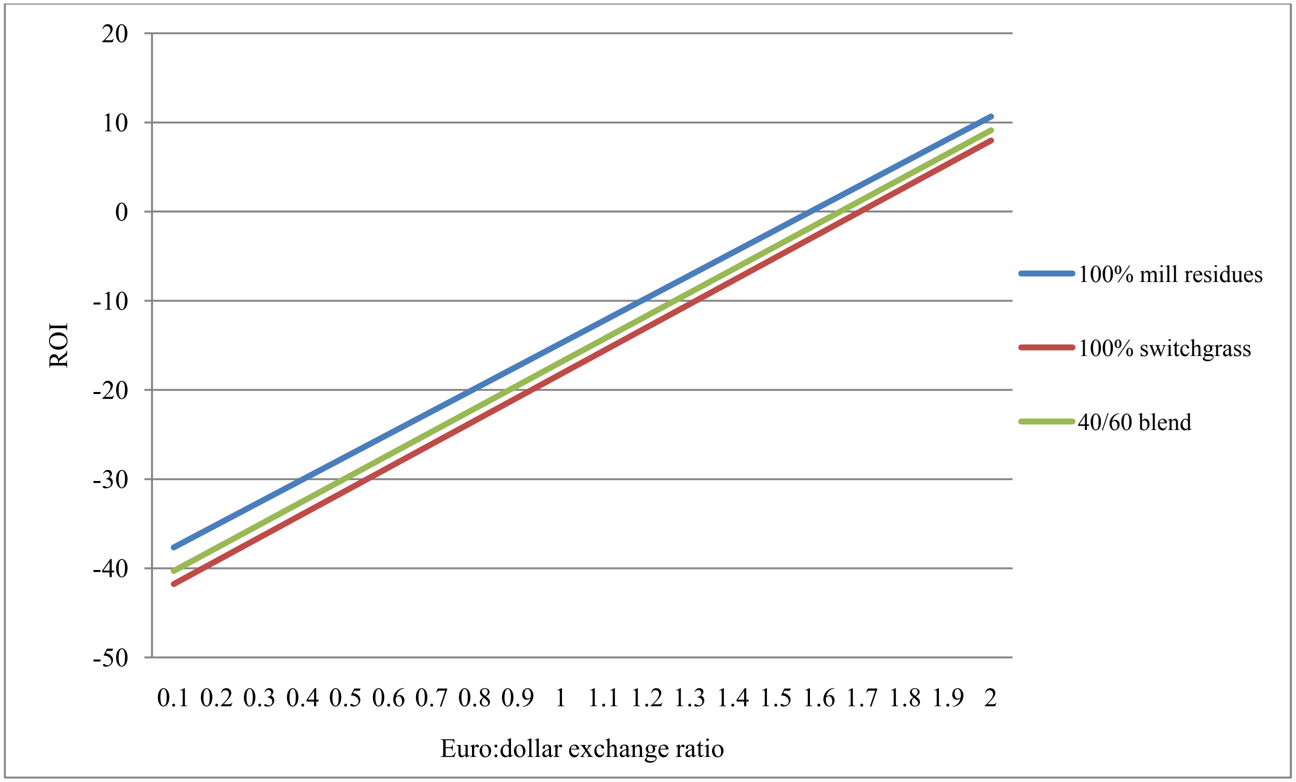

Figure B32. Impact of euro-dollar exchange ratio on ROI (all other model parameters constant)

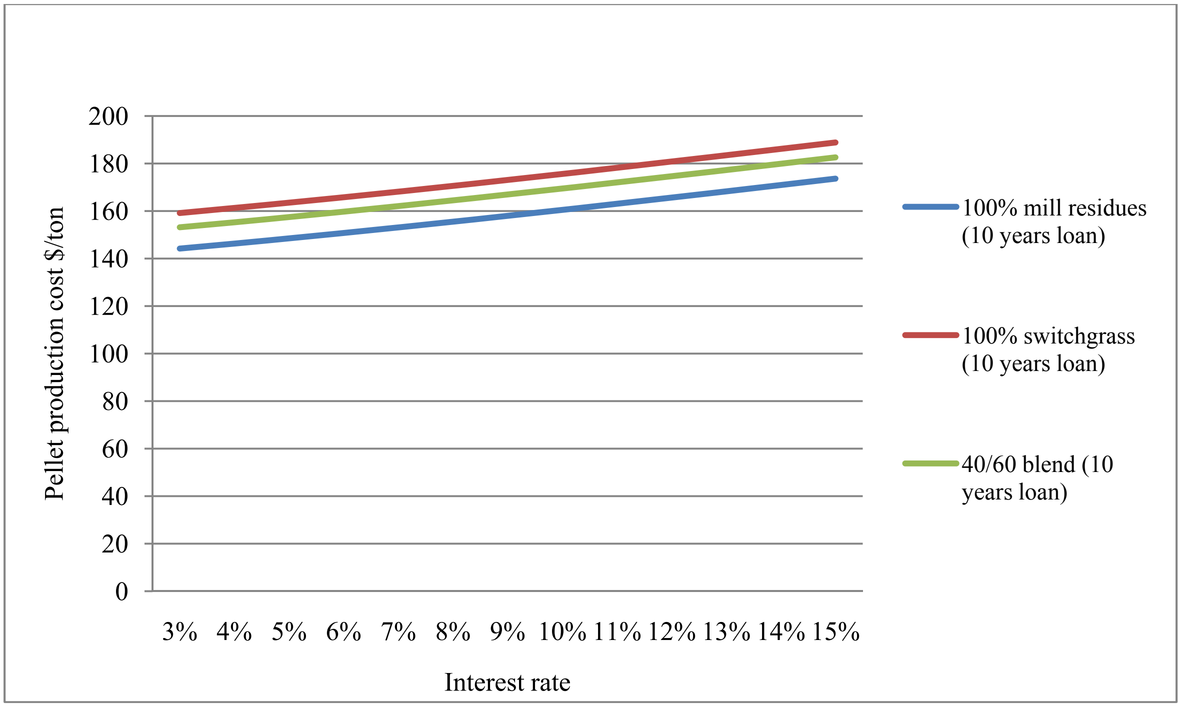

Figure B33. Impact of interest rate change on production cost of pellets assuming 10 annual payments of loan (assuming other base case model parameters constant)

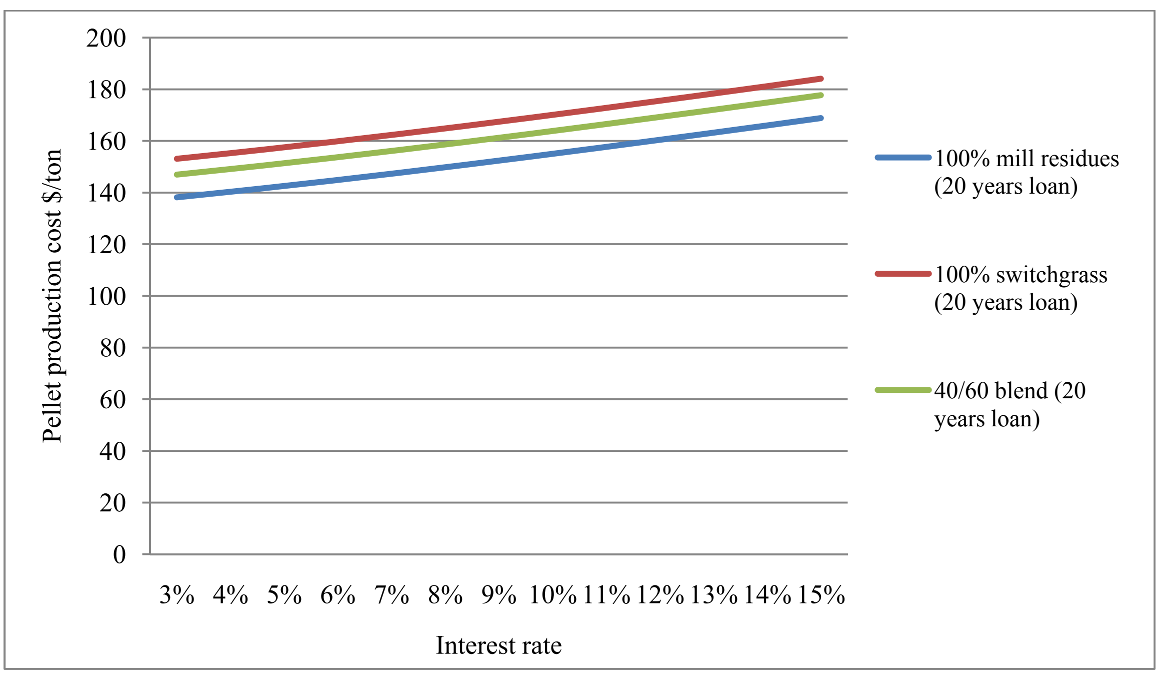

Figure B34. Impact of interest rate change on production cost of pellets assuming 20 annual payments of loan (assuming other base case model parameters constant)

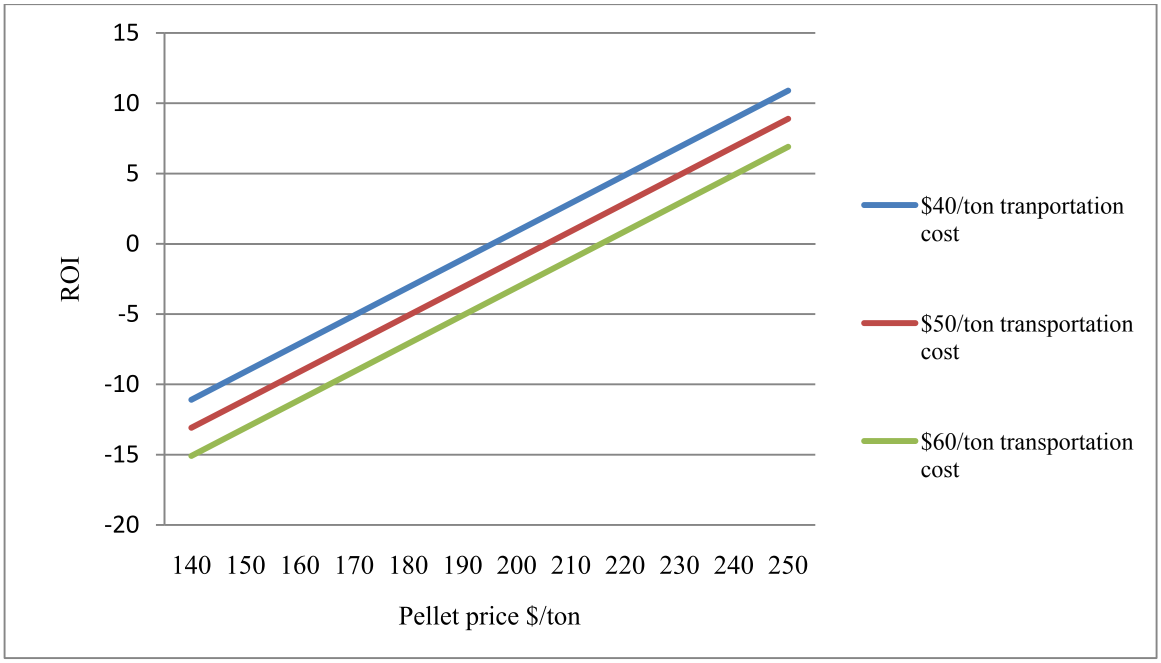

Figure B35. Transportation cost change influence on ROI for 100% mill residues scenario, assuming all other parameters constant

