FEBRUARY 1998 ECN-C--98-013

ECONOMICS OF POWER GENERATION FROM IMPORTED BIOMASS

P. Lako
S.N.M. van Rooijen

Preface

The ECN units Policy Studies and Fossil Fuels have conducted several studies with respect to the availability and procurement of biomass for the Netherlands. The aim of these studies is to get a better insight in:

- the long term perspective of biomass as a renewable energy source,
- possible aims of import of biomass,
- cost effectiveness of import of biomass,
- perspectives of conversion of biomass into liquid fuels.

The ECN project number is 77080.

Abstract

This report deals with the economics of import of biomass to the Netherlands, and subsequent utilisation for power generation, as a means to reduce dependence on (imported) fossil fuels and to reduce CO_2 emission. Import of wood to the extent of 40 PJ or more from Baltic and South American states seems to be readily achievable.

Import of biomass has various advantages, not only for the EU (reduced CO_2 emissions) but also for the countries of origin (employment creation). However, possible disadvantages or risks should be taken into account. With that in mind import of biomass from Baltic states seems very interesting, although it should be noted that in some of those countries the alternative of fuel-switching to biomass seems to be more cost-effective than import of biomass from those countries. Given the expected increase in inland biomass consumption in the Baltic countries and the potential substantial futur demand for biomass in other Western European countries it is expected that the biomass supply from Baltic countries will not be sufficient to fulfil the demand. An early focus on import from other countries seems advisable.

Several power generation options are available with short to medium term potential and long term potential. The margin between costs of biomass fuelled power and of coal fired power will become more and more narrow, due to substantial improvements in generating efficiency and reductions of investment costs of options for power generation from biomass, notably Biomass Gasification Combined Cycle.

CONTENTS

SUMMARY

In the Netherlands the potential of agricultural residues, forest residues, and energy crops, is limited due to conflicting land use objectives (agriculture, habitation, infrastructure) and a high population density. Import of biomass for power generation, e.g. for co-combustion with coal, could reduce the dependence on fossil fuels and could entail a significant reduction of CO_2 emissions from (coal fired) power generation in the Netherlands. This CO_2 reduction option has to be regarded in the framework of the government policy to improve energy efficiency by 33% until 2020, and to increase the share of renewable energy in primary energy demand to 10%. Import of wood to the extent of 40 PJ per year or more from Baltic and South American states seems to be readily achievable.

If the focus is on import of biomass from Baltic countries or elsewhere, it proves that biomass import to the European Union has various advantages, not only for the EU (reduced CO_2 emissions) but also for the countries of origin (employment creation). However, possible disadvantages or risks should be taken into account. With that in mind the biomass potential of Baltic countries seems to be so large, that import from that area could be very interesting for European countries (the Netherlands). The potential for biomass import from Latin America appears to be huge. Additional research, however, seems necessary. For some Baltic countries the alternative of fuel-switching to biomass seems to be more cost-effective than import of biomass from these countries. This deserves examination too. Given the expected increase in inland biomass consumption in the Baltic countries and the potential substantial futur demand for biomass in other Western European countries it is expected that the biomass supply from Baltic countries will not be sufficient to fulfill the demand. An early focus on import from other countries seems advisable.

From calculations with a sea transport cost model, mainly based on data from studies of BTG and KEMA/BTG, and comparison of key power generation options for biomass a number of conclusions can be drawn:

- The relatively short transport distance between the Netherlands and Estonia compared to Uruguay provides a distinctive competitive edge to Estonia.
- Co-combustion with a Torbed reactor mainly has potential for the short term, with additional costs of 3-5 ct/kWh compared to coal fired power.
- Biomass Gasification Combined Cide (BIG-CC), is relatively expensive in 2000; however, in 2020 generating costs are only 1.3-2.7 ct/kWh higher than for coal fired power.
- Pressurised Fluidised Bed Combustion (PFBC) could be rather attractive at the end of the next decade, when the potential of co-firing is fully utilised and BIG-CC is not yet fully developed. In 2020 additional costs compared to coal fired power are 1.5-3.0 ct/kWh, slightly more than for BIG-CC.
- The most expensive option is ‘biocrude’ from Uruguay. ‘Biocrude’ combustion in a PFBC plant is 4.4-9.0 ct/kWh more expensive than coal fired power; the gap declines due to decreasing costs of ‘biocrude’.

1. INTRODUCTION

Recently, a number of studies on import of biomass in the Netherlands were published [1,2,3,4]. Import of biomass is regarded as an economical way to reduce the national CO_2 emission. These studies address economic, organisational, and juridical aspects, and the question of sustainability of import of biomass. The studies have to be regarded in the framework of the government policy to improve energy efficiency by 33% until 2020, and to increase the share of renewable energy in primary energy demand to 10% in 2020, requiring import of biomass to the extent of 40 PJ.

In the Netherlands the potential of agricultural and forest residues is limited. The same holds for energy crops, due to conflicting land use objectives (agriculture, habitation, infrastructure) and a high population density. As a matter of fact, a recent ECN-BS report [5] gives an overview of the potential of biomass in European countries and of the motives for import of biomass to the Netherlands. The Netherlands are well positioned with respect to import of biomass. Baltic states could supply large amounts of wood fuel. Also South American states (e.g. Uruguay) have valuable assets, a.o. Eucalypt plantations. From a resource point of view, import of biomass from such regions could be a sustainable option, presumed criteria with respect to sustainable forest/plantation management are fulfilled. Some studies show that even larger amounts than the aforementioned 40 PJ could be supplied, if need would be. A prerequisite would be timely and adequate forest management measures in the countries of interest.

However, a number of questions arise with respect to the economics of power generation based on imported biomass. The economics of biomass fuelled power depend on the cost of imported biomass, and on the cost of the power generation process. BTG [1] and KEMA/BTG [2] studies provide cost estimates for biomass at the border of exporting countries. Departing from this cost level - plantation management, harvesting, predrying, and transport to the harbour - a simple sea transport cost model is added, including loading, unloading, port and canal rates. Finally, cost per kWh is calculated, taking into account economic characteristics of the power plant.

Chapter 2 presents summaries of a number of studies on import of biomass. Chapter 3 gives an overview of the export potential, and criteria for sustainable forest management in Baltic and South American states. In Chapter 4 the transport cost model used is described, and cost of imported biomass is presented as a function of country of origin (distance), type of wood fuel (logs or chips), size of bulk carrier, and level of fuel oil price (influencing sea transport costs). In Chapter 5 costs of imported biomass from Chapter 4 are used to estimate the cost of power generation, based on dedicated biomass fuelled power plants or co-combustion with coal; these costs are compared to those of conventional power generation based on coal. Chapter 6 presents a number of conclusions on the potential of biomass import, and on the economics of power from imported biomass.

2. RECENT STUDIES ON BIOMASS IMPORT

2.1 Foreign wood fuel supply for power generation in the Netherlands

In 1995 BTG issued a study on the economics of power generation based on co-combustion of imported biomass and coal, on behalf of Novem (EWAB programme) and the FAO (Food and Agricultural Organisation of the UN) [1]. In the following a synopsis of this study is presented.

Coal fired power plants give a contribution of about 55% to the CO_2 emission of Sep (Dutch Electricity Generating Board) power plants. Based on (original) plans of Sep, this contribution would rise to 65% in 2005. This report investigates the biomass co-firing options for pulverised coal fired power plants, with the aim to reduce the CO_2 emissions of Sep.

A 10% substitution of biomass for coal (energy basis) is assumed to be a reasonable mid-term target (2005). This is equal to 1,724,000 t_{20} of biomass per year. Besides indigenous supplies of e.g. forest residues, 1.02 Mt_{20} of additional biomass would be needed to meet this demand.

Two supply options are available: indigenous energy crops and imported biomass. Procurement of energy crops in the Netherlands is a rather expensive option. Import of biomass could be more economic. The latter option is the subject of this report.

Two countries are investigated for the possible import of biomass:

- *Estonia*: A young, rapidly developing country in the Baltic region, with a considerable forestry potential. It has short-term opportunities for forest residue supply and long-term potential for fuelwood supply including sustainably managed forests.
- *Uruguay*: In this South American country wood production was subsidised from 1987. The country has a stable political climate and a history of sustainable fuelwood plantations. This country's export potential is amply sufficient to meet the predefined biomass demand.

An analysis is made of the possibilities and restrictions of import of biomass from these countries, based on research, the work of local consultants, and a field visit. In order to complete the cost analysis, models are developed to estimate sea transport costs and the required biomass preparation costs.

In sum, the financial-economic conclusion is that additional costs for co-firing imported wood from Estonia (approximately *ƒ* 2.9/GJ) may be low enough to compete with coal. This will depend in part on the level of CO_2 reduction instituted by the Dutch government and measures adopted by Sep. Table 2.1 shows the breakdown of co-firing cost for imported wood fuel.

Table 2.1 *Co-firing cost of wood fuel from Estonia and Uruguay (ƒ /GJ)*

	Estonia	Uruguay
Wood production	1.14-1.40	1.68
Local transport[1]	0.56-0.73	0.78
Sea transport[2]	2.01-2.14	4.01-5.36
Total cost to harbour	3.71-4.27	6.47-7.82
Preparation cost[3]	3.01-3.11	3.11
Avoided coal cost	(4.01)	(4.01)
Total cost[4]	2.72-3.18	5.48-6.92

[1] Includes pre-drying cost to MC = 25% (moisture content 25%).

[2] Includes loading and unloading, excludes chipping (included in preparation cost).

[3] Includes chipping and pulverisation, except for Estonian chips (ƒ 3.01/GJ).

[4] The ranges do not directly add to the total cost, due to cost differences for logs or chips.

Exchange rates used: US$ 1 = ƒ 1.6; DM 1 = ƒ 1.12.

One of the possible restrictions to the application of imported biomass is that the energy consumption for long-distance sea transport and biomass preparation could amount to as much as 20-33% of the primary energy content of the fuel. This primary energy comes from fossil fuel which contributes to CO_2 emissions, however it is partly compensated by avoided fossil fuel used in the mining, preparation and transport of coal.

The authors give the following recommendations:

1. On the short term the possibilities of co-crushing wood and coal in pulverised coal fired power plants should be evaluated.
2. The required biomass particle size for co-firing options should be evaluated.
3. Investigations should be started on the possible co-firing rate of biomass in Dutch pulverised coal fired power plants.
4. The high sea transport cost and energetic cost of sea transport and preparation of imported biomass indicates the need for energy concentration techniques. Possibilities should be examined for the production of high-density energy carriers (charcoal, pyrolysis oil), in combination with co-generation (from producer gas and process heat) in the biomass exporting countries. Such a highly efficient conversion process has the potential to considerably reduce energetic and economic transport cost and biomass preparation cost, and to reduce the overall financial cost of co-firing.

The BTG study proved to be a valuable source of information for this study.

2.2 Co-combustion of imported biomass from Estonia in the coal fired power plants Maasvlakte (EHZ) and Borssele (EPZ)

In 1996 a study on the economics of imported biomass for power generation was finalised by KEMA and BTG, on behalf of power generating companies in the Netherlands and Novem [2]. This study focuses on options for import of biofuels from Estonia and on co-combustion options for coal fired power plants at the Dutch coast (Maasvlakte, Borssele). To a lesser extent organisational aspects are addressed. In the following a synopsis is given of sections on the economics of biomass import.

The availability of wood fuel in Estonia for co-combustion of biomass in three coal fired power units is analysed. It is concluded that sufficient biomass for one coal fired power unit is available on the short term (2 years). Import of additional wood fuel would require a longer timespan. Co-combustion or co-gasification also requires lead-times varying from less than 1 year (co-combustion based on pulverised wood fuel) to 3 to 4 years (co-combustion based on a Torbed installation).

