FOOD & BIOBASED RESEARCH
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4F CROPS

Future Crops for
Food, Feed, Fiber and Fuel

The role of 4F crops in EU27 under contrasting future scenarios

Final report on WP6

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Author(s)	H.W. Elbersen, M. van der Zee and H.L. Bos
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Approved by	Arie van der Bent

Wageningen UR Food & Biobased Research
P.O. Box 17
NL-6700 AA Wageningen
Tel: +31 (0)317 480 084
E-mail: info.fbr@wur.nl
Internet: www.wur.nl

Foreword

This reports presents the results obtained in the 4F CROPS project, Work Package 6 *"Scenarios for successful establishment of future crops"*. The following deliverables are integrated in this report:

Deliverable 18: *Report on non-food crops facts and figures including an output markets overview*
Deliverable 19: *Report on potential crop-application-market combinations*
Deliverable 20: *Report on scenarios for implementation of new crop-application-market implementation*

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 212811.

Abstract

The objective of this report is to put into context novel 4F Crops (i.e. future crops for Food, Feed, Fiber and Fuel), that will play a role in supplying the (new) biomass demands for energy and chemicals in the coming years. And to define actions needed to make use of their potential in Europe. For this purpose we have defined in more detail the demands for biomass for energy and the chemical industry in Europe until 2030 within 4 contrasting future scenarios. These scenarios are driven by more or less globalization (open vs. closed markets) and high or low regulation (sustainability is a strong or a weak driver for biomass based energy and chemicals).
As a base for our analysis we translated the bioenergy production in 2020 according to the recently presented EU 27 NREAPs (National Renewable Energy Action Plans) into biomass demands of different categories. For the analysis of the biomass demand for chemicals, we used the potential replacement of fossil based chemicals (as presented in our previous report, D3) by biobased chemicals as a base for our analysis.
Applying the logical assumptions on GDP growth, self-sufficiency, agricultural policy options, oil and CO2 prices, etc. within each scenario, we quantified the demand for different bioenergy categories and the biomass needed in 2020 and 2030. For the demand from the chemical industry the same exercise was executed.
According to our estimations, 656 Mtons of biomass are required to fulfill the ambitions as laid down in the NREAPs of EU27. Of this biomass, 362 Mtons can be sourced from by-products and waste, 184 Mtons will be produced (extra) by crops in EU 27 and 110 Mtons of biomass will have to be imported.
Figure 1 shows the total biomass demand (for energy and chemicals) under scenarios to be between 400 and 700 Mton in 2020, increasing to between 550 and 800 Mtons in 2030.
In the current NREAPs the demand for biomass by the chemical industry appears not to be taken into account. However the demand for biomass for the production of chemicals could be substantial especially compared to the biomass demand for production of biofuels. Using future scenarios we estimate the demand for biomass by the chemical industry to be between 14 and 43 Mtons of biomass (DM) in 2020, increasing to between 28 and 66 Mtons (DM) in 2030. The biomass demand for chemicals can both compete or be in synergy with the demand for biomass to produce biofuels, heat and electricity. Competition is expected with regard to the demand for fermentable sugars. The demand by the chemical industry will amount to between 8 and 40 Mtons in 2020 and between 16 and 53 Mtons (DM) in 2030. This is roughly the same amount as the amount of fermentable sugars required for the production of biofuels (mainly ethanol).
We recommend to take into account the demand for biomass by the chemical industry (including effects of competition, e.g. for fermentable sugars and synergy between the production of Fischer Tropsch biodiesel and glycerin) when developing biomass energy policies and targets. This will require much more detailed knowledge about the biomass demands of the chemical industry than is currently available in the public domain.

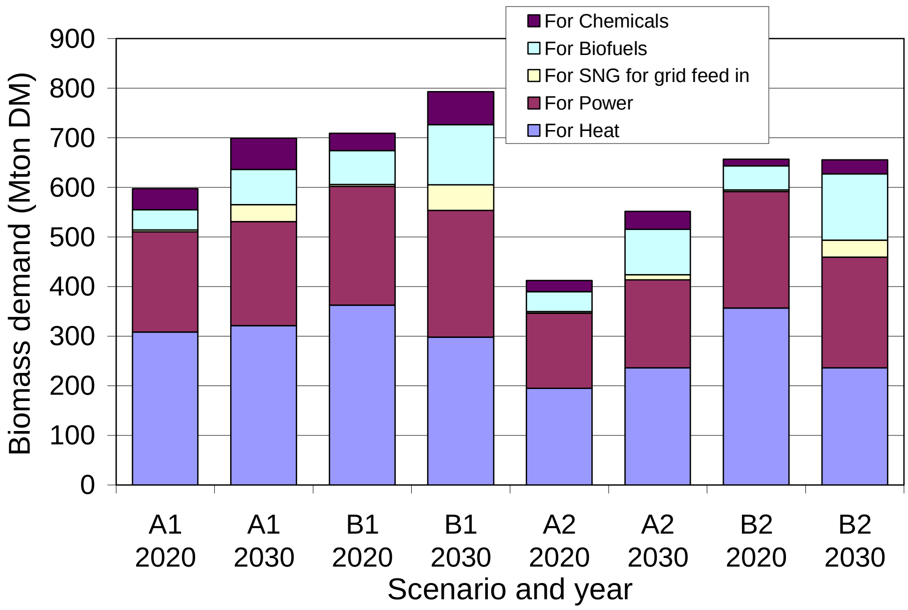

Figure 1 *The biomass demand for different bioenergy options and for biomass based chemicals under 4 scenarios in 2020 and in 2030 for the EU 27.*

With respect to policies we recommend to develop a level playing field between fuels and chemicals (and fibre), or at least that policies take into consideration the synergy and competition that exists between fuels and chemicals.
With respect to crops we conclude that to be able to exploit the advantages that perennial lignocellulosic crops offer to produce sustainable biomass, policies should be adapted to offer a niche to these crops on land less suited for rotation crops (e.g. surplus, marginal, low quality, abandoned land). This requires new policies and an outlook of at least 15 years. Non-energy uses (e.g. bedding, fibre) of perennial lignocellulosic crops should also be considered as a way of introducing these crop into EU agriculture. An integrated vision of the food and biofuel markets should make better use of dual purpose crops such as oil/protein crops. Consequently R&D on perennial lignocellulosic crops should focus on attaining high yields for low inputs on surplus, marginal, low quality, abandoned lands in Europe. This includes development of new varieties adapted to EU conditions and marginal areas. R&D on oil crops should focus on increasing yield and increasing the production and value of by-products (e.g. protein). R&D on sugar crops should focus on yields and the development of more efficient processing. Other production outlets such as ABE (acetone, butanol, ethanol process) and production of chemicals will also have to be considered.

Keywords: NREAP, biomass for energy, biomass for chemicals, oil crops, scenarios, policy,

Content

Abbreviations and conversion factors

J	joule	=	0.2390 calorie	=	1 watt second
kJ	kilojoule	=	10^3 J		
MJ	megajoule	=	10^6 J		
GJ	gigajoule	=	10^9 J		
TJ	terajoule	=	10^{12} J		
PJ	petajoule	=	10^{15} J		
EJ:	exajoule	=	10^{18} J		
kWh	kilowatt hour	=	3.6×10^6 J	=	3.6 MJ
toe	ton oil equivalent	=	41.9 GJ	=	11.630 MWh
Mtoe	million ton oil equivalent				
Mton	million ton				
MT	metric ton				
FAME	fatty acid methyl ester	=	biodiesel		
DM	dry matter				

1 MT of ethanol	=	1267 liter	=	0,64 toe
1 MT of biodiesel	=	1136 liter	=	0,90 toe
1 MT of gasoline	=	1342 liter	=	1,03 toe
1 MT of diesel	=	1195 liter	=	1,02 toe

1 toe ethanol	=	1980 liter of ethanol
1000 liter ethanol	=	0.505 toe
1 toe biodiesel	=	1262 liter of biodiesel

1 Introduction

The 4F CROPS project has studied in detail a number of new (model) crops that have the potential to become important sources of feedstocks for the biobased economy.
These crops include herbaceous perennial biomass crops such as perennial biomass grasses (Miscanthus, switchgrass, Arundo Donax, Reed Canary Grass) and the perennial Cardoon and short rotation woody crops (Willow, Poplar, Eucalyptus) and oil crops (Egyptian mustard and Safflower and new varieties of Sunflower and Oil Seed Rape) and fibre crops (such as Hemp and Flax).

The 4F CROPS project has also studied the potential availability of land needed to accommodate these new crops and the market needs for biobased feedstocks in the energy and chemistry industries both now and in the future.

The objective of the work presented in this report is to explore the future biomass demand for energy and the demand for biomass as feedstock for the chemical industry under different future scenarios, to show what the role of different model crops can play in the European Union in the future; and to determine what strategy is needed to make sure the crops can play this role.

1.1 Methods

The future is always uncertain and we have only limited influence on the basic developments that will shape our future. Forecasting short-run developments is difficult; predicting the long-run is impossible (Mooij and Tang, 2003).

As people have to take decisions and develop strategies under this uncertain future one method for dealing with this is to define contrasting scenarios of the future and analyzing their role/position under each scenario. This makes it possible to develop robust strategies to achieve goals under each scenario.

1.1.1 Scenarios

Scenarios are stories of contrasting futures which combine narrative and data. They do not aim to predict the future, but rather to sketch alternative futures (Mooij and Tang, 2003). These future states of the world form the background against which strategic decisions can be explored. In general 4 sets of contrasting, plausible and within themselves consistent scenarios are developed. They are built along the two key uncertainties leading to a 2x2 matrix where the axes represent the most critical uncertainties. The scenarios are meant to provide a background for decision makers to consider alternative strategic options under uncertainty.

If we want to define what strategies and actions are needed for development of a biobased economy and especially the strategies for introducing and developing new (4F) crops the use of

scenarios is the best option to come to plausible and robust recommendations. The role of new crops is explored under these different future scenarios.
In this report we base our scenarios on strategic scenarios developed by IPCC and the Netherlands Bureau for Economic Policy Analysis (CPB) and further developed for EU agriculture and to some extent for biofuels by the EURuralis project and others (EUruralis; Koppejan et al., 2009; Heilmann and Verburg, 2010).
For our purpose we elaborate on the 4 contrasting scenarios using the assumptions (and calculations) by others and defining them further from a supply side (agriculture) and a demand side (bio-energy and biobased chemical industry).

1.1.2 Crop role

The crops attributes and potentials are described and the strengths and weaknesses of each crop are described. Based on the demand for biomass under each scenario and the way this is filled in under each scenario we explore the role of the model crops. The role of the crops in supplying feedstocks for chemical and bioenergy production is estimated against utilizing biomass by-products wastes (from forestry, agriculture and industry and households) and importing biomass or even using unconventional sources (algae).

Based on the analysis of the strong and the weak points the role(s) of the model crops are defined under the four scenarios after which a strategy is defined for each crop defining priorities and actions for agriculture, industry, policymakers and research.

The horizon we choose is 2020 for the short run and 2030 for the longer run.

2 Scenarios

2.1 General scenarios

We make use of the general scenario's as defined by the EURuralis project. In these scenario's the main differences between the scenarios centre around open vs. regional markets and high vs. low regulation. For the purpose of this exercise we interpret this as high and low importance of sustainability and regulations that promote sustainability (see 2.2 for further explanation).
The general description of the 4 scenarios is given in Figure 2.1.

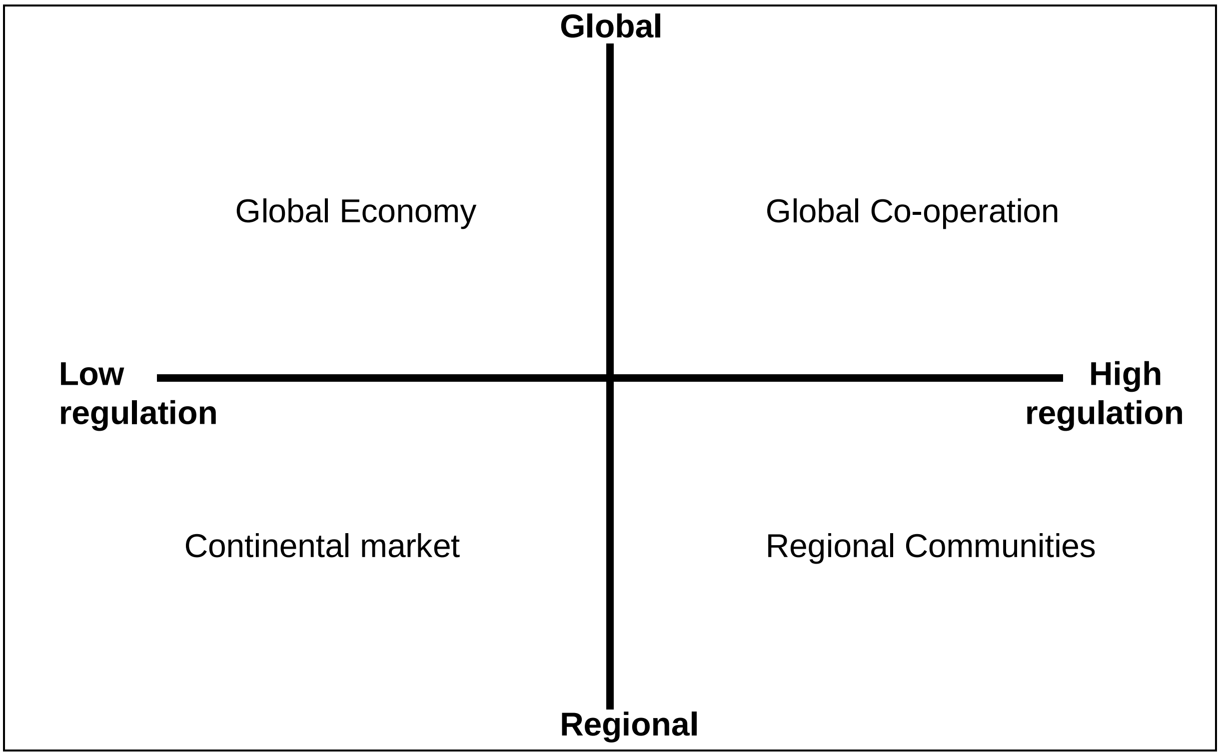

Figure 2.1. *General matrix of 4 contrasting scenarios: A1 Global Economy; B1 Global co-operation; A2 Continental market; B2 Regional communities (based on Eickhout et al., 2008).*

We use basic assumptions as described in Table 2.1 and Table 2.2 and use the translations by others into GDP growth, self-sufficiency, agricultural policy options, oil and CO2 prices, etc. These more specific assumptions have been made for the EU economy and agriculture by CPB, PBL, EUruralis, and others.