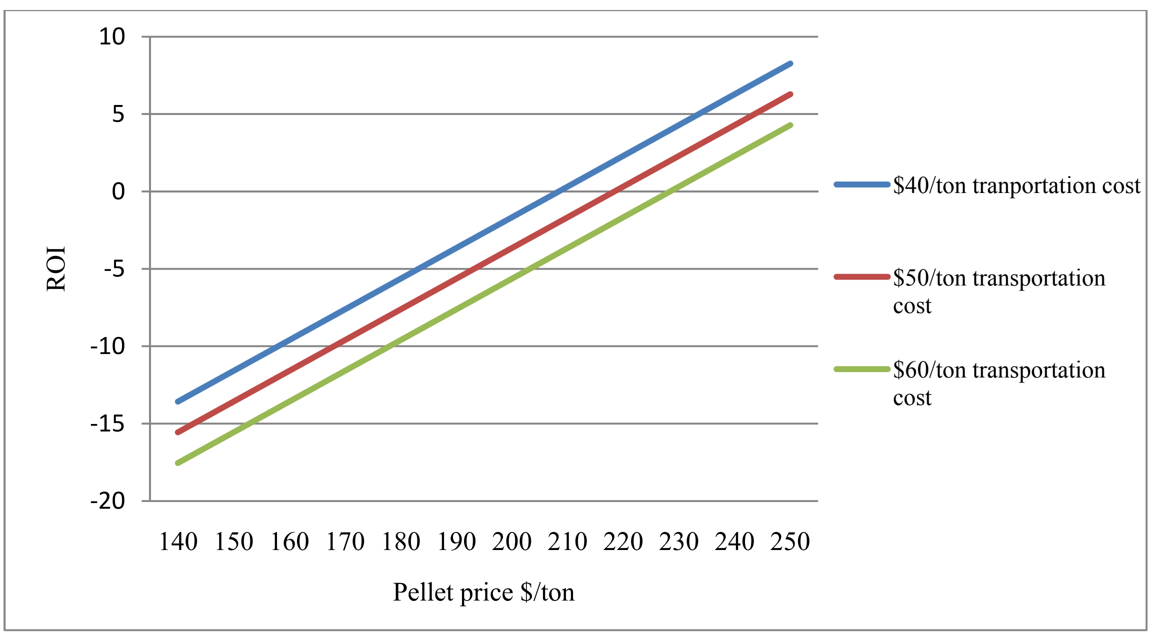

Figure B36. Transportation cost change influence on ROI for 100% switchgrass residues scenario, assuming all other parameters constant

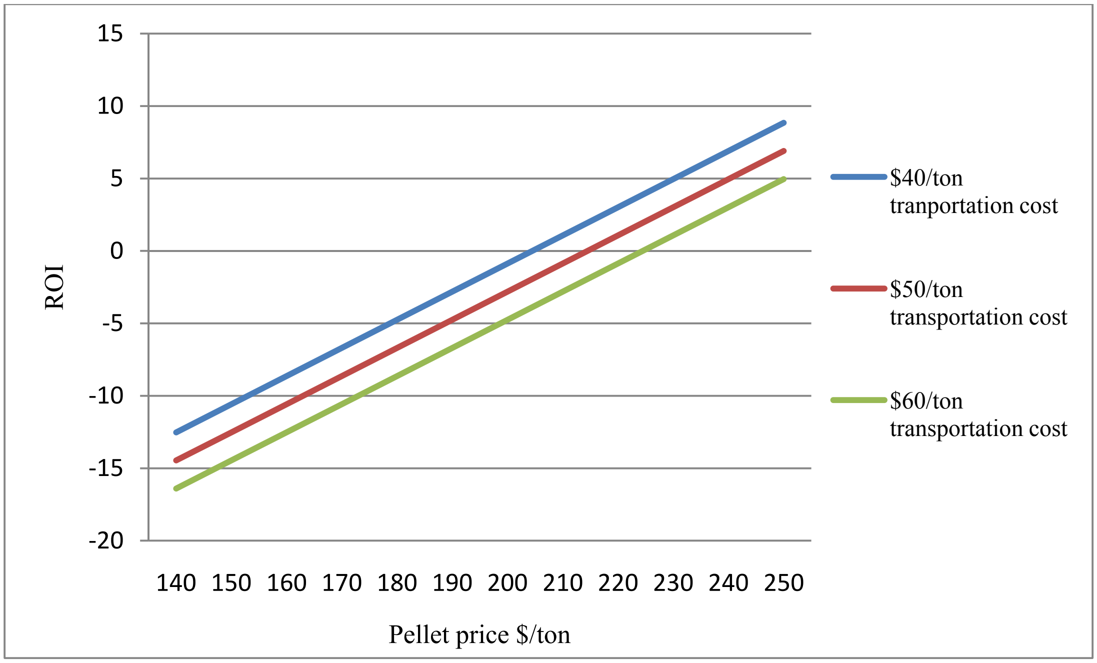

Figure B37. Transportation cost change influence on ROI for 40/60 blend scenario, assuming all other parameters constant

APPENDIX C

Policy Framework

Table C1 Policy framework for development of RES in EU

Date	Reference	Type of policy	Title	Objective	Action
26.11.1997	COM(97)599	Communication from the EC	White Paper for a Community Strategy and Action Plan	Contribute to the achievement of the overall energy policy objectives: - security of supply - environment and competitiveness, - environment protection and sustainable development	Double the contribution of RES to the EU gross inland consumption from 6% to 12% by 2010 Comprehensive strategy and action plan setting out the means to reach this objective
13.10.1998	Directive 98/70/EC	Directive of the European Parliament and of the Council	Relating to the quality of petrol and diesel fuels	Establishes limits on the content of ethanol, ether and other oxygenates in petrol Limits the vapor pressure of petrol	Standard EN590 states that diesel must contain no more than 5% by volume (4.6% in energy terms)
29.11.2000	COM(2000) 769 final		Green Paper on the security of supply		Target of 20% substitution of conventional fuels by alternatives such as biofuels, natural gas and hydrogen by 2020
27.09.2001	Directive 2001/77/EC	Directive of the European Parliament and of the Council	Promotion of electricity produced from renewable energy sources in the internal electricity market	Sets out to create a framework that will facilitate, in the medium term, a significant increase in renewable generated electricity within the EU	Sets a target of 22.1% of renewable electricity in the overall electricity consumption Sets national targets for consumption of electricity from renewable sources of energy Requires member states to take the necessary measures to grant guaranteed access to the transmission and distribution of electricity from RES Guarantee of origin of RES-E
16.12.2002	Directive 2002/92/EC	Directive of the European Parliament and of the Council	Energy performances of buildings	Improvement of energy performance of buildings within the EU through cost-effective measures.	To realize a savings potential of around 22% by 2010 for energy used in heating, air conditioning, hot water and lighting.
8.05.2003	Directive 2003/30/EC	Directive of the European Parliament and of the Council	Promotion of the use of biofuels or other renewable fuels transport	Calls for an increased use of alternative fuels and requires member states to place a proportion of biofuels and other renewable fuels on their market	2% market share (in a volume basis) of all petrol and diesel for transport by 2005 5.75% market share (in a volume basis) of all petrol and diesel for transport by 2010

Table C1 Continued

Date	Reference	Type of policy	Title	Objective	Action
3.08.2003	Directive 2003/17/EC	Directive of the European Parliament and of the Council	Amending the directive 98/70/EC relating to the quality of petrol and diesel fuels		Changed the sulphur limits for petrol and diesel set in the previous directive
27.10.2003	Directive 2003/96/EC	Directive of the European Parliament and of the Council	Restructuring the Community framework for the taxation of energy products and electricit		Allows member states to exempt or reduce excise duties in order to promote biofuels promotion and use
07.12.2005	COM(2005) 628 final	Communication from the European Commissio	Biomass Action Plan	Sets out measures to increase the development of biomass energy from wood, wastes and agricultural crops by creating market-based incentives to its use and removing barriers to the development of the market	Possible revision of the 2003 Directive Propose amendments to the " biodiesel standard" Assessment of the energy crop scheme Amendment of the directive on energy performance of buildings
08.02.2006	COM(2006) 34 final	Communication from the EC	An EU strategy for biofuels	Promote biofuels in the EU and developing countries Prepare for the large scale of biofuels by improving their cost-competitiveness, R&D in second generation etc. Explore the opportunities for developing countries for the production of biofuels feedstock	Stimulating the demand for biofuels Capturing environmental benefits Developing the production and distribution of biofuels Expanding biofuels supplies Expanding trade opportunities Supporting developing countries Supporting R&D
10.01.2007	COM(2006) 848 final	Communication from the Commission to the Council and the European Parliament	Renewable Energy Road Map – Renewable energies in the 21st century: building a more sustainable future	Sets out a long term vision for renewable energy in the EU	Mandatory (legally binding) target of 20% for renewable energy's share of energy consumption by 2020 Legal binding minimum target of 10% for biofuels in 2020 Propose the appropriate modifications to the fuel quality directive (98/70/EC)

Table C1 Continued

Date	Reference	Type of policy	Title	Objective	Action
31.01.2007	COM(2007) 18	Directive of the European Parliament and of the Council	Amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and the introduction of a mechanism to monitor and reduce GHG emissions from the use of road transport fuels.	Reducing air-pollutant and GHG from road and non road fuel use Help to implement the Community strategies on air quality and on climate change	Establishment of a separate petrol blend with higher permitted oxygen content, including up to 10% ethanol Increase of the vapour pressure limit for petrol blended with ethanol

Source: Pons (2007)

