USES OF HYDROGEN FOR ENERGY AND FUEL

Insights from the European perspective

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For: CSG Midwest / German Ministry of Foreign Affairs

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Webinar

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AGENDA

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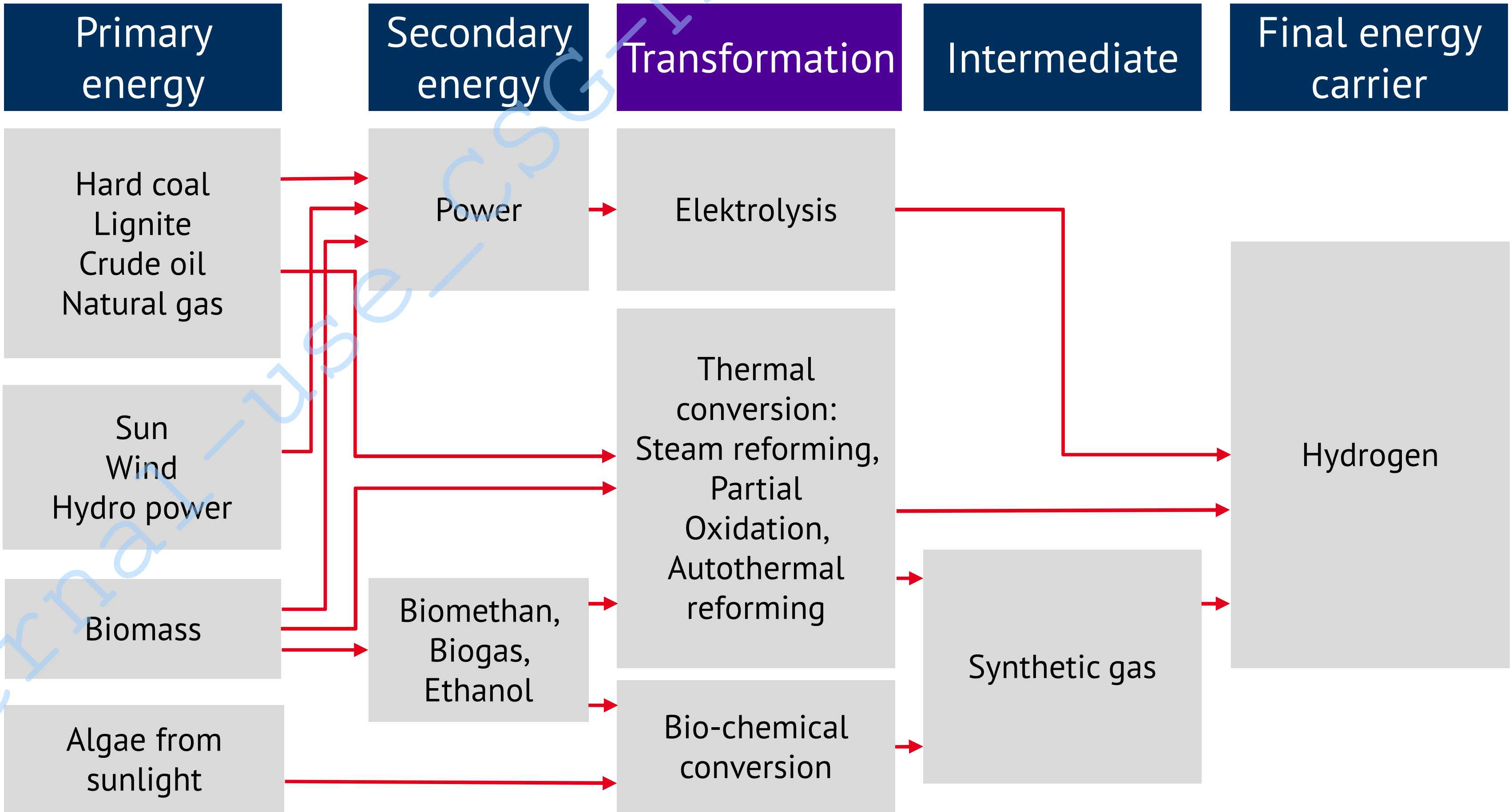
ENERGY TRANSFORMATION CHAIN FOR HYDROGEN



Quelle: Shell/Wuppertal Institut

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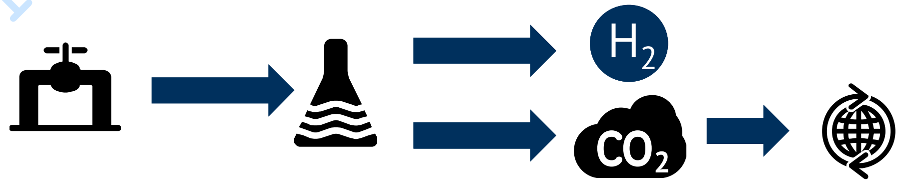
THE COLOURFUL WORLD OF HYDROGEN