Table 2.1 Basic assumptions for the 4 contrasting scenarios (ref: EURURALIS [2])

	Low regulation: Less focus on sustainability more focus on security of supply	**High regulation: More focus on sustainability less focus on security of supply**
Open Markets	**A1 GLOBAL ECONOMY** The Global Economy scenario depicts a world with fewer borders and less government intervention compared with today. Trade barriers are removed and there is an open flow of capital, people and goods, leading to a rapid economic growth, of which many (but not all) individuals and countries benefit. There is a strong technological development. The role of the government is very limited. Nature and environmental problems are not seen as a priority of the government.	**B1 GLOBAL CO-OPERATION** The Global Co-operation scenario depicts a world of successful international Co-operation, aimed at reducing poverty and reducing environmental problems. Trade barriers will be removed. Many aspects will be regulated by the government, e.g. carbon dioxide emissions, food safety and biodiversity. The maintenance of cultural and natural heritage is mainly publicly funded.
Local markets	**A2 CONTINENTAL MARKETS** The Continental Markets scenario depicts a world of divided regional blocks. The EU, USA and other OECD countries together form one block. Other blocks are for example Latin America, the former Soviet Union and the Arab world. Each block is striving for self sufficiency, in order to be less reliant on other blocks. Agricultural trade barriers and support mechanisms continue to exist. A minimum of government intervention is preferred, resulting in loosely interpreted directives and regulations	**B2 REGIONAL COMMUNITIES** The Regional Communities scenario depicts a world of regions. People have a strong focus on their local and regional community and prefer locally produced food. Agricultural policy is aiming at self sufficiency. Ecological stewardship is very important. This world is strongly regulated by government interventions, resulting in restrictive rules in spatial policy and incentives to keep small scale agriculture. Economic growth in this scenario is the lowest of all four.

Table 2.2 Basic assumptions for the 4 contrasting scenarios (ref: EURURALIS [2])

	Population	**Solidarity**	**Economy**	**Globalisation**	**Regulation**
A1 Global Economy	↗	↘	↗	↗	↘
B1 Global Cooperation	↗	↗	↗	↗	↗
A2 Transatlantic Markets	↘	↘	↗	→	↘
B2 Regional Communities	↘	↗	↗	↘	↗

2.2 Agricultural assumptions under 4 scenarios

For our specific purpose we have further defined the relevant agricultural aspects under the 4 scenario's, see Table 2.3.

Table 2.3 *Basic agricultural assumptions for the 4 contrasting scenarios.*

	A1 Global Economy	**B1 Global Cooperation**	**A2 Continental Markets**	**B2 Regional Communities**
CAP Expenditures, billion €	0	15	47	45
Export subsidies(2020)	no	No	yes	no
Self sufficiency	Lowest	Low	High	Highest
Organic agriculture	Lowest	Low	Low	Highest
Land available for non-food in 2020 (Million ha)	High	Highest	Lowest	Low
Land available for non-food in 2030 (Million ha)	High	Highest	Lowest	Low
Type of land released	Low quality	Low quality	Average	Mainly low quality

2.3 Biomass and land availability in 2020 and 2030

Several estimates have been made of the available biomass in the EU in 2020 and 2030. In an EEA study (2006) estimated the maximum availability of biomass in 2020 and 2030 of the EU 25 (See Figure 2.2). From this we have estimated the maximum biomass availability from by-products and waste and forestry at 160 Mtoe in EU 27 in 2020, which equals 368 Mton Biomass. For 2030 this amount would stay the same.

The same study also estimated the amount of biomass from agriculture (crops) for energy in 2020 and 2030 (Figure 2.2). From this we estimated the amount of biomass that could be produced by agriculture (crops) in EU 27 in 2020 at approx 80 - 100 Mtoe (primary) biomass which equals 184 to 230 Mton DM of biomass. In 2030 the estimated amount of crop biomass would be 110-170 Mtoe (primary) biomass which equals 253 - 391 ton DM biomass[1].

[1] *Note that no "unconventional' options have been included here, such as large scale algae production or seaweed production or radical yield improvements in agriculture.*

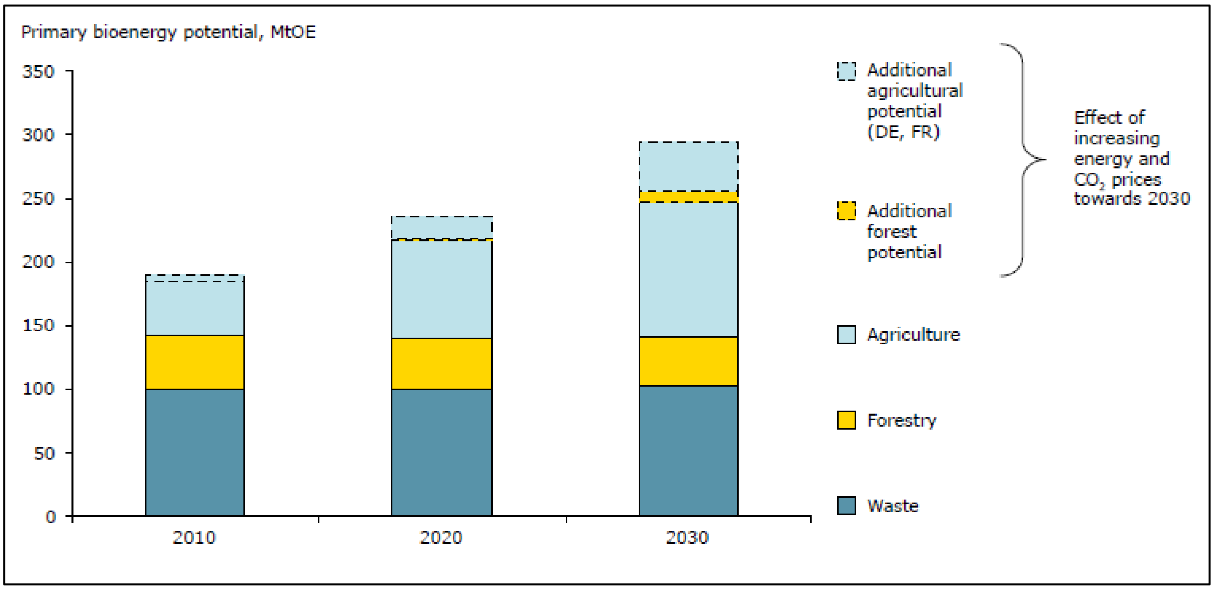

Figure 2.2 *Environmentally-compatible primary bioenergy potential in the EU 25 (EEA, 2006).*

Land availability estimates for non-food crops were also made by Ganko and Kopczynski (2010) They estimate that currently 2.4 million ha are used for energy crops (mostly oil crops and maize for biogas). In the same study projections have also been made for 2020 and 2030 for EU 27 (Krasuska et al., 2010). Future agriculture productivity and changes in population are the most important parameters determining the availability of land.
The total area potentially available for non-food crops in the EU-27 (excluding Cyprus and Malta) was estimated to be 13.2 million ha currently, with fallow land making the largest contribution. In the future additional land would be released from food and fodder crops, resulting in total land potential of 20.5 million ha in 2020 and 26.2 million ha in 2030 (Krasuska et al., 2010).

We assume that in 2020 an average yield per ha of 10 tons DM would be possible resulting in a total potential production of 202 Mton DM. In 2030 this would result in 295 Mton DM assuming a yield of 12 tons per ha on 24,6 million ha.

In Table 2.4 the availability of biomass in EU 27 is presented for 2020 and 2030 based in the described studies. If we use the biomass availability in Table 2.4 as a based case we can project biomass availability under the 4 scenario's (described in Chapters 2.1 and 2.2) using the assumptions in Table 2.3. We assume that the "Base case" biomass availability are high end estimates for 2020.

Table 2.4 *Availability of biomass (tons DM) from waste and byproducts and from biomass crops in the EU27 in 2020 and 2030.*

	2020	2030	ref.
By-products and Waste	370	370	EEA, 2006
Non-food crops	184 - 230	250 - 390	EEA, 2006; Kraususka et al., 2010.
Total	554 - 600	620 - 760	

If we use the biomass availability in Table 2.4 as a based case we can project biomass availability under the 4 scenario's (described in Chapters 2.1 and 2.2) using the assumptions in Table 2.3. We assume that the "Base case" biomass availability are high end estimates for 2020.

This results in projected biomass availability from by-products and waste and from crops under the 4 scenarios of 338 and 511 million tons of biomass DM in 2020 and between 378 and 668 million tons DM in 2030 (See Figure 2.3).

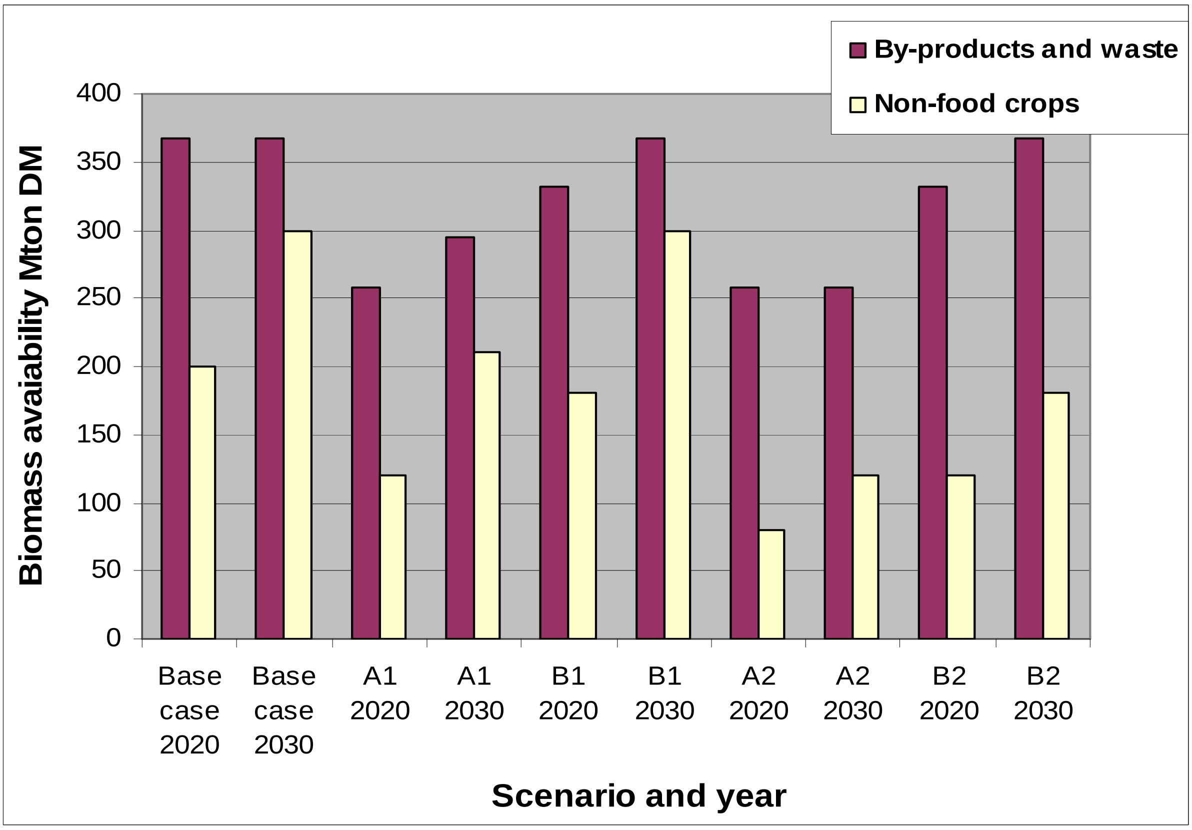

Figure 2.3 *Biomass availability from by-products and waste and from biomass crops under the base case and under 4 scenario's in 2020 and 2030.*

3 Demand for biomass based energy and chemicals

3.1 Biomass demand for bioenergy in EU 27

The Renewable Energy Directive (2009/28/EC) sets legally binding shares of renewable energy in the gross final energy consumption of the EU's 27 member states. In Article 4 of the Directive each Member State is requested to provide a National Renewable Energy Action Plan (NREAP). The estimated bioenergy contribution until 2020 for each category of renewable energy is defined in each NREAP.
Based on these reports the projected contribution of bioenery to the EU 27 energy mix can be calculated (ECN, 2010 and Ehrens pers. comm.).
Based on 20 NREAP reports, plus data from the Primes reference scenario for the remaining 7 countries (which had not yet reported), the contribution of bioenergy to the renewable energy mix has been calculated for 2020. The calculation is based on info from Ehrens (Erens pers. comm.) and elaborated by us. In Table 3.1 the results are presented. Overall 173 Mtoe of final energy is expected to be produced in 2020. Subdivided over biofuel (transport) 28,6 Mtoe, electricity (delivered) 26,7 Mtoe and heat 117,3 Mtoe.

In order to assess the amount and type of biomass needed, assumptions have to be made about the type of biomass that is used and the efficiency at which biomass is converted into biofuel, electricity and into heat. Efficiency of conversion is estimated on the basis of conversion efficiencies for electricity made by ECN for 2020 in The Netherlands (Menkveld, 2007; Koppejan et al., 2009).

The results are presented in Table 3.2, showing that in 2020 it is projected (in the NREAPs) that 657 Mton dry matter (11.990 PJ HHV) primary biomass is needed for production of 4.116 PJ final energy.

Table 3.1 *Estimated bioenergy production in 2020 according to NREAP, Primes model and interpolation.*

Source	EU-country	Primary biomass (Mtoe)	Final energy consumption (Mtoe)	Biofuel all (ktoe)	Total biomass Power (ktoe)	Total biomass Heat (ktoe)
NREAP	Austria	5.46	4.63	584	443	3,607
PRIMES	Belgium	6.95	2.90	874	2,021	
NREAP	Bulgaria	1.48	1.35	200	75	1,073
NREAP	Cyprus	0.10	0.08	38	12	30
PRIMES	Czech Republic	3.05	1.30	597	705	
NREAP	Denmark	5.64	3.67	261	761	2,643
PRIMES	Estonia	0.81	0.32	46	271	
NREAP	Finland	9.95	8.28	560	1,110	6,610
NREAP	France	25.53	21.59	3,660	1,476	16,455
NREAP	Germany	28.62	21.08	5,473	4,253	11,355
NREAP	Greece	2.16	1.95	617	108	1,222
PRIMES	Hungary	4.56	1.87	386	1,486	
NREAP	Ireland	1.25	1.06	482	87	486
NREAP	Italy	13.70	9.82	2,530	1,615	5,670
PRIMES	Latvia	1.32	0.48	82	393	
NREAP	Lithuania	1.53	1.30	167	105	1,023
NREAP	Luxembourg	0.39	0.33	216	29	83
NREAP	Malta	0.04	0.01		12	2
NREAP	Netherlands	7.03	3.79	834	1,431	1,520
PRIMES	Poland	15.16	5.35	1,399	3,952	
NREAP	Portugal	3.58	3.10	477	302	2,322
PRIMES	Romania	3.00	0.93	248	677	
PRIMES	Slovakia	2.56	0.99	216	776	
NREAP	Slovenia	0.88	0.78	191	58	526
NREAP	Spain	11.36	9.32	3,504	861	4,950
NREAP	Sweden	14.45	11.67	810	1,435	9,426
NREAP	United Kingdom	15.01	10.37	4,205	2,249	3,914
	total EU 27	**186**	**173**	**28,657**	**26,703**	**117,345**

The total energy production for the 3 energy categories and for synthetic natural gas made from biomass, has been further defined in the individual NREAPs of EU countries. This information has been used to back calculate the biomass needed for different conversion routes for the production of biofuel (for transport), electricity, heat and the production of synthetic natural gas (Table 3.2).

