Office franco-allemand pour la transition énergétique
Deutsch-französisches Büro für die Energiewende

Technologies and Energy Carriers for an Integrated Energy System

Conference Presentation
Sektorkopplung: Welche Chancen und Herausforderungen für die Energiewende?

French embassy in Berlin

Ralph-Uwe Dietrich
Dan Bauer, Stefan Zunft, Antje Seitz

Berlin, 28. Feb. 2017

DLR

The German energy transition – pathway to a secure, environmentally-friendly and economically successful future

Four energy transition targets by 2020

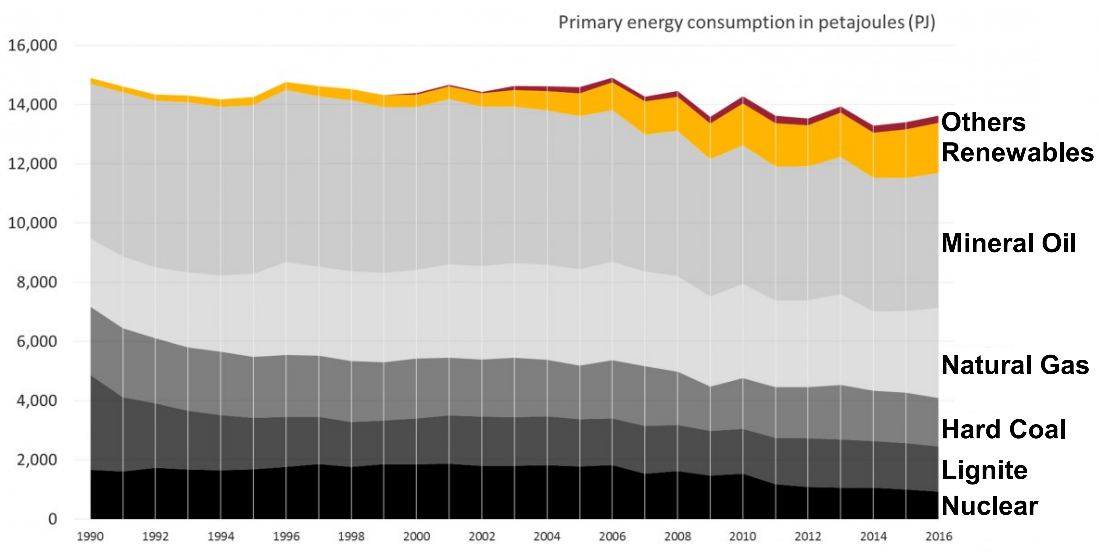
35% of the electricity consumed in Germany to be covered by renewables by 2020

20% less primary energy consumption by 2020 (from 2008)

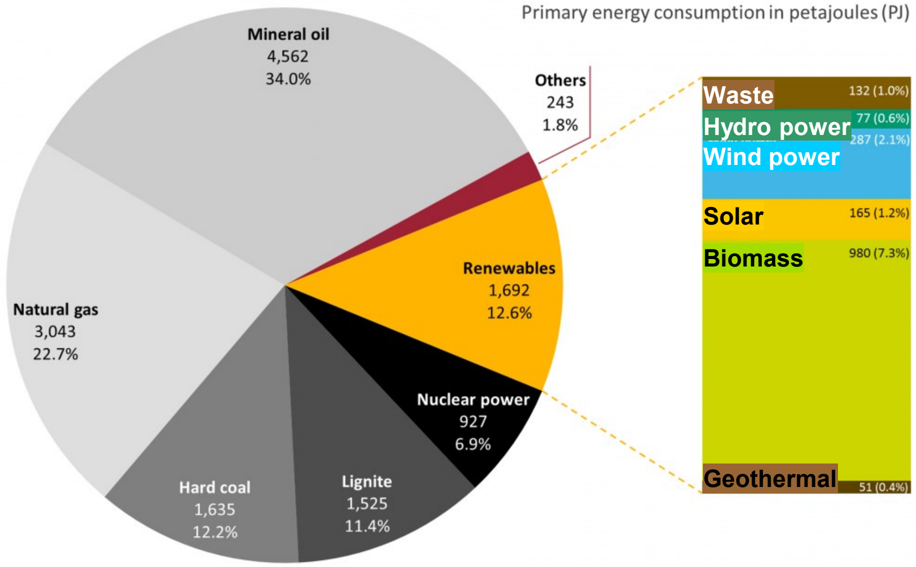
40% less greenhouse gas emissions by 2020 (from 1990)

10% less final energy consumption in transport by 2020 (from 2005)

German energy sources' share in primary energy consumption 1990 - 2016.
Data: AG Energiebilanzen 2016.

