MESTRADO INTEGRADO EM ENGENHARIA DA ENERGIA E DO AMBIENTE

Disciplina: Energia da Biomassa

Aula N 11 – Biomethane

Docente: Santino Eugénio Di Berardino

Santino.diberardino@lneg.pt

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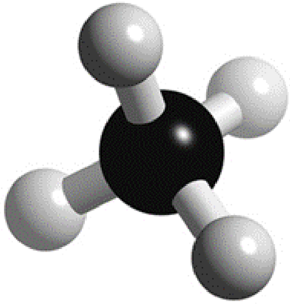
What is biomethane?

- Biomethane is: **methane which is produced from biogenic resources by technical processes**.
- Biomethane can be generated by bio-chemical conversion (via biogas) or thermo-chemical conversion (via Bio-SNG).
- The biogas composition and especially the methane content is upgraded to natural gas quality. In This case biomethane is called **bio natural gas**[5].



Perspective

- According to AEBIOM: biomass currently accounts for 2/3 of renewable energy in Europe and bioenergy will play a **key role** in achieving the ambitious targets approved by the renewable energy directive. 20% of the final energy consumption have to be provided by renewable sources by 2020.
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Why Biomethane?

- ***Fight against climate change****:* replace fossil product and thus can contribute to reduction of greenhouse gases:
- ***Reduction of import dependency****:* offset the depletion of fossil use
- ***Development of the local economy****:*
- ***Environmental Sustainability:*** co-digestion with agricultural and food waste.
- ***A closed and integrated circuit:*** *local production* reduce the impact of logistics. digestate is a natural fertilizer, reducing chemical fertilizers of fossil origin.
- **Biomethane injected** into the network **can meet the needs of local consumption**, saving transportation costs levied on natural gas, imported from abroad.

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Why Biomethane?

- ***A renewable source programmable:*** can be produced continuously throughout year. Can compensate the not programmable unavailability of energy sources, such as wind or photovoltaic. A fundamental component in the construction of intelligent networks (Smart Grid) based of renewable sources, both electric and gas.
- ***Flexibility*: ** biomethane network offers maximum flexibility of use This renewable energy source is available exactly where is used and where it can be used in **the energy-efficient** without depending on the location biogas plant. Biomethane **can be mixed** with natural gas for vehicles, allowing the achievement of blending for biofuels or be produced and stored to cover points of distribution of methane for haulage not reached by the network.

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Impact of biomethane on global warming

- **by using biomethane as a vehicle fuel, does not contribute to the greenhouse effect. It reduces natural gas production by using methane forming products in a strictly controlled fuel production cycle in which the emissions of methane are minimized in all handling steps** [Jarvis. 2004]
- **Biomethane production is a waste management strategy & a clean water solution**
- **Improved agricultural output through biomethane production residues**

Biogas upgrade

- The upgrading of biogas into biomethane has significantly gained in relevance in recent years. In contrast to “on-the-spot conversion into electricity”,
- there are several advantages offered by upgrading bio-gas into biomethane and subsequently feeding it into natural gas grids.

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Biogas upgrade

- Through the use of biomethane at a place with a high demand for heating, the upgrading of biogas into biomethane contributes to a **significant increasing share of externally usable heat energy**; this in turn leads to an increase in the overall efficiency of biogas use. decoupling of production and use in terms of location and also of time.
- bio-methane can **provide energy in accordance with demand**, by means of the storage function of the natural gas grid.
- **flexible possibilities for use**, as bio-methane is similar to natural gas in terms of its composition – thus biomethane is partly also referred to as bio natural gas.
- In terms of energy, biomethane can be used **in the coupled** production of electricity and heat (production in combined heat and power plants – CHP),
- as fuel in natural gas vehicles and also as a natural gas substitute in natural gas-fired burners used for heating. In addition, there is the possibility to use biomethane as a **raw material for the chemical industry**.

Advantage of biomethane - resume

- **Pollution**
- **<u>Clean Environment</u>**
- **<u>availability</u>** and **<u>usability</u>**

EU Legislative Basis for Biomethane Access to Gas Grids

- Directive 2003/55/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in natural gas and repealing Directive 98/30/EC.

Preambel: Member States should ensure that, taking into account the necessary quality requirements, biogas and gas from biomass or other types of gas are granted nondiscriminatory access to the gas system, provided such access is permanently compatible with the relevant technical rules and safety standards. These rules and standards should ensure, that these gases can technically and safely be injected into, and transported through the natural gas system and should also address the chemical characteristics of these gases.

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EU Objective 2020

- ***Biomethane as an alternative source.*** Directive 2009/28 / EC, the biogas from municipal organic waste, manure wet and dry manure, is expressly listed as one of biofuels with highest percentage of reduction of greenhouse gas (over 80%) and the highest level of biofuels produced with the technologies currently available.
- The use of agricultural material such as manure, slurry and other animal and organic waste for biogas production has, in view of the high greenhouse gas emission saving potential, significant environmental advantages in terms of heat and power production and its use as biofuel".
- "Public support is necessary to reach the Community's objectives with regard to the expansion of electricity produced from renewable energy sources, in particular for as long as electricity prices in the internal market do not reflect the full environmental and social costs and benefits of energy sources used".

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EU Objective 2020

- **Directive 2009/28 say (in point 41**) **the priority** that must be paid for plants to produce energy from renewable sources: "
- Directive 2009/73 concerning common rules for the internal market in natural gas, states (26) that *"Member States should take concrete measures to promote wider use of biogas and gas from biomass, the producers of which should get non-discriminatory access to the gas system, provided that such access is compatible permanently with the technical standards and requirements relevant safety*".
- **European Clean Power for Transport (CPT) package** In April 2014 the European Parliament gave its final approval to the Clean Power for Transport (CPT) package. CPT highlights LNG as one of four alternative fuel options for the future and calls for minimum infrastructure coverage for LNG filling stations along major motorways of the Trans-European Transport network (TEN-T) by 2025. Supporting national policy frameworks must be developed by 2016, and member states will set their own paths for further infrastructural development

Others directives

- **European Fuel Quality Directive (FQD)** reduce lifecycle GHG emissions of road fuels by 6 % until 2020. LNG, in combination with biomethane, could achieve both goals.
- **European Renewable Energy Directive (RED)**: The Renewable Energy Directive (RED) mandates a 10 % renewable energy target for the transport sector. As part of a comprehensive renewable and alternative energy strategy, LNG admixtures with up to 100 % biomethane or synthetic methane have the potential to satisfy this policy.
- **The Euro VI emission standard:**The 2014 Euro VI emissions standard substantially tightens heavy-duty vehicle (HDV) emission limits for nitrogen oxide (NO_x) and particulate matter (PM), among others. The new standard leads to substantially increased complexity and costs of diesel power trains over Euro V, enhancing the economic competitiveness of LNG trucks. Dedicated LNG Otto-cycle truck emissions stay below the Euro VI limits without costly after treatment (Scania 2014; Iveco 2014).

Fuel and energy legislation

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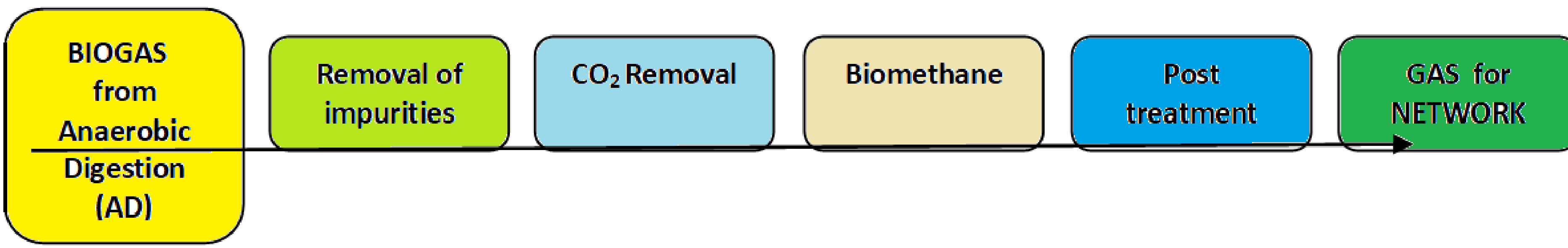
- **EU innovation policy and funding** The European Commission has demonstrated its commitment to LNG as a truck fuel by co-funding the LNG Blue Corridors project, an international research-and-demonstration project.LNG Blue Corridors is intended to improve the knowledge and awareness of LNG for medium and long-distance transport. The project involves the construction of 14 LNG filling stations and the implementation of at least 100 LNG trucks, which will operate along trans-European routes covering twelve EU member states.
- **EU strategy for reducing heavy-duty vehicles' fuel consumption and CO_2 emissions**
- The 2014 strategy targets certification, monitoring and the reporting of HDV emissions. It is addressed to the European Parliament and the Council, which are invited to endorse it and help deliver the actions thus outlined. The Commission plans to introduce legislative proposals in 2015.

Biomethane from biogas:

- Tipical Lay-out



Biogas feedstock

Feedstocks for biogas	
Agriculture	Waste streams
Manure	Landfill
Energy crops, catch crops	Sewage sludge
Landscape management	Municipal solid waste
Grass	Food waste
Other by-products	Other waste

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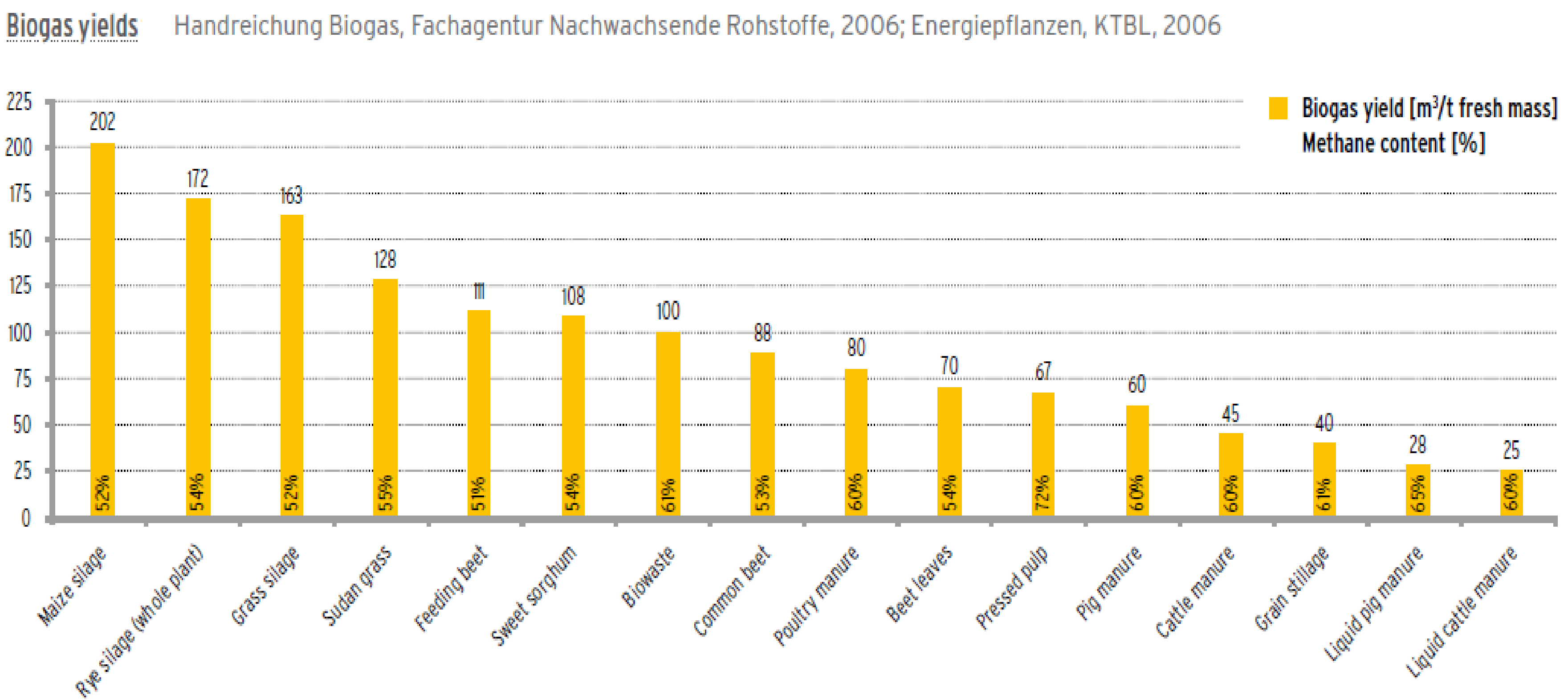
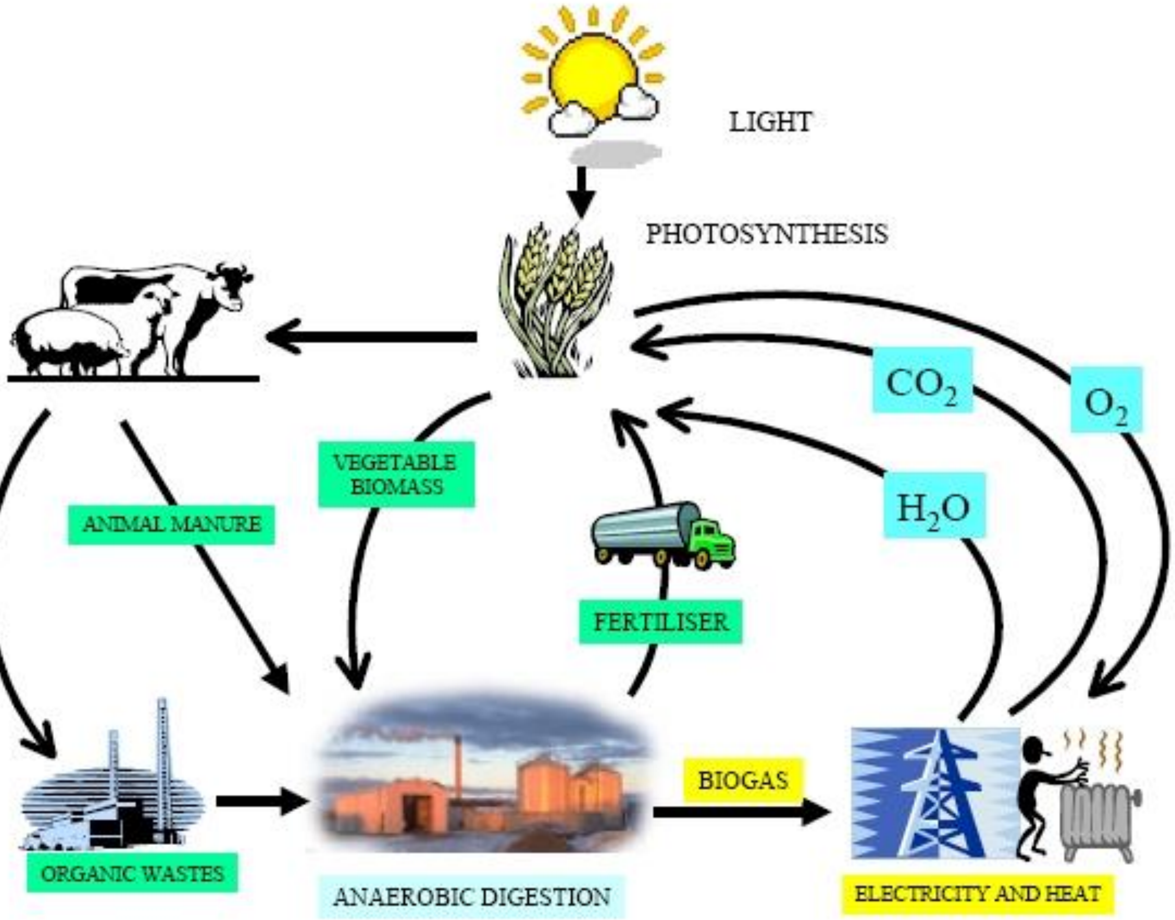
biogas yield and methane content in % for primary source



Biogas Cycle

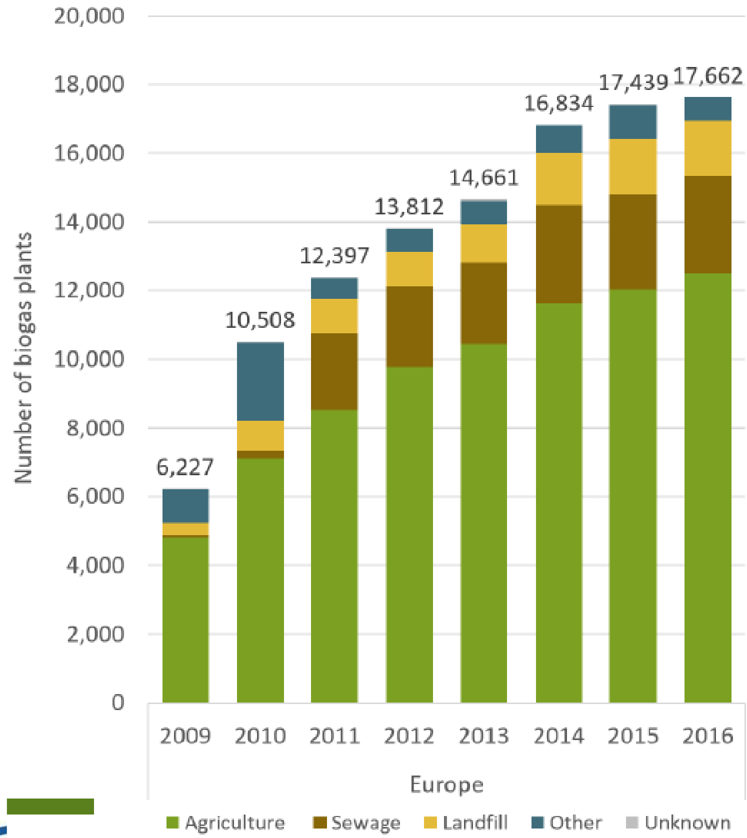


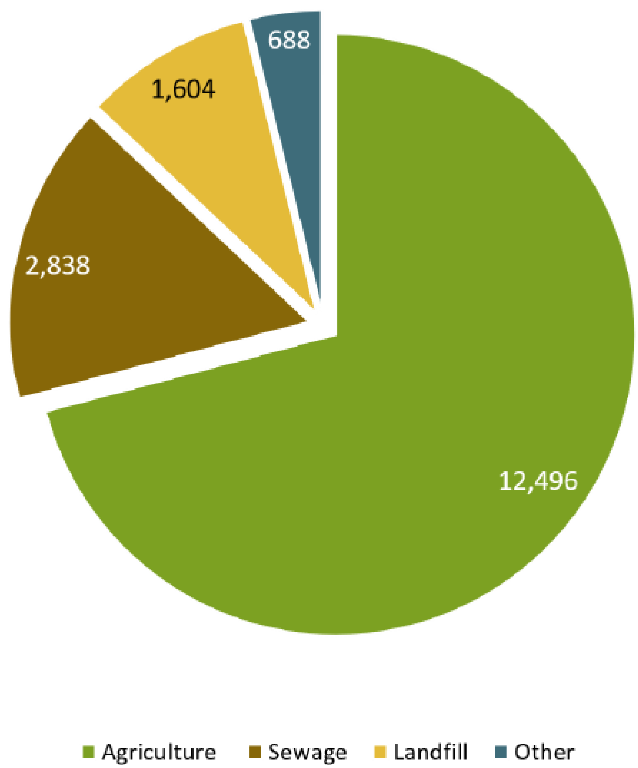
Germany target

- German Federal Government determined that, by the year 2030, a potential can be developed for biogas which corresponds to 10 % of Germany's consumption of natural gas.
- In this context a target was defined, aiming at an annual feed-in of biogas equating to 6 % (ca. 6 bn. m3/a) of German natural gas consumption by 2020 and 10 % (ca. 10 bn. m^3/a) by 2030.
- The legislature's intention in doing this is to reduce import dependency on natural gas, to generate impulses aimed at environmentally friendly energy production, and also to expand both the efficient utilisation of combined heat and power production (CHP) and also the use of biogas as a vehicle fuel.
- The technical primary energy potential for biogas, taking 2020 as the reference year, comprises 503 PJ/a [1]. In comparison to this, 6 bn m3/a of (upgraded) biogas (assuming a methane content of 100 %) corresponds to ca. 215 PJ/a.

