

# Renewable Fuels for Cross Border Transportation

## ANNEX 2: Module sheets for transformation technologies

### Overview:

Pressing of Oil Plants (O)			
C2O1	Rape seed oil	C2O2	Soy bean oil
C2O3	Sunflower oil	C2O4	Olive oil

Thermochemical Conversion (T)			
C2T1	Methanol from woody biomass	C2T2	Pyrolysis oil from biomass
C2T3	Synfuel by therm. processing from biomass		

Fermentation (F) (Ethanol/Gas)			
C2F1	Ethanol from sugar beet	C2F2	Ethanol from maize
C2F3	Ethanol from cereals	C2F4	Ethanol from potatoes
C2F5	Ethanol from Wood or straw	C2F7	Biogas from animal excrements or non-woody plants
C2F8	Biogas from organic waste (incl. pretreatment)		

Electricity from Biomass (E)			
C2E1	Wood combustion for electricity generation	C2E2	Straw combustion for electricity generation
C2E3	Biogas combustion for electr. generation		

Production of Hydrogen (H)			
C2H1	from electrolysis	C2H2	from biomass by thermochemical conversion
C2H3	from natural gas		

Secondary Processing (S)			
C2S1	Esterification of vegetable oils	C2S2	Esterif. of used vegetable oils
C2S3	Biogas upgrading	C2S4	Liquefaction of hydrogen
C2S5	Compression of hydrogen	C2S6	ETBE from ethanol

Refinement of Fossil Fuels (R)	
C2R1	Refinery of crude oil

## **ANNEX 2: Module sheets for transformation technologies**

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<b>No.:</b>	C2-O1	<b>Vegetable Oil from Rape Seed</b>
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class	2	input from:	Modules C1-P1
category	Pressing of Oil Plants	output to:	Modules C2-S1, C3-T5

### General description of the process

Vegetable oil fuels are gained from rape seed in the oil mill (in the refinery process). The co-products are press substrate and extraction grist. They are processed in the forage or nourishment industry at world prices. The vegetable oil fuel can directly be used in suitable engines. Another possibility is to utilise the vegetable oil fuel in diesel engines after a transesterification (see module C2-S1). The extraction of **vegetable oil** from rape seed results from pressing and / or extraction of oil contained in organic substances.

- The fluid oil phase can be separated from the solid phase (the so-called press substrate) by simple **mechanical pressing**.
- An additional or alternative method is the **extraction**. The oily crop is removed from the oil substrate by a solvent. The so-called Miscella (an oil-solvent-mixture) remains as fluid phase, the extraction grist as solid substrate. The Miscella then has to be purified by distillation afterwards. The advantage of the extraction is that in comparison to the pressing, significantly more oil can be gained from the same oil crop. Thus, for very oily crops like rape seed, a combination of pressing and an (downstream) extraction often is realised.

Vegetable oil respectively its raffinate is different in essential characteristics from diesel fuel (e.g. its high viscosity) and even more from petrol-fuel. Effects on engine technologies are considered in the class 4 modules.

### Regional specifications in the EU

The technology has no relevant regional specifications.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

For this well approved technology, no significant technological changes are assumed.

### Internal and external resources

- (1) FEDERAL ENVIRONMENTAL AGENCY (ED.), Germany: Aktuelle Bewertung des Einsatzes von Rapsöl/RME im Vergleich zu Dieselmotoren, (writer: Kraus, K. et al), 1999
- (2) KALTSCHMITT, M.; REINHARDT, G.: Nachwachsende Energieträger – Grundlagen, Verfahren, ökologische Bilanzierung, 1997
- (3) FEDERAL MINISTRY OF CONSUMER PROTECTION, FOOD AND AGRICULTURE (BMVEL) (ED.), Germany: Agenda 2000, Pflanzlicher Bereich, Agrarumweltmaßnahmen, 2000
- (4) SCHARNER, K.: Energy balance, ecological impact and economics of vegetable oil methylester production in Europe as substitute for fossil diesel. Study of the EU: ALTENER 4.1030/E/94-002-1, 1995

Information from web pages:

- (5) THE BAVARIAN MINISTRY OF ECONOMIC AFFAIRS, TRANSPORT AND TECHNOLOGY (BAYSTMWVT) (ED.), Germany ([www.stmwvt.bayern.de/Themen/Erneuerbare\\_Energien/](http://www.stmwvt.bayern.de/Themen/Erneuerbare_Energien/))
- (6) OELMÜHLE LEER CONNEMANN GMBH & CO ([www.biodiesel.de](http://www.biodiesel.de))

- (7) U.S. DEPARTMENT OF ENERGY: Bioenergy Information Network (<http://bioenergy.ornl.gov/doeofd/index.html>)
- (8) UNIVERSITY OF IOWA, Environmental Science and Technology Online (<http://pubs.acs.org/journals/esthag-a/links/energy.html#biofuels>)
- (9) EUROPEAN RENEWABLE ENERGY CENTRES AGENCY (<http://www.eurec.be/htm/expertise/biomass.htm>)
- (10) U.S. DEPARTMENT OF ENERGY, Alternative Fuels Data Centre (<http://www.afdc.nrel.gov/altfuel/biodiesel.html>)
- (11) GERMAN AEROSPACE CENTER, INSTITUT FÜR TECHNISCHE THERMODYNAMIK (<http://www.dlr.de/TT/system/publications/epolitik>)
- (12) UNION FOR THE PROMOTION OF OIL AND PROTEIN PLANTS (<http://www.ufop.de/home.html>)
- (13) FEDERAL ENVIRONMENTAL AGENCY (ED.), Germany (<http://www.umweltbundesamt.de/uba-info-presse-e/presse-informationen-e/p0100e.htm>)
- (14) HESSISCHES DIENSTLEISTUNGSZENTRUM FÜR LANDWIRTSCHAFT, GARTENBAU UND NATURSCHUTZ (<http://www.agrarberatung-hessen.de/markt/analysen/0103102001032101.htm>)

### Description of the calculation to obtain the quantitative figures

**Economy figure:**

Prices for rape seed oil are oscillating in the world market (14).

**Ecology figure:**

The energy content of 1 litre rape oil is approximately 7 % lower than the value of heat oil respectively diesel fuel. In the conversion process within the oil mill, the energy output of the rape seed (approximately 23,8 GJ/t crop) is passed at 60 % on the attained rape oil and to 40 % on the co-product coarse colza meal. Process energy in terms of electrical power up to around 40 kWh per t seed (by a level of oil extraction of approximately 81 % and a water content of 8.3 %) is required for the conversion by the small-technical extraction procedure of rape oil. That means, for a part refinery process an energy need of 530 MJ/(ha a) is required for electricity and steam. The average distance of an oil mill to the procurement market is 240 km. Thereby a transportation loss to the fuel using market (petrol station) of 1 % is supposed as well as a transport power of 15 % by the use of lorries (class E) , of 15 % by trains and of 70 % by inland navigation. Energy and costs are saved as a result of an institutional regulation of exchange in only the accounting area of industrial oil against nourishment oil. Thus, an oil mill on location A, which runs also a biodiesel plant, can undertake contracts (in only the accounting area) for industrial oil from the oil mill B without a transportation of oil or rape seed in reality.

**Efficiency figure:**

60 % of the energy content of the rape seed is found in the rape seed oil (see ecology). So the transformation ratio is 60 %. Considering all input energies, the total efficiency is about 56 %.

### Description of the finding of some qualitative evaluations

readiness for market: The market for rape seed oil is existing for a long time and includes a food and a non-food market. The free market is the best available readiness for market.

<b>Quantitative assessment of the module for the present state</b>	
<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	3 to 3.5
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	2.3 to 2.5
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.60
GJ output energy per GJ of all input energies	0.56

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market					x
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique					
output standardisation				x	

<b>No.:</b>	C2-O2	<b>Vegetable Oil from Soy Beans</b>
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class	2	input from:	Modules C1-P3
category	Pressing of Oil Plants	output to:	Modules C2-S1, C3-T5

### General description of the process

The extraction of the **vegetable oil** of soy beans results from the stability of the soy bean in comparison to the rape seed or the sunflowers by hackling of the soy bean and the extraction of the oil afterwards. Vegetable oil of soy beans has a share of 20 % of the total German oil plants production. The extraction grist is processed in the forage and nourishment industry at world prices. The vegetable oil fuel can directly be used in suitable engines or - indirectly after a transesterification (see module C2-S1) - in conventional diesel engines, too.

By the **extraction**, the oily crop is removed from the oily substrate by a solvent. The so-called Miscella (an oil-solvent-mixture) remains as fluid phase, the extraction grist as solid substrate. The Miscella has to be purified by distillation afterwards. The advantage of the extraction is that in comparison to the pressing, significantly more oil can be gained from the same oil crop. Therefore, for very oily crops like rape seed, a combination of pressing and an (downstream) extraction is often realised.

Vegetable oil respectively its raffinate is different in essential characteristics from diesel fuel (e.g. its high viscosity) and even more from petrol-fuel.

### Regional specifications in the EU

The technology has no relevant regional specifications.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

For this well approved technology, no significant technological changes are assumed.

### Internal and external resources

- (1) KALTSCHMITT, M.; REINHARDT, G.: Nachwachsende Energieträger – Grundlagen, Verfahren, ökologische Bilanzierung, 1997
- (2) FEDERAL MINISTRY OF CONSUMER PROTECTION, FOOD AND AGRICULTURE (BMVEL) (ED.), Germany: Agenda 2000, Pflanzlicher Bereich, Agrarumweltmaßnahmen, 2000
- (3) SCHARNER, K.: Energy balance, ecological impact and economics of vegetable oil methylester production in Europe as substitute for fossil diesel. ALTENER-study 4.1030/E/94-002-1, 1995

#### Information from web pages:

- (4) U.S. DEPARTMENT OF ENERGY: Bioenergy Information Network (<http://bioenergy.ornl.gov/doeofd/index.html>)
- (5) UNIVERSITY OF IOWA: Environmental Science and Technology Online (<http://pubs.acs.org/journals/esthag-a/links/energy.html#biofuels>)
- (6) EUROPEAN RENEWABLE ENERGY CENTRES AGENCY (<http://www.eurec.be/htm/expertise/biomass.htm>)
- (7) U.S. DEPARTMENT OF ENERGY: Alternative fuels Data Centre (<http://www.afdc.nrel.gov/altfuel/biodiesel.html>)
- (8) GERMAN AEROSPACE CENTER, INSTITUT FÜR TECHNISCHE THERMODYNAMIK (<http://www.dlr.de/TT/system/publications/epolitik>)
- (9) UNION FOR THE PROMOTION OF OIL AND PROTEIN PLANTS (<http://www.ufop.de/home.html>)

(10) DEUTSCHE FORSCHUNGSANSTALT FÜR LEBENSMITTELCHEMIE (ED.): Food Composition and Nutrition Tables, (writer: Schmerz, H.; Senser, F.), Stuttgart, 1994.

**Description of the calculation to obtain the quantitative figures**

**Economy figure:**

The transformation cost for soy bean pressing was assumed to be equal to the transformation cost of rape seed pressing because the technologies don't differ significantly.

**Ecology figure:**

The energy input for the pressing was assumed to be equal to the input for the rape oil mill. So the value from the module sheet C2-O1 was transferred to the soy bean oil production.

**Efficiency figure:** n/a

**Quantitative assessment of the module for the present state**

<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	3 to 3.50
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	2.3 to 2.5
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	n/a
GJ output energy per GJ of all input energies	n/a

**Qualitative assessment of the module for the present state**

	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market				x	
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique					
output standardisation				x	

<b>No.:</b>	C2-O3	<b>Vegetable Oil from Sunflower Seed</b>
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class	2	input from:	Modules C1-P4
category	Pressing of Oil Plants	output to:	Modules C2-S1, C3-T5

### General description of the process

In general, the processing of "soft oil plants" in the oil mill (in refinery processes) to vegetable oil fuels is independent on the deployed oil plant in the converting process. The extraction of **vegetable oil** from sunflowers (with a production share of 5 % in the German oil plants production) results from pressing and/ or extraction of the oil contained in organic substances. The co-products press substrate and extraction grist are processed in the forage and nourishment industry at world prices. The vegetable oil fuel can directly be used in suitable engines or - indirectly after a transesterification (see module C2-S1) - in conventional diesel engines, too.

- The fluid oil phase can be separated from the solid phase (the so-called press substrate) by simple **mechanical pressing**.
- An additional or alternative method is the **extraction**. The oily crop is withdrawn from the oil substrate by a solvent. The so-called Miscella (an oil-solvent-mixture) remains as fluid phase, the extraction grist as solid substrate. The Miscella then has to be purified by distillation afterwards. The advantage of the extraction is that in comparison to the pressing, significantly more oil can be gained from the same oil crop. Therefore, in the case of very oily crops like rape seed, a combination of pressing and an (downstream) extraction often is realised.

Vegetable oil respectively its raffinate is different in essential characteristics from diesel fuel (e.g. its high viscosity) and even more from petrol-fuel.

### Regional specifications in the EU

The technology has no relevant regional specifications.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

For this well approved technology, no significant technological changes are assumed.

### Internal and external resources

- (1) KALTSCHMITT, M.; REINHARDT, G.: *Nachwachsende Energieträger – Grundlagen, Verfahren, ökologische Bilanzierung*, 1997
- (2) FEDERAL MINISTRY OF CONSUMER PROTECTION, FOOD AND AGRICULTURE (BMVEL) (ED.), Germany: *Agenda 2000, Pflanzlicher Bereich, Agrarumweltmaßnahmen*, 2000
- (3) SCHARNER, K.: *Energy balance, ecological impact and economics of vegetable oil methylester production in Europe as substitute for fossil diesel*. ALTENER-study 4.1030/E/94-002-1, 1995

#### Information from web pages:

- (4) U.S. DEPARTMENT OF ENERGY: Bioenergy Information Network (<http://bioenergy.ornl.gov/doeofd/index.html>)
- (5) UNIVERSITY OF IOWA: Environmental Science and Technology Online (<http://pubs.acs.org/journals/esthag-a/links/energy.html#biofuels>)
- (6) EUROPEAN RENEWABLE ENERGY CENTRES AGENCY (<http://www.eurec.be/htm/expertise/biomass.htm>)
- (7) U.S. DEPARTMENT OF ENERGY: Alternative fuels Data Centre (<http://www.afdc.nrel.gov/altfuel/biodiesel.html>)

- (8) GERMAN AEROSPACE CENTER, INSTITUT FÜR TECHNISCHE THERMODYNAMIK  
(<http://www.dlr.de/TT/system/publications/epolitik>)
- (9) UNION FOR THE PROMOTION OF OIL AND PROTEIN PLANTS (<http://www.ufop.de/home.html>)
- (10) ZMP GMBH (ED.): Ölsaaten Spezialinfo, 2002-04-30  
([http://www.zmp.de/produkte/leseproben/oelsaaten\\_Spez.pdf](http://www.zmp.de/produkte/leseproben/oelsaaten_Spez.pdf))

### Description of the calculation to obtain the quantitative figures

#### Economy figure:

For sunflower oil, European market prices were taken as an average value from source (10). They are traded at the stock exchange and are submitted to many fluctuations. After subtracting the input price component (price of sunflower seed necessary for 1 GJ sunflower oil) from the output price, the result corresponds to the price for this extraction module.

#### Ecology figure:

The energy input for the pressing was assumed to be equal to the input for the rape oil mill. So the value from the module sheet C2-O1 was transferred to the sunflower oil production.

#### Efficiency figure:

First figure: The energy content of sunflower seed and of its oil was found in (10). Following the personal communication of two independent vegetable oil plant companies, one ton of sunflower seed is transformed into 0,38 tons of sunflower oil within the oil mills. So 59 % of the energy content of the sunflower seed is found in the pressed sunflower oil.