Grey hydrogen

Produced from natural gas through methan reforming, CO_2 emissions to the atmosphere

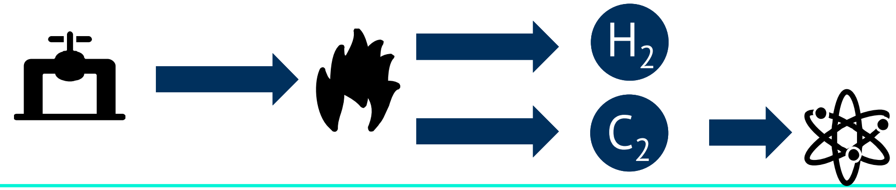


Blue hydrogen

Produced from natural gas through methan reforming, CO_2 emissions captured and sequestred

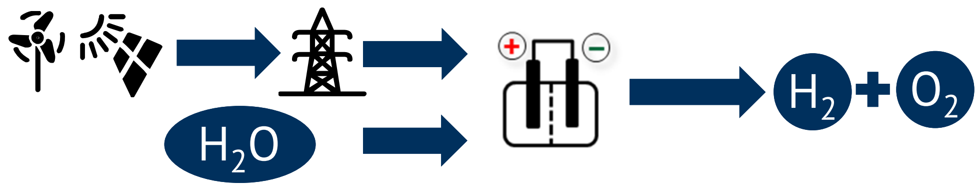
Turquoise hydrogen

Produced from natural gas through methan pyrolysis, solid carbon produced as a by-product, no CO_2 emissions



Green hydrogen

Produced from electric power and water through electrolysis, power from renewable energy sources



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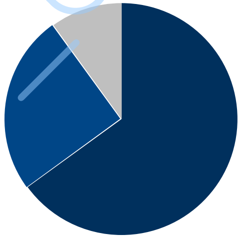
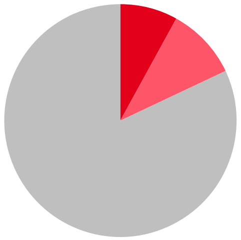
CARBON CAPTURE AND STORAGE

Fact check CCS / CCUS

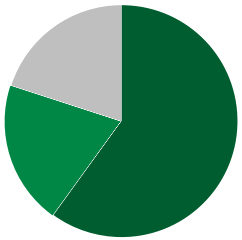
- Storage sites: depleted oil or gas reservoirs, saline aquifers, seabed
- Capture rate: 65-90 %



- Efficiency loss: 8-18 %



- Additional costs: 60-80% per kWh



Risks and challenges

- Release into the subsurface displaces saline groundwater, possibly causing salinisation of groundwater, soils or surface waters.
- Re-entry into the atmosphere
- Transport to storage site required

- Many unanswered questions, high need for research
- Underground spatial planning required to prevent conflicts of use (CCS, geothermal energy, natural gas storage)

Quelle: UBA 2020, IEA 2020, Deutsche Welle 2014

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VALUE CHAIN OF THE HYDROGEN ECONOMY

Purchase primary energy carrier
- Natural gas
- Crude oil
- Biomass
- Power + water

H_2 generation
- Planning, construction and operation of generation plants
- Coupling of RE deployment
- Grid feed-in
- Gas import
- Generation with/without CO2 emissions
- CCS or EUAs

H_2 transport, storage
- Planning, construction and operation of the transport network
- System services and balancing energy
- Large-scale storage
- Liquid or gaseous
- Blending with natural gas or pure H2 network

H_2 distribution, collection
- Petrol stations
- House connection
- Determination of consumption, location/volume
- Operation / maintenance of pipes
- Decentralised generation and feed-in
- Blending with natural gas or pure H2 network

H_2 usage
Sectors:
- Steel and chemical industry
- Transport
- Heat generation
- Electricity storage