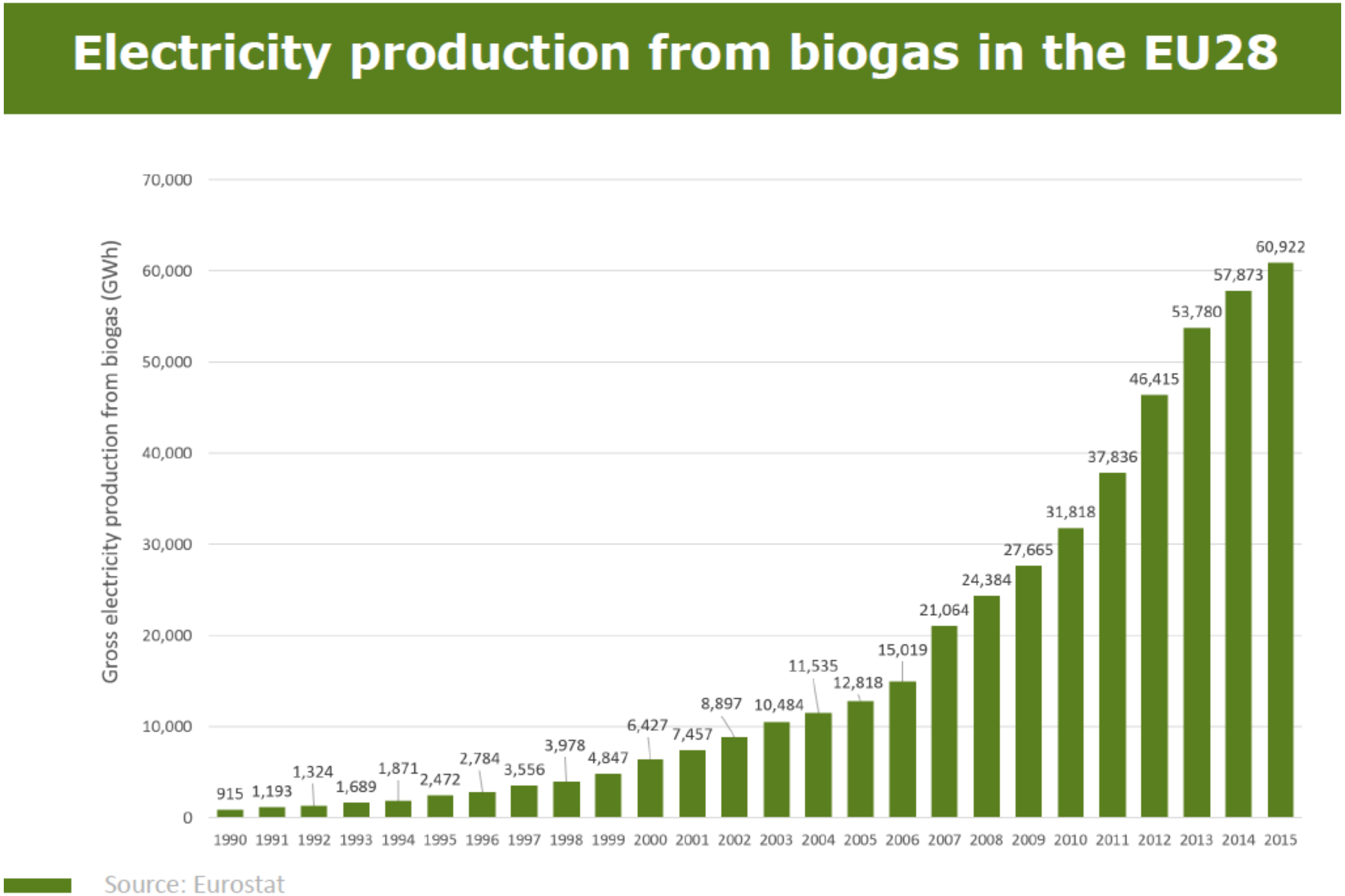
Evolution of Biogas Plants in Europe

Evolution of the number of biogas plants in Europe

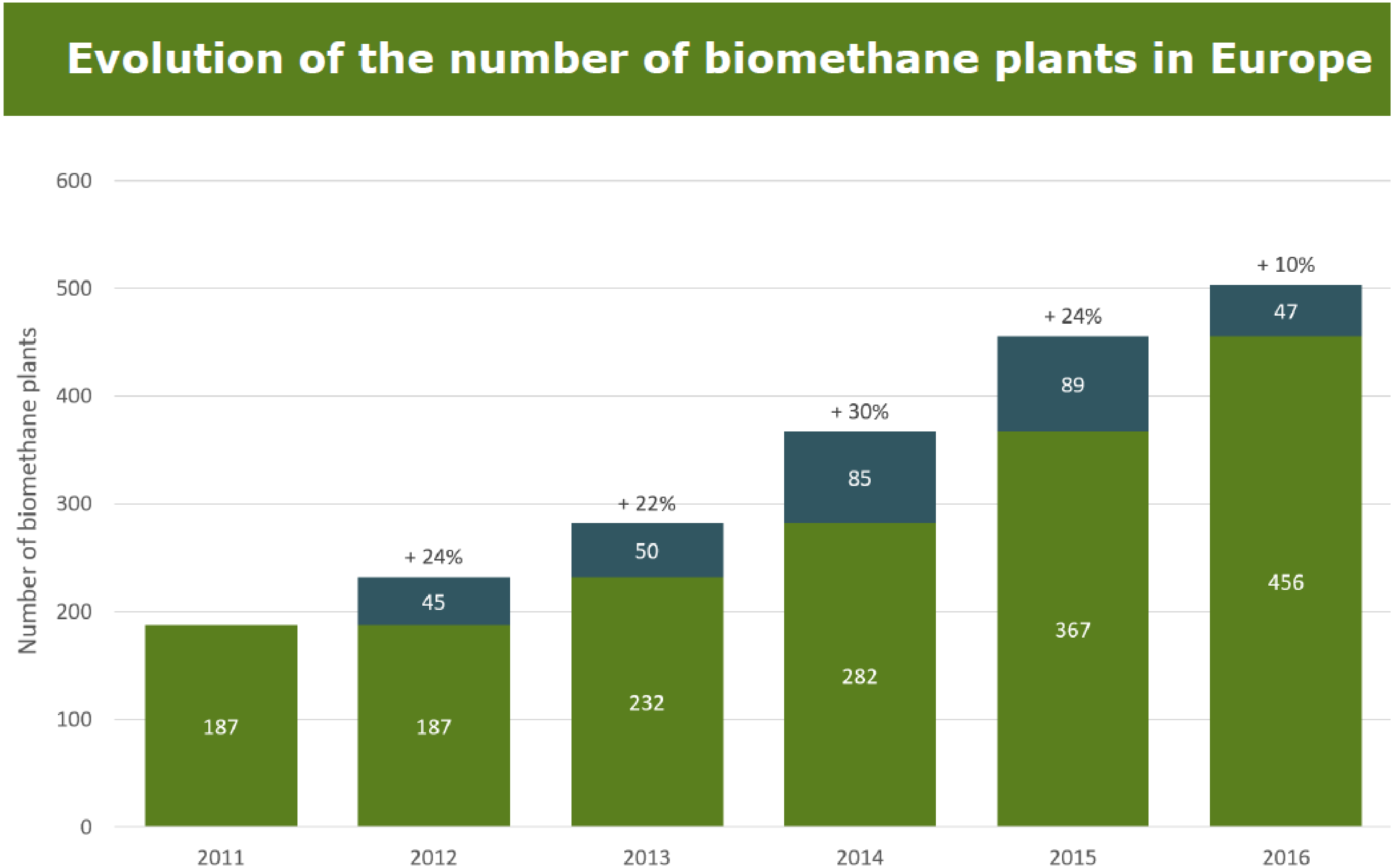




Biogas Electricity production in EU 28

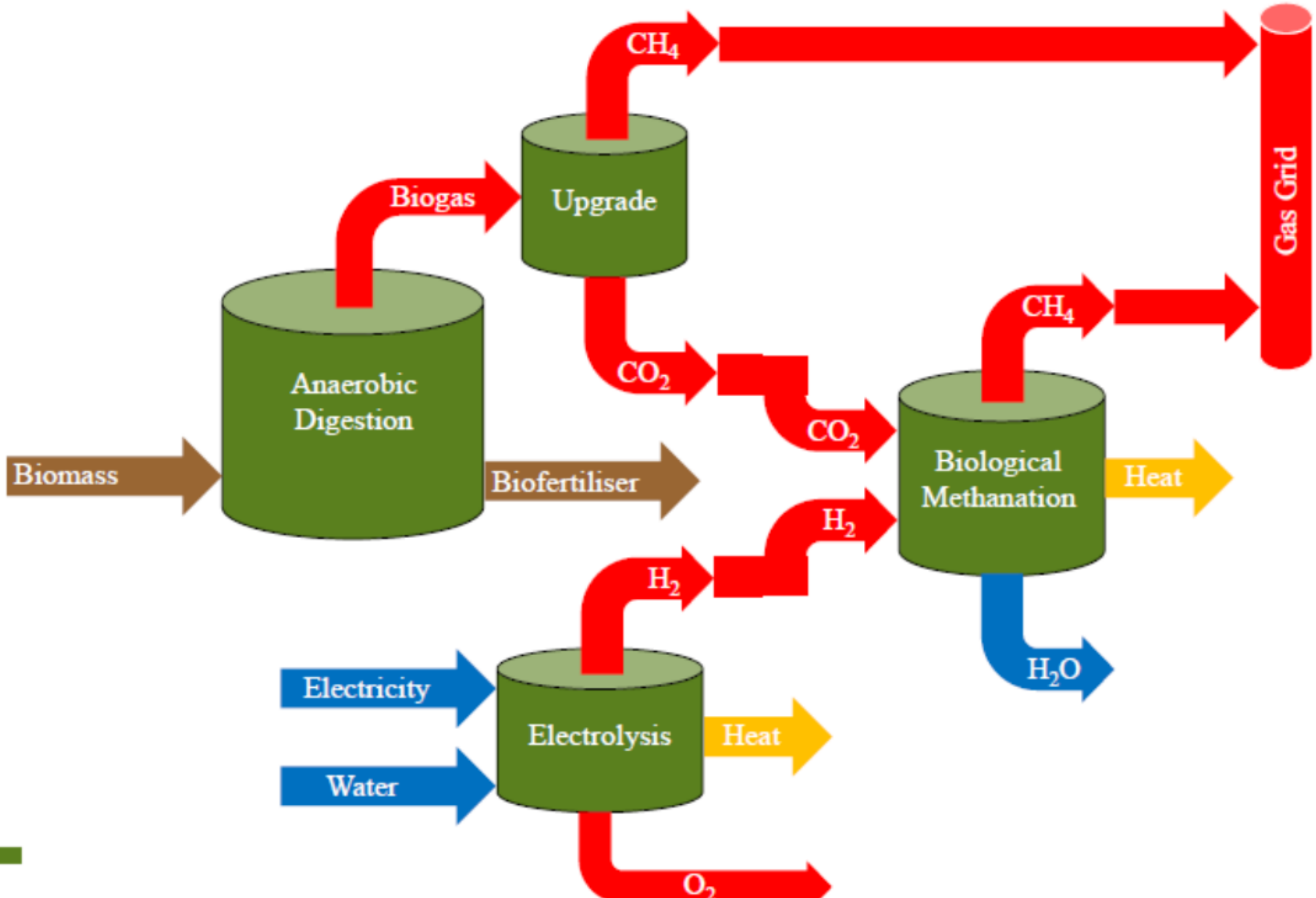


Evolution of number of biomethane plants in EU

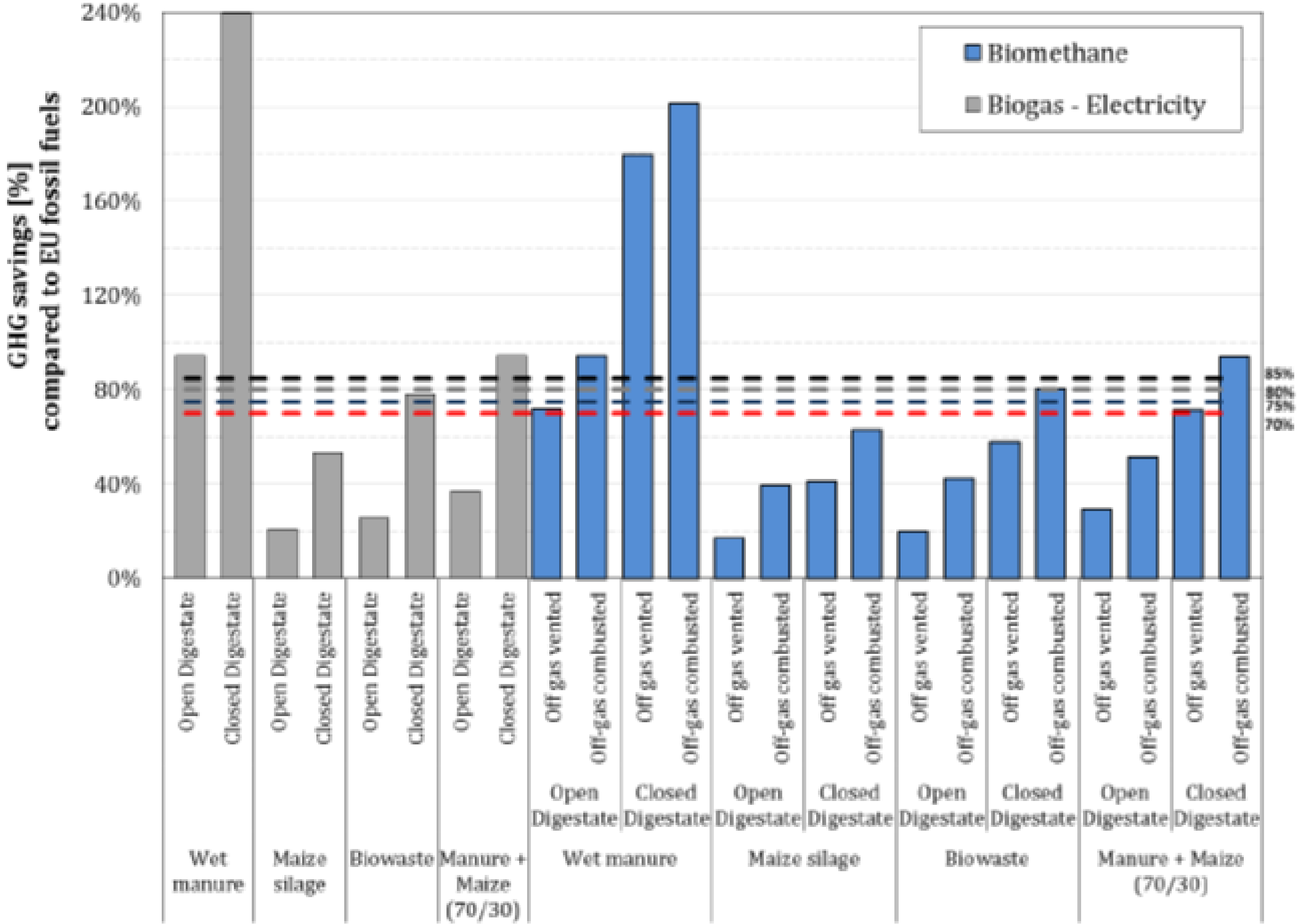


Power to methane (P2G or P2G)

- The production of biomethane makes available CO2 for more methane production. Theoretically about 40 % more methane can be produced.

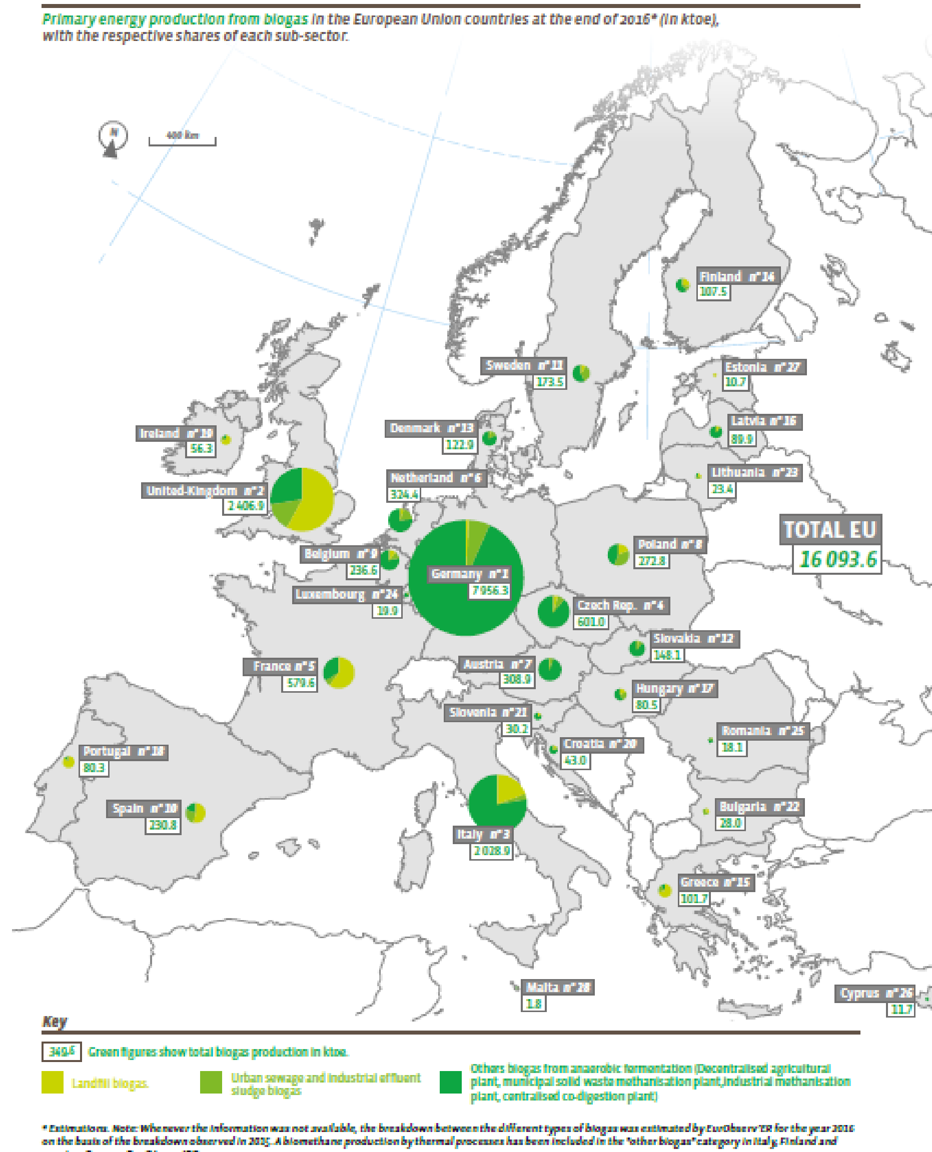


GHG savings of biogas and biomethane



Source: solid and gaseous bioenergy pathways: input values and GHG emissions (JRC 2016)

Biogas Plants In Europe



Environmental consideration of biomethane production – sustainability

- The principle of sustainability originates from the forestry sector and was first formulated in writing at the beginning of the 18th century [3]. The definition of sustainability, still acknowledged to a large degree to this day, originates from the 1987 Brundtland Report of the World Commission on Environment and Development. This defines a development as being sustainable if the needs of the current generation are satisfied without limitations being imposed on future generations in terms of their needs [1].
- Transferring this principle to the concept and operational mode of a biogas or biomethane plant, this means **attaining as relevant an economic gain as possible while safeguarding compatibility with ecological and social considerations.** For that reason, using animal excrements and plant residues counts as a very sustainable way of providing energy. The greatest potential is offered by the use of energy crops. However, the limitations in terms of usable agricultural land and the situation of increasing competition from the use of biomass as an energy source, results in the need for a sustainable mode of production and for the most efficient use possible.

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FROM BIOGAS TO BIOMETHANE

- A simplified generic chemical equation for the overall processes outlined above is as follows:
- $C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$

Biogas composition [15][16][19]

- ***Methane*** is the desired component of the biogas obtained usually from reactions of methanogenesis. from acetic acid or hydrogen, that are products from the fermentation of carbohydrates, proteins and lipids content in the substrate. The methane in biogas is variable quantity from 30 to 70 vol%, this depending by many factors. The minimum value is presented in case of landfills that present infiltration of air, while the highest values, are obtained, from the best digesters loaded with substrates (predominantly lipid or substrate rich in ethanol). Methane production strongly depends on many operating parameters (such as the temperature or the pH in the digester, quality of the substrate, molecular agitation and the water content). It is common perform the physical and chemical pre-treatment of the substrate to make it suitable to meet the design specifications of the digester, designed to maximize the production of methane.
- ***Carbon dioxide*** is one of the main products of fermentation anaerobic, produced in the stages of acidogenesis, acetogenesis and methanogenesis. One biogas can contain 15-50 % vol. In many applications carbon dioxide is not a component undesirable, for example if the biogas is used on site to produce heat is sufficient to adopt an apparatus of suitable for fuel combustion by-step calorific value. In most cases, where it is necessary to transport the gas and use for other applications, is necessary to separate the carbon dioxide from the fuel.

***Biogas composition* [15][16][19]**

- ***Water***: the digesters provide biogas saturated with water vapour. The water comes directly from the substrate, which must be loaded in appropriate conditions of fluidity.
- ***Oxygen:*** molecular oxygen may be present in residual form especially in biogas from landfill (average 1% vol), for air infiltration. Normally the oxygen is consuming because has a part in oxidation reactions but for little residence times there is still a small part in biogas.
- ***Nitrogen:*** molecular nitrogen is located in the biogas, especially from landfill, for mechanisms similar to those that motivate the presence of oxygen. One difference, however, is that the nitrogen not participating in the reaction and is not consumed. For this reason is present in percentages higher (average 15 % in volume).