Table 3.2 *Estimation of the required biomass in 2020 for each of the bioenergy types in the EU 27. Based on the projected bioenergy production (NREAP , Primes or interpolation).*

Type of bioenergy	**Sub type of bioenergy**	**ktoe**	**PJ final**	**Conv. efficiency HHV/ HHV**	**Biomass source / process**	**PJ Primary biomass**	**Energy content biomass (HHV) MJ/kg**	**Biomass demand Mton DM**
Primary biomass	all biomass	286,436				11,990		655.7
Final energy consumption	all biomass	173,830	7,277					
Biofuels	all biofuels	28,506	1,193					
Bioethanol	**Total**	6,949	291	88%		329		19
	BioetOH from EU+imp	*6,481*	*271*	*90%*	*Sugar / starch to ethanol*	*301*	*17*	*17.73*
	Bioethanol-article 21.2	*468*	*20*	*70%*	*Sugars from lignocellulsoe*	*28*	*18*	*1.55*
Biodiesel	**Total**	21,037	881	100%		881		23
	Biodiesel	*19,724*	*826*	*100%*	*oils and fats*	*826*	*38*	*21.73*
	biodiesel-article 21.2	*1,313*	*55*	*100%*	*used oils, fats*	*55*	*38*	*1.45*
Other biofuels	**Total**	1,340	56			75		3.49
	Pure plant oil	*670*	*28*	*100%*	*Pure plant oil and methane from crops*	*28*	*38*	*0.74*
	Biomethane for transport	*670*	*28*	*60%*	*biogas from mainly crops +manure*	*47*	*17*	*2.75*
Other biofuels article 21.2	**Total**	520	22			36		2.13
	FT biodiesel	*260*	*11*	*60%*	*Lignocellulose*	*18*	*17*	*1.07*
	biogas from wates	*260*	*11*	*60%*	*biogas from wates*	*18*	*17*	*1.07*

Type of bioenergy	Sub type of bioenergy	ktoe	PJ final	Conv. efficiency HHV/ HHV	Biomass source / process	PJ Primary biomass	Energy content biomass (HHV) MJ/kg	Biomass demand Mton DM
Biomass power	**Total**	26,535	1,111	27%		4,172		239
	solid biomass	*17,524*	*734*	*30%*	*wood, biomass waste*	*2,445*	*18*	*135.84*
	biogas	*7,231*	*303*	*20%*	*manure, crop, by-prod.*	*1,513*	*16*	*94.59*
	bioliquids	*890*	*37*	*35%*	*Black liquor*	*106*	*38*	*2.80*
	bioliquids	*445*	*19*	*35%*	*oils*	*53*	*17*	*3.13*
	bioliquids	*445*	*19*	*35%*	*Pyrolysis oils*	*53*	*17*	*3.13*
Biomass heat	**Total**	116,503	4,877	69%		6,591		364
	solid biomass	*103,522*	*4,333*	*75%*	*chips, pellets, straw,*	*5,778*	*18*	*320.99*
	biogas	*5,870*	*246*	*60%*	*Manure, crop, by-products*	*410*	*16*	*25.60*
	bioliquids	*3,555*	*149*	*80%*	*Black liquor*	*186*	*22*	*8.46*
	bioliquids	*1,778*	*74*	*80%*	*Oils*	*93*	*38*	*2.45*
	bioliquids	*1,778*	*74*	*60%*	*pyrolysis oils from solids*	*124*	*18*	*6.89*
bio-SNG for grid feed-in	**Total**	946	40			66		3.77
	Bio-SNG from biogas	*473*	*20*	*60%*	*Manure, crop, by-products*	*33*	*17*	*1.94*
	Bio-SNG from gassification	*473*	*20*	*60%*	*wood, biomass waste, etc*	*33*	*18*	*1.83*

Biofuels

Biofuels consist of the categories biodiesel, bioethanol and "other biofuels". The category "other biofuels is made up of pure plant oil and biogas for transport. On top of this biofuels produced under the so called article 21.2[2] are quantified.

[2] *Article 21.2 refers to this article in the EU Renewable Energy Directive (2009) which stipulates that "contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material shall be considered to be twice that made by other biofuels".*

The reported amount of bioethanol produced in 2020 is 6,481 Mtoe (271 PJ) which requires 301 PJ of sugars and/or starch. Assuming an energy content of 17 MJ/kg this requires 17,73 Mton DM of carbohydrates. On top of this some 1,55 Mton of carbohydrates are required for production of bioethanol under article 21.2. We assume this means that 1.55 Mton carbohydrates are mainly derived from lignocellulosic materials which are converted into ethanol at 70% efficiency (for cellulose and hemi-cellulose).
Biodiesel is produced from 21,73 Mton oils and fats and 1,45 Mtons of fats and oils which qualify under article 21.2 (used fats and oils).
We assume that 740.000 tons of pure plant oils (28 PJ) are used for transport and 2,75 Mton DM biomass (mainly crops and manure) is needed for 670 ktoe (28 PJ) transport bio-methane.
Other transportation biofuels include 260 ktoe FT diesel requiring 1.07 Mton DM lignocellulosic biomass. 1.07 Mton DM of waste biomass is also required for transport biogas, qualifying under article 21.2.
The conversion efficiencies assumed in Table 3.2 can increased over time as technology develops.

Electricity
For the production of electricity from biomass different routes are possible. Conversion efficiencies vary from 20% for biogas to 35 % for bioliquids (HHV basis). The amount of CHP was difficult to assess. Therefore we assumed that all the biomass was used for electricity production. The contribution of CHP was expressed by incleasing the efficiency at which heat was produced (and used). So biomass used for CHP is only counted towards electricity. CHP is expressed by a higher conversion (and utilization) efficiency of biomass for heat.
Apart from solid biomass thermal conversion and biogas production electricity routes bioliquid routes were also quantified. There black liquor, oils and pyrolysis oil van de distinguished as feedstocks. We assumed a 35% conversion efficiency (HHV).

Heat
364 Mton Dm of biomass is required for production of heat in 2020. The same categories can be distinguished as for electricity production. Here efficiencies are between 60 and 80%. Note that in the efficiency of pyrolysis oil we have included the efficiency of conversion of biomass to pyrolysis oil and then the efficiency of conversion of pyrolysis oil into heat.
In other documents conversion efficiencies of biomass into usable heat is often not considered. Here we have include efficiency estimates as we need to include CHP adoption and we need to express efficiency increases over time under different scenario's. Tracking the efficiency at which biomass is converted (and used) makes it possible to express advances in conversion efficiency (better stoves). This makes it possible to reach bio-energy targets using less biomass.

Synthetic Natural Gas
Production of synthetic natural gas for grid feed in is only relevant in The Netherlands at this point. We assumed that half would be produced through biogas route and the other half would be produced by the gasification route.

In the NREAPs the amount of imported fuel or feedstock for production of biofuel was reported. The amount of biofuels made form waste or by-products was also reported in the NREAPs and estimated (see Table 3.2). For electricity and heat the contribution of waste and by-products was estimated by assuming that the potential was filled by the estimated biomass potential in 2020 (Table 2.4). Consisting of waste and by-products and (biomass) crop production in 2020. The remainder of the required biomass was assumed to be imported. In Table 3.3 the total amount of different biomass types and the source of that biomass is defined for 2020 based on Table 3.2.

Table 3.3 *Biomass requirements (million tons DW) for the biomass ambitions in the EU 27 in 2020 based on NREAP estimates and own calculations.*

Biomass demand	Total	Byproducts and waste	EU crops	Imports
Carbohydrates 1e generation	17.73	1.77	10.46	5.50
Sugars from lignocellulose 2e gen.	1.55	0.85	0.39	0.31
oils and fats	29.49	1.47	19.17	8.85
Biogas substrate: manure, crop, by-products	125.94	88.16	36.52	1.26
Solids for thermal conv: chips + pellets mainly	469.76	258.37	117.44	93.95
Black liquor	11.26	11.26	0.00	0.00
Total biomass demand	**655.74**	**361.89**	**183.98**	**109.87**

Based on the NREAPs and our own calculation 656 Million tons of primary biomass is needed in the EU 27 in 2020 to fulfill the bioenergy ambition of the renewable energy directive. 546 million DM tons of biomass are sourced in the EU27 and 110 Million tons of biomass are imported.

By far the largest category is 470 Mtons DM solid biomass (bales, wood chips and pellets of all sorts). 126 Mtons (DM) of biomass is needed for the production of biogas, this should mainly consist of wetter biomass categories (manure, crops, by-products).
Oils and fats for the production of biodiesel, pure oils for transport and oils for electricity and heat amount to 29,5 Mtons of which 8,85 Mtons are imported.

17,73 Mtons of sugars or starch is needed for ethanol production. The amount of (lignocellulosic based) sugars for second generation fuel production is only 1,55 Mtons equivalent to 8% in 2020 of total amount of carbohydrates needed for biofuel in 2020.
Black liquor for production of electricity and heat is assumed to be sourced as a by-product or waste from the paper industry and from the emerging second generation biofuel industry.

Overall we estimate that the ambitions in the NREAPs are large (656 Mton DM) compared to the amount of (conventional) biomass that is expected to be available in EU 27 in 2020 (554 – 600 Mton DM). Therefore importing at least 50 to 100 Mton DM (or fuel equivalents) biomass will be needed to achieve the targets under the NREAPs.

3.2 Demand for biomass based chemicals in EU 27

Apart from bioenergy the chemical industry is expected to start demanding very large quantities of biomass to replace fossil fuels as feedstock in the near future. This process has already started and is expected to continue.

Bos et al (2009) have quantified what chemicals (that are currently produced from fossil fuels) can be replaced by biomass based chemicals. In Table 3.4 the total volume of chemicals is presented that could be made from biomass sources. They estimate that it is possible to replace 87,4 million tons of chemicals by biomass based chemicals (based on the total production of chemicals in the European Union in 2005).

Table 3.4 *Estimated potential volume of chemicals from biomass in the EU 27 based on volumes in 2005 (Bos et el., 2009).*

Building blocks from biomass	**Volume possibly bio-based (tons)**
Base chemicals from carbohydrates	46.750.570
Base chemicals from lignin	10.901.839
Base chemicals from glycerin (from oils and fats)	2.178.433
Base chemicals from proteins	10.359.233
Base chemicals from unspecified biomass	17.254.644
Totals	**87.444.719**

Note that in the future this potential would increase as the total production volume of the chemical industry in the European Union would increase as the economy grows.
The amount of biomass (carbohydrates, lignin, glycerin, proteins and unspecified biomass) required can be calculated assuming conversion efficiencies for the production of chemicals biomass to chemicals.

The potential demand from the chemical industry is of the same order of magnitude as present demand for wood and fibre. This shift in demand will definitely not occur overnight, since technology needs to be developed further and existing installation need to be depreciated before new investments are done.
Note that the demand for production of chemicals is to quite some extent demanding the same types of biomass the energy industry requires, especially with respect to carbohydrates and unspecified biomass (mostly lignocellulose). For glycerin there seems to be a synergy as glycerin is a (by-) product from conventional biodiesel production. The same may be the case for lignin as this is a product from the paper industry and in the future from second generation biofuels (ethanol) production.

4 The biomass demand for bioenergy and the chemical industry in EU 27 under 4 contrasting scenarios.

In the NREAPs the biomass demand for production of biomass based chemicals is not included and it also seems that the interaction between the demand for biomass for energy and biomass for chemicals has generally not been included in defining the NREAPs.
This probably follows from the fact that the EU has set clear ambitions for bioenergy in 2020 (see RED) but for biomass based chemicals no such targets exist. At the same time industry with help from EU and national governments is developing this change from fossil to biomass feedstocks at an increasing rate.
In this chapter we evaluate the demand for biomass based chemicals in 2020 and 2030. We use the replacement potential for chemicals by biobased chemicals as a base for making our calculations (see Table 3.4). We use the same 4 general scenarios that have been defined in general terms in chapter 2 and describe the conditions for the chemical industry and markets here.

4.1 Biomass demand for the chemical industry in EU 27 under 4 contrasting scenarios

4.1.1 A1 - Global Economy

General development philosophy:
- Strong commitment to market based solutions in order to obtain an optimal balance between demand and supply of goods, services and environmental quality at national, regional (EU) and global levels
- Government intervention as limited as possible should focus on core responsibilities (basic education, public health, basic security, planning of major infrastructure, ensuring conditions for competitive markets, law enforcement) and market failures.
- Lean government implies low taxes.
- International co-operation is focused on the removal of trade barriers and the creation of a level playing field.

In this scenario the economic growth is highest, it is estimated to be 2.5% per year.
Population growth: 480 million in 2000, 490 million in 2020, 502 million in 2030.

Sourcing for the chemical industry
- The globalization of the economy leads to a world-wide sourcing of biomass, implying that costs per ton including transport will determine which biomass is most attractive.
- This large scale sourcing will preferentially lead to technology development of large scale processes.
- The market for chemical products is expected to increase by about 2.5% per year, in analogy to the economic growth. This means that towards 2030 a shortage in supply of oil for the chemical industry might come up.
- The CO_2 price will be low in this scenario, but the oil price will be high as will be the price for energy. Innovation will be driven towards energy efficient processing routes.

- The price for biomass will be low.

Routes for the chemical industry in scenario A1

Carbohydrate based chemicals

Fermentation route towards basic chemical feedstock

- The use of ethanol as feedstock for ethene, which is one of the main raw materials for the chemical industry. Ethanol will be produced by fermentation near the agricultural area's, where new plants will be constructed.
- Ethanol will be imported for a large part from outside Europe
- Ethanol will be converted into ethane in the European harbours, Ethene is the largest basic feedstock for the petrochemical industry. Biothene will be fed to the existing pipeline infrastructure to supply the chemical plants in the hinterland.
- Fermentation process developments will focus first on the easiest feedstocks, meaning so called first generation technologies, sugarcane will be the most important crop.
- First generation fermentation are proven processes, innovation will be geared towards separation technology and lowering of the energy demand.
- Ethanol will be joined by other basic chemicals that can be produced by fermentation. Isobutanol is a serious candidate, it can be used for the production of propene, the second largest feedstock, etc. In this way the 6 main raw materials for the petrochemical industry will be replaced partially by biobased feedstock, the chemical industry does not need to invest a lot in new production plants.
- The raw materials are made in situ and transported to Europe by ship and to the chemical plants by ship or by (new) pipelines.
- The chemical industry will innovate in the production processes mainly driven by the need to lower the energy demand of the processes.
- The replacement of naphtha by biochemical feedstock can take off quickly, since it is partially based on proven technology , but it will slow down after that, biomass feedstock need to compete with naphtha and the relative prices of the two will determine the % of replacement. We therefore assume 15% biobased chemical in 2020 and 25% biochemical in 2030.
- The conversion efficiency of these processes is not high, of every sugar molecule converted into ethane 70 wt% is lost as water and carbon dioxide.
- In the margin, driven by price advantages also other more functionalized chemicals will be produced, like lactic acid and succinic acid. Conversion efficiency of these processes is much higher, could be up to 100%. However this development will stay limited, because the chemical industry can continue to produce the same materials as before via the ethane route.
- We therefore estimate that the conversion efficiency will be 25% in 2020 and 40% in 2030

We have estimated previously that approximately 46 million tons of the present chemicals produced in Europe might be produced from carbohydrate sources.

Lignin based chemicals

- Lignin is produced in large quantities by the paper industry
- Lignin is presently mainly used for the production of energy to fire the plant, and to deliver the excess electricity to the grid.