For each of the biomass import options a cost range is presented. For comparison of the options average cost levels are used. First of all, it is concluded that the total cost of co-combustion of biomass from Estonia exceeds the fuel cost of coal firing. On the basis of average biomass supply costs the following power generation costs arise:

- Co-combustion of charcoal, produced in Estonia, shows the lowest cost level - approximately 10 ct/kWh - of all options considered.
- Next best in economic terms is co-combustion based on a Torbed installation, with a generation cost of 12 to 12.5 ct/kWh.
- A more conventional option, co-combustion based on pulverised wood, is somewhat more costly: 14 ct/kWh.
- Co-gasification with steam-side integration is deemed to be marginally more costly than conventional co-combustion: 14 to 15 ct/kWh.
- The most expensive option seems to be co-combustion of pyrolysis oil (based on pyrolysis in Estonia): approximately 18 ct/kWh.

Taking into account fiscal instruments for renewable power generation in the Netherlands, the cost for co-combustion of charcoal could be decreased to about 7 ct/kWh. If comparable investment subsidies would be available for charcoal production in Estonia the resulting cost would even be lower. With the same Dutch fiscal instruments, co-combustion based on a Torbed installation would cost about 8.5 ct/kWh, and conventional co-combustion 10.5 ct/kWh. As the avoided cost of coal is about 4 ct/kWh, the gap between the co-combustion cost, inclusive of fiscal incentives, and the avoided coal cost remains 3 to 7 ct/kWh.

2.3 Latvian fuelwood supply to the Netherlands?

In 1996 Factor ITP issued a report on fuelwood supply from Latvia, on behalf of Novem (EWAB programme) [3]. This report addresses organisational, juridical, and economic aspects. In the following the main results of the study are summarised.

Latvia is one of the Baltic states which regained independence in 1990. In the first years after 1990 the economy showed a sharp decline. Recently, Latvia experienced economic growth and a falling level of inflation. The country has a large potential for export of fuelwood. At present 3 million m^3 of unused fuelwood (18.7 PJ) per year is available, either for domestic use or for export. This amount of fuelwood is twice as large as the possible substitution of 10% of the coal in two out of three large coal fired units at the Maasvlakte and Borssele, which equals 1.48 Mt of fuelwood per year (9.25 PJ/y). The latter is considered as a reasonable target for year 2000. After that, much larger amounts of fuelwood could be made available.

With respect to the organisational and juridical aspects, it is not recommended that Dutch power companies would deal directly with today's many small private companies and private forest owners with user's rights in Latvia. Instead, a trade organisation in Latvia, instituted by Dutch power companies, would be preferable. The trade organisation would have to be independent from the Latvian state. It would be an intermediate in contracts between the Dutch power producers and Latvian forest owners, forest managers, and private logging firms.

A possible 'fair' price for Latvian fuelwood at the export harbour would be US$25-29/ton, which is equal to US$54-63/ton of coal equivalent; such a price level could be guaranteed for five years or more. However, for coal the price is about US$58/ton c.i.f. Rotterdam. Therefore, import of fuelwood from Latvia would be more costly, as transport costs have to be added to the aforementioned price of US$25-29/ton (US$54-63/ton of coal equivalent). It is stressed that direct subsidies to Latvian forest owners or forest managers would be counterproductive, as it would prevent the development of a genuine market economy for fuelwood. Instead, eventual subsidies would have to be paid to the power producers to overcome financial obstacles in substitution of fuelwood for coal.

On the long term (2020 and beyond) the export potential of Latvia is much higher. Latvia has 1.7 million ha of abandoned farmland. When the Latvian privatisation and restitution process will be completed, almost 200,000 new owners will have to search for new economic activities on their abandoned farmland. At short notice there is no alternative for wood production. Short rotation plantation of alder and aspen for energy purposes, whether or not in combination with hardwood species, could become an interesting new economic opportunity for these new landowners. Theoretically Latvia has the potential to produce 17 million ton of fuelwood per year on that land area. This is equivalent to about 210 PJ per year, 75% more than the total biomass target of 120 PJ per year for the Netherlands in 2020.

2.4 Sustainability of biomass import for the Dutch energy economy

In 1996 ETC Consultants in Development Programmes issued a report on sustainability of biomass import for the Dutch energy economy, on behalf of Novem (EWAB programme) [4]. In the following the main results are summarised.

A brief inventory of international opinions (through e-mail) shows that import of biomass meets a number of doubts with respect to sustainability. Both the expected growth of biomass consumption for energy purposes and the initial doubts regarding its sustainability underline the need for development of sound sustainability criteria, based on a thorough understanding of the underlying concepts of sustainable development.

During the last years, it has become agreed upon that sustainable development has several interdependent dimensions, notably a social dimension, an economic dimension, and an environmental dimension. Sustainability essentially implies a long timeframe. The risks of impact of activities in one dimension upon the other dimensions should be carefully balanced.

As the balancing of risks is essentially a cultural process, an operational definition of sustainable development can only be made at the local level. In international co-operation this would imply that all parties would have to agree on the sustainability of activities and would have to negotiate compensation for any trade-off. A useful principal for local sustainable development would be reducing dependence on external systems at the lowest level: first local, then regional and global.

With respect to addressing transboundary issues, the different examples of putting sustainable development into practice show considerable variation. The policies and instruments addressing issues with problems as well as solutions in another country (i.e. development co-operation, tropical rainforest) start mostly from the demands, initiatives, and perspectives of the local and national level stakeholders of that country.

However, the situation appears to be more difficult in transboundary issues such as Joint Implementation. Here, the goals (and responsibility) and means have been geographically separated. Where this separation is across different countries and cultures, many discussions and negotiations have been necessary. The most common conclusion of the discussions is that an activity is permitted only, if both parties agree to the desirability of the activity and the activity is supportive of the national development strategy.

An operational definition of sustainable development can only be made at the various appropriate levels, involving the relevant stakeholders. This means that the activity should be considered with respect to the sustainable development agendas of the Netherlands, the biomass exporting country, as well as the local biomass production level. Furthermore, it should of course be acceptable to the international community.

In principle, two approaches can be taken in developing criteria for the evaluation process. The first approach would be to develop an extensive list of indicators combined with a weighing method. However, this approach would be based on the singularity of sustainable development on the one hand (in the sense that one could develop a single weighing mechanism valid for all sustainable development agendas) and the possibility of developing an exhaustive set of (quantifiable) indicators on the other.

In contrast, the second approach focuses on a set of general criteria, with a more holistic perspective. These general criteria could function well as a checklist of points that should be addressed in the design of a project, and could be used effectively for evaluation of a project proposal by either an expert or a panel (combination of different fields of expertise or interests). This approach is therefore considered the most appropriate for the transboundary, multi-dimensional issues at stake here.

Based on this second approach, a set of general, economic, social, and environmental criteria is proposed together with framework conditions for the evaluation process. As an example the following framework conditions are mentioned:

1. The opinion of all involved parties (stakeholders) with respect to the sustainability of the approach should be heard and considered.
2. In performing an evaluation of sustainability, the social, environmental, and economic dimensions and their interrelations should all be considered and balanced.

3. After assessing the impact on all relevant levels, the activity should be agreed upon as sustainable by the parties involved. If any trade-offs appear, appropriate compensation should be negotiated.
4. Activities should not risk unsustainable effects, that cannot be undone within one generation.
5. The activities should cause a minimum dependence upon external systems and should close cycles at the lowest level.
6. Taking local-level accountability as starting point for sustainable forest/plantation management: local claim making power, rights, benefits, capacities.
7. Incorporate local requirements: avoid undue limitations for, promote solving problems experienced by, create competitive advantage for social target groups, i.e. producers and people that can be involved in handling/processing.

3. BIOMASS POTENTIAL

3.1 Background

The Dutch government has the intention to increase the share of renewable energy up to 10% in the year 2020. The role of biomass in this policy target will be significant. In the third energy white paper it is planned that in 2020 about 120 PJ will be generated from biomass and waste.

Three different types of biomass are available to fulfil the targets set:
1. biomass wastes and residues,
2. energy crops (produced in the Netherlands),
3. imported biomass.

Faay 1997 [5] concluded in his thesis that the total energy potential of net available biomass wastes and residues (option 1) amounts to about 70 PJ. The costs of this type of biomass vary from -10 to 5 ECU per GJ. Available integral waste streams (such as household waste) amount to an additional 90 PJ. Concerning the second option, the production of energy crops, Faay forecasts an energy crops supply of 0 to 10 PJ available in 2000 and 27 to 59 PJ available in 2015. The costs of the production of energy crops are estimated at 4.5 ECU per GJ. Total contribution of biomass in the Netherlands is estimated at about 190-220 PJ per year in the period 2010-2015. This amount exceeds the policy target of 120 PJ and Faay therefore concludes that the biomass target for 2020 can be reached without import of biomass.

From economic point of view it might, however, be more attractive to import biomass from countries with a surplus than use domestic biomass (option 1 and 2). This study will focus on the possibilities for this third option, the import of biomass, covering both economic[1] and environmental aspects.

The outline of this Chapter is as follows. Sections 3.2 and 3.3 will briefly discuss the advantages and disadvantages of import of biomass and the relationship with sustainability. In section 3.4 a potential market for biomass will be simulated and attention will be paid to the demand and supply-side and the role of the Netherlands. Finally a link with Joint Implementation and Tradable Permits will be made.

3.2 Advantages and disadvantages of imported biomass

Importing biomass as an energy source has various advantages. The main advantages are:
- increased diversification of energy sources,
- contribution to the policy target of 10% renewable energy in the year 2020,
- contribution to policy target to reduce CO_2 emissions,

---

[1] See Chapters 4 and 5.

- replacement of fossil fuels by inexhaustible energy sources,
- cost effective measure compared to some other renewable energy options,
- contribution to employment and welfare of exporting countries,
- adding value for the Netherlands in the form of technical 'know-how'.

However, the import of biomass also involves some disadvantages and risks:
- possible deforestation and desertification,
- use of chemical inputs for the production of energy crops,
- extraction of nutrients and water,
- conflicting land ownership,
- ethical problems as the agricultural areas are not used for production of food.

Given these disadvantages and risks it is of major importance to assure that the imported biomass is produced in a sustainable way. The next section will focus on biomass and sustainability.

3.3 Biomass and sustainability

Is seems clear that sustainability is a necessary condition for import of biomass. A possible way to evaluate the sustainability concerns the analysis of the complete chain with a so-called 'Life Cycle Assessment' (LCA).

The Centre for Agriculture & Environment (CLM) developed and applied an LCA methodology for evaluation of the sustainability of energy crops in Europe. For eleven energy crops[2] the environmental and socio-economic effects from 'cradle to grave' have been assessed. The following ecological criteria were taken into account:
- energy balance,
- emission of greenhouse gases,
- emission of acidifying gases,
- emission of ozone depleting gases,
- emissions of minerals to soil and water,
- emission of pesticides,
- soil erosion,
- ground water depletion,
- use of resources,
- waste production and utilisation,
- contribution to biodiversity,
- contribution to landscape values.

With respect to the socio-economic sustainability the following aspects were investigated:
- cost price of energy produced,
- cost of abated CO_2 emission,
- employment creation per hectare.

---

[2] Rape seed, sugar beet, winterwheat, sweet sorghum, silage maize, hemp, reed, miscanthus, poplar, willow, eucalyptus and grass fallow.