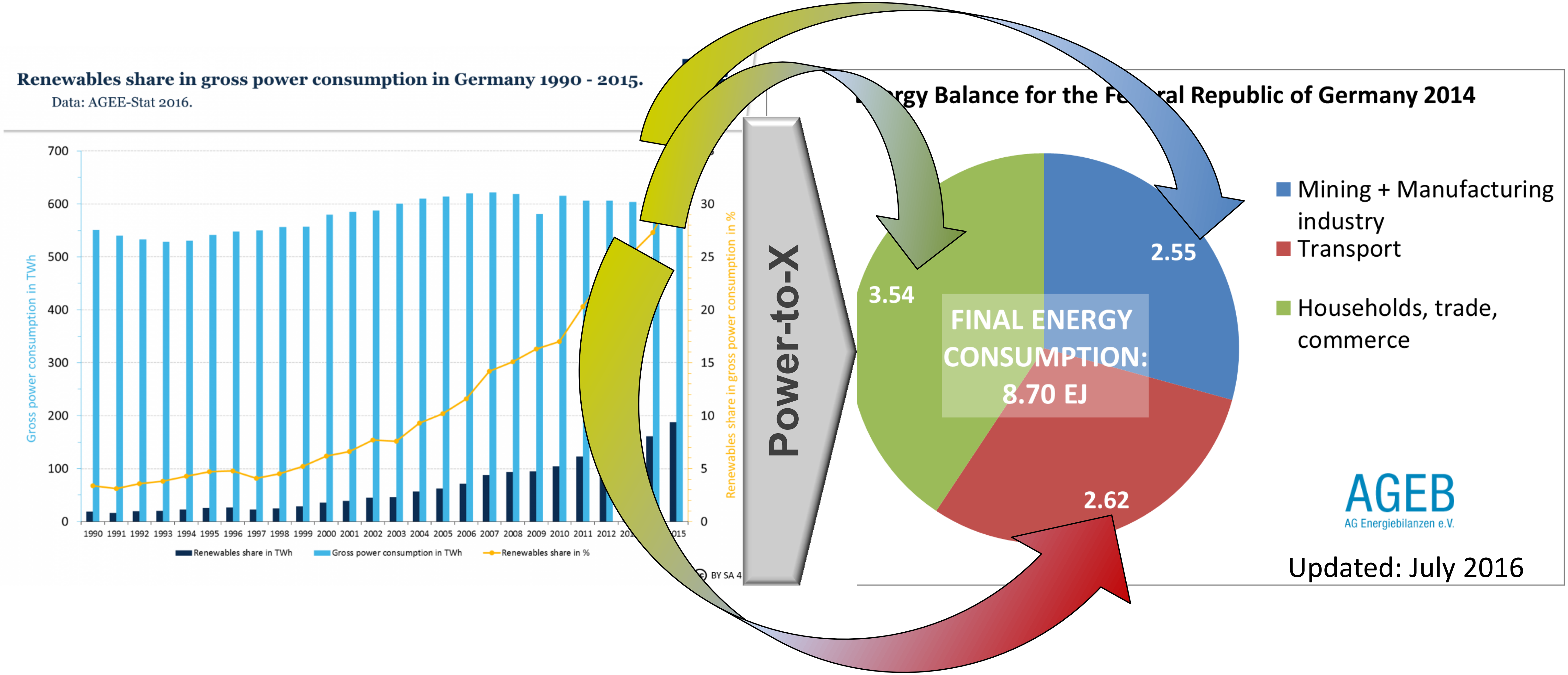


German energy mix 2016: Energy sources' share in primary energy consumption.
Data: AG Energiebilanzen 2016.



Note: Percentages add up to 101.5% as bottom line power exports (-200 PJ, or -1.5%) are not visualised in this graph.

The German energy transition – challenges for renewables integration

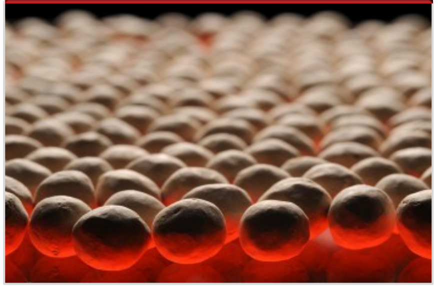


Technology options for Power-to-X

Renewable Electricity

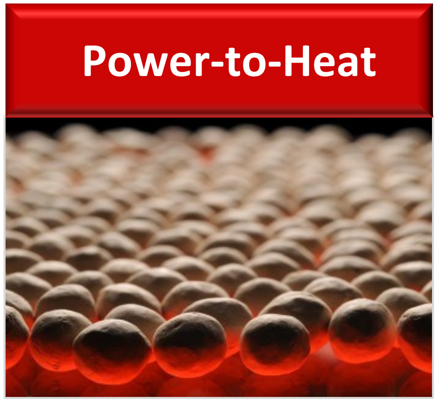
Power-to-X

Power-to-Heat



Power-to-Gas

Power-to-Liquid



Power-to-Heat Applications: Power-operated Heat Pumps

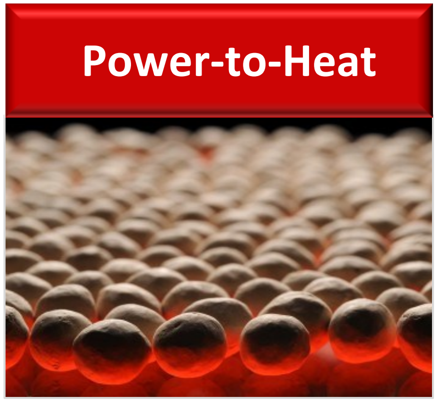
- Fossil fuel substitution by renewable power: 1 kWh_{el} ➔ up to 3-4 kWh_{th}
- Established, user accepted Technologies, small investment required

- District heating
- Large power range (0.1 – 10 MW)
- 330 MW installed
- Huge storage capacity

- Domestic water heating
- Integrated with heating installation, PV, solar heat
- Model region with 200 homes in SH: excess wind power