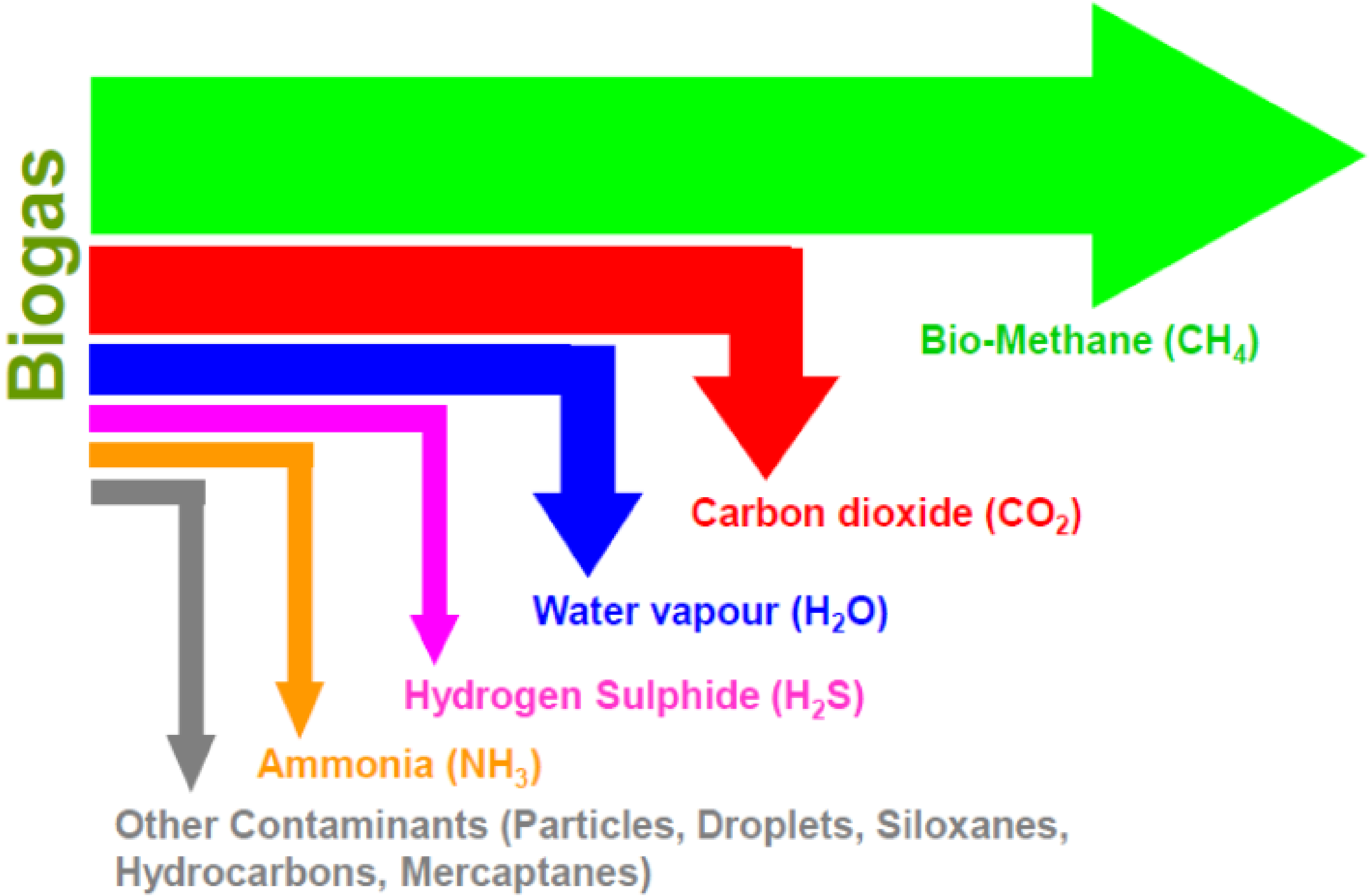
Biogas composition [15][16][19]

- ***Hydrogen:*** molecular hydrogen is developed as a stages sub product of acidogenesis and acetogenesis, it is present in little trace because it is consumed by other phases of the process; it is in higher doses in the landfill gas.
- ***Sulfur compounds***: they are present in the biogas in the form of sulfides, disulfides and mercaptans; due the reducing atmosphere of the digesters, the sulfur is present mainly in the form of hydrogen sulphide. The production of H_2S is attributable to the reduction of sulphates present in the substrate by microorganisms. It is formed by bacterial decomposition of proteins that containing sulfur. The maximum detectable H_2S can be up to 10,000 ppm (1%) in biogas from digestion and 500 ppm in landfill gas. The concentrations are closely related to the compositions of substrates. It is a compound harmful for the environment and for many technical applications because is extremely corrosive.
- ***NH_3:*** is formed by sub product of the acidogenesis reaction in digester. It is found in landfill gas concentrations generally less than 100 ppm; in the landfill gas is present in trace amounts. In high concentrations, it is harmful in many technical applications.
- ***Solids:*** every system of anaerobic digestion provides suspension solid particulate also of large size (up to orders of magnitude of mm), also the flow of biogas can be affected by the formation and by dragging foams.

Biogas composition [15][16][19]

- . ***Halogen compounds*** in the biogas are mostly in the form of molecules containing chlorine or fluorine, such as carbon tetrachloride, chlorobenzene, chloroform, trifluoromethane. They are mostly found in landfill gas due a result of volatilization of MSW, but are rarely in gas digesters. The combustion of these compounds causes the emission of dioxins and furans, micro pollutants of high environmental impact. The total chlorine is detectable in biogas from landfill in amounts of about 20 to 200 mg / Nm^3, in the gases from anaerobic digesters is almost absent (0 to 5 mg / Nm^3).
- ***Siloxanes:*** are volatile organic compounds that contain silicon and oxygen. We can found in higher concentrations in the biogas from the anaerobic digestion of wastewater sewer, due to discharge of urban silicon compounds contained in origin: detergents and cosmetics. The biogas from digestion from sewage purification sewerage show peak concentrations of 400 mg / Nm^3, in the production of biogas from other substrates (from agriculture, livestock) are highlighted instead lower contents, of the order of 30 ÷ 50 mg / Nm^3. A Dena study [5] (German study) shows evidence that only two types of cyclic siloxanes are present to a significant extent in biogas: these are molecules octamethylcyclotetrasiloxane and decamethylcyclopentasiloxane

Biomethane-contaminants to remove



biogas from sludge, agriculture and landfill gas

		Biogas from sludge	Biogas from agriculture	Landfill gas
CH_4	%vol	65-75	45 - 75	45 – 55
C_xH_y	%vol	< 300 mg/Nm3		
CO_2	%vol	20-35	25-55	25-30
CO	%vol	< 0,2		
N_2	%vol	3,4	0,01 - 5,0	10 – 25
O_2	%vol	0,5	0,01 - 2,0	1 – 5
H_2	%vol	tracks	0,5	0
H_2S	mg/Nm^3	< 8000	10 - 30.000	< 8000
Mercaptans	mg/Nm^3	0	< 0,1 - 30	-
S	mg/Nm^3	-	-	-
NH_3	mg/Nm^3	tracks	0,01 – 2,5	Tracks
siloxanes	mg/Nm^3	< 0,1 – 5,0	tracks	< 0,1 – 5,0
Aromatic hydrocarbons	mg/Nm^3	< 0,1 – 5,0	0	< 0,1 – 5,0
CFC	mg/Nm^3	0	20 – 1.000	-
Oil	mg/Nm^3	tracks	tracks	0
Relative humidity	%	100	100	< 100
T°	°C	36 - 60	36 - 60	0 - 25

Biogas Composition and Natural Gas Standards

	Biogas yield (l/kg VS*)	Methane content (%)
Fat	1000–1250	70–75
Protein	600–700	68–73
Carbohydrate	700–800	50–55

*VS = Volatile Solids

[Wellinger et al., IEA Task37 (2009)]

Parameter	Biogas	Specification according to ÖVGW G31	Unit
methane	50 bis 70	-	[mole %]
carbon dioxide	25 bis 45	≤ 2,0	[mole %]
ammonia	up to 1.000	technically free	[mg/m_N^3]
hydrogen sulfide	up to 2.000	≤ 5	[mg/m_N^3]
oxygen	up to 2	≤ 0,5	[mole%]
nitrogen	up to 8	≤ 5	[mole %]
water vapour (dewpoint)	up to 37 @ 1 bar	≤ - 8 @ 40 bar	[°C]
upper heating value	6,7 - 8,4	10,7 - 12,8	kWh/m_N^3
Wobbe-Index	6,9 - 9,5	13,3 - 15,7	kWh/m_N^3

Reduction of greenhouse gas emissions

- A central aspect of sustainability is the protection of climate and resources, resulting in the avoidance of greenhouse gas emissions: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (so-called laughing gas, N_2O) and fluorinated compounds such as chlorofluorocarbons (CFC) [6].
- The following factors along the value chain are crucially responsible for greenhouse-gas emissions the used biomass and its cultivation,
- the transport, storage and conservation (ensilage) of the biomass,
- the biogas plant and fermentation technology,
- the losses of biogas and biomethane into the atmosphere,
- the storage and application of fermentation residue,
- the utilisation of biogas and the upgrading of biogas to natural gas quality and its subsequent use;

- using optimum production-installation technology, the largest proportion of the emissions within the overall process **emerges in producing the biomass**. Accordingly, an intelligent choice of raw materials can positively influence the overall GHG balance; for this reason especially the use of plant residues and waste materials is recommendable.

- Agriculture contributes to climate change with GHG emissions amounting to around 130 m tonnes of CO_2 equivalent/year (ca. 13 % of Germany’s emissions). In this context, the key sources are ruminants’ digestion processes (CH_4), crop production (CO_2 and N_2O), the decomposition of carbon in former fens and the energy requirements of the operating resources used [4]. At the same time, agriculture is not solely a source of greenhouse gases, it also contributes to GHG reduction. This by means of plants storing CO_2 in the process of photosynthesis.
- Biogas and biomethane can also provide a decisive contribution to reducing the burden on the environment by replacing fossil-based energy sources, resulting in a reduction of CO_2 emissions. What is decisive in this regard is essentially the minimization of losses of biogas and biomethane, because methane has a more powerful effect on the climate than CO_2 does, by a factor of 21 [6] or of 25 [7] respectively.
- Aside from greenhouse gas emissions generated in producing biogas and bio-methane, efficient use has a major influence on reduction of greenhouses gases. In particular, producing electricity while simultaneously using the heat generated in that process achieves a noticeable reduction in greenhouse gases. Efforts to achieve efficient use of the biomass deployed are leading to more and more concepts for heat supply in villages and municipalities, based on biogas plants. If no complete and efficient use of the heat is possible at the biogas plant or within a distance of a few kilometres, the opportunity still presents itself to convert the biogas into biomethane. That way, biomethane can be transported via the natural gas grid and used at a location with a high demand for heating.

GHG results for the production of biomethane

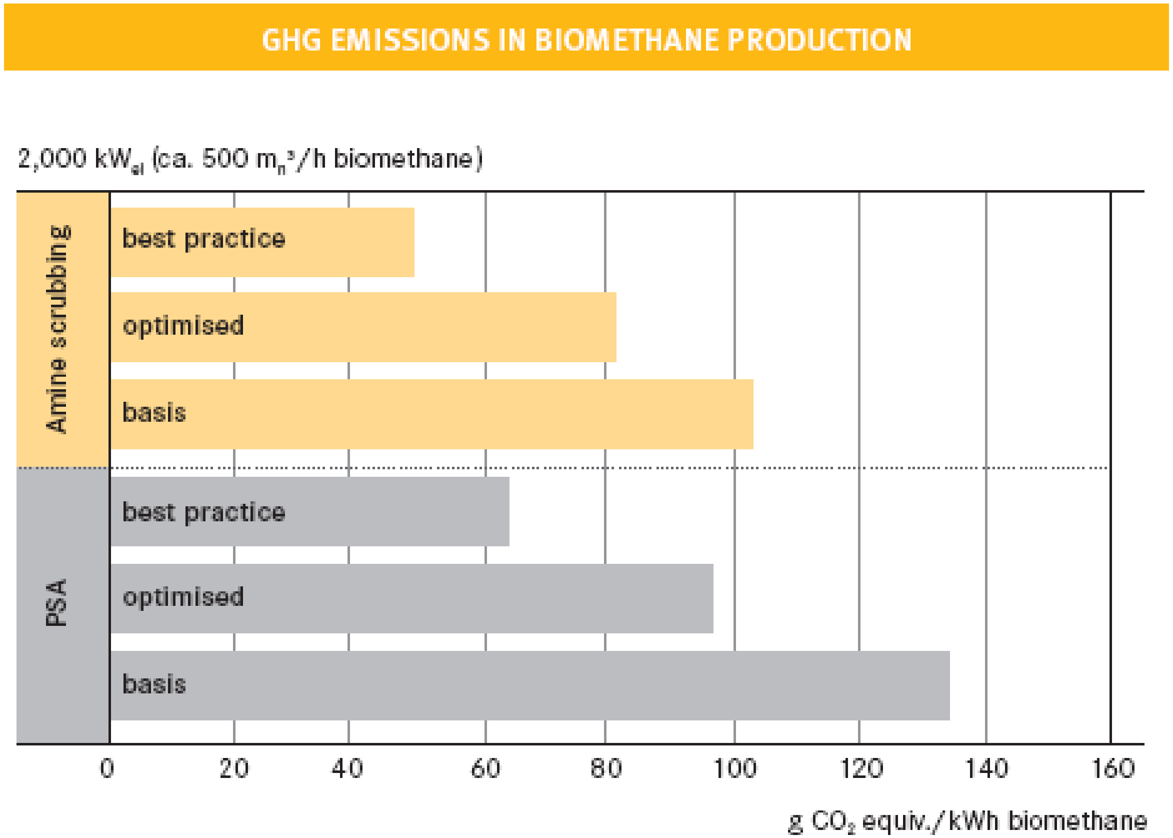


Fig. 4: GHG results for the production of biomethane, basis is a biogas plant of 2,000 kWel; the equivalent corresponds to ca. 500 mn3/h biomethane; increase of pressure up to 16 bar [21]

- Figure 4 compares the greenhouse gas emissions involved in biomethane production for the following upgrading processes: pressure-swing adsorption (PSA) and amine scrubbing. Here both processes are considered based on taking into account three variations (“basic”, “optimised” and “best practice”) for the whole process chain, i. e. the greenhouse gas emissions are added together, starting from biomass production, via transportation and through to the biogas upgrading and the raising of pressure to 16 bar.

- **“Basic”/“optimised”**
- gas-tight covered storage for fermentation residue: no methane emissions
- biogas production: methane emissions of 0.45 %
- plant energy requirement: covered by a biogas-operated combined heat and power installation (CHP); heat-led (i. e. heat requirements are the determinant of operations); 55 % of the electricity production for the biogas plant, 45 % is fed in and booked as a credit entry in the calculation system. Methane emissions of CHP: 0.5 %.
- **“Basic”**
- Processing by PSA: methane emissions and methane slip of 2 %, electricity requirement: 0.3 kWhel/mn3 raw biogas
- Processing by amine scrubbing: methane emissions and methane slip of 0.1 %, electricity requirement: 0.168 kWhel/mn3 raw biogas, heat requirement: 0.4 kWhth/mn3 raw biogas, heat produced by a natural gas heating plant

- **“optimised”**
- Processing by PSA: 2 % methane losses with the use of post-combustion, final methane emissions of 0.01 %, electricity requirement: 0.3 kWhel/mn3 raw biogas
- Processing by amine scrubbing: methane emissions of 0.1 %, energy requirement: 0.168 kWhel/mn3 raw biogas, heat requirement: 0.4 kWhth/mn3 raw biogas; heat regeneratively produced by a biomass heating plant

- **“best practice”**
- beyond the optimised installation concept: lower mass losses during the silage making process; higher gas yield; lower methane emissions from the biogas plant, the CHP installation and in the upgrading process; lower losses of nitrogen in form of ammonia and laughing gas, by means of optimised management of fermentation residues [21]

- It is evident that with “best practice” assumptions, GHG emissions can be reduced by ca. 50 % compared to the basic model [21].
- As a generally valid observation, legislative limits are set regarding the maximum permissible methane emissions into the atmosphere at the upgrading of biogas to biomethane: with the new Gas Grid Access Ordinance (GasNZV), in force since 2010, a biomethane supplier from a new upgrading installation must prove that, based on regular operation of the installation, the maximum methane emissions into the atmosphere do not exceed 0.5 %. In the case of installations connected to the natural gas grid after

- 30 April 2012, the relevant value is reduced to 0.2 %. Likewise, the Renewable Energy Sources Act (EEG) 2012 limits the maximum emissions into the atmosphere to 0.2 % for new installations coming into operation after 1 January 2012, and from 1 May 2012 for installations already in service. In order to be able to guarantee this, and thus to limit emissions into the atmosphere, in the case of upgrading processes which involve higher levels of methane slip, the exhaust gases are subjected to an after-treatment process.
- All things considered, it is evident that, in replacing fossil fuels, biogas and biomethane can contribute decisively to the reduction of CO2 emissions. A precondition for this is low GHG emissions along the whole value chain. The lower the GHG emissions in producing biogas and biomethane, the more relevant the effect are in climate-protection terms.
- Fig. 5:

3 PRODUCTION OF BIOGAS

- Biogas arises during the microbial decomposition of organic matter, subject to the almost complete exclusion of oxygen. This process of decomposition occurs widely in nature, for example in bogs, fens and swamps or in ruminants stomachs. This process is technically performed in biogas plants.
- The biogas produced is a gas mixture comprised of ca. 2/3 methane and 1/3 carbon dioxide, as well as small quantities of water, hydrogen sulphide, nitrogen, oxygen, hydrogen and other trace gases.
- In principle, the biological process of decomposition (fermentation) can be subdivided into four phases, each of them involving different groups of micro-organisms. The phases themselves take place in a biogas plant in parallel and simultaneously. Within this, temperature, pH value, nutrients supply and inhibitors have a substantial influence on the fermentation process:

Use of substrates

As a general observation, biogas can be produced from a large number of substrates. The resources used in agricultural biogas plants, besides animals' excrement (such as cattle slurry and pig slurry), residues of fodder and other agricultural organic residues, are mainly renewable resources. Examples of these are maize, grasses, grain, sunflowers and sugar beets. However, other organic substrates can also be used for biogas production, such as residuals from the food industry, vegetable or other food waste, landscaping material, green cuttings or organic waste from municipal waste disposal. The degree of degradability and the dynamics of fermentation, as well as the yield of biogas, are determined by the substrates used, together with the technical and biological performance characteristics of the production installation and of the fermentation process. [1]

SCHEME OF AN AGRICULTURAL BIOGAS PLANT

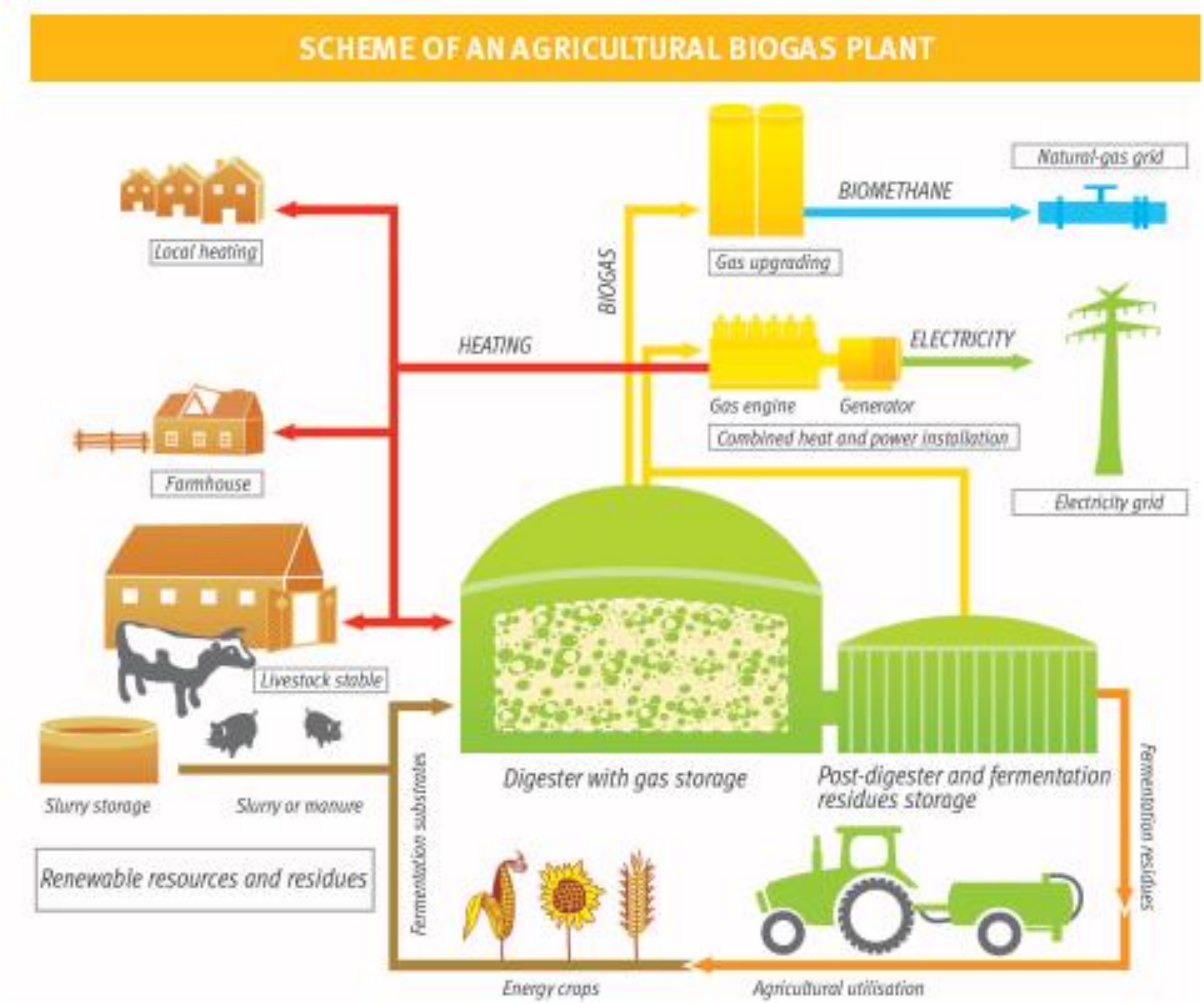


Fig. 6: Scheme of an agricultural biogas plant [14]

Plant engineering

- An agricultural biogas plant usually consists of
- a preliminary tank, with a feed mechanism for solid matter storage,
- a insulated gas-tight and heated digester with a stirring device,
- a gas storage,
- a storage for fermentation residue, and
- the biogas utilisation (e. g. a combined heat and power installation).

The digester is the core element of the unit; it must, Appropriate stirring technology is used to guarantee the homogeneity of the fermentation substrate and to support the formation of gas. The gas storage takes up the biogas while the fermented substrate goes into the store for fermentation residues; the latter usually also serves as a post-digester. While the biogas is then taken to serve its designated purpose, the fermentation residue can be distributed on arable land as valuable farm fertiliser (Figure 6).

Biogas purification

- In order to be able to feed biogas into natural gas grids or to use it as a fuel in natural gas vehicles, the gas needs to be purified of unwanted constituent elements, the methane content needs to be increased, and the CO2 and others pollutants needs to be removed. upgrading of the bio-gas into biomethane.
- biogas upgrading differ according to the use: on-site electricity conversion in CHP installations or gas injection.
- The composition and origin of the biogas (renewable resources, slurry, waste material, sewage sludge, etc.), as well as the subsequent upgrading technology, define the type of purification used for the biogas and the sequence of the steps in the purification process.

