OPTIONS FOR CHEMICAL STORAGE OF RENEWABLE ENERGY

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2014 EU-US Frontiers of Engineering Symposium, Seattle, WA

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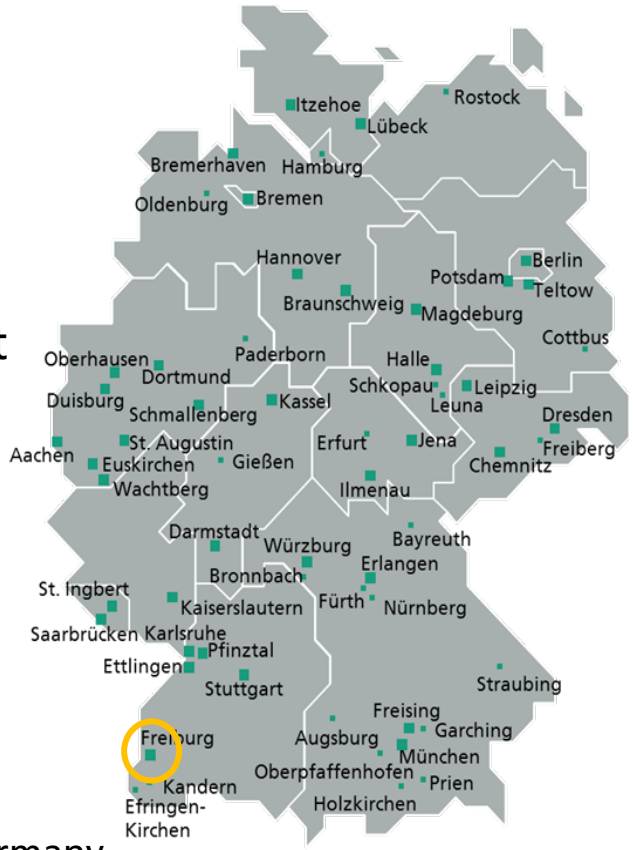
Fraunhofer performs applied R&D for industry

- Figures (2013)
  - 67 institutes
  - staff of over 23,000
  - 1.8 bn Euro annual turnover
    - 10..15 % basic funding from government
    - 30..40 % from industry



locations in Germany

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Storage of Energy Becomes More and More Important

- renewable energy sources (RES) used globally


sunlight


tidal


wind


geothermal

-> electricity, heat


hydro


biomass

-> heat, energy carriers, chemicals

- solar and wind deliver energy in a volatile manner
  - need for storage of energy (heat/electricity) increases

