



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Bundesamt für Energie BFE
Office fédéral de l'énergie OFEN
Ufficio federale dell'energia UFE
Swiss Federal Office of Energy SFOE

Swiss Hydrogen and Fuel Cell Activities in the Context of the National Energy Strategy 2050

Stefan Oberholzer, March 11, 2021



Contents

- **Swiss Energy and Climate Policy**
- Hydrogen and Fuel Cells in Switzerland
 - Production, demand, actors
 - Green Hydrogen in Switzerland
 - Hydrogen mobility
 - Power-to-Gas
- SFOE Hydrogen and Fuel Cells Programme
- International Collaboration
- Conclusions



see presentation from Patrick Huber
(H2 Energy) tomorrow



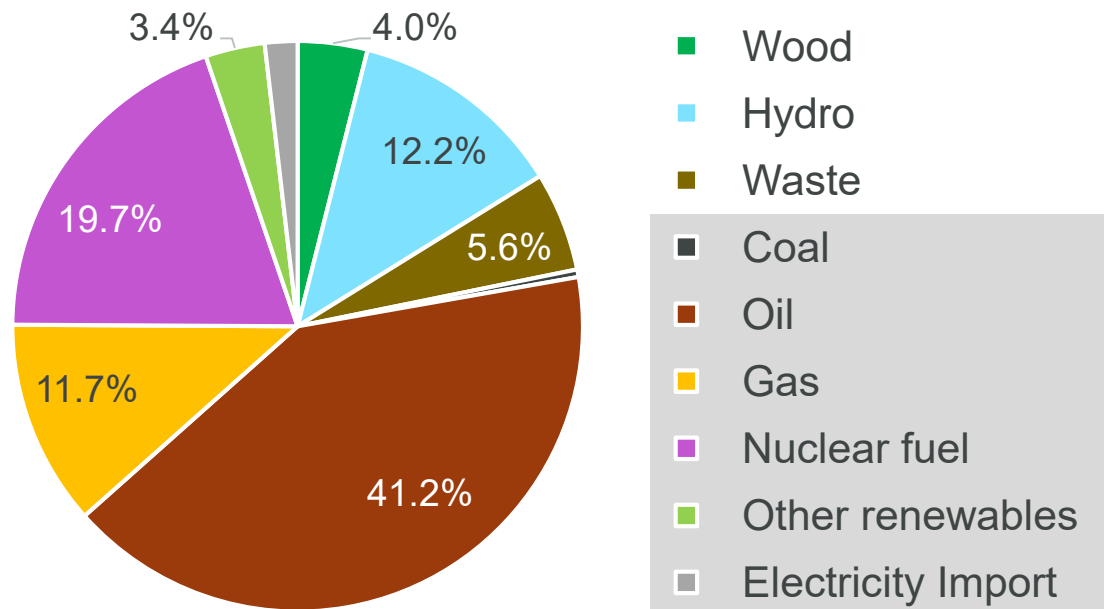
Switzerland

surface: 41 285 km²

population: 8.4 millions

Energy primary consumption: 300 TWh/a

<https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics>



75% from imports

H2 consumption:
0.5 GWh



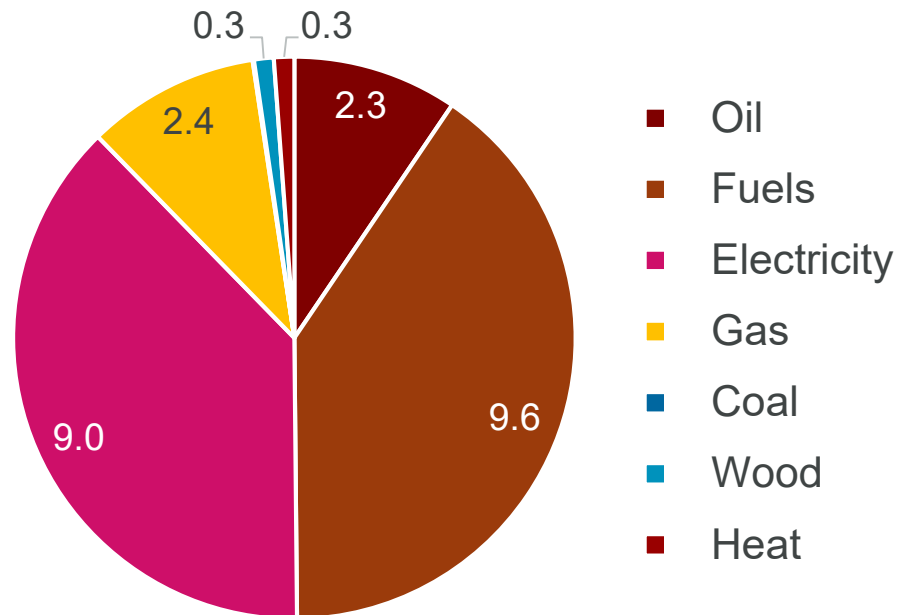
Switzerland

surface: 41 285 km²

population: 8.4 millions

Energy expenditures: 23.8 G€/a (4% GDP)

<https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics>



40 HRS @ 2 M€ / station = 0.08 G€





Climate challenge

<https://www.glamos.ch/en>
<https://www.gletschervergleiche.ch>

1865

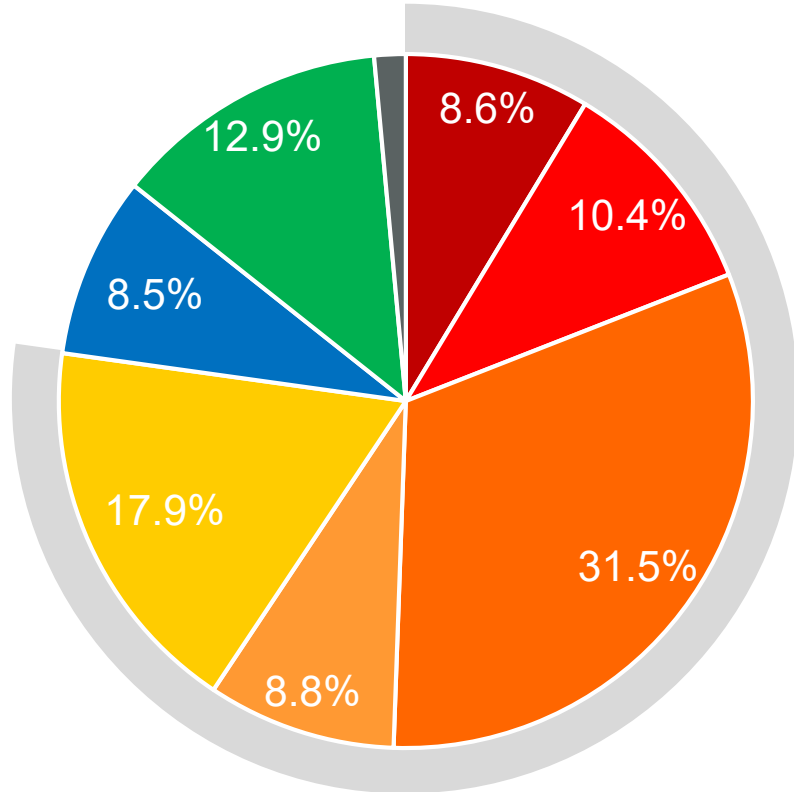


2000





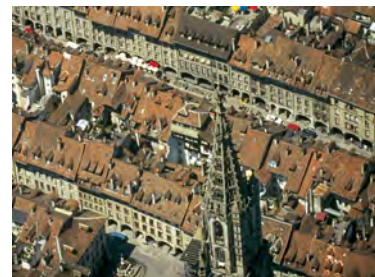
Swiss greenhouse gas emissions



77% energy related

- Waste (energy)
- Industry
- Transport
- Services
- Households

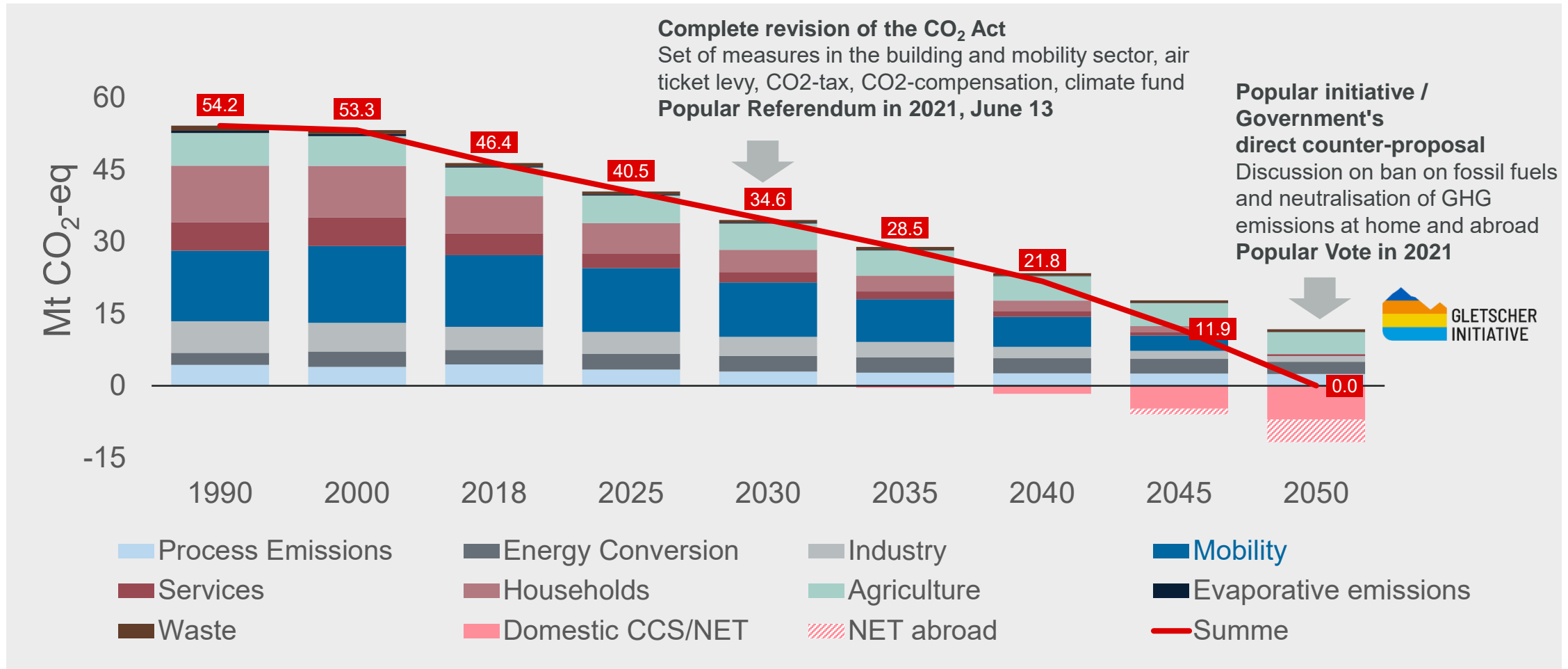
- Industrial Processes
- Agriculture
- Waste