Appliances:
- fuel cell
- gas engine

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GREEN HYDROGEN VALUE CHAIN
A PRACTICAL EXAMPLE

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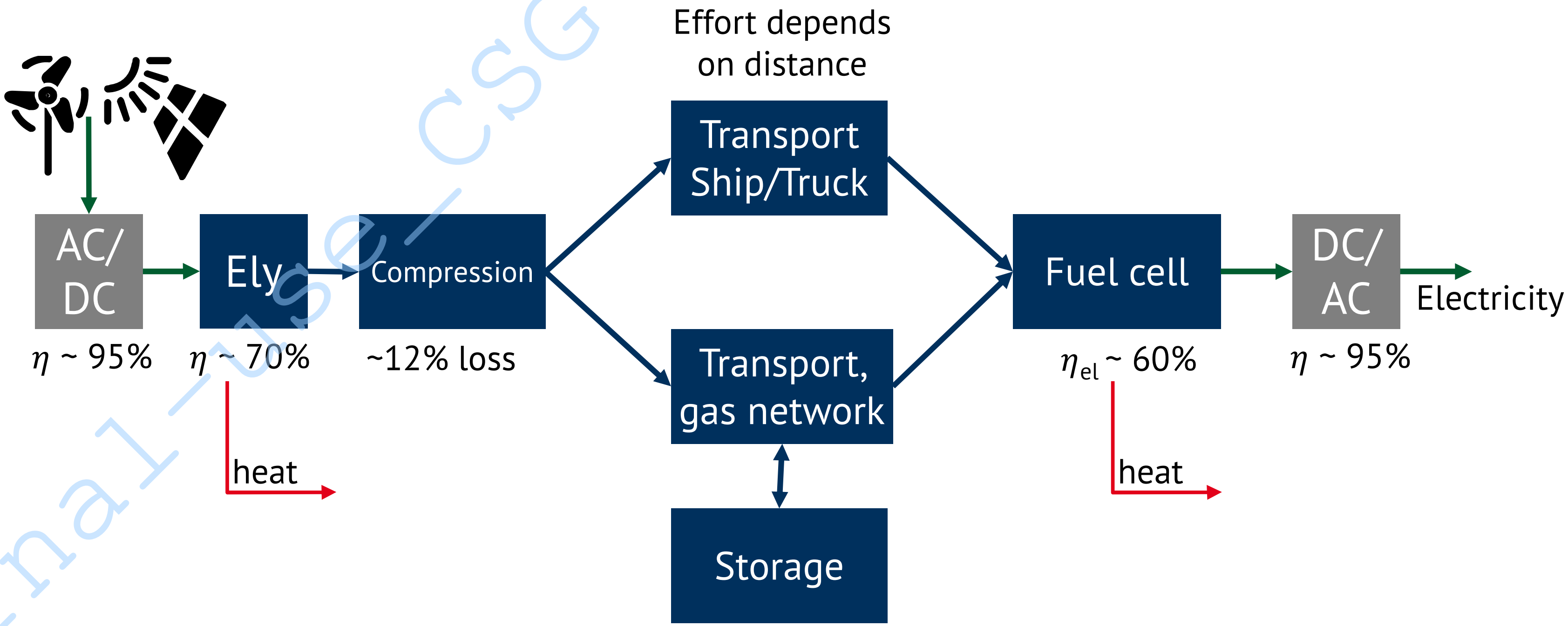

total efficiency of 33 %
without transport, storage and without heat utilization

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FIELDS OF APPLICATION FOR HYDROGEN

Industry	▪ Substitution of current H_2 consumption (basic chemicals, refineries) ▪ new processes such as direct reduction of steel
Transport	▪ conversion to synthetic fuels ("e-fuel") ▪ direct H_2 use: internal combustion engine or fuel cell ▪ Heavy transport: shipping, heavy-duty trucks, substitute for diesel locomotive ▪ People: Aviation, passenger cars
Power generation	▪ Central power plants: gas engines or gas turbines (possibly with steam cycle) ▪ Decentralized power plants: fuel cells or CHP units
Provision of heat	▪ Decentralized: in CHPs for heat in buildings (households, commercial) ▪ Central: for process steam production, in CHPs for heat network

