E.Quadrat energy economy

Gesellschaft zur Entwicklung erneuerbarer Energien in Versorgungssystemen

Biogas from waste - Demands and opportunities for a sustainable production of Renewable Energy

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AHK Geschäftsreise Erneuerbare Energien

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Decision-Making Process – What Bioenergy?

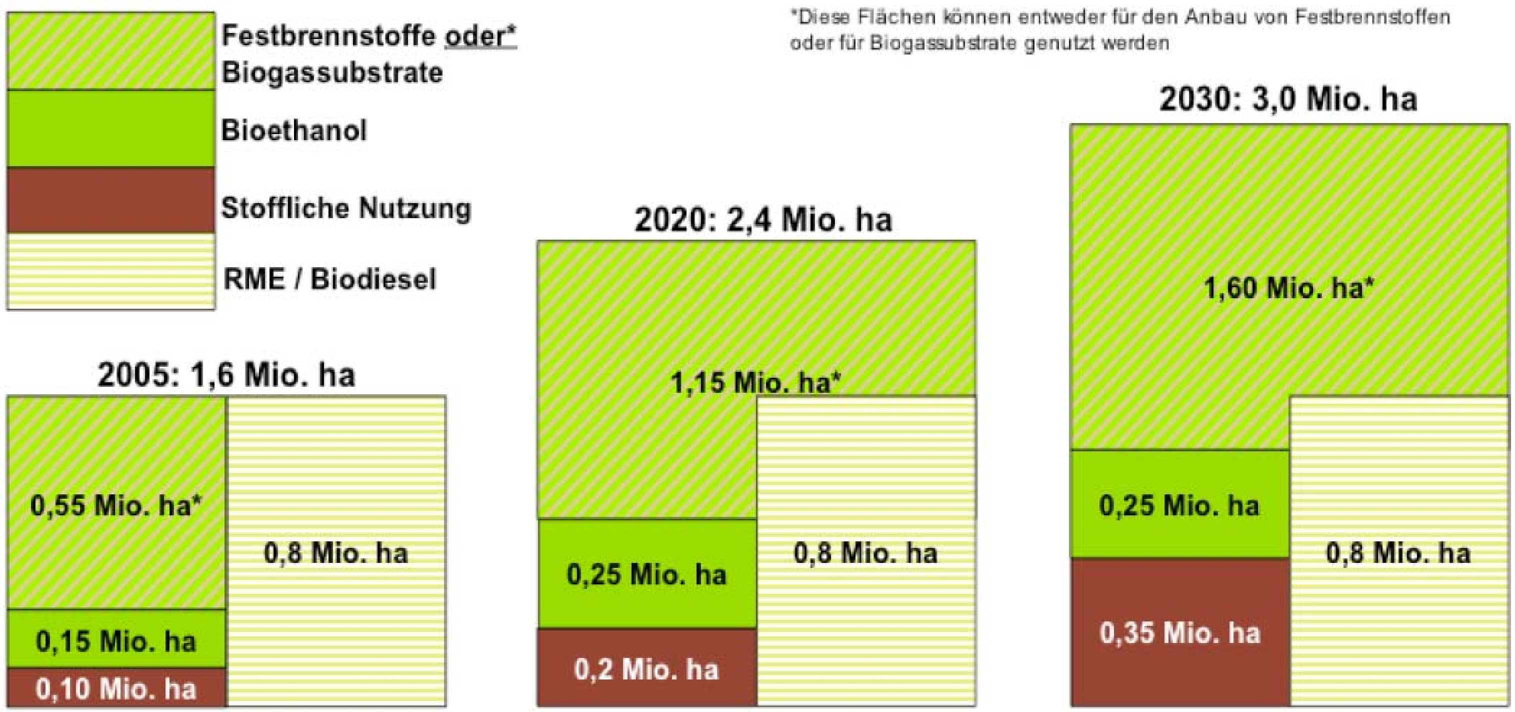
Energy from Biomass		
solid • Coarse wood residues, e. g. from saw mills • Chopped wood chips, e. g. from forestry, countryside conservation • Wood pellets, e. g. from wood shavings, wood chips, straw • Energy grain	**fluid** • Bio oils from oil seeds, e. g. rape seed • Bio ethanol, e. g. from grain • Synthetic fluids, e.g. from wood or plants	**gaseous** • From renewable resources, e.g. liquid manure with corn, whole plant grain • From co-fermentation, e.g. liquid manure with organic waste • From municipal solid waste (mechanical-biological processing) • Thermal gasification of solid biomass
forestry, countryside conservation, sawmills/ wood industry, agriculture	agriculture, usable residues from biomass, waste industry	agriculture, food industry, trade and craft, waste industry
Power plants (up to 20 MW_{el})/ CHP, big heating plants (>50 kW), small heating plants (<50 kW)	Biodiesel filling station, petrol industry (admixture); small CHP with bio oils	Biogas CHP; biomethan feed-in; biomethan as renewable fuel (Gas filling station)