Second figure: The energy input for the pressing was assumed to be equal to the input for the rape oil mill. So the percentage was adapted.

### Description of the finding of some qualitative evaluations

readiness for market: good because widely used in the food industry. Not “very good” because the introduction into the transport sector may need modifications.

<b>Quantitative assessment of the module for the present state</b>	
<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	2.00 to 2.50
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	2.3 to 2.5
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.59
GJ output energy per GJ of all input energies	0.55

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market				x	
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique					
output standardisation				x	

<b>No.:</b>	C2-O4	<b>Vegetable Oil from Olives</b>
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class	2	input from:	Modules C1-P2
category	Pressing of Oil Plants	output to:	Modules C2-S1, C3-T5

<b>General description of the process</b>
Olives are pressed in the regions where they are harvested. Experiences with the procedure exist for a long time. The procurement price of olives is relatively high, hence, a fuel production from olives is not economical. However, the olive oil could achieve a considerable market share in the nourishment industry in spite of its relative prices. Consequently, the extraction of olive oil is primarily relevant for the nourishment industry. An industrial olive oil fuel production is nearly not existing at the moment.
<b>Regional specifications in the EU</b>
The technology has no relevant regional specifications.
<b>Foreseeable intermediate (5-10 years) and long-term (25-30 years) development</b>
For this well approved technology, no significant technological changes are assumed.
<b>Internal and external resources</b>
(1) KALTSCHMITT, M.; REINHARDT, G.: Nachwachsende Energieträger – Grundlagen, Verfahren, ökologische Bilanzierung, 1997 <u>Information from web pages:</u> (2) U.S. DEPARTMENT OF ENERGY: Bioenergy Information Network ( <a href="http://bioenergy.ornl.gov/doeofd/index.html">http://bioenergy.ornl.gov/doeofd/index.html</a> ) (3) UNIVERSITY OF IOWA: Environmental Science and Technology Online ( <a href="http://pubs.acs.org/journals/esthag-a/links/energy.html#biofuels">http://pubs.acs.org/journals/esthag-a/links/energy.html#biofuels</a> ) (4) EUROPEAN RENEWABLE ENERGY CENTRES AGENCY ( <a href="http://www.eurec.be/htm/expertise/biomass.htm">http://www.eurec.be/htm/expertise/biomass.htm</a> ) (5) GERMAN AEROSPACE CENTER, INSTITUT FÜR TECHNISCHE THERMODYNAMIK ( <a href="http://www.dlr.de/TT/system/publications/epolitik">http://www.dlr.de/TT/system/publications/epolitik</a> ) (6) UNION FOR THE PROMOTION OF OIL AND PROTEIN PLANTS ( <a href="http://www.ufop.de/home.html">http://www.ufop.de/home.html</a> )

<b>Description of the calculation to obtain the quantitative figures</b>
<b>Economy figure:</b> Valuable data for large scale applications were not available. For domestic use, the price of olive oil is by far higher than the price of sunflower oil. <b>Ecology figure:</b> Technical data for the olive oil pressing were not available. <b>Efficiency figure:</b> Technical data for the olive oil pressing were not available.
<b>Description of the finding of some qualitative evaluations</b>
Qualitative evaluations have not been carried out.

<b>No.:</b>	C2-T1	<b>Methanol from Woody Biomass</b>
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class	2	input from:	Modules C1-P9, C1-P10, C1-R2, C1-R8
category	Thermochemical Conversion	output to:	Modules C3-T1

<b>General description of the process</b>	
<p>The gasification is an important intermediate step in the production of methanol from fossil fuels. The following processing steps are necessary according to the state-of-the-art of the fuel technology:</p> <ul style="list-style-type: none"> <li>• wood conditioning by comminution and drying</li> <li>• the production of the synthesis gas by gasification, conditioning and purification; the composition of the produced synthesis gas often does not have the necessary requirements of the methanol-synthesis. Therefore, a conversion process follows in order to match the respective synthesis gas characterisations.</li> <li>• The actual methanol-synthesis of the conditioned synthesis gas is already state of the art. After the synthesis follows a process of distillation for the raw methanol, in which by-products are secluded and methanol with the required purity is produced.</li> </ul> <p>A global estimation of the degree of efficiency is very difficult because savings can be obtained by the use of the rejected heat or residual materials. However, this form of a rational energy use is limited. In many cases there is no local demand of the rejected heat and a transport even at short distances is not economical. Furthermore, the by-products of energy transfer mediums often can't be used due to their adverse parameters, e.g. low temperature heat.</p> <p>In the following, each single process step is evaluated of its efficiency. Thereby, it is accessed by the know-how of the classic fuel and energy technology.</p> <ul style="list-style-type: none"> <li>• <b>Comminution</b></li> </ul> <p>Shedder plants are applied for the comminution of wood. Unfortunately, the delivered grist structure is unfavourable to use for a carburettor. An improved result of barks (better grain sizes) can be available with a higher operating expense in future.</p> <p>The process of the comminution requires bunker, interim bunker, possibly cycle circuits with screens and comminution plants. The great amount of required electric energy is estimated of approx. 50 kWh/t. Therefore, an efficiency of <math>\eta_z = 98.0 \%</math> is the outcome of this process step. Whereas the electricity generation is specified with <math>\eta = 70 \%</math>.</p> <ul style="list-style-type: none"> <li>• <b>Drying</b></li> </ul> <p>Heat energy in form of steam, flue gas, hot air and the like must be expended for the drying. The drying expense is about 0.9 - 1.0 kWh/kg vaporised water. One share of the heat can be regained by modern plants via the use of the exhaust vapour heat. Further expenses are necessary in form of electric energy. Hence, a partial efficiency of <math>\eta_T = 94.5 \%</math> is the result excluding the exhaust vapour heat recovery.</p> <ul style="list-style-type: none"> <li>• <b>Producing of the synthesis gas</b></li> </ul> <p>The considerable know-how of the coal upgrading can be used here. Poor-gas generation plants with condensation and purification had a thermal efficiency of 60 %. The optimised proceeding of the solid state pressure gasification with oxygen resulted in 65 % including the valuation of all produced products (gas, tar, oil, phenol) and by a very good gas purification (Rectisol-proceeding). If assumed that a partial converting is required and this process uses great amounts of the rejected heat (efficiency 95 %) then the efficiency of <math>\eta_{SGAS} = 62 \%</math> is for the provision of the synthesis gas.</p>	

- Methanol synthesis

If the yield and consumption performance figures as described before are the basis, the thermal efficiency results in  $\eta_{\text{Syn}} = 57.1\%$  only for the synthesis process. Admittedly, further 28 % are available as secondary energy sources (steam / residue gas). Thus, an efficiency of  $\eta_{\text{Syn}} = 70\%$  results from the synthesis, if it can be provided that 50 % of the secondary energy sources are used.

- The total efficiency of the proceeding chain

The multiplication of the partial efficiencies causes the following total efficiency of the proceeding chain biomass (wood) - liquid energy source methanol:

$$\eta_{\text{Ges B-Meth}} = \eta_Z \cdot \eta_T \cdot \eta_{\text{SGAS}} \cdot \eta_{\text{Meth.}} = 0.40$$

### Regional specifications in the EU

The technology has no relevant regional specifications.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

Methanol-synthesis plants have been built serially for a long time, but they were based on fossile fuels, such as coal or natural gas. Because of this, some technological descriptions of older sources are still valid. For the development of biomass-based plants, the development will lead to smaller plants for making the technology available in a more decentralised grid of transformation plants.

### Internal and external resources

(1) KRÜGER, R.; VOß, A.: Systemanalytischer Vergleich innovativer Kraftstoffe und Antriebssysteme, in: Innovative Fahrzeugantriebe, Tagung Oktober 2000 in Dresden, VDI-Berichte 1565, VDI-Verlag, Düsseldorf, 2000

(2) ECKHARDT, L.: Freiburger Lehrbriefe Organisch-chemische Technologie, Lehrbuch 4, 1961

(3) Ullmanns Enzyklopädie der technischen Chemie, Vol. 12

(4) CHOREN INDUSTRIES (ED.): Erneuerbare Kraftstoffe, Freiberg, 2001

### Description of the calculation to obtain the quantitative figures

#### Economy figure:

Production costs were taken from (4) and refer to German conditions.

#### Ecology figure:

Oxygen is used by the generation of synthesis gas. Thus, 30 % of the synthesis gas volume are transformed into CO<sub>2</sub>. More CO<sub>2</sub> can accrue by the producing of the insert gas. It can be assumed that totally approx. 2 kg CO<sub>2</sub> accrues per deployed ton of dehumidified wood. The CO<sub>2</sub> output caused by the energy input of the different proceeding steps must be added. About 585 kg methanol (energy content 12.3 GJ) is produced by 1 ton dried wood (energy content 18.5 GJ). Therefore, 5.6 GJ auxiliary energy (0.3 GJ electricity and 5.3 GJ process heat) is necessary. This is equivalent to 0.28 GJ auxiliary energy per 1 GJ produced methanol.

128 kg CO<sub>2</sub> accrues for the provision of 1 GJ electricity (EU-mix). Only approx. 64 kg CO<sub>2</sub> accrues by the provision of industrial process heat on natural gas basis.

19.0 kg CO<sub>2</sub> output by auxiliary energies and 0.2 kg CO<sub>2</sub> by the actual process emerge by the production of 1 GJ methanol, which results in 19.2 kg CO<sub>2</sub> totally.

#### Efficiency figure:

The heating value of the methanol output compared with the heating value of the necessary wood input lead to the first efficiency figure.

The composition of the total efficiency was described in the “general description of the process”.

### Description of the finding of some qualitative evaluations

Need of space: The installations are quite compact, thus good

Readiness for market: The technology is developed but actually no large scale industries exist.

Hazardousness: The breathing or the taking of methanol is very toxic – approximately 25 g are lethal. Furthermore, chronic toxications can result from the continued contact with few amounts of methanol. The technology itself is not very dangerous (low accident risk).

### Quantitative assessment of the module for the present state

<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	about 20
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	19.2
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.62
GJ output energy per GJ of all input energies	0.40

### Qualitative assessment of the module for the present state

	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space				x	
<b>Availability</b>					
readiness for market			x		
<b>Other indicators</b>					
hazardousness (health risk)		x			
complexity of technique			x		
output standardisation				x	

<b>No.:</b>	C2-T2	<b>Pyrolysis Oil from Biomass</b>
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class	2	input from:	Modules C1-P9, C1-P10, C1-R2, C1-R8
category	Thermochemical Conversion	output to:	Modules C3-T3

<b>General description of the process</b>
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Solid organic substrates like wood consist of macromolecules. These are cracked during the pyrolysis process - exclusively under the impact of heat - and hence, without external oxygen supply. It forms gaseous, liquid and solid components. Their shares and composition can be influenced by process parameters of the pyrolysis and especially by the heating-up-rate. The resulting liquid components, e.g. by the flash-pyrolysis, are a mixture of different organic blends. Water and charcoal can be solved in it. This mixture is also called pyrolysis oil and is generally not storable because of the oxygen content. Therefore, the pyrolysis oil must be prepared for the use by tractors if necessary. Furthermore, it has to be matched on common features of fossil fuels.

The volumetric consumption of pyrolysis oils is twice as high as the value of diesel because the gross calorific value of the pyrolysis oil is only half of the one of diesel fuel.

The highest possible oil yield of the pyrolysis technology (the reactor water inclusive) is approximately 75 %. The average value is 56 % referring to the dry biomass. The optimal temperature range is about 450-500 °C.

Four chemical product groups emerge of the pyrolysis decomposition. Their shares - in dependency of the selected requirements of the pyrolysis - can vary substantially. The pyrolysis decomposition of the organic mass starts at nearly 220°C with the formation of acetic acid (CH<sub>3</sub>COOH), water and gas. The gas is mainly composed of carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), methanol (CH<sub>3</sub>OH) and of charcoal together with shares of ash.

30 % of the woody substance are decomposed in the temperature range of 320-340°C. The maximums at about 400°C - nearly 70 % loss of weight - mark the end of the removal of cellulose and hemicellulose and the zenith of the lignin decomposition.

In principle, the technical potential of a pyrolysis oil-production is very good. Theoretically, the total solid biomass (in Germany: 1000 to tightly 1200 PJ/a), which is available for an energy recovery, could be used for the pyrolysis-oil-production. Especially in recent years, considerable research funds have been raised for the development of this technology in Europe. Nonetheless, such techniques still exist in a stadium of research and development. To date, it is even not possible to produce a storable fuel with defined characteristics without problems.

When a fuel should be provided for a fleet of vehicles, in which the fuel can be deployed without problems, a relatively high operating expense for the processing is necessary. In the same way, a rise in costs would be inevitable. Therefore, the commercial implementation of this option in the energy sector is negligibly low at the moment. However, this technology comes into operation especially in Canada. The pyrolysis oil production supplies specified flavours for a material use there.

<b>Regional specifications in the EU</b>
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The technology has no relevant regional specifications.

<b>Foreseeable intermediate (5-10 years) and long-term (25-30 years) development</b>
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No information available.

### Internal and external resources

- (1) KALTSCHMITT, M.; HARTMANN, H.: Energie aus Biomasse – Grundlagen, Techniken und Verfahren, 2001
- (2) BRIDGEWATER, A.V.; BRIDGE, S.A.: A review of biomass pyrolysis and pyrolysis technologies, in: Bridgewater, A.V.; Grassi, G. (Eds.) Biomass Pyrolysis Liquids Upgrading and Utilization, Elsevier Appl. Sci., London, S. 11-92, 1991
- (3) Ormrod Diesels, Skelmersdale, Lancashire, 1999
- (4) ANDREWS, R.G. ET AL: Feasibility of firing an industrial gas turbine using a biomass derived fuel, in Bridgewater, A.V.; D.G.B. (Eds.): Developments in Thermochemical Biomass Conversion, Blackie Academic, London, S. 495-506, 1997

### Description of the calculation to obtain the quantitative figures

**Economy figure:**

Currently, no large scale application exist, so no reliable data are available.

**Ecology figure:**

An environmental assessment of the pyrolysis assessment was not found.

**Efficiency figure:**

The efficiency of a technology existing only in the R&D state can not be quantified.

### Description of the finding of some qualitative evaluations

Readiness for market: very bad, because the technology exists only in the R&D state.

Other evaluations have not been carried out.

