“Produktion und Speicherung erneuerbarer Energie

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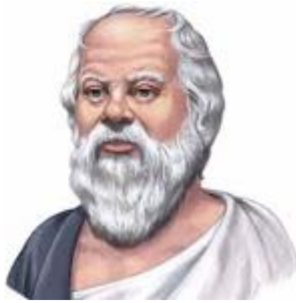
Herbsttagung der
Vereinigung für Umweltrecht (VUR)
24. November 2022

Szenarien sind schöne Geschichten, welche meistens mit der Realität wenig gemeinsam haben.



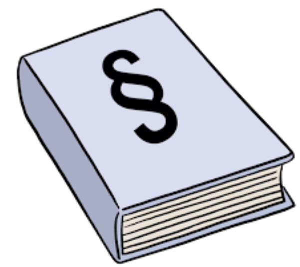
Sokrates
469 – 399 v. Ch.

Naturgesetze
Kausalität, Stetigkeit und Objektivierbarkeit

Werden immer eingehalten, sogar wenn man sie nicht kennt.

$$Leistung = \frac{Energie}{t} \qquad P = \frac{W}{t}$$

Aristoteles
384 – 322 v. Ch.



Das Gesetz ist Vernunft befreit von Leidenschaft.

Ist bekannt, kann abgeändert oder nicht eingehalten werden.