- Process steam generation
- High pressure and capacity

Pictures: Klöpper-Therm GmbH & Co. KG



Power-to-Heat Technologies: Heat Storage

- Uncoupling of heat supply and demand

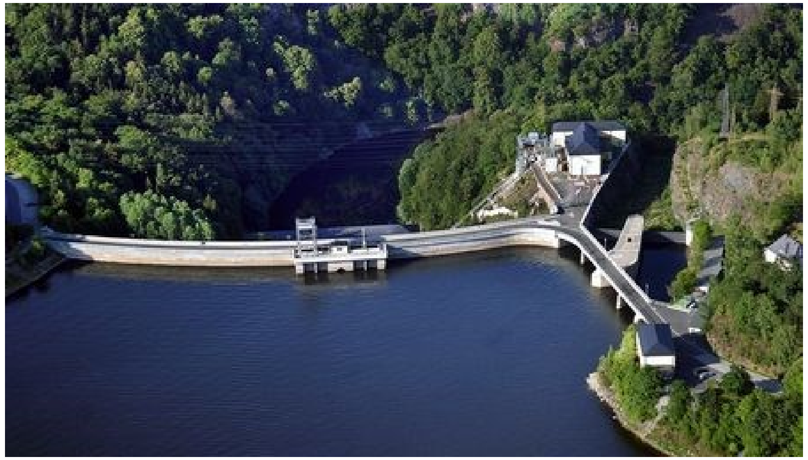
HOTREG test facility: Storing high-temperature heat in small ceramic particles (175 kW, 830 °C)

CeraStorE: Chemical heat storage by reversible gas- and solid-state reactions (High storage capacity using Lime)

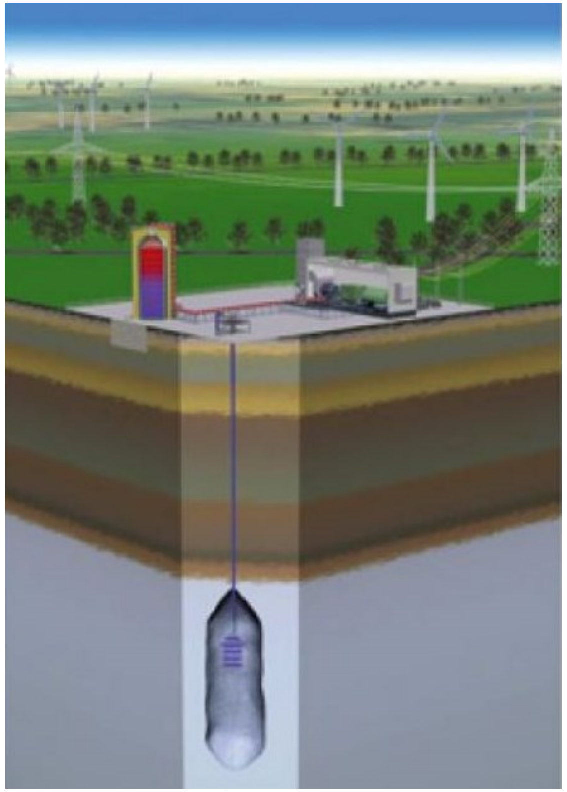
Power-to-Heat

Large scale electricity storage: Power-X-Power

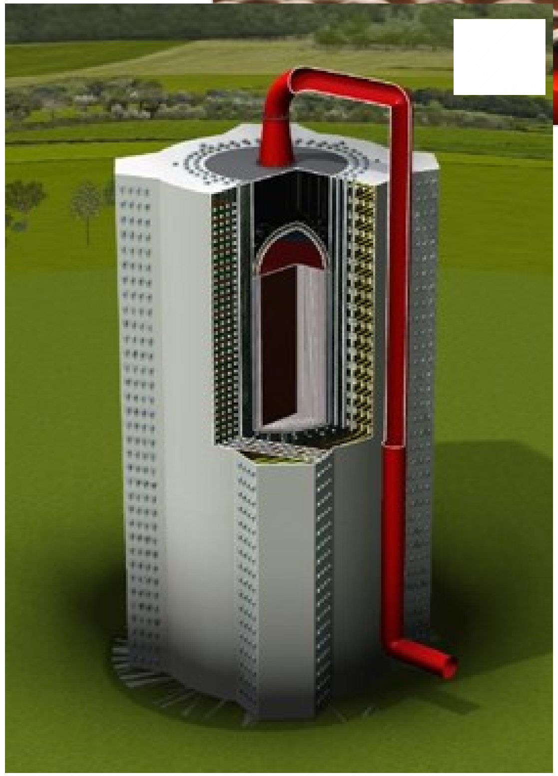
- Seasonal storage



- 33 pumped-storage hydropower plants (Σ: 6,6 GW)
- Limited potential

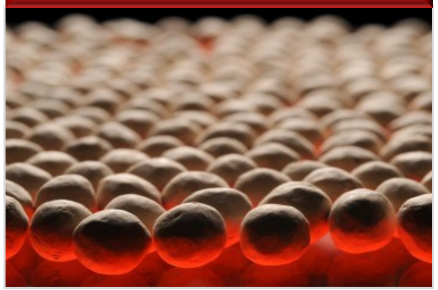


- Compressed Air Energy Storage (CAES)
- 320 MW Demonstration plant (2 h), Efficiency ≈ 42 %