<b>No.:</b>	<b>C2-T3</b>	<b>Synfuel by Thermochemical Processing from Biomass</b>
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class	2	input from:	Modules C1-P9, C1-P10, C1-R2, C1-R8
category	Thermochemical Conversion	output to:	Module C3-T6, C3-P3

<b>General description of the process</b>	
<p>The first steps of synfuel production are the same as for methanol production because both reactions need a synthesis gas. The following processing steps are necessary according to the state-of-the-art of the fuel technology:</p> <ul style="list-style-type: none"> <li>▪ wood conditioning by comminution and drying</li> <li>▪ the production of the synthesis gas by gasification, conditioning and purification; the composition of the produced synthesis gas often does not have the necessary requirements of the methanol-synthesis. Therefore, a conversion process follows in order to match the respective synthesis gas characterisations.</li> </ul> <p>The Fischer-Tropsch synthesis uses carbon monoxide and hydrogen for producing alkanes. The temperatures during the reactions must be strictly controlled.</p> <p>The synthesis has different options: Depending on the pressure, the temperature and on the used catalysts, different mixtures of hydrocarbons will result. For getting fuels substituting petrol, the Kölbl-Rheinpreußen-procedure, a medium pressure variant, can produce the best mixture, containing up to 62 % of petrol (i. e. fluent hydrocarbons from C<sub>5</sub> to C<sub>10</sub>).</p> <p>After using a kiln where the gasses have contact to the catalyst, different condensation steps lead to the isolation of different hydrocarbons. For these steps, the input of auxiliary energies may be 30 % higher than for a methanol synthesis. The resulting fuel is called synfuel and contains no aromates, no naphthene and no sulfur, but all those alkanes that are typical for petrol.</p>	
<b>Regional specifications in the EU</b>	
<p>The Fischer-Tropsch-synthesis has been developed in the 20<sup>th</sup> century. mainly for converting coal to vehicle fuels and other materials. The know-how had been developed in Germany an in Great Britain (as well as outside Europe), but cheap mineral oil displaced the Fischer-Tropsch output during the last four decades of the 20<sup>th</sup> century. So a well established conversion technology has been rediscovered for the conversion of biomass, but there are no existing large scale industries so far in the member or accession countries of the EU.</p>	
<b>Foreseeable intermediate (5-10 years) and long-term (25-30 years) development</b>	
<p>New developments tend to the medium pressure synthesis rather than to normal pressure synthesis because the installations are more compact. New systems of catalysts can lead to more homogenous outputs and less by-products, so that the maximum share of vehicle fuels among the output products may rise. The third tendency is the trend towards more energy recycling (especially heat recycling) for bettering the total energy efficiency.</p>	

<b>Internal and external resources</b>
<p>(1) ECKHARDT; LUDWIG: Freiburger Lehrbriefe Organisch-chemische Technologie, Lehrbuch 4, 1961</p> <p>(2) ULLMANN'S ENZYKLOPÄDIE DER TECHNISCHEN CHEMIE, vol. 12</p> <p>(3) Personal communication of Dr. Berthold Gartner, 2002</p>
<b>Description of the calculation to obtain the quantitative figures</b>
<p><b>Economy figure:</b></p> <p>The costs of the Fischer-Tropsch-synthesis are similar to the methanol synthesis, but the prices of the different output or by-products depend on supply and demand. If the procedure will established in a large scale, the constant demand for the other alkanes may lead to decreasing prices for the by-products, so that the price of the petrol fraction must increase. Supposing this effect, the prices were estimated being 10 % higher than for a methanol synthesis.</p> <p><b>Ecology figure:</b></p> <p>The gasification of the synthesis gas is done with oxygen so that 20-30 % of the gas volume accrues as CO<sub>2</sub>. It can be assumed that totally approx. 2 kg CO<sub>2</sub> accrues per deployed ton of dehumidified wood. Another source of CO<sub>2</sub> is induced by the energy input of all processing steps.</p> <p>The CO<sub>2</sub> output caused by the energy input of the different proceeding steps must be added. For transforming 1 ton of dried wood (energy content 18.5 GJ) into synfuels, about 7.2 GJ auxiliary energy (about 0.4 GJ electricity and 6.8 GJ process heat) is necessary. This is 30 % more than for the methanol production because the number of processing steps is higher (3). This is equivalent to 0.37 GJ auxiliary energy per 1 GJ produced synfuels.</p> <p>128 kg CO<sub>2</sub> accrues for the provision of 1 GJ electricity (EU-mix). Only approx. 64 kg CO<sub>2</sub> accrues by the provision of industrial process heat on natural gas basis.</p> <p>24.7 kg CO<sub>2</sub> output by auxiliary energies and 0.17 kg CO<sub>2</sub> by the actual process emerge by the production of 1 GJ synfuels, which results in 24.8 kg CO<sub>2</sub> totally. This value corresponds to all outputs of the Fischer-Tropsch synthesis. If only the share of energy within the petrol fraction energy is considered, 39.8 kg of CO<sub>2</sub> accrues per produced GJ of synthetic petrol.</p> <p><b>Efficiency figure:</b></p> <p>The efficiency related to the input module (wood) as energy carrier and the petrol fraction as output is calculated by their heating values. The heating value of by-products is excluded, so this efficiency value is by far lower than for the methanol synthesis. If all other fractions of inputs would be taken into consideration, the efficiency would be 62 %, the same as for the methanol synthesis.</p> <p>The total efficiency figure shows the total energy input for the Fischer-Tropsch-Synthesis and the output of only the petrol fraction. If all other fractions of inputs would be taken into consideration, the efficiency would be 38,5 %, a little lower than for the methanol synthesis.</p>
<b>Description of the finding of some qualitative evaluations</b>
<p>Need of space: The installations are quite compact, so the need of space is not too high</p> <p>Readiness for market: The technological know-how is well established, but actually there is not large scale industry in Europe, thus medium. For a decentralised use (for avoiding too long biomass transports) smaller installations may be useful, for these, a need for reseach and development is left.</p> <p>output standardisation: The output can be ruled by the chosen process, so the output can meet any standard required, thus good.</p>

<b>Quantitative assessment of the module for the present state</b>		
<b>Output unit:</b>	GJ	
<b>Economy:</b>	data referring to all Fischer-Tropsch outputs	data referring only to the synthetic petrol fraction
costs (€) per output unit	about 20	about 22
<b>Ecology:</b>		
emission of CO <sub>2</sub> (kg) per output unit	24.8	39.8
<b>Efficiency:</b>		
GJ output energy per GJ input energy carrier	0.62	0.39
GJ output energy per GJ of all input energies	0.39	0.28

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space				x	
<b>Availability</b>					
readiness for market			x		
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique			x		
output standardisation				x	

<b>No.:</b>	C2-F1	<b>Ethanol from Sugar Beet</b>
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class	2	input from:	Modules C1-P5
category	Fermentation	output to:	Modules C2-S6, C3-T2

### General description of the process

Ethanol is a clear, uncoloured liquidity. Ethanol from biomass is referred to as "bio-ethyl-alcohol". In some countries, it is already common as fuel under the name "Gasohol". Ethanol can be mixed with petrol with a share of 10-85 %. Ethanol is produced of vegetable raw materials in a process of fermentation and distillation.

- The **fermentation** describes the process of the transformation of glucose, which is contained in the sugar beet, to ethanol and carbon dioxide via yeast enzyme.
- Afterwards, the solvent **is distilled** and with it the ethanol is concentrated. 96 % ethanol and 4 % water is the max. achievable concentration. The remaining water can be detracted via chemical substances. A concentration level of 100 % can be accomplished.

Only starchy and sugary plants can be used for the production of ethanol. In Europe these are mainly wheat and sugar beets at the moment.

Established procedures were used for the ethanol production of sugar beets. The converting process is divided in different steps: the washing, the break-up and the sugar extraction. In the sugar beet manufacture, the washing water is anaerobic and aerobically treated in existing refurbishment plants. Thereafter it is directed in the on-site pre-flooder. A sugary solvent and beet chips are the end products of the extraction. The raw sap is fermented. Absolute alcohol is produced of the fermented sap by distillation.

Pure ethanol melts at -114°C, boils at 78°C and has a relative density of 0.79 at 20°C. The energy content is comparable with petrol. The possible use of ethanol is similar to the use of conventional fuels.

The bio-ethanol production plants are not operated at full capacity by the exclusive production of bio-ethanol from sugar beets. The harvested sugar beets in autumn have to be processed until the February in the next year. Therefore, the planning of plants which are able to accept more different input substances is recommended to improve the use to capacity of the plants.

### Regional specifications in the EU

Within the EU, bio-ethanol is used only in France as a base for producing ethyl-tertiary-butyl-ether (ETBE) . However, the market penetration is very low because of the absence of the exemption of the mineral-oil-tax.

In Germany only a pilot-plant was operating in the last century.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

In Europe no fixed production targets exist besides the proposal for a directive on the promotion and the use of biofuels for transport (COM 547 (final)).

In France, the bioethanol production will continue to grow. Officials assume that bioethanol could close the gap with fossil fuels at the macro-economic level within the next 10 years in France.

A working group at the Ministry of Agriculture of Latvia is developing a programme of biofuel production and use within 2000 – 2010. Today three ethanol factories with a total annual capacity of 11

million litres of ethanol operate in Latvia.

Bioethanol can be used without any operating problems or environmental risks and the refinery technology for production of bioethanol already exists in Europe. Increased use of biofuels at present can only be obtained if there is a high rate of tax relief and subsidised raw material production.

The Commission proposes that a market-share of two percent for liquid biofuels could still be considered as a pilot phase implementation. This level may well be reached in the short or medium term in some countries (in particular Austria, Germany, France and Italy).

Current and potential future deployment of bioethanol/ETBE in the EU (7)

	Deployment in 1995 (‘000 tonnes/year)	Estimated deployment in 2010 (‘000 tonnes/year)
EU-Wide	344	2.802
Austria	0	100
France	200	1.111
Greece	0	1.000
Italy	120	200
Spain	0	391
Sweden	7	

### Internal and external resources

(1) KALTSCHMITT, M.; REINHARDT, G.: *Nachwachsende Energieträger – Grundlagen, Verfahren, ökologische Bilanzierung*, 1997

(2) Information from the FEDERAL STATISTICAL OFFICE, Germany

(3) FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF) (ED.), Germany: *Nachwachsende Rohstoffe*, 1990

(4) ROESCH, C.: *Monitoring "nachwachsende Rohstoffe", Pflanzliche Öle und andere Kraftstoffe aus Pflanzen, Dritter Sachstandsbericht, TAB Arbeitsbericht Nr. 53*, 1997

(5) EUROPEAN PARLIAMENT: *Briefing Note N° 07/2001, Bioethanol added to fuel*

(6) BERG, C.: *World Ethanol Production*, 2001

(7) EUROPEAN UNION, DIRECTORATE GENERAL XVII OF THE EUROPEAN COMMISSION, *The ATLAS project* ([http://europa.eu.int/comm/energy\\_transport/atlas/htmlu/lbpot1.html](http://europa.eu.int/comm/energy_transport/atlas/htmlu/lbpot1.html))

(8) UNITED NATIONS UNIVERSITY, INSTITUTE OF ADVANCED STUDIES: *Integrated bio-system for biofuel production from agricultural raw materials in Latvia*, (writer: Bekers, M.; Viesturs, U.), 1998 ([www.ias.unu.edu/proceedings/icibs/bekers/paper.htm](http://www.ias.unu.edu/proceedings/icibs/bekers/paper.htm))

(9) Information from the INTERNATIONAL ENERGY AGENCY (IEA)

### Description of the calculation to obtain the quantitative figures

#### Economy figure:

Regarding to the provision costs amounting to 28 €/GJ following (4), based on large plants, conversion costs result with approx. 13,40 €/GJ.

#### Ecology figure:

The following performing figures are relevant for the production of bio-ethanol from sugar beets:

The energy demand of the ethanol production of sugar beets in the sugar manufacture amounts 17.45 kWh (62,6 MJ) per ton of beets including all processing steps plus 0.1055 kWh (0,38 MJ) per kg of pure alcohol. Essentially, heavy heat oil (nearly 50 %), natural gas (15 %), mineral and brown coal (9 to 19 %) are used to cover the energy demand in sugar manufacturing.

The fermentation by microbes leads to transforming 1 kg glucose into 0,51 kg ethanol and 0,49 kg

CO<sub>2</sub>.

The raw material demand is 12.6 t sugar beets per ton of ethanol. Source: (4)

**Efficiency figure:**

The efficiency  $\eta$  is defined as energy output divided by the total expenditures. It results in  $\eta = 40 \%$  for the production from ethanol from sugar beets.

The ratio between the energy content of the sugar beets and the energy content of the resulting ethanol is better (64 %) and was found by comparing the heating values and the assumption of 12,5 tons of sugar beet for 1 ton of ethanol (9).

The calorific value of the bio-ethanol is about 21.3 MJ/l or 27 GJ/t.

**Description of the finding of some qualitative evaluations**

Ethanol is significantly less toxic than methanol. The handling of ethanol is relatively easy (not especially toxic or explosive).

Quantitative assessment of the module for the present state	
<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	approx. 14
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	15 to 20
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.64
GJ output energy per GJ of all input energies	0.4

Qualitative assessment of the module for the present state					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market				x	
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique				x	
output standardisation				x	

<b>No.:</b>	C2-F2	<b>Ethanol from Maize</b>
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class	2	input from:	Modules C1-P11
category	Fermentation	output to:	Modules C3-T2

**General description of the process**

The production of ethanol from biomass results from micro-biological conversion, i.e. fermentation of a sugary solvents by yeast (*Saccharomyces cerevisiae*) or via bacteria (*Zymomonas mobilis*).

The production of bio-ethanol from maize is realised only on selected locations (e.g. USA). The manufacturing of bio-ethanol from starchy raw materials is more expensive than the fermentation of sugary plant content substances but technical feasible.

The starch is hydrolysed by enzymatic or thermal swelling in a pre-treatment. In the saccharification process afterwards, the accrued Oligosaccharides have to be cracked via enzymes or acids in monosaccharids which may be utilised for a fermentation later.

The incurred distillation residues (mashes) are by-products. They are partly rehashed within the plant. Mashers can be used humid or dried as forage or fertiliser. The feeding of fresh mashers is directly tied on the production because of its slight durability. The dehumidification of mashers is technical no problem. Nonetheless, it charged the energy balance of the bio-ethanol production.

Corn gluten feed arises as by-product that is usable for the commercialisation. Corn gluten feed contributes determining to the profitability because of its small raw-fibre-content and the high protein- and colorimeter-content.

The cracked sugar is converted by yeast in the continued process (metabolism) to ethanol and CO<sub>2</sub>:  
1kg glucose (C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>)            0.51 kg bio-ethanol (C<sub>2</sub>H<sub>5</sub>OH<sub>10</sub>) + 0.49 kg carbon dioxide (CO<sub>2</sub>)

The resulted liquidity or mash contains average 5-12 % bio-ethanol. The growth of the biological yeast population decelerates by a higher concentration of alcohol and they would die as consequence of it. The fermentation process is closed after 35-50 hours.

The conversion to the product bio-ethanol processes more continuous by the use of bacteria and is closed after 20 hours. However, the use of bacteria requires a totally sterile mode of operation.

The separated share of the bio-ethanol is concentrated to up to 97 vol. % by distillation. The required purification of 99.8 vol.% is achievable with the help of the molecular-screen-distillation or by the use of Cyclohexan as an entrainer.

Pure ethanol melts at -114°C, boils at 78°C and has a relative density of 0.79 at 20°C. The energy content is comparable with petrol. The possible use of ethanol is similar to the use of fossil fuels.

**Regional specifications in the EU**

Bio-ethanol from maize is produced in the USA (production in form of ETBE) and in China. Actually, bio-ethanol from maize is not produced within the EU countries.

**Foreseeable intermediate (5-10 years) and long-term (25-30 years) development**

The most important development from a global point of view is probably the fact that the US could overtake Brazil by the year 2004, if not earlier. If California should indeed ban all MTBE (produce from petroleum) in 2003, as is currently required by executive order, ethanol demand will rise sharply.

See also page Ethanol form sugar beet.

### Internal and external resources

- (1) FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF) (ED.), Germany: *Nachwachsende Rohstoffe*, 1990
- (2) ROESCH, C.: *Monitoring "nachwachsende Rohstoffe"*, *Pflanzliche Öle und andere Kraftstoffe aus Pflanzen*, Dritter Sachstandsbericht, TAB Arbeitsbericht Nr. 53, 1997
- (3) BERG, C.: *World Ethanol Production*, 2001
- (4) EUROPEAN PARLIAMENT: *Briefing Note N° 07/2001, Bioethanol added to fuel*
- (5) UNITED NATIONS UNIVERSITY, INSTITUTE OF ADVANCED STUDIES: *Integrated bio-system for biofuel production from agricultural raw materials in Latvia*, (writer: Bekers, M.; Viesturs, U.), 1998 ([www.ias.unu.edu/proceedings/icibs/bekers/paper.htm](http://www.ias.unu.edu/proceedings/icibs/bekers/paper.htm))

### Description of the calculation to obtain the quantitative figures

#### **Economy figure:**

Depending on the raw materials and the scale of production, the total cost of production of bioethanol are 0,336 ECU/l in USA (4).

