Thermal Gasification Based Hybrid Systems

PtG & PtL

Dr. Jitka Hrbek

University of Natural Resources and Life Sciences Vienna

6. CEBC 2020

Graz, 24.01.2020

Content

Thermal biomass gasification as a carbon source for renewable fuels

Biomass as feedstock → Gasification → Product gas

For the conversion of biomass to transportation fuels there is too less hydrogen and too much oxygen in the feedstock. $C_1H_{1,44}O_{0,66}$

Most fuels have composition

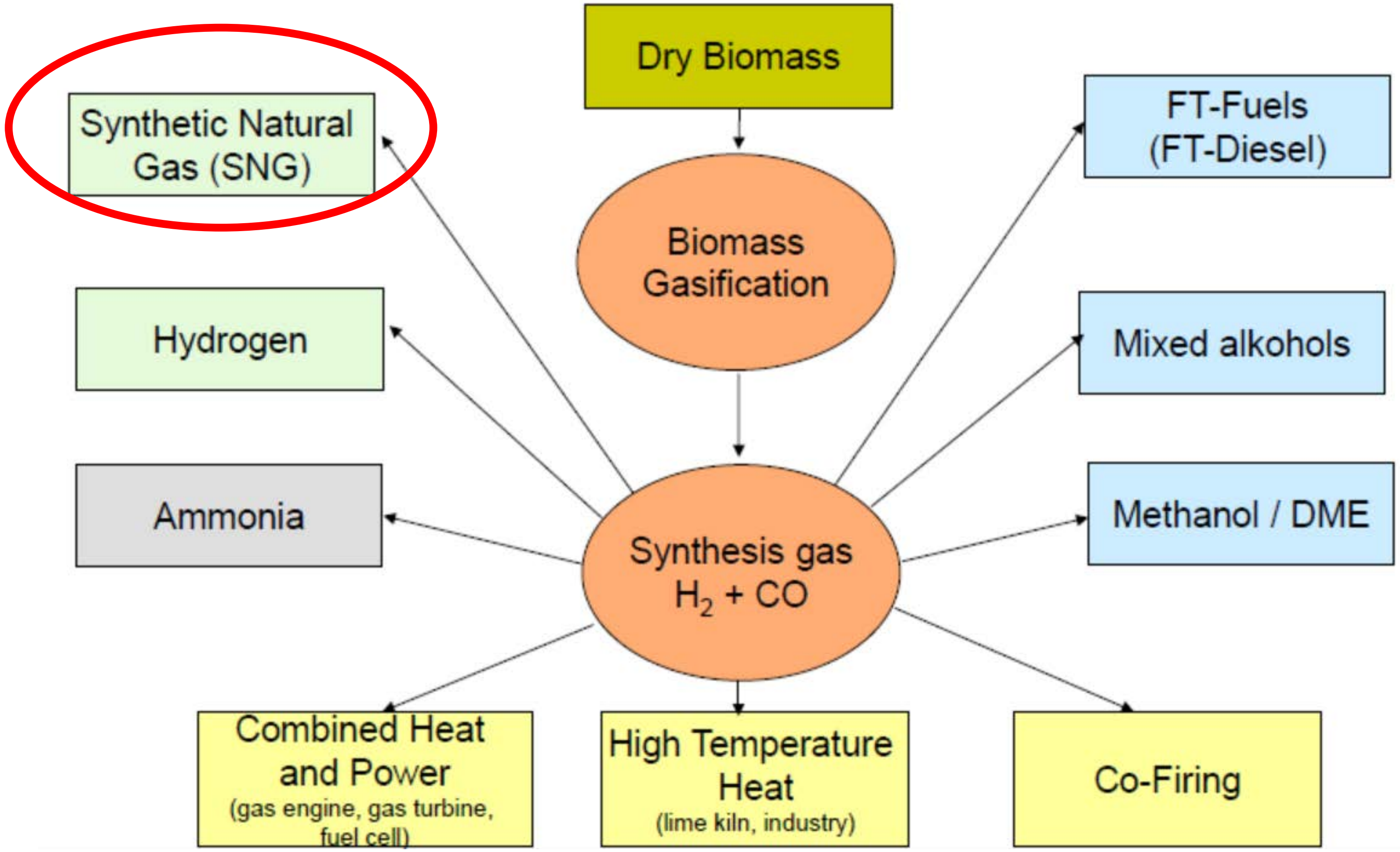
$$-(CH_2)-$$

This results in lower efficiencies compared to e.g. natural gas as a feedstock.

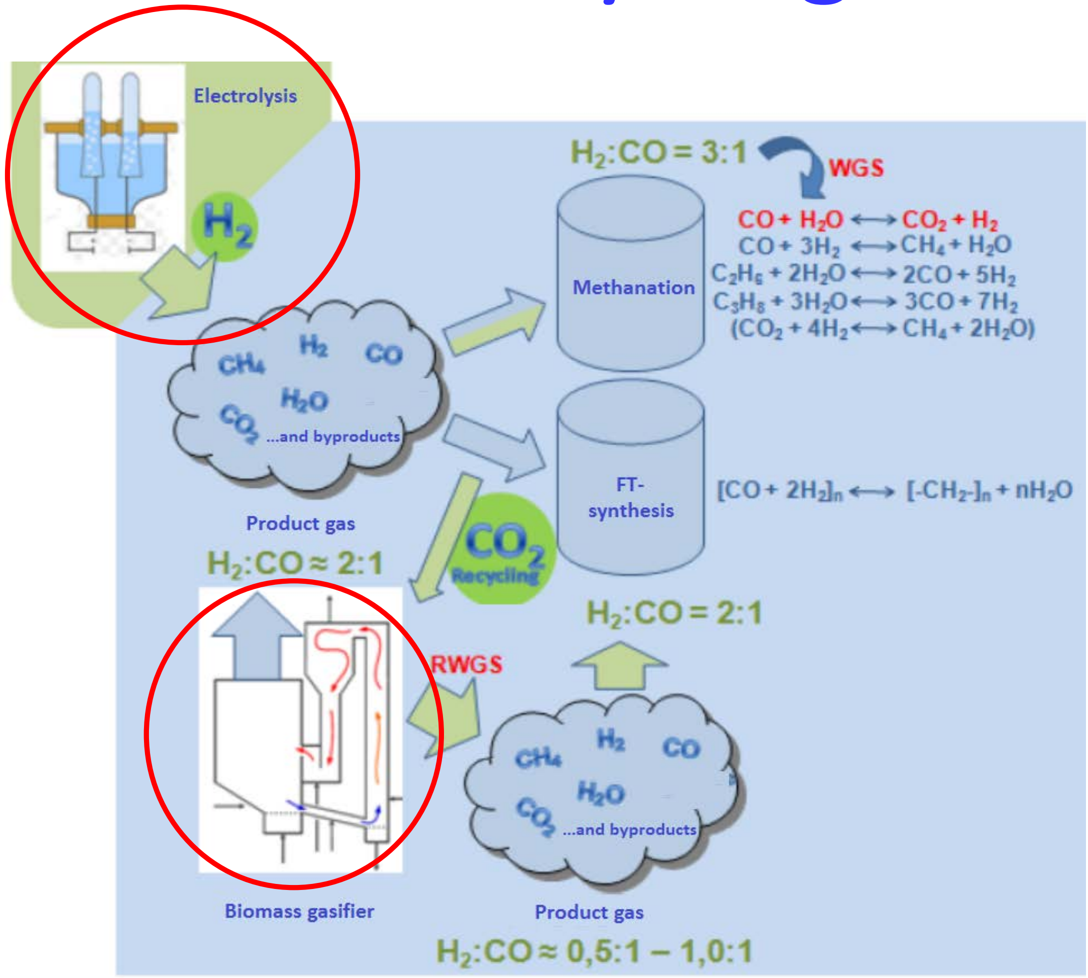
Compound		Air gasification Fixed bed	Oxygen gasification Entrained flow	Steam gasification Fluidized bed
CO	Vol. %	13-18	45-55	25-30
CO_2	Vol. %	12-16	10-15	20-25
H_2	Vol. %	11-16	23-28	35-40
CH_4	Vol. %	2-6	0-1	9-11
N_2	Vol. %	45-60	0-1	0-5
Calorific value	MJ/Nm^3	4-6	10-12	12-14

Source: A.V. Bridgwater, H. Hofbauer, S. van Loo: Thermal Biomass Conversion, 2009, ISBN 978-1-872691-53-4

Synthesis gas utilization



Coupling thermal gasification with additional hydrogen from electrolysis



A system consists of two bed steam gasifier and electrolyser for production of methane (PtG) or FT-products (PtL).