Geschichte der Energie

Dampfturbine

Held von ALEXANDRIA
10 - 70

Hydro- and Windpower

Dampfmaschine

Thomas NEWCOMEN
1712

Opt. Dampfmaschine

James WATT
1783

Dampflokomotive

George STEPHENSON
1828

Standard Oil Company

John D. ROCKEFELLER
1865

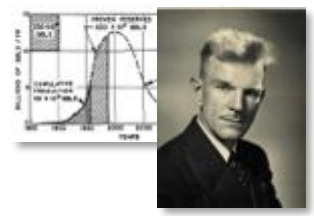
Patent Motorwagen

Carl BENZ
1886

Motorisierter Flug

Wilbur & Orville WRIGHT
1903

Modell für Erdölfelder



M. King HUBBERT
1957

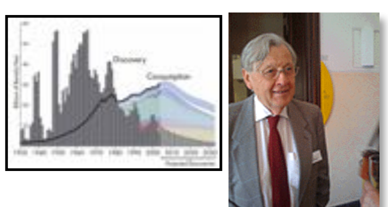
Club of Rome

Jimmy“ CARTER
1978

Solare Energie & H_2

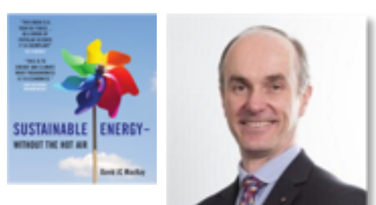
Carl-J. WINTER
1989

Modell Fossile Resourcen



Colin J. CAMPBELL
1998

SEWTHA



Sir David J. C. MACKAY
2008

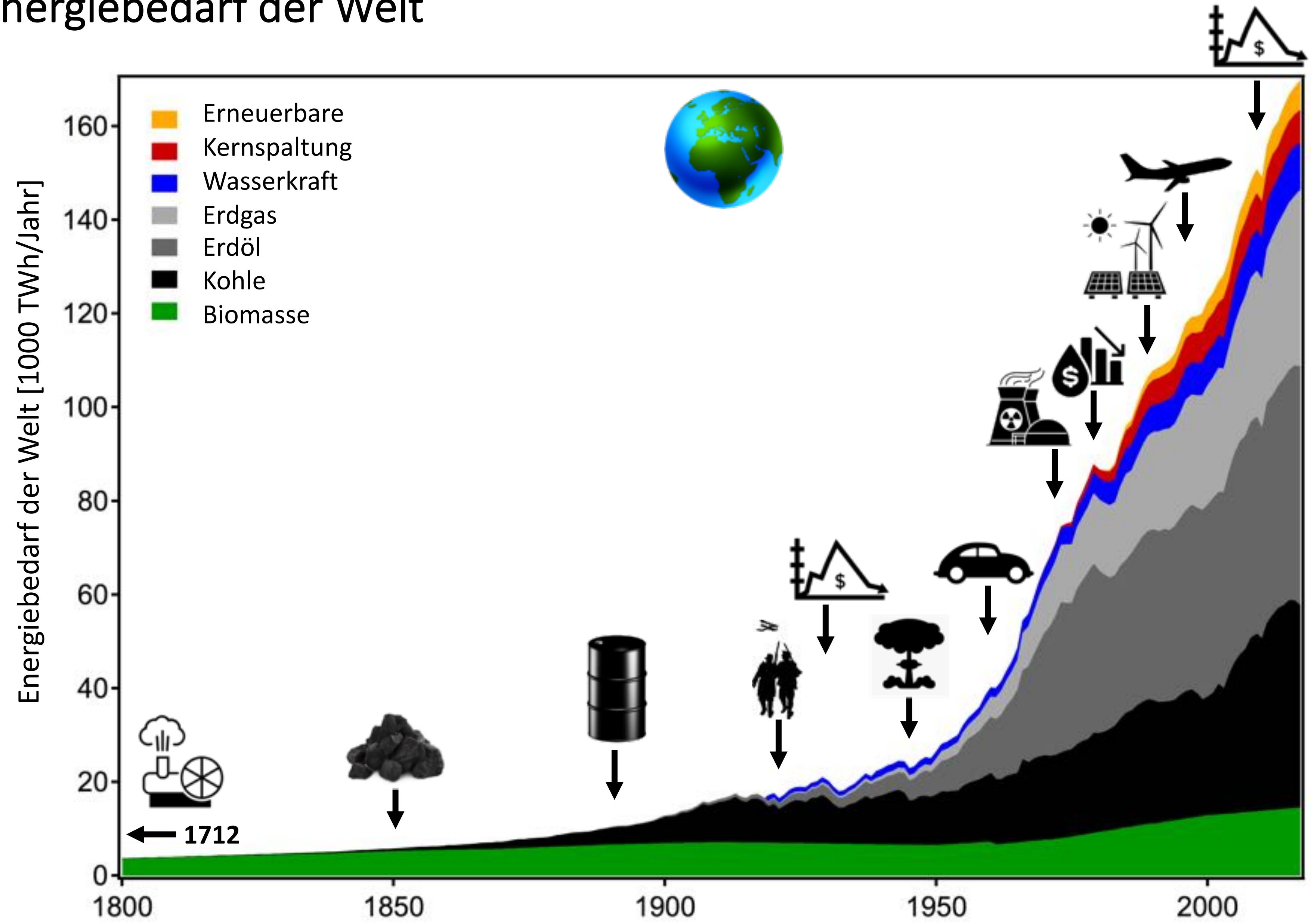
CO_2 aus der Luft

Klaus S. LACKNER
2009

Gapminder

Hans ROSLING
2009

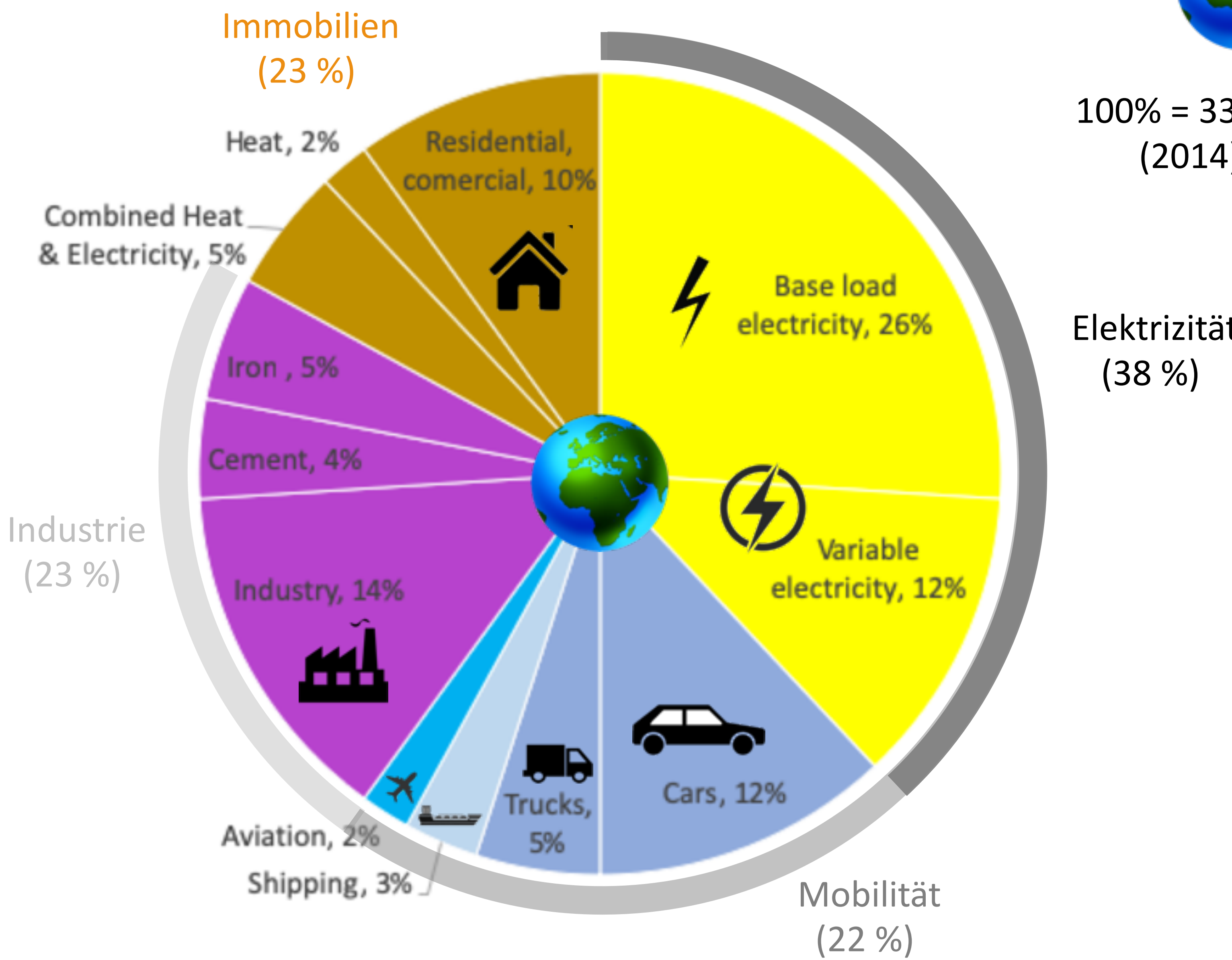
Energiebedarf der Welt



Ref.: https://ourworldindata.org/energy-production-consumption

CO_2 Emitter nach Sektoren

100% = 33.9Gt
(2014)

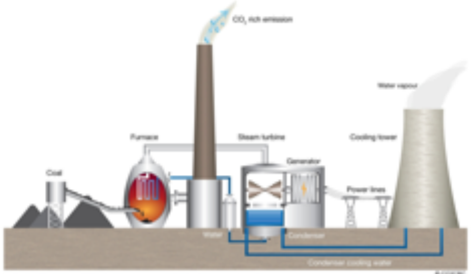


Ref.: Davis, S. J. et al. « Net-zero emissions energy systems », *Science* 360 (2018), pp. 1–9.

Energiebedarf der Welt (19 TW)

