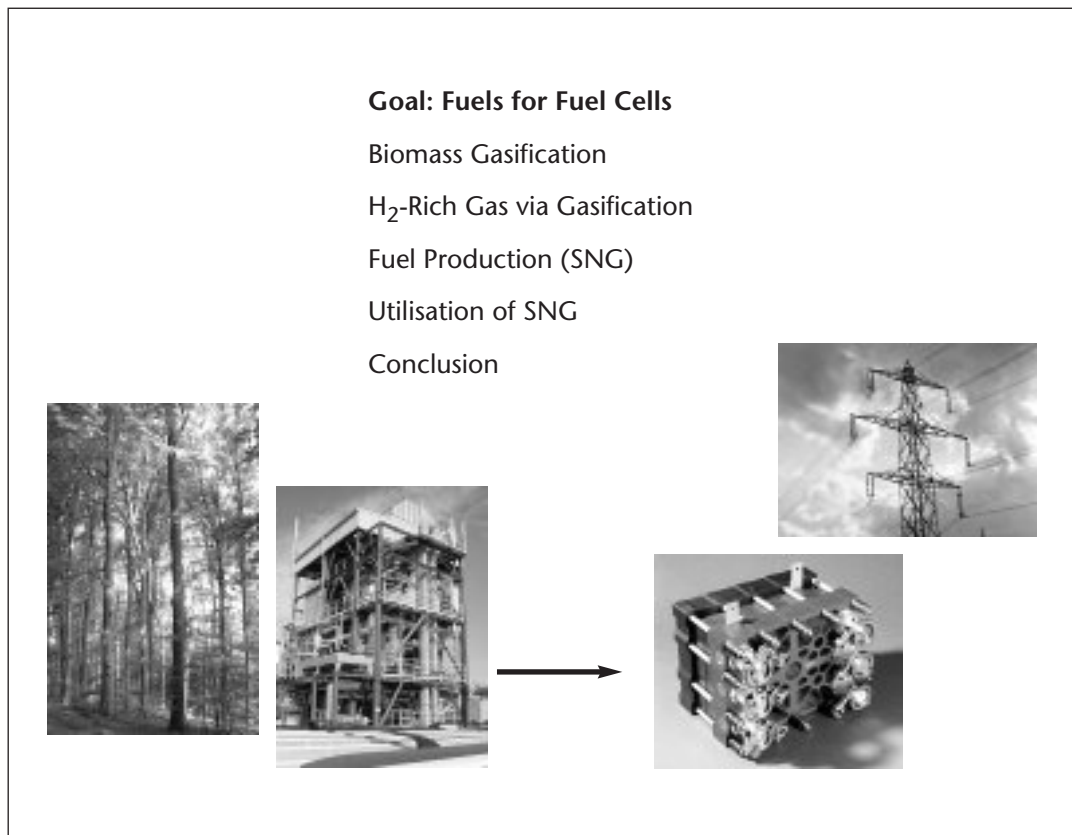


# Regenerativer Wasserstoff durch thermochemische Konversion biogener Brennstoffe

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*Contents: Hydrogen  
(Fuel Cell Fuels) via  
Biomass Gasification*



**What is the best coupling  
Biomass Gasification / Fuel Cell ?**

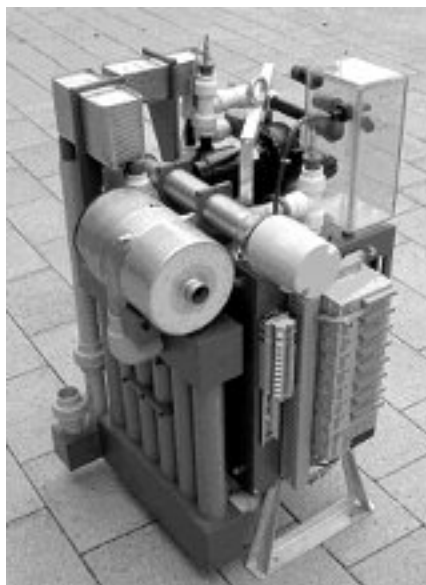


*Why Hydrogen?  
→ Fuel for Fuel Cells  
Resources?  
Where From?  
→ Biomass Option*

**Fuel cells have a high potential for electricity generation, but they do not solve the problems:**

- Dependency on fossile resources
- CO<sub>2</sub>-emissions

**→ These problems can only be solved in combination with renewable fuels.**



*Statement*

*Promising Renewable Fuels for Stationary and Automotive Applications*

**Neat Fuels:**

- Plant Oil
- Fatty Acid Methyl Ester (FAME)
- Ethanol (EtOH)
- Methanol (MeOH)
- Substitute Natural Gas (SNG)
- Fischer-Tropsch Hydrocarbons (FT-HC)
- Dimethyl Ether (DME)
- Hydrogen



**Blends with Conventional Fuels:**

- EtOH in Gasoline
- MeOH in Gasoline
- MTBE (Methyl Tertiary Butyl Ether) in Gasoline
- ETBE (Ethyl Tertiary Butyl Ether) in Gasoline
- FT-HC in Gasoline
- Plant Oil in Diesel
- FAME in Diesel
- MeOH in Diesel
- EtOH in Diesel
- FT-HC in Diesel
- H<sub>2</sub> in NG (Natural Gas)
- SNG in NG