<https://www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/greenhouse-gas-inventory.html>



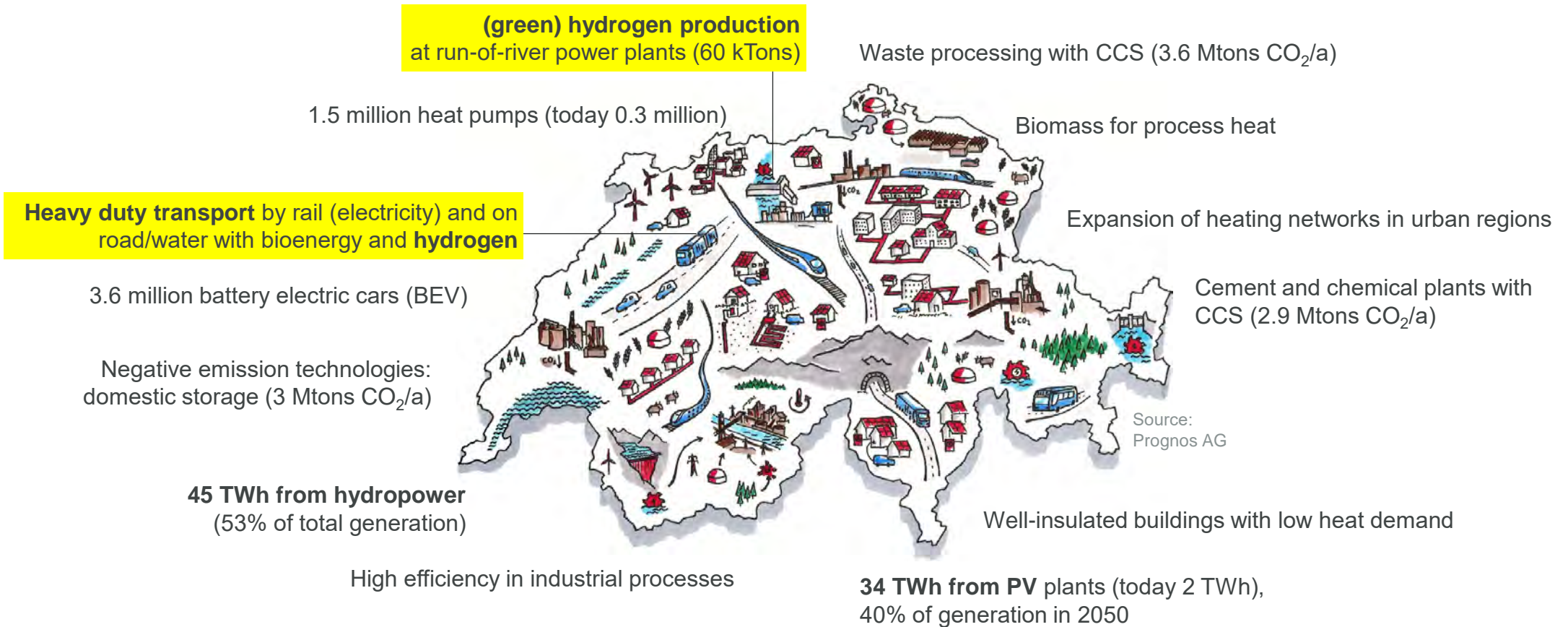
Swiss greenhouse gas emissions: NET ZERO target by 2050



Quelle: Prognos AG / TEP Energy GmbH / INFRAS AG
<https://www.bfe.admin.ch/bfe/de/home/politik/energieperspektiven-2050-plus.html>



Energy perspectives 2050+ published 26.11.2020, full scenarios published in 2021



<https://www.bfe.admin.ch/bfe/de/home/politik/energieperspektiven-2050-plus.html>



Energy strategy 2050

Step out from nuclear power



Revised energy act
(«Energy strategy»)

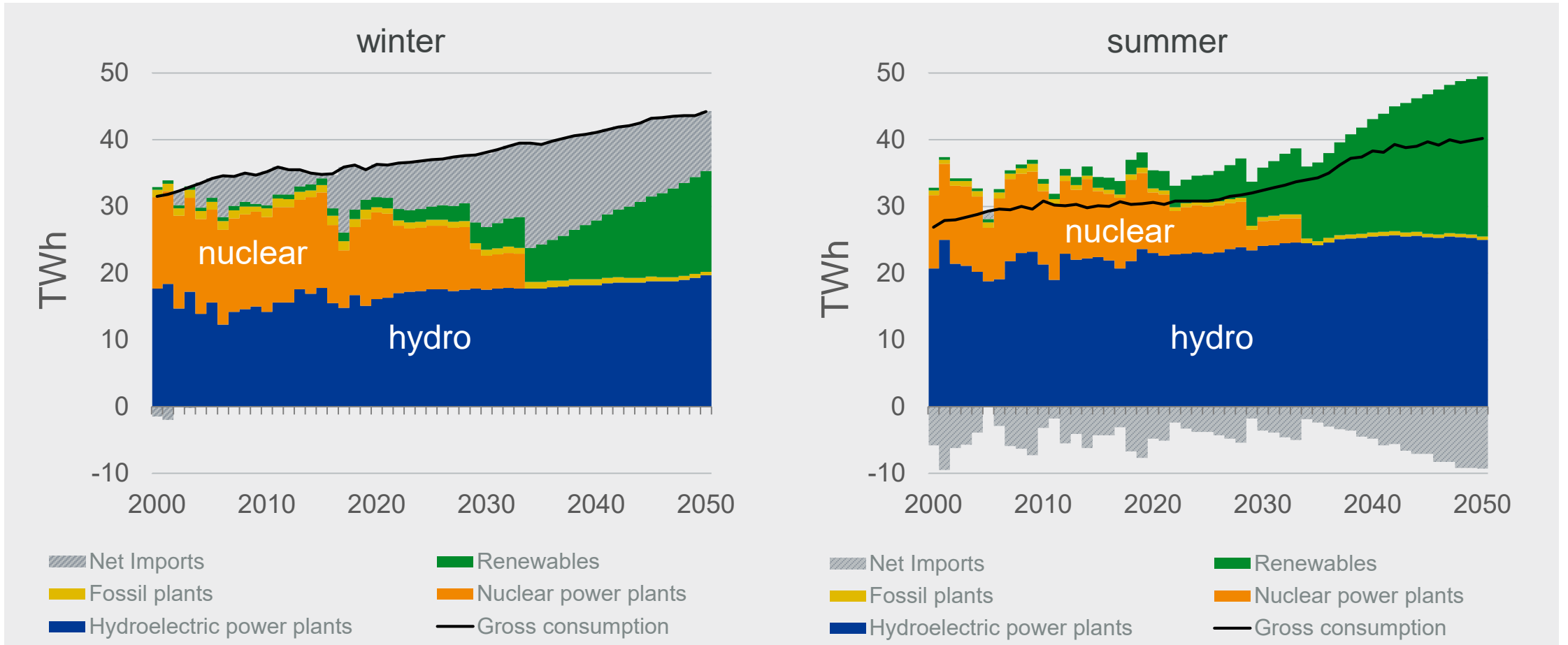
referendum 21.5.2017,
in force since 1.1.2018

First Swiss nuclear power
plant off grid **20.12.2019** after
47 years of operation
(KKW Mühleberg,
373 MW, 3066 GWh 2018)