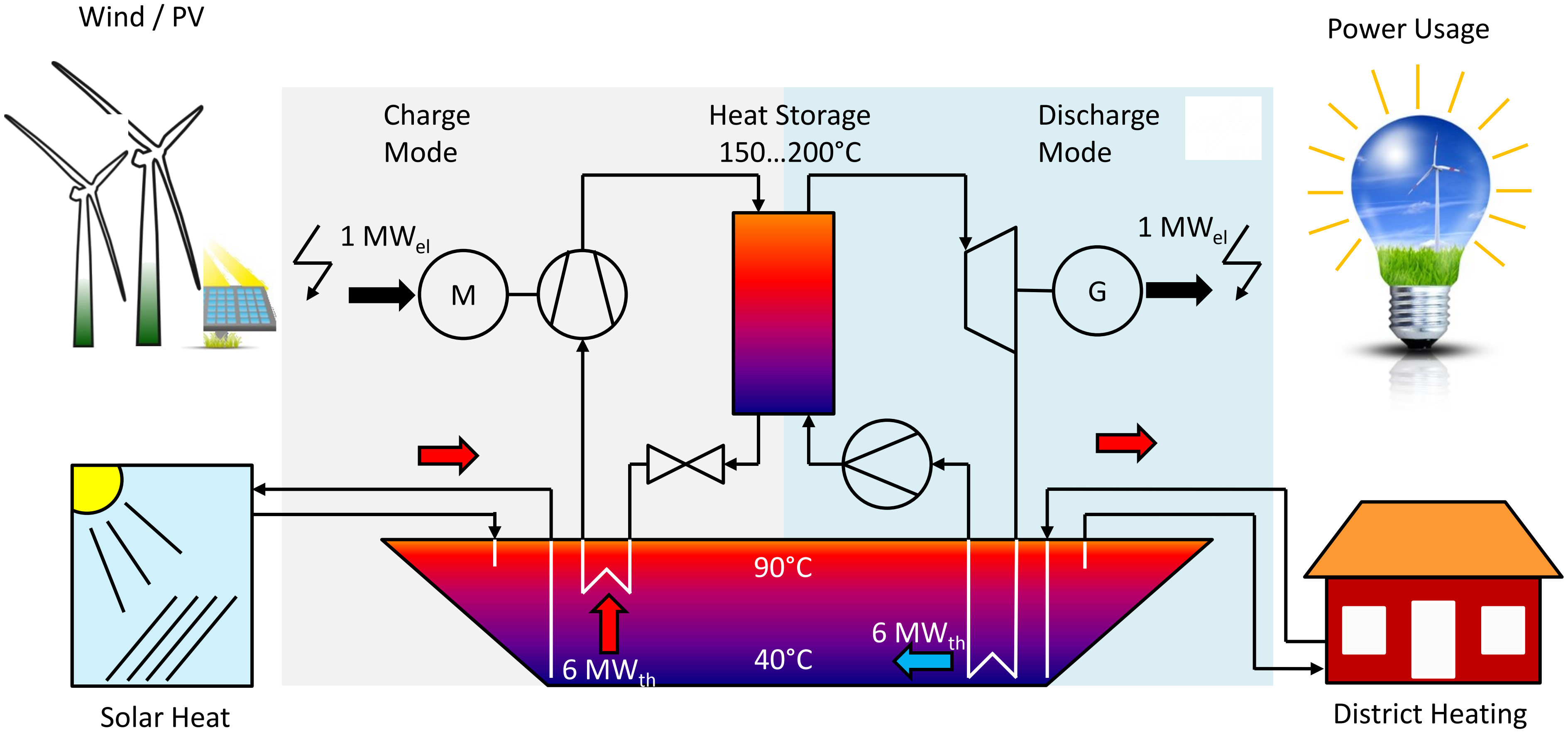
- **Adiabatic** compressed air energy storage concept
- Re-use of compression heat, Efficiency ≈ 70 %

Power-to-Heat



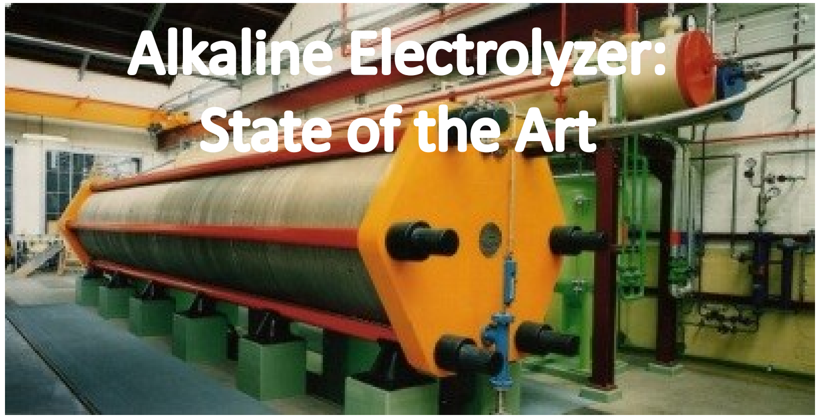
Combining electricity storage and District Heating: Smart District Heating Concept

- Seasonal electricity storage using hot water reservoir



Power-to-Gas: H_2O electrolysis

- Global electrolysis demand by 2030: 330 GW (Boston Consulting Group)
- Established, user accepted technologies – but continuous R&D efforts



- Established industrial applications: Thyssenkrupp, ELB (former Lurgi), …

- Energiepark Mainz: 3*1,3 MW demonstration
- Goal: 200 t/a H_2 @ 35 bar

- R&D: sunfire, DLR, …
- Highest overall efficiency
- Allows reverse operation (SOFC)

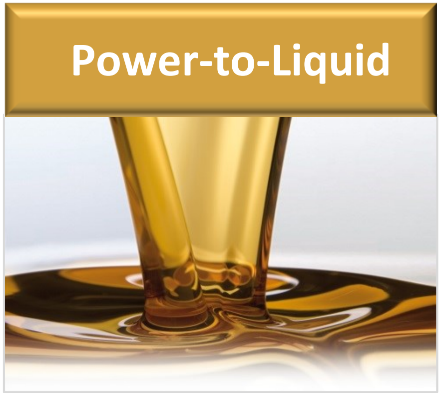
Power-to-Gas

Power-to-Gas: Methane

- Synthetic Natural Gas (SNG) uses current gas infrastructure
- Mobile applications available today
- To compete with import natural gas