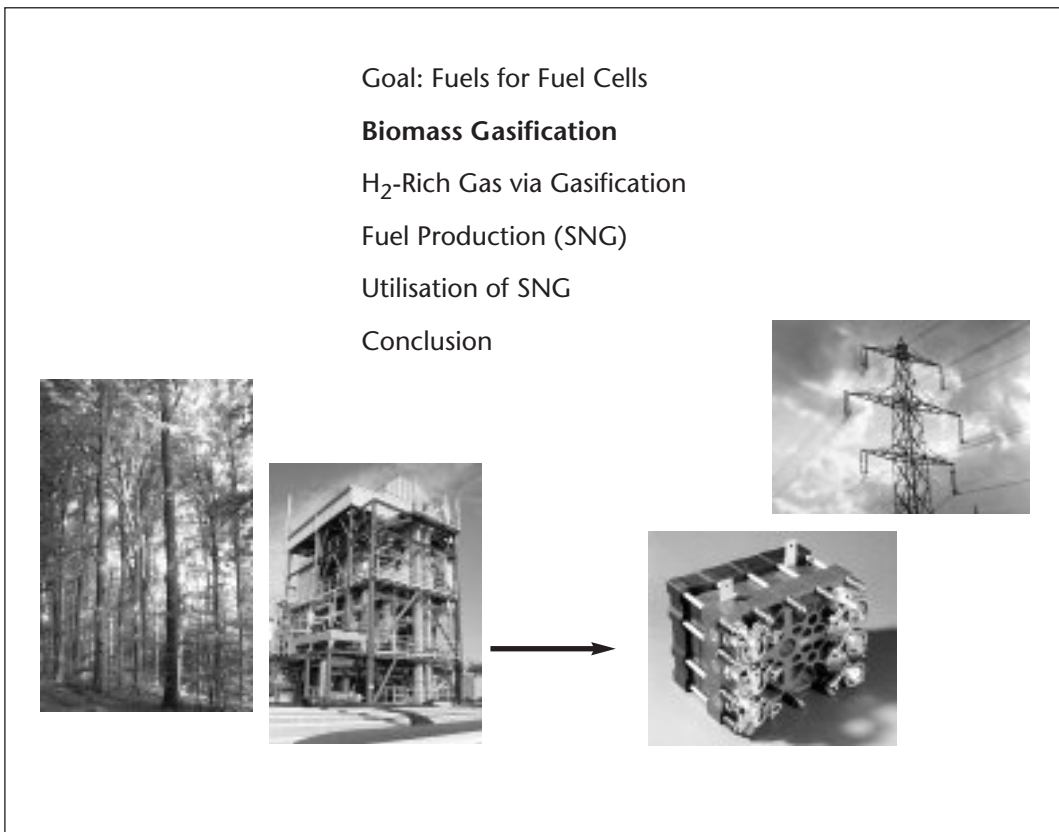


Grey: Usability for Fuel Cells

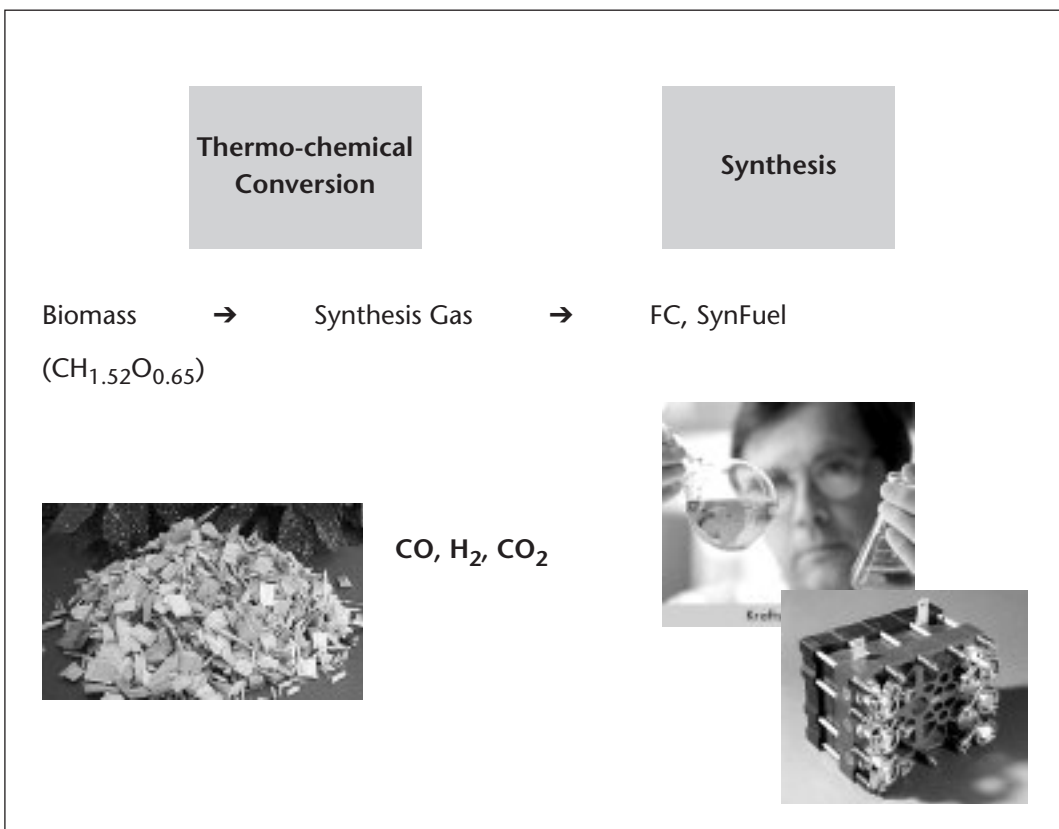
*What are the best Renewable Fuels for Fuel Cells?*

**What are the best Renewable Fuels for Fuel Cells ?**

- Road Transport  
→ Hydrogen
- Gas Grid-Bounded Stationary Fuel Cells  
→ SNG
- Non Gas Grid-Bounded Stationary Fuel Cells  
→ MeOH, DME, EtOH ????
- „4C“-Market (Cordless Tools: Computer, Camcorder ....)  
→ Hydrogen, Methanol



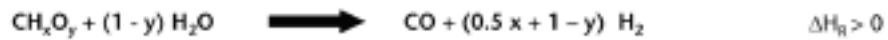
Contents:  
Hydrogen (Fuel Cell Fuels) via Biomass Gasification