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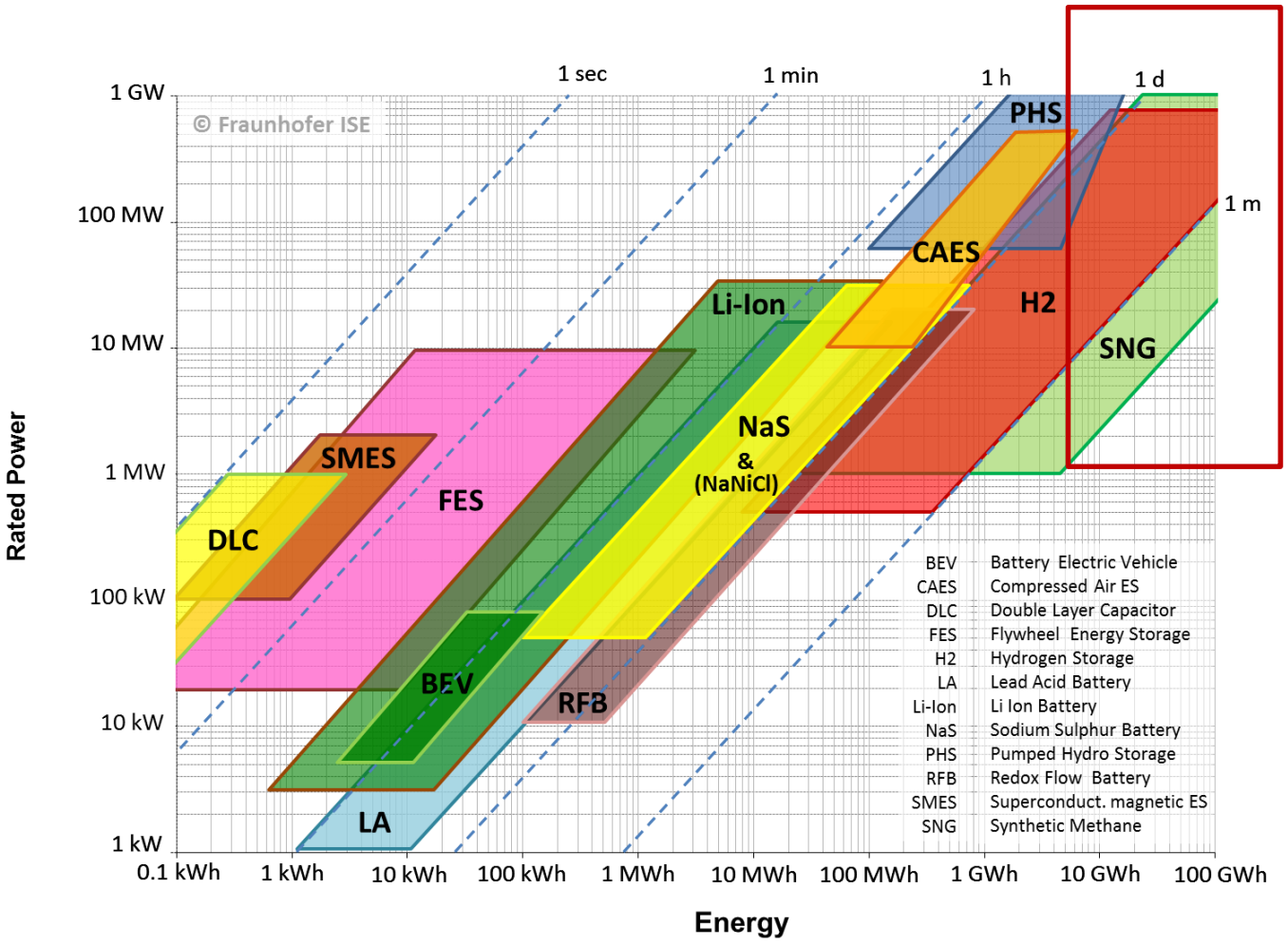
There exist Various Options for Electric Energy Storage



