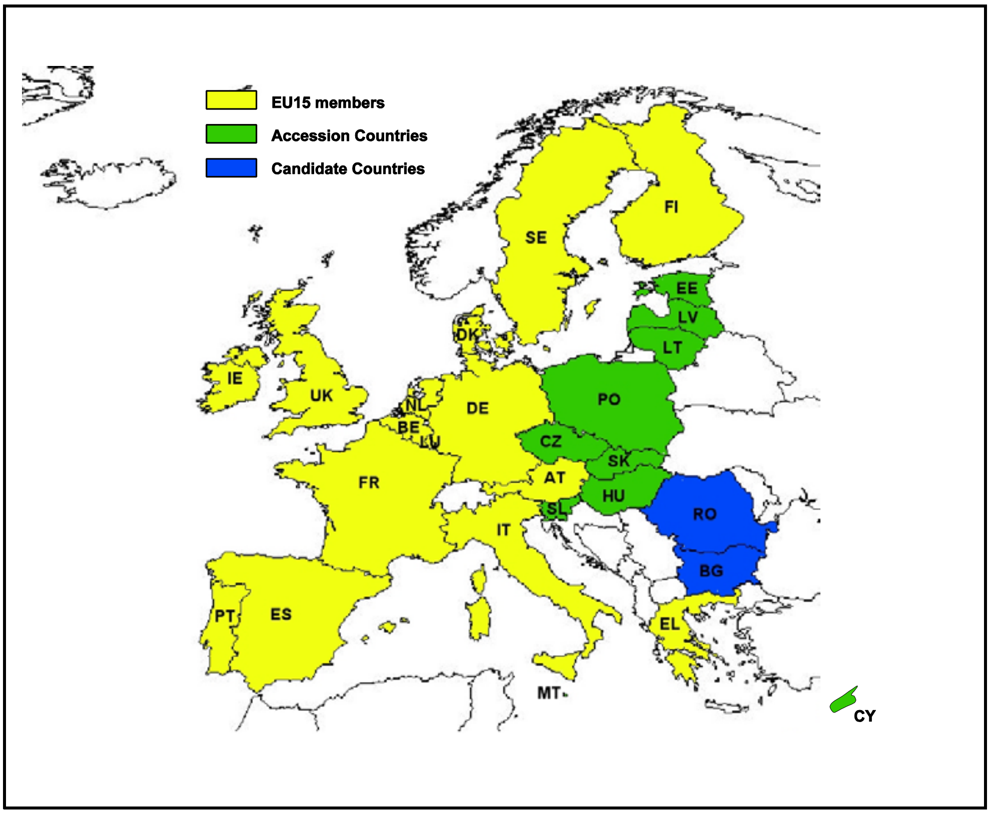
BIO-ENERGY'S ROLE IN THE EU ENERGY MARKET

A view of developments until 2020

Report to the European Commission



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Colophon

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ACRONYMS AND ABBREVIATIONS

BAU	Business As Usual Scenario
BMW	Biodegradable municipal waste
CBA	cost-benefit analysis
CER	Certified emission reduction (traded under the CDM)
CC	combined cycle of a gas turbine with a steam cycle
CDM	Clean Development Mechanism
CHP	combined heat and power
CS	combustion and steam cycle
EC	European Commission
ERU	Emission reduction unit (traded under JI)
ETS	Emission Trading Scheme concerning the trade in GHG emission allowances (EC Directive 2003/87/EC)
EU15	the 15 member states of the European Union since the year 1995
EU+10	the 10 accession states to the European Union (2004)
EU+2	two candidate countries to the European Union (Bulgaria, Romania)
FAO	Food and Agriculture Organisation of the United Nations
FAOSTAT	FAO Statistical Database
GAST	gas turbine and steam turbine configuration of GCC
GAVE	the Dutch programme of climate-neutral liquid and gaseous fuels
GCC	gasifier coupled combined Brayton and Rankine cycle
GHG	greenhouse gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JI	Joint Implementation
KP	Kyoto Protocol
LCA	life-cycle assessment
LCC	liquefier coupled to a combined Brayton and Rankine cycle
OECD	Organisation for Economic Co-operation and Development
PCCC	Pressurised combustion combined cycle for solid fuels
RES	Renewable energy sources
S-premium	Sustainability premium (an add-on to the energy value, reflecting the value of sutainability)
SRC	short-rotation coppice
STIG	steam injected gas turbine configuration of GCC
UNFCCC	United Nations Framework Convention on Climate Change
UUA	Utilised Agricultural Area

SYMBOLS

DR	discount rate (-)
GCV	gross calorific value (GJ/t, MJ/kg, MJ/Nm^3)
IRR	internal rate of return (-)

MC	moisture content (-)
m	mass (g, t)
NCV	net calorific value (GJ/t, MJ/kg, MJ/Nm^3)
NPV	net present value (€)
SGM	standard gross margin (€/(ha.yr))
T	temperature (°C, K)
t	time (s, h, d, yr)
α	ash content (-)
Δ	increase
η	energy efficiency (-)
μ	moisture content (-)
ρ	unit-specific GHG emission coefficient (t GHG/MWh_e)

UNITS

Area

ha	hectare (10,000 m^2)

Distance

m	metre

Energy

J	Joule
toe	tonne oil equivalent (41,868 TJ)
W	Watt (=J/s)
Wh	Watt-hour (3600 J)

Mass

g	gram
g_x	gram of matter at a reference moisture content (MC_w) of x %m
t	tonne (1000 kg)
t_x	tonne of matter at a reference moisture content (MC_w) of x %m

Temperature

°C	degrees Celsius
K	Kelvin

Time

d	day (24 hours)
h	hour
s	second
yr	standard year (365 days, 8760 h)

Volume	
l	litre
Nm^3	cubic metre gas under normal conditions: 273.15°C and 101325 Pa

Prefixes

m	milli (10^{-3})
c	centi (10^{-2})
k	kilo (10^{3})
M	Mega (10^{6})
G	Giga (10^{9})
T	Tera (10^{12})
P	Peta (10^{15})
E	Exa (10^{18})

Subscripts

1	with energy units: primary energy
2	with energy units: secondary energy
b	with m^3: bulk volume (equal to the specific volume times [1-porosity])
d	on a dry basis
daf	on a dry and ash-free basis
e	electric
G	gross
m	with %: mass percent
N	net
p	at constant pressure
s	with m^3: specific (or true) volume of solid material
th	thermal
v	at constant volume
v	with %: volume percent
w	on a wet basis

Currencies

The dominant currency used is the €. Currency conversions from US$ to € were occasionally required. In such cases the average interbank exchange rates applicable in the reference year involved were employed. For the period before 1 January 1999, when the € was established, the exchange rate pertaining to the ECU was taken.

Country acronyms

EU15		
AT	Austria	Republic of Austria
BE	Belgium	Kingdom of Belgium
DE	Germany	Federal Republic of Germany
DK	Denmark	Kingdom of Denmark
EL	Greece	Hellenic Republic

ES	Spain	Kingdom of Spain
FI	Finland	Republic of Finland
FR	France	French Republic
IE	Ireland	Ireland
IT	Italy	Italian Republic
LU	Luxembourg	Grand Duchy of Luxembourg
NL	Netherlands	Kingdom of the Netherlands
PT	Portugal	Portuguese Republic
SE	Sweden	Kingdom of Sweden
UK	United Kingdom	United Kingdom of Great Britain and Northern Ireland
Accession Countries		
CY	Cyprus	Republic of Cyprus
CZ	Czech Republic	Czech Republic
EE	Estonia	Republic of Estonia
HU	Hungary	Republic of Hungary
PL	Poland	Republic of Poland
LT	Lithuania	Republic of Lithuania
LV	Latvia	Republic of Latvia
MT	Malta	Republic of Malta
SI	Slovenia	Republic of Slovenia
SK	Slovakia	Slovak Republic
Candidate Countries		
BG	Bulgaria	Republic of Bulgaria
RO	Romania	Romania
TR	Turkey	Republic of Turkey

1 EXECUTIVE SUMMARY

1.1 OBJECTIVE OF THE STUDY

Bioenergy contributes about 64% of all RES primary energy requirements of the European Union, 9% of RES electricity and about 98% of RES heat. Numerous studies indicate that the overall potential of bioenergy for the EU is very significant, however, often these studies are based on unrealistic assumptions and carry little credibility for policy development. In addition bioenergy has a relative negative image in the public's perception and the public in general is not well informed about bioenergy's importance and contribution. There is an urgent need to address these two areas in order to be in a position to develop effective strategies for the deployment of bioenergy technologies and fuels into the EU energy markets.

The objectives of this study are twofold:

- To provide reliable and realistic **data on bioenergy's contribution** to the EU energy market by 2010 and 2020, while taking into consideration the various policy instruments such the Directive on RES-Electricity, the Directive for renewable fuels (including biofuels) for transport as well as bioenergy's contribution to achieving the EU's Kyoto commitments
- To identify **new approaches for promoting a positive public perception** of bioenergy. Such approaches should primarily address the European citizen, because the building of a more positive perception amongst individual citizens will lead directly to a more positive perception within the technical, industrial and commercial communities.

This volume reports on the first issue only. A second volume is dedicated to public perception.

1.2 EXECUTION

The study was carried out by four partners:

- BTG
- CRES
- ESD
- IFZ.

BTG coordinated the project and was responsible for the contacts with the EC. The project is divided into two main parts (Role and Promotion) and the first was carried out by BTG, ESD and CRES. Thereby ESD concentrated on adapting and running a computer model, simulating economic developments over the time frame considered, and CRES on biomass availability and supply. The second study component (Promotion) was carried out under the main responsibility of IFZ.

On November 18, 2003, a workshop was held at the EC, to discuss interim results and study finalisation.

1.3 ANALYSIS APPROACH

The current and future role of bioenergy fundamentally depends on a number of economic factors, particularly:

- Demand function: The demand for renewable energy in general and biomass in particular.
- Supply function: The supply of biomass and biomass derived fuels.
- Technology development function: The characteristics of biomass fuelled energy conversion technologies.

The equilibrium of these functions determines the role of biomass as a source of renewable energy, and for scenario studies to be realistic, scenario models should properly reflect these functions.

The demand function for renewable energy, including biomass

Several factors were distinguished to analyse the demand function. We differentiate between sector covenants and large-scale market approaches. In the approach of covenants, individual industries or economic sectors are being obliged to produce or use a specified quantity of renewable energy. An example of this approach is the recent EC directive on the promotion of renewable fuels for road transportation (2003/30/EC). In large-scale market approaches a new value component of renewable energy is introduced: i.e. a component of sustainability in addition to the pure energy value, and the manner of implementation is left to market forces. Examples of such sustainability components are tax exemptions associated with renewable energy, traded avoided greenhouse gas (GHG) emissions connected with electricity, and traded GHG emission allowances between electricity generators. In everyday life we observe combinations of the two.

The sector covenant approach towards an increased role of renewable energy is a distinct phenomenon in European policy. According to this approach a political decision is made to implement a specific quantity of renewables in the various economic sectors of the EU (e.g. energy sector, transportation sector). Examples of documents and directives in which these policies are described and established, are the EU's 1997 White Paper on 'Energy for the future', and the EU's directives on the promotion of electricity produced from renewable energy sources in the internal electricity market (2001/77/EC), and the one on the promotion of renewable fuels for road transportation (2003/30/EC). Ultimately, these covenants, applied to the individual sectors, specify a desired quantity of renewable energy. The reasons why these policies are pursued vary, but they can all be grasped with the term 'sustainability'. They are explained in the various official documents describing the policies of the EC. The most commonly recognised reasons for promoting renewable energies are:[1]

- Environmental protection.
- Reducing dependency on energy imports and increasing security of supply (Renewable energy sources are indigenous)

1/ These are taken from the EC's White Paper on 'Energy for the future'.

- Job creation, predominantly among the small and medium sized enterprises which are so central to the Community economic fabric.
- Regional development with the aim of achieving greater social and economic cohesion within the Community.
- Creation of business opportunities for European Union industries (in many third countries, in Asia, Latin America and Africa).

Since, in financial terms (that is, in the immediate view of economic actors, disregarding so-called externalities) renewable energy is generally more expensive than conventional energy, one can analyse the value of 'sustainability' in terms of monetary units per unit of energy (€/GJ or /kWh).

A large market, currently in development, is the result of the Kyoto Protocol (KP) which obliges the so-called Annex I countries to reduce their GHG emissions by a certain quantity. The KP allows its Annex I countries to realise this on an aggregate level (covering all their economic sectors), either by emission caps or trade in emission reductions, within their country, but also outside their country by means of trade (Joint Implementation - JI, the Clean Development Mechanism - CDM). JI and CDM make GHG emission neutrality into a tradable good. The actual development of this new market can be illustrated with the activities of the World Bank managed Prototype Carbon Fund, the emerging CDM programmes, and the existing JI programmes, executed by the USA, and several European countries, and also by the European Emission Trade Scheme (ETS) planned for take-off by 2005 (directive 2003/87/EC). A new value component of renewable energy has thus been introduced: a component of emission neutrality in addition to the pure energy value. Although originally expressed in monetary terms per tonne of GHG emission reduction (€/t CO_2-eq.), emission neutrality can also be analysed in terms of monetary units per energy unit (€/kWh or /GJ).

In a sense, therefore, the two approaches (sector covenants and pure markets) have much in common. And in practice one observes the implementation of mixtures of the two. A consequence of the sectoral covenant approach is the existence of discerned markets of different sizes within which (without interchange) optimisations for sustainability values are sought. If 'sustainability' were allowed to be traded freely between the various economic sectors of the EU (e.g. electricity sector, heat distribution sector, transportation sector, industrial sector), market equilibria in terms of e.g. biomass consumption are likely to emerge at other levels than if single sectors are given specific emission caps or if single sectors are being obliged to implement specific quantities of renewable energy. To a large extent (but not completely), these differentiations could be reflected in the economic model that was used to carry out this study. Specifically for bio-transport fuels, the existing policy of promoting the use of these fuels to a pre-determined level was taken as a starting position, and the costs of this policy, additional to the continued use of fossil energy resources, were calculated. For the heat and electricity market, on the other hand, a 'sustainability premium' was defined, to be taken as an add-up relative to pure energy prices. Ignorant of future price developments, various price levels were assumed for this sustainability premium and elaborated in scenarios. Recognising that there is more to sustainability than GHG emissions alone, analyses of the market for avoided GHG emissions were taken as mere indicators for suitable price levels of a sustainability premium.

The supply function of biomass and biomass derived fuels

Just as sustainability, bio-energy is not supplied on a single market. There are a number of regulations that effectively create a division in the supply of biofuels. This is because part of the biofuels consist of contaminated waste, whereas waste disposal and processing are strictly regulated in such a way that the biofuels which belong to that category cannot be offered on the more general fuel market. Various regulations on a country level, and also on a European level, keep the supply and use of contaminated biomass in check. The relevant European regulations are 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). This is of significant influence on the biomass fuel supply side, particularly on bio-fuels like: manure, slaughter house waste, waste from pulp and paper production, and biodegradable municipal waste and sewage sludge. However, those bio-fuels play an important role today in the gamut of bioenergy, and this study shows that they are likely to play an important role in the future. To stress the strong regulative role of waste management policies in view of the use of these bio-fuels, this study refers to them as 'non-tradeables'. The opposite bio-fuel category, predictably, are the 'tradeables', and these are the clean types of bio-fuels. The impact of policies on the market of these bio-fuels is less direct, as a result of the more distant effects of the relevant policies, i.e. 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 emission trade scheme (2003/87/EC), and the Kyoto Protocol's flexible instruments (CDM, JI). The distinction of bio-fuels into tradeables and non-tradeables enables an allocation of the various bio-fuels to specific applications, in such a manner that the use of non-tradeables is restricted, whereas tradeables can be used anywhere. Additionally, non-tradeables concern biomass types that bear a negative value to the owner, in contrast to tradeables.

In this study, the notion of trade goes further than that. Whereas in previous studies for the EC, notably TERES II[2] and the Shared Analysis Project,[3] biomass was regarded as a local fuel (used close to the place of its production), we assumed the possibility of international trade in biomass fuels, both intra the EU, and into the EU. Intra EU biomass trade was already studied under the EC ALTENER programme.[4] In addition, we specifically included the option of imports from third countries, which was already investigated in studies carried out for the FAO,[5] the Dutch Government and the Dutch electricity sector.[6] Incorporation of this option considerably shifts the level of the biomass supply function, and is particularly relevant in view of a major conclusion of the Shared

2/ ESD (1996).

3/ Capros, Mantzos, Petrellis *et al.* (1999), and EU (1999c).

4/ By Agterberg and Faaij (1998).

5/ Wasser and Brown (1995).

6/ Wasser and Brown (1995), Lako and Gielen (1997), Lako and Van Rooijen (1998).

Analysis Project, i.e. that the growth in biomass energy is constrained by the European biomass resource base. If international trade is a realistic option, biomass fuels would become relevant for the EC policy to reduce the dependence of the EU economies from oil imports,[7] and thus also in this way contribute to increased sustainability.

The technology development function of biomass fuelled energy conversion technologies

Whereas, today, one is able to produce final energy products from biomass (the final energy product being either electricity, heat (or a combination: CHP) or fuel for transportation), biomass energy conversion technologies are strongly in development. Technology is the intermediary between biomass fuels and the final energy product. It is characterised by a conversion efficiency and a capital cost component. Particularly for biomass-fuelled electricity generation technologies, large R&TD programmes are being carried out, aimed at achieving higher energy conversion efficiencies at effective cost levels. To a much lesser extent this is the case with biomass-fuelled CHP and heat generation. The developments in those areas are not so much aimed at the improvement of conversion efficiencies, but rather at emission level control and user convenience. Both types of R&TD issues are relevant for this study. The first is more geared towards the improvement of the economic feasibility, and the latter towards technical feasibility and user acceptance. Specifically the economic objectives in the area of biomass-fuelled electricity generation technologies are investigated in this report, and modelling rules derived for the scenario elaborations with SAFIRE.

With regard to renewable transportation fuels, the EC is explicit about its ambitious objectives, but in most European countries a decisive start with the implementation of this policy still has to be made. At the same time, the technical options to address these EC objectives are numerous. Bio-transportation fuels are among the most attractive ones, but even within this category there exist many technology options, both in terms of bio-fuels and vehicle propulsion techniques. For this study it was attempted to make a realistic estimate of costs and conversion efficiencies of bio-transportation fuels for the time window considered .

Until today, the European distribution grid for natural gas remains absent in the European energy policies as a substantial means for distributing a renewable energy carrier. In terms of technologies, the potential of this grid is discussed. However, they are not further elaborated in the scenario models as candidate applications of biomass fuels that could have a determining impact on the role of bio-energy until 2020.

Seeking equilibria of supply and demand

The future role of biomass fuels was estimated by means of the SAFIRE model that simulates economic investment behaviour. The model was fed with a number of alternative scenarios to test the impact of different hypotheses. These hypotheses concern

7/ As proposed by the EC in its Green Paper 'Towards a European strategy for the security of energy supply', (EU (2000b).

the capital costs of applications, the costs of biomass fuels and the value of sustainability premiums.

For the use of non-tradeable biomass types, as defined above, in electricity and heat generation, several investment levels for conversion technologies were assumed. The acquisition costs of these fuels was taken as zero. The principal background to this approach is that these types of biomass are waste in the first place, the owners of which need to dispose of. Any negative value attached to these fuels was considered to balance the operating and capital costs associated with waste removal, e.g. incineration plants. The costs of processing non-tradeables further, i.e. beyond pure incineration, into electricity or useful heat was considered additional.

For tradeable biomass fuels in electricity and heat applications, biomass fuel prices are being established on a much larger market (as discussed above). Here, the equilibrium prices of biomass fuels were estimated by analysing the supply and demand functions of biomass. The general principle is illustrated in Figure 1, showing projected supply and demand curves of bio-fuels for electricity and heat generation for the year 2010 (the data shown are purely illustrative). For other target years, different supply and demand curves may apply. In an ideally competitive market, all transactions take place at the single price level (P_{2010}) where supply meets demand (Q_{2010}). All scenario studies on the economic role of biomass energy need price data on bio-fuels, however, it is a special characteristic of this study that biomass fuel prices are assessed in a dynamic model and that the assessment is made explicit.

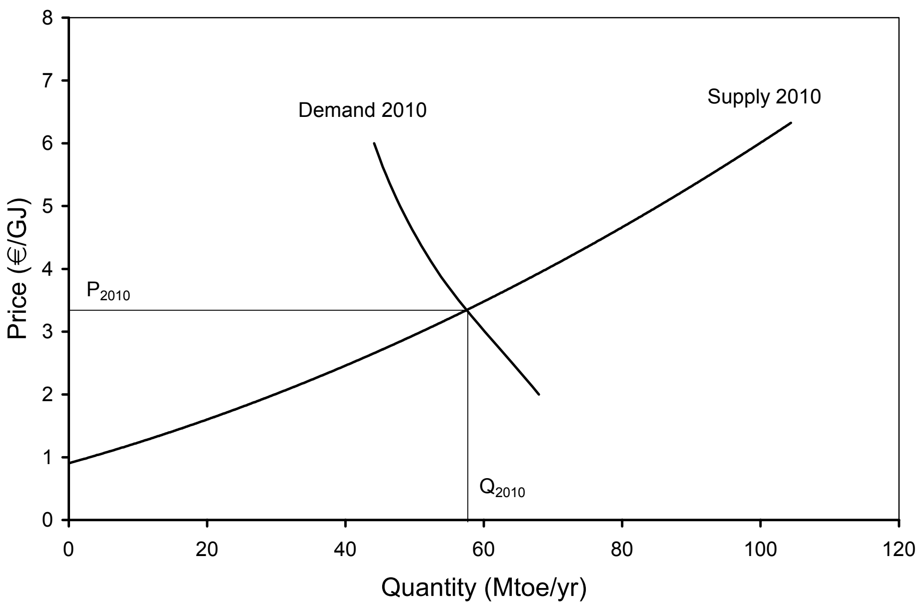


Figure 1, Price determination in a perfectly competitive market for biomass fuels and heat and electricity. (Shown data are purely illustrative).

For bio-transport fuels a different approach was chosen, since it appears that this sector is directly affected by European policies. Here the production costs of bio-transport fuels were taken as an input, and the sustainability premium required to meet the agreed sectoral objectives were determined.

1.4 MAIN FINDINGS

Biomass availability

The study found a total availability of biomass fuels in the EU15 of 130 Mtoe/yr for the year 2000, growing to 170 Mtoe/yr in 2020 (Table 1). These overall figures should be regarded as indicative. In the first place, they are inaccurate. An inaccuracy in the range of ±10% in these figures is the result of an assumption on land use for energy crops, i.e. that the current set-aside area (about 10% of the arable land) is available for energy cropping,[8] and that 50% of that area is available for the raw materials of bio-diesel and bio-ethanol. If, instead, solid energy crops would be produced here, the figures presented would increase by 10 Mtoe/yr. If, on the other hand, liquid bio-fuels would represent the preferential energy crops, the availability would drop by 10 Mtoe/yr. In the second place, these data disregard import possibilities, which, as substantiated in the sources investigated, give rise to unlimited supplies. At a high cost though, however not always more expensive than locally produced energy crops. Within the context sketched here, the availability of tradeable bio-fuels in the EU15 amounts to 86 Mtoe/yr in 2000 (100 Mtoe/yr in 2020), of non-tradeable bio-fuels to 40 Mtoe/yr in 2000 (66 Mtoe/yr in 2020).

8/ This assumption on land availability is not arbitrary. It presumes that a low value product like fuels cannot compete with the usual agricultural products.

Table 1, Availability of bio-energy in Europe in 2000, 2010 and 2020 (Mtoe/yr).

	EU15			Accession States, plus two candidate countries (BG, RO)		
	2000	2010	2020	2000	2010	2020
Tradables:	**86**	**93**	**101**	**21**	**22**	**24**
Forestry byproducts & (refined) wood fuels	34	38	42	7.9	8.7	9.6
Solid agricultural residues	25	28	31	7.3	8.1	8.9
Solid industrial residues	11	12	13	2.1	2.4	2.6
Solid energy crops /a	16	16	16	3.2	3.2	3.2
Non-tradeables:	**40**	**53**	**66**	**7.1**	**9.4**	**13**
Wet manure	11	12	13	3.4	3.8	4.2
Organic waste						
- Biodegradable municipal waste	6.7	17	28	0.5	2.5	5.7
- Demolition wood	5.3	5.8	6.4	0.6	0.6	0.7
- Dry manure	1.9	2	2.3	0.4	0.4	0.5
- Black liquor	9.9	11	12	0.7	0.8	0.9
Sewage gas	1.7	1.9	2.1	0.4	0.4	0.5
Landfill gas	4.0	3.8	2.1	1.1	0.9	0.4
Transport fuels	**4.9**	**4.9**	**4.9**	**0.8**	**0.8**	**0.8**
Bio-ethanol /a	3.7	3.7	3.7	0.5	0.5	0.5
Bio-diesel /a	1.2	1.2	1.2	0.3	0.3	0.3
Total bio-energy	**131**	**151**	**172**	**28**	**32**	**38**

a/ It is assumed that 50% of the set-aside area is available for solid energy crops and 25% each for bio-

The growth in the availability of organic wastes is most striking. This is the result of the EU wide implementation of the EC directive on the landfill of waste (1999/31/EC), discouraging the landfilling of biodegradable waste and a prescribing a time schedule to reduce this manner of waste disposal to a specific level.

On average, supply costs[9] of tradeable biomass fuels in the EU15 vary from 1.6 €/GJ (solid industrial residues) to 5.4 €/GJ (solid energy crops) (Table 2). Specifically for estimating the supply costs of solid energy crops, a new generic methodology had to be prepared and applied. This was because of the multitude of methods employed by the various authors on that subject. The method adopted here, closely resembles the ones commonly used in the EU's analyses of agricultural policies. Estimates were prepared for every single country. On average, the supply costs of solid energy crops are close to those of imported biomass, which was taken at a standard level of 6 €/GJ. Single average supply costs of 23-29 €/GJ were determined for the refined bio-transport fuels bio-ethanol (from sugar beet and wheat) and biodiesel (from rape and sunflower seed).

9/ Delivered to the end-user.

Table 2, Average supply costs of tradable biomass and crops for transport fuels (€/GJ).

	EU15	Accession States, plus two candidate countries (BG, RO)
Tradeables:		
Forestry byproducts	2.4	2.1
Wood fuels	4.3	2.7
Dry agricultural residues	3.0	2.1
Solid industrial residues	1.6	2.5
Solid energy crops	5.4	4.4
Imported biofuels	6	6
Transport fuels:		
Biodiesel	23	23
Bio-ethanol	29	29

Note that these supply costs are not necessarily equal to the prices occurring at market equilibrium. With the information collected, supply curves (costs vs. quantities) were constructed that could serve to analyse the market equilibrium for tradeable bio-fuels.

Equilibrium of supply and demand

Demand curves for bio-fuels were generated by the SAFIRE model, basically by running the model at a variety of biomass fuel prices. Intersection points of supply and demand were determined to assess equilibrium prices and quantities. In terms of primary energy usage, the results for the EU15 are shown in Figures 2-3. Of the data shown, those for the low sustainability-premium scenario are the most realistic, as that scenario is closest to the economic reality of today.

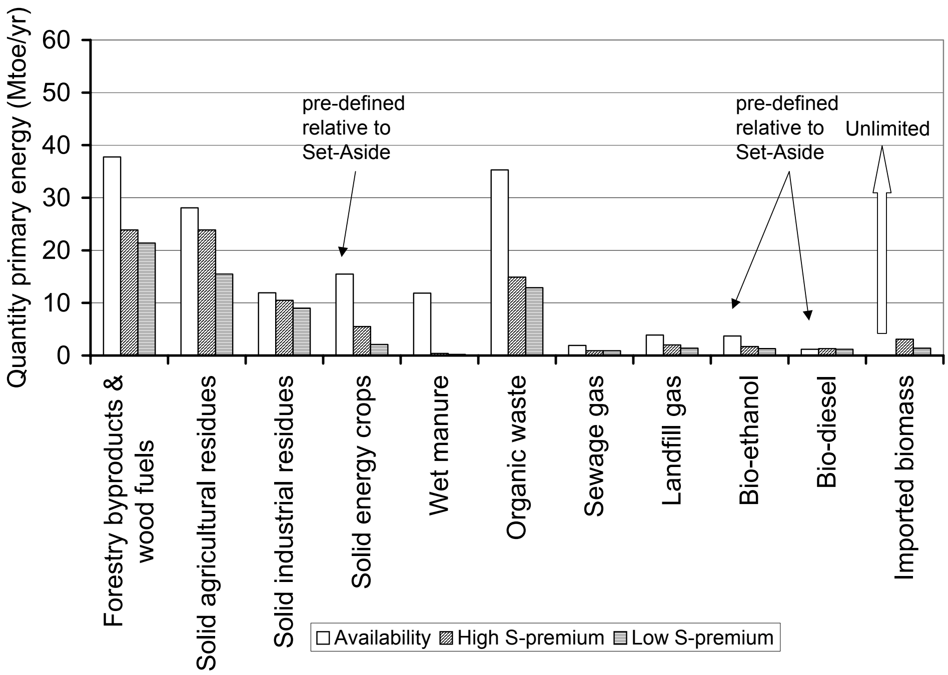


Figure 2, Availability and use of biomass in the EU15 in the Technology Base Case, in 2010. Two scenarios are shown: Low Sustainability Premium (Low S-premium) and High Sustainability Premium (High S-premium).

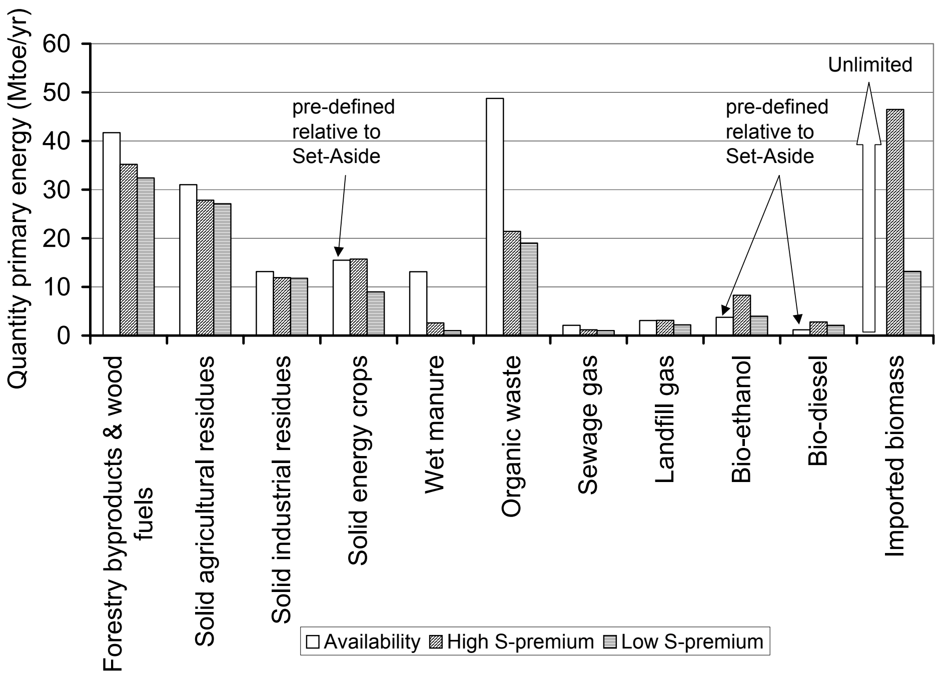


Figure 3, Availability and use of biomass in the EU15 in the Technology Base Case, in 2020.

Among the most outstanding results are:

- The large growth of bioenergy from 41 to 67 and 123 Mtoe/yr (2000-2010-2020). This is much less though than foreseen in 'Energy for the future' (135 Mtoe in

2010), but substantially higher than reported by the 'Shared Analysis Project' (up to a maximum of 72 Mtoe/yr in 2020).

- Most growth is in tradeable biofuels (68 out of 82 Mtoe/yr over 2000-2020)
- The price of tradeables is high, at levels of 3.7-4.9 €/GJ.
- In these scenarios, bio-transport fuels take a small proportion in 2020 (6 Mtoe/yr), and the targets of the bio-transport fuel directive are not met. (The targets imply a quantity of 17 Mtoe of bio-transportfuels per year in 2010). Below, the question is addressed what policies would be needed to achieve those targets.
- There is a large growth in the use of solid agricultural residues.
- There is considerable growth in forestry by-products and refined wood fuels.
- Biofuel imports into the EU takes off.
- Only a small role of solid energy crops, and of energy crops for bio-transport fuels is found.

The transports directive's (2003/30/EC) objective, to replace 5.75% of the energy of all petrol and diesel transport fuels by renewable fuels, is not met in any one of the scenarios shown in Figures 2-3. This conclusion, obviously, builds on the assumption that bio-fuels are the only means to achieve that objective, and disregards other technology options that could serve the purpose (e.g. renewably produced, but non-biomass based, hydrogen for fuel cells).

An intriguing question, then, is how the objectives of the transport directive can be met? To analyse this matter, the sustainability premium was varied (in the base case scenario of existing technologies) to a level where the targets are achieved. Whereas the preceding scenario runs showed that sustainability premiums of 50 - 100 €/tonne CO_2-eq. were not enough to finance the targets set, it was found that the premium had to be increased to an average level of nearly 220 €/tonne CO_2-eq. If that premium applies, the major biofuel producing countries become Germany, France, Spain and the UK. It was also found that the present set aside area is not sufficient to produce sufficient bio-transport fuels within the EU15. If the EU15 wishes to meet the targets of the bio-transport fuels directive with European grown energy crops, 9% of arable land should be dedicated to the production of these non-food crops. A target such as determined in the transport directive does not apply to the accession states, but if there would, about 6% of the total arable land of the EU15 plus the accession states will be required to meet the same target as defined for the EU15 in 2010. Although the modelling results do not show a high penetration of biofuel production in the accession states, there is - given the substantial area of arable land in those countries - a large potential for producing biofuels and exporting them to the other countries. In SAFIRE the production of biofuels is primarily driven by the national demand for biofuels. Trade of biofuels within Europe was postulated as an assumption to define how the overall target should be met in terms of physical quantities, but is not an integral part of the model, and there may be efficiencies involved if SAFIRE would allow such trade. This implies that these results are somewhat pessimistic in terms of the level of the sustainability premium.

Meeting RES targets

There are two EC documents that actually set targets for the role of bioenergy in the sectors of electricity and heat (transport was discussed above). The first, and most general one, is the White Paper on 'Energy for the future'. A plausible interpretation of this document shows that biomass is expected to contribute in the following manner to the 2020 sustainable energy targets of the EU:

31 Mtoe for non-CHP electricity
65 Mtoe for non-CHP heat
32 Mtoe for CHP electricity and heat
18 Mtoe for bio-transportation fuels

The second document is Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market. Actually the directive is broader than biomass alone, setting indicative national targets for electricity produced from renewable resources by 2010. By that year, a total of 22% of the electricity consumed in the EU15 should be made from renewable sources. For the Technology Base Case/Low-Sustainability Premium Scenario, the role of biomass in achieving these targets is presented in Table 3.

Table 3, The role of bio-electricity in achieving the targets for RES electricity by 2010.

	Low Sustainability Premium		
	TWh/yr	share of target	share of total electricity
Technology Base Case			
Bio-electricity (excl. co-combustion)	43	7%	1.4%
Bio-electricity (co-combustion)	35	5%	1.1%
Total bio-electricity	78	12%	2.6%

In this scenario, the role of bio-electricity is limited to 2.6 % of total electricity production by 2010, and bio-energy contributes by 12% to meeting the targets of the RES electricity directive. This is rather limited. At present, the generation of renewable electricity is often heavily subsidised. Subsidies of 50 €/tonne CO_2 as shown in the high sustainability premium scenario, correspond with 0.06 €/kWh of electricity. This level is currently not uncommon in many EU15 countries, such as Germany and the Netherlands. The study shows that these incentives remain necessary if the targets in Directive 2001/77/EC are to be achieved.

Rather than the available quantities of biomass, it is the economy of bio-energy technologies that limits the employment of biomass as a sustainable energy resource. The size of the sustainability premium is therefore essential for biomass to play a significant role in electricity generation. If the European GHG emission trade scheme develops favourably, at the low levels as anticipated, and if ETS develops as an alternative for currently existing incentive schemes, then the role of biomass electricity seems not to be able to become as predominant as anticipated in the past. The same applies to the role of biomass in the transport sector, where extremely high sustainability premiums are needed to finance the achievement of the politically agreed targets. This should not necessarily be an adverse development, if one concludes that the prevailing incentive schemes for biomass energy are less economically efficient. Before doing so, one should remember that the sustainability premium as defined in this study concerns more than carbon emissions alone, but includes issues like supply diversification and independence as well. If those issues are worth our while, the we are willing to afford more than the value of carbon credits alone. How this willingness to pay should be translated in financial terms is an important question, still unanswered, for carrying out this type of studies.

Greenhouse Gas Emissions

A major reason to promote the use of biomass for energy, is its neutralising effect to the global balance of GHG emissions. However, biomass production and use are not entirely GHG neutral. At the same time the precise balance is a complicated matter and, since 1995, a specific task force to investigate “Greenhouse Gas Balances of Bioenergy Systems” (IEA Bioenergy, Task 15) has been established by one of the Implementation Agreements of the IEA. As of 2001, Task 15 is being continued as Task 38 under almost the same name: “Greenhouse Gas Balances of Biomass and Bioenergy Systems”.

Using biomass for fossil fuels is a generally agreed method to reduce GHG emissions. However, the biomass fuel cycle is not entirely GHG neutral. This is because production and transport are involved. Adequate assessment of the GHG emissions from these activities is needed to create a proper accounting system and analysis framework of the GHG issues related to biomass energy systems. However, there is another relevant phenomenon that is often disregarded, i.e. the negative GHG emission (capture) as a result of biomass growth, and the positive GHG emission as a result from using the biomass fuel. They are considered to cancel out, which they do on a global level, but not on a national level if international trade is involved. As an example, consider the production of bio-transportation fuels in Austria for export to and use in Germany. Both countries do have an obligation in view of the Kyoto Protocol to reduce their GHG emissions. Should the capture of CO_2, as a result of the production of bio-diesel, appear on the national GHG balance of Austria? If so, Germany can no longer ignore the GHG emission of the imported bio-transport fuel itself. And, although the global balance, given above, remains valid, the economic benefits of reducing GHG emissions in this manner would not devolve to Germany. This issue is recommended for further elaboration.

One chapter of this report is dedicated to GHG balances of bio-energy. Both analyses of generating systems for electricity, heat and of production/utilisation systems for transportation fuels are reviewed from a broad range of literature resources.

For the year 2000, on an EU15 level, GHG emissions are still higher than the goal, achievable in 1212, agreed in the Kyoto Protocol. There was an excess of about 200 Mt CO_2-eq./yr between the KP target and the 2000 GHG emission. For the EU15, Table 4 shows that the Low Sustainability-Premium Scenario yields net emission reductions, relative to 2000, of 87 Mt CO_2-eq./yr by 2010. In view of the 2000 gap of 200 Mt CO_2-

eq./yr these quantities are substantial, and it implies a quite relevant role for biomass energy.

Table 4, EU15: Avoided GHG emissions as a result of biomass utilisation (Mt CO_2 eq./yr), under the Technology Base Case.

			Low Sustainability Premium	
	1990 /a	2000	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	n.a.	81	132	244
Bio Electr. (tradeable, co-combustion)	n.a.	-	29	59
Bio Electr. & Heat (non-tradeable)	n.a.	39	42	61
Bio Transport Fuels	n.a.	1.4	4.8	11.5
Emission reduction as if all bio-energy is additional	101	122	208	375
Emission reduction relative to 1990	-	21	108	274
Emission reduction relative to 2000	-	-	87	253

a/ The 1990 emission reduction is justified in the main text.

Further research

It might seem that ending a report with suggested topics for further research is nothing but a way to ensure one's own employment. To maintain the confidence of the reader, therefore, the authors hope that the arguments given below will provide protection against the suspicion of hidden conflicts of interest.

Externality costing should be made into an operational tool. A major finding is that, in order to achieve the 2010 targets politically agreed for bio-energy, and in order to enable the industry to go ahead with the developments begun, relatively high sustainability premiums are required. Would this be a reason to reduce the support to European bio-energy? No, not if the price of those premiums balances the value of all sustainability issues, listed before. These sustainability issues concern reduced dependence on imported fossil fuels, environmental values, job creation, etc. A difficulty for policy makers is that they do not have a yardstick at their disposal to judge the matter. We do observe a large difference between the required sustainability premiums and today's price expectations for carbon credits under the various trade schemes of the Kyoto Protocol and the European Emission Trading Scheme. But we do not really know whether the price for sustainability is high or not. An answer to that question seems all the more urgent in view of the well-defined EC decisions concerning the desired role of renewables in the various economic sectors (e.g. refer to the RES Electricity Directive 2001/77/EC and the RES Transport Directive 2003/30/EC). Comparing the latter two sectors, we found that the sustainability premiums required to implement these policies are clearly of different orders of magnitude. This may be justifiable, but is it?

The EXTERNE project[10] carried out during the 1990s by the EC and the US Department of Energy was a major attempt to provide a common basis for comparing energy technologies while including the so-called external effects. One would wish the results of that activity to be translated into a tool by means of which the evaluations such as carried out for this study can be made more objective. And those results need not only

10/ Holland, Berry, Nocker *et al.* (1995).

be translated into such a tool, but they need also to be updated and extended to include all issues that belong to a sustainable development, but that are not yet internalised in the European economy. This would improve the quality of political decision making.

Continued learning from experience is also needed, and the European R&TD and demonstration programmes are important means to make this possible. A major topic that deserves more attention from industry are technologies that facilitate international trade in bio-fuels. The international trade in bio-fuels was found to become more and more important. At the same time it contributes to specific sustainability objectives of the EC's bio-energy policy, particularly a reduced dependence on energy imports and increased security of supply, and, if European technologies are involved, the creation of business opportunities for European Union industries (in Asia, Latin America and Africa). Associated technologies concern production and use of biomass-based energy carriers that can be traded and used cost-effectively. Examples of such energy carriers are bio-ethanol, biodiesel, and pyrolysis oil (bio-oil). Utilisation techniques could involve application in gas turbines for electricity production, and road transport. Innovative intermediate upgrading techniques, such as hydrogenation, could be needed to further adapt imported bio-fuels to end-uses. A review of existing technology developments of industries and governments is therefore suggested.

2 INTRODUCTION

The main question addressed in this study report is what the role of bio-energy can be in the future until 2020, for the entire EU15, the European Union's new Accession Countries (10, in 2004), and two of the Candidate Countries, i.e. Bulgaria and Romania (see Figure 4).

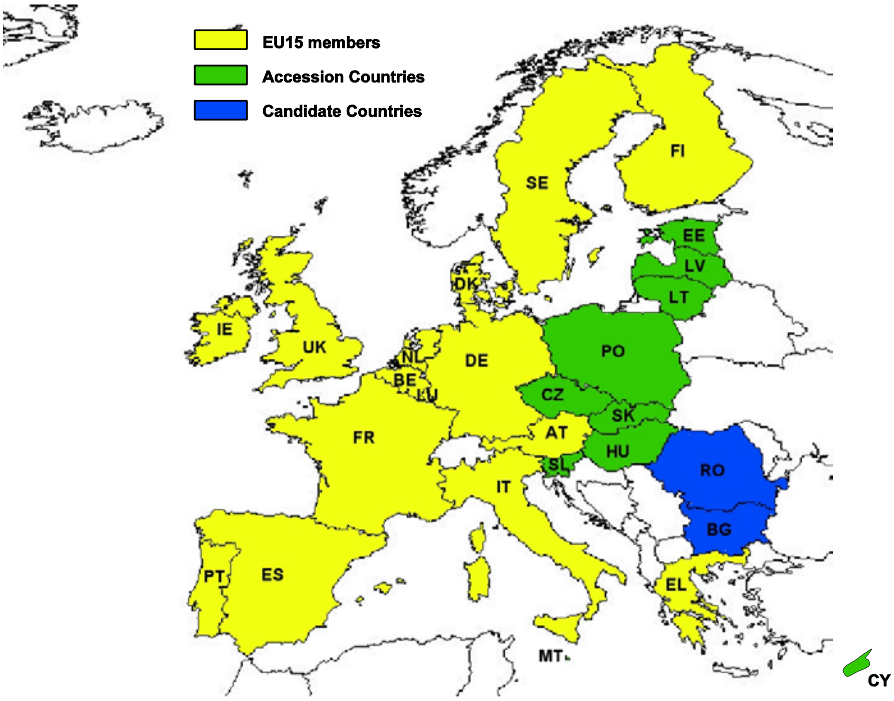


Figure 4, The countries considered in this study.

The future role of bio-energy, and in fact also today's role, depends on the developments of three economic functions:

- The characteristics of biomass fuelled energy conversion technologies.
- The supply of biomass and biomass derived fuels.
- The demand for renewable energy in general and biomass in particular.

The market of bio-energy, unfortunately, is not uniform and simple, so that the analysis of these functions and their interdependence cannot be simple either. A specific research approach, taking the characteristics of that market into account, was therefore specifically developed and is explained in Chapter 3. Following that explanation, the first two of the above mentioned functions (technologies and supply) are investigated in Chapter 4 and 5.

For an assessment of the demand for bio-energy, all value components need to be taken into account, that is, not only the energy value but also the value of its contribution to sustainability. The emerging market for carbon credits is assumed to give crucial indications concerning this value, since a major reason to promote bio-energy is its potential green house gas neutrality. Greenhouse gas balances of the relevant range of technologies are therefore reviewed in Chapter 6. By means of a model of the market for renewable energy (SAFIRE), the demand for bio-energy is then investigated for a number of possible futures, the development which is unavoidably uncertain, and therefore varied for this study. The various parameter values (of the sustainability premium, technology characteristics) are discussed in Chapter 7. And then, finally, SAFIRE is run, and the results are presented in Chapter 8. Interpretations of those results are given in the concluding chapter, 9.

3 APPROACH

3.1 INTRODUCTION TO THE APPROACH

The role of bio-energy, and its development, is a result of a number of economic functions:

- the demand function for bio-energy
- the supply function of biomass and biomass derived fuels
- and of the development function of biomass fuelled energy conversion technologies.

To assess the role of bio-energy, these three functions and their interactions need to be analysed, taking into account that these functions are based within the larger framework of the energy sector, with its own political, economic and technological dynamics.

Distinction between tradeable and non-tradeable bio-fuels

Bio-energy is not supplied and demanded on a single market. There are a number of regulations that effectively create a division in the supply of biofuels, or bio-energy in general. This is caused by the fact that part of the biofuels consist of contaminated waste, whereas waste disposal and processing are strictly regulated in such a way that the biofuels which belong to that category cannot be offered on the more general fuel market. This is mainly controlled by imposing much stricter emission regulations for contaminated wastes than for other fuels, and by prescribing or forbidding certain ways of energy conversion or application. The biofuels to which this applies are:

- Manure
- Slaughter house waste
- Fibrous vegetable waste from virgin pulp production and from production of paper from pulp[11]
- Biodegradable wastes (such as biodegradable municipal waste and sewage sludge)

On a European level this is regulated by the Directive on the incineration of waste (2000/76/EC),[12] by the Directive on the limitation of emissions of certain pollutants into the air from large combustion plants (2001/80/EC),[13] and by the Directive on the landfill of waste (1999/31/EC).[14] Nevertheless, the biofuels indicated above play an important role today in the gamut of bioenergy, and they are likely to play an important role in the future. Their role however is mainly policy driven rather than market driven along the classical dynamics of supply and demand. In this study these fuels are referred to as 'non-tradeables'. Note that this is just a label to show that these fuels are not subject to classical market dynamics. To assess the future role of this type of biofuels, the relevant policies are analysed with respect to their impact on bio-energy development during the time window investigated (2000-2010-2020).

11/ We interpret EC Directive 2000/76/EC in such way that black liquor from paper production is included in this category, EU (2000a).
12/ EU (2000a).
13/ EU (2001b).
14/ EU (1999b).

The trade in clean waste biomass (as opposed to contaminated waste biomass) is less restricted, Siemons (2002b). Together with other biofuels they are referred to, here, as 'tradeable', and they are subject more directly to the classical supply and demand functions. For the tradeable biofuels, this study focuses on the analysis of these functions, and on their interaction. There is an impact of policies on this trade as well. However, it is less direct, for example by creating frameworks for the production and trade in energy products (such as renewable electricity, and transport fuels) in which the tradeable biofuels may play their role. Relevant policies are formulated in:

- the Directive on RES-Electricity (2001/77/EC)[15]
- the Directive on biofuels or other renewable fuels for transport (2003/30/EC)[16]
- the Directive (proposed) on GHG trading[17]
- the Kyoto Protocol's flexible instruments (Clean Development Mechanism, Joint Implementation)[18]

Tradeable biofuels for electricity, heat and transport fuels

Both the Directive on electricity production from renewable energy sources (RES) (2001/77/EC) and the Directive on biofuels or other renewable fuels for transport (2003/30/EC) quantify concrete targets for the respective sub-sectors of electricity and transport over a number of target years (up to 2010).[19] A difference between the two sub-sectors is that the electricity sector is able to satisfy the RES directive by utilising a wide range of renewable resources, i.e. a broad gamut of biofuels, as well as wind, solar, geothermal, wave, tidal, and hydro energy. The heat sector is also able to choose from a wide variety of biofuels. In contrast, the transport sector appears to be less flexible in terms of biomass supplies, the major two alternatives for the transport sector being biodiesel and bioethanol, at least during the time frame considered.[20] Unless imports from oversees are feasible, both these fuels need to be supplied by European agriculture. For this reason, the study analyses the transport sub-sector separately from the sub-sectors of electricity and heat.

Supply and demand curves of tradeable biomass fuels

Like for all scenario studies that consider the role of biomass, an essential question for the current study is, at what cost can tradeable biomass fuels be acquired. The further development of this issue requires a principal market consideration. On the long term, if bio-energy gains in relevance, there are many types of biomass fuels and many biomass suppliers, and there are many different producers of biomass-derived energy employing different technologies and operating on different scales. But they all operate on the same

15/ EU (2001a).

16/ EU (2003b).

17/ EU (2001c).

18/ UNFCCC (1997).

19/ The RES-electricity directive sets an overall target of 22% ultimo 2010 for the EU15, with large variations across the various member states, EU (2001a), Annex. The transport directive imposes a uniform penetration rate of 2% ultimo 2005 and 5.75% ultimo 2010, on an energy basis, EU (2003b), Article 3.

20/ This is justified in Section 4.3 on bio-transport technologies.

market. As a result, once a market has been established, and in the absence of monopolies and monopsonies, differences in gate prices of clean biomass fuels may be expected to depend only on variations in additional processing costs observed by the buyer (such as grinding and drying operations). And so, some biomass fuel providers will obtain higher profit margins than others, the differences depending on their production costs rather than on the sales prices of their product.[21] It would be a mistake to assume that in a market for biomass fuels there will be differences in fuel gate prices solely on the basis of the origin of a fuel. For example, the increased distance between a biofuel production site and the place of use will not necessarily result in higher gate prices due to increased transportation costs, nor will low opportunity values result in low gate prices, and clean wastes will not be less expensive than other purchased biofuels.

For tradeable biofuels, therefore, supply and demand curves need to be assessed, and their interaction analysed. The general principle is illustrated in Figure 5, showing projected supply and demand curves of biofuels for electricity and heat generation for the year 2010 (the data shown are purely illustrative). For other target years, different supply and demand curves may apply. In an ideally competitive market, all transactions take place at the single price level (P_{2010}) where supply meets demand (Q_{2010}).

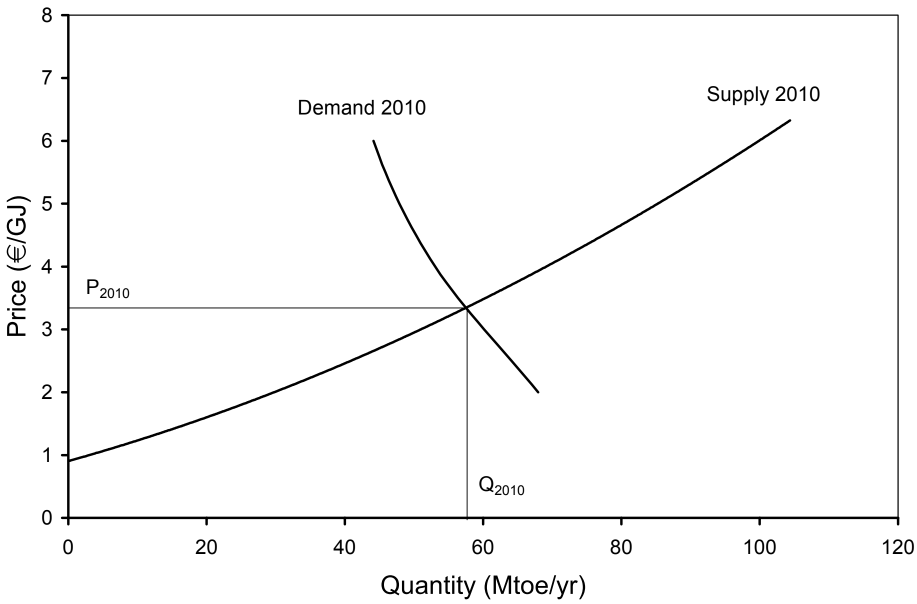


Figure 5, Price determination in a perfectly competitive market for biomass fuels and heat and electricity. (Shown data are purely illustrative).

21/ The argument runs entirely parallel with Ricardo's explanation for the amount of land rent being a result of wheat prices, Ricardo (1821 (1951)).

Comparison of the methodology of this study with that of previous studies

A number of past studies that aimed at investigating the future role of biofuels in general, or of specific biomass-fuelled energy conversion technologies, biofuel prices were also estimated and used as input data in model evaluations. However, no such study was identified in which the fundamental economic mechanism of supply and demand was made explicit. This equally applies to two major studies that also investigated the role of biomass in the next decades, i.e. TERES II[22] and the Shared Analysis Project.[23] In fact biomass prices were used, but not reported by those studies. Some other studies approached the issue of supply and demand in a fundamentally incorrect manner, by supposing an average biofuel price determined by a weighted average of the supply costs of biofuels obtained from different suppliers. In doing so, one arrives at estimates for biomass fuel prices that are too low.

3.2 DETAILED METHODOLOGY

The SAFIRE model, originally developed for and used in TERES II by ESD, is also involved in the study reported here. SAFIRE, is an equilibrium model that balances expected market demand for energy with a set of conventional and renewable supply options, according to economic payback criteria, and using extensive user-entered data on prices, installed capacities etc that are employed by the model to create scenarios for technical potential, market potential and market penetration for renewable energy technologies. Market demand arises from defined growth in the specific end user sectors, and the supply options include most categories of renewables, including 10 biomass options. The SAFIRE model was used in a differentiated manner for the various parts of the energy sector:

- For tradeables in the electricity and heat sector, SAFIRE was used for demand curve analysis only. This is because we intend to make the role of supply and demand of tradeable biomass fuels explicit and debatable. For these biomass fuels, we also allow international trade, thus assuming an unrestricted technical potential (this is justified in Chapter 5 on biomass supply). Supply curves are investigated externally to SAFIRE.
- For non-tradeables in the electricity and heat sector, the usual SAFIRE approach to project supply and demand was followed.
- For bio-fuels in the transportation sector, the usual SAFIRE approach was followed to determine the additional costs (expressed as €/t CO_2-eq.) involved to comply with the renewable transportation fuel directive.

22/ ESD (1996). TERES II served as a background analysis of the EU's White Paper on renewable energy 'Energy for the Future', EU (1997).

23/ The Shared Analysis Project was initiated by the Directorate General for Energy of the European Commission in 1998, with the aim of integrating the potentials for energy policy analysis within the member states of the EU. One of the first publications of the Shared Analysis Project is the 'European Union energy outlook to 2020, 'Capros, Mantzos, Petrellis *et al.* (1999).

3.2.1 Implementation of the SAFIRE model

SAFIRE simulates the energy market in a two-step approach: First the so-called technical potential is given as an input, and secondly the market potential or market penetration are determined by simulating economic decision making.[24] The SAFIRE calculation is divided into five distinct progressive steps, which are:

- Energy consumption
- Technical potentials
- Decentralised market potentials
- Market penetrations
- Cost benefit calculations

Figure 6 shows the SAFIRE calculation procedure.

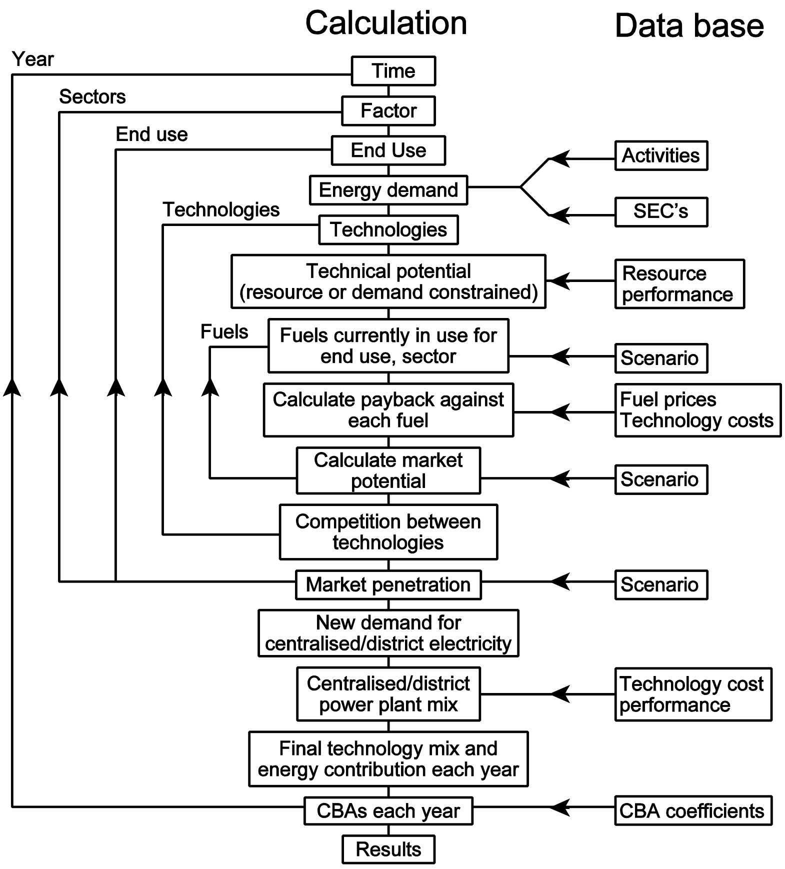


Figure 6, The SAFIRE simulation procedure.

Energy Consumption: The first part of the calculation is critical to SAFIRE. As SAFIRE links its supply calculation to the energy consumption in each country, this data need to be accurate in order to ensure coherent results. In the calculation, demands are considered

24/ See also the available SAFIRE documentation, ESD (1998b), and ESD (1998a).

as either decentralised demands, the demands at each sectoral level (domestic, commercial, industrial etc.), or centralised electricity demand which is entered by the user in terms of the base year generation capacity. SAFIRE aggregates the total energy demand in each sector from the activities within that sector. For each activity, the consumption is further disaggregated by fuel type and specific energy consumption (Table 5). The aggregated sectoral demands are used towards calculating the market potential of each new energy technology that can be utilised in each sector.

Table 5, Sectors and applications considered by SAFIRE.

Domestic		Commercial		Industrial		Agricultural	
1	Space heating	1	Water heating	1	High-temperature process heat >300°C	1	Water heating
2	Water heating	2	Space heating	2	Low-temperature process heat <300°C	2	Space heating
3	Cooling	3	Cooling	3	Space heating	3	Cooling
4	Electricity	4	Electricity	4	Electricity	4	Electricity
		5	Day lighting				

Technical Potentials: The technical potential is the amount of energy that could theoretically be supplied by each renewable energy resource within each country. For some of the technologies the technical potential is resource constrained, i.e. there is a finite amount of resource which can be utilised - as, for example, with agricultural land for energy crops. For other technologies the technical potential is constrained by demand i.e. there is plenty of resource but it can only supply a proportion of the demand. For example, it may be assumed that only 10% of households may be able to use solar thermal collectors in a country because of factors such as orientation, tenure etc. Planning restrictions may also constrain the technical potential. In past studies, the technical potential of biomass fuels was also given as an input, i.e. at a country level. Thus it was assumed that biomass fuels could not be traded among individual countries. In this study we do not accept this as an hypothesis, but allow international trade. Table 6 shows the resource for each technology and any constraints that can be applied to them for the technical potential.

Table 6, Renewable resources and constraints.