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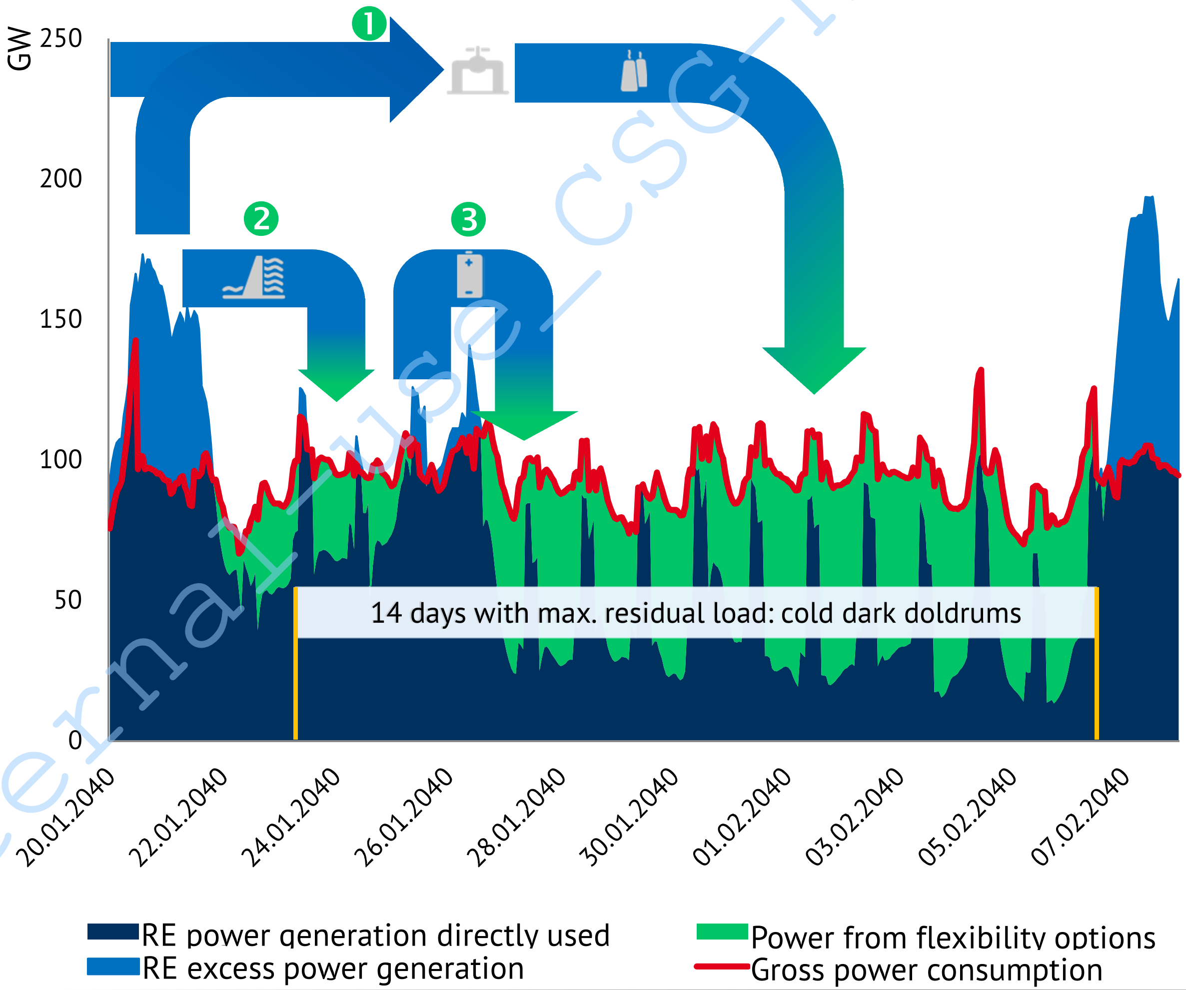
MANAGING COLD DARK DOLDRUMS WITH FLEXIBILITY OPTIONS



❶ **Long-term flexibility:**

An electrolyser produces gas for storage in the gas grid and gas-fired power plants generate climate-neutral electricity in the cold dark periods.

❷ **Medium-term flexibility:**

For example, pumped storage can compensate for generation surpluses over a few days.

❸ **Short-term flexibility:**

For example, battery storage balances electricity supply and demand over a period of hours.