Energy strategy 2050

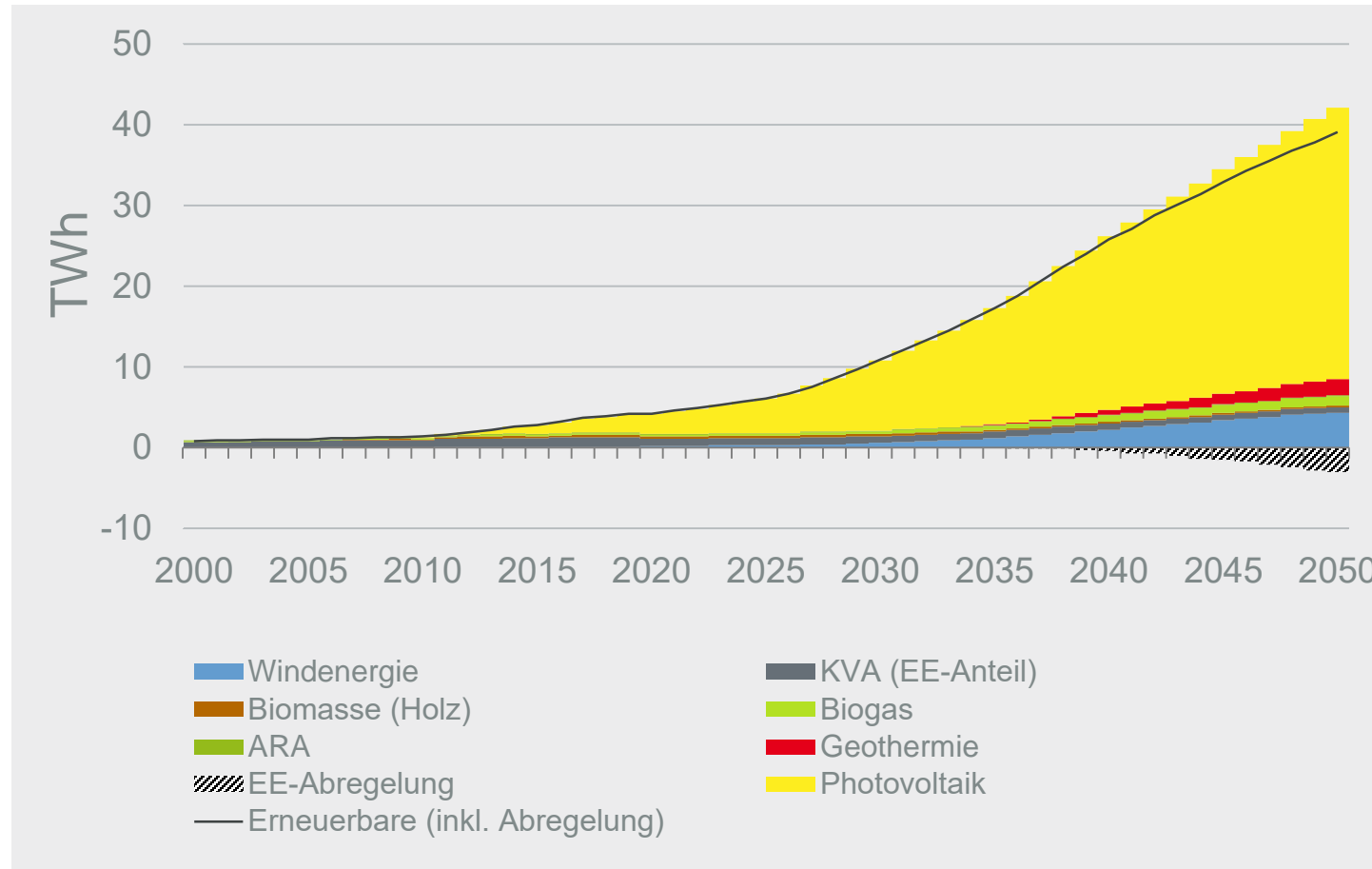
Increase of renewable power



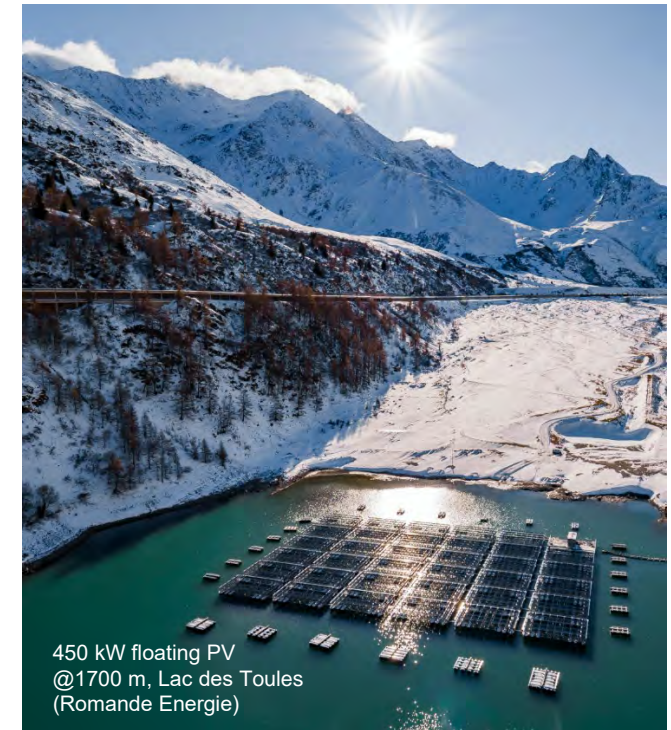
Quelle: Prognos AG / TEP Energy GmbH / INFRAS AG
<https://www.bfe.admin.ch/bfe/de/home/politik/energieperspektiven-2050-plus.html>



Increase of renewable power from 2.2 to 34 TWh PV



Large PV potential:
67 TWh on buildings
& infrastructures

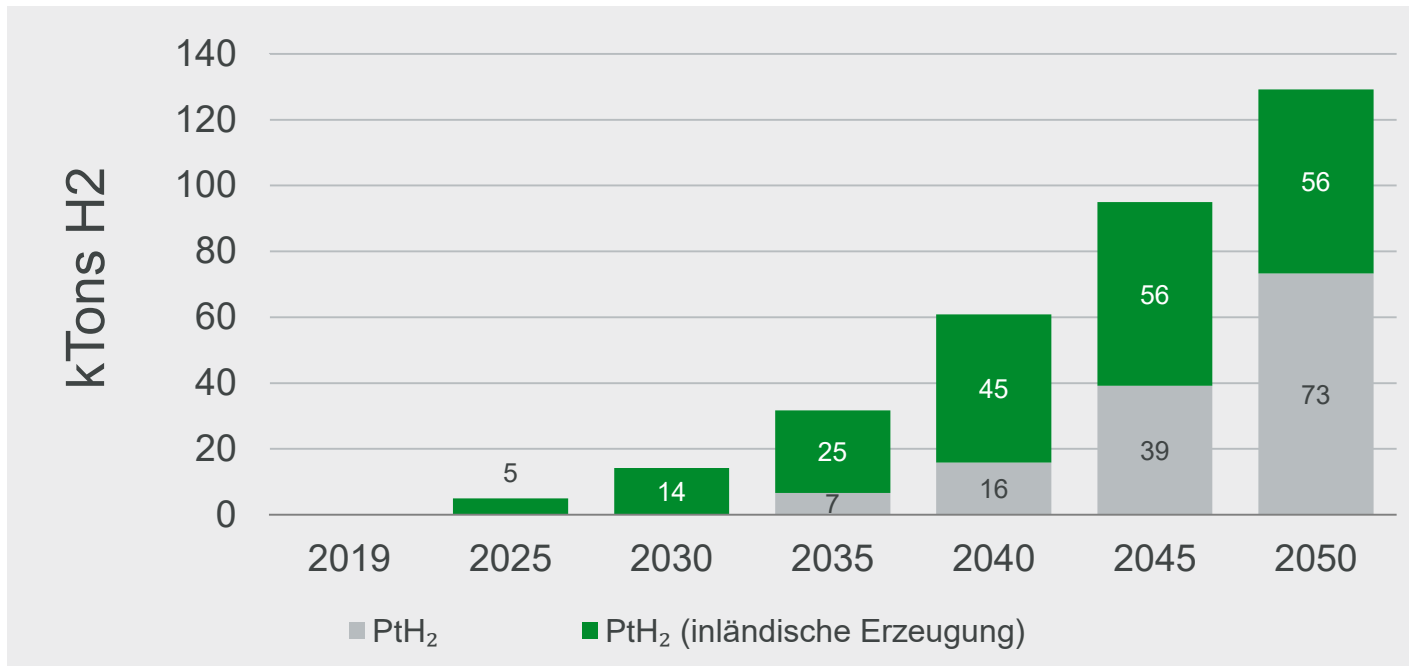


Quelle: Prognos AG / TEP Energy GmbH / INFRAS AG
<https://www.bfe.admin.ch/bfe/de/home/politik/energieperspektiven-2050-plus.html>



Role of green Hydrogen in the Energy perspectives 2050+ (published 26.11.2020)

Electricity-based energy carriers including hydrogen are needed to achieve the Net Zero target, especially in the transport sector



56 kTons of H₂ in 2050:

- 3 TWh (4%)
- 0.5 to 1 GW of electrolysis power

National Strategy on Green Hydrogen in preparation

<https://www.parlament.ch/de/ratsbetrieb/suche-curia-vista/geschaefte?AffairId=20204406>

Quelle: Prognos AG / TEP Energy GmbH / INFRAS AG
<https://www.bfe.admin.ch/bfe/de/home/politik/energieperspektiven-2050-plus.html>



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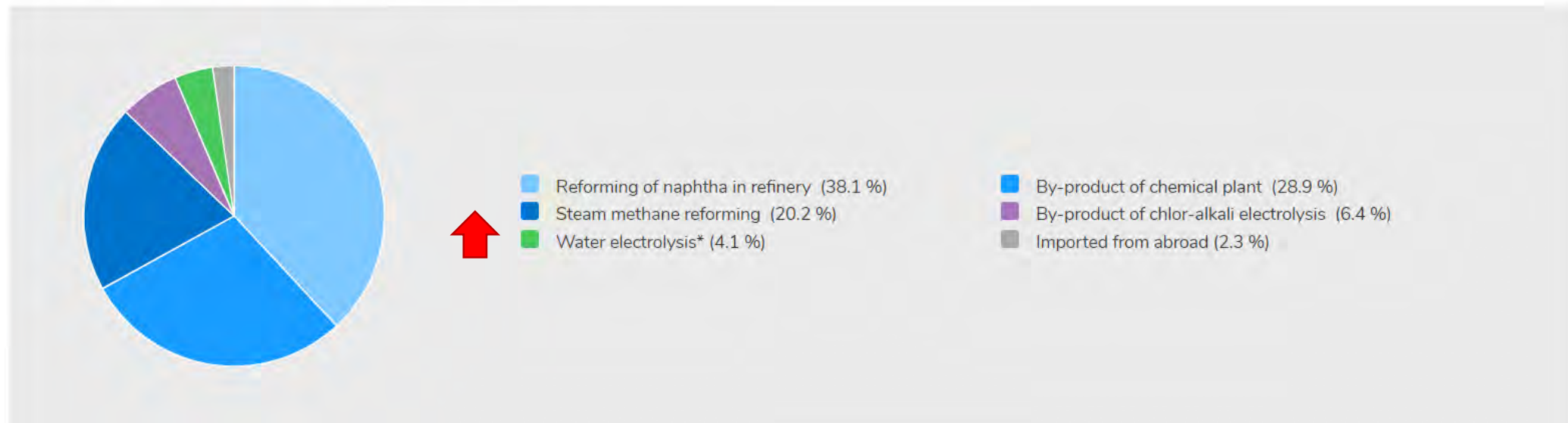


Hydrogen production in Switzerland 22 kTons (95% fossile/grey)

Hydrogen production

| Type of production | Tons/year | Energy feedstock |
|---|---------------|--------------------|
| Reforming of naphtha in refinery | 8'300 | Crude oil refining |
| By-product of chemical plant | 6'300 | LPG |
| Steam methane reforming | 4'400 | Natural gas |
| By-product of chlor-alkali electrolysis | 1'400 | Electricity |
| Water electrolysis* | 900 | Electricity |
| Imported from abroad | 500 | Unknown |
| Total | 21'800 | |