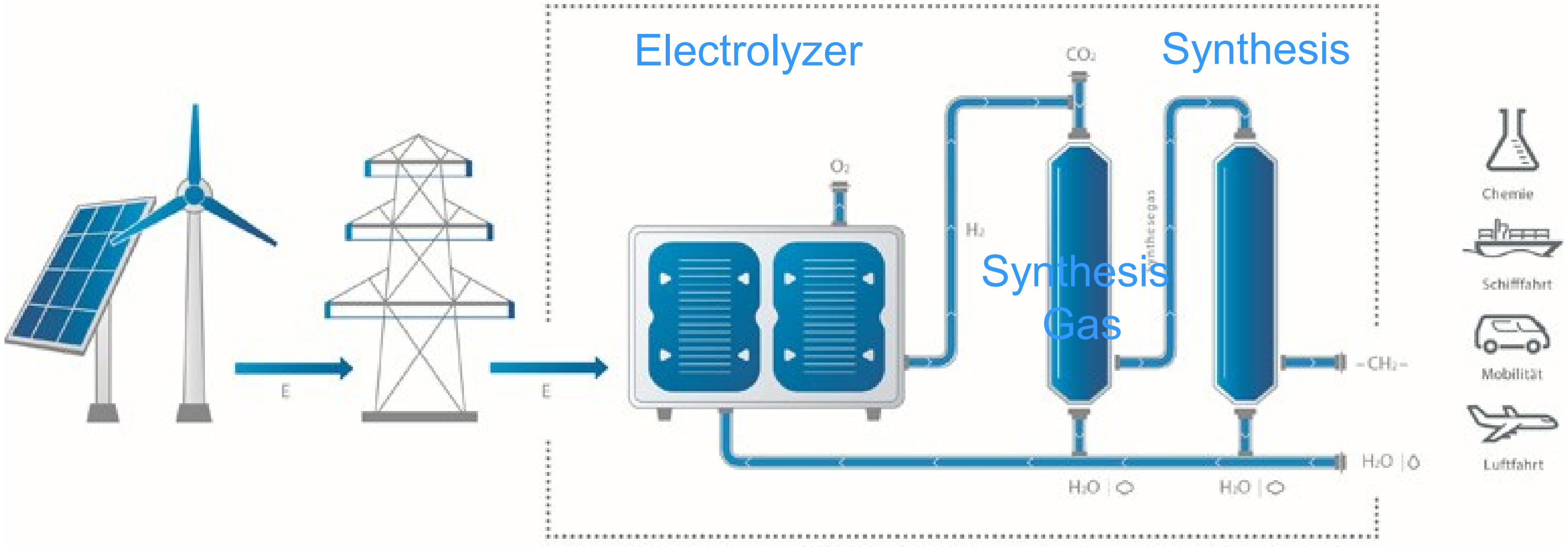
- Audi e-gas plant since 2013
- 1,000 Nm^3/a SNG fueling
  1,500 Audi A3 Sportback g-tron vehicles

- Project pipeline @ www.dvgw-innovation.de



Power-to-Liquid: More than a Concept?

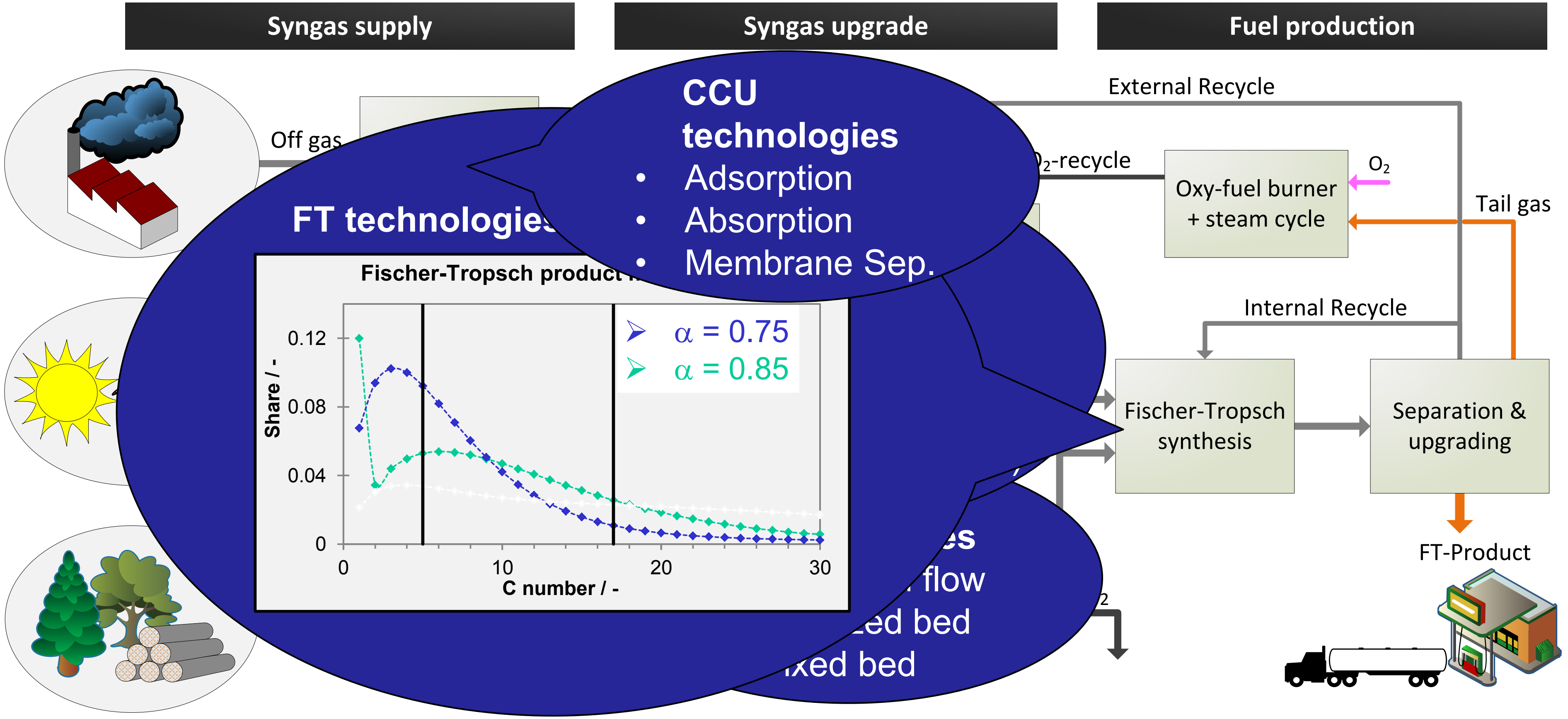
- Advantage: Renewable Transport with current infrastructure
- Challenge: Currently not competitive to fossil fuels