Appendix Table C2 Energy policies and measures, Belgium

Country	Policy Name	Type	Target	Status	Year
Belgium	Advice and support for building professionals: The Facilitator network	•Education and Outreach	•Buildings •Energy Production	In force	
	Car parking management		•Transport	In force	
	Provincial and municipal grants for solar energy - Flanders	•Incentives/Subsidies	•Energy Production	In force	various years (depending on province/municipality)
	Law of obligation for the incorporation of biofuels in fossil fuels	•Regulatory Instruments	•Energy Production •Transport	In force	2009
	New subsidies for freight transport by rail	•Incentives/Subsidies	•Transport	In force	2009
	National Action Plan on Energy Efficiency	•Policy Processes	•Framework Policy •Multi-sectoral Policy	In force	2008
	SOLWATT - Wallonia	•Incentives/Subsidies	•Energy Production	In force	2008
	Brussels region: Exemplary Buildings contest	•Education and Outreach •Incentives/Subsidies	•Buildings	In force	2007
	Flanders: Call-system ecological investment subsidy	•Incentives/Subsidies	•Energy Production	In force	2007
	Grants supporting solar energy - Brussels region	•Incentives/Subsidies	•Energy Production	In force	2007
	Incentives for the purchase of low emission vehicles	•Financial •Incentives/Subsidies	•Transport	In force	2007
	Subsidies for Passive House construction and Low-Energy renovation	•Education and Outreach •Incentives/Subsidies	•Buildings	In force	2007
	Subsidies for renewable energy in tertiary sector buildings - Brussels region	•Education and Outreach •Incentives/Subsidies	•Buildings •Energy Production	In force	2007
	Flanders: grants for solar thermal, micro-CHP and heat pumps	•Incentives/Subsidies	•Energy Production	In force	2006 (expanded 2009)
	Excise Tax Reduction for Biofuels	•Financial	•Energy Production •Transport	In force	2006

Appendix Table C2 Continued

Country	Policy Name	Type	Target	Status	Year
	Flemish Government Second Climate Policy Plan	•Policy Processes	•Framework Policy	In force	2006
	Implementation of EU Energy Performance of Buildings Directive (EPBD)	•Education and Outreach •Policy Processes •Regulatory Instruments	•Buildings	In force	2006
	Implementation of the EU Directive on Biofuels for Transport	•Regulatory Instruments	•Energy Production •Transport	In force	2006
	Support for renewable electricity (photovoltaics) - Green certificates - Flanders	•Tradable Permits	•Energy Production	In force	2006
	Supporting alternative mobility - the Bruxell'Air bonus	•Incentives/Subsidies	•Transport	In force	2006
	Tax deductions on travel to and from home	•Financial •Incentives/Subsidies	•Transport	In force	2005 (amended 2009)
	Brussels Capital - National Allocation Plan 2005 - 2007			In force	2005
	Choosing an eco-friendly vehicle: The ecoscore	•Education and Outreach	•Transport	In force	2005
	CHP Certificates - Flanders	•Education and Outreach •Tradable Permits	•Energy Production •Industry •Multi-sectoral Policy	In force	2005
	EMAS for Federal Administrations	•Regulatory Instruments •Voluntary Agreement	•Buildings	In force	2005
	Energy Fund Grants for Small-Scale Heat Generation - Wallonia	•Incentives/Subsidies	•Energy Production	In force	2005
	Local Action Plans for Demand-side Management (PLAGE)	•Education and Outreach •Voluntary Agreement	•Buildings	In force	2005
	Public procurement rules for Federal administrations and Public services	•Education and Outreach •Public Investment	•Appliances •Transport	In force	2005
	Subsidies for Renewable Energy Investment - Wallonia	•Financial •Incentives/Subsidies	•Energy Production	In force	2005

Appendix Table C2 Continued

Country	Policy Name	Type	Target	Status	Year
	Third Party Financing for energy efficiency investments 2005 - TPF			In force	2005
	Wallonia - National Allocation Plan 2005 - 2007			In force	2005
	Flanders: CHP Certificates	•Regulatory Instruments	•Energy Production	In force	2004 (modified 2007)
		•Tradable Permits			
	Belgium National Allocation Plan 2005 - 2007			In force	2004
	Benchmarking Covenant on Energy Efficiency - Flanders	•Regulatory Instruments		In force	2004
		•Voluntary Agreement			
	Buildings Energy Performance Regulations - Wallonia & Flanders	•Regulatory Instruments	•Buildings	In force	2004
	Decree on energy planning - Flanders	•Regulatory Instruments	•Industry	In force	2004
	Decree on public lighting - Flanders	•Regulatory Instruments	•Appliances	In force	2004
	Electric Appliance Labelling	•Education and Outreach		In force	2004
	Incentives for Environmental Protection and Durable Energy Use – Wallonia			In force	2004
	Off-shore wind plant in the North Sea		•Energy Production	Planned	2004
	Offshore Domanial Concessions for Wind and Ocean Energy Production	•Regulatory Instruments	•Energy Production	In force	2004
	Promotion of modal shift in transport			In force	2004
	Rational Use of Energy Decree - Flanders	•Policy Processes	•Energy Production	In force	2004
		•Regulatory Instruments	•Framework Policy		
			•Industry		
	Application of the European Directive on the Energy Performance of Buildings - Wallonia			Planned	2003
	Energy Fund - Supported Research - Wallonia	•Education and Outreach	•Energy Production	In force	2003
		•RD & D			
	Green Certificate Scheme - Federal	•Incentives/Subsidies	•Energy Production	In force	2003
		•Regulatory Instruments			
	Mobility Plan - Flanders			Planned	2003
	Renewable Energy Support Scheme - Wallonia	•Incentives/Subsidies	•Energy Production	In force	2003
	Tax deductions for investments in energy efficiency and renewable energy- Federal	•Financial	•Buildings	In force	2003

Appendix Table C2 Continued

Country	Policy Name	Type	Target	Status	Year
	Brussels - Subsidy schemes for energy efficiency measures	•Incentives/Subsidies	•Appliances •Buildings •Energy Production	In force	2002 (updated annually)
	Rational Use of Energy Public Service Obligations for Electricity Grid Managers, Flanders	•Regulatory Instruments	•Energy Production •Industry	In force	2002 (amended 2003, 2007, 2008)
	AMURE - Energy Auditing in Wallonia			In force	2002
	Climate Plan - Brussels-Capital	•Policy Processes	•Framework Policy •Multi-sectoral Policy	In force	2002
	Green Certificates Scheme - Flanders	•Education and Outreach •Tradable Permits	•Energy Production	In force	2002
	Green Certificates Scheme - Wallonia	•Incentives/Subsidies •Policy Processes •Regulatory Instruments •Tradable Permits	•Energy Production	In force	2002
	National Climate Plan - Federal	•Policy Processes		In force	2002
	Energy Auditing in Wallonia			Planned	2001
	Flemish Climate Policy Task Force	•Policy Processes	•Framework Policy	In force	2001
	Flemish Gas Market	•Regulatory Instruments	•Energy Production •Framework Policy •Industry	In force	2001
	Local Action Plan for Promoting Energy Efficiency - Wallonia	•Education and Outreach •Financial		In force	2001
	Sustainable Development and Climate Plan - Wallonia			In force	2001
	Vehicle consumption and CO2 label	•Education and Outreach •Regulatory Instruments	•Transport	In force	2001
	Voluntary Agreement with Industry - Wallonia	•Voluntary Agreement		In force	2001

Appendix Table C2 Continued

Country	Policy Name	Type	Target	Status	Year
	Information Networking on Energy Savings - Wallonia, Flanders & Brussels-Capital			In force	2000
	Soltherm - Wallonia	•Education and Outreach	•Energy Production	In force	2000
		•Incentives/Subsidies			
	Subsidies to Improve Energy Efficiency of Public Buildings - Wallonia & Brussels Capital Region	•Financial	•Buildings	In force	2000
		•Incentives/Subsidies			
		•Public Investment			
		•Regulatory Instruments			
	Annual Renewable Energy and Energy Conservation RD&D Tender - Wallonia	•Education and Outreach	•Multi-sectoral Policy	In force	1999
		•RD & D			
	"Entreprise Ecodynamique" (Ecodynamic Company) seal of approval	•Education and Outreach	•Buildings	In force	1999
		•Voluntary Agreement	•Industry		
			•Multi-sectoral Policy		
			•Transport		
	Financial support for demonstration projects - Flanders	•Incentives/Subsidies	•Energy Production	In force	1992
			•Industry		
			•Multi-sectoral Policy		
	Tax deduction for investments in energy efficiency & renewable energy by Enterprises	•Financial		In force	1992
	Support for Pre-Feasability Studies (AMURE) - Wallonia	•Education and Outreach	•Buildings	In force	1990 (updated in 1994)
		•Incentives/Subsidies	•Energy Production		
		•Regulatory Instruments			
	Technology Subsidies - Wallonia, Flanders & Brussels-Capital	•Financial	•Multi-sectoral Policy	In force	1983
		•Incentives/Subsidies			
		•RD & D			

Source: IEA (Related Country and Regional information, www.iea.org)

Appendix Table C3 Energy policies and measures, Denmark

Country	Policy Name	Type	Target	Status	Year
Denmark	Agreement on Green Growth	•Incentives/Subsidies •Policy Processes •RD & D •Regulatory Instruments	•Energy Production •Multi-sectoral Policy	In force	2009
	Energy Tax Reform	•Financial	•Multi-sectoral Policy	In force	2009
	Feed-in premium tariffs for renewable power (Promotion of Renewable Energy Act)	•Incentives/Subsidies	•Energy Production	In force	2009
	Finance Act 2009 - energy target for state institutions	•Regulatory Instruments	•Appliances •Buildings	In force	2009
	Green Transportation Agreement	•Financial •Policy Processes •Public Investment •RD & D	•Transport	In force	2009
	Promotion of Renewable Energy Act	•Incentives/Subsidies •RD & D •Regulatory Instruments	•Energy Production	In force	2009
	Agreement on Danish Energy Policy 2008-2011	•Financial •Incentives/Subsidies •Policy Processes •Public Investment •RD & D	•Framework Policy •Multi-sectoral Policy	In force	2008
	Electricity Savings Action Plan 2008	•Education and Outreach •Voluntary Agreement	•Appliances •Buildings	In force	2008
	Law on design of energy-using products	•Regulatory Instruments	•Appliances	In force	2008