BIOMETHANE PRODUCTION Available technologies

- At present, **there are five different technologies** used in to remove the CO_2, for the purpose of methane enrichment:
- PSA – pressure swing adsorption,
- pressurised water scrubbing,
- physical absorption with organic solvents,
- chemical absorption with organic solvents, and
- membrane processes.
- Cryogenic procedures (in the low-temperature range) are not yet in commercial-scale use in the upgrading of biogas.

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Biogas purification steps

1
- Preconditioning / pretreatment
- Removal of particles, droplets, siloxanes, other trace components

2
- Biogas desulphurisation

3
- Compression

4
- Biogas upgrading
- Separation of CO_2 and H_2O

5
- Final conditioning
- Dewpoint control, adjustment of heating value, offgas treatment

Preconditioning / Pretreatment

- ✓ **Particles, droplets:** use filter, demister
- ✓ **Siloxanes:** use carbon adsorption (water dewpoint control needed - place a chiller + reheater in front of the carbon adsorption tower)
- ✓ **Halogenated hydrocarbons, other hydrocarbons, fatty acids, terpenes:** use carbon adsorption (water dewpoint control needed - place a chiller + reheater in front of the carbon adsorption tower)

Dehumidification/drying

- Biogas is saturated with water vapour and this water must be extracted from the gas, to prevent faults in the subsequent upgrading and also to ensure compliance with the limit values applicable to the feeding-in of biomethane.
- Usually dehumidification/drying takes place at two positions in the bio-methane plant:
- If a compression takes place before entry into the actual CO2 removal stage (e. g. scrubber column, molecular sieve or membrane), a cooling process extracts water from the biogas which is heated by the compression process, in order to prevent an unwanted condensation of the humidity in the system further downstream.
- In the case of scrubbing processes, the bio-methane is dried after it exits the scrubbing column.

Desulfurizationo-removal H2S

- **Various technologies available:**
  - In-situ desulphurisation
  - Air injection
  - External biological desulphurisation
  - Chemical oxidation
  - Adsorptive removal (iron oxide, zinc oxide)
  - Catalytical oxidation and carbon adsorption (KI/I_2 – impregated carbon, needs stochiometric amount of oxygen)
  - Combined with upgrading: water/amine absorption
- Ask, if there is a desulphurisation currently used or implemented
- Check the H_2S concentration and feedstock related fluctuations

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Compatible desulfurization technologies

Compatible:

- External biological desulphurisation in combination with pure oxygen injection
- In-situ desulphurisation using iron salts
- **External chemical scrubber with oxidation using $NaOH/H_2O_2$, recommended for fluctuating H_2S concentrations in the biogas**
- Adsorptive desulphurisation technologies with low excess of O_2 (impregnated activated carbon adsorbents)

Not suitable / incompatible:

- Air injection
- External biological desulphurisation with air injection

Physical Mechanisms

- The **<u>physical absorption</u>** is caused by physical interactions (Van der Waals forces) between the molecules of the species that absorbe and those of the solvent.
- It establishes a linear relationship between the partial pressure of the species to absorb in gas phase and the its quantity dissolved in the solvent. Assuming the thermodynamic equilibrium for the solvent on the bottom of the column it is deduced that it is possible absorb considerable quantity of the species to be separated with relatively little solvent only if its partial pressure in the gas is high (in the case of CO_2 in the biogas).
- The pressure, in fact, has a strong effect on the equilibrium.

chemical Mechanisms

- The chemisorptions is characterized by formation of **chemical bonds** between the molecules of the species that absorbs and those of a compound already dissolved in solvent. Typically, are used compounds that give rise to reactions with chemical balances very favourites, proceeding practically until empty reagent.
- On the bottom of the column is possible to remove good quantity of the substance to absorb, even if it has a modest pressure partial, with moderate amounts of solvent. The increase of the partial pressure of the gas to remove the solvent rapidly becomes saturated.
- In this case the pressure **has little effect** on pressure absorption. You can adopt mixed systems, which combine the advantages of physical and chemical absorbent, using physical solvents which are of dissolved chemical sorbents. This allows you to extend the scope of application and encourage the reutilization of the solvent.

Absorption with water washing

- The system of absorption with water scrubbing is a purely physical method to separate the carbon dioxide from the stream of biogas. The CO_2 is in biogas in high percentage (up to about 50%) and the techniques of absorption physical feature, as mentioned, good removal efficiencies in this condition operational. Is carried out in normal packed columns. Feeding the flow of biogas column, pre-stressed 4 ÷ 12 bar, acid gases such as dioxide carbon dioxide and hydrogen sulphide are removed simultaneously due to the difference between the binding forces of CO_2 and H_2S (polar) and CH_4 (non polar). The project of washing process of gas is realized from gas solubility that , depends on **Temperature, Pressure and Acidity**.

Solubility of CO_2 in water at different T [$kgCO_2$ / kgH_2O]				
T°	0°C	10°C	20°C	30°C
1 bar	0,4	0,25	0,15	0,10
20 bar	3,15	2,15	1,30	0,9
50 bar	7,7	6,95	6,0	4,8

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Removing carbon dioxide- Absorption

- The separation of CO_2 occurs by contact of the biogas flow with a liquid stream that can absorb selectively respect to the other components of biogas. The contact is in counter current.
- It feeds the gas flow (from below) and the liquid (from the top) of a column inside which there are elements to enhance the transfer of material from one phase to another. The purified gas stream exits from the top of column, while, from below, the liquid solvent flows, rich in dioxide carbon that was removed to biogas.
- It is necessary to regenerate the solvent with removal of CO_2 absorb. The processes of absorption are classified also in function of the regeneration mode of the solvent: the species absorb can be released for simple **expansion** of the solvent **(flashing),** by contact of the solvent with an inert gas stream (stripping), or by heating the solvent **(reboiling**).

Removing carbon dioxide- Absorbtion

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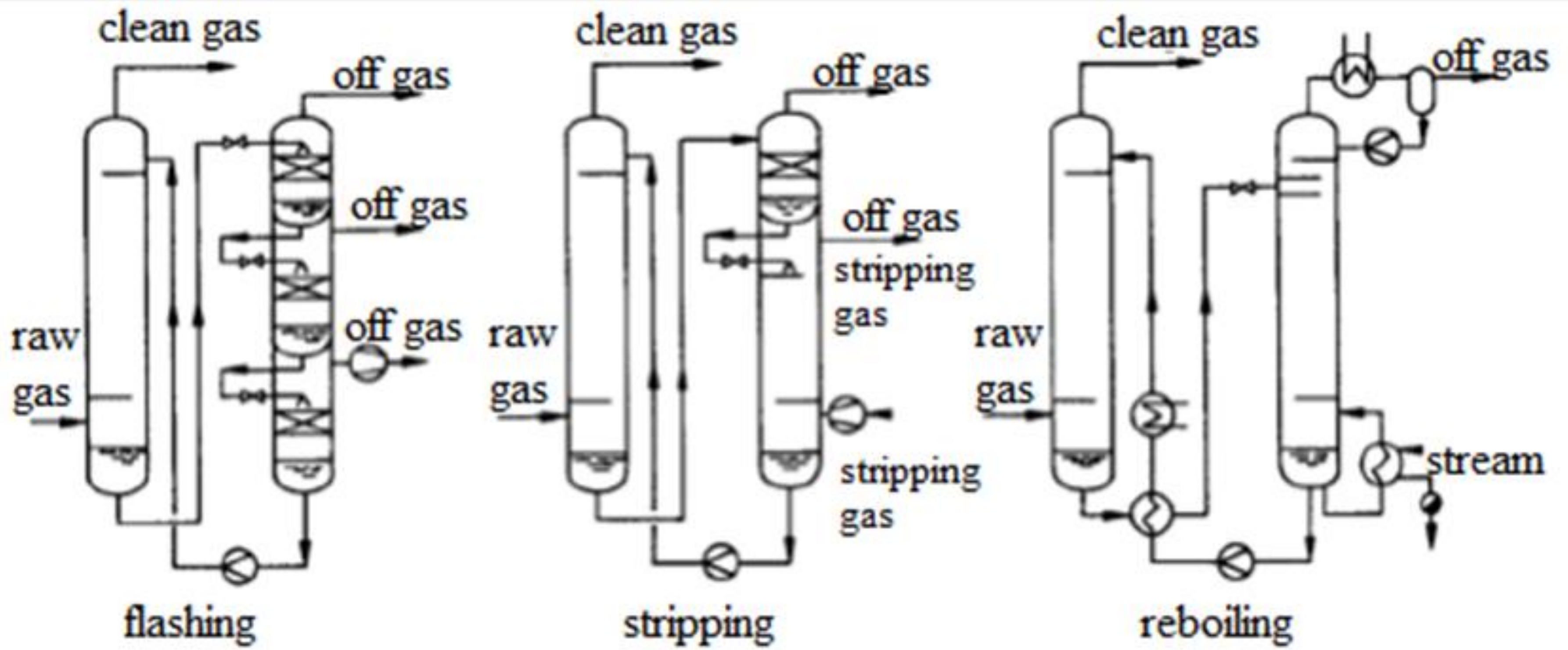
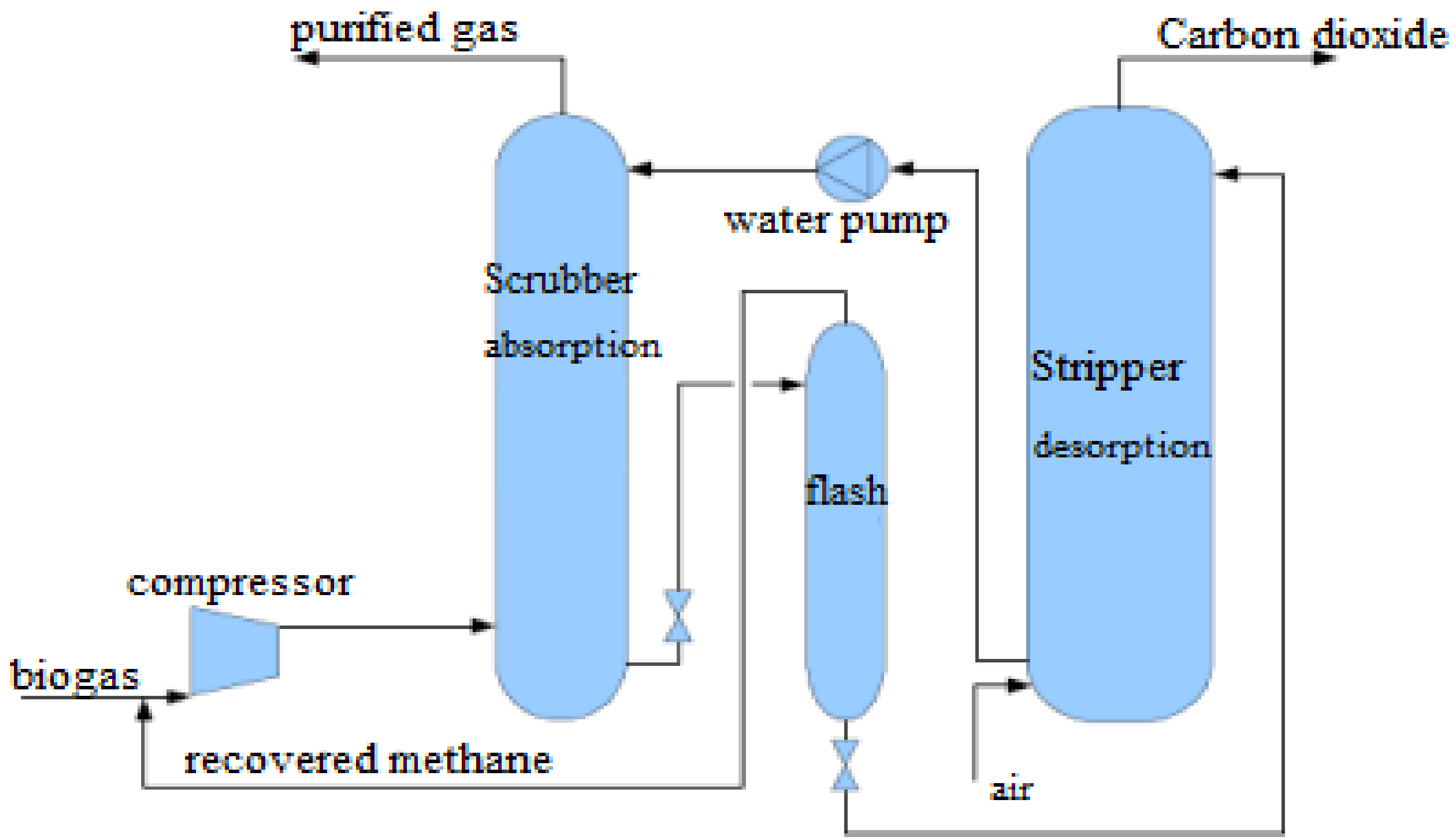
flashing, stripping and reboiling



washing process with regeneration



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Regeneration

- The regeneration is performed by expanding the solvent (flashing), usually in atmospheric pressure. To facilitate the desorption is possible to apply sub-atmospheric pressures, high temperatures and possibly one stripping with air. Depending on the technical requirements and design choices, with this process we can subtract from biogas, as well as the carbon dioxide also hydrogen sulphide. But in this case, during the regeneration both components are released , therefore is necessary to have additional treatments to prevent the introduction of hydrogen sulphide into the environment.
- The alternative is the separation of H_2S before of enrichment of biogas; in this way we avoid the corrosion problems on the plant and can be released directly into the ambient gas desorbed from the solvent. If there is the availability of large amounts of water, as in plants purification of sewage sludge, it is possible to opt for a system with a single column without regeneration. In this way the water used for the absorption will be a large amount, and then the carbon dioxide content will be dispersed directly in the environment (in this case it is appropriate that the concentration of other dissolved contaminants (H_2S) is low to not require a step of post-treatment). In any case, the absorption column is frequently subject to clogging for fouling, is therefore necessary to adopt columns equipped with automatic cleaning.
- the removal efficiency of absorption can incresed mixed physical-chemical, using solutions of calcium hydroxide $Ca(OH)_2$, CO_2 and H_2S that react with it to form $CaCO_3$ and CaS, precipitates insoluble.
-

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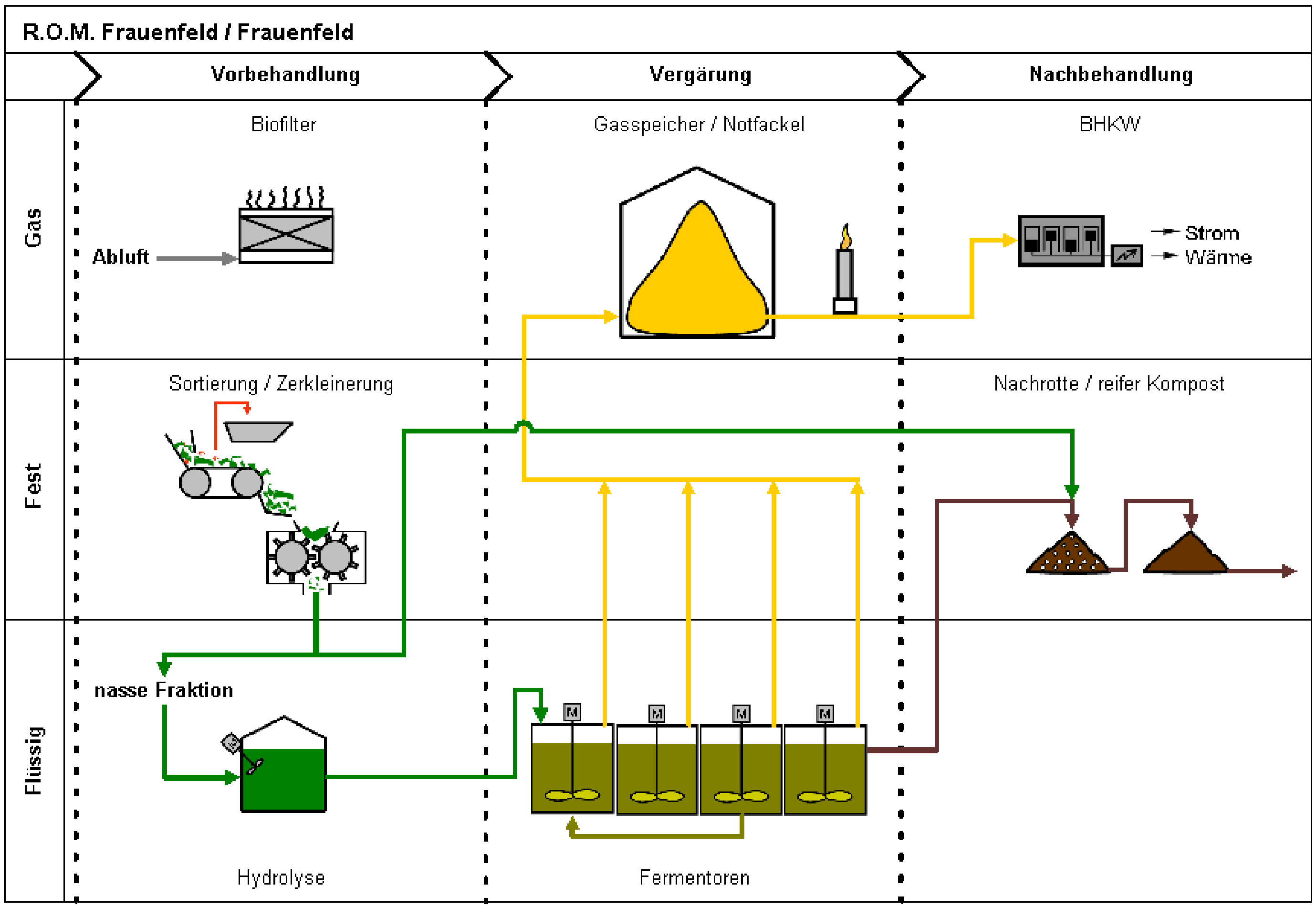

R.O.M. Frauenfeld / Frauenfeld
Vorbehandlung
Vergärung
Nachbehandlung
Gas
Fest
Flüssig
Biofilter
Abluft
Gasspeicher / Notfackel
BHKW
Strom
Wärme
Sortierung / Zerkleinerung
Nachrotte / reifer Kompost
nasse Fraktion
Hydrolyse
Fermentoren
M

Desulphurisation

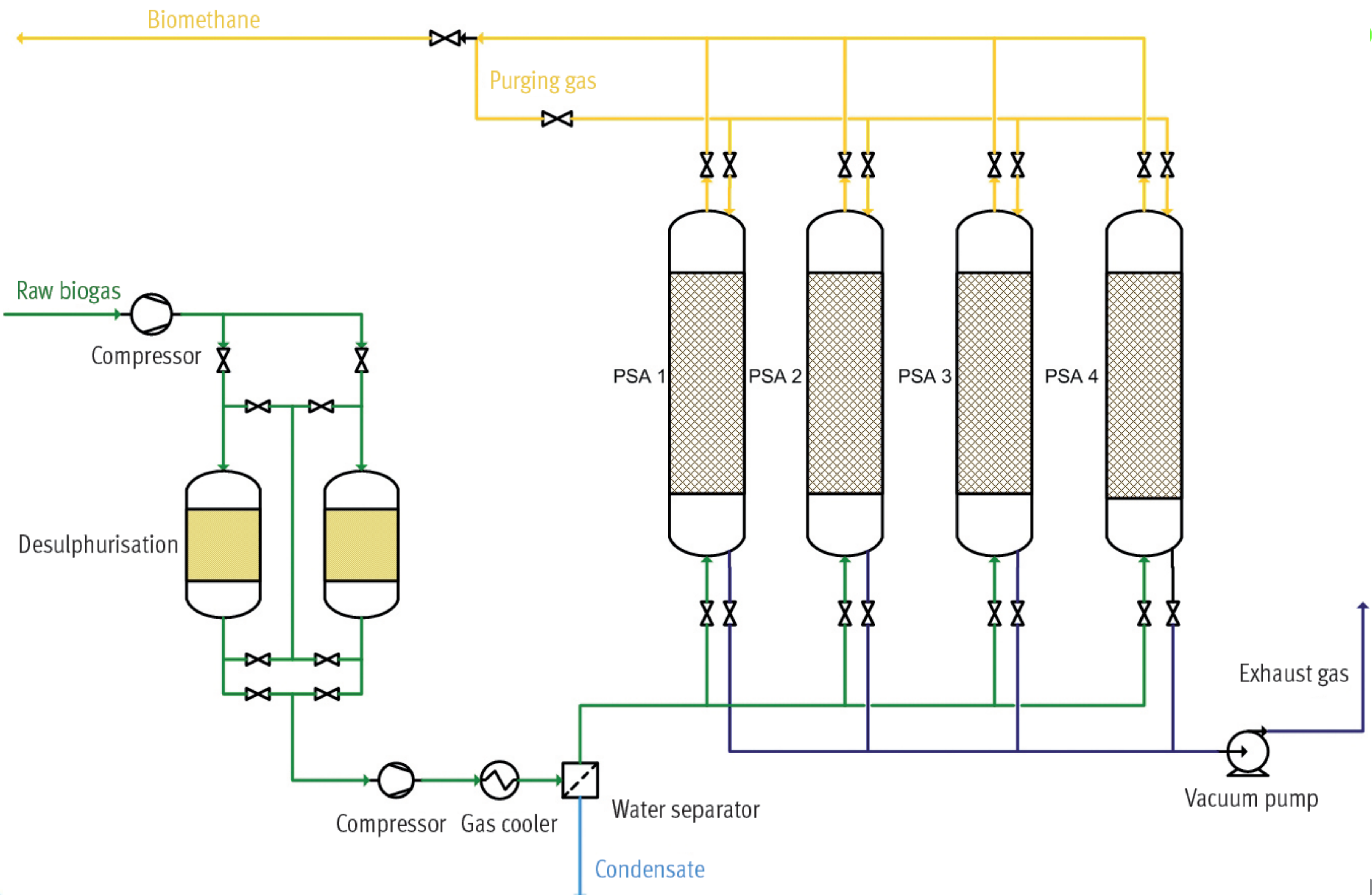
- Hydrogen sulphide (H_2S) can occur, depending on the origin of the biogas, in concentration ranges from ~70 mg/mn3 up to (in some cases) over 10,000 mg/mn3. In combination with water, sulphuric acid can be formed. In order to avoid corrosion of the parts of the production installation and to comply with the quality requirements in force for feeding the biomethane into natural gas grids (the same applies for its direct use as a fuel), the biogas needs to be desulphurised. A basic distinction is made between coarse 14
- desulphurisation and fine desulphurisation processes. For coarse desulphurisation, the biological desulphurisation in conventional agricultural biogas plants directly using gas in CHP units is usually carried out in the fermenter by means of adding doses of air. However, in the case of biogas plants involving biogas upgrading, this process is only applicable to a limited degree and subject to particular preconditions; this is because the result is a thinning of the biogas with atmospheric nitrogen. This cannot be separated off any more by practically any of the biogas upgrading technologies. To avoid these thinning effects, it is mostly the following processes that are applied for coarse desulphurisation:
- Adding doses of iron hydroxide and/or iron salts into the fermenter,
- External biological desulphurisation outside the fermenter or
- Caustic treatment with biological regeneration of the washing agent.

