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Biomass for Swiss Energy Future
Swiss Competence Center for Energy Research

Bioenergy systems for the future

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with contributions from O. Kröcher, A. Calbry-Muzyka, T. Schildhauer, J. Luterbacher, S. Biollaz, S. Nanzer, T. Griffin

PAUL SCHERRER INSTITUT PSI

n|w Fachhochschule Nordwestschweiz

Outline

- Why biomass? Which biomass? At what costs?
- BIOSWEET vision for 2050
- Assessment of *status quo*
- Challenges and opportunities for bioenergy production
- Selected technologies and value chains
- Conclusions

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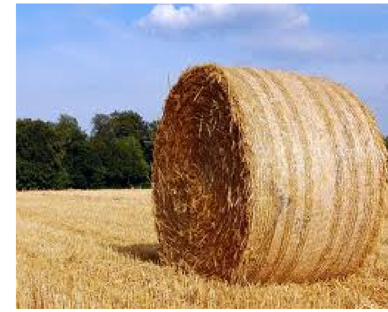
Why biomass?

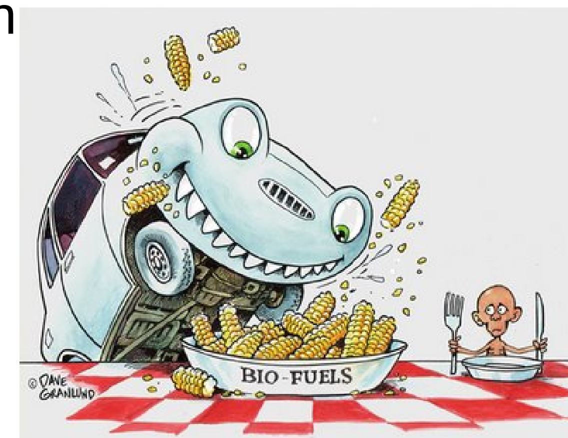
de.fotolia.com

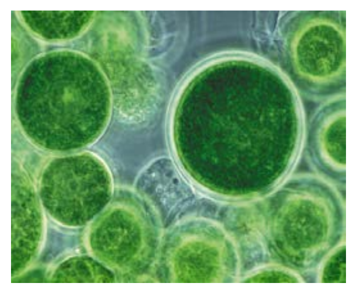
- The only way to store solar energy durably, with minimal losses, and in a transportable form today
- Biomass can be converted to any form of energy carrier (solid, liquid, gaseous fuels) to provide all forms of end energy: heat, cold, electric power
- Already the (sustainable) cultivation of biomass captures CO_2 from the atmosphere ⇨ plant trees!

Which biomass?

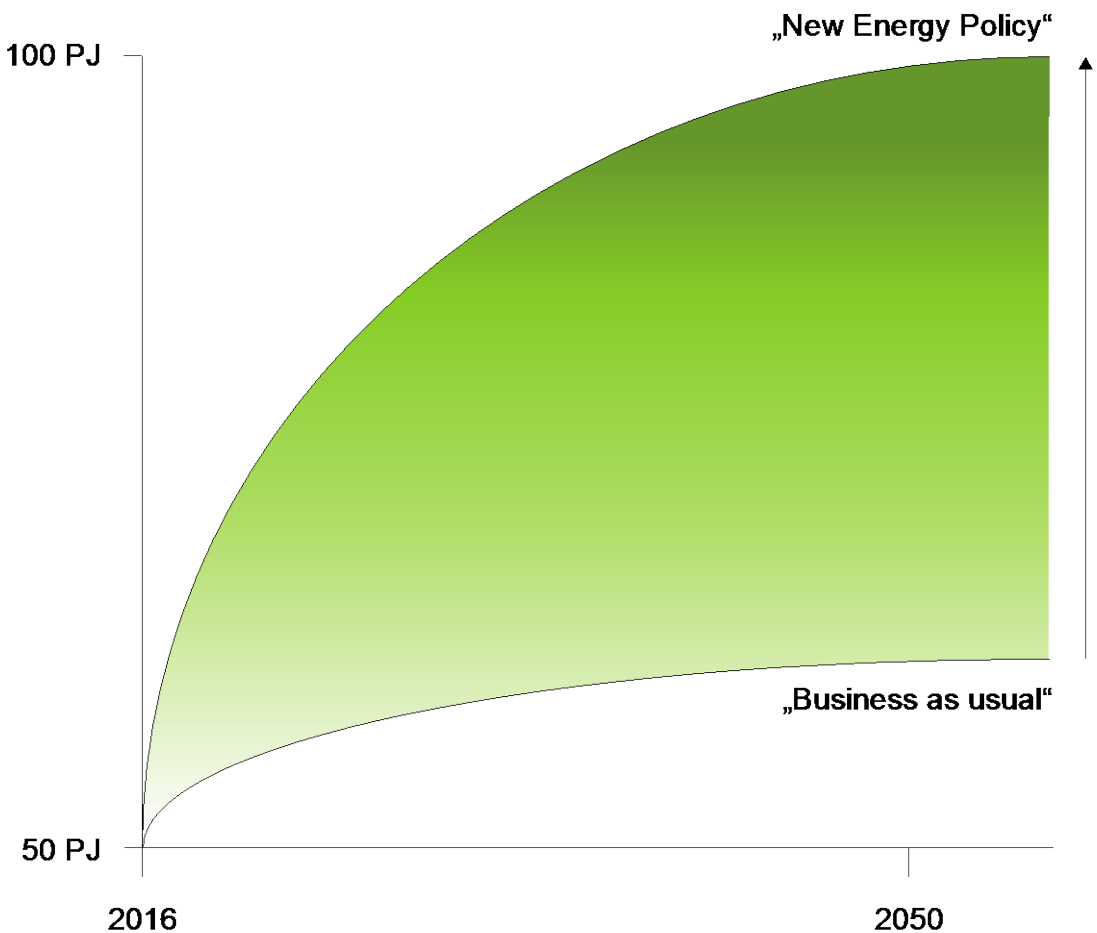


- Biomass is very diverse
- For some categories there exists a competition between food, feed, and fuel production
- Use only biomass for energy purposes for which there is no higher value use
- We focus solely on residual and waste biomass and on algae





The 100 Petajoule Bioenergy Vision



Supply Side

- Higher technical conversion efficiencies
- Improved feedstock utilization
- Optimized energy system integration
- Value-chain innovations

Demand Side

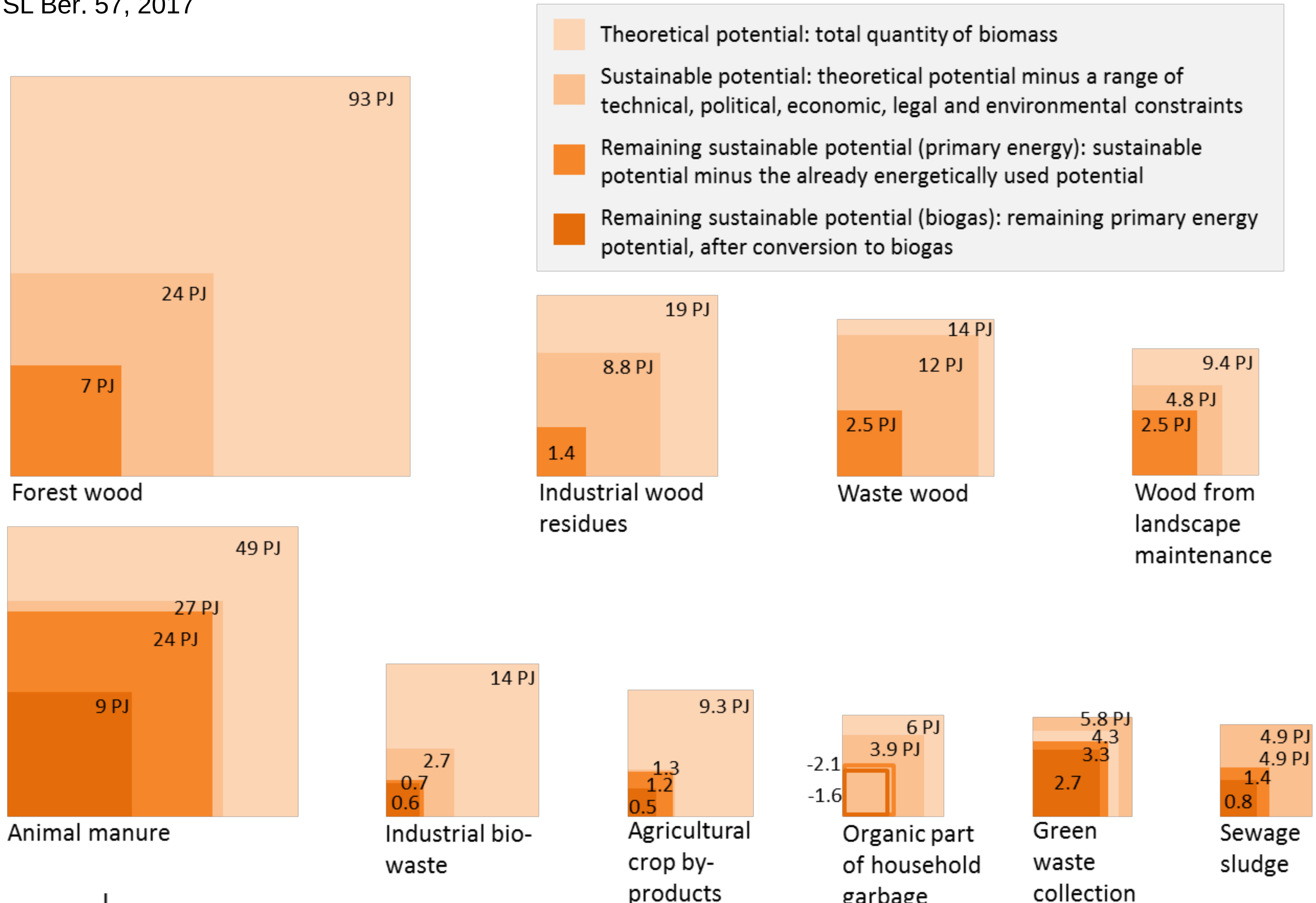
- Substitution of fossils for heat & power
- Substitution of fossils in the mobility sector
- Bioenergy policy and market development