The life cycle assessments lead to the following conclusions:

- 'On the criteria which can be used for a direct comparison of energy crops and fossil energy sources, energy crops score positively, they have positive net energy budgets and positive net greenhouse budgets and their net emission of acidifying gases is near neutral.
- Rape, sugar beet and winter wheat generally score low on ecological and socio-economic criteria. Their 'reason of being' is to produce liquid fuels, but these routes have a low energetic efficiency leading to low scores for energy budget and for greenhouse budget and to high cost prices. Besides each scores low on several other ecological criteria, such as mineral emissions (all three), pesticides (wheat) and erosion (sugar beet). The same applies to sweet sorghum, concerning ecological criteria. Combining a low energy production and bad scores on other ecological criteria, scores on the criteria expressed per GJ are very bad in comparison with those of 'solid fuel crops'.
- Silage maize and hemp, both used in electricity routes, have the highest energy and greenhouse budgets. But for the other criteria these crops are very different. Whereas maize spoils its position by bad scores on most of the other criteria, hemp scores only bad on erosion and resources, which in most regions are criteria of less importance. So in the final weighed average score, hemp comes out as one of the best options for energy cropping.
- The other crops for electricity routes are perennial crops: miscanthus, poplar, willow and eucalyptus. Their scores for energy and greenhouse gases are medium (poplar), reasonable (willow, miscanthus) and very good (eucalyptus). Their scores on nearly all other ecological criteria are reasonable to good. Weaker points are biodiversity and landscape and for eucalyptus also water use. In economic respect they have low costs, but their contribution to employment is also low.'

3.4 Potential market for biomass

Various factors influence a potential market of biomass. The main determining aspects are the supply and demand, both influenced by cost aspects.

Another aspect, although of minor importance, concerns the role of Joint Implementation (JI) and Tradable Permits (TDP) and the potential trade-off between two policy targets:

1. 10% renewable energy (2020),
2. 10% reduction of CO_2 (2010).

The trade-off exists in the fact that biomass in foreign countries can be used to contribute to (i) reduction of CO_2 emissions (second policy target) by implementing a fuel conversion project under the umbrella of Joint Implementation or Tradable Permits, and (ii) increase the use of renewable energy (first policy target) by transporting the biomass to the Netherlands.

In the following sections attention will be paid to the main aspects influencing a potential biomass market:

- costs,
- potential demand and supply (volume).

Subsection 3.4.3 briefly discusses the relationship between imported biomass and Joint Implementation & Tradable Permits.

3.4.1 Costs

Chapter four and five deals with a detailed cost analysis of imported biomass. Since it will not be possible to analyse a potential market for biomass without cost figures some rough data on the production and transport of biomass will be used in this subparagraph. Table 3.1 gives an overview of these figures.

Table 3.1 *Costs of (imported) biomass (ƒ/GJ)*

		Production	Local transport (incl. turnover)	Sea transport	Transshipment	Total
Conventional fuels	Coal					4
	Gas and oil					6
Residues Netherlands	Various residues					to 15
Biomass	Willow	10				10
Netherlands	Miscanthus	16				16
Biomass Brazil[6]		1.6	0.53[3]			2.18
Biomass USA		5.05-7.14				5.05-7.14
Biomass Europe[5]	Average cost	10				10
Biomass Europe[6]	Average cost	6.5				6.5
Import biomass Estonia[2]	Import logs	2.11-2.98	1.12-2.85	2.11-4.16[4]	1.05	6.39-11.04[5]
	Import chips	2.11-2.98	1.68-3.94	1.69-4.16	1.05	6.52-12.13[6]
	Import charcoal	5.89-8.13	1.24-4.04	0.66	0.20	7.99-13.03[7]
	Import pyrolysis oil	12.11-22.49	0.91-2.97	0.59	0.14	13.75-26.19 [8]
Import biomass Estonia[1]	Import chips	1.14-1.50	0.56-0.63[9]	2.01-2.04		3.71-4.17
Import biomass Uruguay[1]	Import logs	1.68	0.78[10]	4.01-5.66[11]		6.47-8.12

Two main conclusions can be drawn from Table 3.1:

- the prices of (imported) biomass exceed the price of conventional fuels in the Netherlands,
- importing biomass is cost-effective compared to the production of biomass as well in the Netherlands and, to some extent, to the use of available residues within the Netherlands.

As discussed in KEMA (1996) it seems difficult to forecast price movements over a longer time period (e.g. 1995-2020). The prices of both conventional and renewable energy options may change. An energy tax like in Sweden and Denmark may for example significantly change the relative prices of the energy options. According to the KEMA the expected increase in the demand for energywood in Estonia (depending on

---

[3] 85 km

[4] 2.3 ƒ/GJ according to [7].

[5] Logging-chipping-grinding/torbed/gasification-co-firing.

[6] Chipping-grinding/torbed/gasification-co-firing.

[7] Co-firing charcoal.

[8] Pyrolysis oil-oillansing-co-firing.

[9] 0.672 ƒ/GJ/150 km.

[10] 120 km.

[11] 4 ƒ/GJ according to [7].

the paper & pulp industry, market of fuel wood and the price for transport fuels) may increase the marketprice for wood at the edge of the forest.

3.4.2 Supply and demand

Apart from the Netherlands other countries might be interested to import biomass in the near future. In this section a rough estimate will be made of the potential importers and exporters on a biomass market.

In an ECN study on 'European biomass scenarios and the need for import of biomass' (1997)[7] it was found that both the Netherlands and Belgium are countries with a low potential for biomass production. High potentials for biomass can be found in Scandinavian and Mediterranean countries (except Italy). Countries with a medium potential[12] are Germany, France and United Kingdom. These figures only reflect the potential in volumes. A costs assessment could change the outcome since countries with a large potential, like Sweden, are presumed to be a competitor (demand-side) on the biomass market due to the relatively high inland production costs.

In a study of NUTEK 'the forecast for biofuel trade in Europe - the Swedish market in 2000' (1993)[7], an attempt is made to forecast the potential for biofuel trade in Europe in the year 2000 based on indicators like the gross supply of industrial residues, the stock of forest biomass and the quantities of biomass residues in agriculture. The following conclusions were drawn:

- 'Europe is in a long perspective a deficit area for biofuels, in the sense that the potential market vastly exceeds the potential biofuel supplies. However, no general deficit is foreseen for the period to the year 2000.
- A few countries and regions have a potential net surplus of biofuels in the year 2000, namely parts of north-western Russia, Finland, Sweden and Norway. Others would have a temporary surplus, due to imbalances between biofuel production and development of the domestic market. Examples of such countries are Estonia, Latvia, Lithuania, Belarus and Spain.
- Costs and prices of biofuels will be considerably lower in Eastern Europe than in the present EC/EFTA area.
- It is likely that the prices of biofuels in the Swedish market will continue to go down slowly, at least in real values. It should be emphasised, however, that the prices are with the assumed taxes included. Thus, the taxes tend to have mainly a switch effect with regard to the pace of the conversion to biofuels and the establishment of new facilities. It means that taxes will affect the size of the biofuel market, but in principal not the price of formation.
- The fact that Swedish fuel users have options to import biofuels could lead to an increase in the demand as import reduces the risks of being exploited by domestic suppliers. Import of biofuels could therefore contribute to a fast and healthy development of the Swedish biofuel market and lead to long term benefits also for the domestic suppliers.'

In a market simulation conducted by NUTEK the Netherlands, Sweden, Denmark, Germany, Belgium, United Kingdom and Italy appeared to be importing countries on a biomass market. Russia, Estonia, Latvia, Lithuania, Norway, Finland, Spain and Can-

---

[12] Less than 10% biomass in 2010 related to primary energy demand of 1990.

ada were identified as potential exporters. More details per country can be found in Annexes A and B.
Based on above insights the following Table has been constructed.

Table 3.2 *Potential importers and exporters of biomass*

Potential importers of biomass	Potential exporters of biomass
The Netherlands	Estonia
Sweden[13] (in long term export potential)	Latvia
Denmark[13]	Lithuania
Germany	Russia (European part)
Belgium	Belarus
United Kingdom	Ukraine
Italy	Romania
Luxembourg	Norway (high costs)
Austria	Finland (high costs)
	Spain (spot market)
	Canada (high (transport) costs)
	Uruguay[1]

Potential importers of biomass - potential competition for the Netherlands

Table 3.3 gives an impression of the potential extent of demand (and competition for the Netherlands) on a biomass market. It is assumed that in all potential importing countries biomass will fulfil respectively 5% (low scenario) and 15% (high scenario) of the total energy requirement in 2020.

Table 3.3 *Potential demand in 2020*

	Low scenario		High scenario	
Potential importers of biomass	Biomass [% TPER[14] 2020]	Demand for biomass [PJ]	Biomass [% TPER[15] 2020]	Demand for biomass [PJ]
The Netherlands	5	168	15	504
Sweden	5	102	15	306
Denmark	5	51	15	153
Germany	5	792	15	2,376
Belgium	5	112	15	336
United Kingdom	5	545	15	1,635
Italy	5	436	15	1,308
Luxembourg	5	8	15	24
Austria	5	66	15	198
TOTAL		2,280		6,840

The presented total demand for biomass exceeds the demand on an international biomass market since a substantial part may be fulfilled by available inland biomass. The presented figures only give insight in the proportions and can be related to the potential supply figures presented hereafter.

---

[13] Also stimulated by significant tax on fossil fuels.

[14] Total Primary Energy Requirement.

Potential exporters of biomass

The following studies have investigated biomass potentials:

- NUTEK, Forecast for biofuel trade in Europe, 1993[7].
- FACTOR ITP, Latvian fuelwood supply to the Netherlands?, 1996[3].
- BTG, Foreign wood fuel supply for power generation in the Netherlands, 1995[1].
- KEMA, Bijstoken van geïmporteerde biomassa uit Estland in de Centrale Maasvlakte (EZH) en de Centrale Borssele (EPZ): economische haalbaarheid, 1996[2].

The study of the NUTEK was briefly discussed before in section 3.4. The results are presented in Table 3.4 and the Annexes A and B.

BTG investigated the foreign wood supply from Uruguay and Estonia for power generation in the Netherlands. In Uruguay only 4% of the land consists of forest and woodland. Around 35% of the forest is used for production of eucalyptus and pine. Most of the wood is used for inland consumption (industrial heating, residential cooling, paper industry). About 4% is exported. It was estimated that a constant export volume of 2.13 Mt_{25}/year (around 30 PJ) until 2015 would be a fair estimate under optimistic conditions. As far as the export potential of Estonia is concerned 9 to 35 PJ would be available according to the BTG study (see also section 2.1).

The study 'Latvian fuelwood supply to the Netherlands' concludes that until the year 2000 around 3 million m^3 of unused fuelwood or 18.7 PJ will be annually available in Latvia. A fair price for the fuelwood is estimated at 1.85 to 2.15 US$ per GJ. After the year 2010 an additional amount of biomass would be available in Latvia. The country has 1.7 million hectares of abandoned farmland. In theory Latvia has the potential to produce 17 million ton or 212 PJ energywood per year on this farmland (see also section 2.3).

According to Hemming Larson[6] the forest in Estonia covers 1.8 million hectares with a growth of 9 million m^3 per year of which only 3 million m^3, i.e. about one third of the growth is harvested annually. The forest area in Latvia and Lithuania is 2.7 and 3 million hectares respectively. Under the condition that 25%[15] of the forest would be harvested annually Estonia, Latvia and Lithuania could produce resp. 68 PJ, 101 PJ and 113 PJ energy wood[16].