- For fine desulphurisation (reducing the concentration of hydrogen sulphide to < 5 mg/mn3), the process of catalytic oxidation and adsorption with impregnated activated carbon is the state of the art; it is to be found in operation at almost all biogas-upgrading facilities.
- Apart from the constituent parts described above, and depending on the origin of the raw biogas, other trace gases can also occur: these also need to be separated off. Among others, these include ammonia, organic silicon compounds, halogens and aromatic compounds. [2]

Carbon dioxide removal
PSA – Pressure swing adsorption

- Pressure swing adsorption constitutes an adsorptive biogas upgrading process. Adsorption should be understood as the deposition of constituent parts of gas (here: CO_2) onto the surface of solid matter (adsorbents). Activated carbons, zeolites or carbon molecular sieves can be used as adsorbents. Apart from CO_2, however, other constituent parts of gas can also be retained, such as water (H_2O) or hydrogen sulphide (H_2S) or also, to a very small degree, nitrogen (N_2) and oxygen (O_2). However, in practical application H_2O and H_2S are already removed before the biogas enters into the adsorption column. [2]
- In this process, there is initially an increase of pressure up to a level of ca. 4 to 7 bar. After the subsequent separating of the water and the fine desulphurisation, the gas is guided into an adsorption column in which the molecular sieve is located. This is where the CO_2 is retained by means of deposition onto the

pressure swing adsorption with four



Pressure swing adsorption [13]

Project Pucking Pressure Swing Adsorption (PSA)

(Photos: M.Harasek)

Pressurised water scrubbing (PWS)

- Pressurised water scrubbing constitutes an absorptive biogas upgrading process. In contrast to adsorption, absorption is the dissolving of gases in fluids (absorbents). In the case of pressurised water scrubbing it is solely water that is used as an absorbent. The process is based on the reversible absorption in water (through physical bonding forces (physisorption)) of CO_2, but also of other constituent parts of gas exerting an acidic effect (e. g. H_2S) and alkaline effect (e. g. ammonia – NH_3). The fine desulphurisation of the biogas in the absorption column is a side effect of this process.
- After compression, usually consisting of several stages and taking the pressure to levels between ca. 7 bar and 10 bar, the raw gas progresses from below into the absorption column. The water streams through the column from top to bottom and is charged with the constituent part of gas which is to be absorbed. The product gas, saturated with water, leaves the column at the upper end and subsequently it still needs to be dried. As some of the CH_4 also formed bonds with the charged water particles, initially this water is subjected to a process of lowering of its surface tension, in a so-called "flash" column. The gas desorbed in this intermediate stage of lowering of surface-tension leaves the "flash" column at the upper end and is guided back into the flow of raw gas. The water, which above all still contains dissolved CO_2, is guided into the desorption column from above; there its surface tension is reduced, taking it to the level of atmospheric pressure. In addition, to accelerate the expulsion of the gas from the water, air is blown into the desorption column from below. The water is now regenerated and can be used once again for the purpose of absorption in the scrubber column. The dissolved exhaust gas leaves the column at the upper end of the desorption column. As the exhaust gas flow still contains residual quantities of CH_4, usually the exhaust gas needs to undergo an after-treatment. [2]

Pressurised water scrubbing [13]

Physical absorption with organic solvents (Genosorb® scrubbing)

- This process also involves a purely physical absorption (physisorption). Yet in contrast to pressurised water scrubbing, an organic reagent (e. g. polyglycol mixes) is used as the absorbent. Before the raw gas enters into the absorption column, compression is used to take the pressure level to ca. 8 bar. Through a cooling of the compressed gas, set up further downstream in the process, water is condensed and subsequently it can be expelled from the system. In the absorption column the stream of absorbent goes through the biogas in counter-flow, forming bonds with CO2 as well as with H2S and H2O. Thus, as is the case with pressurised water scrubbing, the fine desulphurisation process can be omitted. The product gas, dehumidified as well as finely-desulphurised by the hygroscopic characteristics of the absorbent, exits the column at the other end. Depending on the product gas requirements or respectively on the composition of the raw gas, there is the possibility to conduct an additional fine desulphurisation process and/or adsorption drying of the product gas, for example. As in the case of pressurised water scrubbing, what happens here also is initially a lowering of surface tension of the charged washing solution in a "flash" column. The complete desorption takes place through supplying heat (ca. 50–80 °C) and also supplying stripped air in the desorption column. The provision of heat is possible due to the decoupling of waste heat from the compressor. In parallel, the process is characterised by the possibility to have parallel absorption of CO2, H2S and H2O in the scrubber column. In this process also, the exhaust gas flow contains residual quantities of CH4 and thus there usually needs to be an after-treatment of the exhaust gas. [2]

Physical absorption with organic solvents (Genosorb® scrubbing) [13

]

Chemical absorption with organic solvents

- Chemical absorption with organic solvents, often referred to in practice as “amine scrubbing”, constitutes a chemisorptive process. Depending on the production installation manufacturer, different ethanolamine-water mixtures are used (e. g. monoethanolamine or diethanolamine). In contrast to the purely physical washing processes, the scrubber column can carry out an absorption process almost without pressure (ca. 100 mbar). Depending on the manufacturer, however, processes are also used in which the gas is compressed to up to 4 bar before it enters into the absorption column. As co-absorption of H_2S is possible in the cleaning unit, most processes involve a fine desulphurisation of the biogas. As with all other upgrading processes, N_2 and O_2 should be prevented from entering, as N_2 is not absorbed and thus the result can be a thinning of the product gas. The presence of O_2 in the raw gas exerts an additional negative effect in this process, because it can result in an unwanted oxidation of the absorbent. The regeneration of the charged absorbent takes place in the desorber, with heat being applied. Depending on the manufacturer, heat is required at a temperature of 110–160 °C. The particular features of the process are very high levels of purity of the product gas (on the precondition that no N_2 or O_2, or very little, is contained in the raw gas) and, compared to other upgrading processes, a very low level of methane losses. An after-treatment of the exhaust gas, as is necessary in the case of other upgrading processes, can usually be omitted. After the absorption process, the product gas is saturated with humidity, a drying operation is required. [2]

Membrane process

- In the case of membrane processes, also referred to as gas permeation processes, various degrees of permeability of polymer membrane materials are used to separate unwanted constituent parts of gas from the biogas. Polymers used include, among others, cellulose acetate or aromatic polyimides. These membrane materials exhibit high permeability levels for $CO2$, $H2O$, $NH3$ and $H2S$ in comparison to their permeability for $CH4$. Particularly in order to extend the turnaround time of the membranes and to guarantee an optimum performance of the separation activity, in practical application, apart from separating off dusts and aerosols, a drying and fine desulphurisation of raw gas is necessary before it makes contact with the membrane. Thus, before the biogas reaches the membrane modules, firstly it is dried, then it is compressed to ca. 5 to 10 bar; then (depending on choice) before or after the compression the fine desulphurisation is carried out. In the membrane module, $CO2$ penetrates the membrane and the $CH4$ is retained. Mostly, in practical application it is multi-stage processes that are used. Residual quantities of methane in the permeate flow material necessitate an after-treatment of the exhaust gas. Beyond this, a combination of membrane separation/cryogenic processes is possible. [2] [25]

Membrane separation principle gas permeation

- Separation principle: different permeabilities of methane and components to be separated.
- Important parameter: permeability ratio = selectivity.
- After compression biogas is fed to membrane modules.

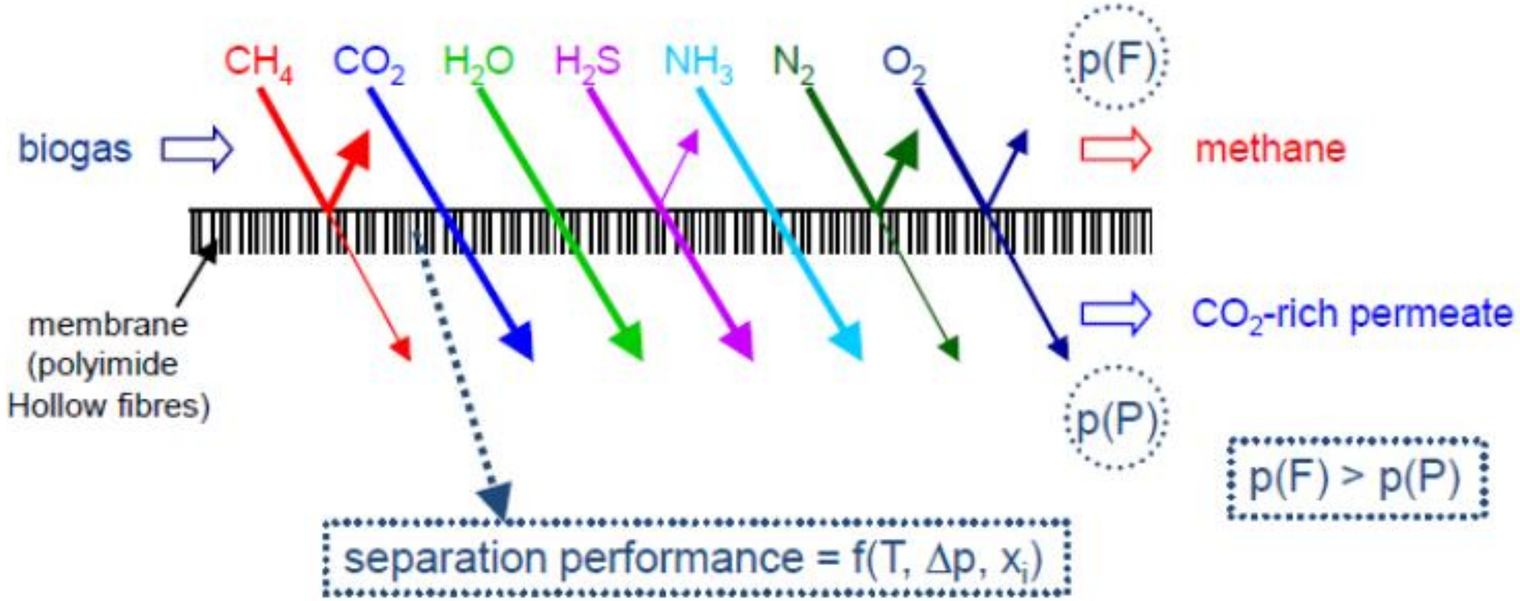


Fig. 10: Membrane installation [13]

Cryogenic separation

- In the case of low-temperature processes, the lowering of the temperature of the gas flow leads to condensation or respectively to re-sublimation of the CO2, whereby the CO2 is present in fluid or solid form. If the CO2 is sufficiently pure, it can be put also to commercial use. So far there has been little commercial-scale experience of using this process. [2]
- Figure 11 shows the extent of use of the different upgrading technologies in Germany.
- As a general observation, most upgrading technologies are also suitable for small-sized upgrading facilities in terms of their technical aspects. This becomes evident particularly when considered the structure of the biogas upgrading projects in other European countries, where on average significantly smaller installation capacities are in operation. Accordingly, there are or there have been (e. g. on a pilot-project scale) upgrading installations operating with raw gas capacities of < 150 mn^3/h for all of the currently in Germany used upgrading technologies on a commercial scale

DEVELOPMENT OF THE VARIOUS UPGRADING TECHNOLOGIES

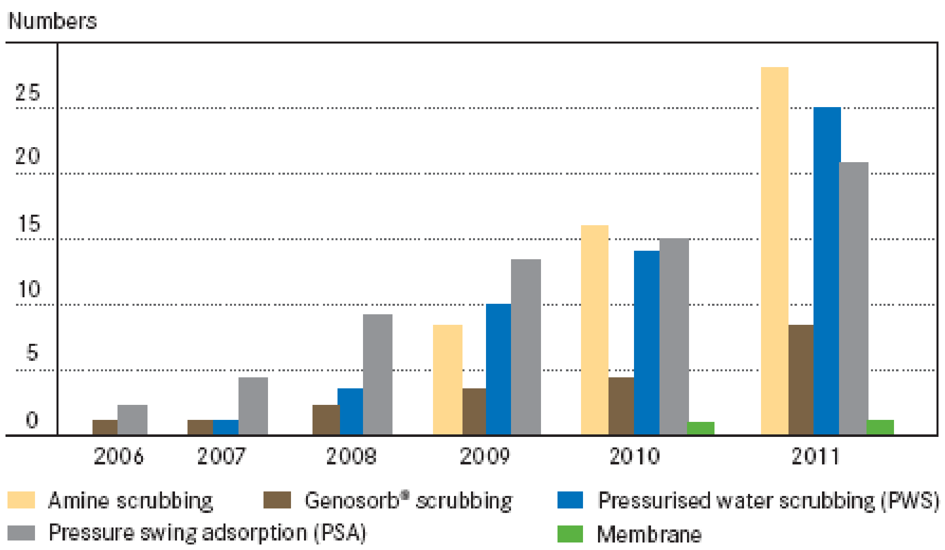


Fig. 11: Number of biogas upgrading plants, according to the upgrading technologies used, over the period 2006–2011 (cumulated) [12]

Compression

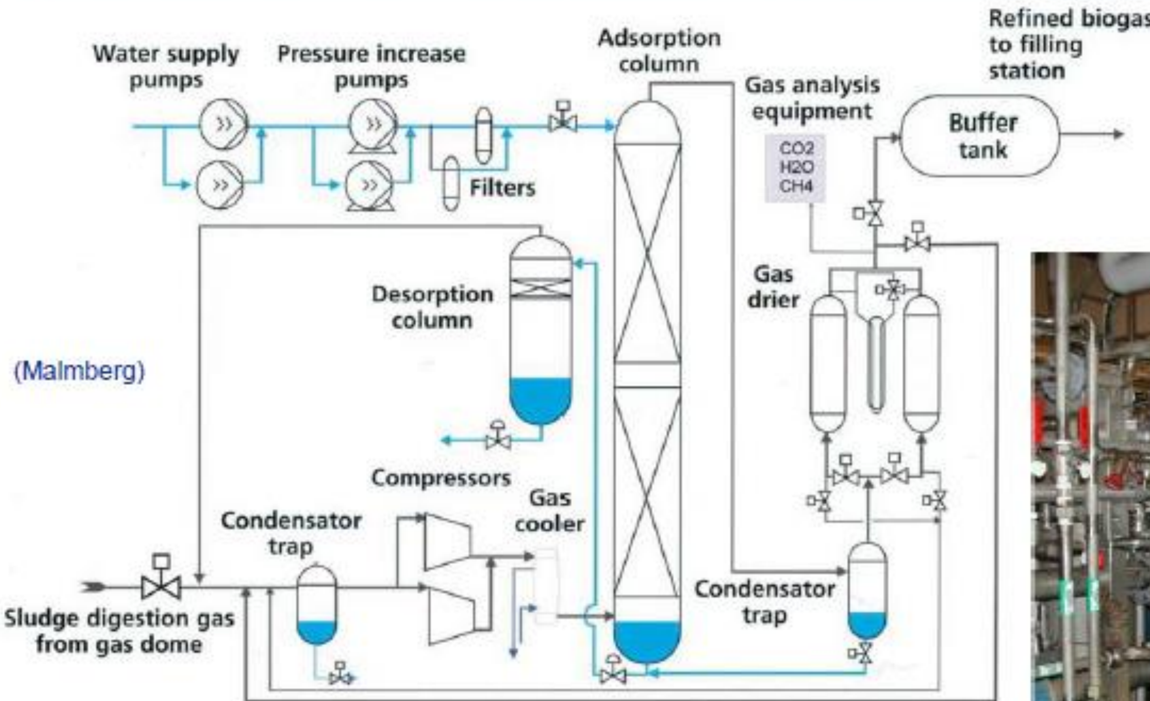
- Various types of compressors available:
  - Piston compressors
  - Screw compressors
  - Water ring pumps
  - Blowers
- Check range of load/capacity variation
- Check delivery pressure requirements
- Consider correct conversion volume flow to operating conditions (temperature, pressure), add recycle if needed
- Do not forget to account for water content / humidity
- Design for worst case and check turn-down ratio of compressor
- Check corrosion resistance, service intervals and lifetime
- Prefer oil-free systems (gear box lubrication only)
- Check cooling requirements – prefer water cooled systems

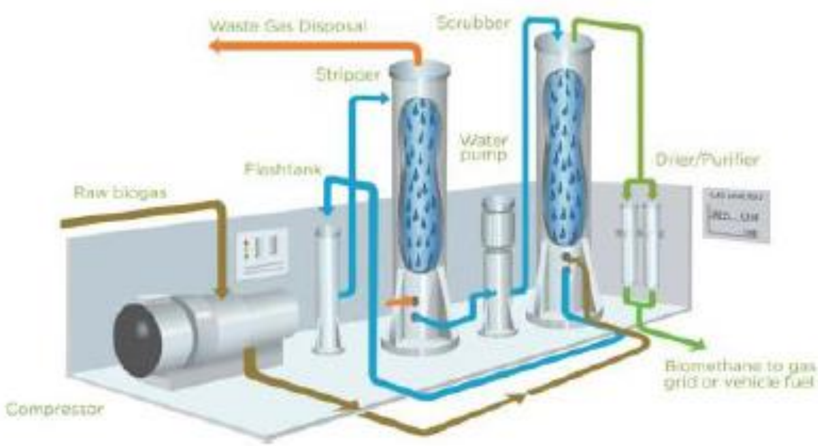
Biogas upgrading

- ✓ **Various technologies available**
  - ✓ Pressure swing adsorption
  - ✓ Water scrubbing
  - ✓ Selexol absorption
  - ✓ Amine absorption
  - ✓ Membrane separation
  - ✓ Cryo separation
  - ✓ Hybrid systems
- ✓ **Decide for suitable technology primarily NOT by investment costs – remember: cheap can be expensive!!**
- ✓ Select suitable technology according to:
  - ✓ upgrading capacity
  - ✓ turn-down ratio
  - ✓ shut-down / start-up performance and ease of operation
  - ✓ product quality needed
  - ✓ Chemicals and energy consumption

Water Scrubbing / Absorption

(Malmberg)

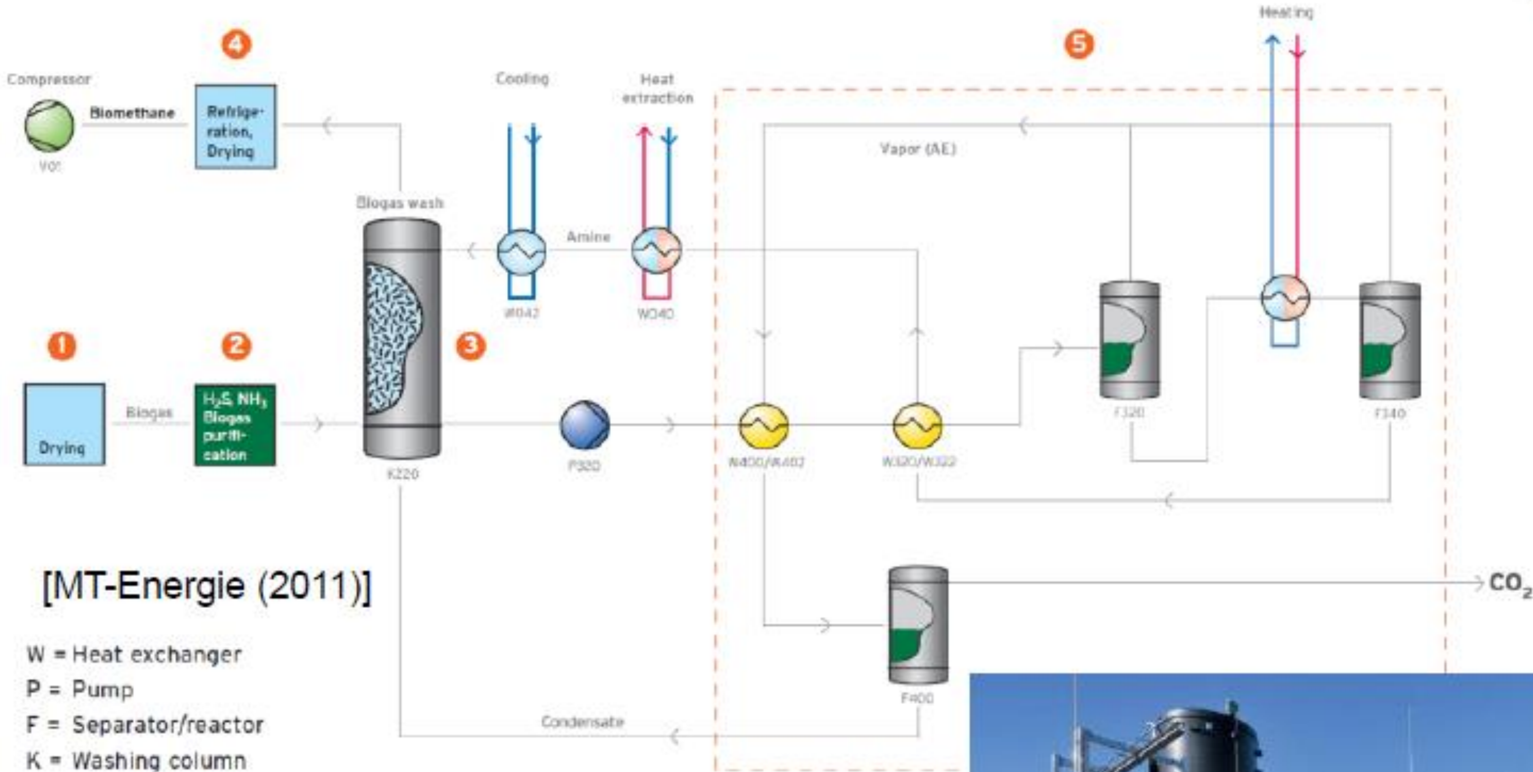




Austria's largest Upgrading Plant

- Waste water treatment plant Asten (near Linz)
- Malmberg – water scrubber (800 m^3/h biogas)