* 3.5 MW AEL (Monthey), 2 MW PEM (Gösigen), 2 MW PEM (Dietikon), 0.5 MW PEM (R&D)





Hydrogen demand in Switzerland

13 kTons

Hydrogen demand

| Application | Tons/year |
|------------------------------|---------------|
| Refinery operations | 11'000 |
| Watch industry | 700 |
| Chemical and pharma industry | 600 |
| Synthetic stone production | 550 |
| Metal processing industry | 50 |
| Various other uses | 50 |
| Heavy duty transport | 300 |
| Total | 13'250 |



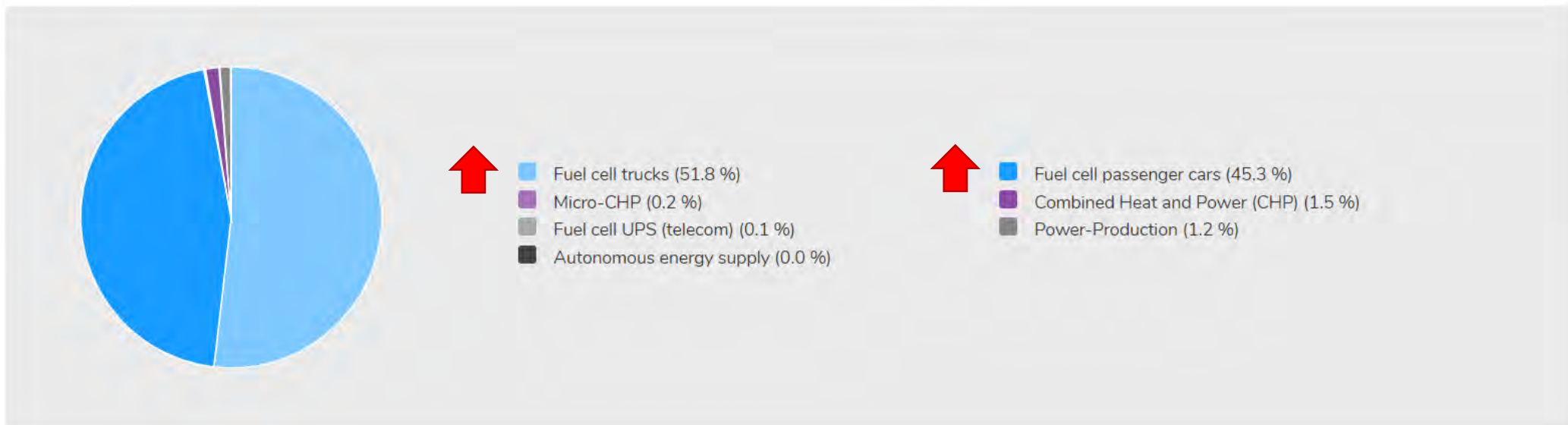


Fuel Cell applications in Switzerland

So far only for transport

Fuel cell applications

| Application | Power (kW) | Description | # |
|-------------------------------|------------|------------------------------------|-----|
| Fuel cell trucks | 8'930 | Hyundai plus 1 Esoro/SwissHydrogen | 47 |
| Fuel cell passenger cars | 7'800 | Hyundai, Toyota, Diverse | 130 |
| Micro-CHP | 30 | | 20 |
| Combined Heat and Power (CHP) | 250 | MCFC installation 2010 | 1 |
| Fuel cell UPS (telecom) | 12 | Swisscom, Polycom | 6 |
| Power-Production | 200 | PSI (ESI) | 1 |
| Autonomous energy supply | 8 | Diverse pilots | 2 |
| Total | 17'230 | | |





Swiss actors in H2 and fuel cells



Swiss actors distributed along the entire value chain from materials, components, stacks, systems, balance of systems, end-use integration up to services

high level science institutes (PSI, ETH Zurich, EPF Lausanne, Empa, EPFL, etc.)

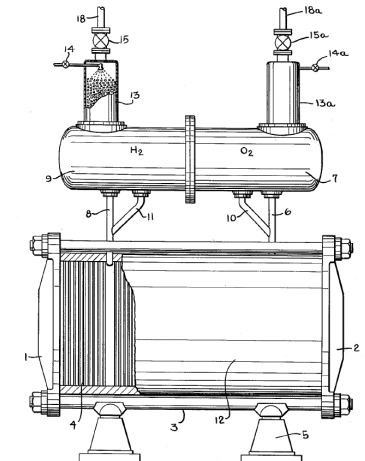
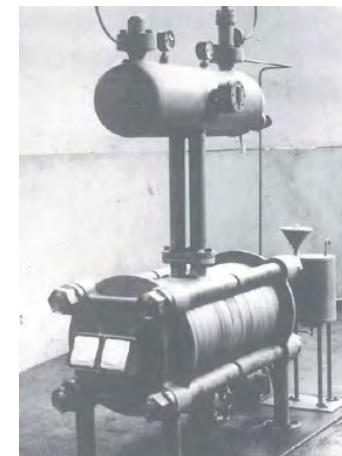
| | Industry/ SMEs | Academia |
|--------------|-------------------|-----------|
| Hydrogen | 31 | 20 |
| Fuel Cells | 22 | 16 |
| Other | 12 | 2 |
| total | 65 | 38 |



Green Hydrogen in Switzerland Electrolysis with clean power for industry

Historically:

- Increasing demand for hydrogen as a chemical feedstock by LONZA (Valais) in the 1940s
- Availability of cheap electricity from hydropower in the Alps
- Development of efficient alkaline pressure electrolysis by Ewald A. Zdansky
- Commercialisation by LURGI / IHT





Green Hydrogen in Switzerland Electrolysis with clean power for industry



Production of Synthetic stones (jewellery/industry) (Verneuil process)

| | |
|--|-------------------------------|
| Pressurised alkaline electrolyser (32bar): | 760 Nm ³ /h |
| Efficiency: | 4.3 kWh/Nm ³ |
| Installed capacity: | 6.6 MW |
| Annual energy demand: | 40 GWh |
| Hydrogen storage: | 20'000 m ³ @ 30bar |

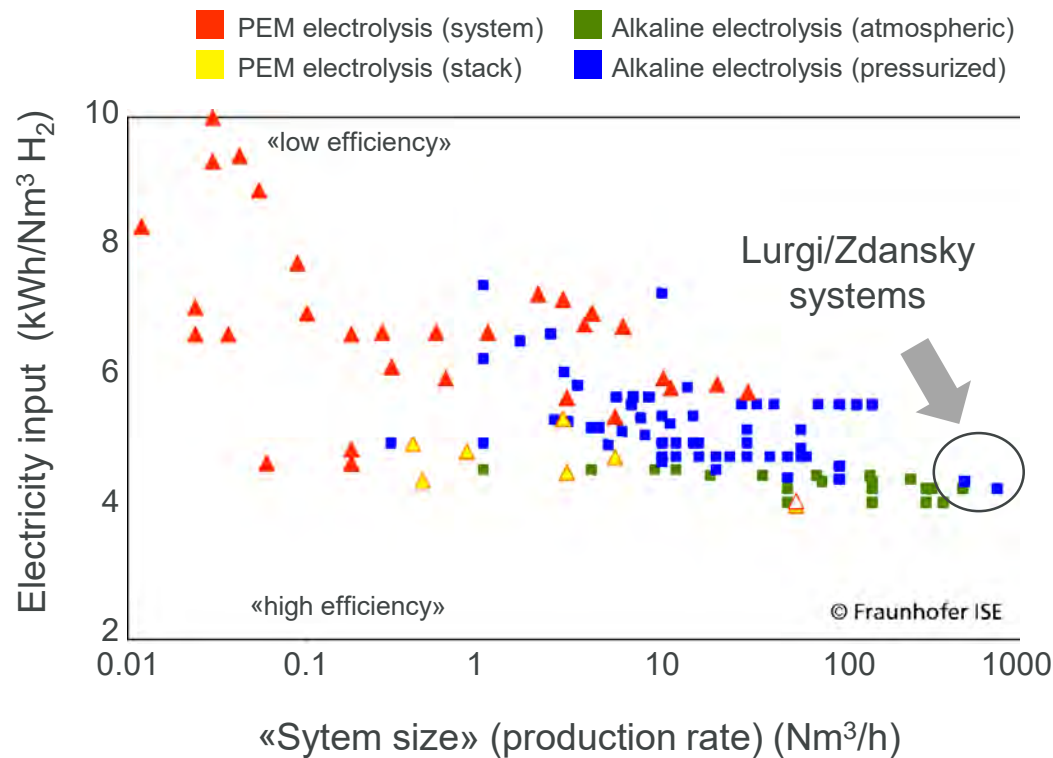


Source: DJEVA SA



High efficient pressurized alkaline electrolyzers

German company Sunfire (SOEC) acquired the Swiss electrolyser maker IHT (January 2021)



SUNFIRE-HYLINK ALKALINE



Source: Fraunhofer ISE (T. Smolinka, 2014)

Source: Sunfire



Green Hydrogen in Switzerland

Electrolysis with clean power for mobility



HYDROSPIDER AG: June, 2020 (in operation)

2 MW PEM electrolysis at run-of-river plant (51 MW) in Gösgen (Alpiq) (no grid)

300 t/a of green H₂ supply for FC trucks



greenH2 AG: 2022 (in planning)