Source: Energy Brainpool, 2017

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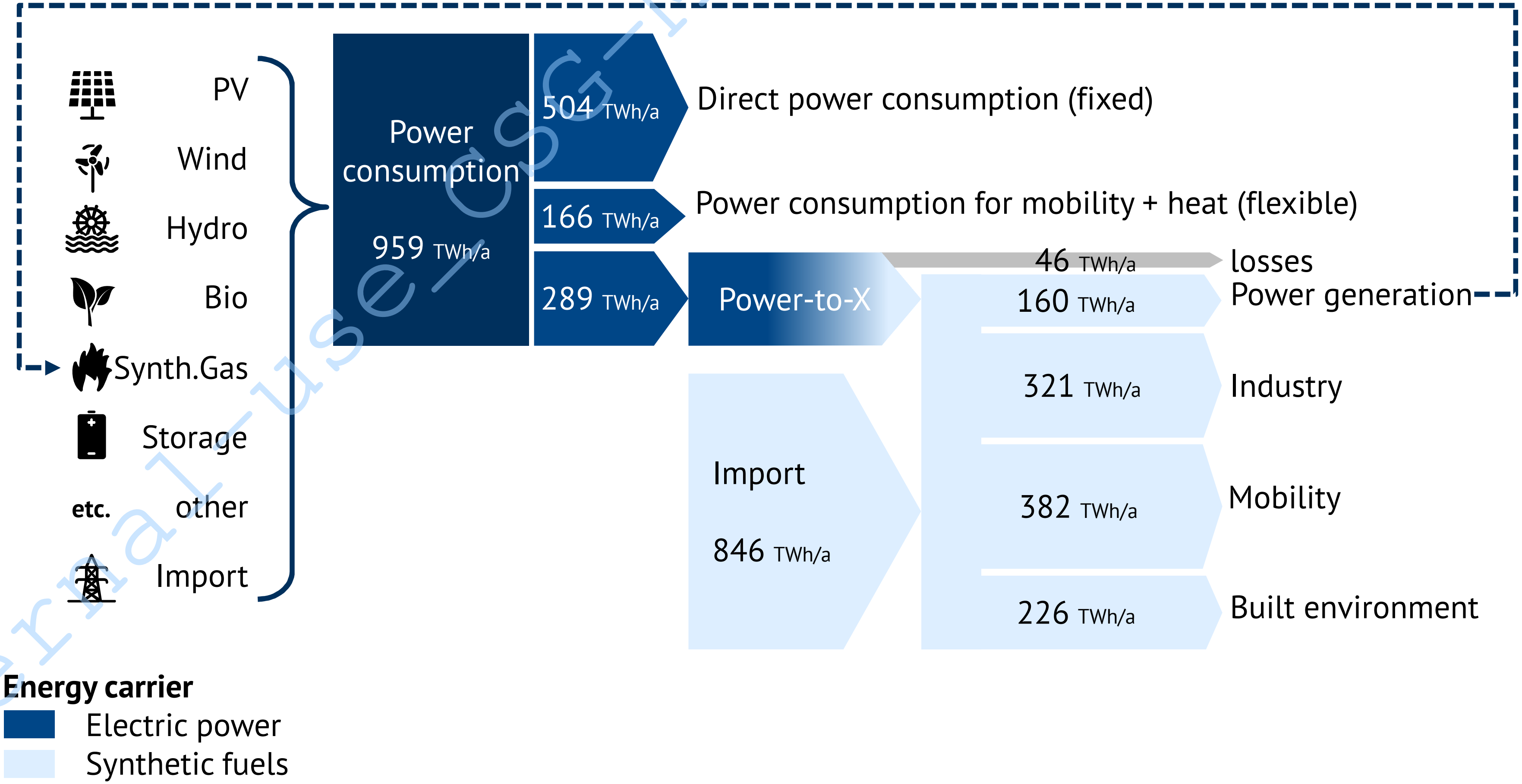
GERMANY AS A NON-FOSSIL POWER SYSTEM



Source: Energy Brainpool 2019

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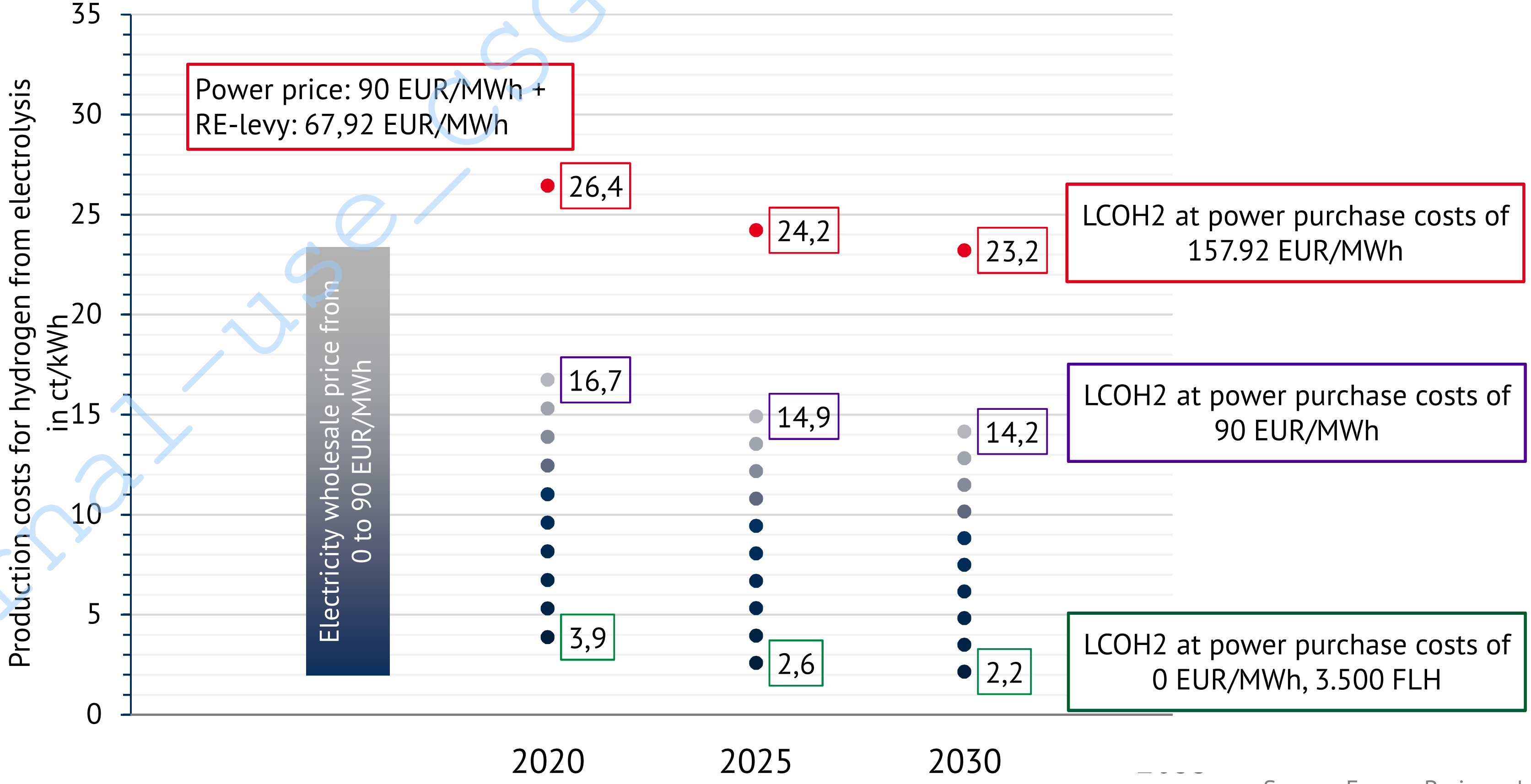
PRODUCTION COSTS FOR HYDROGEN FROM ELECTROLYSIS