Technology/Fuel	Resource factor	Possible Further Constraints
Wind	Wind speed & land area	Local population, site availability, turbine density
Large hydro	Rivers & development costs	Resource development potential
Small hydro	Rivers & development costs	Resource development potential
Photovoltaics	Solar radiation, demand	Unsuitable sites, decision makers
Solar thermal heating	Solar radiation, demand	Unsuitable sites, decision makers
Solar thermal electricity	Solar radiation, demand	
Passive solar	Building construction	-
Forest residues	Forests	Production for each sector
Energy crops	Land available	Yields, wood/biofuels, substitution constraints (biofuels)
Solid agricultural waste	Farming practices	Changes in farming practices
Liquid agricultural waste	Farming practices	Changes in farming practices
Solid industrial waste	Industry	Changes in industry
Liquid industrial waste	Industry	Changes in industry
Municipal solid waste	Rubbish collection	Recycling
Sewage gas	Sewage facilities	Changes in treatment processes
Landfill gas [1]	Landfill sites	Changes in waste disposal
Geothermal [2]	Geothermal sites, development costs	-
Wave	Suitable sites & development costs	-
Tidal	Suitable sites & development costs	-
Off-shore wind	Wind speed & sea area	Sea area availability/suitability

Market Potential: This level of energy, also known as the economic potential, is only calculated for the decentralised technologies, whether for thermal or electricity purposes only, or for cogeneration. The general definition of decentralised is any electricity produced primarily for own use. Therefore, electricity exports are possible, but only as a means of utilising surplus production. It is also assumed that all heat produced is used on-site, unless provide to a district heating scheme. The market potential calculation applies to the following sectors:

- Thermal renewable technologies - renewable
- Cogeneration (CHP) technologies - renewable and conventional
- New conventional technologies
- Growth of district heating networks

The market potential represents the economic fraction of the technical potential that the energy source can supply when compared with the conventional sources of energy commonly available in each country. Once the initial market potential has been calculated, it is then compared against the relevant technical potential and is reduced accordingly if necessary.

Market Penetration: Market penetration applies to both centralised and decentralised energy sources, but uses different methodologies for each. For decentralised energy, the market penetration is the time component of the market potential, as it is assumed that the economic (market) potential does not penetrate immediately, but gradually over time.

- Decentralised market penetration: Given the market potential, the decentralised market penetration is calculated using an 'S'-curve. This reflects the rate at which the new technology will diffuse through the market over a time period up to 30 years. New penetration only occurs if the current market penetration is less than the market potential.

- Centralised electricity market penetration. For this part of the methodology, the basic assumption is that the market penetration depends solely on economic factors, subject to the constraints placed by the regulatory body. The issue is therefore which power plant type provides least cost generation for which load category. Embedded generation is assumed to be a decentralised methodology.

Cost Benefit Calculation: SAFIRE simulates economic decision making on investments in renewables by applying decision criteria (based on acceptable pay-back periods) at specified moments in time. In this manner a new starting position for a next round of decision making is defined.

3.2.2 Classification of biomass types and resources

The biomass resource base is very diverse. To ensure that an investigation is complete, a systematic classification is needed. A possible classification of the various biomass types is given in the below matrix. It is a distinction of biomass types after their origin, and

Supply sector	**Type**	**Example**	**Utilisation sector**
Agriculture	Dry ligocelulosic agricultural residues	Straw	Tradeable, electricity and heat
	Dry lignocellulosic energy crops	Short-rotation wood, miscanthus	Tradeable, electricity and heat
	Livestock waste	Manure	Non-tradeable, waste
	Oil, sugar and starch energy crops	Oil seeds for methylesters	Tradeable, transportation
		Sugar/starch crops for ethanol	Tradeable, transportation
Forestry	Forestry byproducts	Wood blocks, wood chips from thinnings	Tradeable, electricity and heat
Industry	Industrial residues	Industrial waste wood	Tradeable, electricity and heat
		Fibrous vegetable waste from virgin pulp production and from production of paper from pulp, including black liquor	Non-tradeable, waste
		Wet cellulosic industrial residues and slaughter house waste	Omitted
	Industrial products	Pellets, bio-oil (pyrolysis oil), ethanol, biodiesel	Tradeable, electricity and heat, transportation
Waste	Parks and gardens	Prunings, grass	Tradeable, electricity and heat
	Contaminated waste	Demolition wood	Non-tradeable, waste
		Biodegradable municipal waste	Non-tradeable, waste
		Biodegradable landfilled waste, landfill gas	Non-tradeable, waste
		Sewage sludge	Non-tradeable, waste

since the categories are exhaustive (admittedly: some exotics like algae energy crops, have been ignored), all existing biomass fuel types are included. In this manner, a clear distinction is made between clean and contaminated wastes, so as to reflect the separation in the market between tradeable and non-tradeable biofuels as a result of EC legislation. During data analysis care should be taken to translate reported quantities and prices correctly to the various categories. This is a relevant matter because, in literature, other break-downs are often encountered. This applies particularly to the reporting of AFB-net V which was an important data source for this study.[25] Therefore, we briefly explain the meaning of two major biomass fuel categories.

Forestry byproducts are all those biomass fuels that originate in the forests during forestry activities. They include bark and wood chips made from tops and branches, as well as logs and chips made from thinnings. As soon as these byproducts are subject to a manufacturing process (like, e.g., briquetting or pelltising of saw dust and wood shavings) we categorise them under Industrial products.

Industrial residues include industrial waste wood from sawmills and timber mills (bark, sawdust, wood chips, slabs and off-cuts). Also the wastes from paper and pulp mills (e.g. black liquor) are included. *Probably* a large resource of industrial residues is generated in the food industry. These residues may consist of wet cellulosic material (e.g. beet root tails), fats (used cooking oils) and proteins (slaughter house waste). We omitted these residues from this study due to lack of data. Yet this resource may become quite relevant. For the Dutch food industries some larger studies were made, that may illustrate the relevance of this industrial sector.[26] Vis (2002) indicates an energy potential of 44 PJ annually, representing about one third of the total residues from this sector (the other two third are destined to other more valuable applications). In view of a total biomass fuel availability in the Netherlands of 127 PJ/yr in the form of the biomass types counted in this study,[27] the quoted 44 PJ/yr is substantial. The most relevant residues from the Dutch food industries are slaughter house waste (fats), discarded frying oil, and residues from the sugar industry. If the Dutch industries are representative for Europe, the current study is conservative in so far as biomass availability is concerned.

3.2.3 Supply and demand analysis of non-tradeable biomass fuels for electricity and heat

In this study, we consider the following biomass fuels non- tradeable for the electricity and heat market.

25/ Compare Vesterinen and Alakangas (2001), Definitions. The AFB-net studies are being prepared under the ALTENER programme of the EC, see http://afbnet.vtt.fi.

26/ Vis (2002), Elbersen, Kappen and Hiddink (2002).

27/ Compare the data reviewed in Chapter 5 on biomass supply.

Supply sector	Type	Example	Typical SAFIRE decision
Agriculture	Livestock waste	Dry manure (chicken litter)	Thermal conversion for electricity or heat vs. disposal
		Wet manure (pig manure)	Digestion for electricity or heat vs. disposal
Industry	Industrial residues	Fibrous vegetable waste from virgin pulp production and from production of paper from pulp, including black liquor	Thermal conversion for electricity or heat vs. disposal
Waste	Contaminated waste	Demolition wood	Thermal conversion for electricity or heat vs. disposal
		Biodegradable municipal waste	Thermal conversion for electricity or heat vs. disposal
		Landfilled waste, landfill gas	Thermal conversion for electricity or heat vs. flare
		Sewage sludge	Thermal conversion for electricity or heat vs. flare

For the use of non-tradeable biomass types in electricity and heat generation, several investment levels for conversion technologies were assumed. The acquisition costs of these fuels was taken as zero. The principal background to this approach is that these types of biomass are waste in the first place, the owners of which need to dispose of. Any negative value attached to these fuels was considered to balance the operating and capital costs associated with waste removal, e.g. by means of incineration plants. The costs of processing non-tradeables further, i.e. beyond pure incineration, into electricity or useful heat was considered additional.

3.2.4 Supply and demand analysis of biofuels for the transportation sector

Candidate fuels considered for the transportation sector are:

Supply sector	Type	Example	Typical SAFIRE decision
Agriculture	Oil, sugar and starch energy crops	Oil seeds for methylesters	Production (upgrading, distribution, use) vs. rejection of this option
		Sugar/starch crops for ethanol	
Industry	Industrial products	Pellets, bio-oil (pyrolysis oil), ethanol, biodiesel	

The reason to additionally consider ethanol and biodiesel as industrial products, is that these can be imported as direct substitutes. European agriculture is not the only potential supplier of these renewable fuels. For sake of completeness also pellets and bio-oil (pyrolysis oil) are mentioned here. These materials would need upgrading into suitable transport fuels, e.g. by means of gasification followed by Fischer-Tropsch reaction. At today's state-of-the-art, this is not cost-effective though. (see also Chapter 4.3).

Although bio-transport fuels definitely belong to the category of tradeable biomass fuels, this application of biomass is strongly and directly affected by European policies (particularly by Directive 2003/30/EC). The study reported here analysed this sector in two steps. First, the effects of a general and uniform sustainability premium were investigated (given production costs, and given a sustainability premium, what penetration rate is achieved for bio-transport fuels?), and secondly, the sustainability premium required to meet the agreed objectives was determined (given production costs, and given a policy target).

3.2.5 Supply analysis for tradeable biomass fuels in the electricity and heat sector

In this study, we consider the following biomass fuels as tradeable for the electricity and heat market:

Supply sector	Type	Example
Agriculture	Dry ligocelulosic agricultural residues	Straw
	Dry lignocellulosic energy crops	Short-rotation wood, miscanthus
Forestry	Forestry byproducts	Wood blocks, wood chips from thinnings
Industry	Industrial residues	Industrial waste wood, exception: fibrous vegetable waste from virgin pulp production and from production of paper from pulp
		Not included: Wet cellulosic industrial residues
	Industrial products (imported)	Pellets, bio-oil (pyrolysis oil), ethanol, biodiesel
Waste	Parks and gardens (clean wastes)	Prunings, grass

For these types of biomass, over all the countries considered, an investigation was made into:

- The produced quantities to date, and in the future. The latter was done by analysing the trends in the sectors that serve as biomass suppliers (i.e. agriculture, forestry, industry).
- Supply costs and opportunity costs.
- Data analysis, to yield a stepped supply curve. An example of a supply curve is given in Figure 7.

The stepped curve is the result of the sorting of the various resources according to their supply costs. Taken rigorously, the total available amount of a lower-cost resource would be fully utilised before the next inexpensive type of biofuel would be used at all. In reality, the supply market is not that discrete, because the supply costs of a single resource are not constant with varying quantity, so that the supply curve sketched in Figure 8 would emerge. The overlap of supply costs thus makes it necessary to re-draft the supply curve in a more smooth manner. The effect on equilibrium prices of this exercise is only marginal, and within the inaccuracies of the data. Re-sorting the supply costs function does have a large impact though on the role of the individual biofuel types, because it reflects the phenomenon that all biofuel types play a role at market equilibrium, in stead of just the ones of which the supply costs, in the discrete approach of Figure 7, seem to

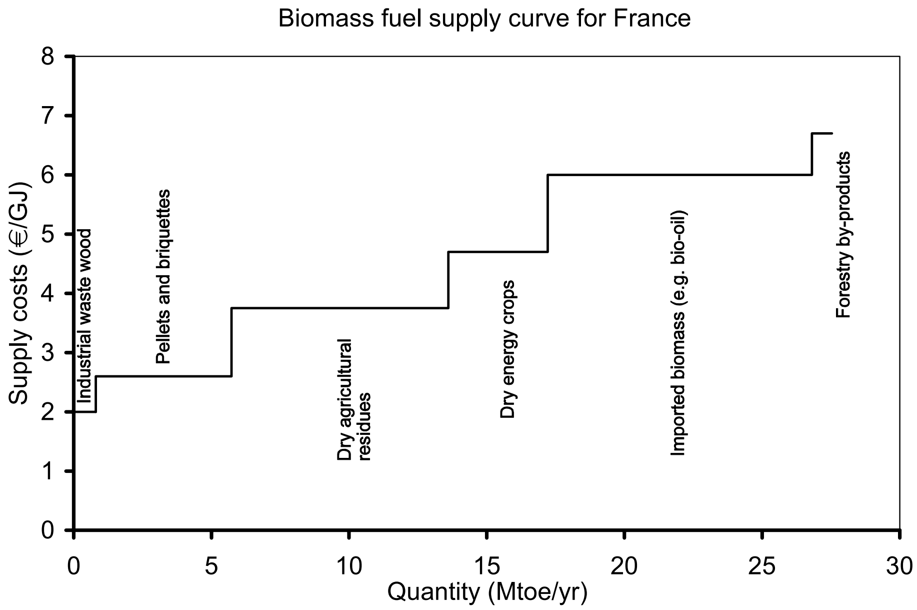


Figure 7, Example of a supply curve for tradeable biomass fuels (France).

be less high than the equilibrium price. In this study, we allocated a utilisation role to the more expensive biofuels by weighting their supply potential relative to that of the less-expensive biofuels.

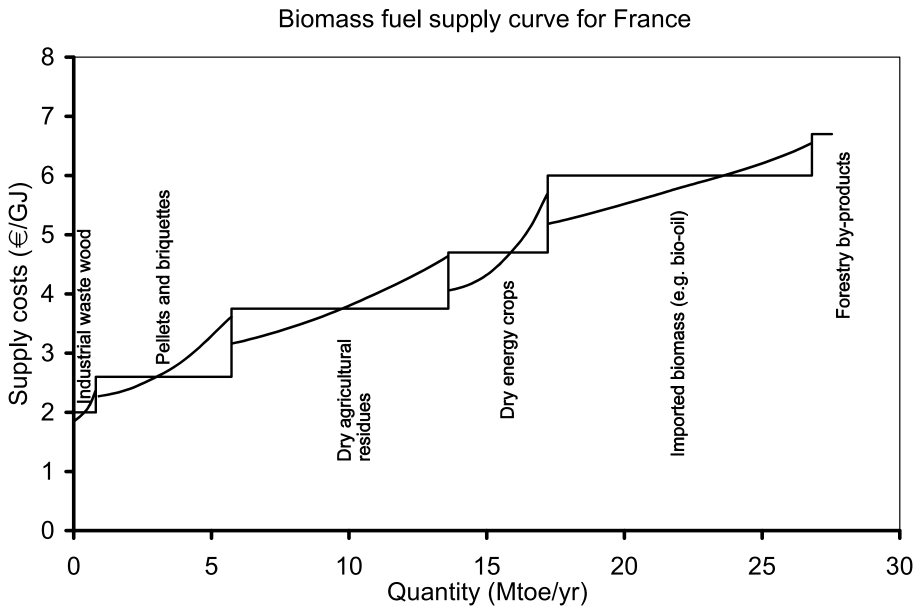


Figure 8, Making a supply curve for tradeable biomass fuels less discrete.

3.2.6 Demand analysis for tradeable biomass fuels in the electricity and heat sector

The SAFIRE algorithms, for biomass assume that the resource categories are available up to a maximum 'technical potential' at an average resource cost. This cost is then used as an input for the investment decisions in the technologies of creating final energy; electricity through grid connected or co-generation installations, heat and transport fuels.

As explained in Section 3.1, this study introduces an additional price analysis by fundamentally addressing the question whether - if a projected demand quantity is the result of a given price - the market is able to supply that quantity at the assumed price. And the study goes yet one step further by assessing at which levels of prices and quantities supply and demand functions are in equilibrium.

The approach is to construct separate biomass supply curves, and to match these graphically to the demand curves produced by a SAFIRE. This has been undertaken in a primary energy terms. Therefore, for the tradeable biomass fuels in the electricity and heat sector, SAFIRE is used for demand curve analysis only. This was done by running SAFIRE at a range of imaginary (virtual) biomass fuel prices, as 2, 4, 6, 8, 10 and 12 €/GJ. These runs were then performed for each country and in each scenario. From the runs, a graph was developed showing the change in biomass penetration according to the change in the biomass fuel price, for three marker years (2000, 2010, 2020). An example of this graph is shown in Figure 9.

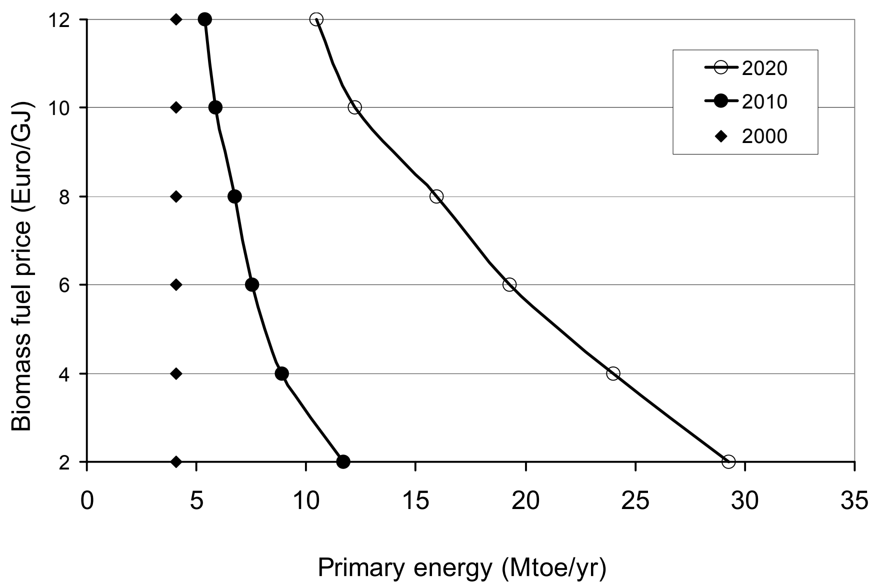


Figure 9, Example of a SAFIRE demand curve for tradeable biomass fuels.

This analysis was made under various assumptions (scenarios) regarding technology costs, energy conversion efficiencies, and support levels for renewable energy (i.e. sustainability premiums), the data of which are justified in the following chapters.

4 TECHNOLOGIES AND APPLICATIONS

This chapter sketches the background of electricity and heat utilisation, as well as of technologies for energy conversion. First, the subject matter is delimited by giving some definitions that are generally applicable throughout this study. A picture is given of the way in which Europe generates its electricity and heat today. Biomass and other renewables will take a position in energy provision by two phenomena: by replacing existing non-renewables and by occupying new generation capacity. For an assessment, reported in the chapters that follow, a view of the characteristics of biomass-fuelled energy technologies and their development is required. This view is given in the sections that follow here. Of particular interest are the state-of-the-art and the development of biomass-fuelled electricity generation, much more than those of biomass-fuelled CHP and heat generation. The reason is that especially for biomass-fuelled electricity generation technologies, large R&TD programmes are being carried out, aimed at achieving higher energy conversion efficiencies at effective cost levels. To a much lesser extent this is the case with biomass-fuelled CHP and heat generation. The developments in those areas are not so much aimed at the improvement of conversion efficiencies (and, thus, at economic feasibility), but rather at emission level control and user convenience, or, in SAFIRE's terminology, at technical feasibility and the rate of market penetration. These issues are important, and taken into account in the SAFIRE model, but not further elaborated here. Following a general introduction on electricity production Europe and the role of biomass (Section 4.1), a specific review of biomass-fuelled electricity generation technologies is given in Section 4.2. Another topic that deserves special attention is that of the bio-transport fuels. There is a wide range of alternatives, and the likely developments for time window considered should be assessed to justify a robust assessment of costs and efficiencies (Section 4.3). Until today, the European distribution grid for natural gas remains absent in the European energy policies as a substantial means for distributing a renewable energy carrier. The potential of this grid is discussed in Section 4.5.

4.1 EXISTING TECHNOLOGIES FOR CENTRAL ELECTRICITY

This section is not particularly about biomass-fuelled electricity production, but about electricity in general, i.e. about central electricity. As opposed to captive power, that concerns electricity that is made by end-users for themselves, central electricity is electricity for distribution by utilities (public sector) or private enterprises to end-users. The European electricity sector is currently being reorganised. Although it seems that, ideally, the objectives are to strictly separate the sector into producers, transmitters, distributers, and end-users the political debate about the extent to which this goal should be realised, and about the appropriate regulations is not yet finalised. Neither do the developments in the various European countries keep precise pace with each other. Whereas, during the past 50 to 100 years or so, the electricity sector was largely governmental in most countries, today, the sector reforms in the United Kingdom, of all the European countries, are among the most market-oriented. Generally, therefore, the roles of those companies that are active in the electricity sector are not entirely clear. For example, it is possible for a so-called distribution company to own and operate a wood-fuelled electricity production plant (until 2000 the Dutch distributor PNEM/MEGA owned a 25 MWe plant located in Cuijk, the Netherlands). In everyday language such electricity production is often called ‘decentralised’. However, since the product is intended for distribution, the term ‘centralised’ would also be appropriate. Despite colloquial language varying from place to place, this type of electricity production, since it is intended for distribution, is deliberately included in the analysis here. Generation capacities vary from those of small co-generation plants providing surplus power to the grids (typically < 4 MWe) to those of large power stations (typically 250-1000 MWe). Some expect even smaller grid suppliers at the level of individual households (micro CHP: < 3 kW). In this study this is still a type of central electricity.

4.1.1 Existing technologies for central electricity

The electricity market of the EU15 and the EU15+10+2 is currently mainly fed by large thermal (coal, oil and gas fuelled) and nuclear power plants (in 2000 by 85%), see Table 7 and Figure 10.[28] Nuclear generated electricity amounts to 34% of the total in the EU15. The capacity of these plants is somewhat smaller than this share (22%), and this shows that their capacity factor is considerably higher than of all the other types of power plant. In the new accession states the situation is somewhat different. Here, nuclear generated electricity reaches only 19% of the total, and installed nuclear power forms 14% of the capacity. In the officially available statistics biomass does not deserve a specific category. It is often lumped with geothermal, solar, wind and waste in ‘other’ fuels. The Eurostat database distinguishes biomass into three: wood&wood waste, MSW and biogas. As shown in the chapter on the approach of this study, such categories are inadequate to carry out the research needed here. In the EU15, these other resources are used to produce 3% of total electricity, in the accession states it is 0%, and in the aggregate EU15+12, other resources contribute still to 3% of the total electricity production.

28/ DOE (2003b)

Table 7, Structure of central electricity production, 2000 data (source: http://www.eia.doe.gov/, International Electricity Information Page).

	Installed capacity (GW)				Electricity production (TWh)			
	Thermal	Hydro	Nuclear	Other	Thermal	Hydro	Nuclear	Other
EU15								
Austria	6.1	8.1	0.0	0.1	15.5	41.6	0.0	1.7
Belgium	8.5	0.1	5.7	0.0	30.8	0.5	45.7	1.2
Denmark	10.2	0.0	0.0	2.4	28.1	0.0	0.0	6.0
Finland	10.6	2.9	2.6	0.0	22.5	14.5	21.3	8.5
France	26.8	21.1	63.2	0.3	46.8	66.2	394.4	3.7
Germany	80.8	4.3	22.4	6.2	334.9	21.5	161.2	18.6
Greece	7.7	2.4	0.0	0.2	46.2	3.7	0.0	0.6
Ireland	4.1	0.2	0.0	0.1	21.1	0.8	0.0	0.3
Italy	54.0	13.4	0.0	1.1	204.7	43.8	0.0	7.6
Luxembourg								
the Netherlands	20.1	0.0	0.4	0.5	75.5	0.1	3.7	5.0
Portugal	6.3	3.9	0.0	0.1	28.4	11.2	0.0	1.7
Spain	25.5	12.9	7.5	1.9	116.2	28.1	58.9	7.1
Sweden	6.7	16.4	9.5	0.2	4.9	78.2	54.1	4.2
United Kingdom	62.0	1.5	12.5	0.4	260.1	5.1	81.7	5.0
Accession states								
Bulgaria	6.3	1.8	3.8	0.0	18.6	3.1	17.3	0.0
Czech Republic	11.5	1.0	2.8	0.0	54.1	1.7	12.9	0.7
Estonia	3.2	0.0	0.0	0.0	8.0	0.0	0.0	0.0
Cyprus								
Latvia					1.2	2.8	0.0	0.0
Lithuania	2.6	0.1	3.0	0.0	2.2	0.6	8.4	0.0
Hungary	6.4	0.0	1.9	0.0	19.7	0.2	13.5	0.1
Malta					1.8	0.0	0.0	0.0
Poland	28.4	2.2	0.0	0.0	132.6	2.1	0.0	0.5
Romania	15.9	6.1	0.7	0.0	29.8	14.6	5.2	0.0
Slovenia					4.5	3.8	4.5	0.1
Slovakia	2.4	2.4	2.6	0.0	8.7	4.7	13.1	0.0

Thermal: coal, oil, and gas.
Other: geothermal, solar, wind, and wood and waste.

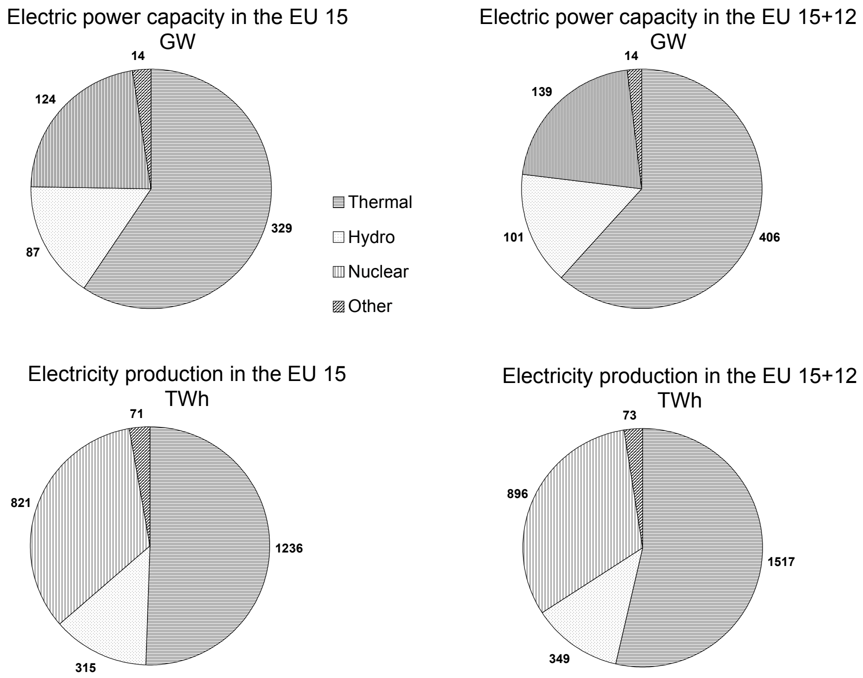


Figure 10, Electricity production in the EU15 and the EU15 + 12, in 2001 (source: DOE, International Energy Annual 2001 (DOE/EIA-0219(2001)), U.S. Department of Energy, Washington, 2003.)

Coal, oil and gas-fuelled power plants

Fossil-fuelled central electricity generation uses a range of mature and proven technological concepts. Today, the two major conversion technologies for fossil fuels are:

- Combustion integrated with a steam cycle (abbreviated here to CS). With this technology, in principle, the energy conversion is performed in two stages. First, the chemical energy contained in the fuel is turned into energy carried by steam in a furnace/boiler. Subsequently, the steam carried energy is converted into electricity by means of a steam turbine and generator.
- Combined cycle (abbreviated to CC) for gaseous or liquid fuels (natural gas, oil). In the combined cycle, the combustion furnace of the CS concept is replaced by a gas turbine. The steam cycle remains and is fed by the gas turbine's exhaust gas. Using the gas turbine a so-called topping cycle is added to the CS technology. A topping cycle converts thermal energy to electricity at a higher temperature. Conversion efficiencies are therefore higher.

Other technologies employed for central electricity production are the diesel engine for liquid fuels such as furnace oil, and the gas turbine for gaseous and liquid fuels. In the EU15 these technologies are mainly used for peak load service. In such economies, because of the lower associated conversion efficiencies in combination with fuel costs, they are not appropriate for providing base load.

Coal-fuelled CS technology is the most widespread technology used in central electricity production. This is understandable in view of fuel availability and cost, as well as the cost and performance of electricity generation technologies. In the USA, 305 GW_e

(41% of total installed capacity) consists of coal fuelled CS technology, whereas the gas fuelled CC technology provides only 15 GW_e (representing 2%) of the capacity (Hong (1998)). A similar situation can be estimated for the total of all IEA countries.[29] Capacities of modern coal fired power plants are in the range of 500-1000 MW_e. Combined cycle power plants fuelled with natural gas or liquid fuels are also numerous and exist worldwide, mainly in the capacity range of 100-600 MW_e.

Biomass

Of the technical concepts for converting biomass into electricity, the CS concept represents the state-of-the-art. It is available in the range of 3-100 MW_e, and also with smaller capacities. The electricity sectors in Denmark, Finland, Sweden, the Netherlands, and the USA have implemented biomass-fuelled CS technology in various power plants, often in CHP plants which produce both electricity and heat. With a capacity of 85 MW_e, the power plant of the International Paper Company (Pine Bluff, USA) is the largest operational 100% wood fuelled CS power plant in the world, producing electricity for the electricity sector. Indeed, the biomass-fuelled CS technology is most commonly installed by industries which provide their own fuels (residues), who entirely or partly utilise the electricity produced, and who have a use for the heat which is unavoidably produced in addition to the electricity. These circumstances apply, for example, to all the cane sugar and palm oil mills, worldwide, and the majority of these mills operate a CS energy plant. The Renewable Electric Plant Information System (maintained by NREL) reports that in the USA the aggregate capacity of this type of technology is about 7,200 MW_e.[30] According to Bain, Overend *et al.* (1998) this concerns approximately 1000 plants, typically in the range of 10-25 MW_e. Captive electricity production is included in this figure.

A particular configuration of the CS technology is co-combustion of biomass with coal. In the context of central electricity provision, co-combustion concerns the partial substitution of biomass for coal in existing coal fired subcritical combustion/steam plants. With start of the European APAS Clean Coal Technology Programme (1992), co-firing has become a strongly promoted technology. This promotion has been continued by the European Commission, for example by means of the White paper for a community strategy and action plan on renewable sources of energy (‘Energy for the future’) (EU (1997)). The reasons for promoting this method of biomass utilisation are probably the rapid implementation opportunities, for which only limited R&D efforts are required, and the achievable economies of scale. Co-firing of biomass with coal in subcritical combustion/steam plants involves relatively small capacities (effectively about 30-60

29/ Based on OECD (1999), p. 240. Assuming an average capacity factor of 80% for all power plants, aggregate electric power capacity is estimated at 1200 GW_e.

30/ Of this figure, 71 MW_e should be subtracted as it is in the form of co-firing capacity in coal-fired power plants, Porter, Trickett and Bird (2000).

MW_e),[31] the basic idea behind this concept being that a small proportions of the capacity[32] would be given over to biomass fuels. In this manner, the biomass component would share, to a large extent, the economies of scale of the entire plant. This concerns the conversion efficiency, the exhaust gas cleaning equipment and plant management. Some of the investment and operational costs could not take advantage of the overall plant's economy of scale; these being the biomass storage, handling and fuel preparation facilities, as well as their operation. The extent of these costs varies with the proportion of biomass used. In comparison with dedicated biomass power plants of the same effective capacity, the conversion efficiency of co-firing is very high, at least in view of state-of-the-art energy technologies. Researchers are aiming to further develop technologies for biomass conversion such that, at even relatively small scales, the conversion efficiency surpasses that of conventional coal fired power plants. If this is achieved, co-firing in combustion/steam power plants will have lost some of its attraction. Given today's standards however, this application is a strong competitor to dedicated biomass-fuelled power plants.

Whether co-firing is equally attractive with innovative coal-conversion concepts, such as the gasification/combined-cycle technology, and the supercritical steam cycle, is uncertain. Specific integration technologies, enabling the coupling of a biomass component to the coal fired unit, will be required. Options include: a separate biomass gasifier providing fuel gas to the combined cycle, a biomass liquefaction plant providing fuel gas and fuel oil to the combined cycle, and a separate biomass reactor providing heat to the steam cycle (this option is called 'steam-side integration'). These, however, result in reduced advantages of scale. In coal-fuelled gasification/combined cycle plants it might also be possible to gasify some biomass in the same gasifier already used for coal. For the co-firing of biomass in supercritical steam boilers, a technical solution to the corrosion difficulties posed by the alkaline content of biomass fuels is to specifically adapt the materials used in the boiler.[33] Again, the loss of economy of scale benefits is obvious. The economic feasibility of such advanced concepts, in comparison with other options for electricity production from biomass, has not yet been studied in a systematic manner. However, the specific application of co-firing foreseen in 'Energy for the future' is typically a short-term option, i.e. technically feasible and economically attractive until the subcritical combustion/steam technology for coal is phased out. An investigation covering all EU-based electricity producers would be required to find out when this is likely to happen, since publications by the IEA do not provide this type of information. Taking the situation in the Netherlands as an example, decommissioning of existing subcritical coal-fired power plants is expected to take place between about 2011 and 2024 (Van Ree, Korbee and De Lange (2000)). The sector is potentially able to contribute significantly to the short-term EU targets. Based on 2000 coal consumption data provided by the IEA,[34] and assuming a 10% substitution on an energy basis, the potential in the EU15 is about

31/ The effective capacity is defined as the total plant capacity multiplied by the energy ratio of biomass substitution.

32/ In the order of 5%-10% (Tillman (2000b)), or even up to 20% and higher (AEA Technology (ETSU), VTT Energy and Sydkraft Konsult AB (2000)).

33/ Biomass fuels are generally rich in alkalines. For technology considerations see Sondreal, Benson, Hurley *et al.* (2001) and Tillman (2000a).

34/ OECD (2003d).

70 TWh_e/yr. The estimates given by AEA Technology (ETSU), VTT Energy and Sydkraft Konsult AB[35] is much lower, but this is due to the fact that they apply an additional constraint by assuming that of the existing coal power plants only 10% can potentially apply co-combustion. They do not give a reason for this assumption, and in fact it is more of an expectation of what the SAFIRE model would refer to as a penetration rate. In our analysis, the maximum rates of co-combustion as given in Table 8 were assumed.

Table 8, Co-combustion in coal fired electricity plants (% coal replacement on an energy basis).

Sustainability premium scenarios (explained in Chapter 6)	2010	2020
0	3%	8%
low	5%	10%
high	7%	15%

Trends in technology development

In an attempt to take advantage of the higher efficiencies achievable with gaseous and liquid fuels using the CC concept, two different approaches for making this concept suitable for solid fuels are being followed. In one approach, the gas turbine is preceded by a gasifier. The resulting fuel gas is subsequently combusted and expanded in a gas turbine. Here, this concept is abbreviated to GCC.[36] Typical fuels for the GCC technology are coal, petcoke and heavy oil (asphalt). Following another approach, the gas turbine is preceded by a pressurised solid fuel combustor. The pressurised combustion products are expanded in a gas turbine and drive a steam generator coupled to the turbine exhaust. Suppliers offering this type of plants, usually employ fluidised-bed combustors, and denote the concept with the acronym PFBC (for Pressurised Fluidised-Bed Combustion). In this systematic review of fundamental concepts, the acronym PCCC (Pressurised Combustion Combined Cycle) is preferred.

With the new GCC technology for solid fossil fuels, already several demonstration plants have been realised (Campbell, McMullan and Williams (2000) and Scott and Nilsson (1999)):

- Buggenum, Netherlands (253 MW_e), start-up 1993;
- Polk Country, USA (250 MW_e), start-up 1996;
- Wabash River, USA (262 MW_e), start-up 1996;
- Puertollano, Spain (300 MW_e), *"under start-up"* 1998;
- Piñon Pine, USA (100 MW_e), commissioned 1999.

The chemical industry is also showing an interest in the GCC concept. A few examples extracted from Stambler (1996) include: the 35 MW_e El Dorado plant (Texaco) which was commissioned in 1996, and, at the end of 1996, the construction of two 500 MW_e projects and of two 250 MW_e projects was about to be started in Italy (respectively the ISAB and SARAS plants, and the API and Agip Petroli plants). Their fuels are asphalt and visbreaker residue. One of the reasons why this industrial sector is establishing this type

35/ In AEA Technology (ETSU), VTT Energy and Sydkraft Konsult AB (2000).

36/ GCC stands for: Gasification followed by a Combined Cycle.

of technology is that the gas resulting from the gasifier can also be utilised as a synthesis gas in the manufacture of various chemical products. Thus, the technology offers flexibility as to the product mix of electricity, heat, and materials (and is therefore sometimes referred to as trigeneration).

There exist also several examples of coal-fuelled PCCC plants:[37]

- The 70 MW_e Tidd Plant in Brilliant, Ohio (since 1990, American Electric Power).
- The 135 MW_e (combining two units) operated by Vartan (Sweden).
- The 80 MW_e unit of Escatron (Spain).
- The 71 MW_e unit of Wakamatsu (Japan).
- The 71 MW_e unit in Cottbus (Germany).
- The 360 MW_e unit of Karita (Japan).

Reasons for the electricity sector to develop the GCC and PCCC concepts, as an alternative to CS, are both economic and environmental. The potentially higher energy conversion efficiency has already been mentioned above. Naturally, if driven by economic motives, the higher efficiency is evaluated in combination with other operational characteristics and the required investment. However, a higher energy efficiency also implies reduced GHG emissions per unit product. Further environmental advantages are the potential to achieve low SO_x and NO_x emissions at a lower cost than with the CS concept. Development of these innovative technologies is supported by the Clean Coal Centre of the IEA, and by development programmes in the EU (e.g. the ECSC Coal RTD Programme, Framework 4, and JOULE/THERMIE) and the USA (Clean Coal Technology Demonstration Program).

Figure 11 gives NCV efficiencies of modern coal-fired GCC power plant and CC power plant fuelled with oil and natural gas.[38]

37/ DOE (2000b) , p. 22.

38/ Sources for the coal-fired plants are: Scott and Nilsson (1999), and DOE (2000a). For the natural gas and oil-fuelled CC power plants: Sheard and Raine (1998) and Chase and Kehoe (2000).

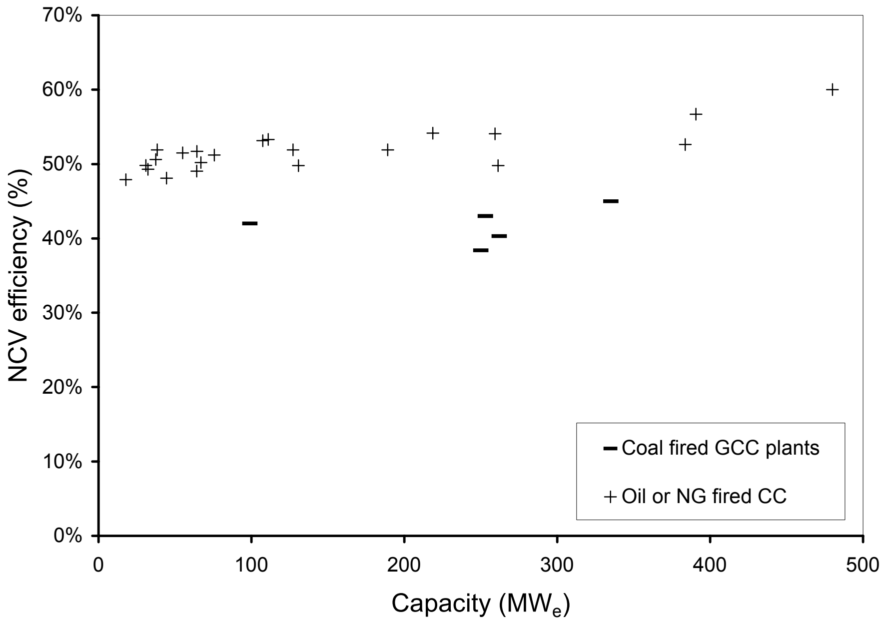


Figure 11, Net energy efficiency of coal-fuelled GCC and of oil and natural gas fuelled CC power plants (Source: Siemons 2002a).

4.2 VIEWS OF LONG-TERM TECHNOLOGY DEVELOPMENTS FOR BIOMASS FUELS IN CENTRAL ELECTRICITY AND HEAT

4.2.1 Biomass-fuelled Combustion & Steam Cycles

Efficiencies of biomass-fuelled CS systems are shown in Figure 12. The data are taken from various surveys given in the literature,[39] and a survey of manufactures offering plants with capacities up to 30 MW_e. Although there is a large scatter, energy efficiency tends to increase with capacity. This increase is only partly technology dependent, and mainly a result of a cost/quality consideration taking place within the market in view of locally prevailing economic conditions. Those cost/quality considerations are also the reason for the wide scatter occurring for each capacity. In other words; at low capacities (e.g. 5 MW_e, where conversion efficiencies are in the range of 10-25%), high energy efficiencies (e.g. 40%) are technically feasible, albeit at very high costs.

39/ Williams and Larson (1993), Bridgwater (1995), Van den Broek, Faaij and Van Wijk (1995), and DeMeo and Galdo (1997). Where necessary, GCV efficiencies were recalculated to NCV efficiencies (for the procedure see Siemons (2002a)).

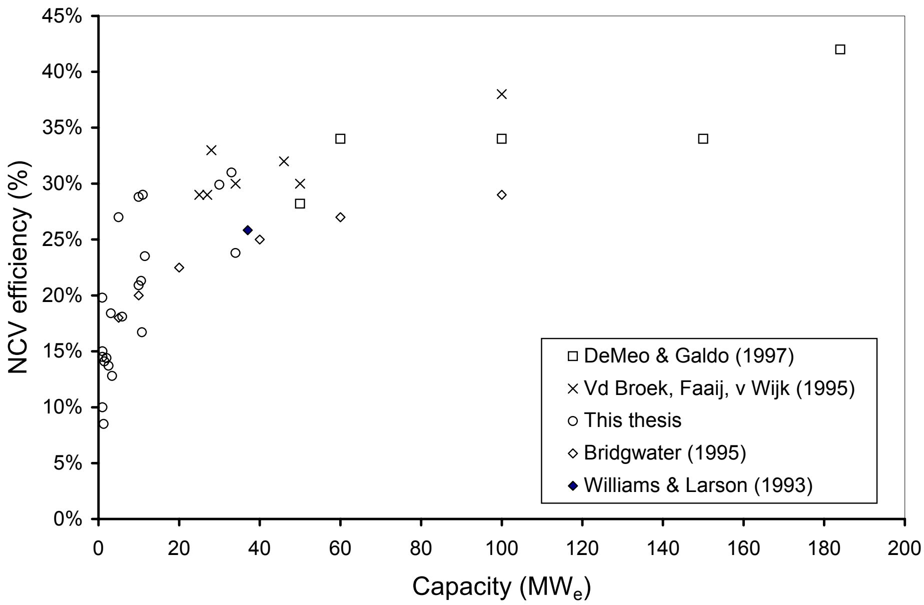


Figure 12, Net energy efficiency of biomass-fuelled CS power plants (Source: Siemons 2002a).

The major parameters responsible for the low efficiencies in the lower capacity range are the applicable steam conditions and the commercial availability and cost of high-efficiency steam turbines. (See Siemons (2002a)).

Estimating the investments needed for constructing a CS power plant, since the technology is already available in an established market in the capacity range up to 100 MW_e, is not too complicated, although some extrapolation to larger capacities is required. Cost data are shown in Figure 13.[40] To make cost estimates comparable, the scopes of the cost items covered should be the same, or, if they are not, they should be normalised. Unfortunately, not all the quoted sources are fully explicit. The data quoted from Van den Broek, Faaij and Van Wijk (1995) and DeMeo and Galdo (1997), as well as the data specially collected, concern installed and commissioned power plants, but exclude land. The systems include biomass storage and handling systems as well as electricity generators, transformers and protection systems. Conventional exhaust gas cleaning equipment, needed to comply with European and USA regulations in the power sector, are assumed. Where the base years of quoted cost estimates differ, they were recalculated to the year 2000 by making use of the Chemical Engineering Plant Cost Index published in the journal on Chemical Engineering. This enabled the establishment of an approximative relationship between plant capacity and cost. As observed, the generally established rule in cost engineering,[41] i.e. that the capacity specific investment costs decrease with a power function of the shape 'C^{s-1}' (where C is capacity, and s is usually in the range 0.4-1), does apply. Here the value of s is about 0.76.

40/ Sources consulted include Siemons (2002a), as well as Williams and Larson (1993), Bridgwater (1995), Van den Broek, Faaij and Van Wijk (1995) and DeMeo and Galdo (1997).

41/ Compare Holland, Watson and Wilkinson (1987), p. 25-65.

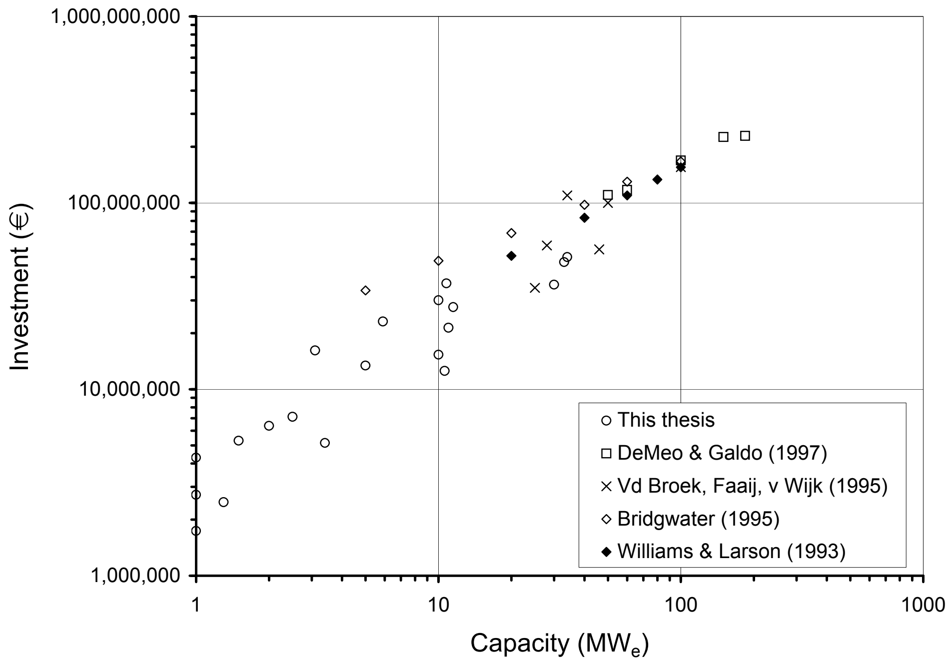


Figure 13, Investment data for biomass-fuelled CS systems (Source: Siemons 2002a).

4.2.2 Biomass-fuelled Combined Cycles

The combined cycle (CC) concept offers also a possibility for the conversion of biomass fuels (here referred to as Biomass-Fuelled CC). Much attention has been given to one particular concept (re. the work reported by IPCC, DOE, EC), i.e. gasification followed by a gas turbine coupled to a steam cycle (Biomass-Fuelled GCC). However, at least three principal options for Biomass-Fuelled CC can be distinguished:

- Gasification followed by a gas turbine and a steam cycle (abbreviated here to Biomass-Fuelled GCC).[42]
- Liquefaction followed by a gas turbine and a steam cycle (abbreviated here to Biomass-Fuelled LCC). (Liquefaction, or pyrolysis, is a thermal process that produces a liquid fuel from biomass. In this study the product is referred to as 'bio-oil').
- A third option is pressurised combustion, followed by a gas turbine and a steam cycle. Although successfully utilised for the conversion of coal into electricity, this concept has received little attention in the biomass research community.

42/ In some literature this concept is referred to by the acronym BIG/GT, and in other by IGCC. The acronym BIG/GT (Biomass fuelled Integrated Gasifier and Gas Turbine) was introduced by Williams and Larson (1993).The expression IGCC refers to an Integrated Gasifier and Combined Cycle. An IGCC may be fuelled by any solid fuel, including biomass. For systematic reasons, we refer to the biomass-fuelled variant of this type of system by the term 'biomass-fuelled GCC'. GCC indicates 'Gasifier coupled to a Combined Cycle'.

Relevant views of the development of biomass gasification technology have been summarised by Siemons (2002a). Particularly:

- Cost analyses (generic, projects)
- Efficiency analyses (generic, projects)

Technology evaluations have gone as far as reviewing the biomass-fuelled GCC concept up to capacities of 100-200 MW_e.[43] This is substantially smaller than the capacities demonstrated for coal-fuelled CC systems. The reason for this difference in size is not clear. To date, for biomass-fuelled GCC, a pilot phase has been reached, but demonstration projects have not been established. Current biomass-fuelled GCC pilot projects are reviewed in Table 9. The largest project planned has a capacity of 75 MW_e. R&D on the biomass-fuelled GCC concept is being carried out both in the EU and the USA (for reviews see Costello (1999) and Maniatis (1999)). External financial support is given by the EU, the World Bank, UNDP, and also by national governmental institutions such as the USA DOE, and the Dutch Novem.

Table 9, Review of GCC projects larger than 5 MW_e (Source: Beenackers and Maniatis (1998) and other contributions to the same issue of Biomass & Bioenergy).

Name (Operator)	Country	Electrical capacity (MW)	Status 1998	Status 2003 (Source: this study)
Värnamo (Sydkraft)	Sweden	6	Operational	Halted
Energy Farm (Biolettrica)	Italy	12	Construction	Halted
ARBRE (ARBRE Energy)	U.K.	8	Construction	Halted
North Holland (ENW)	Netherlands	30	Design	Halted
Maui (IGT)	Hawaii (USA)	5	Construction	Halted
Burlington	Vermont (USA)	15	Construction	Construction
Agripower (MAP)	Minnesota (USA)	75	Planned	Halted
WBP/SIGAME	Brazil	32	Preparation	Halted
Biocycle (Elsam/Elkraft)	Denmark	7	Halted	Halted
Biocycle (Kotka Energy)	Finland	7	Halted	Halted

There is a wealth of literature on the conceptual analyses of the biomass-fuelled GCC system. Efficiency data for both theoretical and existing designs are summarised in Figure 14. For comparison, the efficiencies of coal-fired demonstration GCC plants, as well as those of natural gas and oil-fuelled CC power plants, are indicated.[44] Where necessary, GCV efficiencies were recalculated to NCV efficiencies (for the procedure see Siemons (2002a)).

43/ E.g.: Williams and Larson (1993), Bridgwater (1995), DeMeo and Galdo (1997), and Faaij, Meuleman and Van Ree (1998).

44/ Sources consulted are, for biomass-fuelled GCC projections: Williams and Larson (1993), Bridgwater (1995), Craig and Mann (1996), DeMeo and Galdo (1997), Faaij, Van Ree, Waldheim *et al.* (1997), and Faaij, Meuleman and Van Ree (1998); and for biomass-fuelled GCC plant projects: De Lange and Barbucci (1998), McGowin, Hughes and Holt (1998), Rensfelt and Everard (1998), Salo, Horvath and Patel (1999). Sources for the coal-fired plants are: Scott and Nilsson (1999), and DOE (2000a). For the natural gas and oil-fuelled CC power plants: Sheard and Raine (1998) and Chase and Kehoe (2000).

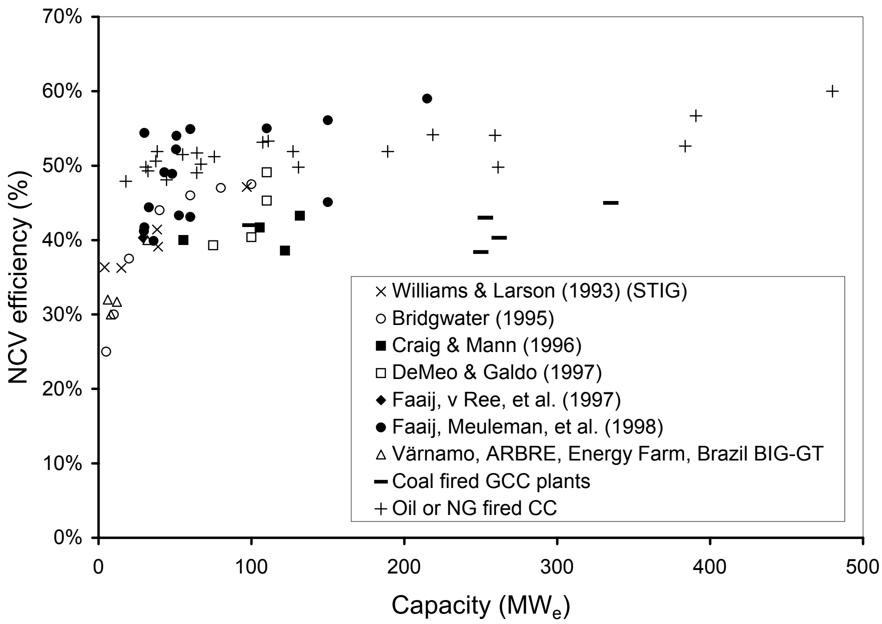


Figure 14, Net energy efficiency of biomass-fuelled GCC power plants compared to those of coal-fired GCC demonstration units, and oil and gas-fuelled combined cycles.

Two Biomass-Fuelled GCC concepts can be distinguished:

- A gas turbine and a steam turbine integrated into a single turbo-machine (often abbreviated STIG, standing for steam injected gas turbine). Steam is released into the air and thus a constant flow of make-up water is required.
- A separate gas turbine and steam turbine (abbreviated to GAST). Here, the gas turbine's exhaust gas is used to generate steam for expansion in a steam turbine placed in a separate condensing cycle.

Especially the STIG concept has received a lot of attention in forums of the United Nations, as it was proposed by Williams and Larson (1993) to the 1992 United Nations Conference on Environment and Development in Rio de Janeiro. Yet, the STIG concept remains an outsider since it does not fit in the general development course towards higher efficiencies. This is because the steam cycle used in the STIG concept is less efficient than in the GAST concept, primarily because:

- In GAST, steam pressures are higher than in STIG,
- In GAST, steam is expanded into a vacuum rather than to the atmosphere (as in STIG).

It cannot, however, be assumed that the STIG concept would not be a winning concept. All depends on an optimisation of costs and quality. However, the STIG concept has not received sufficient attention from the R&D community to enable a balanced comparison of the various concepts.

The efficiency of CC plants in current practice is limited to 49%-56%, with an expectation of a maximum of 60%.[45] Since GAST is an extension of CC, there is no reason why GAST should perform any better than CC at any stage of technology development. In fact there is one issue which gives rise to an inherently *lower* efficiency with GAST. This is the fact that the fuel gas resulting from gasification needs to be cooled before being ignited in the gas turbine. Fuel gas cooling serves to precipitate out the alkalines present in virtually all biomass types to an extent which would harm the gas turbine if they were not removed (Bain, Overend and Craig (1998), Craig and Mann (1996), and DeMeo and Galdo (1997)). As yet, no alternative technical solution to this difficulty has been proposed. Although part of the heat thus removed can be used in the steam cycle (with proper integration of the steam cycle with the gasifier), the efficiency at which this is done is substantially lower than if the entire combined cycle could be used for the energy conversion. Scott and Nilsson (1999) reports the same phenomenon for coal fuelled GAST systems. Note that fuel gas cooling is not an unavoidable necessity in order to limit firing temperatures to technically feasible levels. If a turbine is fuelled by natural gas or oil, the same difficulty has to be faced to the same degree (flame temperatures of biomass made fuel gas are similar to flame temperatures of fossil fuels). With gas and oil-fuelled combined cycles, flame temperatures are controlled in ways which enable the use of the full cycle conversion. An example approach is gas dilution with air, water, or steam prior to, or during, expansion in the gas turbine (Brooks (2000)).

A comparison of projected efficiencies for biomass-fuelled GAST systems and efficiencies of coal-fired demonstration units is also appropriate (for data see also Figure 14). As observed, the latter's efficiencies are in the order of only 38%-45%, which is considerably lower than the efficiencies projected for biomass-fuelled systems. Projections reported in Scott and Nilsson (1999), based on experience with coal-fuelled demonstration units, anticipate future efficiencies of 47% and 51% for 365 and 555 MW_e systems respectively. One characteristic of the evaluated coal-fuelled GAST systems is the choice of oxygen as the gasifying medium instead of air (and thus there is a need for air separation - which consumes work). Note that this choice is not motivated by technical considerations (the Piñon Pine project is air-blown (referred earlier on page 49)). Rather, the choice of oxygen-blown gasification is based on an economic evaluation; with oxygen, the gasifier and heat exchangers for heat recovery prior to fuel gas cleaning are cheaper (since they are smaller) (IEA Coal Research (2001)). The efficiency loss due to power consumption in the air separation unit is 7-9%.[46] Such losses can be avoided with air-blown GAST systems, whether fuelled by coal or biomass. With this argument in mind, one is encouraged to accept the efficiencies for the referred projected biomass-fuelled GAST systems despite them being higher than the cited projections for oxygen-blown coal fuelled GAST concepts.

This assessment should be borne in mind when interpreting Figure 14. Efficiencies of biomass-fuelled GAST systems may be higher than those of similar coal-fuelled systems, but they should be lower than efficiencies of natural gas or oil-fuelled CC systems. The designs described in Faaij, Meuleman and Van Ree (1998) have extremely high efficiencies, much higher than those estimated by others. These are not impossible

45/ For technical background to this statement, see Siemons (2002a).

46/ Derived from IEA Coal Research (2001) and Scott and Nilsson (1999).

in terms of first principles, but in view of *1)* the state-of-the-art and the development of CC technology in general and *2)* gasification technology and system integration in particular; they seem to be somewhat optimistic.

Biomass-fuelled LCC

The integration of biomass liquefaction with the combined cycle into the LCC technology is still at a conceptual stage. The technology was discussed by Solantausta (from VTT), Bridgwater (Aston University) and Beckman (Zeton Inc.) in Solantausta, Bridgwater and Beckman (1995) and, more elaborately, in Solantausta, Bridgwater and Beckman (1996). Further evaluations of the concept have yet to be published. The liquefaction component of the concept has passed the laboratory phase, reached the pilot phase, and is heading towards larger scale demonstration (see Table 10). A literature survey using the ETDE database[47] of the IEA, and the science citation index, reveals that the very first R&D plans for the application of bio-oil in gas turbines were reviewed in 1994 by Andrews, Patnaik, Liu *et al.* (1994). Only a few test results have been published, i.e. by Boucher, Chaala and Roy (2000), Boucher, Chaala, Pakdel *et al.* (2000), and by López-Juste and Salvá-Monfort (2000). On April 2, 2001, the installation and commercial operation of the first bench-scale gas turbine (2.5 MW_e) operated on bio-oil was announced in a press release by Dynamotive, a company active in the development of pyrolysis technology. Although, for the companies involved, the project is about testing and demonstrating a commercial scale technology, it is only a bench-scale project in terms of the appropriate capacities for central electricity production discussed in this study. The latest information on this project is that it was halted due to lack of finance. These developments are mainly financed by the EU, national governmental institutions, and the private sector companies involved.

Table 10, Review of biomass liquefaction projects

Name (Operator)	Country	Thermal capacity (MW_{th})	Status 2003
Bio Oil Exploitation / BON	Belgium	10	Planned, designed
BTG	Netherlands	1	Operational
BTG	Netherlands	5	Design
BTG	Malaysia	10	Design
Dynamotive	Canada	2.5	Commissioning
Dynamotive (Border Biofuel) /a	U.K.	5	Halted
Dynamotive	Canada	7.5	Design
ENEL/Ensyn	Italy	3.1	Halted
Pyrovac	Canada	17.5	Operational
Red Arrow/Ensyn	USA	6.3	Operational
Red Arrow/Ensyn	USA	5	Operational
Vapo Oy (Fortum)	Finland	1.8	Planned
Wellman	U.K.	1.25	Commissioning

a/ Electrical capacity 2.5 MW_e, in collaboration with Orenda gas turbines (sources: http://www.dynamotive.com/english/news/biooil/2001/010402.html, http://www.orenda.com/AMES/AMES_Biofuel/ames_biofuel.html and http://www.newswire.ca/releases/May2001/24/c7880.html).

47/ ETDE = Energy Technology Data Exchange (www.etde.org/etdeweb/).

For an efficiency projection see Figure 15. It was justified in Siemons (2002a).

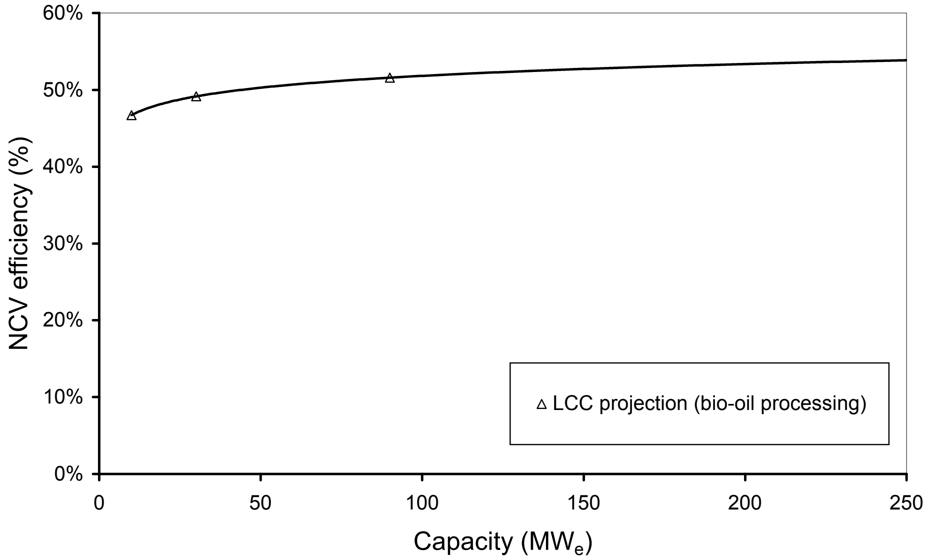


Figure 15, Net energy efficiency of bio-oil-fuelled LCC power plants. Source: Siemons, 2002a.