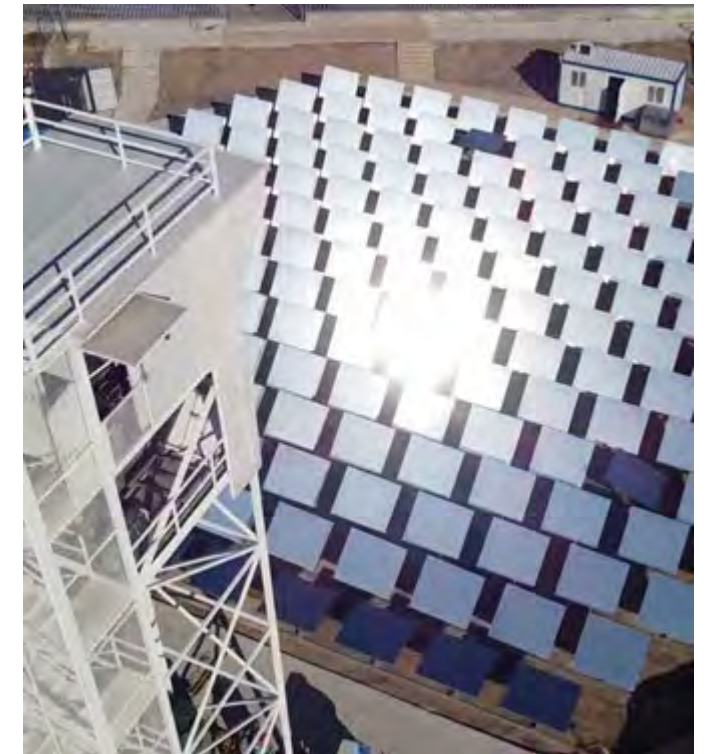
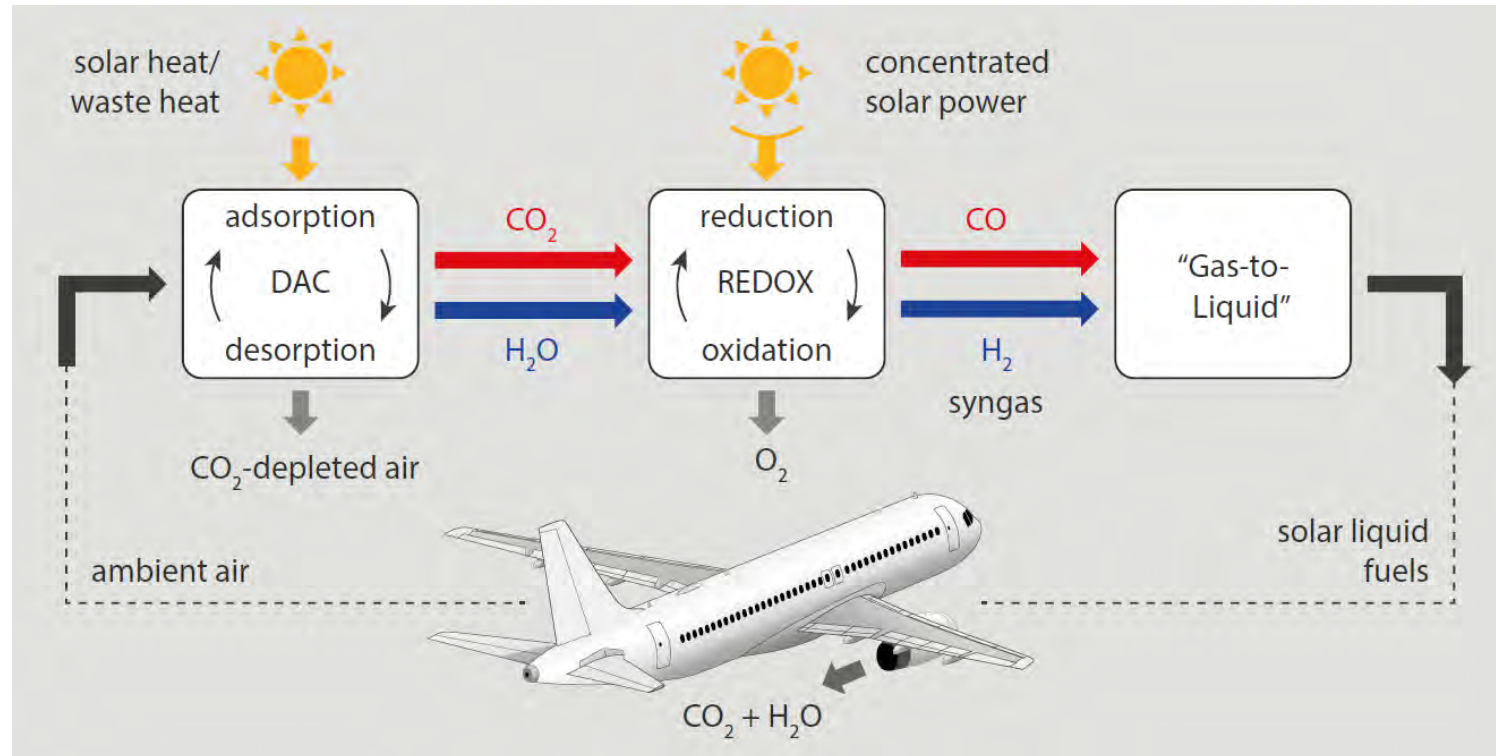
2.5 MW electrolysis at run-of-river plant (100 MW) in Basel (no grid)

260 t/a of green H₂ supply for FC trucks



Green Hydrogen/Fuels from Solar

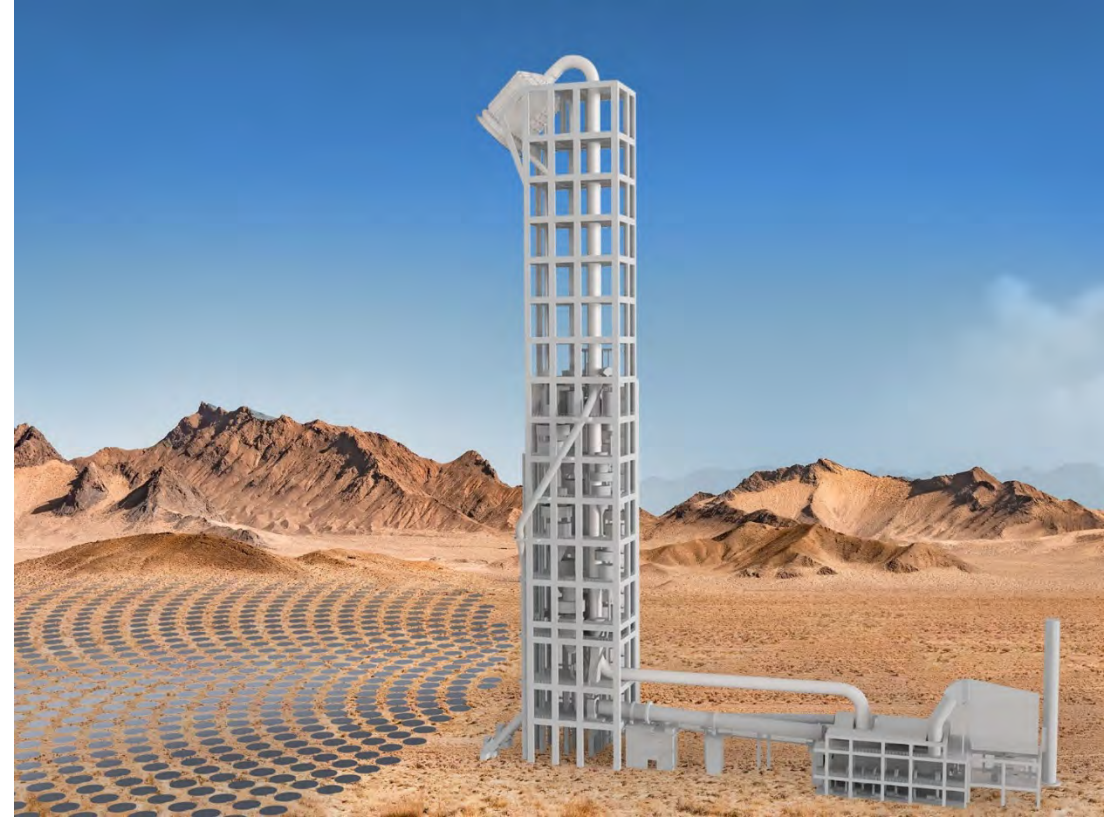
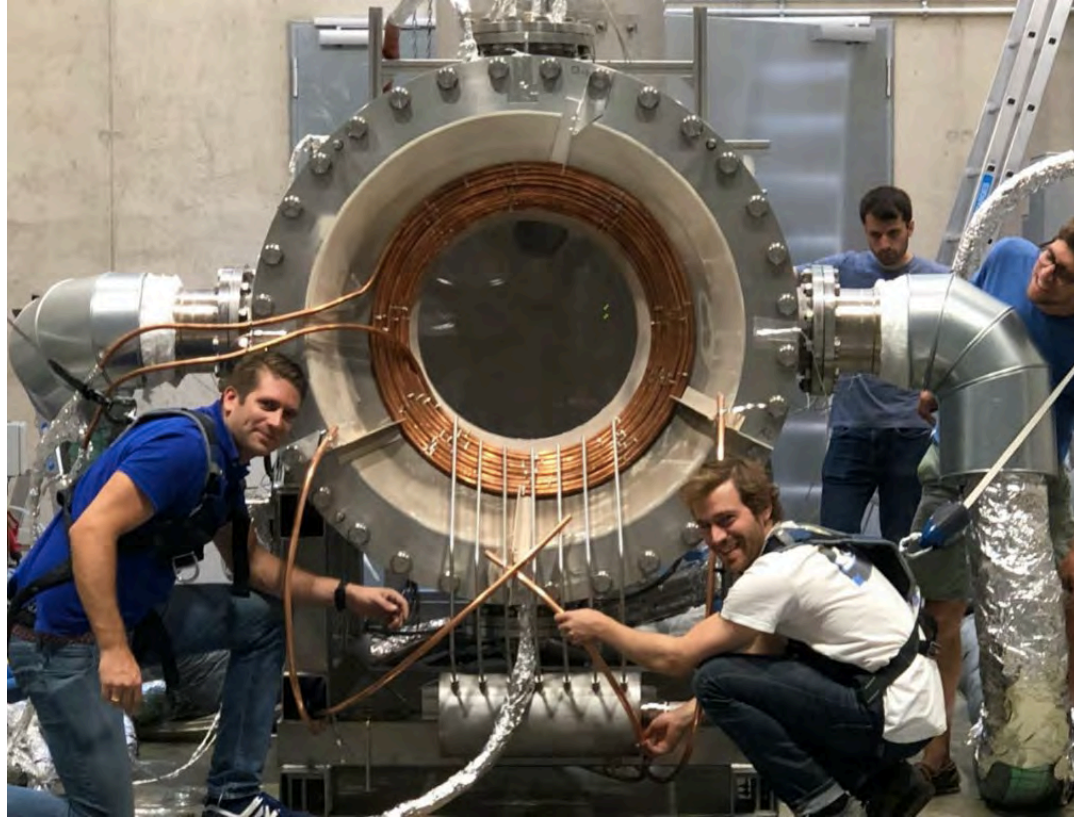
Use concentrated solar power to make solar hydrogen/fuels