Table 3.4 summarises the results. A distinction is made between category 1 countries (countries with highest export potential to the Netherlands given costs, distance and infrastructure) and category 2 countries (countries with lower or less certain export potential given costs and infrastructure).

---

[15] According to BTG assumptions.

[16] Based on a yield of 150 GJ/ha.

Table 3.4 *Potential supply according to various studies.*

		Supply of biomass [PJ]	
Potential exporters of biomass	2000[7]	2020 low estimate	2020 high estimate
Baltic countries			
Estonia	72	9-35 [1]	68
Latvia	75	18.7 [3]	101[17]/212[3]
Lithuania	86		113[17]
CIS	1,690[18]		
Russia (European part)	75		
Ukraine	89		
Belarus			
CEE			
Romania	429[19]		
Latin America			
Uruguay	n.a.	30 [1]	
Total category 1	2,516		
Potential category 1 country[20]			
Brazil	n.a.		
Western countries			
Norway (high costs)	114[21]		
Finland (high costs)	479[22]		
Spain (spot market)	285[23]		
Canada (high (transport) costs)	3,615[24]		
Total category 2	*4,497*		

Based on the methodology of the studies described before some rough estimates are made to forecast the potential supply of biomass in 2020.

To begin with, Table 3.5 presents some key figures for the selected potential suppliers of biomass. From these figures it can be concluded that:

- the population density in the potential supply countries is relatively low,
- huge land areas can be found in Russia and Brazil,
- the land use varies per country.

---

[17] ECN estimate based on Hemming Larson data.
[18] 207 PJ available form agricultural production (incl. agrobusiness).
[19] 73 PJ available form agricultural production (incl. agrobusiness).
[20] Additional research needed.
[21] 6 PJ available form agricultural production (incl. agrobusiness).
[22] 13 PJ available form agricultural production (incl. agrobusiness).
[23] 23 PJ available form agricultural production (incl. agrobusiness).
[24] 210 PJ available form agricultural production (incl. agrobusiness).

Table 3.5 *Key figures potential suppliers of biomass.*

	Land area [1000 ha]	Population density [per 1000 ha]	Energy use 2020 [PJ]	Cropland and pasture [%]	Forest and woodland [%]	Non-productive land [%]
Baltic countries						
Estonia	4,320	376	364	33	31	36
Latvia	6,410	385	278	40	39	21
Lithuania	6,520	559	481	71	16	13
CIS						
Russia	1,699,580	87	35,636	13	45	42
Ukraine	57,935	878	12,190	72	16	12
Belarus	20,748	502	2,068	45	34	21
CEE						
Romania	23,034	940	3,406	64	29	7
Latin America						
Uruguay	17,362	186	699	86	4	10
Potential category 1 country						
Brazil	845,651	192	13,946	27	67	6
Western Countries						
Norway	30,683	141	1,100	3	39	58
Finland	30,461	167	1,648	9	76	15
Spain	49,944	783	5,294	53	32	15
Canada	922,097	31	12,466	12	45	43

Two different biomass options have been worked out. In the first option it is assumed that 25% of the agricultural land in the Baltic countries will be available for energy wood due to a negative/low population growth and an increased productivity in the agricultural sector. Regarding the second option, the assumption is made that of the unharvested volume in all supplying countries 25%[25] could be made available for managed forestry. The energy yield in Latin America is estimated at 300 GJ per hectare. For the Eastern-European countries the yield amounts to 150 GJ per hectare.

Furthermore a maximum inland transport distance has been derived for Eastern-European en Latin American suppliers (see Figure 3.1). Given the biomass production costs in the Netherlands (10 ƒ/GJ), the inland transport of biomass in Eastern-Europe and Latin America can be up to maximum 1000 resp. 450 km to be cost-effective. This implies that 20% of Brazil and 4% of Russia will be accessible.

The results of the two biomass options are presented in Table 3.6.

---

[25] According to BTG (1995) assumptions for Estonia.

Table 3.6 *Biomass potentials selected countries.*

	OPTION 1		OPTION 2	
	'available agricultural area'		'unmanaged forest'	
	Biomass potential [PJ]	Biomass potential [% energy use 2020]	Biomass potential [PJ]	Biomass potential [% energy use 2020]
Baltic countries				
Estonia	53	15	50	14
Latvia	96	35	94	34
Lithuania	174	36	39	8
CIS				
Russia			1,181	13[26]
Ukraine			346	3
Belarus			266	13
CEE				
Romania			251	7
Latin America				
Uruguay			52	7
Total category 1	*323*		*2,280*	
Potential Category 1 country				
Brazil			8,499	61
Western countries				
Norway			447	41
Finland			871	53
Spain			597	11
Canada			15,560	125
Total category 2			*25,974*	

From the analysis the following conclusions can be drawn:

- the biomass potential of the Baltic countries amounts to 506 PJ,
- especially Estonia might use a significant amount of the available biomass for inland consumption (fuel switch from oil shale to energywood),
- the available agricultural areas in Latvia are an attractive option for production of biomass (as concluded in [3]),
- in Europe the demand[27] for biomass will probably exceed the supply[28] (as concluded in [7]),
- a focus on other land areas might be therefore be reasonable,
- the potential of Latin America appears to be huge. Additional research, however, seems necessary.

---

[26] Under the assumption that the Western part of Russia covers 25% of the total energy requirement.
[27] 2,280 to 6,840 PJ minus available inland biomass.
[28] 2,603 PJ minus inland use of biomass.

3.4.3 Import of biomass versus Joint implementation and Treadable Permits

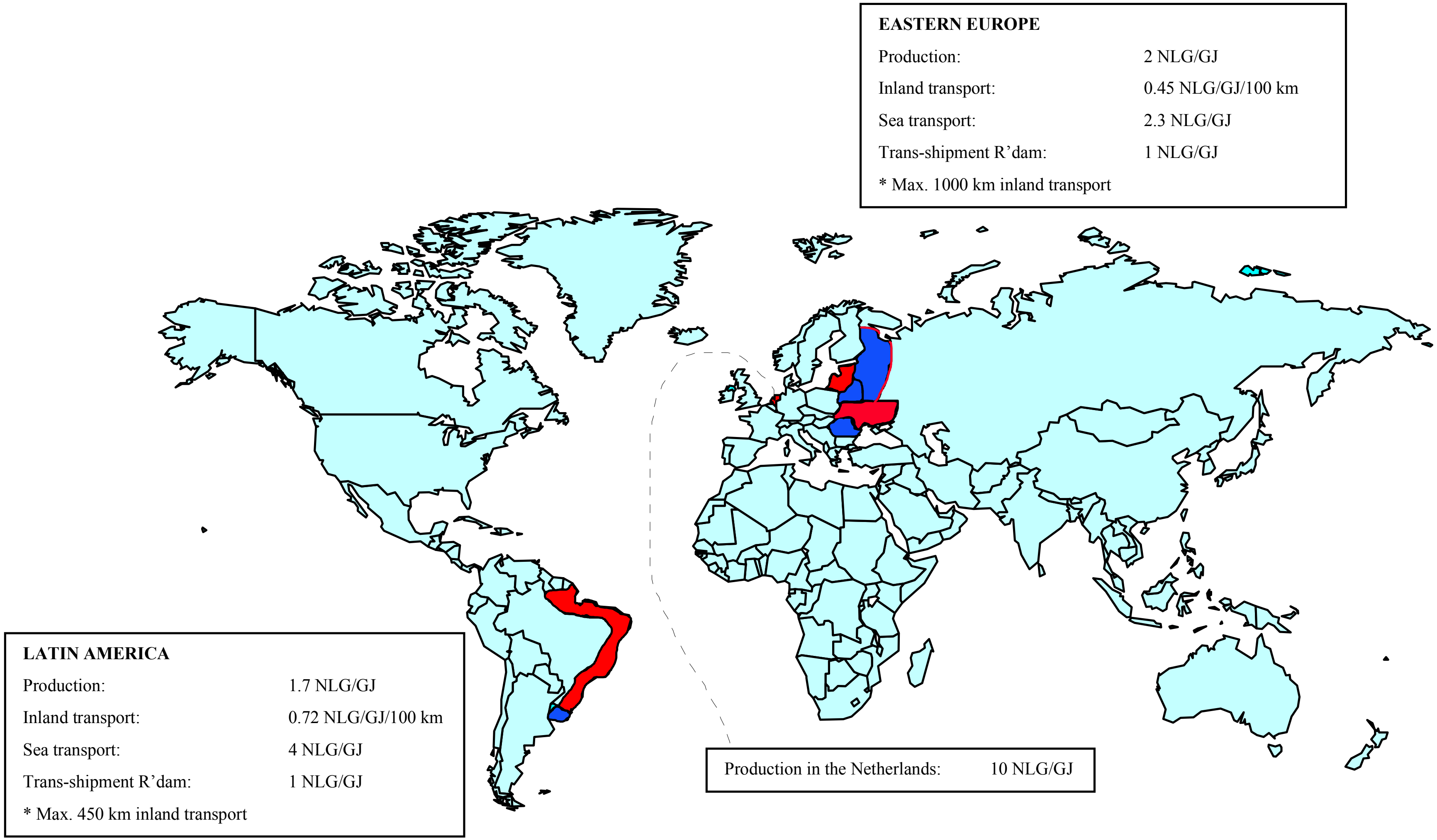
Apart from the policy goal of 10% renewable energy by the year 2020, the Dutch government has also set targets for CO_2 emission reduction by the year 2010. The reduction of CO_2 emissions not necessarily needs to be achieved in the Netherlands itself but, by using the instruments Joint Implementation and Tradable Permits, credits could be purchased from foreign countries as well.

Momentary various JI pilot projects are being executed in Central and Eastern Europe and in developing countries. An example of a pilot project concerns a fuel-switch from oil shale to wood in the Baltic countries. As soon as international crediting will be allowed, the Western countries can include the avoided CO_2 emissions from the foreign projects into their national emission reduction targets.

The fuel-switch projects in the Baltic countries seem to be more cost-effective compared to co-firing (imported) wood in coal-based power plants in the Netherlands. The costs of the fuel-switch projects in Baltic countries vary between 6 to 12 NLG per ton avoided CO_2 [8] while the CO_2 reduction costs of co-firing imported wood from Estonia amounts to 29-34[29]. NLG per ton avoided CO_2 [1]. These calculations are based on the assumption that the emissions of one GJ primary energy (coal) amounts to 93 kg CO_2.

---

[29] Based on incremental costs of 3 to 4 *ƒ* per GJ (related to coal)



EASTERN EUROPE

Production: 2 NLG/GJ

Inland transport: 0.45 NLG/GJ/100 km

Sea transport: 2.3 NLG/GJ

Trans-shipment R'dam: 1 NLG/GJ

* Max. 1000 km inland transport

LATIN AMERICA

Production: 1.7 NLG/GJ

Inland transport: 0.72 NLG/GJ/100 km

Sea transport: 4 NLG/GJ

Trans-shipment R'dam: 1 NLG/GJ

* Max. 450 km inland transport

Production in the Netherlands: 10 NLG/GJ

Figure 3.1 *Biomass potential (logs and chips)*

4. COST OF IMPORTED BIOMASS

4.1 Introduction

Import of biomass for power generation, e.g. for co-combustion with coal, could reduce dependence on fossil fuels and result in a significant reduction of CO_2 emissions from (coal fired) power in the Netherlands. Several questions with respect to economics of import of biomass need to be answered. In this Chapter import of biomass from Estonia and Uruguay is analysed, just like in the BTG study [1]. The KEMA/BTG study focuses on biomass import from Estonia [2].