Long-term storage of large amounts of energy –> chemicals and energy carriers

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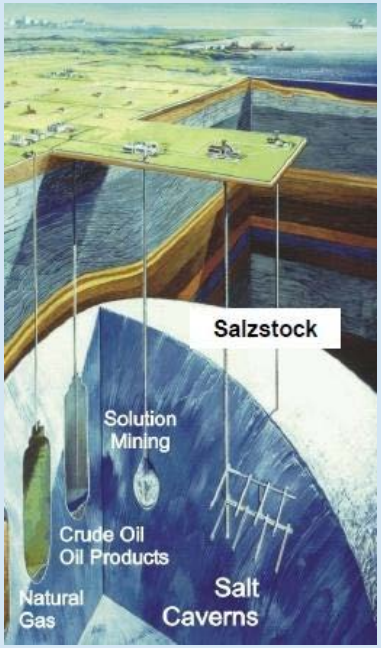
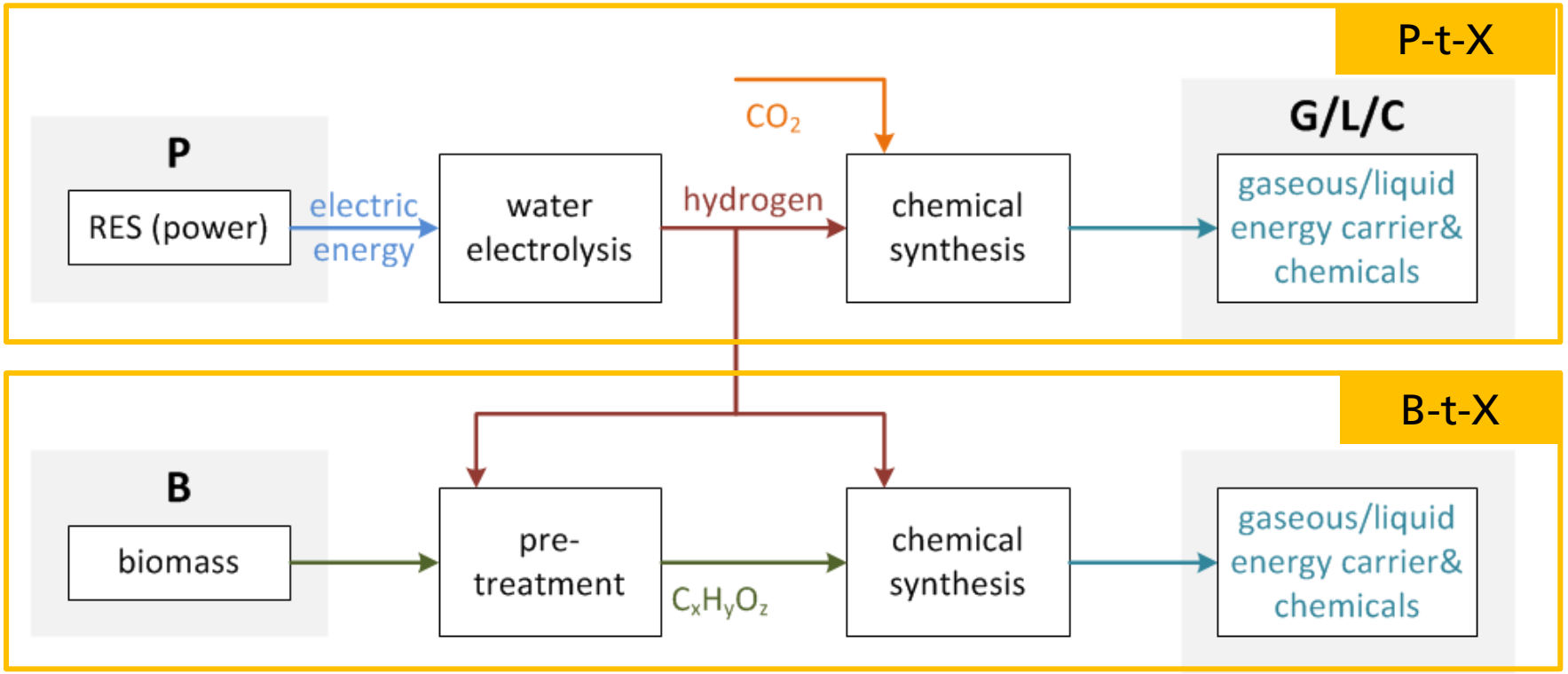
Water Electrolysis is Starting Point to Produce a "Material" Energy Carrier

- ways to convert electricity into a material energy carrier
  - water electrolysis -> H_2 and O_2
  - some work on methane electrolysis (FOE)
- approaches to directly use sunlight to produce hydrogen
  - photocatalytic water splitting (FOE)



- Need to store H_2
  - mobility
  - underground
  - other atoms to facilitate storage (C, N, …)

Possible Carbon Sources are CO_2 and Biomass



- B-t-X approaches -> see Regina's talk

CO_2 as carbon source – possible routes for hydrogenation of CO_2

product	reaction equation	$\Delta_R H$ [kJ/mol]	global production [Mtpy]	price [USD/t]	
CO	$CO_2+H_2 \leftrightarrows CO+H_2O$	43			-> syngas
HCOOH	$CO_2+H_2 \leftrightarrows HCOOH$	-29	0.6	700..1000	
CH_2O	$CO_2+2H_2 \leftrightarrows CH_2O+H_2O$	45	21		
CH_3OH	$CO_2+3H_2 \leftrightarrows CH_3OH+H_2O$	-85	60	350..600	
CH_4	$CO_2+4H_2 \leftrightarrows CH_4+2H_2O$	-163	3300 bn scm	270..800	-> SNG
C_2H_5OH	$2CO_2+6H_2 \leftrightarrows C_2H_5OH+3H_2O$	-212	100	650..1000	
CH_3OCH_3	$2CO_2+6H_2 \leftrightarrows CH_3OCH_3+3H_2O$	-119	5 (2020: 200)	800..1000	