Views of cost developments of Biomass-Fuelled Combined Cycles

The analysis in this study is based on a postulated 1-1 relationship between plant capacity, conversion efficiency and plant cost. This is certainly an idealisation. The IPCC rightly remarks that *"the OECD data ... for power stations ... show that costs can vary considerably between projects, because of national and regional differences and other circumstances. These include the need for additional infrastructure, the tradeoff between capital costs and efficiency, the ability to run on baseload, and the cost and availability of fuels."* Moomaw and Moreira (2001). Nevertheless, this is still a more sophisticated approach than observed in most scenario studies analysing the role of technologies. Often those do not analyse the effects of economy of scale, but rather provide single cases. Exceptions are Bain, Overend and Craig (1998) and Siemons (2002a).

Consistent cost estimating for the biomass-fuelled GCC concept is complicated. In the first place a large range of costs are found in the available literature sources. In principle their data are not based on investigations into established markets. Moreover, a common basis for cost estimating has not been established by the various researchers (after Bain, Overend and Craig (1998)). However, cost data are available for the first biomass-fuelled GCC pilot projects and also for coal-fuelled GCC demonstration projects. As a first approach therefore, a similar cost vs. capacity relationship as found with biomass-fuelled CS, fitted through measured data points of existing biomass-fuelled GCC projects, is a defensible approach. This yields the estimates shown in Figure 16.[48]

48/ Data sources for biomass-fuelled GCC were: De Lange and Barbucci (1998), McGowin, Hughes and (continued...)

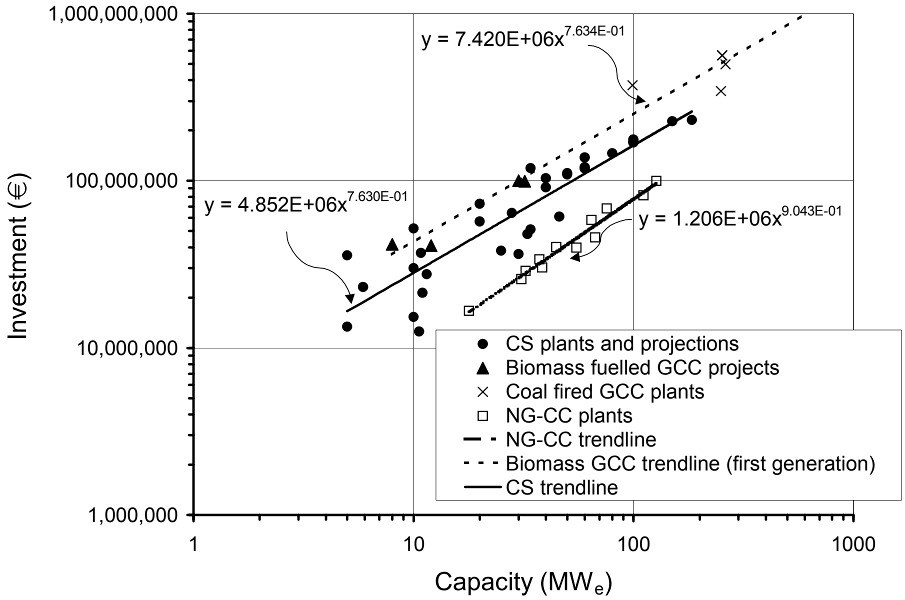


Figure 16, Initial costings for biomass-fuelled GCC (together with those for CS, NG-CC, as well as coal-fuelled GCC) (Source: Siemons 2002a).

One should be aware that cost-capacity relationships thus found represent average power plants. Deviations from the trendlines will occur. Secondly, one should note that the trendline for GCC projections is based on estimates for first-of-a-kind power plants. Since only one such project has been commissioned, the actual investment costs of such projects are not really known. It is not unreasonable to expect that there is scope for cost reductions in the construction of the next generation of biomass-fuelled GCC power plants.

Expectations of future costs: The investment targets for biomass-fuelled GCC cycles, summarized in Table 11, are obtained from a broad range of techno-economic literature. In most of the cases, the authors estimated the investment for the n^{th} plant, to indicate that the so-called learning effect has run its course. Authors who instead indicated projection years also assumed maturity of the technology. The data are plotted in Figure 17, together with other relevant data. It is apparent that the anticipated costs are lower than for biomass-fuelled CS power plants, and higher than those for natural gas-fuelled CC power plants. That is indeed what one would expect, as GCC is an add-on to the CC concept. In general, 100 MW_e systems and long-term cost reductions of about 50% are anticipated (median values).

48/(...continued)
Holt (1998), ARBRE (1998), Salo, Horvath and Patel (1999). Cost data on coal-fuelled GCC power plant are quoted from DOE (2000a) and Holt and Burgt (1999). Cost for natural gas-fuelled combined cycles (NG-CC) originate from Sheard and Raine (1998). In constructing Figure 16 it was assumed that the same system boundaries apply as those for the CS technology indicated above. All data were converted to 1998 € by means of the Chemical Engineering Plant Cost Index.

Table 11, Investment targets as reported in literature (recalculated to 1998 €).

Author (year)	Reference capacity (MW_e)	Reference year or plant number	Investment target	
			€/kW_e	as % of current cost (i.e. the analysed trendline)
DeMeo & Galdo (1997)	75	2000	2385	95%
	100	2005	1872	80%
	110	2020	1425	62%
	110	2030	1259	55%
Faaij, Meuleman, et al. (1998)	51	n	1753	64%
	110	n	1393	61%
	215	n	989	50%
Faaij, v Ree, et al. (1997)	29	n	1572	50%
Craig & Mann (1996)	55.5	n	1329	49%
	55.5	n	1419	53%
	131.7	n	1147	52%
	122	n	918	41%
	105.4	n	1116	48%
McGowin, Hughes, et al. (1998)	100	2030	1364	58%

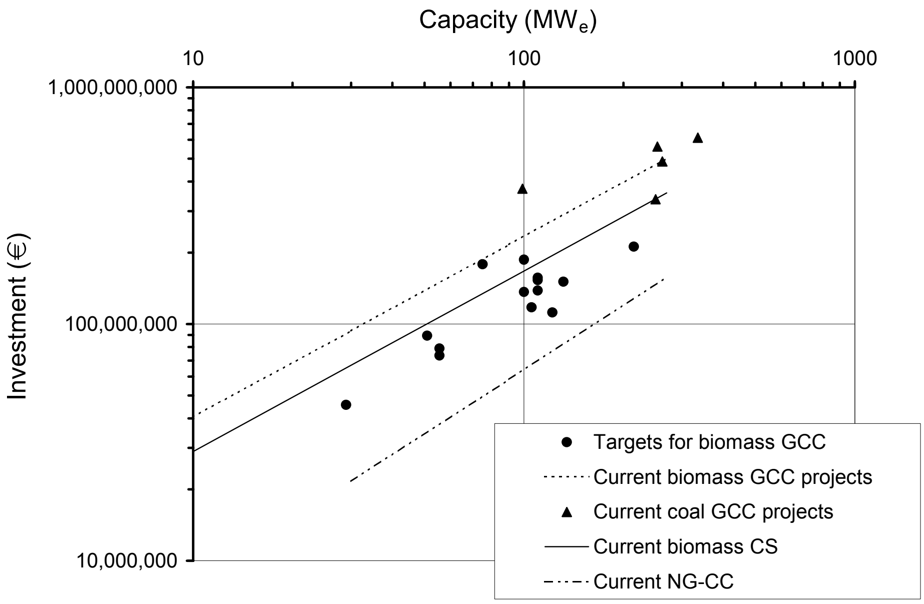


Figure 17, Investment targets reported in literature, compared with other relevant data.

Figure 17 gives a trendline, and the basis for that postulated relationship is formed by the projected data, and the assumption that scale factor is equal to that of CS power plant (i.e. 0.732). The trendline was found by supplementing the data entries with an additional entry at an unknown cost level for an infinitely large capacity. Subsequently the cost level was varied until the desired scale factor was achieved.

The biomass-fuelled LCC cycle received much less attention from the research community and cost estimates are scarce. In his PhD thesis, Siemons (2002) proposed to take the total cost of new natural gas fuelled NG-CC power plants as a basis for the investment estimates, and to add a percentage of 20% for the plant adaptations required to enable the use of bio-oil as a fuel. This allowance is assumed to cover all the changes in terms of fuel storage and handling, eventual fuel quality management such as filtering, as well as combustor retrofits.

Effects of learning: There is a host of literature on learning of technology (usually confined to reduced capex as a function of increasing cumulative installed capacity). The principle message is that the average and most probable progress ratio of any technology is 0.82, meaning that upon doubling of installed capacity costs reduce to a level of 82% of the original (Wene (2000)). People draw nice straight lines through double logarithmic graphs. After reviewing this type of literature, we conclude that we cannot use it for new technologies like biomass-fuelled GCC. Reason: we do not know the initial position. The first such machine still has to be built.

4.2.3 Technology characterisations for central electricity

From the analysis presented in the preceding paragraphs, the relationships displayed in Table 12 were derived for central electricity. These characterisations were used in the scenarios that are further elaborated in Chapter 7.

Table 12, A generalised technology characterisation of central electricity generation, used in the scenario model.

	Capacity (MWe) (selected according to Renard R5/3)					Generalised expressions
	4	16	63	251	1000	
biomass-fuelled GCC (analysis of projects):						
Conversion efficiency on NCV	29%	36%	42%	49%	55%	0.0474 x Ln(C) + 0.2266
Capex (1998 €/kWe)	5342	3846	2779	2003	1443	7.42 × 10^6 × C^ 0.763
biomass-fuelled GCC (analysis of reported targets, n^{th} plant):						
Capex (1998 €/kWe)	2880	2073	1498	1080	778	4.00 × 10^6 × C^ 0.763
biomass-fuelled CS:						
Conversion efficiency on NCV	19%	25%	32%	38%	45%	0.0468 x Ln(C) + 0.1218
Capex (1998 €/kWe)	3492	2514	1817	1309	943	4.85 × 10^6 × C^ 0.763
bio-oil-fuelled CC:						
Conversion efficiency on NCV	45%	48%	51%	54%	57%	0.0222 x Ln(C) + 0.416
Capex (1998 €/kWe)	1261	1104	969	849	743	1.20 x 10^6 x C^ 0.9043 x 120%

Notes:
C: capacity expressed as MWe
GCC: Gasifier followed by gas turbine coupled to steam cycle
CC: Combined cycle of gas turbine followed by steam turbine
CS: (Combustuin &) Steam cycle

4.3 EXISTING TECHNOLOGIES FOR TRANSPORT FUELS

Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport[49] defines biofuels as "liquid or gaseous fuel for transport produced from biomass", where 'biomass' means the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste. It is noticeable that the term 'biomass' of the biofuel directive is somewhat broader than defined in the directives on waste incineration (2000/76/EC) and on emissions from large combustion plants (2001/80/EC). The latter two directives do not consider manure and animal fats to belong to the biomass resources. In the Directive on biofuels for transport, the prefix 'bio' is added to stress the biological origin of these fuels, which is necessary because most of these fuel types can also be produced from fossil materials like oil, natural gas and coal. Notice that pure vegetable oil is mentioned, whereas 'pure animal oil' and 'used frying oil' are omitted, possibly to prevent disputes as these substances suffer a negative public perception. Also bio-electricity could be added as a biofuel, for instance if battery powered cars are used. This option is often regarded as at least worth investigation (See for instance Wang (1999), MacLean and Lave (2003)). Also Directive 2003/30/EC allows this option, as it says that the list contains products that at least shall be considered biofuels,[50] and national governments are allowed to introduce additional biofuels if these comply with the aims of the Directive.[51]

The biofuels considered by Directive 2003/30/EC include, but are not limited to, the following products:[52]

- **Bio-ethanol** is *ethanol produced from biomass and/or the biodegradable fraction of waste, to be used as biofuel.* Bio-ethanol can be produced from any biological feedstock that contains appreciable amounts of sugar or other matter that can be converted into sugar, such as starch or cellulose. Also ligno-cellulosic materials (wood and straw) are often hinted at, but their processing into bio-ethanol is more expensive. Application: SI-engines.[53]
- **Bio-diesel** is *a methyl-ester produced from vegetable or animal oil, of diesel quality to be used as biofuel*. Note the difference with pure vegetable or animal oil, which can be used in adapted diesel engines as well (see below). Application: CI-engines.[54]
- **Biogas** is *a fuel gas produced from biomass and/or the biodegradable fraction of waste, that can be purified to natural gas quality, to be used as biofuel, or wood gas.* This definition covers two main gases derived from different processes:
    - Methane rich (55-60% by volume) gas produced by means of anaerobe digestion of wet biomass.

49/ EU (2003b).

50/ EU (2003b), Article 2, 2.

51/ EU (2003b), Article 4, 2c.

52/ The definitions printed in italic script originate from the directive. Further descriptions are based on: Enguidanos, Soria, Kavalov *et al.* (2002a), MacLean and Lave (2003), and IEA (2003).

53/ SI engine = spark ignition engine (Otto engine).

54/ CI engine = compression ignition engine (Diesel engine).

- Carbon monoxide rich gas made via thermal gasification. Also some hydrogen and methane are present in this gas type.
- Methane rich gas made via thermal gasification, followed by a methane shift reaction.

After de-sulphurization, biogas can be used directly to fuel adapted SI and CI engines. Alternatively methane can be separated out from biogas to be fed into the distribution grid for natural gas, and thus it could be used as a transport fuel in the same manner as fossil compressed natural gas. Application: SI-engines.

- **Bio-methanol** is *methanol produced from biomass, to be used as biofuel*. Methanol can be produced from syngas (a mixture of carbon monoxide and hydrogen). Virtually all syngas for conventional methanol production is produced by steam reforming of natural gas into syngas. In the case of bio-methanol, a biomass is gasified first to produce a syngas from which the bio-methanol is produced. Application: SI engines (blended with petrol), CI- engines (pure), fuel cells.
- **Biodimethylether (DME)** is *dimethylether produced from biomass, to be used as biofuel*. Bio-DME can be formed from syngas by means of oxygenate synthesis. It has emerged only recently as an automotive fuel option. Storage capabilities are similar to those of LPG. Application: CI-engines.
- **Bio-ETBE (ethyl-tertio-butyl-ether)** is *ETBE produced on the basis of bio-ethanol. The percentage by volume of bio-ETBE that is calculated as bio-fuel is 47%.* Application: SI-engines (blends with petrol).
- **Bio-MTBE (methyl-tertio-butyl-ether)** is *a fuel produced on the basis of bio-methanol. The percentage by volume of bio-MTBE that is calculated as biofuel is 36%.* Application: SI-engines (blends with petrol).
- **Synthetic biofuels** are *synthetic hydrocarbons or mixtures of synthetic hydrocarbons, which have been produced from biomass.* This broad definition includes Fischer-Tropsch Diesel which is manufactured from syngas, using a large-scale production process. Syngas is usually produced from coal or natural gas via autothermal reforming, but can also be derived via gasification of biomass or gasification of pyrolysis oil. The process was applied in times of mineral oil scarcity (South Africa during boycott, WWII). Application: CI-engines.
- **Bio-hydrogen** is *hydrogen produced from biomass, and/or from the biodegradable fraction of waste, to be used as biofuel.* Application: fuel cells.
- **Pure vegetable oil** is *oil produced from oil plants through pressing, extraction or comparable procedures, crude or refined but chemically unmodified, when compatible with the type of engines involved and the corresponding emission requirements.* Applications: direct use in adapted CI-engines.

And also the following transportation fuels fall within the general definition of biofuels for transport:

- **Animal oil.** This type of oils can be purified to obtain a fat which is virtually free form water and proteins. It is a common technology in the fat processing industry. Application: Like pure vegetable oil, these oils can be used directly in an adapted IC engine, or they can be used as a raw material for the manufacture of biodiesel.

- **Recycled vegetable oil from the food industry and restaurants.** These oils can be purified and used directly in IC engines. They can also be used as a resource for biodiesel production.
- **Bio-electricity.** This energy carrier can be produced from biomass in various ways, see Section 4.2. Application: Grid fed battery-powered cars.

The associated propulsion technologies for the above biofuels differ substantially from each other. Basically the following four systems can be distinguished:

- Internal combustion engines (ICEs):
    - Spark ignition engines (SI) (Otto principle)
    - Compression ignition engines (CI) (Diesel principle)

  For some biofuels, modifications are needed to fuel storage systems, supply systems or engines. Other biofuels can be used without such modifications.
- Fuel cell vehicles (FCVs):
    - Proton exchange membrane fuel cell (PEM)
    - Phosphoric acid fuel cells
    - Solid oxide fuel cells
- Battery-powered electric motor (BP)
- Hybrid electric vehicle (HEV) (generally ICEs combined with BP)

This distinction makes sense in view of the market introduction en eventual major adaptation of infrastructures. Realistic combinations of biofuels and propulsion systems are reviewed in Table 13.

Table 13, Relevant combinations of biofuels and propulsion techniques.

	Propulsion system	Biofuels
Group 1 (simple market introduction and distribution)	Conventional SI (petrol engines)	Bio-ethanol (blends of 5-22 vol%) (E5-E22)
		Bio-ETBE (blends of 10-15%)
		Bio-MTBE (blends up to 20%)
		Bio-methanol (blends up to 15%)
	Conventional CI (diesel engines)	Bio-diesel (blending 5-20%) (D5-D20)
		Fischer-Tropsch diesel
Group 2 (complicated market introduction and distribution)	Adapted SI	Bio-ethanol (85% bio-ethanol in petrol) (E85)
		Bio-methanol
		Bio-methane (compressed natural gas)
		Biogas (product gas gasification)
		Natural gas (containing bio-methane)
	Adapted CI	Bio-diesel (B100)
		Bio-methanol
		Bio-ethanol (blends up to 15%)
		Bio-dymethylether (DME)
	Fuel cell vehicle	Bio-methanol
		Bio-hydrogen
	Battery-powered engine	Bio-electricity

Two groups are distinguished. **Group 1** consists of biofuels that can be used directly in existing engines. For examples see Table 13. Major advantages include:

- No special vehicles have to be designed

- No changes in vehicle sales and service infrastructure
- No substantial changes in performance of the vehicle
- Less sensitive to consumer preferences.

The biofuels of **Group 2** (such as pure hydrated bio-ethanol and pure biodiesel) are more difficult to introduce in the market. Biofuels of this group that are intended for ICEs are used in a pure form, without being blended with fossil fuels. Apparently, this results in a higher environmental benefit per litre fuel used (assuming equal conversion efficiencies, and equal production impacts). On the other hand, the need for adapted vehicles limits the group of customers that can make use of the biofuels of Group 2. And therefore the overall impact of Group 1 biofuels may become higher.

4.4 VIEWS OF LONG-TERM TECHNOLOGY DEVELOPMENTS FOR BIOMASS FUELS IN TRANSPORT FUELS

4.4.1 Group 1: biofuels for unmodified present day IC-engines

Blends for SI-engines

The biofuels ethanol, ETBE, MTBE and methanol are all oxygenates. Oxygenates have a high molecular oxygen content and are either alcohols or ethers, blended with petrol leading to lower emissions of carbon monoxide and hydrocarbons, and serving as a lead replacer. They also have higher octane ratings than petrol MacLean and Lave (2003).

Bio-ethanol blends (up to 22%): Ethanol can be produced in two forms - hydrated and anhydrous. Hydrated ethanol has a purity of 95-96 % ethanol. As second stage refining process is required to produce anhydrous ethanol with a purity of 99-100%. Anhydrous ethanol will readily blend with petrol. Blends of petrol with up to till 22% anhydrous ethanol can be readily used in unmodified cars. It is expected that factories producing hydrated alcohol for consumption purposes will integrate the second distillation process to produce anhydrous ethanol for blending with petrol as soon as it attractive compared to sale to their traditional markets.

Bio-ETBE: Ethyl tertiary butyl ether (ETBE) is produced by mixing ethanol and isobutylane and reacting them with heat over a catalyst. Blended with petrol ETBE has a similar function as ethanol as an oxygenate and anti knock additive. However, ETBE has some logistic advantages over ethanol, as it does not dilute with water, and therefore it is less likely that it picks up water or other contaminants during handling, for instance in transport lines. Another plus of ETBE is its lower vapour pressure - or evaporative properties, which reduces the volatility of the blend, which is an environmental advantage when air quality is considered CFDC (2003). However, dilution of ethanol with petrol is proven at a large scale in Brazil and the US, and the industrial stakeholders in France and Spain had definitely a role in the choice to produce of ETBE in these countries - a process that includes a refinery step, and thus involvement of the traditional oil industry - instead of using blends of ethanol Monier and Lanneree (2000).

Bio-methanol and bio-MTBE blends: As a fuel for blending with petrol methanol has roughly similar properties like ethanol. For production of bio-methanol a syngas is needed, which can be provided by gasification of biomass, which is technically but not yet commercially feasible IEA (2003). Seen the large commercial potential and technical maturity of bio-ethanol production, bio-methanol is not expected to play a significant role as a fuel for blending in the next two decades. This also accounts for bio-MTBE that is produced with bio-methanol.

Blends for CI-engines

Biodiesel blends: Biodiesel is generic name for fuels obtained by transesterification of a vegetable oil. This produces a fuel with very similar combustion properties to pure diesel, but with lower viscosity. With properties very similar to those of fossil diesel, biodiesel can go almost directly into existing diesel vehicles and it mixes with fossil diesel in any ratio.

Often biodiesel refers to rapeseed oil methylester (RME), the main European biodiesel. Esterified soybean oil is the main United States source of such fuel, called Soy diesel. Some factories produce biodiesel from recycled vegetable oil, but at a smaller scale. Also the use of animal fats for esterification is technically possible, although the need for methanol and catalyst doubles when using animal fats Beld, Assink, Jonge *et al.* (2002). Seen the expected problems with public perception it is also not expected to play an important future role.

Fischer-Tropsch diesel: Fischer-Tropsch diesel is a low sulphur substitute for ordinary diesel, and can be either blended or used in a pure form. The Fischer-Tropsch route starts with the production of syngas by gasification, which is followed by a synthesis process. So far, large-scale Fischer-Tropsch conversion installations only use fossil fuels for the production of synthesis gas. Possibilities for gasification of bio-oil for the production of synthesis gas are currently being investigated. The integration of biomass gasification and Fischer-Tropsch synthesis has not yet been demonstrated Thuijl, Roos and Beurskens (2003). A commercial Fischer-Tropsch plant needs to have a substantial size, with a capacity of tens of thousands barrels per day. It is not expected that such a plant will be build in Europe until Fisher Tropsch with biomass is proven. Moreover, the overall energy yield of 60-65% is much less than achieved in standard refining processes. The uncertainty is too large to include the option in further analysis.

Conclusion

Blends of bio-ethanol, bio-ETBE, and bio-diesel may play an important role as biofuels for transport up to 2020.

4.4.2 Group 2: biofuels for innovative future propulsion techniques

Petrol and diesel substitutes

Bio-ethanol: Bio-ethanol has a higher octane number, broader flammability limits, higher flame speeds and higher heats of vaporisation than petrol. These properties allow for a higher compression ratio, shorter burn time and leaner burn engine, which leads to theoretical efficiency advantages over petrol in an IC-engine. Disadvantages of ethanol include its lower energy density than petrol (need for large fuel tank), its corrosiveness, lower vapour pressure (making cold starts difficult) and miscibility with water MacLean and Lave (2003). Beside engine adjustments, all engine components made from zinc, brass, lead, aluminium or other softer metals should be replaced as pure bio-ethanol could cause leaching from such soft metals. All rubber elements should also be replaced, due to its solvency properties. To prevent cold starting problems usually 15% petrol is added to the anhydrous ethanol; this fuel is known as E85 fuel. Hydrated ethanol, with a purity of 95-96 % ethanol and 4-5% water, cannot be mixed with petrol, but can be used in modified cars as well as is proven at a large scale under the Brazilian ProAlcool program.

Bio-methanol: Like ethanol, methanol has been used as a transportation fuel for quite a long time, especially in the USA Thuijl, Roos and Beurskens (2003). However, according to MacLean and Lave (2003) bio-methanol has some serious limitations as a motor fuel as it is corrosive highly toxic, colourless, odourless and tasteless. In addition, its flame is almost invisible in daylight. IEA (2003) states that methanol has a lower energy density but a quite high octane number, which is used mostly in mixture with petrol for flexible fuelled engines. It could also be used in almost pure form in CI-engines, but has a low cetane number, which requires ignition assistance or additives. Seen the technical drawbacks, and since production of bio-methanol requires a product gas produced by gasification -a technology not yet demonstrated commercially- it is not expected that the next decades bio-methanol will be used at a large scale.

Biodiesel: As biodiesel and fossil diesel have got very similar physical and chemical properties, biodiesel may be used in standard diesel engines. The only modifications required are a two-to-three degree retardation of injection timing and replacement of all natural rubber seals with synthetic ones, due to the solvent characteristics of bio-diesel Enguidanos, Soria, Kavalov *et al.* (2002b).

In Germany mainly pure biodiesel is used as replacement for ordinary diesel. German car manufacturers have given warranties for nearly all the diesel models on the condition of the confirmed quality and a quality assurance of the fuel. DIN standards for biodiesel exists in Germany since 1994 and a European biodiesel standard (EN 14214) has been officially published in July 2003.

Bio-DME: Bio-dymethylether has emerged only recently as an automotive fuel option. Bio-DME can be stored like liquid petrol gas (LPG). Its high cetane number (higher than diesel) makes DME very suitable for CI engines IEA (2003). To produce bio-DME one has to gasify biomass to produce syngas. Like in case of methanol production, with natural gas or biomass a syngas is produced, that is processed further. Large scale gasification of biomass is however not yet commercial, which means that like production of bio-methanol, the production of bio-DME is not expected to be substantial up till 2020, unless new gasification processes, for instance gasification of bio-oil are introduced at a substantial scale within 10 years.

Biofuels for fuel cells: Fuel cells generate electricity by a reaction between hydrogen and oxygen forming water. The electricity is used to fuel the electric motor that drives the car. Electric engines have a conversion efficiency of about 90%, which is much higher than the efficiency of an internal combustion engine. Of course also the efficiency of the fuel cell, and, in case the whole chain is reviewed, the energy used to produce the hydrogen carrier should be taken into account. The leading fuel cell technology for the automotive sector is the proton exchange membrane (PEM) fuel cell, which has according to the National Fuel Cell Research Center greater than 55% efficiency (fuel cell only) when running on hydrogen MacLean and Lave (2003). Because hydrogen's energy content on a volume basis is relatively low, on board storage needs big tanks. Long term storage of hydrogen is difficult to realise because the hydrogen will diffuse through the tank walls. Methanol has better storage capabilities and can easily be converted to hydrogen.

Bio-methanol has to be produced by gasification of biomass, which is, as stated before not yet a commercial technology. Therefore, the short term potential of this technology is limited, unless a breakthrough in gasification (of bio-oil) is anticipated.

Fuels cells are promising but its impact is very limited because the production of bio-methanol and bio-hydrogen is not yet commercial. Its role in the bio-energy market up till 2020 is expected to be limited, and will not be analysed further.

Bio-electricity for battery-powered engines: Finally, battery powered engines are mentioned, which could be fuelled with biomass based renewable electricity. Conversion of stored electrical energy into mechanical energy is possible with efficiencies of 90% MacLean and Lave (2003). However, the production of electricity has much lower efficiencies and should be evaluated as well. A disadvantage of batteries is their low energy density, reducing the radius of action. No current battery technology has the required power, efficiency and life cycle with reasonable economics to compete with standard IC-engines MacLean and Lave (2003). Therefore this technology is expected to have a position in certain niches, (for instance city buses) but not as a general substitution technology for present day low duty vehicles. Battery powered engines are not considered in more detail.

Conclusion

Biodiesel, that requires the least vehicle adaptations could play a substantial role in the supply of biofuels for transport up till 2020. High blends of bio-ethanol (E85) require more substantial engine modifications and larger fuel tank storage capacities and is - although proven in Brazil - not expected to play a major role in Europe.

4.4.3 CONCLUSION

Blended fuels like blends of petrol with ethanol and ETBE and blends of diesel with biodiesel have the strongest position to play a major role in the bio-energy's future in the transport sector, because they can be applied without engine adaptation and in case of obligatory blending, consumers do not need to be convinced to switch over. Biodiesel could also play a major role as pure biofuel because engine adaptations are minimal.

Various other biofuels can be produced technically, but are not expected to become popular in Europe because they require the introduction of adapted vehicles (85%-bio-ethanol) and/or too heavy fuel storage systems (methanol, hydrogen). Some fuels like methanol, MTBE and dimethylether could be/are mass produced with conventional resources but to produce them from biomass requires gasification. Gasification of biomass is not yet commercially available, although gasification of bio-oil might result in a breakthrough.

4.5 EXISTING TECHNOLOGIES FOR DISTRIBUTION GAS

The European connected gas grid is mainly fed with natural gas. Before it came into existance, there were many isolated grids for the distribution of town gas. Generally, town gas was not natural gas, but gas that was produced out of coal, by thermal gasification. The techniques used were:

- Gasification with air (the product was: coal gas)
- Gasification with steam (product: water gas)
- Gasification with steam and oil (product: carburated water gas)
- Exceptionally: cokes oven gas, a by-product of the steel industry

This was the situation in may parts of Europe around the first half of the 19th century, and it lasted until the end of the 60s of the 20th. In the beginning, town gas was used for lighting. When the distribution of electricity was introduced, around 1900, this application disappeared , and the most important application became cooking and heating.

Since about 1960, when the Dutch Slochteren field was discovered, this situation changed drastically. The Dutch, and later the European, interconnected distribution grid was created. First it was fed with the Dutch 'Groningen gas' (an expression that indicates also a particular gas quality). The European grid (Figure 18), distributes gas of various qualities, including:

- Groningen gas
- high-calorific gas
- low-calorific gas
- de-sulphurised gas

The European grid is mainly fed from 5 feed points: the Netherlands, Norway, Russia, the UK and Algeria (Table 14). Of these, the UK can hardly be seen as a net exporter, and in the near future the UK is expected to become an importer.

Table 14, Gas consumption and production balances (PJ/yr, 2000).

	Consumption	Production or Export to Europe
Austria	300	
Belgium	600	
Denmark	180	
Finland	160	
France	1700	
Germany	3200	
Greece	80	
Ireland	160	
Italy	2700	
Luxembourg	30	
Netherlands	1600	3120
Portugal	90	
Spain	700	
Sweden	40	
Switzerland	100	
United Kingdom	3800	3900
Norway		1950
Russia		3120
Algeria		1950
Total	**15440**	**14040**

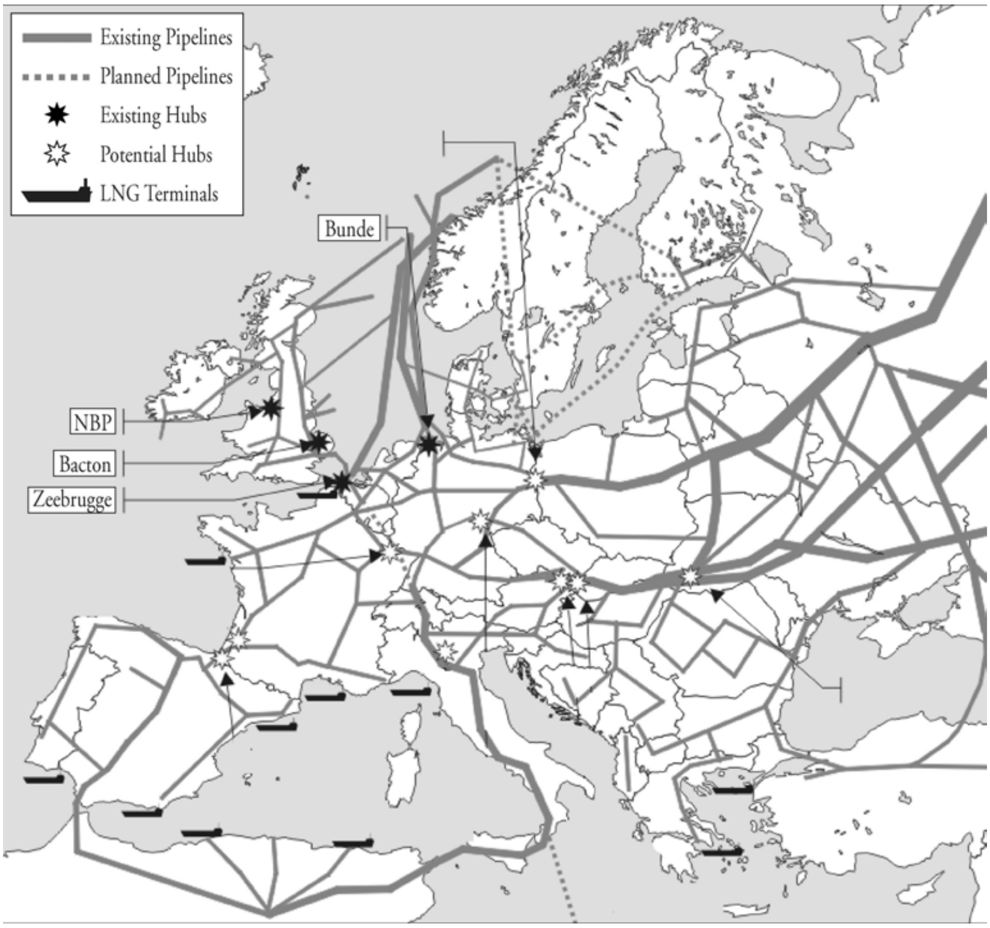


Figure 18, The interconnected European gas distribution grid (IEA, 2002).

Developments in the applications of end-users, and the European interconnection have resulted into strict quality standards for these gas types. These concern:

- Safety related combustion properties ((Wobbe index, Soot Index, and Incomplete Combustion Factor, hydrogen content)
- Trade related calorific value
- Additional components (including total Sulphur, H_2S, COS, mercaptane, HC dewpoint, H_2O dewpoint, O_2, CO_2, N_2)

In view of continued European market integration, these standards are still being developed further.

Although the interconnected grid is mainly fed with natural gas, this fuel is not the only type of feed. Unable to quantify this for the EU, it is reported that in the USA 0.4% of the total gas provision is in the form of Synthetic natural gas, propane air, coke oven gas, refinery gas, biomass gas, air injected for Btu stabilization, and manufactured gas commingled and distributed with natural gas."[55] Also in the EU, there is commingling and distribution of landfill gas and gas from waste treatment plants (for manure, waste water). These gas types are the result of bacterial biomass conversion, and is often called biogas. Upgrading of biogas to 'grid quality' is State-of-the-Art. The processing involves:

- CO_2 removal (e.g. by washing, active coal absorbtion, or membrane separation).
- Drying.
- removal of undesired components (e.g. by washing, active coal absorbtion).
- Pressurising.

4.6 VIEWS OF LONG-TERM TECHNOLOGY DEVELOPMENTS FOR BIOMASS FUELS IN DISTRIBUTION GAS

The biological process to make a distribution gas shows a low yield. A large proportion of the biomass involved remains as a non-digestible sludge. However, it could not be confirmed that other, higher yielding, thermo-chemical techniques to make distribution gas from biomass (like, in the era of town gas, it was done from coal) are used at all in the EU. Such techniques are especially of importance as soon as two developments take place:

- A market has been developed for 'green gas', with a value component for sustainability such as a carbon tax or a GHG emission reduction value.
- That new market is larger than the supply volume from digestion plants, and as a result biomass resources do receive a positive value.

And this is why such techniques deserve some interest here.

In comparison with biological processes, thermo-chemical processes operate at higher temperature levels, and they are therefore less selective for feeds and can yield higher conversion efficiencies. It should be noted that commercially proven thermo-chemical

55/ DOE (2003a).

processes for the production of distribution gas do not exist. A basic concept is shown in Figure 19, and several varieties of this concept can be conceived, such as:

- Gasification with a variety of possible media: air,[56] oxygen, steam, hydrogen, supercritical water.
- Pressurised gasification.
- Gasification with or without the aid of catalysts for specific product optimisation.

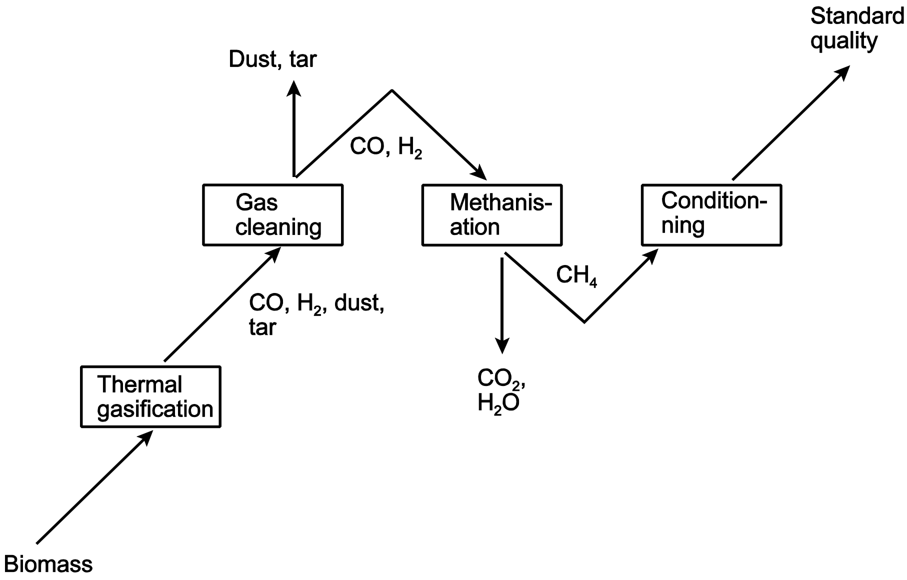


Figure 19, general concept for the thermo-chemical conversion of biomass into distribution gas.

Since in dry biomass the ratio of carbon and hydrogen are not optimal for the formation of methane (CH_4), it is necessary to add hydrogen somewhere during the process, but not necessarily in the shape of H_2. Water (H_2O) is less expensive, and gasification with steam or supercritical water are therefore attractive. For the same reason, wet biomass feeds (such as some waste types from agriculture and industry) are potentially attractive.

Only a few comparative system analyses have been published. Mozaffarian and Zwart (2003) compare four thermo-chemical routes. Gasification with supercritical water was omitted. Neither do they investigate the use of bio-oil as a feedstock. Polman, van Rens, Alderliesten *et al.* (2001)give a limited review. Other studies were not identified, not even after consultation of the library of the IEA. In Japan and Switzerland research is being carried out into the gasification of biomass to methane by means of supercritical water.

There is no doubt about a role for 'green gas' as a commingling product for gas distribution in the EU. However, by and large 'green gas' is mainly considered as an accidentally available byproduct from biological waste processing. Stimulation instruments such as available for renewable electricity do generally not exist for 'green gas'. Especially thermo-chemical conversion technologies for the production of 'green

56/ If air is used as gasification medium, the so-called 'indirect' gasification system ensures that the product gas is not diluted with nitrogen from the atmosphere.

gas' from biomass are not placed on the research agenda of the EC DG-TREN's Framework Six Programme (2002-2006).[57] The issue of 'green gas' was, however, recognised in the preparations of the Dutch GAVE programme.[58] 'Green gas' is now considered by GAVE, and other Dutch programmes (e.g. Transition) as being a candidate application of biomass on the middle and long term.[59]

In this study we assume that during the time frame considered (until 2020), a market for the GHG component in 'green gas' is established. At the same time, we assume that the resource of waste biomass is sufficiently large to provide for this market by means of present day's biological conversion processes. Steps towards the development of thermo-chemical processes to make 'green gas' may be taken during that time frame, but the state of this development does not result in large scale commercialisation. This is a limitation in scope, but there is no factual basis to make further reaching conjectures.

57/ http://europa.eu.int/comm/research/energy/nn/nn_rt_en.html.

58/ GAVE = GAsvormige en Vloeibare klimaatneutrale Energiedragers (Gaseous and liquid climate neutral energy carriers). GAVE aims at stimulating the introduction of such energy carriers, and is coodinated by the Dutch Novem.

59/ Van Halen (2000), p. 31. And also www.transitie.nl.

5 BIOMASS SUPPLY

5.1 OVERVIEW

Availability

In 2000 a total of 159 Mtoe of biomass fuels was available for energy production. 131 Mtoe of this amount was available in the EU15[60] (Table 15) and 28 Mtoe in the Accession States (succinctly abbreviated with the acronym: EU+10)[61] and Bulgaria and Romania (abbreviated: EU+2) (Table 16). In these figures the potential for growing bio-ethanol and biodiesel crops are also taken into account. Note however, that for all energy crops (those for solid fuels and those for liquid transport fuels) a maximum allowable land area of the total current set-aside was assumed. So the potential given here is somewhat arbitrary, but it provides a feeling for the data. Still the potential represented by these biofuels is small in comparison with other available biofuels. It should also be noted that biofuels can be imported into the EU, thus increasing the potential. If by 2010 all EU15+10+2 countries would comply with the renewable transport fuel Directive (2003/30/EG), bio-ethanol and biodiesel would be grown in a quantity of 15 Mtoe.

Table 15, Availability of bio-energy in the EU15 in 2000, 2010 and 2020 (Mtoe).

	2000	2010	2020
Tradables:			
Forestry byproducts & (refined) wood fuels	34.2	37.8	41.7
Solid agricultural residues	25.4	28.1	31.0
Solid industrial residues	10.8	11.9	13.2
Solid energy crops /a	15.5	15.5	15.5
Non-tradeables:			
Wet manure	10.7	11.9	13.1
Organic waste			
- Biodegradable municipal waste	6.7	16.5	28.0
- Demolition wood	5.3	5.8	6.4
- Dry manure	1.9	2.0	2.3
- Black liquor	9.9	10.9	12.0
Sewage gas	1.7	1.9	2.1
Landfill gas	4.0	3.8	2.1
Transport fuels			
Bio-ethanol /a	3.7	3.7	3.7
Bio-diesel /a	1.2	1.2	1.2
Total bio-energy	131	151	172

a/ It is assumed that 50% of the set-aside area is available for solid energy crops and 25% each for bio-ethanol and biodiesel.

60/ This figure was assessed while neglecting Luxembourg.

61/ In the assessment the following accession countries were neglected: Cyprus, Malta.

Table 16, Availability of bio-energy in the EU+10+2 in 2000, 2010 and 2020 (Mtoe).

	2000	2010	2020
Tradables:			
Forestry byproducts & (refined) wood fuels	7.9	8.7	9.6
Solid agricultural residues	7.3	8.1	8.9
Solid industrial residues	2.1	2.4	2.6
Solid energy crops /a	3.2	3.2	3.2
Non-tradeables:			
Wet manure	3.4	3.8	4.2
Organic waste			
- Biodegradable municipal waste	0.5	2.5	5.7
- Demolition wood	0.6	0.6	0.7
- Dry manure	0.4	0.4	0.5
- Black liquor	0.7	0.8	0.9
Sewage gas	0.4	0.4	0.5
Landfill gas	1.1	0.9	0.4
Transport fuels			
bio-ethanol /a	0.5	0.5	0.5
bio-diesel /a	0.3	0.3	0.3
Total bio-energy	28	32	38

/a It is assumed that 50 percent of the set aside area is available for solid energy crops and 25 percent each for bio-ethanol and biodiesel.

Supply costs

Supply costs of the tradable biomass have been determined per country and per type of biomass. Single average supply costs have been determined for bio-ethanol (from sugar beet and wheat) and biodiesel (from rape and sunflower seed). Table 17 shows these costs. The (non-weighted) average supply costs show that solid industrial residues and forestry by-products are among the cheapest biomass resources. Solid agricultural residues are slightly more expensive. The next expensive biomass fuel type is comprised of solid energy crops, with supply costs of about 5 €/GJ, which is close to the supply costs of imported biomass (taken at a standard level of 6 €/GJ, see Section 5.3.6). All costs reflect the delivered fuels at the end-user (i.e. the plant in the case of electricity and heat production, the driver in the case of transport fuels).

Table 17, Average supply costs of tradable biomass and crops for transport fuels (€/GJ).

	EU15+10+2	EU15	EU+10+2
Tradeables:			
Forestry byproducts	2.3	2.4	2.1
Wood fuels	3.6	4.3	2.7
Dry agricultural residues	2.6	3.0	2.1
Solid industrial residues	2.0	1.6	2.5
Solid energy crops	5.0	5.4	4.4
Transport fuels:			
Biodiesel	23	23	23
Bio-ethanol	29	29	29

This chapter first discusses data collection methods - a theme that is then followed by a section on the availability and supply costs of tradeables (Section 5.3), and of non-tradeables (Section 5.4).

5.2 DATA COLLECTION METHODS

The assessment of biomass resources, particularly if all biomass types for relatively large geographical areas are concerned, generally faces two related problems, namely the definition of available resources and the reliability of data. This difficulty is intensified since availability is often understood in a context of combined technical and economic boundaries. And also of those boundaries interpretations differ among researchers. In this study, we made a serious attempt to strictly separate the meaning of availability, supply costs, and prices. However, this is not always the case in the data sources.

Biomass sources are varied and disparate. Many biomass residues have no market and remain in forest and agricultural fields after harvesting operations. These are not traded and there are hence no trade records. Many residues that are used are traded informally - such as domestic firewood, straw for animal feed - and trade records are unreliable. The assessment of energy crops faces similar problems. The area of land suitable for cropping is clearly a primary consideration and, given reasonable agricultural land use, is reasonably straightforward to estimate. However, the area of land available for energy cropping depends largely on the extent to which it is competitive with alternative land uses.

The resource assessment in this study was made in three steps:

1. The first step was to find country information on the technical resource potential, defined as the total annual production of all resources, given no economic limits. This potential represents the total quantity of biomass resources in a region and can be considered as the upper bound of biofuels (if disregarding international trade). To allow comparison and conversion, all resource estimates were expressed as oven dry tonnes (zero moisture content).
2. The second step was to find country information on the available resource potential, defined as all resources available with estimated, realistic limits, considering: technical, physical, environment, agronomic and silvicultural factors. Economic boundaries were taken into account in so far as alternative uses create unrealistically high opportunity costs for biomass to be used for energy.
3. Thirdly, the energy potential of the different biomass resources expressed in PJ/year was estimated on the basis of the Gross Calorific Value of each resource category (see Table 18).

Table 18, Calorific values (dry basis) for the various biofuels.

	GCVd (GJ/t0)
Tradeables:	
Forestry byproducts & Refined wood fuels	18
Solid agricultural residues	18
Solid industrial residues	18
Solid energy crops	18
Non-tradeables:	
Wet manure	9
Organic waste:	
Biodegradable municipal waste	12
Demolition wood	18
Dry manure	14.5
Black liquor	10
Sewage gas	9
Landfill gas	9
Transport fuels:	
Bio-ethanol	21 (NCVd, MJ/l)
Biodiesel	33 (NCVd, MJ/l)

The reference year for all data is 2000, or as close to 2000 as possible in view of data availability. No data from before 1995 were used. If literature sources were not accessible or available, own estimates based on commonly used methodologies were prepared. For each biofuel type (in their separate Sections, below), the particulars to the methodology employed to estimate biomass quantities and supply costs are elaborated.

No supply costs were allocated to non-tradeable biomass types. Their costs for bio-energy purposes is set at zero. It is acknowledged that the collection of for instance biodegradable municipal waste is not for free, but the related costs are assumed to be included in the tariffs that are imposed to the households or organisations for waste disposal. Anaerobic digestion is the preferred technology for energy recovery from wet manure. After this process has been completed, nearly the same quantity of digested manure is left behind. Both products bear roughly the same economic value as a fertiliser. Therefore, the supply cost of manure was neglected in this process. Dry manure and demolition wood can be sold for either positive or negative prices, depending on specific market conditions which are not modelled in SAFIRE. Their supply costs are set at zero. Black liquor needs to be combusted so as to recover the chemicals contained. For that reason no supply cost was allocated to its use for energy.

5.3 AVAILABILITY AND SUPPLY COSTS OF TRADABLE BIOMASS FOR HEAT AND POWER

5.3.1 Forestry by-products

Availability

The European continent has nearly 215 million ha of forests and other wooded land, accounting in total for nearly 30% of the continent's land area and about 5% of the world's forests. There is about 0.28 ha of forest and other wooded land for every European, while the world average is 0.63 ha per capita. Unlike those of many other regions, were deforestation is proceeding at a rapid pace, European forests have been expanding steadily since the beginning of the 20th century (apart from times of war) in both area and growing stock. Almost all of Europe's forests are managed, and have been managed for a very long time and primary or virgin forests are limited.

The total energy potential of forestry by-products in the EU15 is estimated at 17.5 Mtoe/yr (Table 19). For the accession countries no separate figures were found of forestry residues and wood fuels. The combined figures for the accession countries are reported in the next section on wood fuels.

Table 19, Availability of forestry by-products in the EU15.

Country	Available quantity (ktonnes/year)	according to (data source)	Energy potential (ktoe/year)		
			2000	2010	2020
AT	8333	Vesterinen and Alakangas (2001)	3583	3958	4372
BE	411	Vesterinen and Alakangas (2001)	177	195	216
DE	7900	Vesterinen and Alakangas (2001)	3396	3752	4144
DK	611	AFB Network (2002)	263	290	321
EL	99	ALTENER (2002)	43	47	52
ES	3250	Vesterinen and Alakangas (2001)	1397	1543	1705
FI	5333	Vesterinen and Alakangas (2001)	2293	2533	2798
FR	2111	Vesterinen and Alakangas (2001)	908	1003	1107
IE	128	Rice (2003)	55	61	67
IT	860	ALTENER (2002)	370	408	451
NL	260	AFB Network (2002)	112	123	136
PT	1173	ALTENER (2002)	504	557	615
SE	9333	Richardson, Björheden, Hakkila *et al.* (2002)	4013	4432	4896
UK	889	Vesterinen and Alakangas (2001)	382	422	466
Total	40692		17494	19325	21346

Supply costs

The supply costs of forestry by-products found in literature shows considerable variation within and between countries, see Figures 20-21. Within countries, the average values of the found price ranges are used in SAFIRE. It is assumed that the costs of collection and transport of forestry residues at least implies supply costs of 1.5 €/GJ. Reported supply costs higher than 5 €/GJ are supposed to be unrealistically high in comparison with the supply costs in other countries. In those cases the European average of 2.4 €/GJ was used.

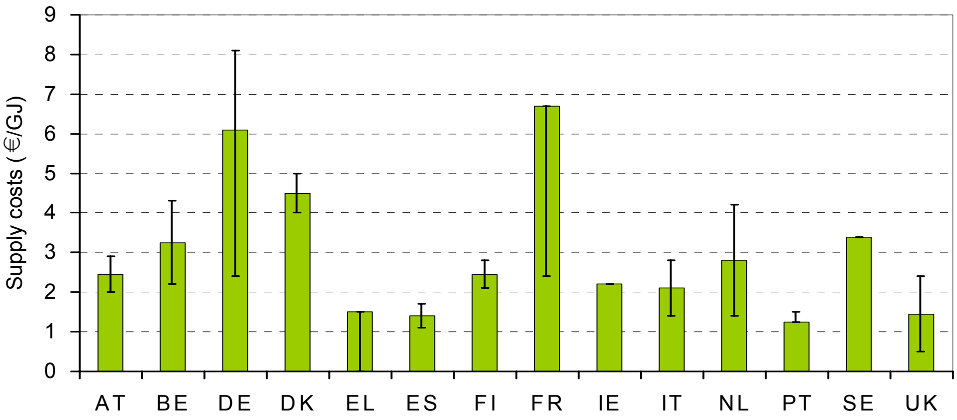


Figure 20, EU15: Supply costs of forestry by-products (€/GJ)

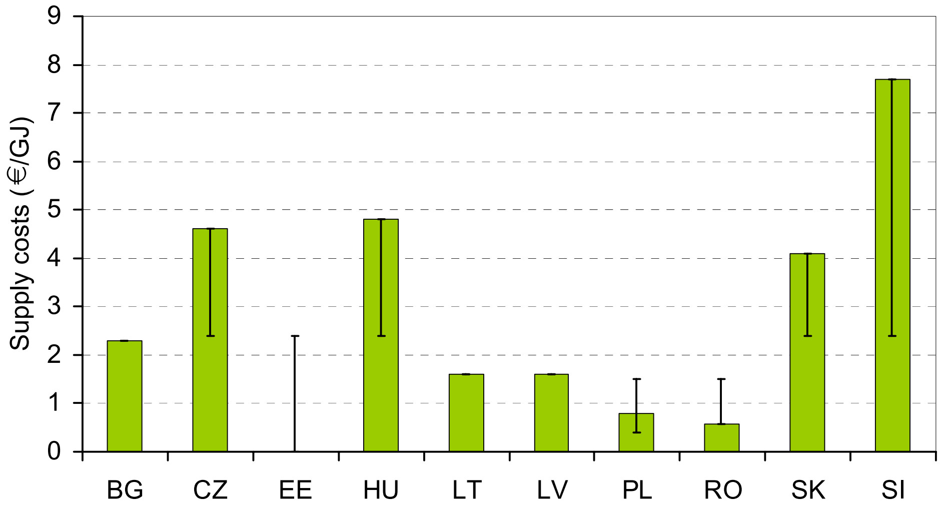


Figure 21, EU+10+2: Supply costs of Forestry by-products (€/GJ).

5.3.2 Refined wood fuels

Availability

Refined wood fuels, defined by Vesterinen and Alakangas (2001) as *pellets, briquettes and other such solid wood fuel products* are made from residues from the forestry sector and the wood processing industry. Because of the additional processing costs, they are investigated separately from forestry by-products and solid industrial waste. Data on the use and availability of wood fuels in the EU15 were mainly taken from Vesterinen and Alakangas (2001). The future availability of wood fuels in the EU15 should not be regarded as limited by the numbers presented in Table 20, as in the eventually forestry residues and solid industrial residues can also be used to produce refined wood fuels.

Table 20, Availability of refined wood fuels in the EU15

Country	Available quantity (ktonnes/year)	according to (data source)	Energy potential (ktoe/year)		
			2000	2010	2020
AT	2389	Vesterinen and Alakangas (2001)	1027	1134	1253
BE	18	Vesterinen and Alakangas (2001)	8	8	9
DE	4722	Vesterinen and Alakangas (2001)	2030	2243	2477
DK	389	Vesterinen and Alakangas (2001)	167	185	204
EL	1100	CRES (2002)	473	522	577
ES	672	Vesterinen and Alakangas (2001)	289	319	353
FI	2778	Vesterinen and Alakangas (2001)	1194	1319	1457
FR	14333	Vesterinen and Alakangas (2001)	6162	6807	7519
IE	189	Vesterinen and Alakangas (2001)	81	90	99
IT	4611	Vesterinen and Alakangas (2001)	1982	2190	2419
NL	639	AFB Network (2002)	275	303	335
PT	1522	Vesterinen and Alakangas (2001)	654	723	799
SE	3961	Vesterinen and Alakangas (2001)	1703	1881	2078
UK	1500	Vesterinen and Alakangas (2001)	645	712	787
Total	38823		16691	18437	20366

Table 21 shows the aggregated availability of wood fuels and forestry residues in the EU+10+2. In these countries a large part of the wood fuels originate directly from forest residues, contrary to refined wood fuels used in the EU15. Given the fact that these wood fuels are often collected directly from the forest, the difference between them is not always that obvious. Therefore the consulted literature allows only to present aggregated data.

Table 21, Availability of wood fuels in the EU+10+2.

Country	Available quantity (ktonnes/year)	according to (data source)	Energy potential (ktoe/year)		
			2000	2010	2020
BG	2654	Ministry of Agriculture & Forestry (2001)	1141	1260	1392
CZ	300	Appendix A	129	142	157
EE	1600	Vesterinen and Alakangas (2001)	688	760	839
HU	874	Appendix A	376	415	458
LT	1917	Server (2003), Lithuanian Energy Institute (2001)	824	910	1006
LV	2267	Vesterinen and Alakangas (2001)	974	1076	1189
PL	2267	Appendix A	975	1077	1189
RO	6103	Appendix A	2624	2898	3202
SK	90	Appendix A	39	43	47
SI	305	Appendix A	131	145	160
Total	18377		7901	8727	9640

Supply costs

Wood fuels are available in many qualities, varying from simple wood chips and pieces of wood used in fire places up to high quality wood pellets that can be fed automatically into central heating systems. The variation in supply costs between countries reflects the differences in these qualities (See Table 22 and Figures 22-23).

Table 22, Supply costs of (refined) wood fuels in the EU15+10+2.

Country	Supply costs according to source: (€/GJ)		Supply costs assumed (€/GJ)
AT	2.3-4.1	Luger (1999)	3.2
BE	6.1	Vesterinen and Alakangas (2001)	6.1
DE	5.6-8.2	Heinz (1999)	6.9
DK	2-3.35	Kristensen (1999)	2.7
EL	6	Panoutsou, Nikolaou and Alexpoulou (1999)	6
ES	3.8	Vesterinen and Alakangas (2001)	3.8
Fi	2.1	Hemming and Sahramaa (1999)	2.1
FR	2.4-2.8	Bewa (1999)	2.6
IE	2.2	Van den Broek, Faaij and Van Wijk (1995)	2.2
IT	4.81	Vesterinen and Alakangas (2001)	4.8
NL	n.a.	Scherpenzeel and Van den Berg (1999)	4.1
PT	2.78	Vesterinen and Alakangas (2001)	2.8
SE	3.39-4.75	Vesterinen and Alakangas (2001)	4.1
UK	3.33-14	Vesterinen and Alakangas (2001)	8.7
BG	2.2	Ministry of Agriculture & Forestry (2001)	2.2
CZ	4.1	Appendix A	4.1
EE	1.05	Vesterinen and Alakangas (2001)	1.1
HU	4.2	Appendix A	4.2
LT	1.5	Vesterinen and Alakangas (2001)	1.5
LV	1.5	Rochas (2003), Vesterinen and Alakangas (2001)	1.5
PL	3.4-4	Appendix A	3.7
RO	1.24	Vesterinen and Alakangas (2001)	1.2
SK	3.8	Appendix A	3.8
SI	7	Appendix A	4.2

No literature reference of the supply costs in the Netherlands were found. The European average was used in the model. The supply costs in Slovakia appear excessively high in comparison with the other accession countries, therefore the second highest supply costs were used in the model.

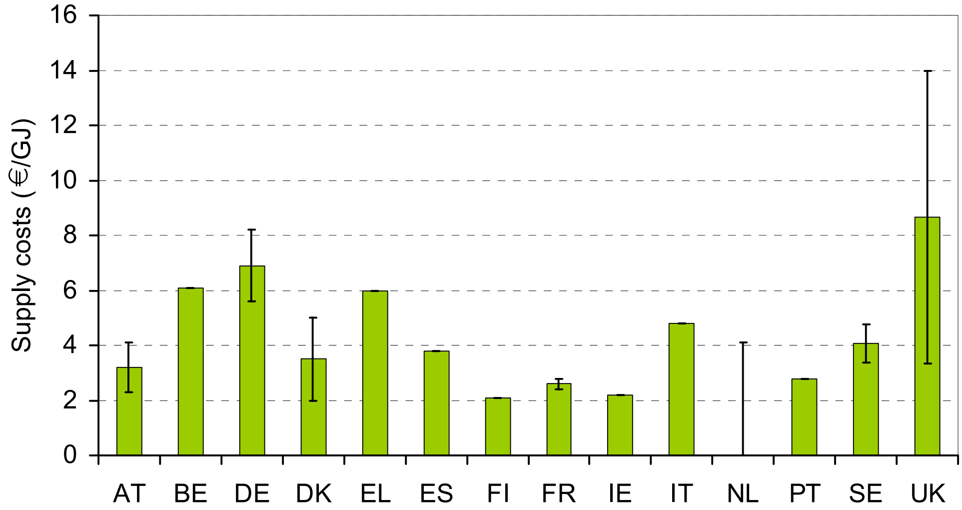


Figure 22, EU15: Supply costs of refined wood fuels (€/GJ).

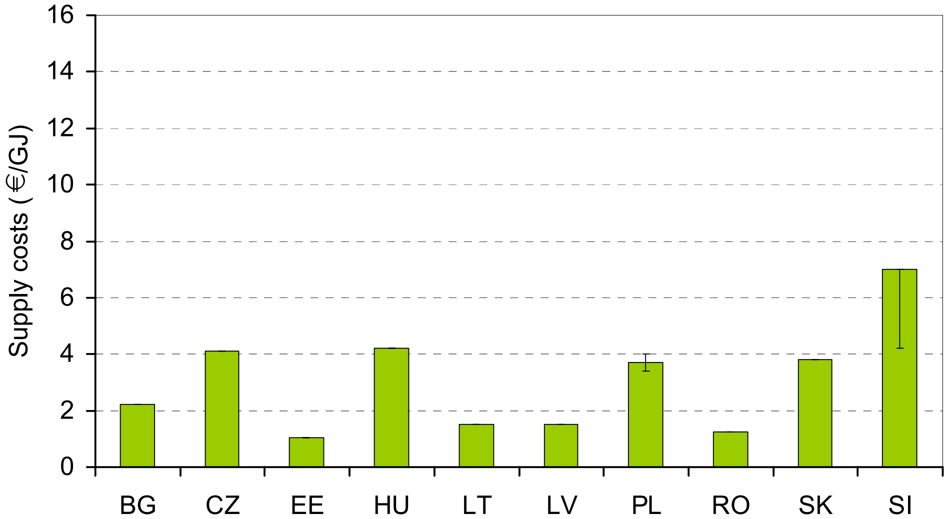


Figure 23, EU+10+2: Supply costs of (refined) wood fuels (€/GJ).