Elektrizität 7.3 TW = 3.2 TW$_{el.}$

2000 GW 40% 17%



Kohle-, Öl- und Gaskraftwerke

380 GW

Kernkraftwerke

500 GW + 300 GW

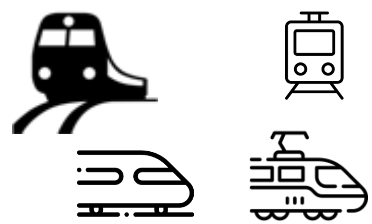
PV- und Wind

Wasserkraftwerke

Mobilität 4.2 TW

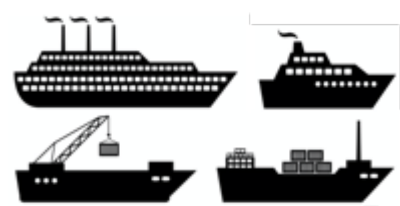
3230 GW

24 GW



380 GW

570 GW



Immobilien 7.5 TW

1200 GW

Wohnen

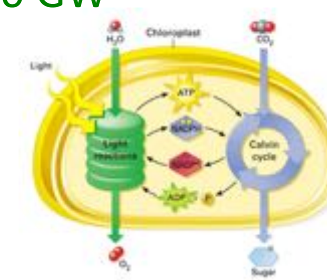
1900 GW

Gewerbe

4370 GW

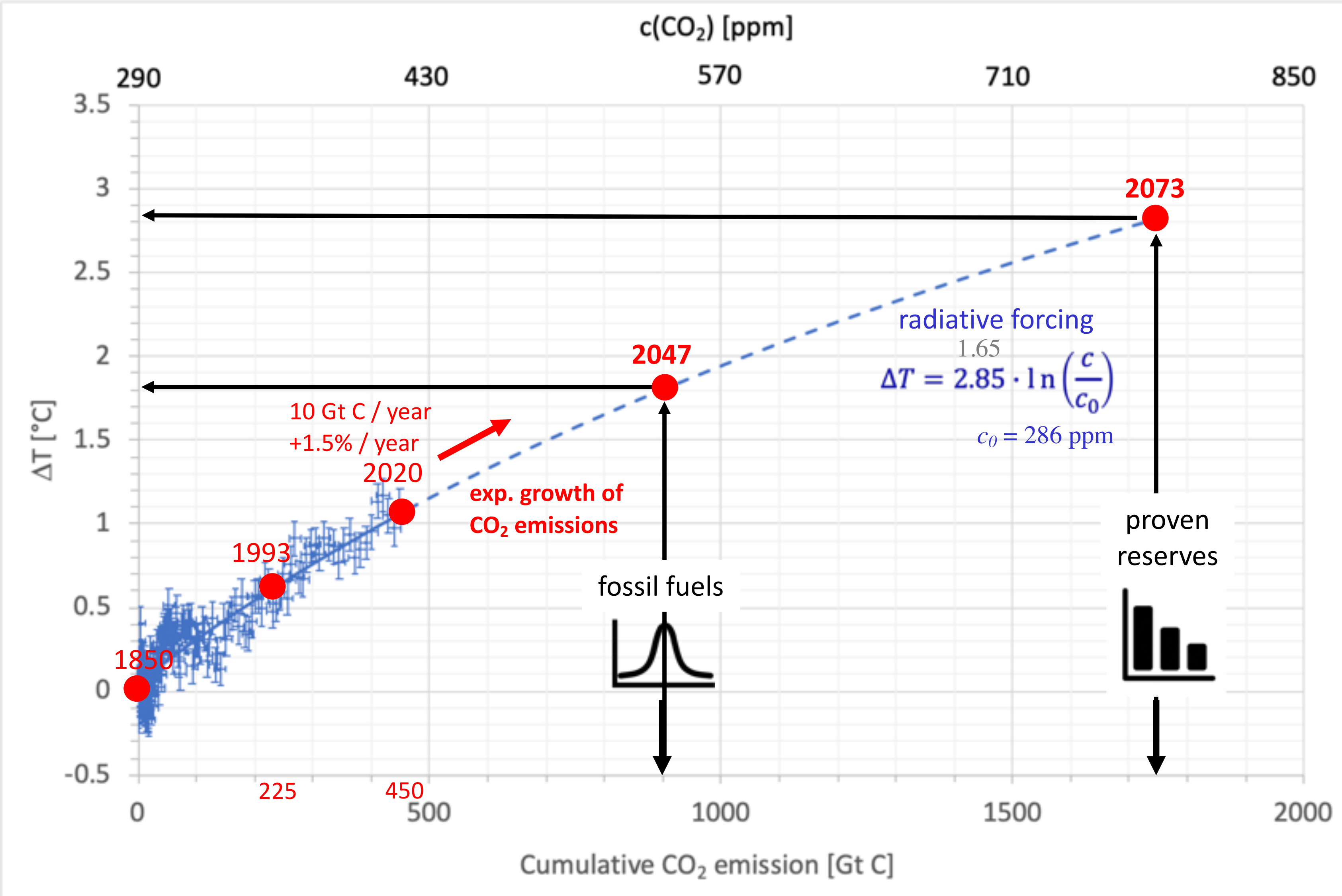
Industrie

1200 GW



Biomasse

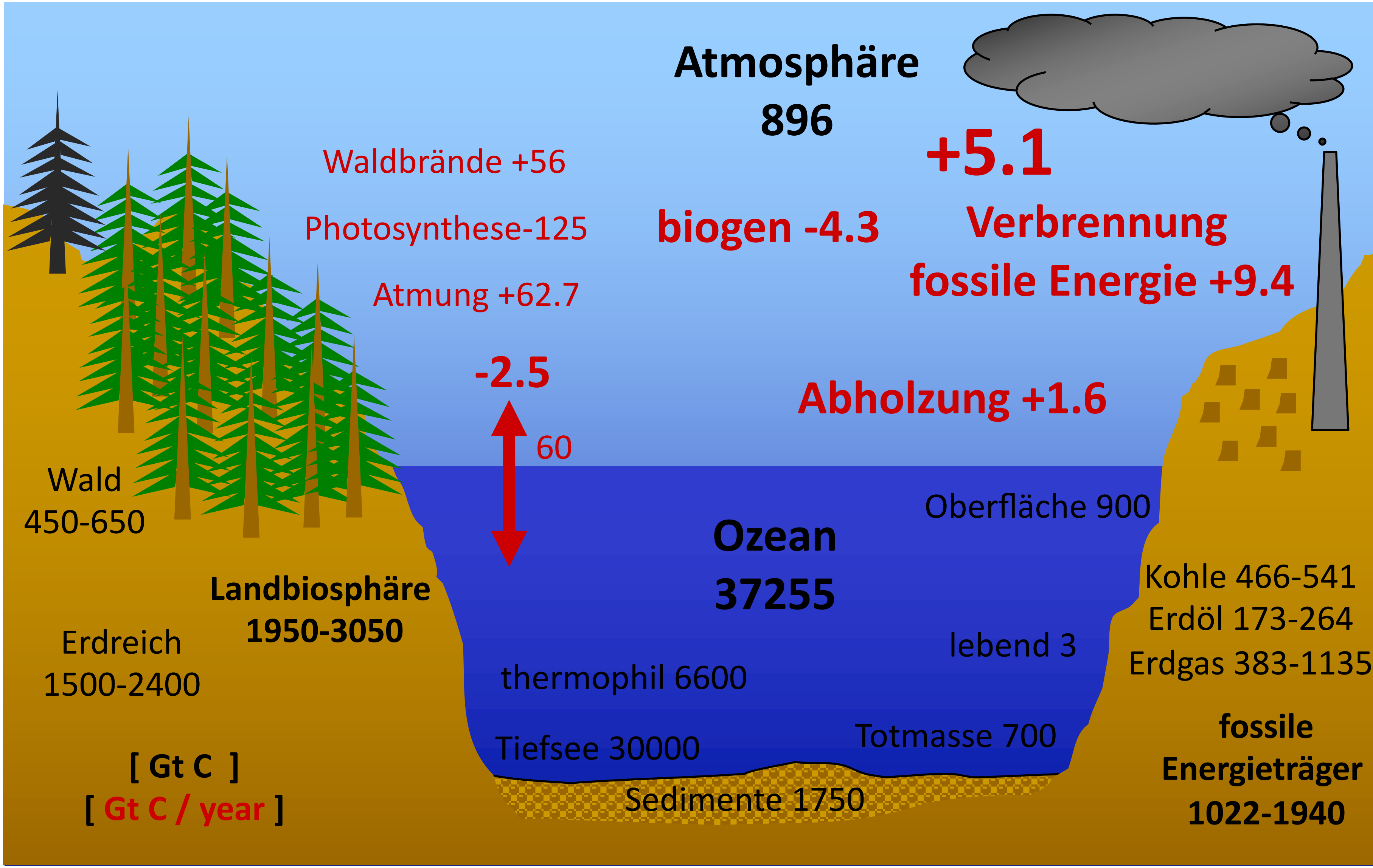
Globale Erwärmung vs. kumulierte CO_2 Emissionen



Ref.: http://www.globalwarmingequation.info/global%20warming%20eqn.pdf and Ollila, A. (2014), “The potency of carbon dioxide (CO2) as a greenhouse gas”, Development in Earth Science, Vol. 2, pp. 20-30, available at: www.seipub.org/des/paperInfo.aspx?ID=17162