- It is likely that this application will remain in place but some innovation towards application of lignin as basis for chemicals will also occur.
- In this scenario the production of biofuels will be limited, therefore the available lignin will come mainly from the paper industry.
- Since 2% of lignin is already used for non-food products, we assume that this will grow slowly. We therefore assume that in 2020 3% of the possibly lignin derived chemicals will be made from lignin, and in 2030 6%.
- The route towards the basic components BTX, however is long and cumbersome and other applications of lignin in resins for instance might occur far sooner.
- Conversion efficiency is estimated to lie around 50 %. The route from lignin to phenol can have maximum 50% conversion efficiency. Routes towards resins can have a higher theoretical conversion efficiency, but will start off lower than maximum, estimated 50%.

Protein based chemicals

There will be little room for protein based chemicals in this scenario, because the innovation hurdle is expected to be too high and risky. Proteins will be used for feed.

Natural oil based chemicals

The development of chemicals of natural oils will be driven by the development of biodiesel from natural oils. The expected biodiesel production from oils is large compared to the demand of chemicals from natural oils. We estimate that in this scenario in 2020 15 % of the possibly natural oil derived chemicals will be made from biomass and in 2030 25%. The conversion efficiency is in both years 0.15, since this is close to the maximum theoretical conversion efficiency, in case mainly the glycerol side stream is applied, which is already reached.

Unspecified (mainly lignocellulosic) biomass

This route will be influenced strongly by the FT biofuels development. Two product families can be made:
- Syngas, since for FT syngas needs to be produced, some extra can be made as feedstock for other processes.
- The FT route also can produce 5% C1-C4 and 15% naphtha. This means that mainly the chemicals that can be produced from carbohydrates can also be produced from this stream. This thus can add an extra feedstock, to be used for the production of the unfunctionalised base chemicals.

The production of syngas eventually followed by Fisher-Tropsch process:
- Biomass can be gasified towards syngas which can subsequently be transformed in the feedstock for the chemical industry. Syngas is a mixture of CO and H_2 with eventually some other components. From this methanol of DME can be produced, which can be used in the chemical industry as reagents
- The Fisher-Tropsch route produces mainly alkanes and waxes, which are not very useful as feedstock for the chemical industry, although they might be cracked into smaller compounds that could be useful as feedstock..
- The implementation of this route will be driven by the biofuels development.

- The FT-route is for biomass not yet scaled up and many technological hurdles exist, for instance in cleaning the syngas.
- This production route can only be profitable at a very large scale, because the FT process is run at high temperature. Gasification to syngas however is already feasible at much smaller scales.
- Feedstock can be less critical than for the fermentation routes, lignocellulose can be used.
- The plants will be built in the middle of the biomass sourcing areas.

Overall the infrastructure of the chemical industry will remain relatively unchanged within this scenario, and its sourcing might become more strongly dependent on the relative price between oil and biomass. Especially the route via fermentable sugars might lead to a fast change in feedstock.

4.1.2 B1 - Global co-operation.

General development philosophy:
- Sustained development can only be achieved through well-coordinated efforts at regional and global level towards a fair distribution if wealth, social justice and environmental stewardship.
- Govermetn intervention: relatively strong, aimed at internalizing environmental and social costs in order to channel market forces, removing their bias on short-term economic gains. Strong policy instruments at national, regional and global levels are developed to achieve this.
- Large government implies high taxes (in between A2 and B2).
- International cooperation is intensive, focused on the gradual removal of trade barriers and support to developing regions to eliminate poverty and reap the benefits of freer trade, while concurrently working towards high international standards for product quality, working conditions, environmental quality etc.

In this scenario the economic growth is medium, it is estimated to be 2.3 % per year.
Population growth: 480 million in 2000, 485 million in 2020, 490 million in 2030.

Sourcing for the chemical industry
- Chemicals demand is estimated to grow by 2.3% per year.
- Sourcing of biomass will be done world wide, however there will be sustainability requirements, which means that the biomass with the lowest inputs and highest yield per hectare will be preferred.
- The CO_2 price will be high in this scenario.
- The oil price and the price for biomass will also be high
- These circumstances lead to large scale technology that will provide a high saving of CO_2 and energy per product produced compared to the present petrochemical alternatives.

Routes for the chemical industry in scenario B1

Carbohydrate based chemicals

- In the first instance bio-ethene might start the greening of the chemical industry.
- In the next step the circumstances will favour the development of higher functionalized chemicals over the ethene route. The chemical industry will innovate towards new processes, where chemicals that were previously produced via the ethene route will now be fermented directly from biomass.
- Second generation technologies to increase the production of sugars from more sustainable feedstocks will take a high flight.
- The chemical industry will develop towards smaller scale technologies. The market for functionalized products like di-acids and di-alcohols that can be made easily from sugars, will grow faster than for other products.
- GMO will be accepted to increase the yield in easily fermentable sugars of the crops.
- The percentage of BBE based chemicals can be highest in this scenario, due to the large savings in energy and CO_2 emissions to be expected.

Lignin based chemicals

Ligning is produced in large quantities by the paper industry

- Lignin is presently mainly used for the production of energy to fire the plant, and to deliver the excess electricity to the grid.
- Because 2[nd] generation lignocellulose technology will take a high flight a lot of extra lignin will become available, this can be used for energy production, as feedstock for FT and for the production of chemicals.
- It is likely that innovation will be geared towards the production of higher value components of this abundant side streams and thus to the production of chemicals.
- The route towards the basic components BTX, however is long and cumbersome and other applications of lignin in resins for instance might occur far sooner.
- We therefore estimate that in 2020 10% of the possibly lignin based chemicals will be produced from lignin and in 2030 30%. Conversion efficiency will remain 50%.

Protein based chemicals

There will be some room for protein based chemicals in this scenario, although many proteins will go to feed. Development of protein based chemicals however is a long and cumbersome route. We therefore estimate that in 2020 3% of the possibly protein based chemicals will be produced from proteins, and in 2030 6%. The conversion efficiency is low for these chemicals, because comparatively little nitrogen is available in the proteins. We estimate is will be 20% in 2020 and 25% in 2030. This is based on the theoretical maximum conversion efficiency of the pool of chemicals that can actually be made from proteins (see Bos *et al.*, 2009)

Natural oil based chemicals

The development of chemicals of natural oils will be driven by the development of biodiesel from natural oils. The expected biodiesel production from oils is large compared to the demand of chemicals from natural oils. We estimate that in this scenario in 2020 20 % of the possibly natural oil derived chemicals will be made from biomass and in 2030 40 %. The conversion efficiency is in both years 0.15, since this is close to the maximum theoretical conversion efficiency, in case mainly the glycerol side stream is applied, which is already reached.

Unspecified (mostly lignocellulosic) biomass
This route will be influenced strongly by the FT biofuels development. Furthermore, also the development of plants as producers of specialty chemicals has a place in this scenario. This will be case specific for all applications. It will not involve large quantities of biomass, but it can be economically interesting (low volume- high value)

4.1.3 A2 - Continental Markets

General development philosophy:
- Social and cultural values can best be preserved in regional political alliances, within which nation states should keep as much sovereignty as possible. Optimum resource allocation among co-operating societies can largely be obtained by market-based solutions, but protection from other markets is necessary because different standards regarding e.g. working conditions, food safety, animal well-being and the environment impede the creation of a level playing field
- Self-sufficiency is the key to steady development, shielded against the vagaries of third countries.
- Government intervention should be limited to core responsibilities with a strong focus on defense and security.
- Relatively lean government but high costs related to security (and support to agriculture) imply higher taxes than A1.
- International co-operation: non-interference unless vital interests of the alliance are at stake (e.g. combating international crime). Humanitarian ais, mostly by private initiatives, is given in reaction to catastrophes. Loose ad hoc alliances, driven by political motives, may be formed with third countries.

In this scenario economic growth is medium, it is estimated to be 2.0% per year.
The population will decline: 480 million in 2000, 472 million in 2020, 460 million in 2030.

Sourcing for the chemical industry
- Chemicals demand is estimated to grow by 2.0% per year.
- Sourcing of biomass will be done more locally in this scenario i.e. within Europe
- Because the agricultural policy will not be reformed much, the price for sugars will be high, even though the price for other sources of biomass might be low.
- The high price of sugars limits the development of new fermentation technology for chemicals.
- Due to the high sugar price 2nd generation technology development is boosted, leading halfway this period to installation of 2nd generation plants.
- Because the CO_2 price is relatively low, ethanol will be converted into ethane and used as basic feedstock for the chemical industry.
- Direct production of functionalised chemicals will grow, but more slowly than in A1 and B1.

Routes for the chemical industry in scenario A2

Carbohydrate based chemicals

- Because the CO_2 price is relatively low, ethanol will be converted into ethene and used as basic feedstock for the chemical industry.
- Direct production of functionalised chemicals will grow, but more slowly than in A1 and B1.
- We therefore estimate that in 2020 10% and in 2030 20% of the possibly carbohydrate based chemicals will be produced from carbohydrates. Since there is at first little attention for the development of fermentation technology, the conversion efficiency will be low.
- When 2nd generation sugars become available, development of fermentation technology will speed up and conversion efficiency will increase. We therefore estimate it to grow from 0.3 to 0.5

Lignin based chemicals

Lignin is produced in large quantities by the paper industry

- Lignin is presently mainly used for the production of energy to fire the plant, and to deliver the excess electricity to the grid.
- It is likely that this application will remain in place but some innovation towards application of lignin as basis for chemicals will also occur. The route towards the basic components BTX, however is long and cumbersome and other applications of lignin in resins for instance might occur far sooner.
- When 2nd generation technology is installed more lignin will become available, which will speed up innovation.
- We therefore estimate that in 2020 3% of the possibly lignin based chemicals will actually be produced from lignin and in 2030 10%. Conversion efficiency will remain 50%.

Protein based chemicals

- Protein rich streams will go to feed and will not become available for chemistry.

Natural oil based chemicals

The development of chemicals of natural oils will be driven by the development of biodiesel from natural oils. The expected biodiesel production from oils is large compared to the demand of chemicals from natural oils. We estimate that in this scenario in 2020 10 % of the possibly natural oil derived chemicals will be made from biomass and in 2030 20 %. The conversion efficiency is in both years 0.15, since this is close to the maximum theoretical conversion efficiency, in case mainly the glycerol side stream is applied, which is already reached.

Unspecified (mostly lignocellulosic) biomass

This route will be influenced strongly by the FT biofuels development and is a function of the development of FT biofuels.

4.1.4 B2 - Regional Communities

General development philosophy:
- Sustainable development should be geared to local dynamics. Social and cultural values can best be preserved at the community level. Resource allocation cannot be left to the market. Local communities are the cornerstone of society.
- Self-reliance, ecological stewardship and equity are the keys to sustainability.
- Participatory bottom-up approaches towards policy making at local level. Government intervention is necessary to facilitate negotiations between stakeholders and enforce decisions, rather than impose regulations.
- International co-operation is necessary to obtain sustainable development at global level. This should be targeted at the elimination of poverty by promoting self-reliance regarding food and energy in the poorest countries.
- Large government and high costs to maintain social achievements, cohesion, agriculture etc., imply the highest tax levels as compared to the other 3 scenarios.

In this scenario economic growth is lowest, it is estimated to be 1.3 % per year.
The population will decline: 480 million in 2000, 470 million in 2020, 447 million in 2030.

Sourcing for the chemical industry
- Chemicals demand is estimated to grow by 1.3% per year.
- Sourcing of the biomass will be done locally in this scenario. Because of strong local participation small scale transportable conversion plants, that will perform the first processing near the field will get a strong boost.
- The price of CO_2 will be high, the oil price will be relatively low, and the price of biomass will be highest in this scenario.
- Availability of feedstock will be rather scattered over the country, inducing smaller scale chemistry.
- Replacement of feedstock at the ethylene level will not take a high flight, due to the scattered availability, but since the biomass is expensive it will be used as optimally as possible, which will include the small scale production of functional chemicals.
- Also in this scenario there is a lot of room for specialized crops that produce specialty ingredients, GMO however will not be acceptable.

Routes for the chemical industry under scenario in scenario B2

Carbohydrate based chemicals
- Replacement of feedstock at the ethylene level will not take a high flight, due to the scattered availability, but since the biomass is expensive it will be used as optimally as possible, which will include the small scale production of functional chemicals.
- Smaller scale fermentation technology will be developed, leading to integrated chemicals production at local biorefineries sites. This production will have a high conversion efficiency, we estimate it to rise from 0.7 in 2020 to 1 in 2030.

- The percentage of chemicals that can be replaced in this way is relatively small due to the scale difference between production and possible demand. We estimate it to range from 10% in 2020 to 25% in 2030.

Lignin based chemicals

Lignin is produced in large quantities by the paper industry

- Lignin is presently mainly used for the production of energy to fire the plant, and to deliver the excess electricity to the grid. This will stay in place.
- Due to the local biorefineries, lignin will become available as a side stream from 2nd generation ethanol production. Since the availability will be rather locally scattered, applications of lignin on smaller scale chemicals use will be favoured. This indicates that lignin as basis for resins will take a high flight. (next to the present day applications in asphalt and cement). We estimate that in 2020 10 % and in 2030 25% of possibly lignin based chemicals will be produced from lignin. The conversion efficiency will increase from 50 to 70%.

Protein based chemicals

Proteins will be mainly used for feed, but some room for protein based chemicals will become available in this scenario. Development of protein based chemicals however is a long and cumbersome route. We therefore estimate that in 2020 3% of the possibly protein based chemicals will be produced from proteins, and in 2030 6%. The conversion efficiency is low for these chemicals, because comparatively little nitrogen is available in the proteins. We estimate this will be 20% in 2020 and 25% in 2030. This is based on the theoretical maximum conversion efficiency of the pool of chemicals that can actually be made from proteins (see 4Fcrops market report).

Natural oil based chemicals

The development of chemicals of natural oils will be driven by the development of biodiesel from natural oils. The expected biodiesel production from oils is large compared to the demand of chemicals from natural oils. We estimate that in this scenario in 2020 20 % of the possibly natural oil derived chemicals will be made from biomass and in 2030 40 %.
Next to the application of glycerol also the development of chemicals from the fatty acid part of the oils will be continued. This leads to an additional rise in application of oils for chemicals of plus an increase in conversion efficiency from 0.15 to 0.3.

Unspecified (mostly lignocellulosic biomass)

This route will be influenced strongly by the FT biofuels development and is a function of the development of FT biofuels.

4.1.5 Summary of the biomass demand for the chemical industry under 4 contrasting scenarios

Based on the assumptions per scenario as described in chapter 4.1 the demand for biomass to make chemicals components was calculated. The specific assumptions with respect to market increase and % replacement and conversion efficiency are summarized in Appendix 1.

In Table 4.1 and Figure 4.1 the demand for biomass for production of chemicals is shown[3]. We see that the largest demand from the chemical industry comprises fermentable sugars (for ethanol) which are sourced from sugar crops and from starch crops and also from pre-treated lignocellulosic materials, which are expected to mostly have a real impact after 2020. After fermentable sugars the demand for lignin is the most relevant especially after 2020 when lignin is expected to be available from pre-treatment facilities producing sugars from lignocellulosic materials. Protein demand for production of chemicals can play a role in production of specific functionalized chemicals. Only in scenarios driven by sustainability will this have a limited impact. Glycerin based chemicals are already relevant in the market. The development will mainly depend on the availability of glycerin from biodiesel production facilities (which generate glycerin as a by-product). The use of biomass based chemicals is largest in scenarios where open markets exist (A1 and B1) and market expansion and sustainability give biomass based chemicals a market share.