Amine absorption



[MT-Energie (2011)]

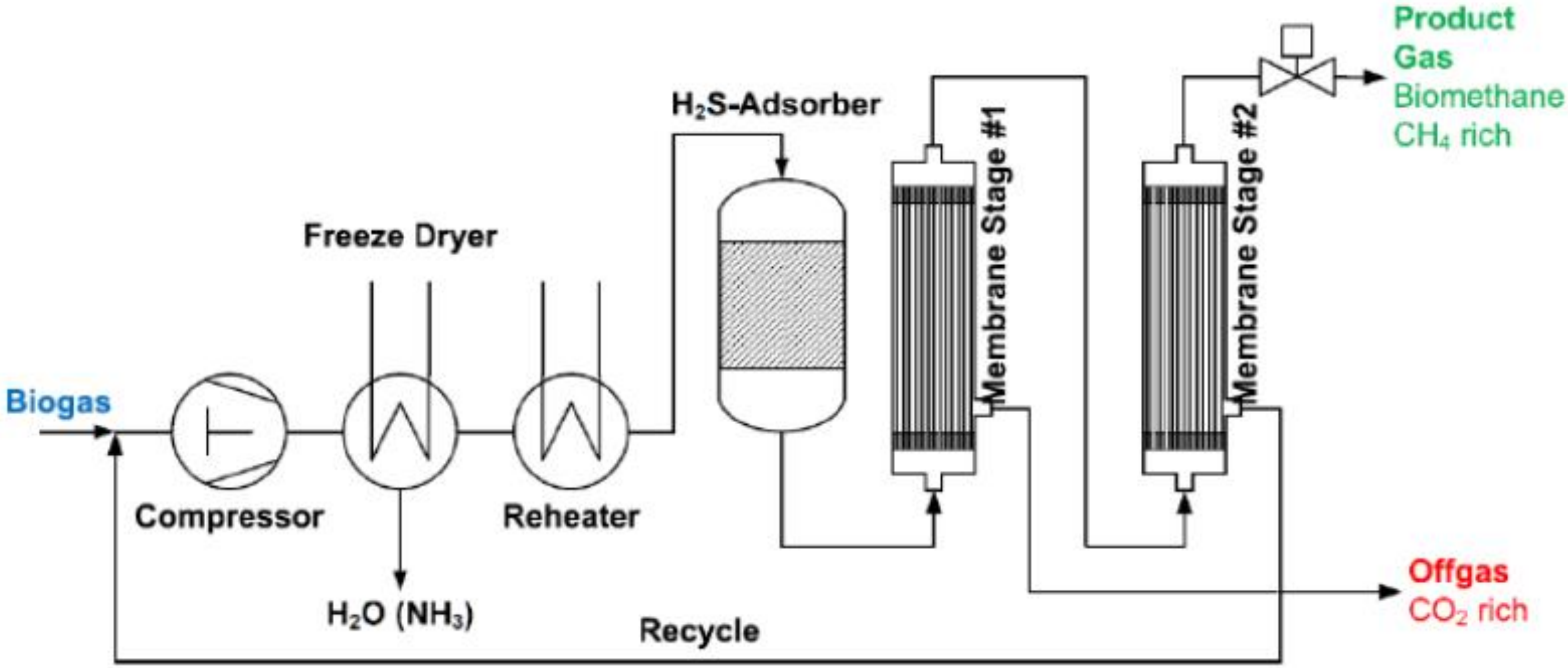
- Alkanol amines (MEA, DEA, MDEA) used for CO_2 absorption
- High desorption temperatures in recycle loops
- Low pressure operation possible

Biogas Engerwitzdorf – Grid injection

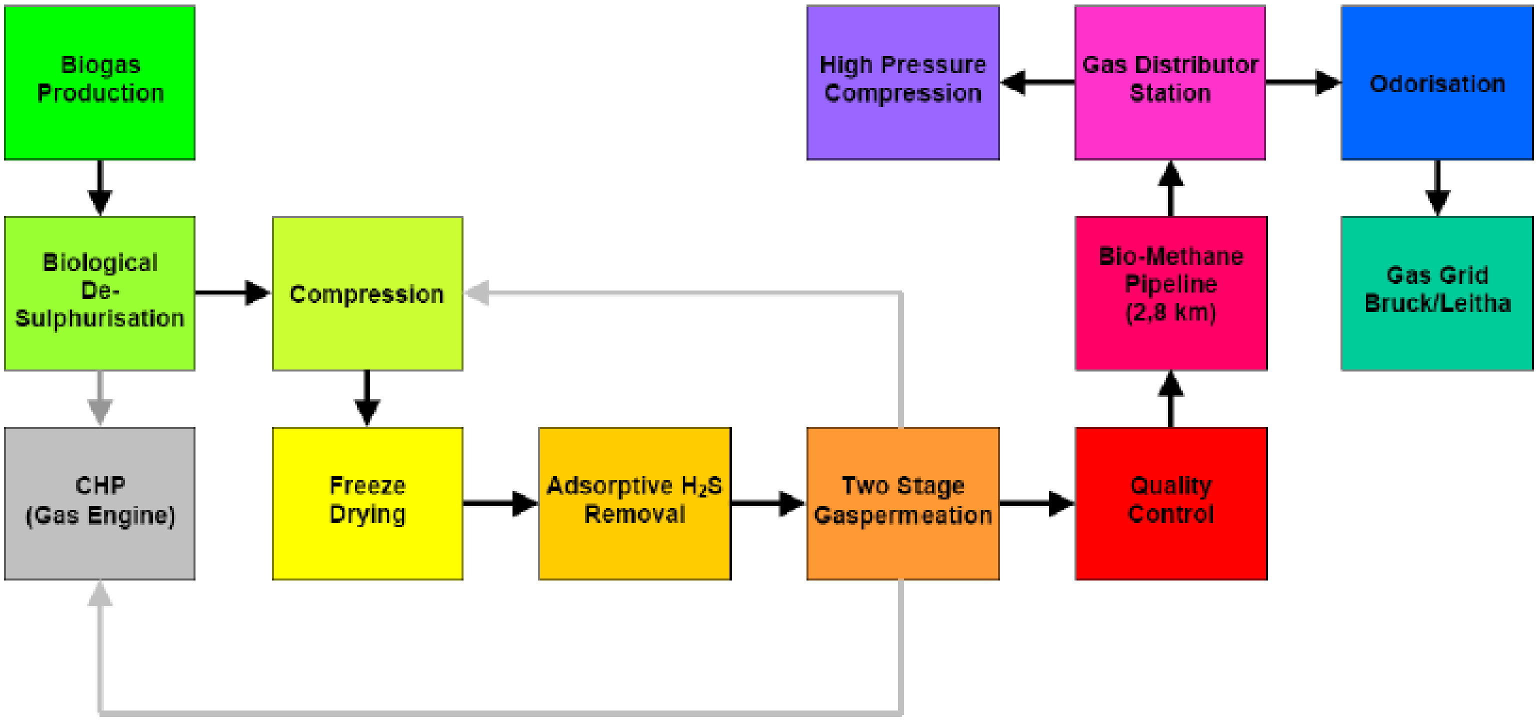
- Capacity 1,000.000 m³ Bio-methane / a
- BCM (MT-Energie) amine scrubber

Two stahge membrane separation process

- **Two-stage separation process** with recycle and a single compressor



Process Integration (Two-stage design)



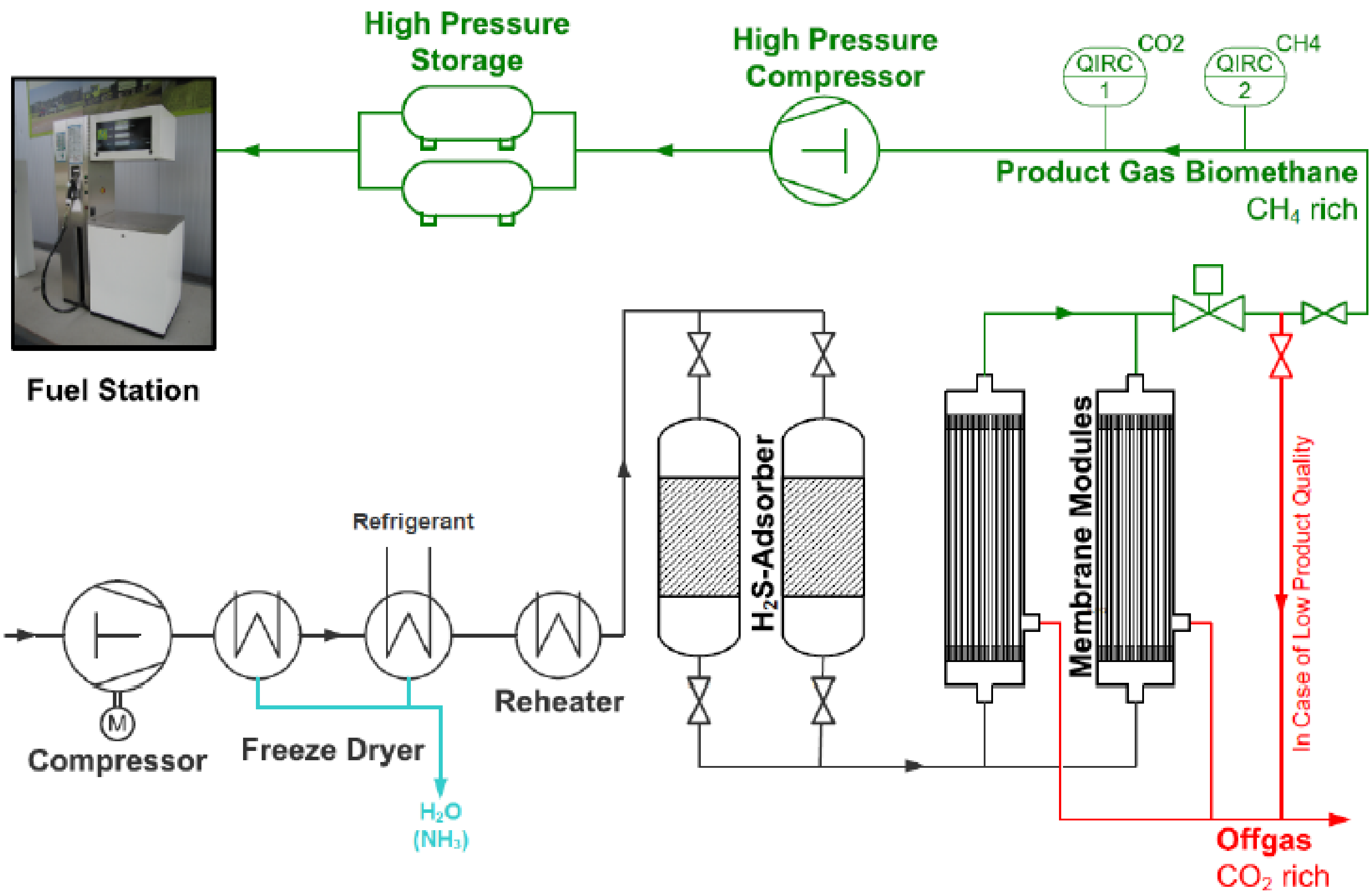
- Biological desulphurisation prior to membrane treatment
- Permeate is recycled to CHP plant – „zero methane“ emission of upgrading system

Upgrading plant in Bruck/Leitha

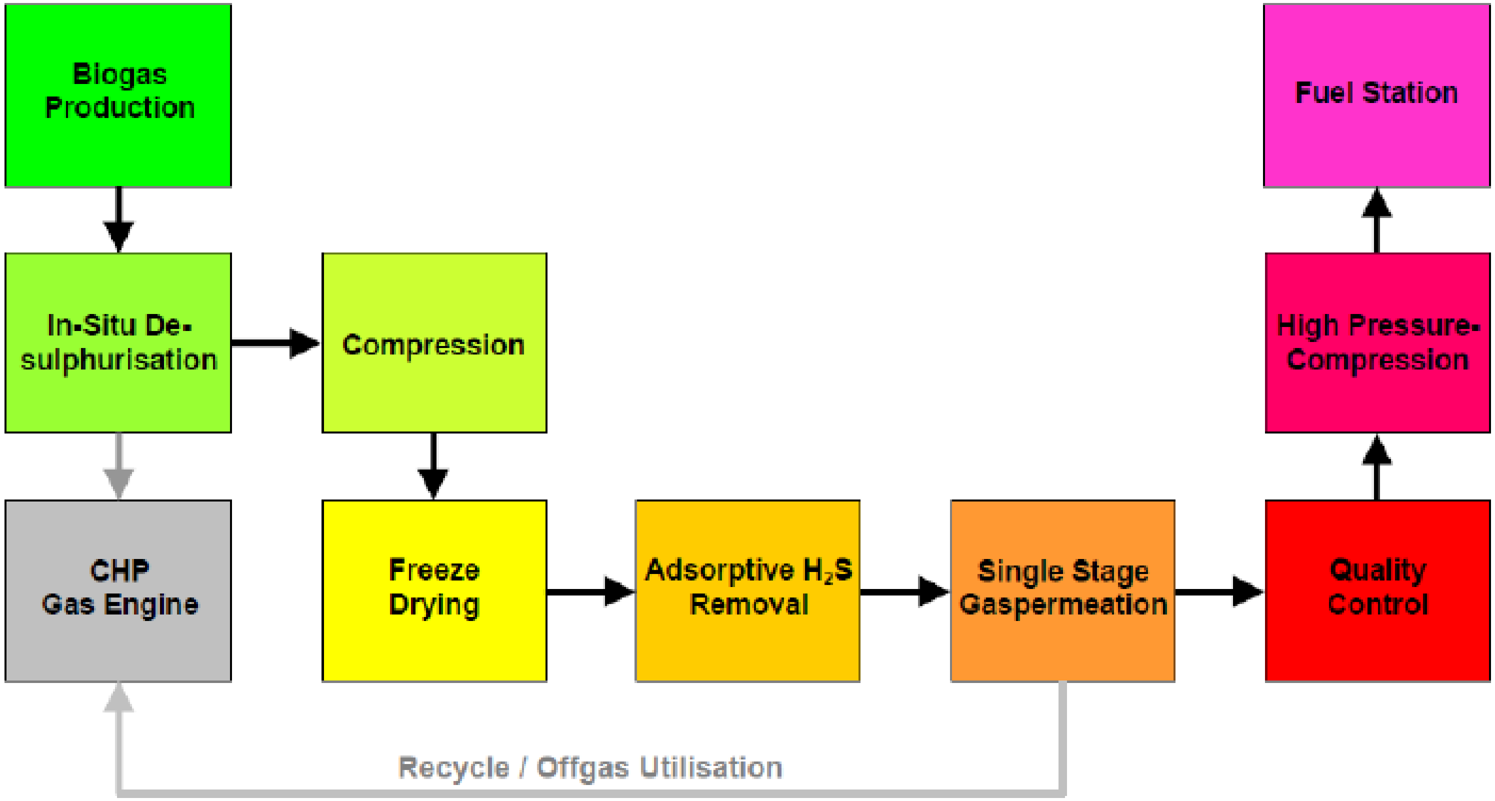
180 m³/h biogas / 100 m³(STP)/h biomethane @ 6 bar

Details: http://www.virtuellesbiogas.at

Biomethane Fuel Station: Single Stage Upgrading



Process Integration (Margarethen am Moos)



- In-situ desulphurisation (addition of iron salts into the fermentation broth to catch suphides)
- Permeate is recycled to CHP plant – „zero methane“ emission of upgrading system

Bio-CNG with on-site fuel station



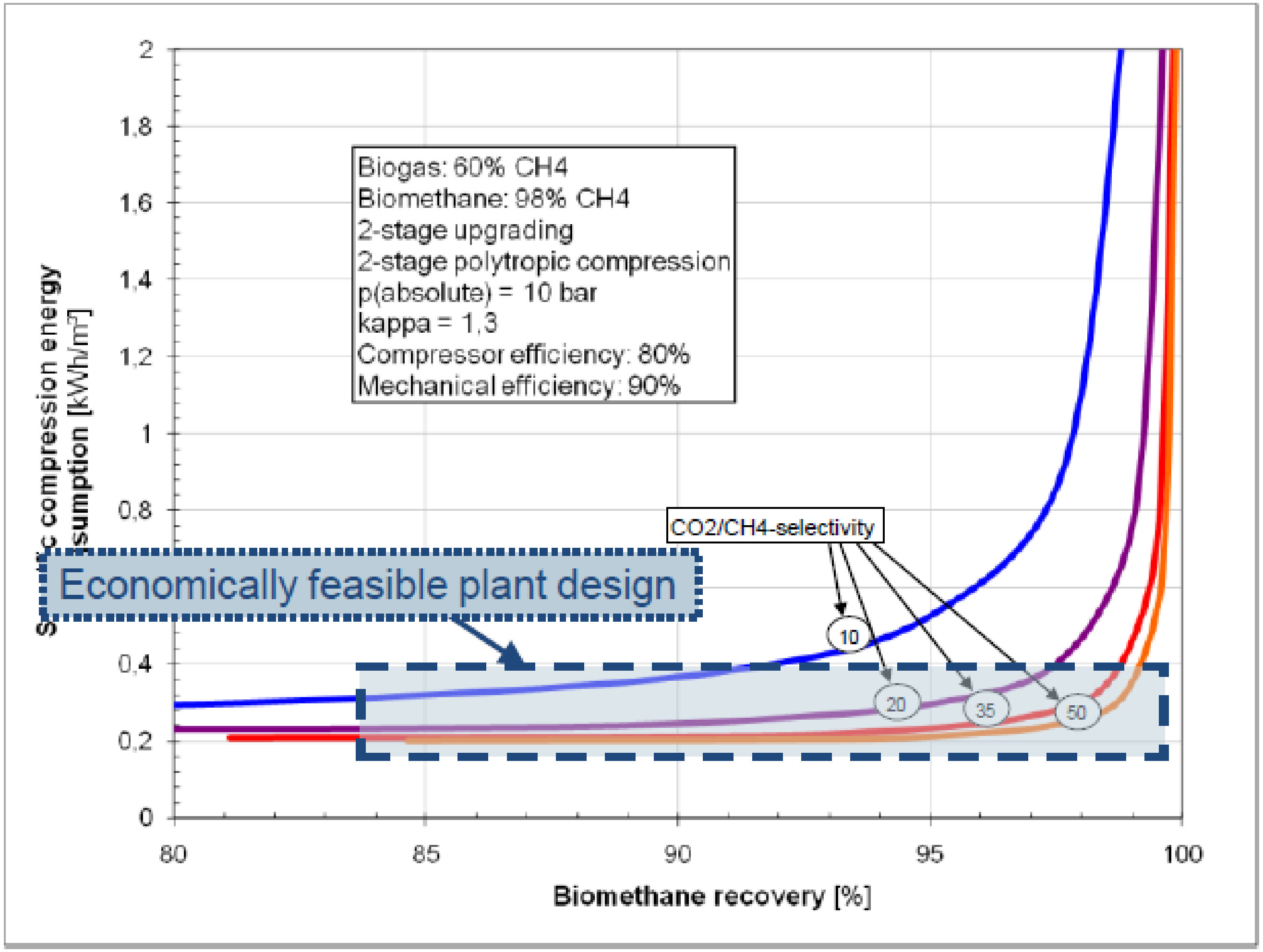


- Capacity: 500 kg/d bio-methane
- Bio-methane as fuel alternative (tractors, harvesting)

Bio-methane Wiener Neustadt

- Capacity: 220 (300) m³/h biogas
- Axiom – Membrane separation

Compression Energy Consumption per m³ Product



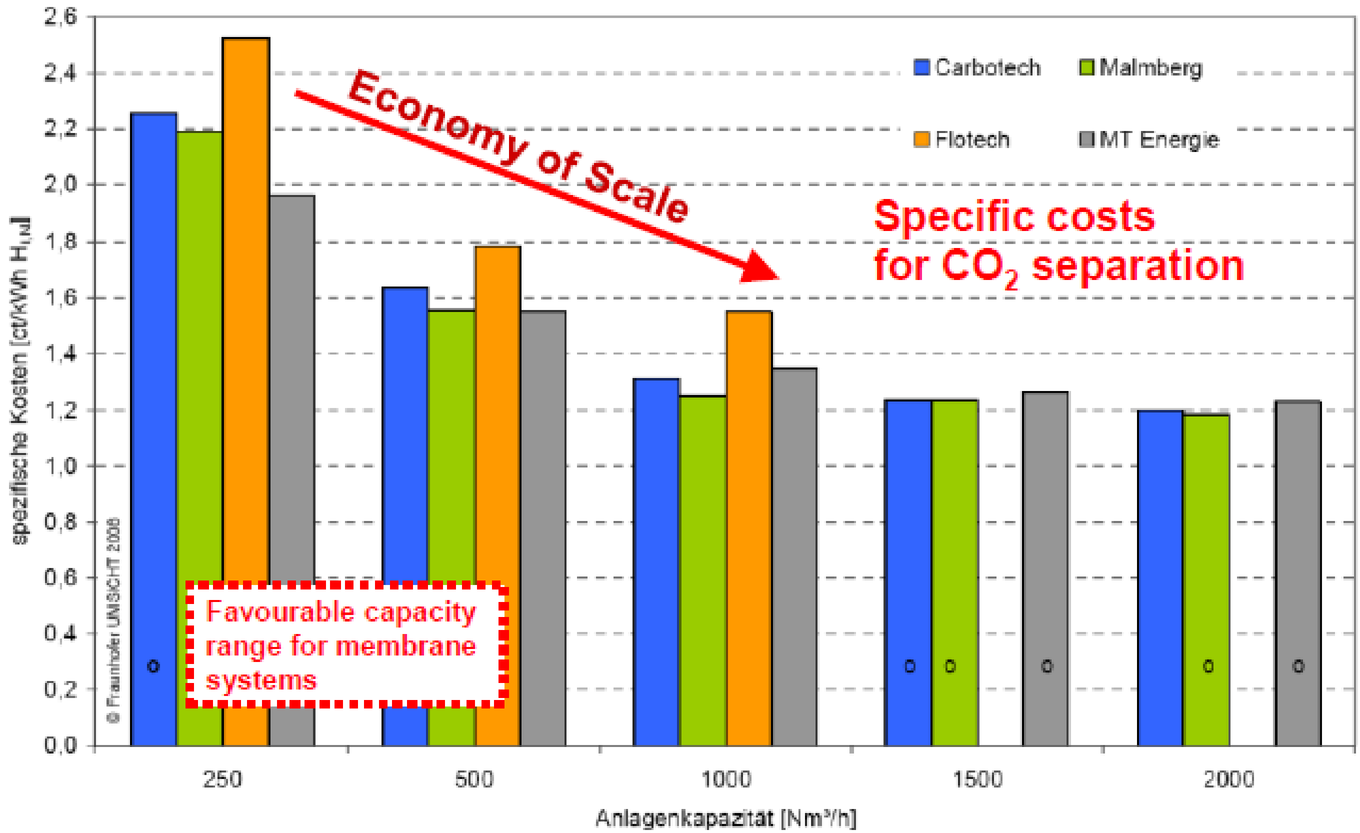
Final Conditioning / Offgas Treatment

- **Final conditioning needs depend on upgrading technology and requirements of gas grid or fuel use:**
  - All absorption based upgrading technologies (water scrubbing, selexol absorption, amine absorption) need gas drying by glycol scrubbing or molecular sieve adsorption
  - PSA may need mixing buffer tank to level out product concentration fluctuations
- Heating value correction: propane dosing to adjust heating value – consider need for gas quality and product gas flow measurement for dosing control
- Delivery pressure adjustment: pressure reduction or increase depends on feed-in conditions
- Odor dosing: e.g. THT (tetrahydrothiophene) or similar dosing equipment and control
- Gas quality measurement: local regulations and agreements may require continuous quality measurement (e.g. process gas chromatography – consider calibration needs!)