Gross energy consumption CH (2016)
= 1’088 PJ (total)
= 225 PJ (renewables)

Biomass resource potential (WSL)

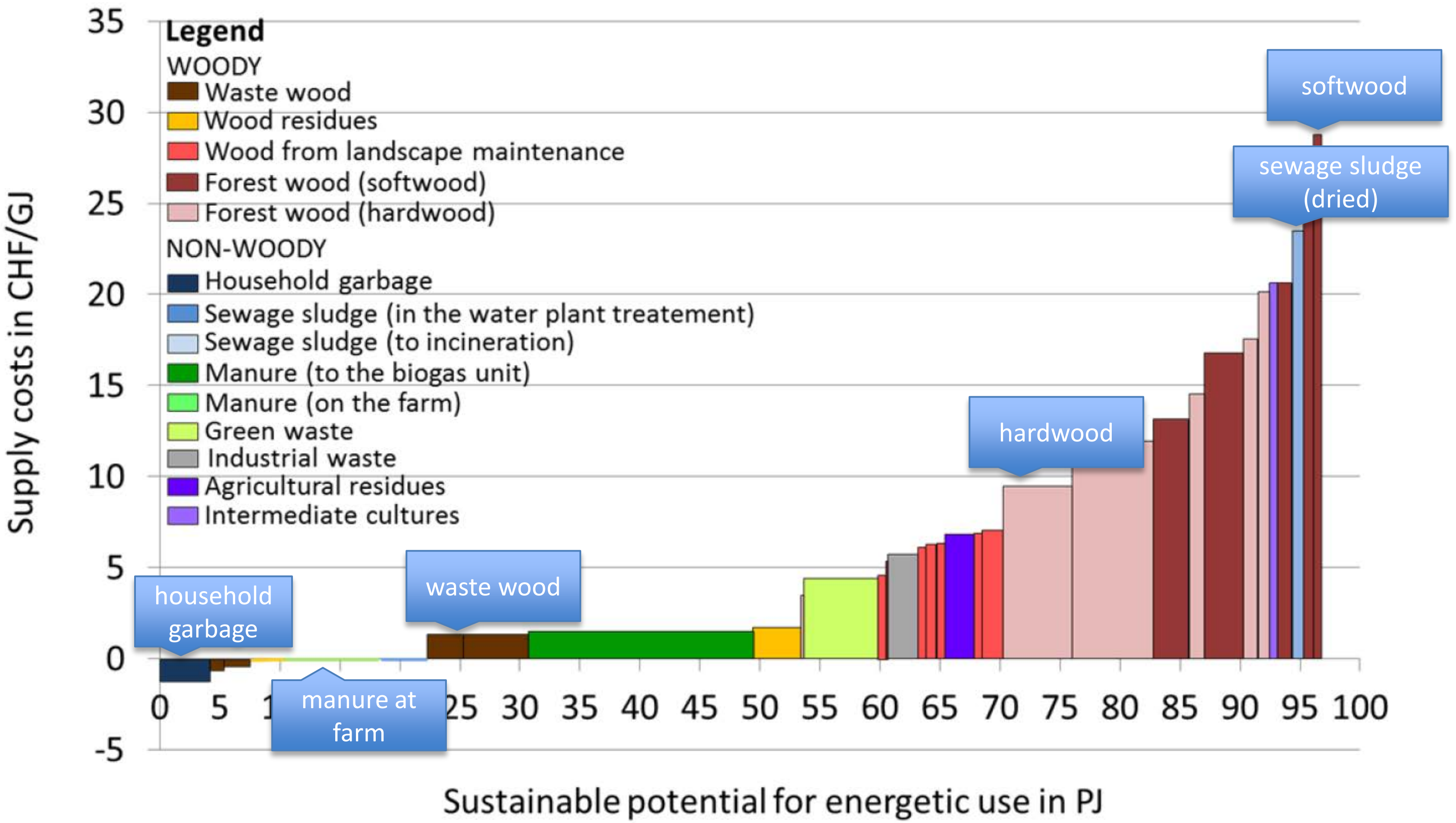
Areas are scaled to PJ/year of energy resources in Switzerland.

Thees et al., WSL Ber. 57, 2017



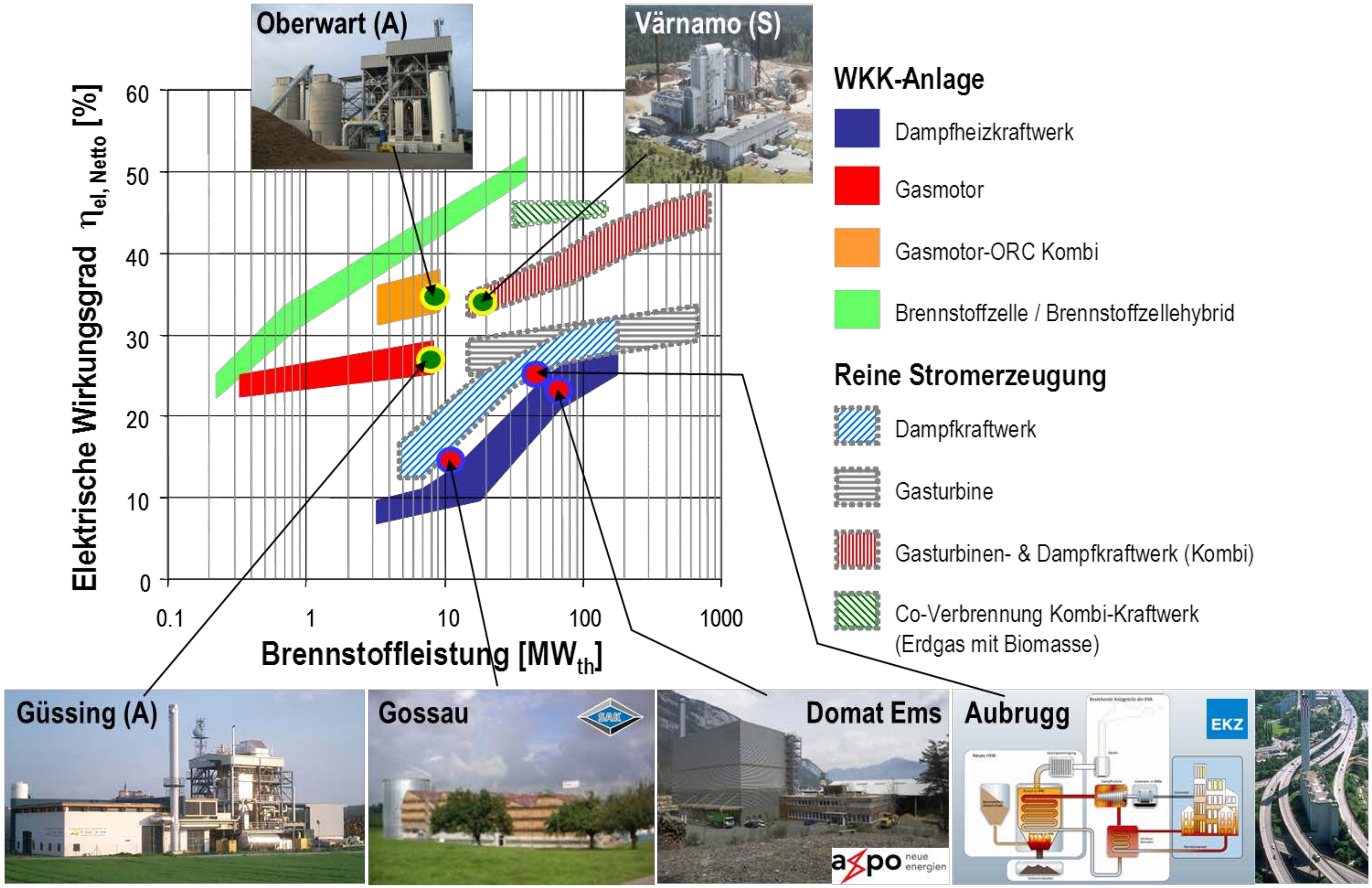
Biomass resource prices (WSL)