Expectations for Biogas in Europe

- In 2020 the demand for gas in Europe (currently 500 billion m³ p. a.) can be met by biogas[1]
  - Increase of energy efficiency assumed
- Biogas will reduce the European CO_2 production by 15 % in 2020[1]
- Biogas reduces the dependence from gas imports from Russia and the Middle East
- Biogas can stabilize prizes for energy
- Biogas will take a share in the local development, especially in rural areas
- Best use of biogas is made by heat-controlled combined heat and power (CHP) plants

[1)] Leipziger Institut für Energie und Umwelt (IE)

Assumption for the development of available area

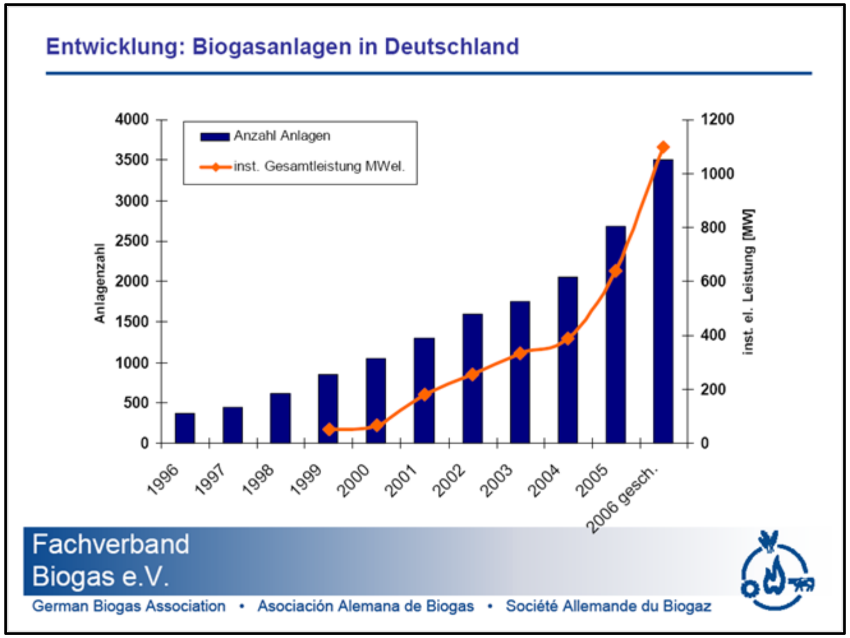


Until 2050 6,1 million ha expected!

Source: IE, Leipzig

Development of biogenic electricity market – Biogas assets and installed capacity in Germany

	2006 Prognosis	2020
Assets	3.500	-
installed electric capacity (cum.)	1.100 MW	9.500 MW
Electricity production	> 5 billion kWh[1]	76 billion kWh
Share of German electricity production	> 1 %	17 %
turnover plant engineering and construction	> 1 bilion EUR	7,6 billion EUR
jobs	ca. 10.000	85.000
CO_2 reduction	5 Mill. t/a	103 Mill. t/a



1 : depending on comissioning of new plants

Source: Fachverband Biogas/Bundesverband BioEnergie

Development of biogas plants

- Trend towards bigger and more powerful biogas plants
  - Currently most biogas plants in Germany have a capacity between 150 and 500 kW
  - E.ON Ruhrgas, E.ON Bayern and Schmack Biogas AG are planning the biggest European biogas plant at Schwandorf (Bavaria)
    - Organic throughput 61,500 t p. a.
    - Biogas production 16 Mill. m³ p. a.
    - Total capacity (Gas) 10 MW
    - Total capacity (Electricity) 4 MW

- Conclusion: biomass demand per plant is rising

Restrictions for rising biogas market

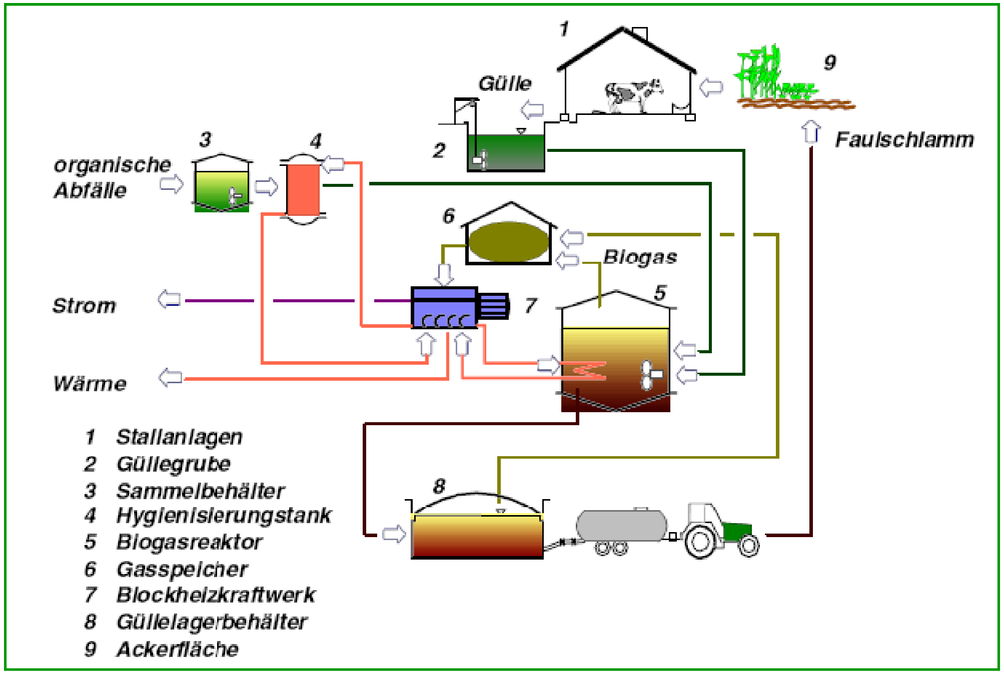
- Surface availability
- Competition with food production
- Increasing prices for foot
  - Feedstock costs query profitability of biogas plants