Production cost for green hydrogen depend largely on power prices and additional charges/levys/taxes



Source: Energy Brainpool

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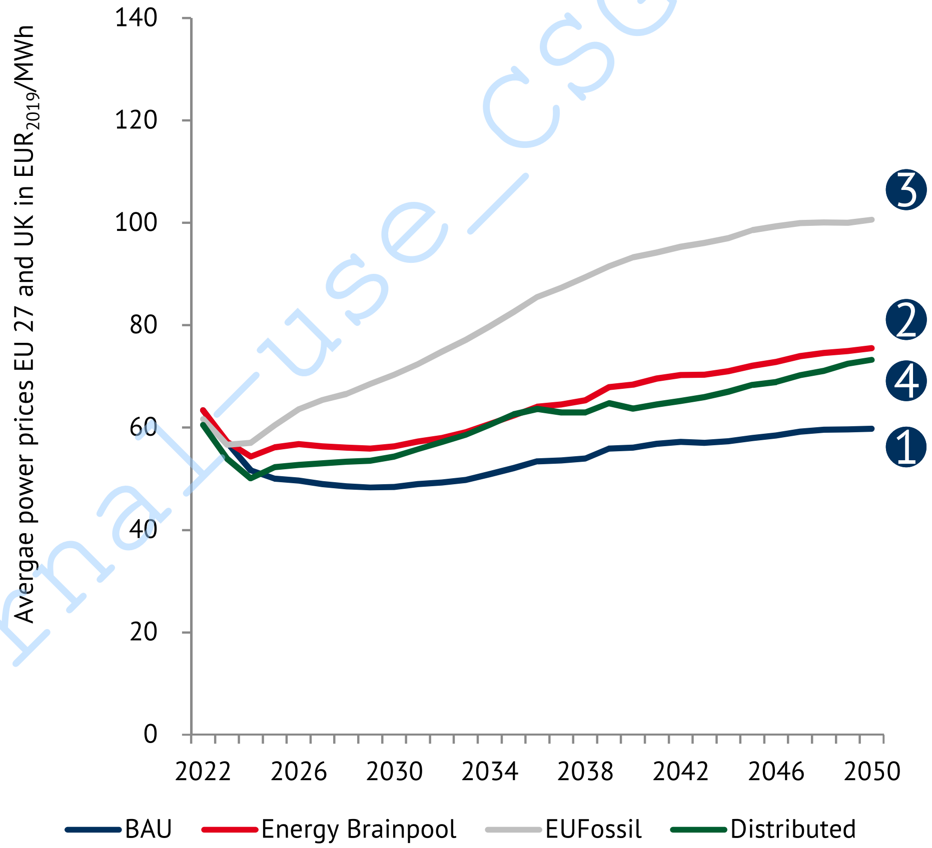
EU ENERGY OUTLOOK: POWER PRICES OF SELECTED EU COUNTRIES IN SCENARIO COMPARISON

Comparison of the baseload prices



1 Scenario „**BAU**“:
- Moderately rising coal and gas prices, stagnating CO_2-prices

2 Scenario „**Energy Brainpool** “**(EBP)**:
- Sharply rising CO_2-prices with stagnating coal and gas prices

3 Scenario „**EUFossil**“:
- sharply rising commodity prices
- Lower installation rate of the renewables

4 Scenario „**Distributed**“:
- Very high installation rate of the renewables
- Sharply rising CO_2-prices
- Lots of e-mobility and PV home storage