Thees et al., WSL Ber. 57, 2017



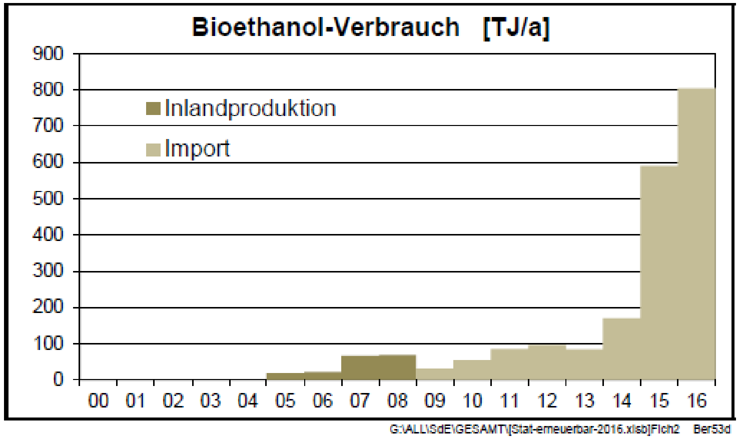
Power plant landscape (status quo)

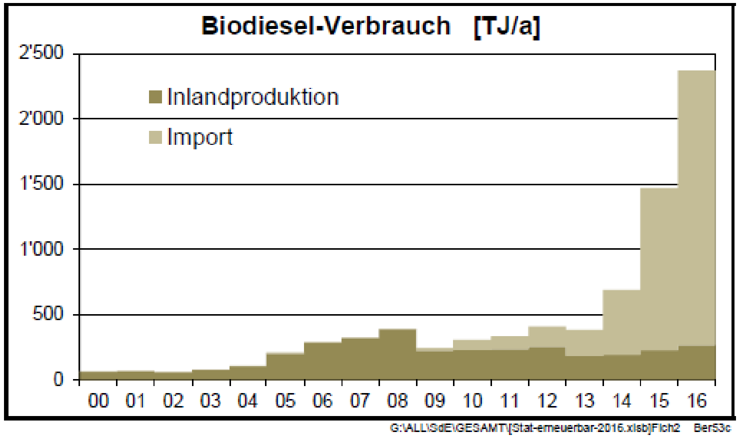
S. Biollaz, PSI

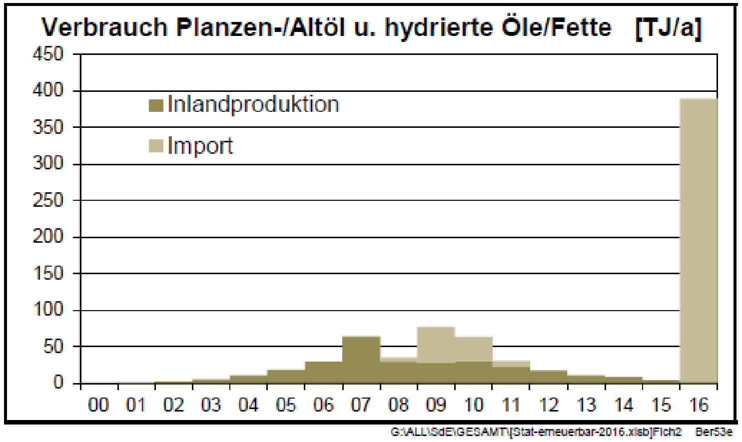


Liquid biofuels: mostly imported

- Surge in imported liquid biofuels due to CO_2 law in force since 2014 (blending of 7% with diesel and 5% with gasoline)







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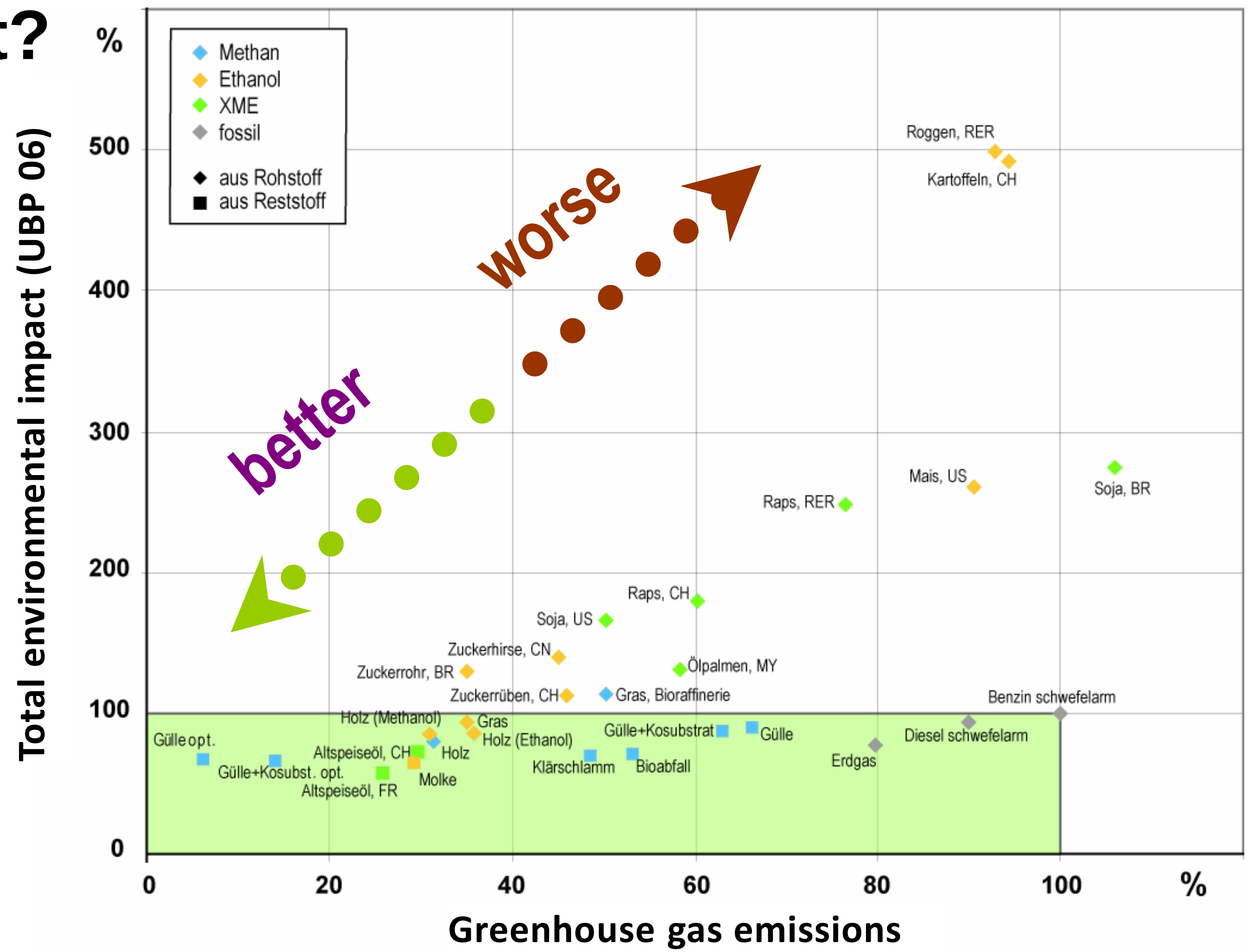
Life Cycle Assessment – What is good for the environment?



RER: Europe
BR: Brazil
MY: Malaysia
CN: China
FR: France

XME = Biodiesel

Blue = Biomethane (Biogas)

Reference: R. Zah et al., Ökologische Bewertung von Biotreibstoffen, EMPA, Bericht des BFE/BAFU/BLW, Mai 2007.

Assessment of status quo (1)

- Dry biomass (wood, ~~straw~~, ~~grass~~)
  - Combustion: Small plants with high thermal but low electric efficiency (< 20%). Installed capacity: 11 plants with total 27 MW_e and 67 plants with total 17 MW_e
  - Gasification: not established (1 CHP unit in Stans, 1 MW_e class); potentially much higher efficiency if combined with fuel cells;
- Wet biomass residues (sludges, manure, wet residues)
  - Biogas: residual sludges due to incomplete conversion
  - Large plant footprint (land is expensive in CH!)
  - Low electric efficiency (< 15% biomass to electricity)
  - Manure is heavily underused although it has largest single potential
  - Digested sewage sludge is disposed of, not valorized energetically

Assessment of status quo (2)