- Conclusion
  - Interest in new feedstock is rising
  - Residues and waste come into focus

Gasification of solid biomass

- In principle there are three different ways to produce fluid or gaseous fuels from solid biomass
  - fermentation,
  - pyrolysis and
  - thermal gasification.

- The process currently most wide-spread is the anaerobic *fermentation* or fermentation within biogas plants.



Source: FNR

Restrictions for biomass fermentation

- Anaerobic fermentation currently can not be applied if organic waste or wood-like fuels, meaning fuels containing lignin or even plastics, should be used.
- Thus, only a very small part of the potential of biogenous fuels can really be utilized.
- By using thermal gasification, however, wood-like and other carbonaceous fuels can be converted to combustible gas, too.

Biomass gasification at higher temperatures (1)

- Biomass gasifiers are reactors that heat biomass in a low-oxygen environment to produce a fuel gas that contains from one fifth to one half (depending on the process conditions) the heat content of natural gas.
- The gas produced from a biomass gasifier can drive highly efficient devices such as turbines and fuel cells to generate electricity.
- Theoretically, any biomass material with moisture content of 5 - 30% can be gasified as the basic composition of carbon, hydrogen and oxygen is same.
- This means that agricultural wastes such as cotton stalks, saw dust, nutshells, coconut husks, rice husks and forestry residues - bark, branches and trunk can be used for gasification.

Biomass gasification at higher temperatures (2)

- The essence of gasification process is the conversion of solid carbon fuels into carbon monoxide by thermo chemical process.
- The gasification of solid fuel is accomplished in air sealed, closed chamber, under slight suction or pressure relative to ambient pressure.
- Gasification is quite complex thermo chemical process. Splitting of the gasifier into strictly separate zones is not realistic, but nevertheless conceptually essential.
- Gasification stages occurs at the same time in different parts of gasifier.

The gasification process in details (1)

- **Drying**
  - Biomass fuels consist of moisture ranging from 5 to 35 %.
  - At temperatures above 100 °C, water is removed and converted into steam.
  - In the drying, fuels do not experience any kind of decomposition.
- **Pyrolysis**
  - Pyrolysis is the thermal decomposition of biomass fuels in the absence of oxygen. Pyrolysis involves release of three kinds of products:
    - solid,
    - liquid and
    - gases.
  - The ratio of products is influenced by the chemical composition of biomass fuels and the operating conditions.
  - The heating value of gas produced during the pyrolysis process is low (3.5 - 8.9 MJ/m^3).
  - It is noted that no matter how gasifier is built, there will always be a low temperature zone, where pyrolysis takes place, generating condensable hydrocarbon.

The gasification process in details (2)

- Oxidation
  - The oxidation takes place at the temperature of 700-2000 C.
  - Heterogeneous reaction takes place between oxygen in the air and solid carbonized fuel, producing carbon monoxide.

    $C + O_2 = CO_2$ + 406 MJ/kmol

    In reaction 12.01 kg of carbon is completely combusted with 22.39 m^3 of oxygen supplied by air blast to yield 22.26 m 3 of carbon dioxide and 393.8 MJ of heat.

    Hydrogen in fuel reacts with oxygen in the air blast, producing steam .
    $H_2 + ½ O_2 = H_2O$ + 242 MJ/kmol

The gasification process in details (3)

- Reduction
  - In reduction zone, a number of high temperature chemical reactions take place in the absence of oxygen. The principal reactions that takes place in reduction are
    - Boudouard reaction $CO_2 + C = 2CO - 172.6$ MJ/kmol
    - Water-gas reaction $C + H_2O = CO + H_2 - 131.4$ MJ/kmol
    - Water shift reaction $CO_2 + H_2 = CO + H_2O + 41.2$ MJ/kmol
    - Methane production $C + 2\ H_2 = CH_4 + 75$ MJ/kmol
  - Main reactions show that heat is required during the reduction process.
  - Hence, the temperature of gas goes down during this stage.
  - If complete gasification takes place, all the carbon is burned or reduced to carbon monoxide, a combustible gas and some other mineral matter is vaporized.
  - The remains are ash and some char (unburned carbon).