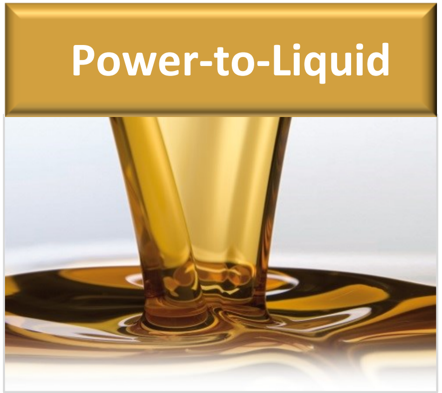


- Dresden, 14.11.2014: Federal Minister of Education and Research Johanna Wanka fills the first 5 l of synthetic fuel from sunfire demo plant into her ministry car

DLR

Power-to-Liquid combined with biomass processing: Multiple Options for Renewable Transport





Power-to-Liquid: Process Performance

Case study equipment selection and assumptions:

- PEM electrolyzer, η = 4.3 kWh/Nm³ [6]
- Entrained flow gasifier, T = 1200 ℃, p = 30 bar, pure O2 [7]
- Fischer-Tropsch synthesis, T = 225 ℃, p = 25 bar, a = 0.85, XCO = 40 % [8]

Process parameter	BTL	PBTL	PTL
Energy efficiency η_{XTL}	36,3 %	51,4 %	50,6 %
Power consumption	- 4.2 kWh/kg_{fuel}*	15.8 kWh/kg_{fuel}	24.4 kWh/kg_{fuel}
Biomass/CO_2 demand	7.6 kg_{BM}/kg_{fuel}	2.0 kg_{BM}/kg_{fuel}	3.1 kg_{CO2}/kg_{fuel}
Carbon efficiency η_C	24.9 %	97.7 %	98.9 %

*BTL can generate electricity from exhaust heat

- BTL fuel yield can be **increased by the factor 3 – 4** by the PBTL concept
- Approximately full carbon conversion for PBTL and PTL applying oxy-fuel combustion and recycle concept
- High XTL-efficiency for PTL and PBTL

[6] T. Smolinka, M. Günther and J. Garche, „Stand und Entwicklungspotenzial der Wasserelektrolyse zur Herstellung von Wasserstoff aus regenerativen Energien,“ NOW GmbH, 2011.
[7] K. Qin, „Entrianed Flow Gasification of Biomass, Ph. D. thesis,“ Technical University of Denmark (DTU), Kgs. Lyngby, 2012.
[8] P. Kaiser, F. Pöhlmann and A. Jess, "Intrinsic and effective kinetics of cobalt-catalyzed Fischer-Tropsch synthesis in view of a Power-to-Liquid process based on renewable energy,“ *Chemical Engineering Technology,* vol. 37, pp. 964-972, 2014.

