Techno-Economic Analysis of Large Wind-Hydrogen Plants in Germany – A Preview of Results –

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Structure of the Presentation

1. Scope of work
2. Techno-economic parameters
3. Generating revenue in two market segments
4. Results: Is cost-covering operation of a large wind-hydrogen system feasible?
5. Discussion, conclusions and outlook

1. The Project

- **Start: August 2011, public presentation: January 2013**
  Budget 220.000 €
- **Contractors:**

PLANET GbR · fachhochschule lübeck PROJEKT-GMBH · Fraunhofer ISI · IFEU Institut für Energie und Umwelt e.V. · KBB UNDERGROUND TECHNOLOGIES

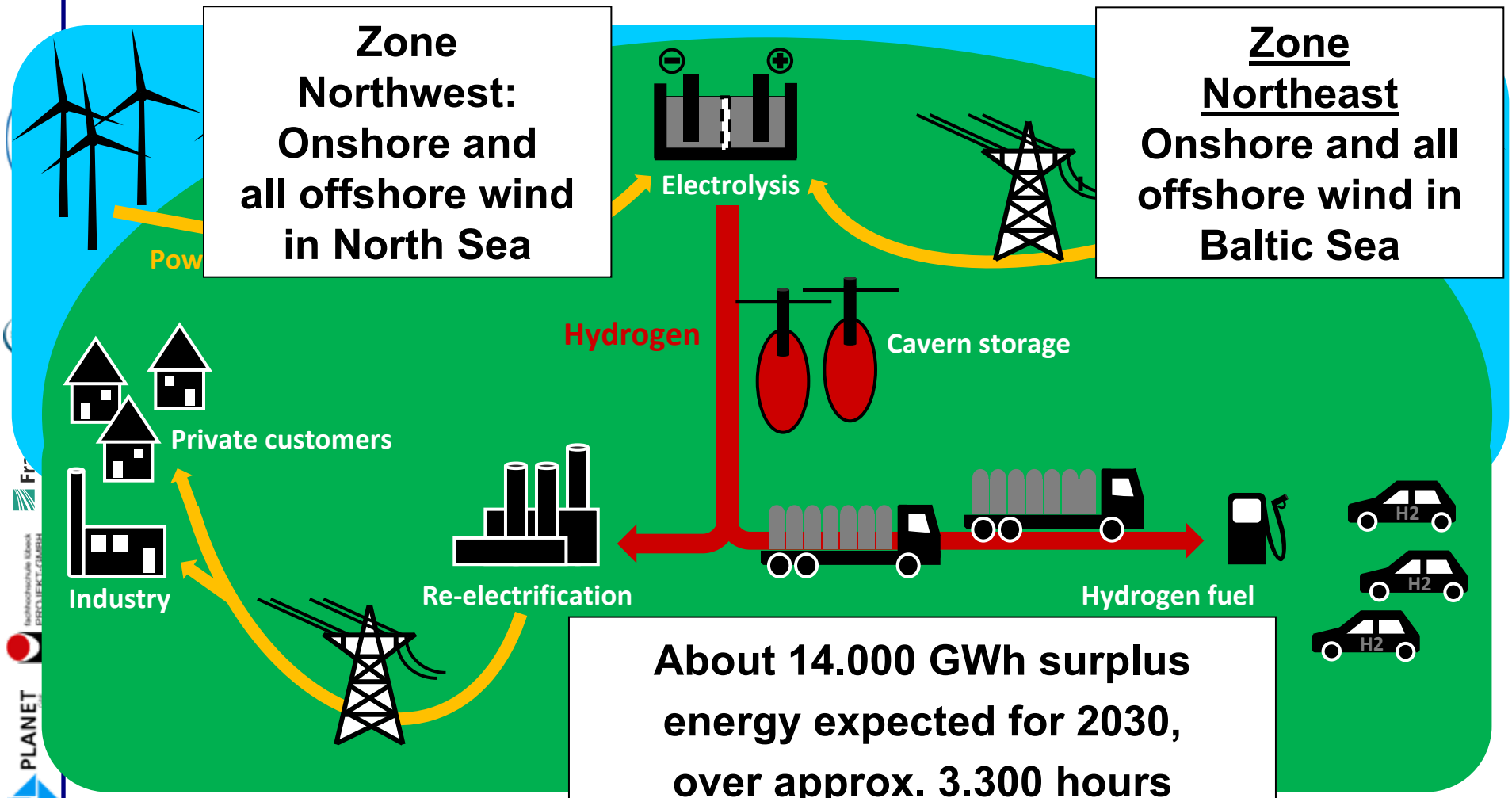
- **Commissioned by:** NOW Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie
- **Advisory committee of eight companies**
  (car manufacturer, electricity producers / grid operators, industrial gases supplier and wind farm developer/operator)