Appendix Table C3 Continued

Country	Policy Name	Type	Target	Status	Year
Denmark	Denmark National Allocation Plan 2008-2012	•Tradable Permits	•Framework Policy •Multi-sectoral Policy	In force	2007
	Energy Efficiency Action Plan	•Policy Processes	•Multi-sectoral Policy	In force	2007
	Electricity Saving Trust Purchasing Guidelines	•Education and Outreach •Public Investment •Voluntary Agreement	•Appliances •Buildings	In force	2006 (updated 2008)
	Promotion of energy savings in buildings	•Education and Outreach •Regulatory Instruments	•Buildings	In force	2006 (implementation continued to 2009)
	Implementation of EU Energy Performance of Buildings Directive (EPBD)	•Education and Outreach •Regulatory Instruments	•Buildings	In force	2006
	Thermal Building Code Revision	•Regulatory Instruments	•Buildings	In force	2006
	Promoting energy efficiency in the public sector	•Public Investment •Regulatory Instruments	•Appliances •Buildings	In force	2005 (expanded 2007, 2009)
	Action Plan for Renewed Energy Conservation	•Policy Processes	•Multi-sectoral Policy	In force	2005
	Agreement on Energy Saving Initiatives	•Policy Processes	•Multi-sectoral Policy	In force	2005
	Danish Carbon Fund			In force	2005
	Establishment of Climate Policy Monitor			In force	2005
	Implementation of the EU Linking Directive			In force	2005
	CO2 Tax Revenue to Fund Company Environmental Projects			In force	2004
	Law on CO2 Quotas			In force	2004
	Climate Change Strategy	•Policy Processes	•Framework Policy	In force	2003

Appendix Table C3 Continued

Country	Policy Name	Type	Target	Status	Year
	Regional Testing Ground Agreement for Flexible Mechanisms			In force	2003
	National Strategy for Sustainable Development	•Policy Processes	•Framework Policy	In force	2002
	Act on the Promotion of Savings in Energy Consumption	•Policy Processes	•Framework Policy	In force	2000
	Energy Labelling of New Cars	•Education and Outreach	•Transport	In force	2000
	Increase in Energy Tax			In force	2000
	Carbon Tax/Green Tax System	•Financial		In force	1999
	Heat Supply Act	•Regulatory Instruments	•Buildings	In force	1979 (updated 2006)
			•Energy Production		

Source: IEA (Related Country and Regional information, www.iea.org)

Appendix Table C4 Energy policies and measures, Netherlands

Country	Policy Name	Type	Target	Status	Year
Netherlands	Incentive Scheme for Sustainable Energy Production	•Financial •Incentives/Subsidies	•Energy Production	In force	2009
	Environmental Tax on Flights from Netherlands	•Financial	•Transport	In force	2008
	Long-term agreements with industry 3 (MJA 3)	•Voluntary Agreement	•Industry	In force	2008
	More with less Programme	•Education and Outreach •Incentives/Subsidies •Voluntary Agreement	•Buildings	In force	2008
	Policy for heating and cooling (aanvalsplan warmte)	•Education and Outreach •Incentives/Subsidies •Policy Processes	•Buildings •Energy Production •Framework Policy •Industry •Multi-sectoral Policy	Planned	2008
	SDE (stimulering duurzame energie): Renewable energy and CHP production aid scheme	•Incentives/Subsidies	•Energy Production	In force	2008
	Biofuels sales requirement: Transport Biofuels Act 2007	•Regulatory Instruments	•Energy Production •Transport	In force	2007
	Clean and Efficient: New Energy for Climate Policy	•Policy Processes	•Framework Policy •Multi-sectoral Policy	In force	2007
	Energy Efficiency Action Plan	•Policy Processes	•Multi-sectoral Policy	In force	2007
	Kilometre Pricing System for Road Usage	•Financial	•Transport	Planned	2007
	Compass (Kompas)	•Education and Outreach •Financial •Incentives/Subsidies •Policy Processes	•Buildings	In force	2006

Appendix Table C4 Continued

Country	Policy Name	Type	Target	Status	Year
	EcoDriving (Het Nieuwe Rijden)	•Education and Outreach	•Energy Production	In force	2006
		•Financial			
		•Incentives/Subsidies			
		•RD & D			
		•Regulatory Instruments			
	Energy Transition	•Education and Outreach	•Buildings	In force	2006
		•Policy Processes	•Energy Production		
		•Regulatory Instruments	•Framework Policy		
		•Voluntary Agreement			
	Implementation of EU Energy Performance of Buildings Directive (EPBD): Energy Performance Certificate and Energy Labeling	•Education and Outreach	•Buildings	In force	2006
		•Regulatory Instruments			
	Labelling of Vehicle Efficiency (Energielable voor autos)	•Education and Outreach	•Energy Production	In force	2006
	Tax Benefits for Energy-Efficient Cars (Belasting van personenauto's en motorrijwielen - BPM)	•Education and Outreach	•Energy Production	In force	2006
		•Financial	•Transport		
	Energy Efficiency Policy Framework			In force	2005
	Energy-Saving Subsidy Scheme for Households with Low Incomes			In force	2005
	Energy Tax Increase			In force	2005
	Energy Tax Regime	•Tradable Permits	•Energy Production	In force	2005
		•Financial			
		•Incentives/Subsidies			
	Expanded Subsidies for Biomass Plant Operators			In force	2005
	Kyoto Protocol Period Emissions Allocation			Planned	2005
	Low-PFC Aluminum Production			In force	2005

Appendix Table C4 Continued

Country	Policy Name	Type	Target	Status	Year
	Mobile Machinery Emissions Standards			In force	2005
	Requirements for Bio-component in Auto Fuel			Planned	2005
	Energy Investment Tax Deduction (EIA)	•Financial		In force	2004
	Energy Research Strategy (EOS)	•Incentives/Subsidies •RD & D	•Multi-sectoral Policy	In force	2004
	Guarantees of Origin			In force	2004
	Housing Energy Subsidies			Planned	2004
	Netherlands Carbon Facility			In force	2004
	Netherlands' National Allocation Plan 2005-2007			In force	2004
	Biomass Action Plan			Planned	2003
	Energy Tax Modifications			In force	2003
	Energy Transition Management			Planned	2003
	World Bank and European Bank for Reconstruction and Development (EBRD) Carbon Fund	•Tradable Permits •Policy Processes	•Multi-sectoral Policy	In force	2003
	Voluntary Agreements with Coal Power Companies			In force	2002
	Clean Development Mechanism Certified Emission Reduction Units (CERs) Purchasing Strategy			In force	2001
	Climate-Neutral Government Operations by 2012	•Policy Processes	•Energy Production •Multi-sectoral Policy	In force	2001
	Energy Labels on Passenger Cars	•Education and Outreach •Regulatory Instruments	•Energy Production	In force	2001
	Energy Savings in Greenhouse Horticulture (GLAMI)	•Regulatory Instruments •Voluntary Agreement	•Energy Production •Carbon Capture and Storage	In force	2001
	Fourth National Environmental Policy Plan	•Policy Processes	•Buildings	In force	2001
	Green Certificate Trading	•Tradable Permits	•Energy Production	In force	2001

Appendix Table C4 Continued

Country	Policy Name	Type	Target	Status	Year
	Renewables for Government Buildings	•Public Investment •Regulatory Instruments •Policy Processes	•Buildings •Energy Production	In force	2001
	Second Generation Long-Term Agreements on Energy Efficiency (LTA2)			In force	2001
	Tax for Commuters	•Financial		In force	2001
	Climate Policy Implementation Plan Part II - Flexible Mechanisms			In force	2000
	Contribution to the Prototype Carbon Fund			In force	2000
	Energy Performance Standards for Buildings Strengthened		•Buildings	In force	2000
	Joint Implementation Emission Reduction Units (ERUs) Purchasing Strategy			In force	2000
	Transport Avoidance Project	•Education and Outreach •Financial •Incentives/Subsidies	•Energy Production	In force	2000
	Voluntary Agreements	•Voluntary Agreement		In force	2000
	Climate Policy Implementation Plan Part I			In force	1999
	Energy Efficiency Benchmarking Covenant	•Voluntary Agreement	•Industry	In force	1999
	Energy Tax Increases	•Financial •Education and Outreach		In force	1999
	Energy Investment Deduction (EIA)	•Financial	•Multi-sectoral Policy	In force	1997
	Activities Implemented Jointly (AIJ)	•Financial •Incentives/Subsidies •Policy Processes •Public Investment •RD & D •Voluntary Agreement	•Energy Production •Multi-sectoral Policy	In force	1995
	Green Funds	•Incentives/Subsidies •Financial •Tradable Permits	•Multi-sectoral Policy	In force	1995

Source: IEA (Related Country and Regional information, www.iea.org)

Appendix Table C5 Energy policies and measures, Sweden

Country	Policy Name	Sector	Energy	Year
Sweden	Appliance and Equipment Labelling			
	Biofuels Support (in relation to Directive 2003/30/EC) - Fiscal Incentives	•Transport	•Other	
	Biofuels Support (in relation to Directive 2003/30/EC) - Removal of 5 percent limit on blends	•Transport	•Other	
	Building Performance Standards (Building Codes)			
	Car Fuel Consumption Information			
	District Heating and CHP			
	Driving Behaviour Education			
	Eco-driving	•Transport	•Fossil Fuels	
	Equipment and Production Standards			
	Graduated Vehicle Excise Duty	•Transport	•Fossil Fuels	
	Implementation of EU Directives			
	Information and Advisory Services			
	Instruments for increased introduction of green cars	•Transport	•Other	
	Motor fuel tax	•Transport	•Fossil Fuels	
	Participation in International Car-Free Day for Cities (In town without my car!) & European Mobility Week			
	Purchaser Group Networks			
	Railway Infrastructure Investment			
	Research and Development			
	Road Transport Fuel and Vehicle Taxes			
	Supply Chain Efficiency Agreements			
	Swan Label for tyres	•Transport	•Fossil Fuels	
	Taxation of cars received as benefit	•Transport	•Fossil Fuels	
	Technology Procurement			
	Support for solar heating investments			2009
	National Energy Efficiency Action Plan			2008
	Vehicle Ethanol Conversion Regulation			2008
	Eco Car Subsidy			2007
	Energy Efficient Home Consumer Campaign	•Residential		2007
	Grant for local authority land use planning for wind power	•Power Generation		2007
	Information Sheet: The Government's Climate Policy			2007
	Commission on Oil Independence: Final Report, Targets Published	•Framework Policies		2006
	Energy Declaration of Buildings Act - Incentives for Investment in Lower-Energy Buildings	•Industry •Power Generation	•Renewables	2006
	Grants for Residential Heating Conversion	•Power Generation		2006
	Requirement to Sell Renewable Motor Fuels	•Power Generation		2006
	Vehicle Taxation (Including in relation to Biofuels)	•Power Generation		2006
	Advisory Council for the Promotion of Wind Power	•Power Generation	•Renewables	2005
	Anglo-Swedish Initiative for Greener Buildings	•Residential	•Other	2005