Goal:  
Electricity/SynFuel from Biomass

Gasification of Biomass:  
Main (Homogeneous) Gas-Phase Reactions

Steam Reforming of Biomass Decomposition Products



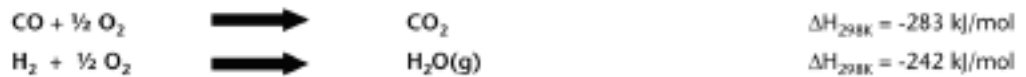
Homogeneous Water Gas Shift Reaction



Homogeneous Methanation



Oxidation Reactions

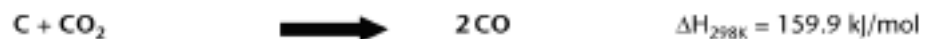


Gasification of Carbon:  
Main (Heterogeneous) Reactions

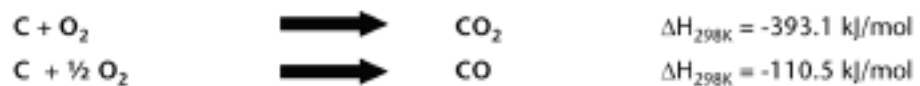
Heterogeneous Water Gas Shift Reaction



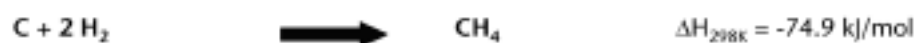
Boudouard-Reaction



(Partial) Oxidation



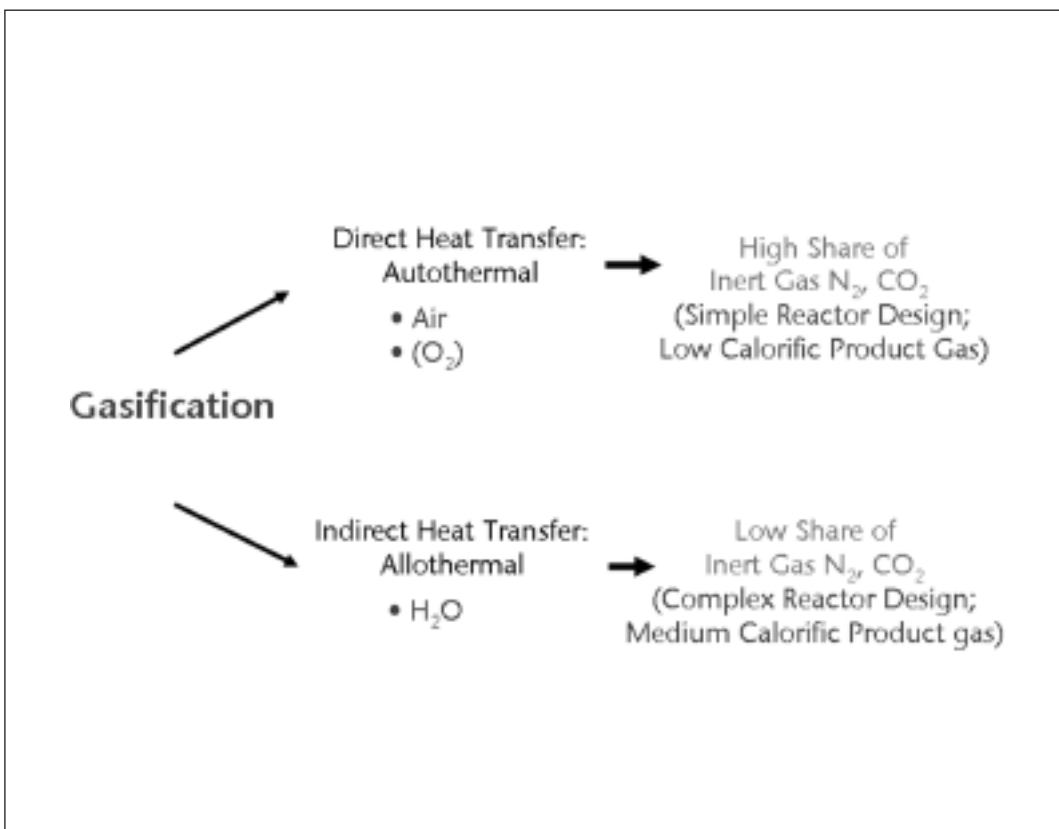
Heterogeneous Methanation



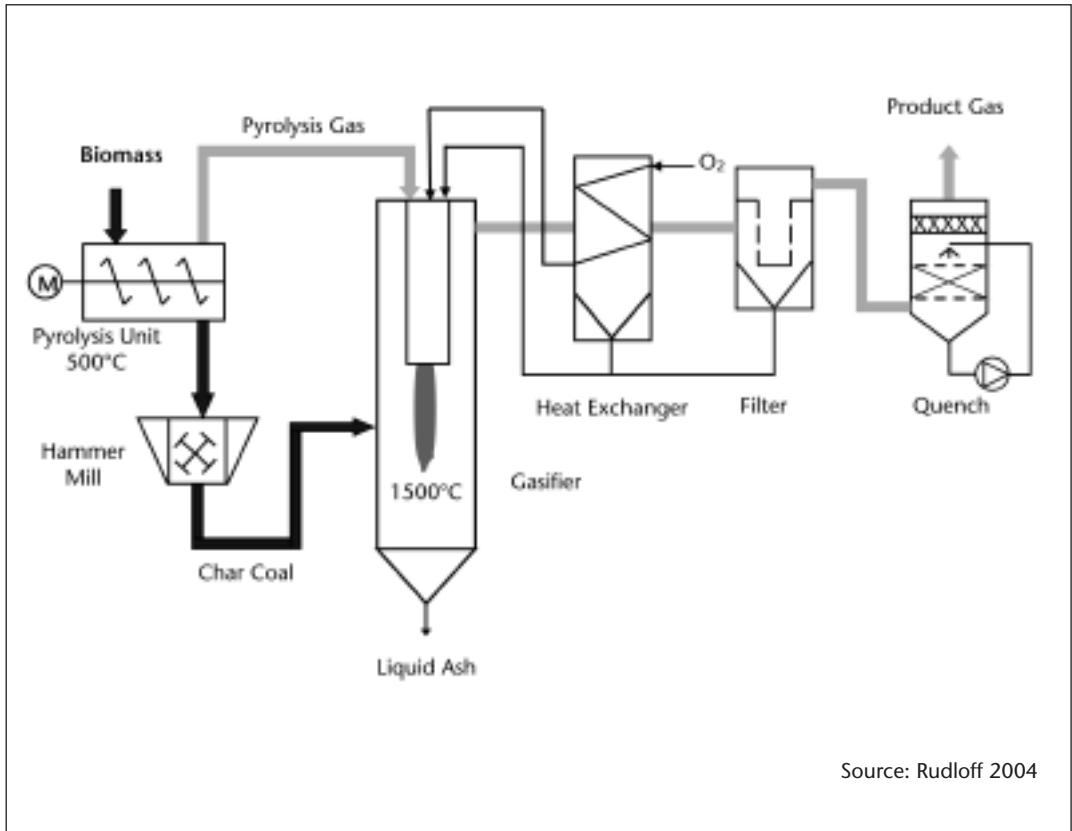
*Classification of Gasification Processes*

- **Operation Mode**
  - Autothermal (Partial Oxidation of Biomass)
  - Allothermal (Indirect Heating)
  
- **Gasifier Type**
  - Fixed Bed Gasifier 0.2 - 5 (25) MW<sub>th</sub>
  - Fluidised Bed Gasifier 5 - 100 MW<sub>th</sub>
    - Bubbling Fluidised Bed (BFB)
    - Circulating Fluidised Bed (CFB)
  - Entrained Flow Gasifier 50 - 500 MW<sub>th</sub>