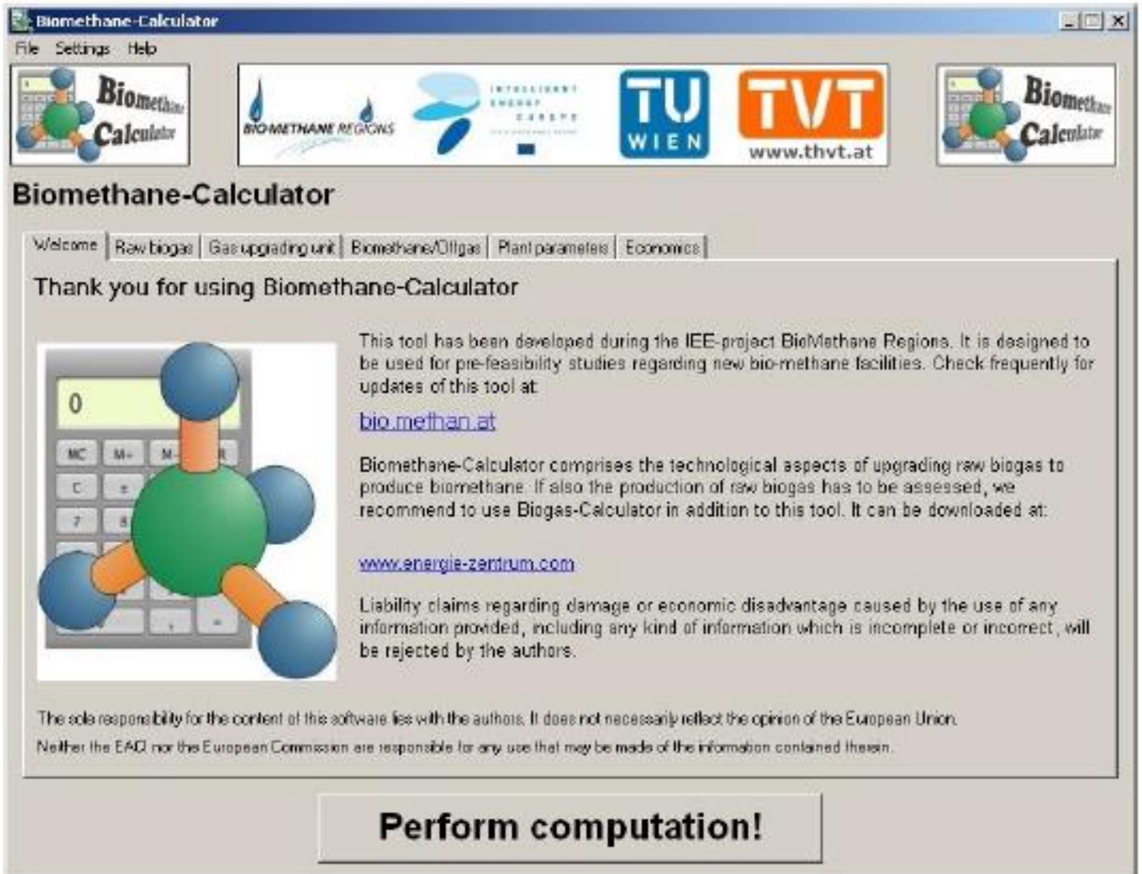
Gas quality Measurement / Offgas Treatment

Costs for CO_2 Separation

Calculations by Fraunhofer Institut UMSICHT (2008)



Biomethane Calculator



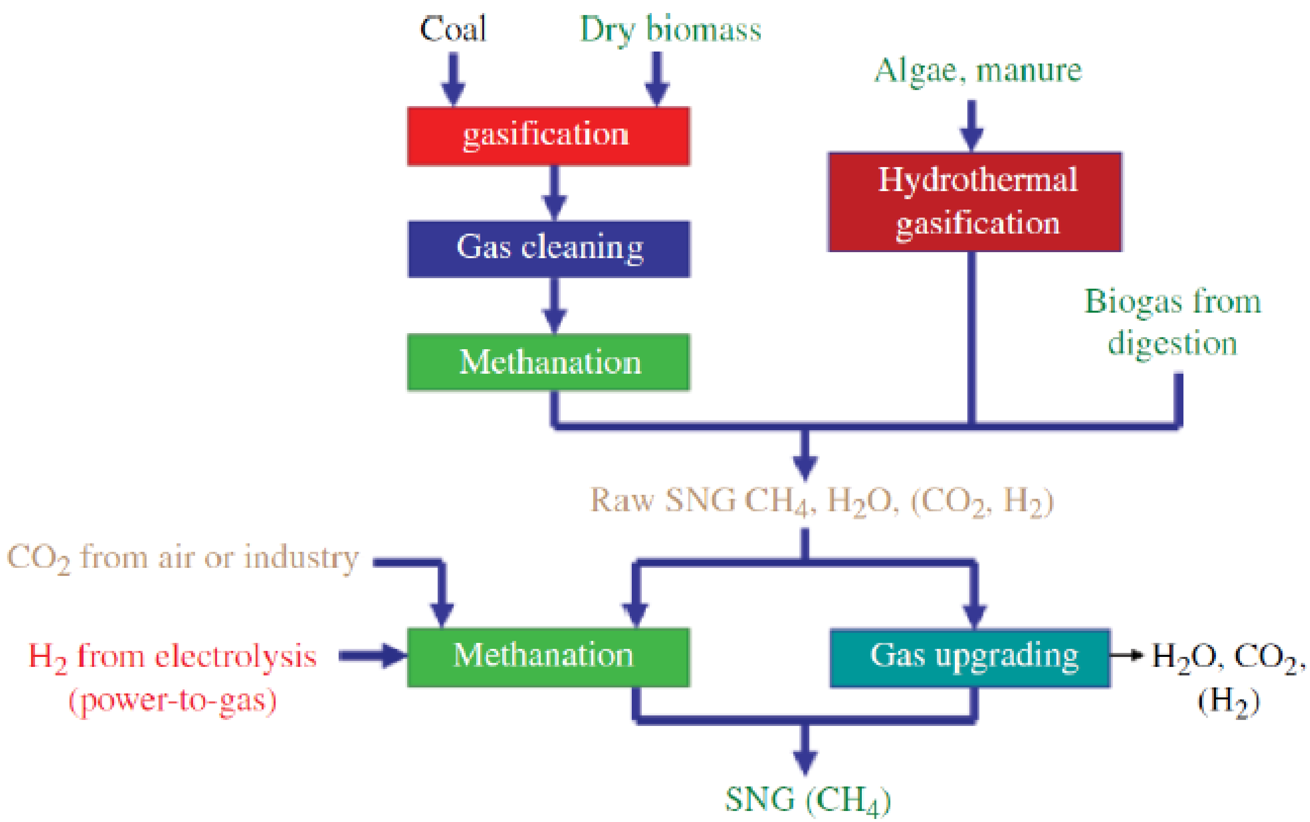
Free download @ http://bio.methan.at

Synthetic Natural Gas production from biomass (BioSNG)

- SNG is referred to as Synthetic Natural Gas and is a **substitute for natural gas that can be derived either from fossil coal** (brown coal, black coal), **municipal solid waste or from renewable biomass**.
- **In** contrast to anaerobic digestion, the BioSNG production requires organic matter **with low water content** and **with woody characteristic (lignocellulosic material**).
- The large amount of appropriate biomass available, e.g. agricultural and forest residues, lignocellulosic content of energy crops or municipal paper waste, is a reason why this production pathway is considered to be able to **contribute significantly to green the natural gas grid**. The resource potential of biomass that is accessible for BioSNG production in the EU27 has been estimated to exceed 2500 PJ per year [1].
- The technical process BioSNG production is **based on the gasification of biomass**. Gasification is a partial oxidation process in which biomass is transformed into carbon monoxide (CO), hydrogen (H2) and carbon dioxide (CO2) using high temperatures. This mixture of gases will at a later stage be upgraded to a high quality natural gas substitute: BioSNG. BioSNG production process consists mainly on five steps (Figure 2 which will be described in the following

Gasification Scheme process

Drying → Gasification → Gas cleaning → Methanation → Gas upgrade



Source: Synthetic Natural Gas from Coal, Dry Biomass, and POWER-TO-GAS Applications (Tilman 2016)

Steps

- **Drying:** During this step biomass has to be dried to remove water and lower the moisture content; this allows a reduction of energy input at elevated temperature during the gasification process and increases its efficiency. The most widely applied drying techniques are steam drying, flue gas drying and low temperature air drying.
- **Gasification:** Once the biomass is dried, it is ready to be gasified. The solid material is converted to a gaseous phase and gasification is achieved due to partial oxidation at temperatures of around 700-900°C. The usable technologies depend on the biomass to be fed in; the most common technologies are fixed bed, fluidised bed and entrained flow gasification. In contrast to gasification plants with direct CHP utilisation which are often using air as gasification agent, BioSNG production suffers from the input of inert gases such as N_2 due to its negative effect on the heating value of the product gas. For this reason, biomass is gasified by using gasifying agents such as pure oxygen or water steam
- **Gas cleaning:** The product of gasification is a gas containing mainly CO, H_2, CO_2, CH_4 , higher carbons and some impurities (e.g. dust, tars); reason for which this gas must be cleaned. To achieve the desired gas quality and composition, cyclones, fabric filters and scrubbing separators are used.
- **Methanation**: During the methanation step CO_2 and CO are converted to CH_4 according to the following reactions:

Conversion

- $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
- $CO + 3H_2 \rightarrow CH_4 + H_2O$

- The methanation process requires a catalyst while most often nickel catalysts are used. Fixed bed reactor can be considered as the state of the art technology. However, there are other technologies using fluidised bed or slurry reactors as well.

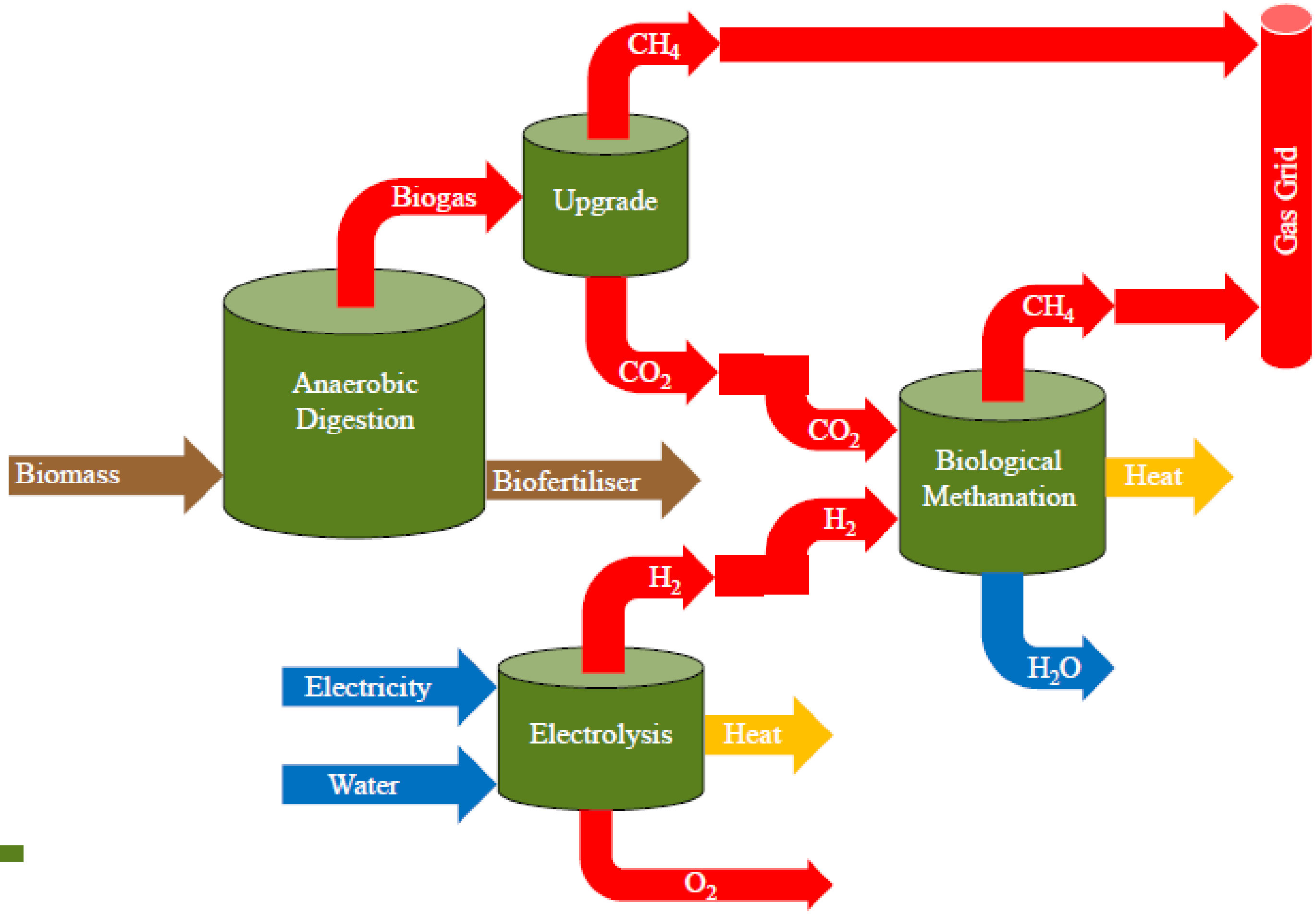
Gas upgrade

- The received product gas is to be upgraded by CO_2 and CO removal. Depending on the grid specification and the product gas quality H_2 is to be separated and moisture is to be reduced by an appropriate drying technology.
- The comprehensive gas treatment technology, which is required when producing BioSNG, results in high investment costs. These costs contribute significantly to BioSNG production costs whereas plants with high gas production capacity benefit from scaling effects. Urban estimated BioSNG production costs for a 60 MW plant (fuel capacity) and resulted in roughly 58 €/MWhHi,N considering investment conversion and fuel costs1 [2].
- Cost estimation for production costs for a plant capacity of 100 MWth to be 63 €/MWhHi,N for BioSNG production with steam reforming and 68 €/MWhHi,N with oxygen reforming [3].

Power to methane: biological methanation of renewable hydrogen

- Efficient concepts for storage of electric power are crucial for the success of the energy transition in addition to the expansion of renewable energies. The energy storage concept “power to gas” converts the excess electrical power into hydrogen or methane. In this way on sunny and windy days renewable electricity from PV or wind can be stored and later used in times when they are needed.
- Integrating the natural gas grid and its cavern storages, the concept of power to gas has the greatest capacity among all other storage technologies and is today considered as the only option to store electricity in order of several TWh over a long period of time (Figure 3).

Power to methane (P2G or P2G)



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The technical process

- The conversion of carbon dioxide (CO_2) and hydrogen (H_2) into methane (CH_4) and water (H_2O) is described by the following reaction:
- $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
- This conversion can take place by means of thermo-chemical or biological processes. In thermo-chemical processes, metal catalysts are used to enable the chemical reaction of CO_2 and H_2. Most often nickel catalysts are used which requires highly pure starting gas streams. This thermo-chemical conversion runs at temperatures of about 340-500 °C and pressure conditions in the range of 10 bars. Due to the strong exothermic nature of the reaction cooling is essential to ensure proper operating. The option that is discussed in this report is the conversion of CO_2 to methane via the biological pathway, called “Power to BioGas”. In contrast to the thermo chemical process, the metabolic reactions of biological methanation occur naturally when specialised microorganisms are present. Methanogenic use hydrogen and carbon dioxide as source for their metabolism – as a product methane is produced