During the steam gasification a gas with H_2 : CO = 2 ratio is produced, but for methanation a gas with ratio H_2 : CO = 3 is necessary, it means further hydrogen from electrolyser is needed.

Advantage:

Coupling the thermal gasification of biomass with hydrogen from electrolysis can doubled the production of renewable fuels in comparison if only product gas from gasification is used.

Advantages of biomass gasification integration into PtG (SNG is the product)

- Total carbon exploitation from biomass can be more than doubled
- Higher overall process efficiency (larger product yield and possibility of heat integration)
- O_2 from electrolysis can be used for gasification
- By adding hydrogen from electrolysis, the use of the water-gas shift reaction can be avoided
- Large H_2 storage can be avoided
- By non-available surplus electricity, the methanation can be operated with synthesis gas from gasification only

Energy flow/energy conversion/mass yeld

(Methane via steam gasification)

Configuration:

- Steam gasification
- Alkaline electrolyzer

	No additional hydrogen	With additional hydrogen
Methane output	63,7 MW	140 MW
Mass yield	193 kg/tonne$_{dry}$	370 kg/tonne$_{dry}$

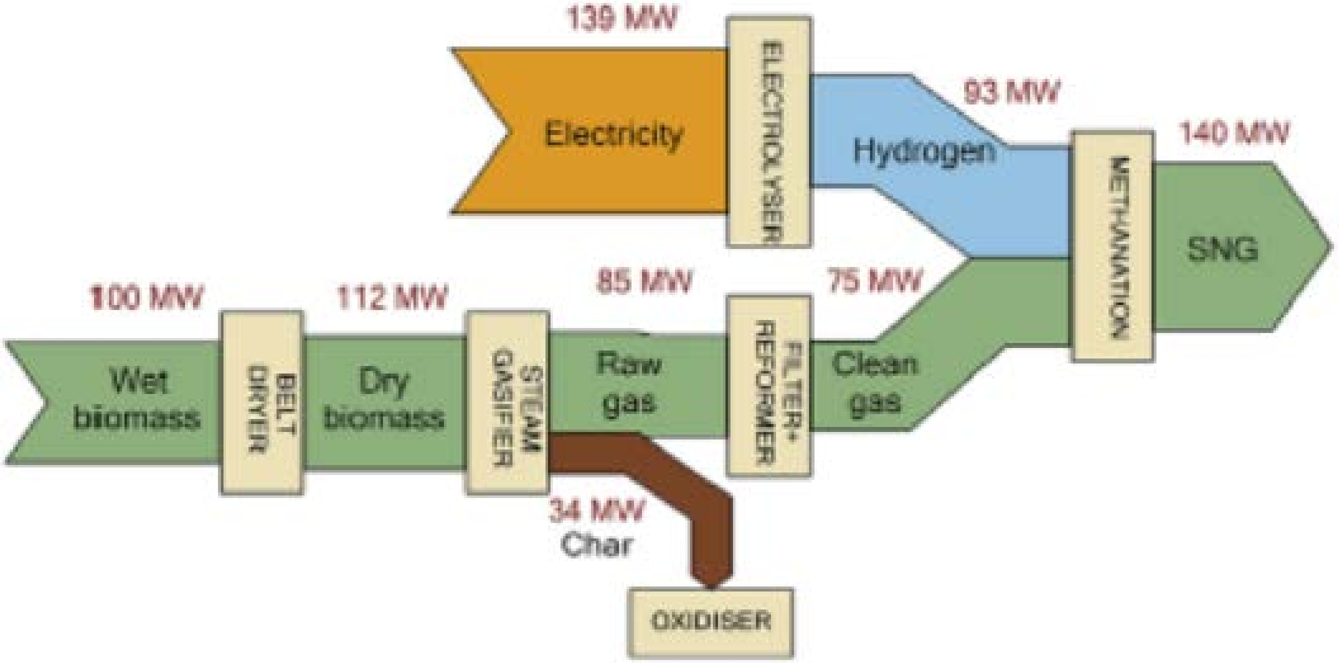


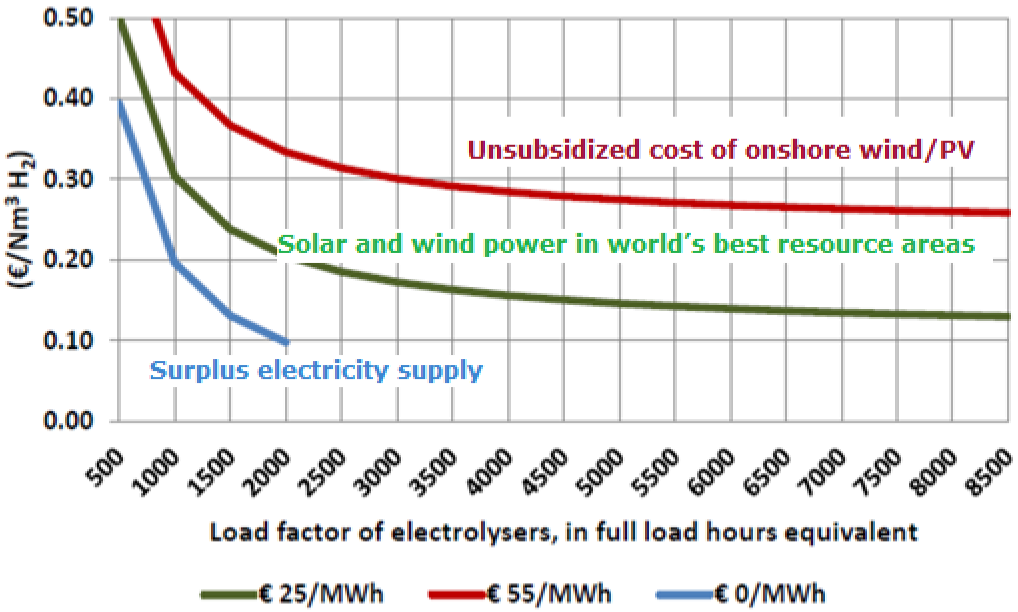
Fig.: Energy flow for methane (SNG) with hydrogen addition

Source: I. Hannula: Energy 104

Economics

Important parameters influencing the renewable fuel price:

- Costs of renewable hydrogen (costs of electrolyzer, op. costs, hydrogen storage?)



- Costs of biomass
- Size of gasification unit (investment and operation costs)
- Size of methanation unit (investment and operation costs)
- Number of operating hours
- Process heat utilization
- Usage or selling of oxygen from electrolysis
- Subsidy
- Location
- Etc.

Assumptions: Capex electrolysers USD 450/kWin+30% installation +20% Opex; lifetime 30y; Weighted average capital cost 7%; efficiency 70%
Source:. IEA and EC Workshop on electro fuels, Brussels, 10 September 2018
Background document