Costs of plantation management, harvesting, pre-drying, and inland transport are derived from the BTG study. Furthermore, a sea transport cost model, based on sea transport cost data - including rates for loading and unloading, ports and canals - from the BTG study and other studies, has been developed. For biomass import from Uruguay relatively large Panamax carriers are taken into account. The BTG study did not regard this option, as dredging of the Martin Garcia Channel, providing access to the harbour of Nueva Palmira, was not sure by the time this study was issued (1995). Today, dredging to depth of 32 feet is firmly planned[9].

Besides, this study includes an assessment of production and transport of a quasi fuel oil from biomass, viz. so-called ‘biocrude’ from the HTU process. The scope of this study is rather wide, in order to find optimal solutions, which could be outside the range analysed by BTG. It should be noted that the KEMA/BTG study [2] touched on this subject (import of pyrolysis oil).

In Section 4.2 the data underlying the economic analysis and the sea transport cost model are shortly described. Also the economic results for various fuel oil prices, types of wood (logs, chips) and carriers (Panamax, Handymax, etc.) are shown for logs and chips from Estonia and Uruguay. Section 4.3 shows comparable data on biocrude from the HTU process.

4.2 Import of logs or chips

4.2.1 Biomass procurement in Estonia and Uruguay

The economic data with respect to forest/plantation management, harvesting, pre-drying, and inland transport for Estonia and Uruguay are derived from the BTG study.

For Estonia two sets of prices at the harbour are presented, based on either logs or chips (from a chipping installation at the harbour) from residue wood. These costs are shown in Table 4.1. Cost of drying at the roadside is the financial cost in terms of interest. Inland transport cost is based on a mean round trip of 150 km by truck. BTG also presents cost figures for managed forestry wood. These cost figures are slightly lower than those in Table 4.1; woodfuel cost at the roadside for this option is deemed to be typically 20%

cheaper than residue wood. Although managed forestry could be more representative on the long term, it seems prudent to use the more conservative data for residue wood.

Table 4.1 *Cost breakdown for Estonian residue wood (logs or chips)*

Cost item	DM/m^3	DM/t_{25}	DM/GJ	US$/GJ[1]
Woodfuel cost at roadside[2]	10.0	16.7	1.2	0.87
Drying cost at roadside	0.7	1.2	0.1	0.06
Transport to harbour	4.5	7.5	0.6	0.39
Total cost at harbour (logs)	*15.2*	*25.4*	*1.9*	*1.33*
Chipping at harbour	3.1	5.2	0.4	0.27
Total cost at harbour (chips)	*18.3*	*30.6*	*2.3*	*1.60*

[1] Based on the same exchange rates as used in the BTG study: US$ 1 = / 1.60, DM 1 = / 1.12.

[2] Assumed density: 0.6 t_{25}/m^3; lower heating value (LHV) = 13.4 GJ/t

Source: [1]

For Uruguay similar cost data are derived from the BTG study (Table 4.2).

Table 4.2 *Cost breakdown for Eucalyptus wood (logs or chips) in Uruguay*

Cost item	US$/$m^3$	US$/$t_{25}$	US$/GJ
Plantation management cost	2.37	3.56	0.27
Harvesting cost	7.0	10.50	0.79
Pre-drying and inland transport cost[1]	4.37	6.56	0.49
Total cost at harbour (logs)	*13.74*	*20.62*	*1.54*
Chipping at harbour	2.41	3.62	0.27
Total cost at harbour (chips)	*16.15*	*24.24*	*1.81*

[1] Assumed density after pre-drying at road side: 0.667 t_{25}/m^3; LHV = 13.3 GJ/t

Source: [1]

As for Estonian pine wood, pre-drying at the road side until 25% moisture content (MC25) is assumed. Inland transport cost is based on a mean round trip of 120 km by truck. For comparison with imported wood from Estonia, the option of chipping at the harbour in Uruguay is considered.

Total costs at the harbour of Eucalyptus wood from Uruguay are somewhat higher than those of pine wood from Estonia, due to both higher plantation management and harvesting costs and higher transport costs in Uruguay.

4.2.2 Economic data on bulk carriers of interest

Wood fuel is shipped to the Netherlands in bulk carriers of different sizes: a large Panamax carrier for biomass from Uruguay, and smaller Handymax and Handysize carriers for biomass from Uruguay and Estonia (Table 4.3).

Table 4.3 *Deadweight (dwt)[1] and net tonnage [2] for different bulk carriers and various cargoes respectively (logs or chips)*

Origin	Cargo	Panamax (dwt 60,784)	Handymax (dwt 49,751)	Handysize (dwt 24,355)
Estonia	pine logs[3]		29.671	14.525
	pine chips[3]		14.129	6.917
Uruguay	Eucalyptus logs[4]	42.294	34.617	16.946
	Eucalyptus chips[4]	20.715	16.955	8.300

[1] Deadweight (dwt) is the weight that the ship can carry, including fuel and stores.

[2] Net tonnage is a measure of the space and weight concerned with some cargo.

[3] Cargo density for pine logs (MC25) is 0.42 t/m3, for pine chips is 0.2 t/m^3.

[4] Cargo density for Eucalyptus logs (MC25) is 0.49 t/m^3, for Eucalyptus chips is 0.24 t/m^3.

Sources: [1], [10]

As a general rule the loading volume is calculated by multiplying the deadweight by 1.42 (m^3 per dwt). The relatively low cargo density of chips is disadvantageous: net tonnage for chips is only half the amount for logs. Therefore, logs are preferable at large distances (Uruguay), as will be shown.

Fuel consumption of this kind of bulk carriers is based on data from[10]: a so-called 'J' Multiplier is used to calculate the consumption of fuel oil for different speeds (Table 4.4).

Table 4.4 *Fuel consumption of different bulk carriers (tonne of fuel oil/day)*

Speed (knots)	'J' multiplier	Consumption of fuel oil		
		Panamax (dwt 60,784)	Handymax (dwt 49,751)	Handysize (dwt 24,355)
10	0.47	20.758	18.8	14.355
11	0.57	25.175	22.8	27.385
12	0.69	30.475	27.6	21.045
13	0.83	36.658	33.2	25.315
14	1	44.167	40	30.5
15	1.2	53	48	36.6
16	1.43	63.168	57.2	43.615

Source: [10]

Figure 4.1 shows that the relationship between vessel speed and fuel oil consumption is almost linear. Figure 4.1 shows this relationship, based on the figures presented in Table 4.4, for a Panamax carrier.

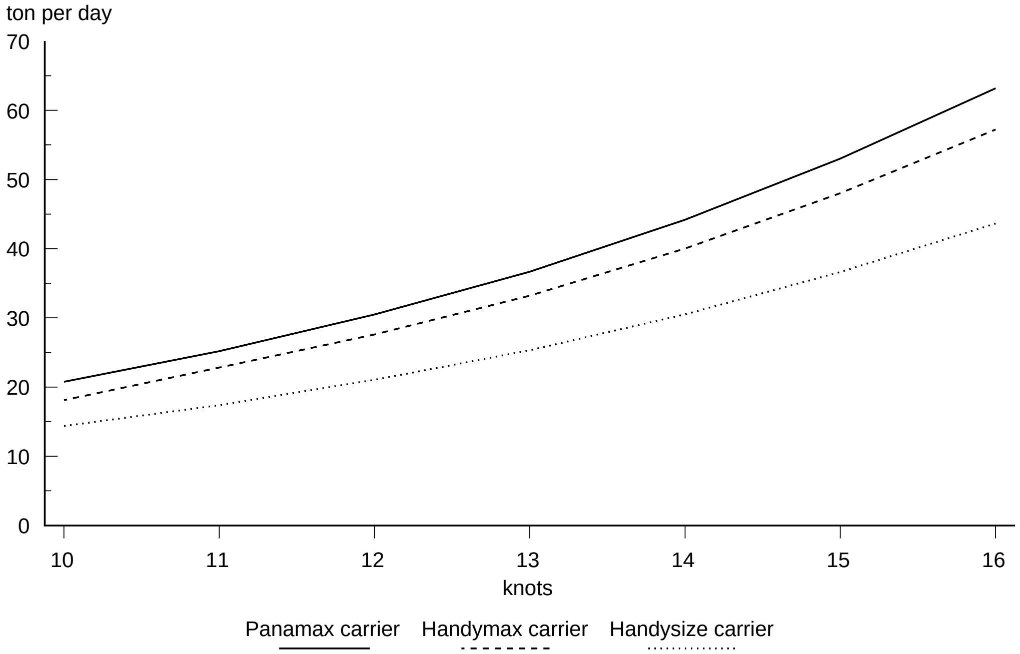


Figure 4.1 *Fuel oil consumption as a function of vessel speed*

The characteristics for different types of bulk carriers in Table 4.4 are used as reference for the sea transport model. Other cost data, e.g. rates for loading and unloading[30], ports and canals, are based on the BTG study. Figure 4.2 shows the dependence of voyage cost (the sum of capital cost, annual operation cost, and fuel cost[31]) from speed and fuel oil price.

---

[30] Unloading cost is based on the KEMA/BTG study [2] (/ 1.05/GJ for both logs and chips).

[31] Annex C gives details about capital cost and annual operation cost of representative new built bulk carriers.

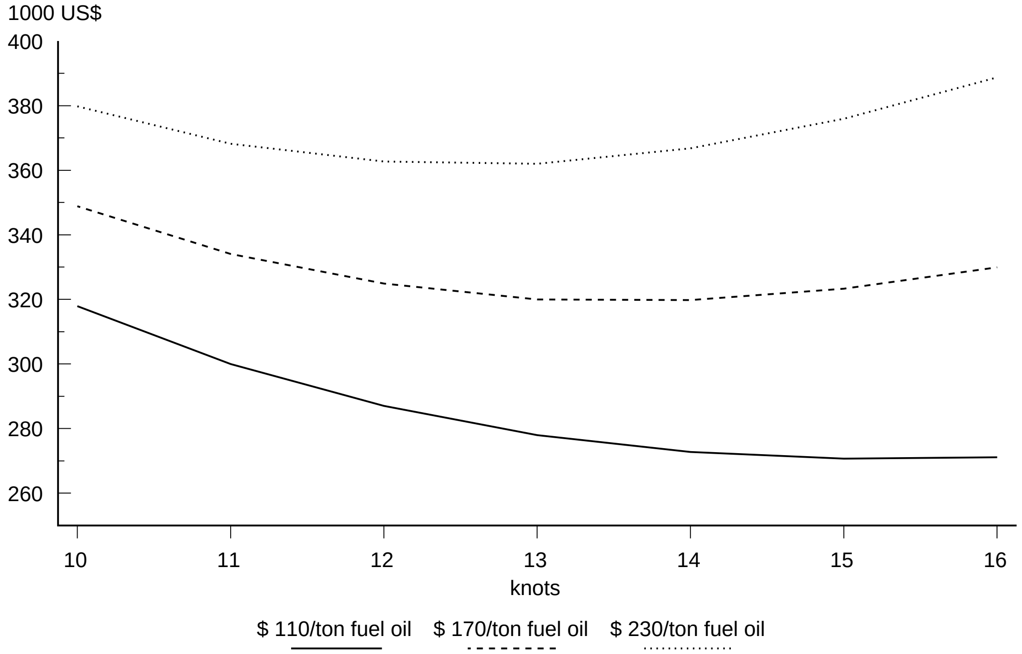


Figure 4.2 *Voyage cost for a Panamax carrier with Eucalyptus logs from Uruguay as a function of speed and fuel oil price*

Optimal speeds for low, medium, and high fuel oil prices are 15, 14, and 13 knots respectively for Panamax and Handymax carriers (Figure 4.2). For Handysize carriers (loaded with logs) the corresponding figures are 16, 13, and 12 knots. For all vessels considered optimum speeds in ballast are 16, 15, and 14 knots for low, medium, and high fuel oil prices respectively. These results show much agreement with those of the BTG study, which appears to validate the sea transport model developed for this study.