See: <https://prec.ethz.ch/research/solar-fuels.html>



Green Hydrogen/Fuels from Solar Scale-up

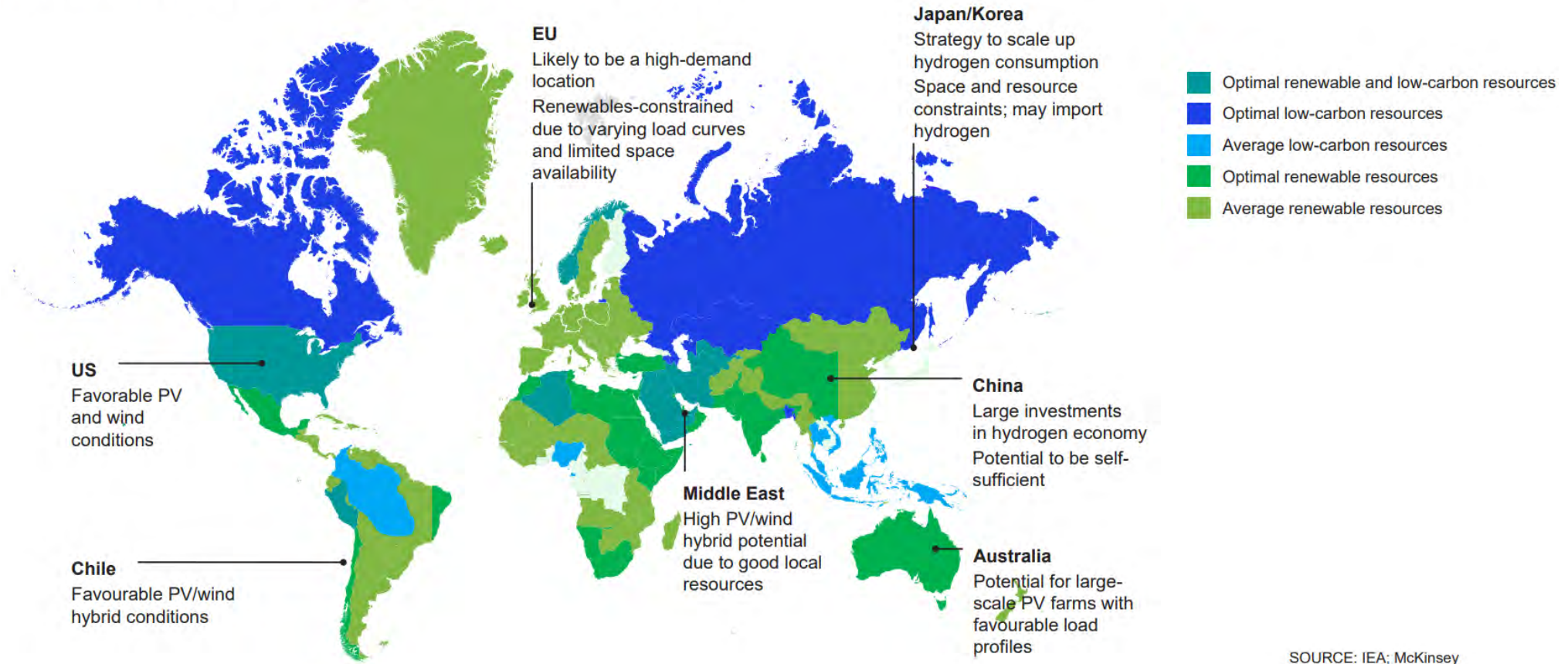


<https://synhelion.com/>
<https://www.solarpaces.org/at-synhelion-solar-jet-fuels-get-ready-for-take-off/>



Green Hydrogen Imports?

Best source of low-carbon hydrogen in different regions



https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf



Hydrogen mobility in Switzerland

- No technology-oriented subsidies, but regulatory framework (e.g. tightening of CO₂ emission limits)
- Public support to build up competences (application oriented R&D) and for innovation (projects with SMEs)
- Public support for pilot & demonstration for experience building and basic infrastructure (clarification of approval procedure, technical feasibility, safety aspects, LCA)
- Foster stakeholder dialogue



Francois Isaac de Rivaz (1752-1828)

First vehicle with internal combustion engine using a mixture of hydrogen and oxygen, operated in Vevey (Switzerland) in 1813.



Hydrogen mobility in Switzerland

Bus demo 2011 to 2016



- first Swiss HRS: on-site production of green hydrogen
- very high operational reliability (>93%)
- five buses with total mileage of 1'370'000 km






Final report:
<https://www.aramis.admin.ch/Default.aspx?DocumentID=45619>





Hydrogen mobility in Switzerland

Truck demo & infrastructure demo 2016 to 2020

| Run-of-river power | Electrolysis | Storage & Distribution | Hydrogen filling station | Fuel Cell Trucks |
|--|---|---|---|--|
| EniwaAG, Aare (Aarau) | PEM-Electrolysis (no grid) | Trailer-Delivery | Station Hunzenschwil AG | «COOP»-truck (Esoro) |
|  |  |  |  |  |
| <p><u>Power:</u> 16 MW</p> <p><u>Annual production:</u> 101 GWh/a</p> <p><u>Emissions:</u> 4.3 gCO₂/kWh</p> | <p><u>PEM-Elektrolysis (30 bar):</u> 174.0 kW</p> <p><u>Compressor (200 bar):</u> 10.7 kW</p> <p><u>Cooling and BOS:</u> 22.0 kW</p> <p><u>Energy input:</u> 76.7 kWh/kg H₂</p> | <p><u>Hydrogen storage:</u> 223 kg</p> <p><u>Distance to station:</u> 22 km</p> <p><u>Consumption:</u> 31 L/100km</p> <p><u>Energy input:</u> 0.3 kWh/kg H₂</p> | <p><u>Compressor (350/700bar):</u> 3.2 kWh/kg</p> <p><u>Pre-cooling (700bar):</u> 0.5 kWh/kg</p> <p><u>Standby:</u> 30.7 kWh/Tag</p> <p><u>Energy input:</u> 3.3 kWh/kg H₂</p> <p>National HRS guide (https://www.snv.ch)</p> | <p><u>Consumption:</u> 8 kg/100km (LKW 35t) 1 kg/100km (PW)</p> <p><u>Emissions:</u> 67.4 gCO₂/km (LKW 35t) (-93%) 8.4 gCO₂/km (PW) (-96%)</p> <p><u>Conventional Emissions:</u> 931.2 gCO₂/km (LKW 35t) 208.7 gCO₂/km (PW)</p> <p><u>Energy input:</u> 642.4 kWh/100km (LKW) 80.3 kWh/100km (PW)</p> |

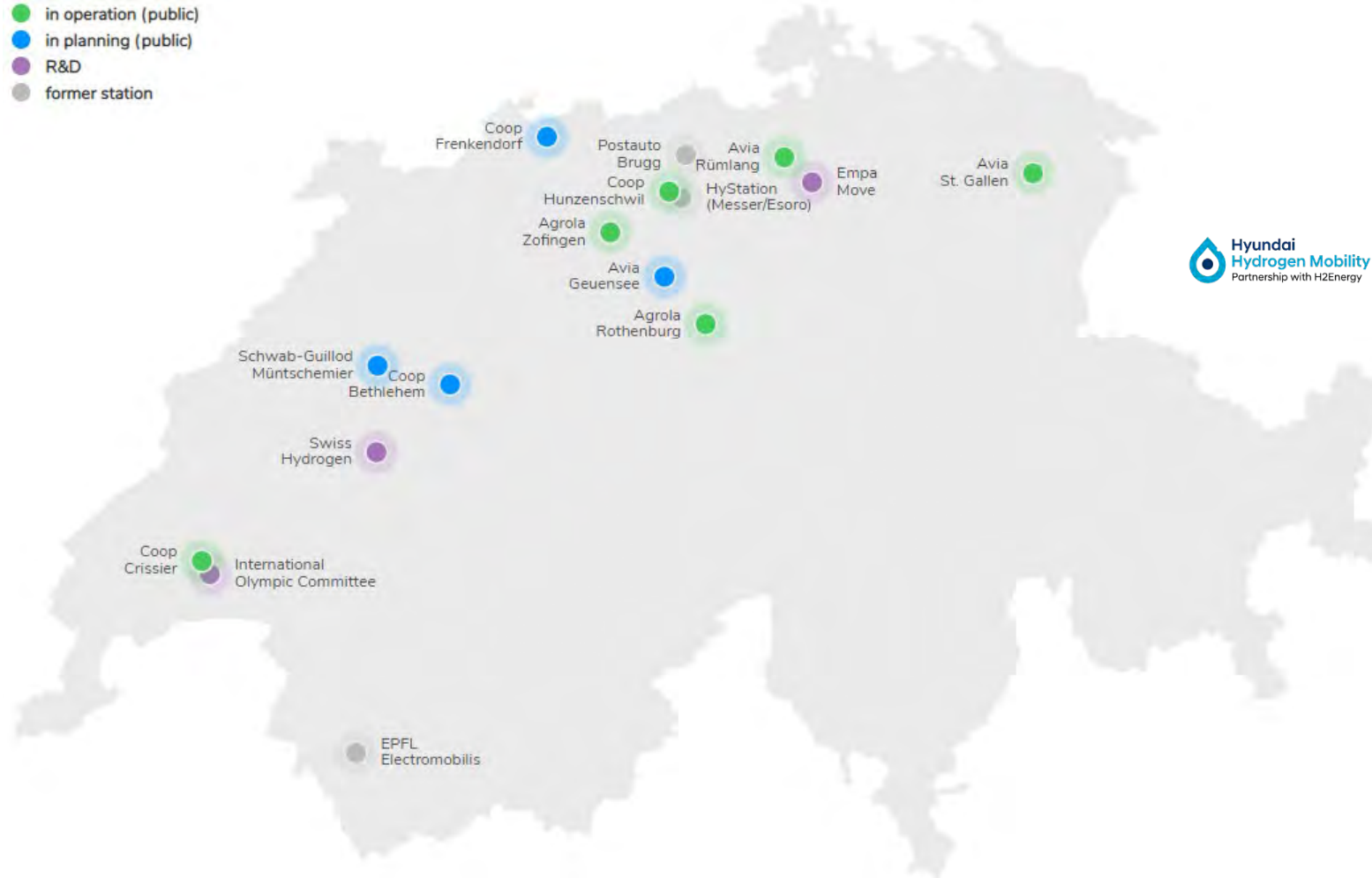
Public reports: www.aramis.admin.ch/Texte/?ProjectID=36922, www.aramis.admin.ch/Texte/?ProjectID=38263, www.aramis.admin.ch/Texte/?ProjectID=38378