Economics of PtG systems

Focus on CO_2 source

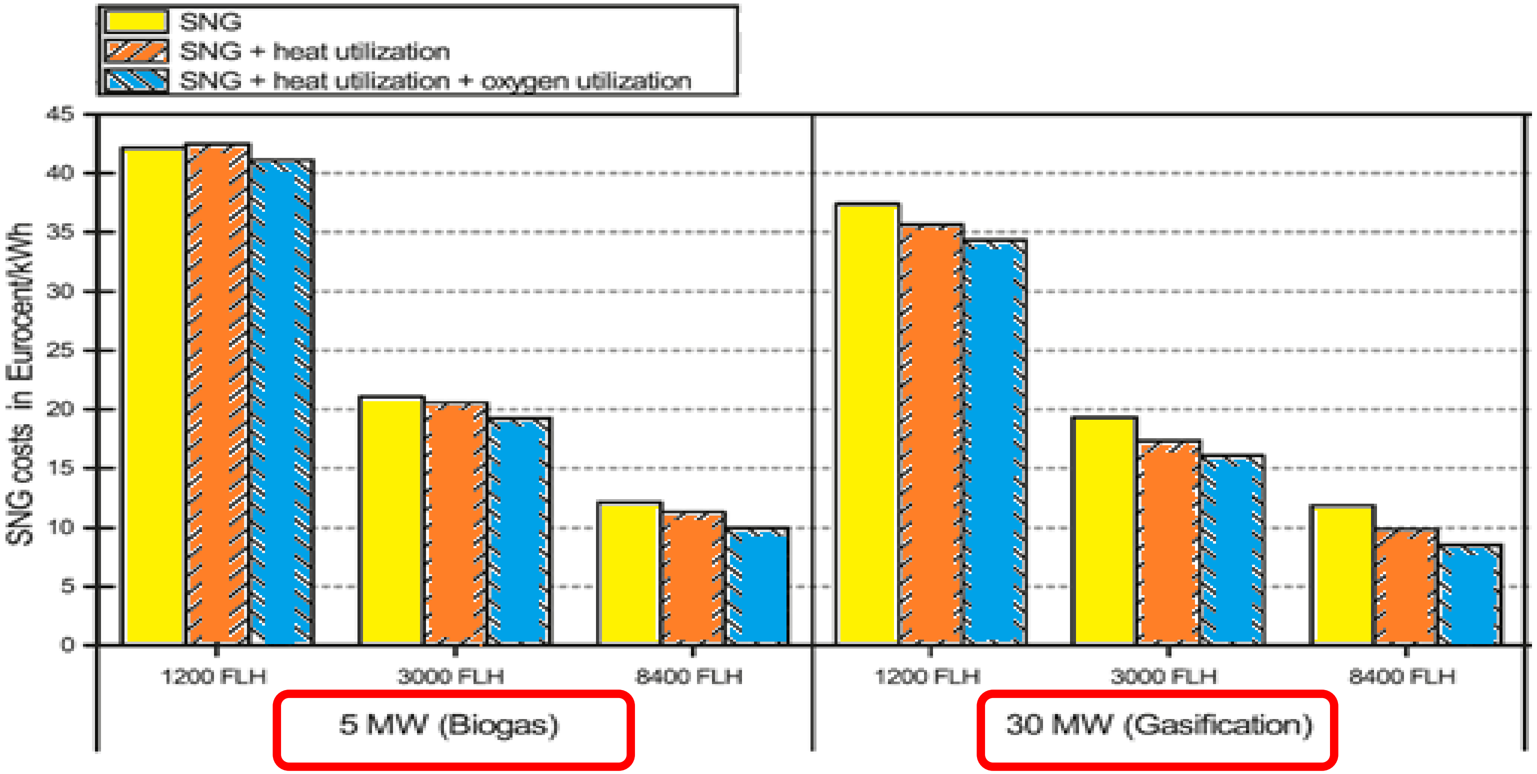


Fig.: SNG generation costs for the coupling of PtG with different CO_2 sources (FLH-full load hours)

Source: M. Götz at al. /Renewable Energy 85

Prices configuration:

- Electricity 5 €ct/kWh
- Heat 4 €ct/kWh
- Oxygen 7 €ct/m^3

Compared with natural gas (approx. 2-3 €ct/kWh),

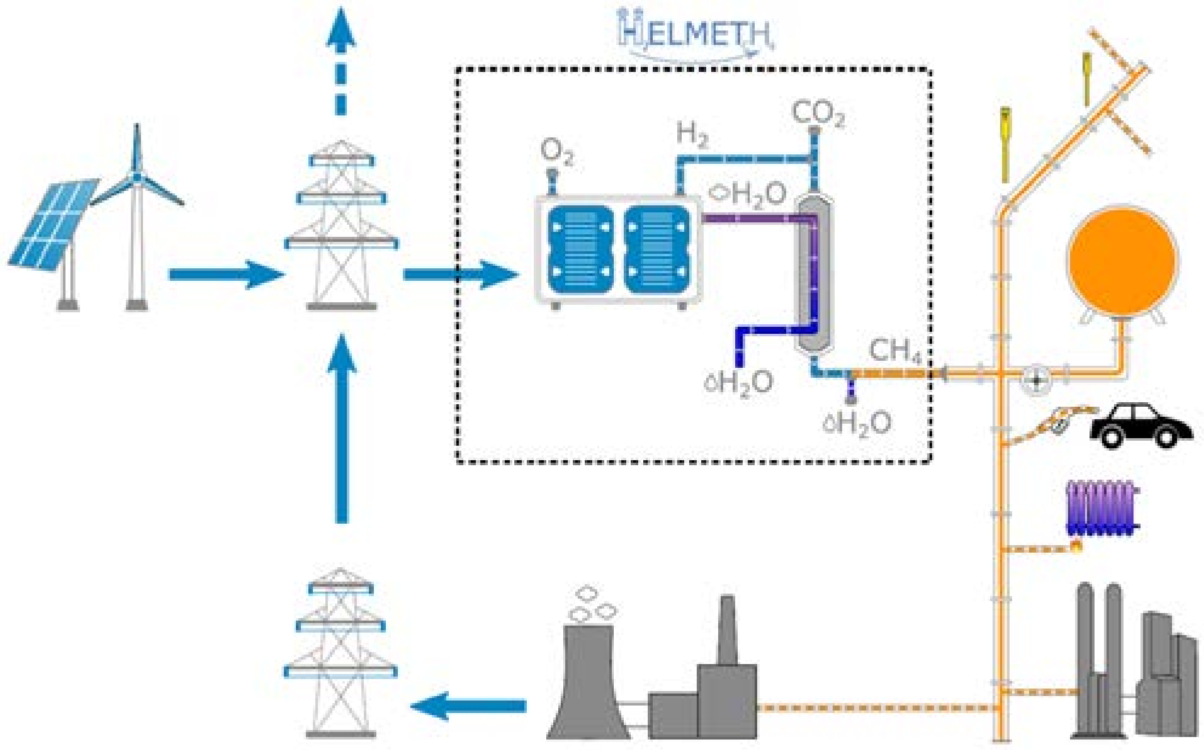
the costs of renewable SNG are much higher.

For economic feasibility, annual operational times and low electricity costs are obligatory.

PtG: Projects

HELMETH

(Integrated high-temperature electrolysis (SOEC) and methanation for effective power to gas conversion)



- Project partners: Sunfire, KIT
- First pressurized high-temperature electrolyser system in operation (Sunfire)
  - Pressure levels up to 15 bar, Input power up to 10 kW, Temperature 850°C
- Multistep CO_2-methanation module working with a boiling water cooling. SNG with hydrogen contents below 2 vol.-% (KIT)
- Challenge: the accurate flow and pressure control of steam at high pressures and the thermal insulation at high pressures
- In a first step, a detailed theoretical analysis of an integrated pressurized high-temperature electrolyser and methanation unit has been performed. It has been shown that the upper efficiency limit is 89 %HHV, where a practical efficiency limit is at about 85 %.
- For economic feasibility of PtG technology is the low natural gas price and overabundance challenging
- PtG needs sophisticated business concepts in order to be viable.