Appendix Table C5 Continued

Country	Policy Name	Sector	Energy	Year
	Grants for Conversion, Energy Efficiency and Solar in Public Buildings	•Power Generation		2005
	Market Standards for Transport Biofuels	•Transport	•Renewables	2005
	Program for Energy RD&D	•Framework Policies	•Electricity •Fossil Fuels •Other •Renewables	2005
	Programme for improving energy efficiency in energy-intensive industries (PFE)	•Industry	•Other	2005
	Tax Credits for Household Fuel-Switching	•Residential	•Other	2005
	Tax Reduction for Environmental and Energy Investments in Public Buildings	•Residential	•Other	2005
	ClimateAid Campaign	•Framework Policies	•Other	2004
	Sweden National Allocation Plan 2005-2007	•Industry •Power Generation	•Other	2004
	Tax Reduction for Fossil Fuels used for Heat Production in CHP Plants	•Power Generation	•Electricity	2004
	Tax Reduction for Installation Cost of Biomass Heating Systems and Energy Efficient Windows	•Residential	•Renewables	2004
	Climate Investment Programmes (Klimp)	•Framework Policies		2003
	Funding for Wind Power Pilot Projects	•Power Generation	•Renewables	2003
	Green Certificate Scheme	•Power Generation	•Renewables	2003
	Measures to Support Wind Farms in Difficult Locations	•Power Generation	•Renewables	2003
	Regional Testing Ground Agreement for Flexible Mechanisms	•Framework Policies	•Other	2003
	Energy Policy	•Framework Policies •Industry •Power Generation	•Other	2002
	International Climate Investments	•Framework Policies		2002
	Swedish Climate Strategy	•Framework Policies	•Other	2002
	Tax Reduction for Wind Power - Prolongation	•Power Generation	•Renewables	2002
	Bill on Climate Policy	•Framework Policies		2001
	Report on Long Term Agreements for Energy Efficiency in Industry	•Industry		2001
	Sustainable Municipalities Programme	•Framework Policies		2001
	Tax Breaks to Employees Receiving Alternative Fuel Autos From Employers	•Transport		2001
	Grant for Solar Heating			2000 (extended 2006)
	Green Tax Shift			2000
	Support for Small Scale Electricity Production			2000
	The Environmental Code			1999
	Local Investment Programmes (LIP)	•Framework Policies		1998 (revised in 2003)

Table C5 Continued

Country	Policy Name	Sector	Energy	Year
	Baltic Energy Efficiency Group (BEEG)	•Industry •Power Generation •Residential	•Renewables	1998
	Feed-in tariffs			1998
	Technology Procurement Programme			1998
	EKO Energy	•Industry		1997
	Energy policy programme			1997
	Guaranteed Power Purchase Contracts			1997
	Local Investment Programme (LIP)			1997
	RD&D			1997
	Renewable Energy Investment Support Programme			1997
	Environmental Bonus for Wind Power	•Power Generation	•Renewables	1994 (regular modifications)
	Renewables Tax Exemption: Act 1776			1994
	Nitrogen Oxides (NOx) Charge	•Framework Policies	•Electricity •Fossil Fuels	1992
	Energy, Carbon and Sulphur Dioxide Taxation	•Framework Policies		1991
	Energy Research and Development			1975

Source: IEA (Related Country and Regional information, www.iea.org)

Appendix Table C6 Energy policies and measures, United Kingdom

Country	Policy Name	Type	Target	Status	Year
United-Kingdom	Feed-in Tariffs for renewable electricity	•Incentives/Subsidies	•Energy Production	In force	2010
	Low Carbon Transition Plan	•Incentives/Subsidies •Policy Processes •Public Investment •RD & D •Regulatory Instruments	•Buildings •Carbon Capture and Storage •Energy Production •Industry •Multi-sectoral Policy •Transport	In force	2009
	Renewable Energy Strategy 2009	•Incentives/Subsidies •Policy Processes •RD & D •Regulatory Instruments	•Energy Production •Transport	In force	2009
	Vehicle Excise Duty (VED): fuel type and CO2 emission vehicle bands	•Financial •Regulatory Instruments	•Transport	In force	2009
	Carbon Emissions Reduction Target (Energy Efficiency Commitment 3)	•Regulatory Instruments •Tradable Permits	•Industry	In force	2008
	Climate Change Act	•Policy Processes •Regulatory Instruments •Tradable Permits	•Multi-sectoral Policy	In force	2008
	Community Energy Savings Programme (CESP)	•Education and Outreach •Incentives/Subsidies	•Buildings	Planned	2008
	Energy Act 2008	•Policy Processes	•Multi-sectoral Policy	In force	2008
	Energy Saving Scotland Home Help	•Education and Outreach •Policy Processes	•Buildings	In force	2008
	PAS 2050: Specification for assessing the life-cycle GHG emissions of goods and services	•Education and Outreach	•Multi-sectoral Policy	In force	2008
	Planning and Energy Act 2008	•Regulatory Instruments	•Energy Production •Multi-sectoral Policy	In force	2008
	Renewable Transport Fuels Obligation (RTFO)	•Regulatory Instruments	•Energy Production •Transport	In force	2008

Appendix Table C6 Continued

Country	Policy Name	Type	Target	Status	Year
United Kingdom	Carbon Reduction Commitment (CRC)	•Regulatory Instruments	•Industry	In force	2007
	Act on CO2 advice line	•Education and Outreach	•Buildings	In force	2007
	Code for Sustainable Homes	•Education and Outreach •Regulatory Instruments	•Buildings	In force	2007
	Energy Efficiency Action Plan	•Policy Processes	•Multi-sectoral Policy	In force	2007
	Energy Efficiency Loans for Small or Medium sized Enterprises (SMEs)	•Incentives/Subsidies	•Industry	In force	2007
	Energy Technologies Institute	•Policy Processes •RD & D •Voluntary Agreement	•Energy Production •Multi-sectoral Policy •Transport	In force	2007
	Energy White Paper - Meeting the Challenge	•Policy Processes	•Multi-sectoral Policy	In force	2007
	Environmental Transformation Fund	•Incentives/Subsidies	•Multi-sectoral Policy	In force	2007
	International Task Force for Sustainable Products (ITFSP)	•Tradable Permits	•Appliances	In force	2007
	Low Carbon Transport Innovation Strategy	•Public Investment •RD & D •Tradable Permits	•Transport	In force	2007
	Scotland - Scottish Energy Efficiency and Microgeneration Strategy	•Policy Processes	•Energy Production •Multi-sectoral Policy	Planned	2007
	Smart Metering and Billing		•Buildings	In force	2007
	Stamp Duty Relief for Zero Carbon Homes	•Financial	•Buildings	In force	2007
	Sustainable Transport Policy	•Policy Processes	•Transport	In force	2007
	Technology Strategy Board	•RD & D	•Buildings •Multi-sectoral Policy •Transport	In force	2007
	Voluntary Agreement on the Phase Out of Incandescent Light Bulbs	•Voluntary Agreement	•Appliances	In force	2007
	Building Regulations Part L	•Education and Outreach •Regulatory Instruments		In force	2006
	Climate Change and Sustainable Energy Act		•Energy Production •Multi-sectoral Policy	In force	2006

Appendix Table C6 Continued

Country	Policy Name	Type	Target	Status	Year
United Kingdom	Climate Change Programme 2006	•Policy Processes •Public Investment	•Multi-sectoral Policy	In force	2006
	Low Carbon Buildings Programme	•Education and Outreach •Incentives/Subsidies •RD & D	•Buildings •Energy Production	In force	2006
	Market Transformation Programme - Partnership with China	•Education and Outreach •Policy Processes •RD & D •Regulatory Instruments •Voluntary Agreement		In force	2006
	Market Transformation Programme - Standards for Energy Efficiency of Electric Motor Systems (SEEEM) Membership	•Education and Outreach •Policy Processes •Voluntary Agreement		In force	2006
	Microgeneration Strategy	•Incentives/Subsidies •Policy Processes •RD & D	•Energy Production	In force	2006
	National Action Plan on Sustainable Procurement: "Procuring the Future"	•Public Investment •Policy Processes	•Multi-sectoral Policy	In force	2006
	Northern Ireland - Efficiency Upgrade for Building Regulations	•Education and Outreach •Regulatory Instruments		In force	2006
	Salix Project	•Incentives/Subsidies	•Buildings •Multi-sectoral Policy	In force	2006
	The Stern Review on the Economics of Climate Change	•Policy Processes •RD & D		In force	2006
	Anglo-Swedish Initiative for Greener Buildings	•Education and Outreach		In force	2005
	Biomass Task Force	•RD & D •Policy Processes •Education and Outreach •Financial	•Energy Production	In force	2005
	Marine Research Development Fund	•RD & D	•Energy Production	In force	2005
	UK Implements EU Linking Directive		•Multi-sectoral Policy	In force	2005

Appendix Table C6 Continued

Country	Policy Name	Type	Target	Status	Year
	ZeroCarbonCity			In force	2005
	Bio-energy Infrastructure Scheme		•Energy Production	In force	2004
	Combined Heat and Power Strategy to 2010	•Financial •Voluntary Agreement		In force	2004
	Energy Act 2004	•Regulatory Instruments	•Energy Production •Multi-sectoral Policy	In force	2004
	Exemption from Climate Change Levy for Energy-Intensive Businesses Under Climate Change Agreements	•Financial •Voluntary Agreement		In force	2004
	Funding for Using Willow as a Renewable Energy Source	•Incentives/Subsidies		In force	2004
	Landlords' Energy Saving Allowance (LESA)	•Financial	•Buildings	In force	2004
	Regional Approval for Renewable Energy Projects	•Policy Processes		In force	2004
	Research Councils Energy Programme (RCEP)	•RD & D	•Carbon Capture and Storage •Energy Production •Multi-sectoral Policy •Transport	In force	2004
	UK-US Partnership for Clean Energy			In force	2004
	United Kingdom - Methane to Markets Partnership		•Energy Production •Industry	In force	2004
	Bio-energy Infrastructure Scheme	•Incentives/Subsidies	•Energy Production	In force	2003
	Renewable Energy Guarantee of Origin (REGO)	•Education and Outreach •Regulatory Instruments •Tradable Permits		In force	2003
	Renewables Obligation Order	•Education and Outreach •Financial •Policy Processes •Regulatory Instruments •Tradable Permits	•Energy Production	In force	2002 (last amended 2009)
	Preferential Tax Regimes for Biofuels	•Financial	•Energy Production •Transport	In force	2002 (amended 2005, 2008)
	Bio-energy Capital Grants Scheme	•Incentives/Subsidies		In force	2002
	Company Car Tax Reform	•Financial	•Transport	In force	2002
	Offshore Wind Capital Grants Scheme	•Incentives/Subsidies		In force	2002