4.2.3 Optimal voyage costs

Optimal voyage costs for various fuel oil prices, types of wood (logs, chips) and carriers (Panamax, Handymax, etc.) are calculated for wood shipped from Estonia and Uruguay. To the voyage costs are added the costs of forest management, pre-drying, and transport to the harbour (Table 4.1 and 4.2), as well as the costs of loading and unloading, and port and canal rates, derived from the BTG study [1]. According to the BTG study, fuel consumption of an empty carrier (ballast) is 65% of that of a fully loaded carrier. Tables 4.5 and 4.6 show results in terms of c.i.f.[32] biomass costs.

---

[32] C.i.f. = Cost Insurance Freight.

Table 4.5 *C.i.f. biomass costs for logs or chips from Estonia ($/GJ)*

	Handymax carrier			Handysize carrier		
	Fuel oil			Fuel oil		
	$110/t	$170/t	$230/t	$110/t	$170/t	$230/t
Pine logs						
Woodfuel cost at roadside	0.87	0.87	0.87	0.87	0.87	0.87
Drying at roadside	0.06	0.06	0.06	0.06	0.06	0.06
Transport to harbour	0.39	0.39	0.39	0.39	0.39	0.39
Loading Estonia	0.45	0.45	0.45	0.45	0.45	0.45
Port cost Estonia	0.05	0.05	0.05	0.05	0.05	0.05
Sea transport	0.12	0.14	0.16	0.20	0.23	0.26
Unloading and port R'dam	0.76	0.76	0.76	0.76	0.76	0.76
Total	2.71	2.73	2.75	2.79	2.83	2.85
Pine chips						
Wood fuel cost at roadside	0.87	0.87	0.87	0.87	0.87	0.87
Drying cost at roadside	0.06	0.06	0.06	0.06	0.06	0.06
Transport to harbour	0.39	0.39	0.39	0.39	0.39	0.39
Chipping and loading Estonia	0.54	0.54	0.54	0.54	0.54	0.54
Port cost Estonia	0.11	0.11	0.11	0.11	0.11	0.11
Sea transport	0.24	0.29	0.32	0.40	0.47	0.53
Unloading and port R'dam	0.88	0.88	0.88	0.88	0.88	0.88
Total	3.10	3.14	3.17	3.26	3.32	3.38

Table 4.6 *C.i.f. biomass costs for logs or chips from Uruguay ($/GJ)*

	Panamax carrier			Handymax carrier			Handysize carrier		
	Fuel oil			Fuel oil			Fuel oil		
	$110/t	$170/t	$230/t	$110/t	$170/t	$230/t	$110/t	$170/t	$230/t
Eucalyptus logs									
Plantation management	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Harvesting	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Pre-drying and in land transport	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Loading Uruguay	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Port cost Uruguay	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Sea transport	0.90	1.06	1.19	1.00	1.17	1.32	1.65	1.93	2.17
Unloading and port Rotterdam	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Total	3.51	3.67	3.81	3.61	3.78	3.93	4.26	4.54	4.78
Eucalyptus chips									
Plantation management	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Harvesting	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Pre-drying and in land transport	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Chipping and loading Uruguay	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
Port cost Uruguay	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Sea transport	1.78	2.09	2.35	1.97	2.31	2.60	3.26	3.81	4.27
Unloading and port Rotterdam	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Total	4.81	5.11	5.37	5.00	5.33	5.62	6.29	6.83	7.30

Total costs from Tables 4.5 and 4.6 are presented in Figure 4.3.

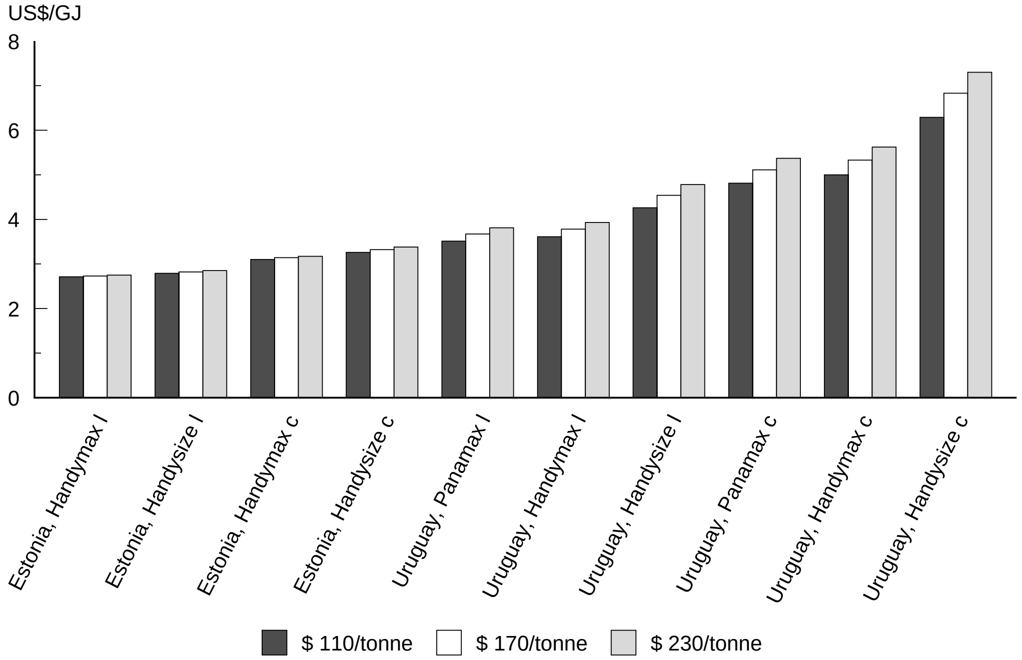


Figure 4.3 *C.i.f. biomass costs for logs or chips from Estonia or Uruguay*

Note: l = logs, c = chips.

Chips from Uruguay appear to be very costly due to the low cargo density of chips. Biomass costs from Estonia vary from $ 2.7/GJ for logs in Handymax carriers to $ 3.3/GJ for chips in Handysize carriers. For Uruguay the range is from $ 3.5/GJ for logs in Panamax carriers to $ 6.3/GJ for chips in Handysize carriers.

In Table 4.7 results from this study are compared to those of BTG [1], by conversion of cost figures from Table 4.5 and 4.6 in $/GJ into ƒ/GJ.

Table 4.7 *C.i.f. biomass costs from Estonia or Uruguay (ƒ/GJ)*[1]

	Estonia		Uruguay	
	this study	BTG study	this study	BTG study
Wood production	1.40	1.14-1.40	1.68	1.68
Local transport[2]	0.73	0.56-0.73	0.78	0.78
Sea transport[3]	2.22-3.10	2.01-2.14	3.14-7.58	4.01-6.09 [4]
C.i.f. cost	*4.34-5.22*	*3.71-4.27* [5]	*5.62* [5]*-10.06*	*6.47-8.39* [4]

[1] Fuel oil price $ 110/tonne.

[2] Includes pre-drying cost to MC = 25%.

[3] Includes loading and unloading, port and canal rates, and (if applicable) chipping.

[4] For reasons of consistency, cost of chipping in Uruguay (included in sea transport cost) is assumed to be the same as for Estonia, viz. US$0.27/GJ.

[5] Figures in italics are used as reference costs in Chapter 5.

Comparison of the cost figures from this study and the BTG study shows the following agreements and differences:

- *Estonia*:Cost figures for wood from Estonia show much agreement with figures from the BTG study. Import of logs from Estonia could be cheaper, if wood from managed forests would have been regarded (ƒ 3.71/GJ according to BTG). Our lower cost figure (ƒ 4.34/GJ) is in close agreement with the higher cost figure from the BTG study (ƒ 4.27/GJ). Both refer to logs, shipped with medium sized bulk carriers. However, the BTG study also regards self-unloading vessels. This appears to be optimal for transport of chips on relatively short distances, with sea transport costs of ƒ 2.14/GJ, including chipping in Estonia. For conventional bulk carriers, sea transport cost is ƒ 2.85-3.10/GJ.

- *Uruguay:* Total wood fuel costs from Uruguay in this study show much agreement with figures from the BTG study. Wood chips from Uruguay are very expensive and are disregarded for that reason. The most expensive option remaining is logs transport by a Handysize carrier, which has a lower net load than the bulk carrier of the BTG study. Therefore, maximum total costs in this study exceed the maximum of the BTG study. However, this study includes relatively large vessels (up to 60,000 dwt) for import of biomass from Uruguay. In the BTG study the maximum considered is 30,000 dwt. It has been noted that Panamax carriers will be able to load at Nueva Palmira, according to current dredging plans. Substitution of a Panamax carrier for a medium sized bulk carrier reduces transport cost by at least ƒ 0.85/GJ.

4.3 Import of 'biocrude'

The HTU process (Hydro Thermal Upgrading) is used for production of 'biocrude' from biomass. Subsequently biocrude can be upgraded to gas oil. Here the focus is on production of biocrude from biomass in Uruguay. It is assumed that the crude oil will be transported to the Netherlands and used for power generation or combined heat and power production.

The origin of the HTU process is research at Shell, some ten years ago[11]. From[12] it can be deduced that the thermal efficiency of conversion of biomass into biocrude is about 69%. The relation between the cost of biocrude and that of biomass is shown in Figure 4.4.

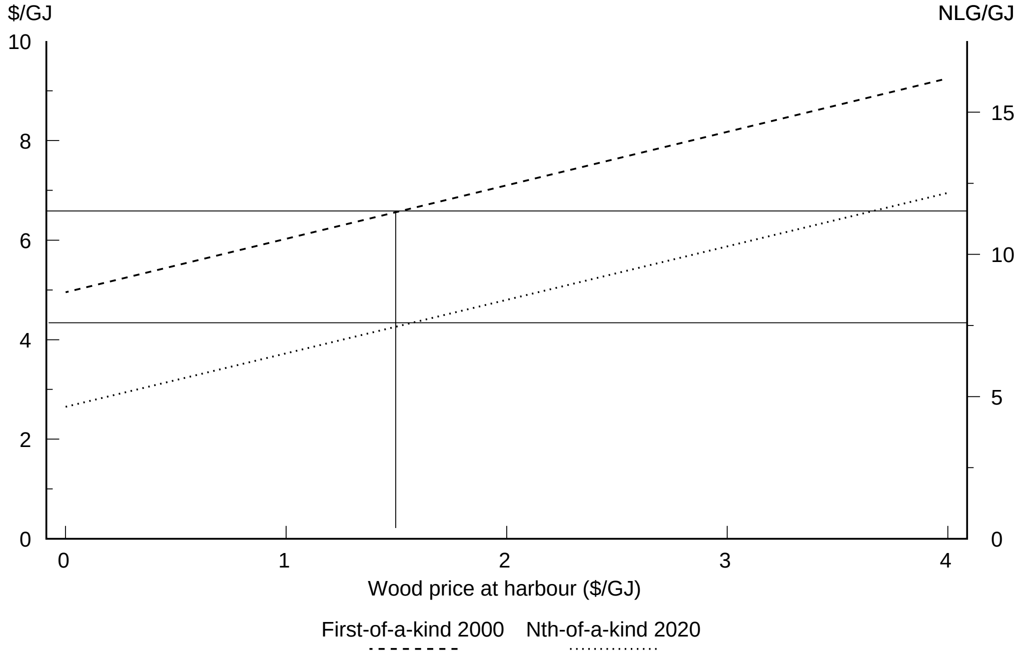


Figure 4.4 *Production cost of biocrude based on Eucalyptus wood in Uruguay ($/GJ)*
Source: [11]

Assuming the same cost level for Eucalyptus wood as for import of logs or chips from Uruguay (about $ 1,5/GJ at the harbour, Table 4.6), production cost of biocrude will decrease from *ƒ* 11,50/GJ in 2000 for a first-of-a-kind HTU plant to *ƒ* 7,50/GJ for a Nth-of-a-kind HTU plant in 2020. Freight rate for transport to Europe is estimated at $ 1,5/barrel, or about *ƒ* 0,50/GJ.

