Decarbonisation with renewable H2-production - Case study of a 1000 MW plant

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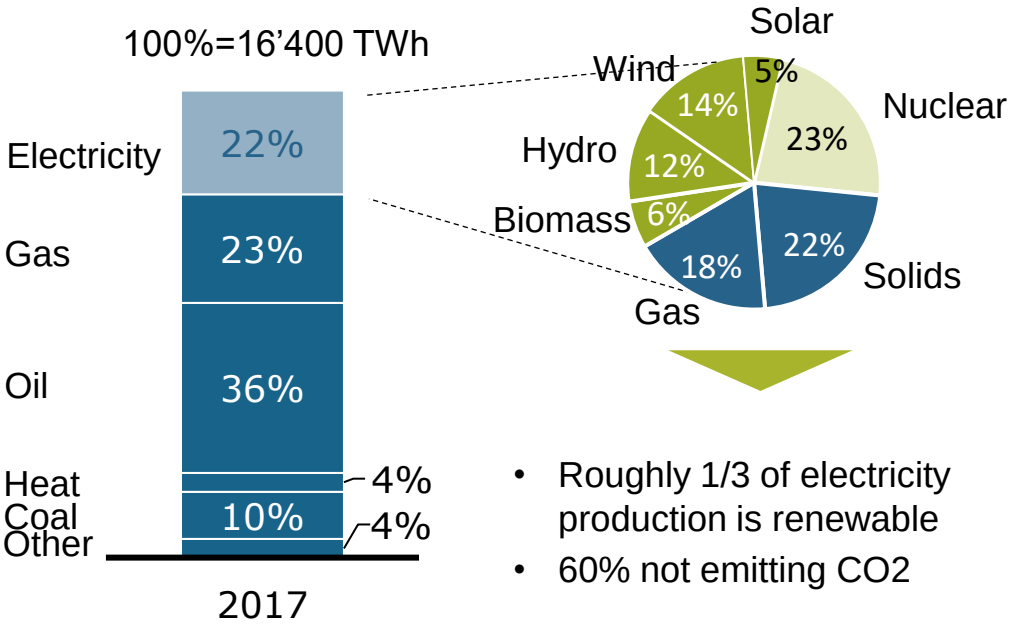
85% of the current European final energy consumption must be decarbonised until 2050

Total European Final Energy Consumption



- Roughly 1/3 of electricity production is renewable
- 60% not emitting CO2

Source: H2 Energy internal database

Green Deal Europe

- CO_2 neutral Europe until 2050
- Intelligent sector coupling (electricity, gas & heat)
- Use hydrogen for “hard to decarbonise sectors”

Decarbonise total of 14’100 TWh energy/a

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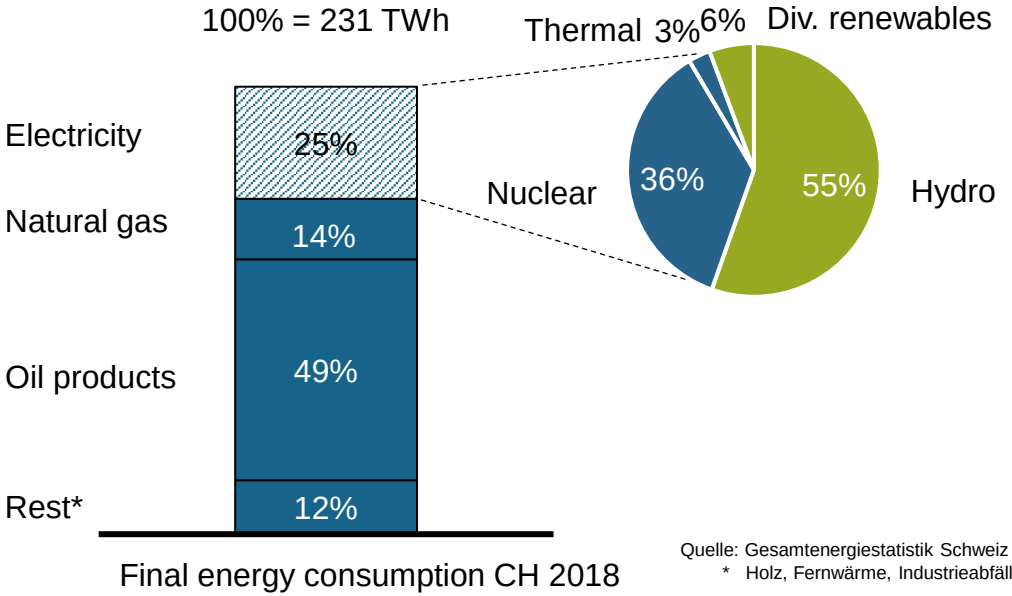
85% of current final energy consumption equal. >1700 GW@8000h/a