-> Methanol as example to highlight:
GHG, economics, dynamics

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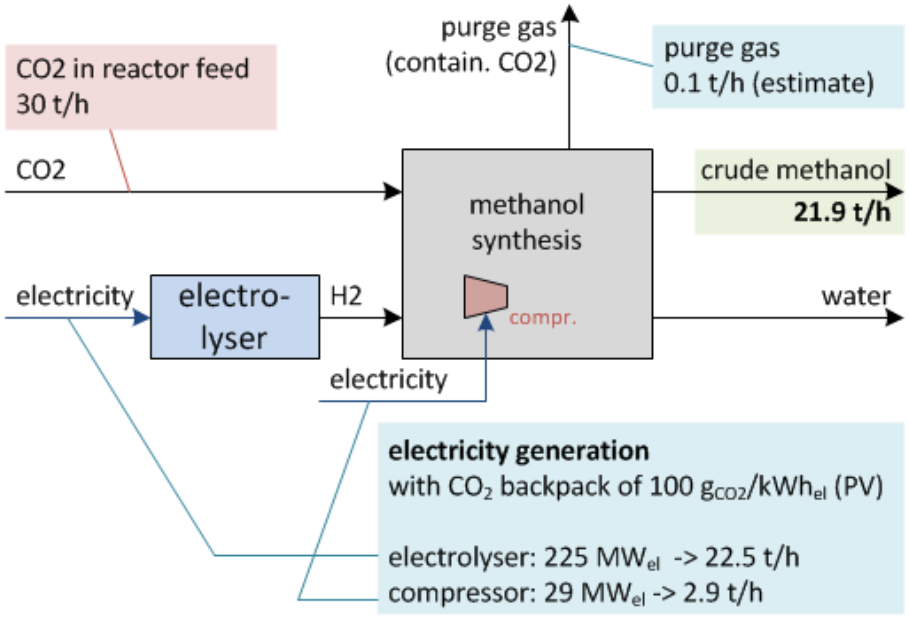
GHG Emissions
- There is Only a GHG Benefit When Using RES.

CO_2 sources	wind	PV	grid (GER)
g_{CO2}/kWh_{el}	25	100	544
t/h			
electrolysis		22.5	
compressor		2.9	
purge gas		0.1	
sum	6.4	25.5	139
CO_2 sink			
reactor feed	-30	-30	-30
net	-23.6	-4.5	109
spec. t_{CO2}/t_{MeOH}	-1.1	-0.2	5.0