5.3.3 Solid agricultural residues

Availability

Residues from crops that cover over 1% of the total Utilized Agricultural Area (UAA) in EU15 and produce dry lignocellulosic residues (moisture content <50%) were considered. These concern: common wheat (10,8% of UAA), durum wheat (2,9% of UAA), barley (8,7% of UAA), maize (3,3% of UAA), sunflower (1,6% of UAA), rapeseed (2,8% of UAA), olive trees (2,8% of UAA) and vines (2,7% of UAA). The technical potential of these crop residues was estimated on the basis of cultivated area or agricultural production for each crop in each country, for the year 2000 (Source: Eurostat) and average product to residue ratios or residue yields (in dry tonnes/ha) derived from literature (Table 23).

Table 23, Product/residue ratio (wet basis) and moisture content of the main agricultural crop residues for Europe (Dalianis and Panoutsou, 1995).

Crop	Residue	Moisture conten (%, wet basis)	Product/Residue ratio
Cereals	Straw	15	05 (Central-Northern Europe)
		15	0.9 (Southern Europe)
Maize	Stalks	50	0.7
Rapeseed	Stalks	45	1.6
Sunflower	Stems & Leaves	40	3.3
Vineyard	Prunings	45	1.5 t/ha
Olive trees	Prunings	35	0.3 t/ha

Straw estimates were based on an average 0.5 grain/straw ratio for Central-Northern EU countries and on an 0.9 straw/grain ratio for Southern European countries. Corn residues include stalks and ear cobs and were estimated according to a 0.7 corn grain/corn residue ratio. The respective ratio for rape seed according to the same source is 1.6 seed/residue ratio, and for sunflower 3.3. The estimates for olive tree prunings were based on an average of 120 trees/ha and 25 kg dry prunings per tree, resulting in a yield of 0.3 t/ha. The estimates for grapevine prunings were based on an average production of 1.5 t/ha.

The availability of these types of residues for energy purposes is restricted by several technical, environmental or economic factors that are difficult to be quantified. According to Dalianis and Panoutsou (1995) from the total agricultural residues produced in EU15, 48% are being exploited in non-energy (e.g. animal feeding) or traditional energy applications and a further 40-45% of the unexploited quantity cannot be exploited for various technical and/or economical reasons. Based on the findings of this study it was chosen to use this conservative availability factor of 30% for all agricultural field residues under consideration in Europe. Table 24 shows the availability of agricultural residues on a country basis.

Table 24, Availability of agricultural residues in the EU15+10+2.

Country	Available quantity according to (data source) (ktonnes/year)		Energy potential (ktoe/year)		
			2000	2010	2020
AT	500	Wörgetter, Rathbauer, Lasselsberger *et al.* (2003)	215	237	262
BE	379	FAOSTAT (2000)	163	180	199
DE	7222	AFB Network (2002)	3105	3430	3789
DK	1605	AFB Network (2002)]	690	762	842
EL	3833	Mardikis, Nikolaou, Djouras *et al.* (2003)	1648	1820	2011
ES	7006	FAOSTAT (2000)	3012	3327	3675
FI	541	FAOSTAT (2000)	233	257	284
FR	22889	FAOSTAT (2000) Vesterinen and Alakangas (2001)	9840	10870	12007
IE	117	Rice (2003)	50	55	61
IT	9072	ALTENER (2002)	3900	4308	4759
NL	620	Faaij, van Doorn, Curvers *et al.* (1997)	267	294	325
PT	1433	ALTENER (2002)	616	681	752
SE	304	AFB Network (2002)	131	144	159
UK	3600	AFB Network (2002)	1548	1710	1889
BG	2681	Appendix A	1153	1273	1406
CZ	796	Appendix A	342	378	417
EE	54	FAOSTAT (2000)	23	26	28
HU	1439	Appendix A	619	683	755
LT	340	Vrubliauskas and Krusinskas (2000)	146	161	178
LV	72	Rochas (2003), European Commission (2002)	31	34	38
PL	6930	Appendix A	2979	3291	3635
RO	4128	FAOSTAT (2000), ICPA (2003)	1775	1960	2165
SK	512	Appendix A	220	243	269
SI	56	Appendix A	24	27	30
Total EU15	59120		25417	28076	31013
Total EU+10+2	17008		7312	8077	8922
Total EU15+10+2	76128		32729	36153	39936

In the EU15, agriculture is the most important land use in geographic terms occupying 40% (130 million ha) of the total land area. Agricultural activities lead to the production of a vast amount of agricultural residues and by-products. It was estimated that in the EU15+10+2 yearly about 32.7 Mtoe of relevant agricultural residues are released, of which 25 and 7.3 Mtoe result from the EU15 and EU+10+2 respectively.

Supply costs

In order to be utilised, agricultural residues that are released on the field have to be collected and transported to a central place. The bulk density of agricultural residues is generally low. To bring transport costs at an acceptable level, therefore, the residues usually need to be densified, for instance by baling. Even if the residues can be obtained for free, the supply costs will at least value 1 €/GJ. The supply costs of agricultural residues could increase substantially under the influence of transport costs, costs of storage, and opportunity costs.

Table 25 shows that supply costs of agricultural residues show no extreme differences between countries. In case of Portugal and Belgium, no data were available. The average price level in the EU15 was taken as an estimate.

Table 25, Supply costs of agricultural residues in the EU15+10+2.

Country	Supply costs (€/GJ)	according to source:	Supply costs assumed (€/GJ)
AT	2.9-3.4	Luger, E. (1999)	3.2
BE	n.a.	n.a.	3
DE	3.1-3.6	Heinz, A. (1999)	3.4
DK	3-4	Kristensen, E. (1999)	3.5
EL	1.2-5	Panoutsou, C., Nikolaou, A. et al. (1999), Public Power Corporation S.A. (2002)	4.5
ES	1.1-1.7	Esteban, L.S., Ciria, M.P. et al. (2002)	1.4
FI	1.4-3.3	Hemming, M. and Sahramaa, M. (1999)	2.4
FR	3.6-3.9	Bewa, H. (1999)	3.8
IE	n.a.	n.a.	3
IT	1.1-2.8	Scherpenzeel, J. (1999a)	2
NL	2.8-5	Scherpenzeel, J. and Van den Berg, D. (1999a)	3.9
PT	0		3
SE	3-4	Hadders, G. (1999)	3.5
UK	1.6-2.8	Rushton, K. (1999)	2.2
BG	1.4-3.2		2.2
CZ	1.5	Appendix A	1.5
EE	2.39		2.4
HU	1.6	Appendix A	1.6
LT	2.3		2.3
LV	2.2		2.2
PL	1.8	Appendix A	1.8
RO	1.3-2.6	PHARE (2003)	1.9
SK	1.3-4	Appendix A	2.7
SI	2.5	Appendix A	2.5

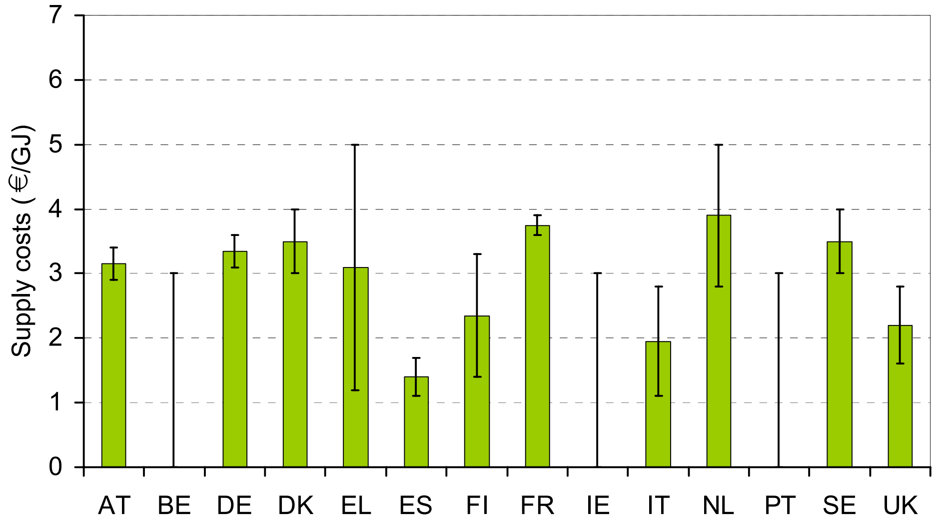


Figure 24, EU15: Supply costs of agricultural residues (€/GJ).

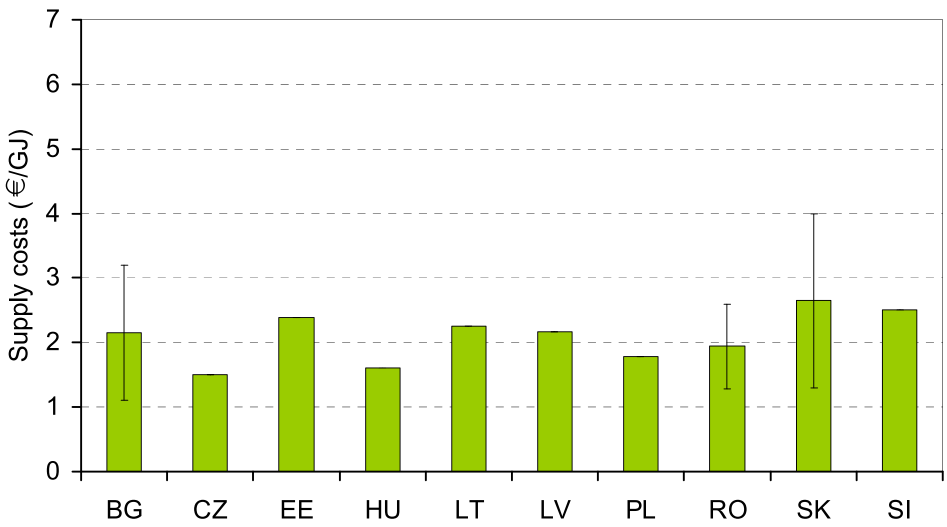


Figure 25, EU+10+2: Supply costs of agricultural residues (€/GJ).

5.3.4 Solid industrial residues

Availability

Solid industrial residues consist mainly of clean wood fractions from the secondary wood processing industry. These residues are often already dried and are released at a central location, which reduces logistic and pre-treatment costs. Wood industries already use part of these residues for heating purposes like space heating and wood drying. Some residues like sawdust are suitable for wood pellet production. Table 26 shows the availability of industrial residues in the European countries. With 13 Mtoe in the EU15+10+2, of which 2 Mtoe from the EU+10+2 and 11 Mtoe from the EU15 it is a substantial biomass resource.

Table 26, Availability of industrial residues in the EU15+10+2.

Country	Available quantity (ktonnes/year)	according to (data source)	Energy potential (ktoe/year)		
			2000	2010	2020
AT	2778	Vesterinen and Alakangas (2001)	1194	1319	1457
BE	700	Vesterinen and Alakangas (2001)	301	332	367
DE	2222	Vesterinen and Alakangas (2001)	955	1055	1166
DK	278	Vesterinen and Alakangas (2001)	119	132	146
EL	590	Mardikis, Nikolaou, Djouras *et al.* (2003)	254	280	310
ES	4850	Vesterinen and Alakangas (2001)	2085	2303	2544
Fi	2611	Vesterinen and Alakangas (2001)	1123	1240	1370
FR	2333	Vesterinen and Alakangas (2001)	1003	1108	1224
IE	260	Rice (2003)	112	123	136
IT	2000	Vesterinen and Alakangas (2001)	860	950	1049
NL	189	Vesterinen and Alakangas (2001)	81	90	99
PT	1500	Vesterinen and Alakangas (2001)	645	712	787
SE	4148	Richardson, Björheden, Hakkila *et al.* (2002)	1783	1970	2176
UK	667	Vesterinen and Alakangas (2001)	287	317	350
BG	70	NSI (2000)	30	33	37
CZ	760	Appendix A	327	361	399
EE	350	Vesterinen and Alakangas (2001)	150	166	184
HU	378	Appendix A	162	179	198
LT	416	Server (2003)	179	198	218
LV	667	Rochas (2003)	287	317	350
PL	806	Appendix A	347	383	423
RO	1278	Vesterinen and Alakangas (2001)	549	607	670
SK	161	Appendix A	69	77	85
SI	92	Appendix A	40	44	48
Total EU15	25126		10802	11932	13181
Total EU+10+2	4977		2140	2364	2611
Total EU15+10+2	30103		12942	14296	15792

Supply costs

The supply costs of industrial residues can be very low if the residues are used at the site where the biomass is released. If pre-treatment and transport is required, supply costs could increase a bit. However, in general fairly low supply costs of 1-3 €/GJ are anticipated (Table 27). Industrial residues like sawdust from softwood are suitable for the production of wood pellets, and could lead to higher prices because of competition.

In some Eastern European countries higher prices of industrial residues were found. In case of Slovenia the price exceeded 5 €/GJ, which is not regarded as realistic. Therefore the second highest supply costs of 4.3 €/GJ were used. For Greece and Estonia no values were found. In those countries a standard price of 1 €/GJ was applied.

Table 27, Supply costs of industrial residues in the EU15+10+2.

Country	Supply costs (€/GJ)	according to source:	Supply costs assumed (€/GJ)
AT	0.92	Luger, E. (1999)	0.9
BE	1.05	Vesterinen and Alakangas (2001)	1.1
DE	1-5.6	Heinz, A. (1999)	3.3
DK	1.05	Vesterinen and Alakangas (2001)	1.1
EL	n.a.		1
ES	1.38-2.28	Vesterinen and Alakangas (2001)	1.8
FI	2.1	Hemming, M. and Sahramaa, M. (1999)	2.1
FR	2	Bewa, H. (1999)	2
IE	1.4-3.5	Van den Broek, R., Teeuwisse, S. et al. (2000)	2.5
IT	2.39	Vesterinen and Alakangas (2001)	2.4
NL	0-2.8	Scherpenzeel, J. and Van den Berg, D. (1999)	1.4
PT	1.37	Vesterinen and Alakangas (2001)	1.4
SE	2.89	Vesterinen and Alakangas (2001)	2.9
UK	0-2.6		1.3
BG	1.07		1.1
CZ	4.1	Appendix A	4.1
EE	n.a.		1
HU	4.3	Appendix A	4.3
LT	0.8		0.8
LV	0.8	Vesterinen, P. and Alakangas, E. (2001), Rochas, C. (2003)	0.8
PL	0-1.8	Appendix A	0.9
RO	0.58	Vasile, C. (2003)	0.6
SK	3.7	Appendix A	3.7

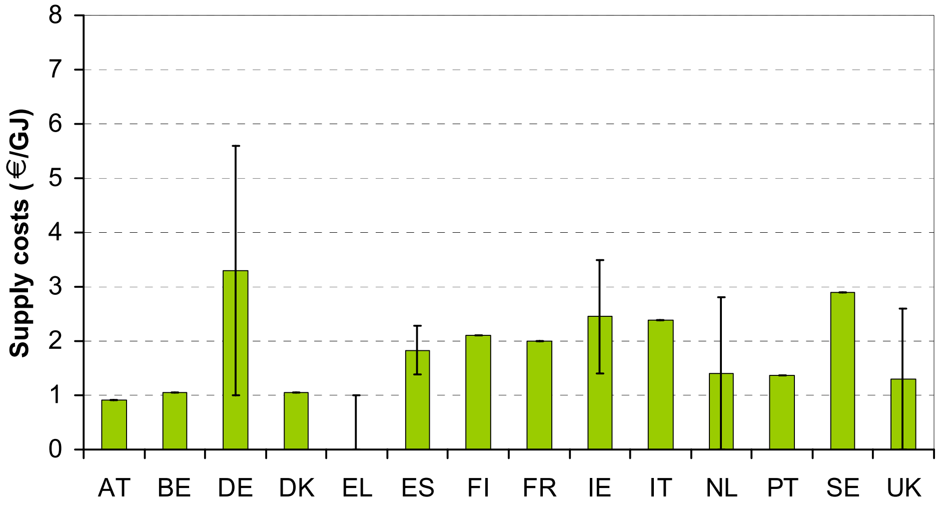


Figure 26, EU15: Supply costs of industrial residues (€/GJ).

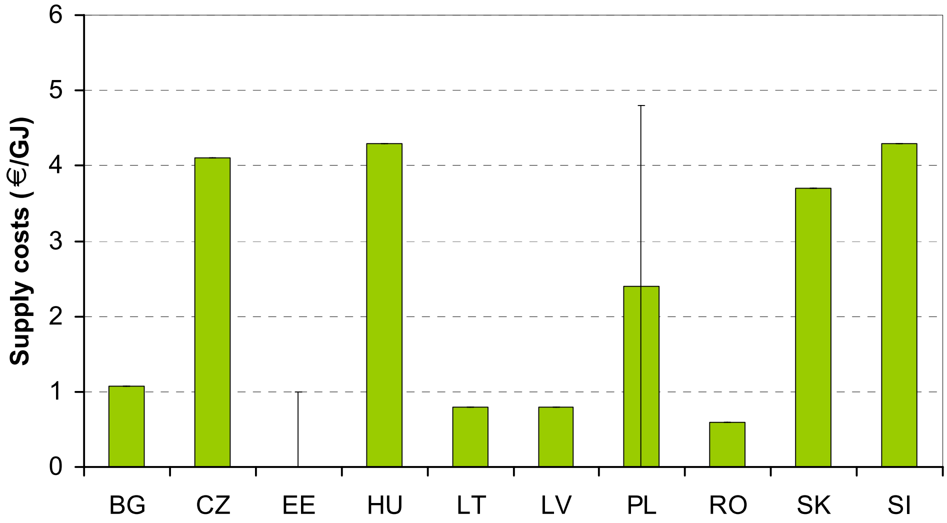


Figure 27, EU+10+2: Supply costs of industrial residues (€/GJ).

5.3.5 European-grown ligno-cellulosic energy crops

Availability

For all energy crops a maximum allowable land area of the total current set-aside was assumed. This is a modeller's choice, based on the experience that farmer's income from energy crops is usually lower than from food crops, and on the tacit assumption that the present day's division of land use into food and non-food is a reasonable reflection of developments until 2020. If the scenario evaluations reported in Chapter 8 show that the resource of energy crops gets utilised close to this maximum, there is a good reason to question this assumption and make a closer analysis. At this stage of the investigations, the assumption of linking energy crops availability to set-aside is useful to get an impression of the potential of this resource, relative to other resources.

Information on the land set-aside under the two set-aside schemes of the Common Agricultural Policy namely voluntary and compulsory set-aside, were collected for 2000. For the accession countries information was collected for the agricultural land that is left idle. In Poland, for which no information was found on idle agricultural land, 10% of the land cultivated with cereals, were considered that could be cultivated with energy crops. Table 28 shows areas assumed to be available for energy cropping in Europe.

Table 28, Arable and set aside land in Europe.

Country	Arable land (1000 ha)	Set aside land (1000 ha)	% set aside land
AT	1399	107	8%
BE	815	24	3%
DE	11804	1137	10%
DK	2281	213	9%
EL	2741	30	1%
ES	13317	1329	10%
FI	2187	177	8%
FR	18440	1489	8%
IE	1050	29	3%
IT	7984	231	3%
NL	909	16	2%
PT	1990	80	4%
SE	2706	264	10%
UK	5876	567	10%
BG	3524	293	8%
CZ	3082	70	2%
EE	1128	220	20%
HU	4902	215	4%
LT	2946	300	10%
LV	2946	443	15%
PL	14071	130	1%
RO	9906	500	5%
SK	1450	29	2%
SI	173	10	6%
EU15	73499	5693	8%
EU+10+2	44128	2210	5%
EU15+10+2	117627	7903	7%

Source: http://europa.eu.int/comm/dgs/agriculture/

Supply costs

Energy crops that can provide dry ligno-cellulosic fuels are miscanthus and switch grass (both grass types), willow and poplar (both as short rotation coppice (SRC)). At present these crops are not grown in Europe on any commercial scale. This makes it difficult to assess their production costs. For this study, CRES made a literature review, investigating many different sources of information. The conclusion is unavoidable that whereas various studies into the production costs of these crops exist, the costs reported vary widely. This was especially apparent when comparing the costs reported for energy crops grown in the new accession countries and for those cultivated in the EU15. The reasons for these differences are due to differences in analysis methods, and to differences in parameter values used. Therefore, a uniform and general estimation method was devised, based on available agricultural statistics for non-energy crops and a fundamental costing method.

The most straightforward method of cost calculation would follow the schedule presented in Table 29. In view of the investment character of both costs and yields,[62] annual production and cash flows would be determined for the year of their occurrence and then they would be discounted at the applicable rate. Unit specific production costs would result from dividing the discounted costs by the discounted production. If sufficient parameter values could be established, the method could be employed both for existing farms switching to the cultivation of energy crops, and for newly established companies dedicated to such production. In practice, this is barely possible for existing farms, due to difficulties in assessing parameter values for the costs of self-provided labour and land use in agriculture. With regard to self-provided labour, there are no accounts on which its value can be determined. As for land use, land is either owned or rented, and only in the latter case are the costs explicit. It appears that land rents are way below the interest rates prevailing on the capital market (1.75% vs. 6.5% is not uncommon).

Table 29, Review of cost items in the determination of production costs for energy crops.

Capital costs	
	Land
	Buildings
	Machinery
Operational costs	
	Labour (farmer, assistants)
	Supplementary services
	Rented machinery
	Materials (seeds, seedlings, fertiliser, fuels, etc.)
	Maintenance
Subsidies (subtract)	
Total	

A method proposed by the Dutch Agricultural Economics Researh Institute (LEI-DLO)[63] and employed in Dinkelbach, Doorn, Jager *et al.* (1998) calculates a standardized net hourly labour income for a typical arable farmer (equivalent to 7.95 €/h) as well as the physical labour input required for the production of energy crops. Labour costs for energy crop production are subsequently found by multiplying the two. Since, in comparison with traditional agriculture, considerably less labour is needed for growing energy crops (at least this applies to the multi-annual crops, miscanthus, SRC-willow, and SRC-poplar), farmer incomes would decrease sharply if energy crops were sold for a price reflecting the costs thus determined, unless additional types of income could be generated. As a result of this approach, energy crops cannot be considered a serious option for the agricultural sector. CPV, IMAG-DLO and ECN (1996) employed a similar evaluation methodology, albeit by assuming a twice as high cost for unpaid labour by the farmer. Additionally they applied a margin of 5% over the turnover. Costs calculated in this manner are more favourable for the farmer. However, the cost calculations in both studies bear no

62/ A particular characteristic of multi-annual energy crops is that substantial onetime costs for start-up and termination are involved and that these crops achieve their maximum yields only after a prolonged starting period of several years.

63/ Meeusen-Van Onna (1997).

relationship with the real cash flows required in farming, and the resulting values cannot be considered to reflect production cost indicators.

Evaluations by Venturi, Huisman and Molenaar (1997) and Bullard (2001) start from the standard gross margin (SGM), as defined in the EU's agricultural accountancy data network. On an enterprise level, the gross margin is defined as the value of production minus certain costs. Standardization is achieved by taking an average, based on region and farm type. Making use of regionally averaged farm sizes, the SGM is expressed on an area basis (€/(ha.yr)), SGM_a. The cost items subtracted are defined in Commission Decision 85/377/EEC concerning a common typology for agricultural holdings in the EU.[64] They concern costs which can be directly allocated to the crop produced, and include supplementary contracted services. Agricultural subsidies are included in the SGM as positive proceeds.[65] Unit specific production costs (€/t crop) result by dividing the sum of SGM_a and directly allocated costs, by area specific yield:

$$UPC = \frac{SGM_a + \text{area specific direct cost}}{\text{area specific yield}}.$$

In the calculation of the SGM, capital costs, the fuels to operate machinery, and self-provided labour are not deducted. As a result, the gross margin is available to finance precisely these non-deducted costs, including the farmer's income. Therefore, in contrast with the analysis method of LEI-DLO, the production costs calculated in this manner do reflect accepted incomes in agriculture since the accepted farmer income is a result of the aggregate area-specific gross margin of established holdings. The prevailing variations in holding size and farmer's income are taken as a given fact. If, however, in the longer term, the average holding size substantially increases *ceteris paribus* farmer's income, then such an estimate of production costs of energy crops, based on currently prevailing SGMs, would be too high. A further drawback is that an SGM-based cost analysis leaves implicit any distinction between farmer's income and capital costs (land, buildings and machinery). Hence, the method does not enable production cost calculations for enterprises specifically established for the growing of energy crops.

The agricultural subsidies applicable to certain crops in the EU15 complicate the matter. There is one agricultural subsidy that may also be paid out to the producer of energy crops, i.e. the existing subsidy for fallow (Commission Regulation (EC) No 2461/1999).[66] This implies that part of the production costs is paid by the government and that, as long as the subsidy is granted, the relevant value should be deducted from the production costs (as perceived by the farmer) of energy crops. The system of agricultural subsidies is under political debate almost continually, and it may change. If it changes, it will do so as a result of its own social, political and economic dynamics which do not depend on the relatively small events in the field of biomass energy. It is therefore reasonable to accept the current subsidies for energy crops as a true factor leading to reduced production costs. Since the subsidy applicable to energy crops differs in size from the subsidies paid for

64/ EU (1985).
65/ EU (1985), p.4.
66/ EU (1999a).

food crops, a correction should be made in the method applied by Venturi and Huisman, and by Bullard. While taking the necessary discounting operations into account, an improved cost estimate for existing farmers would proceed as follows:

$$UPC = \frac{SGM_a - \text{average standard subsidy} + \text{fallow subsidy} + \text{area specific direct costs}}{\text{area specific yield}}.$$

In this calculation, the average standard subsidy consists of all agricultural subsidies including the one for fallow, since the average of all subsidies is included in the SGM_a.

Data to apply this method were taken from Statistical and Economic Information 2002, provided by DG-Agriculture of the EC.[67] From that source, the Tables 3.2.3S1 and 3.2.3.1S1 provide the average holding size and average total financial outputs of farms growing field crops in the European Union and in the Accession Countries. The total financial output, decreased by a standard subsidy for fallow (€ 300/ha in the EU15),[68] was taken to represent the SGM plus direct costs. By doing so, we assumed that there is no significant difference between the direct costs observed for the average field crops and the new energy crops. Thus analysed, production costs reflect the transaction between producer and user; agricultural subsidies are paid in addition by the government to the producer.

Energy crop yields across entire Europe were estimated by taking the yields of common wheat as a reference. This crop was chosen for this purpose because it is grown all over Europe. The same report on Statistical and Economic Information 2002 served as a data source. Yields of ligno-cellulosic energy crops are systematically higher than those of common wheat, since they concern the entire crop rather than just the grains. A correction factor to the yields of common wheat as large as 2.17 was found, placing an average European yield of solid energy crops at 12.5 t_0/(ha.yr). With this factor the yields in highly productive countries reach 15 t_0/(ha.yr). In view of the yields achieved with beetroot and silage maize (a whole crop too) these yields appear to be a reasonable long-term expectations for ligno-cellulosic energy crops. However, taking common wheat as a single reference fuel, bears the risk that countries with low common wheat yields are regarded automatically as if being less suitable for ligno-cellulosic energy crops. This could be a mistake. To reduce the modelling effects of this type of error, the differences in yield between the various countries were levelled slightly.

One €/GJ was added for transport of the biofuels to the users. The supply costs of energy crops thus found are shown in Figure 28 and in Table 30.

67/ EU (2003a).

68/ For the accession countries we assumed a subsidy of €100/ha.

Table 30, Calculated supply costs of solid energy crops.

	Normalised average yield (t0/(ha.yr))	Supply costs at factory (€/GJ)		Normalised average yield (t0/(ha.yr))	Supply costs at factory (€/GJ)
EU15			**Accession Countries and Candidate Countries**		
AT	11.8	5.7	BG	6.6	4.7
BE	15.1	6.3	CZ	8.4	5.4
DE	14.3	5.2	EE	5.6	4.0
DK	14.2	4.9	HU	7.8	4.4
EL	9.1	5.1	LT	6.8	3.9
ES	9.5	4.6	LV	6.3	4.2
FI	9.5	5.3	PL	7.3	4.3
FR	14.1	4.6	RO	6.4	4.7
IE	15.5	4.1	SI	7.6	4.1
IT	11.3	6.4	SK	7.7	4.2
NL	15.0	8.0			
PT	7.8	7.1			
SE	12.6	4.2			
UK	14.6	4.6			

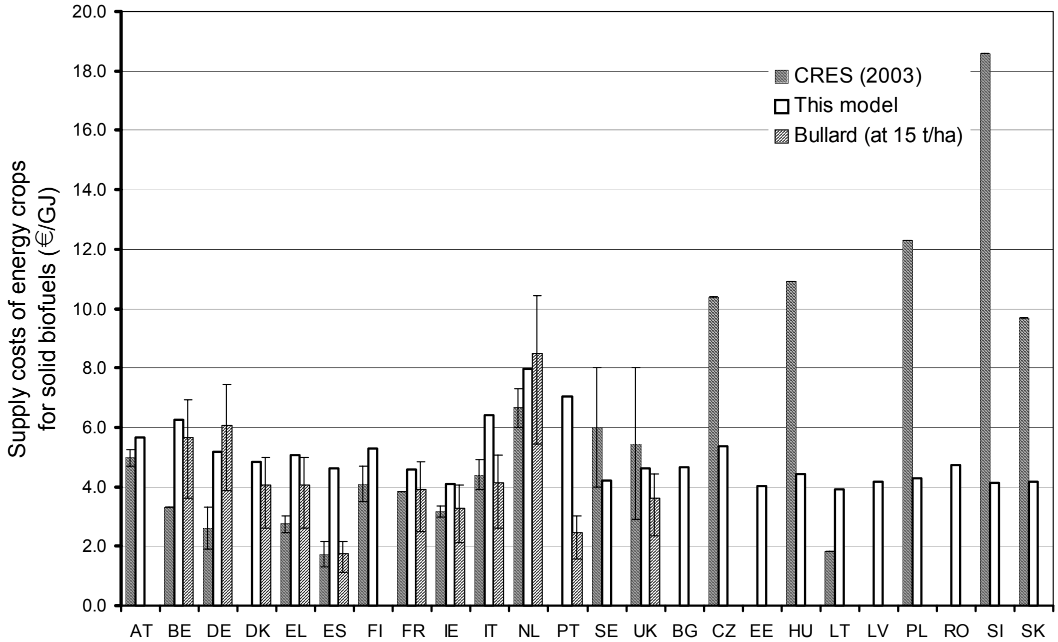


Figure 28, Supply costs of energy costs for the various countries. The data quoted from Bullard (2001) concern miscanthus and are based on the assumption that an average yield of 15 t0/(ha.yr) is feasible everywhere. The range given for Bullard's data are based on uniform yields of 12 and 24 t/(ha.yr).

Among the accession and candidate countries the calculated supply costs show less variation than among the EU15. The reason is that the average turnover per hectare of

Poland, Slovenia, Bulgaria and Romania were not available from the statistical data employed, and therefore, the average turnover of the other accession countries was used.

For most of the countries the calculated costs of energy crops are more expensive than the estimates found in the earlier collected literature. This is partly due to the fact that often higher crop yields are assumed. Another reason is the tendency to systematically underestimate production costs, by disregarding the farmer's opportunity costs to grow alternative crops (refer to the discussion at the beginning of this section).

5.3.6 Imported biomass

Today, large quantities of biomass fuels are imported from outside the EU. For example, a quantity of about 0.1 Mtoe biomass fuel pellets is imported annually from Canada to Rotterdam for use in Dutch power plants (co-firing with coal). The fact that trade in biomass fuels actually exists proves that biomass is, unlike many other renewables, not an essentially 'local' fuel that is destined for conversion or end-use at the place where it is produced. The importation of biomass fuels from outside the EU may further develop if external biomass resources are attractive from a cost/quality point of view. Two cost factors are determinant here, i.e. f.o.b purchase costs and transportation costs.

If the option of biomass fuel imports into the EU is to be taken seriously, the issue of biomass fuel trade should be considered on a world-wide level. After all, the EU is not, or should not be, the only party interested in increasing its share of biomass fuels. A global perspective of the use and provision of biomass fuels is therefore in place here. Issues addressed are:

- How much biomass fuels are currently being used (relative to total primary energy supplies)?
- What is the world-wide resource potential of biomass fuels on the long run?

Current biomass fuel utilisation

Already, biomass is a fuel resource of considerable importance. In the first place this applies to most developing countries; the relevant sectors being household energy (cooking, space heating), informal industries (e.g. brick making), and several agro-industries (e.g. palm oil and sugar manufacture). In industrialised countries, biomass fuels are rarely used in the household sector, but industries do make use of these fuels if they become available as one of their by-products. Examples are timber industries using their sawdust, shavings and off-cuts as fuel for drying kilns and the heat provision to panel presses (for plywood, MDF, etc.), and paper mills using their residues for the generation of process electricity and process heat. Figure 29 shows a current world-wide primary energy supply of about 10,000 Mtoe, of which approximately 1000 Mtoe is supplied as biomass fuels.

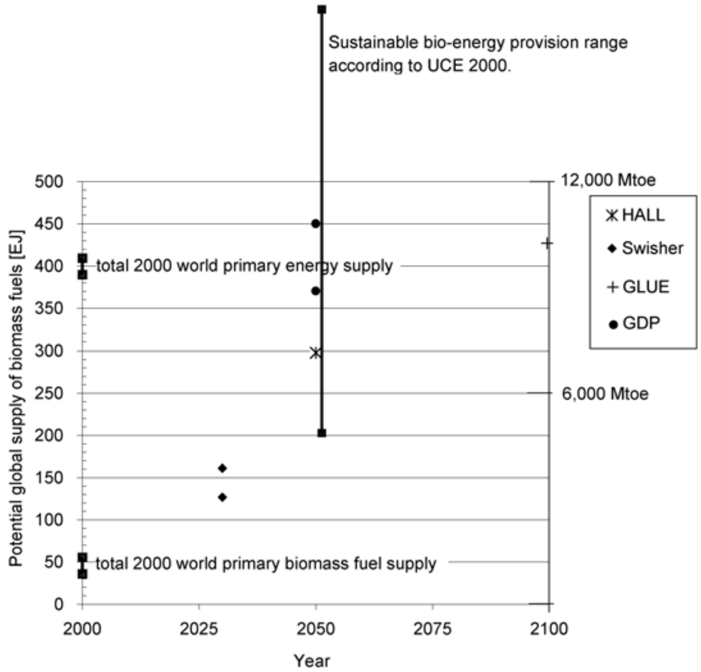


Figure 29, Long-term expected biomass fuel production according to various studies (elaborated after UCE, UU-NW&S et al. (2000)).

To gain an impression of where all this biomass is used, some estimates have been produced by making use of FAO statistics (FAOSTAT), and experience gained with the preparation of investment appraisals (Table 31). The relevant data taken from FAOSTAT concern fuelwood and charcoal production as well as the production of cane sugar, industrial wood products and palm oil. It appears that most biomass fuel consists of fuelwood (480 Mtoe/yr) utilised by households and small industries for the manufacture of bricks, tiles, and tea. The next largest biomass consumers are cane sugar manufacturers (90 Mtoe/yr) and wood panel industries (40 Mtoe/yr). These consumers account for more than 65% of the total estimated biomass fuel consumption (compare with Figure 29). Admittedly, with this estimate, data quality is doubtful. It is not even clear to what extent non-traded fuelwood, grown in plantations for the direct provision of agro-industries such as tea and tobacco manufacture, is included in the FAO database.

Table 31, Biomass consumption in major sectors (Mtoe) (estimate for the year 1998).

	Fuelwood /a	Cane sugar (bagasse)	Wood industries /b	Palm oil (residues)	Total of these sectors
World	481	92	40	8	620
Developed Countries	41	7	30	0	78
Developing Countries	439	85	10	8	542

a/ Fuelwood includes:	Households, charcoal manufacture, industries other than wood processing
b/ Wood industries include:	Fibreboard, Hardboard, MDF, Particle Board, Plywood

Underlying production data (t/yr) are taken from FAOSTAT (http://apps.fao.org/).

Assumptions:

Fuelwood moisture content	20%	wet basis (kg/kg)
NCV_w fuelwood	14	GJ/t_{20}
Wood conversion yield for charcoal	12%	t_5/t_{20}
Cane fibre content	17%	t_0/t_0
NCV_w bagasse	18	GJ/t_0
Industrial biomass fuel use	100%	of output (kg used/kg produced)
Primary energy use in palm oil manufacture	3.3	GJ/t Fresh Fruit Bunch

Neither in developing countries, nor in industrialised countries, are biomass fuels used at significant levels for electricity production by the electricity sector. For the IEA member countries this is reflected in Table 32. Coal, oil and natural gas together make up about 60% of the fuels used. The share of biomass has steadily increased but, by the year 2000, the biomass contribution was still only 1.9%.

Table 32, Total IEA Electricity Generation by Fuel (source: Energy Policies of IEA Countries, 1999 Review, IEA/OECD).

	1973		1979		1997		1998		2000	
	Output (TWh)	Share (%)	Output (TWh)	Share (%)	Output (TWh)	Share (%)	Output (TWh)	Share (%)	Output (TWh)	Share (%)
Coal	1570.8	36.9	1977.7	37.7	3144.5	38.3	3165.9	38.3	3258.2	37.3
Oil	1088.4	25.5	1016	19.3	510.1	6.2	507.7	6.1	546.2	6.3
NaturalGas	512.2	12	597.6	11.4	1125.3	13.7	1142.1	13.8	1358.6	15.6
Combustable Renewables & Wastes	6.9	0.2	11.8	0.2	133.5	1.6	134.8	1.6	168.8	1.9
Nuclear	188.3	4.4	570.3	10.9	1967.2	24	2015.2	24.4	2041.6	23.4
Hydro	888.8	20.9	1069.1	20.4	1290.2	15.7	1252.7	15.2	1307.6	15
Geothermal	6.4	0.2	8.6	0.2	24.7	0.3	24.4	0.3	27.5	0.3
Solar/Wind	0.6	0	0.5	0	13.3	0.2	14.5	0.2	19.7	0.2
Total	4262.4	100	5251.6	100	8208.9	100	8257.2	100	8728.4	100

Future world-wide biomass fuel use

Any estimate of the future bio-energy resource potential has to be based on scenario assessments. And since about 1990, numerous scenario studies on this subject have been published. There are many scenarios and they are based on many different assumptions. 17 of such studies were reviewed by Hoogwijk, Van den Broek, Berndes *et al.* (2000).[69] The relevant studies reviewed by them arrive at resource potentials ranging between 3000 and 10700 Mtoe/yr (see also Figure 29). They also found that not all resources were taken into account by all studies, and this implies that the range is actually extended to a much

69/ The quoted studies are listed in Appendix B.

higher level. According to UCE, UU-NW&S, RIVM *et al.* (2000)), the most relevant parameters which determine the bio-energy resource potential are:

- Population growth and economic developments
- Production manner of food production systems
- Production potential of marginal lands and competition with reafforestation
- Production potential of forests
- Use of biomass for other renewable applications (materials)

However, this is not the place to further investigate the uncertainties of world-wide biomass provision scenarios. The integrated assessment reported by UCE, UU-NW&S, RIVM *et al.* (2000) (that encompasses the review by Hoogwijk, Van den Broek, Berndes *et al.* (2000)) arrives at a range of 5,000-17,000 Mtoe/yr for a world that utilises bio-energy on a large scale in the year 2050. These values are much higher than the estimates in the individual studies reviewed by Hoogwijk, Berndes, Broek *et al.*, and, as explained above, this is caused by the aggregation of the various potential resource types which are not fully covered in the individual assessments. The window of 5,000-17,000 Mtoe/yr is equivalent to 50%-170% of current world-wide primary energy supplies (10,000 Mtoe), both renewable and non-renewable. Time horizons for these assessments, however, range between 2025 and 2100; and by then, total primary energy supplies can be expected to have risen. Nevertheless, it can be safely concluded that there exists a sustainable bio-energy supply possibility up to considerable levels of energy utilisation, and that there is, at least in terms of technical potentials, scope for substantial world-wide trade in biomass fuels.

Relevant biomass resources for imports into the EU

Two cost factors determine whether the importation of biomass fuels from outside the EU develops further: the f.o.b purchase costs and transportation costs. On the long run, the lowest purchase prices can be obtained from:

- Industrial residues that become available in a concentrated manner (from agro-industries, wood processing industries),
- Large-scale energy cropping on marginal lands.

Some examples of the least expensive biomass fuels from the first category are given in Table 33. The table also quantifies these resources. To this end a ‘potential factor’ is introduced, by means of which the fact is taken into account that the considered resources are also needed for industry-internal purposes (crop processing, drying, etc.). The data thus generated give ballpark indications of the quantitative relevance of these resources.

Low-cost short-term supplies may also be obtained from new (or renewed) forestry developments (the first thinnings of currently underutilised forests, e.g. in Eastern Europe).

Table 33, The current least expensive resources for biomass fuels.

Type	Production 2000 (t0)	Potential factor	Relevant quantity		
			t0/yr	Mtoe/yr	PJ/yr
Cane sugar bagasse (World)	213,000,000	50%	106,500,000	46	1917
Developed Countries	16,400,000	50%	8,200,000	4	148
Developing Countries	197,000,000	50%	98,500,000	42	1773
Cane sugar molasses (World)	37,700,000	50%	18,850,000		
= ethanol equivalent				0.1	4
Straw in Europe [a] (Barley, Oats, Rice, Rye, Wheat)	166,000,000	50%	83,000,000	36	1494
Rice husk (World)	133,000,000	50%	66,500,000	23	958
Wood processing residues (World) [b]	29,000,000	50%	14,500,000	6	268
Palm oil processing residues (World)		38%		6	243
Total				117	4888

a) Includes: Albania, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Macedonia,The Fmr Yug Rp, Malta, Republic of Moldova, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Serbia and Montenegro, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom.

b) Assumed: 5% of annual industrial roundwood production.

Data sources and assumptions:

Primary production data	FAOSTAT		
For bagasse and molasses:			
Cane fibre content	17%	t0/t0 of cane	
Molasses production	3%	t molasses/tw of cane	
Ethanol from molasses	10	litre EtOH/t molasses	Thomas (2001)
For straw			
Straw ratio	0.5	t0 straw/t0 crop	
For rice husk:			
Husk ratio	20%	t0/t paddy	Kapur (1998)
Ash content	20%	dry basis	
For palm oil			
Primary energy use in palm oil manufacture	3.3	GJ/t Fresh Fruit Bunch	[Siemons EC]

Supply costs

The supply costs of biomass consist of costs of overseas production, harvesting, collection, processing and transportation costs. In this section a distinction is made between:

- F.o.b. costs (i.e. production, harvesting, collection, processing, transport to port, loading) and;
- Marine transport costs, including unloading.

After being unloaded imported biomass fuels may be further transported to the end-user, which adds to the costs.

The following tradeables (biomass types for electricity and heat) were considered:

- Wood chips
- Wood logs
- Wood pellets

- Charcoal
- Liquified biomass (pyrolysis oil or bio-oil).

And the following importable transport fuels:

- Bio-ethanol
- Biodiesel

Non-tradable biomass like municipal wastes, and wet organic materials were excluded from this investigation. Although international trade in wastes does exist, it is not regarded as practical nor efficient to transport these materials over large distances for energy purposes, mainly because of its low energy densities, high handling costs and anticipated import restrictions.

Overseas production costs: The estimation of overseas production costs is presented in Table 34. The estimation of local solid biomass supply costs are fairly general, and comprises for a large part of the costs to collect and pre-treat the biomass. More specific cost estimations do exist, but vary considerable per country and per situation. The relatively low price levels were estimated in the expectation that an effective global market for biomass will develop.

Table 34, Overseas production costs (ex factory).

	Production costs (€/GJ)	Remark
Logs	1	10 €/tonne for biomass with an NCV of 10 GJ/tonne
Chips	1	10 €/tonne for biomass with an NCVof 10 GJ/tonne
Bales	1	10 €/tonne for biomass with an NCV of 10 GJ/tonne
Wood pellets	1.5 - 3	Estimation based on Vis and Berg (2003)
Charcoal	2.5	BTG
Charcoal briquettes	2.5-3	BTG
Ethanol	13.4	Source: Oestman (2000), Tuite (2003)
Biodiesel	19	Biodiesel production costs excl. distribution in Europe, see Section 5.5.
Pyrolysis oil	2	BTG

Ethanol is produced world-wide and can be produced significantly cheaper in Brazil and North America than in Europe. The overseas market for biodiesel is less developed, and it was not possible to provide detailed estimates for overseas biodiesel consumption. Therefore the European price level was assumed.

Port delivery and loading: These costs consist of the following components:

- Local transport (from fuel supplier to port, unloading)
- Storage
- Departure port (harbour fees or groundage, loading costs)

The major cost component is local transport. Its costs depend on various factors, such as the transport distance, fuel costs, means of transport, taxes, and type of biomass. They vary considerably from situation to situation. Therefore, to make any calculation possible at all, it is necessary to generalise substantially. The following general assumptions are made:

- Transport in units of 24 tonnes biomass;

- The maximum load limited by a volume of 100 m3, so that transport units for products with a bulk density of less than 240 kg/m3 are limited by volume rather than weight.;
- A transport distance of 250 km (to make the coastal regions of countries accessible).

For various biofuels Table 35 provides the resulting estimated local transport costs per GJ. They are primary related to the energy density on a mass basis. Differences in transport costs due to loading and unloading were neglected, and so were differences in investment and maintenance costs between tanker trucks and ordinary trucks. It is expected that these differences compensate each other more or less (i.e. tanker trucks are more expensive but have short loading/unloading times).

Table 35, Local transport costs per GJ fuel for different biofuels.

	NCVw (GJ/tonne)	Bulk density (tonne/m3)	Moisture content (% wet basis)	Transport costs (€/GJ)	
				Developing countries & Eastern Europe	USA
Logs	11	400	40	0.9-1.1	1.5
Chips	11	250	40	0.9-1.1	1.5
Bales	11	250	40	0.9-1.1	1.5
Wood pellets	17	600	10	0.6-0.7	1
Charcoal	31	260	5	0.4-0.5	0.6
Charcoal briquettes	25	480	5	0.3-0.4	0.5
Methanol	20	790	-	0.5-0.6	0.8
Ethanol	26.8	794	-	0.4-0.5	0.6
Biodiesel	37.2	880	-	0.3	0.4
Pyrolysis oil	17	1200	-	0.6-0.7	1

Long-term storage is considered to take place at the production site, and its costs are regarded as part of production costs. Short-term storage costs do exist, but are expected to have minor impact on the final resulting costs and are therefore not taken into consideration.

Sea transport: Table 36 shows that, for the solid biofuels, the marine transport of wood pellets and charcoal briquettes is the least expensive per GJ. Wood pellets show a relatively high bulk density and high loading speeds can be achieved for this fuel type by the use of spouts. The high calorific value of charcoal does more or less compensate for its low bulk density. Transport of chips and bales is particularly unattractive, due to the combination of low calorific values and bulk densities and long loading/unloading times.

Table 36, Costs of sea transport of biofuels over a distance of 10.000 km with a non-dedicated 30,000 dwt vessel.

	Moisture content (% wet basis)	True density (tonne/m3)	Bulk density (tonne/m3)	NCVw (GJ/tonne)	Costs per tonne (€/tonne)	Costs per bulk volume (€/m3)	Costs per energy unit (€/GJ)
Logs	40%	0.55	0.45	11	42[a)]	18.9	3.8
Chips	40%	0.55	0.4	11	55[a)]	22	5
Bales	40%	0.45	0.35	11	66[a)]	23.1	6
Wood pellets	10%	1.12	0.6	17	27	16	1.6
Charcoal	5%	0.4	0.26	31	62	16	2
Charcoal briquettes	5%	0.7	0.48	25	33	16	1.3
Methanol			0.79	20	32	25.3	1.6
Ethanol			0.79	26.8	32	25.4	1.2
Biodiesel			0.88	37.2	30	26.4	0.8
Pyrolysis oil			1.2	17	35	42	2.1

a) Source: Suurs (2002).
Note: other calculations based on careful analysis of various quotes

In general, liquid biofuels have higher energy densities on a volume base than solid biomass. This resulting in lower costs per GJ transported fuel. Of the liquid fuels, biodiesel has the highest energy density, thanks to the combination of a high mass density, high calorific value and low transport costs per tonne. The energy specific costs of marine transport of liquid biofuels differ mainly because of the differences in NCV. With transport costs of 1.2 €/GJ wood pellets can compete quite well with the liquid energy carriers. Although the data of Suurs (2002) and Wagenaar and Vis (2002) who studied the transport of bio-oil from Indonesia to the Netherlands show similar results, it should be noted that pyrolysis oil has not yet been transported in large volumes.

In Table 37the total costs of imports delivered at a large European harbour are reviewed. Biomass could be imported from North America, South America or West Africa. The average transport distance for sea transport is therefore set at 10,000 km. Also Asian countries like Indonesia, India, Malaysia have large biomass resources. From those countries, the costs of sea transport would increase by about a factor of 1.5.

Table 37, Costs of imported biofuels (€/GJ).

	Production	Local transport	Sea transport	Total
Logs	1	1.1	3.8	>5.9
Chips	1	1.1	5	>7.1
Bales	1	1.1	6	>8.1
Wood pellets	1.5 - 3	0.7	1.6	3.8 - 5.3
Charcoal	2.5	0.5	2	5
Charcoal briquettes	2.5-3	0.4	1.3	4.2-4.7
Bio-methanol	-	0.6	1.6	>2.2
Bio-ethanol	13.4	0.5	1.2	15.1
Biodiesel	19	0.3	0.8	11.1
Pyrolysis oil	2	0.7	2.1	4.8

Charcoal, wood pellets and bio-oil are the most attractive biofuels for imports. Assuming European local transport costs of 1.5 €/GJ, it is estimated that substantial imports of biomass are realised if the general price level for biomass reaches a value of 6 €/GJ for biomass fuels delivered at the energy conversion plant.

5.4 AVAILABILITY AND SUPPLY COSTS OF NON-TRADABLE BIOMASS FOR HEAT AND POWER

5.4.1 Wet manure

The average volume of faeces and urine largely differ from one type of animal to another and mainly depend on their age and liveweight.[70] However, in order to assist in the planning, design and operation of manure collection, storage, pre-treatment and utilisation systems for livestock enterprises mean values have been developed by various researchers. In this analysis we adopt the ASAE standard coefficients, presented in Table 38. The values represent fresh faeces and urine. Having in mind the possibilities for collection and energy use of the manure (in view of keeping animals outdoors, or in small farms), it is assumed that only 50% can be considered available for energy production.

Table 38, Coefficients of waste generated per animal category (ASAE D384.1 DEC99)

Animal category	Typical live animal mass (kg)	Total fresh manure per 1000 kg animal liveweight per day	Total solids (%)
Dairy	640	86	0.14
Veal	91	62	0.08
Swine	61	84	0.13

Table 39 shows the availability of wet manure in the EU15+10+2. About 14 Mtoe of wet manure is available for anaerobe digestion in the EU15+10+2 of which 11 Mtoe in the EU15 and 3.4 Mtoe in the EU10+2.

70/ Steffen, Szolar and Graun (2000).

Table 39, Availability of wet manure in the EU15+10+2.

Country	Available quantity according to (data source) (ktonnes/year)		Energy potential (ktoe/year)		
			2000	2010	2020
AT	110	Wörgetter, Rathbauer, Lasselsberger *et al.* (2003)	24	26	29
BE	1990	Eurostat (2000),ASAE (2000)	428	472	522
DE	10570	Eurostat (2000),ASAE (2000)	2272	2510	2772
DK	2486	Eurostat (2000),ASAE (2000)	534	590	652
EL	516	Mardikis, Nikolaou, Djouras *et al.* (2003)	110	121	134
ES	4857	Eurostat (2000),ASAE (2000)	1044	1153	1274
FI	768	Eurostat (2000),ASAE (2000)	165	182	201
FR	9441	Eurostat (2000),ASAE (2000)	2029	2242	2476
IE	2644	Rice (2003)	568	628	694
IT	5828	Eurostat (2000),ASAE (2000)	1253	1384	1529
NL	4010	Eurostat (2000),ASAE (2000)	862	952	1052
PT	832	Eurostat (2000),ASAE (2000)	179	197	218
SE	974	Eurostat (2000),ASAE (2000)	209	231	255
UK	4950	Eurostat (2000),ASAE (2000)	1064	1175	1298
BG	145	Ministry of Agriculture and Fores try (2001)	31	34	38
CZ	1988		427	472	522
EE	90	FAOSTAT (2000)	19	21	24
HU	1950		419	463	511
LT	247	Server (2003)	53	59	65
LV	135	Rochas (2003)	29	32	35
PL	9300		1999	2208	2439
RO	1308	FAOSTAT (2000)	281	311	343
SK	120		26	28	31
SI	552		119	131	145
Total EU15	49973		10741	11865	13107
Total EU+10	15835		3404	3760	4153
Total EU15+10+2	65808		14145	15625	17260

5.4.2 Dry manure

Dry manure consists of poultry manure. To estimate the relevant quantities, the FAOstat chicken stocks were used, combined with a co-efficient of 0.03 dry kg/(animal.day).[71] It was assumed that 50 percent of the poultry manure could be utilised for energy purposes (Table 40).

71/ Stanev (1995)

Table 40, Availability of dry manure in the EU15+10+2.

Country	Available quantity (ktonnes/year)	Energy potential (ktoe/year)		
		2000	2010	2020
AT	118	25	28	31
BE	468	101	111	123
DE	917	197	218	240
DK	179	38	42	47
EL	516	52	58	64
ES	1090	234	259	286
FI	67	14	16	18
FR	1984	427	471	520
IE	100	22	24	26
IT	852	183	202	223
NL	916	197	217	240
PT	298	64	71	78
SE	62	13	15	16
UK	1338	288	318	351
BG	119	25	28	31
CZ	116	25	28	31
EE	21	5	5	5
HU	220	47	52	58
LT	54	12	13	14
LV	28	6	7	7
PL	422	91	100	111
RO	589	127	140	154
SK	120	26	28	31
SI	36	8	9	10
Total EU15	8905	1856	2050	2264
Total EU+10	1725	371	410	452
Total EU15+10+2	10630	2226	2459	2716

5.4.3 Biodegradable municipal waste: land fill gas and incineration

Biodegradable waste (BMW) is defined by Article 2 (m) of the Council Directive (1999/31/EC)[72] on the landfill of waste, i.e. as follows: " 'biodegradable waste' means any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard." Synthetic organic materials such as plastics are excluded from this definition, since they are not biodegradable. It is recognised that energy recovery from these non-renewable materials like plastics takes place and could be encouraged. However, the focus is on biomass residues that can contribute to a net reduction in carbon emissions.

The landfill directive reallocates BMW from landfill to other possible uses, for instance to incineration with energy recovery. The targets set by the landfill directive are set out in Article 5 of the directive:

- Not later than 16 July 2006, biodegradable municipal waste going to landfill must be reduced to 75 % of the total amount by weight of biodegradable municipal waste

72/ EU (1999b).

produced in 1995 or the latest year before 1995 for which standardised Eurostat data are available;

- Not later than 16 July 2009, biodegradable municipal waste going to landfill must be reduced to 50 % of the total amount by weight of biodegradable municipal waste produced in 1995 or the latest year before 1995 for which standardised Eurostat data is available;
- Not later than 16 July 2016, biodegradable municipal waste going to landfill must be reduced to 35 % of the total amount by weight of biodegradable municipal waste produced in 1995 or the latest year before 1995 for which standardised Eurostat data is available.

Member States which in 1995 (or the latest year before 1995 for which standardised Eurostat data are available) put more than 80 % of their collected municipal waste to landfill may postpone the attainment of the targets set out above by a period not exceeding four years.

The technical potential offered by BMW was estimated by means of Crowe, Nolan, Collins *et al.* (2002), who presents an operational baseline for BMW in the EU15 by 1995, which is subject to the agreement of each EEA-member country and Eurostat. The growth of waste quantities in 2000, 2010 and 2020 are based on GDP growth.[73] To determine the BMW quantities in accession countries, various resources were consulted, indicated in Table 41. For 2010 and 2020 an annual growth of waste quantities of 3% was assumed.

The following assumptions were further made:

- Member states will fulfil their obligations at the latest time possible. Thus, a reduction to 75 % of the 1995 number is assumed in 2010; and 35% in 2020.
- All EU15 and accession countries will comply with the Landfill Directive.
- In case countries presently produce less BMW for landfill than stated in the Landfill Directive, these countries will limit the amount of landfilled waste at the present level, and not increase these quantities.
- All BMW that does not go to landfill is available for incineration.
- The moisture content of BMW was estimated at 35% (wet basis).

In Table 41 the resulting quantities of waste for landfill and incineration are reviewed.

73/ Taken from Capros, Mantzos, Petrellis *et al.* (1999).

Table 41, Availability of biodegradable municipal waste in 2000, 2010 and 2020 for landfill and incineration with energy recovery (ktonnes dry)

	2000			2010			2020		
	Total	Landfill	Incineration	Total	Landfill	Incineration	Total	Landfill	Incineration
AT /a	972	196	775	1367	196	1170	1610	196	1413
BE /a	2803	1558	1245	3981	1558	2423	4735	981	3754
DE /a	18655	13096	5559	26495	13096	13399	31360	6529	24831
DK /a	1178	133	1045	1674	133	1540	1942	133	1809
EL /a	1747	1747	0	2941	1310	1631	3934	612	3322
ES /a	7561	5735	1827	11780	5671	6109	14788	2647	12141
FI /a	1082	705	376	1684	705	979	1993	379	1615
FR /a	10235	3892	6343	14536	3892	10644	17375	3582	13793
IE /a	644	587	57	1363	483	880	1678	225	1453
IT /a	5961	4434	1527	8181	4434	3747	9683	2086	7597
NL /a	3140	887	2252	4750	887	3863	5791	887	4903
PT /a	2146	2142	4	3718	1609	2109	4973	751	4222
SE /a	1726	621	1105	2381	621	1760	2763	604	2159
UK /a	10638	9539	1099	15407	7978	7428	18506	3723	14783
BG /b	2320	1600	720	3287	1740	1547	4289	812	3477
CZ /b	837	790	48	1105	628	478	1442	293	1149
EE /b	568	568	0	809	426	383	1056	199	857
HU /b	1259	1161	99	1722	945	778	2247	441	1806
LT /b	278	278	0	403	209	194	526	97	429
LV /b	410	225	184	598	307	291	780	143	636
PL /b	3360	3360	0	4471	2520	1951	5834	1176	4658
RO /b	3796	3417	379	5394	2847	2547	7038	1328	5709
SK /b	442	296	146	614	331	283	801	155	647
SI /b	314	274	39	425	235	190	554	110	445
Total EU15	68487	45273	23213	100258	42575	57683	121130	23336	97795
Total EU+10+2	13583	11969	1614	18829	10187	8642	24568	4754	19814
Total EU15+10+2	79750	55642	24108	115800	51023	64778	141409	27278	114131

a/ Source: Crowe, Nolan, Collins *et al.* (2002)
b/ Sources: NSI (2000), Larsen, H. (1997), Pallo, T. (2003), Latvian Environmental Agency (2003), Ministry of Waters, F.a.E.P. (1998)

In Table 42, these quantities have been translated in terms of energy. For two applications: landfill gas and, and incineration with energy recovery. For the energy potential of landfill gas the maximum quantity of gas that can be extracted from a given quantity of dumped waste is taken, using a calorific value of 3.71 GJ/tonne dry BMW. This value was derived by making use of the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories,[74] and verified with the Guidance note on recuperation of landfill gas from municipal solid waste landfills by the World Bank.[75] As a result of implementing the Landfill Directive, the quantities of landfill gas will decrease significantly over time.

In determining the availability of BMW for incineration with energy recovery, it was assumed that all BMW not sent to landfill is available for this purpose. These results are presented in Table 43. An NCV of 12 GJ/tonne dry matter was assumed. Note the

74/ IPCC (1996), p. 6.2.
75/ Johannessen (1999).

considrable increase of the availability of BMW for incineration with energy recovery. Its resource is expected to quadruple in 20 years.

Table 42, Availability of landfill gas.

