HYDROGEN IN AN INTEGRATED ENERGY SYSTEM

Germany‘s Research Interests on Hydrogen

Christopher Hebling,
Tom Smolinka

Fraunhofer Institute for Solar Energy Systems ISE

19th PEFC & Electrolyzer Symposium at the
236th Meeting of the Electrochemical Society
Atlanta, October 14, 2019
www.ise.fraunhofer.de

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ISE

The Fraunhofer Institute for Solar Energy Systems ISE

Part of the German Fraunhofer Association for Applied Research

- 72 instituts and research institutions
- 26,600 employees
- 2.2 Mrd €/a contract research

Directors:
Prof. Dr. Hans-Martin Henning
Dr. Andreas Bett

Staff: approx. 1,250

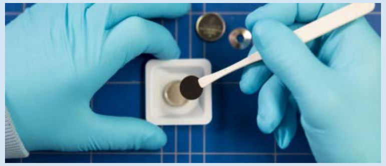
Budget 2018: 94.3 Mio. €

Established: 1981

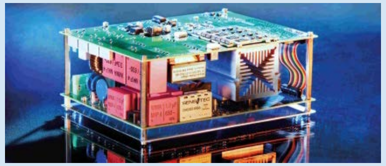
Photovoltaics

Energy Efficient Buildings

Solar Thermal Power Plants and Industrial Processes



Hydrogen Technologies and Electrical Energy Storage



Power Electronics, Grids and Smart Systems

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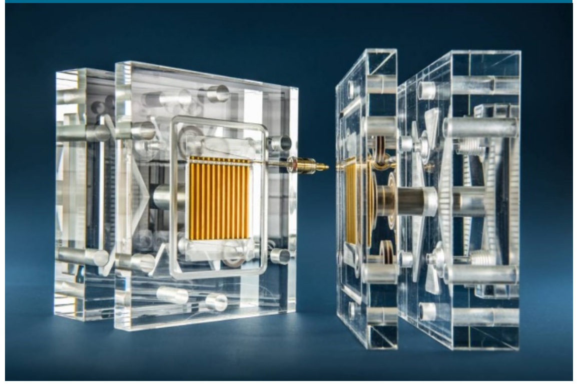
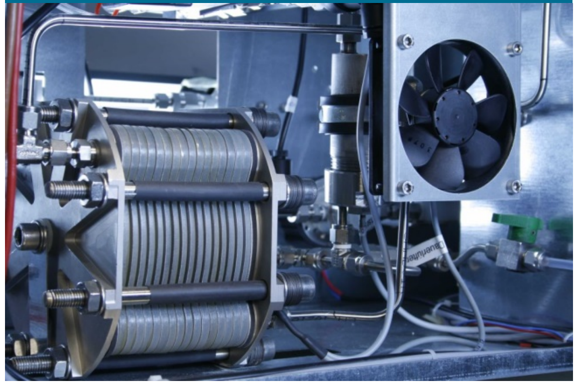
Research Topic: Electrolysis and Power to Gas

Characterisation of Materials and Components



- Elektrochemical Characterisation
- Investigation of life-time / Accelerated stress tests
- Ex-situ analysis

Development of PEM Water Electrolysis Systems



- New Cell concepts
- Laboratory PEM stacks
- Energy-optimised balance of plant
- Control strategies

Power to Gas

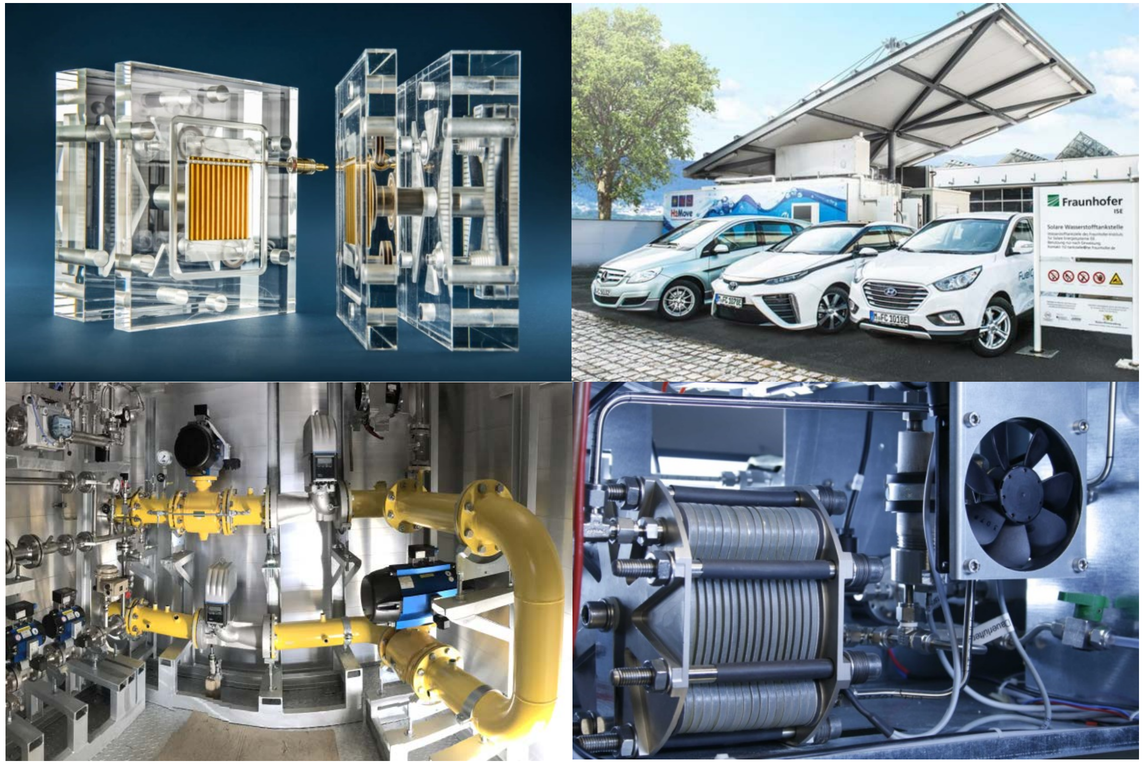
- Dynamic system modelling of PtG systems
- Development of system and plant concepts
- H_2 yield assessment

Hydrogen Infrastructure

- Technology consulting
- Techno economical analysis /market survey
- Roll out H_2 technologies
- Life cycle assessment

OUTLINE OF THE TALK

- Introduction to Fraunhofer ISE ✓
- Challenges in the German energy transition
- Current state and future trends on Power to X applications in Germany
- Main Drivers for hydrogen production costs
- Evaluation of business opportunities for PtX installations
- Summary and conclusions



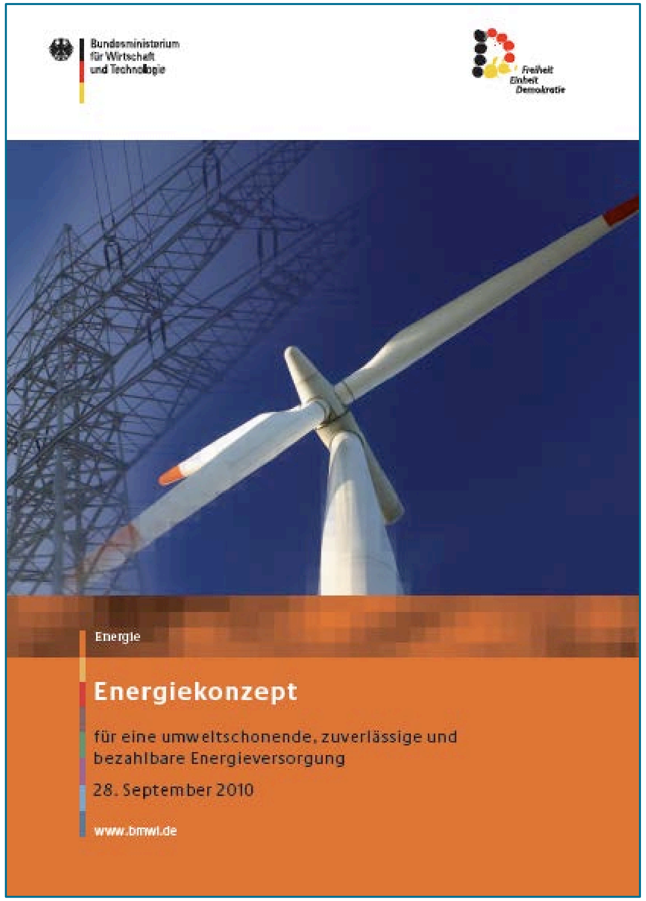
Energy Transformation in Germany

The goal: Extensive greenhouse gas neutrality until 2050

- Main driver
  - high level of security of supply based on RES
  - effective climate and environm. protection
  - economically viable energy supply
- Ambitious goals by the German government (Energy Concept from 2010)

	2020	2030	2040	2050
GHG reduction by	- 40 %	-55 %	-70 %	- 80 to - 95%
Total RES share	18 %	30 %	45 %	60 %
RES share in electricity	35 %	50 %	65 %	80 %

The Federal Government: "Energy concept for an environmentally friendly, reliable and affordable energy supply" Merseberg, 28 September 2010