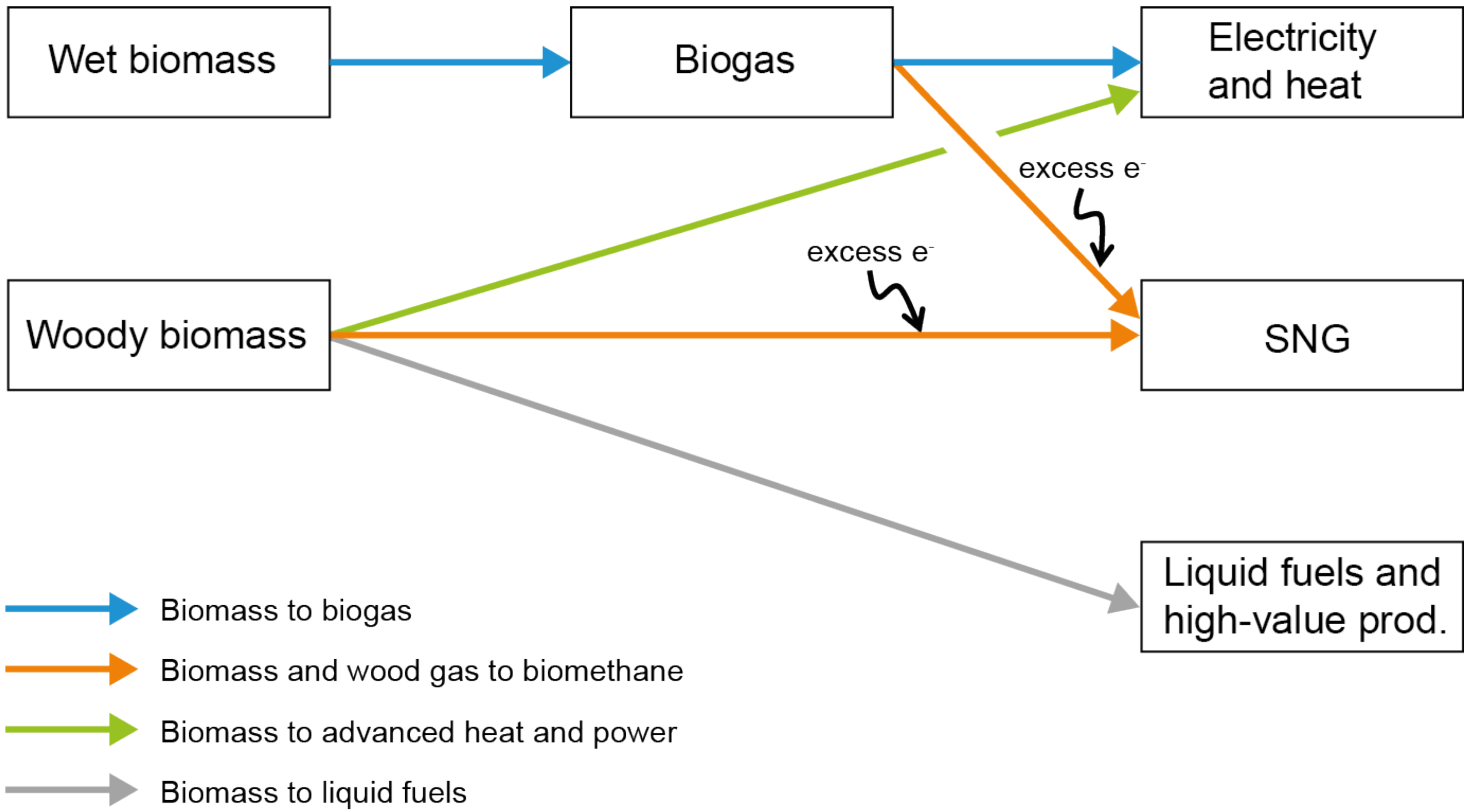
- Biofuels
  - Biomethane: Several biogas plants with upgrading and injection into gas grid; ca. 130 CNG filling stations (natural gas + biomethane)
  - Liquid biofuels: Large ecological potential in CH, because transport sector contributes the largest share of 32% to total CO_2 emissions
  - Sustainable biofuels are exempt from fuel taxes (ca. 75 Rp./L)
  - Negligible domestic production, increasing imports

Challenges & Opportunities

- Dry biomass (wood, straw, grass)
  - First produce valuable chemicals in a biorefinery (this step of the cascade is missing in CH!)
  - Business case largely influenced by waste heat market ⇨ increase electrical efficiency

- Wet biomass residues (sludges, manure, wet residues)
  - Recover and recycle valuable nutrients such as phosphorus
  - Increase end energy output by converting the whole biomass, not just parts of it
  - Implement feed-flexible technologies to cope with fluctuating feedstock availability and quality
  - Develop also small-scale units that have high efficiency

The SCCER BIOSWEET R&D Field



Advanced heat and power

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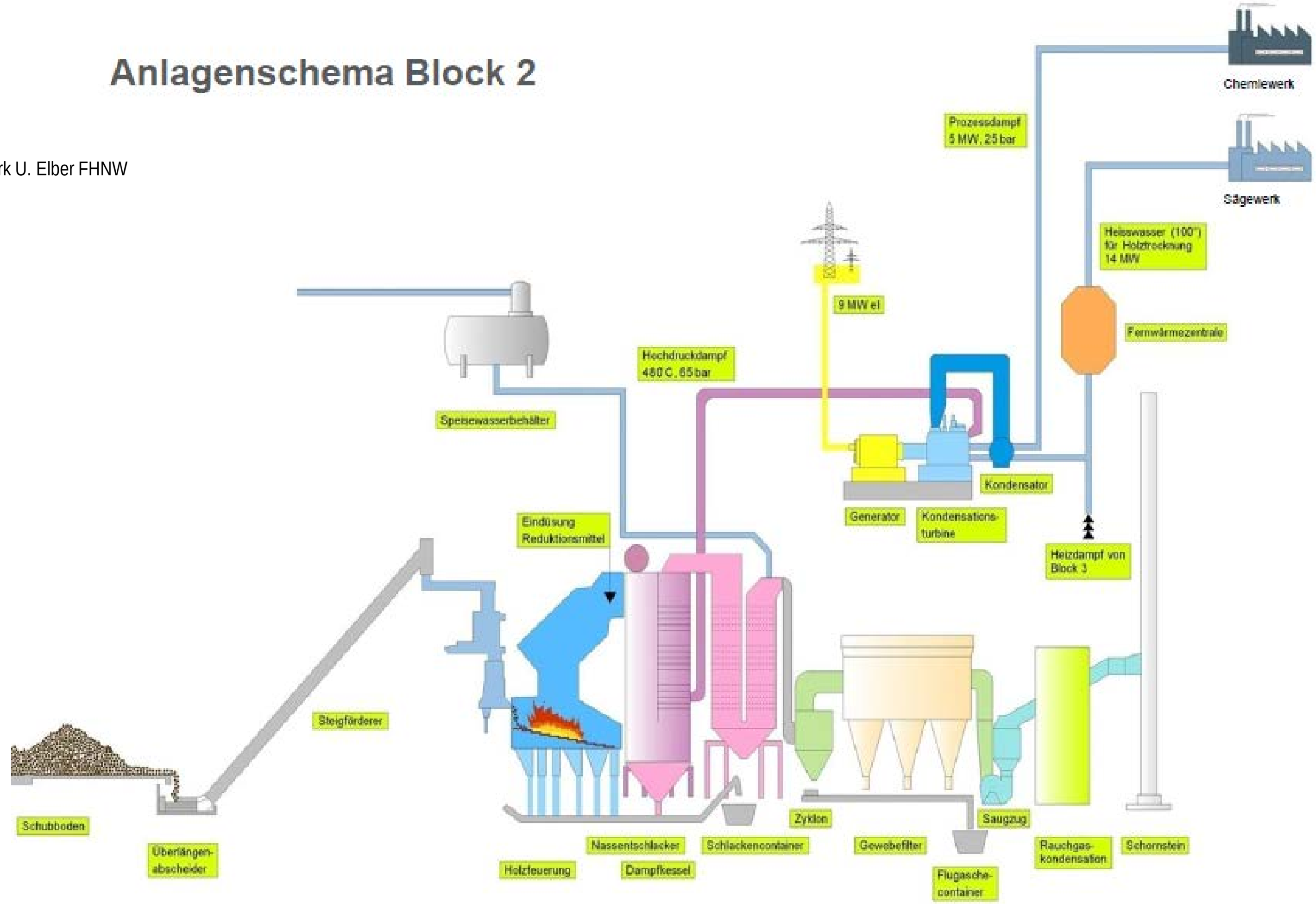
Large wood power plant (ex. Tegra Domat/Ems)

Kurs Holzkraftwerk U. Elber FHNW
28.4.2014



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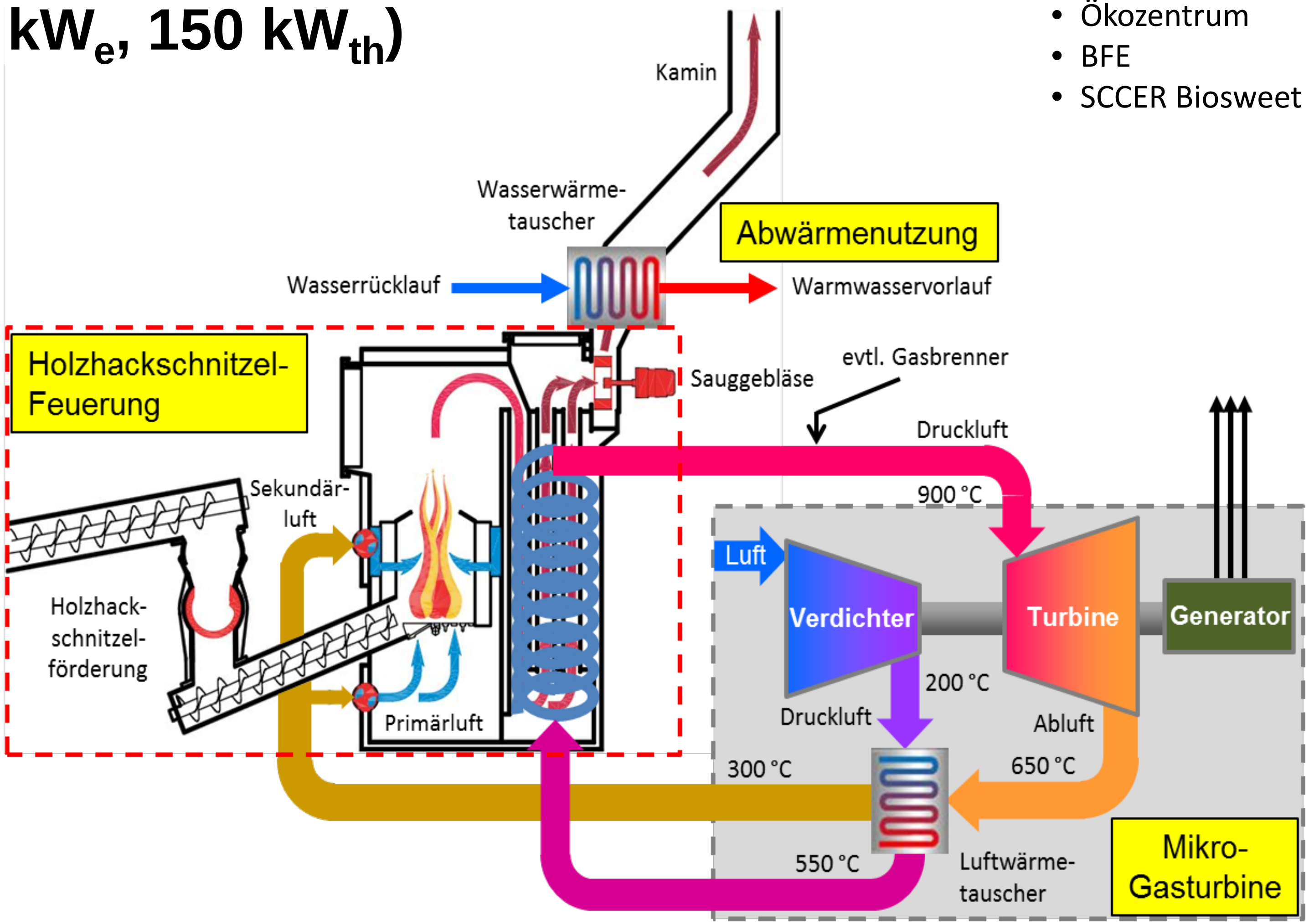
Small-scale CHP «Micro-GT» (60 kW_e, 150 kW_{th})