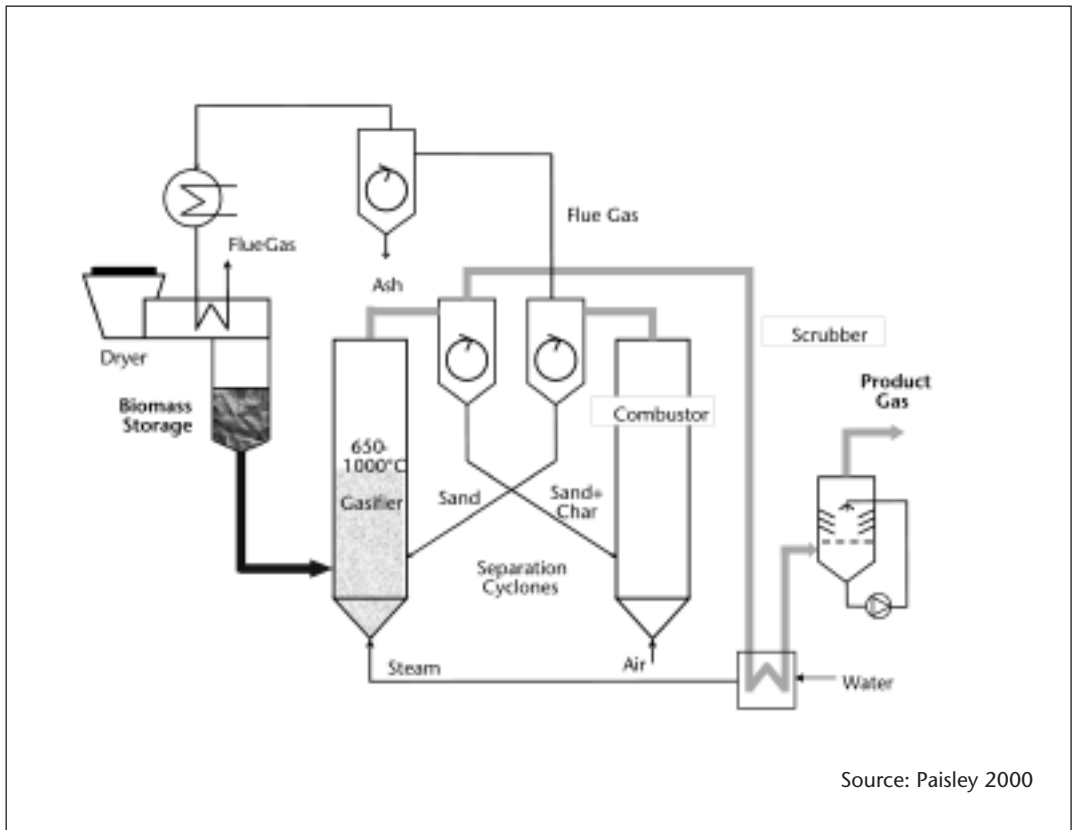
*Heat Transfer: Autothermal and Allothermal*



Carbo-V / CHOREN –  
 Process:  
 Entrained Flow  
 Gasifier – Autothermal  
 ( $T > 1000\text{ °C}$ )



Battelle/FERCO  
 (SilvaGas) Process:  
 Twin Fluidised Bed  
 Gasifier – Allothermal  
 ( $T < 1000\text{ °C}$ )



Contents: Hydrogen (Fuel Cell Fuels) via Biomass Gasification

Goal: Fuels for Fuel Cells

Biomass Gasification

**H<sub>2</sub>-Rich Gas via Gasification**

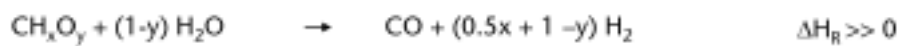
Fuel Production (SNG)

Utilisation of SNG

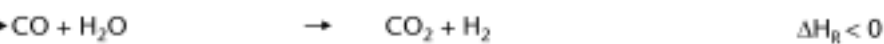
Conclusion



**Steam Reforming / Gasification of Biomass**



**CO Shift Reaction**



**Combined with a HT-CO<sub>2</sub> Absorption**



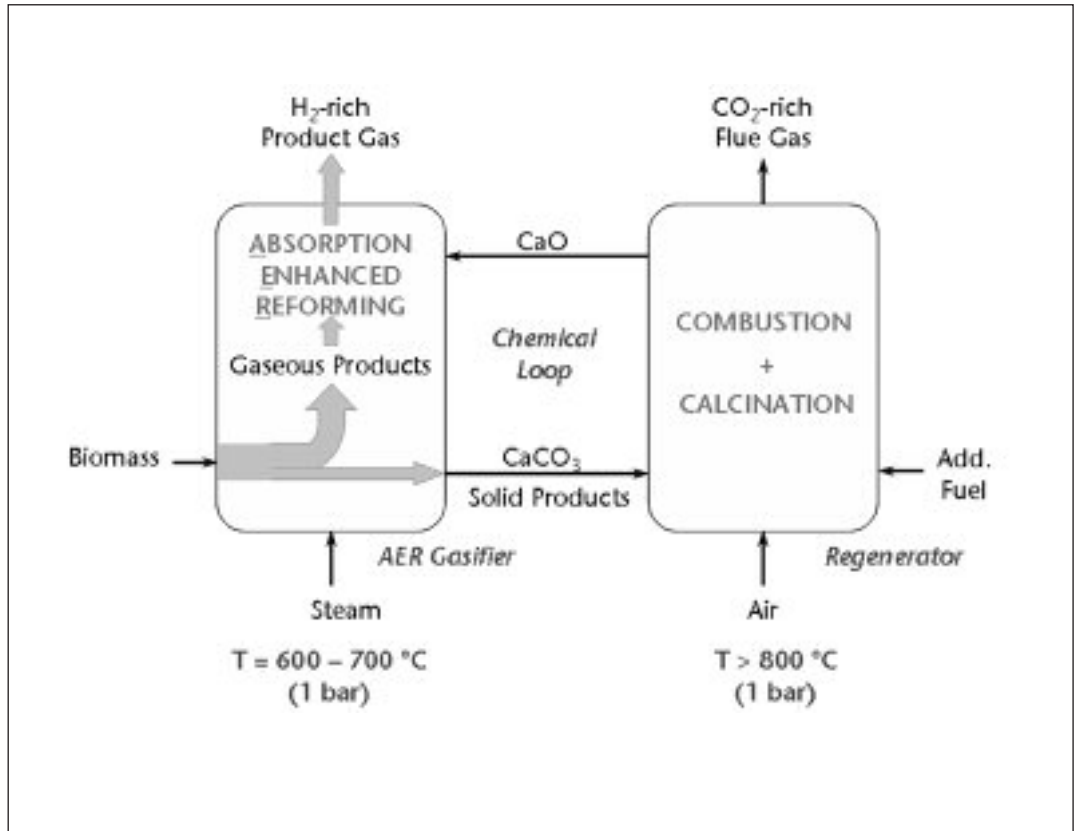
**Overall (600 – 700 °C, 1 bar)**



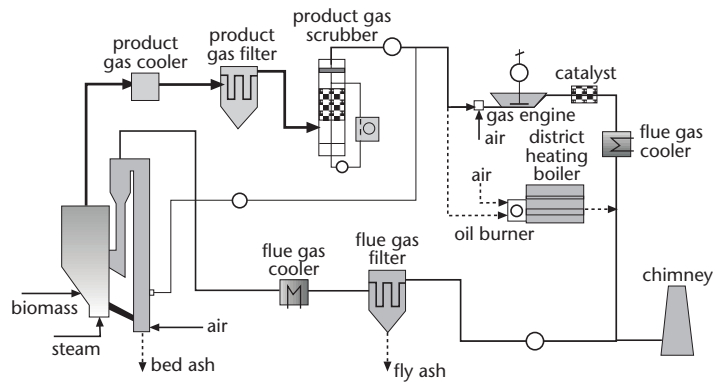
AER - Reactions (Absorption Enhanced Reforming)