Roll out of H2 infrastructure 6 Hydrogen fuelling stations (w/o subsidies)

→ see presentation from Patrick Huber (H2 Energy) tomorrow

- in operation (public)
- in planning (public)
- R&D
- former station



Association pro
H2 mobility Switzerland



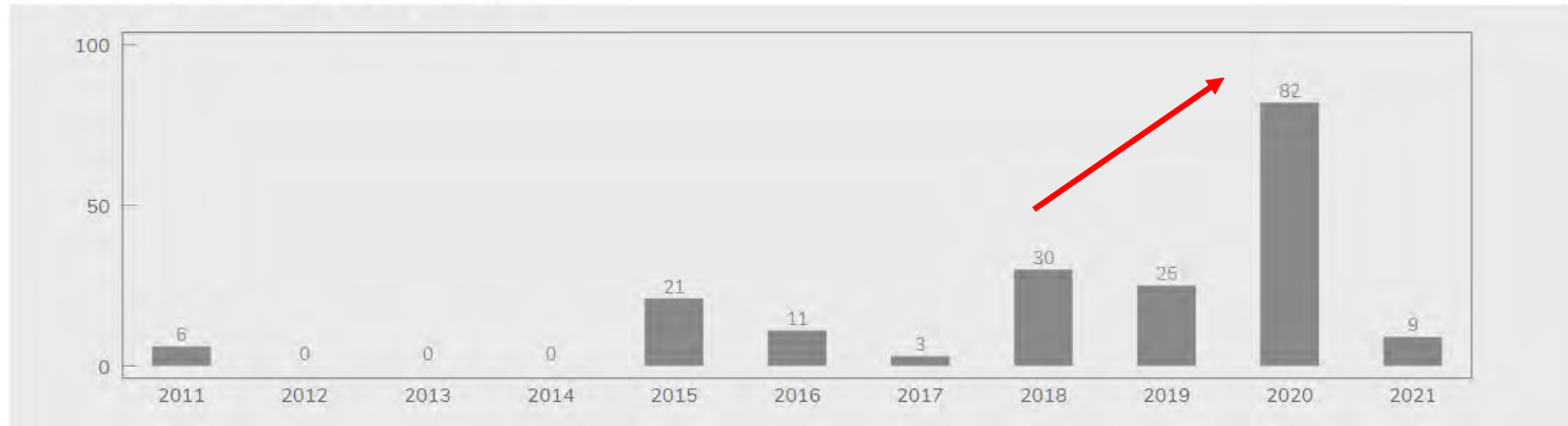
<https://h2mobilitaet.ch/>



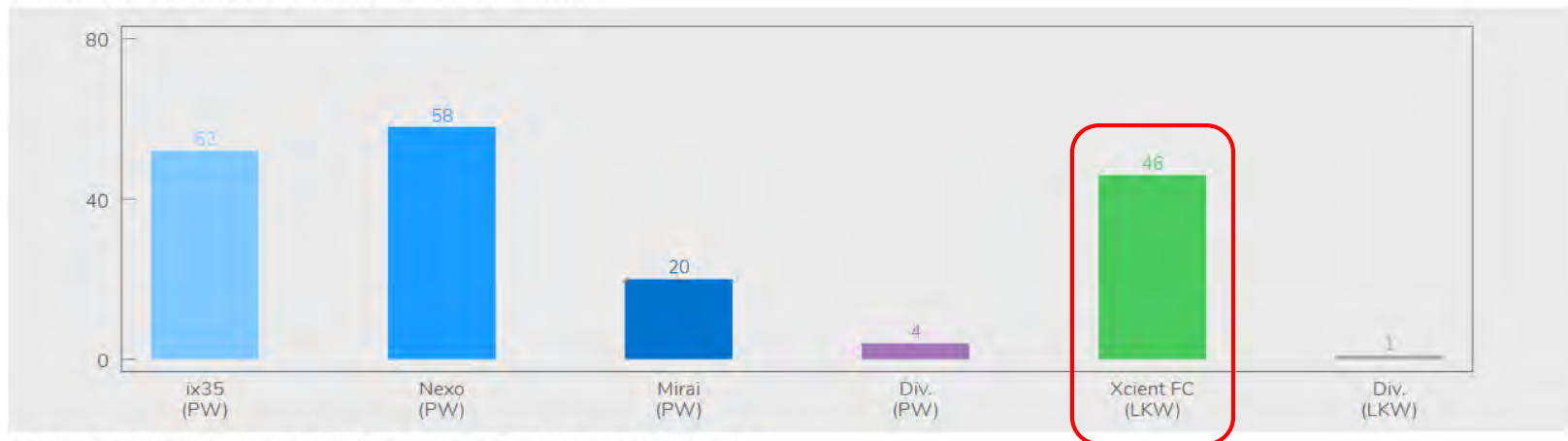
...and fuel cell electric vehicles especially trucks

→ see presentation from Patrick Huber (H2 Energy) tomorrow

Number of newly registered fuel cell vehicles in recent years



Cumulative number of fuel cell vehicles registered on Swiss roads



ix35: Hyundai ix35 FCEV, Nexo: Hyundai NEXO, Mirai: Toyota Mirai, Xcient FC: Hyundai XCIENT Fuel Cell





History of Swiss Hydrogen powered vehicles



<https://h2fc.ch>

Hydrocat (Swiss Alps 3000)



| | | | |
|-------------|---------------------|-------------|-------------------------------|
| type: | snowcat | powertrain: | NN |
| production: | pilot | fuel cell: | none (ICE) |
| status: | not active (3.2004) | H2: | 5 kg (300kg M ⁻¹) |
| number: | 1 | O2: | air |
| weight: | NN | battery: | NN |
| | | H2 use: | NN |
| | | range: | NN |

CityCat H2 (Bucher Schörling/Empa)



| | | | |
|-------------|--------------------------|-------------|-----------------|
| type: | municipal vehicle | powertrain: | 28+12 kW |
| production: | pilot | fuel cell: | 20 kW |
| status: | on the road (since 2007) | H2: | 7.5 kg (700bar) |
| number: | 1 | O2: | air |
| weight: | >2500 kg | battery: | 12 kWh |
| | | H2 use: | NN |
| | | range: | NN |

Citro FuelCELL (Evobus)



| | | | |
|-------------|------------------------------|-------------|----------------|
| type: | bus | powertrain: | 160 kW |
| production: | pre-serial | fuel cell: | 2x60 kW |
| status: | not active (12.2011-02.2017) | H2: | 35 kg (350bar) |
| number: | 5 | O2: | air |
| weight: | 13.2-18 t | battery: | 26.9 kWh |
| | | H2 use: | 8 kg/100km |
| | | range: | 440 km |

HyCarPRO (Esoro)



| | | | |
|-------------|-------------------|-------------|-----------------|
| type: | concept car | powertrain: | 35 kW |
| production: | pilot | fuel cell: | 6 kW |
| status: | not active (2001) | H2: | 2.5 kg (200bar) |
| number: | 1 | O2: | air |
| weight: | 1160 kg | battery: | NN |
| | | H2 use: | NN |
| | | range: | 360 km |

Belenos ELV2 (Belenos Clean Power/PSI)



| | | | |
|-------------|------------------------------|-------------|-----------------|
| type: | passenger car | powertrain: | NN |
| production: | pilot | fuel cell: | 25 kW |
| status: | not active (10.2011-08.2012) | H2: | 2.4 kg (700bar) |
| number: | 1 | O2: | 20 kg (130bar) |
| weight: | NN | battery: | NN |
| | | H2 use: | NN |
| | | range: | 300 km |

ix35 Fuel Cell (Hyundai)



| | | | |
|-------------|--------------------------|-------------|-----------------|
| type: | passenger car (SUV) | powertrain: | 100 kW |
| production: | serial | fuel cell: | 100 kW |
| status: | on the road (since 2015) | H2: | 5.6 kg (700bar) |
| number: | 52 | O2: | air |
| weight: | 1921 kg | battery: | 0.95 kWh |
| | | H2 use: | 0.95 kg/100km |
| | | range: | 590 km |

Hy-SAM (BFH/Cree AG)



| | | | |
|-------------|-------------------|-------------|--------------------------------|
| type: | passenger car | powertrain: | 15 kW |
| production: | pilot | fuel cell: | 6 kW |
| status: | not active (2004) | H2: | 0.3 kg (18kg M ⁻¹) |
| number: | 1 | O2: | air |
| weight: | NN | battery: | NN |
| | | H2 use: | NN |
| | | range: | NN |

Fiat500e Fuel Cell (Swiss Hydrogen)



| | | | |
|-------------|-----------------------------|-------------|-----------------|
| type: | passenger car | powertrain: | 20 kW |
| production: | pilot | fuel cell: | 10 kW |
| status: | on the road (since 08.2013) | H2: | 1.7 kg (700bar) |
| number: | 1 | O2: | air |
| weight: | 1500 kg | battery: | 26 kWh |
| | | H2 use: | 0.85 kg/100km |
| | | range: | 200+200 km |

«Coop-LKW» (Esoro/Swiss Hydrogen)



| | | | |
|-------------|--------------------------|-------------|----------------|
| type: | truck | powertrain: | 250 kW |
| production: | pilot | fuel cell: | 100 kW |
| status: | on the road (since 2016) | H2: | 31 kg (350bar) |
| number: | 1 | O2: | air |
| weight: | 34 t | battery: | 120 kWh |
| | | H2 use: | 8 kg/100km |
| | | range: | 380 km |