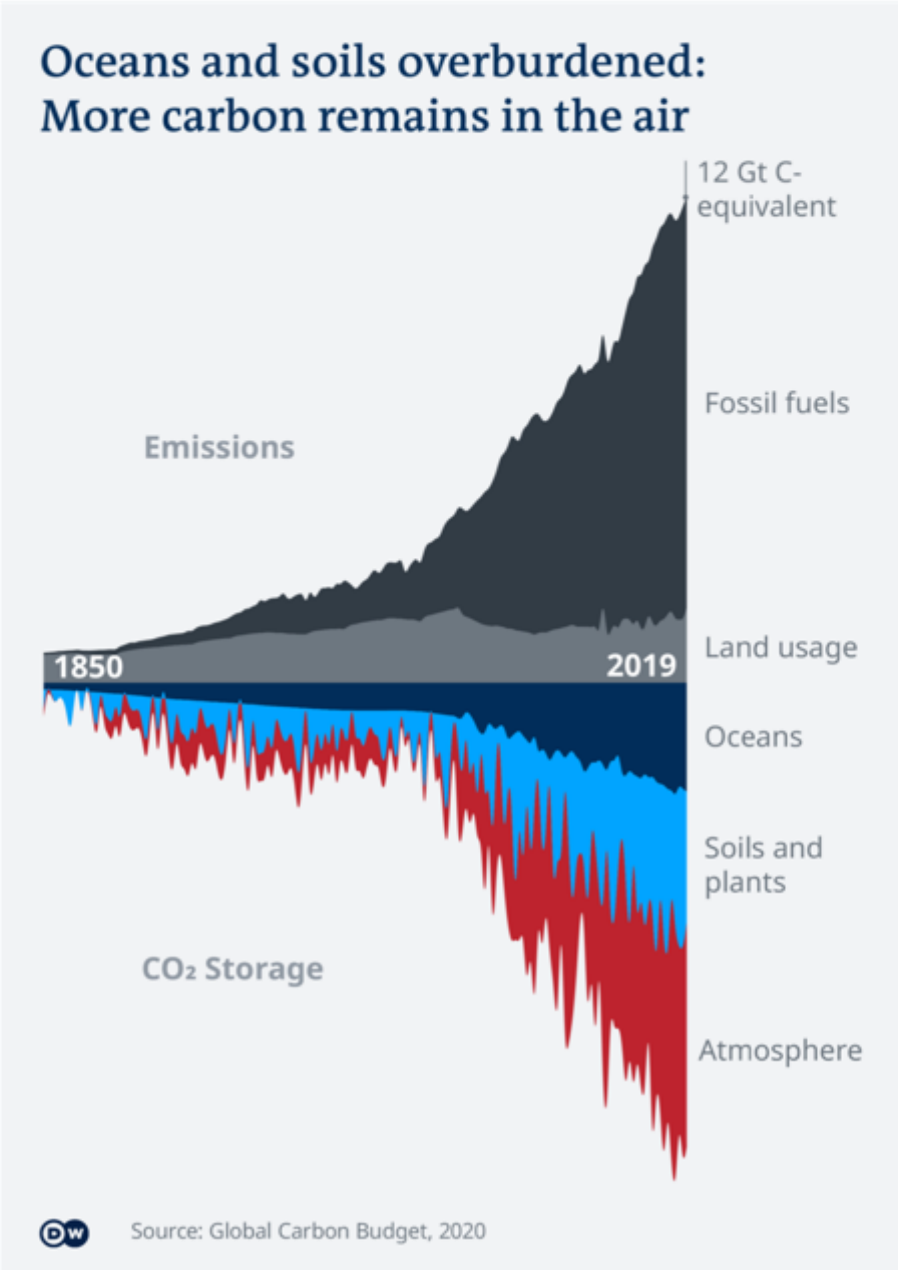
Globaler Kohlenstoffzyklus

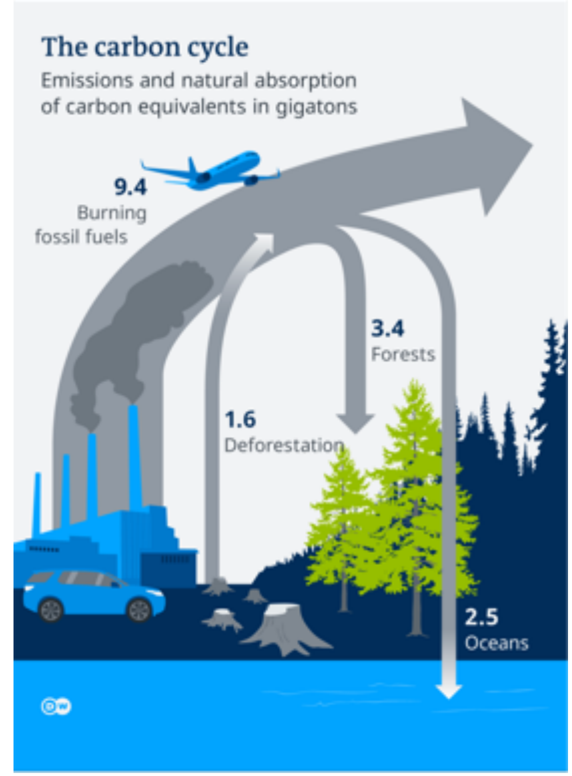
2020



Kandasamy S and Nagender Nath B (2016) “Perspectives on the Terrestrial Organic Matter Transport and Burial along the Land-Deep Sea Continuum: Caveats in Our Understanding of Biogeochemical Processes and Future Needs.”, Front. Mar. Sci. 3:259. doi: 10.3389/fmars.2016.00259

CO_2 Emissionen und Senken





CO_2 Emissions:

Burning fossil fuels: +9.4 $Gt \cdot y^{-1}$

Deforestation: +1.6 $Gt \cdot y^{-1}$

Ocean: - 2.5 $Gt \cdot y^{-1}$ (±5%)

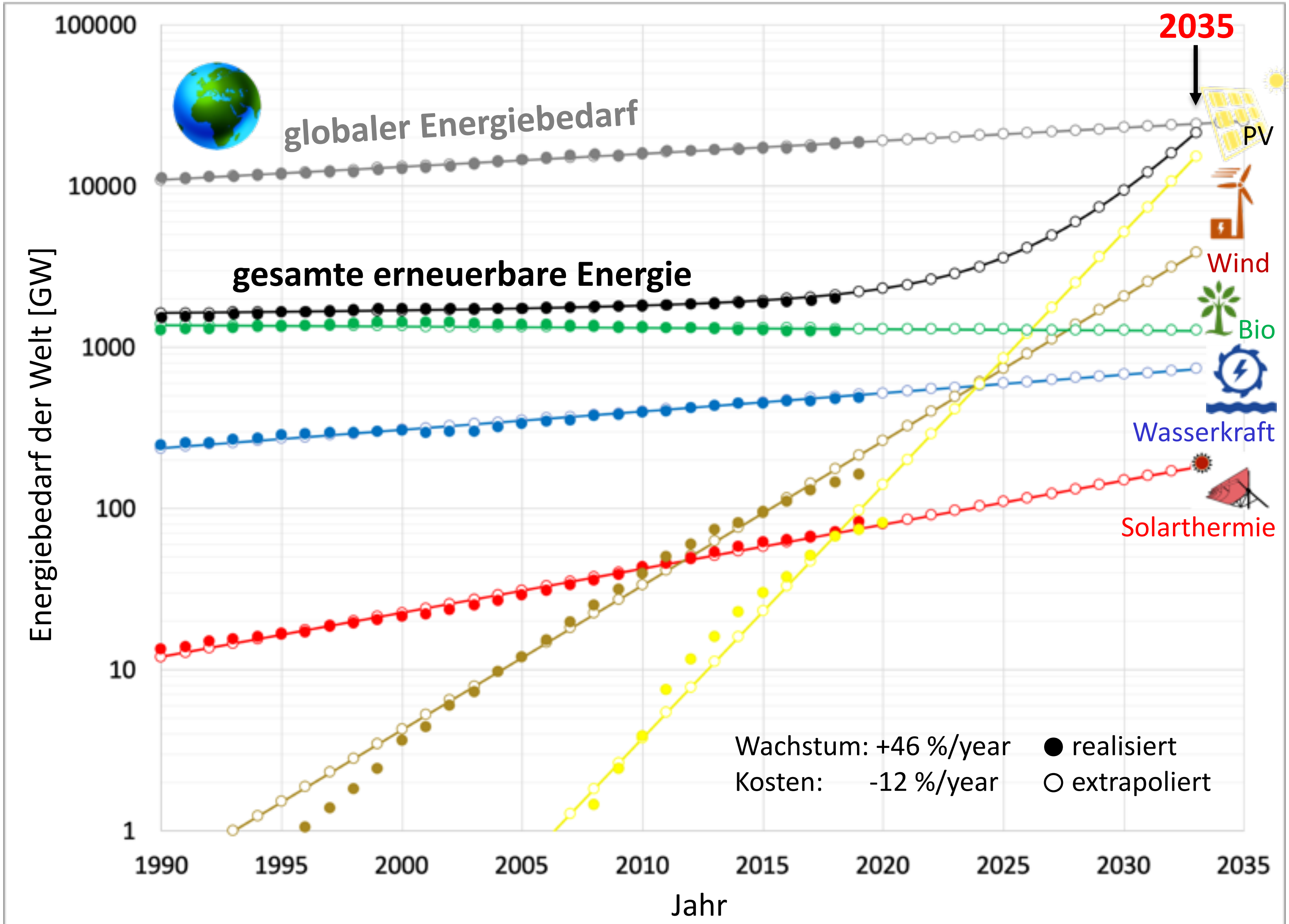
Forests: -3.4 $Gt \cdot y^{-1}$ (±20%)