Source: https://www.bmwi.de/Redaktion/DE/Downloads/E/energiekonzept-2010.html

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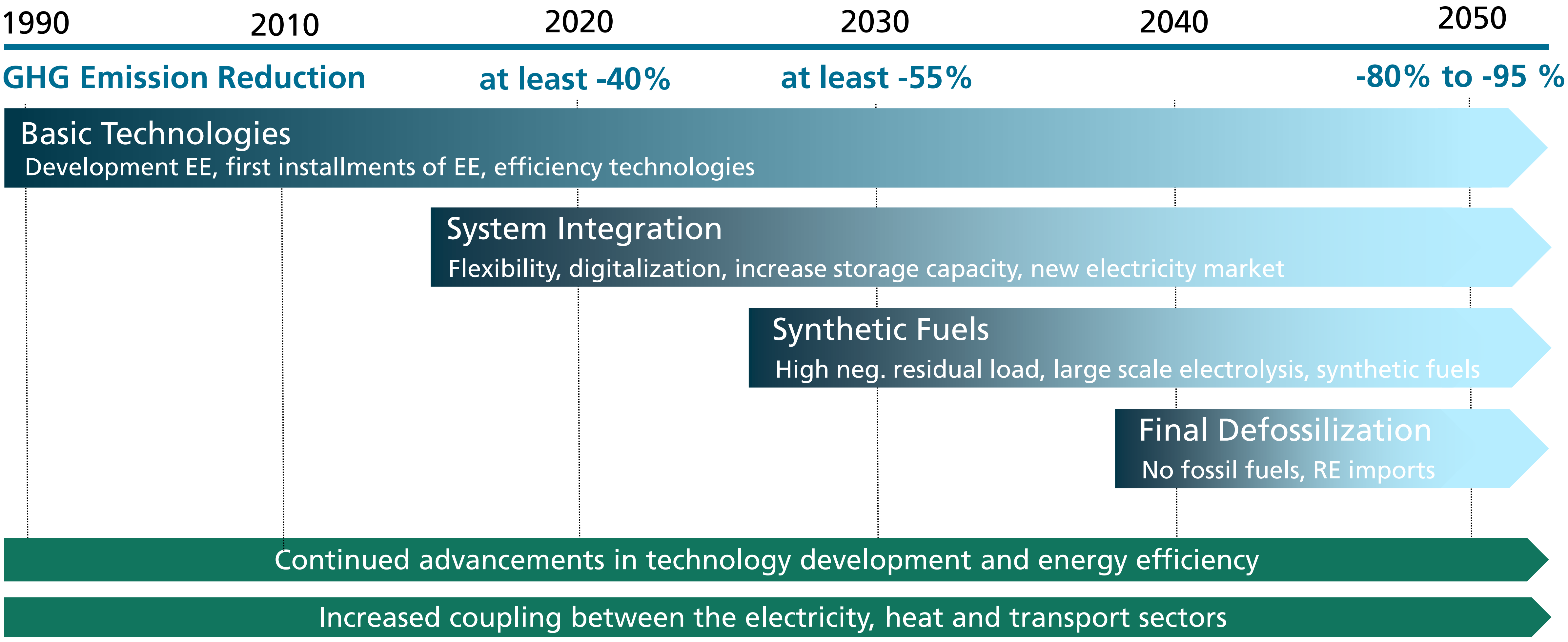
Energy Transformation in Germany

Targets and phases for a cost and climate compatible transformation.



According to acatech (November 2017):
»Sektorenkopplung - Optionen für die nächste Phase der Energiewende«.

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Energy Transformation in Germany
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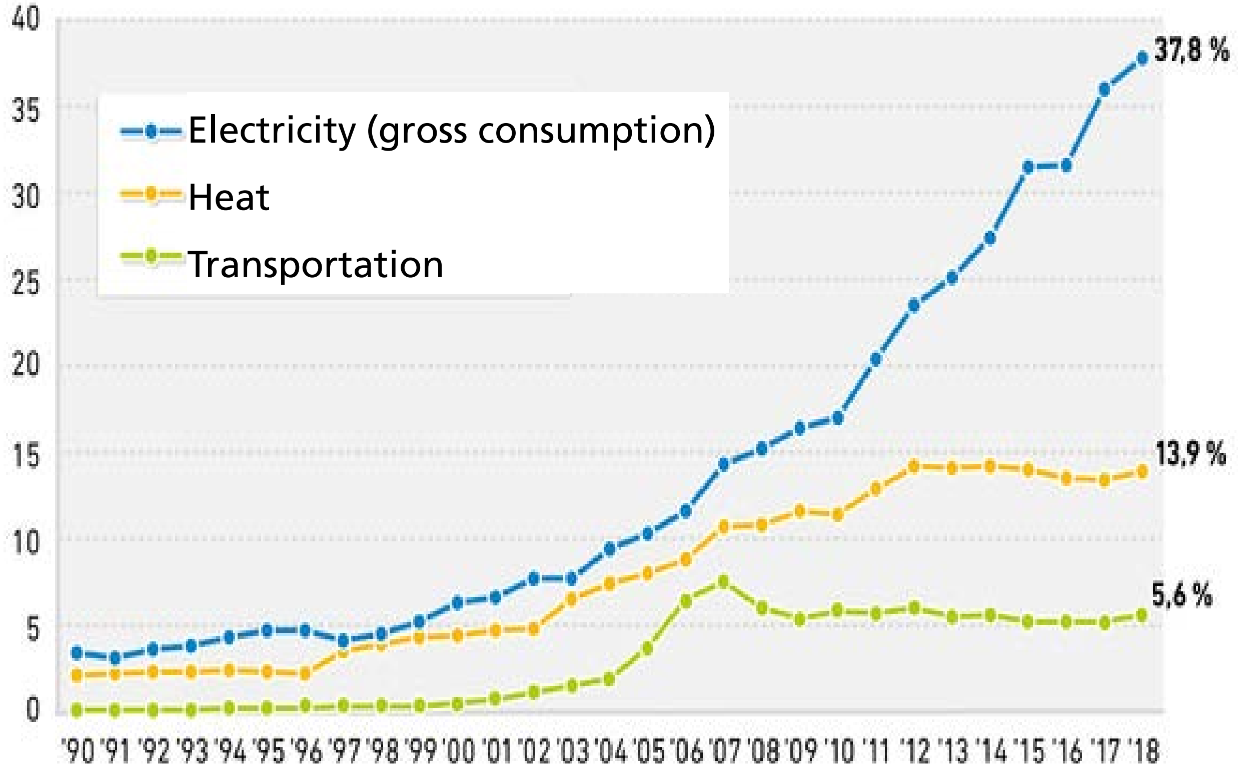

Share of renewable energies in the electricity, heat and transport sectors in the years 1990 to 2018 (Source: AGEE Statistic 03/2019)

Source: Renewable Energy Agency:https://www.unendlich-viel-energie.de/mediathek/grafiken?page=2

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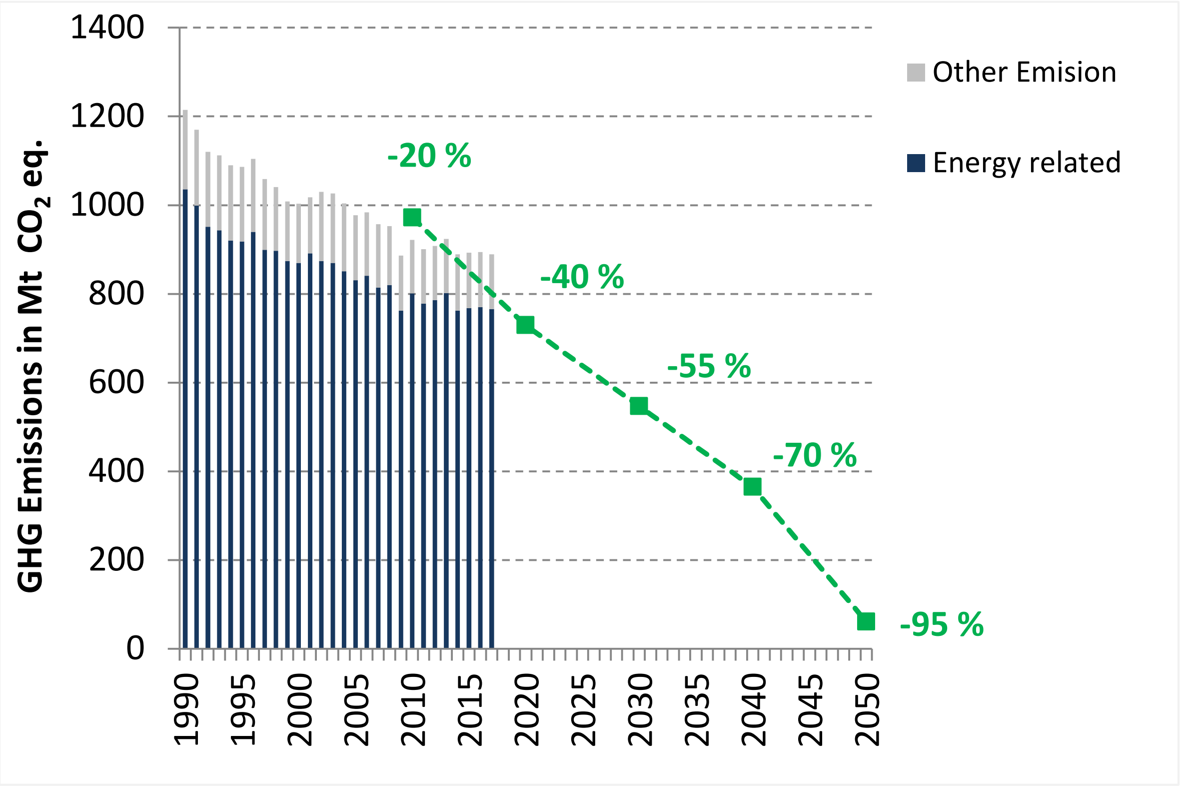

