WHAT WILL BE THE COST OF RENEWABLE HYDROGEN TODAY AND IN THE FUTURE

Results of a Comprehensive Techno-Economic Simulation-Based Analysis of one Representative Power-to-Hydrogen Plant (D3.2)

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AGENDA

Techno-Economical Analysis of a Power-to-Hydrogen Plant:

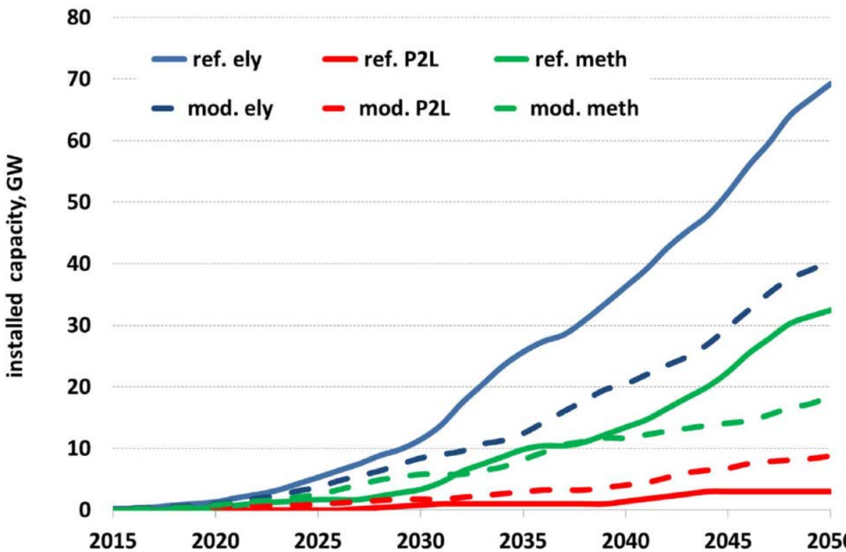
- Motivation for Power-to-Hydrogen
- Methodology – Our toolbox
- Results of a large scale Wind-H_2 plant
- Conclusion

Hydrogen Refuelling Station at Fraunhofer ISE in Freiburg

Motivation for Power-to-Hydrogen
Residual Load and Sector Coupling: "Push and Pull" for Renewable Hydrogen

"Push": "Excess electric energy" or residual load converted to hydrogen is a necessary measure for our future energy system

"Pull" / Sector Coupling: Green H_2 is needed to reduce CO_2-Emissions in other sectors.



H_2 generation capacity of future Energy System [1]

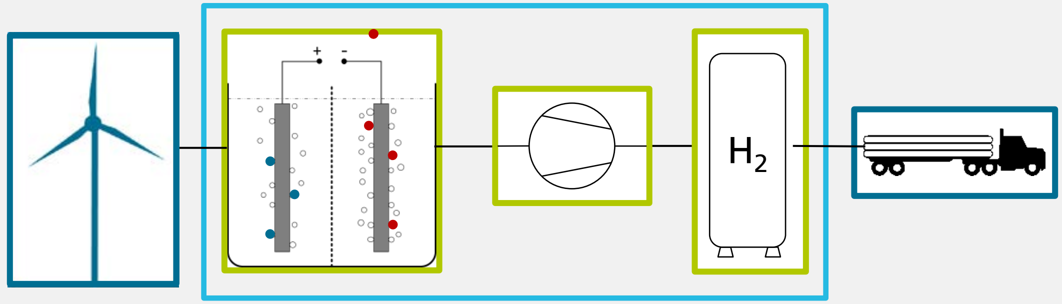
[1] Henning (IRES 2017): "Cross-Sectoral Storage Demand in Future Energy Systems"

Methodology for Techno-Economic Analysis

System-Simulations-Tool H2ProSim

H2ProSim

- Operation strategy
- Operation management
- Dynamic modeling of relevant components
- Hydrogen production costs
- Optimization algorithm



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

- Analysis and assessment of PtX-bussiness models
- Optimized design of plants and components
- Prognosis of H_2-yield und LCOHy

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established in 2012

Methodology for Techno-Economic Analysis
Hydrogen Production Costs

CAPEX
- Capital expenditure
- PEM-electrolysis-system, H_2-storage, wind- and/or PV-plants

Distribution Factor
- Distribution of reinvest costs (i.e. stack) over plant lifetime

$$RVF_1 = \frac{1}{(1+i)^r} * \frac{(1-i)^n * i}{(1+i)^n - 1}$$

Residual Value
- Distribution of residual value of some components over the plant life time (e.g. cavern)
- Assumed life time: 20 years

$$LCOHy = \frac{ANF \cdot CAPEX + OPEX_t + RVF_1 \cdot CAPEX_{Reinvest} - RVF_2 \cdot R_t}{m_{H2}}$$

Annuity Factor
- Conversion of CAPEX to annual payment incl. ROI

$$ANF = \frac{(1+i)^n * i}{(1+i)^n - 1}$$

Operational Costs
- Operation & Maintenance
- Costs of electric power (if connected to grid)
- Taxes and surcharges

Amount of H_2 Produced
- Amount produced per year
- Delivery obligation (demand has to be met 99% of time) considered via constraint

Methodology for Techno-Economic Analysis
Cost Model Hydrogen Plant

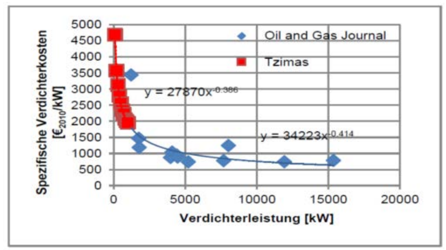
Approach

- Site specific costs like planning, risks, land (approx. 10 – 30% of overall costs[1]) were neglected
- Cost functions for major components
  - Literature
  - Expert information (projects)
  - Budget quotes
  - Electrolysis cost model
- OPEX as "% of CAPEX" of major components