According to source (5) production costs of bioethanol from maize are 0,163 €/l. These costs are based on a EC analysis, discussed during the 10<sup>th</sup> European Conference an Technology Exhibition held on 8-11 June 1998 in Wurchburg.

#### **Ecology figure:**

The fermentation by microbes leads to transforming 1 kg glucose into 0,51 kg ethanol and 0,49 kg CO<sub>2</sub>, following (2)

#### **Efficiency figure:**

The following performing figures are relevant by the production of bio-ethanol from maize:

raw material demand: 3.2 t/t ethanol

ethanol output: 1.82-2.22 t/ha or 2270-2780 l/ha

The calorific value of the bio-ethanol is 21.2-21.4 MJ/l.

Source: (2)

### Description of the finding of some qualitative evaluations

Hazardousness: Ethyl alcohol is significantly less toxic than methanol. The handling of ethyl alcohol is relatively easy (not especially toxic or explosive).

<b>Quantitative assessment of the module for the present state</b>	
<b>Output unit:</b>	GJ
<b>Economy:</b>	
Costs (€) per output unit	approx. 24
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	approx. 18
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.61 to 0.67
GJ output energy per GJ of all input energies	0.37

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market				x	
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique				x	
output standardisation				x	

<b>No.:</b>	C2-F3	<b>Ethanol from Cereals (e.g. Winter Wheat)</b>
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Class	2	input from:	Modules C1-P6, C1-P7
Category	Fermentation	output to:	Modules C3-T2

### General description of the process

Ethanol is a clear, uncoloured liquidity. Ethanol from biomass is referred to as "bio-ethyl-alcohol". In some countries, it is already common as fuel under the name "Gasohol". Ethanol can be mixed with petrol with a share of 10-85 %. Ethanol is produced of vegetable raw materials in a process of fermentation and distillation.

- The **fermentation** describes the process of the transformation of the glucose, which is contained in the input materials, to ethanol and carbon dioxide via yeast enzyme.
- Afterwards, the solvent **is distilled** and with it the ethanol concentrated. 96 % ethanol and 4 % water is the max. achievable concentration. The remaining water can be detracted via chemical substances. A concentration level of 100 % can be accomplished.

A modern mash-procedure with enzymatic saccharification and continuous fermentation is the basis of the production of fuel alcohol from wheat. The mash is separated in a thin and a thick phase. A share of the thin mash is evaporated in the mash procedure. Afterwards, it is dehumidified together with the thick mash. The end product DDGS (Distiller's Dried Grain & Solubles) is a high-quality, transportable and tradable feeding stuff with approximately 24-30 % protein and a water content of 10 %. The distillation takes place in the same type of manufacture plant as it is used by the production of ethanol from sugar beets.

The total energy demand of the ethanol production is 156 kWh/t wheat and 0.08 kWh/kg pure alcohol. Thereby, different processing levels are passed through: mashing, fermentation and subsidiary plants as well as distillation and mash evaporation. 293.5 kg respectively 372 litre pure alcohol can be produced from the starch of 1 ton wheat.

Pure ethanol melts at -114°C, boils at 78°C and has a relative density of 0.79 at 20°C. The energy content is comparable with petrol. The possible use of ethanol is similar to the use of conventional fuels.

### Regional specifications in the EU

Spain is said to become the largest bioethanol producer in the EU by 2004, when the third and largest plant will come an stream in Salamenca. The plant will have a production capacity of two million hl and will use biomass (cereals, wheat). One bioethanol plant is up and running in Cartagena with a total capacity of one million hl a year from barley.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

See page Ethanol from sugar beet

In Spain ethanol will be transformed into ETBE (185.000 t/a) in existing MTBE installations.

### Internal and external resources

(1) KALTSCHMITT, M.; REINHARDT, G.: Nachwachsende Energieträger – Grundlagen, Verfahren, ökologische Bilanzierung, 2001

(2) Information from the FEDERAL STATISTICAL OFFICE, Germany

- (3) FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF) (ED.), Germany: *Nachwachsende Rohstoffe*, 1990
- (4) ROESCH, C.: *Monitoring "nachwachsende Rohstoffe", Pflanzliche Öle und andere Kraftstoffe aus Pflanzen*, Dritter Sachstandsbericht, TAB Arbeitsbericht Nr. 53, 1997
- (5) BERG, C.: *World Ethanol Production*, 2001
- (6) SCHARMER, K.: *Alternative Fuels from Renewable Resources*, GET – Gesellschaft für Entwicklungstechnologie mbH, Jülich
- (7) UNITED NATIONS UNIVERSITY, INSTITUTE OF ADVANCED STUDIES: *Integrated bio-system for biofuel production from agricultural raw materials in Latvia*, (writer: Bekers, M.; Viesturs, U.), 1998 ([www.ias.unu.edu/proceedings/icibs/bekers/paper.htm](http://www.ias.unu.edu/proceedings/icibs/bekers/paper.htm))

### Description of the calculation to obtain the quantitative figures

#### Economy figure:

Regarding to the provision costs amounting to 33-39 €/GJ, large plants are the basis, conversion costs result with approx. 24-30 €/GJ (0,322-0,403 €/l).

According to source (7) production costs of bioethanol from wheat are 0,095 €/l. These costs are based on a EC analysis, discussed during the 10<sup>th</sup> European Conference an Technology Exhibition held on 8-11 June 1998 in Wurchburg.

#### Ecology figure:

The following performing figures are relevant by the production of bio-ethanol from cereals:

	<i>dry-procedure:</i>	<i>wet-procedure:</i>
raw material demand:	3.46 t/t ethanol	3.46 t/t ethanol
ethanol output:	1.925 t/ha or 2420 l/ha	2.475 t/ha or 3120 l/ha
net-energy output:	5-37 GJ/(ha*a)	5-37 GJ/(ha*a)

source: (4)

#### Efficiency figure:

The efficiency is defined as net energy output divided by the gross energy input. It results in 53 % for the production from ethanol from cereals, following 4.

The calorific value of the bio-ethanol is 27 MJ/l.

### Description of the finding of some qualitative evaluations

Hazardousness: Ethanol is significantly less toxic than methanol. The handling of ethanol is relatively easy (not especially toxic or explosive).

<b>Quantitative assessment of the module for the present state</b>	
<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	24-30
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	approx. 45
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.53
GJ output energy per GJ of all input energies	data not available

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market				x	
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique				x	
output standardisation				x	

<b>No.:</b>	C2-F4	<b>Ethanol from Potatoes</b>
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class	2	input from:	Modules C1-P12
category	Fermentation	output to:	Modules C3-T2

### General description of the process

Ethanol is a clear, uncoloured liquidity. Ethanol from biomass is referred to as "bio-ethyl-alcohol". In some countries, it is already common as fuel under the name "Gasohol". Ethanol can be mixed with petrol with a share of 10-85 %. Ethanol is produced of vegetable raw materials in a process of fermentation and distillation.

- The **fermentation** describes the process of the transformation of the glucose, which is contained in the input materials, to ethanol and carbon dioxide via yeast enzyme.
- Afterwards, the solvent **is distilled** and with it the ethanol concentrated. 96 % ethanol and 4 % water is the max. achievable concentration. The remaining water can be detracted via chemical substances. A concentration level of 100 % can be accomplished.

For the production of alcohol from potatoes, it can be assumed that the size of the manufacture plant is comparable to the sugar beet plant. Hence, the same distillation procedure is used. The difference to the production of bioethanol from sugar beets or wheat is that the mash can be led back only in few amounts (approximately 15 %) because of procedural cause. The mash comprised a high concentration of water. Therefore, an evaporation of the mash is not suggestive presently because of energy reasons.

41.2 kWh/t potatoes and 0.2455 kWh/kg pure alcohol are needed for the different processing levels (mashing, fermentation, distillation, wash water treatment, mash evaporation). 82.1 kg respectively 104.6 litre pure alcohol can be produced per 1 ton potatoes by a starchy content of 17 %. This is equivalent to a maximum possible crop of ethanol of 85 %. The ratio between mash and pure alcohol is supposed with 1 litre mash per 1 litre pure alcohol.

Pure ethanol melts at -114°C, boils at 78°C and has a relative density of 0.79 at 20°C. The energy content is comparable with petrol. The possible use of ethanol is similar to the use of fossil fuels.

### Regional specifications in the EU

The production of bioethanol from potatoes in the EU-15 is unknown. Only in Latvia, grain, potato and sugar beet can be used for the bioethanol production

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

See page Ethanol from sugar beet

### Internal and external resources

- (1) KALTSCHMITT, M.; REINHARDT, G.: *Nachwachsende Energieträger – Grundlagen, Verfahren, ökologische Bilanzierung*, 2001
- (2) Information from the FEDERAL STATISTICAL OFFICE, Germany
- (3) FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF) (ED.), Germany: *Nachwachsende Rohstoffe*, 1990
- (4) ROESCH, C.: *Monitoring "nachwachsende Rohstoffe", Pflanzliche Öle und andere Kraftstoffe aus Pflanzen, Dritter Sachstandsbericht, TAB Arbeitsbericht Nr. 53*, 1997
- (5) UNITED NATIONS UNIVERSITY, INSTITUTE OF ADVANCED STUDIES: *Integrated bio-system for biofuel production from agricultural raw materials in Latvia*, (writer: Bekers, M.; Viesturs, U.),

**Description of the calculation to obtain the quantitative figures**

**Economy figure:**

According to source (5) production costs of bioethanol from potatoe are 0,50 €/l. These costs are based on a EC analysis, discussed during the 10<sup>th</sup> European Conference an Technology Exhibition held on 8-11 June 1998 in Wurchburg.

**Ecology figure:**

personal communication of T. Kahl (IE).

**Efficiency figure:**

Following (4), 10 t of potatoes are needed to produce 1 t of bio-ethanol.

**Description of the finding of some qualitative evaluations**

Hazardousness: Ethanol is significantly less toxic than methanol. The handling of ethanol is relatively easy (not especially toxic or explosive).

**Quantitative assessment of the module for the present state**

<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	6.82
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	60
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.93
GJ output energy per GJ of all input energies	data not available

**Qualitative assessment of the module for the present state**

	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market			x		
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique				x	
output standardisation					

<b>No.:</b>	C2-F5	<b>Ethanol from Wood or Straw</b>
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class	2	input from:	Modules C1-P9, C1-P10, C1-R1, C1-R2, C1-R8
category	Fermentation	output to:	Modules C3-T2

### General description of the process

The production of ethanol from biomass results from micro-biological conversion, i.e. fermentation of a sugary solvents by yeast (*Saccharomyces cerevisiae*) or via bacteria (*Zymomonas mobilis*).

The production of bio-ethanol from wood and straw are difficult from the procedural point of view because of cellulose and hemicellulose, that is synthesised by glucose units, have a crystalline structure. These structures complicates the inward flow of enzymes or sour catalysts. Furthermore, these structures are protected by the lignin.

At the moment, the conversion of Ligno-cellulose is fundamentally possible by two different processes.

The acid decomposition is already examined since the beginning of the 20<sup>th</sup> century and was used in times of crises. However, this process has only small chances in future because of its technical problems, inefficiency and environmental incompatibility.

The encymical hydrolysis decomposition was already tested in pilot plants in France, Austria, Japan, Canada and in the USA concerning its technical applicability. A large-scale technical proving regarding its economical viewpoints is still not made to date.

The cracked sugar is converted by yeast in the continued process (metabolism) to bio-ethanol and carbon dioxide:



The resulting liquidity or mash contains in average 5-12 % bio-ethanol. The growth of the biological yeast population decelerates by a higher concentration of alcohol and they would die as consequence of it. The fermentation process is closed after 35-50 hours.

The conversion to the product bio-ethanol processes more continuous by the use of bacteria and is closed after 20 hours. However, the use of bacteria requires a totally sterile mode of operation.

The separated share of the bio-ethanol is concentrated to up to 97 vol. % by distillation. The required purification of 99.8 vol. % is achievable with the help of the molecular-screen-distillation or by the use of Cyclohexan as an entrainer.

Pure ethanol melts at -114°C, boils at 78°C and has a relative density of 0.79 at 20°C. The energy content is comparable with petrol. The possible use of ethanol is similar to the use of conventional fuels.

### Regional specifications in the EU

The Nordic countries Norway, Sweden and Finland there are vast wood resources from the forests that can form the basis for production of ethanol. Such production is taking place today as a by-product of wood-processing. In all three countries several studies have shown that available wood resources are large enough to produce 100 motor-alcohol for the whole transport sector without limiting other users of wood resources or weakening environmental limits. Sweden is most active in the development of ethanol production from woody biomass.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

In Sweden the largest barrier to the spreading of bioethanol blends of fuels is the abovementioned Directive, which has been interpreted in Swedish environmental law such that petrol mixed with 5 to 30% ethanol cannot be sold as normal petrol. Sweden, alone in Europe, has persuaded national car producers to guarantee that their cars can adapt to 10 to 20 percent blends of ethanol. These blends are of course higher than those permitted by the Swedish law and cannot therefore be used.

### Internal and external resources

- (1) FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF) (ED.), Germany: *Nachwachsende Rohstoffe*, 1990
- (2) ROESCH, C.: *Monitoring "nachwachsende Rohstoffe"*, *Pflanzliche Öle und andere Kraftstoffe aus Pflanzen*, Dritter Sachstandsbericht, TAB Arbeitsbericht Nr. 53, 1997
- (3) JONK, G.: European Environmental Bureau (EEB) background paper 18-03-2002, *On the use of biofuels for transport*
- (4) EUROPEAN PARLIAMENT: Briefing Note N° 07/2001, *Bioethanol added to fuel*

### Description of the calculation to obtain the quantitative figures

**Economy figure:** data not available

**Ecology figure:** data not available

**Efficiency figure:** data not available

### Description of the finding of some qualitative evaluations

Hazardousness: Ethanol is significantly less toxic than methanol. The handling of ethanol is relatively easy (not especially toxic or explosive).

### Qualitative assessment of the module for the present state

	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market		x			
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique					
output standardisation					

<b>No.:</b>	<b>C2-F7</b>	<b>Biogas from Animal Excrements or Non-woody Plants</b>
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class	2	input from:	Modules C1-P8, C1-R4, C1-R6
category	Fermentation	output to:	Modules C2-E3, C2-S3

### General description of the process

Digestion plants were first built for waste water treatment. Towards the end of the second world war when the fuel was limited, anaerobic digestion became popular. Half of the gas was utilised to run vehicles. The major design criteria for agricultural biogas plants depends on the mode of feeding and the substrate characteristics (dry matter or suspend solids etc.) To digest Substrates with more than 15 % of solid concentration a discontinuously batch –system is used. Here the plant is fed once and after three or four weeks it is emptied. The predominant waste material in agricultural digestion is animal waste (manure and / or slurry with total solid concentrations between 6 and 12 %) It is co-digested with energy crops and harvest remains for instance. So the most applied digester system is the continuous-flow tank reactor. The raw material is pumped regularly into a digester, displacing an equal volume of digested material.

An agricultural biogas plant is usually built up of the following elements. First there is a pre-treatment tank for buffering, size reduction and premixing the manure and the other agricultural feedstocks. Nearby there is the digester which is feeded from the pre-treatment tank semi-continuously (from once or twice a day to intervals less than one hour) by pumps. The digester itself is a gas-tight tank which is most made out of concrete or steel. It is insulated because there must be a fixed optimal temperature inside. The predominant types of Digestion are the so called mesophillic digestion (with about 35 °C) and the thermophillic digestion (with about 55 °C). Inside the digester there is a stirrer. This stirrer is responsible for complete mixing the digesters contents. The major reasons for mixing are: distribution of heat to achieve an even temperature through out the digester and avoiding or disrupt of swimming layers and/or sedimentation. The average hydraulic retention time (HRT) is (depending on substrates) between 20 and 40 days. The anaerobic degradation occurs in three basic steps as an result of the activity of a variety (at least for different groups) of microorganisms (2), (3).