Partners:

- FHNW (T. Griffin)
- MPT GmbH
- Ökozentrum
- BFE
- SCCER Biosweet



Biomethane

Wood for mobility?

http://www.oldtimerplus.de

Methane: a universal and clean fuel

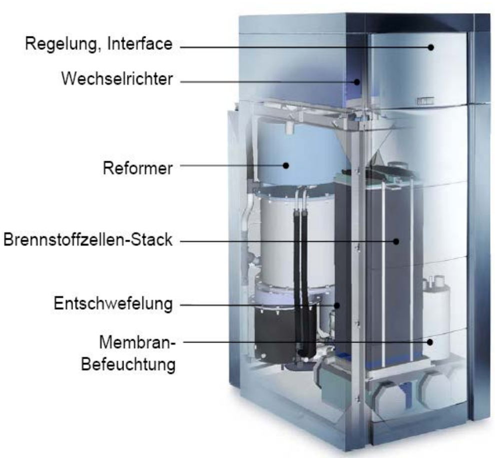
…for centralized, decentralized, and transport applications

VIESSMANN climate of innovation

plugpower

HEXIS

Vaillant



$1 - 4.6\ kW_{el}$
$1.5 - 7\ kW_{th}$

$1\ kW_{el}$
$1.8\ kW_{th}$

Already available and affordable today!
88 g CO_2/km (Gasoline: 115 g CO_2/km)

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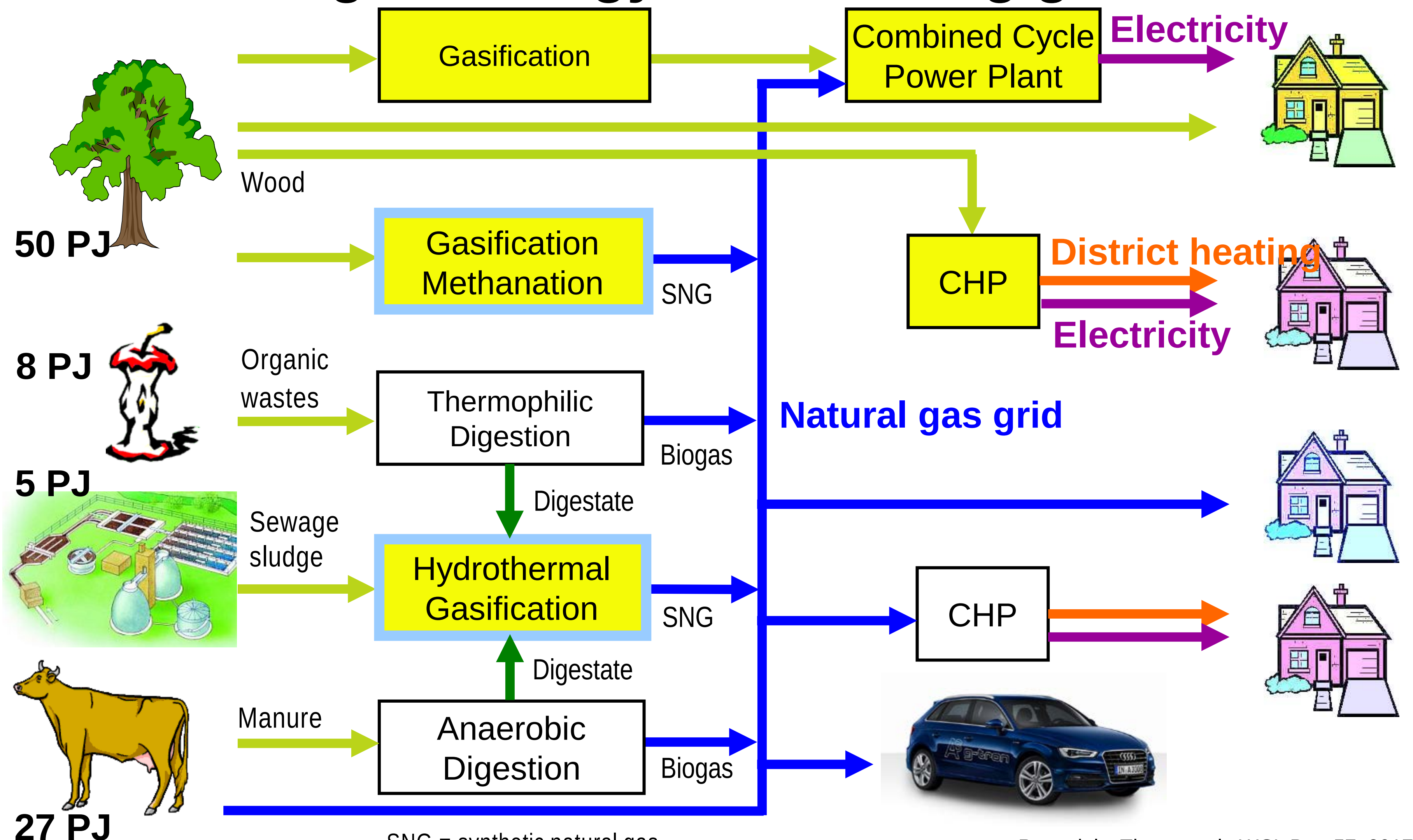
Introducing bioenergy into existing grids