Total in atmosphere: +5.1 $Gt \cdot y^{-1}$ (±50%)

Total absorption: -5.9 $Gt \cdot y^{-1}$ (at 410 ppm)

Ref.: https://p.dw.com/p/433zw

Globale erneuerbare Energieproduktion



Ref.: https://ourworldindata.org/energy

Erneuerbare Elektrizitätsproduktion

Globale Electrizitätsbedarf 3.2 TW
Erneuerbare Energie: 0.9 TW

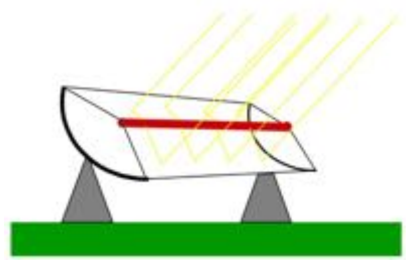
0.5 TW_{el}
1 TW_p

500 GW (*3000 GW*)

Wasserkraft

0.33 TW
2.21 TW_P

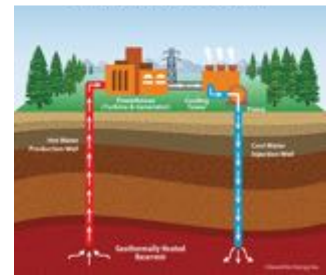
80 GW (*23000 GW*)



Solarthermie

0.04 TW

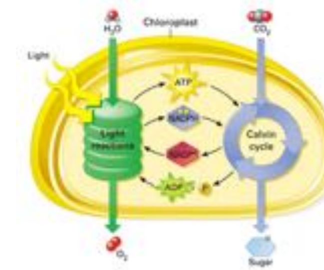
21 GW (*2000 GW*)