The first step is the hydrolysis. The animal or plant matter is decomposed by exo-enzymes to soluble and usual-sized molecules (such as sugar) which are taken up by the bacteria. In the second step (fermentation) the products of the hydrolysis are converted by fermentative bacteria into acids. In the third step (methane formation) the acids are converted to methane gas. Further methane is also formed from hydrogen and CO<sub>2</sub> by methanogenic bacteria. The major components of the resulting biogas are: methane (CH<sub>4</sub> from 50 to 70 %, carbon dioxide (CO<sub>2</sub> from 25 to 40 %) and 0 to 5 % of various other gases such as sulphuric acid (H<sub>2</sub>S) (2), (3), (5).

After drying and cleaning the gas it is stored in a gas holder. From the gas-holder there is a continuously supply to a gas or diesel gas engine. Here heat and electricity is produced. The second output of the process is the digested substrate. It is stored in a normal manure storage tank before it will be used as a fertiliser.

### Regional specifications in the EU

Most countries are interested in using biogas for combined heat- and power (CHP) production to increase the supply with green electricity. In Sweden there is a strong interest in using biogas as a vehicle fuel, due the relative low prices on electricity and heat. In countries such as Germany, Denmark and Austria, the investors in anaerobic technology receive investment subsidies, a higher sale price for electricity and reduced interest of bank loans. In Italy, the Netherlands and the UK there are also federal and regional programmes to develop and to support renewable energies including biogas. In Belgium, Greece, Ireland and Portugal there are no special rules regarding legislation, guidelines, stan-

dards policies and fiscal actions.

Another problem in many countries is a lack of appropriate legislation regarding the limit values of heavy metals in digested materials. Therefore regulations such as waste, nitrate, fertiliser and sewage sludge directives have a potential impact on the use of digestate as organic fertiliser. Further there are different legislations regarding the nutrient (nitrogen) load on farmland and the storage capacities of digestate. The concern for human and animal welfare has led some countries to legislate on pathogen control. (1), (5)

### **Foreseeable intermediate (5-10 years) and long-term (25-30 years) development**

In a recent survey undertaken by ALTENER Energy from waste Network (EfW), the total amount of agricultural waste in the 15 EU countries was estimated. A result was, that even in "developed" countries such as Germany and Austria only a minor part (0.5 to 3 %) of this huge amount is currently treated in agricultural anaerobic digesters. Probably improved and uniform programmes for investment subsidies and an EU-wide electricity feed law is able to double the share of energy producing by biogas plants in the next 15 years (1).

### **Internal and external resources**

(1) NORDBERG, A.: Legislation in different European countries regarding implementation of anaerobic digestion, AD-Nett, Technical Paper 33 p, 1999

(2) STEFFEN, R.; SZOLAR, O.; BRAUN, R.: Feedstocks for anaerobic digestion, AD Nett Technical Paper 21, 1999

(3) WELLINGER, A.: Process design of agricultural digesters, 1999

(4) KLINGER, B.: German Biogas Association, Environmental aspects of Biogas technology, 1998

(5) THE ANAEROBIC DIGESTION NETWORK (<http://www.ad-nett.org>)

### **Description of the calculation to obtain the quantitative figures**

#### **Economy figure:**

On average a biogas plant in Germany has an electrical export capacity of 100 kW. This is what approximately 700 cows (700 livestock units) demand. One cow produces approximately 50 kg manure a day.

$$V_{\text{manure}} = 700 \times 50 \text{ kg/d} = 35 \text{ t/d} / \text{nearly } 35 \text{ m}^3 / \text{d}.$$

Biogas yield =  $12.775 \text{ m}^3 \text{ manure} / \text{a} \times 28 \text{ m}^3 \text{ biogas} = 357.700 \text{ m}^3 \text{ biogas} / \text{a}$  The using of several co-ferments could double the yield.

The capital, the operating and maintenance costs are based on averages from agricultural biogas plants in Germany (only manure is digested) For this example it could be assumed with 70 k€ / a.

On average 1 livestock unit or 0.1 ha energy crop demands 0.15 kW of electrical export capacity. The full capacity of the CHP- unit is estimated nearly 7500 hours a year.

Approximately 40 % (10 % electricity and 30 % heat) of the produced energy is needed for the process itself. Electricity can be sold to the nearest public utility company – in Germany according with the so-called Renewable Energy Law. The use of the rest of the heat is varying because of the different requirements on the farms. Therefore a credit for the heat is not considered.

The costs per kW electrical export capacity in Germany is about 2000 € to 4000 €. Because the most farms use their own slurry, manure and agricultural remain there is no need for transportation. Growing, harvesting and storage of energy plants causes approximately 35 € / ha. Selling or using the di-

gested materials (fertiliser) obtains approximately 80 € / ha. Operating the biogas plant takes approximately 2 hours a day.

The economics of biogas plants could be further improved if the environmental benefits of the plants were costed. For example a plant can contribute to reduce greenhouse gas emissions, reduced water and odour pollution.

**Ecology figure:**

Building a biogas plant for 50 livestock units causes CO<sub>2</sub> emissions of 85,000 kg. The emission of CO<sub>2</sub>- equivalents (including other gases which cause global warming) amount 92,000 kg. Based on 20 years the plant works, in this time 700 livestock units (see description above) produce about 7.154 million m<sup>3</sup> biogas. Building a plant for 700 livestock units causes 1,190 tons of CO<sub>2</sub> emissions.

Methane emissions occur in any anaerobic processes with organic materials. It has been estimated that methane emissions from agriculture contribute 33 % to the global greenhouse effect. About 7 % result from animal excrement which is similar 20-30 million tons of methane per year.

Through anaerobic treatment of animal excrement a renewable energy is generated, which has an important dual climatic effect. The use of biogas reduces the CO<sub>2</sub>- emissions through a reduction of the demand of fossil fuel (1 m<sup>3</sup> biogas substitutes 0.5 kg oil and reduces 2.6 kg CO<sub>2</sub>-emissions). At the same time the process reduces uncontrolled methane generation by capturing methane. Through an implementation of biogas technology about half of the methane emissions could be reduced. Very few detailed information are available about the reduction potential of nitrous oxides. Considering all the effects of the anaerobic digestion of animal waste an N<sub>2</sub>O-reduction potential of about 10 % could be assumed.(4)

**Efficiency figure:**

The gas production from the manure and / or slurry, agricultural remain and energy crops varies from 28 Nm<sup>3</sup> biogas / m<sup>3</sup> cattle manure and 36 Nm<sup>3</sup> / m<sup>3</sup> pig manure to 400 Nm<sup>3</sup> / t corn-cob-mix.

The net calorific value of biogas with 65 % methane is about 6,5 kWh / Nm<sup>3</sup>. An electric efficiency of 30 % and a total efficiency of 90%(CHP) means, that from 1 Nm<sup>3</sup> Biogas can be produced 1,95 kWh<sub>el.</sub> and 3,9 kWh<sub>heat.</sub> Nearly 25 % (15 % electricity; 85 % heat) of the produced energy is needed for the maintenance of the process.

**Description of the finding of some qualitative evaluations**

Based on literature (see "Internal and external resources")

Output standardisation: The methane content of the resulting biogas depends on the input composition and other factors. The use for other purposes than burning (electricity production) needs an upgrading.

<b>Quantitative assessment of the module for the present state</b>		
<b>Output unit:</b>	m <sup>3</sup> Biogas	GJ
<b>Economy:</b>		
costs (€) per output unit	0,035 to 0,15	1,5 to 6,4
<b>Ecology:</b>		
emission of CO <sub>2</sub> (kg) per output unit	0,17	7,3
<b>Efficiency:</b>		
GJ output energy per GJ input energy carrier	1,0	
GJ output energy per GJ of all input energies	0,75	

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space			x		
<b>Availability</b>					
readiness for market				x	
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique			x		
output standardisation		x			

<b>No.:</b>	C2-F8	<b>Biogas from Organic Commercial and Household Waste (incl. Pretreatment)</b>
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class	2	input from:	Modules C1-R5, C1-R7
category	Fermentation	output to:	Modules C2-E3, C2-S3

<b>General description of the process</b>
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Digestion plants were first built for waste water treatment. Towards the end of the second world war when the fuel was limited, anaerobic digestion became popular. Half of the gas was utilised to run vehicles. The major design criteria for biogas plants depends on the mode of feeding and the substrate characteristics (dry matter or suspend solids etc.) To digest substrates with more than 15 % of solid concentration a discontinuously batch –system is used. Here the plant is fed once and after three or four weeks it is emptied. The predominant waste materials in industrial digestion-plants are Biowaste, separately collected in households, fats, market wastes, residues from food industry and similar substances which are delivered by trucks. Manure sometimes is delivered from surrounding farms and it is used as basic material. The deliveries are often made in closed halls to reduce odour emissions.

The most applied digester system is the continuous-flow tank reactor. Digesting materials with more than 15 % dry matter share (so called dry fermentation) is usual too. Industrial plants compared to agricultural plants are built in larger scales. The most solid waste streams require sorting and crushing (Shredder). Because of faulty collection there are some plastics, batteries, stones etc. included. Sorting can be done either manually or/and mechanically. Further there is a need for hygienisation. It is most performed at 70°C for one hour with a max. particle size of 1 cm. Hygienisation is connected with the pre-treatment tank for buffering, size reduction and premixing the waste. Nearby there is the digester which is feeded from the pre-treatment tank semi-continuously (from once or twice a day to intervals less than one hour) by pumps. The digester itself is a gas-tight tank which is most made out of concrete or steel. It is insulated because there must be a fixed optimal temperature inside. The predominant types of digestion are the so called mesophillic digestion (with about 35 °C) and the thermophillic digestion (with about 55 °C). Inside the digester there is a stirrer. This stirrer is responsible for complete mixing the digesters contents. The major reasons for mixing are: distribution of heat to achieve an even temperature through out the digester and avoiding or disrupt of swimming layers and/or sedimentation. The average hydraulic retention time (HRT) is (depending on substrates) between 30 and 50 days. The anaerobic degradation occurs in three basic steps as an result of the activity of a variety (at least for different groups) of microorganisms.

The first step is the hydrolysis. The organic matter is decomposed by exoenzymes to soluble and usual-sized molecules (such as sugar) which are taken up by the bacteria. In the second step (fermentation) the products of the hydrolysis are converted by fermentative bacteria into acids. In the third step (methane formation) the acids are converted to methane gas. Further methane is also formed from hydrogen and CO<sub>2</sub> by methanogenic bacteria. The major components of the resulting biogas are: methane (CH<sub>4</sub> from 50 to 70 %, carbon dioxide (CO<sub>2</sub> from 25 to 40 %) and 0 to 5 % of various other gases such as sulphuric acid (H<sub>2</sub>S) (5), (6), (9).

After drying and cleaning the gas it is stored in a gas holder. From the gas-holder there is a continuously supply to a gas or diesel gas engine. Here heat and electricity is produced. The second output of the process is the digested substrate. Before storing the digestate is screened. A part of the output is treated by a sludge press and the reject is brought to landfill. Solid liquid separation is usually applied when part of the digestate has to be transported in combination to reduce the volume The rest is stored in a storage tank before it will be used as a fertilizer (3).

### Regional specifications in the EU

Most countries are interested in using biogas for combined heat- and power (CHP) production to increase the supply with green electricity. In Sweden there is a strong interest in using biogas as a vehicle fuel, due the relative low prices on electricity and heat. In countries such as Germany, Denmark and Austria, the investors in anaerobic technology receive investment subsidies, a higher sale price for electricity and reduced interest of bank loans. In Italy, the Netherlands and the UK there are also federal and regional programmes to develop and to support renewable energies including biogas. In Belgium, Greece, Ireland and Portugal there are no special rules regarding legislation, guidelines, standards policies and fiscal actions.

Another problem in many countries is a lack of appropriate legislation regarding the limit values of heavy metals in digested materials. Therefore regulations such as waste, nitrate, fertiliser and sewage sludge directives have a potential impact on the use of digestate as organic fertiliser. Further there are different legislations regarding the nutrient (nitrogen) load on farmland and the storage capacities of digestate. The concern for human and animal welfare has led some countries to legislate on pathogen control (1), (4), (9).

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

Even in "developed" countries such as Germany and Austria only a minor part (0.5 to 3 %) of the huge amount of organic waste is currently treated in anaerobic digesters. In accordance with the EU-directive on landfilling, there will be a ban on landfilling organic waste by the year 2005. So the quantity of potential materials for digesting will increase. Probably improved and uniform programmes for investment subsidies and an EU-wide electricity feed law is able to double the share of energy producing by biogas plants in the next 15 years (4).

### Internal and external resources

(1) EUROPEAN UNION (ED.): Energy for the future: Renewable sources of energy: White paper COM (1997)

(2) HIGHMAN, I.: Economics of anaerobic digestion of agricultural waste. AEA Technology Environment, 1998

(3) COLERAN, E.: Hygienic and sanitation requirements in biogas plants treating animal manures or mixtures of manures and other organic wastes, AD-Nett, Technical paper , 13 p, 1999

(4) NORDBERG, A.: Legislation in different European countries regarding implementation of anaerobic digestion. AD-Nett, Technical Paper 33 p, 1999

(5) STEFFEN, R.; SZOLAR, O.; BRAUN, R.: Feedstocks for anaerobic digestion. AD-Nett Technical Paper 21, 1999

(6) WELLINGER , A.: Process design of agricultural digesters; AD-Nett Technical Paper, 1999

(7) KLINGER, B.: German Biogas Association, Environmental aspects of Biogas technology, 1998

(8) FOLKECENTER FOR RENEWABLE ENERGY, DENMARK (<http://www.folkecenter.dk>)

(9) THE ANAEROBIC DIGESTION NETWORK (<http://www.ad-nett.org>)

### Description of the calculation to obtain the quantitative figures

#### Economy figure:

On average a industrial biogas plant in Germany has an electrical export capacity of 500 to 600 kW. This is what approximately 25,000 t/a different organic wastes demand. The costs per kW electrical export capacity in Germany is about 3500 € (large plants) to 5000 € . Depending on the origin and the quality of the input material, the gas production from organic wastes varies from 60 Nm<sup>3</sup> to 600 Nm<sup>3</sup> biogas per ton. For example:  $m_{\text{waste}} = 25,000 \text{ t/a} \times 100 \text{ Nm}^3 \text{ biogas per ton (waste)} = 2.5 \text{ Million Nm}^3$

biogas / a.

The full capacity of the CHP- unit is estimated nearly 7500 hours a year. Almost 50 % (10 % electricity and 40 % heat) of the produced energy is needed for the process itself.

The operator of an industrial or a cofermentation plant increases his earnings in two ways: first, just by taking the coferments from people who want to dispose them and second, through higher biogas production. The prices for purchasing the coferments (wastes) varies from 0 € to 75 € per ton. For all the wastes there is a need for transportation to the biogas plant. To use the full capacity of the plant continuously the wastes are transported up to distances of 400 km and more.

The capital, the operating and maintenance costs are based on averages from biogas plants in Germany. For the example it could be assumed with 300 k€ / a.

The economics of biogas plants could be further improved if the environmental benefits of the plants were costs. For example a plant can contribute to reduce greenhouse gas emissions, reduced water and odour pollution (2).

#### **Ecology figure:**

CO<sub>2</sub> emissions especially for industrial biogas plants are not available. It is assumed that the emissions are similar to the agricultural plants (see module C2-F6).