Development of German GHG emissions 1990 - 2017 and target values until 2050 (The Energy Concept of Germany)

Source: https://www.umweltbundesamt.de/daten/klima/treibhausgas-emissionen-in-deutschland

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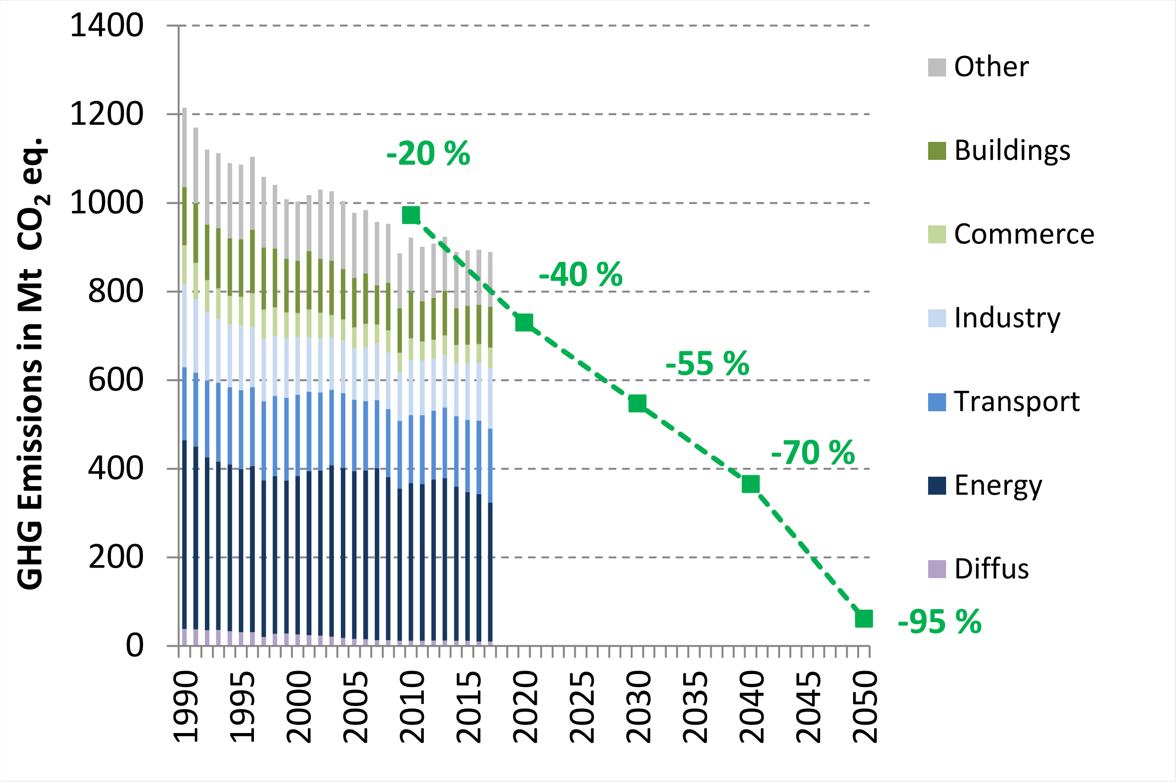
Energy Transformation in Germany

Germany is very likely to miss its GHG emission targets 2020!

- Main driver
  - high level of security of supply based on RES
  - effective climate and environm. protection
  - economically viable energy supply
- Ambitious goals by the German government (Energy Concept from 2010)

- Nearly no GHG reduction in the last 10 years!
- Detailed look at different sectors:
  - ➔ No reduction in transport sector
  - ➔ Struggle with process related GHG emissions in industry
  - ➔ Slow progress in buildings



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Source: https://www.umweltbundesamt.de/daten/energie/energiebedingte-emissionen

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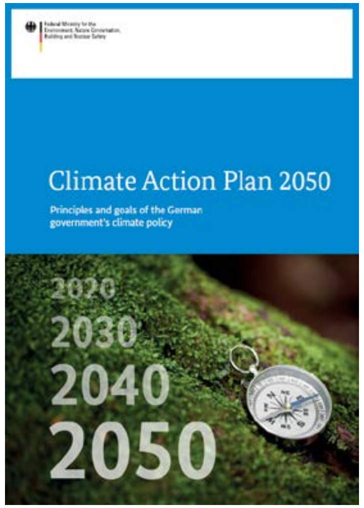
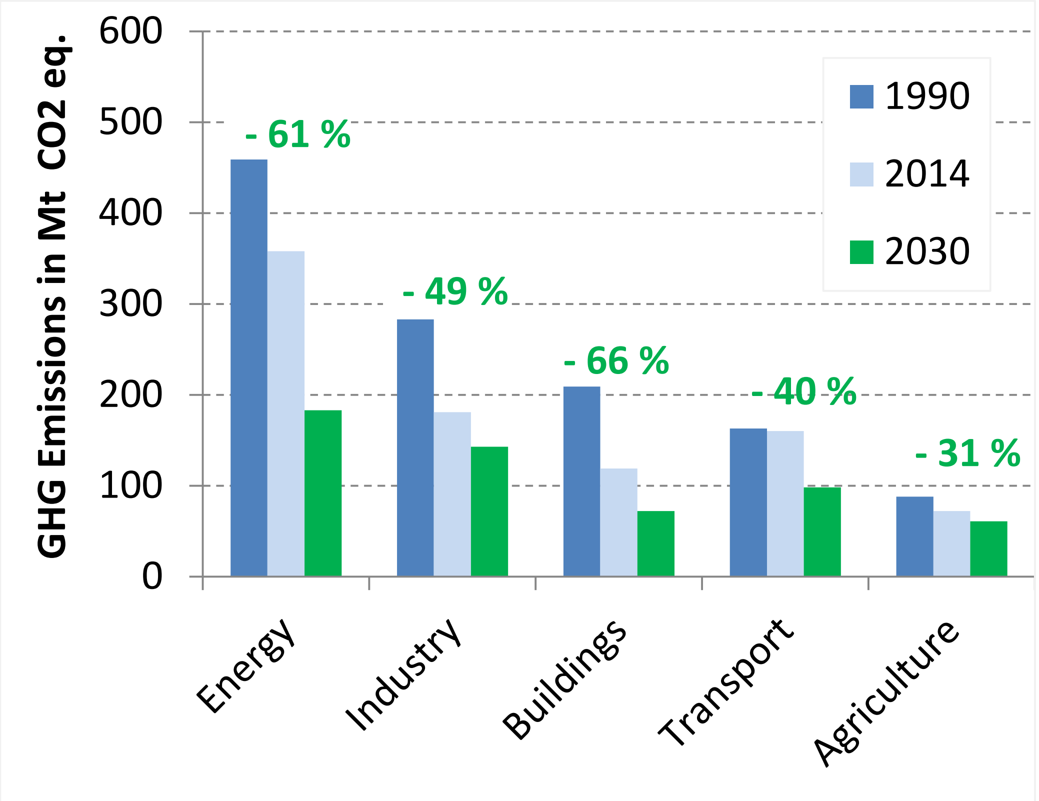
Energy Transformation in Germany

Climate Action Plan 2050: Specific targets for each sector until 2030

- Additional pressure from the Paris Agreement to limit global warming to 1.5 °C
  - Signed at 2015 UN Climate Change Conference in Paris (COP21)[1]
  - Reduce global GHG emissions to zero by 2045 - 2060
  - CO_2 removal from atmosphere by CCS and/or CCU



→ Next phase of energy transformation only possible with intersectoral coupling & PtX technologies



Specific reduction targets on GHG emissions Climate Action Plan 2050 (passed the German Government in Nov. 2016)