In Switzerland Electricity counts today for ¼ of final energy consumption but still ¾ **based on fossil fuels**

Final energy consumption CH



Nearly 2/3 of power production is renewable

Conflict of targets

- Security of supply of electricity for CH
- Decarbonisation of energy sector

Quelle: Gesamtenergiestatistik Schweiz 2018

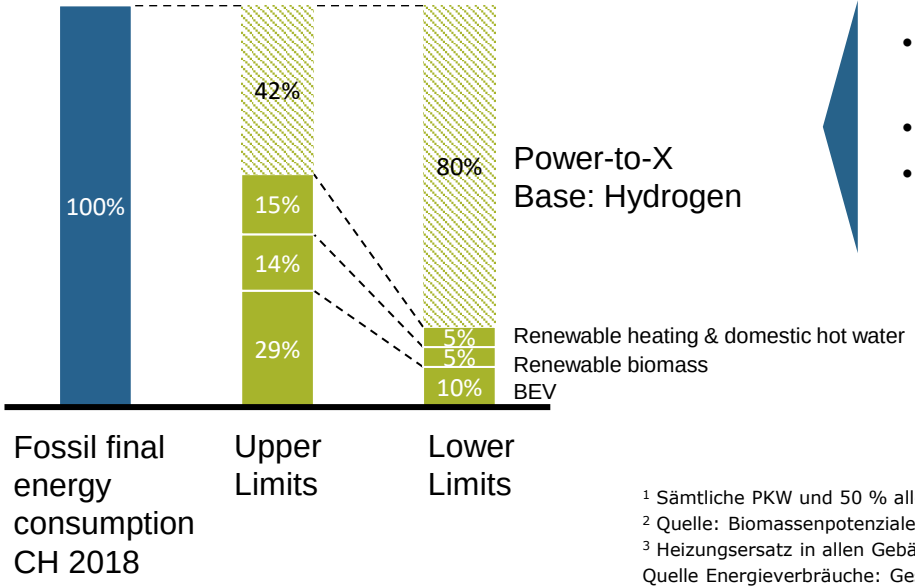
* Holz, Fernwärme, Industrieabfälle, übrige erneuerbare Energien (ca. 3%), Kohle

42-80% of fossil energy will have to be shifted towards hydrogen for decarbonization

Conversion of today's fossil energy carriers to renewable carriers (Switzerland)

In TWh and percent

100% = 196 TWh



- Massive shift to hydrogen-based energy economy
- Adaptation of infrastructure needed
- Massive GHG-free power production needed

[1] Sämtliche PKW und 50 % aller leichten Nutzfahrzeuge in der CH verwenden BEV (Upper Limits)
[2] Quelle: Biomassenpotenziale der Schweiz für die energetische Nutzung 2017 (Upper Limits)
[3] Heizungsersatz in allen Gebäuden der Schweiz abzgl. Heizung mit Biomassespeicher im Gebäude (Upper Limits)
Quelle Energieverbräuche: Gesamtenergiestatistik der Schweiz 2018

BEV vs. FCEV-trucks: Total energy consumption (Wh/t*km) within 10% per energy service comparison

BEV HD truck

Additional tours compared to Diesel (reference pay load) + 21%

FCEV HD truck

Additional tours compared to Diesel (reference pay load) + 5%

Assumptions BEV 40to:

Range	400 km
Consumption	1‘300 Wh/km
Battery-system	130 Wh/kg
Battery usage	0.8 Kapazität
Battery mass	5‘000 kg
Reference pay load	29 to
Pay load	24 to

Assumptions FCEV 40to:

Range	400 km
Consumption	0.08 kg H2/km
Battery mass	545 kg
Mass FC and tank	788 kg
Reference pay load	29 to
Pay load	27.7 to

BEV
51% Losses PV-power
60% Losses CH-Consumer-Mix power

FCEV
55% Losses with heat usage
65% Losses without heat usage

Difference of energy loss of transport service BEV vs. FCEV is <10%

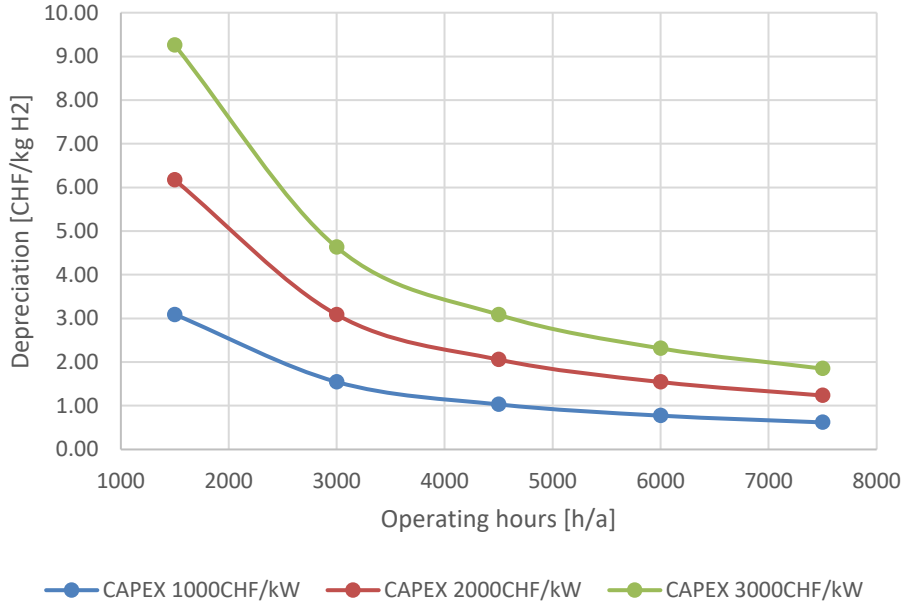
Power is the main cost driver of renewable H2 production

Cost contribution in CHF/kg H2: as function of power-price and power-demand

- **Grid fee and taxes for power consumption of 65 kWh/kg lead to >2 CHF/kg H2**
- **Even without grid fees cost of >4 CHF/kg H2 results at energy prices >60 CHF/MWh**