Methane emissions occur in any anaerobic processes with organic materials. It has been estimated that methane emissions from agriculture contribute 33 % to the global greenhouse effect. About 7 % result from animal excrement which is similar to 20-30 million tons of methane per year.

Through anaerobic treatment of animal excrement a renewable energy is generated, which has an important dual climatic effect. The use of biogas reduces the CO<sub>2</sub>- emissions through a reduction of the demand of fossil fuel (1 m<sup>3</sup> biogas substitutes 0.5 kg oil and reduces 2.6 kg CO<sub>2</sub>-emissions: At the same time the process reduces uncontrolled methane generation by capturing methane. Through an implementation of biogas technology about half of the methane emissions could be reduced. Very few detailed information are available about the reduction potential of nitrous oxides. Considering all the effects of the anaerobic digestion of animal waste a N<sub>2</sub>O-reduction potential of about 10 % could be assumed (7).

#### **Efficiency figure:**

The gas production from organic commercial and household waste varies from 82 Nm<sup>3</sup> biogas / ton (yeast remains from Breweries) to almost 1.000 Nm<sup>3</sup> biogas / ton (fat and flotation slurry from slaughterhouses) (8).

The net calorific value of biogas with 65 % methane is about 6,5 kWh / Nm<sup>3</sup> biogas. An electric efficiency of 30 % and a total efficiency of 90%(CHP) means, that from 1 Nm<sup>3</sup> Biogas can be produced 1,95 kWh<sub>el.</sub> and 3,9 kWh<sub>heat.</sub> Nearly 25 % (15 % electricity; 85 % heat) of the produced energy is needed for the maintenance of the process.

### **Description of the finding of some qualitative evaluations**

Based on literature (see internal and external resources).

Output standardisation: The methane content of the resulting biogas depends on the input composition and other factors. The use for other purposes than burning (electricity production) needs an upgrading.

Quantitative assessment of the module for the present state		
<b>Output unit:</b>	m <sup>3</sup> Biogas	GJ
<b>Economy:</b>		
costs (€) per output unit	0,035 to 0,15	1,5 to 6,4
<b>Ecology:</b>		
emission of CO <sub>2</sub> (kg) per output unit	0,17	7,3
<b>Efficiency:</b>		
GJ output energy per GJ input energy carrier	1,0	
GJ output energy per GJ of all input energies	0,75	

Qualitative assessment of the module for the present state					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space			x		
<b>Availability</b>					
readiness for market				x	
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique			x		
output standardisation		x			

<b>No.:</b>	C2-E1	<b>Combustion of Wood for Electricity Generation</b>
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class	2	input from:	Modules C1-P9, C1-P10, C1-R2, C1-R8
category	Electricity from Biomass	output to:	Modules C3-E1

### General description of the process

Wood is transported from collection points to power-plants. A pretreatment is necessary to generate small wood chips. The wood is burned in the power-plant, where water is evaporated. The produced steam is generating electricity in a turbine.

Burning wood for producing electricity is the most spread form to use wood as an energy source.

Economic and ecological frame conditions are fixed in dependence on German law demands (BiomasseV and EEG).

Maximum size of new biomass-power-plants are 20 MWel (example for Germany / corresponding to German law demands).

### Regional specifications in the EU

The technology has no relevant regional specifications.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

For this well approved technology, no significant technological changes are assumed.

### Internal and external resources

#### Information from web pages:

- (1) INSTITUTE FOR ENERGY ECONOMICS AND THE USE OF ENERGY (IER), Biomass Information Centre (BIZ) ([www.biomasse-info.net](http://www.biomasse-info.net))
- (2) FACHAGENTUR NACHWACHSENDE ROHSTOFFE E.V. ([www.fnr.de](http://www.fnr.de))
- (3) BUNDESINITIATIVE BIOENERGIE E.V. ([www.bioenergie.de](http://www.bioenergie.de))
- (4) CENTRALES AGRAR-ROHSTOFF-MARKETING- UND ENTWICKLUNGSNETZWERK E.V., (C.A.R.M.E.N E.V.) ([www.carmen-ev.de](http://www.carmen-ev.de))
- (5) INFORMATIONSDIENST DES FACHINFORMATIONSZENTRUMS KARLSRUHE GMBH (<http://bine.fiz-karlsruhe.de/>)
- (6) FEDERAL MINISTRY OF CONSUMER PROTECTION, FOOD AND AGRICULTURE (BMVEL) (ED.), Germany ([www.verbraucherministerium.de](http://www.verbraucherministerium.de))
- (7) FEDERAL ENVIRONMENTAL MINISTRY (BMU) (ED.), GERMANY ([www.bmu.de](http://www.bmu.de))
- (8) INTERNATIONAL ECONOMIC FORUM RENEWABLE ENERGIES (IWR) ([www.iwr.de](http://www.iwr.de))

### Description of the calculation to obtain the quantitative figures

#### **Ecology figure:**

Only transportation and pretreatment are relevant for CO<sub>2</sub>-emission. The CO<sub>2</sub>-emission of the burned wood is not taken into account because the regenerative source fixes the same amount of CO<sub>2</sub>. If wood is not burned but put into the forest for decomposition, the same amount of CO<sub>2</sub> will be set free.

For the transportation, an average transport distance of 50 km is assumed. This leads to an CO<sub>2</sub>-output of 7.23 kg CO<sub>2</sub> per ton of wood. Each ton of wood corresponds to the electricity production of 1 MWh, so these values can be transferred to the output unit "MWh".

For the pretreatment, the CO<sub>2</sub>-output is 3.13 kg per ton of typical (not dried) wood

**Efficiency figure:**

The electricity necessary for the fan is taken from the produced electricity and influences that way the efficiency. The efficiency depends mainly on the plant size. 25 % is a typical value for a 10-MW-power plant, smaller plants have far lower efficiencies (sometimes only 8 %). In Sweden, large plants reach efficiencies of more than 30 %.

<b>Description of the finding of some qualitative evaluations</b>

<b>Quantitative assessment of the module for the present state</b>		
<b>Output unit:</b>	MWh	GJ
<b>Economy:</b>		
costs (€) per output unit	86.1 – 101.2 €	310 – 364 €
<b>Ecology:</b>		
emission of CO <sub>2</sub> (kg) per output unit	10,37 kg/MWh	37,3 kg/GJ
<b>Efficiency:</b>		
GJ output energy per GJ input energy carrier	0.25	0.25
GJ output energy per GJ of all input energies		

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market					x
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique			x		
output standardisation					x

<b>No.:</b>	C2-E2	<b>Combustion of Straw for Electricity Generation</b>
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class	2	input from:	Modules C1-R1
category	Electricity from Biomass	output to:	Modules C3-E1

<b>General description of the process</b>	
<p>Straw is transported from the farms to power-plants.</p> <p>The straw is burned in the power-plant, where water is evaporated.</p> <p>The produced steam is generating electricity in a turbine.</p> <p>Economic and ecological frame conditions are fixed in dependence on German law demands (BiomasseV and EEG).</p> <p>Maximum size of new biomass-power-plants are 20 MWel (example for Germany / corresponding to German law demands).</p>	
<b>Regional specifications in the EU</b>	
<p>Today, commercial straw-based power plants exist only in Denmark.</p>	
<b>Foreseeable intermediate (5-10 years) and long-term (25-30 years) development</b>	
<p>n/a</p>	
<b>Internal and external resources</b>	
<p>n/a</p>	

<b>Description of the calculation to obtain the quantitative figures</b>	
<p><b>Economy figure:</b></p> <p>Burning straw leads to about 10 % higher costs than burning wood. This has technical reasons but includes also a higher transportation demand because the lower calorific value of straw is lower than of wood.</p> <p><b>Ecology figure:</b></p> <p>The CO<sub>2</sub>-emission per GJ electricity output is approximately the same as in the C1-E1 module: Transport needs more energy, but pretreatment is easier.</p> <p><b>Efficiency figure:</b></p> <p>The efficiency per MJ input energy is approximately the same as for wood burning.</p>	
<b>Description of the finding of some qualitative evaluations</b>	
<p>n/a</p>	

<b>Quantitative assessment of the module for the present state</b>	
<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	370 €/GJ
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	37 kg/GJ
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.25
GJ output energy per GJ of all input energies	

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market					
<b>Other indicators</b>					
hazardousness (health risk)				x	
complexity of technique			x		
output standardisation					x

<b>No.:</b>	<b>C2-E3</b>	<b>Combustion of Biogas for Electricity Generation</b>
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class	2	input from:	Modules C2-F7, C2-F8
category	Electricity from Biomass	output to:	Modules C3-E1

<b>General description of the process</b>	
<p>Combined heat and power plants (CHP) represent a approved and field-tested technology. For producing electricity and heat in a CHP biogas can be used alike natural gas, diesel fuel etc.. A CHP is an installation where there is simultaneous generation of usable heat and power (usually electricity) in a single process. The basic elements of a CHP plant comprise one or more prime movers usually driving electrical generators, where the heat generated in the process is utilised via suitable heat recovery equipment for a variety of purposes including: industrial processes, community heating and space heating. CHP can provide a secure and highly efficient method of generating electricity and heat at the point of use. Due to the utilisation of heat from electricity generation and the avoidance of transmission losses because electricity is generated on site. CHP typically achieves a 35 per cent reduction in primary energy usage compared with power stations and heat only boilers. This can allow the host organisation to make economic savings where there is a suitable balance between the heat and power loads (1), (2), (3).</p>	
<b>Regional specifications in the EU</b>	
The technology has no relevant regional specifications.	
<b>Foreseeable intermediate (5-10 years) and long-term (25-30 years) development</b>	
<p>CHP is considered as a tool for the EU in order to achieve its energy policy objective of improving energy efficiency and its environmental objective of reducing greenhouse gas emissions. The European Commission estimates that doubling the amount of CHP electricity in the EU will result in CO<sub>2</sub> reductions corresponding to half those to which the EU has committed itself. Increasing the use of District Heating is and will be an essential factor for going from the present CHP generated electricity of the total EU electricity market to 18% (4).</p> <p>In 1994 the electricity generation by CHP plants was 204 TWh (9 % of the total electricity generation). According to analysis, a doubling of the share of CHP from 9 % to 18 % of the total gross electricity generation of the Community produced by CHP by the year 2010, is realistically achievable. The environmental benefits of this would be significant. A rough estimate indicates that if a doubling of CHP share was achieved, it could reduce CO<sub>2</sub> emissions by 150 megaton per year or approx. 4 % of the total EU CO<sub>2</sub> emissions in 2010. In 1998 district heating is supplied to 22 million people in the EU, or 6 % of its population (4), (5).</p>	

<b>Internal and external resources</b>
<p>(1) Blockheizkraftwerke '99. Technik und Entwicklung, Wirtschaftlichkeit, Betriebserfahrung, VDI-Gesellschaft Energietechnik, 1999</p> <p>(2) SUTOR, W.: Praxis Kraft-Wärme-Kopplung, Verlag C.F. Müller, Karlsruhe</p> <p>(3) BHKW Kenndaten 2001, Module– Anbieter- Kosten, ASUE e. V. Kaiserslautern, 2001</p> <p>(4) NORDBERG, A.: Legislation in different European countries regarding implementation of anaerobic digestion. AD-Nett, 1999</p> <p><u>Information from web pages:</u></p> <p>(5) FOLKECENTER FOR RENEWABLE ENERGY, DENMARK (<a href="http://www.folkecenter.dk">http://www.folkecenter.dk</a>)</p> <p>(6) EUROPEAN COMMUNITY, SAVE II PROGRAMME, Combined heat and power (<a href="http://www.chp-info.org/techniques">http://www.chp-info.org/techniques</a>)</p>
<b>Description of the calculation to obtain the quantitative figures</b>
<p><b>Economy figure:</b></p> <p>In a year a CHP unit with an electrical export capacity of 160 kW produces (7500 h / a) about 1,2 million KWh (4.320 GJ). The CHP causes operating costs (maintenance, depreciation, insurance etc.) of approximately 54.000 € a year.</p> <p><b>Ecology figure:</b></p> <p>Building a CHP unit with an electrical export capacity of 160 kW causes about 100 tons of CO<sub>2</sub> emission and about 600 MWh energy is needed.</p> <p>The current mix of CHP installations achieves a reduction of over 30 per cent in CO<sub>2</sub> emissions in comparison with generation from coal-fired power stations, and over 10 per cent in comparison with gas fired combined cycle gas turbines. The newest installations achieve a reduction of over 50 per cent compared with generation from coal-fired power stations (6).</p> <p><b>Efficiency figure:</b></p> <p>The net calorific value of biogas with 65 % methane is about 6,5 kWh / Nm<sup>3</sup>. An electric efficiency of 30 % and a total efficiency of 90%(CHP) means, that from 1 Nm<sup>3</sup> Biogas can be produced 1,95 kWh<sub>el</sub>. Electricity and 3,9 kWh<sub>heat</sub> heat.</p>
<b>Description of the finding of some qualitative evaluations</b>
<p>Based on literature (see "Internal and external resources").</p>

<b>Quantitative assessment of the module for the present state</b>		
<b>Output unit:</b>	MWh	GJ
<b>Economy:</b>		
costs (€) per output unit	45	12,5
<b>Ecology:</b>		
emission of CO <sub>2</sub> (kg) per output unit	16	4,4
<b>Efficiency:</b>		
GJ output energy per GJ input energy carrier	0.30	
GJ output energy per GJ of all input energies	0.30	

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space				x	
<b>Availability</b>					
readiness for market					x
<b>Other indicators</b>					
hazardousness (health risk)			x		
complexity of technique				x	
output standardisation				x	

<b>No.:</b>	C2-H1	<b>Hydrogen from Electrolysis</b>
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class	2	input from:	Modules C1-E1, C1-E2, C1-E3, C1-E4, C1-E5, C2-E1, C2-E2, C2-E3
category	Production of Hydrogen	output to:	Modules C2-S4, C3-T7, C3-P1

### General description of the process

Hydrogen (H<sub>2</sub>) is a reactive, colourless, odourless and unflavoured gas. It can be produced by numerous different processes. The production of hydrogen is possible from fossil fuels like natural gas or coal. Equally, the hydrogen production is possible by biological sources like biomass or by water via electrical current (electrolysis).

Hydrogen can be produced from water by the electrolysis and the use of electrical energy. The handling of hydrogen is difficult because of several reasons. An economy of scale is not possible before all technical barriers are solved.

To date and in foreseeable time, the electrolysis is the procedure for the production of hydrogen from water that has the most practical importance. The conventional form of the water electrolysis is the alkaline electrolysis which is commercially utilised at ambient pressure, since over 80 years.

By the end of the 80's, an estimated share of only 0.5-1 billion Nm<sup>3</sup>/a hydrogen (approx. only 0.1-0.2 % of the world production) was directly produced by the electrolysis, mostly in connection with water power as primary energy source. However also these slight amounts fall presently, since the electrolytic hydrogen production for the fertiliser production is not more comparable with the fertiliser production from natural gas, due to the general decline of energy prices.

Electric current is necessary for the electrolytic production of hydrogen. Hence, a potential location can only be economical where the electric current is extremely cheap.

In future, also local solutions are imaginable (hydrogen as storage for the supply of isle-grid-systems, e.g. wind-hydrogen) in an energy supply system that is based on regenerating energy sources. Furthermore, the hydrogen production on the petrol station itself is in preparation.

#### Principal procedure:

The fragmentation of water by electrolysis consists of 2 part-reactions on both electrodes. These electrodes are separated by an ionic-conductive electrolyte. Hydrogen originates on the negative electrode (cathode) and oxygen on the positive electrode (anode). Thus, water is fragmented in H<sub>2</sub> and ½ O<sub>2</sub> by the input of electric work and heat.