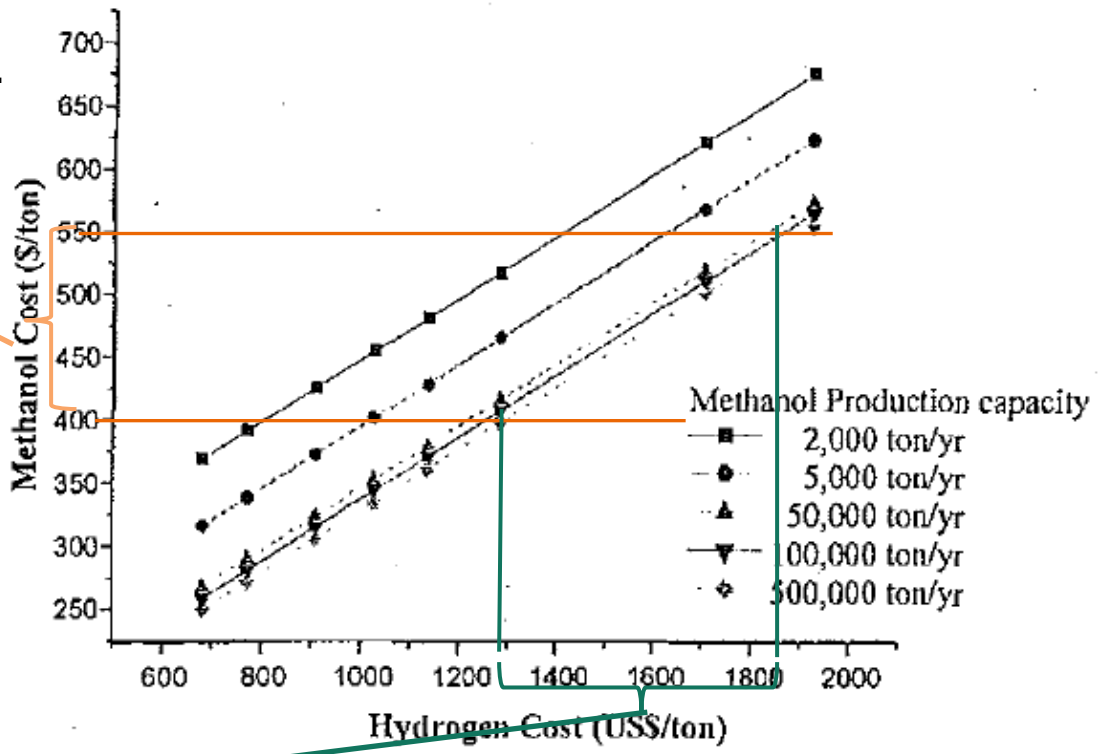


MeOH from NG –
the conventional way:
0.94 t_{CO2}/t_{MeOH}

Economics
- Methanol Price Influences Production Cost for H_2

- H_2 costs are ½ to $^2/_3$ of overall production costs…

World market price of MeOH 400..530 USD/t



„acceptable " H_2 price 1300..1850 USD/t

reference: Joo et al., Studies Surface Sci. Cat. 2004

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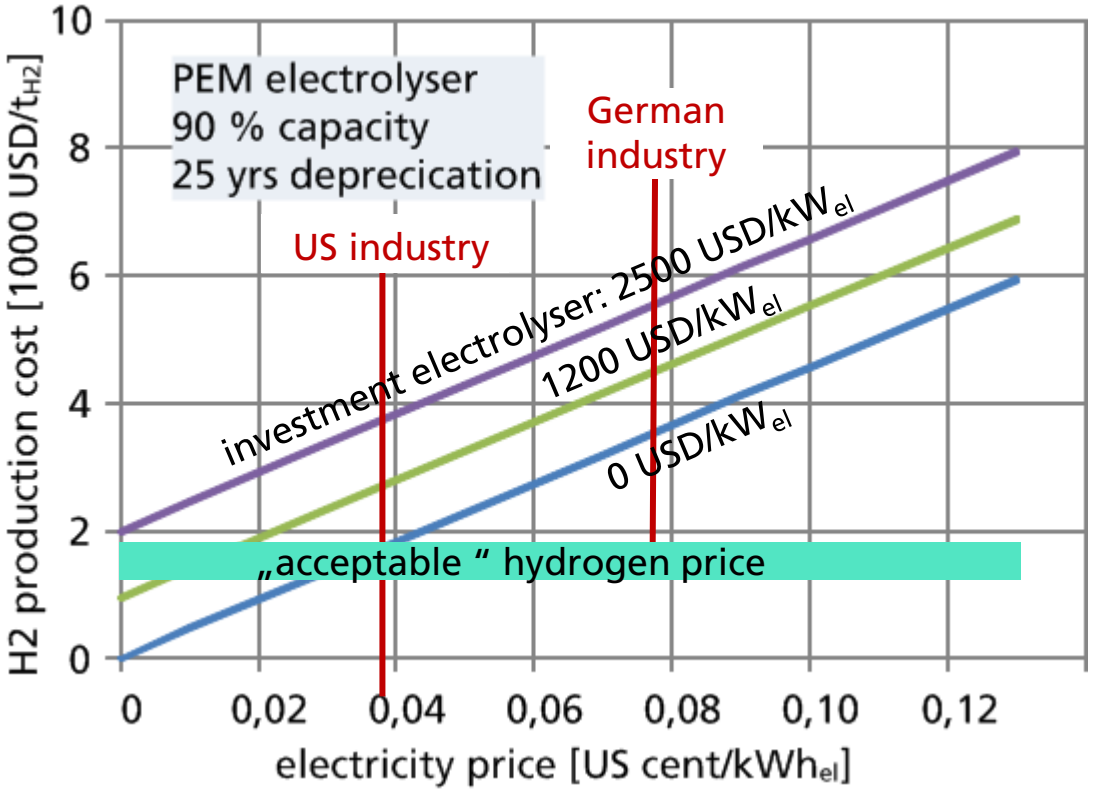
How Much is Hydrogen From Water Electrolysis?