High investment costs demand for elevated operating hours

Depreciation in CHF/kg H2: as function of CAPEX and utilisation rate



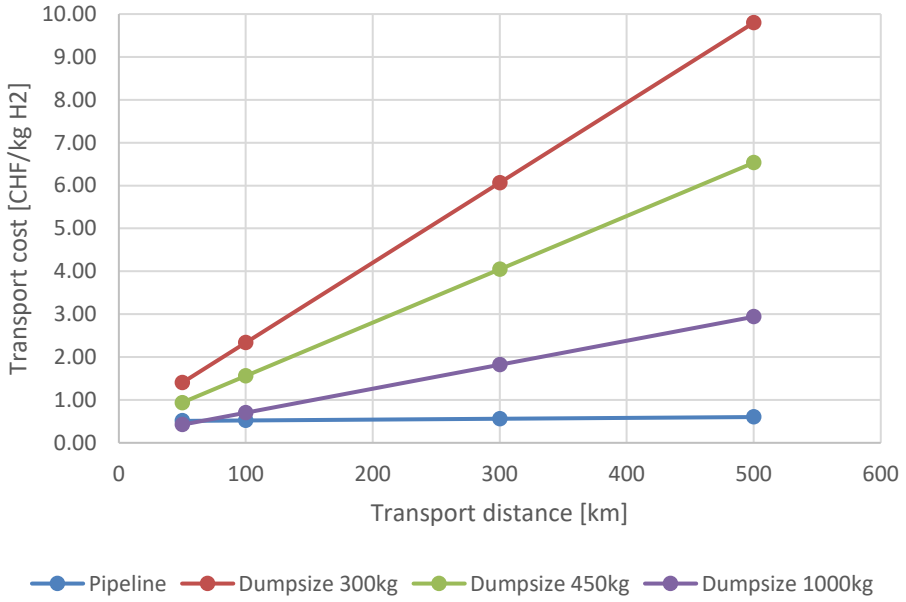
Assumptions

- Depreciation period 12 years

Utilisation rate of >4500 h/a open depreciation rate of <2 CHF/kg H2 at total plant-CAPEX of <2000 CHF/kW

Pipelines are key for large-scale international H2 logistics

Transport cost in CHF/kg H2: as function of distance and transport mode

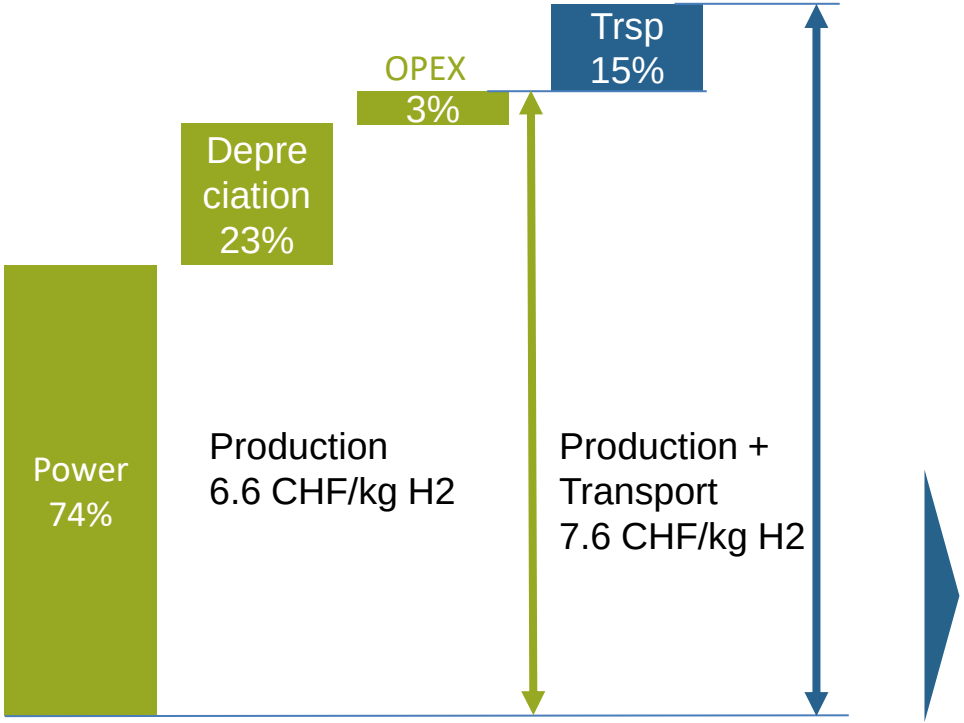


Assumptions

- Road logistics with 300 – 1000 kg dump-size per truck-loading
- Pipeline capacity of >0.5 Mio to/a

Last mile distribution <150-200 km on the road is an adequate mode

Power is the dominant cost driver of renewable H2 prod.