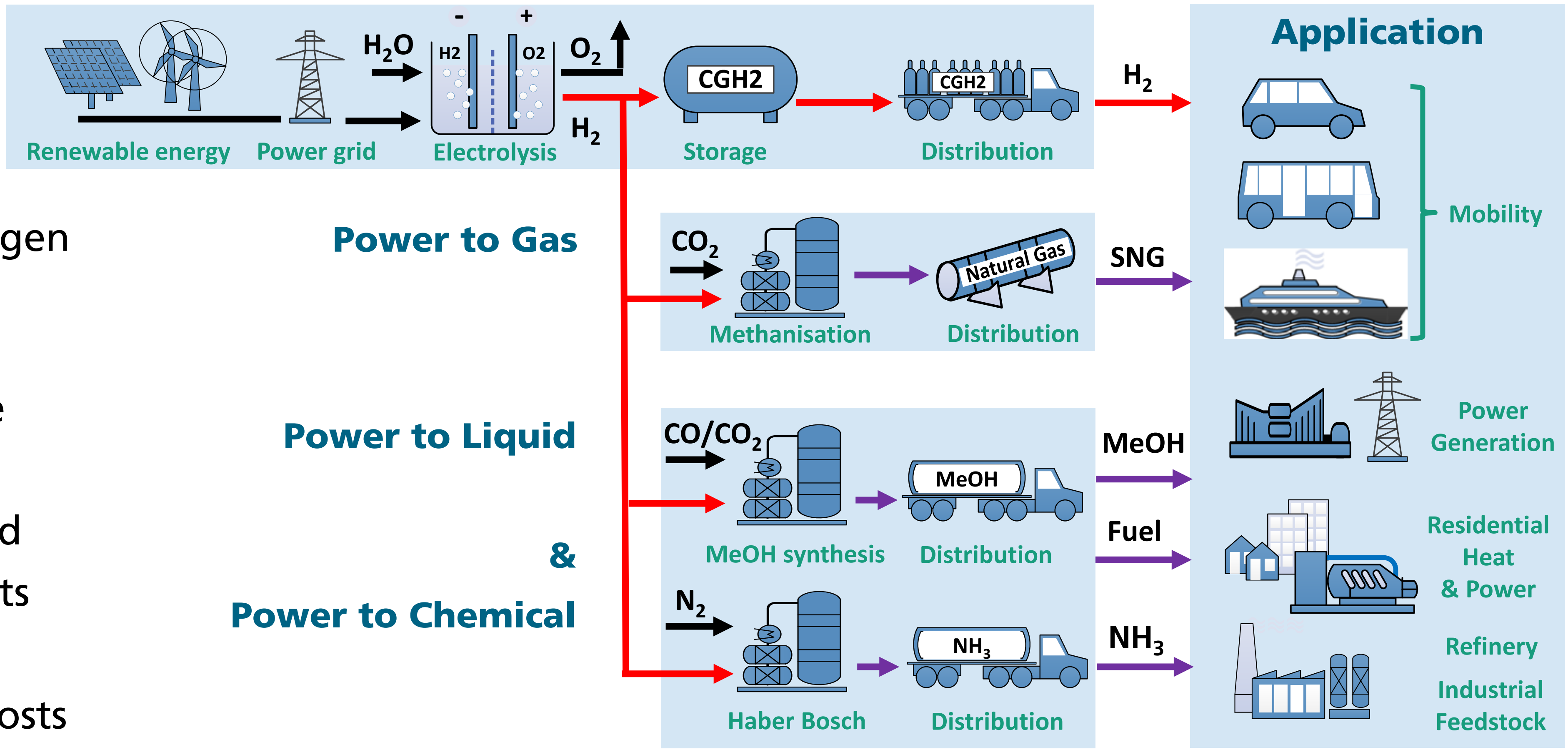
Source: https://www.bmu.de/themen/klima-energie/klimaschutz/nationale-klimapolitik/klimaschutzplan-2050/

1 COP 21: United Nations Framework Convention on Climate Change, 21st Conference of the Parties

Current State on Power-to-X Applications in Germany

Water electrolysis is a key element in all PtX applications.*

Power to Hydrogen



Main driver for hydrogen production costs

- Site-related
  - Electricity price
  - Full load hours
- Technology-related
  - Investment costs
  - Efficiency
  - Maintenance costs

* Exception: Power to heat is not regarded here.

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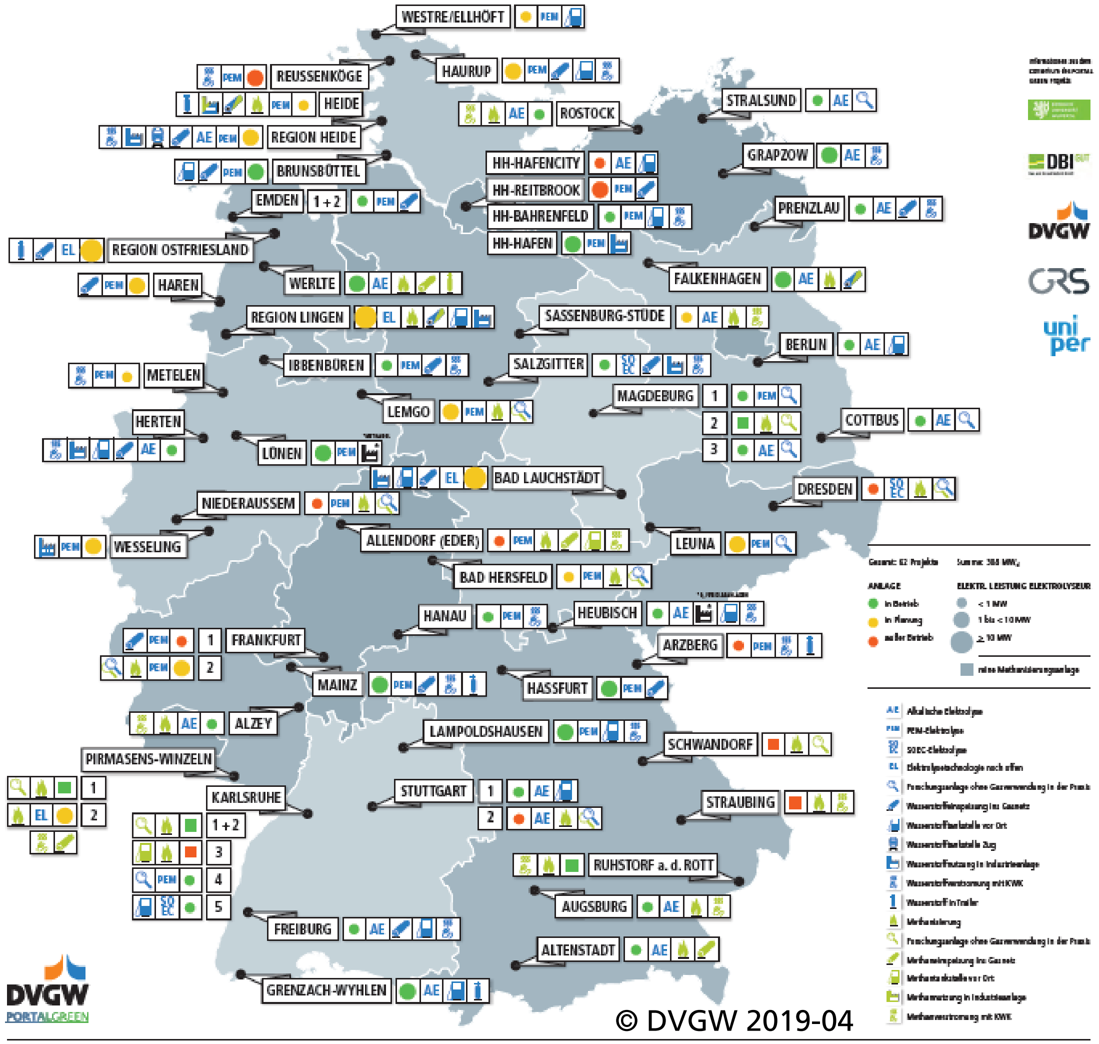
Current State on Power-to-X Applications in Germany

Industial-scale plants are still the exception.

- Several PtX installations in Germany since 2010
  - kW and single-digit MW range
  - First two-digit MW plants under construction
  - Total capacity of 55 MW in operation/planing
- Different applications:
  - Direct H_2 injection in NG pipeline
  - Methanisation and SNG injection
  - Secondary control reserve
  - Power balancing
  - Hydrogen for FCEV mobility
  - Industrial use and PtX
- Demonstration stage with public support



https://www.dvgw.de/der-dvgw/aktuelles/presse/presseinformationen/dvgw-presseinformation-vom-24042019-ptg-map/

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Current State on Power-to-X Applications in Germany
Selected projects

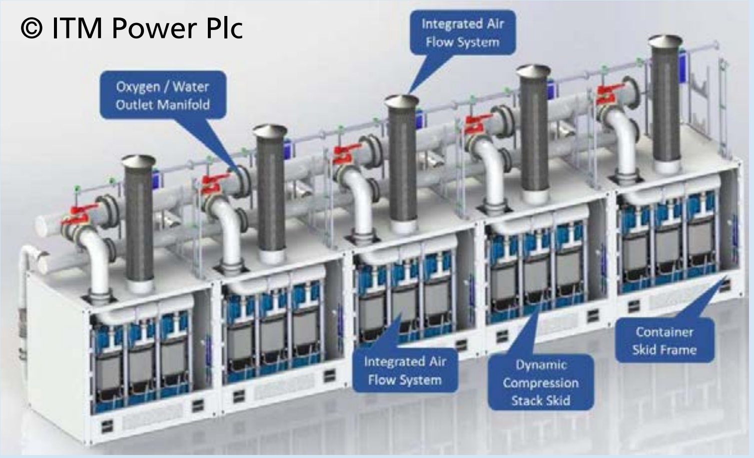
Carbon2Chem®

- AEL system by thyssenkrupp UCE
  - Atmospheric operation
  - 2 MW / 440 Nm³/h H_2
  - „short stack“ for 5 MW module
- CO_2 from steel mill gas and H_2 for chemical feedstock (as MeOH)

2 MW pilot plant in the C2C project

REFHYNE

- PEMEL system by ITM Power
  - Shell Rhineland Refinery
  - 10 MW / 1,800 Nm³/h H_2
  - 15 stacks à 670 kW
- Load balancing and replacement of steam reformed hydrogen



Standardised 10 MW stack skid

GrInHy

- SOEL system by Sunfire
  - 150/30 kW RSOC system
  - 40 Nm³/h in EL mode
  - 30 kW in FC mode
- Green H_2 for downstream process and onsite power generation