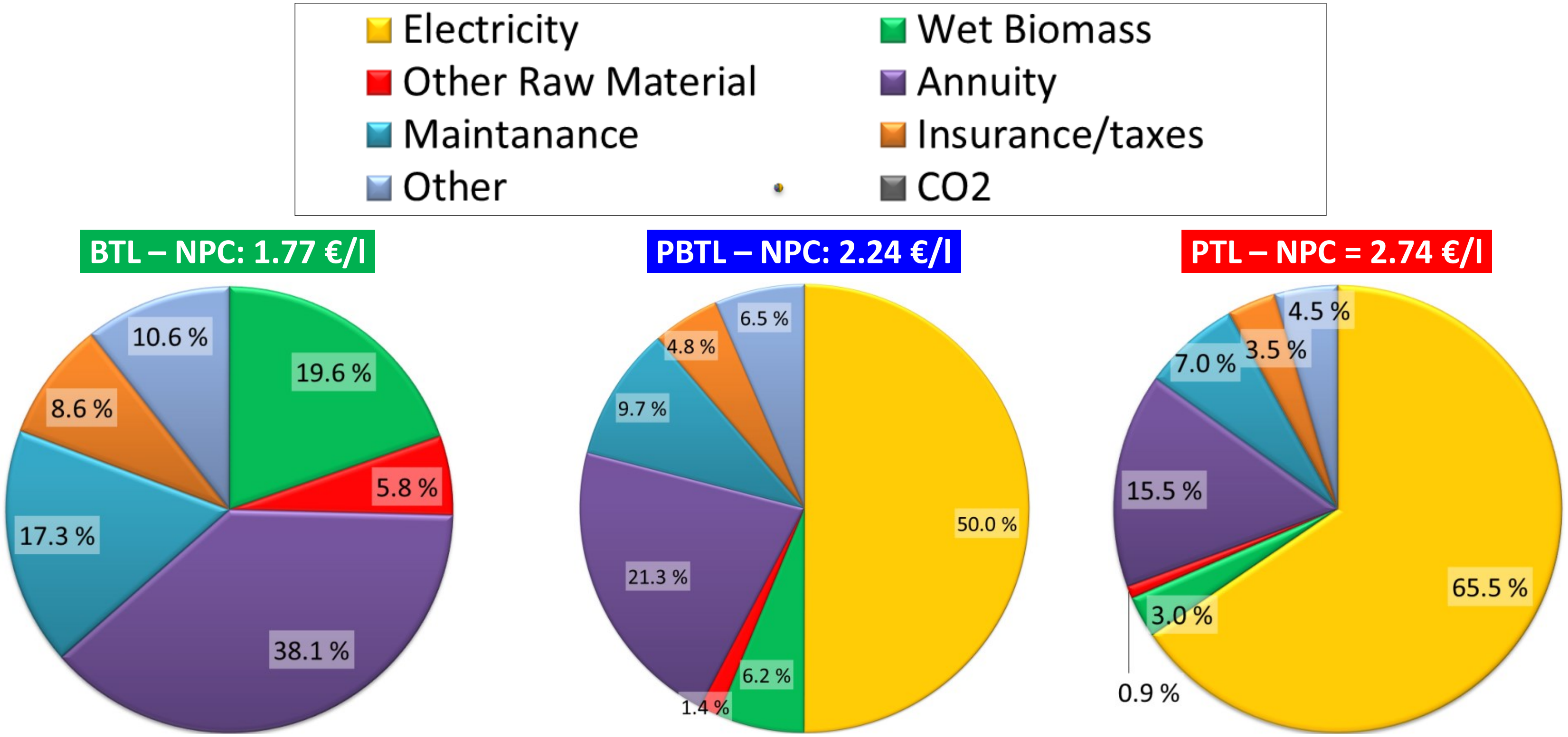
DLR

Power-to-Liquid

Power-to-Liquid: Production costs for 11 t_{fuel}/h capacity (2014)

Case study operating funds assumptions:

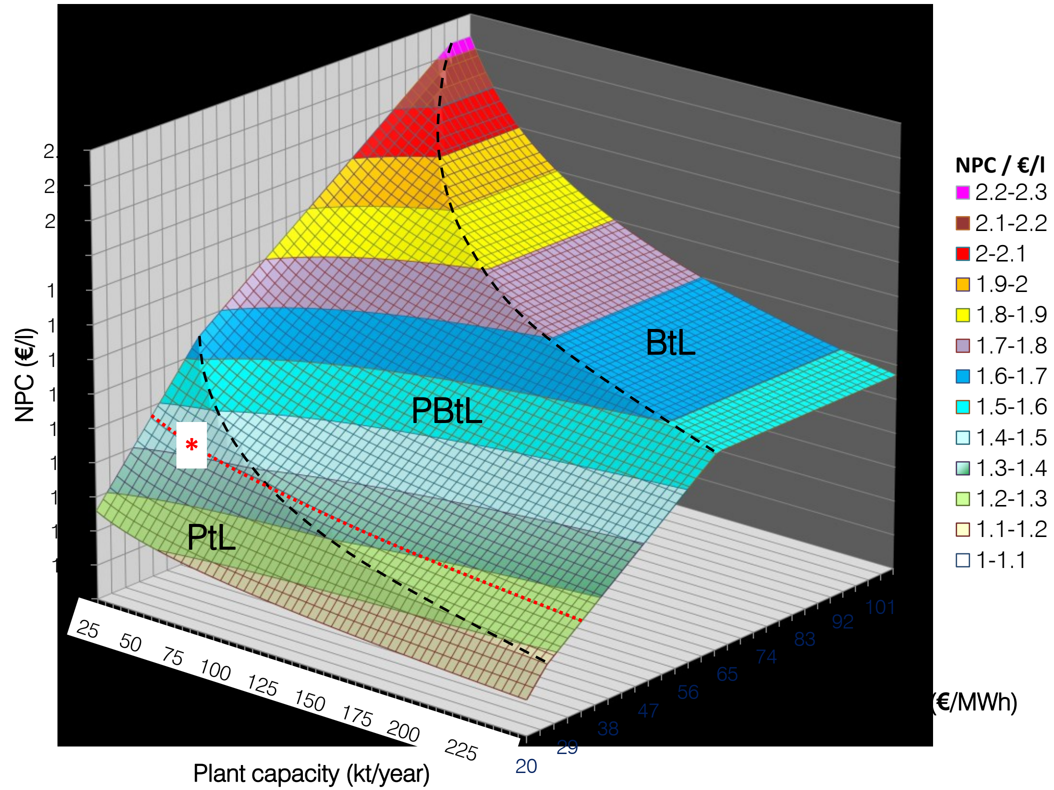
- Electricity: 105 €/MWh [12]
- Biomass (wood chips): 100 €/t_{wet} [13]



[12] Eurostat, „Electricity prices for industrial consumers - bi-annual data (from 2007 onwards), 2016.
[13] C.A.R.M.E.N e.V., „Price development of wood chips“, 2015.