SNG = synthetic natural gas

Potentials: Thees et al., WSL Ber. 57, 2017

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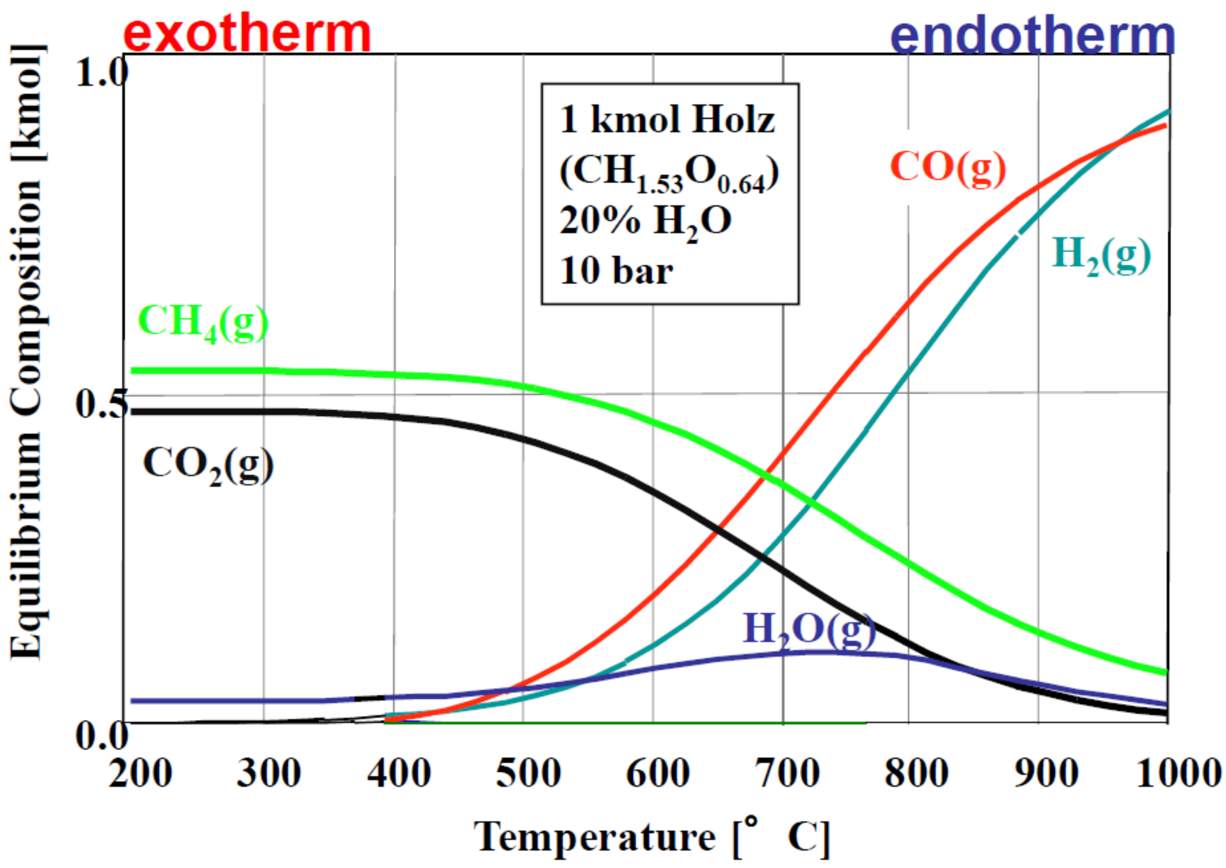
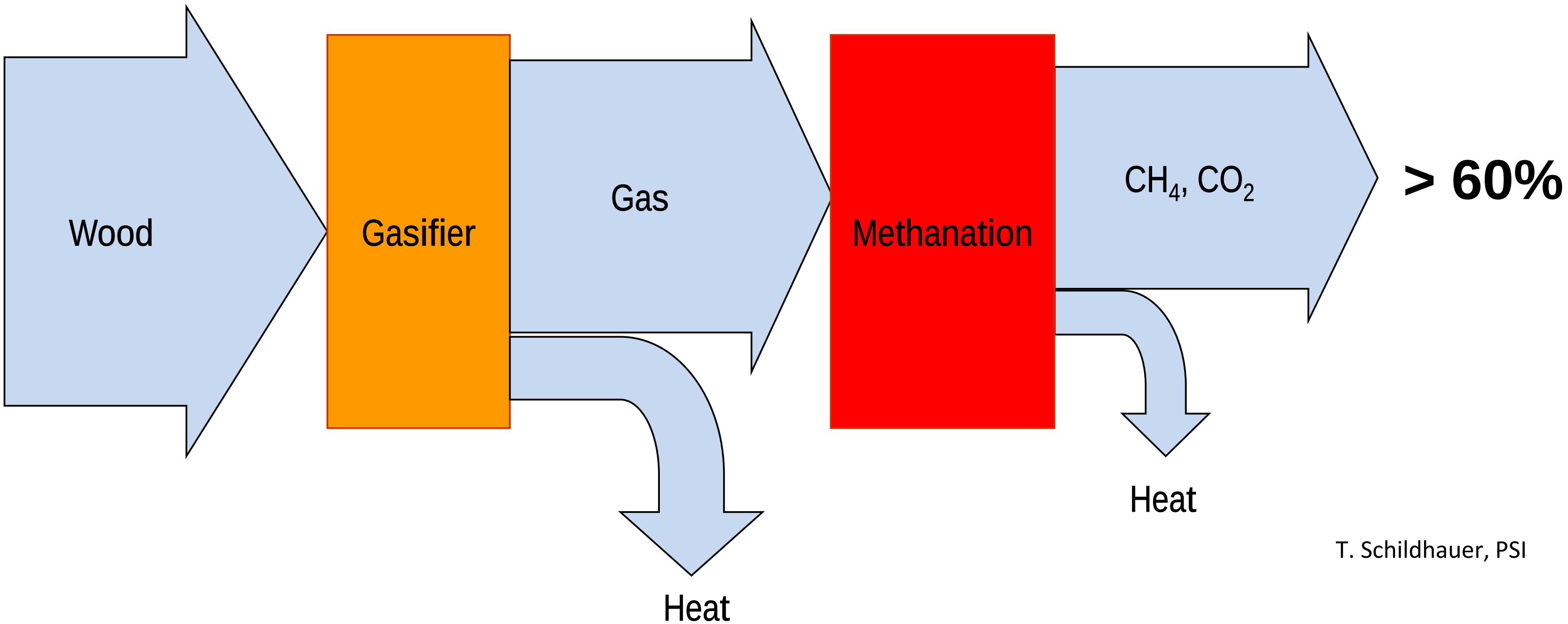
S. Stucki, PSI

Steam gasification of wood



Gasification and methanation to biomethane



Autothermal gasification:
Losses depend on gas exit temperature, heat losses in the reactor, and on the wood moisture

Exothermic methanation:
Losses depend on selectivity and gas composition. The more methane in the gas, the higher **η**!

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Synthetic Natural Gas (SNG) from Wood

S. Biollaz, PSI

Research on methanation and gas cleaning in Güssing, A

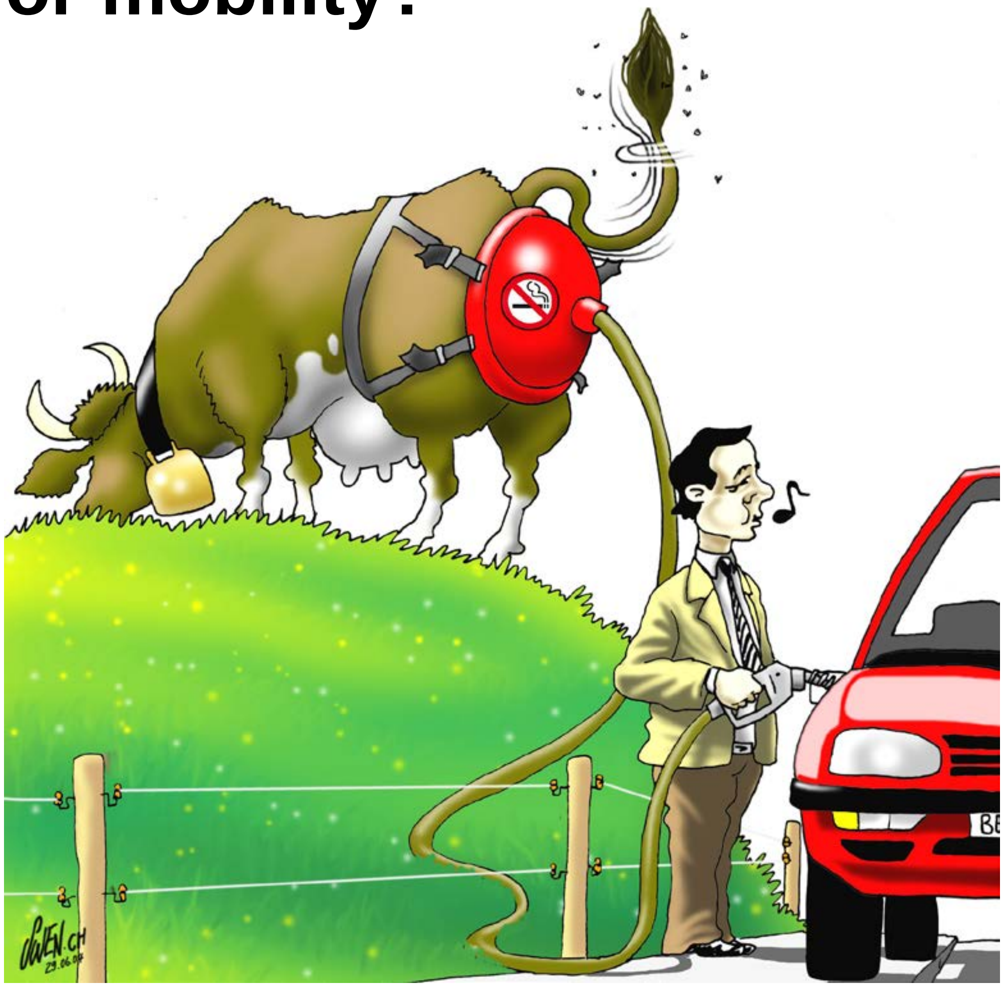
1 MW_{SNG} Pilot plant

- before 1000 h at 10 kW scale (PSI)
- advanced gas cleaning
- methane synthesis
- H_2/CO_2 separation