1. Key Objective of the Study

Establish the conditions that facilitate an economically viable operation of wind-hydrogen plants in 2030

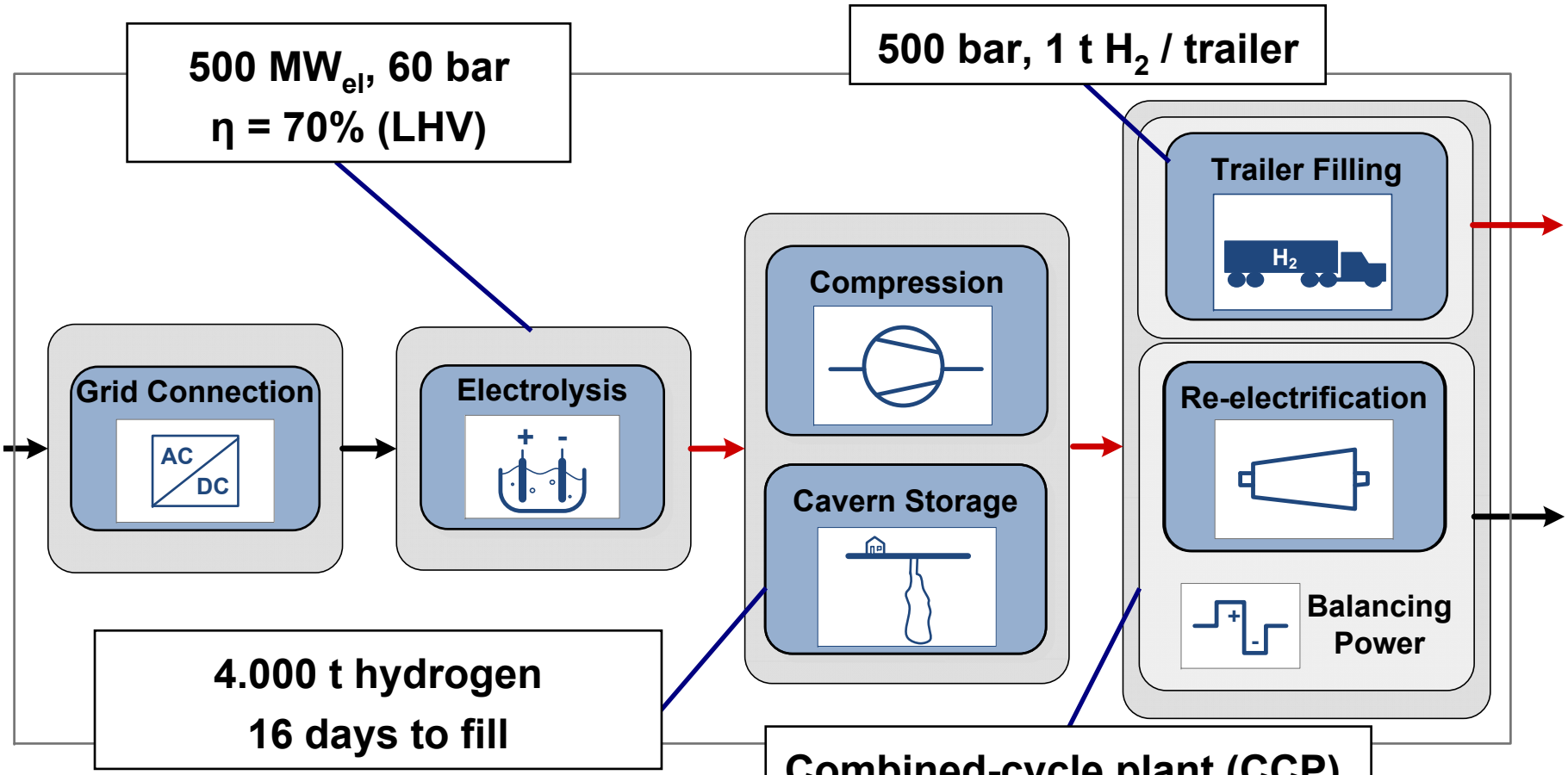
- **Concentrating on surplus electricity in the transportation grid and on longer-term hydrogen storage**
- **Focussing on two market segments for selling hydrogen**
  - **Hydrogen as a fuel for road vehicles**
  - **Re-electrification**
- **Identifying synergies that arise from serving these markets**