Geothermie

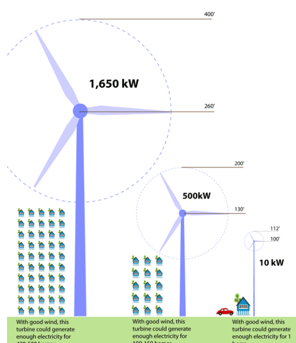
1.2 TW

1200 GW (*2400 GW*)



Biomasse

170 GW (*70000 GW*)

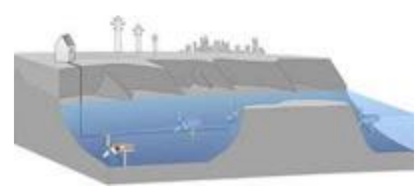


Windenergie

80 GW (*3000 GW*)

Photovoltaik

19 GW (*300 GW*)

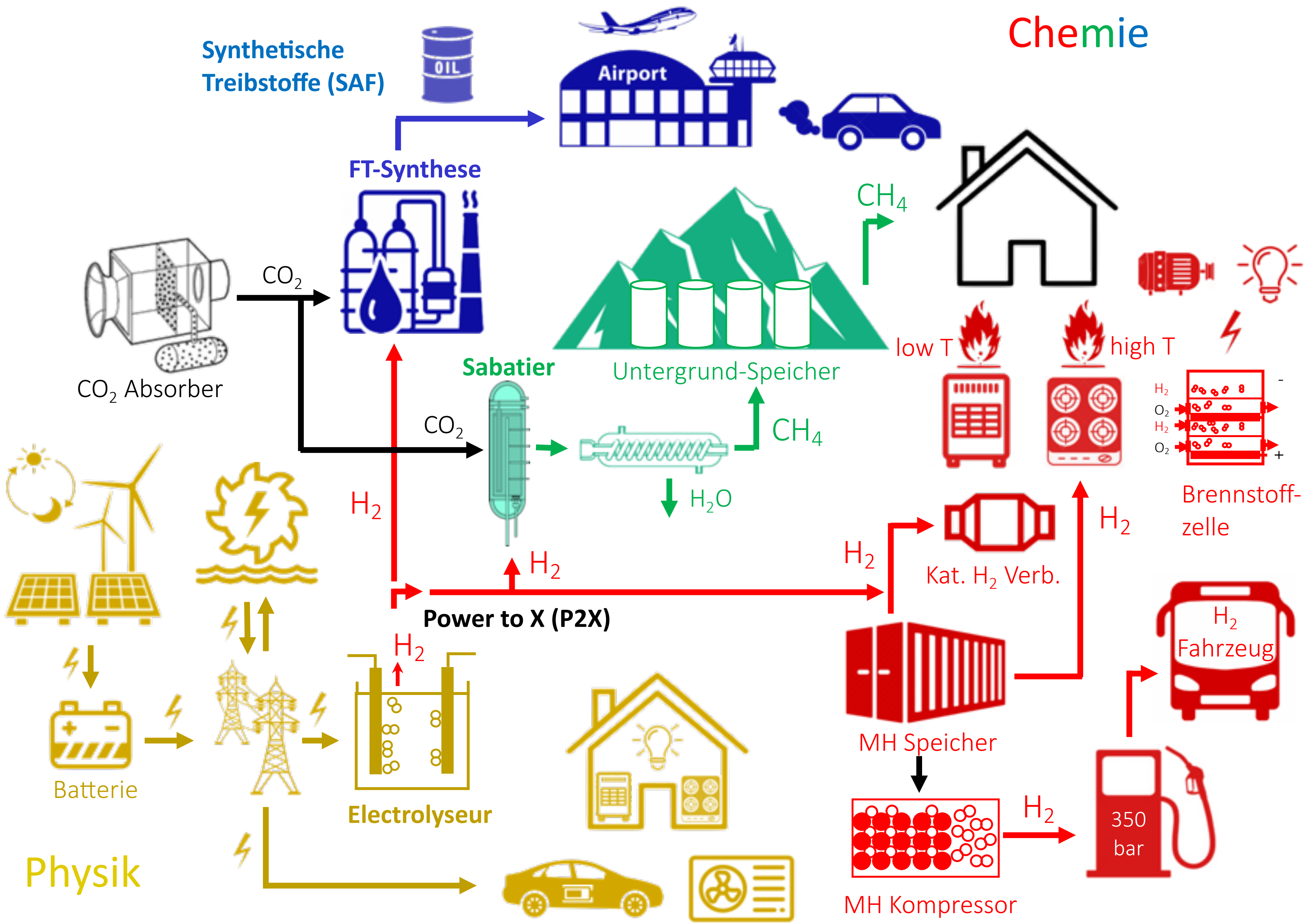


Gezeiten

Saison in der Schweiz

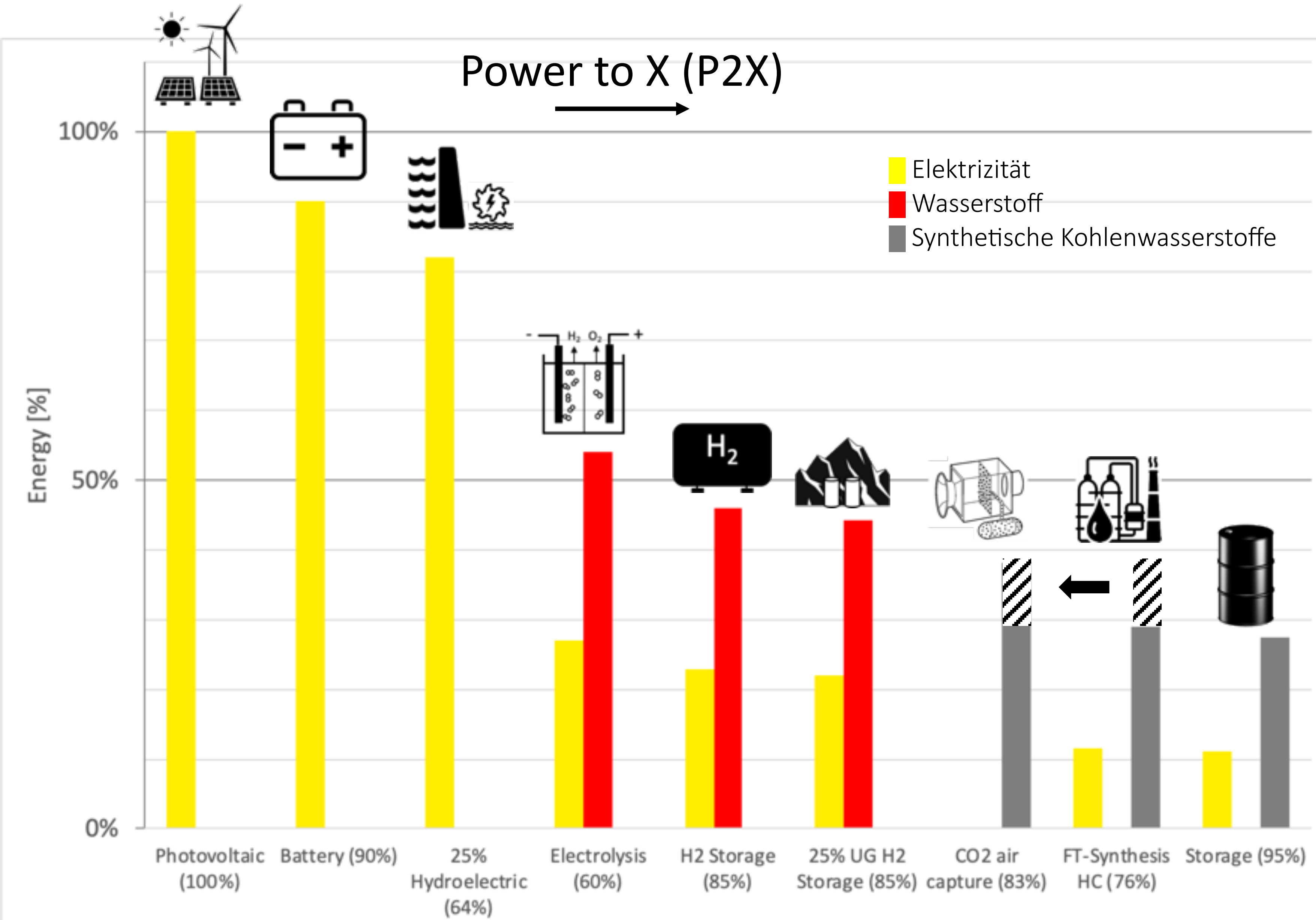
100 $W \cdot m^{-2}$ | 160 $W \cdot m^{-2}$ | 100 $W \cdot m^{-2}$ | 40 $W \cdot m^{-2}$ | mittlere Sonnenintensität