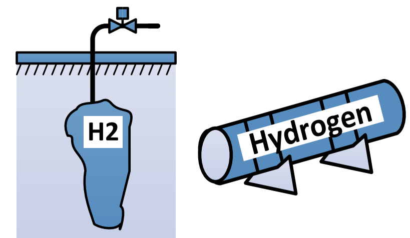
Result

- CAPEX and OPEX for H_2-plant

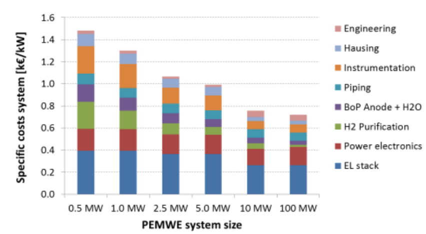
Literature



Expert information



Cost functions of major plant components



Electrolysis cost model

Budget quotes

[1] Compared to results from: G. Müller-Syring (2015): „Ergebnispräsentation zur Metastudie zur Untersuchung der Potenziale von Wasserstoff für die Integration von Verkehrs- und Energiewirtschaft"

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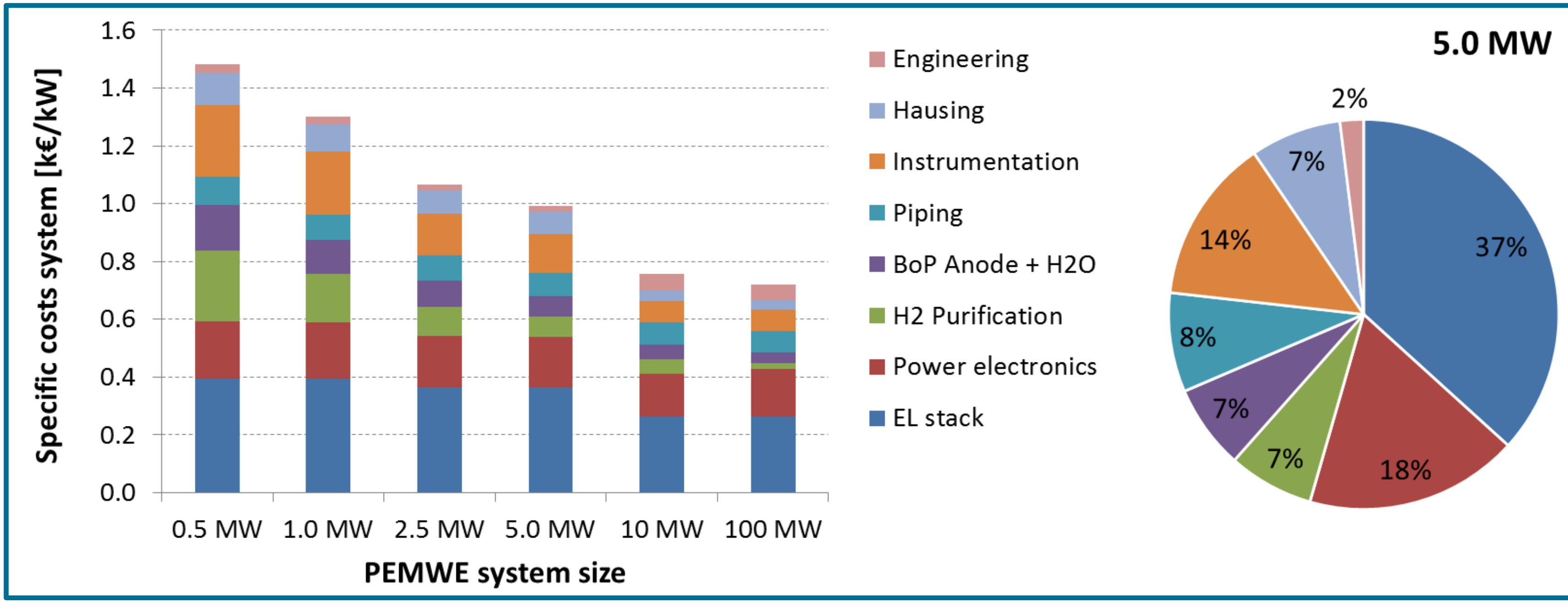
Methodology for Techno-Economic Analysis
Cost Model PEM Water Electrolysis 2015/2017



- Base of cost model: stack and system concept
- Component costs from: quotes, commercial planners, material & production costs
- Result: cost break down for state of the art stack technology (2015)
  - Extrapolation for huge plants, technology forecast for future scenarios

Smolinka et. Al.: „Cost Break Down and Cost Reduction Strategies for PEM Water Electrolysis Systems“ auf 6th EUROPEAN PEFC & Electrolyser Forum, Luzern, Juli 2017