Country	Energy potential (ktoe/year)		
	2000	2010	2020
AT	17	17	17
BE	138	138	87
DE	1160	1160	579
DK	12	12	12
EL	155	116	54
ES	508	503	235
FI	62	62	34
FR	345	345	317
IE	52	43	20
IT	393	393	185
NL	79	79	79
PT	190	143	67
SE	55	55	54
UK	845	707	330
BG	142	154	72
CZ	70	56	26
EE	50	38	18
HU	103	84	39
LT	25	18	9
LV	20	27	13
PL	298	223	104
RO	303	252	118
SK	26	29	14
SI	24	21	10
Total EU15	4012	3773	2068
Total EU+10+2	1061	903	421
Total EU15+10+2	5072	4675	2489

Table 43, Availability of BMW for incineration with energy recovery.

Country	Energy potentia (ktoe/year)		
	2000	2010	2020
AT	222	335	405
BE	357	694	1076
DE	1593	3840	7117
DK	300	441	519
EL	0	467	952
ES	524	1751	3480
FI	108	281	463
FR	1818	3051	3953
IE	16	252	416
IT	438	1074	2177
NL	646	1107	1405
PT	1	604	1210
SE	317	504	619
UK	315	2129	4237
BG	206	443	997
CZ	14	137	329
EE	0	110	246
HU	28	223	518
LT	0	56	123
LV	53	83	182
PL	0	559	1335
RO	109	730	1636
SK	42	81	185
SI	11	54	127
Total EU15	6653	16533	28029
Total EU+10+2	463	2477	5679
Total EU15+10+2	7116	19010	33708

5.4.4 Demolition wood

Quantities of demolition wood were difficult to collect. Brodersen, Juul and Jacobsen (2002) provides useful information. In countries for which no data were identified the availability of demolition wood was set at zero. For te EU15+10+2 total of 5.8 Mtoe is conservative (Table 44).

Table 44, Availability of demolition wood in the EU15+10+2.

Country	Available quantity (ktonnes/year)	according to (data source)	Energy potential (ktoe/year)		
			2000	2010	2020
AT	389	Wörgetter, Rathbauer, Lasselsberger *et al.* (2003)	167	185	204
BE	72	Brodersen, J., Juul, J. et al. (2002)	31	34	38
DE	4500	Brodersen, J., Juul, J. et al. (2002)	1935	2137	2361
DK	52	Brodersen, J., Juul, J. et al. (2002)	22	25	27
EL	n.a.	n.a.	0	0	0
ES	354	Brodersen, J., Juul, J. et al. (2002)	152	168	185
FI	307	Brodersen, J., Juul, J. et al. (2002)	132	146	161
FR	6167	Brodersen, J., Juul, J. et al. (2002)	2651	2929	3235
IE	7	Brodersen, J., Juul, J. et al. (2002)	3	3	3
IT	n.a.	n.a.	0	0	0
NL	170	Faaij, van Doorn, Curvers *et al.* (1997)	73	81	89
PT	n.a.	n.a.	0	0	0
SE	241	Brodersen, J., Juul, J. et al. (2002)	103	114	126
UK	0	n.a.	0	0	0
BG	0	n.a.	0	0	0
CZ	192	Appendix A	82	91	101
EE	n.a.	n.a.	0	0	0
HU	187	Appendix A	80	89	98
LT	n.a.	n.a.	0	0	0
LV	n.a.	n.a.	0	0	0
PL	813	Appendix A	349	386	426
RO	n.a.	n.a.	0	0	0
SK	100	Appendix A	43	48	53
SI	37	Appendix A	16	18	19
Total EU15	12257		5270	5821	6430
Total EU+10+2	1329		571	631	697
Total EU15+10+2	13586		5841	6452	7127

5.4.5 Black liquor

Industrial black liquors are liquid by-products from the pulp industry, that contain valuable energy and converted inorganic cooking chemicals. There are several processes which have been developed for recovering the organic combustion heat and chemicals. They are usually utilised at the production site where the black liquor is produced. Its heat can be used elsewhere in the process. Table 45 shows that especially Finland and Sweden produce 61 percent of all black liquor in the EU15+10+2.

Table 45, Availability of black liquor in the EU15+10+2.

Country	Available quantity (ktonnes/year)	according to (data source)	Energy potential (ktoe/year) 2000	2010	2020
AT	2491	FAO Forestry (2003)	595	657	726
BE	760	Vesterinen and Alakangas (2001)	182	201	221
DE	1676	FAO Forestry (2003)	400	442	488
DK	161	FAO Forestry (2003)	38	42	47
EL	0	n.a.	0	0	0
ES	2250	Vesterinen and Alakangas (2001)	537	594	656
FI	14354	AFB Network (2002)	3428	3787	4183
FR	4508	FAO Forestry (2003)	1077	1189	1314
IE	0	Vesterinen and Alakangas (2001)	0	0	0
IT	177	FAO Forestry (2003)	42	47	52
NL	0	Vesterinen and Alakangas (2001)	0	0	0
PT	2240	Vesterinen and Alakangas (2001)	535	591	653
SE	12500	Vesterinen and Alakangas (2001)	2986	3298	3643
UK	195	FAO Forestry (2003)	47	51	57
BG	86		21	23	25
CZ	573		137	151	167
EE	48		11	13	14
HU	0		0	0	0
LT	0		0	0	0
LV	0		0	0	0
PL	1103		263	291	321
RO	300	Vesterinen and Alakangas (2001)	72	79	87
SK	674		161	178	196
SI	170		41	45	50
Total EU15	41312		9867	10900	12040
Total EU+10+2	2954		706	779	861
Total EU15+10+2	44266		10573	11679	12901

5.4.6 Sewage gas

In waste water treatment of urban and industrial wastewater sewage gas is recovered which can be used for energy purposes. Sewage sludge is a residual product from the treatment of urban and industrial wastewater. The quantities of sewage sludge was taken as a measure for the amount of biogas that can be produced. It was assumed that 1 dry tonne of sewage sludge corresponds with 9 GJ of sludge. For every country, data on sludge production could be obtained. In total about 2.1 Mtoe of sewage gas is available in the EU15+10+2 (Table 46).

Table 46, Availability of gas from sewage sludge in the EU15+10+2.

Country	Available quantity (ktonnes of sludge/year)	according to (data source)	Energy potential (ktoe/year)		
			2000	2010	2020
AT	212	Brodersen, Juul and Jacobsen (2002)	46	50	56
BE	113	Brodersen, Juul and Jacobsen (2002)	24	27	30
DE	2661	Brodersen, Juul and Jacobsen (2002)	572	632	698
DK	200	Brodersen, Juul and Jacobsen (2002)	43	47	52
EL	86	Brodersen, Juul and Jacobsen (2002)	18	20	23
ES	787	Brodersen, Juul and Jacobsen (2002)	169	187	206
FI	158	Brodersen, Juul and Jacobsen (2002)	34	38	41
FR	878	Brodersen, Juul and Jacobsen (2002)	189	208	230
IE	43	Brodersen, Juul and Jacobsen (2002)	9	10	11
IT	924	ALTENER (2000)	199	219	242
NL	349	Brodersen, Juul and Jacobsen (2002)	75	83	92
PT	238	Brodersen, Juul and Jacobsen (2002)	51	56	62
SE	236	Brodersen, Juul and Jacobsen (2002)	51	56	62
UK	1193	Brodersen, Juul and Jacobsen (2002)	256	283	313
BG	74		16	18	19
CZ	1165		250	277	306
EE	35		8	8	9
HU	65		14	15	17
LT	57		12	13	15
LV	14		3	3	4
PL	256		55	61	67
RO	110		24	26	29
SK	90		19	21	24
SI	4		1	1	1
Total EU15	8078		1736	1918	2119
Total EU+10+2	1870		402	444	491
Total EU15+10+2	9948		2138	2362	2609

5.5 AVAILABILITY AND SUPPLY COSTS OF SELECTED BIO-TRANSPORT FUELS

In this section the supply costs of bio-ethanol and biodiesel are discussed. In SAFIRE it is assumed that the demand for bio-ethanol and biodiesel in each country is supplied by the resources of the same country. As a general assumption this is incorrect, since one can imagine that bio-ethanol and biodiesel will be traded among the various countries that are going to use this fuel type, and that as a result bio-ethanol and biodiesel will be produced where conditions are the most favourable. Nevertheless, accepting the existing methodology of SAFIRE, we gave the model its data inputs in terms of available land for bio-ethanol, biodiesel and area-specific yields, over the entire range of countries considered.

5.5.1 Bio-ethanol

Availability

To obtain the ha-yield of ethanol made from wheat, the average yield of common wheat in the period 1998-2001 for each country, taken from DG-Agriculture's Statistical and Economic Information 2002,[76] was multiplied by an ethanol to wheat ratio of 350 (litres ethanol/tonne of wheat).[77] The ha-yield of sugar beet based ethanol was derived in a similar manner from sugar production data,[78] this time by means of the beet to sugar ratio of 7.14 (tonne sugar beet/tonne of sugar)[79] and by the ethanol to beet ratio of 100 (litre ethanol/tonne of sugar beet).[80] The resulting area-specific yields of ethanol from wheat and sugar beet crops in the EU15+10+2 and the new countries are shown in Tables 47-48.

The tables also show the quantity of land currently used for growing common wheat and sugar beat. Common wheat is grown throughout the EU15+10+2. Sugar beet crops are grown in all of the EU15 countries and in most of the accession and candidate countries. Sugar beet yields substantially more ethanol per hectare than wheat. A given target for bio-ethanol production and minimised land use would direct towards the cultivation of sugar beet rather than wheat. However, land is not the only input to bio-ethanol production, and a more elaborate investigation into the costs of production is required. For ethanol, this is done in below, and for bio-diesel in the following section. It is shown that beet ethanol is slightly cheaper. Assuming that priority should be given to effective land use, it is assumed that in all EU15+10+2 countries 70% of the bio-ethanol consumed will be produced from beet, and 30% from wheat.

76/ EU (2003a), Table 4.1.1.1.

77/ Enguidanos, Soria, Kavalov *et al.* (2002a).

78/ EU (2003a) Table 4.3.1.1.

79/ Swaaij and Maassen (2003).

80/ Enguidanos, Soria, Kavalov *et al.* (2002a).

Table 47, Potential ethanol yields, and current shares of common wheat and sugar beet in the EU15.

	Potential area specific ethanol yield made of common wheat (litres/ha)	Current share of common wheat in UAA (%) /a	Potential area specific ethanol yield, made of sugar beet (litres/ha)	Current share of sugar beet in UAA (%) /a
AT	1792	8%	6,677	1.30%
BE	2847	15%	6,970	6.50%
DE	2620	17%	6,384	2.60%
DK	2561	23%	6,399	2.20%
EL	916	4%	4,926	1.30%
ES	1052	6%	6,181	0.50%
FI	1057	2%	3,440	1.50%
FR	2554	17%	7,980	1.40%
IE	2996	2%	4,710	0.70%
IT	1637	4%	4,346	1.60%
NL	2839	7%	6,472	5.60%
PT	499	0%	5,234	0.20%
SE	2069	14%	5,266	1.90%
UK	2686	13%	6,355	1.10%
Average EU15	2323	11%	6,331	1.50%

a/ UAA = Utilised Agricultural Area.

Table 48, Potential ethanol yields, and current shares of common wheat and sugar beet in the accession and candidate countries.

	Potential area specific ethanol yield made of common wheat (litres/ha)	Current share of common wheat in UAA (%) /a	Potential area specific ethanol yield, made of sugar beet (litres/ha)	Current share of sugar beet in UAA (%) /a
BG	978	20%	-	0.00%
CZ	1568	23%	4,982	1.40%
EE	659	7%	-	0.00%
HU	1365	18%	n.a.	1.00%
LT	1050	11%	2,964	0.80%
LV	908	6%	3,036	0.50%
PL	1215	15%	3,555	1.80%
RO	934	13%	n.a.	0.30%
SI	1330	8%	4,040	1.70%
SK	1360	17%	3,486	1.30%
Average	1169	15%	3,693	1.40%

a/ UAA = Utilised Agricultural Area.
- = The crop is not grown in the country, and therefore the potential ethanol yield is unknown.
n.a. = Data are missing.

Supply costs

The main crops for the production of bio-ethanol are starch crops (such as common wheat) and sugar beet. These crops are traded on a well established in the European market. For this reason variations in crop prices between countries may be limited, and one single price was estimated that is assumed to be applicable in all EU15+10+2 countries. For common wheat we assume a price of 140 €/tonne. This is in accordance with the

Prospects for Agricultural Markets 2002-2009[81] of DG-Agriculture. For sugar beet we assume a feedstock costs of 26.2 €/tonne. This is based on the average of the producer prices of B-quota sugar beet and the world sugar beet price taken from Enguidanos, Soria, Kavalov *et al.* (2002a). In the ethanol production process valuable by-products are being generated. The so-called co-product credit effectively reduces the production costs of ethanol. In case of ethanol from wheat the co-product is Dried Distillers Grains Soluble (DDGS). Its value is equivalent to 0.145 €/litre ethanol.[82] The by-product of beet sugar ethanol is sugar beet pulp, and this is valued at an equivalent of 0.03 €/litre ethanol.[83] The high co-product credit of wheat ethanol compensates a large proportion of the high feedstock cost. Table 49 shows the analysis of the production costs of bio-ethanol used in the SAFIRE model.

Table 49, Production costs of bio-ethanol in the EU15+10+2

	(€/litre)		Source
	Wheat based	Beet based	
Net feedstock cost			
- Feedstock	0.4	0.26	Wheat: EU (2002) Sugar beet: Enguidanos, Soria, kavalov *et al.* (2002)
- Co-product credit	-0.15	-0.03	Enguidanos, Soria, kavalov *et al.* (2002)
Subtotal feedstock cost	0.25	0.23	
Conversion costs	0.28	0.22	Enguidanos, Soria, kavalov *et al.* (2002)
Blending costs (incl. Adaptation of gasoline)	0.05	0.05	Elam (2000)
Distribution costs	0.1	0.1	Van den Broek, Walwijk, Niermeijer *et al.* (2003), p. 174
Total costs at petrol station	0.68	0.6	

In estimating ‘conversion costs’, and ‘blending costs’[84] it was assumed that anhydrous[85] ethanol is used in a blend of 5% with petrol. ‘Distribution costs’ are those of bringing the fuel from factory to the end-user, and they are estimated at 0.10 €/litre.[86] The total production costs for wheat ethanol are 0.68 €/litre, which is slightly more expensive than beet ethanol of 0.60 €/litre.

5.5.2 Biodiesel

Availability

The main crops for the production of bio-diesel are rape and sunflower seed crops. The potential yields of ethanol from those crops in the EU-15 and accession countries are

81/ EU (2002).

82/ Enguidanos, Soria, Kavalov *et al.* (2002a).

83/ Enguidanos, Soria, Kavalov *et al.* (2002a).

84/ These costs are related to additional storage and logistics costs, and to the costs of adapting petrol for avoiding excessive vapour pressure.

85/ Anhydrous ethanol is required with a purity >99.9%.

86/ Van den Broek, Walwijk, Niermeijer *et al.* (2003). The estimation is based on three estimates available from the UK of 0.07 €/litre, from Sweden of 0.10 €/litre, and from the website of Shell of 0.14 €/litre.

shown in Table 50-51. Rape seed is grown throughout Europe, while sunflower seed crops are grown in the warmer areas only. The potential yields for SAFIRE are derived from average rape and sunflower yields in those countries given by DG-Agriculture's Statistical and Economic Information 2002,[87] multiplied by the oil yields of 360 and 400 kg oil per tonne rape seed and sunflower seed respectively.[88] In the biodiesel production process about 110 kg methanol is added to 1000 kg vegetable oil, resulting in 1000 kg methyl ester (biodiesel) and 110 kg Glycerol.[89] Therefore, the ratio of vegetable oil to biodiesel is 1:1.

Table 50, Potential biodiesel yields, and current shares of common rape and sunflower in the EU15.

	Potential area-specific biodiesel yield made of rape seed (litres/ha)	Current share of rape seed in UAA (%) /a	Potential area-specific biodiesel yield, made of sunflower seed (litres/ha)	Current share of sunflower seed in UAA (%) /a
AT	1055	2%	1,130	0.70%
BE	1,360	0%	-	0.00%
DE	1,327	6%	1,116	0.20%
DK	1,193	4%	-	0.00%
EL	-	0%	500	0.40%
ES	608	0%	429	3.30%
FI	540	2%	-	0.00%
FR	1343	4%	1,041	2.40%
IE	1,287	0%	-	0.00%
IT	1,023	0%	1,156	1.40%
NL	1,298	0%	-	0.00%
PT	-	0%	340	1.30%
SE	846	2%	-	0.00%
UK	1,188	3%	-	0.00%
Average EU15	1089		816	

a/ UAA = Utilised Agricultural Area.

87/ EU (2003a) Table 4.1.1.1.

88/ Enguidanos, Soria, Kavalov *et al.* (2002b)

89/ Enguidanos, Soria, Kavalov *et al.* (2002b)

Table 51, Potential biodiesel yields, and current shares of rape and sunflower in the accession and candidate countries.

	Potential area-specific biodiesel yield made of rape seed (litres/ha)	Current share of rape seed in UAA (%) /a	Potential area-specific biodiesel yield, made of sunflower seed (litres/ha)	Current share of sunflower seed in UAA (%) /a
BG	n.a.	0%	466	10.60%
CZ	1105	8%	961	0.70%
EE	536	3%	-	0.00%
HU	n.a.	2%	770	5.40%
LT	662	2%	-	0.00%
LV	627	0%	-	0.00%
PL	923	2%	-	0.00%
RO	489	1%	478	5.90%
SI	n.a.	n.a.	n.a.	n.a.
SK	607	4%	777	2.90%
Average	707		690	

a/ UAA = Utilised Agricultural Area.
\- = The crop is not grown in the country, and therefore the potential ethanol yield is unknown.
n.a. = Data are missing.

Supply cost

The production costs of biodiesel are presented in Table 52. In the period from 2000/01 to 2009/10, rape seed prices are expected to rise from 226 to 240 €/tonne and those of sunflower seed from 245 to 271 €/tonne. In the model, the average prices of 233 and 258 €/tonne for rape and sunflower are used. Expressed in €/litre of biodiesel, the feedstock prices are similar, because of the slightly higher oil yield of sunflower seed. The conversion costs and co-product credit are derived from the average values of three biodiesel plants with production capacities of 75, 80 and 125 kton/year, given by Eibensteiner and Danner (2000). The production costs of biodiesel from rape seed and sunflower are nearly the same. The per hectare yield of rape seed is generally slightly higher. In the scenario analysis it was assumed that rape seed and sunflower seed will be successfully grown as energy crops in any country, if they already occupy a share of the Utilised Agricultural Area (UUA) of more than 0.1%. If this occurs for both crops, these biodiesel crops are assumed to become grown in a 50/50 ratio.

Table 52, Production costs of biodiesel in the EU15+10+2.

	(€/litre)		Source
	Rape seed based	Sunflower seed based	
Net feedstock cost			
- Feedstock	0.57	0.568	EU (2003) (p53)
- Co-product credit	0.011	0.011	Derived from data given by Eibensteiner and Danner (2000)
Subtotal feedstock cost	0.559	0.557	
Conversion costs	0.07	0.07	Derived from data given by Eibensteiner and Danner (2000)
Blending costs (incl. Adaptation of gasoline)	0.01	0.01	den Uil, Bakker, Deurwaarder *et al.* (2003)
Distribution costs	0.1	0.1	Van den Broek, Walwijk, Niermeijer *et al.* (2003), p. 174
Total costs at petrol station	0.739	0.737	

6 GREENHOUSE GAS BALANCES

The employment of biomass as a source of energy may have a large influence on the global balance of GHG emissions, and in fact this is one of the reasons to promote the use of biomass for energy. Since 1995, a specific task force to investigate "Greenhouse Gas Balances of Bioenergy Systems" (IEA Bioenergy, Task 15) has been established by one of the Implementation Agreements of the IEA. As of 2001, Task 15 is being continued as Task 38 under almost the same name: "Greenhouse Gas Balances of Biomass and Bioenergy Systems".[90] The objective is to investigate all processes involved in the use of bioenergy systems on a full fuel-cycle basis with the aim of establishing overall GHG balances. This is not a trivial matter, because biomass production and use are not entirely GHG neutral. In general terms, the GHG emission reduction as a result of employing biomass for energy, read as follows:

+ GHG emission from avoided mining of fossil resources
- GHG emission from biomass production
+ GHG emission from avoided fossil fuel transport (from producer to user)
- GHG emission from biomass fuel transport (from producer to user)
+ GHG emission from avoided fossil fuel utilisation

The real gains are made with the last issue, i.e. that of avoided emissions from the use of fossil fuels. There are indications that the balance of the other four matters is not neutral, and in fact slightly negative for the biomass system. Further, note that two GHG emission types are omitted from the above balance: the negative emission (capture) as a result of biomass growth, and the positive emission as a result from using the biomass fuel. They are considered to cancel out.

A further complication is that, although the global climate system is indifferent as to *where* GHGs are emitted or not, under the framework of the UNFCCC it *does* matter in which country GHGs are being emitted or captured. The above given GHG balance is not adequate to illustrate this fact, since several terms of the GHG balance that cancel out on a global level were omitted. Such terms remain relevant on a country level. As an example, consider the production of bio-transportation fuels in Austria for export to and use in Germany. Both countries do have an obligation in view of the Kyoto Protocol to reduce their GHG emissions. Should the capture of CO_2, as a result of the production of bio-diesel, appear on the national GHG balance of Austria? If so, Germany can no longer ignore the GHG emission of the imported bio-transport fuel itself. And, although the global balance, given above, remains valid, the economic benefits of reducing GHG emissions in this manner would not devolve to Germany. This issue is elaborated in detail by Siemons (2002a).

90/ For a description, see http://www.ieabioenergy.com/.

In terms of economic transactions, buyers and sellers of GHG related products are likely to incorporate such considerations in their assessment of prices. In our modelling efforts with SAFIRE, we assumed a uniform price level for all EU countries.

6.1 GHG EMISSION BALANCES FOR BIOMASS-FUELLED ELECTRICITY AND HEAT APPLICATIONS

GHG balances for a wide range of technologies to produce electricity and heat were prepared by Elsayed, Matthews and Mortimer (2003). System boundaries encompassed the entire chain from fuel production to end-use. Although some biomass systems[91] show net GHG emissions of more than 40% of the substituted fossil alternatives (the net avoided GHG emissions resulting from employing the next straw fuelled power plant would equal 100%-40% of the emissions of the general power supply system feeding the power grid), there are a number of biomass-fuelled alternatives that show net GHG emissions of just 4%. Therefore any number between these two extremes can be true, and a valid choice depends on one's expectations as to the dominant types of technologies involved on the long run. In Table 53 the selection of this study is reviewed. Note that the total GHG emissions from contaminated biomass fuels (non-tradeables) were set at 0, since these fuels are available anyway. There existence cannot be avoided, and all GHG emissions associated with their production should be allocated to the products from which they are the unavoidable result.

91/ The case of large-scale combustion of straw.

Table 53, GHG savings for selected technologies to produce electricity and heat from biomass fuels.

	Total GHG emissions (secondary energy basis) /a	Total GHG emissions (primary energy basis)		Total net GHG savings (primary energy basis)
Heat from conversion of tradeable biomass fuels	t CO_2-eq./GJ heat	t CO_2-eq./GJ primary energy	Mt CO_2-eq./Mtoe	Mt CO_2-eq./Mtoe
Heat from energy crops wood	0.007	0.005	0.22	3.30
Heat from fuel wood	0.007	0.005	0.22	3.30
Heat from forestry byproducts	0.007	0.005	0.22	3.30
Electricity from conversion of tradeable biomass fuels	t CO_2-eq./GJ electricity	t CO_2-eq./GJ primary energy	Mt CO_2-eq./Mtoe	Mt CO_2-eq./Mtoe
Forestry byproducts	0.022	0.0055	0.23	2.35
Agricultural residues	0.066	0.0165	0.69	1.89
Energy crops: miscanthus	0.026	0.0065	0.27	2.31
Energy crops: short rotation coppice	0.024	0.006	0.25	2.33
Heat or electricity from non-tradeable biomass fuels	t CO_2-eq./GJ electricity or heat	t CO_2-eq./GJ primary energy	Mt CO_2-eq./Mtoe	Mt CO_2-eq./Mtoe
Heat	0	0	0	3.52
Electricity	0	0	0	2.58
Reference system				
UK electricity grid	0.162	0.062	2.58	
Heat oil boiler	0.105	0.084	3.52	
Assumptions:				
Electric efficiency (biomass)		25%		
Thermal efficiency (biomass)		75%		
Electric efficiency (grid)		38%		
Thermal efficiency (heat oil boiler)		80%		

a/ Source: Elsayed, Matthews and Mortimer (2003).

6.2 GHG EMISSION BALANCES OF SELECTED BIO-TRANSPORT FUELS

The replacement of fossil fuel by biofuels results in a change in the release of three types of emissions:

- Greenhouse gases (carbon dioxide, nitrous oxide, methane, sulphur hexafluoride, and perfluorocarbons)
- Air pollutants (carbon monoxides, oxides of nitrogen, sulphur dioxide, non-methanic volatile organic compounds, and particles)
- Air toxics (compounds such as benzene, and aldehydes)

In this section we investigate the GHG emission savings that can be achieved by the production and use of biofuels in transport. During the past few years a wealth of Life-Cycle Assessments (LCAs) have been published determining the global warming reductions that can be achieved with various biofuels. Relevant LCA review studies are those by ADEME (2003), MacLean and Lave (2003) and IEA (2003). IEA (2003) presents an summary of well-to-wheel emissions of biofuels in comparuson with fossil fuels. Emissions of air pollutants from biofuels should meet the pollution control standards of Euro 3 and 4 as defined in EU legislation (98/69/EC). In the context of this study, the emissions of air pollutants and toxics are not investigated in detail. Interested readers might consult the LCAs by, e.g., Wang (1999), Beer, Grant, Morgan *et al.* (2001) and the review study by MacLean and Lave (2003).

The further introduction of biofuels in European transport may not only result in reduced environmental impacts, but also in increased ones. The European Environmental Board criticises the European biofuel promotion policy because of the negative effects on biodiversity, because of increased intensive farming, and because of impacts on soil and groundwater. For details see Jonk (2002). These matters are not discussed further here, but rather we focus on GHG emission reductions that can be achieved with biofuels, taking into account the whole chain from well-to-wheel.

For an assessment of GHG emission reduction that result from replacing fossil transport fuels by biofuels, the entire life cycle of the respective fuels is usually considered, from craddle to grave, or well to wheel. Comparison requires definition of the so-called functional unit. In accordance with the European standards for LCA,[92] the societal service rendered by the fuel should be taken for this unit. This can be a vehicle-km, t-km, or a litre of fuel. Well balanced LCAs take utilisation efficiencies into account. Occasionally less suitable functional units are used in LCAs, such as a hectare of agricultural land. This is less desirable, because land use is not an economic product or service.[93] Several LCA indicators are being reported:

- The energy output/input ratio. This indicator compares the net energy resulting from a unit of biofuel with the fossil energy used to produce this unit.
- GHG emission reductions, in terms of t CO_2-eq. per functional unit.
- GHG emission ratios, comparing GHG emissions from biofuels and those from fossil fuels.

A complete LCA of emissions takes into account the direct emissions from vehicles and also those associated with the fuel's production process, which includes:

- Extraction
- Production
- Transport
- Processing
- Distribution.

92/ ISO 14040 (1997), ISO 14041 (1998), ISO 14042 (2000) and ISO 14043 (2000).

93/ For an elaborate debate on the issue of functional units in LCA, see Siemons (2002a).

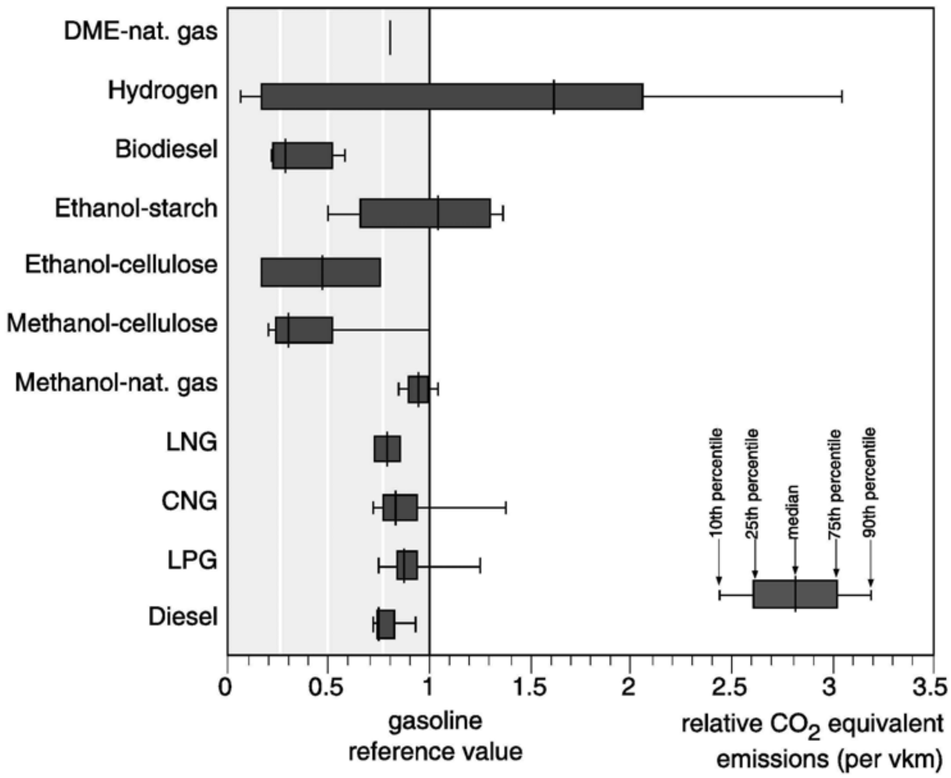


Figure 30, Short-term well-to-wheel GHG emissions of LDVs running on various fuels. Source: IEA (2003).

These are often referred to as upstream emissions or well-to-tank emissions. In general the production and conversion phase of biofuels are more energy and carbon intensive than those of fossil fuels, which results in higher well-to-tank-emissions. Short-term and long-term well-to-wheel greenhouse balances of the use of biofuels in low duty vehicles, like passenger cars, are presented in Figures 30-31.

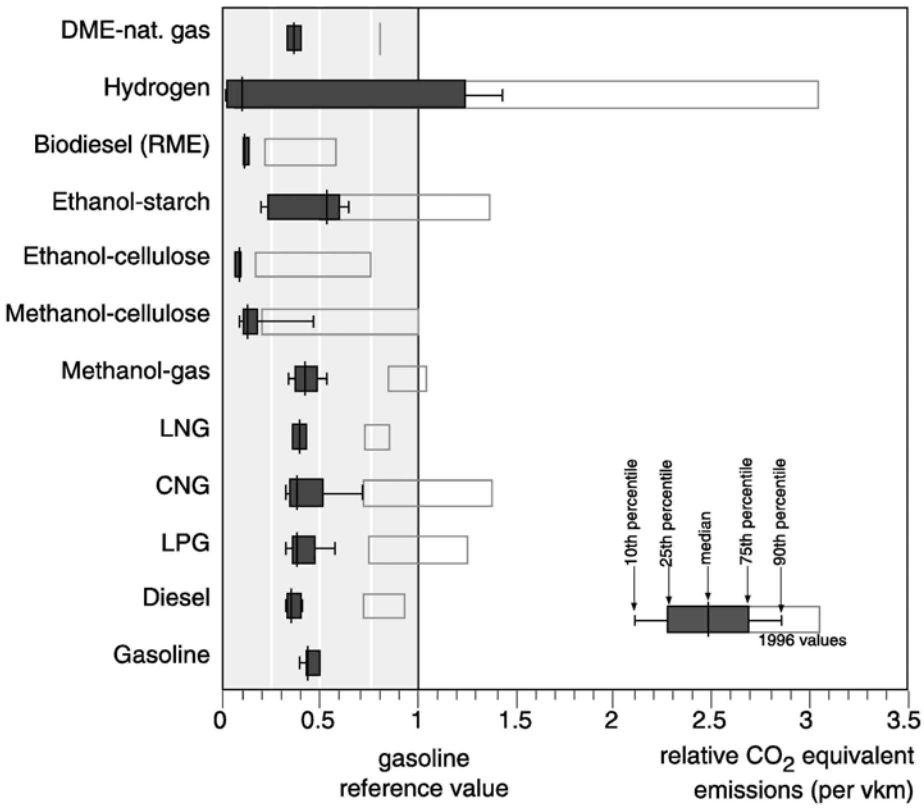


Figure 31, Long-term well-to-wheel GHG emissions of LDVs running on various fuels. Source IEA (2003).

Ranges in data result from local variations between fuel routes and differences in technology, which may occur at all stages of the well-to-wheel fuel chain. The pivots indicate the uncertainty related to the used data. Uncertainties are particularly large for hydrogen. From a comparison of Figures 30-31 it appears that the well-to-wheel emissions of all fuels are expected to be reduced on the long term (unfortunately a time span is not provided by the cited source). This may be the result of improved vehicle efficiencies. Relative to conventional fuels the performance of biofuels is expected to remain about the same.

The substitution of biodiesel for petrol results in a total GHG emission reduction of 45-80%. If replacing fossil diesel fuel, this emission reduction is smaller, because diesel shows lower CO_2-equivalent well-to-wheel emissions than petrol. The range of ethanol-starch is quite broad, which can be partly explained by differences in crop (corn, sugar beet, molasses), and differences in technology. Remarkable is the difference between well-to-wheel GHG emission reductions for ethanol from starch and ethanol from cellulose. This is partly due to the selection of the LCA-boundary. If using (ligno-cellulosic) waste or by-products, the analyst has a choice whether or not to take the energy consumed for producing the waste/by-product into account, whereas in the case of (starch) crops the production phase has to be included within the system boundaries anyway. Biodiesel and bio-ethanol are investigated in more detail in the following section.

6.2.1 Well-to-wheel GHG emissions from bio-ethanol

In Figure 32 the GHG emissions of petrol (premium unleaded petrol), and a number of anhydrous E85 ethanol fuels from molasses, wheat, and wheat starch, wood waste, and from fossil fuels (ethylene) are presented. Ethanol can be produced by means of three general methods; from petroleum and natural gas by hydration of ethylene (C2H4), from biomass via the fermentation of sugar derived from grain starchs or sugar crops, or from biomass via the utilisation of the non-sugar ligno-cellulosic fractions of crops or wastes. The figure shows that of all bio-ethanol types, ethanol made from wood waste results in the largest emission reduction of GHGs, namely 70-80%. Note that there are no carbon emissions allocated to the production of the wood waste resource. For a case of using woody energy crops, where the system boundaries would encompass the wood production activity, therefore higher emission values would be found. Ethanol from sugar crops like wheat, starch and molasses results in a 25-60% emission reduction in compasiron with petrol from fossil origin (premium unleaded petrol, 'PULP'). The case of molasses shows that the selection of the system boundaries has a distinct effect on LCA results.[94]

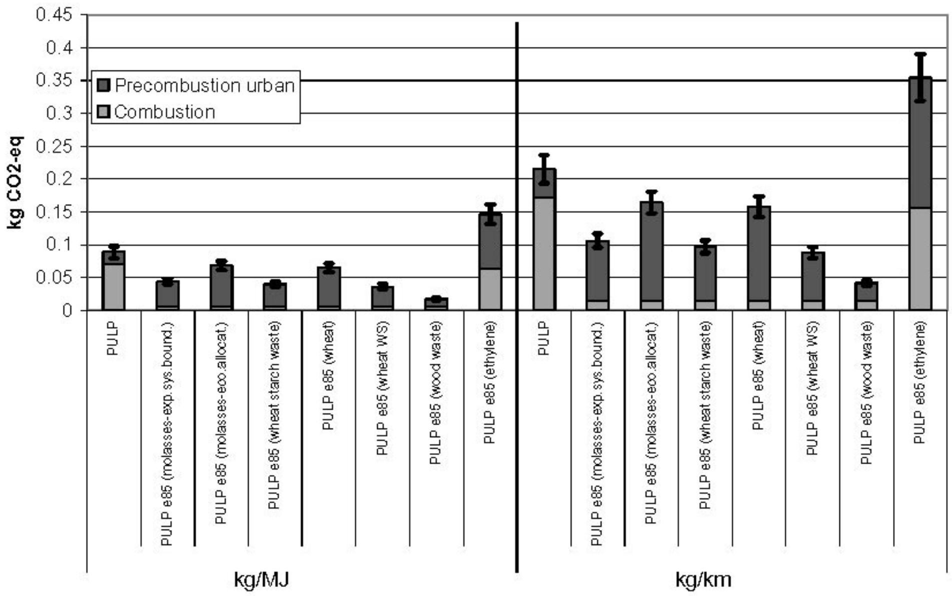


Figure 32, Emissions of GHGs for premium unleaded petrol (PULP) and anhydrous ethanol (E85P) source: Beer, T., Grant, T. et al. (2001).

6.2.2 Well-to-wheel GHG emissions from biodiesel

In Figure 33 the GHG emissions of biodiesel are compared with those of low-sulphur diesel (LSD). Various biomass resources are considered. Rape is the most common energy crop for the production of biodiesel in Europe, and shows a GHG emission reduction of 50%-60%. Other energy crops for biodiesel show similar results, although the best results are obtained from soy beans. Waste oil results in the largest GHG emission reduction since the production phase of the oil is not accounted for in the LCA.

94/ Compare the numbers given for 'PULP d85 (molasses-exp-sys.bound)' and 'PULP d85 (molasses-eco. allocat)'

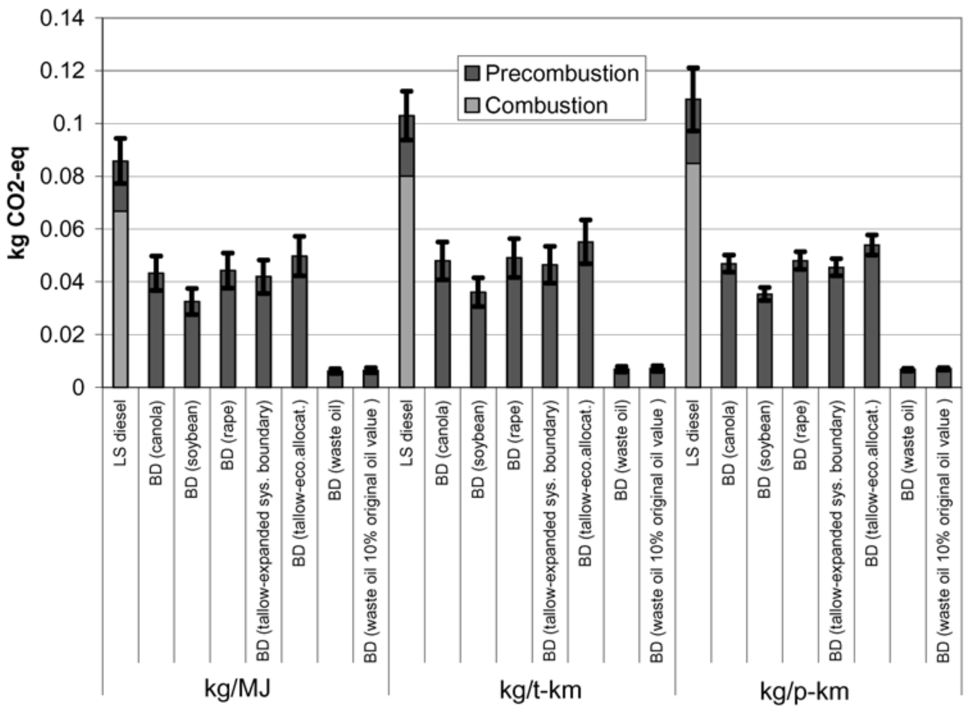


Figure 33, GHG emissions of biodiesel compared with low sulphur diesel (LSD, the reference fuel).The two different data sets for tallow and cooking oil are the result of using two sets of system boundaries. Source: Beer, T., Grant, T. *et al.* (2001).

6.2.3 Generic GHG emission level of biofuels for transport used in this study

For the assessments made by means of SAFIRE the emission factors reviewed in Table 54 were used.

Table 54, GHG savings for selected bio-transport fuels.

	Total GHG emissions (secondary energy basis) /a	Total GHG emissions (primary energy basis)		Total net GHG savings (primary energy basis)
Transport fuels	t CO_2-eq./GJ (on NCV)		Mt CO_2-eq./Mtoe	Mt CO_2-eq./Mtoe
Biodiesel	0.041		1.72	1.93
Bioethanol (sugar beet)	0.040		1.67	1.72
Bioethanol (wheat)	0.029		1.21	2.18
Reference system				
Diesel fuel	0.087	0.087	3.64	-
Petrol	0.081	0.081	3.39	-

a/ Source: Elsayed, Matthews and Mortimer (2003).

7 SCENARIO DEFINITION

SAFIRE simulates investment behaviour within a future that is defined by a set of external parameters. An eventual future defined in such manner is called a scenario. For this study a Base Case Scenario was run, together with a number of variants that were used to analyse the influence of certain parameters.

All scenarios start from the same base year, i.e. the year 2000, and the starting position had to be defined with a large number of parameter values. Much of the base year data used in the analysis has been from pre-existing runs of the SAFIRE model, from studies that have investigated the potential for renewable energy on a national basis across Europe. These key studies covered either or both of the EU15[95] and the Accession States.[96] In several areas of the SAFIRE database, these source numbers have been updated where the data has changed historically (e.g. installed capacities) or where information specific to this project is necessary (e.g. biomass, waste and biofuel resources).

For each sector, the underlying energy data regarding energy demands comes from International Energy Agency (IEA) sectoral statistics.[97] IEA data is used, particularly for the industrial sector, as it is the most similar to the format in SAFIRE. This is particularly important for looking at the biomass CHP potential in this and other sectors. For the domestic, agricultural and commercial sectors, the total electricity and energy demands were compared with IEA figures and where necessary alterations were made to ensure consistency. Following the initial analysis and data entry, the IEA data was cross-checked further, against the numbers in the European Commission publication on energy and transport trends to 2030,[98] which covers all of the EU15 and Accession states. The forecasts for changes in sectoral energy consumption were then applied to the starting point data, using forecasts from energy and transport trends to 2030.

Installed capacities of renewable energy for the 2000 base year were entered from the EuroStat database, together with base year load factors, calculated to ensure both capacity and energy output figures matched. However, for biomass, the EuroStat database is comprehensive, but its aggregated numbers are not sufficiently detailed for SAFIRE use. Therefore, CRES & BTG reviewed and updated the biomass and waste consumption for each type of fuel, which was subsequently entered into SAFIRE. For other technologies, EuroStat data has been used for all countries, with manual updates within the SAFIRE database for installations between 2000 and 2003.

For prices of the conventional fuels part of the SAFIRE database, a number of sources have been used, owing to the range of countries included in the study.[99] IEA and EuroStat have been the primary sources of information, but they have not covered all of

95/ MITRE (2000), ESD (2000), Whiteley (2001), ESD (1996).

96/ Newly Associated States – Renewable Electricity Targets, DG TREN 2002 (4.1030/S/02-002/2002), Whiteley (2001), ESD (1996).

97/ OECD (2003b), OECD (2003a), OECD (2003d), OECD (2003c).

98/ Mantzos, Capros, Kouvaritakis *et al.* (2003).

99/ IEA (2001), Eurostat (2002), Eurostat (2003), National Statistical Agencies (all countries, particularly Bulgaria, Estonia, Latvia, Lithuania, Slovenia), See-Search Campaign for the Same Fuel Prices Across Europe (SFPAE) (http://www.see-search.com/business/fuelandpetrolpriceseurope-december2002.htm).

the countries in Central and Eastern Europe. Therefore, additional sources have been used in order to complete the fossil fuels database. This missing information has come from national statistical agencies, with additional and supporting data also coming from any other sources that provide the required data, which has been produced by other organisations within Europe. Two different sources have been used for energy price forecasts, covering short and long term price effects. As the base year for the SAFIRE calculation in this study is the year 2000, the team has made concerted efforts to reflect real energy price changes since then, based upon a trend between 2000 and 2005. For the longer term forecast after 2005, a single source is used for future fossil fuel prices.[100] The trends are based upon a standard forecast across the whole region as opposed to figures on a country by country basis, but as the majority of these fuels are imported into the region, the team decided that using international trends is the best methodology.

Agricultural land areas for all the EU15 countries have been updated in SAFIRE, using figures provided by CRES and BTG.[101] The typical land availability assumption is based upon current set-aside areas in each Member State. For the Accession States, potential available land area data provided by national government or other relevant organisations. In SAFIRE, of this land availability, a proportion has also been reserved for transport biofuels. However, as biofuels are transportable on a global scale, a high resource has been created in the SAFIRE database for the potential for biofuel imports, particularly from countries already producing biofuels in large quantities, such as Brazil.

Another element that is common to all scenarios investigated, is the set of policies that control the ‘non-tradeable’ biofuels. These policies[102] have a distinct influence on the availability of biomass for energy, particularly for bio-fuels like manure, slaughter house waste, waste from pulp and paper production, and biodegradable municipal waste and sewage sludge. The effects of these policies were analysed and given as input data to the SAFIRE model.

7.1 SCENARIOS USED FOR PARAMETER ANALYSIS

Scenario variation was used to test the effects of changes to the following parameters:

- The value of a ‘sustainability premium’.
- Application or absence of subsidies on investments in emerging biomass energy conversion technologies.
- Failure to succeed in introducing more efficient biomass technologies

They are discussed in the following sections.

100/ Mantzos, Capros, Kouvaritakis *et al.* (2003).

101/ See also the discussion in Section 5.3.5.

102/ Particularly: 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).

7.1.1 The sustainability premium

Methodology

Policies to support renewable energy are many and varied. Their existence is usually justified with a reference to sustainability. Subsidies are available for renewables in many countries, but their exact form varies, often restricted to specific users, technologies, or annual caps on expenditure. Planning and other factors may restrict or slow down development (e.g. for wind farms) while other "non-market" policies such as advice and information, campaigns promoting a technology, research and support for small and medium sized enterprises can have a major impact. Technical or physical factors such as climate and the industrial mix affect certain technologies - costs and emission issues differ greatly for use of industrial wastes from paper, food and chemical industries for instance. Many other factors may affect uptake in one country rather than another, which may include: traditions and public attitudes; level of centralisation of planning/energy systems; legislation on matters such as third party grid access; existence of infrastructure for district heating or combined heat and power schemes; how established a technology is already; and the general level of bureaucracy or government attitude. Policies in the future may vary according to whether targets have been reached, or desired cost reductions and/or technological advances achieved.

It was not the objective of this study to analyse the effects of the existing wide gamut of policies that support the implementation of renewable energy. Rather the main purpose was to analyse the role of bio-energy, given the absence or presence (and to what extent?) of generic supportive policies. Therefore, the team decided to focus on a clear and simple set of scenarios, thus eliminating the confusion of an aggregated effect of the various distinct policies towards renewable energy. Consequently, the intricacies of the policies in the individual countries included in this study have been overturned in order to create this straightforward analysis. Note that supportive policies were not eliminated per se, rather they were replaced by single measures, that are uniform across the countries investigated.

We expressed sustainability in terms of 't CO_2-eq. emission', although there is more 'sustainability' to biofuels than avoided CO_2 emissions alone. According to 'Energy for the future', the objectives of increased use of biofuels include:[103]

- Environmental protection.
- Reducing dependency on energy imports and increasing security of supply (Renewable energy sources are indigenous)
- Job creation, predominantly among the small and medium sized enterprises which are so central to the Community economic fabric.
- Regional development with the aim of achieving greater social and economic cohesion within the Community.
- Creation of business opportunities for European Union industries (in many third countries, in Asia, Latin America and Africa).

103/ EU (1997), p. 4.

A difficulty here is how these notions can be translated in a measurable unit, suitable for quantitative analysis. Not all of these issues are quantified in a generally accepted manner (e.g. in terms of €/energy unit). An exception is the reduction of GHG emissions, which is generally recognised as a key environmental value. It is also measurable, and a market is emerging. We selected this parameter as the single indicator for the entire set of additional values listed above. Therefore we should use somewhat higher values than can be found in the markets for GHG emission reductions. At the same time, one should be aware of the fact that even one would know the value of avoided GHG emissions, one still does not know how much more we should add to that value in order to represent the total value of ‘sustainability’.

In the SAFIRE model this approach was uniformly implemented for all renewables (including solar, hydro, etc.), by removing all taxes and subsidies related to the sustainability of energy systems, pre-programmed in SAFIRE, and by applying a uniform add-on to consumer electricity and heat prices, that is equivalent to the avoided GHG emissions. This resulted in higher prices for non-sustainable forms of energy, and consequently to an end-user preference for the sustainable alternatives.

Before selecting meaningful values for sustainability premiums, we investigate the market for avoided or reduced GHG emissions.

Prices of carbon credits

The international climate policies, related to GHG emissions, officially started with the United Nations framework Convention on Climate Change (UNFCCC)[104] of 1992, and the Kyoto Protocol (1994) (abbreviated here to KP)[105] and were further developed in the Marrakech Accords (2001). The EU is party to these international treaties, and, as a result, has certain obligations.

The KP created a market value for a particular type of sustainability, i.e. climatic stability. The market for prevented GHG emissions is not the first market for environmental issues, for example, in several states of the USA nitrous and sulphur oxide emissions are kept under control by means of an emissions trade system. A distinct phenomenon of the KP, however, is its international character, as it recognises several international market options through which its signatories can fulfil their obligations: the transfer of assigned emission amounts (AAs), the Clean Development Mechanism (CDM) and Joint Implementation (JI). With these options, the KP allows its signatories to not only seek GHG emission reductions within their own countries, but also to buy such reductions from other countries. In comparison with an obligation to effectuate GHG emission reductions within each committed country separately, the expected results are that the overall cost of globally achieving stabilised GHG emissions levels will be lower and will harmonise within a smaller range.

104/ UNFCCC (1992).
105/ UNFCCC (1997).

The parties to the KP agreed to ensure, *"individually or jointly"*, *"that their aggregate greenhouse gases emissions do not exceed their assigned amounts"*, determined *"with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012."*[106] Annex 1 to the UNFCCC lists those parties to the KP who will bear an emission obligation, once the KP is effective. Note that not all Annex 1 parties will be obliged to reduce their emissions (assuming that the KP will actually become effective), because there exist parties that do not need their assigned amounts (AAs) for their own economy. Examples of such parties are mainly the countries in the area of the former Soviet Union and Eastern Europe. On the basis of this obligation of the KP, therefore, parties that do have an emission reduction obligation can arrange for this in basically two manners (see Figure 34):

- By acquiring assigned amounts from other Annex 1 parties (sold as Assigned Amount Units, AAUs)
- By physically reducing reducing GHG emissions.

The latter, in turn, can be realised in two ways, and this is the result of the other recognised implementation modalities of the KP:

- Domestically, within the boundaries of the party
- Abroad, outside the party's country boundaries.

And for the latter there exist, again, two methods:

- Joint Implementation (in collaboration with other Annex 1 parties)
- The Clean Development Mechanism (in collaboration with developing countries - that are not listed in Annex 1 to the UNFCCC).

For the sake of argument we refer to these GHG emission reduction performances by the term carbon credits. We are interested here in estimates of future carbon credit prices.

106/ UNFCCC (1997), Article 3.

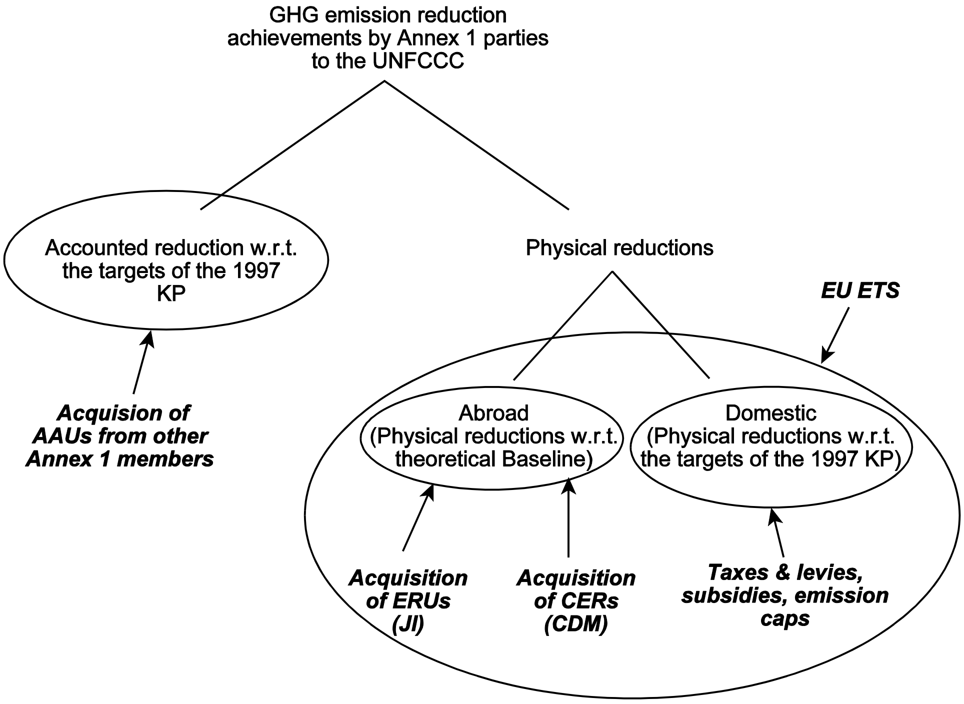


Figure 34, The various types of GHG emission reduction performances, and the manners (in italic script) in which Annex 1 countries can manage their obligations.

One of the manners in which the EU attempts to comply is by its Emission Trading Scheme (ETS) dedicated to the trade in GHG emission allowances, layed down in Directive 2003/87/EC.[107] However, the EC does more, as ETS is linked to CDM (CERs) and JI (ERUs). By means of the EU's emission trade scheme (ETS), made effective with Directive 2003/87/EC, the initiative is placed strongly at the level of selected industries from the private and public sector (energy activities, production and processing of ferrous metals, mineral industry, pulp & paper). In the ETS, those firms are given a GHG emission allowance, and to a large extent they are free to handle their emissions by trade in allowances, trade in ERUs and CERs, and actual reductions of their emission resulting from their own production activities.

If the KP is ultimately implemented, and/or even further developed, then there will develop a sort of a single market for all the above mentioned carbon credits. However, it should be noted that there will remain a strict division between the markets of AAUs and the other type of carbon credits, since AAUs can only be traded between governments (according to Article 17 of the KP), whereas the traders of ERUs, CERs and other domestic carbon credits are firms acting under the market regulations of the individual countries. As, for the time being, the European ETS is limited to selected types of industries, part of the latter group of carbon credits are also part of the European ETS. Since transaction costs may differ systematically among the two types of markets covering AAUs and other carbon credits, prices may remain different. There are several other

107/ EU (2003c).

reasons why prices of AAUs are likely to settle at levels that differ from the other market component of ERUs, CERs and domestic carbon credits. Jepma (2003) reviews them as follows:

- Costs of AAUs are opportunity costs reflecting the risk of selling amounts that at the moment of settlement (2008-1012) might turn out not to be available from the economy of the selling country.
- Transactions costs are different (ERUs, CERs and domestic carbon credits need measurement, and monitoring)
- Especially ERUs and domestic carbon credits can be traded between firms, without much government intervention.
- The market volume of ERUs, CERs and domestic carbon credits is dependent on private supply initiatives, and a wide range of demand initiators.

The range of available estimates of carbon credit prices is quite broad. In the late 1990s, the actually prevailing value applicable for Dutch domestically produced GHG-neutral electricity could be calculated at 65 €/t CO_2-eq.[108] The Dutch JI tender for the year 2000 resulted in an average ERU value of 8.75 €/t CO_2-eq.[109] Other indications of current carbon credit values are reviewed in Table 55.

Table 55, Prices of Carbon Credits in various emission trade systems.

Type	Year	US$/t CO_2-eq.
VERs (verified emission reductions; without government approval)		
Annex B VERs	1991-2007	0.60 - 1.51
Annex B VERs	2008-2012	1.66 - 3.02
CDM VERs	2000-2001	1.77 - 3.02
Compliance Tools (government approval)		
Dutch ERUs	2008-2012	4.44 - 8.07
Danish Allowances — Mid-market bid offer	2001-2003	3.81
European ERUs — Indicative Bids	2008-2012	7.06 - 12.1
Australian Early Action AAUs — Indicative Offer	2008-2012	6.05 - 12.1
UK permits — Mid market bid-offer	2003	8.53
BP international Allowances — Pilot Phase	1999	10.08 - 25.07
BP international Allowances — Full-scale internal trading	2000-2001	0.50 - 25.20

Source: Jepma, C.J. (2003), citing Maggiora, C. della, (2002) Climate Change in Latin America and the Caribbean, April.

In fact, however, we are interested in carbon credit values during the next two decades. The analyst who assumes that society is perfectly rational and fully informed would base a value estimate on an economic analysis of the global climate change issue. Initial attempts at such an evaluation were made in the early 1990s, and these were further integrated by the IPCC in its Second Assessment Report of 1995.[110] With the Kyoto Protocol (1997), the international emissions reduction market has taken off, and the implications of the Protocol, together with the uncertainties around its implementation, actually make an objective scientific assessment less meaningful in the short term. Among

108/ Siemons (2002a).

109/ http://www.senter.nl.

110/ Pearce, Cline, Achanta et al. (1995).

the uncertainties one should consider is the eventual future participation of the USA, and the pool of participants in an emission reduction market. How the carbon credits market will develop after 2010 is a matter of speculation, but it is not unreasonable to construct a scenario on the basis of the current perspectives of the Kyoto Protocol, the assumption being that either there will be no carbon credit market after the end of the current term of the Kyoto Protocol, or there will be a market resembling the current one. Some 20 recent studies on the future carbon credit market were reviewed for UNCTAD by Morozova and Stuart (2001). The target year for which demand and supply curves were determined was 2010. Carbon credit values reported varied between 26-77 1998 US$ (Table 56). The wide range is a result of the uncertainties attached to the Protocol.

Table 56, Average value of carbon credits by 2010 (1998 US$/t CO_2-eq.) (Source: Morozova, S. and Stuart, M. (2001)).

Domestic abatement	Annex 1 JI and trade	CDM	Permit based global trade
77	37	30	26

Jepma (2003) summarises today's trends as follows:

- The implementation of the KP had to face the withdrawal of the USA. This results in strongly reduced demand for AAUs from C&E Europe and the former Soviet Union. Conceivable that a post Kyoto policy will be developed for implementation after 2012. Also in collaboration with the USA.
- Whether the Russian Federation will participate is still surrounded by uncertainties. Russian ratification is necessary though, for the KP and the associated carbon credit market to become truly effective, other than a voluntary exercise.
- Average current prices are around 5 €/t CO_2-eq.
- Prices of futures in the ETS are around 10 €/t CO_2-eq.
- The availability of AAUs (that are on the market without production costs, but to which the risk of a prosperous economic development is attached) is considerable.

And he concludes prudently to 2010 carbon credit prices at levels of 5-10 €/t CO_2-eq. For the sustainability premium, we select the values reported in Table 57.

Table 57, Scenarios for the sustainability premium.

	2010	2020
0-value sustainability premium scenario	0 €/t CO_2-eq.	0 €/t CO_2-eq.
Low-value sustainability premium scenario	25 €/t CO_2-eq.	50 €/t CO_2-eq.
High -value sustainability premium scenario	50 €/t CO_2-eq.	100 €/t CO_2-eq.

7.1.2 Technology development related scenarios

Also the effect of capital subsidies intended to stimulate certain technology developments, and of the eventual failure of introducing the biomass-fuelled GCC technology were investigated by scenario analysis.

The rationale and effect of capital subsidies

Capital subventions are often justified with a view to 'learning'. In the context of energy conversion technology, learning describes the observation that capital costs for new energy conversion plants decrease with the aggregate capacity installed previously. The extent to which this decrease takes place is called the 'progress ratio'. Relevant research into the learning of energy technologies was published by Grübler, Nakicenovic and Victor (1999). The theoretical and experimental background to technology learning and the progress ratio are not further elaborated here, and the reader is referred to Wene (2000) who provided an accessible review of the principles. For the innovative biomass-fuelled energy conversion technologies considered in this study there is no experimental evidence to justify a particular progress ratio. In such situations, often an average standard progress ratio of 0.82 is assumed. This means that doubling of the aggregate installed capacity over time would result in an investment level of 82% (of the original investment) for a next new and similarly sized plant. The reverse of the economic reality of learning is that certain technology developments that are socially, environmentally or economically desired may not be able to take the hurdle of market introduction, and that society gets locked into specific technologies and their off-springs that are less desirable. Capital subsidies would be able to remove this barrier, and then alternative technology developments could take their course, until learning had achieved sufficient cost reductions for the subsidy to be removed.

Providing government subsidies and the effect of learning can be modelled, but the associated type of feedback loops are not supported by the SAFIRE model. For testing the role of subsidies and learning we simplified the above described mechanism, by distinguishing two scenarios. One with capital subvention for certain type of power plants, and one without. This was particularly investigated for highly-efficient large-scale (typically 100 MW_e) stand-alone biomass-fuelled power technologies during their introduction into the market. The learning potential of this technology was analysed in Chapter 4. In accordance with the data produced in that chapter, the scenarios are defined as given in Table 58.