- Methanol from H_2 and CO_2 could become economic…

- significantly reduce CAPEX of PEM electrolysers

-> Frontier of Engineering



reference: Smolinka et al., NOW-Studie 2011

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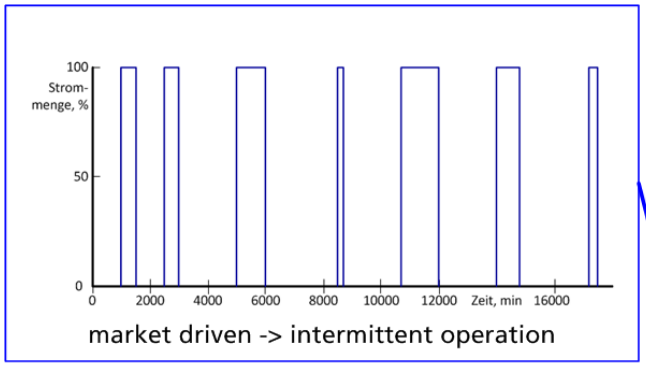
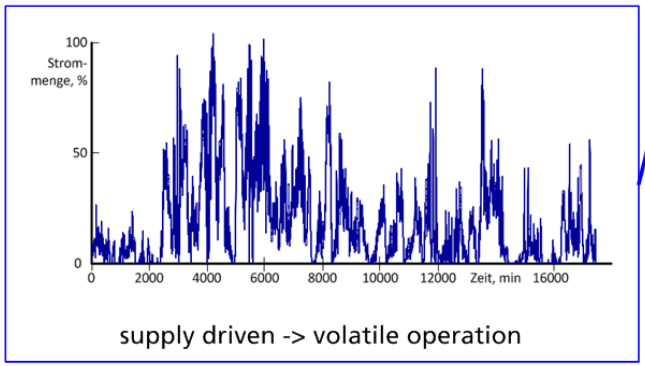
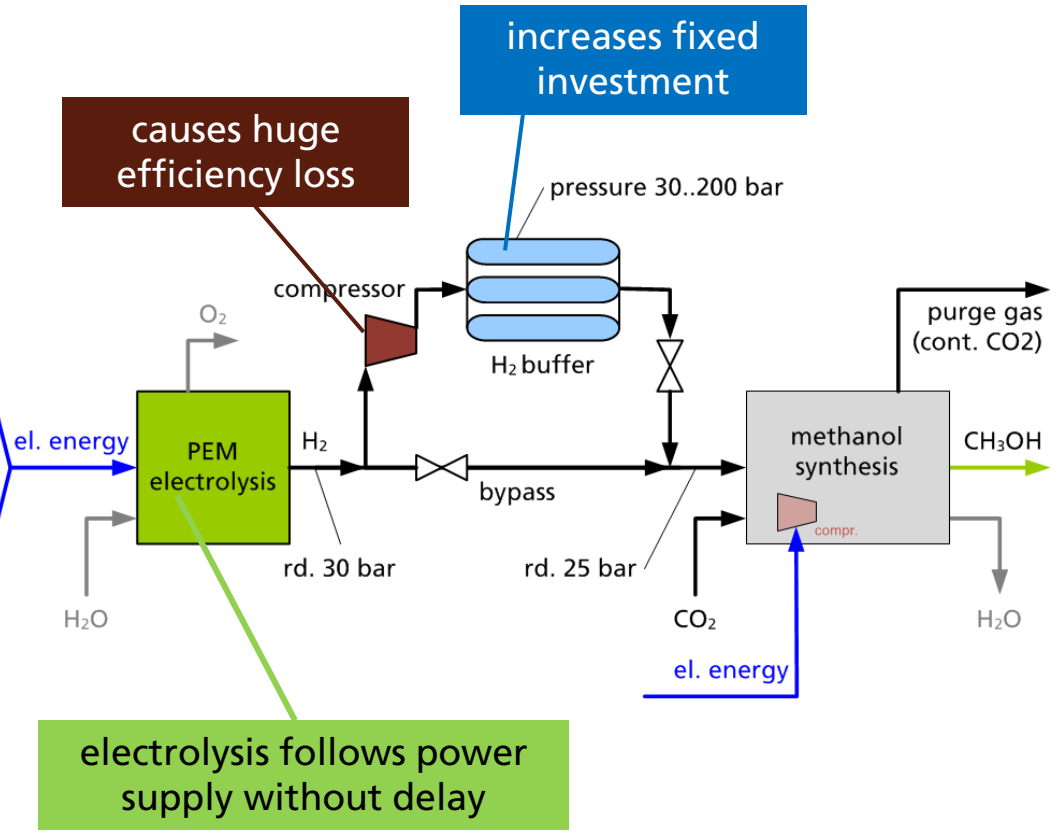
Dynamics of Chemical Processes