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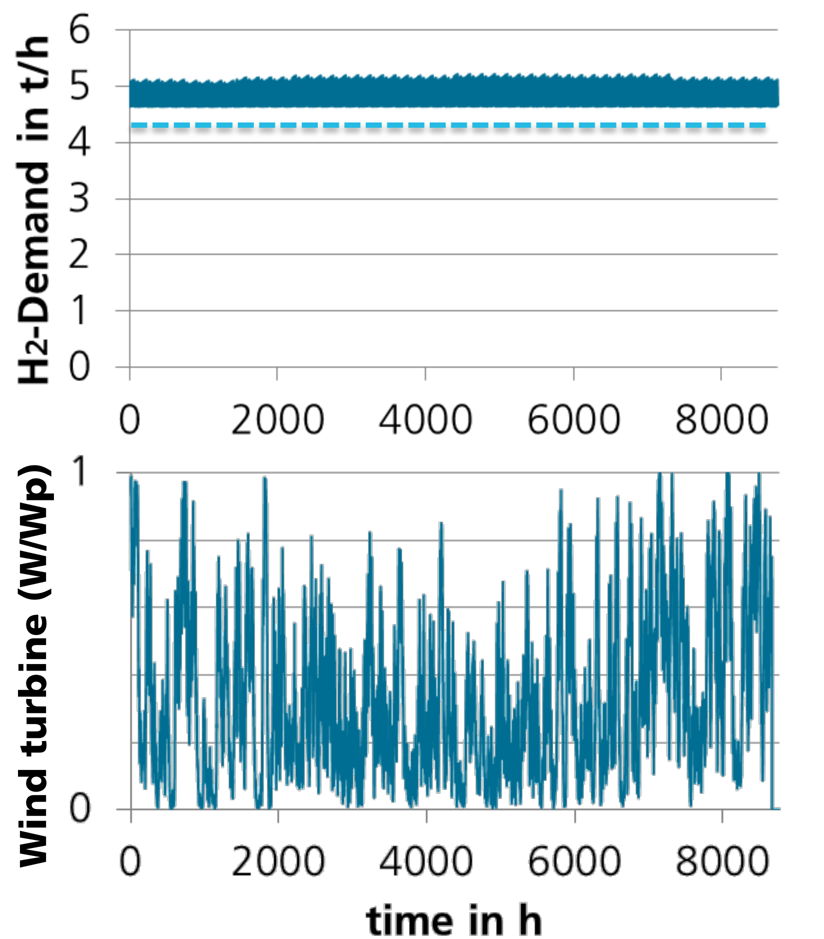
Scenario: Huge Water Electrolysis Supplying a H_2-Grid
Assumptions and Boundary Conditions

Objective: Huge water electrolysis supplying a large scale hydrogen grid

- Input
  - Synth. fuel demand profile + const. hydrogen demand of industry
  - Onshore wind turbine in East-Ger. (2 MW Turbines @ 2009)
- Deployment strategy:
  - Off-grid system – no connection to the electric grid
  - H_2-demand has to be met
- Optimization algorithm can change:
  - Size of electrolysis
  - Size of wind farm
  - Size of storage



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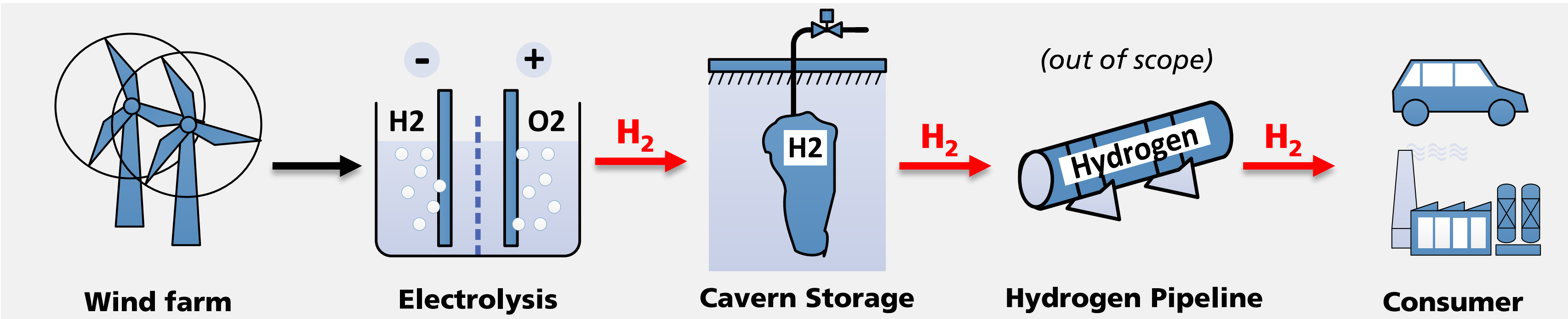
Scenario: Huge Water Electrolysis Supplying a H_2-Grid

The Resulting Plant

970 MW	590 MW	530,000 m³ (=4.6 kt H2)

Industry: 40 kt/a +
Mobility: 12,500 cars
(or 340 busses)



Wind farm	Electrolysis	Cavern Storage
968 €/kW	**619 €/kW**	**54 m€**
OPEX: 3,4 % of CAPEX (= 43 €/MWh)[1]	OPEX: 2 % of CAPEX	OPEX: 4 % of CAPEX
	Stack life time 40,000h	

Date: 02/18
Scenario: EIMN17

[1]Result of EEG wind tenders: 01.08.2017 - 1GW Wind for 4.28 ct/kWh

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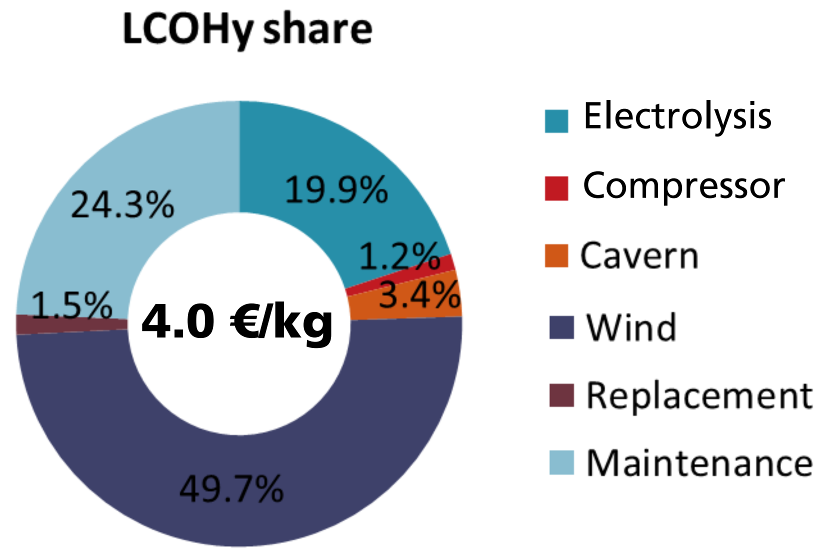
Scenario: Huge Water Electrolysis Supplying a H_2-Grid

Economics

- CAPEX: 1.4 bn. €
- Maintenance caused by wind farm (76%) and electrolysis (17%)
- Costs dominated by wind farm
- Seasonal energy storage for 4.6% of hydrogen costs (= 18 ct/kg or 0.54 ct/kWh_{LHV})
- Results for base year 2017. Improvement possible!