Source: Energy Brainpool, EU Energy Outlook 2050, WEO 2020

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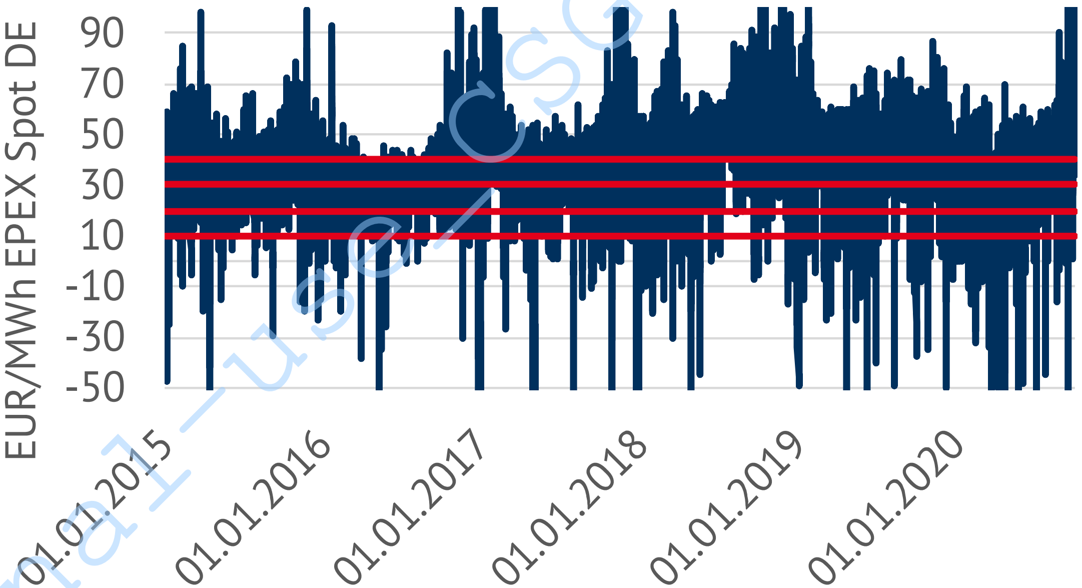
OPERATIONAL BEHAVIOUR OF ELECTROLYSERS IS DECIDED AT THE SPOT MARKET



Hourly power prices at the wholesale market (Germany)

Trigger prices for the use of the electrolyser (10, 20, 30 or 40 EUR/MWh)

Trigger price < Power price Spot	Trigger price ≥ Power price Spot
Sale of power bought at derivatives market at a high spot market price	Operation of the electrolyser, maybe purchase of power at the spot market

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OPERATIONAL BEHAVIOUR OF ELECTROLYSERS IS DECIDED AT THE SPOT MARKET

TRIGGER PRICE	2015	2016	2017	2018	2019	2020
Achieved Full Load Hours in h/a						
10	289	357	473	280	416	702
20	1,284	1,389	1,143	652	660	1,671
30	4,145	4,941	2,963	1,454	1,898	3,658
40	6,642	7,615	6,430	3,169	5,004	5,363
Achieved power purchase price on average at the spot market in EUR/MWh						
10	- 1.0	- 0.4	- 3.7	- 4.5	- 6.8	- 2.7
20	11.9	11.9	6.9	6.9	1.3	8.1
30	21.7	21.2	19.0	17.2	17.9	17.4
40	26.5	25.8	27.5	27.0	28.7	22.9

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A Different types of hydrogen (colour spectrum)

B Hydrogen value chain & sample use cases

C Development of production costs for hydrogen

D Another issue: the regulatory framework

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EU CRITERIA FOR GREEN HYDROGEN

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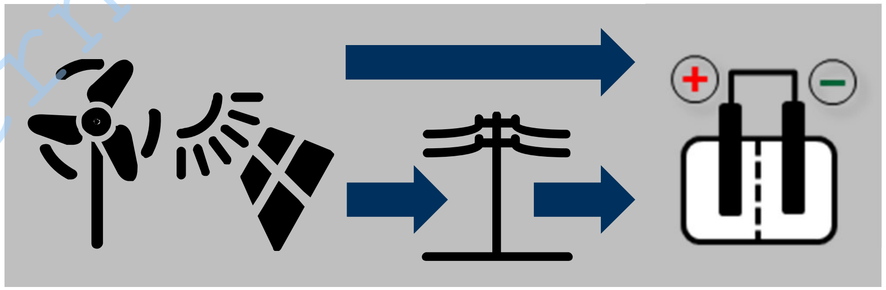
Criteria from EU regulation (prelim.), implementation on national level needed