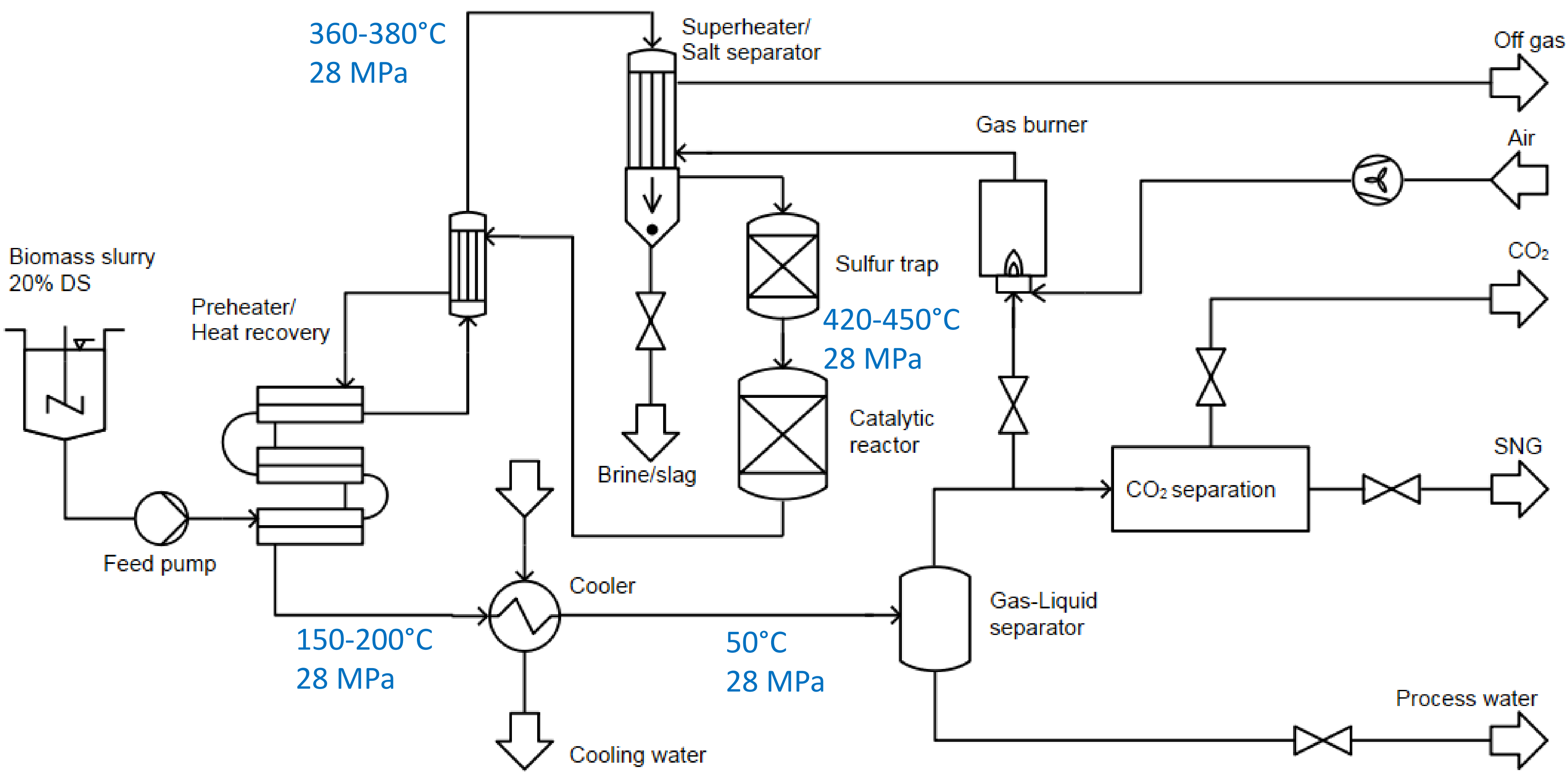

Pilot and Demonstration Unit (PDU)

Wet biomass to biomethane

Manure for mobility?



PSI's supercritical water gasification process



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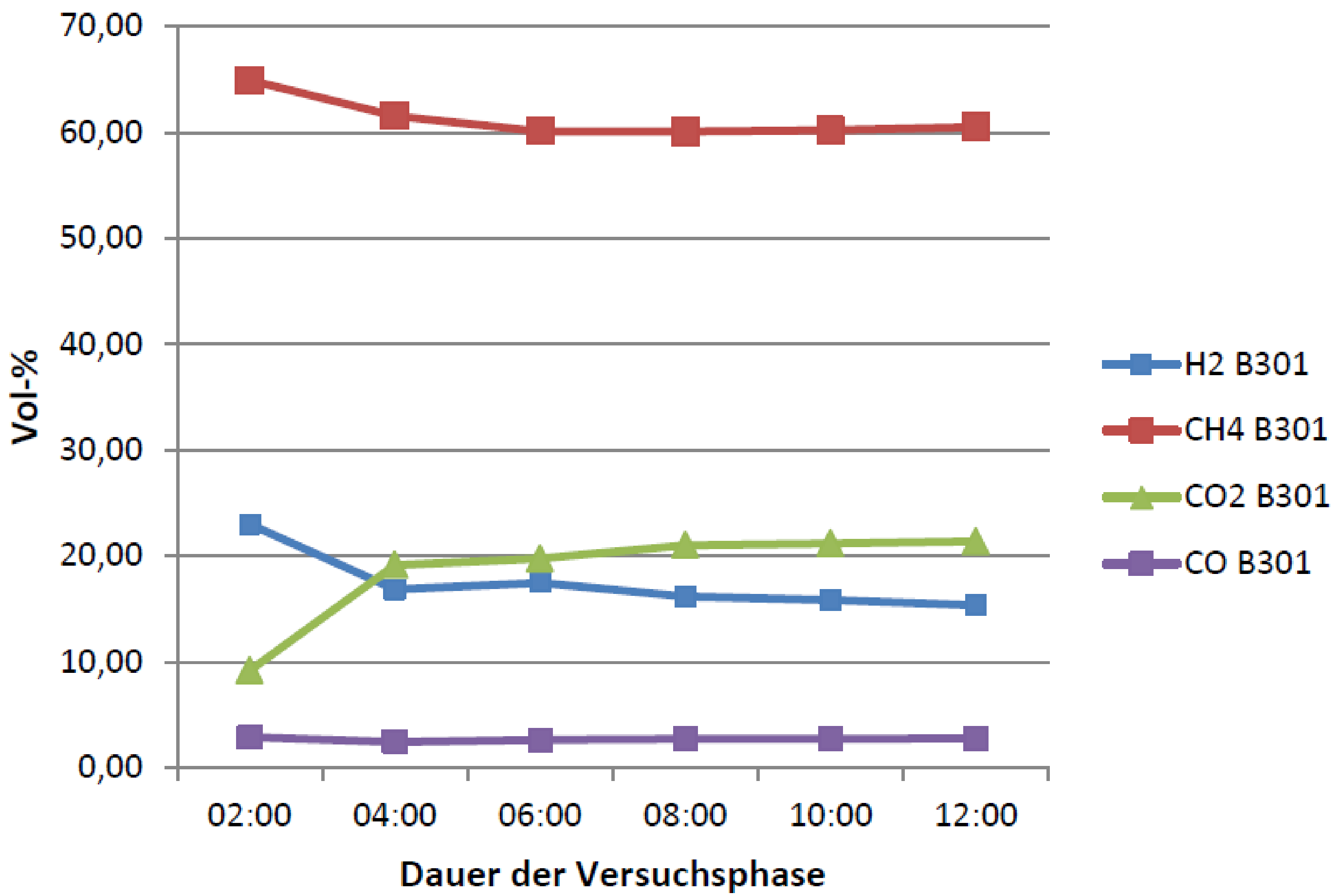
Product gas composition with digestate

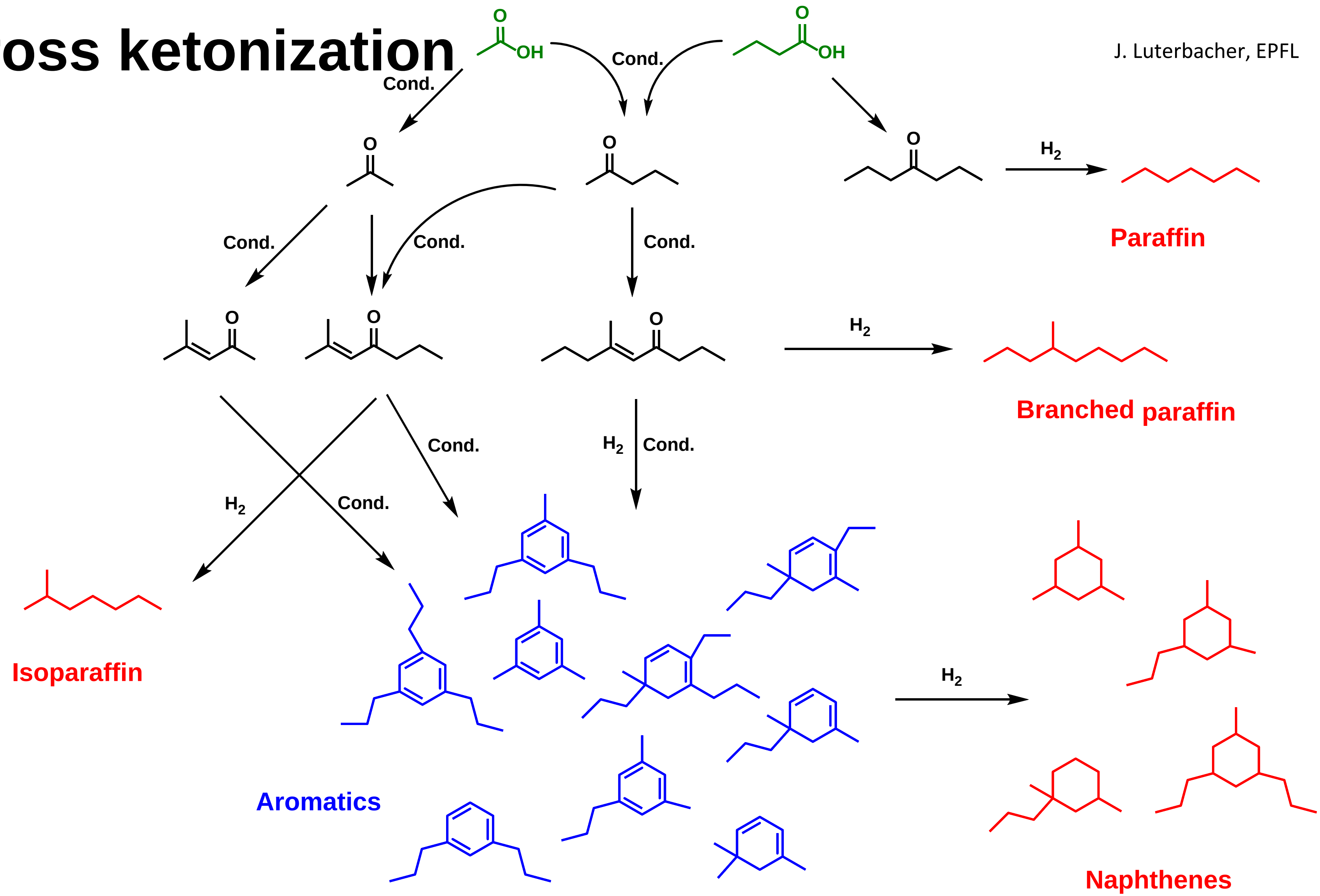


Source: S. Herbig, E. Hauer, N. Boukis, Sachbericht zum Projekt «EtaMax: Mehr Biogas aus lignozellulosearmen Abfall- und Mikroalgenreststoffen durch kombinierte Bio-/Hydrothermalvergasung, Teilprojekt 4: Hydrothermale Vergasung von Gärresten der Biogasherstellung, KIT, November 2015