Table 58, Technology cost related scenarios.

Scenarios for electricity only plant (typically 100 MWe): Specific investment (€/kWe); NCV efficiency (%)	2000		2010		2020	
Base Case Technology scenario						
Solid clean fuels - all sectors	1628	34%	1628	34%	1628	34%
	CS		CS		CS	
Solid dirty fuels - all sectors	2556	18%	2556	18%	2556	18%
	CS		CS		CS	
Liquid dirty fuels (biogas) - all sectors	3250	25%	3250	25%	3250	25%
Bio-oil	1628	34%	1628	34%	1628	34%
	CS		CS		CS	
Non-Subsidised Innovative Technology scenario						
Solid clean fuels - all sectors	1628	34%	2491	44%	1343	44%
	CS		Introduction of GCC			
Solid dirty fuels - all sectors	2556	18%	2556	18%	1343	27%
	CS		Continued use of CS		Introduction of GCC	
Liquid dirty fuels (biogas) - all sectors	3250	25%	3250	38%	2680	38%
Bio-oil	1628	34%	927	52%	927	52%
	CS		Introduction of CC			
Subsidised Innovative Technology scenario						
Solid clean fuels - all sectors	1628	34%	1343	44%	1343	44%
	CS		Introduction of GCC			
Solid dirty fuels - all sectors	2556	18%	2108	27%	2108	27%
	CS		Introduction of GCC			
Liquid dirty fuels (biogas) - all sectors	3250	25%	3250	38%	2680	38%
Bio-oil	1628	34%	927	52%	927	52%
	CS		Introduction of CC			

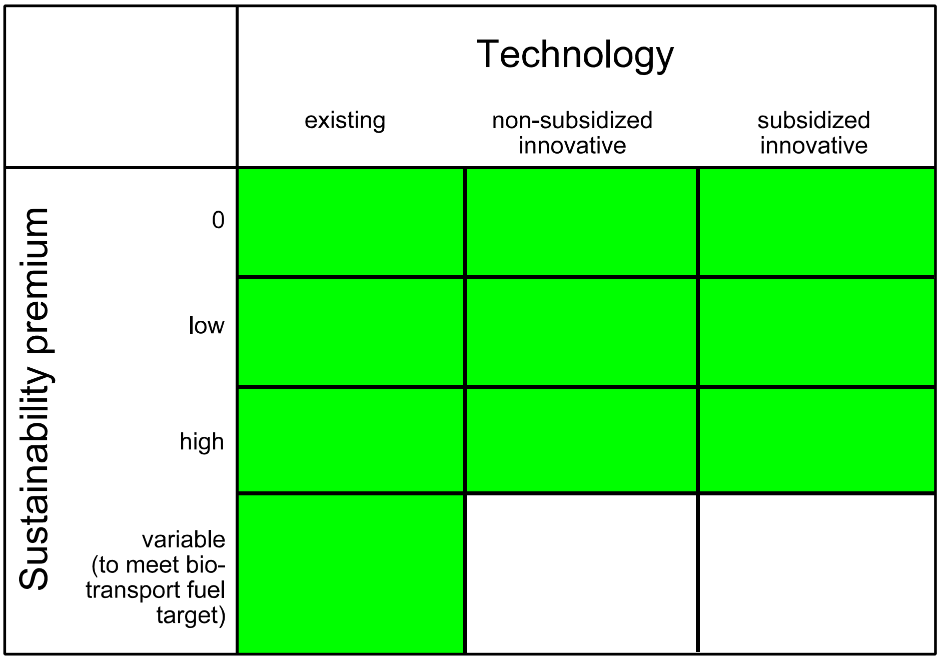
CC: Combined cycle technology (bio-oil fired in gas turbine, coupled to a steam a cycle)
CS: Combustion furnace coupled to steam cycle
GCC: Gasifier coupled to CC.

Failure of developing and introducing two innovative technologies: the biomass-fuelled GCC, and the bio-oil fuelled CC technology

In view of the difficulties faced by the large-scale biomass gasification R&TD projects, also a scenario was tested in which the associated biomass-fuelled GCC technology is not successfully introduced. The according scenario definition is also reported in Table 58.

8 MODELLING RESULTS

The interpretation methodology is explained in the matrix below. The subsequent sections of this chapter follow the technology route: existing technology, non-subsidised innovative and subsidised innovative. Within each of those technology scenarios, the scenarios of sustainability premiums (further called 'S-premium') are discussed.



Before starting the description of the modelling results, one should be made aware of some constraints to the scenario developments created by SAFIRE. The model simulates economic decision making within a changing context. In the starting year (2000) this context is the existing situation of actually installed power capacities and actual fuel consumption. The 2000 situation is also characterised by a number of existing capital subsidies, and other market realities of CO_2 taxes, tax exemptions, and other measures to stimulate bioenergy and other renewables. Removing all those economic support mechanisms (as is done in the zero sustainability premium scenario), creates a sudden rupture, under the conditions of which many bioenergy projects would be halted in the real world. This is particularly so in the case of tradeable biomass, which - unlike wind, hydro and solar energy - is characterised by considerable operating costs (i.e. the biomass fuel costs). Hence a situation may occur that operating costs exceed revenues. As soon as economic support mechanisms that affect running cash flows are being removed, biomass energy loses part of its attractiveness. And there may arrive an economic condition that the operation of a biomass-fuelled plant is halted. This type of behaviour is not modelled in SAFIRE, and the model assumes that the capacity that had been installed by 2000 will not cease to be operational in 2010 and 2020. The precise interpretation of the Zero Sustainability Premium Scenario, therefore, is that no sustainability premium is available for new bio-energy capacity, but for existing capacity this premium is maintained.

8.1 TECHNOLOGY BASE CASE: EXISTING TECHNOLOGIES

8.1.1 The EU15

In brief, the following occasions are observed:

No sustainability premium

- Prices of tradeables remain modest, at levels of 3.2-3.7 €/GJ.
- There is a slow growth of bioenergy from 41 to 75 Mtoe/yr (2000-2020). Note that 'Energy for the future'[111] foresees a biofuel consumption of 135 Mtoe/yr for 2010.
- Most growth is in tradeable biofuels (14 out of 15 Mtoe/yr over 2000-2010)
- Bio-transport fuels take a small proportion (2.5-3 Mtoe/yr). And the targets of the transport fuel directive[112] are not met.
- There is a large growth in the use of solid agricultural residues.
- There is a considerable growth forestry by-products and refined wood fuels.
- Solid energy crops and energy crops for bio-transport fuels have only a small role.
- International trade in biofuels is at a low level.

Low sustainability premium

- The price of tradeables is considerably higher, at levels of 3.7-4.9 €/GJ.
- There is a large growth of bioenergy from 41 to 67 and 123 Mtoe/yr (2000-2010-2020). This is still much less though than foreseen in 'Energy for the future' (135 Mtoe in 2010).
- Most growth is in tradeable biofuels (68 out of 82 Mtoe/yr over 2000-2020)
- Bio-transport fuels take small proportion in 2020 (6 Mtoe/yr). And the targets of the bio-transport fuel directive are not met.
- There is a large growth in the use of solid agricultural residues.
- There is considerable growth in forestry by-products and refined wood fuels.
- Biofuel imports into the EU takes off.
- The scenario shows a small role of solid energy crops, and of energy crops for bio-transport fuels.

High S-premium

The growth in bioenergy is now from 41 to 84 and 176 Mtoe in 2000-2010-2020. This is still too low in comparison with the expectations of 'Energy for the future'.

111/ EU (1997).

112/ EU (2003b)

Table 59, EU15; Technology Base Case: Biofuel consumption (primary energy, Mtoe/yr).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	26	34	45	42	78	51	114
Bio Electr. (tradeable, co-combustion)	-	4.7	13	7.8	16	11	24
Bio Electr. & Heat (non-tradeable)	14	14	15	15	23	18	28
Bio Transport Fuels	0.7	2.4	3.2	2.6	6.1	2.9	11
Total bio-energy	41	56	75	67	123	84	176
Other renewables	34	45	49	50	66	56	77
Total renewables	75	101	124	117	189	140	253
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	16	19	25	21	32	24	35
Solid agricultural residues	1.3	9.5	14	12	24	16	24
Solid industrial residues	7.9	10	13	12	15	14	15
Solid energy crops	0.1	0.3	3.1	2.1	9.0	5.5	16
Imported biomass	0.0	0.2	2.6	1.4	13	3.1	46
Non-tradeables:							
Wet manure	0.1	0.1	0.3	0.2	1.0	0.4	2.6
Organic waste /b	12	12	12	13	19	15	21
Sewage gas	0.8	0.8	0.9	0.9	1.0	0.9	1.2
Landfill gas	1.1	1.3	1.3	1.4	2.2	2.0	3.1
Transport fuels:							
Bio-ethanol	0.1	1.3	1.6	1.3	4.0	1.7	8.3
Biodiesel	0.6	1.1	1.6	1.2	2.1	1.3	2.8
Total bio-energy	41	56	75	67	123	84	176
a/ At an average equilibrium price of (E/GJ):		3.2	3.7	3.7	4.9	4.0	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Table 60, EU15; Technology Base Case: Biofuel Capacity of heat and electricity production (secondary energy, GW).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	99	142	187	137	169	185	357
Bio Electr. (tradeable, co-combustion)	0	3.2	8.5	5.3	11	7.5	16
Bio Electr. & Heat (non-tradeable)	23	23	23	24	31	26	40
Bio Transport Fuels							
Total bio-energy	121	168	219	166	211	219	412
Other renewables	114	160	190	184	264	208	342
Total renewables	235	327	409	350	475	427	755

In Figure 36 the use of biomass according to the low- and high-S-premium scenario's in 2010 are compared with the availability of biomass in Europe. Wood fuels, forestry byproducts, solid industrial residues and agricultural residues are utilised to a large degree. In the high-S-premium scenario, energy crops are getting relevant too. Note that the role of agricultural residues is quite large, because these residues are available in substantial quantities at relatively low prices. This result can only emerge on the condition that technical difficulties like corrosion and deposit formation due to alkalines and chlorine that are present in agricultural residues, are effectively dealt with, and that prices for logistics and storage remain as low as indicated by the various literature resources. If these conditions are not met, the role of agricultural residues will be limited, and other types of biomass could be obtained from solid energy crops and imports, however, at higher price levels.

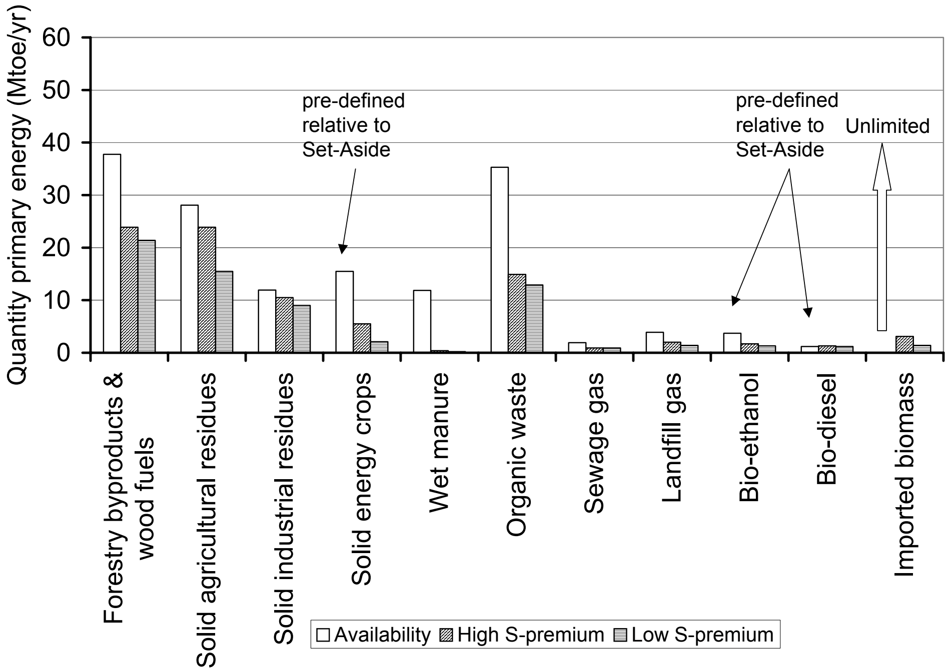


Figure 36, Availability and use of biomass in the EU15 in the Technology Base Case, in 2010.

The tangible energy that is available in wet manure is marginally utilised, because anaerobic digestion of wet manure is applied at a relatively small farm-scale, which is expensive compared to large-scale biomass applications. The category of organic waste includes biodegradable municipal waste (16.5 Mtoe), demolition wood (5.8 Mtoe), black liquor (10.9 Mtoe) and dry manure (2 Mtoe). All black liquor is utilised, making it the major source of the organic waste category. Disregarding black liquor, large proportions of biodegradable waste and demolition wood are not utilised in 2010. Note that in the period 2000-2010 the availability of biodegradable municipal waste will grow by 10 Mtoe on an annual basis, as the Landfill Directive (1999/31/EC) largely blocks the landfilling of biodegradable waste. The sewage gas and landfill gas resources are utilised intensively, but form a small share of the total non-tradable biomass resource.

In Figure 36, the availability of land for solid and liquid energy crops is limited to the set aside-area. This is not a real constraint, and merely indicated to give an impression of the role of energy crops in relation to the amount of arable land. The maximum availability of solid energy crops indicated, is proportional to 50% of the set-aside land. That of bio-ethanol and biodiesel is set at 25% of set-aside each. In the high-S-premium scenario about 40% of the total set aside area is used for solid and liquid energy crops. Solid energy crops occupy 7% of the set aside land, and generate 2.1 Mtoe primary energy per year. About 33% of the set aside area in the EU15 is used to produce 2.5 Mtoe transport fuels. Clearly, solid energy crops generate about four times more primary energy than the usual crops for bio-transport fuels. Under these scenarios, the objectives of the Transport Directive (2003/30/EC) are not met. This directive states that, by 2010, the proportion of biofuels and renewable fuels should reach a level of 5.75% of all petrol and diesel transport fuels (on an energy basis), and this corresponds to 17 Mtoe. The sustainability premiums of the high-S-premium scenario are not even sufficient to meet this target by 2020. Sustainability premiums for meeting the agreed targets of bio-transportation fuels are further analysed in Section 8.3.

For the same Technology Base Case, Figure 37 shows the development of availability and use of biomass in the EU15 by 2020. The available quantities of forestry byproducts & wood fuels, agricultural residues and solid industrial residues are now almost optimally utilised. In this situation, the quantities of indigenous tradable residues are not sufficient to meet the European demand for bio-energy. Higher prices are paid for biomass, making it attractive to produce solid energy crops and import of biomass. Especially in the high S-premium scenario a quite substantial quantity of 47 Mtoe of biomass is imported into the EU15. All across Europe, the supply costs of imported biomass are estimated at about 6 €/GJ. The supply costs of energy crops are estimated to vary between 4.2 €/GJ (Sweden) and 8 €/GJ (Netherlands). In countries with high supply costs of energy crops, like the Netherlands, Belgium, Italy, Portugal, the demand for biomass energy will mainly be met by biomass imports.

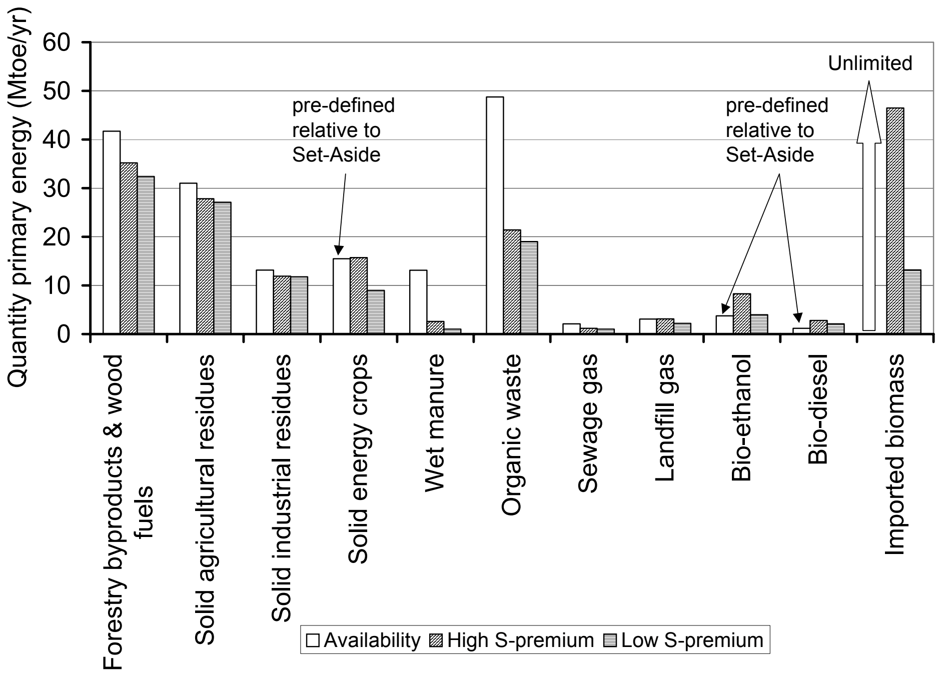


Figure 37, Availability and use of biomass in the EU15 in the Technology Base Case, in 2020.

Between 2010 and 2020 the availability of organic waste grows by 13.5 Mtoe/yr to a quantity of 48.8 Mtoe/yr. This is mainly due to the increased availability of biodegradable municipal waste (BMW) as a result of the Landfill Directive. See Figure 38. Note that the quantity of black liquor remains constant. 70% of this resource is available in Sweden, Finland and France.

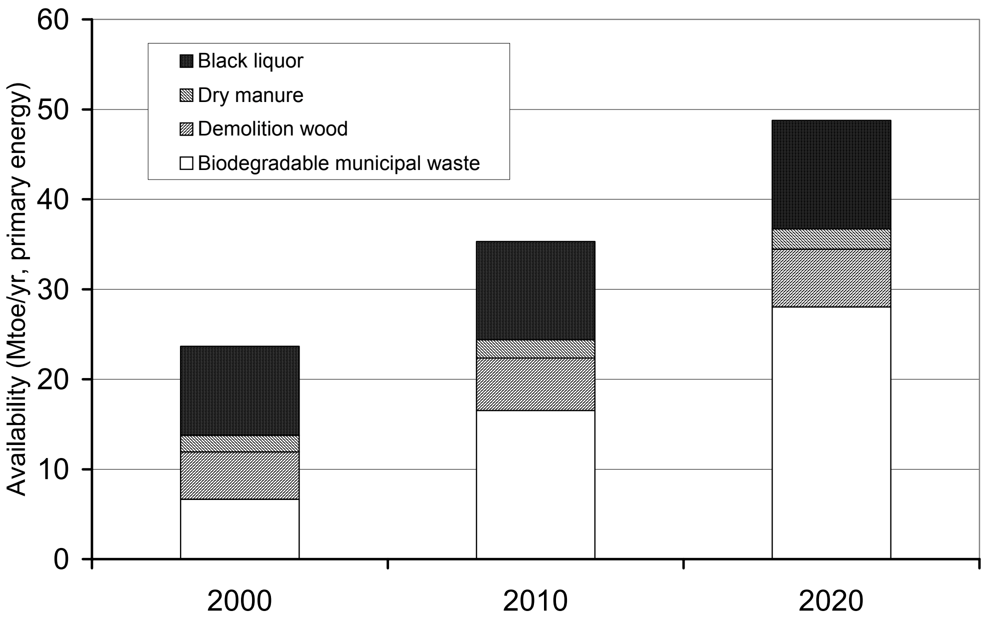


Figure 38, The increasing availability of biodegradable waste in the EU15.

By 2020, only a small fraction of the BMW (25% of the 1995 quantity) is allowed to be landfilled, and thus most BMW is redirected to other ways of processing, mainly incineration with or without energy recovery. Under the low-S-premium scenario, the use of organic waste grows from 12.9 to 19.0 Mtoe/yr, under the high-S-premium scenario from 14.9 to 21.4 Mtoe/yr. Even in the high-S-premium scenario, 27 Mtoe/yr of organic waste remains unused.

The use of energy crops for bio-transport fuels grows considerably, and exceeds the imaginary boundaries indicated in the chart (Figure 37), i.e. the land required occupies more than 50% of the set-aside area.

8.1.2 The EU+10+2

In brief, the observations are as follows:

No sustainability premium

- Prices of tradeables remain modest, at levels of 2.1-4.1 €/GJ.
- There is an increase of bioenergy from 8.8 to 23.8 Mtoe/yr (2000-2020), which is relatively a much larger increase compared to that of the EU15 (170% versus 85%).
- Growth is mainly in tradeable biofuels (12.1 out of 15 Mtoe/yr over 2000-2010).
- Compared to the EU15 the growth in the non tradeables is considerable.
- The role of bio-transport fuels is modest (2.1 Mtoe/yr in 2020).

- There is a strong growth in the use of solid agricultural residues of 6 Mtoe/yr (2000 - 2020).
- The use of forestry by-products and refined wood fuels increases slightly.
- The role of solid energy crops, and of energy crops for bio-transport fuels remains small.
- The are no biofuel imports in 2010, but in 2020 import into some EU+10+2 countries takes off.

Low sustainability premium

- The price of tradeables is considerably higher, at levels of 2.9-5.4 €/GJ.
- Bio-energy consumption increases to 19 and 35 Mtoe/yr in 2010 and 2020, which is 35% tot 47% higher compared to the scenario without S-premium.
- Tradeable biofuels profit most from the sustainability remium (a growth of 9 Mtoe/yr by 2020 compared to the situation without sustainability premium)
- There is also a considerable increase in the use of non-tradebles due to the sustainability premium (4.5 Mtoe/yr in 2020 versus 2.6 Mtoe/yr without premium)
- The role of bio-transport fuels is still modest (2.4 Mtoe/yr in 2020).
- Also the role of solid energy crops remains small.
- Imports of biomass fuels are further increased in 2020.

High sustainability premium

The growth within the high sustainability premium scenario (compared with low premium scenario) is predominantly caused by strong increase of imports. The share of imported biomass raises to 45% of total used tradeable biomass.

Table 61, EU+10+2: Technology Base Case: Biofuel consumption (primary energy, Mtoe/yr).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	7	10	15	12	22	15	32
Bio Electr. (tradeable, co-combustion)	-	1.7	4.4	2.8	5.5	3.9	8.3
Bio Electr. & Heat (non-tradeable)	1.1	1.3	2.6	2.3	4.5	2.7	5.5
Bio Transport Fuels	0.8	1.0	2.1	1.2	2.4	1.2	2.5
Total bio-energy	8.8	14	24	19	35	23	48
Other renewables	3.2	5.6	6.9	5.9	8.8	6.3	10
Total renewables	12	20	31	25	44	29	59
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	5.9	5.3	6.9	6.8	8.6	7.8	8.6
Solid agricultural residues	0	4.9	6.0	6.4	8.0	7.2	8
Solid industrial residues	1	1.3	2.0	1.5	2.2	1.7	2.2
Solid energy crops	0	0.0	0.7	0.4	2.5	0.8	3.4
Imported biomass	0	0.0	3.5	0.2	6.5	1.8	18
Non-tradeables:							
Wet manure	0	0.2	0.4	0.3	1.2	0.4	2
Organic waste /b	1	1.0	2.0	1.8	2.9	2.0	3
Sewage gas	0	0.0	0.0	0.0	0.1	0.1	0.2
Landfill gas	0	0.0	0.1	0.2	0.3	0.3	0.4
Transport fuels:							
Bioethanol	0.7	0.9	1.4	1.0	1.6	1.0	1.6
Biodiesel	0.1	0.1	0.7	0.2	0.9	0.2	0.9
Total bio-energy	8.8	14	24	19	35	23	48
a/ At an average equilibrium price of (E/GJ):		2.1	4.1	2.9	5.4	4	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Table 62, EU+10+2: Technology Base Case: Biofuel Capacity of heat and electricity production (secondary energy, GW).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	22	28	34	27	31	34	69
Bio Electr. (tradeable, co-combustion)	0	1.1	3.0	1.9	3.8	2.6	5.6
Bio Electr. & Heat (non-tradeable)	2.8	3.3	4.3	3.7	5.4	4.0	6.9
Bio Transport Fuels							
Total bio-energy	25	32	41	33	41	41	81
Other renewables	16	25	30	25	35	26	46
Total renewables	41	57	71	58	76	67	127

Figure 39 shows the 2010 availability and use of biomass in the EU+10+2 under the Technology Base Case. In 2010 32.6 Mtoe of bio-energy is available on a yearly basis, which is 18% of the European total. According to the low-S-premium scenario, 18.7 Mtoe of biomass is consumed in 2010 (22% of European biomass consumption in 2010).

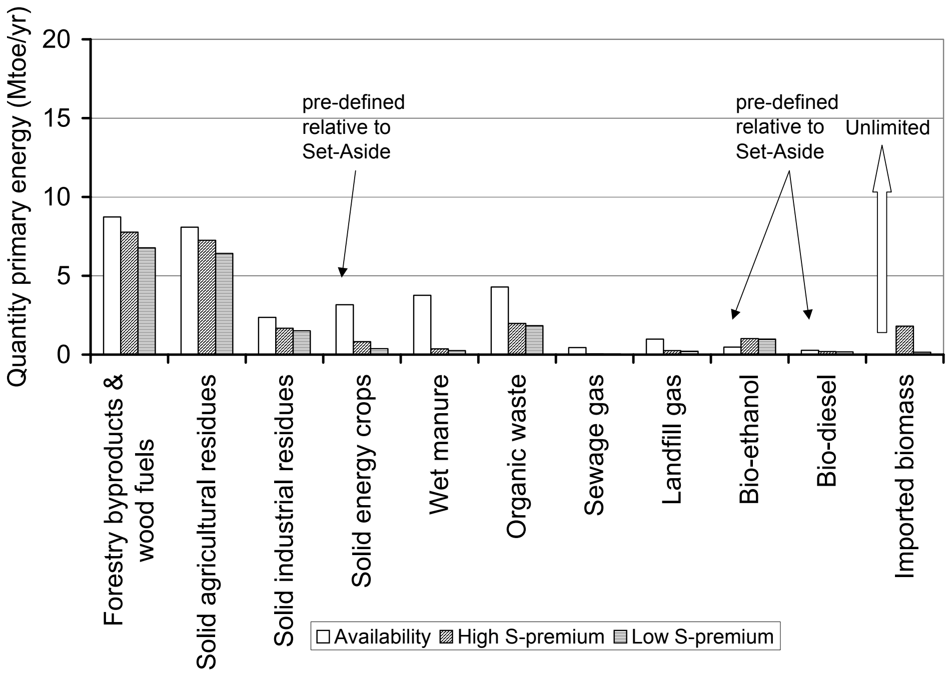


Figure 39, Availability and use of biomass in the EU+10+2 in the Technology Base Case, in 2010.

The consumption of biomass shows a pattern that is similar to that of the EU15:

- A high utilisation of tradable forestry byproducts & woodfuels and residues.
- A relatively high share of agricultural residues, keeping in mind that some uncertainty exists about the price level and technological feasibility.
- Energy crops and imports are at a relatively low level.
- A low utilisation of wet manure, since being a relatively expensive technology at the small scale of application.
- The consumption of organic waste includes a large share (0.8-0.9 Mtoe) of black liquor.
- Sewage gas and landfill gas play a minor role.
- Bio-ethanol has a rather large share, mainly by the development of a market for bio-ethanol in Poland, and to a lesser degree the Czech republic.

Figure 40 shows the development of the consumption of primary bio-energy in the EU+10+2 by 2020. The most striking number is the import of biomass (18 Mtoe/yr) under the high-S-premium scenario. Imports are particularly large in Poland (6 Mtoe/yr) and the Czech Republic (4.7 Mtoe/yr). The accession countries show generally a lower price level than the EU15, and the uniform S-premium of 100 €/t CO_2-eq. has a strong effect on the demand for renewable energy. However, in view of the fact that the accession countries emit less GHGs than the ceilings as agreed in the Kyoto Protocol, it is highly questionable whether such high S-premiums are realistic.

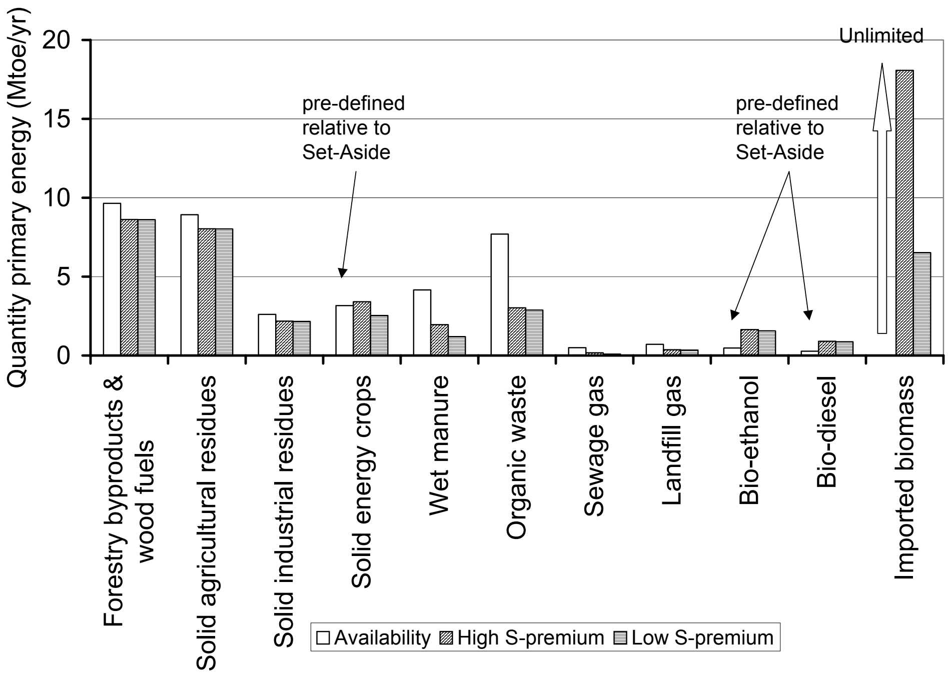


Figure 40, Availability and use of biomass in the EU+10+2 in the Technology Base Case, in 2020.

8.2 NON-SUBSIDISED AND SUBSIDISED INNOVATIVE TECHNOLOGIES

8.2.1 Non-subsidised technologies in the EU15

Compared to the Technology Base Case, the following main differences stand out:

- Growth in bio-energy until 2010 is only slightly higher (for example, total bio-energy consumption increases from 17 versus 15 Mtoe/yr in 2010 in the zero sustainability premium scenario).
- Growth until 2020 higher compared to Technology Base Case (for example increase of 43 versus 34 Mtoe/yr in 2020 in the zero sustainability premium scenario).
- The largest change in the consumption of biomass occurs in the use of imported fuels (60 versus 47 Mtoe/yr in 2020 in the zero sustainability premium scenario).

8.2.2 Non-subsidised technologies in the EU+10+2

Compared to the Technology Base Case, the following main differences stand out:

- Growth in bio-energy until 2010 is only slightly higher (for example, total bio-energy consumption increases from 6 versus 5 Mtoe/yr in 2010 in the zero sustainability premium scenario).
- Growth until 2020 higher compared to Technology Base Case (for example increase of 54 versus 48 Mtoe/yr in 2020 in the zero sustainability premium scenario).

- Also here, the largest change in the consumption of biomass occurs in the use of imported fuels (21 versus 18 Mtoe/yr in 2020 in the zero sustainability premium scenario).

Table 63, EU15; Non-subsidised Innovative Technology: Biofuel consumption (primary energy, Mtoe/yr).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	26	36	52	45	93	54	127
Bio Electr. (tradeable, co-combustion)	-	4.7	12.6	7.8	15.7	11.0	23.5
Bio Electr. & Heat (non-tradeable)	14	14	15	16	28	19	33
Bio Transport Fuels	0.7	2.4	3.2	2.6	6.1	2.9	11
Total bio-energy	41	57	83	71	143	87	195
Other renewables	34	44	49	50	67	57	77
Total renewables	75	102	132	121	210	144	272
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	16	20	26	22	34	25	35
Solid agricultural residues	1.3	10	17	13	24	16	25
Solid industrial residues	7.9	11	14	13	15	14	15
Solid energy crops	0.1	0.2	5.0	2.4	12	5.7	16
Imported biomass	0	0.3	2.8	1.9	23	5.1	60
Non-tradeables:							
Wet manure	0.1	0.1	0.4	0.2	1.3	0.4	3
Organic waste /b	12	12	12	13	23	15	25
Sewage gas	0.8	0.8	0.9	0.9	1.1	0.9	1.3
Landfill gas	1.1	1.3	1.3	1.5	3.2	2.3	4
Transport fuels:							
Bioethanol	0.1	1.3	1.6	1.3	4.0	1.7	8.3
Biodiesel	0.6	1.1	1.6	1.2	2.1	1.3	2.7
Total bio-energy	41	57	83	71	143	87	195
a/ At an average equilibrium price of (E/GJ):		3.2	3.9	3.7	5.2	4.3	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Table 64, EU15; Non-subsidised Innovative Technology: Biofuel Capacity of heat and electricity production (secondary energy, GW).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	99	144	213	139	191	181	366
Bio Electr. (tradeable, co-combustion)	0	3.2	8.5	5.3	10.7	7.5	16
Bio Electr. & Heat (non-tradeable)	23	23	23	24	36	27	46
Bio Transport Fuels							
Total bio-energy	121	170	245	168	238	215	428
Other renewables	114	159	190	184	264	208	342
Total renewables	235	329	434	352	502	423	770

Table 65, EU+10+2: Non-subsidised Innovative Technology: Biofuel consumption (primary energy, Mtoe/yr).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	7	10.5	17.0	13.8	25.7	15.5	35.4
Bio Electr. (tradeable, co-combustion)	-	1.7	4.4	2.8	5.5	3.9	8.3
Bio Electr. & Heat (non-tradeable)	1.1	1.3	2.9	2.5	5.5	2.8	6.4
Bio Transport Fuels	0.9	1.4	2.5	1.6	2.8	1.6	3.6
Total bio-energy	8.9	14.9	26.7	20.6	39.6	23.8	53.7
Other renewables	3.2	5.6	6.9	6.0	8.8	6.4	10.5
Total renewables	12.1	20.5	33.6	26.6	48.4	30.2	64.2
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	5.9	5.7	8.2	7.4	8.6	7.7	8.6
Solid agricultural residues	0	5.1	6.2	7.1	8.0	7.2	8
Solid industrial residues	1	1.3	2.1	1.5	2.2	1.7	2.2
Solid energy crops	0	0.0	0.7	0.4	3.0	0.9	3.4
Imported biomass	0	0.1	4.2	0.2	9.4	1.8	21.4
Non-tradeables:							
Wet manure	0	0.2	0.5	0.2	1.7	0.4	2.3
Organic waste /b	1	1.0	2.1	2.0	3.2	2.1	3.3
Sewage gas	0	0.0	0.0	0.0	0.1	0.0	0.2
Landfill gas	0	0.0	0.2	0.2	0.5	0.3	0.5
Transport fuels:							
Bioethanol	0.8	1.0	1.5	1.0	1.6	1.1	2
Biodiesel	0.1	0.5	1.0	0.5	1.2	0.6	1.5
Total bio-energy	8.9	15	27	21	40	24	54
a/ At an average equilibrium price of (E/GJ):		2.1	4.2	2.8	5.4	3.7	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Table 66, EU+10+2: Non-subsidised Innovative Technology: Biofuel Capacity of heat and electricity production (secondary energy, GW).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	21.7	29.8	38.5	28.3	33.8	35.6	75.2
Bio Electr. (tradeable, co-combustion)	0	1.1	3.0	1.9	3.8	2.6	5.6
Bio Electr. & Heat (non-tradeable)	2.8	3.3	4.5	3.8	6.3	4.1	7.9
Bio Transport Fuels							
Total bio-energy	24.5	34.2	46.0	33.9	43.9	42.3	88.7
Other renewables	16.1	24.8	29.7	24.9	35.3	26.3	46.4
Total renewables	40.7	59.0	75.7	58.7	79.2	68.6	135.1

8.2.3 Subsidised technologies in the EU15 and the EU+10+2

The results of this scenario differ only slightly from the previous one with non-subsidised technologies. Since those technologies are mainly in the electricity sector, this means that this sector takes up biomass only marginally anyway in both cases.

In the technology scenarios it was assumed that innovative technologies become available on a large scale no sooner than 2010. Therefore any impacts from subsidy programmes can only be expected for the period 2010-2020. Figures 41-42 show that such subsidies do have a noteworthy impact in the case of international biomass trade, and some in the case of solid energy crops. For all other biomass fuels, except organic waste and wet manure, capita subsidies are of a small influence.

Table 67, EU15: Subsidised Innovative Technology: Biofuel consumption (primary energy, Mtoe/yr).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	25.7	36	53.6	46.1	95.3	55.9	130.7
Bio-energy (tradeable, co-combustion)	-	4.7	12.6	7.8	15.7	11.0	23.5
Bio-energy (non-tradeable)	14.1	14.4	14.7	15.5	28.2	18.9	33.4
Bio-energy (transport fuels)	0.7	2.4	3.2	2.6	6.1	2.6	6.1
Total bio-energy	40.5	57.5	84.1	72.0	145.4	88.3	193.8
Other renewables	34.5	44.5	49.2	49.5	66.6	56.5	76.8
Total renewables	75	102.0	133.3	121.5	212.0	144.8	270.6
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	16.3	19.6	26.3	23.5	33.7	25.5	35.3
Solid agricultural residues	1.3	10.0	17.2	13.1	24.1	16.7	24.5
Solid industrial residues	7.9	10.6	14.1	13.0	15.1	13.6	15.2
Solid energy crops	0.1	0.3	5.1	2.4	12.6	5.9	15.9
Imported biomass	0	0.3	3.5	2.0	25.5	5.2	63.4
Non-tradeables:							
Wet manure	0.1	0.1	0.4	0.2	1.3	0.4	3.1
Organic waste /b	12.1	12.1	12.1	13.0	22.7	15.3	25.1
Sewage gas	0.8	0.8	0.9	0.9	1.1	0.9	1.3
Landfill gas	1.1	1.3	1.3	1.5	3.2	2.2	4
Transport fuels:							
Energy crops - bioethanol	0.1	1.3	1.6	1.3	4.0	1.3	4
Energy crops - biodiesel	0.6	1.1	1.6	1.2	2.1	1.2	2.1
Total bio-energy	40.5	57.5	84.1	72.0	145.4	88.3	193.8
a/ At an average equilibrium price of (E/GJ):		3.2	4.0	3.7	5.2	4.5	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Table 68, EU15: Subsidised Innovative Technology: Biofuel Capacity of heat and electricity production (secondary energy, GW).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	98.7	146.2	215.8	140.7	193.4	182.4	374.5
Bio-energy (tradeable, co-combustion)	0	3.2	8.5	5.3	10.7	7.5	16
Bio-energy (non-tradeable)	22.7	22.8	23.3	24.1	36.2	26.9	46.1
Bio-energy (transport fuels)							
Total bio-energy	121.4	172.2	247.7	170.1	240.2	216.8	436.6
Other renewables	113.6	159.6	189.9	183.6	263.6	207.6	342.5
Total renewables	234.9	331.8	437.6	353.7	503.9	424.4	779.2

Table 69, EU+10+2 Subsidised Innovative Technology: Biofuel consumption (primary energy, Mtoe/yr).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	7	10.6	17.0	14.5	26.1	16.2	36.5
Bio-energy (tradeable, co-combustion)	-	1.7	4.4	2.8	5.5	3.9	8.3
Bio-energy (non-tradeable)	1.1	1.3	2.9	2.5	5.5	2.8	6.4
Bio-energy (transport fuels)	0.8	1.0	2.1	1.2	2.4	1.2	2.4
Total bio-energy	8.8	14.6	26.4	21.0	39.5	24.1	53.6
Other renewables	3.2	5.6	6.8	6.0	8.7	6.3	10.4
Total renewables	12.1	20.2	33.2	26.9	48.2	30.4	64
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	5.9	5.7	8.2	7.6	8.6	7.7	8.6
Solid agricultural residues	0	5.1	6.2	7.1	8.0	7.2	8
Solid industrial residues	1	1.3	2.1	1.5	2.2	1.8	2.2
Solid energy crops	0	0.0	0.7	0.6	3.2	1.2	3.4
Imported biomass	0	0.1	4.2	0.4	9.5	2.3	22.5
Non-tradeables:							
Wet manure	0	0.2	0.5	0.3	1.7	0.4	2.3
Organic waste /b	1	1.0	2.1	2.0	3.2	2.1	3.4
Sewage gas	0	0.0	0.0	0.0	0.1	0.0	0.2
Landfill gas	0	0.0	0.2	0.2	0.5	0.3	0.5
Transport fuels:							
Energy crops - bioethanol	0.7	0.9	1.4	1.0	1.6	1.0	1.6
Energy crops - biodiesel	0.1	0.1	0.7	0.2	0.9	0.2	0.9
Total bio-energy	8.8	14.6	26.4	21.0	39.5	24.1	53.6
a/ At an average equilibrium price of (E/GJ):		2.1	4.2	2.9	5.5	3.8	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Table 70, EU+10+2: Subsidised Innovative Technology: Biofuel Capacity of heat and electricity production (secondary energy, GW).

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	21.7	29.8	38.8	28.3	33.4	36.9	77
Bio-energy (tradeable, co-combustion)	0	1.1	3.0	1.9	3.8	2.6	5.6
Bio-energy (non-tradeable)	2.8	3.3	4.5	3.8	6.3	4.1	7.9
Bio-energy (transport fuels)							
Total bio-energy	24.5	34.2	46.3	34.0	43.4	43.6	90.5
Other renewables	16.1	24.8	29.6	24.9	35.3	26.2	46.2
Total renewables	40.7	59.0	75.9	58.9	78.7	69.8	136.7

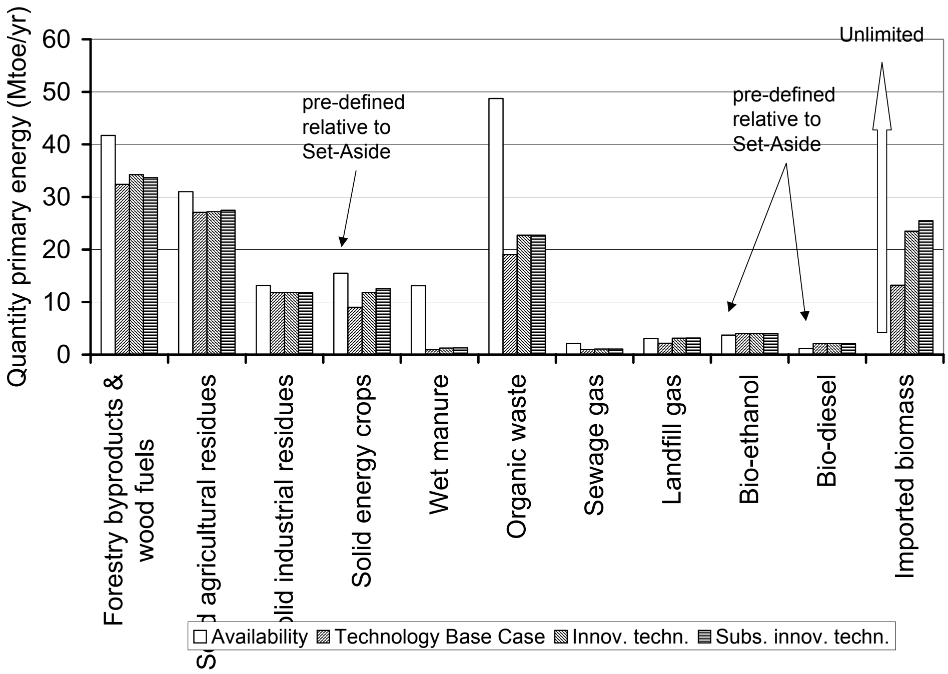


Figure 41, EU15 in 2020: Comparing the technology scenarios under the low-S-premium scenario.

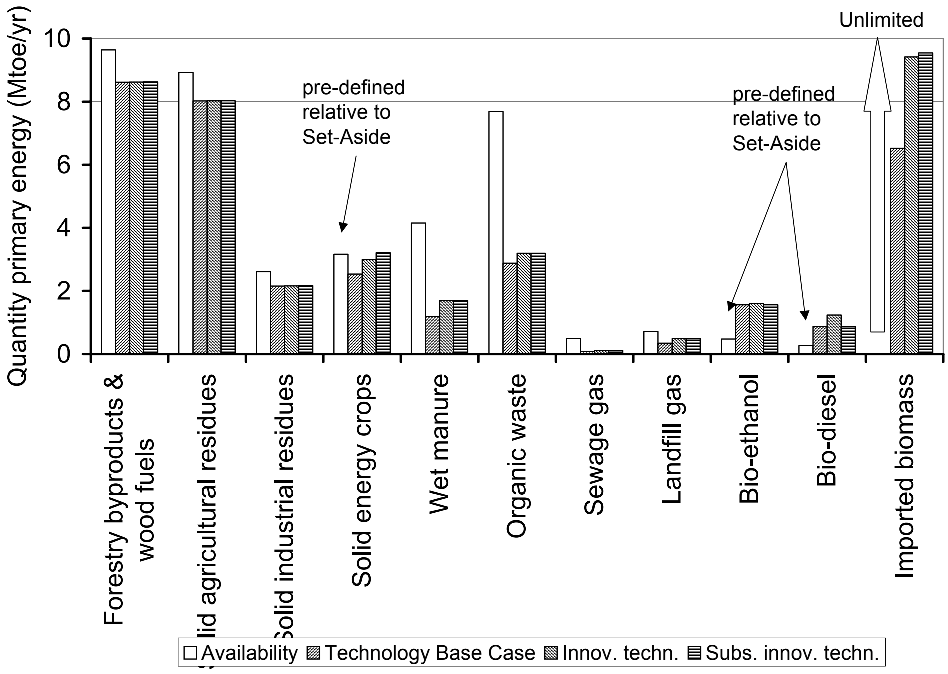


Figure 42, EU+10+2 in 2020: Comparing the technology scenarios under the low-S-premium scenario.

8.3 BIO-TRANSPORTATION FUELS

The scenario for bio-transportation fuels is a variation to the base case of existing technologies. Here, the sustainability premium is found at which the 'transport directive' (Directive 2003/30/EC) can be achieved. This directive demands from the Member States to ensure that a minimum proportion of biofuels and other renewable fuels is placed on their markets. By 31 December 2010 this proportion should reach a level of 5.75% of all petrol and diesel transport fuels (on an energy basis). In the first place, the percentage set by the directive is an overall one, applicable to the aggregate transport fuel consumption of the entire EU, and the directive allows individual countries to distract from the indicative value. Table 71 shows the penetration of biofuels in the scenario's discussed above (varying from 0 to high sustainability premiums). It is clear that the transports directive's objective is met in none of those scenarios.

Table 71, Bio-transport fuels in the three technology scenarios with fixed sustainability premium.

	Total consumption of transport fuels	Consumption of liquid biofuels in the Base Case Technology Scenario					
		no sustainability premium		Low s-premium		High s- premium	
	Mtoe	Mtoe	%	Mtoe	%	Mtoe	%
EU15	291	2.4	0.8%	2.6	0.9%	2.9	1.0%
EU+10+2	36	1	2.8%	1.2	3.2%	1.2	3.4%
EU15+10+2	327	3.4	1.0%	3.7	1.1%	4.1	1.3%

Even in the scenarios with a sustainability premium of 50 and 100 €/tonne CO_2, the EU-wide target of 5.75 % is not met. Therefore, a separate scenario was run so as to determine at which premium the targets are met, and what quantities of land are needed to attain these targets. The following assumptions were made:

- All transport fuels are grown within Europe, so no bio-ethanol and biodiesel is imported from outside the EU.
- Not every individual country needs to achieve the biofuel directive but the total of European countries should meet the targets.
- A rapid market adoption of the technology was assumed.
- The consumption of petrol and diesel was derived from the Primes model.

In SAFIRE it is further assumed that national consumption of bio-transport fuels is met by national supplies. In reality this is not required, and one can imagine forms of intra European trade in bio-transport fuels, which could be economically more efficient.

The model returned a sustainability premium of 219 €/tonne CO_2. Table 72 shows the bio-transport fuel consumption on a country level. The major biofuel producing countries are Germany, France, Spain and the UK. Different market shares between the various countries show that the uniformly applied sustainability premium has different effects in the individual countries. The competition for land between energy crops and crops for transport fuels does exist in reality, but was kept limited during the model runs, because it was assumed that not only set aside land would be available for liquid energy crops.

Table 72, The 2010 consumption of bio-transport fuels in the EU15+10+2 at sustainability premium of 219 €/tonne CO_2 so that the target of the transport directive (2003/30/EC) is met.

Country	Total transport fuel consumption 2010* (ktoe)	Consumption of liquid bio-transport fuels (ktoe)	Share of total consumption (%)	Land area required (ha)
AT	6800	450	6.7	128000
BE	8700	560	6.5	129000
DE	65300	4800	7.3	1511000
DK	3900	220	5.5	80000
EL	6300	230	3.7	36000
ES	31800	1900	6	2110000
Fi	4100	210	5.1	115000
FR	48800	3800	7.7	1170000
IE	4400	170	4	29000
IT	41700	1400	3.3	76000
NL	11900	640	5.4	146000
PT	6900	310	4.4	454000
SE	6800	580	8.5	237000
UK	43600	1900	4.3	192000
BG	2600	0	0	1000
CZ	5700	270	4.7	157000
EE	700	0	2	18000
HU	4200	0	0	0
LT	1500	0	2.5	12000
LV	900	50	5.9	10000
PL	11100	1100	10.1	523000
RO	5700	180	3.1	133000
SK	1900	170	8.7	118000
SI	1500	0	1.7	14000
EU15	291000	17100	5.87	6410000
EU+10+2	35800	1900	5.18	985000
EU15+10+2	327000	18900	5.79	7400000

Table 73 shows that the present set aside area is not sufficient to produce sufficient bio-transport fuels within the EU15. In some countries, like Portugal and Spain a high share of arable land would be needed, which can be explained by a relatively low yield of energy crops for transport fuels in those countries. In case of Belgium and the Netherlands the high share can be explained by the relatively high population density, with a large demand for transport, but yet a low availability of land. If the EU15 wishes to meet the targets of the bio-transport fuels directive, 9% of arable land should be dedicated to these non-food crops.

Table 73, Land requirement to produce the quantity of biofuels required to meet the target of the transport directive (2003/30/EC).

Country	Needed area (ha)	Arable land (1000 ha)	Needed share of arable land	Set aside land (1000 ha)	Needed share of set aside land
AT	130	1400	9%	107	120%
BE	130	820	16%	24	537%
DE	1500	11800	13%	1137	133%
DK	80	2300	4%	213	38%
EL	40	2700	1%	30	119%
ES	2100	13300	16%	1329	159%
FI	120	2200	5%	177	65%
FR	1200	18400	6%	1489	78%
IE	30	1100	3%	29	101%
IT	80	8000	1%	231	33%
NL	150	910	16%	16	910%
PT	450	2000	23%	80	567%
SE	240	2700	9%	264	90%
UK	190	5900	3%	567	34%
BG	1	3500	0%	293	0%
CZ	160	3100	5%	70	224%
EE	18	1100	2%	220	8%
HU	0	4900	0%	215	0%
LT	12	2900	0%	300	4%
LV	10	2900	0%	443	2%
PL	520	14100	4%	130	402%
RO	130	9900	1%	500	27%
SK	120	1500	8%	29	408%
SI	14	170	8%	10	137%
EU15	6400	73500	8.7%	5693	113%
EU+10+2	1000	44100	2.2%	2210	45%
EU15+10+2	7400	118000	6.3%	7903	94%

In the EU15+10+2, about 6.3 percent of the total arable land is required to meet the same target as defined for the EU15 in 2010. The Czech Republic, Poland and Romania are the most important biofuel producers of the EU+10+2. Although the modelling results do not show a high penetration of biofuel production in those countries, there is - given the substantial area of arable land in accession countries - a large potential to produce biofuels for the other countries. In SAFIRE the production of biofuels is primarily driven by the national demand for biofuels. Trade of biofuels within Europe was postulated as an assumption to define how the overall target should be met in terms of physical quantities, but is not an integral part of the model, and there may be efficiencies involved if SAFIRE would allow such trade. This implies that the above results are somewhat pessimistic in terms of the level of the sustainability premium.

9 CONCLUSIONS

In this last chapter, the modelling results are interpreted. The main topics discussed are:

- a comparison with previously published studies on similar topics
- the relevance of the various biomass types
- the relevance of the different energy conversion techniques
- the role of biomass in meeting RES targets
- the role of biomass in meeting the targets of the Kyoto Protocol

9.1 COMPARISON WITH OTHER SCENARIO STUDIES

Two major studies that also investigated the role of biomass in the next decades are TERES II[113] and the 'European Union energy outlook to 2020'.[114] TERES II served as a background analysis of the EU's White Paper on renewable energy 'Energy for the Future'.[115] The 'European Union energy outlook to 2020' is more recent and was prepared under the Shared Analysis Project. In 1998, this project was initiated by the Directorate General for Energy of the European Commission with the aim of integrating the potentials for energy policy analysis within the member states of the EU.

Including wastes, the Best Practice Scenario of TERES II estimates an amount of 160 Mtoe/yr in 2020, from 'crops, residues and wastes' (Table 74).[116] This includes the applications of electricity and heat, and also transportation fuels.

Table 74, Contribution of three biomass fuel types in the Best Practice Scenario for 2020 of TERES II (it is assumed that primary energy is concerned).

	Mtoe/yr
Crops	71
Waste	56
Residues	35

Extracting the market expectations contained in 'Energy for the future' is complicated. This is due to the fact that end-use data on electricity and heat production are reported without reference to the technical assumptions regarding current and future conversion efficiencies. Siemons (2002a) showed that a likely division of biofuels over the various utilisation sectors is as displayed in Table 75.

113/ ESD (1996).
114/ Capros, Mantzos, Petrellis *et al.* (1999).
115/ EU (1997).
116/ ESD (1996), p. xv.

Table 75, An interpretation of 2010 projections given in 'Energy for the future' (Source: Siemons (2002)).

Year	1995			2010		
End-uses	Biomass fuels supply (Mtoe)	Electricity produced (TWh)	Heat supplied (Mtoe)	Biomass fuels supply (Mtoe)	Electricity produced (TWh)	Heat supplied (Mtoe)
Non-CHP electricity	2	11	0	31	136	0
Non-CHP heat	42	0	36	65	0	56
CHP electricity and heat	4	12	2	32	94	19
Liquid transportation fuels	0			18		
Total	48	23	38	147	230	75
Additional biomass (2010 - 1995) (Mtoe/yr)					98	
CHP Biomass share (2010) of additional biomass (based on primary energy)					33%	
Heat/Power ratio		2.4			2.4	
Assumed efficiencies:						
Non-CHP electricity		38%			38%	
Non-CHP heat supplied		85%			85%	

The other study referred to here is the 'European Union energy outlook to 2020', produced by the Shared Analysis Project. The assumed Baseline Scenario is reported in sufficient detail to derive projected biomass fuel consumptions. For the combined flows of biomass and waste, the referred to study reports an increase in thermal input from 44.2 Mtoe in 1995 to 52.5 Mtoe in 2010.[117] Specifically, for the power and steam generation sector, a figure of 31 Mtoe is given.[118] As no further details are given for biomass fuel consumption under the more climate friendly scenarios also investigated, one has to fall back on an interpretation based on other reported indicators. This is done below, in Table 76, using the assumption that the contribution of biomass varies proportionally to the contribution of renewables in general. The Shared Analysis Project foresees no significant introduction of biomass-based liquid transportation fuels due to "expectations of costs and the absence of new policy initiatives".[119]

Table 76, The future consumption of biomass and waste fuels in the EU15 according to four scenarios (Source: Siemons (2002)).

Year	2010				2020			
Scenario	Baseline	S0	S3	S6	Baseline	S0	S3	S6
Biomass and waste (Mtoe/yr)	53 /a	57	61	64	57 /a	66	69	72
Increase in renewable energy sources /b		8.6%	15.0%	21.1%		17%	22%	27%

a/ European Union energy outlook to 2020, p. 52.
b/ European Union energy outlook to 2020, p. 74

The 'European Union energy outlook to 2020' explains the limited growth in biomass energy as a result of the constrained resource base, in other words, the supply side.[120] Unfortunately, the authors do not present an analysis to justify this position, nor do they

117/ Capros, Mantzos, Petrellis *et al.* (1999), p. 186.
118/ Capros, Mantzos, Petrellis *et al.* (1999), p. 176.
119/ Capros, Mantzos, Petrellis *et al.* (1999), p. 133.
120/ Capros, Mantzos, Petrellis *et al.* (1999), p. 96.

make reference to any biomass sourcing study. In contrast, TERES II, one of the background papers for the EU's policy on renewables, estimates the technical potential for biomass and waste in the EU15 at 210 Mtoe/yr - a figure three times as large as the projected usage by the 'European Union energy outlook to 2020'.[121] With a supply potential of 150 Mtoe in 2010 (disregarding the potential of imports) (Chapter 5, Table 15) the present study is less optimistic than TERES II, but still, this contradicts the view that the limited availability of biomass prevents its use above a level of about 70 Mtoe/yr. Naturally, the supply elasticity of biomass is decisive in the position adopted in the 'European Union energy outlook to 2020', further information about which is not given in TERES II. An analysis of this elasticity seems a major contribution of the present study. In this context it is also relevant to note that not one of the scenarios evaluated in the 'European Union energy outlook to 2020', or in TERES II, foresees imports into the EU of biomass fuels or of biomass-derived fuels. Technically, this is an option and it was further investigated in this study.

Nevertheless, the resulting quantities of biofuels presented by this study are quite close to those reported by the 'European Union energy outlook to 2020'. TERES II was more optimistic. Most likely this is caused by differences in starting positions. The SAFIRE model is strong in extrapolating the developments that result from stimulating policies - policies that were rigorously removed here, to place all renewables on a single EU-wide level playing field, and to examine the value that one tacitly attaches to sustainability in the broadest sense.

9.2 RELEVANT BIOMASS TYPES

Tradeables

Refined wood fuels, forestry by-products and solid industrial residues (mainly from the secondary wood processing industries) are already an important resource, and their relevance is growing. Solid agricultural residues, such as wheat straw, are a major source of biomass fuels that is still underutilised in most countries. There are several technical difficulties related to this resource (e.g. excessive corrosion in heat exchangers), and agricultural residues are released seasonally. This makes careful planning of logistics and storage necessary. In all countries biomass imports are expected by 2020. If low sustainability premiums are continued to be applied, imports are necessary in 2010. Without international trade in biofuels, bio-energy's role remains very limited. If sustainability premiums become high, import provides most of the growth in bio-energy.

Non-tradables

Wet manure is abundantly available. However, this resource has a low energy density. It cannot be transported cost-effectively and needs to find applications virtually on a farm scale. At such relatively small scales of application, capital costs involved remain high. This is why wet manure contributes only little to achieving targets set for bio-energy. Of

121/ ESD (1996), p. xv.

course, there is a level of sustainability premiums which makes the energy conversion of wet manure attractive.

Organic waste forms a substantial part of the bio-energy resource of the EU15+10+2. The implementation of the landfill directive redirects biodegradable municipal waste from landfill toward other purposes, mainly incineration with energy recovery, and a s a result the potential of this resource increases considerably. The modelling shows that this resource may play an important role in the consumption of bio-energy. At the same time, the potential of sewage gas and landfill gas stabilises at a low level.

Transport fuels

The consumption of energy crops for transport fuels does not increase much in the scenarios of fixed sustainability premiums, even if values of as high as 100 €/tonne CO_2-eq. are applied. In the analysis, no other incentives than the sustainability premiums were applied to any of the bio-transport fuels. Tax exemptions, such as employed in several countries, were not applied in the scenarios. Note that a tax reduction of about 0.10 €/litre for biodiesel and ethanol, corresponds to sustainability premiums of 50 and 90 €/tonne CO_2, respectively.

International trade

The scenarios simulated the option of international trade (intra European and also imports into the EU). A standard price of 6 €/GJ was applied for which large imports are possible. In both the low and high sustainability premium scenarios most of the growth of bio-energy's role in 2020 is possible because of this type of trade. As it appears, imports will be most relevant in the following countries (under the low sustainability-premium scenario): Germany, Belgium, Greece, the Netherlands, Denmark, and the United Kingdom.

Trade flows can only develop for derived biofuels of high energy densities. Examples are bio-ethanol, pellets and pyrolysis oil. Also shipping (rather than road or rail transport) seems a general prerequisite. Transporting pellets by road over a distance of 300 km can be more expensive than their transport over 10.000 km by means of a bulk carrier.