market driven -> intermittent operation



supply driven -> volatile operation



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Frontier of Engineering: Dynamic Operation of Packed Bed Reactors

process intensification

- research topic since the 1960's
  - forced unsteady-state operation
  - wrong-way behavior
  - ring reactor systems, reverse flow

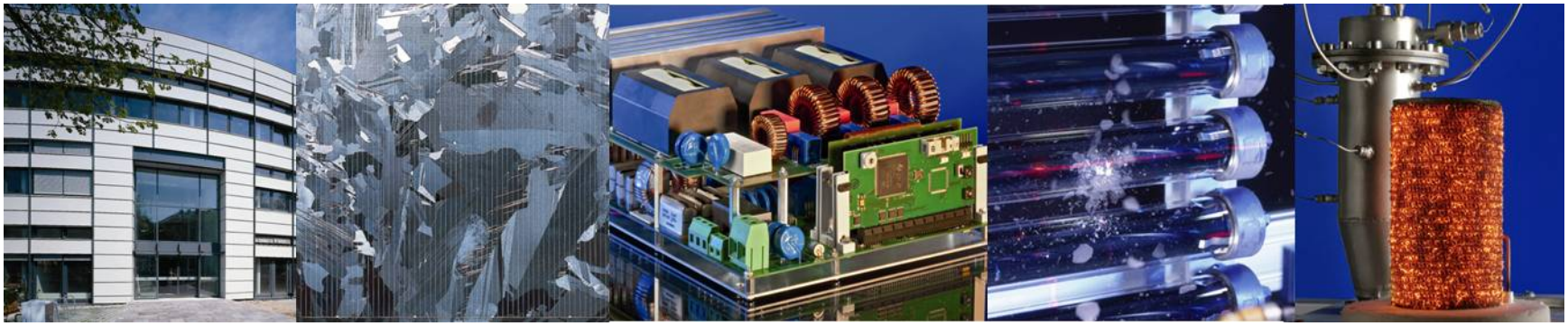
dynamic operation

- in the last 5 years
  - dynamic response of step changes
  - volatile syngas feed (solar, wind)
  - catalyst lifetime
  - BOP

Summary

- PtX concepts
  - promising options for long-term energy storage
- Frontiers of Engineering (FOE) in this context
  - cost of H_2 generation via electrolysis
  - dynamic operation of chemical plants
  - photocatalytic water splitting
  - methane electrolysis

Thank you for your kind attention!



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