Biomass and waste suitable for gasification

- Theoretically, almost all kinds of biomass and organic waste with moisture content of 5 - 30 % can be gasified;
- However, not every biomass fuel lead to the successful gasification. The following biomass fuels show good results for gasification
  - wood,
  - charcoal
  - wood waste
    - branches
    - roots
    - bark
    - saw dust
  - agricultural residues
    - maize cobs,
    - coconut shells,
    - cereal straws,
    - rice husks.
- Most of the development work is carried out with common fuels such as coal, charcoal or wood. Key to a successful design of gasifier is to understand properties and thermal behavior of fuel as fed to the gasifier.

Impact of fuel properties on gasification

- Energy content of fuel
  - Fuel with higher energy content is always better for gasification.
  - The most of the biomass fuels (wood, straw) has heating value in the range of 10-16 MJ/kg, whereas liquid fuel (diesel, gasoline) posses higher heating value.
- Fuel moisture content
  - The moisture content of the most biomass fuel depends on the type of fuel, it´s origin and treatment before it is used for gasification.
  - Moisture content of the fuel is usually referred to inherent moisture plus surface moisture.
  - The moisture content below 15% by weight is desirable for trouble free and economical operation of the gasifier.
  - Higher moisture contents reduce the thermal efficiency of gasifier and results in low gas heating values.
  - Igniting the fuel with higher moisture content becomes increasingly difficult, and the gas quality and the yield are also poor .

Impact of fuel properties on gasification (2)

- Particle size and distribution
  - The fuel size affect the pressure drop across the gasifier and power that must be supplied to draw the air and gas through gasifier.
  - Large pressure drops will lead to reduction of the gas load in downdraft gasifier, resulting in low temperature and tar production.
  - Excessively large sizes of particles give rise to reduced reactivity of fuel, causing start-up problem and poor gas quality.
  - Acceptable fuel sizes depend to certain extent on the design of gasifier.
    - In general, wood gasifier work well on wood blocks and wood chips ranging from 80x40x40 mm to 10x5x5 mm.
    - For charcoal gasifier, charcoal with size ranging from 10x10x10 mm to 30x30x30 mm is quite suitable.

- Bulk density of fuel
  - Bulk density is defined as the weight per unit volume of loosely tipped fuel.
  - Bulk density varies significantly with moisture content and particle size of fuel.
  - Volume occupied by stored fuel depends on not only the bulk density of fuel, but also on the manner in which fuel is piled.
  - It is also recognized that bulk density has considerable impact on gas quality, as it influences the fuel residence time in the fire box, fuel velocity and gas flow rate.

Impact of fuel properties on gasification (3)

- Fuel form
  - The form in which fuel is fed to gasifier has an economical impact on gasification.
  - Densifying biomass has been practiced in the US for the past 40 years.
  - Cupers and Pelletizers densify all kinds of biomass and municipal waste into "energy cubes".
  - These cubes are available in cylindrical or cubic form and have a high density of 600-1000 kg/m³.
  - The specific volumetric content of cubes is much higher than the raw material from which they are made.

- Volatile matter content of fuel
  - Volatile matter and inherently bound water in the fuel are given up in pyrolyis zone at the temperatures of 100-150 o c forming a vapor consisting of water, tar, oils and gases.
  - Fuel with high volatile matter content produces more tar, causing problems to internal combustion engine.
  - Volatile matters in the fuel determine the design of gasifier for removal of tar.
  - Compared to other biomass materials (crop residue : 63-80 %, Wood : 72-78 %, Peat : 70 %, Coal: up to 40 %), charcoal contains least percentage of volatile matter (3-30 %)

Impact of fuel properties on gasification (4)

- Ash content of fuel
  - Ash content and ash composition have impact on smooth running of gasifier.
  - Melting and agglomeration of ashes in reactor causes slagging and clinker formation.
  - If no measures are taken, slagging or clinker formation lead to excessive tar formation or complete blocking of reactor.
  - In general, no slagging occurs with fuel having ash content below 5 %.
  - Ash content varies fuel to fuel.
    - Wood chips has contains 0.1% ash, while rice hust contains high amount of ash (16-23%)
- Reactivity of fuel
  - Reactivity determines the rate of reduction of carbon dioxide to carbon monoxide in the gasifier.
  - Reactivity depends upon the type of fuel. It has found that wood and charcoal are more reactive than coal. There is relationship between reactivity and the number of active places on the char surfaces.
  - It is well known fact that reactivity of char surface can be improved through various processes including stream treatment (activated carbon) or treatment with lime and sodium carbonate.
  - There are number of elements which act as catalyst and influence the gasification process. Small quantities of potassium, sodium and zink can have large influence on reactivity of the fuel.