9.3 RELEVANT CONVERSION TECHNOLOGIES

From a comparison of the three technology scenarios, and the trends encountered within each of the scenarios, it appears that the real difference between today's employment of bio-energy for electricity and heat is not made by the introduction of innovative gasification technology as a successor to the combustion & steam cycle. Rather, it is international trade in bio-fuels that seems to enable the development towards an increased use of bio-energy. At the same time it is obvious that international trade especially contributes to specific sustainability objectives of the EC's bio-energy policy, particularly a reduced dependence on energy imports and increased security of supply, and, if European technologies are involved, the creation of business opportunities for European

Union industries (in Asia, Latin America and Africa). Although not analysed specifically, it is safe to conjecture that international trade has also the potential to play a significant role in the bio-energy supply to the transport sector. Associated technologies concern production and use of biomass-based energy carriers that can be traded and used cost-effectively. Examples of such energy carriers are pellets, bio-ethanol, biodiesel, and pyrolysis oil (bio-oil). Innovative intermediate upgrading techniques, such as hydrogenation, could be needed to further adapt imported bio-fuels to end-uses. Utilisation techniques could involve application in gas turbines, and road transport. Hence, a major topic that deserves more attention from industry and the R&TD community are technologies that facilitate international trade in bio-fuels.

9.4 MEETING RES TARGETS

There are two EC documents that actually set targets for the role of bioenergy in the sectors of electricity and heat (transport has been discussed elsewhere). The first, and most general one, is 'Energy for the future'.[122] The quantified targets were reviewed and interpreted in Section 9.1, Table 75). In terms of Mtoes, in 2020, biomass is expected to contribute by:

31 Mtoe for non-CHP electricity
65 Mtoe for non-CHP heat
32 Mtoe for CHP electricity and heat
18 Mtoe for bio-transportation fuels

The second document is Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market. Actually the directive is broader than biomass alone, setting indicative national targets for electricity produced from renewable resources by 2010. By that year, a total of 22% of the electricity consumed in the EU15 should be made from renewable sources. If the 'Shared analysis project'[123] is correct, this will be a total of 665 TWh (22% of 3024 TWh, i.e. 146 Mtoe of biomass if a conversion efficiency of 40% is assumed - just for the sake of argument. Biomass is not the only renewable). Table 77 shows the role of biomass in achieving these targets and its role in total electricity production, under the various scnarios investigated here.

122/ EU (1997).
123/ Capros, Mantzos, Petrellis *et al.* (1999).

Table 77, The role of bio-electricity in achieving the targets for RES electricity by 2010.

	0 sustainability premium			Low sustainability premium			High sustainability premium		
	TWh	share of target	share of total electricity	TWh	share of target	share of total electricity	TWh	share of target	share of total electricity
Technology Base Case									
Bio-electricity (excl. co-combustion)	36	5.4%	1.2%	43	7%	1.4%	77	12%	2.6%
Bio-electricity (co-combustion)	21	3.1%	0.7%	35	5%	1.1%	49	7%	1.6%
Total bio-electricity	57	8.5%	1.9%	78	12%	2.6%	126	19%	4.2%
Non-subsidised Innovative Technology									
Bio-electricity (excl. co-combustion)	36	5.50%	1.20%	49	7%	1.60%	83	12%	2.70%
Bio-electricity (co-combustion)	21	3.10%	0.70%	35	5%	1.10%	49	7%	1.60%
Total bio-electricity	57	8.60%	1.90%	83	13%	2.80%	131	20%	4.30%

In the 0 and low sustainability-premium scenario (and Technology Base Case), the role of bio-electricity is limited to 1.9-2.6 % of total electricity production by 2010. In the high sustainability premium scenario a more substantial contribution by bio-energy of 4.2 % is shown. In the three scenarios bio-energy contributes 8.5, 12 and 19 % respectively to meeting the targets of the RES electricity directive, which is rather limited. At present, the generation of renewable electricity is often heavily subsidised. Subsidies of 50 €/tonne CO_2 as shown in the high sustainability premium scenario, correspond with 0.06 €/kWh of electricity. This level is currently not uncommon in many EU15 countries, such as Germany and the Netherlands. The scenarios show that these incentives remain necessary if the targets in Directive 2001/77/EC are to be achieved.

Table 77 also shows that the introduction of expensive but efficient GCC-technology does not lead to a substantial additional production of electricity from biomass. This is despite the fact that, in terms of capacity units (as large as 100 MW_e), however, the scenario is quite optimistic, assuming favourable economies of scale.

These conclusions are in accordance with the findings of the Shared Analysis Project, i.e. that neither in their Baseline Scenario, nor in any of the other three scenarios investigated by that study, the political objective expressed in the EU's White Paper on 'Energy for the future' (*"12% renewable by 2010"*) is achieved. In the most optimistic scenario (S6) one only reaches 7.3% by 2010, and 8.4% by the year 2020. However, unlike the Shared Analysis Project, we do not attribute this result to limitations in the available quantities of biomass. In our view, it is the economy of bio-energy technologies that limits the employment of biomass as a sustainable energy resource. The size of the sustainability premium is therefore essential for biomass to play a significant role in electricity generation. If the European GHG emission trade scheme develops favourably, at the low levels as anticipated, and if ETS develops as an alternative for currently existing incentive schemes, then the role of biomass electricity seems not to be able to become as predominant as anticipated in the past. The same applies to the role of biomass in the transport sector, where extremely high sustainability premiums are to be paid in order to finance the achievement of the targets set. This should not necessarily be an adverse development, if one concludes that the prevailing incentive schemes for biomass energy are less economically efficient. Before doing so, one should remember that the sustainability premium as defined in this study concerns more than carbon emissions alone, but includes issues like supply diversification and independence, etc.

9.5 BIOMASS'S CONTRIBUTION TO MEETING KYOTO'S CO2 EMISSION TARGETS

On a global level, the KP targets are defined as a total emission at 5% below that of 1990 (KP, Article 3). In Figure 43, the history of actual GHGs in Europe are shown, and compared to the 2012 European GHG emission targets. A distinction was made between the EU15 and the EU+10+2. Generally the agreed target is somewhat stricter for the European countries than for most signatories to the KP. Except Hungary, that is committed to a reduction by 6%, the European countries agreed to an emission reduction by 8%.

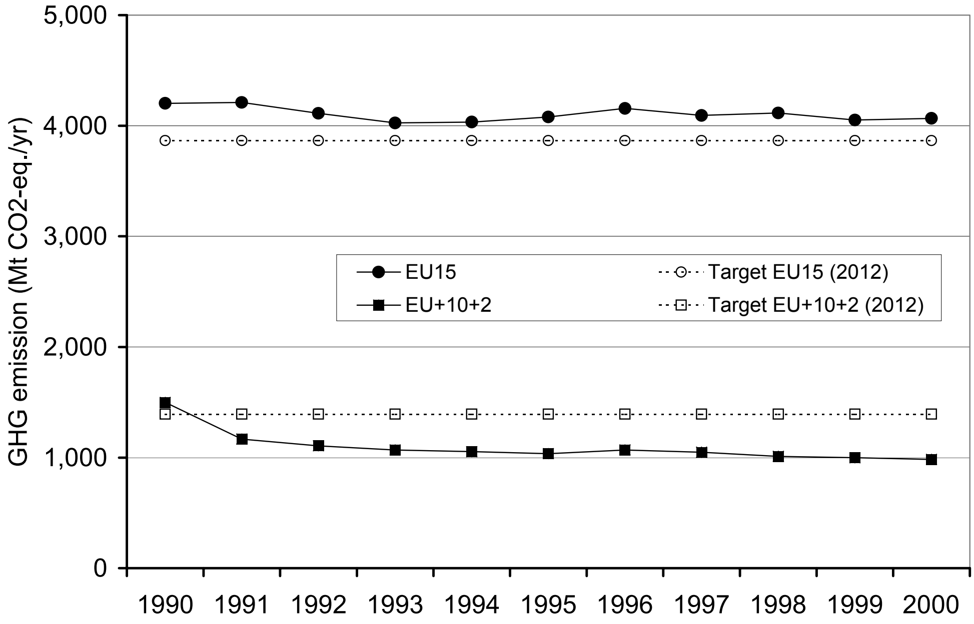


Figure 43, The European GHG emissions since 1990 (Data originate from the database of the UNFCCC at http://unfccc.int/, retrieved at 23 February 2004. Missing data were estimated by the authors).

The targeted emission levels are absolute quantities, and so are the emission *reductions* needed in base year 1990, and also in any past year of which the emissions are known. However, it is quite uncertain how large the package of emission reductions should be in the future target period 2008-2012. In view of those years, the quantity of required emission reductions is the imaginary result of subtracting the target emission (95% of those of 1990) from the emissions that are supposed to occur at that time in the absence of the KP. The latter are quantified by means of business-as-usual scenarios (BAU), and there exist several of them. Given a BAU scenario, there is a total of required emission reductions, and this total is the result of a large package of activities that include energy saving, fuel switching, and carbon credit trade (see Section 7.1.1). Biomass energy is part of that package, and only in view of the total package can the relative role of biomass in meeting the KP target be assessed. The size of the entire package being defined in relation to the state of a business-as-usual scenario at a fixed moment in time (for the KP: somewhere between 2008-2012), such assessment is not the objective of this study. Therefore, the contribution of biomass energy to achieving the KP target (the quantity A-B in Figure 44) has not been determined here.

There are some other ways in which the role of biomass energy with respect to GHG emissions can be viewed. One is as follows: The utilisation of biomass energy, as determined by SAFIRE - also for a moment within the KP target period 2008-2012 - can be interpreted as a manner to avoid using fossil energies. Thus, the role of biomass energy, via an avoided role of fossil fuels, corresponds to avoided GHG emissions (the quantity B-K in Figure 44). Those emissions can be compared with the absolute allowable GHG emission level (K: the Assigned Amount of the KP) of the target year.

The same emission reduction achievable with biomass by the target year, can also be compared with what still has to be achieved, relative to known emission levels of the past, for example of the year 2000. For this year, on an EU15 level, Figure 43 shows that there is a gap of about 200 Mt CO_2-eq./yr between the KP target and the actual GHG emission. This would be an assessment that is irrespective of the developments in emission levels after 2000, and in any case irrespective of any BAU scenario.

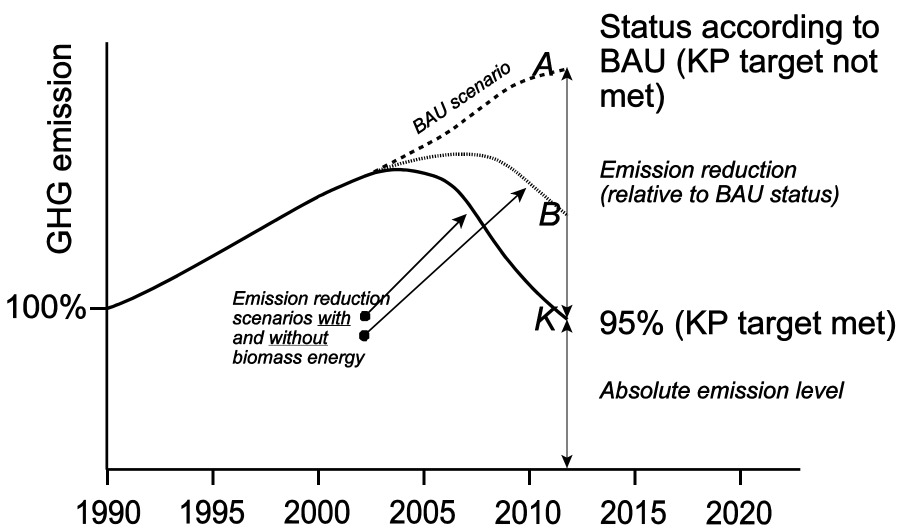


Figure 44, The contribution of biomass energy to the Kyoto Protocol targets, assuming that they are met.

A complication is that not all biomass energy estimated for 2010 is additional in terms of the UNFCCC methodologies. After all, SAFIRE builds its results on an existing situation in which biomass energy already plays a role, and also in 1990 biomass was already utilised as an energy source. For this study, no data were collected on the use of biomass energy in 1990. Nevertheless, an estimate could be made on the basis of emission data provided by the UNFCCC. For GHGs emitted from the combustion of biofuels in 1990 and 2000, the UNFCCC reports 119 and 144 Mt CO_2-eq. respectively.[124] These emissions correspond to a quantity of biomass fuels, and those can be interpreted as if substituting for a quantity of fossil fuels, with their associated GHG emissions. Assuming that this relationship in 1990 was equal to that of 2000, it was estimated that the emission reduction in 1990 equalled 101 Mt CO_2-eq./yr. With this background, Table 78 was prepared. It shows the avoided CO_2 emissions achieved by the use of biomass according to the Technology Base Case, with the various scenarios for sustainability premiums. The row indicating the 'absolute emission reduction' shows the emission reduction as if all biomass replaces fossil fuels. It is merely shown for methodological reasons. The next row gives the emission reduction with reference to 1990. This row is relevant for understanding biomass energy's role in view of the Kyoto Protocol that uses 1990 as the base year. Any net emission reductions realised after 1990 are relevant in achieving Kyoto's targets. The row showing emission reductions with reference to 2000 helps to understand the effects of the sustainability premiums.

Table 78, EU15: Avoided GHG emissions as a result of biomass utilisation (Mt CO_2 eq./yr), under the Technology Base Case.

			No S-premium		Low S-premium		High S-premium	
	1990 /a	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	n.a.	81	109	142	132	244	160	350
Bio Electr. (tradeable, co-combustion)	n.a.	-	18	47	29	59	41	88
Bio Electr. & Heat (non-tradeable)	n.a.	39	40	40	42	61	49	75
Bio Transport Fuels	n.a.	1.4	4.5	6.1	4.8	11.5	5.5	20.7
Emission reduction as if all bio-energy is additional	101	122	171	235	208	375	255	534
Emission reduction relative to 1990	-	21	70	135	108	274	154	433
Emission reduction relative to 2000	-	-	49	113	87	253	133	412

a/ The 1990 emission reduction is justified in the text.

For the EU15, the no-, low- and high sustainability-premium scenarios yield net emission reductions, relative to 2000, of 49, 87 and 133 Mt CO_2-eq./yr by 2010. In view of the 2000 gap of 200 Mt CO_2-eq./yr these quantities are substantial, and it implies a quite relevant role for biomass energy.

124/ UNHCCC (2004).

APPENDIX A
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APPENDIX B
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APPENDIX C
EXISTING POLICIES SUPPORTING BIOMASS ENERGY

Country	RES price support	RES quota (gen or supply)	RES priority network access	RES environ bonus/ subsidy	RES/biomass target installed capacity	Biomass resource use target	Agr & forestry support for biomass	Biomass capital grant	Biomass equip't soft loans/grants	Biomass equip't tax relief	Bio-fuel tax relief	Biomass R&D	CO_2 target	CO_2 tax	Green cert
Austria	●	○			●			○ ■			● ■	●			
Belgium	●■	■	●		●			● ■		●	● ■	●	● ■		● ■
Denmark	●■	● ■		●		● ○ ■		■	■ (?)			●	● ■		● ■
Finland				●	● ○ ■	● ■	●	● ■		■ (?)		●	●	●	●
France	●■	●			●			●	●	■	●	●	●		
Germany	○ ■							● ■	■		● ○ ■	●	●		
Greece	●		●		●			● ■		● ■		●			
Ireland	●■				●			●				●	●	●	
Italy	○	■			● ○		● ○	○ ●			● ○	●	●	●	● ■
Luxembourg						■		■							
Netherlands	■				● ■				●	●		●	■	●	■
Portugal	● ■	■	●		●			● ■				●			
Spain	● ○ ■		●					○ ■			●	●			
Sweden		○ ■					● ■	● ■			●	●	●	●	●■
UK	● ■	■			●		●	● ■	●			●	● ■	●	●
Bulgaria															
Cyprus					● □			● □							
Czech Republic					● ○ □		□	□			□(?)		●		
Estonia															
Hungary					● □			● □							
Latvia	□				● □								●		
Lithuania	□	□			● □								●		
Malta															
Poland	□	□			● □			●							
Romania													●		
Slovak Republic		□			● □										
Slovenia	○	○			● □								●		

● = EUBIONET ref; ○ = AEBIOM ref; ■ = MITRE ref; □ = MHW Accession country overviews ref

APPENDIX D
COUNTRY TABLES: TECHNOLOGY BASE CASE SCENARIO

EU15+10+2: Consumption of bio-energy (primary energy, Mtoe/year) (Technology base case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	33	44	59	54	100	67	146
Bio Electr. (tradeable, co-combustion)	-	6.4	17	11	21	15	32
Bio Electr. & Heat (non-tradeable)	15	16	17	18	28	21	34
Bio Transport Fuels	1.5	3.4	5.3	3.7	8.5	4.1	14
Total bio-energy	49	70	99	86	157	107	225
Other renewables	38	50	56	55	75	63	87
Total renewables	87	120	155	142	233	170	312
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	22	24	31	28	41	32	44
Solid agricultural residues	1.3	17	23	22	35	27	36
Solid industrial residues	9.0	9.2	12	10	14	12	14
Solid energy crops	0.1	0.3	3.8	2.5	12	6.3	19
Imported biomass	0.0	0.3	6.1	1.5	20	4.9	65
Non-tradeables:							
Wet manure	0.1	0.3	0.7	0.5	2.2	0.7	4.5
Organic waste /b	13	13	14	15	22	17	24
Sewage gas	0.8	0.9	0.9	0.9	1.1	0.9	1.3
Landfill gas	1.2	1.3	1.4	1.6	2.5	2.3	3.5
Transport fuels:							
Bioethanol	0.9	2.2	3	2.3	5.6	2.7	9.9
Biodiesel	0.7	1.2	2.2	1.4	3	1.4	3.7
Total bio-energy	49	70	99	86	157	107	225
a/ At an average equilibrium price of (E/GJ):		2.9	3.8	3.5	5	4	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

EU15: Consumption of bio-energy (primary energy, Mtoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	26	34	45	42	78	51	114
Bio Electr. (tradeable, co-combustion)	-	4.7	13	7.8	16	11	24
Bio Electr. & Heat (non-tradeable)	14	14	15	15	23	18	28
Bio Transport Fuels	0.7	2.4	3.2	2.6	6.1	2.9	11
Total bio-energy	41	56	75	67	123	84	176
Other renewables	34	45	49	50	66	56	77
Total renewables	75	101	124	117	189	140	253
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	16	19	25	21	32	24	35
Solid agricultural residues	1.3	12	17	16	27	20	28
Solid industrial residues	7.9	7.9	9.6	9.0	12	11	12
Solid energy crops	0.1	0.3	3.1	2.1	9.0	5.5	16
Imported biomass	0.0	0.2	2.6	1.4	13	3.1	46
Non-tradeables:							
Wet manure	0.1	0.1	0.3	0.2	1.0	0.4	2.6
Organic waste /b	12	12	12	13	19	15	21
Sewage gas	0.8	0.8	0.9	0.9	1.0	0.9	1.2
Landfill gas	1.1	1.3	1.3	1.4	2.2	2	3.1
Transport fuels:							
Bioethanol	0.1	1.3	1.6	1.3	4.0	1.7	8.3
Biodiesel	0.6	1.1	1.6	1.2	2.1	1.3	2.8
Total bio-energy	41	56	75	67	123	84	176
a/ At an average equilibrium price of (E/GJ):		3.2	3.7	3.7	4.9	4	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

EU+10+2: Consumption of bio-energy (primary energy, Mtoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	7.0	10	15	12	22	15	32
Bio Electr. (tradeable, co-combustion)	-	1.7	4.4	2.8	5.5	3.9	8.3
Bio Electr. & Heat (non-tradeable)	1.1	1.3	2.6	2.3	4.5	2.7	5.5
Bio Transport Fuels	0.8	1.0	2.1	1.2	2.4	1.2	2.5
Total bio-energy	8.8	14	24	19	35	23	48
Other renewables	3.2	5.6	6.9	5.9	8.8	6.3	10
Total renewables	12	20	31	25	44	29	59
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	5.9	5.3	6.9	6.8	8.6	7.8	8.6
Solid agricultural residues	0.0	4.9	6	6.4	8.0	7.2	8.0
Solid industrial residues	1.0	1.3	2.0	1.5	2.2	1.7	2.2
Solid energy crops	0.0	0.0	0.7	0.4	2.5	0.8	3.4
Imported biomass	0.0	0.0	3.5	0.2	6.5	1.8	18
Non-tradeables:							
Wet manure	0.0	0.2	0.4	0.3	1.2	0.4	2.0
Organic waste /b	1.0	1.0	2.0	1.8	2.9	2.0	3.0
Sewage gas	0.0	0.0	0.0	0.0	0.1	0.1	0.2
Landfill gas	0.0	0.0	0.1	0.2	0.3	0.3	0.4
Transport fuels:							
Bioethanol	0.7	0.9	1.4	1.0	1.6	1.0	1.6
Biodiesel	0.1	0.1	0.7	0.2	0.9	0.2	0.9
Total bio-energy	8.8	14	24	19	35	23	48
a/ At an average equilibrium price of (E/GJ):		2.1	4.1	2.9	5.4	4.0	6.0

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Austria: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	2526	2996	4188	3123	5405	4020	6628
Bio Electr. (tradeable, co-combustion)	-	35	92	58	115	81	173
Bio Electr. & Heat (non-tradeable)	622	625	625	625	833	706	926
Bio Transport Fuels	24	50	122	50	160	62	424
Total bio-energy	3172	3705	5028	3855	6513	4868	8150
Other renewables	3584	4016	4112	4072	4244	4089	4385
Total renewables	6756	7721	9140	7927	10757	8957	12535
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1308	1842	2951	1988	4057	2894	5057
Solid agricultural residues	23	21	27	24	149	24	235
Solid industrial residues	1195	1166	1300	1166	1306	1180	1311
Solid energy crops	0	0	0	0	1	0	114
Imported biomass	0	1	2	1	7	2	83
Non-tradeables:							
Wet manure	2	2	2	2	2	2	2
Organic waste /b	603	604	604	604	811	684	901
Sewage gas	8	8	8	8	8	8	8
Landfill gas	8	12	12	12	12	12	14
Transport fuels:							
Bioethanol	0	17	17	17	17	30	271
Biodiesel	24	32	105	32	142	32	154
Total bio-energy	3172	3705	5028	3855	6513	4868	8150
a/ At a uniform equilibrium price of (E/GJ):		2.5	2.5	2.5	3.2	2.5	5.7

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Belgium: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	143	555	944	589	1738	763	2427
Bio Electr. (tradeable, co-combustion)	-	115	306	191	382	267	573
Bio Electr. & Heat (non-tradeable)	271	281	281	281	398	300	912
Bio Transport Fuels	17	43	352	127	409	226	778
Total bio-energy	432	994	1883	1188	2927	1556	4690
Other renewables	65	123	311	173	434	189	716
Total renewables	497	1117	2194	1361	3361	1745	5406
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	8	175	194	176	196	176	198
Solid agricultural residues	0	162	179	162	179	162	179
Solid industrial residues	136	299	330	299	330	299	330
Solid energy crops	0	0	3	1	9	2	19
Imported biomass	0	34	544	143	1407	391	2275
Non-tradeables:							
Wet manure	0	0	0	0	0	0	1
Organic waste /b	251	251	251	251	368	269	827
Sewage gas	21	30	30	31	31	31	31
Landfill gas	0	0	0	0	0	0	53
Transport fuels:							
Bioethanol	0	12	12	12	12	109	366
Biodiesel	17	31	340	115	398	117	412
Total bio-energy	432	994	1883	1188	2927	1556	4690
a/ At a uniform equilibrium price of (E/GJ):		6	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Denmark: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	793	960	1152	963	1535	1176	1968
Bio Electr. (tradeable, co-combustion)	-	161	428	268	535	375	803
Bio Electr. & Heat (non-tradeable)	138	143	143	143	158	161	245
Bio Transport Fuels	0	0	40	0	120	0	319
Total bio-energy	931	1263	1763	1373	2348	1711	3334
Other renewables	387	777	822	810	1046	835	1127
Total renewables	1318	2040	2585	2183	3394	2546	4461
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	370	270	417	315	441	377	466
Solid agricultural residues	310	647	738	647	747	668	756
Solid industrial residues	113	119	131	119	131	119	131
Solid energy crops	0	50	211	89	546	270	681
Imported biomass	0	34	83	60	204	115	737
Non-tradeables:							
Wet manure	31	31	31	31	44	48	123
Organic waste /b	77	77	77	77	77	77	77
Sewage gas	16	16	16	16	18	17	26
Landfill gas	14	19	19	19	19	19	19
Transport fuels:							
Bioethanol	0	0	40	0	120	0	158
Biodiesel	0	0	0	0	0	0	161
Total bio-energy	931	1263	1763	1373	2348	1711	3334
a/ At a uniform equilibrium price of (E/GJ):		4.5	4.9	4.5	4.9	4.9	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Finland: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	2329	2408	2555	2667	5009	3186	5291
Bio Electr. (tradeable, co-combustion)	-	92	245	153	306	214	459
Bio Electr. & Heat (non-tradeable)	3444	3449	3452	3457	3494	3464	4245
Bio Transport Fuels	0	0	2	0	29	0	97
Total bio-energy	5773	5949	6254	6277	8837	6864	10092
Other renewables	1287	1351	1533	1369	1664	1404	1816
Total renewables	7060	7300	7787	7646	10501	8269	11908
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1200	1508	1623	1754	3825	2252	3828
Solid agricultural residues	0	132	176	159	255	180	255
Solid industrial residues	1124	859	1000	905	1232	966	1233
Solid energy crops	5	0	0	0	1	1	354
Imported biomass	0	1	1	1	2	2	79
Non-tradeables:							
Wet manure	1	5	7	10	37	15	71
Organic waste /b	3429	3429	3429	3429	3432	3429	4118
Sewage gas	10	11	11	11	14	12	17
Landfill gas	4	4	4	7	10	8	39
Transport fuels:							
Bioethanol	0	0	0	0	0	0	35
Biodiesel	0	0	2	0	29	0	63
Total bio-energy	5773	5949	6254	6277	8837	6864	10092
a/ At a uniform equilibrium price of (E/GJ):		2.4	2.5	2.5	2.5	2.5	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

France: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	4083	7772	11225	9078	20956	11909	26624
Bio Electr. (tradeable, co-combustion)	-	253	675	422	844	591	1266
Bio Electr. & Heat (non-tradeable)	1491	1543	1721	1602	2099	1663	3012
Bio Transport Fuels	339	555	555	555	1292	555	2512
Total bio-energy	5913	10123	14176	11657	25191	14718	33415
Other renewables	6254	6824	8099	8140	11023	8578	14257
Total renewables	12167	16947	22275	19797	36214	23296	47672
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	3791	6595	7481	6772	7717	6772	7760
Solid agricultural residues	94	412	3142	1649	10128	4417	10756
Solid industrial residues	198	978	1089	986	1100	986	1101
Solid energy crops	0	34	162	80	2480	280	4826
Imported biomass	0	6	26	13	376	45	3446
Non-tradeables:							
Wet manure	0	33	183	80	532	136	1260
Organic waste /b	1380	1380	1380	1380	1380	1380	1380
Sewage gas	62	68	79	74	99	76	114
Landfill gas	49	61	79	68	87	70	258
Transport fuels:							
Bioethanol	58	152	152	152	888	152	2109
Biodiesel	282	404	404	404	404	404	404
Total bio-energy	5913	10123	14176	11657	25191	14718	33415
a/ At a uniform equilibrium price of (E/GJ):		2.6	3.8	3.8	4.7	3.8	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Germany: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	4357	5467	6578	6611	12082	7045	19253
Bio Electr. (tradeable, co-combustion)	-	2033	5422	3389	6778	4745	10167
Bio Electr. & Heat (non-tradeable)	2114	2138	2140	2353	2916	2776	3577
Bio Transport Fuels	206	1181	1181	1181	2189	1181	3599
Total bio-energy	6677	10819	15320	13533	23965	15747	36597
Other renewables	3035	6511	6657	7386	9787	8598	12624
Total renewables	9712	17330	21977	20919	33752	24344	49220
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	3342	3367	3749	3383	3812	3384	3879
Solid agricultural residues	60	3055	3374	3055	3403	3080	3409
Solid industrial residues	955	941	1039	941	1047	948	1049
Solid energy crops	0	94	2225	1724	3518	3185	3794
Imported biomass	0	43	1613	897	7080	1193	17289
Non-tradeables:							
Wet manure	31	31	31	38	168	68	496
Organic waste /b	1490	1490	1490	1690	1690	1751	1751
Sewage gas	373	387	388	392	437	405	518
Landfill gas	220	230	230	233	622	552	813
Transport fuels:							
Bioethanol	0	970	970	970	1979	970	3389
Biodiesel	206	210	210	210	210	210	210
Total bio-energy	6677	10819	15320	13533	23965	15747	36597
a/ At a uniform equilibrium price of (E/GJ):		5.2	5.2	5.2	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Greece: Consumption of bio-energy (primary energy, ktoe/year)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	718	780	893	1333	2256	1696	4259
Bio Electr. (tradeable, co-combustion)	-	220	587	367	734	514	1101
Bio Electr. & Heat (non-tradeable)	1	7	7	181	580	266	603
Bio Transport Fuels	0	39	361	87	393	87	393
Total bio-energy	719	1046	1849	1968	3964	2563	6357
Other renewables	623	985	1053	1197	1820	1336	2004
Total renewables	1342	2031	2901	3166	5784	3899	8361
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	473	48	58	52	348	176	449
Solid agricultural residues	0	645	1044	1305	1772	1604	1789
Solid industrial residues	245	252	279	252	279	252	279
Solid energy crops	0	5	8	8	61	56	63
Imported biomass	0	50	92	83	530	122	2780
Non-tradeables:							
Wet manure	0	0	0	0	0	0	3
Organic waste /b	0	0	0	152	509	195	514
Sewage gas	1	1	1	1	1	1	2
Landfill gas	0	6	6	28	69	70	85
Transport fuels:							
Bioethanol	0	39	361	87	393	87	393
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	719	1046	1849	1968	3964	2563	6357
a/ At a uniform equilibrium price of (E/GJ):		4.5	4.5	4.5	6	5.999	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Ireland: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	114	238	282	300	1049	336	2454
Bio Electr. (tradeable, co-combustion)	-	57	153	96	191	134	287
Bio Electr. & Heat (non-tradeable)	25	25	25	26	177	30	205
Bio Transport Fuels	0	0	0	13	127	31	144
Total bio-energy	139	320	460	434	1544	530	3089
Other renewables	106	292	365	330	588	371	725
Total renewables	245	612	825	764	2132	901	3815
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	81	133	148	134	149	135	149
Solid agricultural residues	0	45	53	48	55	50	55
Solid industrial residues	27	108	121	110	123	111	123
Solid energy crops	5	5	71	66	109	98	109
Imported biomass	0	4	41	37	804	75	2304
Non-tradeables:							
Wet manure	0	0	0	0	4	1	41
Organic waste /b	0	0	0	1	148	4	138
Sewage gas	1	1	1	1	1	1	1
Landfill gas	24	24	24	24	24	24	24
Transport fuels:							
Bioethanol	0	0	0	0	0	0	6
Biodiesel	0	0	0	13	127	31	139
Total bio-energy	139	320	460	434	1544	530	3089
a/ At a uniform equilibrium price of (E/GJ):		3	4.1	4.1	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Italy: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	1761	2681	3216	3815	6370	4654	10195
Bio Electr. (tradeable, co-combustion)	-	189	504	315	630	441	945
Bio Electr. & Heat (non-tradeable)	152	172	173	189	1378	643	1765
Bio Transport Fuels	67	70	70	70	70	70	70
Total bio-energy	1980	3113	3963	4390	8448	5808	12975
Other renewables	6821	7886	8164	9397	15017	13958	15872
Total renewables	8801	10998	12127	13786	23465	19766	28847
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1379	129	143	284	1535	373	2509
Solid agricultural residues	0	2575	3394	3644	4277	3871	4283
Solid industrial residues	382	165	182	201	941	849	944
Solid energy crops	0	0	0	0	11	0	116
Imported biomass	0	1	1	1	236	2	3289
Non-tradeables:							
Wet manure	4	4	4	12	35	19	111
Organic waste /b	116	120	120	126	1206	506	1386
Sewage gas	32	48	48	49	53	50	56
Landfill gas	0	0	0	2	83	68	211
Transport fuels:							
Bioethanol	0	3	3	3	3	3	3
Biodiesel	67	67	67	67	67	67	67
Total bio-energy	1980	3113	3963	4390	8448	5808	12975
a/ At a uniform equilibrium price of (E/GJ):		2	2	2.1	4.81	2.4	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Netherlands: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	394	405	396	492	1743	1138	2695
Bio Electr. (tradeable, co-combustion)	-	185	494	309	617	432	926
Bio Electr. & Heat (non-tradeable)	341	347	347	760	1093	830	1119
Bio Transport Fuels	0	0	64	0	266	0	709
Total bio-energy	735	937	1302	1560	3718	2400	5448
Other renewables	86	266	267	300	455	372	528
Total renewables	820	1203	1569	1860	4173	2772	5976
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	341	258	419	380	419	380	421
Solid agricultural residues	0	214	295	267	295	267	295
Solid industrial residues	53	81	89	81	89	81	89
Solid energy crops	0	0	0	0	0	0	0
Imported biomass	0	37	87	73	1557	843	2814
Non-tradeables:							
Wet manure	1	1	1	1	1	1	4
Organic waste /b	227	227	228	561	768	562	784
Sewage gas	50	51	51	51	51	51	51
Landfill gas	63	68	68	147	272	216	280
Transport fuels:							
Bioethanol	0	0	0	0	0	0	308
Biodiesel	0	0	64	0	266	0	401
Total bio-energy	735	937	1302	1560	3718	2400	5448
a/ At a uniform equilibrium price of (E/GJ):		4.1	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Portugal: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	1136	1298	1652	1664	2397	2214	4271
Bio Electr. (tradeable, co-combustion)	-	82	218	137	273	191	410
Bio Electr. & Heat (non-tradeable)	535	535	535	536	1166	755	1268
Bio Transport Fuels	0	0	0	0	78	0	243
Total bio-energy	1671	1915	2405	2336	3914	3160	6191
Other renewables	1211	1623	1866	1768	2397	1809	2579
Total renewables	2882	3538	4272	4104	6311	4969	8770
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	655	691	983	965	1272	1150	1272
Solid agricultural residues	0	63	190	201	676	610	676
Solid industrial residues	480	626	694	631	708	641	708
Solid energy crops	0	0	0	0	0	0	6
Imported biomass	0	1	3	3	14	4	2018
Non-tradeables:							
Wet manure	1	1	1	1	4	3	13
Organic waste /b	534	534	534	534	1161	734	1182
Sewage gas	0	0	0	0	0	0	1
Landfill gas	0	0	0	0	1	18	72
Transport fuels:							
Bioethanol	0	0	0	0	78	0	243
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	1671	1915	2405	2336	3914	3160	6191
a/ At a uniform equilibrium price of (E/GJ):		2.8	2.8	3	6	3	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Spain: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	3107	3471	4237	4686	5971	5455	9177
Bio Electr. (tradeable, co-combustion)	-	429	1143	715	1429	1000	2144
Bio Electr. & Heat (non-tradeable)	731	755	755	788	2125	1545	2659
Bio Transport Fuels	50	408	408	408	408	408	1061
Total bio-energy	3888	5062	6543	6595	9933	8408	15041
Other renewables	3640	5524	6342	6068	7335	6238	7971
Total renewables	7528	10587	12885	12664	17268	14646	23012
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	780	933	1321	1284	1693	1390	1850
Solid agricultural residues	707	2515	2926	2804	3296	2992	3307
Solid industrial residues	1620	450	1127	1307	2271	2068	2290
Solid energy crops	0	2	5	4	118	4	2900
Imported biomass	0	0	1	1	21	1	973
Non-tradeables:							
Wet manure	11	11	11	30	99	69	277
Organic waste /b	708	728	728	728	1881	1337	1989
Sewage gas	13	14	14	16	31	22	61
Landfill gas	0	2	3	14	115	117	332
Transport fuels:							
Bioethanol	50	50	50	50	50	50	414
Biodiesel	0	358	358	358	358	358	647
Total bio-energy	3888	5062	6543	6595	9933	8408	15041
a/ At a uniform equilibrium price of (E/GJ):		1.5	1.83	1.83	3.8	1.83	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Sweden: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	3271	4278	6152	5064	8167	5249	9731
Bio Electr. (tradeable, co-combustion)	-	22	58	37	73	51	110
Bio Electr. & Heat (non-tradeable)	3106	3131	3136	3145	3308	3182	3771
Bio Transport Fuels	28	62	62	62	564	298	717
Total bio-energy	6405	7493	9408	8306	12113	8780	14328
Other renewables	6790	7021	7181	7056	7526	7105	8140
Total renewables	13195	14514	16589	15362	19639	15885	22468
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1973	2596	4178	3303	5833	3486	6250
Solid agricultural residues	38	45	49	45	138	45	143
Solid industrial residues	1148	1584	1900	1677	1935	1695	1957
Solid energy crops	112	61	67	61	272	61	782
Imported biomass	0	14	15	14	62	14	708
Non-tradeables:							
Wet manure	2	2	2	3	9	4	31
Organic waste /b	3037	3042	3046	3055	3202	3090	3637
Sewage gas	31	31	33	32	41	33	48
Landfill gas	36	56	56	56	56	56	56
Transport fuels:							
Bioethanol	28	28	28	28	476	264	610
Biodiesel	0	34	34	34	88	34	107
Total bio-energy	6405	7493	9408	8306	12113	8780	14328
a/ At a uniform equilibrium price of (E/GJ):		3.4	3.4	3.4	4.1	3.4	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

United Kingdom: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	988	1165	1143	1208	3116	2656	8584
Bio Electr. (tradeable, co-combustion)	-	835	2227	1392	2784	1949	4176
Bio Electr. & Heat (non-tradeable)	1127	1214	1215	1242	3400	1891	3964
Bio Transport Fuels	0	0	0	0	0	0	0
Total bio-energy	2115	3214	4585	3842	9300	6496	16724
Other renewables	581	1361	2443	1477	3055	1602	4106
Total renewables	2696	4575	7028	5319	12355	8098	20830
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	644	377	884	628	1110	949	1120
Solid agricultural residues	72	1334	1695	1533	1699	1537	1700
Solid industrial residues	273	282	315	285	315	285	315
Solid energy crops	0	5	366	109	1894	1524	1929
Imported biomass	0	2	110	45	882	310	7697
Non-tradeables:							
Wet manure	0	0	1	2	33	11	142
Organic waste /b	233	251	251	277	2395	915	2765
Sewage gas	163	177	178	178	187	180	225
Landfill gas	732	785	785	785	785	785	831
Transport fuels:							
Bioethanol	0	0	0	0	0	0	0
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	2115	3214	4585	3842	9300	6496	16724
a/ At a uniform equilibrium price of (E/GJ):		2.2	4.7	4.6	6	4.7	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Bulgaria: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	560	1304	1764	1550	2800	2056	3840
Bio Electr. (tradeable, co-combustion)	-	126	336	210	420	294	630
Bio Electr. & Heat (non-tradeable)	45	81	178	125	479	229	490
Bio Transport Fuels	0	0	0	0	0	0	1
Total bio-energy	606	1511	2278	1885	3699	2579	4962
Other renewables	195	405	516	433	650	466	775
Total renewables	800	1915	2794	2317	4349	3046	5736
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	546	550	911	731	1253	1131	1253
Solid agricultural residues	5	849	1154	997	1266	1143	1266
Solid industrial residues	9	29	33	29	33	30	33
Solid energy crops	0	1	1	1	436	36	436
Imported biomass	0	1	1	1	233	10	1483
Non-tradeables:							
Wet manure	0	7	13	10	26	11	32
Organic waste /b	45	59	148	87	356	171	354
Sewage gas	0	3	4	5	8	5	9
Landfill gas	0	12	13	23	89	42	95
Transport fuels:							
Bioethanol	0	0	0	0	0	0	1
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	606	1511	2278	1885	3699	2579	4962
a/ At a uniform equilibrium price of (E/GJ):		2.21	2.21	2.21	6	4.7	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Czech Republic: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	166	286	1372	392	3183	1467	4230
Bio Electr. (tradeable, co-combustion)	-	314	838	524	1047	733	1571
Bio Electr. & Heat (non-tradeable)	19	20	173	99	386	145	634
Bio Transport Fuels	241	241	241	241	241	241	241
Total bio-energy	426	861	2624	1255	4858	2586	6675
Other renewables	174	337	523	374	769	406	802
Total renewables	601	1199	3147	1629	5627	2992	7477
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	129	118	141	128	141	128	142
Solid agricultural residues	2	339	376	340	376	340	376
Solid industrial residues	35	116	356	316	356	322	358
Solid energy crops	0	2	125	71	125	113	136
Imported biomass	0	25	1213	61	3233	1297	4789
Non-tradeables:							
Wet manure	2	3	5	9	84	30	227
Organic waste /b	13	13	150	67	228	75	249
Sewage gas	0	1	2	4	43	16	122
Landfill gas	3	3	17	19	31	24	36
Transport fuels:							
Bioethanol	183	183	183	183	183	183	183
Biodiesel	58	58	58	58	58	58	58
Total bio-energy	426	861	2624	1255	4858	2586	6675
a/ At a uniform equilibrium price of (E/GJ):		4.05	6	5.4	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Estonia: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	506	646	1506	1090	1510	1184	1630
Bio Electr. (tradeable, co-combustion)	-	54	144	90	180	126	270
Bio Electr. & Heat (non-tradeable)	1	9	198	86	202	87	207
Bio Transport Fuels	0	0	0	0	11	0	29
Total bio-energy	507	709	1848	1266	1903	1397	2136
Other renewables	1	16	23	17	27	18	31
Total renewables	508	724	1871	1283	1930	1416	2167
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	380	547	755	684	755	684	755
Solid agricultural residues	0	2	25	23	25	23	25
Solid industrial residues	126	149	166	151	166	151	166
Solid energy crops	0	1	283	256	283	256	283
Imported biomass	0	0	419	66	459	196	669
Non-tradeables:							
Wet manure	0	3	6	3	6	4	6
Organic waste /b	0	3	172	63	174	63	179
Sewage gas	0	1	1	1	1	1	1
Landfill gas	1	2	19	19	21	19	21
Transport fuels:							
Bioethanol	0	0	0	0	11	0	29
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	507	709	1848	1266	1903	1397	2136
a/ At a uniform equilibrium price of (E/GJ):		1.7	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Hungary: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	295	544	500	831	1266	927	1682
Bio Electr. (tradeable, co-combustion)	-	66	175	110	219	153	329
Bio Electr. & Heat (non-tradeable)	3	4	7	59	122	74	290
Bio Transport Fuels	0	0	0	0	0	0	0
Total bio-energy	298	614	682	999	1607	1154	2300
Other renewables	142	245	508	255	361	267	576
Total renewables	441	859	1190	1255	1968	1421	2876
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	295	5	5	300	358	314	363
Solid agricultural residues	0	604	669	613	679	614	679
Solid industrial residues	0	0	0	3	42	29	48
Solid energy crops	0	1	1	17	331	96	389
Imported biomass	0	0	0	8	75	26	531
Non-tradeables:							
Wet manure	0	0	1	2	28	11	121
Organic waste /b	0	1	3	53	89	58	160
Sewage gas	2	2	2	2	2	2	5
Landfill gas	2	2	2	3	3	4	4
Transport fuels:							
Bioethanol	0	0	0	0	0	0	0
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	298	614	682	999	1607	1154	2300
a/ At a uniform equilibrium price of (E/GJ):		1.6	1.6	3.3	4.4	4.4	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Latvia: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	820	869	1098	1079	1528	1274	2237
Bio Electr. (tradeable, co-combustion)	-	1	2	1	2	1	3
Bio Electr. & Heat (non-tradeable)	60	60	61	176	217	199	222
Bio Transport Fuels	0	16	83	16	83	16	83
Total bio-energy	880	946	1244	1272	1830	1490	2545
Other renewables	316	357	372	372	437	399	446
Total renewables	1196	1303	1616	1644	2267	1888	2990
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	605	596	789	795	1068	961	1070
Solid agricultural residues	0	4	5	4	34	25	34
Solid industrial residues	215	269	304	279	315	284	315
Solid energy crops	0	1	2	1	105	4	651
Imported biomass	0	0	0	0	9	1	170
Non-tradeables:							
Wet manure	0	0	0	1	6	2	14
Organic waste /b	60	60	60	172	197	189	193
Sewage gas	0	0	0	0	0	0	0
Landfill gas	0	0	0	3	14	8	15
Transport fuels:							
Bioethanol	0	16	83	16	83	16	83
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	880	946	1244	1272	1830	1490	2545
a/ At a uniform equilibrium price of (E/GJ):		1.6	1.6	1.6	4.2	2.17	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Lithuania: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	627	790	890	1145	1650	1240	1780
Bio Electr. (tradeable, co-combustion)	-	0	0	0	0	0	0
Bio Electr. & Heat (non-tradeable)	205	208	210	210	258	239	324
Bio Transport Fuels	0	11	59	11	59	11	59
Total bio-energy	832	1009	1159	1366	1967	1490	2163
Other renewables	36	82	254	98	264	101	268
Total renewables	868	1091	1413	1464	2231	1591	2431
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	512	602	681	816	904	816	905
Solid agricultural residues	3	15	17	143	160	143	160
Solid industrial residues	113	171	190	178	196	178	196
Solid energy crops	0	2	2	7	363	96	480
Imported biomass	0	0	0	1	28	7	38
Non-tradeables:							
Wet manure	0	4	6	5	24	7	38
Organic waste /b	202	202	202	202	228	228	276
Sewage gas	3	3	3	3	4	3	5
Landfill gas	0	0	0	0	1	0	5
Transport fuels:							
Bioethanol	0	7	36	7	36	7	36
Biodiesel	0	4	23	4	23	4	23
Total bio-energy	832	1009	1159	1366	1967	1490	2163
a/ At a uniform equilibrium price of (E/GJ):		1.55	1.55	3.9	3.9	3.9	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Poland: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	1073	2279	4275	2066	3571	2052	6547
Bio Electr. (tradeable, co-combustion)	-	921	2455	1535	3069	2148	4604
Bio Electr. & Heat (non-tradeable)	436	586	1374	615	1352	689	1836
Bio Transport Fuels	524	703	1527	835	1740	836	1740
Total bio-energy	2032	4489	9631	5051	9732	5725	14726
Other renewables	192	795	1044	639	1335	755	2067
Total renewables	2224	5284	10675	5689	11066	6481	16793
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	770	452	1070	700	1070	964	1070
Solid agricultural residues	5	2740	3272	2893	3272	2959	3272
Solid industrial residues	298	2	366	2	366	64	380
Solid energy crops	0	3	217	3	217	168	219
Imported biomass	0	3	1806	3	1716	45	6209
Non-tradeables:							
Wet manure	24	161	355	189	921	263	1400
Organic waste /b	388	388	927	388	388	388	388
Sewage gas	18	19	20	19	20	19	21
Landfill gas	5	18	72	19	23	20	27
Transport fuels:							
Bioethanol	524	676	1027	738	1078	739	1078
Biodiesel	0	27	500	97	663	97	663
Total bio-energy	2032	4489	9631	5051	9732	5725	14726
a/ At a uniform equilibrium price of (E/GJ):		2.6	6	2.6	6	4.8	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Romania: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	2833	3038	3029	4026	5846	4678	8352
Bio Electr. (tradeable, co-combustion)	-	102	271	170	339	237	509
Bio Electr. & Heat (non-tradeable)	0	4	5	575	952	589	960
Bio Transport Fuels	0	0	110	8	256	58	341
Total bio-energy	2833	3144	3415	4778	7393	5562	10160
Other renewables	1171	1856	1940	2042	2596	2114	2865
Total renewables	4004	5000	5355	6820	9989	7676	13025
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	2622	2352	2434	2475	2881	2608	2881
Solid agricultural residues	0	252	278	1178	1948	1760	1949
Solid industrial residues	211	535	588	540	603	546	603
Solid energy crops	0	0	0	1	616	1	743
Imported biomass	0	0	0	0	137	0	2684
Non-tradeables:							
Wet manure	0	2	2	2	3	2	4
Organic waste /b	0	1	2	463	806	463	810
Sewage gas	0	0	0	0	0	0	0
Landfill gas	0	0	0	110	143	124	145
Transport fuels:							
Bioethanol	0	0	41	2	135	36	195
Biodiesel	0	0	69	6	121	22	145
Total bio-energy	2833	3144	3415	4778	7393	5562	10160
a/ At a uniform equilibrium price of (E/GJ):		1.4	1.4	1.94	4.7	1.94	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Slovakia: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	16	60	132	158	245	246	839
Bio Electr. (tradeable, co-combustion)	-	40	107	67	134	94	201
Bio Electr. & Heat (non-tradeable)	239	244	250	250	261	255	261
Bio Transport Fuels	47	47	47	47	47	47	47
Total bio-energy	302	391	536	522	687	642	1348
Other renewables	595	953	1064	1032	1550	1100	1774
Total renewables	897	1344	1600	1554	2237	1741	3122
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	15	4	8	18	41	37	42
Solid agricultural residues	0	93	226	197	238	216	242
Solid industrial residues	2	1	3	5	38	34	42
Solid energy crops	0	1	1	2	36	31	54
Imported biomass	0	1	1	3	25	23	659
Non-tradeables:							
Wet manure	0	2	5	4	11	7	10
Organic waste /b	239	239	239	239	239	239	239
Sewage gas	0	2	3	4	8	6	8
Landfill gas	0	1	2	3	3	3	4
Transport fuels:							
Bioethanol	35	35	35	35	35	35	35
Biodiesel	12	12	12	12	12	12	12
Total bio-energy	302	391	536	522	687	642	1348
a/ At a uniform equilibrium price of (E/GJ):		2.7	2.7	3.1	4.2	4.2	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Slovenia: Consumption of bio-energy (primary energy, ktoe/year) (Base Case)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	61	112	147	135	730	333	905
Bio Electr. (tradeable, co-combustion)	-	33	88	55	110	77	165
Bio Electr. & Heat (non-tradeable)	64	90	116	128	266	143	293
Bio Transport Fuels	0	0	0	0	0	0	0
Total bio-energy	125	235	351	318	1106	553	1363
Other renewables	401	549	622	675	773	677	789
Total renewables	526	784	973	993	1879	1230	2152
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	61	115	141	128	144	130	144
Solid agricultural residues	0	24	26	24	27	24	27
Solid industrial residues	0	1	25	10	42	38	42
Solid energy crops	0	1	19	17	22	20	22
Imported biomass	0	4	24	11	606	198	836
Non-tradeables:							
Wet manure	0	24	49	25	82	27	105
Organic waste /b	60	60	60	94	170	105	173
Sewage gas	0	0	0	0	0	0	0
Landfill gas	4	6	6	9	13	11	13
Transport fuels:							
Bioethanol	0	0	0	0	0	0	0
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	125	235	351	318	1106	553	1363
a/ At a uniform equilibrium price of (E/GJ):		3.3	4.8	4.8	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

APPENDIX E
COUNTRY TABLES: NON-SUBSIDISED INNOVATIVE TECHNOLOGIES SCENARIO

EU15+10+2: Consumption of bio-energy (primary energy, Mtoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	33	46	69	59	119	70	163
Bio Electr. (tradeable, co-combustion)	-	6.4	17	11	21	15	32
Bio Electr. & Heat (non-tradeable)	15	16	18	18	34	22	40
Bio Transport Fuels	50	3.8	5.7	4.1	8.9	4.5	15
Total bio-energy	98	72	110	92	183	111	249
Other renewables	38	50	56	56	75	63	87
Total renewables	136	122	166	147	258	174	336
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	22	25	35	30	43	33	44
Solid agricultural residues	1.3	18	26	23	35	26	36
Solid industrial residues	9.0	9.3	13	12	14	12	14
Solid energy crops	0.1	0.2	5.6	2.8	15	6.7	19
Imported biomass	0.0	0.3	7.0	2.2	33	6.8	81
Non-tradeables:							
Wet manure	0.1	0.3	0.9	0.5	3.0	0.7	5.3
Organic waste /b	13	13	14	15	26	18	28
Sewage gas	0.8	0.9	0.9	0.9	1.2	0.9	1.5
Landfill gas	1.2	1.3	1.5	1.7	3.6	2.6	4.5
Transport fuels:							
Bioethanol	0.9	2.2	3.1	2.3	5.6	2.7	10
Biodiesel	0.7	1.6	2.6	1.8	3.3	1.8	4.3
Total bio-energy	49	72	110	92	183	111	249
a/ At an average equilibrium price of (E/GJ):		2.9	4.0	3.5	5.3	4.2	6.0

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

EU15: Consumption of bio-energy (primary energy, Mtoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	26	36	52	45	93	54	127
Bio Electr. (tradeable, co-combustion)	-	4.7	13	7.8	16	11	24
Bio Electr. & Heat (non-tradeable)	14	14	15	16	28	19	33
Bio Transport Fuels	0.7	2.4	3.2	2.6	6.1	2.9	11
Total bio-energy	41	57	83	71	143	87	195
Other renewables	34	44	49	50	67	57	77
Total renewables	75	102	132	121	210	144	272
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	16	20	26	22	34	25	35
Solid agricultural residues	1.3	13	20	16	27	19	28
Solid industrial residues	8	8	11	10	12	11	12
Solid energy crops	0.1	0.2	5.0	2.4	12	5.7	16
Imported biomass	0.0	0.3	2.8	1.9	23	5.1	60
Non-tradeables:							
Wet manure	0.1	0.1	0.4	0.2	1.3	0.4	3.0
Organic waste /b	12	12	12	13	23	15	25
Sewage gas	0.8	0.8	0.9	0.9	1.1	0.9	1.3
Landfill gas	1.1	1.3	1.3	1.5	3.2	2.3	4.0
Transport fuels:							
Bioethanol	0.1	1.3	1.6	1.3	4.0	1.7	8.3
Biodiesel	0.6	1.1	1.6	1.2	2.1	1.3	2.7
Total bio-energy	41	57	83	71	143	87	195
a/ At an average equilibrium price of (E/GJ):		3.2	3.9	3.7	5.2	4.3	6.0

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

EU+10+2: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	7.0	11	17	14	26	15	35
Bio Electr. (tradeable, co-combustion)	-	1.7	4.4	2.8	5.5	3.9	8.3
Bio Electr. & Heat (non-tradeable)	1.1	1.3	2.9	2.5	5.5	2.8	6.4
Bio Transport Fuels	0.9	1.4	2.5	1.6	2.8	1.6	3.6
Total bio-energy	8.9	15	27	21	40	24	54
Other renewables	3.2	5.6	6.9	6.0	8.8	6.4	11
Total renewables	12	21	34	27	48	30	64
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	5.9	5.7	8.2	7.4	8.6	7.7	8.6
Solid agricultural residues	0.0	5.1	6.2	7.1	8.0	7.2	8.0
Solid industrial residues	1.0	1.3	2.1	1.5	2.2	1.7	2.2
Solid energy crops	0.0	0.0	0.7	0.4	3.0	0.9	3.4
Imported biomass	0.0	0.1	4.2	0.2	9.4	1.8	21.4
Non-tradeables:							
Wet manure	0.0	0.2	0.5	0.2	1.7	0.4	2.3
Organic waste /b	1.0	1.0	2.1	2.0	3.2	2.1	3.3
Sewage gas	0.0	0.0	0.0	0.0	0.1	0.0	0.2
Landfill gas	0.0	0.0	0.2	0.2	0.5	0.3	0.5
Transport fuels:							
Bioethanol	0.8	1.0	1.5	1.0	1.6	1.1	2.0
Biodiesel	0.1	0.5	1.0	0.5	1.2	0.6	1.5
Total bio-energy	8.9	15	27	21	40	24	54
a/ At an average equilibrium price of (E/GJ):		2.1	4.2	2.8	5.4	3.7	6.0

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Austria: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	2526	3156	4508	3513	6065	3920	6788
Bio Electr. (tradeable, co-combustion)	-	35	92	58	115	81	173
Bio Electr. & Heat (non-tradeable)	622	625	625	625	948	625	1061
Bio Transport Fuels	24	50	122	50	160	62	424
Total bio-energy	3172	3865	5348	4245	7288	4688	8445
Other renewables	3584	4016	4112	4072	4243	4089	4385
Total renewables	6756	7881	9459	8317	11532	8777	12830
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1308	1998	3267	2371	4649	2795	5059
Solid agricultural residues	23	24	27	24	214	24	236
Solid industrial residues	1195	1166	1304	1173	1310	1179	1311
Solid energy crops	0	0	0	0	1	0	228
Imported biomass	0	2	2	2	7	2	126
Non-tradeables:							
Wet manure	2	2	2	2	2	2	2
Organic waste /b	603	604	604	604	923	604	1030
Sewage gas	8	8	8	8	8	8	8
Landfill gas	8	12	12	12	16	12	21
Transport fuels:							
Bioethanol	0	17	17	17	17	30	271
Biodiesel	24	32	105	32	142	32	154
Total bio-energy	3172	3865	5348	4245	7288	4688	8445
a/ At a uniform equilibrium price of (E/GJ):		2.5	2.5	2.5	3.2	2.5	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Belgium: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	143	585	1314	639	1968	753	3667
Bio Electr. (tradeable, co-combustion)	-	115	306	191	382	267	573
Bio Electr. & Heat (non-tradeable)	271	281	281	281	942	296	1283
Bio Transport Fuels	17	43	352	127	409	226	778
Total bio-energy	432	1024	2253	1238	3701	1542	6301
Other renewables	65	123	311	173	434	189	719
Total renewables	497	1147	2564	1411	4135	1731	7020
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	8	175	195	176	196	176	198
Solid agricultural residues	0	162	179	162	179	162	179
Solid industrial residues	136	299	330	299	330	299	330
Solid energy crops	0	0	5	1	11	2	20
Imported biomass	0	63	911	193	1634	382	3512
Non-tradeables:							
Wet manure	0	0	0	0	0	0	3
Organic waste /b	251	251	251	251	911	265	1151
Sewage gas	21	30	31	31	31	31	32
Landfill gas	0	0	0	0	0	0	98
Transport fuels:							
Bioethanol	0	12	12	12	12	109	366
Biodiesel	17	31	340	115	398	117	412
Total bio-energy	432	1024	2253	1238	3701	1542	6301
a/ At a uniform equilibrium price of (E/GJ):		6	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Denmark: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	793	970	1242	963	1805	1226	2298
Bio Electr. (tradeable, co-combustion)	-	161	428	268	535	375	803
Bio Electr. & Heat (non-tradeable)	138	143	143	143	184	161	267
Bio Transport Fuels	0	0	40	0	120	0	319
Total bio-energy	931	1273	1853	1373	2645	1761	3686
Other renewables	387	777	822	807	1045	833	1126
Total renewables	1318	2050	2675	2180	3689	2594	4812
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	370	275	417	315	466	377	466
Solid agricultural residues	310	647	738	647	756	668	756
Solid industrial residues	113	119	131	119	131	119	131
Solid energy crops	0	53	272	89	681	299	681
Imported biomass	0	36	112	60	307	136	1067
Non-tradeables:							
Wet manure	31	31	31	31	68	48	146
Organic waste /b	77	77	77	77	77	77	77
Sewage gas	16	16	16	16	20	17	26
Landfill gas	14	19	19	19	19	19	19
Transport fuels:							
Bioethanol	0	0	40	0	120	0	158
Biodiesel	0	0	0	0	0	0	161
Total bio-energy	931	1273	1853	1373	2645	1761	3686
a/ At a uniform equilibrium price of (E/GJ):		4.5	4.9	4.5	6	4.9	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Finland: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	2329	2448	3365	3147	5394	3596	7031
Bio Electr. (tradeable, co-combustion)	-	92	245	153	306	214	459
Bio Electr. & Heat (non-tradeable)	3444	3449	3471	3458	3653	3464	4327
Bio Transport Fuels	0	0	2	0	29	0	97
Total bio-energy	5773	5989	7082	6758	9382	7274	11914
Other renewables	1287	1351	1534	1371	1663	1404	1809
Total renewables	7060	7340	8617	8128	11045	8679	13724
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1200	1474	2378	2177	3825	2582	3828
Solid agricultural residues	0	159	189	174	255	200	255
Solid industrial residues	1124	905	1040	948	1232	1026	1233
Solid energy crops	5	0	1	1	224	1	354
Imported biomass	0	1	2	2	164	2	1819
Non-tradeables:							
Wet manure	1	5	19	10	62	15	102
Organic waste /b	3429	3429	3429	3429	3561	3429	4139
Sewage gas	10	11	14	11	16	12	19
Landfill gas	4	4	9	7	13	8	68
Transport fuels:							
Bioethanol	0	0	0	0	0	0	35
Biodiesel	0	0	2	0	29	0	63
Total bio-energy	5773	5989	7082	6758	9382	7274	11914
a/ At a uniform equilibrium price of (E/GJ):		2.5	2.5	2.5	5.3	2.5	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