Hy-light (Michelin/PSI)



| | | | |
|-------------|-------------------|-------------|-------------|
| type: | passenger car | powertrain: | 30 kW |
| production: | pilot | fuel cell: | 30 kW |
| status: | not active (2004) | H2: | NN (350bar) |
| number: | 1 | O2: | NN |
| weight: | 850 kg | battery: | NN |
| | | H2 use: | NN |
| | | range: | 400 km |

Renault Kangoo ZE HY-REX10 (Swiss Hydrogen)



| | | | |
|-------------|-----------------------------|-------------|-----------------|
| type: | passenger car | powertrain: | 44 kW |
| production: | pilot | fuel cell: | 10 kW |
| status: | on the road (since 09.2017) | H2: | 1.7 kg (700bar) |
| number: | 1 | O2: | air |
| weight: | 1.740 kg | battery: | 22 kWh |
| | | H2 use: | 1 kg/100km |
| | | range: | 170+170 km |

Mirai (Toyota)



| | | | |
|-------------|--------------------------|-------------|---------------|
| type: | passenger car | powertrain: | 113 kW |
| production: | serial | fuel cell: | 114 kW |
| status: | on the road (since 2019) | H2: | 5 kg (700bar) |
| number: | 9 | O2: | air |
| weight: | 1850 kg | battery: | 1.6 kWh |
| | | H2 use: | 1 kg/100km |
| | | range: | 500 km |

PAC-Car II (ETH Zurich)



| | | | |
|-------------|-------------------|-------------|--------|
| type: | concept car | powertrain: | NN |
| production: | pilot | fuel cell: | 0.8 kW |
| status: | not active (2005) | H2: | NN |
| number: | 1 | O2: | air |
| weight: | 32 kg | battery: | NN |
| | | H2 use: | NN |
| | | range: | NN |

H2 Speed (Green GT)



| | | | |
|-------------|---------------------|-------------|-----------------|
| type: | race car | powertrain: | 370 kW |
| production: | mini-serial | fuel cell: | 210 kW |
| status: | active (since 2016) | H2: | 6.1 kg (700bar) |
| number: | 1 | O2: | air |
| weight: | 1420 kg | battery: | 8 kWh |
| | | H2 use: | NN |
| | | range: | NN |

Nexo (Hyundai)



| | | | |
|-------------|--------------------------|-------------|-----------------|
| type: | passenger car (SUV) | powertrain: | 120 kW |
| production: | serial | fuel cell: | 95 kW |
| status: | on the road (since 2019) | H2: | 6.3 kg (700bar) |
| number: | 32 | O2: | air |
| weight: | 1889 kg | battery: | 1.56 kWh |
| | | H2 use: | 0.95 kg/100km |
| | | range: | 660 km |

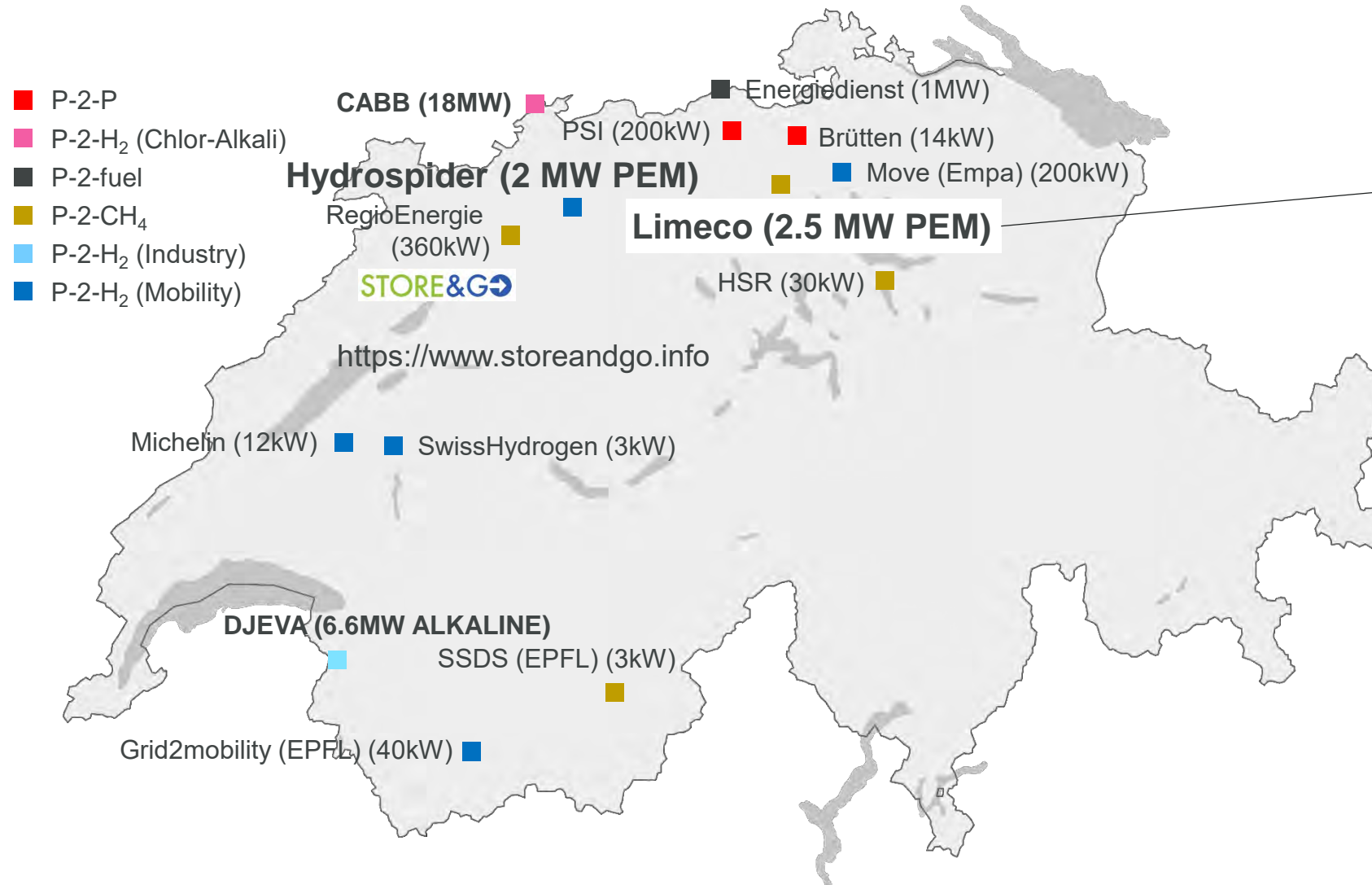
H2 Xcient Fuel Cell (Hyundai)



| | | | |
|-------------|--------------------------|-------------|----------------|
| type: | truck | powertrain: | NN |
| production: | serial | fuel cell: | 2x95 kW |
| status: | on the road (since 2020) | H2: | 35 kg (350bar) |
| number: | 1 | O2: | air |
| weight: | 34 t | battery: | NN |
| | | H2 use: | 9 kg/100km |
| | | range: | 400 km |



Power-to-Gas



- under construction:
- 2.5 MW PEM electrolysis
 - powered by waste incineration plant (15 GWh/year)
 - CO₂ from sewage gas used for biological methanisation
 - 18,000 MWh of renewable gas per year



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- **International Collaboration**
- Conclusions

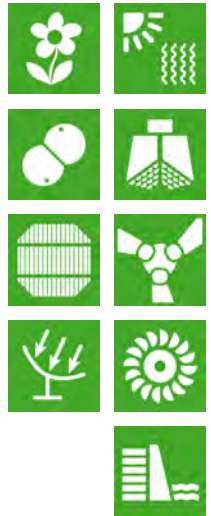


see presentation from Patrick Huber
(H2 Energy) tomorrow



SFOE Hydrogen and Fuel Cells Programme R&D and pilote & demonstration

Renewable Energy



- Biomass & Wood
- **Hydrogen**
- Photovoltaics
- CSP & Solar Process Heat
- Solar Heating and Cooling
- Geothermal Energy
- Wind
- Hydropower
- Dams

Energy Efficiency



- Buildings
- Transports & Accumulators
- Grids
- Process engineering
- Electricity technology
- **Fuel Cells**
- Heat Pumps, Cogeneration, Refrigeration
- Combustion

Nuclear Energy (not SFOE)



- Regulatory Safety Research
- Nuclear Technology and Safety
- Nuclear Fusion
- Nuclear Waste

Cross-sectional Themes



- Energy policy fundamentals



Main topics in SFOE H2 and FC programme

The funds available in the SFOE Hydrogen and Fuel Cell Program are used as seed money to coordinate and initiate various activities in national research and demonstration projects.

Fuel cells for stationary applications: SOFC & PEFC

- Micro CHP with SOFC (R&D, Demo): lifetime, degradation, costs
- Gas-to-Power: larger PEFC system for storage
- Back-up power systems (UPS)

Fuel cells for automotive applications: PEFC

- PEFC R&D: lifetime, degradation, modelling
- PEFC system: 10-30 kW for EV range extender
- BoS: efficient turbo compressor for PEFC systems

Hydrogen

- **Production from renewables** (Solar Hydrogen, PEC, high temperature solar, electrolysis)
- Storage (metal hydrides, compressed H₂)
- Hydrogen compression
- Hydrogen refueling



International Collaboration

Cooperation within the framework of the International Energy Agency (IEA) is of particular importance to Switzerland. The SFOE participates in various IEA “Technology Collaboration Programmes”, where FC and H2 is a topic:



On a European level, Swiss actors strongly participate in FCH JU



Swiss Hydrogen SA (Plastic Omnium) is involved in the Hydrogen Council

H2 Energy AG: board member of Hydrogen Europe



Conclusions

- Hydrogen mobility complements pure battery electric mobility to reduce greenhouse gas emissions in transport.
- Clear political framework conditions and a sufficiently fast ramp-up are important to become economically viable in the near term. Private initiatives in Switzerland have been pioneering here.
- The availability of green hydrogen is important, as well as the exact labelling (trading).
- The increase in renewable energies must be significantly accelerated, which will free up capacities for hydrogen production. This renders discussions about hydrogen, which revolve solely around efficiency, superfluous.



Thank you for your attention



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photo: Swiss Hydrogen / Race4water