Suitability of some biomass fuels (1)

- **Wood**
  - The main combustible components of wood are cellulose and lignin which are compounds of carbon, hydrogen and oxygen.
  - Other minor combustible components in wood are resins and waxes.
  - The major non-combustible component of wood is water which is present up to 50 % in freshly cut wood.
  - Though the ash content is low (less than 1 %), but because of high oxygen content, the calorific value is low (16-20 MJ/kg).
  - Next to charcoal, wood is quite suitable fuel for fixed bed gasifiers.
  - As wood contains high volatile matter, updraft gasifier system produce the gas containing tar, which need to be cleaned before using in engines.
  - Cleaning of gas is difficult and labour intensive process. Hence, wood is not suitable in updraft gasifier coupeled with internal combustion engines.
  - However, the gas containing tar from updraft gasifier can be used for direct burning.
  - Downdraft can be designed to produce relatively tar-free gas. After passing the gas through simpel clean-train, it can be used in the internal combustion engines.

Suitability of some biomass fuels (2)

- **Sawdust**
  - Unpellatized sawdust lead to the problems of excessive tar production, inadmissible pressure drop and lack of bunker flow. Such problems can be minimized by use of densified (pelletized) sawdust.
  - Small sawdust particles can be used in fluidized gas producers to produce burning gas.
  - If this gas is used to be in internal combustion engines, fairly good clean-up system is essential.
- **Peat**
  - Peat is the first stage of coal formation.
  - It is not strictly a coal or it can be termed as the most immatured coal.
  - Freshly mined peat contains 90 % moisture and 10 % of solid.
  - It cannot be utilised unless air dried to reduce moisture content to 30 % or less.
  - Its heating value (around 20 MJ/kg) is slightly greater than wood.
  - As peat contains very high level of moisture and ash, it creates problems in the gasification process.
  - Small downdraft gasifiers fueled with dry peat-pallets have been successfully tested in gas-engine system.

Suitability of some biomass fuels (3)

- **Agricultural residues**
  - If wood is scarce and costly, more abundant or accessible but otherwise less favored fuels is used instead.
  - Agricultural residues are basically biomass materials that are by product of agriculture.
  - It includes cotton stalks, wheat and rice straw, coconut shells, maize cobs, jute sticks, rice husks etc.
  - Many developing countries have a wide variety of agricultural residues in ample quantizes.
  - Coconut shells and maize cobs have been successfully tested for fixed bed gasifiers and they unlikely creates any problems.
  - Most cereal straws contains ash content above 10% and present slagging problem in downdraft gasifier.
  - Rice husk with ash contents above 20% is difficult to gasify.

Thermal gasification

- Thermal gasification of biogenous solid fuels is a key technology for large-scale utilization of biomass, a CO_2-free fuel, for power generation.
- The essential challenge, however, is the fact that a wide-spread utilization can often be attained only if there are small plants available to generate power locally.
- It is true that the thermal gasification of biogenous solid fuels is necessary in order to use efficient working machines like micro gas turbines or fuel cells in the lower performance range as well.
- However, particularly in this range investment costs and sizes of plants that could provide the necessary gas quality are too high by far.

Troubles with gasification systems

- Gasification of biomass is quite complex and sensitive process.
- There exists high level of disagreement about gasification among engineers, researchers, and manufacturers.
- Many manufacturers claim that their unit can be operated on all kinds of biomass. But it is quite questionable fact as physical and chemical properties varies fuel to fuel.
- Gasifier is too often thought of as simple device that can generate a combustible gas from any biomass fuel.
- A hundred years of research has clearly shown that key to successful gasification is gasifier specifically designed for a particular type of fuel.
- Those interested in this technology must remember that it requires hard work and tolerance.
- Although technology is inconvenient, it is economical at many places and may lead to self-reliance in fuel crisis.

Core problems (1)

- The essential core problem of using fuel gases from thermal biomass gasification to date has been the tar problem.
- Due to their low heating value these “weak gases” normally can only be used in gas engines.
- For this kind of utilization, however, the fuel gas must always be cooled down.
- During thermal combustion processes it can not be avoided that hydrocarbons with higher aromatics are produced, which then condense out at temperatures lower than 200 – 250 °C and form thick tar films on pipelines or within the engine compartment.
- Tars that have not already condensed out before entering the engine piston produce deposits on the valves or within the piston itself.