PtG: Projects

STORE & GO

Integration of PtG into the daily operation of European energy grids to investigate the maturity level of the technology

Three different demonstration sites in Germany, Switzerland and Italy offer highly diverse testing grounds for PtG:

- available energy sources (high wind power; PV and hydro; PV and wind power)
- local consumers (low consumption; municipal region; rural area)
- electricity grid type (transmission grid; municipal distribution grid; regional distribution grid)
- gas grid type (long distance transport; municipal distribution grid; regional distribution grid)
- type of CO_2 source (biogas; waste water; atmosphere)
- heat integration (veneer mill; district heating; CO2 enrichment)

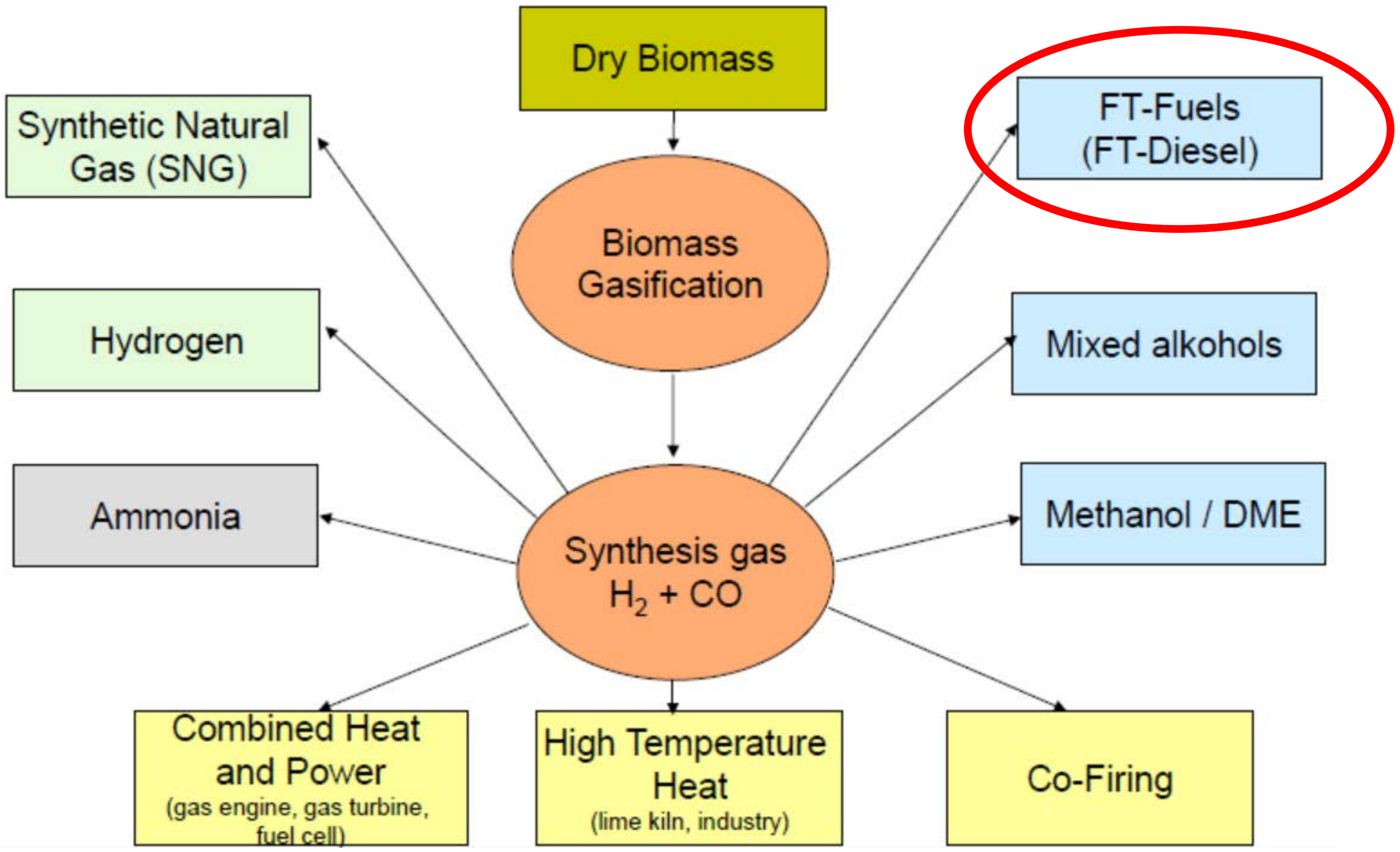
Last news – all sites operational

- Demo site in Germany produduces 1 400 m3 SNG/day (14 500kW/h), now above 700 oph., purity 99%
- Demo site in Switzerland – biological methanation (CO2 converted to biomethane using Archaea microorg).
- Italian demo site- CO2 capture

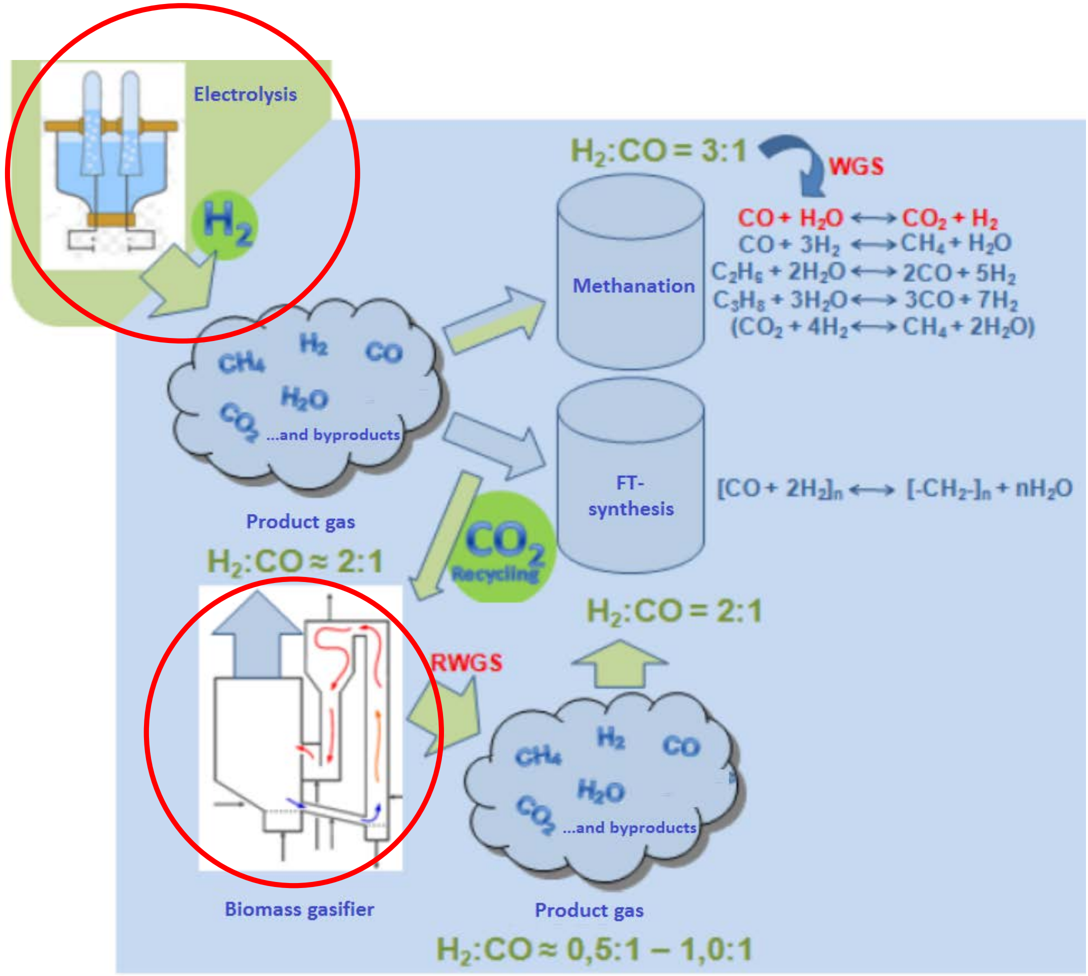
Status quo

- **Analyses show: Power-to-gas increases energy security and lowers total costs of the energy system**
- From a technological point of view, renewable gases are ready to be integrated within the energy system.
- However, the current legal and regulatory framework and market conditions impede the installation of industrial-scale power-to-gas plants and the ramp up of gas production.
- The STORE&GO project partners are working on channeling the results into a European PtG roadmap
- **Project ends with 29.02.2020**

Synthesis gas utilization



Power to Liquids (FT products)



Compound		Air gasification Fixed bed	Oxygen gasification Entrained flow	Steam gasification Fluidized bed
CO	Vol. %	13-18	45-55	25-30
CO_2	Vol. %	12-16	10-15	20-25
H_2	Vol. %	11-16	23-28	35-40
CH_4	Vol. %	2-6	0-1	9-11
N_2	Vol. %	45-60	0-1	0-5
Calorific value	MJ/Nm^3	4-6	10-12	12-14

Source: A.V. Bridgwater, H. Hofbauer, S. van Loo: Thermal Biomass Conversion, 2009, ISBN 978-1-872691-53-4