1. Utilise Surplus Wind Energy via Hydrogen



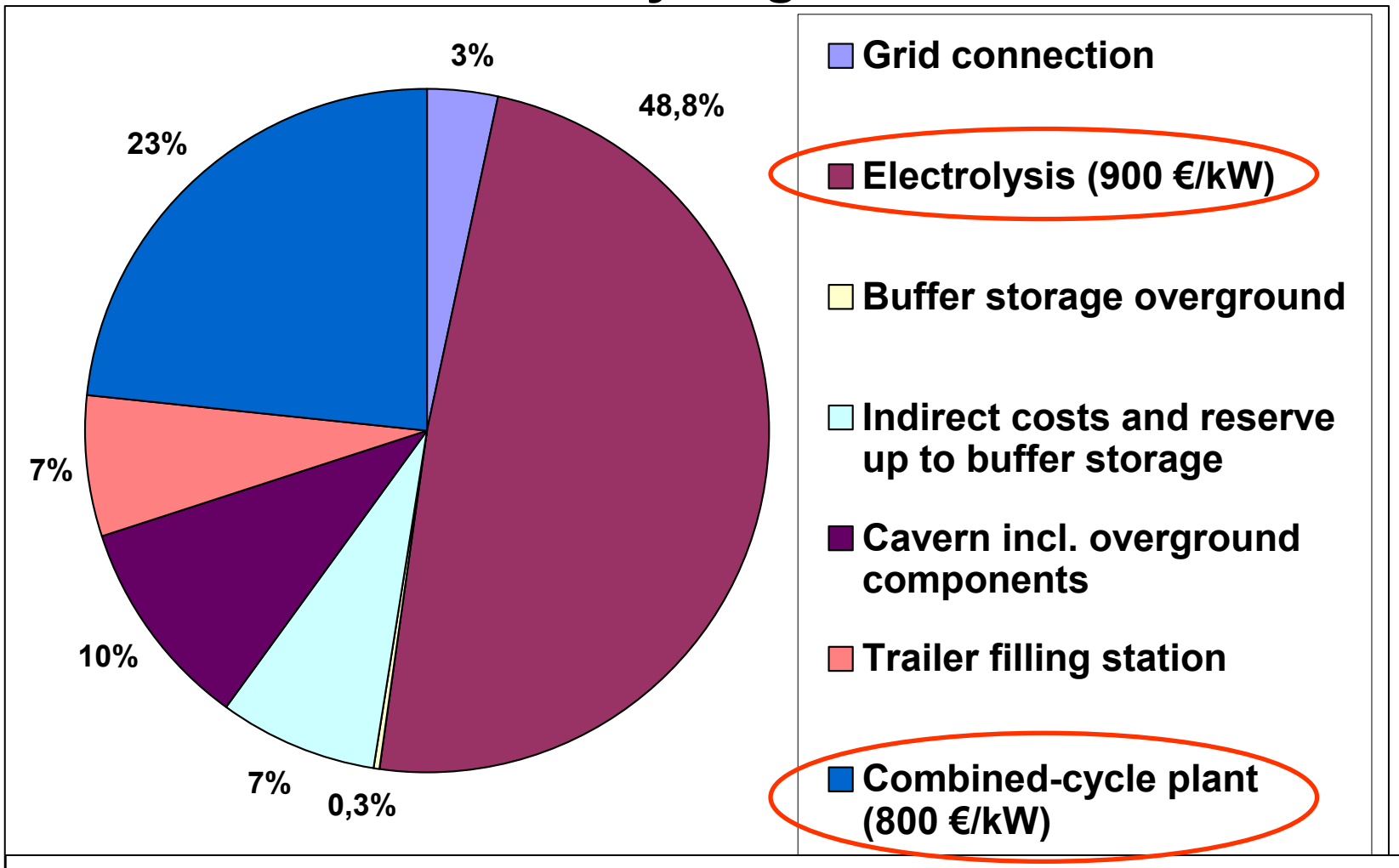
Preview of Results

2. Build a 500 MW Wind-Hydrogen Plant



Preview of

2. Investment for Wind-Hydrogen Plant: 923 million €



- Conservative assumptions regarding specific investment
- Annuity at 8% internal rate of return; depreciation 30 years (CCP 20 yrs.)

2. Costs / 1

- **Fixed costs** — about 110 million €/a
  - Annuity — approx. 85 million €/a
  - Annual fix expenses O&M — approx. 25 million €/a
- **Variable costs**: Focus on electricity for electrolysis
  - Buy on spot market, [for the moment] only during periods of surplus power
    → Cost is 0 €/MWh_{el} as a results of markets mechanisms (negative prices were prohibited in the model)
  - Wind farm operator remunerated in advance, in line with the German feed-in tariff system
  - Exemption from grid charges and any taxes assumed

2. Costs / 2

<u>However</u>:

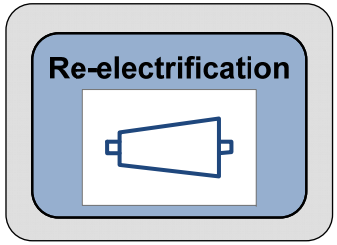
- **0 €/MWh$_{el}$ may be not be realistic (all the time)**

  → Study effects of higher power prices:

  - **40 €/MWh$_{el}$ → 61 million € per year**
    → variable costs about half of the fixed costs
  - **80 €/MWh$_{el}$ → variable costs about equal with the fixed costs**