Erneuerbare Energiesysteme

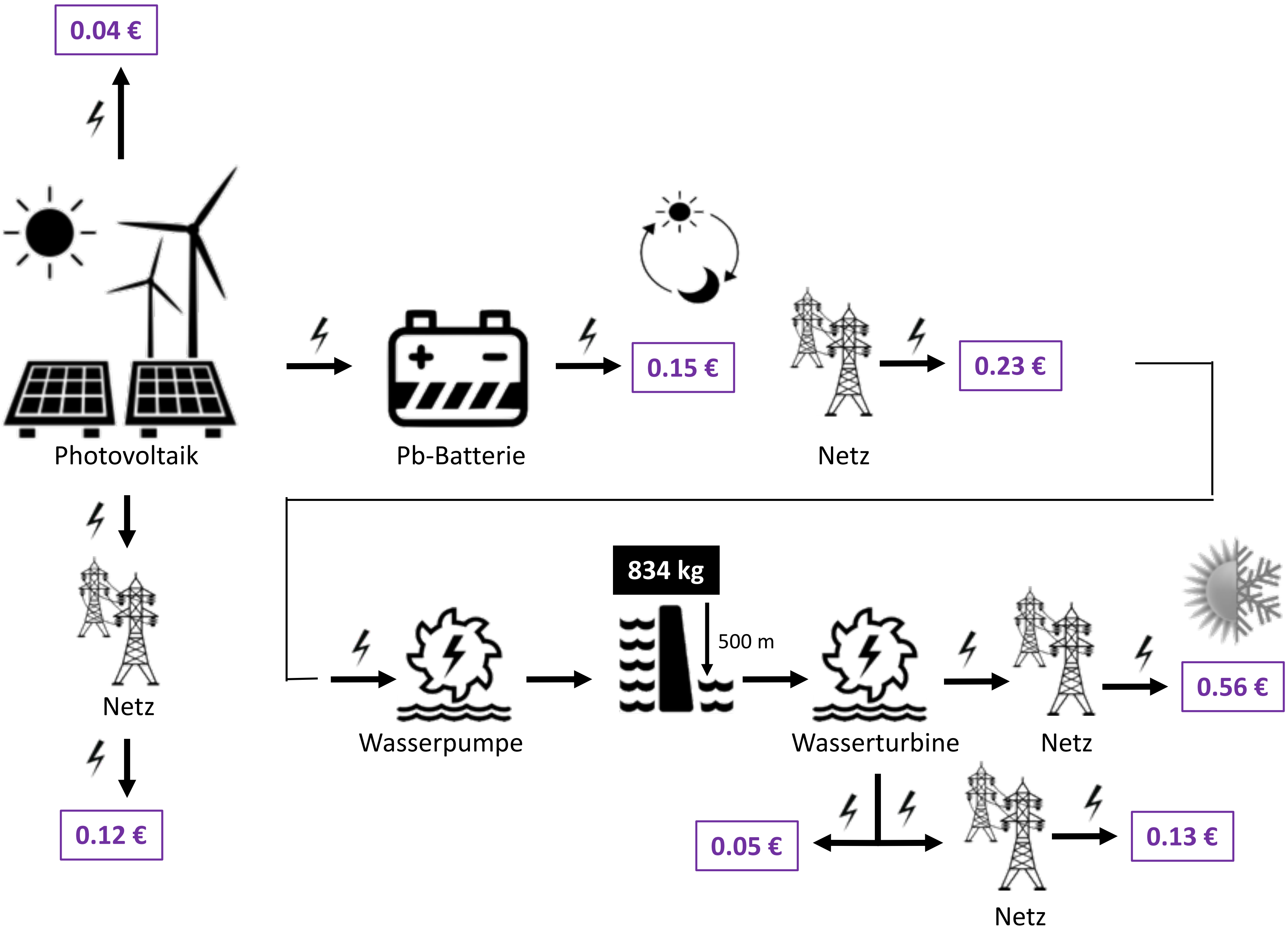


Effizienz der erneuerbaren Energiewandlung

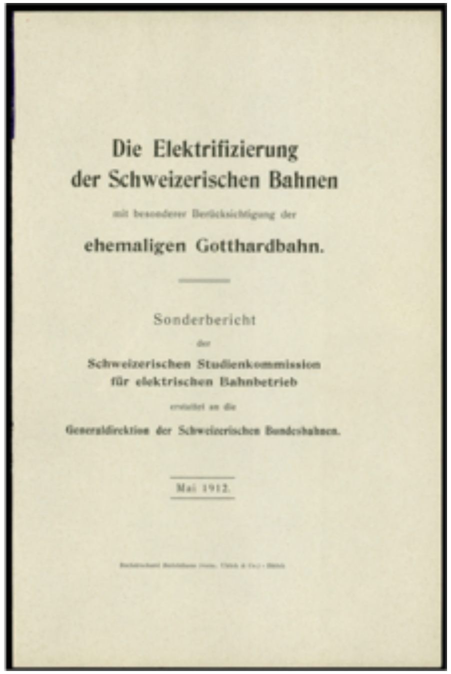
Produktion und Speicherung erneuerbarer Enbergie



Kosten für 1 kWh Elektrizität



Die Entscheidung Kohle durch Elektrizität zu ersetzen 1912


Die Elektrifizierung
der Schweizerischen Bahnen
mit besonderer Berücksichtigung der
ehemaligen Gotthardbahn.

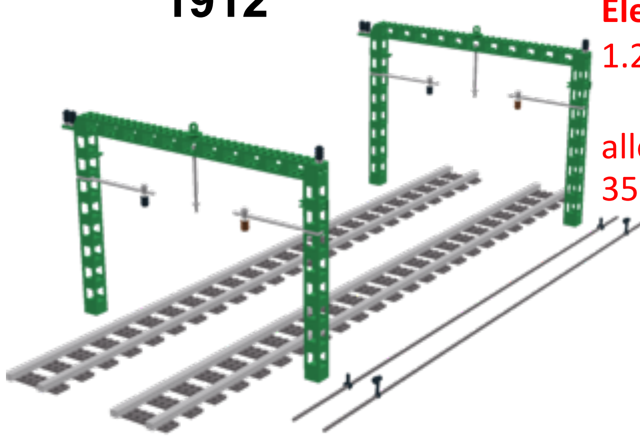
Sonderbericht
der
Schweizerischen Studienkommission
für elektrischen Bahnbetrieb
erstattet an die
Generaldirektion der Schweizerischen Bundesbahnen.

Mai 1912.

1912

Die Bedeutung der Elektrifizierung der Bahnen für die Schweiz liegt nicht nur in rein technischen Vorteilen, sondern auch in der Nutzung der eigenen Wasserkraft anstelle des Imports von Kohle aus dem Ausland. Die für diese Betriebsweise kalkulierten Projekte für den elektrischen Betrieb der Gotthardbahn zeigen, dass es für den Verkehr, wie er bei Einführung der Elektrifizierung sein wird, auch bei den aktuellen Kohlepreisen, unter der Annahme von deutlich höheren Geschwindigkeiten, deutlich günstiger sein wird als der Dampfbetrieb, daher Vorteile der Rauchfreiheit und die Möglichkeit der besseren Nutzung des Schienensystems.

Ref.: "Die Elektrifizierung der Schweizerischen Bahnen mit besonderer Berücksichtigung der ehemaligen Gotthardbahn.", Sonderbericht der Schweizerischen Studienkommission für elektrischen Bahnbetrieb erstattet an die Generaldirektion der Schweizerischen Bundesbahnen. Mai 1912.



Elektrifizierung
1.23 – 2.6 Mio.€/km

alle 27m ist ein Mast,
35 – 70 k€ pro Mast

Schienen kosten 62 Mio. CHF/km
(Autobahn kostet 150 - 330 Mio.CHF/km)

Ref.: Germany: Lindau -München 500 Mio.€ for 189 km incl. noise protection, new train station...
Denmark: whole railway 1'600 Mio.€ for 1300 km

Wechsel der Energie Strategie

Fukushima Dai-ichi Kernkraftwerk Desaster

11. March 2011

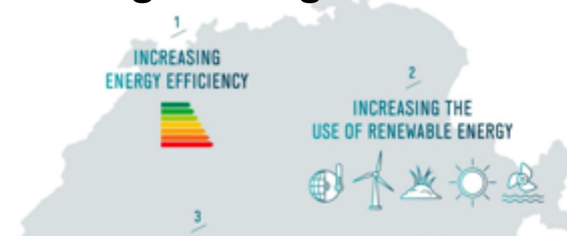
24. March 2011

11. March 2011 Erdbeben

25. Mai 2011 Der Bundesrat hat entschieden, künftig nicht mehr auf Atomkraft zu setzen. Die bestehenden Kernkraftwerke sollen so lange am Netz bleiben, wie sie sicher sind. Bestätigt durch das nationale Parlament am 8. Juni 2011.