Appendix Table C6 Continued

Country	Policy Name	Type	Target	Status	Year
United Kingdom	The Carbon Trust			In force	2001
	Climate Change Agreements	•Financial •Voluntary Agreement	•Industry	In force	2001
	Climate Change Levy	•Financial	•Energy Production •Industry •Transport	In force	2001
	Climate Change Projects Office			In force	2001
	Decent Homes	•Regulatory Instruments	•Buildings	In force	2001
	Enhanced Capital Allowances (ECA) - Energy Technology List	•Financial •Incentives/Subsidies	•Multi-sectoral Policy	In force	2001
	Northern Ireland Warm Homes Scheme	•Incentives/Subsidies	•Buildings	In force	2001
	Scottish Government Central Heating Programme	•Incentives/Subsidies	•Buildings	In force	2001
	Energy Crops Scheme - England	•Incentives/Subsidies	•Energy Production	In force	2000
	Reduced VAT for energy saving materials	•Financial	•Appliances •Buildings •Energy Production •Multi-sectoral Policy	In force	2000
	Wales Home Energy Efficiency Scheme (HEES)	•Incentives/Subsidies	•Buildings	In force	2000
	Warm Front Scheme	•Incentives/Subsidies	•Buildings	In force	2000
	Scotland - Small business energy efficiency loans	•Incentives/Subsidies	•Buildings •Energy Production	In force	1999
	Scottish Government Warm Deal Programme	•Incentives/Subsidies	•Buildings	In force	1999
	Reduced VAT for energy-saving materials	•Financial	•Appliances •Buildings	In force	1998
	Northern Ireland - Energy Efficiency Levy	•Incentives/Subsidies •Regulatory Instruments	•Multi-sectoral Policy	In force	1997
	The Energy Savings Trust	•Education and Outreach	•Multi-sectoral Policy	In force	1992

Source: IEA (Related Country and Regional information, www.iea.org)

APPENDIX D

Pelletizing Process Description

Description of the pellet production process

This part will give short description of all facilities and equipment necessary for normal functioning of the 100,000 t/year pellet plant. The planning and budgeting of a pellet plant is difficult because there are no engineering companies or contractors with already created templates or design packages for pellet plants (Campbell 2007). However, the industry standards for pellet plant design and construction do not exist at the moment (Campbell 2007). Thus, we will use "Renewable energy technical assessment" study from EPRI, to calculate cost for site development, home construction and offices, field cost, proreAppendix Table Cost and other cost. As already mentioned, cost for the processing equipment will be calculated using information obtained from engineers and manufacturers, and sometimes information from other feasibility studies.

Site location and site development

Access to Class A roads is an imperative requirement for any type of biofuel plant. U.S. Highway 411 is the primary Class A road which passes by Niles Ferry Industrial Park (plant location). The rail road is also adjacent to the plant location. Rail access is advantage in plant sitting because it allows pellets to be shipped greater distances for much less cost than using a truck transport. This also opens possibility for pellets export overseas, because it connects pellet plant with ports on the South Eastern coast. Through this rail connection pellet plant has access to the larger markets for its product, like Atlanta, Columbia, Montgomery, Nashville and Jackson. Plant could possibly use water ways for transporting pellets, because it is located in a close proximity to the river. This study will not evaluate river transport.

Campbell (2007) estimates that pellet plant with 8TPH production could occupy 6-10 acres of land, but suggest purchase of a larger parcel to leave a room for possible expansion or reconfiguration of storage and truck flow. He also assumes that building of 20,000 square feet would be enough for 14TPH pellet plant. According to the mentioned plant layout, suggested dimensional requirements for a building is around 40,000 square feet. BBI estimates that footprint of 4TPH plant would be less than 22,000 square feet.

Receiving station and scale

Since farmers would be paid based on the amount of switchgrass they deliver to the pellet plant, it needs receiving station and scale to properly accomplish these tasks. Campbell (2007) assumes $130,000 cost for receiving station and scale, regardless of the production capacity of a commercial-scale pellet plant. Switchgrass will be received as big round (5x4 square feet) or rectangular (4x8 square feet) bales. Wheel loader is used to move feedstock from receiving station to on-plant storage and from storage to primary grinder. The average wheel loader cost able to handle up to 30 large square bales per hour according to Campbell (2007) is $110,000 while Mani (2006) uses $100,000 cost for his calculations. This study assumed tht 14TPH plant will need two wheel loaders, $110,000 each.

Feedstock storage

Long-time storage is necessary if there is a gap between feedstock production and densification (Van Loo and Koppejan, 2008). Campbell assumes that 14TPH pellet plant would need storage lot for switchgrass bales of 120,000 square feet enough for two-week supply of feedstock. He also assumes storage lot cost of $3/square foot. We use this numbers for our calculations as well. Prior to plant delivery, part of the bales would be stored on field edges for 200 days without cover on them (Wang et al 2009). The storage lot would be made from asphalt, because crushed rock may cause rocks to end up in the pellet plant equipment (Campbell 2007).

Storage in a pile or at the roadside results in 35-45% moisture for wood chips (assuming 50% original moisture) while covered storage results in 1.5% decrease in moisture for the same feedstock (>20% moisture) per month (Suurs et al. 2002). While outdoor storage in a pile or at the roadside results in 15% dry matter losses per month, covered outdoor storage causes up to 3% dry matter losses per month as a result of decomposition, if kept for a longer time (Suurs et al. 2002). Roofed, bunker, silo and tank storage have less or no influence on the biomass characteristics (Hamelinck et. al. 2005). Campbell (2007) estimates that 20,000-square foot partially enclosed building of this type, with door openings on at least two walls, is necessary and cost about $280,000. Duffy (2008) estimates that cost for construction of tarped hoop type structure for storing switchgrass would cost $12/square foot. The same building of 20,000 square feet can be constructed for mill residues, and would be enough to store feedstock required for two-weeks of interruptible operation.

Primary grinder

Since pellet plant will use both mill residues and switchgrass as a feedstock, it will need primary grinder (usually a heavy-duty hammermill, tub grinder, hog or shredder) to process possible large particles of wood and baled switchgrass. In case that only sawdust will be used as a feedstock there is no need for primary grinder, but since we do not have information what portion of mill residues come from sawdust we will assume primary grinder in all scenarios. Manufacturer representative (Gruss 2010) recommended us hog grinder for the plant size and feedstock characteristic we provided him. According to this representative price for the electric grinder (wood hog) is $460,000 while for one with diesel engine it is $570,000 and both can process all type of mill residues and large switchgrass bales. Campbell (2007) estimates the similar price for primary grinder of $650,000. Both of the estimates do not include freight or installation cost. Jackson estimates total cost for bale shredder system of $900,000 including freight and installation cost.

Drying

Drying is very important stage in pelletizing process, with substantial share on the total pellet production cost (Thek and Obernberger, 2004). Drying improves combustion efficiency of biomass, reduces susceptibility to decomposition, associated matter loses and fire and health hazards (Hamelinck et al. 2005). While superheated steam dryers, flash dryers, spouted bed dryers and belt dryers are common in the European countries but are not largely used in North America (Mani et al. 2006). Rotary drum dryer is commonly used in wood pelleting and alfalfa dehydration plants (Campbell 2007). According to Hamelinck et al. 2005, rotary drum dryer applies a proven technique and is applicable at large scale. Desired moisture content for pelletizing depends on the kind of feedstock used (Van Loo and Koppejan 2008) and as already mentioned different sources report 8-12% of optimal feedstock moisture prior to pelletizing. Pelletizing equipment operates the most efficiently and produces the most consistently density pellets with moisture content of 12% according to BBI (2009). We assume this moisture as optimal in our study as well. In order to calculate drying cost following drying requirements were used: drying of mill residues from 50% to 12% and switchgrass from 15% to 12% moisture. Natural gas was used as fuel although other sources may produce lower cost and reduce emissions. Dryer can produce many volatile organic compounds, thus possibly making environmental review and permitting process necessary (Campbell 2007) it will not be included in this study. Mani estimated $560,000 cost for rotary drum dryer including installation cost. Campbell (2007) reports $426,000-690,000 price for 14TPH pellet plant for natural gas or propane-fired rotary drum dryers without connected equipment like furnace, fan etc. or freight and installation cost included. Manufacturer's representatives gave as wide range of estimates for drying systems from $900,000 – 4,500,000 depending on fuel that will be used for drying and equipment included. The most expensive dryers are those that can use wet bark thus saving a lot of money for fuel, and comprise sometimes more than half of the total price of dryer. Sam Jackson estimated dryer cost around $2 million using wood as a fuel. Bill Moran estimates $1.5 million for energy and dryer system for plant of this size that would use 50-50 ratio of mill residues and grasses. In this study we will use estimate of $900,000 (including rotary drum dryer, furnace and fan) with complete energy balance during the drying stage provided from Schroeder.

Grinding

Hammermill is used for reduction and homogenization of raw material to suiTable size for pelletizing, which depends on the final size of produced pellets (Van Loo and Koppejan 2008). Homogenous and well conditioned raw material is said to be the main parameter for achieving a high quality pellets (Pastre 2002). Production of pellets requires particle size between 3-10mm (Hamelinck et al. 2005). The particle size of feedstock that passes to the hammermill is determined by the screen which is changeable (Campbell 2007) with screen size between 3.2 to 6.4 mm (Mani et al. 2006). However, smaller particle size increases the density and hardness of the pellets (Campbell 2007) saves transport and handling cost with improvement in combustion efficiency (Hamelinck 2005).

The budget estimates provided by manufacturers ranged between $60,000 to 100,000 but most of them concurred a price of $100,000 for an optimal hammermill for a plant of this size. They were asked for hammermills that can process both switchgrass and mill residues. Sam Jackson uses somewhat higher price of $200,000 in his budgets. Mani et al. (2006) used $60,000 for their study (6t/h pellet plant).

Conditioning and milling

Once when desired moisture and size of raw material has been achieved, and blend ratio of feedstock is optimized, pellets are being fed into pellet presses (BBI 2009). Removal of air is performed by cyclones which then fed pelletizing equipment using augers to drive a constant stream of product into the mouth of the pellet press (BBI 2009). Two main technologies are available for pelletizing: ring die and flat die pellet mills (Thek and Obenberger 2004). The size of pellets should be 0.250 – 0.285 inches (6.35-7.25 mm) in order to be compatible with PFI standards for all grade pellets. A roller presses material through the die, and blades cut the pellet to the desired length on the outside of the die (BBI 2009). Conditioning includes steam and/or water application to the feedstock in order to soften raw material fibres before densification (Pastre 2002). Conditioning can also be performed by additives or binding agents. The binding agent is lignin by itself (Hamelinck et al. 2005). The conditioner and pellet mill are integrated components and temperature of feedstock must be increased to 220 to 240 degrees Fahrenheit with sufficient moisture in order for lignins to release (Campbell 2007). A 100HP boiler is sufficient to generate the steam for a 14TPH pellet mill throughput (Campbell 2007). As one experiment showed, adding water to the pellet mill using switchgrass as a feedstock produced harder pellets and fewer fines (Pastre 2002). Since lignin is a natural binder, using woody biomass as a feedstock does not require conditioning (Mani et al. 2005) and will not be included in calculating cost of production for 100% mill residues and 40/60 ratio scenarios. Scenario with switchgrass as the only feedstock will include steam conditioning prior to pelletization.