Table 4.1 *Biomass demand for chemical production in EU 27 in 2020 and 2030 under 4 contrasting future scenarios.*

	Year	Fermentable sugar demand	Lignin demand	Protein demand	Glycerin demand	Biomass demand
A1 - Global Economy	2020	40.03	0.96	0.36	0.80	1.23
	2030	53.43	2.45	0.74	2.04	4.51
B1 - Global Cooperation	2020	25.69	3.07	2.09	1.54	1.98
	2030	40.12	11.51	4.19	3.84	6.35
A2 - Continental Market	2020	20.49	0.88	0.33	0.33	0.38
	2030	29.82	3.57	0.65	0.65	1.18
B2 - Regional Communities	2020	7.96	2.67	1.82	1.82	0.34
	2030	15.84	5.41	3.31	3.31	1.67

[3] *See Appendix 2 for the specific demand for biomass for production of chemicals under scenarios*

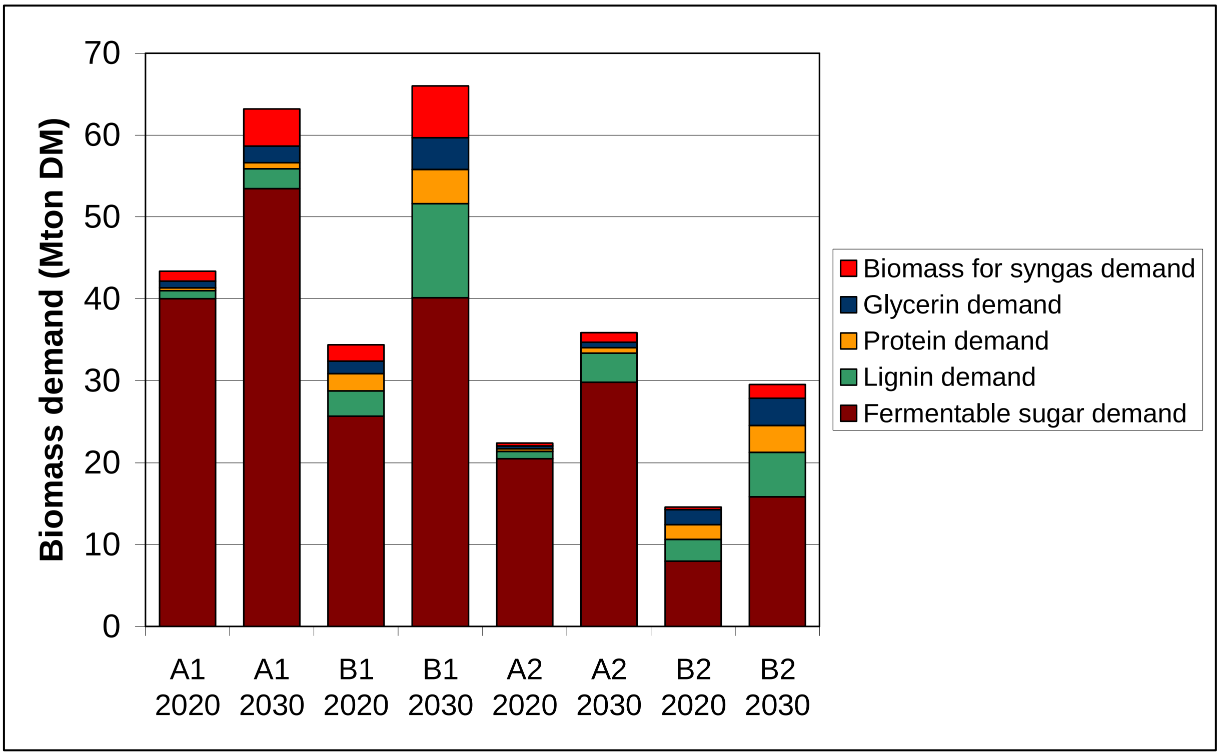

Figure 4.1 *Biomass demand for chemical production in EU 27 in 2020 and 2030 under 4 contrasting future scenarios.*

4.2 Biomass demand for bioenergy under 4 contrasting scenarios

As with the chemicals the bioenergy conditions have been described under the 4 scenario's (Table 4.2). Together with the general conditions under the scenarios we have made logical assumptions for the development of bioenergy in 2020 and in 2030. We have used the bioenergy production under the NREAPs (Table 3.3) as the base case. We assume that the ambitions in NREAPs are quite high amd will only be reached in ambitious scenarios (B1 and B2).

For each scenario the total amount of energy produced, the efficiency of conversion of biomass into final energy and the sourcing of the biomass (imports vs by-products and waste vs EU produced crops) was defined. As base case we used the volumes and efficiencies as described in Table 3.2 for the NREAPs.

Table 4.2 *Bioenergy assumptions for the 4 contrasting scenarios.*

	A1 Global Economy	**B1 Global Co-Operation**	**A2 Continental Markets**	**B2 Regional Communities**
Biomass price	Low	High	High	Highest
CO2 price	Low	High	Low	Highest
Biomass efficiency	Low	High	Low	High
Biomass switch from E+H to transport and chemicals	Average	Fastest	Slow	Fast
Advanced biofuels introduced	Slow	Fastest	Slowest	Fast
Sustainability criteria	Not strict	Strict and mainly focused on GHG	Not very strict	Very strict and broad
ILUC	Not relevant	Most relevant	Not relevant	Relevant
"Inertia of infrastructure"	High	Low	High	Lowest
Biomass CHP	Low	High	Low	High
Biorefinery implementation	Large scale / price driven	High / larges scales	Low / only traditional	High / also smaller scales

In Table 4.3 an example of the approach is given for scenario A1 (Global Economy) in 2020. The total biomass demand for energy and chemicals is shown in Table 4.4. In scenario A1 the bioenergy ambitions are lower, which is partially compensated by a larger overall demand for energy. As open markets prevail a large part of the biomass demand is imported. Conversion efficiencies are a bit lower than for B1 and B2 scenarios. Development of advanced biofuels (second generation ethanol and FT diesel) is a bit slower than under scenario B1 (Global Cooperation).

Table 4.3 *Scenario A1 in 2020 compared to the base case described in Table 3.2 and Table 3.3.*

A1 compared to base case in 2020:	**Volume difference**	**Efficiency difference**
Biofuels 1 gen.	80%	95%
Pure oils	50%	100%
Second generation:	100%	90%
Imports	150%	
By-products/waste	80%	
Other biofuels article 21.2 not 2e gen	80%	95%
Power	80%	95%
Heat	80%	95%
Oils for Electricity and Heat	80%	
Pyrolysis oil	100%	95%
Bio-SNG for grid feed-in	100%	95%

Table 4.4 *The demand of biomass for the production of bio-energy and chemicals under scenario Global Economy (A1) in 2020. Based on the assumptions described in Table 4.2.*

	Total energy	**Total Chemicals**	**Total E+C**	**Byproducts and waste**	**EU Commod. / crops**	**Imports**
Carbohydrates 1st generation	14.93	35.88	50.81	4.06	23.12	23.63
Sugars from lignocellulse 2nd generation	1.73	4.15	5.88	2.59	1.53	1.76
Oils and fats	23.61		23.61	0.94	12.04	10.62
Glycerin for chemicals		0.80	0.80	0.03	0.41	0.36
Proteins for chemicals		0.36	0.36	0.01	0.18	0.16
Biogas substrate: manure, crop, by-products	106.47		106.47	59.62	45.25	1.60
Solids for thermal conv. chips + pellets mainly	398.37	1.23	399.60	175.82	103.90	119.88
Black liquor - lignin	9.48	0.96	10.44	10.44	0.00	0.00
Total biomass demand	**554.58**	**43.38**	**597.96**	**253.53**	**186.42**	**158.01**

In Figure 4.2 and Table 4.5 the overall demand for biomass and the amount of final energy produced from this biomass is shown for 2020 and in 2030 for the 4 scenarios. The efficiency of biomass conversion into electricity and heat is also indicated (HHV basis). Higher conversion efficiencies are achieved by installation of more efficient conversion systems and especially adoption of combined heat and power (CHP) production where residual heat from electricity production is used to save fossil fuel use.

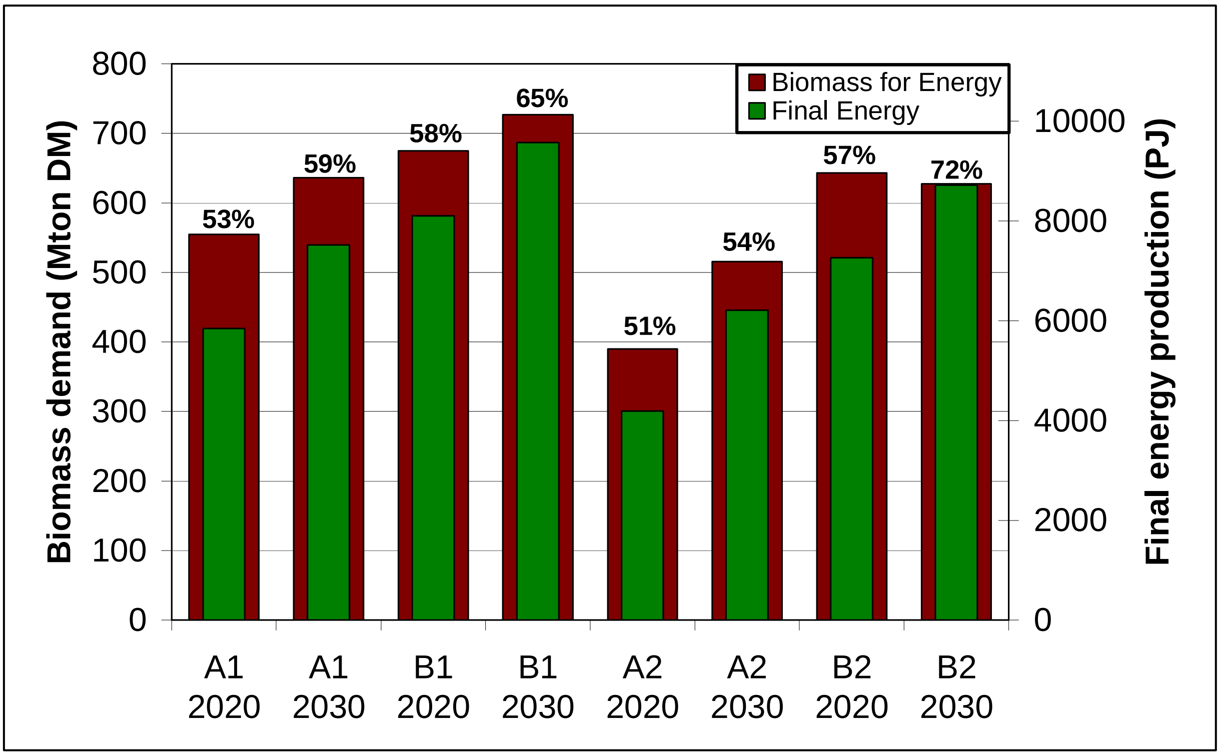

Figure 4.2 *Demand for biomass for the production of Fuels, electricity and heat under 4 scenarios in 2020 and 2030. The percentages indicate the efficiency at which biomass is converted into electricity and heat.*

Under scenarios driven by sustainability (B1 and B2) efficient use of biomass is important. This is achieved by utilzation of more byproducts and waste exhausting the potentially available byproducts and waste completely (see also Table 2.4). Figure 4.2 and Table 4.5 show that for all 4 scenarios the efficiencies of biomass use are increased from 2020 to 2030. The contribution of bioenergy to the energy mix is increased by utilising more biomass and especially by utilizing the biomass more efficiently.

Table 4.5 *Biomass demand for production of energy and chemicals in 2020 and 2030 under 4 scenarios.*

Scenario	For Energy *Mton DM*	Final energy *PJ*	E+H efficiency *% of HHV*	For Chemicals *Mton DM*	Total E+C *Mton DM*	Byproducts and waste *Mton DM*	EU agriculture *Mton DM*	Imports *Mton DM*
A1 2020	555	5845	53%	43	598	254	186	158
A1 2030	636	7521	59%	63	699	263	188	249
B1 2020	675	8105	58%	34	709	354	230	124
B1 2030	727	9576	65%	66	793	341	273	178
A2 2020	390	4196	51%	23	412	173	174	65
A2 2030	515	6211	54%	36	552	226	247	78
B2 2020	643	7267	57%	14	657	377	192	89
B2 2030	628	8722	72%	28	656	393	180	83

5 Matching demand and supply under 4 contrasting scenarios

5.1 Characterising the biomass demand for energy and chemicals under scenarios

See Appendix 2 for the detailed biomass demands per scenario's for energy and for chemicals in 2020 and 2030.

In all scenarios the demand of biomass for heat is the largest. This demand does not increase after 2020 and may even be reduced after 2020 under scenarios B1 and B2. This is explained by an improved conversion efficiency partially achieved by more CHP.

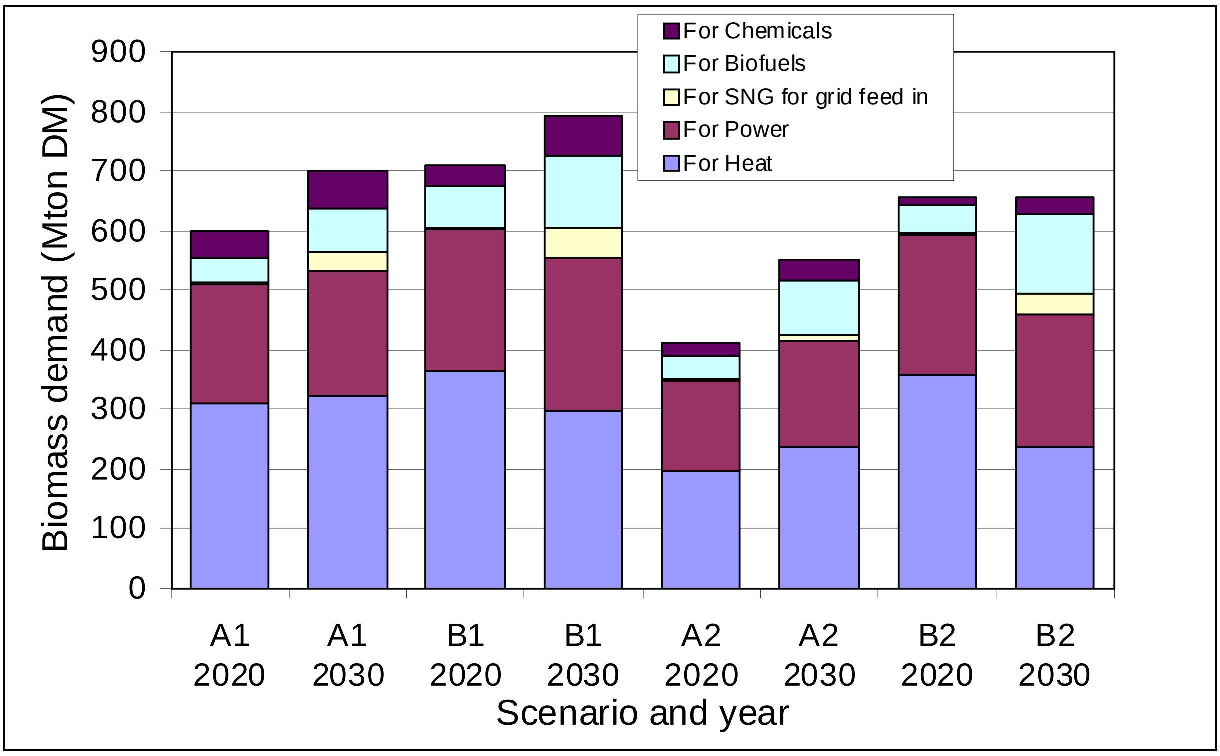

Figure 5.1. *The biomass demand for different bioenergy options and for biomass based chemicals under 4 scenarios in 2020 and in 2030 for the EU 27 (A1 – Global Economy; B1 – Global Co-operation; A2 – Continental Markets; B2 – Regional Communities).*

The biomass demand for chemicals small compared to the biomass demand for energy. Comprising between 2 and 9% of the total biomass demand (in ton DM). Still compared to the demand for biofuels it is significant. In some cases the demand for carbohydrates for chemicals can be larger that the demand for biofuels (ethanol).