The necessary charging compensation occurs by ionic-conduction. To make sure that a division of the production gases takes place, the two reaction rooms must be separated by an ionic-permeable diaphragm.

The data refer to optimised systems of the hydrogen production. These are the low-pressure-water-electrolysis (is deemed to be an well-engineered procedure), the high-temperature- and high-pressure-water-electrolysis (they are still both in the stadium of R&D). The chlorine-alkali-electrolysis is not discussed here because their primary purpose is the chlorine-production which is not relevant for this study.

### Regional specifications in the EU

The technology has no relevant regional specifications.

<b>Foreseeable intermediate (5-10 years) and long-term (25-30 years) development</b>
n/a
<b>Internal and external resources</b>
(1) FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF) (ED.), Germany: Auf dem Wege zu neuen Energiesystemen, 1975  (2) L-B-SYSTEMTECHNIK, the Hydrogen and Fuel Cell Information System (HyWeb) (www.hydrogen.org)

<b>Description of the calculation to obtain the quantitative figures</b>
<p><b>Economy figure:</b> Hydrogen can be fluidised to simplify its transport and storage. But this process is expensive and energy consuming because hydrogen is fluidised at very low temperatures. Hydrogen is gaseous at room temperature and fluid by -253°C.</p> <p>Large commercial electrolyzers cost between 250-500 €/kW<sub>el</sub>, whereby small plants are fundamentally more expensive. Hence, the costs of a small electrolyser can be about 5000 €/kW<sub>el</sub>. The costs will be reduced in the area of much more MW of up to 250 €/kW<sub>el</sub>.</p> <p><b>Ecology figure:</b> n/a</p> <p><b>Efficiency figure:</b> Small electrolyzers have an efficiency of over 50-60 %, large electrolyzers even 65-70 %.</p>
<b>Description of the finding of some qualitative evaluations</b>
<p>Hazardousness: Hydrogen is problematical because of its gaseous constitution and the easy inflammability. Nonetheless, hydrogen arises in case of leakages or accidents because of its low weight similar to natural gas. The hazards are: deflagration, detonating gas reaction, unresolved system-closeness.</p>

Quantitative assessment of the module for the present state	
<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	6-8
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	
GJ output energy per GJ of all input energies	

Qualitative assessment of the module for the present state					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market				x	
<b>Other indicators</b>					
hazardousness (health risk)		x			
complexity of technique			x		
output standardisation				x	

<b>No.:</b>	<b>C2-H2</b>	<b>Hydrogen from Biomass by Thermochemical Conversion</b>
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class	2	input from:	Modules C1-P9, C1-P10, C1-R2, C1-R8
category	Production of Hydrogen	output to:	Modules C2-S4, C3-T7, C3-P1

<b>General description of the process</b>
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Gasification is the thermal-chemical conversion to a fuel gas by partial oxidation. This happens by the under-stoichiometric addition of free or bounded oxygen.

**General gasification procedure:** heating up - drying - pyrolysis - oxidation - reduction

At first, the biofuel-particle is heated up. Thereby, the contained water (respectively the additionally inserted water in the reactor) evaporates until a temperature level of approx. 200°C.

Biomass consists of macromolecules. A thermal induced fragmentation of these macromolecules takes place by temperatures between 150 and 500°C after the heating up and the drying procedure of the particles. Thereby, it emerges gaseous carbon hybrid connections, pyrolysis-oil and pyrolysis-coke.

By the oxidation, the developed gaseous, liquid and solid products react with the oxygen by the impact of heat. This effects a temperature increase of over 500°C.

The main part of the combustible substances of the product gas is produced by the reduction afterwards. Thereby, the emerged combustion products of the oxidation CO<sub>2</sub> and H<sub>2</sub>O are reduced to CO and H<sub>2</sub>.

The free product gas composition is depending on many factors, e.g.:

- physical and chemical properties of the fuel
- kind and quantity of the gasification medium
- reactor times
- reactor type (fixed bed, fluidized bed (bubbling or circulating), electricity of the aircraft turbine engine)
- gasification temperature
- pressure
- catalysts etc.

The major problem concerning the application of the produced gasification gas - both by the use in the gas engine/ turbine and by the planned use in the H<sub>2</sub> production - are the high dust and tar contents in spite of an expensive gas cleanup.

A conversion is required by the transformation of the produced synthesis gas from the biomass gasification. A similar procedure is necessary by the natural gas reforming. Thereby, flush-gas (H<sub>2</sub>, CO, CO<sub>2</sub>, CH<sub>4</sub>) results during the fine-purification of the hydrogen in the pressure-change-adsorption-plant. Then, the flush-gas could be used in a gas turbine or combustion engine.

The availability of this procedure is expected in the next 2-3 years.

<b>Regional specifications in the EU</b>
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The technology has no relevant regional specifications.

<b>Foreseeable intermediate (5-10 years) and long-term (25-30 years) development</b>
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n/a

<b>Internal and external resources</b>
(1) L-B-SYSTEMTECHNIK, the Hydrogen and Fuel Cell Information System (HyWeb) (www.hydrogen.org)
(2) Tetzlaff: Synnergie von Wasserstoff und Biomasse nutzen, Deutscher Wasserstoffverband
(3) NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY: The use of Producer Gas from Biomass Gasification for Electricity Production in a Gas Engine, 2001
(4) VON STILLFRIED, N.: Wasserstofftechnologie aus der Sicht des Bayrischen Wirtschaftsministeriums. Vortrag anlässlich der "World Hydrogen Energy Conference" WHEC 11 in Stuttgart, 1996
(5) KALTSCHMITT, M., HARTMANN, H.: Energie aus Biomasse, Springer Verlag, Berlin, 2001

<b>Description of the calculation to obtain the quantitative figures</b>
From internal and external resources.
<b>Description of the finding of some qualitative evaluations</b>

<b>Quantitative assessment of the module for the present state</b>	
<b>Output unit:</b>	
<b>Economy:</b>	
costs (€) per output unit	7.5 to 8
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	approx. 19
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.37
GJ output energy per GJ of all input energies	

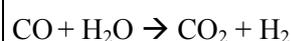
<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market			x		
<b>Other indicators</b>					
hazardousness (health risk)		x			
complexity of technique		x			
output standardisation		x			

<b>No.:</b>	C2-H3	<b>Hydrogen from Natural Gas</b>
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class	2	input from:	Module C1-F2
category	Production of Hydrogen	output to:	Modules C2-S4, C3-T7, C3-P1

### General description of the process

Steam reforming is defined as the endothermic catalytic transformation of light carbon hybrids (from methane to naphtha) with water steam. These processes are run in the industrial production at temperatures of 800-900°C and pressures of about 2.5 MPa normally. Afterwards, the exothermic catalytic transformation (shift-reaction) of the formed carbon monoxides with water vapour takes place:



The energy released by this reaction can not directly be used for the reforming because of its high temperature level (200-500°C). The carbon dioxides are removed from the gas mixture by adsorption or membrane separation. In addition, it must be cleaned up from further undesirable substances. The remaining gas has 60 % of combustible substances (H<sub>2</sub>, CH<sub>4</sub>, CO) and is used together with a part of the insert-gas for the heating of the reformer.

Large steam-reforming-plants have a production capacity of up to 100,000 Nm<sup>3</sup> H<sub>2</sub>/hour per unit. Also smaller plants are available on the market for the local hydrogen production (e.g. in the semiconductor industry). The procedure is well-engineered. Thus, a H<sub>2</sub>-purification of 99.9 % is attained.

### Regional specifications in the EU

The technology has no relevant regional specifications.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

For this well approved technology, no significant technological changes are assumed.

### Internal and external resources

Information from web pages:

L-B-SYSTEMTECHNIK, the Hydrogen and Fuel Cell Information System (HyWeb) ([www.hydrogen.org](http://www.hydrogen.org))

### Description of the calculation to obtain the quantitative figures

#### Economy figure:

The pure investment costs of a steam reformer (inclusive SO<sub>2</sub>-removal, Co-conversion, cleanup and the use of the remaining gas) with a yearly capacity of 800 million Nm<sup>3</sup> H<sub>2</sub> (by a natural gas input of 340 million Nm<sup>3</sup>/a) are between 75 and 100 million €.

0.10 €/Nm<sup>3</sup> hydrogen initial costs results in an apportionment of all capital and operating costs. Whereby, this price is heavily influenced by the primary energy delivery costs.

The specific hydrogen production costs by the natural-gas-steam-reforming are nearly 8 US\$/GJ presently.

Description of the finding of some qualitative evaluations

Quantitative assessment of the module for the present state	
<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	7.5-8
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	16-20
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.35-0.4
GJ output energy per GJ of all input energies	

Qualitative assessment of the module for the present state					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market					x
<b>Other indicators</b>					
hazardousness (health risk)		x			
complexity of technique				x	
output standardisation					x

<b>No.:</b>	C2-S1	<b>Esterification of Vegetable Oils</b>
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class	2	input from:	Module C1-O1, C1-O2, C1-O3, C1-O4
category	Secondary Processing	output to:	Modules C3-T4, C3-T5

### General description of the process

Vegetable oil can be produced from oil seeds like the rape plant. It can indirectly be used in conventional diesel engines after a process of refinement - the transesterification -.

Rape oil consists of tri-glycerine to 95-98 %. The oleic acid is its most important fatty acid with 54-64 %, than follow the linoleic acid (16-22 %) and the linolenic acid (8-10 %). The high content of macromolecular tri-glycerine is responsible for the higher viscosity of the rape oil in comparison to the diesel fuel. In the case of transesterification, the trivalent glycerol-alcohol contained in the tri-glycerine is replaced by an univalent alcohol (methanol or ethanol) by the catalytic conversion process. The resulting rape-oil-fatty-acid-methyl-ester (RME = biodiesel) is characterised by: a lower viscosity, a lower tendency of carbonization, a better frost resistance and a higher cetane number as rape oil. On the basis of RME's similarity with petroleum diesel, it can be mixed together without noteworthy problems of stability.

1010 to 1040 kg rape oil, 6-7 kg catalyst (mostly NaOH), 109 kg methanol and depending on the procedure 1-2 kg acids are necessary for the production of one ton of biodiesel. 93-106 kg raw glycerol emerges as co-product of the esterification.

For this procedure, about 52 kWh (188 MJ) of electricity and 1674 MJ of process heat per ton of RME output are needed.

The extracted vegetable oil can be matched on characteristics of the conventional diesel fuel by a chemical conversion process - the transesterification - afterwards, e.g. regarding viscosity, density and ignition willingness. In Germany, the most famous vegetable-oil-methyl-ester is the rape-oil-methyl-ester (RME) or also called biodiesel. It is produced by the transesterification of rape oil with methanol under the release of glycerol. RME can be used as a substitute for diesel fuel nearly without a special modulation of existing engines.

### Regional specifications in the EU

The provision of vegetable oil and vegetable-oil-methyl-ester (VME) is state of the art. RME, as the mostly produced vegetable-oil-methyl-ester in Germany and Europe, can be delivered at many filling stations. The release of the use of this fuel exists for nearly all vehicle manufacturers. The largest spread use of RME in Europe is in France

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

For this well approved technology, no significant technological changes are assumed.

### Internal and external resources

#### Information from web pages:

- (1) U.S. DEPARTMENT OF ENERGY: Bioenergy Information Network  
(<http://bioenergy.ornl.gov/doeofd/index.html>)
- (2) UNIVERSITY OF IOWA: Environmental Science and Technology Online  
(<http://pubs.acs.org/journals/esthag-a/links/energy.html#biofuels>)
- (3) EUROPEAN RENEWABLE ENERGY CENTRES AGENCY

(<http://www.eurec.be/htm/expertise/biomass.htm>)

- (4) U.S. DEPARTMENT OF ENERGY: Alternative fuels Data Centre  
(<http://www.afdc.nrel.gov/altfuel/biodiesel.html>)
- (5) GERMAN AEROSPACE CENTER, INSTITUT FÜR TECHNISCHE THERMODYNAMIK  
(<http://www.dlr.de/TT/system/publications/epolitik>)
- (6) UNION FOR THE PROMOTION OF OIL AND PROTEIN PLANTS (UFOP)  
(<http://www.ufop.de/home.html>)
- (7) FEDERAL ENVIRONMENTAL AGENCY, Germany (<http://www.umweltbundesamt.de/uba-info-presse-e/presse-informationen-e/p0100e.htm>)

#### Description of the calculation to obtain the quantitative figures

The already considerable utilisation of biodiesel results of the fuel prices on petrol stations. These are slightly under the price of conventional diesel fuel. This fact, that biodiesel can be offered to nearly the same heat-value-equivalent-price like conventional diesel fuel, is to constitute with the multiple subsidies. Actually, the RME production is characterised by noticeable higher delivery costs in comparison with fossil diesel.

- On one side, rape can be cultivated for a further material or energy application under the usage of a surface-closing-bonus, which is guaranteed of the EU to reduce the overproduction. The surface grant is 275-430 €/ha in accordance to the region.
- On the other side, RME is completely free of the mineral oil in Germany.

Additionally, some existing transesterification plants were state-aided with public funds in Germany.

#### Description of the finding of some qualitative evaluations

Biodiesel is quickly biodegradable. Therefore, the use of biodiesel in ecological sensitive areas like water protection areas or national parks is especially meaningful.

#### Quantitative assessment of the module for the present state

<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	approx. 3
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	3 - 4
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	nearly 1
GJ output energy per GJ of all input energies	

<b>No.:</b>	C2-S2	<b>Esterification of Used Vegetable Oil</b>
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class	2	input from:	Module C1-R3
category	Secondary Processing	output to:	Modules C3-T4, C3-T5

<b>General description of the process</b>
The esterification process corresponds to the esterification of unused vegetable oils (see module No. C2-S1). The difference is the need for a cleaning of the used oil that can contain several other substances when collecting it from kitchens.
<b>Regional specifications in the EU</b>
The first experiences with an esterification of used vegetable oil have been made in Great Britain. There is no information about the application of this technology in other European countries.
<b>Foreseeable intermediate (5-10 years) and long-term (25-30 years) development</b>
Important technical developments are not expected because the potential of raw material for this technology is very limited.

<b>No.:</b>	<b>C2-S3</b>	<b>Biogas Cleaning and Upgrading</b>
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class	2	input from:	Modules C2-F7, C2-F8
category	Secondary Processing	output to:	Modules C3-T6, C3-P4

### General description of the process

Raw biogas, produced in a digester, is normally treated in order to remove water, H<sub>2</sub>S, dust and /or CO<sub>2</sub>. The choice of the cleaning method and the compound to be removed depends on the type of end use of the gas.

Removal of water and foam is always needed for the prevention of corrosion in the biogas line. The condensation method (demisters; cyclone separators; moisture traps) and the drying method (adsorption of the gas to silica; glycol drying unit) are the basic methods for removing water. Water removal is normally accomplished with the removal of foam and dust.

A number of techniques have been developed over the years for the removal of H<sub>2</sub>S from biogas. Very low investment and exploitation costs and very easy to realise is the air or oxygen dosing to the biogas system. The technique is based on the biological aerobic oxidation of H<sub>2</sub>S to elemental sulphur ( $2 \text{H}_2\text{S} + \text{O}_2 \rightarrow 2\text{S} + 2 \text{H}_2\text{O}$ ). The results obtained with this method are very promising. Further techniques are: addition of iron chloride to the digester; adsorption using iron oxide pellets.

Upgrading of biogas to substitute natural gas (SNG) involves a number of steps. At first, water (vapour) and H<sub>2</sub>S have to be removed. Subsequently CH<sub>4</sub>/CO<sub>2</sub> separation must be carried out, using one of the following techniques for the removal of CO<sub>2</sub>: Pressure swing adsorption; membrane separation; physical or chemical CO<sub>2</sub>-absorption.