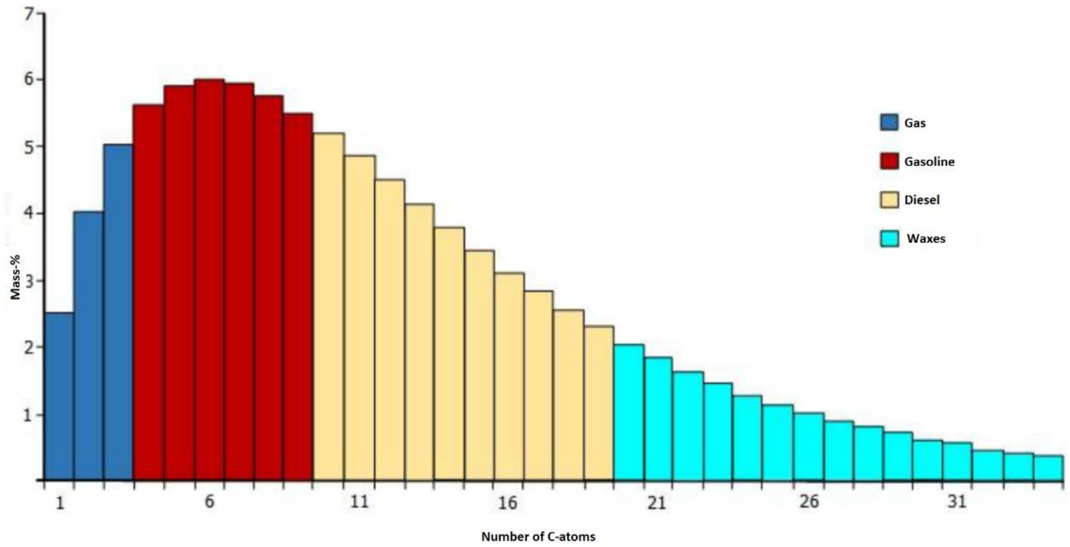
A system consists of two bed steam gasifier and electrolyser for production of methane (PtG) or FT-products (PtL).

During the steam gasification a gas with H_2 : CO = 2 ratio is produced, which is optimal for FT-synthesis.

By FT synthesis is the usage of additional hydrogen from electrolyser a little bit different. The principle is based on CO_2 recycling, it means, the inert CO_2 will not be released to the atmosphere, but it will serve as an additional fluidizing agent in the gasification unit as a carbon source for further reactions with hydrogen from electrolysis.

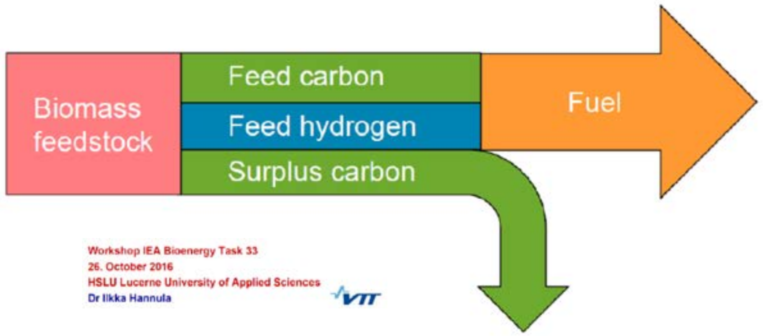
From synthesis gas to FT products

- Synthesis gas – H_2 and CO mixture
- For FT synthesis necessary ratio H_2:CO = 2:1

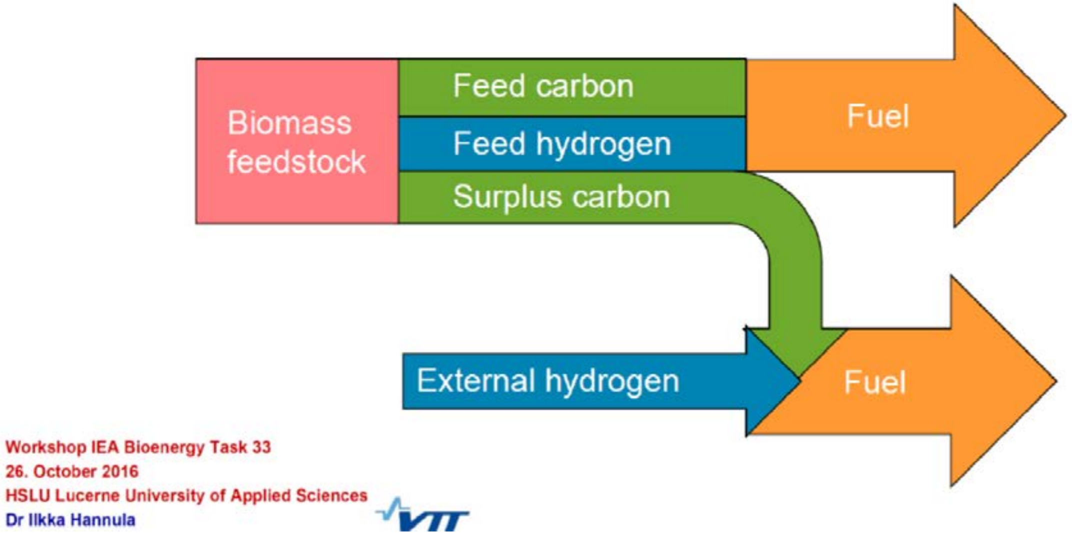


- Surplus carbon in product gas is not used in the syntesis process, as there is not enough hydrogen for the conversion

Compound		Air gasification Fixed bed	Oxygen gasification Entrained flow	Steam gasification Fluidized bed
CO	Vol. %	13-18	45-55	25-30
CO_2	Vol. %	12-16	10-15	20-25
H_2	Vol. %	11-16	23-28	35-40



Boosting the production with external hydrogen - Fischer Tropsch products



Using of additonal (external) hydrogen the FT products amount could be doubled

Advantages:

- Conversion of surplus electricity and surplus carbon to high valuable products
- Higher carbon utilization
- Biomass acts as base load (8000 oph/y possible), no start-stop operation, only load change

Advantages of the FT liquids

- As a synthetic fuel, PtL offers improved combustion with fewer pollutants, which makes it attractive for production of e.g. aviation fuels.

- While methanol-based biodiesel must be blended with petroleum-based diesel, renewable diesel can fully substitute it – and renewable jet fuel is accepted in 50% blend in aviation, at least in Europe.
- In aviation today, only jet fuels from FT process have already satisfied all tests for being used as drop-in fuels.
- FT-based pathway has been approved for use in commercial aviation in blends of up to 50% with conventional jet fuel (Schmidt et al., 2018).

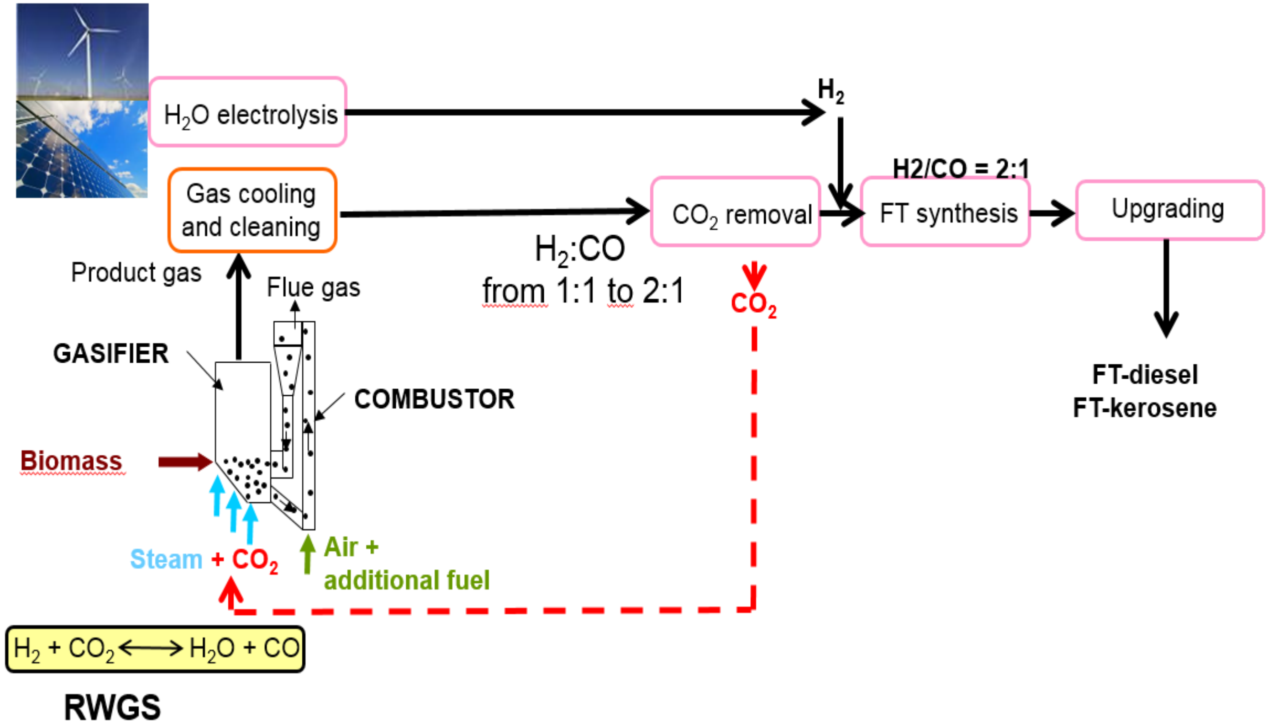
Conventional diesel fuel (left) and F-T ultra pure diesel (right)