France: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	4083	7772	12325	8978	21256	11309	26514
Bio Electr. (tradeable, co-combustion)	-	253	675	422	844	591	1266
Bio Electr. & Heat (non-tradeable)	1491	1544	1791	1600	2241	1664	2812
Bio Transport Fuels	339	555	555	555	1292	555	2512
Total bio-energy	5913	10124	15346	11555	25633	14119	33104
Other renewables	6254	6755	7970	8139	11038	8708	14306
Total renewables	12167	16879	23316	19695	36672	22826	47410
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	3791	6595	7481	6772	7720	6772	7760
Solid agricultural residues	94	412	4154	1554	10167	3879	10756
Solid industrial residues	198	978	1089	986	1100	986	1101
Solid energy crops	0	34	238	76	2702	226	4826
Imported biomass	0	6	39	12	411	37	3336
Non-tradeables:							
Wet manure	0	33	248	80	517	136	961
Organic waste /b	1380	1380	1380	1380	1380	1380	1380
Sewage gas	62	68	83	73	104	77	108
Landfill gas	49	62	80	66	241	71	362
Transport fuels:							
Bioethanol	58	152	152	152	888	152	2109
Biodiesel	282	404	404	404	404	404	404
Total bio-energy	5913	10124	15346	11555	25633	14119	33104
a/ At a uniform equilibrium price of (E/GJ):		2.6	3.8	3.8	4.7	3.8	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Germany: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	4357	5387	7288	6611	12852	7855	20973
Bio Electr. (tradeable, co-combustion)	-	2033	5422	3389	6778	4745	10167
Bio Electr. & Heat (non-tradeable)	2114	2138	2143	2353	3251	2870	4029
Bio Transport Fuels	206	1181	1181	1181	2189	1181	3599
Total bio-energy	6677	10739	16033	13534	25070	16651	38769
Other renewables	3035	6511	6657	7386	9788	8597	12627
Total renewables	9712	17250	22691	20920	34858	25248	51396
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	3342	3367	3735	3383	3827	3391	3879
Solid agricultural residues	60	3055	3403	3055	3403	3080	3409
Solid industrial residues	955	941	1047	941	1047	948	1049
Solid energy crops	0	31	3518	1724	3518	3185	3827
Imported biomass	0	26	1007	897	7835	1996	18975
Non-tradeables:							
Wet manure	31	31	32	38	192	68	600
Organic waste /b	1490	1490	1490	1690	1690	1751	1751
Sewage gas	373	387	390	392	472	405	569
Landfill gas	220	230	230	233	897	646	1109
Transport fuels:							
Bioethanol	0	970	970	970	1979	970	3389
Biodiesel	206	210	210	210	210	210	210
Total bio-energy	6677	10739	16033	13534	25070	16651	38769
a/ At a uniform equilibrium price of (E/GJ):		5.2	6	5.2	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Greece: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	718	850	1253	1483	3536	1906	4899
Bio Electr. (tradeable, co-combustion)	-	220	587	367	734	514	1101
Bio Electr. & Heat (non-tradeable)	1	7	8	220	863	325	887
Bio Transport Fuels	0	39	361	87	393	87	393
Total bio-energy	719	1116	2209	2157	5527	2833	7280
Other renewables	623	985	1050	1197	1818	1336	2003
Total renewables	1342	2101	3259	3354	7344	4168	9283
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	473	49	58	52	348	293	504
Solid agricultural residues	0	705	1404	1455	1772	1604	1799
Solid industrial residues	245	252	279	252	279	252	279
Solid energy crops	0	5	8	8	61	56	65
Imported biomass	0	59	92	83	1810	216	3354
Non-tradeables:							
Wet manure	0	0	0	0	1	0	5
Organic waste /b	0	0	0	185	759	240	765
Sewage gas	1	1	1	1	1	1	2
Landfill gas	0	6	6	34	102	84	115
Transport fuels:							
Bioethanol	0	39	361	87	393	87	393
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	719	1116	2209	2157	5527	2833	7280
a/ At a uniform equilibrium price of (E/GJ):		4.5	4.5	4.5	6	5.999	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Ireland: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	114	243	537	310	2369	496	3454
Bio Electr. (tradeable, co-combustion)	-	57	153	96	191	134	287
Bio Electr. & Heat (non-tradeable)	25	25	25	26	256	30	287
Bio Transport Fuels	0	0	0	13	127	31	144
Total bio-energy	139	325	715	444	2942	690	4171
Other renewables	106	292	365	330	576	371	715
Total renewables	245	617	1081	774	3519	1061	4886
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	81	134	149	135	149	135	149
Solid agricultural residues	0	48	55	50	55	50	55
Solid industrial residues	27	109	123	111	123	111	123
Solid energy crops	5	6	109	98	109	98	109
Imported biomass	0	3	254	10	2124	235	3303
Non-tradeables:							
Wet manure	0	0	0	0	9	1	82
Organic waste /b	0	0	0	1	220	4	179
Sewage gas	1	1	1	1	1	1	1
Landfill gas	24	24	24	24	26	24	25
Transport fuels:							
Bioethanol	0	0	0	0	0	0	6
Biodiesel	0	0	0	13	127	31	139
Total bio-energy	139	325	715	444	2942	690	4171
a/ At a uniform equilibrium price of (E/GJ):		4.1	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Italy: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	1761	2871	4496	4365	7175	4654	10475
Bio Electr. (tradeable, co-combustion)	-	189	504	315	630	441	945
Bio Electr. & Heat (non-tradeable)	152	172	177	189	2110	792	2531
Bio Transport Fuels	67	70	70	70	70	70	70
Total bio-energy	1980	3303	5247	4940	9985	5957	14021
Other renewables	6821	7886	8164	9393	15242	13951	15871
Total renewables	8801	11188	13411	14333	25227	19908	29892
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1379	129	386	357	2330	373	2521
Solid agricultural residues	0	2765	4072	3745	4281	3871	4283
Solid industrial residues	382	165	540	576	943	849	944
Solid energy crops	0	0	0	0	11	0	116
Imported biomass	0	1	2	2	239	2	3557
Non-tradeables:							
Wet manure	4	4	4	12	67	19	199
Organic waste /b	116	120	123	126	1748	569	1935
Sewage gas	32	48	49	49	57	50	64
Landfill gas	0	0	0	2	239	154	333
Transport fuels:							
Bioethanol	0	3	3	3	3	3	3
Biodiesel	67	67	67	67	67	67	67
Total bio-energy	1980	3303	5247	4940	9985	5957	14021
a/ At a uniform equilibrium price of (E/GJ):		2	2.4	2.4	4.81	2.4	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Netherlands: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	394	455	466	982	2633	1288	4005
Bio Electr. (tradeable, co-combustion)	-	185	494	309	617	432	926
Bio Electr. & Heat (non-tradeable)	341	347	348	931	1591	979	1635
Bio Transport Fuels	0	0	64	0	266	0	709
Total bio-energy	735	987	1372	2221	5107	2699	7274
Other renewables	86	266	267	303	451	372	528
Total renewables	820	1253	1639	2524	5559	3072	7802
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	341	290	419	380	420	380	422
Solid agricultural residues	0	232	295	267	295	267	296
Solid industrial residues	53	81	89	81	89	81	89
Solid energy crops	0	0	0	0	0	0	0
Imported biomass	0	37	157	563	2446	993	4122
Non-tradeables:							
Wet manure	1	1	1	1	2	1	8
Organic waste /b	227	227	228	669	1135	671	1167
Sewage gas	50	51	51	51	51	51	52
Landfill gas	63	68	68	210	403	257	408
Transport fuels:							
Bioethanol	0	0	0	0	0	0	308
Biodiesel	0	0	64	0	266	0	401
Total bio-energy	735	987	1372	2221	5107	2699	7274
a/ At a uniform equilibrium price of (E/GJ):		4.1	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Portugal: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	1136	1428	2382	1744	3177	2214	4801
Bio Electr. (tradeable, co-combustion)	-	82	218	137	273	191	410
Bio Electr. & Heat (non-tradeable)	535	535	536	536	1477	824	1500
Bio Transport Fuels	0	0	0	0	78	0	243
Total bio-energy	1671	2045	3136	2416	5005	3229	6953
Other renewables	1211	1623	1866	1768	2384	1809	2583
Total renewables	2882	3668	5001	4184	7388	5039	9536
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	655	777	1260	972	1272	1150	1272
Solid agricultural residues	0	105	628	272	676	610	676
Solid industrial residues	480	626	708	631	708	641	708
Solid energy crops	0	0	0	0	1	0	7
Imported biomass	0	2	5	4	793	4	2547
Non-tradeables:							
Wet manure	1	1	1	1	6	3	20
Organic waste /b	534	534	534	534	1401	786	1365
Sewage gas	0	0	0	0	1	0	2
Landfill gas	0	0	0	0	69	35	114
Transport fuels:							
Bioethanol	0	0	0	0	78	0	243
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	1671	2045	3136	2416	5005	3229	6953
a/ At a uniform equilibrium price of (E/GJ):		2.8	3	3	6	3	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Spain: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	3107	3951	5257	5736	8331	5700	11617
Bio Electr. (tradeable, co-combustion)	-	429	1143	715	1429	1000	2144
Bio Electr. & Heat (non-tradeable)	731	755	762	788	2528	1595	3223
Bio Transport Fuels	50	408	408	408	408	408	1040
Total bio-energy	3888	5542	7570	7645	12696	8702	18023
Other renewables	3640	5524	6338	6071	7333	6249	7974
Total renewables	7528	11066	13908	13716	20029	14951	25997
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	780	1224	1470	1390	1835	1533	1850
Solid agricultural residues	707	2703	3190	2991	3306	2984	3307
Solid industrial residues	1620	450	1734	2064	2288	2056	2290
Solid energy crops	0	2	5	4	1997	108	2900
Imported biomass	0	0	1	1	335	19	3413
Non-tradeables:							
Wet manure	11	11	14	30	220	69	478
Organic waste /b	708	728	728	728	1975	1374	2271
Sewage gas	13	14	15	16	57	22	100
Landfill gas	0	2	6	14	276	130	374
Transport fuels:							
Bioethanol	50	50	50	50	50	50	414
Biodiesel	0	358	358	358	358	358	626
Total bio-energy	3888	5542	7570	7645	12696	8702	18023
a/ At a uniform equilibrium price of (E/GJ):		1.5	1.83	1.83	4.8	3.8	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Sweden: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	3271	4378	6447	4964	8827	5649	10311
Bio Electr. (tradeable, co-combustion)	-	22	58	37	73	51	110
Bio Electr. & Heat (non-tradeable)	3106	3131	3141	3145	3449	3182	3998
Bio Transport Fuels	28	62	62	62	564	298	721
Total bio-energy	6405	7593	9708	8206	12914	9180	15139
Other renewables	6790	7021	7181	7056	7533	7028	7977
Total renewables	13195	14614	16888	15263	20446	16208	23116
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1973	2682	4364	3213	6119	3855	6250
Solid agricultural residues	38	45	130	45	141	45	143
Solid industrial residues	1148	1599	1911	1668	1949	1726	1957
Solid energy crops	112	61	82	61	599	61	782
Imported biomass	0	14	19	14	92	14	1288
Non-tradeables:							
Wet manure	2	2	3	3	22	4	46
Organic waste /b	3037	3042	3048	3055	3332	3090	3845
Sewage gas	31	31	34	32	40	33	49
Landfill gas	36	56	56	56	56	56	58
Transport fuels:							
Bioethanol	28	28	28	28	476	264	610
Biodiesel	0	34	34	34	88	34	111
Total bio-energy	6405	7593	9708	8206	12914	9180	15139
a/ At a uniform equilibrium price of (E/GJ):		3.4	3.5	3.4	4.3	3.4	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

United Kingdom: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	988	1365	1593	1638	7536	3621	10484
Bio Electr. (tradeable, co-combustion)	-	835	2227	1392	2784	1949	4176
Bio Electr. & Heat (non-tradeable)	1127	1214	1216	1217	4703	2085	5496
Bio Transport Fuels	0	0	0	0	0	0	0
Total bio-energy	2115	3414	5036	4247	15023	7655	20156
Other renewables	581	1361	2443	1477	3056	1604	4104
Total renewables	2696	4775	7479	5723	18080	9259	24260
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	644	382	884	800	1110	1005	1125
Solid agricultural residues	72	1527	1695	1534	1699	1538	1700
Solid industrial residues	273	285	315	285	315	285	315
Solid energy crops	0	5	719	314	1894	1714	1946
Imported biomass	0	2	208	96	5302	1028	9575
Non-tradeables:							
Wet manure	0	0	2	2	92	11	304
Organic waste /b	233	251	251	251	3607	1108	4018
Sewage gas	163	177	178	178	207	180	276
Landfill gas	732	785	785	785	797	786	898
Transport fuels:							
Bioethanol	0	0	0	0	0	0	0
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	2115	3414	5036	4247	15023	7655	20156
a/ At a uniform equilibrium price of (E/GJ):		2.2	4.7	4.7	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Bulgaria: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	560	1354	2214	1850	3260	2016	4510
Bio Electr. (tradeable, co-combustion)	-	126	336	210	420	294	630
Bio Electr. & Heat (non-tradeable)	45	80	238	122	573	235	546
Bio Transport Fuels	0	0	0	0	0	0	1
Total bio-energy	606	1560	2788	2182	4253	2545	5687
Other renewables	195	405	516	433	649	466	773
Total renewables	800	1965	3304	2614	4902	3011	6460
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	546	573	1250	939	1253	1047	1253
Solid agricultural residues	5	876	1264	1090	1266	1061	1266
Solid industrial residues	9	29	33	30	33	30	33
Solid energy crops	0	1	2	1	436	171	436
Imported biomass	0	1	1	1	693	1	2153
Non-tradeables:							
Wet manure	0	6	16	10	31	11	34
Organic waste /b	45	59	195	85	403	171	374
Sewage gas	0	3	6	5	11	5	10
Landfill gas	0	12	20	22	127	47	127
Transport fuels:							
Bioethanol	0	0	0	0	0	0	1
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	606	1560	2788	2182	4253	2545	5687
a/ At a uniform equilibrium price of (E/GJ):		2.21	2.3	2.21	6	2.3	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Czech Republic: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	166	376	1712	537	4033	1327	5680
Bio Electr. (tradeable, co-combustion)	-	314	838	524	1047	733	1571
Bio Electr. & Heat (non-tradeable)	19	20	262	117	638	164	868
Bio Transport Fuels	241	241	241	241	241	241	241
Total bio-energy	426	951	3053	1419	5959	2465	8359
Other renewables	174	337	516	374	763	406	797
Total renewables	601	1288	3570	1792	6722	2871	9156
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	129	119	141	128	142	128	142
Solid agricultural residues	2	339	376	340	376	340	376
Solid industrial residues	35	177	356	322	357	322	359
Solid energy crops	0	4	125	113	132	113	142
Imported biomass	0	51	1553	157	4074	1157	6232
Non-tradeables:							
Wet manure	2	3	12	9	167	30	292
Organic waste /b	13	13	219	81	354	90	357
Sewage gas	0	1	7	4	70	15	168
Landfill gas	3	3	24	24	46	29	50
Transport fuels:							
Bioethanol	183	183	183	183	183	183	183
Biodiesel	58	58	58	58	58	58	58
Total bio-energy	426	951	3053	1419	5959	2465	8359
a/ At a uniform equilibrium price of (E/GJ):		4.05	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Estonia: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	506	726	1596	1025	1610	1224	1830
Bio Electr. (tradeable, co-combustion)	-	54	144	90	180	126	270
Bio Electr. & Heat (non-tradeable)	1	9	230	104	233	106	245
Bio Transport Fuels	50	408	408	408	408	408	1040
Total bio-energy	557	1196	2377	1627	2431	1863	3385
Other renewables	1	16	23	17	27	18	31
Total renewables	558	1212	2401	1644	2458	1881	3416
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	380	626	755	683	755	684	755
Solid agricultural residues	0	2	25	23	25	23	25
Solid industrial residues	126	150	166	151	166	151	166
Solid energy crops	0	1	283	228	283	256	283
Imported biomass	0	0	509	31	559	236	869
Non-tradeables:							
Wet manure	0	3	6	3	6	5	6
Organic waste /b	0	3	195	77	196	77	207
Sewage gas	0	1	1	1	1	1	1
Landfill gas	1	2	28	23	31	23	31
Transport fuels:							
Bioethanol	50	50	50	50	50	50	414
Biodiesel	0	358	358	358	358	358	626
Total bio-energy	557	1196	2377	1627	2431	1863	3385
a/ At a uniform equilibrium price of (E/GJ):		1.7	6	4	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Hungary: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	295	544	865	831	1266	997	2212
Bio Electr. (tradeable, co-combustion)	-	66	175	110	219	153	329
Bio Electr. & Heat (non-tradeable)	3	4	17	67	209	79	426
Bio Transport Fuels	0	0	0	0	0	0	0
Total bio-energy	298	614	1057	1007	1694	1229	2966
Other renewables	142	245	508	255	361	267	589
Total renewables	441	859	1565	1261	2055	1496	3555
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	295	5	333	300	358	317	363
Solid agricultural residues	0	604	677	613	679	614	679
Solid industrial residues	0	0	3	3	42	32	48
Solid energy crops	0	1	18	17	331	146	389
Imported biomass	0	0	8	8	75	41	1061
Non-tradeables:							
Wet manure	0	0	3	2	79	11	192
Organic waste /b	0	1	11	61	126	62	223
Sewage gas	2	2	2	2	3	2	7
Landfill gas	2	2	2	2	2	4	5
Transport fuels:							
Bioethanol	0	0	0	0	0	0	0
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	298	614	1057	1007	1694	1229	2966
a/ At a uniform equilibrium price of (E/GJ):		1.6	3.3	3.3	4.4	4.5	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Latvia: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	820	799	1378	1079	1918	1279	2487
Bio Electr. (tradeable, co-combustion)	-	1	2	1	2	1	3
Bio Electr. & Heat (non-tradeable)	60	60	62	199	228	201	238
Bio Transport Fuels	0	16	83	16	83	16	83
Total bio-energy	880	876	1525	1295	2230	1497	2811
Other renewables	316	357	372	372	437	396	445
Total renewables	1196	1233	1897	1667	2667	1893	3256
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	605	531	1059	795	1069	963	1070
Solid agricultural residues	0	4	5	4	34	28	34
Solid industrial residues	215	263	314	279	315	285	315
Solid energy crops	0	1	2	1	452	4	651
Imported biomass	0	0	0	0	50	1	420
Non-tradeables:							
Wet manure	0	0	1	1	11	2	16
Organic waste /b	60	60	60	194	195	189	198
Sewage gas	0	0	0	0	0	0	0
Landfill gas	0	0	0	4	22	10	22
Transport fuels:							
Bioethanol	0	16	83	16	83	16	83
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	880	876	1525	1295	2230	1497	2811
a/ At a uniform equilibrium price of (E/GJ):		1.6	1.6	1.6	4.2	2.17	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Lithuania: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	627	990	1120	1145	1740	1200	1920
Bio Electr. (tradeable, co-combustion)	-	0	0	0	0	0	0
Bio Electr. & Heat (non-tradeable)	205	208	214	210	277	239	335
Bio Transport Fuels	0	11	59	11	59	11	59
Total bio-energy	832	1209	1393	1366	2075	1450	2313
Other renewables	36	82	254	98	264	101	259
Total renewables	868	1291	1647	1464	2340	1551	2572
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	512	796	845	816	905	816	905
Solid agricultural residues	3	15	73	143	160	143	160
Solid industrial residues	113	177	193	178	196	178	196
Solid energy crops	0	2	7	7	451	59	480
Imported biomass	0	0	1	1	28	4	178
Non-tradeables:							
Wet manure	0	4	9	5	32	7	41
Organic waste /b	202	202	202	202	239	228	277
Sewage gas	3	3	3	3	4	3	5
Landfill gas	0	0	0	0	1	0	11
Transport fuels:							
Bioethanol	0	7	36	7	36	7	36
Biodiesel	0	4	23	4	23	4	23
Total bio-energy	832	1209	1393	1366	2075	1450	2313
a/ At a uniform equilibrium price of (E/GJ):		1.55	2.25	3.9	3.9	3.9	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Poland: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	1073	2489	4505	2386	4751	2172	6327
Bio Electr. (tradeable, co-combustion)	-	921	2455	1535	3069	2148	4604
Bio Electr. & Heat (non-tradeable)	436	583	1474	611	1686	693	2075
Bio Transport Fuels	524	703	1527	835	1740	836	1740
Total bio-energy	2032	4696	9961	5366	11246	5849	14745
Other renewables	192	795	1037	639	1332	755	2064
Total renewables	2224	5491	10997	6005	12578	6604	16809
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	770	567	1070	955	1070	964	1070
Solid agricultural residues	5	2835	3272	2957	3272	2959	3272
Solid industrial residues	298	2	366	2	366	138	379
Solid energy crops	0	3	217	3	217	168	219
Imported biomass	0	3	2036	3	2896	91	5989
Non-tradeables:							
Wet manure	24	158	425	185	1252	266	1629
Organic waste /b	388	388	916	388	388	388	395
Sewage gas	18	19	20	19	20	19	22
Landfill gas	5	18	112	19	26	20	28
Transport fuels:							
Bioethanol	524	676	1027	738	1078	739	1078
Biodiesel	0	27	500	97	663	97	663
Total bio-energy	2032	4696	9961	5366	11246	5849	14745
a/ At a uniform equilibrium price of (E/GJ):		2.6	6	2.6	6	4.8	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Romania: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	2833	3048	3209	4631	5851	4673	8602
Bio Electr. (tradeable, co-combustion)	-	102	271	170	339	237	509
Bio Electr. & Heat (non-tradeable)	0	4	5	702	1046	724	1058
Bio Transport Fuels	0	0	110	8	256	58	341
Total bio-energy	2833	3154	3595	5510	7492	5691	10509
Other renewables	1171	1856	1940	2052	2646	2204	2903
Total renewables	4004	5010	5535	7562	10137	7895	13412
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	2622	2362	2610	2591	2881	2607	2881
Solid agricultural residues	0	252	278	1661	1948	1755	1949
Solid industrial residues	211	536	592	545	603	546	603
Solid energy crops	0	0	0	1	621	1	746
Imported biomass	0	0	0	0	137	0	2930
Non-tradeables:							
Wet manure	0	2	3	2	3	2	6
Organic waste /b	0	1	2	571	829	571	836
Sewage gas	0	0	0	0	0	0	0
Landfill gas	0	0	0	130	214	151	216
Transport fuels:							
Bioethanol	0	0	41	2	135	36	195
Biodiesel	0	0	69	6	121	22	145
Total bio-energy	2833	3154	3595	5510	7492	5691	10509
a/ At a uniform equilibrium price of (E/GJ):		1.4	1.4	1.94	4.7	1.94	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Slovakia: Consumption of bio-energy (primary energy, ktoe/year) (Innovative Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	16	80	173	163	346	201	749
Bio Electr. (tradeable, co-combustion)	-	40	107	67	134	94	201
Bio Electr. & Heat (non-tradeable)	239	244	254	249	262	254	264
Bio Transport Fuels	47	47	47	47	47	47	47
Total bio-energy	302	411	581	526	789	596	1261
Other renewables	595	953	1064	1032	1546	1100	1893
Total renewables	897	1364	1646	1558	2336	1696	3154
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	15	6	36	20	42	36	42
Solid agricultural residues	0	110	232	200	242	213	242
Solid industrial residues	2	2	6	5	42	30	42
Solid energy crops	0	1	3	2	54	8	54
Imported biomass	0	1	3	3	99	8	569
Non-tradeables:							
Wet manure	0	2	8	4	11	6	10
Organic waste /b	239	239	239	239	239	239	239
Sewage gas	0	2	5	4	8	6	10
Landfill gas	0	1	3	2	3	3	4
Transport fuels:							
Bioethanol	35	35	35	35	35	35	35
Biodiesel	12	12	12	12	12	12	12
Total bio-energy	302	411	581	526	789	596	1261
a/ At a uniform equilibrium price of (E/GJ):		2.7	3.1	3.1	6	3.7	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Slovenia: Consumption of bio-energy (primary energy, ktoe/year) (Innovative technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio Electr. & Heat (tradeable, dedicated plant)	61	116	192	155	930	363	1105
Bio Electr. (tradeable, co-combustion)	-	33	88	55	110	77	165
Bio Electr. & Heat (non-tradeable)	64	90	129	138	345	156	366
Bio Transport Fuels	0	0	0	0	0	0	0
Total bio-energy	125	239	409	348	1385	596	1636
Other renewables	401	549	622	680	773	675	789
Total renewables	526	788	1031	1028	2157	1271	2425
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	61	119	144	128	144	130	144
Solid agricultural residues	0	24	27	24	27	24	27
Solid industrial residues	0	1	42	21	42	38	42
Solid energy crops	0	1	22	17	22	20	22
Imported biomass	0	4	46	20	806	228	1036
Non-tradeables:							
Wet manure	0	24	61	25	102	27	112
Organic waste /b	60	60	60	103	225	115	236
Sewage gas	0	0	0	0	0	0	0
Landfill gas	4	6	7	10	18	13	18
Transport fuels:							
Bioethanol	0	0	0	0	0	0	0
Biodiesel	0	0	0	0	0	0	0
Total bio-energy	125	239	409	348	1385	596	1636
a/ At a uniform equilibrium price of (E/GJ):		3.3	6	4.8	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

APPENDIX F
COUNTRY TABLES: SUBSIDISED INNOVATIVE TECHNOLOGIES SCENARIO

EU15+10+2: Consumption of bio-energy (primary energy, Mtoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	33	47	71	61	121	72	167
Bio-energy (tradeable, co-combustion)	-	6.4	17	11	21	15	32
Bio-energy (non-tradeable)	15	16	18	18	34	22	40
Bio-energy (transport fuels)	1.5	3.4	5.3	3.7	8.5	3.7	8.5
Total bio-energy	49	72	110	93	185	112	247
Other renewables	38	50	56	56	75	63	87
Total renewables	87	122	167	148	260	175	335
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	22	25	35	31	42	33	44
Solid agricultural residues	1.3	18	27	23	36	27	36
Solid industrial residues	9.0	9.3	13	12	14	12	14
Solid energy crops	0.1	0.3	5.8	3.0	16	7.1	19
Imported biomass	-	0.3	7.7	2.4	35	7.5	86
Non-tradeables:							
Wet manure	0.1	0.3	0.9	0.5	3.0	0.7	5.4
Organic waste /b	13	13	14	15	26	17	28
Sewage gas	0.8	0.9	0.9	0.9	1.2	0.9	1.5
Landfill gas	1.2	1.3	1.5	1.7	3.6	2.5	4.5
Transport fuels:							
Energy crops - bioethanol	0.9	2.2	3.0	2.3	5.6	2.3	5.6
Energy crops - biodiesel	0.7	1.2	2.2	1.4	3.0	1.4	3.0
Total bio-energy	49	72	110	93	185	112	247
a/ At an average equilibrium price of (E/GJ):		2.9	4.0	3.5	5.3	4.3	6.0

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

EU15: Consumption of bio-energy (primary energy, Mtoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	26	36	54	46	95	56	131
Bio-energy (tradeable, co-combustion)	-	4.7	13	7.8	16	11	24
Bio-energy (non-tradeable)	14	14	15	16	28	19	33
Bio-energy (transport fuels)	41	2.4	3.2	2.6	6.1	2.6	6.1
Total bio-energy	41	57	84	72	145	88	194
Other renewables	34	45	49	50	67	56	77
Total renewables	75	102	133	122	212	145	271
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	16	20	26	23	34	25	35
Solid agricultural residues	1.3	13	21	16	27	20	28
Solid industrial residues	7.9	8.0	11	10	12	11	12
Solid energy crops	0.1	0.3	5.1	2.4	13	5.9	16
Imported biomass	-	0.3	3.5	2.0	26	5.2	63
Non-tradeables:							
Wet manure	0.1	0.1	0.4	0.2	1.3	0.4	3.1
Organic waste /b	12	12	12	13	23	15	25
Sewage gas	0.8	0.8	0.9	0.9	1.1	0.9	1.3
Landfill gas	1.1	1.3	1.3	1.5	3.2	2.2	4.0
Transport fuels:							
Energy crops - bioethanol	0.1	1.3	1.6	1.3	4.0	1.3	4.0
Energy crops - biodiesel	0.6	1.1	1.6	1.2	2.1	1.2	2.1
Total bio-energy	40	58	84	72	145	88	194
a/ At an average equilibrium price of (E/GJ):		3.2	4.0	3.7	5.2	4.5	6.0

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

EU+10+2: Consumption of bio-energy (primary energy, Mtoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	7.0	11	17	15	26	16	36
Bio-energy (tradeable, co-combustion)	-	1.7	4.4	2.8	5.5	3.9	8.3
Bio-energy (non-tradeable)	1.1	1.3	2.9	2.5	5.5	2.8	6.4
Bio-energy (transport fuels)	0.8	1.0	2.1	1.2	2.4	1.2	2.4
Total bio-energy	8.8	15	26	21	39	24	54
Other renewables	3.2	5.6	6.8	6.0	8.7	6.3	10
Total renewables	12	20	33	27	48	30	64
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	5.9	5.7	8.2	7.6	8.6	7.7	8.6
Solid agricultural residues	5.9	5.1	6.2	7.1	8.0	7.2	8.0
Solid industrial residues	0.0	1.3	2.1	1.5	2.2	1.8	2.2
Solid energy crops	1.0	0.0	0.7	0.6	3.2	1.2	3.4
Imported biomass	0.0	0.1	4.2	0.4	9.5	2.3	22
Non-tradeables:							
Wet manure	0.0	0.2	0.5	0.3	1.7	0.4	2.3
Organic waste /b	1.0	1.0	2.1	2.0	3.2	2.1	3.4
Sewage gas	0.0	0.0	0.0	0.0	0.1	0.0	0.2
Landfill gas	0.0	0.0	0.2	0.2	0.5	0.3	0.5
Transport fuels:							
Energy crops - bioethanol	0.7	0.9	1.4	1.0	1.6	1.0	1.6
Energy crops - biodiesel	0.1	0.1	0.7	0.2	0.9	0.2	0.9
Total bio-energy	8.8	15	26	21	39	24	54
a/ At an average equilibrium price of (E/GJ):		2.1	4.2	2.9	5.5	3.8	6.0

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Austria: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	2526	3156	4508	3513	6085	4370	6818
Bio-energy (tradeable, co-combustion)	-	35	92	58	115	81	173
Bio-energy (non-tradeable)	622	625	625	625	948	625	1061
Bio-energy (transport fuels)	24	50	122	50	160	50	160
Total bio-energy	3172	3865	5348	4245	7308	5125	8211
Other renewables	3584	4016	4112	4072	4243	4089	4385
Total renewables	6756	7881	9459	8317	11552	9214	12596
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1308	1998	3267	2371	4667	3241	5059
Solid agricultural residues	23	24	27	24	215	24	236
Solid industrial residues	1195	1166	1304	1173	1310	1183	1311
Solid energy crops	0	0	0	0	1	0	228
Imported biomass	0	2	2	2	7	2	156
Non-tradeables:							
Wet manure	2	2	2	2	2	2	2
Organic waste /b	603	604	604	604	923	604	1030
Sewage gas	8	8	8	8	8	8	8
Landfill gas	8	12	12	12	16	12	21
Transport fuels:							
Energy crops - bioethanol	0	17	17	17	17	17	17
Energy crops - biodiesel	24	32	105	32	142	32	142
Total bio-energy	3172	3865	5348	4245	7308	5125	8211
a/ At a uniform equilibrium price of (E/GJ):		2.5	2.5	2.5	3.2	2.5	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Belgium: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	143	585	1314	639	1968	753	3687
Bio-energy (tradeable, co-combustion)	-	115	306	191	382	267	573
Bio-energy (non-tradeable)	271	281	281	281	942	296	1284
Bio-energy (transport fuels)	17	43	352	127	409	127	409
Total bio-energy	432	1024	2253	1238	3701	1442	5953
Other renewables	65	123	311	173	434	189	719
Total renewables	497	1147	2564	1411	4135	1632	6672
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	8	175	195	176	196	176	198
Solid agricultural residues	0	162	179	162	179	162	179
Solid industrial residues	136	299	330	299	330	299	330
Solid energy crops	0	0	5	1	11	2	20
Imported biomass	0	63	911	193	1634	382	3532
Non-tradeables:							
Wet manure	0	0	0	0	0	0	3
Organic waste /b	251	251	251	251	911	265	1151
Sewage gas	21	30	31	31	31	31	32
Landfill gas	0	0	0	0	0	0	98
Transport fuels:							
Energy crops - bioethanol	0	12	12	12	12	12	12
Energy crops - biodiesel	17	31	340	115	398	115	398
Total bio-energy	432	1024	2253	1238	3701	1442	5953
a/ At a uniform equilibrium price of (E/GJ):		6	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Denmark: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	793	970	1242	963	1805	1316	2328
Bio-energy (tradeable, co-combustion)	-	161	428	268	535	375	803
Bio-energy (non-tradeable)	138	143	143	143	184	161	267
Bio-energy (transport fuels)	0	0	40	0	120	0	120
Total bio-energy	931	1273	1853	1373	2645	1851	3517
Other renewables	387	777	822	807	1044	833	1126
Total renewables	1318	2050	2675	2180	3689	2684	4643
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	370	275	417	315	466	377	466
Solid agricultural residues	310	647	738	647	756	668	756
Solid industrial residues	113	119	131	119	131	119	131
Solid energy crops	0	53	272	89	681	343	681
Imported biomass	0	36	112	60	307	182	1097
Non-tradeables:							
Wet manure	31	31	31	31	68	48	145
Organic waste /b	77	77	77	77	77	77	77
Sewage gas	16	16	16	16	20	17	26
Landfill gas	14	19	19	19	19	19	19
Transport fuels:							
Energy crops - bioethanol	0	0	40	0	120	0	120
Energy crops - biodiesel	0	0	0	0	0	0	0
Total bio-energy	931	1273	1853	1373	2645	1851	3517
a/ At a uniform equilibrium price of (E/GJ):		4.5	4.9	4.5	6	4.9	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Finland: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	2329	2448	3375	3147	5394	3746	7231
Bio-energy (tradeable, co-combustion)	-	92	245	153	306	214	459
Bio-energy (non-tradeable)	3444	3449	3471	3458	3653	3465	4327
Bio-energy (transport fuels)	0	0	2	0	29	0	29
Total bio-energy	5773	5989	7092	6758	9381	7425	12046
Other renewables	1287	1351	1534	1371	1663	1401	1808
Total renewables	7060	7340	8627	8129	11044	8826	13854
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1200	1474	2386	2177	3825	2708	3828
Solid agricultural residues	0	159	190	174	255	206	255
Solid industrial residues	1124	905	1042	948	1232	1044	1233
Solid energy crops	5	0	1	1	224	1	354
Imported biomass	0	1	2	2	164	2	2019
Non-tradeables:							
Wet manure	1	5	19	10	62	15	102
Organic waste /b	3429	3429	3429	3429	3560	3429	4140
Sewage gas	10	11	14	11	16	12	19
Landfill gas	4	4	9	7	13	9	67
Transport fuels:							
Energy crops - bioethanol	0	0	0	0	0	0	0
Energy crops - biodiesel	0	0	2	0	29	0	29
Total bio-energy	5773	5989	7092	6758	9381	7425	12046
a/ At a uniform equilibrium price of (E/GJ):		2.5	2.5	2.5	5.3	2.5	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

France: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	4083	7772	13225	9178	22356	12109	27904
Bio-energy (tradeable, co-combustion)	-	253	675	422	844	591	1266
Bio-energy (non-tradeable)	1491	1543	1842	1602	2275	1663	2911
Bio-energy (transport fuels)	339	555	555	555	1292	555	1292
Total bio-energy	5913	10123	16297	11757	26767	14918	33373
Other renewables	6254	6813	8085	8141	11026	8566	14260
Total renewables	12167	16936	24381	19898	37794	23484	47633
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	3791	6595	7481	6772	7740	6772	7760
Solid agricultural residues	94	412	4960	1744	10453	4593	10756
Solid industrial residues	198	978	1089	986	1101	986	1101
Solid energy crops	0	34	319	85	3495	300	4826
Imported biomass	0	6	52	14	411	49	4726
Non-tradeables:							
Wet manure	0	33	292	80	546	136	1061
Organic waste /b	1380	1380	1380	1380	1380	1380	1380
Sewage gas	62	68	85	74	104	77	116
Landfill gas	49	62	84	68	245	71	354
Transport fuels:							
Energy crops - bioethanol	58	152	152	152	888	152	888
Energy crops - biodiesel	282	404	404	404	404	404	404
Total bio-energy	5913	10123	16297	11757	26767	14918	33373
a/ At a uniform equilibrium price of (E/GJ):		2.6	3.8	3.8	4.7	3.8	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Germany: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	4357	5477	7428	6711	13352	7875	20823
Bio-energy (tradeable, co-combustion)	-	2033	5422	3389	6778	4745	10167
Bio-energy (non-tradeable)	2114	2138	2143	2353	3252	2870	4028
Bio-energy (transport fuels)	206	1181	1181	1181	2189	1181	2189
Total bio-energy	6677	10829	16173	13633	25571	16671	37207
Other renewables	3035	6511	6656	7386	9785	8598	12628
Total renewables	9712	17340	22829	21019	35356	25269	49836
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	3342	3367	3736	3384	3838	3392	3879
Solid agricultural residues	60	3055	3403	3055	3403	3080	3409
Solid industrial residues	955	941	1047	941	1047	948	1049
Solid energy crops	0	101	3518	1769	3518	3185	3824
Imported biomass	0	45	1146	951	8325	2015	18828
Non-tradeables:							
Wet manure	31	31	32	38	191	68	599
Organic waste /b	1490	1490	1490	1690	1690	1751	1751
Sewage gas	373	387	390	392	472	405	569
Landfill gas	220	230	230	233	899	646	1109
Transport fuels:							
Energy crops - bioethanol	0	970	970	970	1979	970	1979
Energy crops - biodiesel	206	210	210	210	210	210	210
Total bio-energy	6677	10829	16173	13633	25571	16671	37207
a/ At a uniform equilibrium price of (E/GJ):		5.2	6	5.2	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Greece: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	718	850	1253	1563	3586	1936	4989
Bio-energy (tradeable, co-combustion)	-	220	587	367	734	514	1101
Bio-energy (non-tradeable)	1	7	8	220	863	322	885
Bio-energy (transport fuels)	0	39	361	87	393	87	393
Total bio-energy	719	1116	2209	2237	5577	2859	7369
Other renewables	623	985	1050	1197	1818	1336	2003
Total renewables	1342	2101	3259	3434	7394	4194	9372
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	473	49	58	52	348	308	510
Solid agricultural residues	0	705	1404	1535	1772	1604	1800
Solid industrial residues	245	252	279	252	279	252	279
Solid energy crops	0	5	8	8	61	56	65
Imported biomass	0	59	92	83	1860	230	3436
Non-tradeables:							
Wet manure	0	0	0	0	1	0	5
Organic waste /b	0	0	0	185	759	240	765
Sewage gas	1	1	1	1	1	1	2
Landfill gas	0	6	6	34	102	80	113
Transport fuels:							
Energy crops - bioethanol	0	39	361	87	393	87	393
Energy crops - biodiesel	0	0	0	0	0	0	0
Total bio-energy	719	1116	2209	2237	5577	2859	7369
a/ At a uniform equilibrium price of (E/GJ):		4.5	4.5	4.5	6	5.999	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Ireland: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	114	243	537	315	2379	506	3464
Bio-energy (tradeable, co-combustion)	-	57	153	96	191	134	287
Bio-energy (non-tradeable)	25	25	25	26	256	30	287
Bio-energy (transport fuels)	0	0	0	13	127	13	127
Total bio-energy	139	325	715	449	2952	683	4164
Other renewables	106	292	365	330	577	371	715
Total renewables	245	617	1081	779	3529	1054	4879
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	81	134	149	135	149	135	149
Solid agricultural residues	0	48	55	50	55	50	55
Solid industrial residues	27	109	123	111	123	111	123
Solid energy crops	5	6	109	98	109	98	109
Imported biomass	0	3	254	15	2134	245	3313
Non-tradeables:							
Wet manure	0	0	0	0	9	1	82
Organic waste /b	0	0	0	1	220	4	179
Sewage gas	1	1	1	1	1	1	1
Landfill gas	24	24	24	24	26	24	25
Transport fuels:							
Energy crops - bioethanol	0	0	0	0	0	0	0
Energy crops - biodiesel	0	0	0	13	127	13	127
Total bio-energy	139	325	715	449	2952	683	4164
a/ At a uniform equilibrium price of (E/GJ):		4.1	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Italy: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	1761	2891	4496	4785	7180	4859	10625
Bio-energy (tradeable, co-combustion)	-	189	504	315	630	441	945
Bio-energy (non-tradeable)	152	172	177	189	2110	756	2517
Bio-energy (transport fuels)	67	70	70	70	70	70	70
Total bio-energy	1980	3323	5247	5360	9990	6126	14157
Other renewables	6821	7886	8164	9399	15250	13959	15874
Total renewables	8801	11208	13411	14758	25240	20084	30030
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1379	129	386	1131	2335	554	2526
Solid agricultural residues	0	2785	4072	3378	4281	3872	4283
Solid industrial residues	382	165	540	589	943	852	944
Solid energy crops	0	0	0	0	11	1	116
Imported biomass	0	1	2	2	239	21	3701
Non-tradeables:							
Wet manure	4	4	4	12	66	19	195
Organic waste /b	116	120	123	126	1748	569	1934
Sewage gas	32	48	49	49	57	50	64
Landfill gas	0	0	0	2	239	118	324
Transport fuels:							
Energy crops - bioethanol	0	3	3	3	3	3	3
Energy crops - biodiesel	67	67	67	67	67	67	67
Total bio-energy	1980	3323	5247	5359	9990	6126	14157
a/ At a uniform equilibrium price of (E/GJ):		2	2.4	2.4	4.8	4.8	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Netherlands: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	394	455	466	982	2633	1288	4025
Bio-energy (tradeable, co-combustion)	-	185	494	309	617	432	926
Bio-energy (non-tradeable)	341	347	348	931	1591	979	1635
Bio-energy (transport fuels)	0	0	64	0	266	0	266
Total bio-energy	735	987	1372	2221	5107	2699	6851
Other renewables	86	266	267	303	451	372	528
Total renewables	820	1253	1639	2524	5559	3072	7379
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	341	290	419	380	420	380	422
Solid agricultural residues	0	232	295	267	295	267	296
Solid industrial residues	53	81	89	81	89	81	89
Solid energy crops	0	0	0	0	0	0	0
Imported biomass	0	37	157	563	2446	993	4142
Non-tradeables:							
Wet manure	1	1	1	1	2	1	8
Organic waste /b	227	227	228	669	1135	671	1167
Sewage gas	50	51	51	51	51	51	52
Landfill gas	63	68	68	210	403	257	408
Transport fuels:							
Energy crops - bioethanol	0	0	0	0	0	0	0
Energy crops - biodiesel	0	0	64	0	266	0	266
Total bio-energy	735	987	1372	2221	5107	2699	6851
a/ At a uniform equilibrium price of (E/GJ):		4.1	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Portugal: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	1136	1428	2442	1774	3317	2214	4851
Bio-energy (tradeable, co-combustion)	-	82	218	137	273	191	410
Bio-energy (non-tradeable)	535	535	536	536	1477	824	1514
Bio-energy (transport fuels)	0	0	0	0	78	0	78
Total bio-energy	1671	2045	3196	2446	5145	3229	6852
Other renewables	1211	1623	1866	1768	2380	1809	2603
Total renewables	2882	3668	5061	4214	7525	5039	9455
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	655	777	1067	991	1272	1150	1272
Solid agricultural residues	0	105	392	283	676	610	676
Solid industrial residues	480	626	697	632	708	641	708
Solid energy crops	0	0	0	0	2	0	7
Imported biomass	0	2	502	4	932	4	2597
Non-tradeables:							
Wet manure	1	1	1	1	6	3	19
Organic waste /b	534	534	534	534	1401	786	1382
Sewage gas	0	0	0	0	1	0	2
Landfill gas	0	0	0	0	69	35	111
Transport fuels:							
Energy crops - bioethanol	0	0	0	0	78	0	78
Energy crops - biodiesel	0	0	0	0	0	0	0
Total bio-energy	1671	2045	3193	2446	5145	3229	6852
a/ At a uniform equilibrium price of (E/GJ):		2.8	3	3	6	3	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Spain: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	3107	3951	5257	5736	8371	5740	12457
Bio-energy (tradeable, co-combustion)	-	429	1143	715	1429	1000	2144
Bio-energy (non-tradeable)	731	755	762	788	2532	1594	3227
Bio-energy (transport fuels)	50	408	408	408	408	408	408
Total bio-energy	3888	5542	7570	7645	12740	8742	18235
Other renewables	3640	5524	6337	6067	7329	6240	7972
Total renewables	7528	11066	13907	13712	20069	14982	26207
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	780	1224	1470	1390	1835	1549	1850
Solid agricultural residues	707	2703	3190	2991	3306	2984	3307
Solid industrial residues	1620	450	1734	2064	2288	2056	2290
Solid energy crops	0	2	5	4	2036	128	2900
Imported biomass	0	0	1	1	335	23	4253
Non-tradeables:							
Wet manure	11	11	14	30	220	69	486
Organic waste /b	708	728	728	728	1979	1374	2269
Sewage gas	13	14	15	16	57	22	99
Landfill gas	0	2	6	14	276	130	374
Transport fuels:							
Energy crops - bioethanol	50	50	50	50	50	50	50
Energy crops - biodiesel	0	358	358	358	358	358	358
Total bio-energy	3888	5542	7570	7645	12740	8742	18235
a/ At a uniform equilibrium price of (E/GJ):		1.5	1.83	1.83	4.8	3.8	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Sweden: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	3271	4428	6452	5144	9097	5539	10871
Bio-energy (tradeable, co-combustion)	-	22	58	37	73	51	110
Bio-energy (non-tradeable)	3106	3131	3141	3145	3448	3182	3978
Bio-energy (transport fuels)	28	62	62	62	571	62	571
Total bio-energy	6405	7643	9713	8386	13189	8834	15529
Other renewables	6790	7021	7180	7056	7532	7105	8110
Total renewables	13195	14664	16893	15442	20721	15939	23639
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	1973	2726	4341	3376	5481	3753	6250
Solid agricultural residues	38	45	124	45	131	45	143
Solid industrial residues	1148	1605	1881	1685	1910	1718	1957
Solid energy crops	112	61	133	61	519	61	782
Imported biomass	0	14	30	14	1129	14	1848
Non-tradeables:							
Wet manure	2	2	3	3	22	4	45
Organic waste /b	3037	3042	3048	3055	3332	3090	3827
Sewage gas	31	31	34	32	39	33	49
Landfill gas	36	56	56	56	56	56	58
Transport fuels:							
Energy crops - bioethanol	28	28	28	28	476	28	476
Energy crops - biodiesel	0	34	34	34	95	34	95
Total bio-energy	6405	7643	9713	8386	13188	8834	15529
a/ At a uniform equilibrium price of (E/GJ):		3.4	4.07	3.4	4.3	3.4	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

United Kingdom: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	988	1365	1623	1638	7816	3661	10644
Bio-energy (tradeable, co-combustion)	-	835	2227	1392	2784	1949	4176
Bio-energy (non-tradeable)	1127	1214	1216	1217	4703	2085	5494
Bio-energy (transport fuels)	0	0	0	0	0	0	0
Total bio-energy	2115	3414	5066	4247	15303	7695	20314
Other renewables	581	1361	2443	1477	3057	1603	4107
Total renewables	2696	4775	7509	5724	18360	9298	24421
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	644	382	884	800	1110	1005	1126
Solid agricultural residues	72	1527	1695	1534	1699	1538	1700
Solid industrial residues	273	285	315	285	315	285	315
Solid energy crops	0	5	741	314	1896	1714	1947
Imported biomass	0	2	216	96	5579	1068	9733
Non-tradeables:							
Wet manure	0	0	2	2	92	11	303
Organic waste /b	233	251	251	251	3607	1108	4017
Sewage gas	163	177	178	178	207	180	276
Landfill gas	732	785	785	785	797	786	898
Transport fuels:							
Energy crops - bioethanol	0	0	0	0	0	0	0
Energy crops - biodiesel	0	0	0	0	0	0	0
Total bio-energy	2115	3414	5066	4247	15303	7695	20314
a/ At a uniform equilibrium price of (E/GJ):		2.2	4.7	4.7	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Bulgaria: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	560	1384	2214	2100	3300	2016	4430
Bio-energy (tradeable, co-combustion)	-	126	336	210	420	294	630
Bio-energy (non-tradeable)	45	81	237	114	561	209	578
Bio-energy (transport fuels)	0	0	0	0	0	0	0
Total bio-energy	606	1591	2787	2424	4281	2519	5638
Other renewables	195	405	516	447	649	464	771
Total renewables	800	1995	3303	2872	4930	2983	6408
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	546	588	1250	1047	1253	1047	1253
Solid agricultural residues	5	891	1264	1061	1266	1061	1266
Solid industrial residues	9	29	33	30	33	30	33
Solid energy crops	0	1	2	171	436	171	436
Imported biomass	0	1	1	1	733	1	2073
Non-tradeables:							
Wet manure	0	7	16	10	31	11	35
Organic waste /b	45	59	195	81	394	146	403
Sewage gas	0	3	6	4	9	5	11
Landfill gas	0	12	20	19	127	46	129
Transport fuels:							
Energy crops - bioethanol	0	0	0	0	0	0	0
Energy crops - biodiesel	0	0	0	0	0	0	0
Total bio-energy	606	1591	2787	2424	4281	2519	5638
a/ At a uniform equilibrium price of (E/GJ):		2.21	2.3	2.3	6	2.3	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Czech Republic: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	166	386	1732	627	4043	1697	5670
Bio-energy (tradeable, co-combustion)	-	314	838	524	1047	733	1571
Bio-energy (non-tradeable)	19	20	262	117	636	164	866
Bio-energy (transport fuels)	241	241	241	241	241	241	241
Total bio-energy	426	961	3073	1509	5968	2836	8348
Other renewables	174	337	512	373	763	406	797
Total renewables	601	1298	3585	1882	6730	3241	9145
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	129	120	141	128	142	128	142
Solid agricultural residues	2	339	376	340	376	340	376
Solid industrial residues	35	187	356	322	357	322	359
Solid energy crops	0	4	125	113	132	113	142
Imported biomass	0	51	1573	247	4084	1527	6222
Non-tradeables:							
Wet manure	2	3	12	9	166	30	291
Organic waste /b	13	13	219	81	354	90	357
Sewage gas	0	1	7	4	70	15	168
Landfill gas	3	3	24	24	46	29	50
Transport fuels:							
Energy crops - bioethanol	183	183	183	183	183	183	183
Energy crops - biodiesel	58	58	58	58	58	58	58
Total bio-energy	426	961	3073	1509	5968	2836	8348
a/ At a uniform equilibrium price of (E/GJ):		4.05	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Estonia: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	506	726	1596	1140	1620	1224	1840
Bio-energy (tradeable, co-combustion)	-	54	144	90	180	126	270
Bio-energy (non-tradeable)	1	9	230	104	233	106	245
Bio-energy (transport fuels)	0	0	0	0	11	0	11
Total bio-energy	507	789	1970	1334	2044	1456	2366
Other renewables	1	16	23	17	27	18	31
Total renewables	508	804	1993	1351	2072	1474	2396
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	380	626	755	684	755	684	755
Solid agricultural residues	0	2	25	23	25	23	25
Solid industrial residues	126	150	166	151	166	151	166
Solid energy crops	0	1	283	256	283	256	283
Imported biomass	0	0	509	116	569	236	879
Non-tradeables:							
Wet manure	0	3	6	3	6	5	6
Organic waste /b	0	3	195	77	196	77	207
Sewage gas	0	1	1	1	1	1	1
Landfill gas	1	2	28	23	31	23	31
Transport fuels:							
Energy crops - bioethanol	0	0	0	0	11	0	11
Energy crops - biodiesel	0	0	0	0	0	0	0
Total bio-energy	507	789	1970	1334	2044	1456	2366
a/ At a uniform equilibrium price of (E/GJ):		1.7	6	6	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Hungary: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	295	544	865	831	1281	1157	2512
Bio-energy (tradeable, co-combustion)	-	66	175	110	219	153	329
Bio-energy (non-tradeable)	3	4	17	73	213	98	435
Bio-energy (transport fuels)	0	0	0	0	0	0	0
Total bio-energy	298	614	1057	1013	1713	1408	3275
Other renewables	142	245	508	255	361	267	588
Total renewables	441	859	1565	1267	2074	1675	3864
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	295	5	333	300	363	320	363
Solid agricultural residues	0	604	677	613	679	614	679
Solid industrial residues	0	0	3	3	48	35	48
Solid energy crops	0	1	18	17	389	257	389
Imported biomass	0	0	8	8	21	83	1361
Non-tradeables:							
Wet manure	0	0	3	2	77	10	182
Organic waste /b	0	1	11	67	132	82	242
Sewage gas	2	2	2	2	3	2	7
Landfill gas	2	2	2	2	2	4	5
Transport fuels:							
Energy crops - bioethanol	0	0	0	0	0	0	0
Energy crops - biodiesel	0	0	0	0	0	0	0
Total bio-energy	298	614	1057	1013	1713	1408	3275
a/ At a uniform equilibrium price of (E/GJ):		1.6	3.3	3.3	6	4.5	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Latvia: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	820	799	1378	1199	2068	1279	2557
Bio-energy (tradeable, co-combustion)	-	1	2	1	2	1	3
Bio-energy (non-tradeable)	60	60	62	199	229	202	237
Bio-energy (transport fuels)	0	16	83	16	83	16	83
Total bio-energy	880	876	1525	1415	2381	1498	2880
Other renewables	316	357	372	372	437	397	445
Total renewables	1196	1233	1897	1787	2819	1895	3326
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	605	531	1059	911	1070	963	1070
Solid agricultural residues	0	4	5	4	34	28	34
Solid industrial residues	215	263	314	283	315	285	315
Solid energy crops	0	1	2	1	601	4	651
Imported biomass	0	0	0	0	50	1	490
Non-tradeables:							
Wet manure	0	0	1	1	11	2	17
Organic waste /b	60	60	60	194	196	190	198
Sewage gas	0	0	0	0	0	0	0
Landfill gas	0	0	0	4	22	10	23
Transport fuels:							
Energy crops - bioethanol	0	16	83	16	83	16	83
Energy crops - biodiesel	0	0	0	0	0	0	0
Total bio-energy	880	876	1525	1415	2381	1498	2880
a/ At a uniform equilibrium price of (E/GJ):		1.6	1.6	1.6	4.2	2.17	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Lithuania: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	627	990	1130	1170	1740	1300	1960
Bio-energy (tradeable, co-combustion)	-	0	0	0	0	0	0
Bio-energy (non-tradeable)	205	208	214	210	277	239	330
Bio-energy (transport fuels)	0	11	59	11	59	11	59
Total bio-energy	832	1209	1403	1391	2076	1550	2349
Other renewables	36	82	254	98	264	101	268
Total renewables	868	1291	1657	1489	2340	1652	2617
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	512	796	851	816	905	816	905
Solid agricultural residues	3	15	77	143	160	143	160
Solid industrial residues	113	177	194	178	196	178	196
Solid energy crops	0	2	7	31	451	150	480
Imported biomass	0	0	1	2	28	13	218
Non-tradeables:							
Wet manure	0	4	9	5	32	7	39
Organic waste /b	202	202	202	202	240	229	277
Sewage gas	3	3	3	3	4	3	6
Landfill gas	0	0	0	0	1	0	8
Transport fuels:							
Energy crops - bioethanol	0	7	36	7	36	7	36
Energy crops - biodiesel	0	4	23	4	23	4	23
Total bio-energy	832	1209	1403	1391	2076	1550	2349
a/ At a uniform equilibrium price of (E/GJ):		1.55	2.25	3.9	3.9	3.9	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Poland: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	1073	2489	4505	2386	4831	2252	6817
Bio-energy (tradeable, co-combustion)	-	921	2455	1535	3069	2148	4604
Bio-energy (non-tradeable)	436	583	1474	617	1691	689	2054
Bio-energy (transport fuels)	524	703	1527	835	1740	835	1740
Total bio-energy	2032	4696	9961	5372	11331	5924	15214
Other renewables	192	795	1037	634	1330	755	2062
Total renewables	2224	5491	10998	6007	12662	6680	17276
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	770	567	1070	955	1070	964	1070
Solid agricultural residues	5	2835	3272	2957	3272	2959	3272
Solid industrial residues	298	2	366	2	366	177	380
Solid energy crops	0	3	217	3	217	168	220
Imported biomass	0	3	2036	3	2976	132	6478
Non-tradeables:							
Wet manure	24	158	425	191	1257	262	1608
Organic waste /b	388	388	917	388	388	388	395
Sewage gas	18	19	20	19	20	19	22
Landfill gas	5	18	112	19	26	20	28
Transport fuels:							
Energy crops - bioethanol	524	676	1027	738	1078	738	1078
Energy crops - biodiesel	0	27	500	97	663	97	663
Total bio-energy	2032	4696	9961	5372	11331	5924	15214
a/ At a uniform equilibrium price of (E/GJ):		2.6	6	2.6	6	4.8	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Romania: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	2833	3048	3209	4741	5851	4673	8692
Bio-energy (tradeable, co-combustion)	-	102	271	170	339	237	509
Bio-energy (non-tradeable)	0	4	5	702	1046	724	1060
Bio-energy (transport fuels)	0	0	110	8	256	8	256
Total bio-energy	2833	3154	3595	5620	7492	5641	10516
Other renewables	1171	1856	1940	2051	2579	2126	2855
Total renewables	4004	5010	5535	7671	10070	7767	13370
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	2622	2362	2610	2607	2881	2607	2881
Solid agricultural residues	0	252	278	1755	1948	1755	1949
Solid industrial residues	211	536	592	546	603	546	603
Solid energy crops	0	0	0	1	621	1	747
Imported biomass	0	0	0	0	137	0	3019
Non-tradeables:							
Wet manure	0	2	2	2	3	2	6
Organic waste /b	0	1	2	571	829	571	838
Sewage gas	0	0	0	0	0	0	0
Landfill gas	0	0	0	130	214	151	216
Transport fuels:							
Energy crops - bioethanol	0	0	41	2	135	2	135
Energy crops - biodiesel	0	0	69	6	121	6	121
Total bio-energy	2833	3154	3595	5620	7492	5641	10516
a/ At a uniform equilibrium price of (E/GJ):		1.4	1.4	1.94	4.7	1.94	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Slovakia: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	16	105	173	183	376	246	839
Bio-energy (tradeable, co-combustion)	-	40	107	67	134	94	201
Bio-energy (non-tradeable)	239	244	254	249	260	253	261
Bio-energy (transport fuels)	47	47	47	47	47	47	47
Total bio-energy	302	436	581	546	817	640	1348
Other renewables	595	953	1064	1032	1544	1099	1759
Total renewables	897	1389	1645	1578	2361	1739	3107
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	15	7	36	31	42	37	42
Solid agricultural residues	0	133	232	209	242	216	242
Solid industrial residues	2	2	6	5	42	34	42
Solid energy crops	0	1	3	2	54	31	54
Imported biomass	0	1	3	3	129	23	659
Non-tradeables:							
Wet manure	0	2	8	4	11	7	9
Organic waste /b	239	239	239	239	239	239	239
Sewage gas	0	2	5	4	7	5	9
Landfill gas	0	1	3	2	3	3	3
Transport fuels:							
Energy crops - bioethanol	35	35	35	35	35	35	35
Energy crops - biodiesel	12	12	12	12	12	12	12
Total bio-energy	302	436	581	546	817	640	1348
a/ At a uniform equilibrium price of (E/GJ):		2.7	3.1	3.1	6	4.2	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

Slovenia: Consumption of bio-energy (primary energy, ktoe/year) (Subs. Innov. Technologies)

		No S-premium		Low S-premium		High S-premium	
	2000	2010	2020	2010	2020	2010	2020
Bio-energy (tradeable, dedicated plant)	61	132	192	155	940	403	1135
Bio-energy (tradeable, co-combustion)	-	33	88	55	110	77	165
Bio-energy (non-tradeable)	64	90	129	138	345	156	366
Bio-energy (transport fuels)	0	0	0	0	0	0	0
Total bio-energy	125	255	409	348	1395	636	1666
Other renewables	401	549	622	680	773	675	789
Total renewables	526	804	1031	1028	2167	1311	2455
Details bioenergy							
Tradeables: /a							
Forestry byproducts & Refined wood fuels	61	121	144	128	144	130	144
Solid agricultural residues	0	24	27	24	27	24	27
Solid industrial residues	0	2	42	21	42	38	42
Solid energy crops	0	8	22	17	22	20	22
Imported biomass	0	10	46	20	816	268	1066
Non-tradeables:							
Wet manure	0	24	61	25	102	27	112
Organic waste /b	60	60	60	103	225	115	236
Sewage gas	0	0	0	0	0	0	1
Landfill gas	4	6	7	10	18	13	18
Transport fuels:							
Energy crops - bioethanol	0	0	0	0	0	0	0
Energy crops - biodiesel	0	0	0	0	0	0	0
Total bio-energy	125	255	409	348	1395	636	1666
a/ At a uniform equilibrium price of (E/GJ):		4.2	6	4.8	6	6	6

b/ Organic waste consists of biodegradable municipal waste, demolition wood, dry manure and black liquor.

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