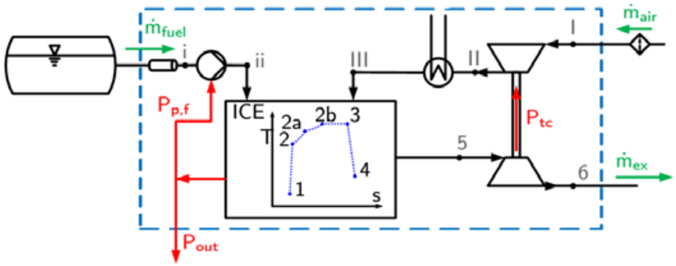
Liquid biofuels

Cross ketonization

J. Luterbacher, EPFL



Ultimate Fuel



Thermodynamic Model of spark ignition engine built, allows comparison of different molecules as gasoline replacement

fuel	η_{FL} [%]	η_{PL} [%]	η_{WLTC} [%]	P_{FL} [kW]	$e_{CO_2,FL}$ [g/kWh]	$e_{CO_2,WLTC}$ [g/km]	mileage_{WLTC} [l/100 km]	ε_{CR} [-]
gasoline	33.7	20.2	27.1	70.8	769	150	6.39	7.70
iso-octane	34.5	20.7	27.6	74.1	724	142	6.66	7.97
n-heptane				*knocking cycles*				
cyclohexane	32.3	19.4	25.1	69.4	803	162	6.68	7.33
benzene	33.0	20.0	26.2	72.0	931	184	6.24	8.73
MTBE	35.2	21.2	28.6	74.6	731	141	7.68	8.97
methanol	30.2	18.2	23.8	69.4	823	164	15.15	9.60
ethanol	36.0	22.7	23.5	80.0	705	170	11.30	18.34
n-butanol	36.5	22.1	30.0	79.7	703	135	7.03	11.64
MF	34.6	20.2	27.4	76.7	915	181	7.40	10.41
DMF	35.9	21.6	27.5	79.2	850	175	7.14	10.02

MF: methylfuran
DMF: 2,5-dimethylfuran
MTBE: methyl tert butyl ether
ε_{CR}: compression ratio
P: power output

$*_{FL}$: full load
$*_{PL}$: part load
$*_{WLTC}$: Worldwide harmonized Light duty Test Cycle
e_{CO2}: specific CO_2 emissions

Summary and conclusions

- Forest wood and manure offer the largest single potentials in CH
- To mobilize large amounts of bioenergy, either a few (very) large plants or a large number of small units must be installed
- Public acceptance and biomass distribution/availability in Switzerland are more in favor of medium to small-sized units
- Main challenge: develop such small units with high conversion efficiency (biomass to end energy), negligible emissions and low specific costs (Rp./kWh and Fr./kW)
- There is room for a few large(r) plants in CH but the business case is very challenging
- Increasing electric efficiency at the expense of heat production would facilitate many business cases greatly

Summary and conclusions (2)

- Efficiencies biomass to electricity > 50% are extremely challenging to reach ⇨ heat market will always play a major role
- (Wood) Biorefineries are a must for a sustainable and economic use of large amounts of biomass (wood) in the future. This is somewhat in contradiction to advocating for small units
- Biofuels (liquids and biomethane) can make the largest impact on CO_2 emissions in CH but the domestic biofuel potential is limited

A bright future for bioenergy

- Good news
  - Bioenergy use is strongly increasing in CH since 2006
- Better news
  - We can still do (much) better!
- Best news
  - We all can be part of it

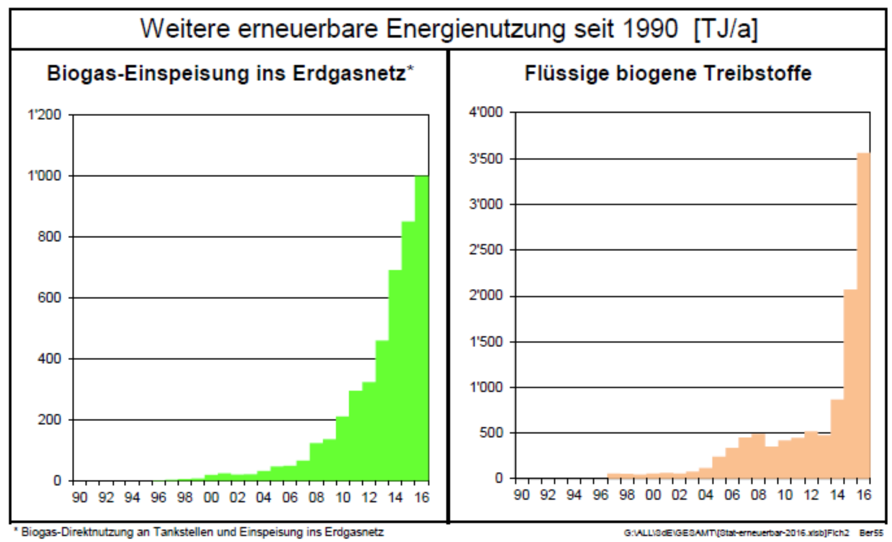


Bild 1.11 **Entwicklung weiterer Formen der erneuerbaren Energienutzung seit 1990**

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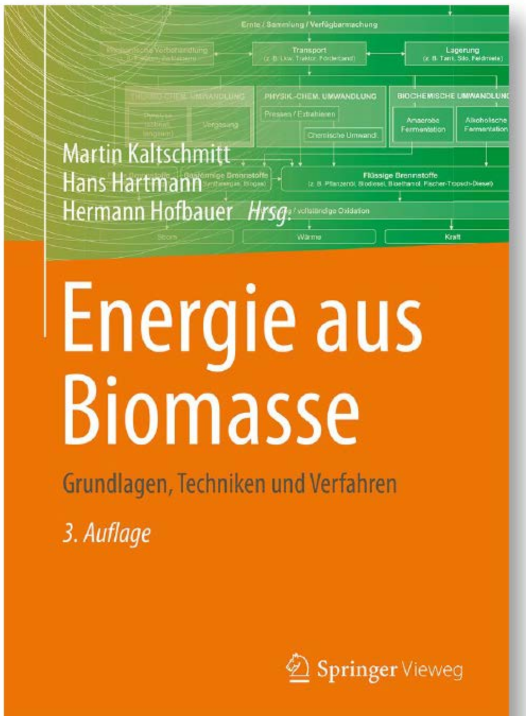
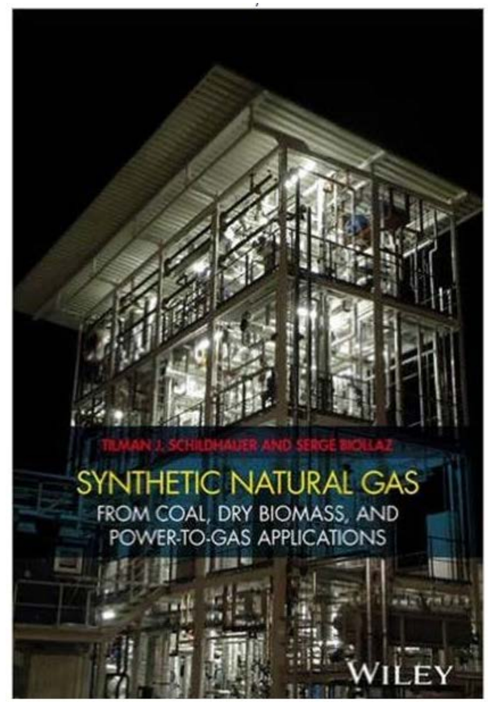
Recent Books involving BIOSWEET authors

Springer



3., aktualisierte Aufl. 2016, XXX, 1867 S. 750 Abb.



Schildhauer, Tilman J. / Biollaz, Serge M. A. (eds.)
Synthetic Natural Gas From Coal, Dry Biomass, and Power-to-Gas Applications
1. Edition August 2016, 328 Pages, Hardcover, - Wiley & Sons Ltd -

Acknowledgement

- My colleagues in the SCCER BIOSWEET who helped me with this presentation
- …and my apologies to the BIOSWEET colleagues whose projects I could not mention

In cooperation with the CTI

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Commission for Technology and Innovation CTI