  assuming about 32.000 tonnes H_2 produced during some 3.000 full load hours of electrolysis operation

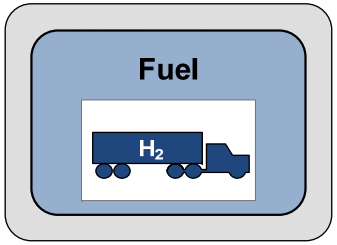
3. Generating Revenue / 1



Spot market

- Simulation model considers demand, conventional and renewable generation, storage capacities and markets
- Market mechanisms as in place today
  (Offer → merit order → offer accepted or rejected)

3. Generating Revenue / 2



Fuel market

- Constant fuel demand over the year can be assumed
- Target price at the dispenser: 10 €/kg H_2
  to be competitive with conventional fuels in terms of €/km
- Based on 10,00 €/kg
  - ➢ 19% VAT (fuel tax exemption assumed) -1,60 €/kg
  - ➢ Costs for trailer transportation (300 km) and storage/handling at the retail station -2,43 €/kg

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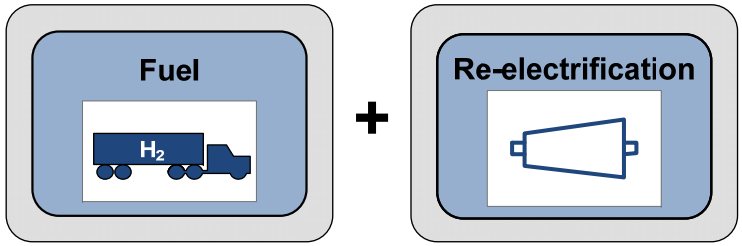
→ Specific revenue of (about) 6 €/kg H_2 is feasible 5,97 €/kg

3. Generating Revenue / 3



Optimisation

Maximise the economic performance of the wind-hydrogen plant by employing "perfect foresight" algorithms

Decisive point in terms of economic viability:

Does the Required Specific Revenue for hydrogen fuel remain below 6 €/kg, so that costs can be covered?