Power-to-Liquid

Power-to-Liquid: Techno-economic assessment



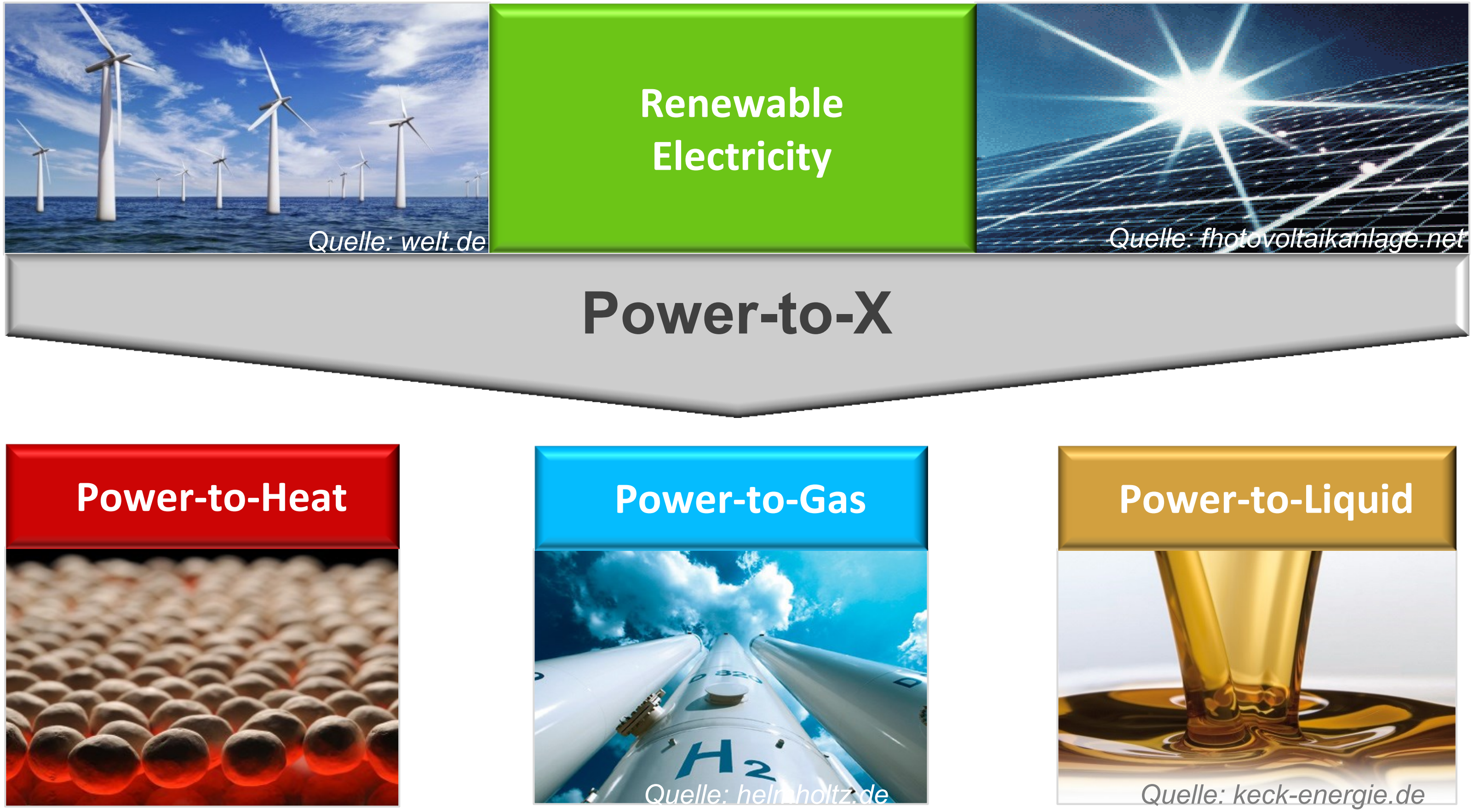
* Red line indicates stock exchange power price

Fuel production costs (NPC) over plant size and electricity price

- PtL preference: small plant size, cheap electricity
- PBTL preference: larger plant size (biomass availability?), current electricity prices

DLR

Technology options for Power-to-X

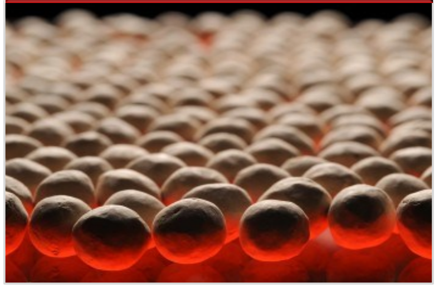


Technology options for Power-to-X

Renewable Electricity

Power-to-X

Power-to-Heat



- Cheap, state-of-the-art electroboiler for low temperature applications (exergy loss included)
- Currently not for saisonal storage
- High temperature applications required for sustainable industry

Technology options for Power-to-X

Renewable Electricity

Power-to-X

Power-to-Gas

- Industrial hydrogen demand can be supplied sustainable
- Growing demand of hydrogen applications not clear
- Hydrogen economy will require Power-to-Gas
- Gas production includes exergy losses
- Methane can be used for power production (grid stabilization)

Technology options for Power-to-X

Renewable Electricity

Power-to-X

Power-to-Liquid

- Sustainable transport with current infrastructure requires sustainable fuels
- Sustainable chemistry from renewable power
- Exergy losses unavoidable for current transport system
- Huge long term storage potential

Technology Demand for Power-to-X

Renewable Electricity

Power-to-X

- Large scale energy storage technologies (efficiency, maturity, costs)
- Electrolyzer mass production
- Efficient synthesis technologies for renewable transport

The future integrated energy system will look different!

THANK YOU FOR YOUR ATTENTION!

German Aerospace Center (DLR)
Institute of Engineering Thermodynamics, Stuttgart
Research Area Alternative Fuels

ralph-uwe.dietrich@dlr.de
http://www.dlr.de/tt/en

DLR

Knowledge for Tomorrow