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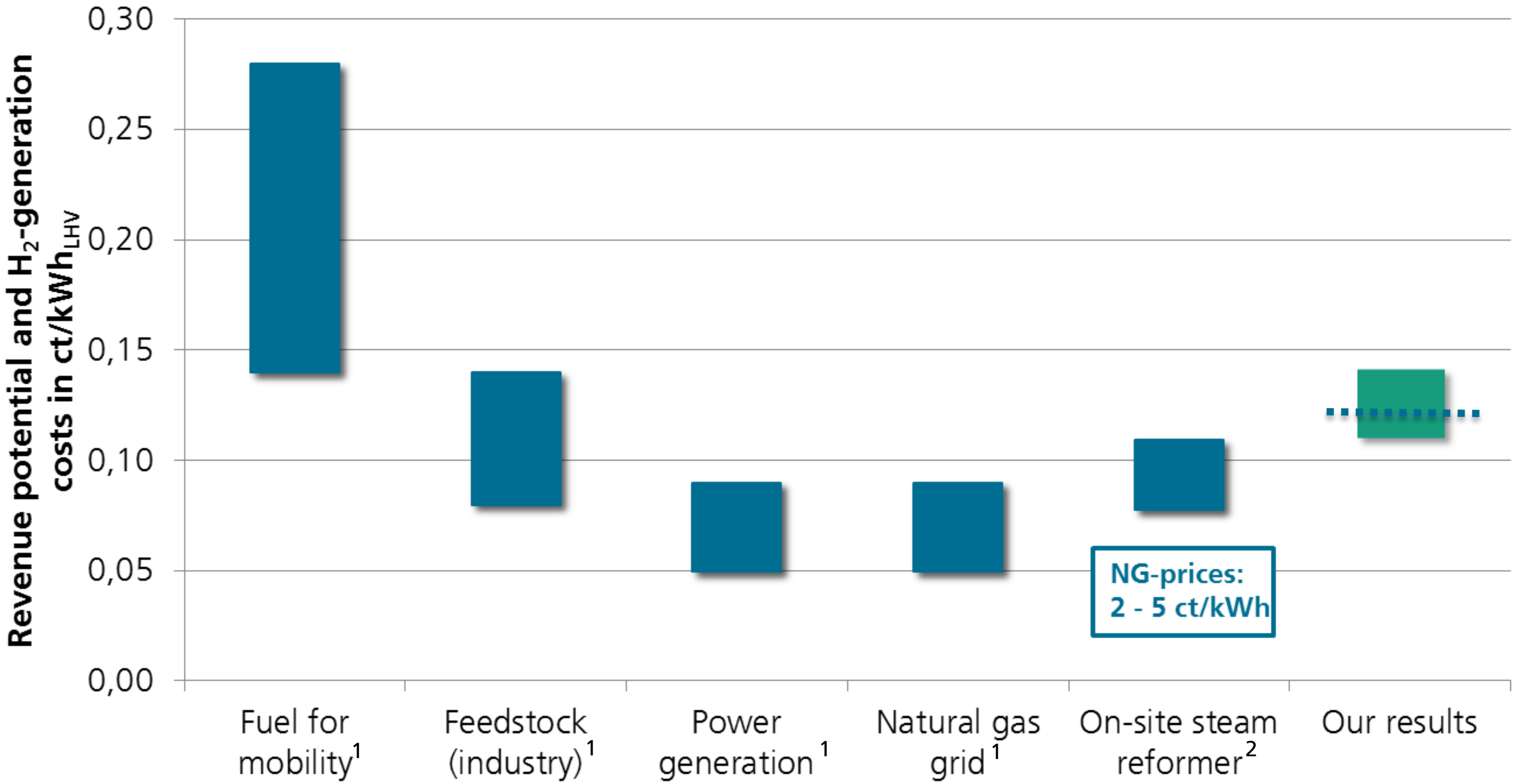
Scenario: Huge Water Electrolysis Supplying a H_2-Grid

Is this economically feasible? Depends on the Case



[1] Revenue potential @2030 according to Carolin Schenuit et al. (2016): „Potenzialatlas Power to Gas."

[2] production costs of hydrogen from steam reformer. Own calculations – methodology identical to LCOHy for wind-H_2-plant

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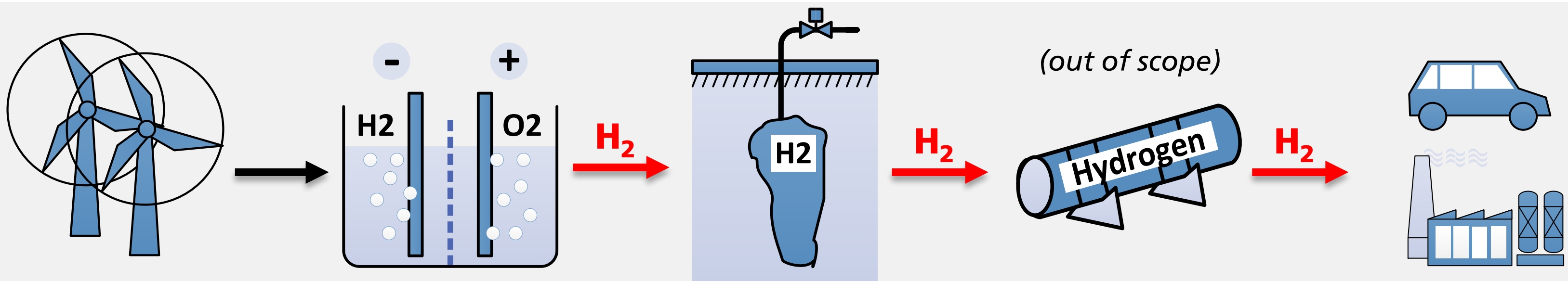
Scenario: Huge Water Electrolysis Supplying a H_2-Grid