HyLink Gen. 0 in Salzgitter

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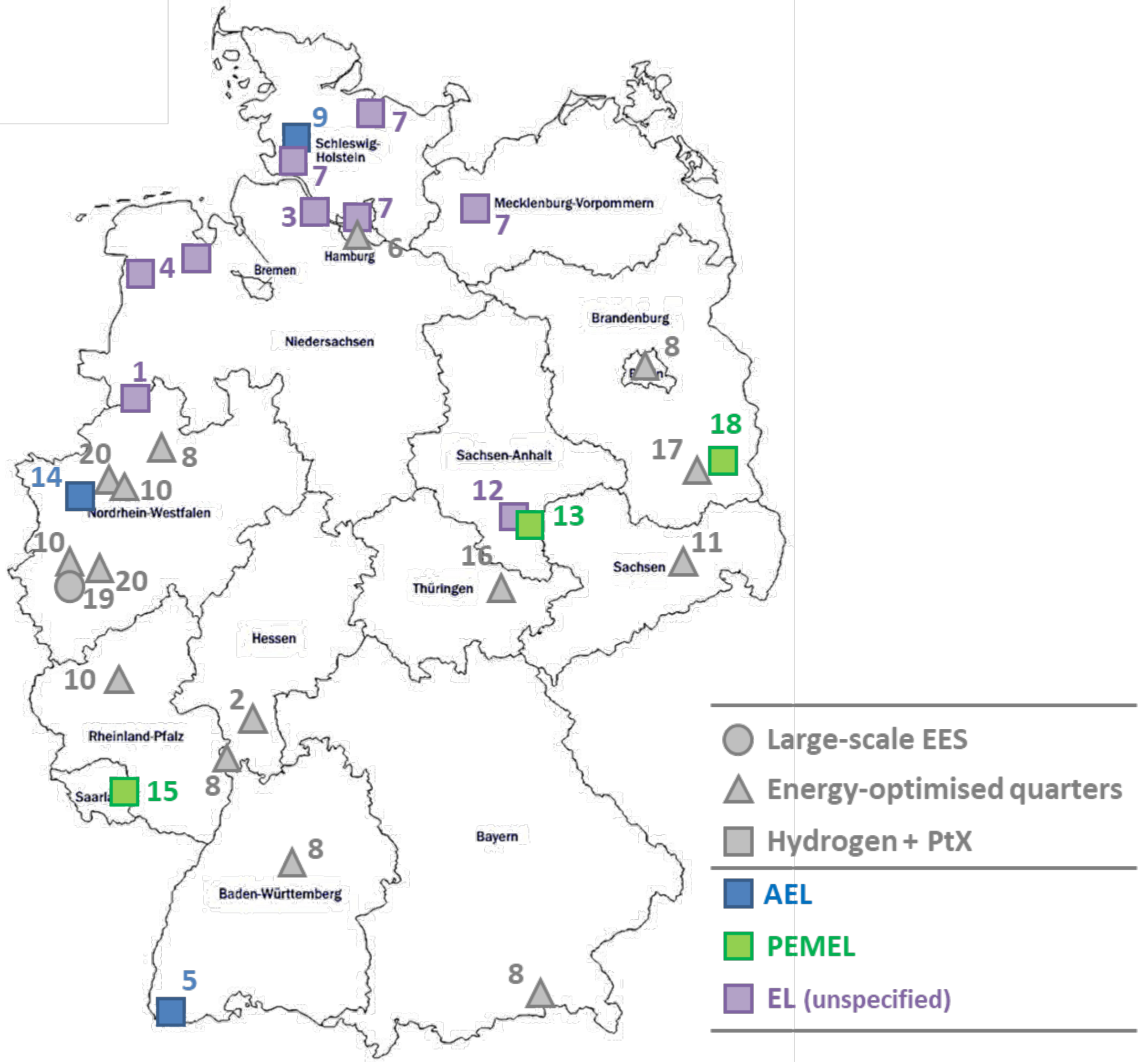
Future Trends in Power-to-X Applications in Germany

Next phase: “Real laboratories” of the energy transition are coming.

- Assessment of new technologies for the energy transition
  - under real conditions and on an industrial scale in a limited area
  - with own legal and regulatory framework for new business models
- Call of the Federal Ministry of Economics “Reallabore der Energiewende”
  - Hydrogen with low CO_2 footprint
  - Energy-optimised quarters
- Funding: 100 Mio €/a for 4 years
  - Additional 200 Mio € for region of structural change (coal phase-out)



Source: https://www.bmwi.de/Redaktion/DE/Downloads/P-R/reallabore-der-energiewende-karte.html

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Future Trends in Power-to-X Applications in Germany

Next phase: Real laboratories of the energy transition are coming.

	Acronym	PtX	CO2 source	Main applications	Electrolysis
1	CCU P2C Salzbergen	$PtCH_4$	CCU waste incineration	SNG injection	??
3	DOW Stade-Green MeOH	PtL	CCU GT power plant	MeOH	??
4	Element Eins	PtH	--	H2 injection	100 MW (wind)
5	H2 Wyhlen	PtH	--	H2 for trade + heat	10 MW AEL (hydro)
7	Norddt. Reallabor	$PtH + PtCH_4$	CCU refinery	SNG injection + H2 for mobility	77 MW
9	ReWest100	PtH + PtC	CCU cement plant	H2 (cavern/grid) for chemicals	30 MW AEL (wind)
12	EnergieparkBL	PtH	--	H2 (cavern/grid): mobility + chemicals	35 MW (wind)
13	GreenHydroChem	PtH	--	H2 for refinery	50 MW PEMEL
14	H2Stahl	PtH	--	H2 for steel	50 MW AEL
15	HydroHub Fenne	PtH	--	H2 for steel + injection + mobility + heat	17.5 MW PEMEL
18	RefLau	PtH	--	H2 for mobility + injection + trade	10 MW PEMEL

Source: https://www.bmwi-energiewende.de/EWD/Redaktion/Newsletter/2019/07/Meldung/topthema.html

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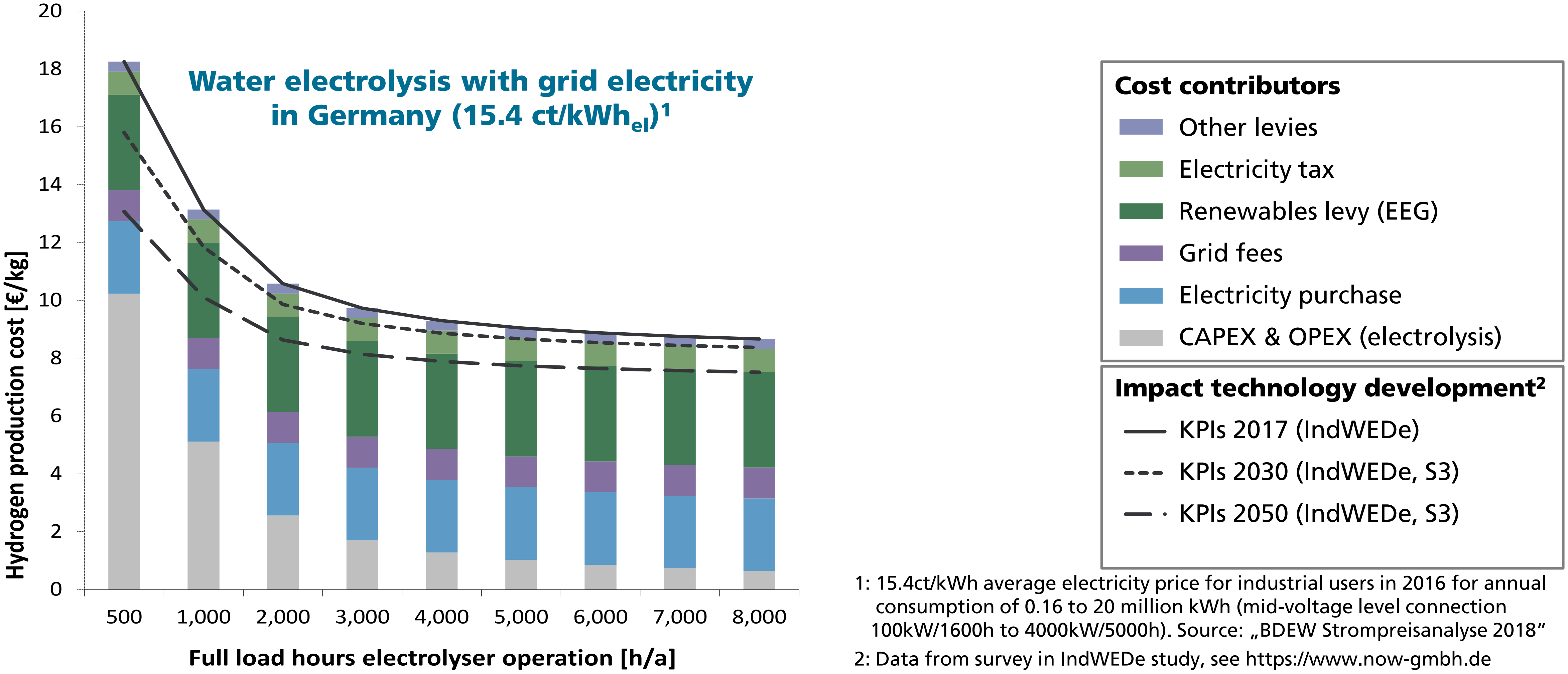
Main Drivers for Hydrogen Production Costs

Currently levies & taxes for electricity make hydrogen expensive in Germany.