AER-Process: Twin  
Fluidised Bed Gasifier -  
Allothermal - in situ  
CO<sub>2</sub> Removal



Test of AER-Process  
in Biomass 8 MW<sub>th</sub>  
FICFB Power Plant  
Güssing / Austria

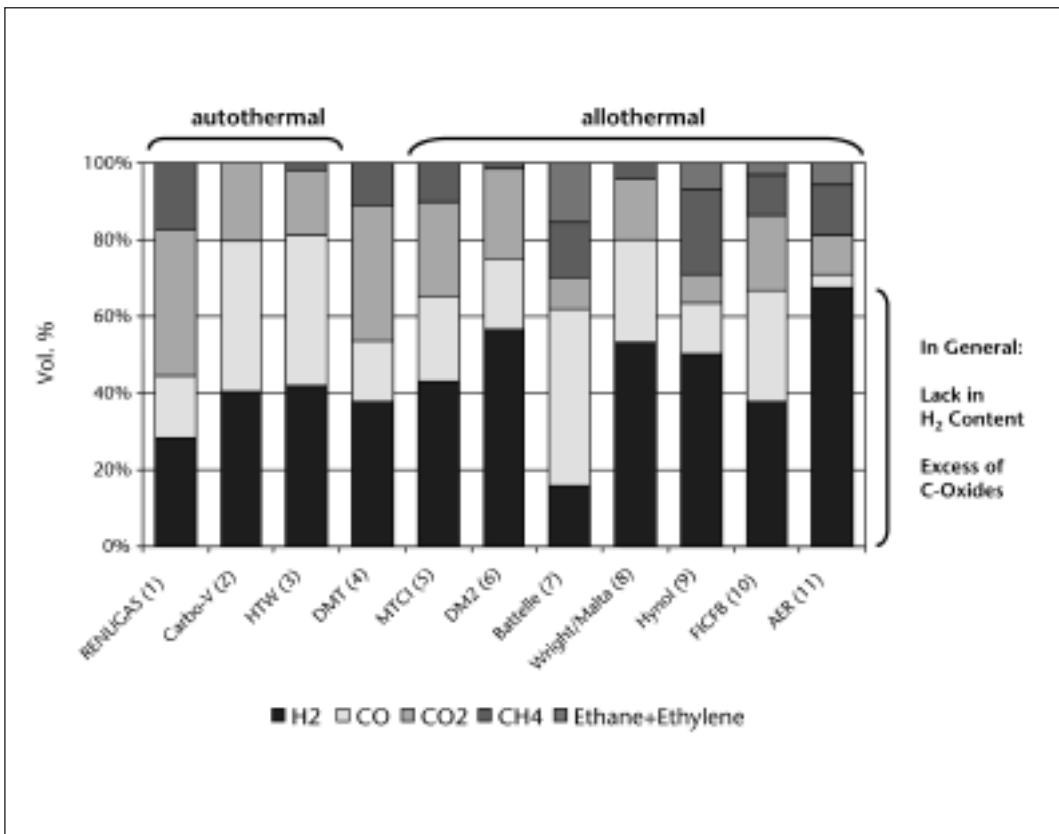


Source: TUV

AER Advantages:

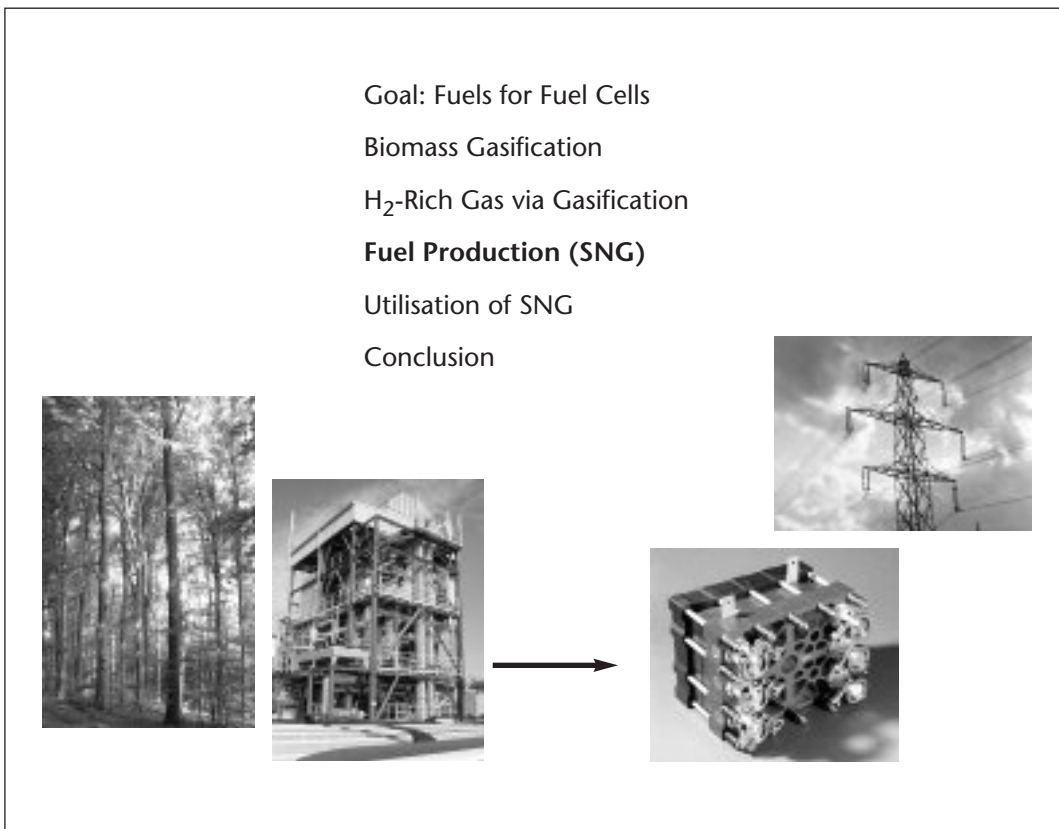
- High Efficiency
- High H<sub>2</sub> Content (70 Vol.%)
- Low Rank Biomass
- Adapted Gas

2007: First AER Test Campaign in Güssing!



Producer Gas from Different Biomass Gasifiers – Are they Suitable for Fuel Cells and SynFuels ?