The Same Plant in 2030

880 MW	590 MW	560,000 m³ (=4.9 kt H2)

Industry: 40 kt/a +
Mobility: 12,500 cars
(or 340 busses)



Wind farm | Electrolysis | Cavern Storage | Hydrogen Pipeline | Consumer

734 €/kW

OPEX: 3,4%
of CAPEX
(= 33 €/MWh)[1]

566 €/kW

OPEX: 2 %
of CAPEX

54 m€

OPEX: 4 %
of CAPEX

Stack life time
60,000h

2.9 €/kg

Date: 02/18
Scenario: EIMN17

[1] Further cost reduction of 24 % assumed.

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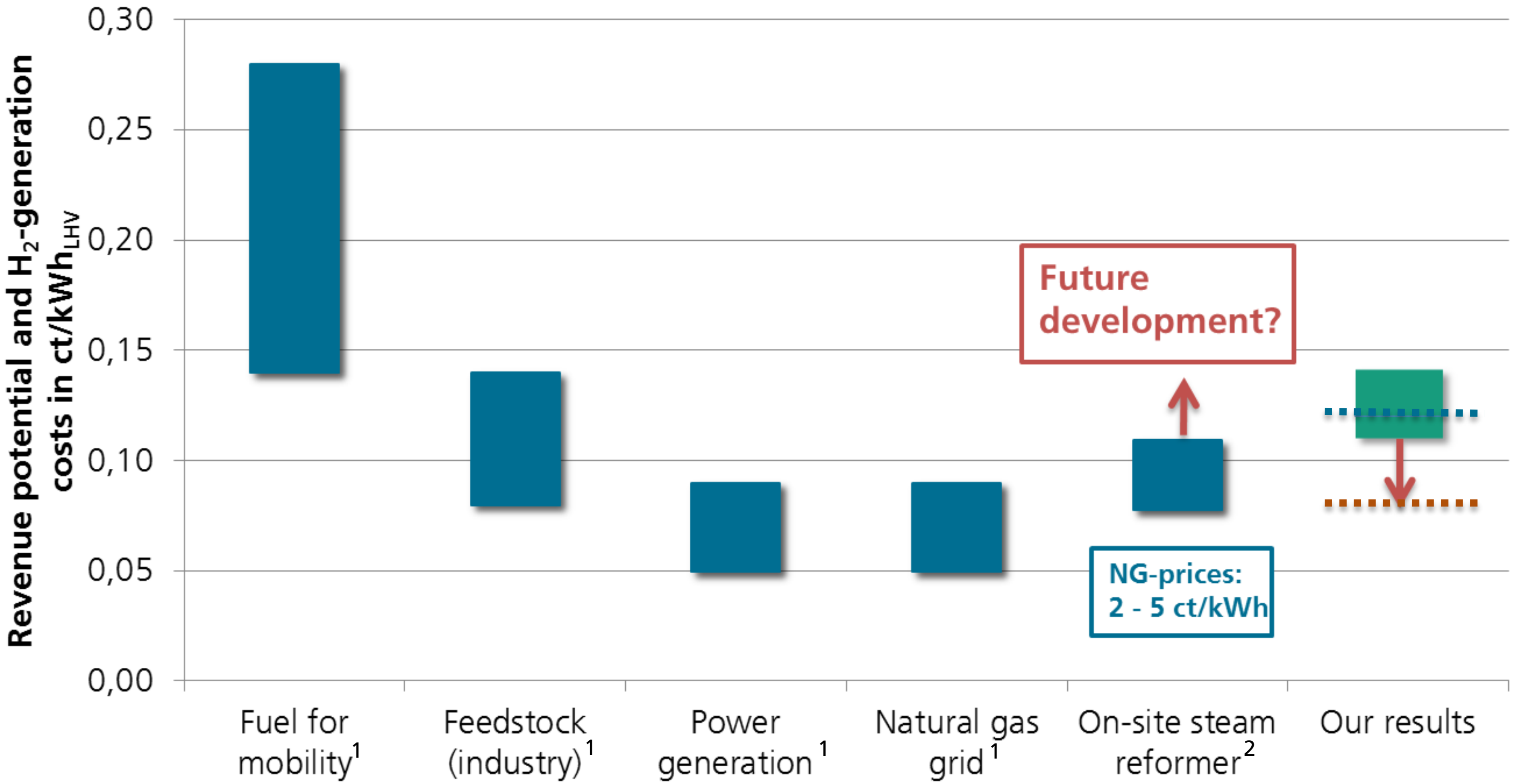
Scenario: Huge Water Electrolysis Supplying a H_2-Grid

Is this economically feasible in 2030?
Depends on cost development of wind and natural gas.