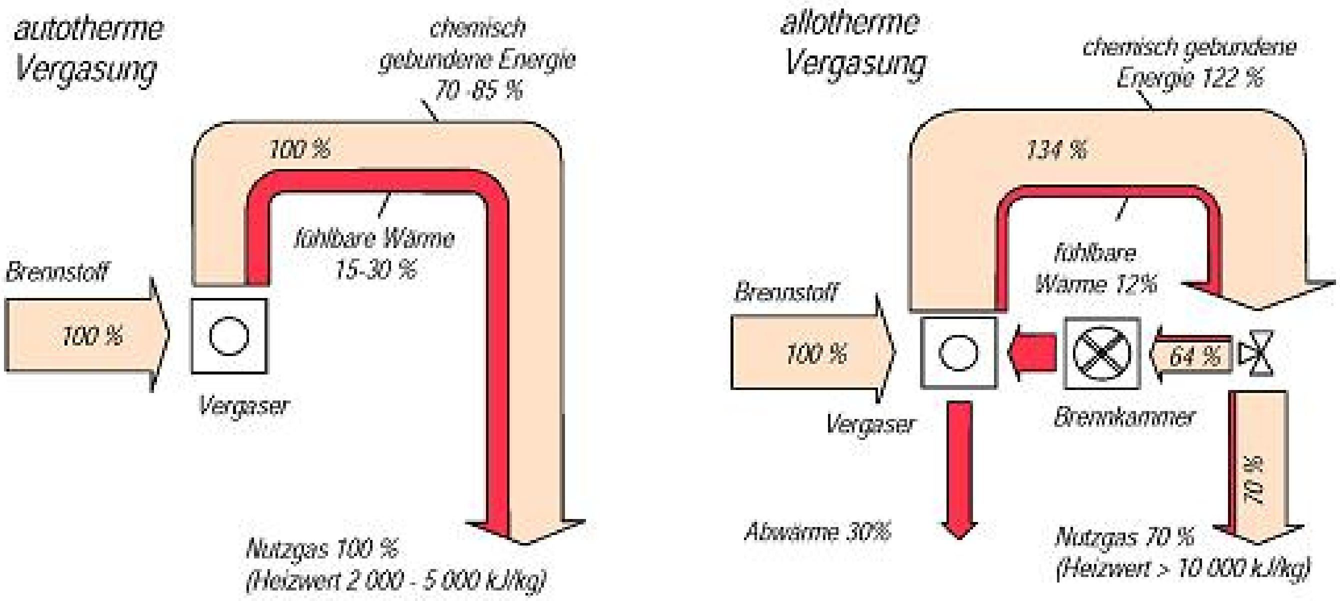
Core problems (2)

- Wood gasifiers combined with gas engines were already used for motor vehicles
- A stationary power generation application, however, requires running times of several thousand operating hours per year, which still have not been attained.
- The second core problem consists in the low heating values of the fuel gases produced, which rules out the use of the fuel gases, for instance in traditional gas turbines.

Different concepts of thermal gasification

- In principle there are three possible concepts for solving the tar problem:
- „Tar-free gasifiers“:
  - A „tar-free gasification“ can only be realized at extremely high temperatures attainable for example in entrained flow gasifiers (Shell gasifier, Prenflo gasifier, CarboV gasifier etc.).
  - These high temperatures can only be attained by gasifying pure oxygen.
  - Due to high investment costs (oxygen separation unit!) these concepts are only used in very large plants.
- Concepts with cold gas cleaning and gas engine
  - As only piston engines (Diesel or Otto engines) can be used for the utilization of weak gases from gasifying by air, almost all concepts recommend a cooling and cleaning of fuel gases using wet cleaners (water or organic solvents), catalysts or electric filters.
  - For 70 years now none of these concepts has been able to establish itself because of its high investment, operating and - above all - disposal costs (polluted waste water, toxic filter dusts).
- Concepts with hot gas cleaning, gas turbines and high-temperature fuel cells
  - The simplest way to avoid the tar problem is to cool down the fuel not below the tar condensation temperature.
  - So the hydrocarbons remain in vapor phase and – in all probability - even improve the gas characteristics during the combustion process within the combustion chambers of the gas turbine.
  - These concepts, however, require gases with higher heating values and therefore an allothermal gasification.

Energy balance autothermal and allothermal gasification



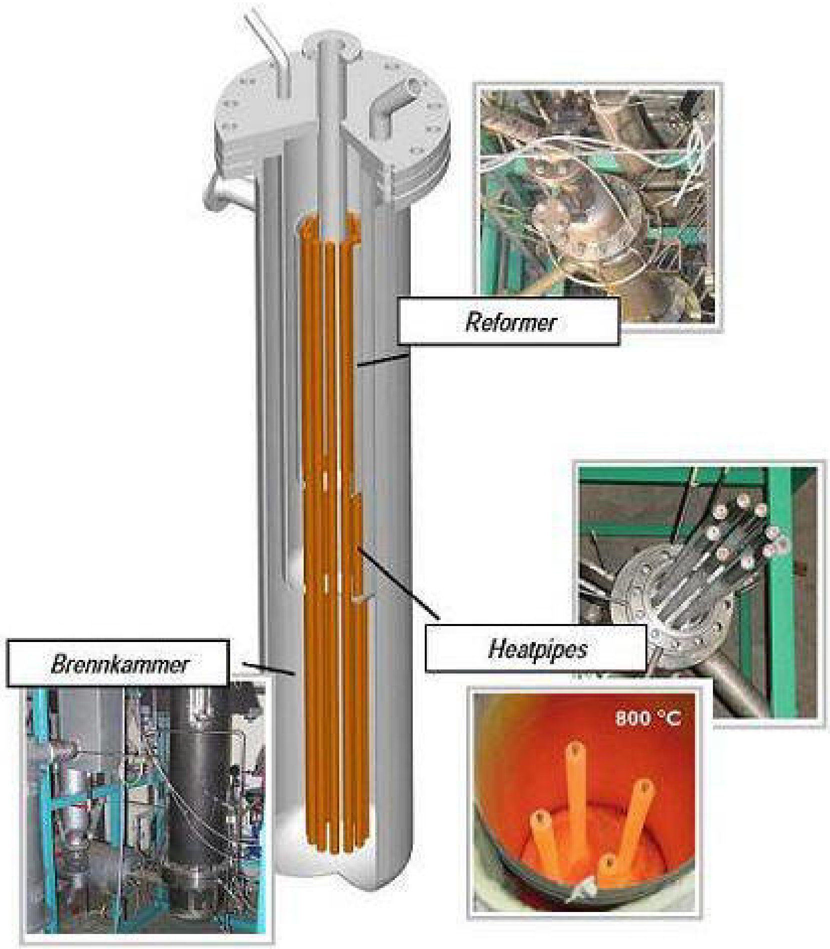
Autothermal vs. allothermal gasification