If the freight rate (*ƒ* 0,50/GJ) is added to the production costs of 'biocrude' in Uruguay, a declining trend for 'biocrude' cost in the Netherlands emerges, starting from *ƒ* 12/GJ in 2000, and ending up at *ƒ* 8/GJ in 2020. The latter figure is in good agreement with the figure of *ƒ* 8,50/GJ in [11].

5. POWER GENERATION COSTS

5.1 Introduction

Biomass imported from Estonia or Uruguay (logs or chips) can be used for co-combustion in pulverised coal fired power plants. Depending on the technology applied, this can be done on short notice, or within a few years. Substantial investments are required. However, co-combustion is favoured on the short term, as additional investment costs per kW_e of biomass fired capacity are much lower than for dedicated biomass fuelled power plants, and investment costs in existing coal fired power plants, with a remaining economic life of 15 to 30 years, have to be regarded as sunk costs.

Also dedicated biomass fuelled power plants and power generation from imported 'biocrude' are regarded. Section 5.2 gives an overview of economic parameters of key power generation options. In Section 5.3 power generation costs based on the options considered are presented.

5.2 Key power generation options

Co-combustion of biomass in a coal fired power plant is only considered as an option for existing pulverised coal fired power plants. For new coal fired capacity dedicated biomass fuelled options have been considered. There are different options for co-combustion. Here the focus is on a novel technology: co-firing of chips in a so-called Torbed reactor (Table 5.1).

Table 5.1 *Co-firing of chips in a Torbed reactor coupled with a pulverised coal fired power plant*

	2000	2005	2010	2020
Year average net efficiency [%]	40.3	40.3	40.3	40.3
Fraction of fuels				
- Coal [%]	92	92	92	92
- Chips [%]	8	8	8	8
Investment cost [NLG_{1993}/kW_e]	1200[1]	1200[1]		
O&M cost [$NLG_{1993}/kW_e/yr$]	40	40	40	40
Life [yr]	15	15	15	15
Upper bound [GW_e]				

[1] Investment cost and O&M cost related to the capacity related to biomass.

Source: [2].

In order to get comparable power generation costs for co-combustion in existing coal fired power plants and for dedicated biomass fuelled power plants, capital costs of existing coal fired power plants are added[13]:

- *ƒ* 2150/kW_e for investment costs,
- *ƒ* 50/kW_e/yr for fixed operation and maintenance costs,
- *ƒ* 0.7/GJ_e for variable operation and maintenance costs.

Key technologies for dedicated biomass fuelled power plants are:

- Blomass Gasification Combined Cycle (BIG-CC);
- Pressurised Fluidised Bed Combustion (PFBC) adapted to use of biomass or 'bio-crude'.

The economic characteristics of Blomass Gasification Combined Cycle (BIG-CC), are based on a number of recent publications (1996 and 1997)[9,10,11,12,13,14] (Table 5.2).

Table 5.2 *Costs and efficiencies of BIG-CC system for district heating*

	2000	2005	2010	2020
Year average net efficiency[1] [%]	41.0	44.0	47.0	52.0
District heating efficiency				
- Electrical [%]	35.0	38.0	41.0	46.0
- Thermal [%]	36.5	36.5	36.5	36.5
Investment cost [NLG_{1993}/kW_e]	4200[2]	3500	3000	2500
O&M cost [$NLG_{1993}/kW_e/yr$]	165	156	147	130
Life [yr]	25	25	25	25
Upper bound [GW_e]	0.1	0.5		

[1] Sole power production.

[2] Second BIG-CC project after Noord-Holland project.

At last the characteristics of Pressurised Fluidised Bed Combustion (PFBC), based on[15],[16],[17],[18], are shown in Table 5.3.

Table 5.3 *Combustion of chips and/or HTU 'biocrude' in a Pressurised Fluidised Bed Combustion (PFBC) power plant*

	2000	2005	2010	2020
Year average net efficiency[1] [%]	41.5	42.5	43.5	45
District heating efficiency				
- Electrical [%]	35.5	36.5	37.5	39
- Thermal [%]	36.5	36.5	36.5	36.5
Investment cost [NLG_{1993}/kW_e]	2600	2500	2400	2300
O&M cost [$NLG_{1993}/kW_e/yr$]	140	135	130	125
Life [yr]	25	25	25	25
Upper bound [GW_e]				

[1] Sole power production.

5.3 Resulting power generation costs

Power generation costs are calculated based costs of imported biomass from Chapter 4 and economic parameters of power generation options in Section 5.1. Biomass costs are derived from Table 4.7, viz. ƒ4,27/GJ for chips from Estonia, and ƒ 5,62/GJ and ƒ 12-8/GJ for logs and biocrude respectively from Uruguay. Using a real discount rate of 5%, power generation costs based on chips from Estonia are shown in Figure 5.1.

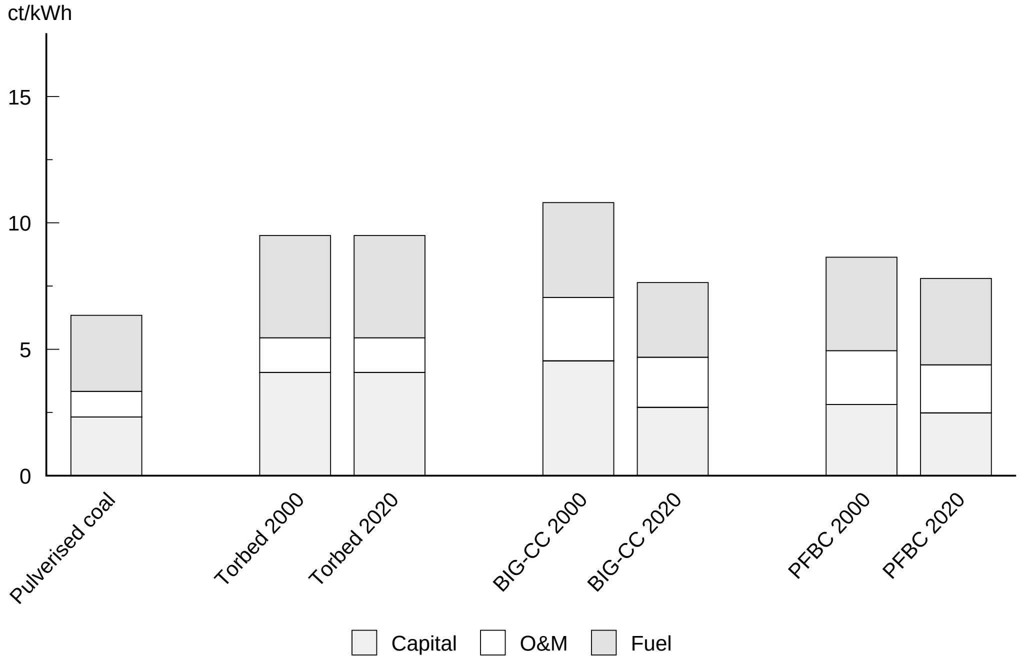


Figure 5.1 *Power costs; import of chips from Estonia*

Alternatively power can be generated from logs or 'biocrude' originating from Uruguay, using the same 5% real discount rate (Figure 5.2).

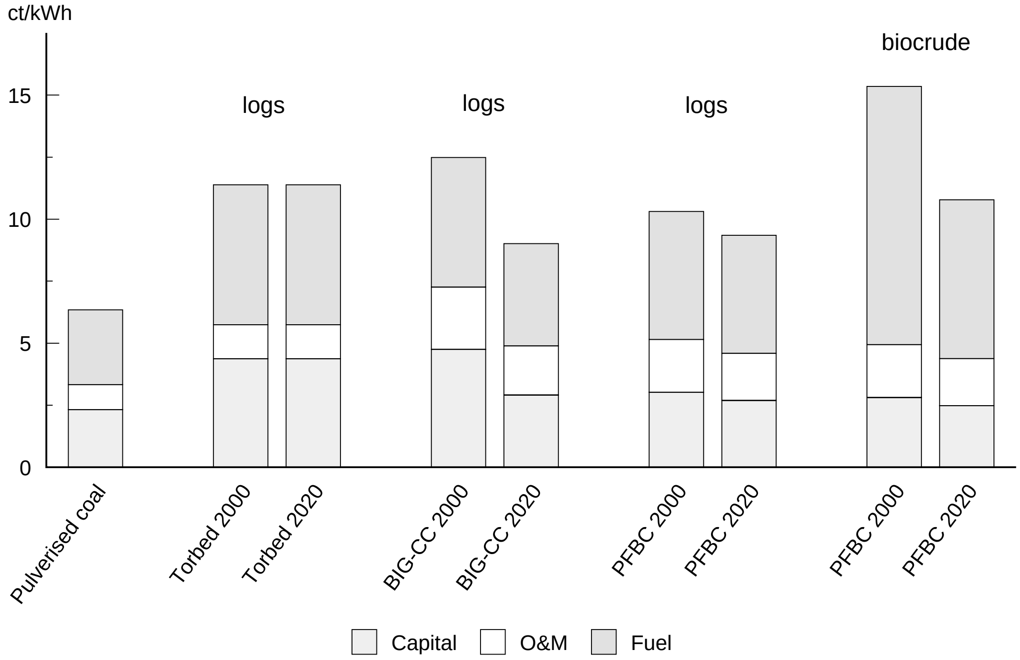


Figure 5.2 *Power costs; import of logs or 'biocrude' from Uruguay*

Figures 5.1 and 5.2 show that there are large differences between the options considered. One of the most promising options for the short and medium term is co-combustion with a Torbed reactor, with additional costs of 3-5 ct/kWh compared to coal fired power, depending on the origin of the biomass. The second option considered, BIG-CC, is relatively expensive in 2000; however, in 2020 generating costs are only 1.3-2.7 ct/kWh higher than for coal fired power.

The third option, PFBC, could be relatively attractive at the end of the next decade, when the potential of co-firing is fully utilised and BIG-CC is not yet fully developed. In 2020 additional costs compared to coal fired power are 1.5-3.0 ct/kWh, slightly more than for BIG-CC. These costs refer to chips from Estonia or logs from Uruguay (the most expensive of the two).

Alternatively, 'biocrude' produced with the HTU process in Uruguay could be fired in a PFBC plant. This would be really expensive, with additional costs of 9.0-4.4 ct/kWh compared to coal fired power; the gap declines due to decreasing costs of 'biocrude'.

In Table 5.4 the margins in generating costs compared to coal fired power are shown for each of the key power generation options in 2000 and 2020.