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Conclusion / Outlook

- We showed a potential setup for a **large scale hydrogen plant** that could produce **green hydrogen for 4 €/kg** (marginal costs) today
- We showed that **seasonal energy storage** with hydrogen and salt caverns is possible for **very small costs** (18 ct/kg or 0,54 ct/kWh$_{LHV}$)
- **Wind farm land demand** might be an issue in **densely populated countries**, going off-shore might help and might increase full load hours
- The **costs of hydrogen** are **strongly influenced** by the costs of the **wind farm**
- Results might **improve** with
  - use of heat and oxygen
  - technical optimization
  - technological progress

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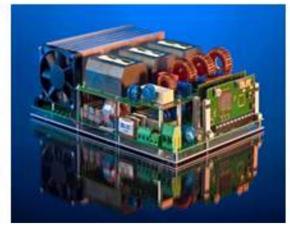
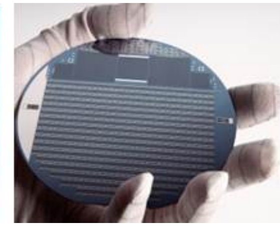


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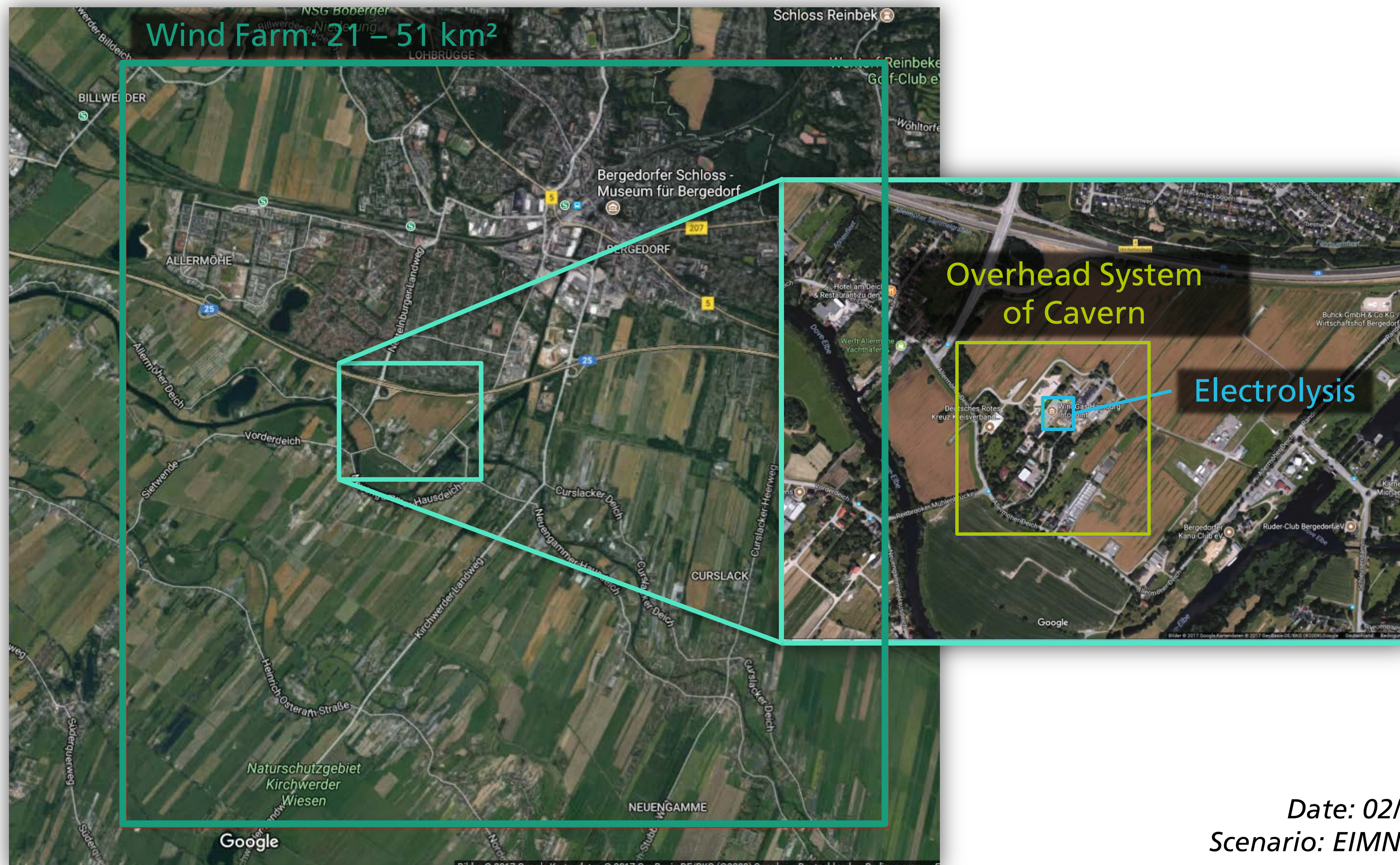
Scenario: Huge Water Electrolysis Supplying a H_2-Grid

Estimated Land Consumption



Date: 02/18
Scenario: EIMN17

Outskirts of Hamburg, Reitbrook (Germany)
Pictures © 2017 Google, map data © GeoBasis-DE/BKW (©2009), Google

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Scenario: Huge Water Electrolysis Supplying a H_2-Grid
Operation Profile of Plant