Another trend that is visible is that the total biomass demand does not change much though the character of the demand does change. There is a shift towards higher quality applications (fuels and chemicals) and there is an increase in the conversion efficiency this is especially visible in the B 1 and B2 scenario's where sustainability is the main driver.

The source of the biomass is shown in Figure 5.2. The contribution of by-products and waste is very large in scenarios B1, B2 and also in A2, this is explained by strict sustainability requirements which are expected to make using by-products and waste more attractive.

In scenarios with less possibilities for imports (A2 and B2) will leave less room for local biomass production and less room for importing biomass this will lead to less bioenergy production (A2) or it will lead to very efficient use of the biomass (B2).

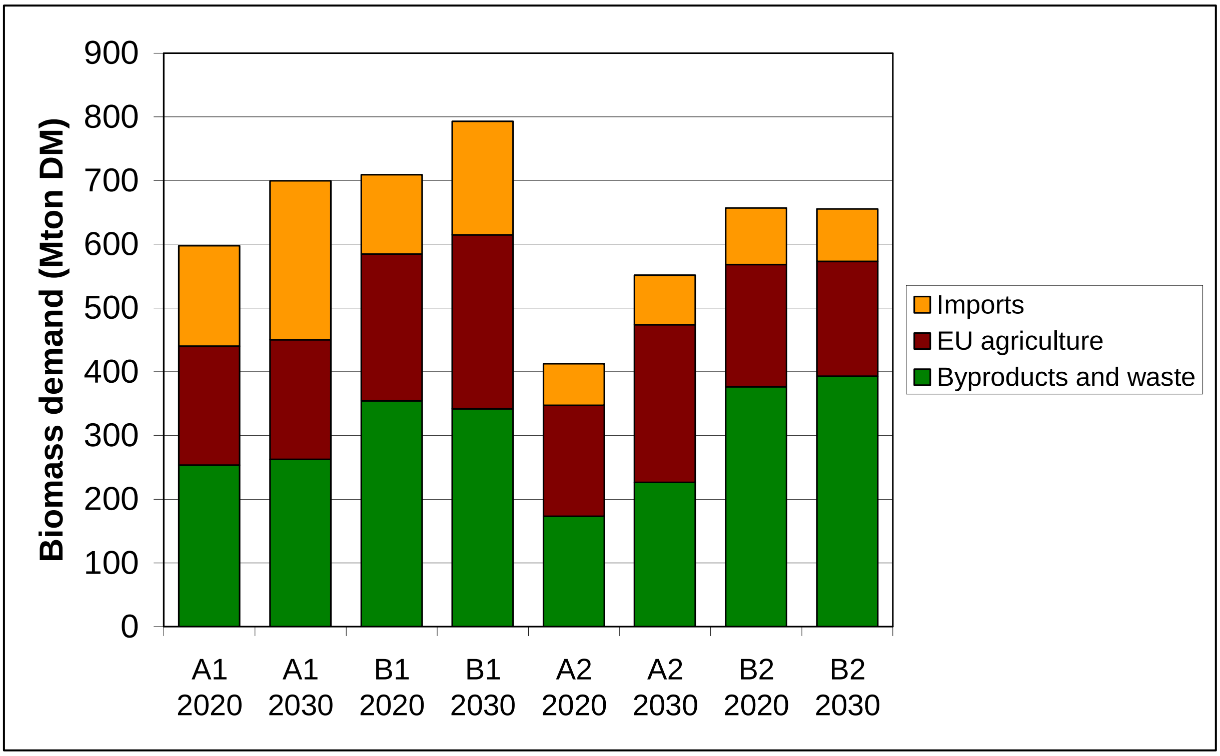

Figure 5.2 *Biomass sourcing for energy and chemicals in 2020 and 2030 under scenario's for the EU 27 (A1 – Global Economy; B1 – Global Co-operation; A2 – Continental Markets; B2 – Regional Communities).*

5.2 Specific biobased feedstock for energy and chemical industry

In Table 5.1 and Figure 5.3 the demand for biomass is further characterized.

5.2.1 Proteins

The smallest demand is expected for proteins for the production of (functionalized) chemicals (see 4.1). The demand in the EU 27 should be between 0.3 and 2.1 million tons in 2020 increasing to between 0.7 and 4.2 million tons in 2030. This market is still uncertain and should develop especially under scenario's driven by sustainability, efficient biomass use. The proteins should therefore be produced in a sustainable way and with a minimum of competition with food

Table 5.1 *Demand for biomass by general category in 2020 and 2030 under 4 scenarios (A1 – Global Economy; B1 – Global Co-operation; A2 – Continental Markets; B2 – Regional Communities).*

	2020				2030			
	A1	**B1**	**A2**	**B2**	**A1**	**B1**	**A2**	**B2**
Carbohydrates 1e generation	50.8	48.9	33.7	24.2	46.9	45.2	51.0	29.9
Sugars from lignocell. 2nd generation	5.9	4.3	3.1	2.1	39.1	46.2	11.4	19.1
Oils and fats	23.6	39.0	23.5	28.9	26.6	40.1	40.2	34.1
Glycerin for chemicals	0.8	1.5	0.7	1.0	2.0	3.8	0.9	1.9
Proteins for chemicals	0.4	2.1	0.3	1.8	0.7	4.2	0.7	3.3
Biogas substrates	106.5	127.3	78.1	124.1	112.5	144.3	107.4	171.3
Solid biomass thermal conversion	399.6	471.7	266.1	460.9	460.8	489.8	329.5	383.7
Black liquor - lignin	10.4	14.3	7.1	13.7	10.7	19.3	10.6	12.3
Total biomass demand	**598.0**	**709.2**	**412.5**	**656.8**	**699.3**	**792.9**	**551.6**	**655.6**

and feed. It seems logically that by-products unfit for food/feed could be a source. An other option are unconventional sources such as algae (this has not been included in this report). Another option is the production of specific proteins in specially selected protein crops. This option will need further development.

The sourcing of proteins for chemicals is uncertain as shown by the wide range in volumes under different scenarios. The source of proteins is also uncertain though specific protein demands may lead to the use of micro-organisms or modified crops.
In scenario B2 it seems likely that by-products and crops are a source of proteins while in Scenario A1 and B1 modified micro-organisms and crops could be used.

5.2.2 Glycerin

Another plant based product that is relevant is glycerin for the production of chemicals (see 4.1). The production and utilization in the chemical industry depends completely on the production of biodiesel by classical transesterification. Where glycerin is released. The expected demand is between 0.7 and 1.5 million tons in 2020 increasing to 0.9 and 3.8 million tons in 2030. In scenario A1 and B1 a large part of the glycerin could be sourced from abroad. Also in B1 and B2 unconventional sources of oil and fats will become important (algae).

5.2.3 Carbohydrates, first generation

"First generation" carbohydrates are sugar and starch products from conventional crops (wheat, sugar beet, sugar cane, etc). The application foreseen is for the production of transportation fuels (mainly ethanol for now) and for chemicals. The demand is expected to be between 24 and 51 million tons by 2020 decreasing slightly to between 30 and 51 million tons by 2030 as "second generation" sources have a real impact. The concern about competition for food (and land) leading to indirect land use change (ILUC) is a sustainability concern which may be solved by sourcing the sugars from unconventional sources such as pretreated lignocellulose and other sources. These alternatives are thought to have a real impact towards 2020.

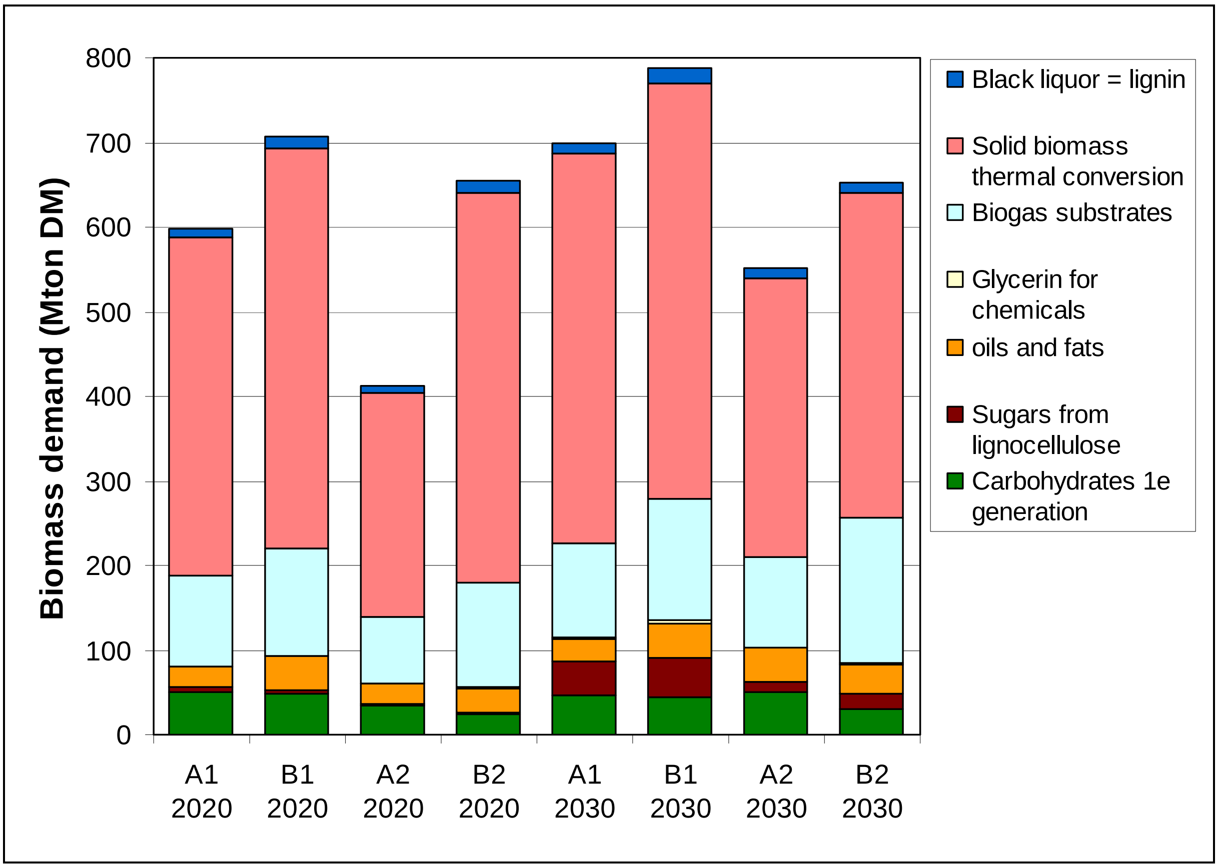

Figure 5.3 *Overview of the types of biomass demand under 4 scenarios in 2020 and 2030 (A1 – Global Economy; B1 – Global Co-operation; A2 – Continental Markets; B2 – Regional Communities).*

5.2.4 Sugars from lignocellulose, 2nd generation

The production of sugars from lignocellulose (second generation) is currently the main road to making large amounts of (advanced) biofuels mainly through fermentation info ethanol but also into butanol another potential advanced biofuel. As we have seen in Table 4.1 the demand for sugars for fermentation processes may be larger that the demand from the biofuels industry in 2020 and 2030.

The demand is expected to be significant in 2020 between 2.1 and 5.9 million tons, requiring 2 to 3 lignocellulosic biomass (= 4 to 18 million tons of lignocellulosic material). After 2020 a large increase should be expected reaching between 11 and 40 million tons in 2030. This implies a lignocellulosic biomass demand of 20 to 120 million tons in 2030.

5.2.5 Black liquor - lignin

Black liquor (lignin) is produced in the paper and pulp industry but should in future also be produced when pre-treating lignocellulose for carbohydrate production (see above). As can be seen in Table 4.3 and Annex 1 the chemical industry could become a large user of lignin. The supply being dependent on the production in the paper industry and especially in the advanced biofuel industry. The main application should be for heat and power generation and in the future also for production of chemicals. The demand is expected to lie between 7 and 14 million tons in 2020 growing to 11 to 20 million tons in 2030.

5.2.6 Oils and fats

Oils and fats are used for mainly biodiesel production. The glycering produced in the process has applications in feed and in the chemical industry. Other applications include straight fuel (without transesterification) and power and heating. The demand for oils and fats should lie between 23 and 39 million tons in 2020 staying stable towards 2030 as advanced biofuels become important. As with first generation carbohydrates there are sustainability concerns due to competition with food and feed leading to ILUC. In the case of biodiesel it is expected that lower impact lignocellulosic based Fischer Tropsch biodiesel will have an impact especially after 2020.

5.2.7 Biogas substrates

Biomass substrates for the production of biogas include a wide range of generally lower quality biomass types which are less suited for thermal conversion. They include manure and a wide range of by-products and wastes. The demand is expected to be between 78 and 127 million tons DM in 2020 growing to 107 and 171 million tons in 2030.

5.2.8 Solid biomass for thermal conversion

Solid biomass for thermal conversion processes are by far the most important biomass demanded. Mast of it being used for production of heat and power. In most scenarios the demand will decrease for heat and power while the demand for lignocellulose for production of advanced biofuels or for chemicals production (Fischer Tropsch and second generation sugars through pretreatment) will take over part of the demand. The demand should be 266 to 461 million tons DM in 2020 hardly increasing to between 330 and 490 tons in 2030.

6 Crops

From the previous discussion we see what the demand will be for cultivated biomass from Europe. Apart from the traditional crops, new (4FCrops) with special attributes will have a role to play depending on the opportunities that exist under future scenarios.

6.1 Land availability under scenarios

In the analysis by Krasuska et al (2010) into the availability of land for energy crops the main type of land that would be available would be fallow land. Land would become available due to increases in productivity per ha. At the same time the demand for bioenergy would also favour multi purpose crops producing an energy component and another (non-energy) component. Therefore both crops that fit into current agriculture and crops that are suitable for released land would be demanded as a result of the demand for biomass for energy (and chemicals).

Here we will focus on three main crop types that have been evaluated in detail in the 4F CROPS project:

- Perennial biomass grasses
- Oil Crops (i.e. oil/protein crops)
- Sugar Crops

6.2 Perennial biomass grasses

The main perennial biomass grasses considered in Europe are switchgrass, Miscanthus, Arundo donax and Reed Canary Grass. These grasses are typically established for a period of 15 years and harvested yearly in winter. They deliver relatively high yields of lignocellulosic material at low cost and low environmental impacts. These grasses should be compared to Short Rotation Coppice crops which are based on tree crops which are harvested (coppiced) at 2 to 4 yearly interval and have a life span of 25 years.