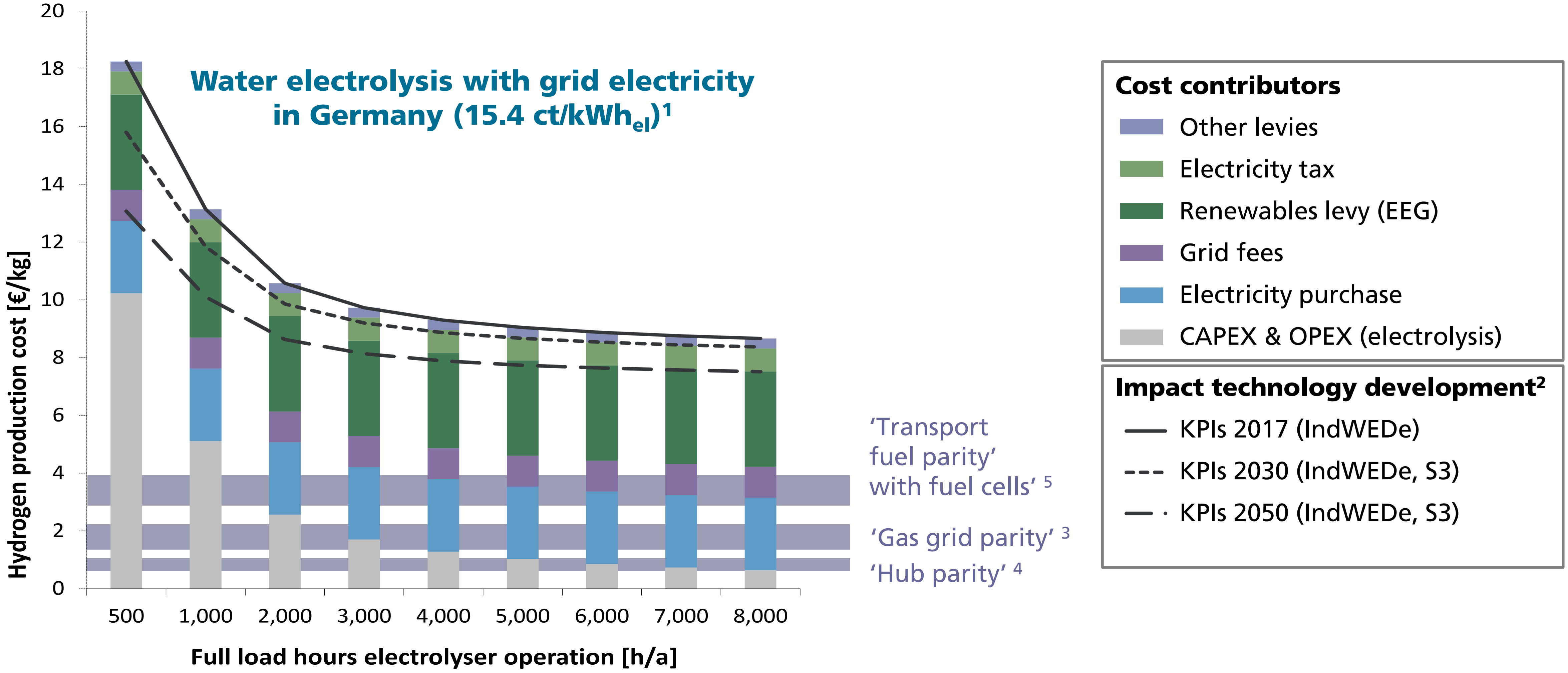


1: 15.4ct/kWh average electricity price for industrial users in 2016 for annual consumption of 0.16 to 20 million kWh (mid-voltage level connection 100kW/1600h to 4000kW/5000h). Source: „BDEW Strompreisanalyse 2018"

2: Data from survey in IndWEDe study, see https://www.now-gmbh.de

Main Drivers for Hydrogen Production Costs

Can 'green' hydrogen from RES achieve cost parity with fossil technologies?



3: 1.13 and 2.16 €/kg based on natural gas prices (2016) for residential customers in Germany 6.5 ct/kWh, large customers 3.4 ct/kWh (source: Eurostat)
4: 0.30 - 0.80 €/kg based on natural gas (Henry Hub 2017): 3 USD/MMBtu and Japan LNG cif: 8 USD/MMBtu (Source: BP)
5: Assumption: Competitive hydrogen prices at the nozzle 6 €/kg (diesel car 5 l/100km at 1,20 €/l, fuel cell car 1 kg H2/100km), 2-3 €/kg deducted for distribution and HRS costs. Prerequisite: Introduction of fuel cell vehicles and filling stations and continuation of the tax exemption for hydrogen as fuel.

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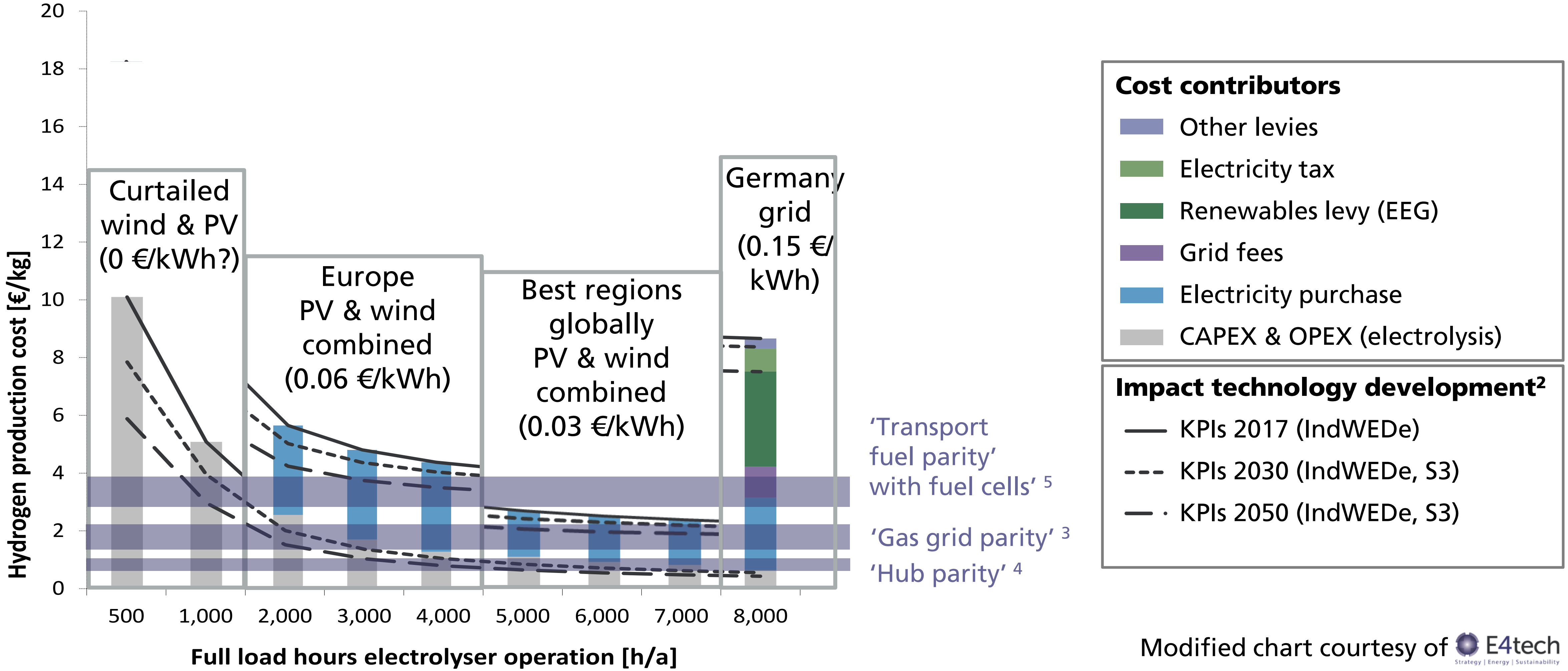

Modified chart courtesy of E4tech

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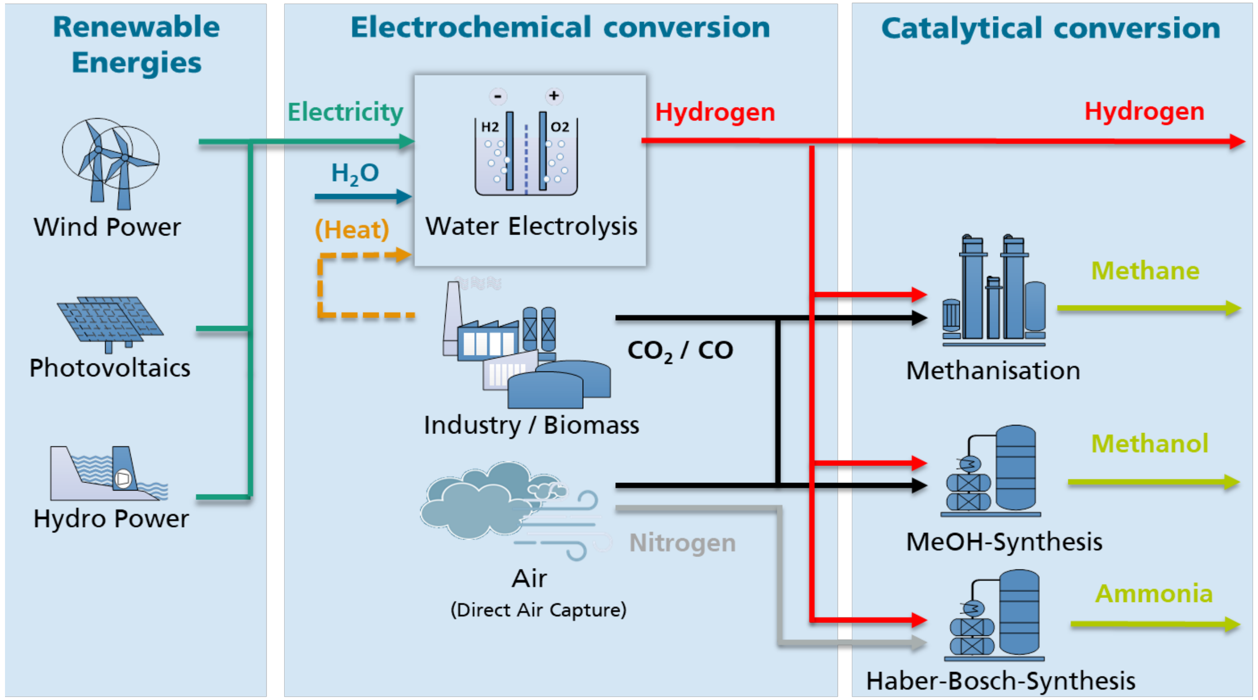
Evaluation of Business Opportunities for PtX Installations