: Power to gas concept with biological methanation

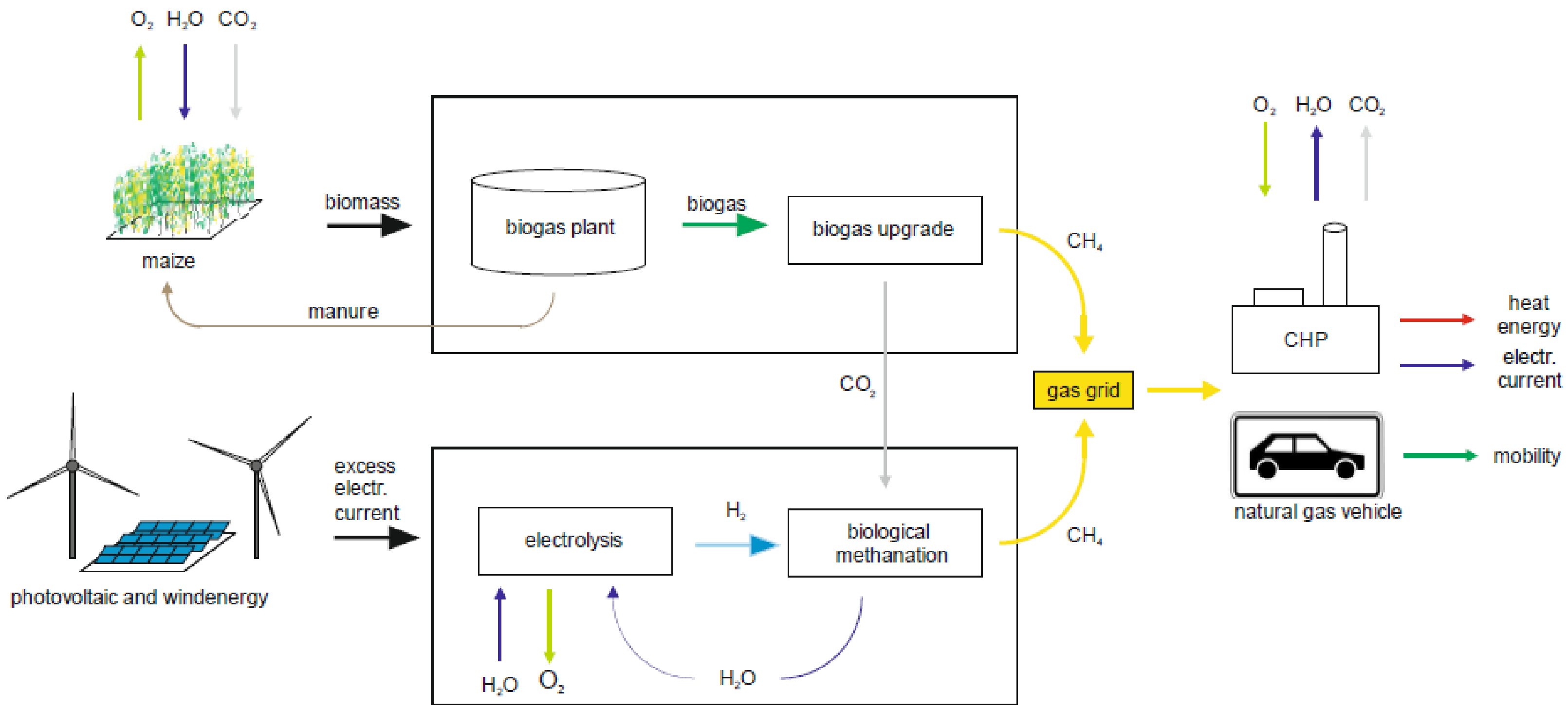


Figura 4

Power to BioGas:biological methanation of renewable hydrogen

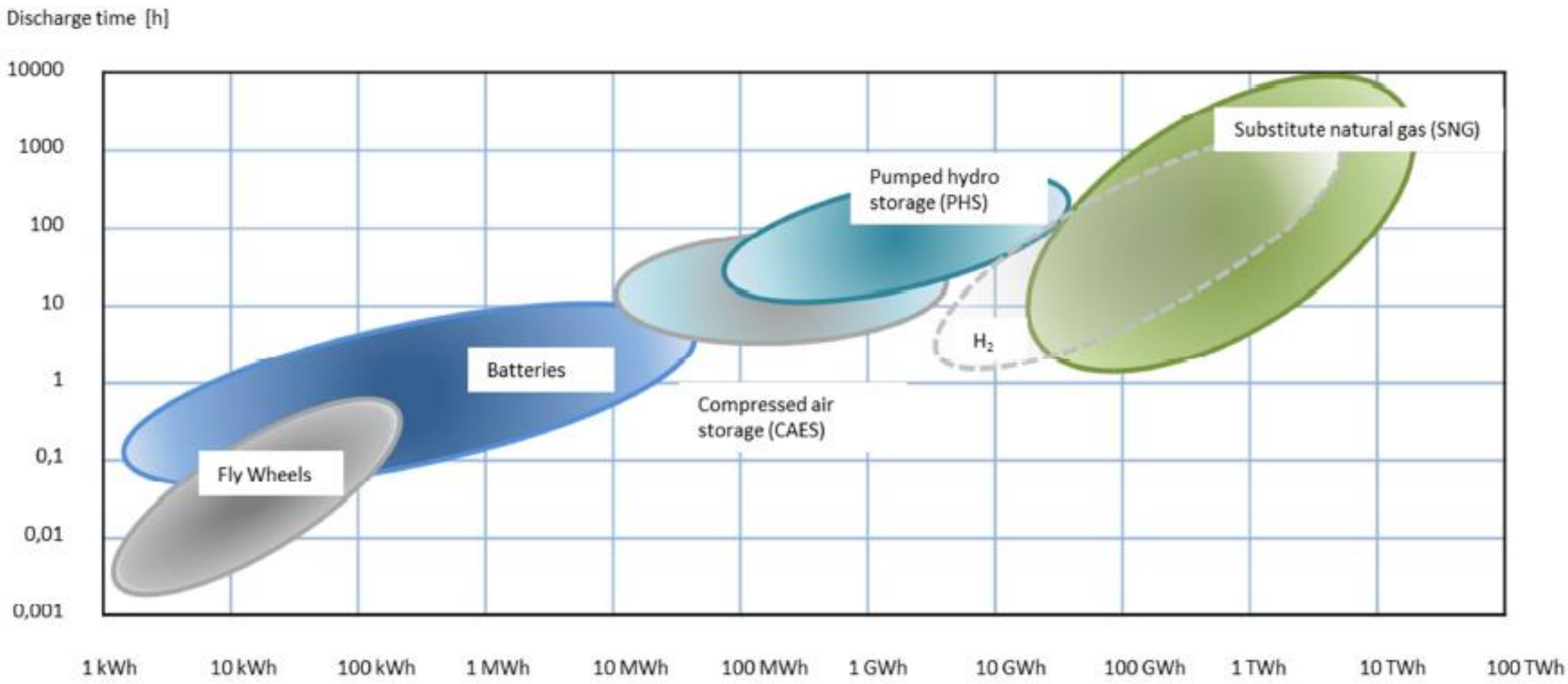


Figura 3 : Demand for storage solutions will rise with the increase of fluctuating renewable energies. The natural gas grid offers interesting options via biomethane and PtG solutions. (source ZSW 2009)

- These are the same microorganisms that are responsible for the methane-forming step in biogas, landfill gas and sewage gas production. Power to BioGas is at a development stage, however, from the current point of view it offers certain benefits such as described in the following:
- Mild process conditions with low temperature and pressure conditions (35-70 °C; reaction already at ambient pressure) ease the engineering and operation. These conditions are very similar to the ones in biogas plants.
- Cost-effectively because of the use of microorganisms from freely available by-and waste products such active biomass from digestate from biogas plants
- High tolerance against contaminants. Hydrogen sulfide as a nutrient source is even beneficial to the process; therefore in contrast to the thermo chemical pathway the biological methanation does not require comprehensive gas treatment.
- High reactivity results in fast start and stop operation [13].
- High selectivity of the microorganisms which means that methane is produced without intermediate products.

Costs

- Whereas the implementation of biological methanation into an existing biogas plant is not expected to involve extraordinary financial efforts, the production of renewable hydrogen is considered to be the most important economical challenge.
- The high investment costs for an electrolyser of 800 to 1500 €/kW 2 [12] make up a significant part of the production costs. The exploitation of the biological methanation technology will therefore strongly depend on the development of electrolysis technology for low costs. Production costs are estimated to range from ca. 80 to 150 €/MWhHs, provided excess electricity is delivered without charge3.
- An additional challenge will be to optimise the conversion rate of biological methanation. The conversion rate is strongly linked to the accessibility of the feed to the bacteria which is limited by the solubility of the feed gases. More research is needed to future investigate and optimise the process of biological methanation before it reaches maturity for being realized at industrial scale.

Biomethane production

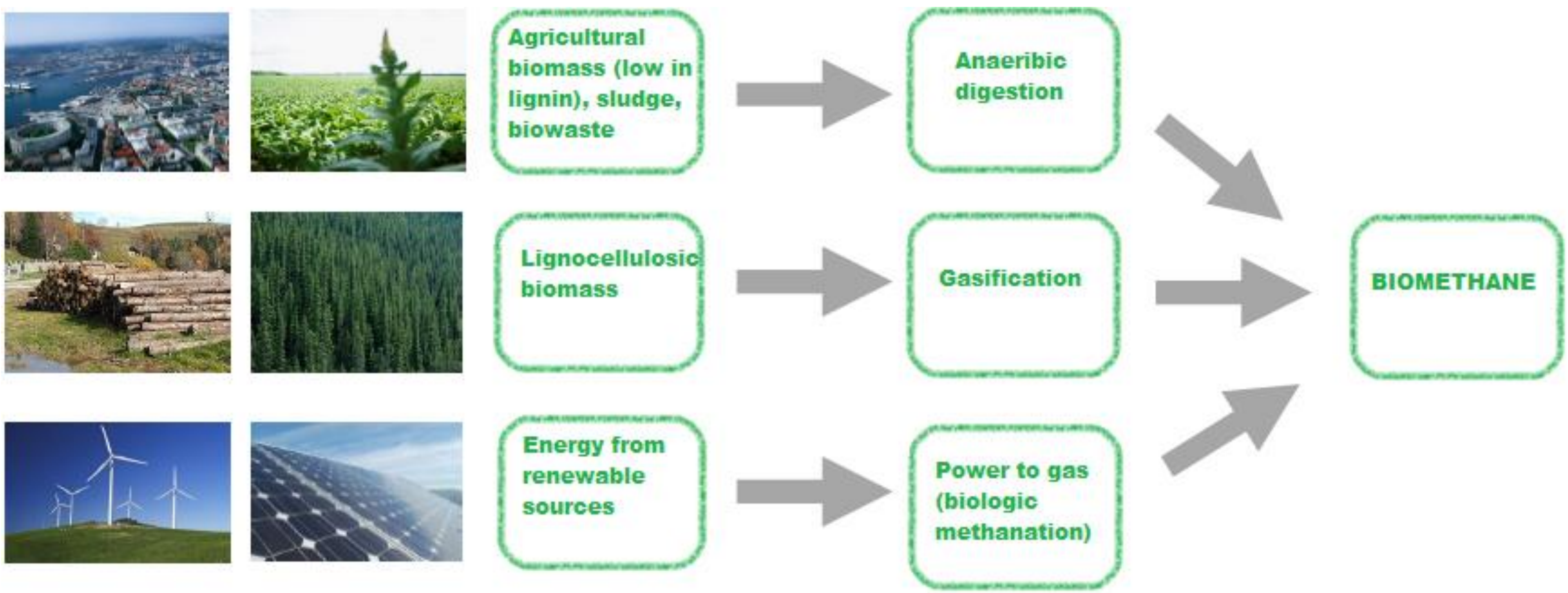


Figure : schematic version for product biomethane from Agricultural biomass, sludge, biowaste or from Lignocellulosic biomass or from FER (renewable energy)

Comparative analysis

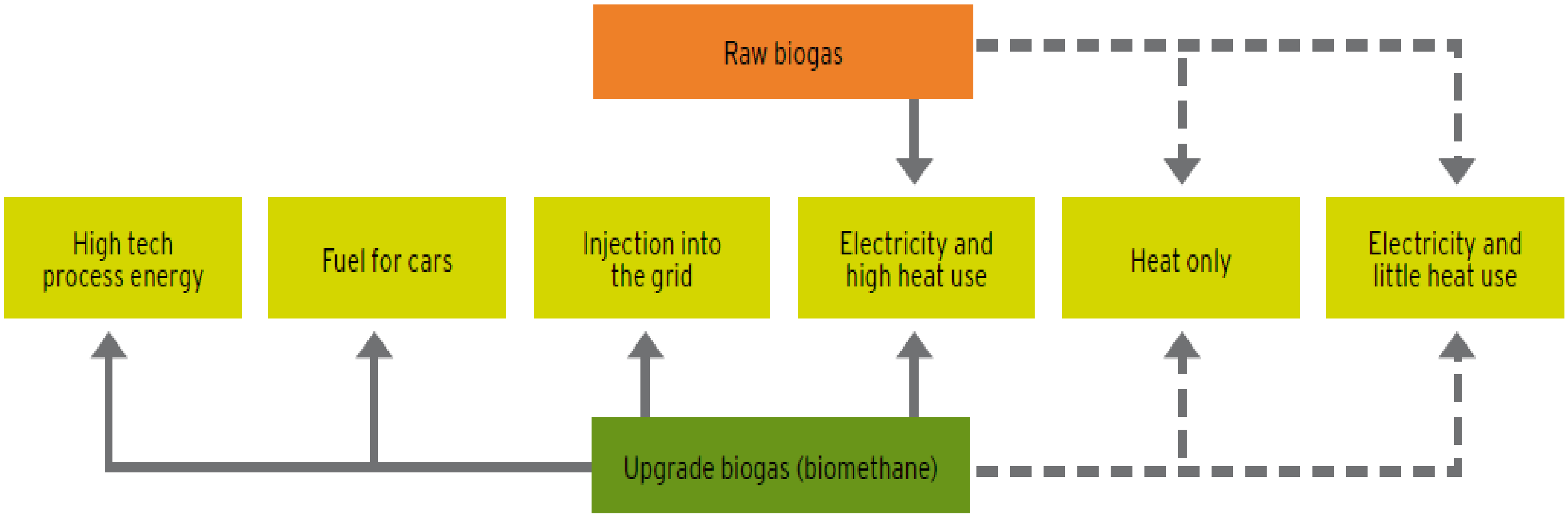
Criterion	BIOMETHANE		
	Biomethane from biogas via bio-chemical way	BioSNG via thermo-chemical way	Power to BioGas via biological methanation
Processed resources	Wet biomass  e.g. manure, bio-waste, energy crops	Woody biomass  e.g. residual forest wood	Renewable H_2  e.g. from electrolysis of excess electricity
Biomass Potential	+ 1112 PJ/a [1]	++ 2587 PJ/a [1]	++ no restrictions linked to biomass; appropriate CO_2 source required
State of development / plant number industrial scale in EU	++ >200 plants [2]	+ 1 plant industrial scale, 1 pilot plant	O only plants at pilot stage, demonstration plants in the pipeline
Economical scale	3–20 MW	>20 MW	flexible
Production costs	65–83 €/MWh_{Hs} [15]	ca. 53–62 €/MWh_{Hs}* [2]; [3]	ca. 80–150 €/MWh_{Hs}**

* modified Värnamö gasifier, 20 MW, 70 €/t wood
** own calculations by Fraunhofer UMSICHT, assumptions: 2000 operation hours of electrolysis, excess electricity w/o charge

Bildquellen:
1 www.pixelio.de; Christoph Aaron
2 www.pixelio.de; Uwe Schlick
3 www.pixelio.de; Uwe Schlick

- several ways are available for producing biomethane.
- A large range of biomass substrates can be used to generate biomethane, and even excess electricity and appropriate CO2 sources can be converted via the Power to BioGas technology. Concerning stage of development, it can be stated that biomethane from AD is the most developed pathway. The three pathways have their specific characteristics concerning the appropriate technical and economical scale. BioSNG production is considered to be appropriate for large scale projects due to issues such as availability of substrates and cost degradation effects: Biomethane from AD projects in

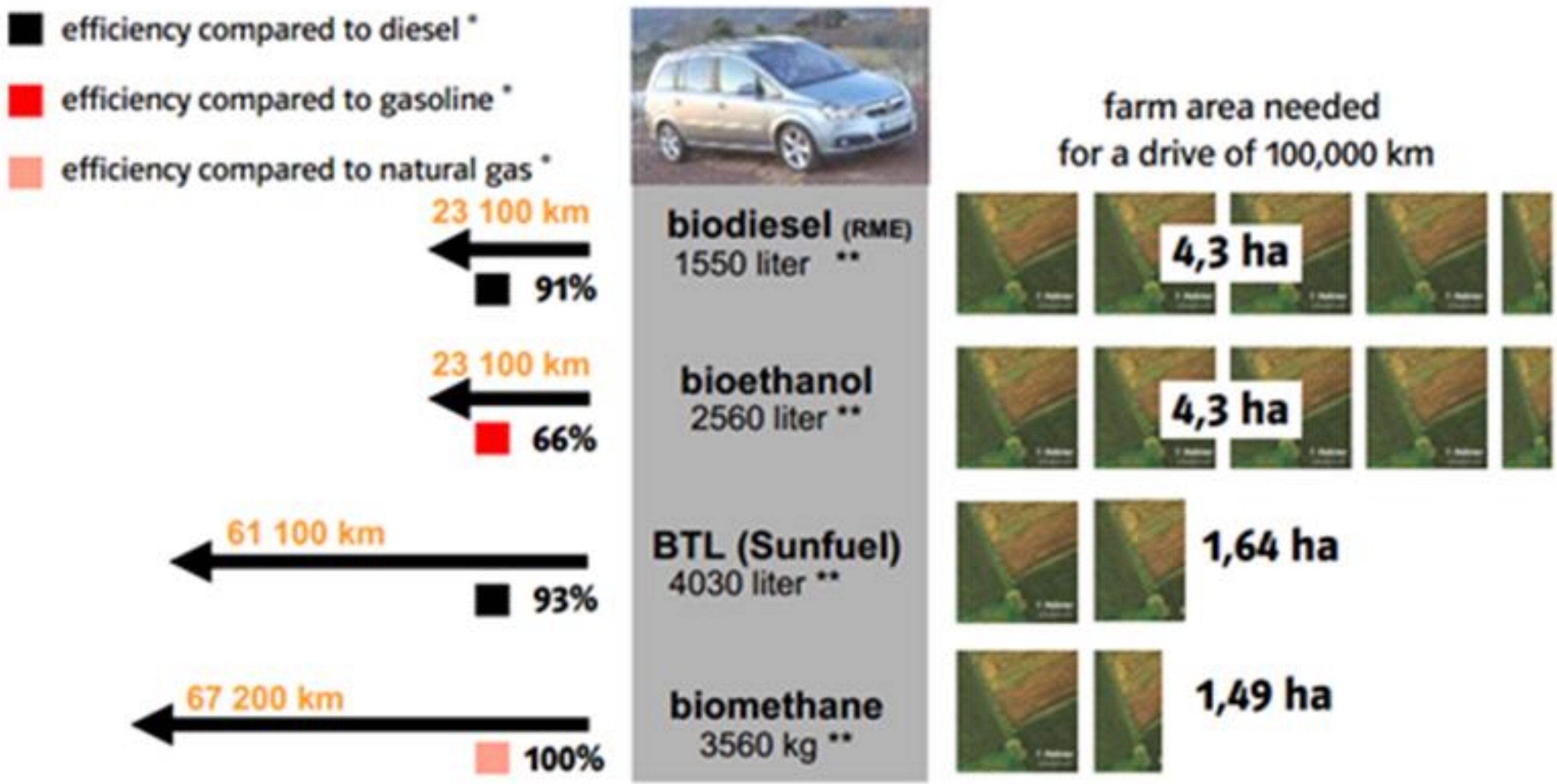
USE OF BIOMETHANE



Biomethane as a vehicles fuel

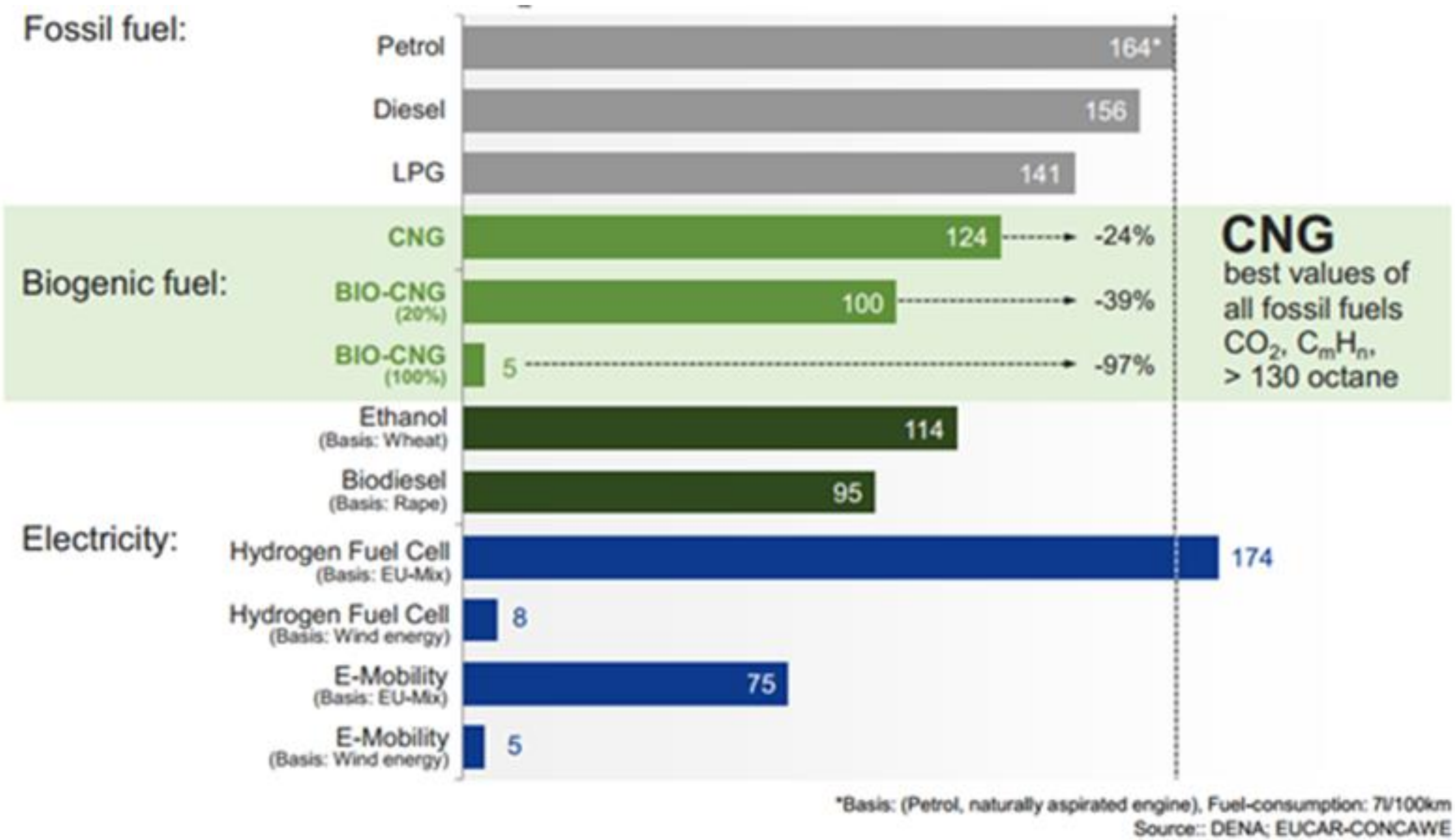
Advantages	Challenges
The existing natural gas filling stations can be used for biomethane	Costly cleaning and upgrading of biogas
Energetic efficiency relatively high	Legislative framework (e.g. subsidies for natural gas insome countries)
Injection into the natural gas grid after upgrading possible	Initial cooperation with natural gas needed (in order to increase the market share of vehicles running on gas)
High fuel equivalent output per hectare. The use of catch crops can further increase the output and decrease the competition for arable land	Methane slip (the upgrading technology that removes unwanted CO2 sets free methane as well; latest technologies reduce the slip to less than 0,1%)
More and more gas-vehicles enter the market. Improved cruising range and comfort.	High conversion costs of existing vehicles
Favourable combustion properties (e.g. the emission of nitrogen oxides and reactive hydrocarbon can be reduced up to 80% compared to petrol and diesel)	Low number of gas vehicles in Europe
	Gaseous fuel reduces the cruising range compared to liquid fuels
	Gas storage

Biomethane *VS.* other fuels



* base: fuel consumption of Opel Zafira (gasoline, diesel, CNG)
** source: Fachagentur Nachwachsende Rohstoffe

CO_2 Emission



EU data

Source: NGVA Europe, 31.12.2013