Date: 02/18
Scenario: EIMN17

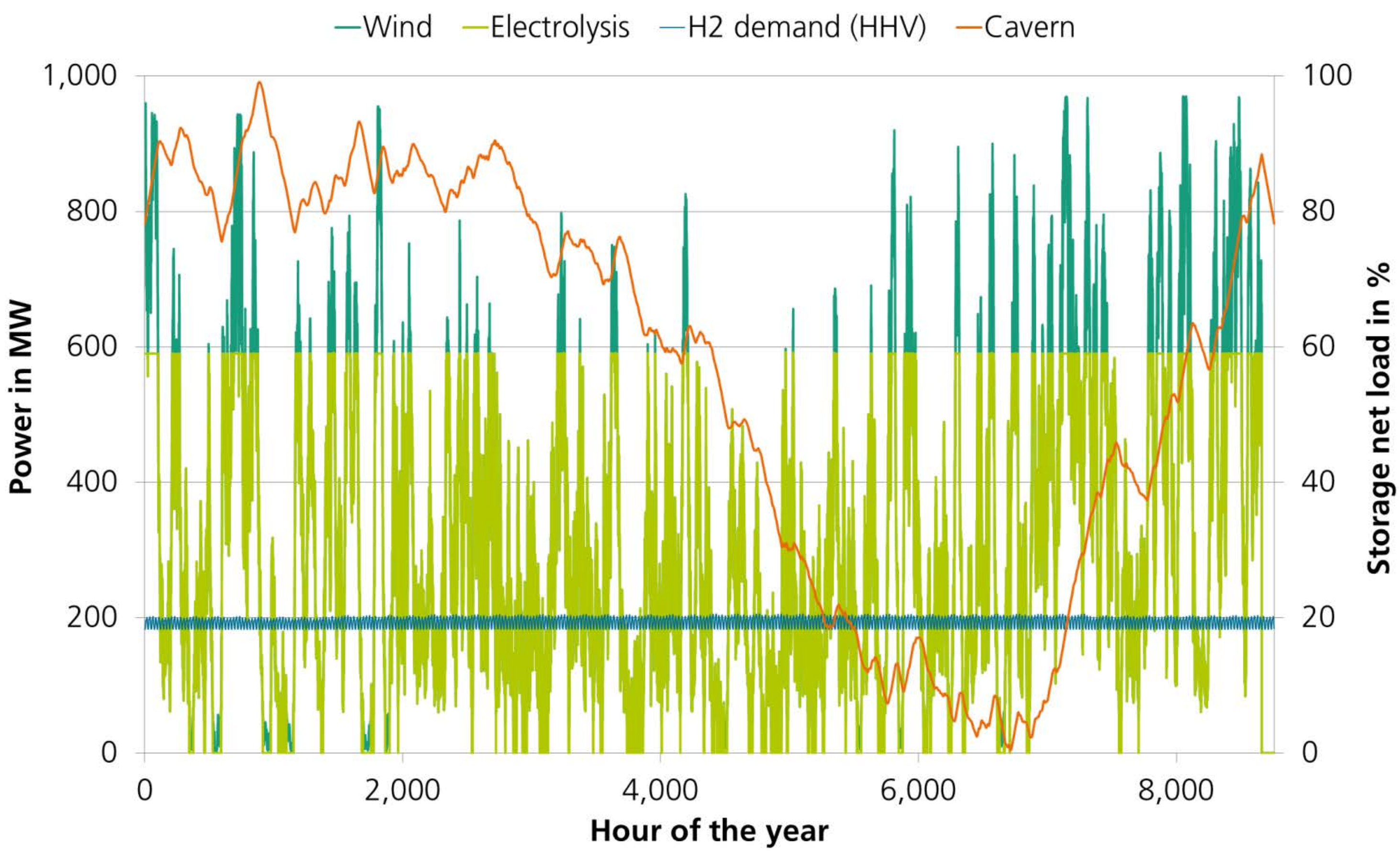
<u>Wind Farm</u>

6,7 % of energy curtailed

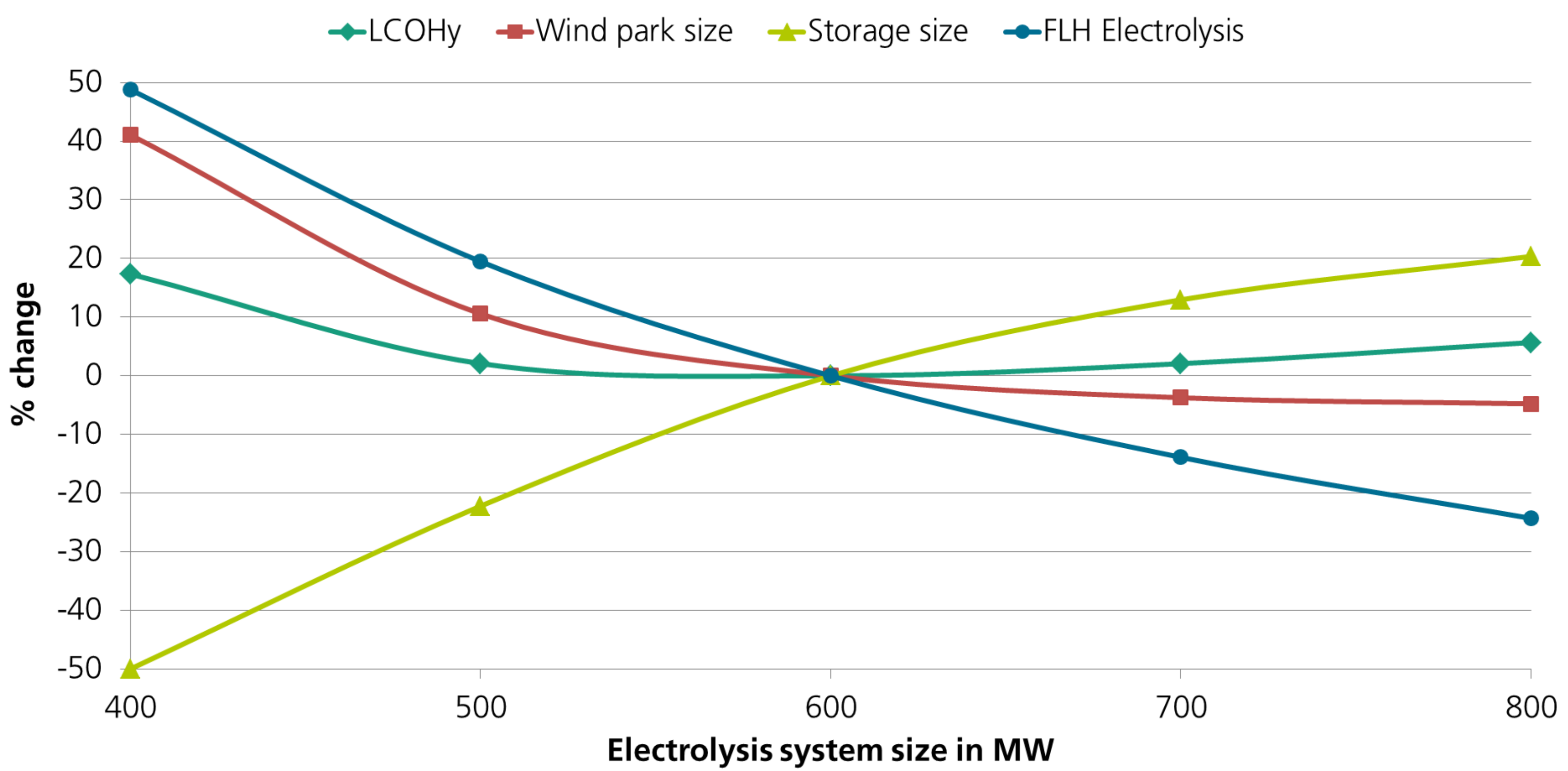
<u>Electrolysis</u>

4.286 FLH

7.752 OH



Scenario: Huge Water Electrolysis Supplying a H_2-Grid
Sensitivity-Analysis



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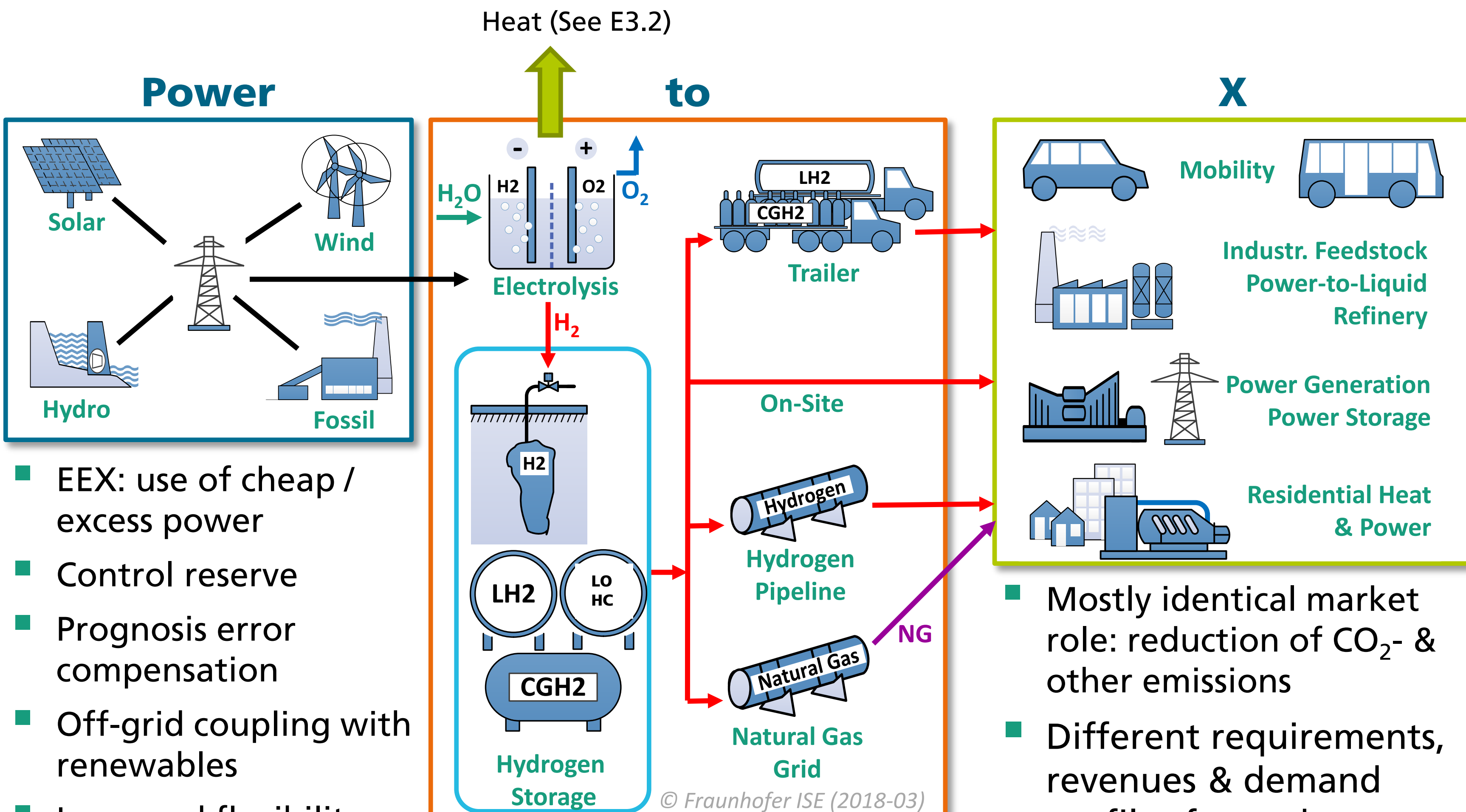
Overview on Business Models

PtHy Plant has Market-Roles on Both Sides



- EEX: use of cheap / excess power
- Control reserve
- Prognosis error compensation
- Off-grid coupling with renewables
- Increased flexibility

- Mostly identical market role: reduction of CO_2- & other emissions
- Different requirements, revenues & demand profiles for each case

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