Electrolysers have opportunities and market roles on both sides

Electrical market role

- Grid services
  - Control reserve
  - Prognosis error compensation
  - Cut of negative residual load
- Off-grid coupling with renewable energies



Gas market role

- Supply of green hydrogen for
  - Mobility
  - Industrial Feedstock
  - Heating
  - Power generation
- Reduction of CO_2 emissions

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Evaluation of Business Opportunities for PtX Plants

Tool box H_2ProSim developed @ Fraunhofer ISE

- Analysis and assessment of PtX business models
- Optimization of plant setup and design of components
- Prognosis of H_2 yield and LCOHy

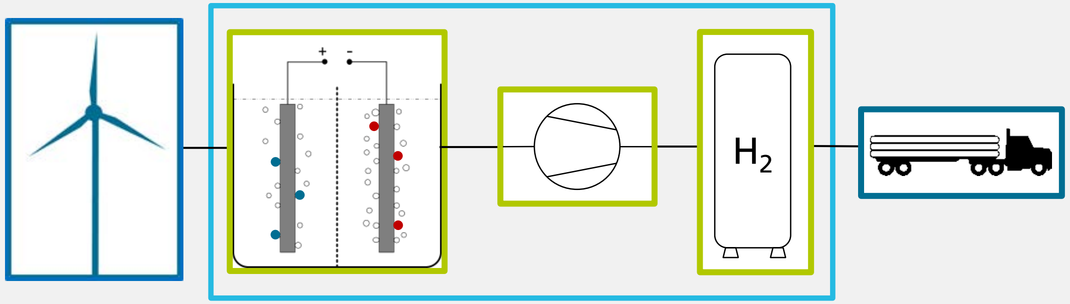
Operation strategy

Operation management

Dynamic modeling of relevant components

Hydrogen production costs

Optimization algorithm



$$LCOHy = \frac{Overall\ Costs}{H_2 - yield}$$

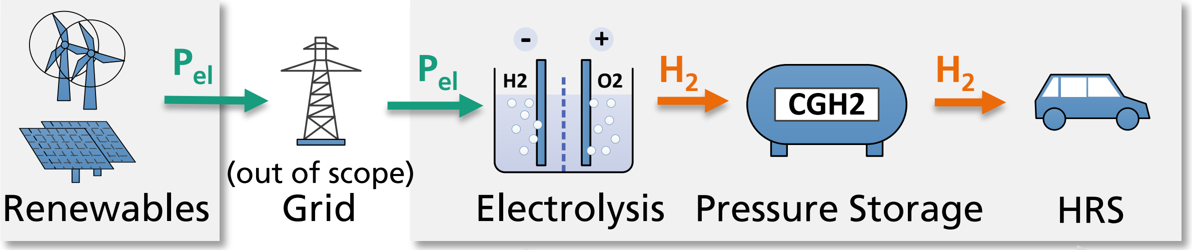
- Model needs input time series (e.g. for available renewable energies)
- Uses predefined physical correlations (can be adjusted for each project)
- Works by solving numerical equations of physical effects (mass and energy balances)
- Gives optimal setup und dimensions of the plant and its components

Evaluation of Business Opportunities for PtX Plants

Case Study 1: Grid connected onsite water electrolyser for HRS (2014)

Motivation / Business opportunity

- Grid-assistive electrolysis operation for a refueling station
- Continuous hydrogen supply for mobility
- Optimization goal:
  Minimise Levelised Costs of Hydrogen (LCOHy)

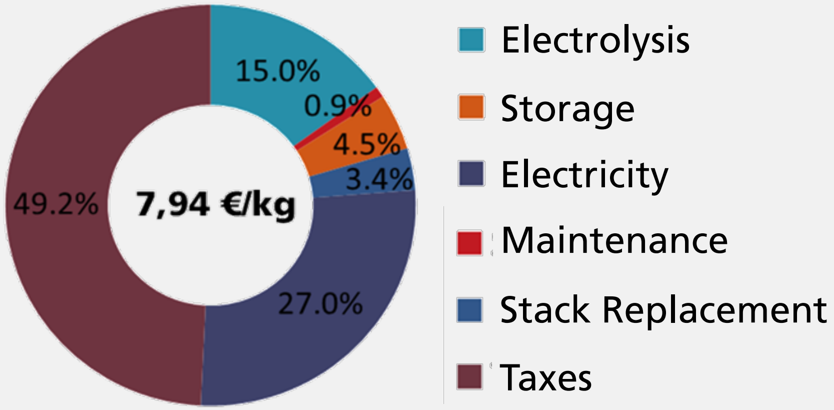


Input

Stack lifetime
40,000 h

H_2 demand
690 kg/d

LCOHy



Results

Electricity Costs
EC < 88 €/MWh
→ Electrolyser on full load

Install. Power
3.1 MW

Invest
1,061 €/kW

Size
52 Nm^3

- Additional costs for refueling station: 1.5 €/k
- To date not cost competitive to grey hydrogen!

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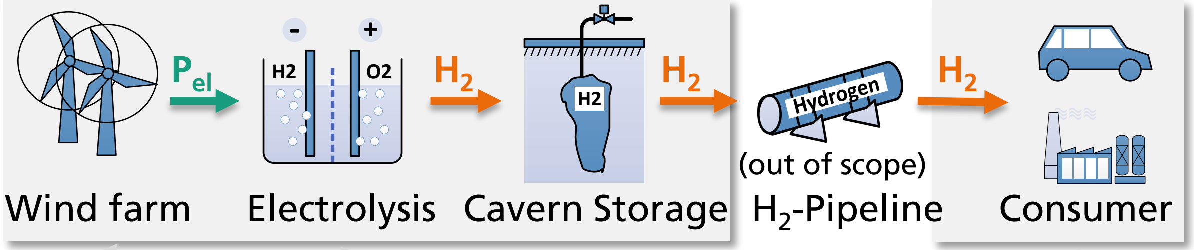
Evaluation of Business Opportunities for PtX Plants

Case Study 2: Large-scale offgrid electrolysis plant supplying a H_2 grid (2017)



Invest 968 €/kW	Stack Lifetime 40,000 h	H_2 Demand 43,8 kt/a

Results

Install. Power 970 MW	Install. Power 590 MW	Volume 530,000 Nm^3
	Invest 619 €/kW	Invest 54 million €

Total invest
1.4 bn €

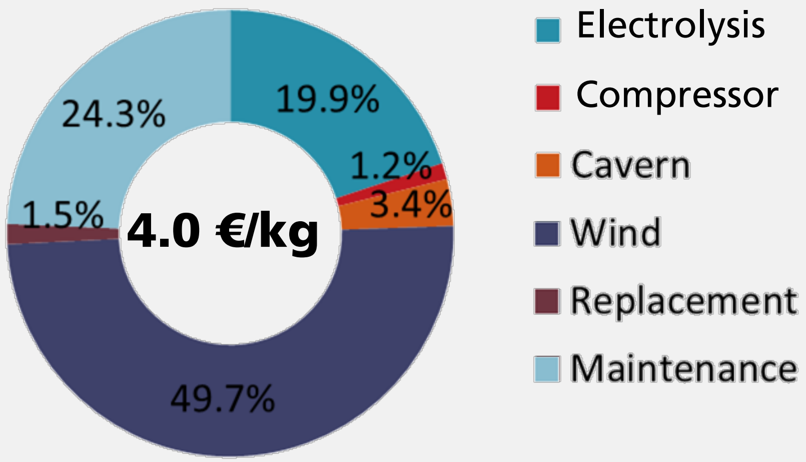
Date: 02/18
Scenario: EIMN17

- Cheap green H_2 production including seasonal storage already possible; but large investment!