PtL projects (FT liquids)

WindDiesel

Advantages of this concept:

- As the H2 should come from excess electricity, the Winddiesel plant that is based on biomass gasification and Fischer Tropsch synthesis can be operated in its main parts with high annual operating hours.
- The addition of H2 from excess electricity brings a surplus in product yield and conversion rate of the used biomass but is not necessary for the synthesis process.



Base case:

- 100 MW Biomasse
- 0 MW Wind
- 49 MW FT-Product
- Carbon Conversion: 0.31

Maximum Windenergy

- 100 MW Biomasse
- 67 MW Wind electricity
- 88 MW FT-Product
- Carbon Conversion: 0.53

The additional CO_2, which is used as a fluidizing agent together with steam causes the shift of H_2 : CO ratio in favor of CO, thus the ratios between 0,5:1 and 1,9:1 can be achieved.

PtL projects

1st BLUE CRUDE PLANT

The core element is the steam electrolysis process (SOEC) that efficiently splits steam into its components hydrogen and oxygen.

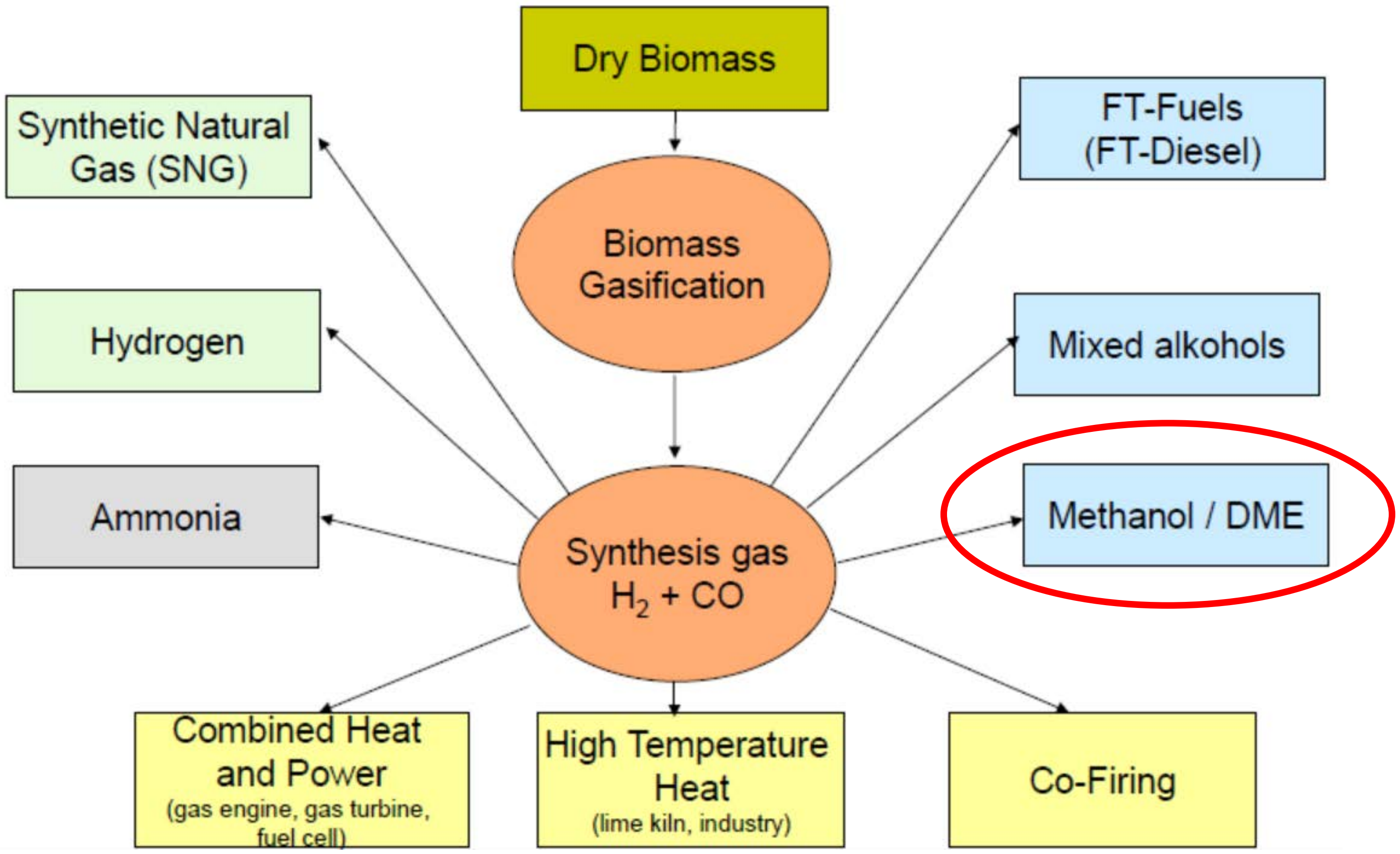
Subsequently the CO_2 is transformed into carbon monoxide (CO) and then the synthesis towards Blue Crude is effectuated.

The gaseous CO_2, employed as carbon source, is partly extracted on-site from the ambient air by using the Direct Air Capture (DAC) technology, developed by the Swiss company Climeworks.

Especially the exploitation of the waste heat from the Sunfire process makes the DAC technology highly efficient.

- 10 million liters per year shall be produced (8 000 tons/y) from CO_2, water, and 20 MW of hydroelectric power
- The product Blue Crude consists of
    - 50% high value wax for use in the cosmetics industry
    - 30% middle distillate usable as high performance and quality diesel
    - 20% naphtha, refinable to gasoline
- Production in the industrial park Heroya in Norway shall start in 2020
- Full production capacity expected in 2022
- Price of Synthetic crude oil substitute called Blue Crude, which is a CO_2-neutral alternative for mobility and chemical sector should be less than 2.00 Euros

Synthesis gas utilization

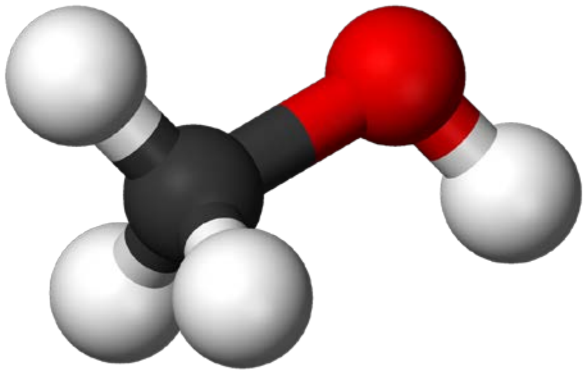


Methanol production

Methanol could be produced according to

$CO_2 + 3\ H_2 \rightarrow CH_3OH + H_2O$

$CO + 2\ H_2 \rightarrow CH_3OH$



Disatvantages:

- No existing infrastructure for direct usage in transportation sector
- For the production process of renewable methanol, it is necessary to consider:

• storage of hydrogen

• production, storage and distribution of methanol

• methanol utilization

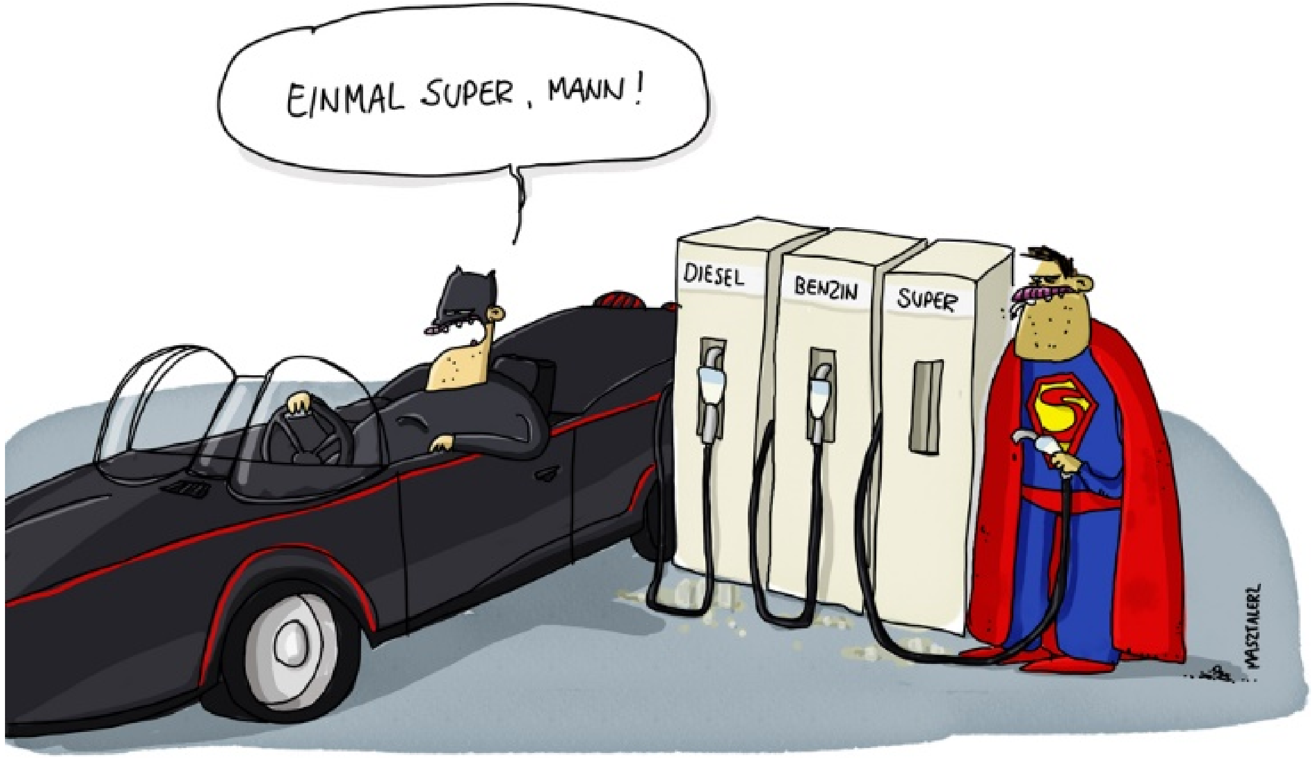
Methanol production

Advantages:

- Relatively simple and efficient production
- It is possible to convert methanol to gasoline

$$nCH_3OH \rightarrow (CH_2)_n + nH_2O$$

Gasoline can be used immediately in existing infrastructure



Boosting the production with external hydrogen - Gasoline

Configurations

- Allothermal gasif./steam
- Autothermal gasif./steam+oxygen

Input

- 100 MW (LHV) of wet (50%) biomass (5,92 kg/s of dry biomass)

Output gasoline

Steam gasification

- 51,0 MW / 98,0 MW

Oxygen gasification

- 51,8 MW / 134,0 MW

Energy 104 (2016) 199–212

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

ELSEVIER

Hydrogen enhancement potential of synthetic biofuels manufacture in the European context: A techno-economic assessment

Ilkka Hannula*

VTT Technical Research Centre of Finland Ltd, P.O. Box 1000, FI-02044 VTT, Finland

ARTICLE INFO

Article history:
Received 15 December 2015
Received in revised form
2 March 2016
Accepted 25 March 2016

Keywords:
Biomass residues
Gasification
Electrolysis
Carbon dioxide
Synthetic fuels

ABSTRACT

Potential to increase biofuels output from a gasification-based biorefinery using external hydrogen supply (enhancement) was investigated. Up to 2.6 or 3.1-fold increase in biofuel output could be attained for gasoline or methane production over reference plant configurations, respectively. Such enhanced process designs become economically attractive over non-enhanced designs when the average cost of low-carbon hydrogen falls below 2.2–2.8 €/kg, depending on the process configuration. If all sustainably available wastes and residues in the European Union (197 Mt/a) were collected and converted only to biofuels, using maximal hydrogen enhancement, the daily production would amount to 1.8–2.8 million oil equivalent barrels. This total supply of hydrogen enhanced biofuels could displace up to 41–63 per cent of the EU (European Union)'s road transport fuel demand in 2030, again depending on the choice of process design.

Workshop IEA Bioenergy Task 33
26. October 2016
HSLU Lucerne University of Applied Sciences
Dr Ilkka Hannula

Table 2
Summary of examined plant configurations.

Configurations	Gasifier type	Stoichiometry adjusted by	CO_2 removal	Electrolyser	ASU[a]	End product
OG	O_2	Sour shift	Yes		Yes	Gasoline
OG+	O_2	H_2 addition		Yes		Gasoline
OM	O_2	Sour shift	Yes		Yes	Methane
OM+	O_2	H_2 addition		Yes		Methane
SG	Steam	Gasifier	Yes		Yes	Gasoline
SG+	Steam	H_2 addition		Yes		Gasoline
SM	Steam	Gasifier	Yes		Yes	Methane
SM+	Steam	H_2 addition		Yes		Methane

[a] ASU = cryogenic Air Separation Unit.

Boosting the production with external hydrogen - Gasoline

By an external hydrogen source following maximal fuel output could be achieved:

- **1,9 – fold for steam gasification**
- **2,6 – fold for oxygen gasification**

Overall carbon conversion for enhanced configurations:

- **58,4 % for steam gasification**
- **79,4 % for oxygen gasification**

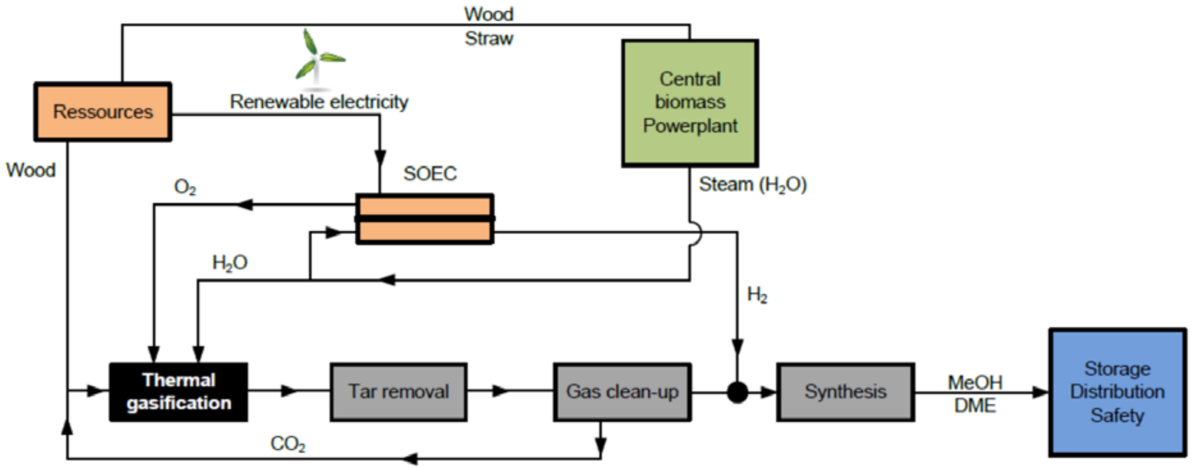
Economically feasible over base case when hydrogen cost is lower than:

- **2,7 €/kg for steam gasification**
- **2,8 €/kg for oxygen gasification**

PtL projects (Methanol)

GreenSynFuel

- The project “GreenSynFuel” focused on large-scale plants (input 1000 t/day)
- Pressurized bubbling fluidized bed gasifier
- Using the electrolysis production efficiency was boosted from 59% to 71%. Overall efficiency was 81,6%



- Gasification only 1000 t wood = 523 t methanol
- Gasification + additional hydrogen 1000 t wood = 1053 t methanol
- Economic analysis: green methanol can be produced at an oil equivalent price of 120 USD/barrel if SOEC were readily commercial available today

Barriers of commercialization of PtG and PtL systems

Surplus electricity

- Not available continously
- Limited number of operation hours (<2000) during the year
- No existing market with surplus electricity
- Surplus wind power and photovoltaics are, at least in Germany, also recompensed if the units are idling due to a low demand in the grid

Electrolysis

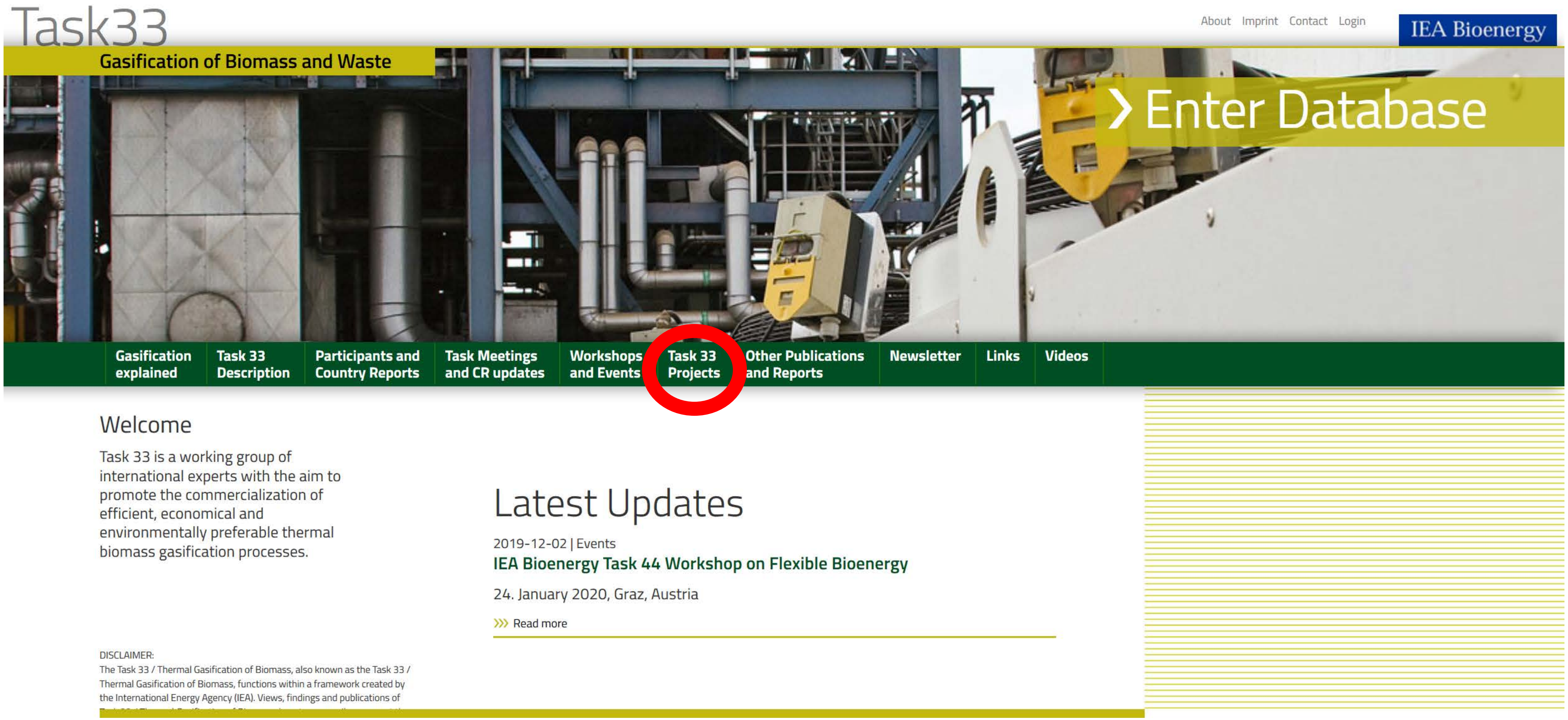
- SOEC not yet commercially available

Price

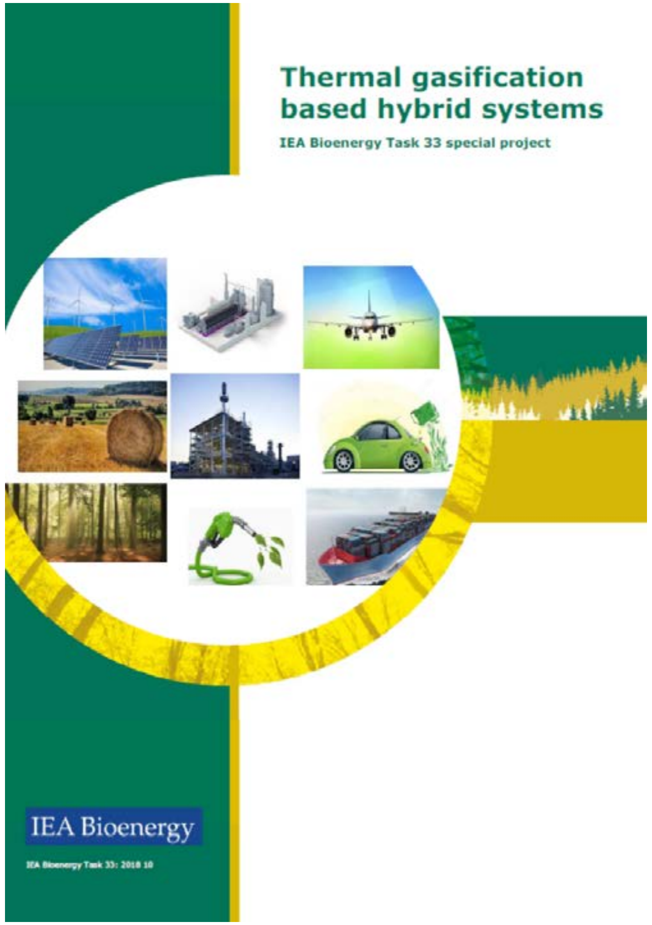
- Renewables could not be competitive without subsidies by actual oil price

- Taking an electricity price of 4-5 €ct/kWh results in a SNG price of 5.7-7.1 €ct/kWh (70% efficiency assumed) if only operational costs are considered. The market price of natural gas is in the range of 2-3 €ct/kWh. Furthermore, natural gas is overabundant now.
- Thereby, SNG is not directly competitive at this time.

www.task33.ieabioenergy.com



IEA Bioenergy Task 33
Gasification of biomass and waste



Special reports

SP1: Waste gasification

SP2: Fuel pretreatment for gasification systems

SP3: Biomass gasification for CCUS

SP4: Success stories on gasification of biomass

SP5: Gasification-based hybrid systems

SP6: Hydrogen production via gasification

SP7: Status report

SP8: Biomass gasification history and lessons learned

SP9: Valorization of byproducts from small scale gasification

SP10: Gas sampling in biomass gasification systems

Conclusions

- Thermal gasification as a source of carbon for PtG and PtL production offers a great possibility of technologies and products synergies
- Renewable hydrogen access is not essential for the gasification process but boosts the amount of final product (fuel) significantly
- Fuels from renewable sources are still more expensive than fossil ones
- It is time to stop to compare renewable fuels with fossil ones

  only on a financial base, but to see the whole picture

Thank you very much for your attention

Dr. Jitka Hrbek
University of Natural Resources and Life Sciences, Vienna
jitka.hrbek@boku.ac.at

www.task33.ieabioenergy.com