Table 5.4 *Margin between power based on biomass and on coal (ct/kWh)*

	2000	2020
Chips from Estonia		
Torbed	3.2	3.2
BIG-CC	4.5	1.3
PFBC	2.3	1.5
Logs from Uruguay		
Torbed	5.0	5.0
BIG-CC	6.1	2.7
PFBC	4.0	3.0
'Biocrude' from Uruguay		
PFBC	9.0	4.4

It can be concluded that:

- Co-combustion of biomass and coal, based on a Torbed reactor, could be a rather cost-effective option for the short to medium term.
- One of the most promising options for the long term seems to be Biomass Gasification Combined Cycle (BIG-CC). Its higher generating efficiency (52% in 2020) compared to PFBC (45% in 2020) outweighs the higher investment cost of BIG-CC compared to PFBC in 2020: the margin is 0.15-0.25 ct/kWh in favour of BIG-CC in 2020.
- The least-cost option is chips from Estonia, followed by logs from Uruguay. 'Biocrude' is costly compared to logs from Uruguay (additional cost of 1.75 ct/kWh in 2020). This is because 'biocrude' production essentially entails two processes: first the HTU process in Uruguay, then the PFBC power plant in the Netherlands. Lower transport costs for 'biocrude' compared to logs from Uruguay do not offset the higher capital costs and lower energy efficiency for the 'biocrude' route.

6. CONCLUSIONS

In the Netherlands the potential of agricultural residues, forest residues, and energy crops, is limited due to conflicting land use objectives (agriculture, habitation, infrastructure) and a high population density. However, the Netherlands are well positioned with respect to import of biomass.

If the focus is on import of biomass from Baltic countries or elsewhere, it proves that biomass import to the European Union has various advantages, not only for the EU (reduced CO_2 emissions) but also for the countries of origin (employment creation). However, possible disadvantages or risks should be taken into account. With that in mind the biomass potential of Baltic countries seems to be so large, that import from that area could be very interesting for European countries (the Netherlands). The potential for biomass import from Latin America appears to be huge. Additional research, however, seems necessary. For some Baltic countries the alternative of fuel-switching to biomass seems to be more cost-effective than import of biomass from those countries. This deserves examination too. Given the expected increase in inland biomass consumption in the Baltic countries and the potential substantial futur demand for biomass in other Western European countries it is expected that the biomass supply from Baltic countries will not be sufficient to fulfill the demand. An early focus on import from other countries seems advisable.

So, import of biomass for power generation, e.g. for co-combustion with coal, could reduce the dependence on fossil fuels and could entail a significant reduction of CO_2 emissions from (coal fired) power in the Netherlands. This CO_2 reduction option has to be regarded in the framework of the government policy to improve energy efficiency by 33% until 2020, and to increase the share of renewable energy in primary energy demand to 10%. Import of wood to the extent of 40 PJ - and even more, if need would be - from Baltic and South American states seems to be readily achievable.

After a number of studies, questions remain with respect to the economics of import and utilisation of biomass. From calculations with a sea transport cost model, mainly based on data from studies of BTG and KEMA/BTG, and comparison of key power generation options for co-combustion or dedicated biomass fuelled power, a number of conclusions can be drawn:

- The relatively short transport distance between the Netherlands and Estonia compared to Uruguay provides a distinctive competitive edge to Estonia. Even considering relatively large Panamax carriers for import of logs from Uruguay, this cost advantage is *ƒ* 1.35/GJ.
- One of the most promising options for the short and medium term is co-combustion with a Torbed reactor, with additional costs of 3-5 ct/kWh compared to coal fired power, depending on the origin of the biomass.
- The second option considered, BIG-CC, is relatively expensive in 2000; however, in 2020 generating costs are only 1.3-2.7 ct/kWh higher than for coal fired power (the lower figure refers to chips from Estonia, the higher figure refers to logs from Uruguay).

- The third option, PFBC, could be rather attractive at the end of the next decade, when the potential of co-firing is fully utilised and BIG-CC is not yet fully developed. In 2020 additional costs compared to coal fired power are 1.5-3.0 ct/kWh, slightly more than for BIG-CC. This is because BIG-CC has a higher generating efficiency than PFBC (52% and 45% respectively in 2020), which offsets its higher investment costs.
- The most expensive option is ‘biocrude’ from Uruguay. ‘Biocrude’ combustion in a PFBC plant is 9.0-4.4 ct/kWh more expensive than coal fired power; the gap declines due to decreasing costs of ‘biocrude’. However, lower transport costs for ‘biocrude’ compared to logs from Uruguay do not offset the higher capital costs and lower energy efficiency for the ‘biocrude’ route.

ANNEX A. POTENTIAL INDEX AND PRODUCTION COSTS

Country	Potential index[33]	Production costs	Remarks
Finland	high	high	potential exporter if cost be managed
Norway	very high	high	potential exporter
Sweden	very high		ST importer & LT exporter
Belgium	very low		potential importer from CEE
Denmark	low		
Germany	very low		big potential importer
Ireland	very low		
Luxembourg	very low		possibly importer
The Netherlands	very low		potential for imports of biofuel
UK	very low		potential importer
Austria	low	high	potential of cheap imports from CEE
Switzerland	high	very high	small supply of biofuels
France	medium	high	big supplies
Portugal	medium		
Spain	low		spot market exports
Belarus			high forest fuel potential
Estonia			relatively big forest fuel potential
Latvia	medium	low	relatively big supplies of forest fuels
Russia	very low (?)	low	varying conditions in different regions[34]
Hungary	low		relatively big agricultural biofuel potential
Poland	very low	low	potential for limited exports of biofuels[35]
Ukraine	big market?		
Bulgaria	low		
Romania	medium	low	potential exporter
Turkey	low	low	
Canada	very high	high	high costs prohibit large-scale export to Europe
USA	a low vast market		hardly competitive as an exporter

Source: [7]

---

[33] The potential index is a measure of the degree of self-sufficiency for solid biofuels with the present number of boilers possible to convert a biofuel operation.

[34] Potential for large scale exports, especially from the St. Petersburg region. The political and economic instability in the country have to be settled before the export potentials can materialise.

[35] It is however expected to consume its biofuel potential on the domestic market.

ANNEX B. BIOMASS POTENTIAL 2000 AND 2010

		NUTEK [7]		ECN [8]	
	TPER 1990 [PJ]	Biomass Potential 2000 [PJ]	SSR 2000[36]	Biomass Potential 2020 [PJ]	SSR 2020[37]
Albania	104	7	7%		
Austria	1,048	112	11%	154	15%
Belgium	1,973	6	0%	101	5%
Belarus	1,781	89	5%		
Bulgaria	1,137	118	10%		
Canada	8,807	3,615	41%		
Former CFSR	2,991	180	6%		
Denmark	762	55	7%	103	14%
Estonia	398	72	18%		
Finland	1,179	479	41%	646	55%
France	9,244	643	7%	1,067	12%
Germany	15,327	459	3%	840	5%
Greece	918	112	12%	216	24%
Hungary	1,212	121	10%		
Iceland	88		0%	0	0%
Ireland	428	16	4%	59	14%
Italy	6,433	486	8%	566	9%
Latvia	318	75	24%		
Lithuania	763	86	11%		
Luxembourg	149	-1	-1%	6	4%
Netherlands	2,804	28	1%	148	5%
Norway	966	114	12%	257	27%
Poland	4,128	349	8%		
Portugal	745	140	19%	124	17%
Romania	2,527	429	17%		
Russia[37]	34,291	1,690	5%		
Spain	3,730	285	8%	729	20%
Sweden	1,953	614	31%	687	35%
Switzerland	1,062	53	5%	92	9%
UK	8,833	193	2%	724	8%
Ukraine	10,496	75	1%		
USA	80,179	5,347	7%		
rem. Yugoslavia	1,853	100	5%		
TOTAL	57,641	16,147	28%	6,520	11%

---

[36] Self Sufficiency Rate: biomass potential 2000 as percentage of TPER 1990.

[37] European part.

ANNEX C. COSTS OF BULK CARRIERS

Estimates of capital cost and operation and maintenance cost of representative types of bulk carriers have been derived from e.g. [1]. Typical capital cost of new built bulk carriers are shown in Table A.1.

Table C.1 *Typical capital cost of new built bulk carriers*

Ship type	Dwt	Newbuilding price (million $)	Capital cost[1] ($/day)
Capesize	120,000	29.6	8398
Panamax	60,784	19.2	5448
Handymax	49,751	16.5	4682
Handysize	24,355	12	3405

[1] Capital cost at 8% interest, 15 year depreciation, rest value 15% over new price.

Table C.2 gives figures for annual operation cost of such bulk carriers.

Table C.2 *Typical annual operation cost of new built bulk carriers*

Ship type	Dwt	Manning	Repair & maint.	Insurance	Others	Total	
	10^3 t	10^3 $/yr	10^3 $/yr	10^3 $/yr	10^3 $/yr	10^3 $/yr	$/day
Capesize	120	865	250	250	635	2,000	5714
Panamax	60	750	235	235	370	1,590	4543
Handymax	50	730	230	230	340	1,530	4371
Handysize	24	700	225	225	300	1,450	4143

REFERENCES

[1] *Foreign wood fuel supply for power generation in the Netherlands.* BTG, August 1995.

[2] *Bijstoken van geïmporteerde biomassa uit Estland in de Centrale Maasvlakte (EZH) en de Centrale Borssele (EPZ): economische haalbaarheid.* KEMA/BTG, oktober 1996.

[3] *Latvian fuelwood supply to the Netherlands?* Factor ITP, July 1996.

[4] *Sustainability of biomass import for the Dutch energy economy.* ETC Consultants in Development Programmes, July 1996.

[5] J.A. Faaij: *Energy from biomass and waste.* Thesis university of Utrecht, September 1997.

[6] Swedisch National Board for Industrial and Technical Development (NUTEK): The forecast of biofuel trade in Europe - The Swedish market, 1993.

[7] P. Lako, D.J. Gielen: *European biomass scenarios and the need for import of biomass.* ECN-R--97-009.

[8] A.K. van Harmelen, S.N.M. van Rooijen, C.J. Jepma, W. van der Gaast*: Joint Implementation met Midden- en Oosteuropa.* ECN-C--97-078.

[9] A.A.C.M. Beenackers, K. Maniatis: *Gasification technologies for heat and power from biomass.* Proceedings of the 9th European Bioenergy Conference, 24-27 juni 1996, Copenhagen. Volume 1, 228-259.

[10] K. Stähl: *Biomass IGCC overview and the Värnamo power plant.* Proceedings of the 9th European Bioenergy Conference, 24-27 jnni 1996, Copenhagen. Volume I, 176-185.

11] P. Basbucci, G. Neri: *An IGCC plant for power generation from biomass.* Proceedings of the 9th European Bioenergy Conference, 24-27 juni 1996, Copenhagen. Volume 2, 1068-1073.

[12] K. Pitchner *et al.*: *The development of a gasification plants utilising Short Rotation Coppice; Project ARBRE.* Proceedings of the 9th European Bioenergy Conference, 24-27 jnni 1996, Kopenhagen. Volume 2, 1096-1101.

[13] K. Pitcher *et al.*: *The development of a gasification plant utilising short rotation coppice: project ARBRE.* De markt voor energie uit afval & biomassa. Roermond, 5-6 November 1997.

[14] C. Daey Ouwens: *30 MWe gasification project.* De markt voor energie uit afval & biomassa. Roermond, 5-6 November 1997.

[15] A. Saldana: *Retrofitting the Escatrón pressurised fluid bed plant.* Power Generation Technology 1995, 52-57.

[16] P. Almhem *et al.*: *Cottbus opts for PFBC repowering.* Modern Power Systems, Supplement September 1996, 27-36.

[17] K. Omata *et al.*: *Karita 360 MW PFBC an imminent prospect.* Modern Power Systems, April 1997, 33-38.

[18] Modern Power Systems, March 1997, 17-20.