In General:  
Lack in H<sub>2</sub> Content  
Excess of C-Oxides



Contents:  
Hydrogen (Fuel Cell Fuels) via Biomass Gasification

Substitute Natural Gas (SNG) from Thermo-Chemical Biomass Conversion

### Which Thermo-Chemical Energy Conversion?

„Low-Temperature“ Gasification in Fluidised Bed:

Main Products: H<sub>2</sub>, CO, CO<sub>2</sub>, CH<sub>4</sub>

→ Electricity Production (HT Fuel Cell) / SNG

„High-Temperature“ Gasification in Entrained Flow Gasifier:

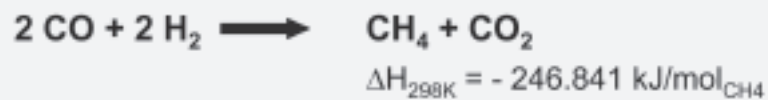
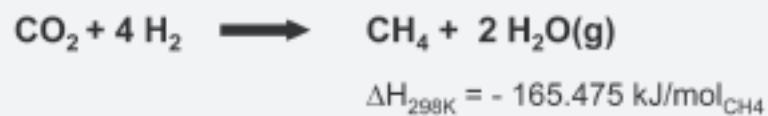
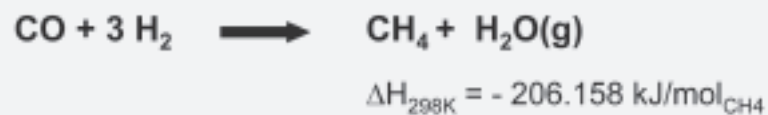
Main Products: H<sub>2</sub>, CO, CO<sub>2</sub>

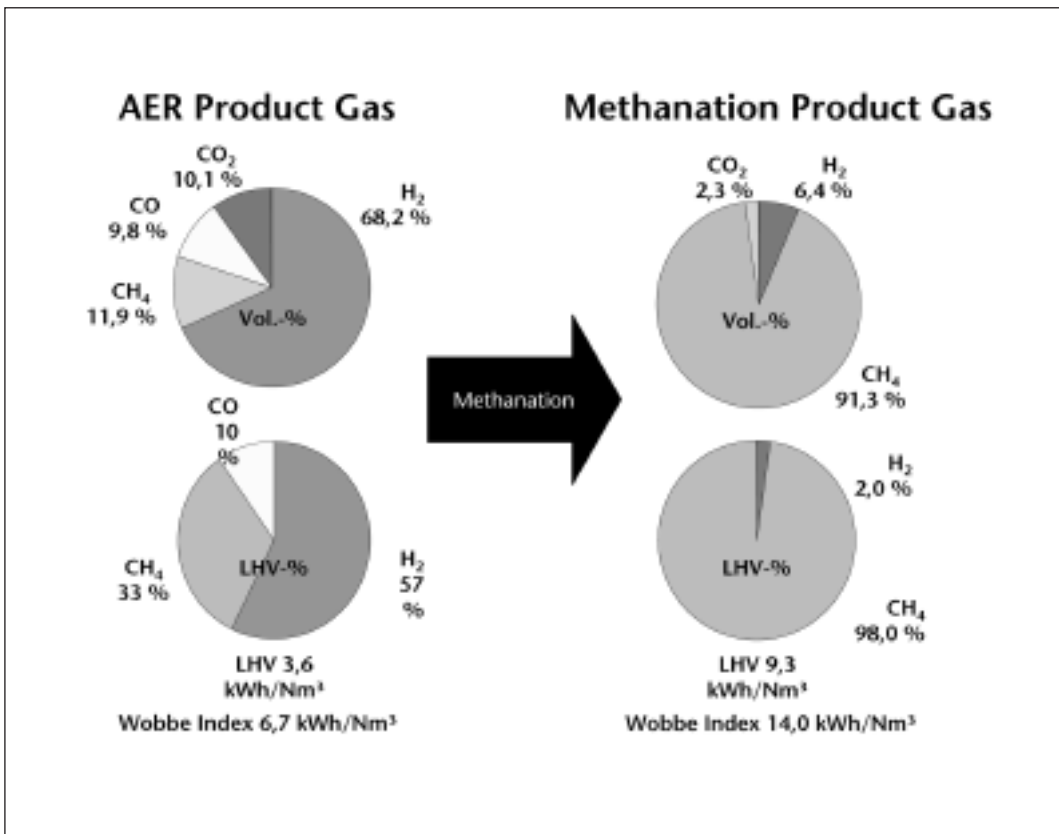
→ Electricity Production / Liquid Synfuels

### Process Realisation with AER-Process:

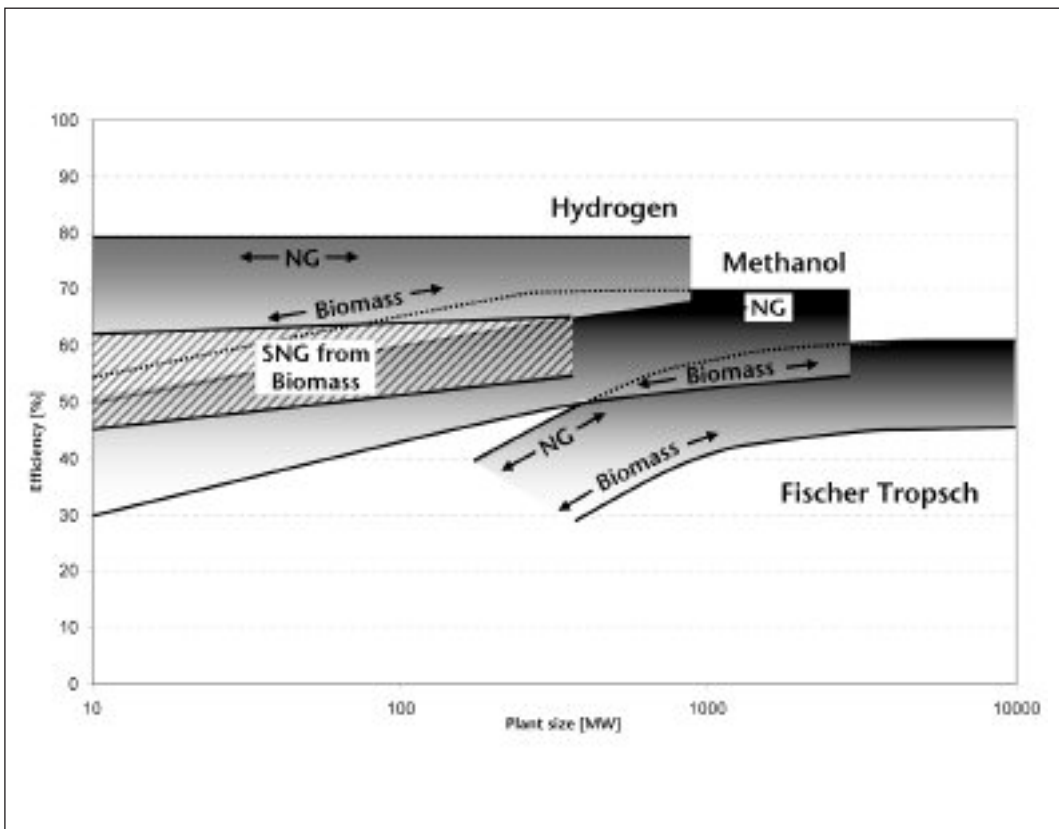
1. Step: Biomass Gasification with
  - High H<sub>2</sub> and High CH<sub>4</sub> Content
  - Low CO<sub>x</sub>-Content
2. Step: Methanation of Rest-CO<sub>x</sub>