Pellet mills can range from 40HP to 500HP in size, with general rule of thumb (100HP per one tone of pellet) (Campbell 2007). The most common pellet presses have output between 4-6 TPH (Pastre 2002). Hourly rates of production for 400HP pellet mill for different feedstock are given in Table D1. We can see that throughput of switchgrass is the same as that of hardwood and almost the same with that of softwood. Pellet density ranges from 550 to 700kg/m^3 depending on the size of pellets. We decided to use four 500HP/5TPH pellet mills for this study, although three pellet mills would be enough, in order to allow for interruptible production in case that one of the pellet mills requires maintenance. It was suggestion from the representative that provided us with pellet plant layout.

The price for such pellet mill (some of them were also 400HP) ranged from $300,000 to 350,000 according to different manufacturers. Mani estimated $315,000 for pellet mill, while Campbell (2007) estimated price of $580,000 including boiler ($51,000) and conditioner ($87,900). Jackson estimated price of $409,000 including freight and installation cost. The price of $350,000 will be used in our calculations for the pellet mill and $35,000 for the pellet mill steam system.

Table D1 Pelletmill's hourly production of pellets from different feedstock

Hourly	Production of 400-HP Pellet Mill
Feedstock	(Tons)
Hardwood	4 to 5
Softwood	5 to 6
Switchgrass	4 to 5
Soybean straw	5 to 7
Hay	7 to 9
Sugar beet pulp	8 to 9
Corn stover	8 to 10
Wheat straw	9 to 11
Oat hulls	11 to 13
Soybean hulls	22 to 25
Wheat middlings	22 to 25
Corn distillers grains	26 to 28

Source: Campbell (2007)

Cooling and screening

After the pellet mill, the temperature of pellets ranges between 70°C to 90°C (Mani et al. 2006); they remain fragile and soft until they are cooled (Urbanowski 2005). The increased temperature is due to the frictional heat generated during extrusion and material pre-heating (Mani et al. 2006). They are than delivered to the cooler to cool the pellets to about 80F with ambient air drawn through the pellets to evaporate excess moisture (Campbell 2007). This enables solidification of lignins, thus improving durability and hardness of pellets (Campbell 2007). Pellets are than passed over the screener for fines removal. The fines are then returned for re-pelleting or used as a solid biomass fuel if such a dryer is used (Campbell 2007). Pastre (2002) expects that between 3-4% of pellets made from sawdust will be screened out as fines, while loss of fines during the pelleting, cooling and temporary storage stages of switchgrass produced 91% yield on a dry matter basis (Jannasch et al. 2001). We assume that produced fines will be re-used in production with dust collection system.

One manufacturer estimated $60,000 for air cooler with air system, while Moran estimated cooler with discharge conveyor to cost $112,000. Mani (2006) gives purchase cost for cooler of $32,000 (for 6t/h plant) while Campbell (2007) estimates cost for cooler from $69,800 to $92,000 for 14TPH pellet plant. Jackson estimated higher installed cost for pellet cooling system ($330,000).

In our study we assume use of three screeners: one after the primary grinder and before the hammermill, the second after dry silos and the third after pellet mill. According to manufacturers, prices for screeners range from $17,000 – $35,000 depending on size and energy requirements. One manufacturer estimated cost for screener after pellet mill to be $42,000. Campbell (2007) estimated screener cost from $18,000 – 26,100 and Mani et al. (2006) used

$24,000 in their study. In our study we used $38,000 price for dry material screener and $19,000 for pellet screener, estimates provided from the manufacturer (Grason 2010).

Pellet storage

After screening of pellets, they are transported by bucket elevator to bulk load out silo. Storage space has to keep pellets dry in order to avoid their reversion to sawdust (Urbanowski 2005). Since pellet plant will produce utility pellets for the large European customers, probably under long-term contract, it will need larger storage. This is because there will be 2 to 4 overseas shipments during the year using large vessels of 25,000 to 55,000 of bulk capacity and sending pellets in smaller shipments would increase the cost of transport significantly. Pellets can be stored in warehouse, grain storage bins, grain storage building or in silos. Although silo storage may be the best option from operational perspective it is also the most expensive option (Campbell 2007). Some pellet plants have storage space up to 40% of their annual production (Urbanowski 2005). However, in this study we assume that plant will have 6 silos with 4,000 metric tons capacity ($0.6 million each, including conveyors and attached equipment).

Pellet properties

In order to be distributed on specific market pellets have to fulfill that market's standards. The pellet fuel industry has developed fuel standards and determined, through Pellets Fuel Institute, that pellet mills are responsible for testing and certification of their product (PFI 2010). PFI-graded pellets have to meet tests for the following criteria: density, dimensions, fines, chlorides and ash content (PFI). Requirements for different grades of pellets in US are given in Table A2. Export-oriented pellet mills will also have to fulfill pellet standards determined by importing country or by common European standard CEN-14931 if implemented. Table A3 shows limit values in existing national standards for fuel pellets in the EU. Some companies may have their own requirements for pellets quality like the biggest power generator (Electrabel) in Belgium (Table D2). Product specifications for industrial wood pellets created by ENDEX are presented in Table D3.

While dimensions, moisture and fines characteristics depend on the type of equipment and technology of production, others like: net calorific value, ash and chlorine content are largely dependent on feedstock properties. Those characteristics dependent on feedstock properties are the primary constituents when discussing biomass energy potential (BBI 2009). While wood pellets (without bark) may meet the standards for “Premium” and “Super Premium” pellets, those made from switchgrass will most likely fall in the utility grade, mainly due to its higher ash content.

Although there is no value requirement or range for heating value by PFI standards, the most of the European pellet standards require heating value greater than 16.9GJ/t (Sweden and Italy), 18GJ/t (Austria) and between 17.5 and 19.5GJ/t (Germany). Both wood and switchgrass pellets meet this standards.

Ash content is an important characteristic because inorganic ash is not combustible (higher-ash fuel has lower energy value than low-ash fuel). Higher ash content: requires more frequent cleaning of ash pan, can shut down the appliance when the ash tray is full (or when chunks of melted ash are formed) and reduce the efficiency of the pellet appliance (Campbell 2007).

Table D2 Qualitative norms for pellets required by Electrabel power company (as of Sep 04)

Parameters	Units	Electrabel
Diameter	mm	4-10 mm
Length		10-40 mm
Volatile matter		
Water content	% dry matter	< 10%
Bulk (apparent) density	kg/m3	> 600
Low heating value	GJ/ton as rec	> 17
Ash content	% dry matter	< 1%
Bark content		< 5%
Initial melting temperature (red cond)	C	> 1,200C
Cl	% dry matter	< 0.03%
S	% dry matter	< 0.2%
F	ppm	< 30
Additives (past, vegetal oil)	Qualitative	FORBIDDEN
Waste wood		FORBIDDEN
Heavy metals	mg/kg dry matter	
As	mg/kg dry matter	< 2
Cd	mg/kg dry matter	< 1
Cr	mg/kg dry matter	< 15
Cu	mg/kg dry matter	< 20
Hg	mg/kg dry matter	< 1
Pb	mg/kg dry matter	< 20
Zn	mg/kg dry matter	
Benzo-a-pyrene	mg/kg dry matter	< 0.5
Pentachlorphenol	mg/kg dry matter	< 3
Particle size distribution		minimum
% < 3mm (Durability)		100%
% < 2mm		95%
% < 1.5mm		75%
% < 1mm		50%

Source: Energie Facteur 4

Table D3 Product specification-ENDEX Industrial Wood Pellets (bulk)

Description	Industrial Wood pellets (bulk), Rotterdam - Diameter: 4<D<10 mm - Length: < 50 mm - Raw density > 1.12 kg/dm^3 - Moisture: < 10 wt% - Ash: < 1.5 wt% - Net Caloric Value: basis 17,0 MJ/kg as received (cp) - Sulphur: < 0.08 wt% - Nitrogen: < 0.30 wt% - Chlorine < 0.03 wt% - Additives: < 2 wt% - Fines: <3 wt% At the request of the Buyer, the Seller will prove that the industrial wood pellets have been manufactured in a sustainable way and will provide the Buyer with all necessary documents in this regard, such as labels, certificates, etc.
Delivery	Cost Insurance Freight (CIF) Rotterdam standard cargo size parcels with forward delivery between one and six weeks from the date of price assessment
Delivery point	Rotterdam
Contract series	Front to three (3) months ahead Front to three (3) quarters ahead Front year
Contract size	1,000 metric tons
Pricing	In EUR per metric ton (€ /MT), excluding taxes
Minimum tick	Twenty-five euro cents per metric ton (€ 0.25/MT)
Expiration	Last Thursday of each calendar month (in case the last Thursday of the calendar month is not a Business Day, the next following Business day)
Introduction	Introduction of new contract series is at expiry of old contract series
Reference Prices	Fixing every Thursday (in case the Thursday is not a Business Day, the next following Business Day) between approximately 14:00 – 16:00 hrs (CET)
Terms and conditions of contracts	Generally accepted Master Agreement for the trade of Industrial Wood Pellets (bulk)
Payment terms	98% of invoice amount within 48 hours after bill of loading, balance adjusted for actual net caloric value to be settled 48 hours after discharge

Source: www.endex.nl

The PFI requires less than 0.5%, 1%, 2% and 6% of ash content for Super Premium, Premium, Standard and Utility grade pellets, respectively. The most of the European standard call for ash content between 0.5 and 1.5% (existing standards are mostly for premium pellets) with exception of British code of good practice that allows the ash content up to 3% for some grades of pellets. Industrial wood pellets traded through ENDEX cannot have more than 1.5% of ash, while Electrabel quality norm requires less than 1%. While most of the tree species have the ash content less than 1% (without bark) the ash content of switchgrass can vary from 2.3 – 9% and depends on switchgrass population, where and how it is grown, fertilizers used, time and type of harvest etc. According to the Agricultural Utilization Research Institute's (AURI) analysis on different biomass feedstock, ash content of switchgrass was 5.51% (Campbell 2007). Samson (2008) reports ash content from 2.7% to 3.2% for spring harvested and 4.5-5.2% for fall harvested switchgrass. Due to its higher ash content switchgrass pellets will be classified as utility grade pellets by PFI standards and as industrial pellets in EU. Some manufacturers started producing multi-fuel appliances that use low-grade wood and agricultural biomass pellets, and development of this technology will possibly increase demand for these types of pellets (Campbell 2007).