Though these grasses have been evaluated for more than 15 years in Europe these grasses have not really penetrated the market, current areas of production are estimated at less than a few hundred (switchgrass, Arundo donax) or less than a few thousand ha (Miscanthus and Reed Canary Grass) (Zegada et al 2010). Most of the perennial grasses are largely undomesticated and are at their early stages of development and management. As the SWOT analysis shows (Table 6.1), these crops show some advantages over annual crops in terms of agricultural inputs, yields, production costs, food security, reduced greenhouse gas emissions, and environmental sustainability (Zegada, 2010). In Table 6.1 a SWOT analysis is presented to characterize the perennial biomass grasses. The main strength of these crops, their low cost and low impact which is mainly a result of their perennial nature is at the same time their main weakness because it makes production within the current (rotational) farming system difficult.

We conclude that these perennial crops seem to have a role to play in producing biomass on land that is less suited for normal (rotation) agriculture. This will generally be lower quality less productive land where these crops appear to be still quite productive. Analysis by Soldatos (Lisbon, 2010) appear show that Miscanthus has a positive profit per ha on marginal land while annual crops such as rape and wheat have a negative balance under these conditions.

On the basis of the characteristics in Tabel 6.1 the logical role of these crops is presented under our 4 contrasting scenarios in Table 6.2.

Table 6.1 *General SWOT for Perennial biomass grasses (Miscanthus, switchgrass, Arundo donax and Reed canary grass) based on 4FCrop project analyses (Rettenmaier et al., 2010; Soldatos et al., 2010; Fernando et al., 2010., 2010; Zegada et al., 2010 and different reports).*

Strength	Weakness
- Low inputs required (agr-ichemicals and labor) - Low cost of production per ton en per ha - Low nutrient runoff compared to annual crops - Production cost generally lower than for woody crops (SRC= willow, eucalyptus, etc) - Diseases are limited - Excellent GHG balance compared to annual and woody crops - High water use efficiency - Relatively good yield on low quality soils	- Does not fit in rotation system - life span >15years is an economic weakness especially for non seeded grasses (Miscanthus gigantheus and Arundo donax) - Low value product - No valuable by-products - Added value per ha is low - Due to higher ash content quality of biomass is generally lower (for thermal conversion) compared to wood. - Some of the grasses are weedy (Arundo donax and Reed Canary Grass).
Opportunity	**Threat**
- High productivity on low quality soils - Low risk of erosion - High nutrient efficiency - Higher biodiversity than arable crops - Good crops for second generation (lignocellulosic based) biofuels - Also useful application for fibre applications and animal bedding	- Without specific policies no market seems possible - Most grasses are not native to EU → - Not much practical experience exists - Knowledge is still limited (in EU) - Second generation fuels delayed - Low impact attribute is not (yet) appreciated

The type of strategy that would be recommended for these crops should focus on:

- Establishing in further detail the performance of perennial biomass crops under good and especially marginal land in Europe
- Establishing in further detail the impacts (or lack) of under different conditions
- Develop these crop for low quality/marginal soils as these soils are likely to become available for these crops
- Development of new varieties that increase the positive aspects (high yields at low inputs) and reduce existing problems such as winter losses, establishment cost or establishment risks, etc.
- Policies that value the positive aspects of these crops should help to get the crops introduced. Specific policies should also be examined that value the positive effects of these crops and that give these crops a niche in EU agriculture.

Table 6.2 *Role and opportunities of perennial biomass grasses under 4 scenarios.*

A1 – Global Economy	**B1 – Global Co-Operation**
- Limited potential on lower quality/released land. - Importing biomass is possible only part of potential available land will be used - 15 year cycle is an economic risk for implementation	- Large potential mainly of lower quality/released land - Importing biomass is possible. Low impact + GHG efficiency give it an advantage - 15 year cycle is less risk → stable policies are possible - In short term there is competition from by-products
A2 – Continental Markets	**B2 – Regional Communities**
- Limited potential - Policies are likely to favour arable crops - Amount of released land is limited and low impact is not rewarded - 15 year cycle is problem though guarantees could be given also on good land	- Good potential on lower quality/released land - Less land is available due to more needs for local production and ecological agriculture and strict regulations - Low 15 year cycle should be less of a risk because of guarantees/policies

6.3 Oil Crops

The main oil crops in Europe are oil seed rape (mainly northern areas) and sunflower (mainly southern drier areas). Other crops are also relevant like Ethiopian mustard, oil flax and hemp. These crops can also be seen as multipurpose crops providing oil and protein and possibly straw. In Table 6.3 a SWOT analysis is presented that characterizes the outlook for oil crops in Europe.

Table 6.3 *General SWOT for oil crops in Europe based on 4FCrop project analyses (Rettenmaier et al., 2010; Soldatos et al., 2010; Fernando et al., 2010; Fritsche et al., 2010; Zegada et al., 2010 and different project reports).*

Strength	**Weakness**
- There is a ready market for oil crops - Protein co-product is valuable, lowering the overall impact of the energy (oil) component - Crops fit in the rotation system - Quality of (rape oil) is excellent for biodiesel production - Europe has strong knowledge basis in oil crops (rape, sunflower)	- GHG efficiency is limited - Cost of production is high (compared to imports) - Oil is subsidizing protein
Opportunity	**Threat**
- Imported oil seeds (soy) and oils (palm) appear to have a larger iLUC problem - Significant yield increased seem possible - More value in specialty proteins possible - Proteins for chemicals are an opportunity - The value of protein can be increased by breeding and processing - Glycerin is a potentially valuable feedstock for chemical industry - Oil industry has diesel shortage and prefers biodiesel to bioethanol - As a food/fuel crop less impact and risk - Straw may also have a value	- Current estimates of the GHG effect of iLUC leads to a negative GHG balances for most EU oil crops - More liberalization may make EU oil crops uncompetitive - Hydrogenated biodiesel will make waste oils and cheaper imported oils more competitive - Second generation (FT) diesel should have better GHG efficiency (direct and indirect)

Oil crops already have a very large and expanding biodiesel market in the EU. In 2009 8 Mtoe of biodiesel were used in EU 27 (Christou et al., 2010) most of the oil is sourced from rape seed, while soy and sunflower are also relevant sources in the EU. Though the future looks bright large challenges exist. Imported oil and biodiesel are taking up part of this market and reaching sufficiently high GHG emission reduction (> 35% better than the fossil equivalent) is difficult, especially when GHG emissions related to iLUC are included. Alternative options for producing biofuels seem to have lower impacts and seem to be able to achieve the better GHG balances (Rettenmaier et al., 2010; Fritsche et al., 2010). These alternatives include second generation Fischer Tropsch diesel and also diesel from algae.

In Table 6.4 the role of EU oil crops is described under scenarios. It seems that in scenarios where open markets dominate low cost imports provide a problem. In scenario's where GHG reduction is a driver for biofuels and iLUC is a relevant factor alternative production options for biodiesel may provide an alternative sooner or later.

At the same time options exist to make oil crops more competitive and increase GHG benefits. Higher productivity per ha, higher added value for co-products and by-products and optimization of the whole production system are needed and seem possible.

Table 6.4 *Role and opportunities of oil crops under 4 scenarios.*

A1 – Global Economy - Cheap import of oils limits market share - Protein co-product should also have a good value - Higher oil prices may stimulate demand for biodiesel	**B1 – Global Co-Operation** - EU oil crops will have to be competitive and provide real GHG benefits - 2nd gen options and algae will become competitive sooner
A2 – Continental Markets - EU oil crops fit well in the agricultural system - Oil crops will fit well in the fuel industry - Oil crops will stay competitive longer against 2nd generation options (i.e. FT and algae)	**B2 – Regional Communities** - Oil crops fit well in local small scale local production systems - Positive environmental is still very relevant - Second generation options will become an alternative

6.4 Sugar Crops

Worldwide sugar cane is the most important sugar crop followed at a distance by sugar beet, the main sugar crop in Europe. In recent years sweet sorghum has been developed in Europe. The crop has not been fully commercialized but promise as a low cost source for ethanol production, mainly in Southern Europe. In Table 6.5 a SWOT analysis is given for sugar crops in Europe with special focus on sweet sorghum.

The fuel ethanol market is not as large as for biodiesel in Europe and is expected to stay much smaller for the coming decade. At the same time our analysis shows that the demand from the chemical industry may become a very substantial in the next decade.
Apart from sugar crops, starch crops can be used to produce ethanol. Compared to oil crops sugar crops seem to have a more favorable GHG balance, though GHG emissions related to iLUC also pose a challenge for sugar crops.

Table 6.5 *SWOT analysis for sugar crops in Europe based on 4FCrop project analyses (Rettenmaier et al., 2010; Soldatos et al., 2010; Fernando et al., 2010; Fritsche et al., 2010; Zegada et al., 2010 and different project reports).*

Strength	**Weakness**
- Strong knowledge base (sugar beet) - good water use efficiency and salt / heat tolerance (especially sweet sorghum). - Co-products also have a value lowering overall impact	- Cost is generally high compared to imported sugar or ethanol (see Brazil) - iLUC is hard to avoid - The short harvest campaign (sugar beet and sweet sorghum) adds to processing cost of sugar and of ethanol
Opportunity	**Threat**
- More by-products could be values (proteins?) - Apart from ethanol other fuel production options exist. - Potential as a feedstock for fermentation industry and feedstock for chemical industry is huge! - As a food/fuel crop impacts and risks can be reduced - High yields may compensate GHG emissions associated with iLUC	- Open markets will lead to increased competition from imported sugar and ethanol - Second generation options (e.g. lignocellulosic ethanol) have a better impact especially if ILUC is also considered - Starch (crops) are also an alternative for most applications (energy and chemicals) without having the drawback of a limited "campaign". - The market of ethanol (fuel) is much smaller than for biodiesel, due to a relative overproduction of gasoline in refineries.

In Table 6.6 the role of sugar crops under contrasting scenarios is described. As with oil crops scenarios where open markets prevail may lead to large competition from imported sugars and ethanol while in scenarios where GHG emission reduction is the main driver for biofuels the GHG emissions associated with iLUC will have to dealt with. Second generation options may be brought closer to the markets by these developments.

It seems that further improvements in efficient crop production are

Table 6.6 *Role and opportunities of sugar crops under 4 scenarios.*

A1 – Global Economy - Imports of sugar and ethanol will be very competitive - - The large demand from the chemical industry for ethanol (and sugars) as feedstocks will provide a much larger market then only for fuels	**B1 – Global Co-Operation** - A large sugar and ethanol market will exist still demanding a positive GHG balance - 2nd generation will become more attractive
A2 – Continental Markets - A much smaller but attractive EU market for sugars and ethanol will exist	**B2 – Regional Communities** - Sugar crops should provide a good feedstock for local biorefineries - A positive GHG balance is essential - 2nd generation options will become an alternative

7 Conclusions and recommendations

7.1 Conclusions

- According to our estimations, 656 Mtons of biomass are required to fulfill the ambitions as laid down in the NREAPs of EU27. Of this biomass, 362 Mtons can be sourced from by-products and waste, 184 Mtons will be produced (extra) by crops in EU 27 and 110 Mtons of biomass will have to be imported.
- Using future scenarios, we estimate that the total biomass demand (for energy and chemicals) will be between 400 and 700 Mton in 2020, increasing to between 550 and 800 Mtons in 2030.
- In the current NREAPs the demand for biomass by the chemical industry appears not to be taken into account. However the demand for biomass for the production of chemicals could be substantial. Using future scenarios we estimate the demand for biomass by the chemical industry to be between 14 and 43 Mtons of biomass (DM) in 2020, increasing to between 28 and 66 Mtons (DM) in 2030.
- The biomass demand for chemicals can both compete or be in synergy with the demand for biomass to produce biofuels, heat and electricity.
- Competition is expected with regard to the demand for fermentable sugars. The demand by the chemical industry will amount to between 8 and 40 Mtons in 2020 and between 16 and 53 Mtons (DM) in 2030. This is roughly the same as the amount of fermentable sugars required for the production of biofuels (mainly ethanol).
- Synergy is expected with respect to biodiesel production based on oils and fats, leading to the production of glycerin which has a large potential in the chemical industry.

- In a future scenario driven by open markets and low regulation (**A1, Global Economy**), biomass (for energy and chemicals) will mainly be used in (or adapted to) the current infrastructure leading to a large demand for conventional options. This will require fermentable sugars (or ethanol) for fuels and chemicals and biomass to electricity in conventional plants. Due to high economic growth total demand will be large. However sourcing will be on the basis of cost and security of supply, leading to large imports and suboptimal use of by-products.
- Agriculture will be large scale and specialized in order to be efficient enough to compete on the world market.
- Lignocellulosic perennial crops (grasses) will play a limited role. Production will only be possible on surplus (marginal, low quality, abandoned) land which cannot be economically used for rotation crops. Production systems have to be efficient and large scale but are exposed to competition from cheap imported biomass
- Oil crops will have a large market though competition from imports is substantial.
- Sugar Crops will have a large market which includes biofuels and chemicals. Imported sugars (or ethanol) are inexpensive therefore the role of these crops will still be limited.

- In a future scenario driven by open markets and high regulation (**B1, Strong Europe**), biomass (for energy and chemicals) will be used in an efficient way to support GHG emission reduction policies. This will lead to a demand for large volumes and efficient use of biomass. Adaptation of infrastructure to accommodate available biomass, including fast introduction of advanced options (second generation, algae) and production of functionalized chemicals from biomass.
- Agriculture will be efficient and will have to comply with internationally accepted sustainability demands.
- The role of lignocellulosic perennials crops will be relevant on surplus (marginal, low quality, abandoned) land. Due to their low environmental impact the crops will have an advantage in the market over other (imported) biomass. Policies will be in place to "reward" these crops for low impact production. The biomass will also be used for the production of advanced (2^{nd} generation) biofuels and chemicals.
- Oil crops have a large market and have to comply with sustainability demands. At the same time imports are possible if they comply with sustainability demands. Crops will have to be highly productive and produce high quality by-products (e.g. proteins) to acceptable and competitive. Furthermore competition is expected from novel alternative options that will become relevant before 2020 (e.g. FT diesel and oil from algae).
- Sugar crops will have a large market but will also be exposed to competition from imports (sugar and ethanol). Efficient large scale production agriculture and processing is required to be able to be competitive.

- In a future scenario driven by limited globalization and low regulation (**A2, Continental Markets**) the market for bioenergy will be driven mainly by security of supply and cost. Some subsidies and targets will define the market.
- The role of lignocellulosic perennial crops will be limited as they do not fit into the agricultural (rotation) systems, surplus land is limited and policies favour conventional rotation agriculture. A set-aside system may provide some possibilities but the perennial nature is problematic (10-15 year).
- Oil crops will have a good EU market fitting in the existing agricultural system and fuel industry. Alternatives (FT diesel and, algae oil) will not become relevant until after 2020.
- Sugar Crops will have a smaller market than under other scenarios. Lack of competition will limit scale increases.

- In a future scenario driven by limited globalization and high regulation (**B2, Regional Communities**) the market for bioenergy will be driven by sustainability demands (GHG emission reduction). Demand will favor efficient use of by-products and waste and biomass from crops that have a low environmental impact and limited or no competition with food production.