- So-called 'indirect' or 'autothermal gasifiers' produce weak gases that can only be used for engines.
- The result of this is the “tar problem” already described, that has remained unsolved for decades.
- The simplest way to avoid this problem may be “allothermal gasification”, because using this type of gasification will lead to improved gas qualities, and thus alternative working machines - such as fuel cells and micro turbines - could be used.
- Allothermal gasification is particularly interesting because gases with a high heating value are produced and this allows the appropriate use of gas turbines (for example microturbines) and fuel cells.
- In order to attain the high heating values desired, the heat which is necessary for endothermal gasification reactions has to be transferred from external heat sources to the gasification reactor.
- Contrary to the conventional autothermal gasification, here the fuel produced does not have to be diluted with flue gas and nitrogen from the combustion air supplied

Example : The Heatpipe Reformer

- Due to the rising interest in biomass gasification many efforts where made in the past 15 years to make a breakthrough.
- Some of the known processes are
  - Hofbauer Gasifier, Güssing
  - MBG Process
  - MTCI Gasifier
  - …
- One of them is the so called Heatpipe Reformer, developed at the Technical University Munich.
  - The Biomass Heatpipe Reformer presents a new gasification concept generating high-grade hydrogen-rich gases even with a wattage of only a few hundred kW.
  - Due to an innovative concept for transfering heat, into a small, but particularly simply designed gasifier, gases with a hydrogen rate of up to 50% can be generated from multiple biogenous fuels. This becomes reality for the first time because so-called heat pipes are used and integrated in a compact, but easy-to-handle system.

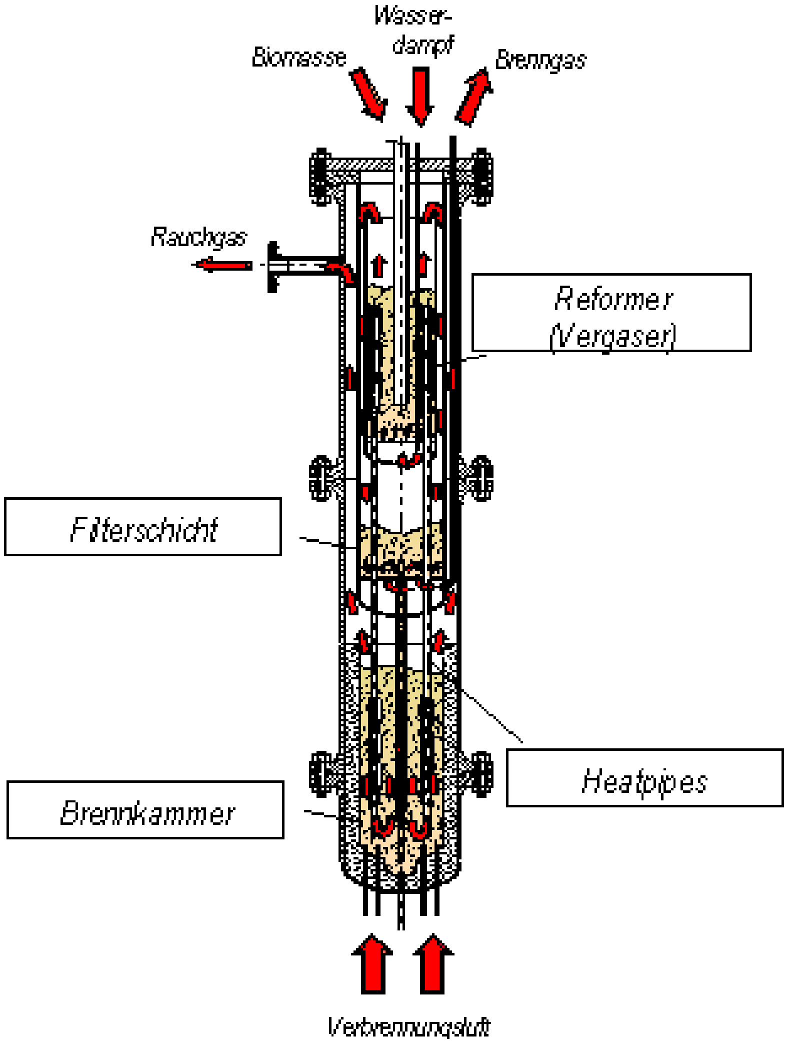
Heatpipe Reformer (2)