Motivation / Business opportunity

- Green hydrogen as cheap as currently possible
- Seasonal hydrogen storage
- Optimisation goal:
  Minimize Levelised Costs of Hydrogen (LCOHy)

LCOHy



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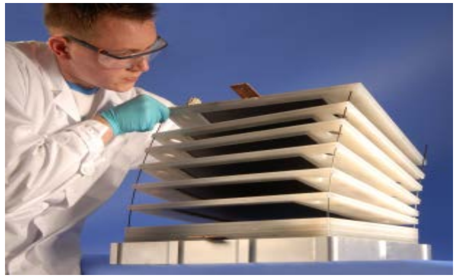
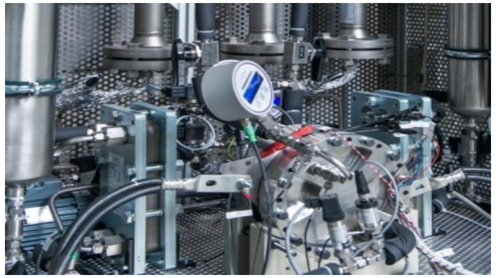
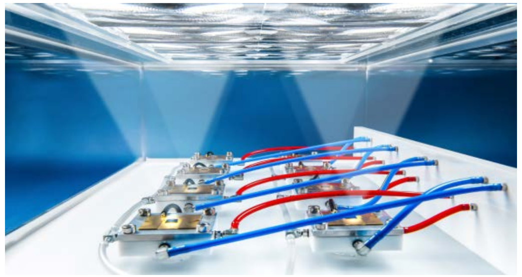
Summary and Conclusion

- Reduction in GHG emissions and reliable energy supply are main drivers for the German Energy Transition
- Most likely Germany will miss its own set GHG emission targets in 2020
  - most concern about transportation, industry and buildings
  - increased pressure to push intersectoral coupling to reach 2030 targets
- Water electrolysis and power to X technologies are key elements for intersectoral coupling
  - More than 35 PtX projects (in total 55 MW) are in operation or under construction in Germany
  - "Laboratories for the Energy Transition" will result in new installation with approx. 300 MW in the next years
  - Using of green hydrogen in industry (steel and feedstock) gains importance
- Levies & taxes for electricity make hydrogen expensive – not only in Germany
  - but 'green' hydrogen from RES can achieve cost parity with fossil technologies
- Water electrolysis for PtX have business opportunities either in the electricity or in the gas market
  - electrical market role is mostly chosen to fulfill requirements given by gas market role
  - no globally feasible business opportunities known yet – business cases always site/project specific

Thanks a lot for your kind attention!







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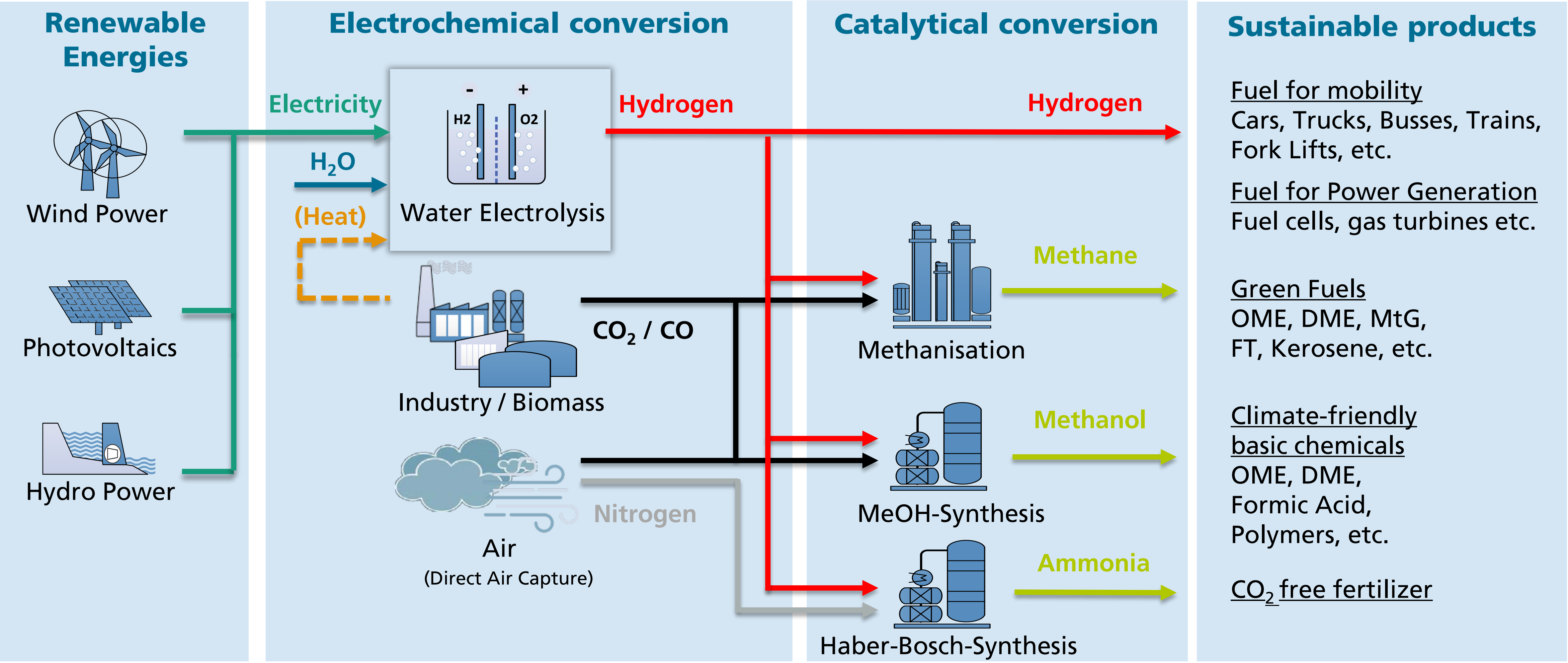
Current State on Power-to-X Applications in Germany

Intersectoral coupling is essential to reach CO_2 reduction goals



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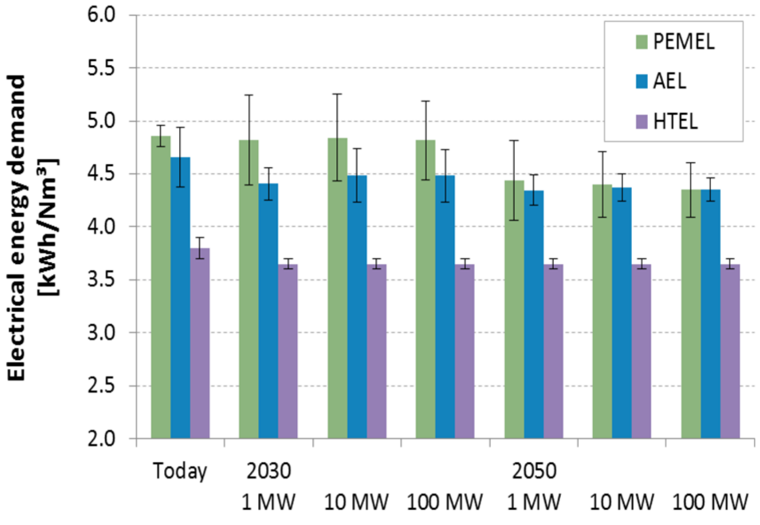
Future Trends in Power-to-X Applications in Germany

The technology is ready for use - but still has great potential for improvement.

- Development status and potential of water electrolysis according to stakeholder survey (IndWEDe study[1])

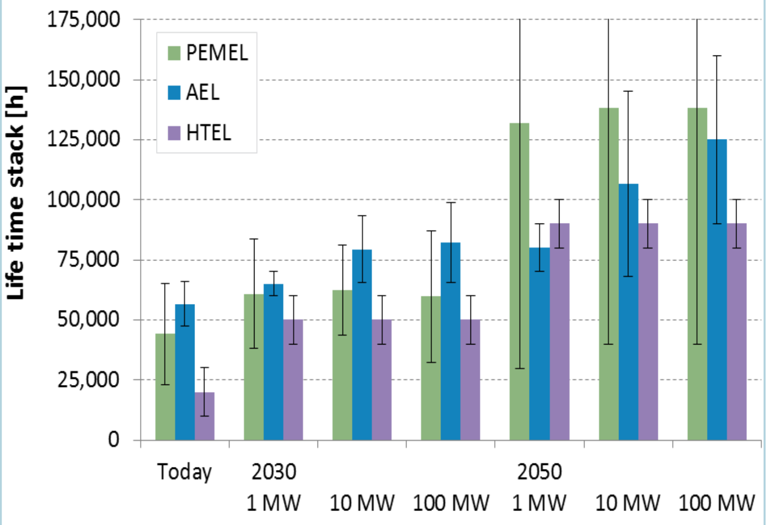
Electrical energy demand

- On the long term (2030/50) efficiency will increase only slightly.



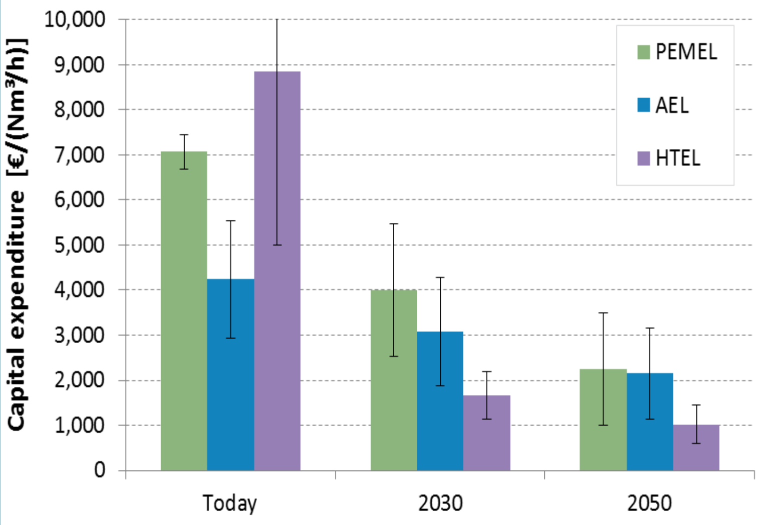
Life-time stack (technical)

- There is still a large potencial of improvement for all three technologies.



Investment costs

- Strong CAPEX reduction is feasib-le already today by economy of scale.



Black bars indicate the standard deviation.

1: https://www.now-gmbh.de/content/1-aktuelles/1-presse/20180917-aktuelle-studie-zeigt-wege-zur-industrialisierung-der-wasserelektrolyse/indwede-studie_v04.1.pdf

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