Methanation of CO<sub>x</sub> in Bio-Syngas



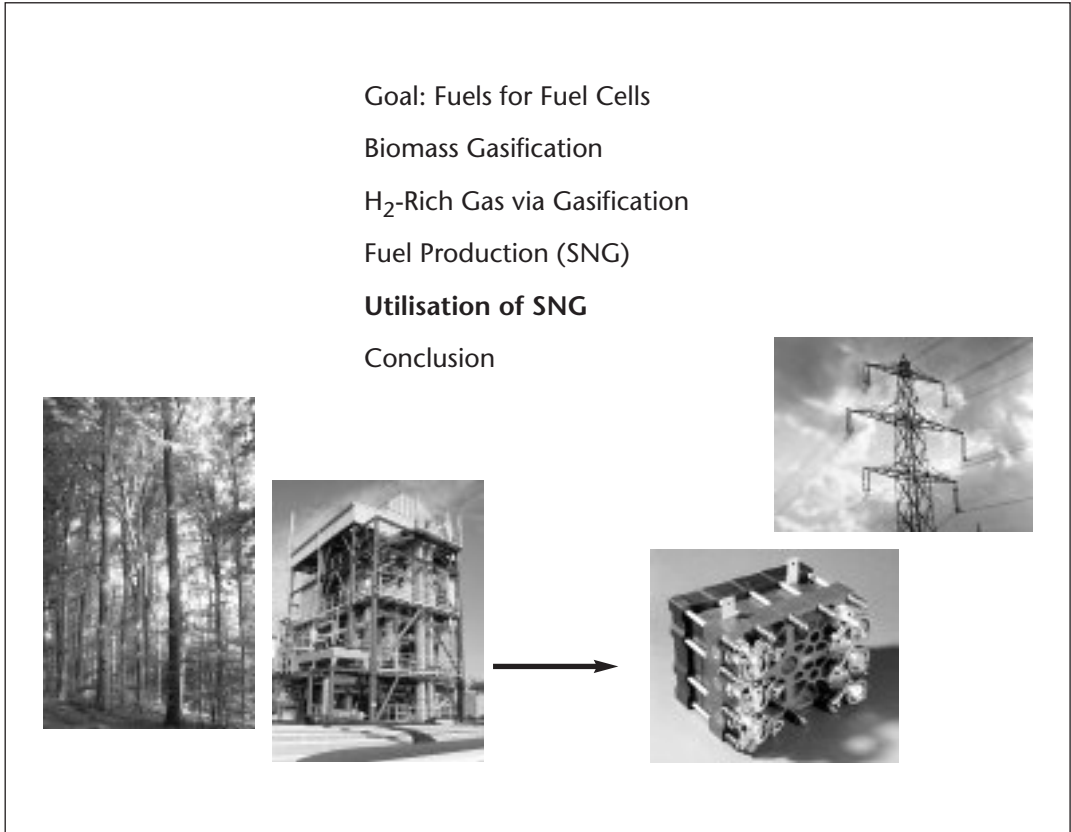


Experimental Result:  
SNG from AER  
Product Gas

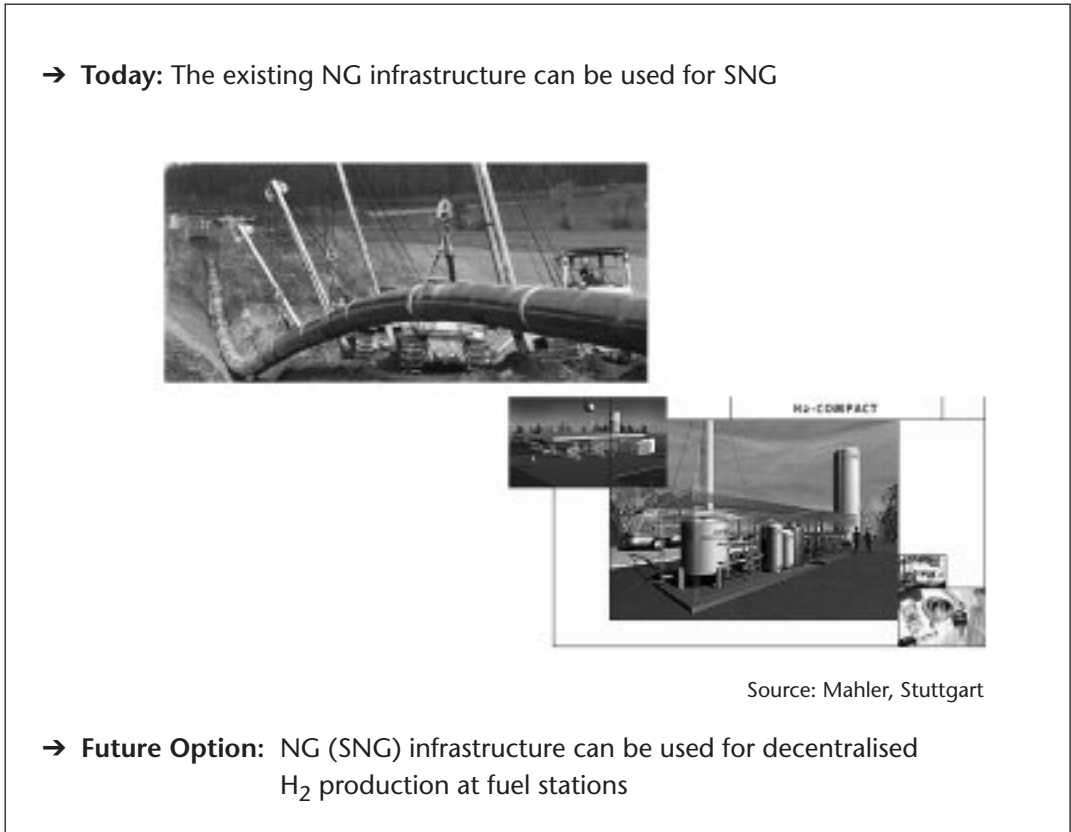


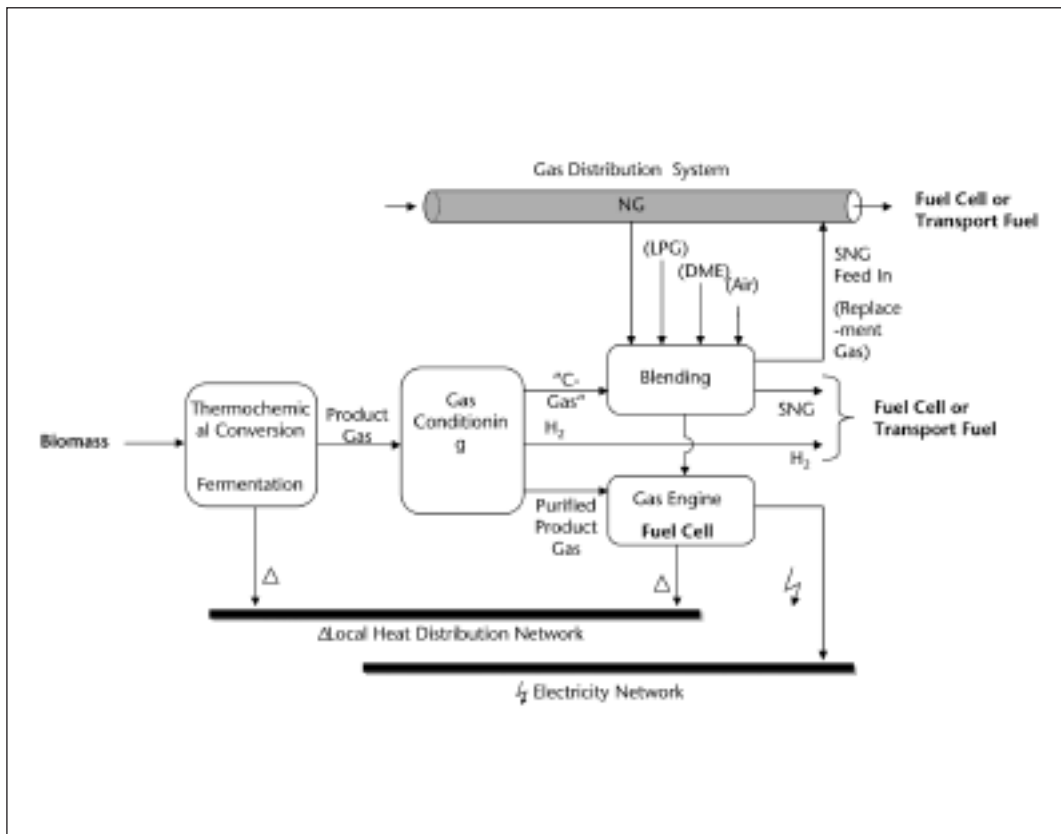
Efficiency Range of  
Biomass-to-Synfuel/  
Hydrogen and Natural  
Gas-to-Synfuel/  
Hydrogen Conversion

Contents:  
 Hydrogen (Fuel Cell  
 Fuels) via Biomass  
 Gasification



Substitute Natural  
 Gas (SNG) - Why?



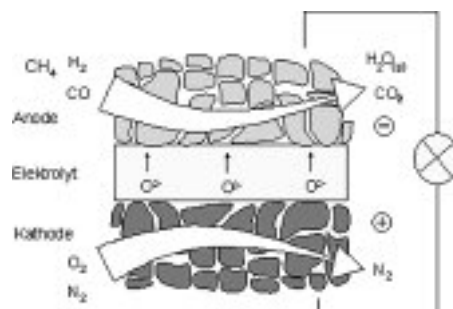


Electricity, Heat and Transport Fuel from Biomass: „Vectorisation“ of Renewable Energy

### Advantages

- Utilisation of the Existing Gas Distribution System
  - Higher Electric Efficiency of High Temperature-FCs compared to H<sub>2</sub>
  - CO<sub>2</sub> Removal Option is an Integrated Component of an NG / SOFC-System
- (S)NG is an Excellent Energy Carrier for Stationary Fuel Cell Systems
- A H<sub>2</sub> Pipeline Infrastructure is not Essential for Stationary Fuel Cell Systems

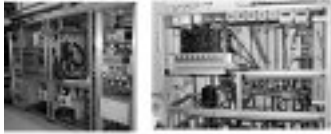
Utilisation of (Substitute) Natural Gas for Stationary High Temperature Fuel Cell Systems




ZSW – Technology  
Platform Stationary  
PEM Fuel Cell Systems

### System Integration

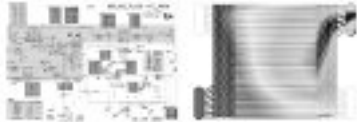
#### Test Equipment



- Evaluation of Main Components
- Pre-Qualification of BOP Components
- Characterisation of Catalyst Materials



#### Modelling & Simulation



- Modelling/Simulation of Stacks
- Modelling/Simulation of Components
- Process Simulation & Engineering

→ Goal: Utilisation of SNG as renewable fuel !

Contents:  
Hydrogen (Fuel Cell Fuels) via Biomass Gasification

Goal: Fuels for Fuel Cells




Biomass Gasification