- The role of lignocellulosic perennials will be relevant on surplus (marginal, low quality, abandoned) land, though the availability of land will be limited due to competition from ecological agriculture and other demands requiring land.
- Oil crops will have a good (EU) market fitting in the existing agricultural system and fuel industry, proteins will also have a high value. However, oil crops are expected to rapidly encounter competition from novel advanced (2nd generation) options such as FT diesel and oil from algae).
- Sugar crops will have a good market and will provide feedstock for smaller scale bio-refineries. Competition from alternative sugar sources (second generation lignocellulose sugars) is expected to become relevant before 2020.

7.2 Recommendations

- We recommend to take into account the demand for biomass by the chemical industry (including effects of competition, e.g. for fermentable sugars and synergy between the production of Fischer Tropsch biodiesel and glycerin) when developing biomass energy policies and targets.
- This will require much more detailed knowledge about the biomass demands of the chemical industry than is currently available in the public domain.

Policy

- A level playing field between fuels and chemicals (and fibre) should be developed or at least policies should take into consideration the synergy and competition that exists between fuels and chemicals.
- To be able to exploit the advantages that perennial lignocellulosic crops offer to produce sustainable biomass, policies should be adapted to offer a niche to these crops on land less suited for rotation crops (e.g. surplus, marginal, low quality, abandoned land). This requires new policies and an outlook of at least 15 years.
- The concerns about GHG emissions associated with iLUC (indirect Land Use Change) will have to be dealt with by switching to alternative "advanced" biofuel options much faster and/or by substantially increasing production efficiency of existing agricultural crop used for biofuel feedstock production.
- Non-energy uses (e.g. bedding, fibre) of perennial lignocellulosic crops should also be considered as a way of introducing these crop into EU agriculture.
- An integrated vision of the food and biofuel markets should make better use of dual purpose crops such as oil/protein crops.

R&D

- R&D on perennial lignocellulosic crops should focus on attaining high yields for low inputs on surplus, marginal, low quality, abandoned lands in Europe. This includes development of new varieties adapted to EU conditions and marginal areas
- R&D on oil crops should focus on increasing yield and increasing the production and value of by-products (e.g. protein).
- R&D on sugar crops should focus on yields and the development of more efficient processing. Other production outlets such as ABE (acetone, butanol, ethanol process) and production of chemicals will also have to be considered.

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Appendix 1 Specific conditions defining the demand for biomass by the chemical industry in EU 27 in 2020 and 2030 under 4 contrasting future scenarios.

	year	Growth of chemical markets	Fermentable sugar demand		Lignin demand		Protein demand		Glycerin demand		biomass demand	
			Replace-ment	Conversion efficiency	Replace-ment	Conversion efficiency.	Replace-ment	Conversion efficiency.	Replace-ment	Conversion efficiency.	Replace-ment	Conversion efficiency.
A1 Global Economy	2020	2.5%	15%	25%	3%	50%	0.5%	20%	20%	80%	3%	60%
	2030	2.5%	25%	40%	6%	50%	1.0%	25%	40%	80%	10%	70%
B1 Global Cooperation	2020	2.3%	20%	50%	10%	50%	3.0%	20%	40%	80%	5%	60%
	2030	2.3%	40%	80%	30%	50%	6.0%	25%	80%	80%	15%	70%
A2 Continental Markets	2020	2.0%	10%	30%	3%	50%	0.5%	20%	18%	80%	1%	60%
	2030	2.0%	20%	50%	10%	50%	1.0%	25%	20%	80%	3%	70%
B2 Regional Communities	2020	1.3%	10%	70%	10%	50%	3.0%	20%	30%	80%	1%	60%
	2030	1.3%	25%	100%	25%	70%	6.0%	25%	50%	80%	5%	70%

Appendix 2 Biomass demands for energy and chemicals per scenario's in 2020 and 2030.

Table A2.1 *Biomass demand for energy and chemicals (Mton DM) in scenario A1 – Global Economy - 2020.*

	Total energy	Total Chemicals	Total E+C	Byproducts and waste	EU Commodities / crops	Imports	Byproducts and waste	EU Commodities / crops	Imports
Carbohydrates 1e generation	**14.93**	**35.88**	**50.81**	4.06	23.12	23.63	8.0%	45.5%	46.5%
Sugars from lignocellulose 2e gen	**1.73**	**4.15**	**5.88**	2.59	1.53	1.76	44.0%	26.0%	30.0%
oils and fats	**23.61**		**23.61**	0.94	12.04	10.62	4.0%	51.0%	45.0%
Glycerin for chemicals		**0.80**	**0.80**	0.03	0.41	0.36	4.0%	51.0%	45.0%
Proteins for chemicals		**0.36**	**0.36**	0.01	0.18	0.16	4.0%	51.0%	45.0%
Biogas substrate: manure, crop, by-products	**106.47**		**106.47**	59.62	45.25	1.60	56.0%	42.5%	1.5%
Solids for thermal conv: chips + pellets mainly	**398.37**	**1.23**	**399.60**	175.82	103.90	119.88	44.0%	26.0%	30.0%
Black liquor = lignin	**9.48**	**0.96**	**10.44**	10.44	0.00	0.00	100.0%	0.0%	0.0%
Total biomass demand	**554.58**	**43.38**	**597.96**	**253.53**	**186.42**	**158.01**			

Table A2.2 Biomass demand for energy and chemicals (Mton DM) in scenario A2 – Continental markets - 2020.

	Total energy	Total Chemicals	Total E+C	Byproducts and waste	EU Commodities / crops	Imports	Byproducts and waste	EU Commodities / crops	Imports
Carbohydrates 1e generation	**14.93**	**18.75**	**33.69**	2.69	21.59	9.40	8.0%	64.1%	27.9%
Sugars from lignocellulose 2e gen	**1.38**	**1.74**	**3.12**	1.37	1.18	0.56	44.0%	38.0%	18.0%
oils and fats	**23.46**		**23.46**	0.94	16.19	6.34	4.0%	69.0%	27.0%
Glycerin for chemicals		**0.66**	**0.66**	0.03	0.46	0.18	4.0%	69.0%	27.0%
Proteins for chemicals		**0.33**	**0.33**	0.01	0.23	0.09	4.0%	69.0%	27.0%
Biogas substrate: manure, crop, by-products	**78.06**		**78.06**	43.71	33.64	0.70	56.0%	43.1%	0.9%
Solids for thermal conv: chips + pellets mainly	**265.67**	**0.38**	**266.05**	117.06	101.10	47.89	44.0%	38.0%	18.0%
Black liquor = lignin	**6.22**	**0.88**	**7.10**	7.10	0.00	0.00	100.0%	0.0%	0.0%
Total biomass demand	**389.73**	**22.74**	**412.47**	**172.92**	**174.39**	**65.15**			

***Table A2.3** Biomass demand for energy and chemicals (Mton DM) in scenario B1 – Global Co-operation - 2020.*

	Total energy	Total Chemicals	Total E+C	Byproducts and waste	EU Commodities / crops	Imports	Byproducts and waste	EU Commodities / crops	Imports
Carbohydrates 1e generation	**25.33**	**23.62**	**48.95**	4.65	29.13	15.17	9.5%	59.5%	31.0%
Sugars from lignocellulose 2e gen	**2.22**	**2.07**	**4.29**	2.24	1.19	0.86	52.3%	27.8%	20.0%
oils and fats	**38.99**		**38.99**	1.85	25.44	11.70	4.8%	65.3%	30.0%
Glycerin for chemicals		**1.54**	**1.54**	0.07	1.00	0.46	4.8%	65.3%	30.0%
Proteins for chemicals		**2.09**	**2.09**	0.10	1.36	0.63	4.8%	65.3%	30.0%
Biogas substrate: manure, crop, by-products	**127.28**		**127.28**	84.64	41.36	1.27	66.5%	32.5%	1.0%
Solids for thermal conv: chips + pellets mainly	**469.74**	**1.98**	**471.72**	246.47	130.90	94.34	52.3%	27.8%	20.0%
Black liquor - lignin	**11.26**	**3.07**	**14.33**	14.33	0.00	0.00	100.0%	0.0%	0.0%
Total biomass demand	**674.82**	**34.37**	**709.19**	**354.36**	**230.39**	**124.44**			

Table A2.4 *Biomass demand for energy and chemicals (Mton DM) in scenario B2 – Regional Communities - 2020.*

	Total energy	Total Chemicals	Total E+C	Byproducts and waste	EU Commodities / crops	Imports	Byproducts and waste	EU Commodities / crops	Imports
Carbohydrates 1e generation	**16.89**	**7.32**	**24.21**	2.54	15.66	6.00	10.5%	64.7%	24.8%
Sugars from lignocellulose 2e gen	**1.48**	**0.64**	**2.12**	1.23	0.56	0.34	57.8%	26.3%	16.0%
oils and fats	**28.90**		**28.90**	1.52	20.45	6.94	5.3%	70.8%	24.0%
Glycerin for chemicals		**1.00**	**1.00**	0.05	0.71	0.24	5.3%	70.8%	24.0%
Proteins for chemicals		**1.82**	**1.82**	0.10	1.29	0.44	5.3%	70.8%	24.0%
Biogas substrate: manure, crop, by-products	**124.12**		**124.12**	91.23	31.90	0.99	73.5%	25.7%	0.8%
Solids for thermal conv, FT, Syn gas: chips + pellets mainly	**460.55**	**0.34**	**460.89**	266.17	120.98	73.74	57.8%	26.3%	16.0%
Black liquor = lignin	**11.04**	**2.67**	**13.71**	13.71	0.00	0.00	100.0%	0.0%	0.0%
Total biomass demand	**642.98**	**13.79**	**656.77**	**376.53**	**191.54**	**88.69**			

Table A2.5 *Biomass demand for energy and chemicals (Mton DM) in scenario A1 – Global Economy - 2030.*

	Total energy	Total Chemicals	Total E+C	Byproducts and waste	EU Commodities / crops	Imports	Byproducts and waste	EU Commodities / crops	Imports
Carbohydrates 1e generation	**17.73**	**29.12**	**46.85**	3.28	14.52	29.05	7.0%	31.0%	62.0%
Sugars from lignocellulose 2e gen	**14.80**	**24.31**	**39.11**	15.06	8.41	15.64	38.5%	21.5%	40.0%
oils and fats	**26.58**		**26.58**	0.93	9.70	15.95	3.5%	36.5%	60.0%
Glycerin for chemicals		**2.04**	**2.04**	0.07	0.74	1.22	3.5%	36.5%	60.0%
Proteins for chemicals		**0.74**	**0.74**	0.03	0.27	0.44	3.5%	36.5%	60.0%
Biogas substrate: manure, crop, by-products	**112.47**		**112.47**	55.11	55.11	2.25	49.0%	49.0%	2.0%
Solids for thermal conv: chips + pellets mainly	**456.24**	**4.51**	**460.75**	177.39	99.06	184.30	38.5%	21.5%	40.0%
Black liquor = lignin	**8.28**	**2.45**	**10.73**	10.73	0.00	0.00	100.0%	0.0%	0.0%
Total biomass demand	**636.11**	**63.17**	**699.28**	**262.60**	**187.82**	**248.86**			

***Table A2.6** Biomass demand for energy and chemicals (Mton DM) in scenario A2 – Continental Markets - 2030.*

	Total energy	Total Chemicals	Total E+C	Byproducts and waste	EU Commodities / crops	Imports	Byproducts and waste	EU Commodities / crops	Imports
Carbohydrates 1e generation	**26.60**	**24.39**	**50.99**	4.08	34.26	12.64	8.0%	67.2%	24.8%
Sugars from lignocellulose 2e gen	**5.92**	**5.43**	**11.35**	4.99	4.54	1.82	44.0%	40.0%	16.0%
oils and fats	**40.18**		**40.18**	1.61	28.93	9.64	4.0%	72.0%	24.0%
Glycerin for chemicals		**0.89**	**0.89**	0.04	0.64	0.21	4.0%	72.0%	24.0%
Proteins for chemicals		**0.65**	**0.65**	0.03	0.47	0.16	4.0%	72.0%	24.0%
Biogas substrate: manure, crop, by-products	**107.39**		**107.39**	60.14	46.39	0.86	56.0%	43.2%	0.8%
Solids for thermal conv: chips + pellets mainly	**328.31**	**1.18**	**329.49**	144.98	131.80	52.72	44.0%	40.0%	16.0%
Black liquor = lignin	**7.07**	**3.57**	**10.64**	10.64	0.00	0.00	100.0%	0.0%	0.0%
Total biomass demand	**515.47**	**36.11**	**551.58**	**226.50**	**247.03**	**78.05**			

***Table A2.7** Biomass demand for energy and chemicals (Mton DM) in scenario B1 – Global Co-operation - 2030.*

	Total energy	Total Chemicals	Total E+C	Byproducts and waste	EU Commodities / crops	Imports	Byproducts and waste	EU Commodities / crops	Imports
Carbohydrates 1e generation	**25.33**	**19.84**	**45.17**	3.61	23.35	18.20	8.0%	51.7%	40.3%
Sugars from lignocellulose 2e gen	**25.90**	**20.28**	**46.19**	20.32	13.86	12.01	44.0%	30.0%	26.0%
Oils and fats	**40.06**		**40.06**	1.60	22.84	15.62	4.0%	57.0%	39.0%
Glycerin for chemicals		**3.84**	**3.84**	0.15	2.19	1.50	4.0%	57.0%	39.0%
Proteins for chemicals		**4.19**	**4.19**	0.17	2.39	1.63	4.0%	57.0%	39.0%
Biogas substrate: manure, crop, by-products	**144.32**		**144.32**	80.82	61.62	1.88	56.0%	42.7%	1.3%
Solids for thermal conv: chips + pellets mainly	**483.49**	**6.35**	**489.84**	215.53	146.95	127.36	44.0%	30.0%	26.0%
Black liquor - lignin	**7.77**	**11.51**	**19.28**	19.28	0.00	0.00	100.0%	0.0%	0.0%
Total biomass demand	**726.88**	**66.01**	**792.89**	**341.49**	**273.20**	**178.20**			

Table A2.8 Biomass demand for energy and chemicals (Mton DM) in scenario B2 – Regional Communities - 2030.

	Total energy	Total Chemicals	Total E+C	Byproducts and waste	EU Commodities / crops	Imports	Byproducts and waste	EU Commodities / crops	Imports
Carbohydrates 1e generation	**20.26**	**9.66**	**29.93**	3.29	19.21	7.42	11.0%	64.2%	24.8%
Sugars from lignocellulose 2e gen	**12.95**	**6.18**	**19.13**	11.57	4.50	3.06	60.5%	23.5%	16.0%
oils and fats	**34.13**		**34.13**	1.88	24.06	8.19	5.5%	70.5%	24.0%
Glycerin for chemicals		**1.89**	**1.89**	0.10	1.33	0.45	5.5%	70.5%	24.0%
Proteins for chemicals		**3.31**	**3.31**	0.18	2.33	0.79	5.5%	70.5%	24.0%
Biogas substrate: manure, crop, by-products	**171.32**		**171.32**	131.92	38.03	1.37	77.0%	22.2%	0.8%
Solids for thermal conv: chips + pellets mainly	**381.99**	**1.67**	**383.66**	232.11	90.16	61.39	60.5%	23.5%	16.0%
Black liquor - lignin	**6.84**	**5.41**	**12.25**	12.25	0.00	0.00	100.0%	0.0%	0.0%
Total biomass demand	**627.51**	**28.12**	**655.63**	**393.32**	**179.63**	**82.68**			