Chloride content is also important since it causes corrosion of metals, and alkali chlorides cause slagging and fouling in a combustion system (Campbell 2007). PFI standardization gives only recommendations for chloride content (<300parts per million or 0.03%). Swedish, German and Italian standards call for <0.03% as well. Austrian standard is more strict and calls for less than 0.02% of chlorine content while British code of good practice recommends <800ppm. While this requirement is hard to be achieved by most of agricultural biomass, spring-harvested switchgrass has 0.02% of chlorine due to nutrients leaching from switchgrass material during the winter (Samson et al. 2000). Product specifications for industrial wood pellets (ENDEX) call for <0.03% the same as Electrabel's quality norms for power generation. The extent to which chloride content is harmful to appliances (causing more corrosion, slagging and fouling) is not well documented (Campbell 2007). Multi-fuel appliances advertised as corrosion-resistant make the issue of the chloride content a lesser concern.

Since oak-hickory forest-type covers the largest overall area in Tennessee, especially white and red-oak-hickory (Oswalt et al. 2004) it is assumed that most of the mill residues will come from this type of wood. Table D4 shows compositional analysis of woody biomass and switchgrass feedstock assumed to be used for the production of pellets (Miles et al. 1995).

Delivery to the European market

There is no official database tracking the freight prices for wood pellets and they vary significantly based on contracts with rail company and different consumers. Rail companies hold this information confidental. Couple of studies (Suurs, 2002; Hamelinck et al. 2005; Dornburg, 2008) analyzed long-distance supply chain for biomass, including wood pellets. Suurs provided train transportation costs (including transfer) for pellets as follows: \$9.4/t (500km); \$13.4/t (1000km); \$17.5/t (1,500km) and \$21.5/t (2,000km) (exchange ratio from 12/31/2002 of €1:\$1.05 was used).

Table D4 Compositional analysis of woody biomass and switchgrass feedstock assumed to be used for the production of pellets

Fuel	**Switchgrass**		**Switchgrass**		**Wood**		**Wood**		**Wood**		**Wood**		**Wood**		**Wood**	
Type	**Summer-MM, MN**		**Columbus, OH**		**Red Oak Sawdust**		**Fir Mill Waste**		**Hybrid Poplar**		**Alder/Fir Sawdust**		**Poplar-Coarse**		**Forest Residuals**	
	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry
Proximate Analysis																
Fixed Carbon	12.47	14.37	12.93	14.34	11.92	13.47	6.47	17.5	11.63	12.5	9.14	19.31	11.44	12.26	6.96	13.62
Volatile Matter	71.93	82.94	69.14	76.69	76.35	86.22	30.38	82.1	78.97	84.8	36.27	76.56	80.33	86.14	42.1	82.41
Ash	2.33	2.69	8.09	8.97	0.28	0.31	0.15	0.41	2.51	2.7	1.96	4.13	1.49	1.6	2.03	3.97
Moisture	13.27	--	9.84	--	11.45	--	63	--	6.89	--	52.63	--	6.74	--	48.91	--
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Ultimate Analysis																
Carbon	41.21	47.51	42.09	46.68	44.24	49.96	18.95	51.2	46.72	50.2	24.17	51.02	47.39	50.82	25.7	50.31
Hydrogen	5.03	5.8	5.25	5.82	5.24	5.92	2.21	5.98	5.64	6.06	2.75	5.8	5.49	5.89	2.35	4.59
Oxygen	37.81	43.6	33.87	37.57	38.76	43.77	15.66	42.3	37.66	40.4	18.25	38.54	38.32	41.08	20.42	39.99
Nitrogen	0.31	0.36	0.69	0.77	0.03	0.03	0.02	0.06	0.56	0.6	0.22	0.46	0.55	0.59	0.53	1.03
Sulfur	0.04	0.04	0.17	0.19	<0.01	0.01	0.01	0.03	0.02	0.02	0.02	0.05	0.02	0.02	0.06	0.11
Ash	2.33	2.69	8.09	8.97	0.28	0.31	0.15	0.41	2.51	2.7	1.96	4.13	1.49	1.6	2.03	3.97
Moisture	13.27	--	9.84	--	11.45	--	63	--	6.89	--	52.63		6.74	--	48.91	--
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
HHV, Btu/lb	6,920	7,979	7,002	7,766	7,415	8,374	3,248	8,779	7,615	8,178	4,150	8,760	7,590	8,139	4,429	8,670
Chlorine %	<0.01	0.01	0.17	0.19	<0.01	<0.01	0.07	0.19	0.01	0.01	<0.01	0.02	0.04	0.04	0.02	0.04

Source: Miles et al. 1995

Trains were considered to carry a volume of 1,000t (2,500m^3) with an average speed of 75km/h. He also calculated cost of ship transport, including: capital cost, operation and maintenance cost, fuel cost, transfer cost and port charges. He assumed that vessel will be owned by exporting company and that they would be all unloaded by the port cranes. Table _ shows different type of vessels that are being used for ocean shipping (Suurs 2002). According to Suurs (2002), speed of loading and unloading of pellets ranges between 100-1,000 tons per hour, while cost range between $2.7 and $4.5 per ton with slower speed for unloading. For his calculation he used the highest rates found at that moment. Total specific cost of sea transport for wood pellets (8% moisture content) with CV-II type of vessel used are €21/t for non dedicated transport and between €27-39/t (1-0.5 y/y operation window) for dedicated transport (Suurs 2002). The cost for dedicated ships is higher as a result of additional fuel use during the return trip (Suurs 2002). Siemons et al. (2004) calculated cost of sea transport over distance of 10,000km for wood pellets (10% moisture, 600kg/m^3 bulk density and 17GJ/t NCV) to be €27/t or €1.6/GJ. We used the exchange ratio from European Central Bank for the end of the 2002 to convert euro to dollars and then inflated these cost from Siemons et al. (2004) to 2009 dollars with production price indexes for deep ocean freight transportation (Bureau of Labor Statistics) to get cost for sea transport of $37/t. This is in line with current freight rates $30-60/t depending on type of vessel, origin, destination and cargo type according to representative from Brunswick port Jay Baird (Logistec Inc) and with $30-35/t for wood pellets estimates from Bodo Frey.

Table D5 and D6 lists current freight rates for train and ocean transport for soybeans (they have similar properties like pellets) for selected destinations in US and EU.

Table D5 Train freight rates for soybeans in 2009 for selected destinations

Effective date	Origin region	Destination region	Tariff rate/car	Fuel surcharge per car	tariff plus surcharge per metric ton
Unit train					
12/7/2009	Chicago, IL	Baton Rouge,LA	3,178	$121	$36.37
	Council Bluffs, IA	Baton Rouge,LA	3,192	$130	$36.61
	Minneapolis, MN	Portland, OR	4,110	$622	$52.16
	Evansville, IN	Raleigh, NC	3,204	$146	$36.92
	Chicago, IL	Raleigh, NC	3,804	$181	$43.93
8/3/2009	Chicago, IL	Baton Rouge,LA	3,178	$91	$36.03
	Council Bluffs, IA	Baton Rouge,LA	3,192	$97	$36.26
	Minneapolis, MN	Portland, OR	3,910	$553	$49.19
	Evansville, IN	Raleigh, NC	3,008	$120	$34.48
	Chicago, IL	Raleigh, NC	3,608	$149	$41.41
4/6/2009	Chicago, IL	Baton Rouge,LA	3,178	$0	$35.03
	Council Bluffs, IA	Baton Rouge,LA	3,192	$0	$35.19
	Minneapolis, MN	Portland, OR	4,360	$415	$52.63
	Evansville, IN	Raleigh, NC	3,008	$43	$33.63
	Chicago, IL	Raleigh, NC	3,608	$53	$40.36
2/9/2009	Chicago, IL	Baton Rouge,LA	3,178	$71	$35.81
	Council Bluffs, IA	Baton Rouge,LA	3,192	$76	$36.02
	Minneapolis, MN	Portland, OR	4,360	$314	$31.23
	Evansville, IN	Raleigh, NC	3,008	$518	$42.62
	Chicago, IL	Raleigh, NC	3,608	$304	$34.07
Shuttle train					
12/7/2009	Council Bluffs, IA	Houston, TX			
	Minneapolis, MN	Portland, OR			
8/3/2009	Council Bluffs, IA	Houston, TX	2,787	$324	$34.29
	Minneapolis, MN	Portland, OR	3,502	$553	$44.70
4/6/2009	Council Bluffs, IA	Houston, TX	2,787	$243	$33.40
	Minneapolis, MN	Portland, OR	3,502	$415	$43.17
2/9/2009	Council Bluffs, IA	Houston, TX	2,787	$304	$34.07
	Minneapolis, MN	Portland, OR	3,502	$518	$44.32

A unit train refers to shipments of at least 52 cars. Shuttle train rates are available for qualified shipments of 75-110 cars that meet railroad efficiency requirements.
2Approximate load per car = 100 st (90.72 tons): corn 56 lbs. /bu., wheat & soybeans 60 lbs. /bu.

Source: Agricultural Marketing Service, USDA

Table D6 Ocean freight rates in 2009 for selected product and destinations

Week ending	Export region	Import region	Grain type	Loading date	Volume loads (Metric tons)	Freight rate ($/metric ton)
12/5/2009	U.S.Gulf	Morocco	Hvy Grain	Aug 25/Sep 5	25,000	38
8/15/2009	U.S.Gulf	Morocco	Corn/soybean meal	Aug 1/10	20,000	40
	U.S.Gulf	Morocco	Hvy Grain	July 17/18	25,000	36
	River Plate	Poland	Soybeans	Aug 25/Sep 5	25,000	39
	Brazil	Morocco	Soybeans	Jun 1/10	30,000	29
	Brazil	France	Soybean meal	Aug 18/28	25,000	34.5
4/11/2009	U.S.Gulf	Egypt Mediterranean	Hvy Grain	Jan 14/18	60,000	12.15
	Brazil	Greece	Soybeans	Feb 18/16	24,000	24
	U.S.Gulf	China	Hvy Grain	Jan 1/15	55,000	21
2/21/2009	River Plate	Sp Mediterranean	Soybean meal	Dec 5/10	25,000	18
	U.S.Gulf	China	Hvy Grain	Feb 1/10	55,000	23.75

Source: Agricultural Marketing Service, USDA

VITA

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