H<sub>2</sub>-Rich Gas via Gasification

Fuel Production (SNG)

Utilisation of SNG

**Conclusion**



→




**Technology**

- Biomass gasification
- SNG production / CO/CO<sub>2</sub> methanation
- SNG feed-in into NG grid
- H<sub>2</sub> production / H<sub>2</sub> separation
- Utilisation of H<sub>2</sub>/SNG in Fuel Cells



**R&D Demands**

- Thermochemical gasification to produce adapted Syngas/Fuel Gas or Hydrogen for downstream processes
- System complexity
- System costs

*R&D Demand:  
SNG/H<sub>2</sub> Production  
via Biomass  
Gasification /  
SNG/H<sub>2</sub> Utilisation in  
Fuel Cells*

**Technology**

- 1 – 5 kW<sub>e</sub> Based on Natural Gas (SNG)
- Mainly NT-PEM and HT-PEM
- SOFC



**R&D Demands**

- Lifetime (e.g. stack > 25.000h in 2012)
- Efficiency ( $\eta_e = 33-35\%$ )
- System complexity
- System costs



(Details: National Development Plan 2007)

*R&D Demand:  
Stationary Fuel Cell  
Systems for Home  
Energy Supply*



Conclusions

- **Indirect coupling Biomass Gasification / Fuel Cell:**

„Low temperature gasification“ with high  $\text{CH}_4/\text{C}_n\text{H}_m$ -content, SNG production and SNG feed-in into NG-grid

- Utilisation of SNG:

- In stationary fuel cell systems for home energy supply
- SNG-reforming at fuel stations for  $\text{H}_2$ -generation for fuel cell propulsion in road transport
- In central Combined Cycle/SOFC/MCFC power stations, in NG vehicles, etc.

- **Direct coupling Biomass Gasification / Fuel Cell:**

„Low temperature gasification“ with high  $\text{CH}_4/\text{C}_n\text{H}_m$ -content and „High temperature fuel cell“: MCFC or SOFC

→ No need of a  $\text{H}_2$  infrastructure!