4. Results for Zone Northeast / 1

Operating strategy	Electrolysis	Surplus driven	
	Fuel Marketing	Fix, 56 tpd	Band, 63 - 105 tpd
Number of electrolysis full load hours		3.052	3.052
Amount of hydrogen generated (tonnes per year)		32.044	32.044
Hydrogen share used for re-electrification		38%	7%
		Required Specific Revenue to break even [€/kg H_2 fuel]	
Electricity price for electrolysis €/MWh	Spot market price (0 €/MWh during surplus)	3,71	2,92
	40 €/MWh	6,80	5,00
	80 €/MWh	9,90	7,08

Plant is economically viable at up to 30 €/MWh (Fix) and 60 €/MWh (Band) for electricity

tpd = tonnes per day

Preview of Results

4. Results for Zone Northeast / 2

Operating strategy	Electrolysis	Surplus driven		Price driven
	Fuel Marketing	Fix, 56 tpd	Band, 63 - 105 tpd	
Number of electrolysis full load hours		3.052	3.052	
Amount of hydrogen generated (tonnes per year)		32.044	32.044	
Hydrogen share used for re-electrification		38%	7%	
		Required Specific Revenue to break even [€/kg H_2 fuel]		
Electricity price for electrolysis €/MWh	Spot market price (0 €/MWh during surplus)	3,71	2,92	
	40 €/MWh	6,80	5,00	
	80 €/MWh	9,90	7,08	

Buy additional cheap electricity outside surplus periods if this improves the economic outcome, with the drawback of a non-renewable share in the hydrogen portfolio

Preview of Results

4. Results for Zone Northeast / 2

Operating strategy	Electrolysis	Surplus driven		Price driven
	Fuel Marketing	Fix, 56 tpd	Band, 63 - 105 tpd	Band, 42 - 70 tpd
Number of electrolysis full load hours		3.052	3.052	4.905
Amount of hydrogen generated (tonnes per year)		32.044	32.044	51.504
Hydrogen share used for re-electrification		38%	7%	51%
		Required Specific Revenue to break even [€/kg H_2 fuel]		
El fo	e plus)	3,71	2,92	2,71
		6,80	5,00	
		9,90	7,08	

Less fuel sold (29.800 t → 25.200 t), even though the Required Spec. Revenue has reduced → Synergy / 2 Markets

Preview of Results

5. Summary and Discussion

- For 2030, substantial amounts of surplus wind power in the German transportation grid must be expected over long periods.
- This is an opportunity for energy storage by means of hydrogen.
- The study establishes for the first time at a high level of detail:
  - The quantity and temporal distribution of surplus energy
  - The costs of hydrogen generation and storage at large scale
  - The potential to market this hydrogen
- There were many assumptions required and many variables to consider.
  → Results for “go / no-go” decisions cannot be provided.

5. Conclusions

- **<u>Decisive</u>: For surplus-driven operation of electrolysis – which is the basic idea of wind-hydrogen systems – there is a generally positive economic perspective, a firm "corridor of cost recovery".**
- **In particular: Power for electrolysis is required at favourable conditions but does not have to come "for free".**
- **Wind-hydrogen for mobility will be affordable and will be more profitable than stationary use.**
- **On the other hand, operating in very different market segments, fuel and power, supports acting flexibly and facilitates synergies.**
- **Flexibility in operation improves the economic situation.**

5. Outlook

- **A "snapshot 2030" has been presented. Depreciation over 30 years means operation up to 2060 (at least).**
  - **During the lifetime of the plant, due to the further expansion of wind energy past 2030, the economic conditions can be expected to develop favourably (as indicated by figures for the "price driven" strategy / higher capacity factor of electrolysis operation).**
- **Systems to be operational in 2030 must be planned and implemented from 2022, the decisive factor being the storage cavern.**
- **Before that, focussed research and demonstration activities are required for almost all components and at the system level.**

Thank you for your attention!

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