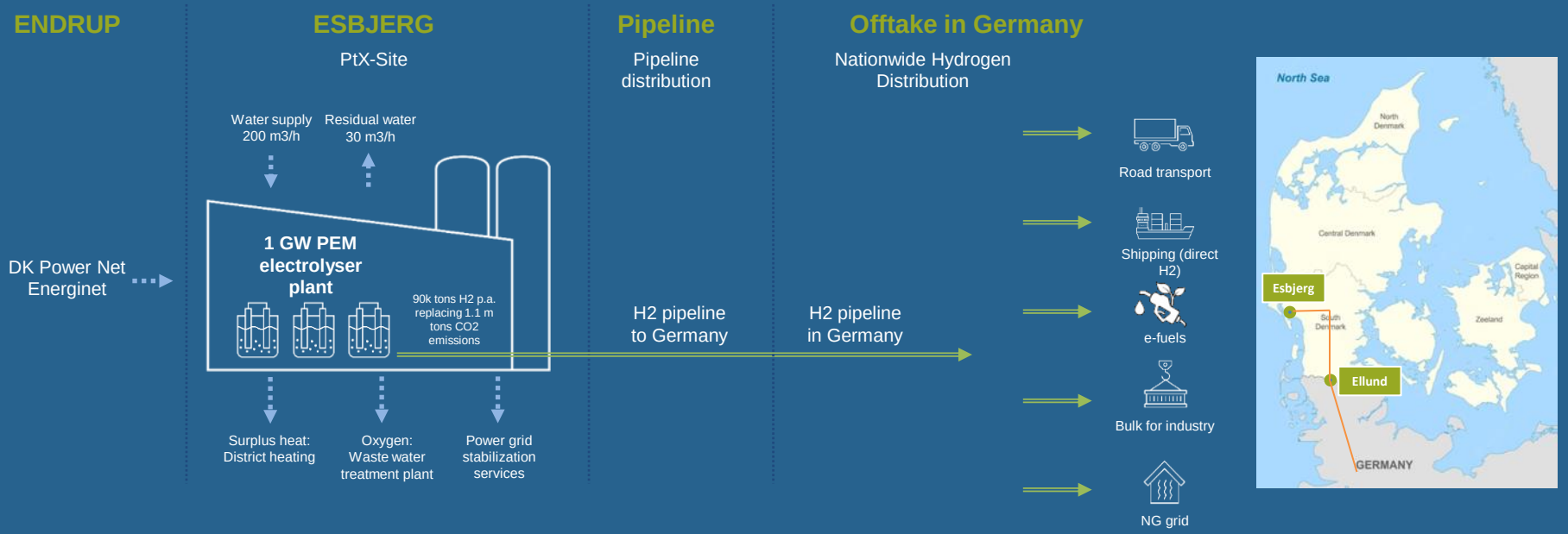


Assumptions

- Power-price 75 CHF/MWh w/o grid fees
- Power demand 65 kWh/kg H2@30 barg
- Operating hours 6000 h/a
- CAPEX 2000 CHF/kW
- Depreciation period 12a
- Transport 500 km pipeline + 50 km truck

Cost of <8 CHF/kg H2 delivered to Customer (industry or HRS)

Project ‘Njordkraft’ – Production in Esbjerg and Offtake in Germany



H2energy Europe

Finding (1): Main topics for larger H2 production capacities

Power

Renewable electrical energy cost
Grid connection fees & additional taxes
Grid services

Plant

CAPEX (Specific process equipment, power supply, infrastructure, safety)
OPEX (Operation 24-7, maintenance, optimization)

Logistics

Access to off-takers (Pipeline access, logistic chains)

- **Check legal framework for grid fees and grid services**
- **Keep an eye on safety aspects and power-distribution onsite**
- **Access to pipeline is key for large plants**

Findings (2): Market value of renewable hydrogen?

Reliable legal frame work needed

- How is RFNBO compatible power defined?
- How will be the framework 2030+?
- Which THG quotas will be in place, for which market?

- How will be the reference of H2 to other fuels in the mobility sector designed?
  - H2 vs. Grid-charged battery vehicles?
  - H2 vs. liquid bio-fuels/e-methanol?

- **Clear and stable political/legal frame-work (technology agnostic) could avoid potential stranded investments**
- **Provide a simple base for a fair economic competition**

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