- ✓ Electricity for electrolysis must come from additional (new) RE plants
- ✓ RE plant built at the same time as the Ely or max. 12 months later
- ✓ Direct supply contract between RE plant and Ely required
- ✓ Choice: direct connection between RE plant and Ely or draw electricity from the grid
- ✓ RE plant + Ely are in the same bidding zone, there are no systematic grid bottlenecks
- ✓ 15-minute balancing of RE feed-in and Ely consumption
- ✓ Alternatively: more RE power was produced in the bidding zone than on average
- ✓ RE plants must not receive or have received financial support



Sources: press articles, May 2021

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TRANSITIONAL REGULATION FOR HYDROGEN

TARGET	Proposal of a possible regulatory framework	Legal and planning security on long-term investments
	Support for building up the hydrogen infrastructure	Increasing international competitive position
CONTENT	Basics of tariff design	Rules for the formation of sub-networks
	Specification of how to determine grid utilisation fees	Incentive regulation when switching from natural gas to hydrogen grids

Quelle: BMWi

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Thank you!

What questions do you have?

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BACKUP SLIDES

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HYDROGEN STORAGE

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Gaseous

- **Short-term:** storage in the gas grid
- Small storage volumes in steel or steel-composite pressure vessels
- **Long-term:** Large-scale underground storage mainly in salt caverns (approx. 100 bar)
- **Pressure:**
  - "Low": 50 bar
  - "High": up to 1000 bar
  - Typical: 350 or 700 bar (mobility sector)
- **Energy input** for compression: 5-15 %

Fluid

- **Deep-frozen** to -253°C (at normal pressure)
- Strong insulation required to retard evaporation
- Lower volumetric density than LNG
- **Application** in aerospace, chip industry
- **Energy input** required for liquefaction: 20-30%

Material-based

- Still in the **research stage**
- Compound by adsorption to carriers
- **Types:**
  - Metal hydride storage (e.g. palladium)
  - Liquid organic hydrogen carriers
  - Surface storage (zeolites, carbon nanotubes)

Sources: Umlaut 2020; Shell / Wuppertal Institut 2017

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PARAMETERS FOR MODELLING

		2020	2025	2040
Investment costs electrolyser	EUR/kW_el	800	700	600
Technical lifetime	a	20	20	20
Weighted average cost of capital	%	7%	7%	7%
Full Load Hours (FLH)	h/a	3,500	3,500	3,500
Efficiency	%	70%	73%	75%
Operational costs	% Invest in EUR/kW	3.5%	3.5%	3.5%
Annualised capital costs	EUR/(MW_th a)	-107,877.63	-90,513.76	-75,514.34
Total operational costs	EUR/(MW_th a)	28,000	24,500	21,000

- Assumptions of investment costs and efficiencies according to Prof. Dr.-Ing. Michael Sterner - OTH Regensburg.
- Assumption of operating costs, interest rates and full load hours according to Energy Brainpool

Source: Energy Brainpool

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CASE STUDY: HYDROGEN FOR TRUCKS

H_2 trucks	• Fuel cell-powered trucks for long-distance and heavy goods (climate-neutral)
Advantages/ Disadvantages	• Less weight than battery-powered trucks • Fast refueling and ranges between 400 and 800 km • Very expensive, refueling station infrastructure, supply
Challenges	• 150 service stations in Europe, 91 in Germany, more in cities • Political framework (subsidies or tax breaks) • Technology development still in progress

Germany

H_2 Haul by 2030:
100,000 hydrogen trucks and
1500 filling stations

Switzerland

First commercial vehicle fleet (Hyundai XCIENT Fuel Cell Truck) with standard hydrogen-electric drive;
2021: 46 in operation, 2025: 1600 planned

Sources: Futurefuels, Frauenhofer, Eurotransport

CASE STUDY: HYDROGEN ON RAILROADS

A train can save 260 t CO_2 compared to a diesel locomotive per year

Germany:

- Only 61% of rail lines are electrified
- 39% are covered by diesel drives
- Expansion of overhead contact line is very slow

Alstrom

- Coradia iLint hydrogen-powered
- 2016 test runs in Germany
- First trains in regular service from 2022
- Range of 1000 km
- Emission-free (low noise, only water vapor and condensation)
- First passenger train worldwide to run on hydrogen

Advantages: Low emissions, ideal for non-electrified routes, long range, comparable refueling time.

Siemens Mobility AG

- New development Mireo Plus H
- All-rounder, range of 600 km (two wagons)
- Test period in 2024
- H2goesRail joint project with DB: Provision of a hydrogen refueling station

Disadvantages: Use only on non-electrified lines, no freight transport, drive too weak

Sources: Alstrom, DB, Siemens

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