- The Heatpipe Reformer consists of three parts:
- The fuel is transferred through a lock system into the actual fluidized bed gasifier, the reformer.
- Within such a fluidized bed a sandbed is held in suspension by a gas flow. In the case of the Heatpipe Reformer technology steam is used for this.
- The fuel particles admix in an ideal way within this „fluidized“ and highly turbulent sandbed and begin – at temperatures of about 800 °C - to convert into a gas mix mainly consisting of hydrogen and carbon monoxide.

Source: www.heatpipe-reformer.com

Heatpipe Reformer (3)



- An essential advantage of this procedure is that the fuel supplied must not be completely gasified.
- A part of the fuel is discharged in the form of residual coke or char downward through a filter system into a fluidized bed combustor.
- This second fluidized bed then is fluidized with air.
- The residual coke combusts within this fluidized bed at temperatures of about 900 °C and so generates heat which finally is put back into the reformer via heatpipes.

Source: www.heatpipe-reformer.com

The chemical process

- During allothermal reformation biomass (empirical formula CH_nO_m)– together with steam (H_2O) - generates a synthesis gas with about 30 - 40% hydrogen (H_2) and 20 - 30% carbon monoxide (CO)

$$CH_nO_m + (1-m)\, H_2O \rightarrow (n/2 + 1 - m)\, H_2 + CO$$

- Due to parallel reactions additional 10 - 20% carbon dioxide (CO_2), 5 % methane (CH_4), 20 - 30% steam and small quantities of higher hydrocarbons, so-called tars, are generated.
- There is a standard size planned for the market launch
- fuelfuel inputpower outputheat outputViRoe500
- wood pellets
  wood chips500 kW100 kW230 kW

Energetic use of organic waste gasification

- Synthesis gas can be used as a replacement for fossil fuels in existing power stations. The process then works without direct emissions.

- If the local circumstances do not permit use in an existing power station, a biomas or waste gasification facility can be equipped with its own power production, depending on the achievable electric current yield:

  - Use in high efficiency gas engines
  - Use in a steam turbine process
  - Use in fuel cells

Material usage of organic waste gasification (1)

- Methanol synthesis from synthesis gas
  - The production of methanol from synthesis gas is state of the art:

$$CO + 2\ H_2 \rightarrow CH_3OH$$

  - Approx. 300 kg methanol can be produced from each tonne of MSW. Methanol is used e.g. as a fuel and petrol substitute, in fuel cells and as a solvent for paints and varnishes.
- Diesel production
  - By "Fischer-Tropsch Synthesis", a technology developed in the thirties of the last century, the synthesis gas can be converted into diesel fuel and other liquid hydrocarbons. Based on the actual energy prices, that could be a very interesting alternative to fuel production in refineries.

Material usage of organic waste gasification (2)

- Hydrogen production
  - Hydrogen may be the energy carrier of the 21st century: During combustion it leaves no residues apart from water, especially no carbon dioxide, and therefore relieves the problems of the greenhouse effect. Together with regenerative primary energies it provides a basis for the energy industry of the future.
  - Over 30% of the synthesis gas produced during the gasification process consists of hydrogen and over 30 % is carbon monoxide. By using a conventional reformer – which converts the carbon monoxide fraction into pure hydrogen when water vapour is added – approx. 600 m³ hydrogen can be produced from 1000 m³ synthesis gas or one metric tonne of MSW.
  - The trendsetting fuel cell technology for producing electrical energy with the highest possible efficiencies requires hydrogen or fuels containing hydrogen. Fuel cells for stationary energy production are operated commercially worldwide.

E.Quadrat GmbH: Company for the development of renewable energies in energy supply systems

- **Main areas of expertise**
  - Structuring and execution of business concepts for the entrance in renewable energy as company objective or for single projects
  - Development of company structures and processes for project management, material management, plant operation and business management
  - Development of energy projects and realization inclusive project management and structures for project finance
  - International concept and project development for renewable energies in Europe and USA
  - Bioenergy (solid, fluid, gaseous), district heating, large scale solar energy (electricity and heat), hydro power, large scale geothermal energy

- **Additional products**
  - Consulting on establishment of new business concepts and products I renewable energy
  - Detailed feasibility studies, risk analysis, evaluation of economic efficiency, potential and competition studies
  - Project structuring, competitive tendering, negotiation of service and works contracts as well as claim management
  - Preparation and assistance in project financing up to financial close
  - Consulting in development and negotiation of procurement contracts for biomass (solid, fluid and gaseous)
  - Establishment of operational structures, operation processes, standards for company staff and operational supervision
  - Service for plant administration and operation

Your questions…?

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