If the gas is meant for input in natural gas piping system, it has to be cooled and compressed. Dust and (halogenated ) hydrocarbons have to be removed, and the gas needs to be odorised for safety reasons.

For utilisation of biogas as vehicle fuels the same upgrade technique is used as for natural gas. In practice the upgrading of biogas up to vehicle fuel quality involves removal of CO<sub>2</sub>, H<sub>2</sub>S, NH<sub>3</sub>, particles and water. The methane contents should be at least 95%. Once cleaned and upgraded, biogas is conveyed by pipeline at a pressure of 4 bar (for instance) to a filling station. It is then compressed up to 200 bars (1), (2).

### Regional specifications in the EU

In the EU the requirements for biogas to be injected in natural gas pipelines are different. At the moment no European standard has been defined, but it can be assumed that differences in European countries will be small. Quality requirements for vehicle fuel of biogas are also different in the EU countries. (4)

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

The next step to an improved stage of development and a better economics in using biogas is providing urban vehicles like buses (public transport) and garbage trucks. More filling stations could be built if the demand for biogas fuel increases (taxis, company and delivery vehicles and private cars). In combination with increasing prices for fossil fuels there could be a fast spreading of gas filling stations especially along important traffic routes outside the urban areas too. More experiences and a better efficiency of the removal/upgrading techniques will cause lower costs for investing, operating and maintenance (3), (5).

### Internal and external resources

(1) Evaluation of landfill gas upgrading project Carbiogas B.V: (1992) at Nuenen; Novem / Gastec,

The Netherlands

(2) Guidebook on landfill gas extraction and utilisation, Novem / Thermie, The Netherlands, 1997

(3) Technical summary on gas treatment; AD Nett; Project Fair CT96-2083 (DG12-SSM), 2000

Information from web pages:

(4) BIOGAS FORUM, SWITZERLAND (<http://www.biogas.ch>)

(5) THE ANAEROBIC DIGESTION NETWORK (<http://www.ad-nett.org>)

**Description of the calculation to obtain the quantitative figures**

**Economy figure:**

Units for upgrading biogas to natural gas quality are expensive in the present. This is because there is a low grade of standardisation. The costs for a biogas upgrading unit (present standing- for about 500 m<sup>3</sup> / h) varies from 0,25 million to 1,5 million € (5). Upgrading units approximately are available for volume streams from 200 to 4000 m<sup>3</sup> / h. All in all there are not enough data to describe the costs exactly.

**Ecology figure:** Data not available

**Efficiency figure:** Assumption based on pilot plant projects.

**Description of the finding of some qualitative evaluations**

<b>Quantitative assessment of the module for the present state</b>	
<b>Output unit:</b>	m <sup>3</sup> Biogas (upgraded- natural gas quality)
<b>Economy:</b>	
costs (€) per output unit	10,7 to 64,1
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	data not available
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.7
GJ output energy per GJ of all input energies	0.5

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space		x			
<b>Availability</b>					
readiness for market			x		
<b>Other indicators</b>					
hazardousness (health risk)					
complexity of technique			x		
output standardisation					

<b>No.:</b>	C2-S4	<b>Liquefaction of Hydrogen</b>
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class	2	input from:	Modules C1-H1, C1-H2, C1-H3
category	Secondary Processing	output to:	Modules C3-T8, C3-P2, C3-P3

### General description of the process

For transportation and storage, a transformation of hydrogen to liquid phase is very useful. In this phase the hydrogen can be made usable for an application in fuel cells. In general, the hydrogen can be delivered in gaseous as well as liquid phase. For the supply with gas bottles the sevenfold required space is necessary in comparison to the supply via liquid hydrogen. Hence, the liquid condition of hydrogen is interesting in respect to the transportation volume. The gas is step-by-step catalytically cooled off for the liquefaction. Thereby, it is transformed from the Ortho-form into Para-form.

Liquid hydrogen can be stored at temperatures of 20 K and a pressure of 1 bar (0,1 MPa) as well as at 32 K and a pressure of 11 bar (1,1 MPa).

### Regional specifications in the EU

The technology has no relevant regional specifications.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

Liquefaction prices depend especially on electricity prices. For lower electricity cost and large dimensioned liquefaction plants, less than 13 €/GJ were found in (1). In the same source, a 30 % cost decrease in a mid-term view was estimated, due to technical optimisation.

### Internal and external resources

Information from web pages:

(1) Zittel, W.; Wurster, R.; Weindorf, W.: Wasserstoff in der Energiewirtschaft, chapter 6, 1997 (www.hydrogen.org)

L-B-SYSTEMTECHNIK, the Hydrogen and Fuel Cell Information System (HyWeb) (www.hydrogen.org)

### Description of the calculation to obtain the quantitative figures

#### Economy figure:

The costs of the liquefaction from hydrogen are depending on the size of the plant and its utilisation.

Presently, the liquefaction costs of hydrogen are approx. 0.06-0.08 €/kWh (about 19,40 €/GJ) concerning to the EQHHPP project as a calculation basis.

#### Ecology figure:

The only energy input for liquefaction is electricity. Other inputs are not known. If the hydrogen has to be produced from renewable electricity, there is no CO<sub>2</sub>-emission (if a typical european electricity mix, UCPTE, is used, it reaches 48,9 g/MJ compressed hydrogen).

#### Efficiency figure:

The liquefaction does not lead to a noteworthy loss of the energy content of the hydrogen.

The external energy necessary for the liquefaction system is 0,35 MJ of electricity for the compression

of 1 MJ of hydrogen (best available technology today), following (2). If this energy is taken from renewable sources, primary energy and electricity don't differ. In this case, the total energy input is 1,35 MJ for 1 MJ of output energy (liquefied hydrogen).

### Description of the finding of some qualitative evaluations

The readiness for market is medium if the demand of the transport sector with its specific demand is considered.

### Quantitative assessment of the module for the present state

<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	19,40
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	0
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	1
GJ output energy per GJ of all input energies	1,35

### Qualitative assessment of the module for the present state

	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market			x		
<b>Other indicators</b>					
hazardousness (health risk)			x		
complexity of technique		x			
output standardisation				x	

<b>No.:</b>	C2-S5	<b>Compression of Hydrogen</b>
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class	2	input from:	Modules C1-H1, C1-H2, C1-H3
category	Secondary Processing	output to:	Modules C3-T7, C3-P1

<b>General description of the process</b>
<p>When hydrogen is produced by one of the different forms (electrolysis, from biomass or from natural gas), it needs a compression before transporting it in vehicles (transportation to the filling station – if the production site is not integrated within the filling station – and for the transportation on board of the driven vehicle).</p> <p>Here, it will be considered the most probable case that gaseous hydrogen is produced by electrolysis and exists as a gas with a pressure of 3 MPa.</p> <p>For the on-board-transportation, a pressure of 70 MPa (at low temperature) or 88 MPa (at room temperature) a booster system is needed. This system needs 0,065 MJ of electrical energy for compressing 1 MJ of hydrogen.</p>
<b>Regional specifications in the EU</b>
The technology has no relevant regional specifications.
<b>Foreseeable intermediate (5-10 years) and long-term (25-30 years) development</b>
<b>Internal and external resources</b>
<p>(1) Zittel, W.; Wurster, R.; Weindorf, W.: Wasserstoff in der Energiewirtschaft, chapter 6, 1997 (www.hydrogen.org)</p> <p>(2) SCHINDLER, J.; WEINDORF, W.: Kraftstoffe aus Erneuerbaren Energien im Vergleich, transparencies from the world forum for renewable energies, Berlin, 2002, and personal information of W. Weindorf, LBST, Ottobrunn</p>

<b>Description of the calculation to obtain the quantitative figures</b>
<p><b>Economy figure:</b></p> <p>The costs of the hydrogen compression are depending on the size of the plant and its utilisation (1). Current data are missing.</p> <p><b>Ecology figure:</b></p> <p>Following (2), the compression unit needs 0,065 MJ of electricity for the compression of 1 MJ of hydrogen. Other inputs are not known. If the hydrogen has to be produced from renewable electricity, there is no CO<sub>2</sub>-emission (if a typical european electricity mix, UCPTe, is used, it reaches reaches 9,09 g/MJ compressed hydrogen).</p> <p><b>Efficiency figure:</b></p> <p>The compression does not lead to a noteworthy loss of the energy content of the hydrogen. The external energy necessary for the compression system is 0,065 MJ of electricity for the compression.</p>

sion of 1 MJ of hydrogen, following (2). If this energy is taken from renewable sources, primary energy and electricity don't differ. In this case, the total energy input is 1,065 MJ for 1 MJ of output energy (compressed hydrogen).

**Description of the finding of some qualitative evaluations**

Readiness for market is estimated as “medium” this corresponds to the phase of pilot plants.

**Quantitative assessment of the module for the present state**

<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	no current data available
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	0
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	1
GJ output energy per GJ of all input energies	1,065

**Qualitative assessment of the module for the present state**

	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space					
<b>Availability</b>					
readiness for market			x		
<b>Other indicators</b>					
hazardousness (health risk)			x		
complexity of technique			x		
output standardisation				x	

<b>No.:</b>	<b>C2-S6</b>	<b>ETBE from Ethanol</b>
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class	2	input from:	Modules C2-F1, C2-F2, C2-F3, C2-F4, C2-F5, C2-F6
category	Secondary Processing	output to:	Modules C3-T2

### General description of the process

Ethyl tertiary butyl ether (ETBE) is produced by mixing ethanol and isobutylene (iC4) and reacting them with heat over a catalyst. 0.45 t of ethanol and 0.55 t of iC4 are used for producing 1 t of ETBE.

The butadiene-free C4-fraction and ethanol in a mole-ratio 1 : 1 are heated to 60 – 90 °C before entering the reactor. The chemical reaction takes place at the liquid phase under a pressure of 1 – 2 MPa over an acid ion-exchange-catalyst. (4, 5)

### Regional specifications in the EU

Fuel-Ethers were invented 25 years ago in the EU and Europe is still leading the way with ETBE with relevant experience that has been accumulated in manufacturing, blending and usage of the bio-ethanol-derived products for any "Otto"-cycle engines. (1)

Europe has 7 ETBE plants (France, Spain, Poland) and 6 more being developed, prefers ETBE over Ethanol (3)

Bio-ethanol in form of ETBE is practised in the USA (production from maize) and in Brasilia (from sugar pipes). There are tax incentives for the use of bio-ethanol in these countries as well as in France.

### Foreseeable intermediate (5-10 years) and long-term (25-30 years) development

For this well approved technology, no significant technological changes are assumed.

ETBE capacity is today around 600 000 t/y in Europe with new capacity planned for another 500 000 t/y. Furthermore the entire existing MTBE capacity of 3.5 million tons per year could be converted to ETBE. (1)

ACEA favours the use of ETBE up to 15% rather than the direct use of bioethanol. In fact, due to its nature, ETBE is fully compatible with the hydrocarbon basic petrol. It does not create any problem in terms of fuel quality (volatility, material compatibility), neither with respect to the distribution system. Large experience exists on the use of ethers (especially MTBE) blended in petrol (3). By employing Fuel-Ethers such as ETBE the quantity of ETOH that can be used in modern fuels can be maximized without the need to modify existing petrol regulation. The ether allows 26% more alcohol in the blend. (1, 3)

### Internal and external resources

- (1) EFOA input - EUC RFCBT.doc (Mr. Mirabella)
- (2) ETBE - A RFS Solution for the Future - Sept 2002 - Piel - TEIR Associates.ppt
- (3) W-Mirabella on ETBE – Excerpt from Presentation 2002.ppt
- (4) TECHNISCHE UNIVERSITÄT CLAUSTHAL, INSTITUT FÜR THERMISCHE VERFAHRENSTECHNIK ([www.itv.tu-clausthal.de/ICVT/forschung/etbe.html](http://www.itv.tu-clausthal.de/ICVT/forschung/etbe.html))
- (5) TU BERGAKADEMIE FREIBERG, INSTITUT FÜR ENERGIEVERFAHRENSTECHNIK UND CHEMIEINGENIEURWESEN
- (6) Biofuels data EU.ppt (some slides as personal communication from EFOA - European Fuel Oxygenates Association, 2003)

<b>Description of the calculation to obtain the quantitative figures</b>
<p><b>Economy figure:</b> Price data were not available.</p> <p><b>Ecology figure:</b> The CO<sub>2</sub> emission depends on the energy used within the process. Following (6), the etherification needs 17 648 MJ of energy. Its composition (electricity, heat) was not found out. So the CO<sub>2</sub> emission linked to the process could not be determined.</p> <p><b>Efficiency figure:</b> first figure: personal communication of Dr. Mirabella (Jan. 2003). The second figure was calculated from (6) assuming the same energy content in 1 t of ETBE and 1 t of ethanol. It refers to the use of sugar beet based ethanol.</p>
<b>Description of the finding of some qualitative evaluations</b>
The readiness for market is good because of the existing commercial ETBE plants in Europe.

<b>Quantitative assessment of the module for the present state</b>	
<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	data not available
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	data not available
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.995
GJ output energy per GJ of all input energies	0.475

<b>Qualitative assessment of the module for the present state</b>					
	very bad	bad	medium	good	very good
<b>Ecology</b>					
need of space			x		
<b>Availability</b>					
readiness for market				x	
<b>Other indicators</b>					
hazardousness (health risk)					
complexity of technique					
output standardisation				x	

<b>No.:</b>	C2-R1	<b>Refinery of Crude Oil</b>
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class	2	input from:	Module C1-F1
category	Refinement of Fossil Fuels	output to:	Modules C3-T9, C3-P5

<b>General description of the process</b>
<p>Crude oil is imported by vessels.</p> <p>Beginning at the sea port, the oil is transported by pipeline or inland navigation to the refinery. In the refinery, the crude oil is transformed into different fractions for different uses. Two of the most important forms are petrol and diesel.</p> <p>The transformation needs about 10 % of the energy content of the crude oil.</p>
<b>Regional specifications in the EU</b>
<p>Transport distances between port and refinery vary because of the different distribution and importance of oil import ports in the different EU member countries. Differences in the process itself are not important because the petrol and diesel output is standardized for all European Countries.</p>
<b>Foreseeable intermediate (5-10 years) and long-term (25-30 years) development</b>
<p>Petrol and Diesel are EU-wide implemented.</p>
<b>Internal and external resources</b>
<p>(1) ASSOCIATION OF THE GERMAN PETROLEUM INDUSTRY: Personal communication of price development for diesel fuel and its composition (import price, taxes, transformation cost).</p> <p>(2) FRISCHKNECHT, R.; HOFSTETTER, P.; KNOEPFEL, I.; DONES, R.; ZOLLINGER, E.: Ökoinventare für Energiesysteme, 3. Ed., Zürich, 1996</p>

<b>Description of the calculation to obtain the quantitative figures</b>
<p><b>Economy figure:</b></p> <p>Value of Diesel and normal petrol fuel (imported products) following (1) in spring 2002 were about 0,21 €/litre. Half of this price corresponds to the crude oil supply (see module C1-F1), so the rest is the transformation cost.</p> <p><b>Ecology figure:</b></p> <p>LCA-Data for the oil refinement in Europe are used from the following source:</p> <p>Data from (2).</p> <p><b>Efficiency figure:</b></p> <p>About 90 % of the energy content of the crude oil is transformed into fuels.</p>

<b>Quantitative assessment of the module for the present state</b>	
<b>Output unit:</b>	GJ
<b>Economy:</b>	
costs (€) per output unit	2,93 €/GJ (without taxes)
<b>Ecology:</b>	
emission of CO <sub>2</sub> (kg) per output unit	5.14 kg
<b>Efficiency:</b>	
GJ output energy per GJ input energy carrier	0.9
GJ output energy per GJ of all input energies	