Paris Klimaabkommen 2014

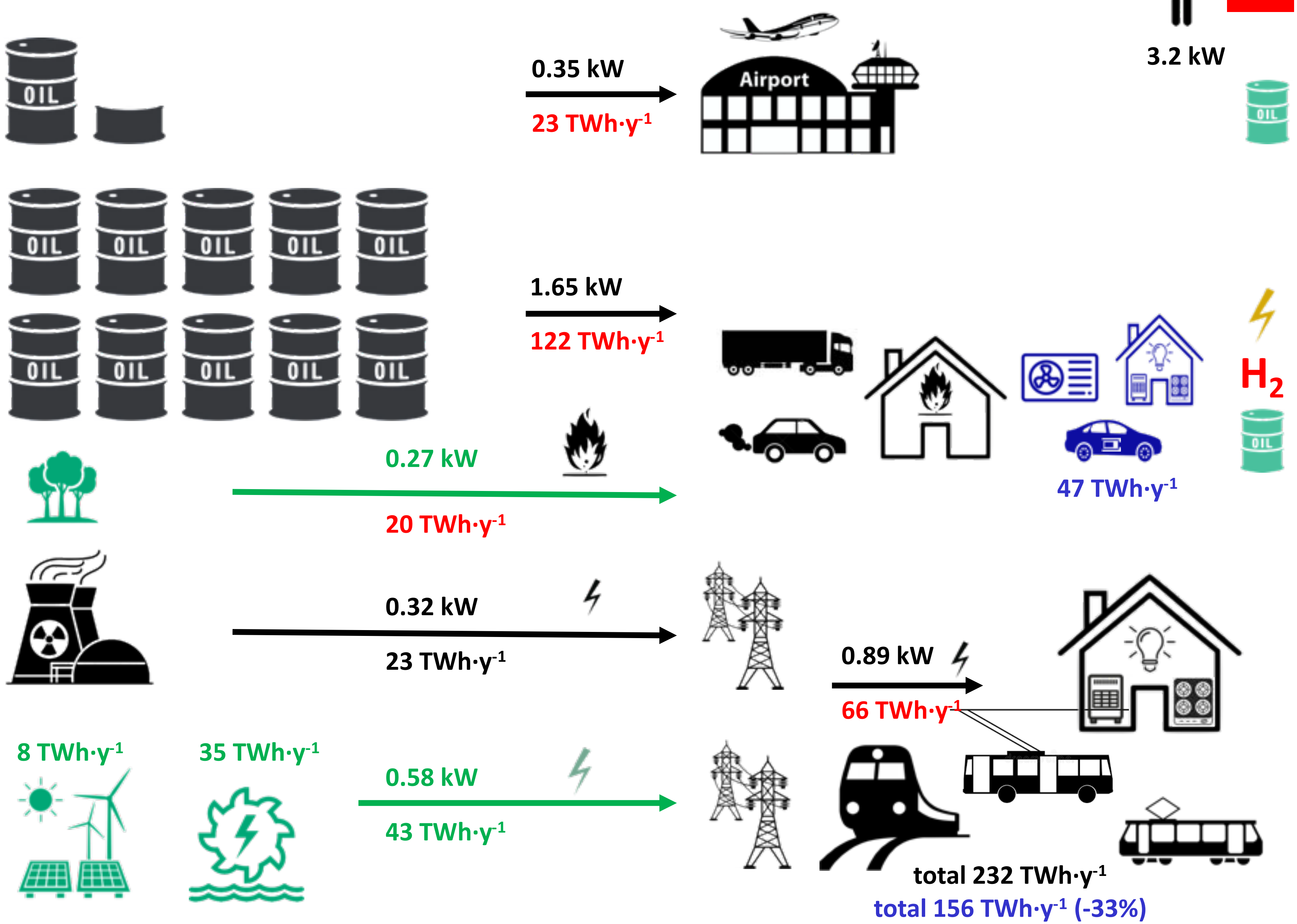
Energiestrategie Schweiz 2050



Am 21. Mai 2017 hat das Schweizer Stimmvolk das revidierte Bundes-energiegesetz angenommen. Die Ziele der Überarbeitung sind die Senkung des Energieverbrauchs, die Steigerung der Energieeffizienz und die Förderung der Nutzung erneuerbarer Energien. Zudem verbietet die überarbeitete Fassung den Bau neuer Kernkraftwerke.

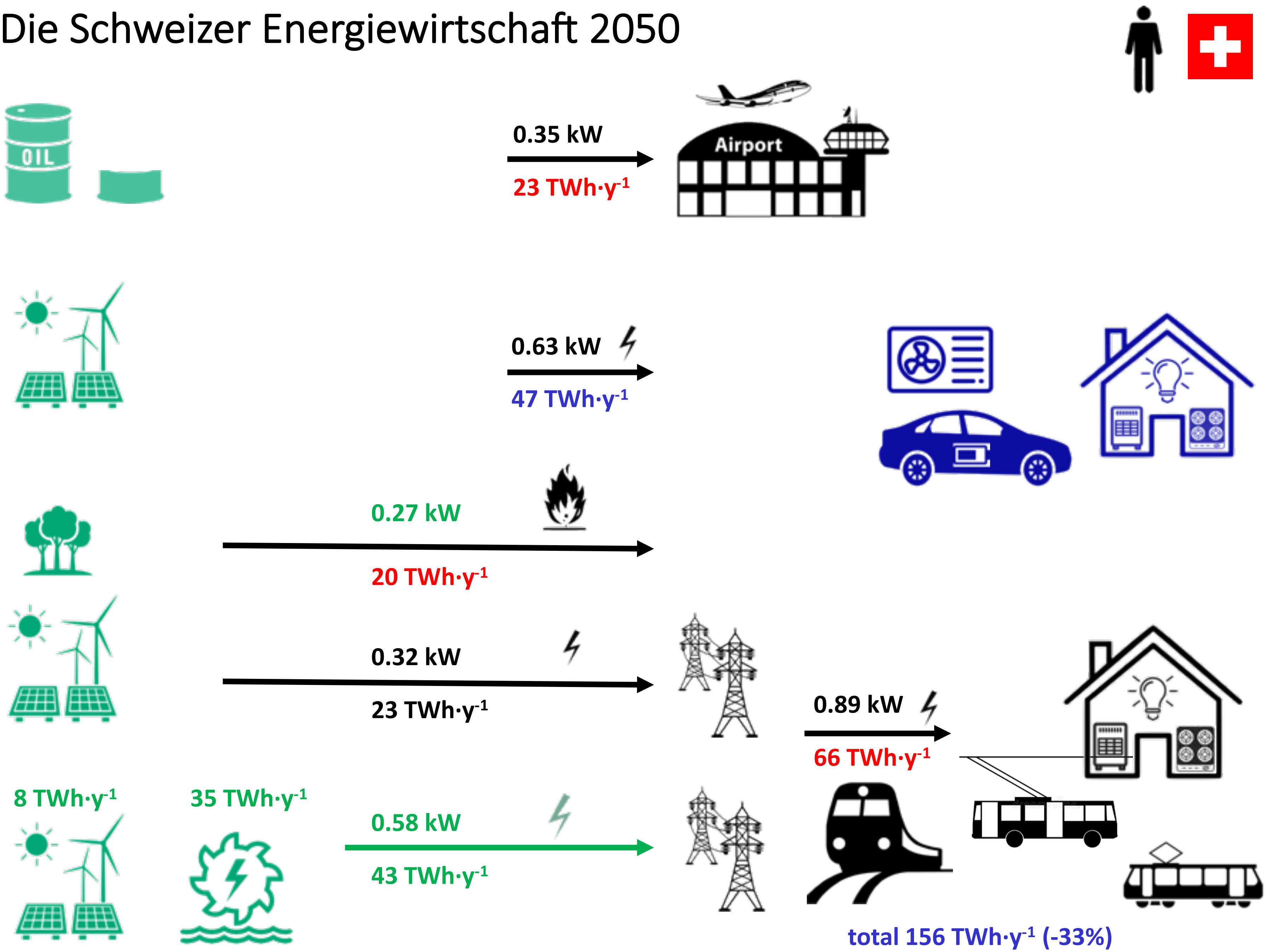
Produktion und Speicherung erneuerbarer Enbergie

Die Schweizer Energiewirtschaft 2019



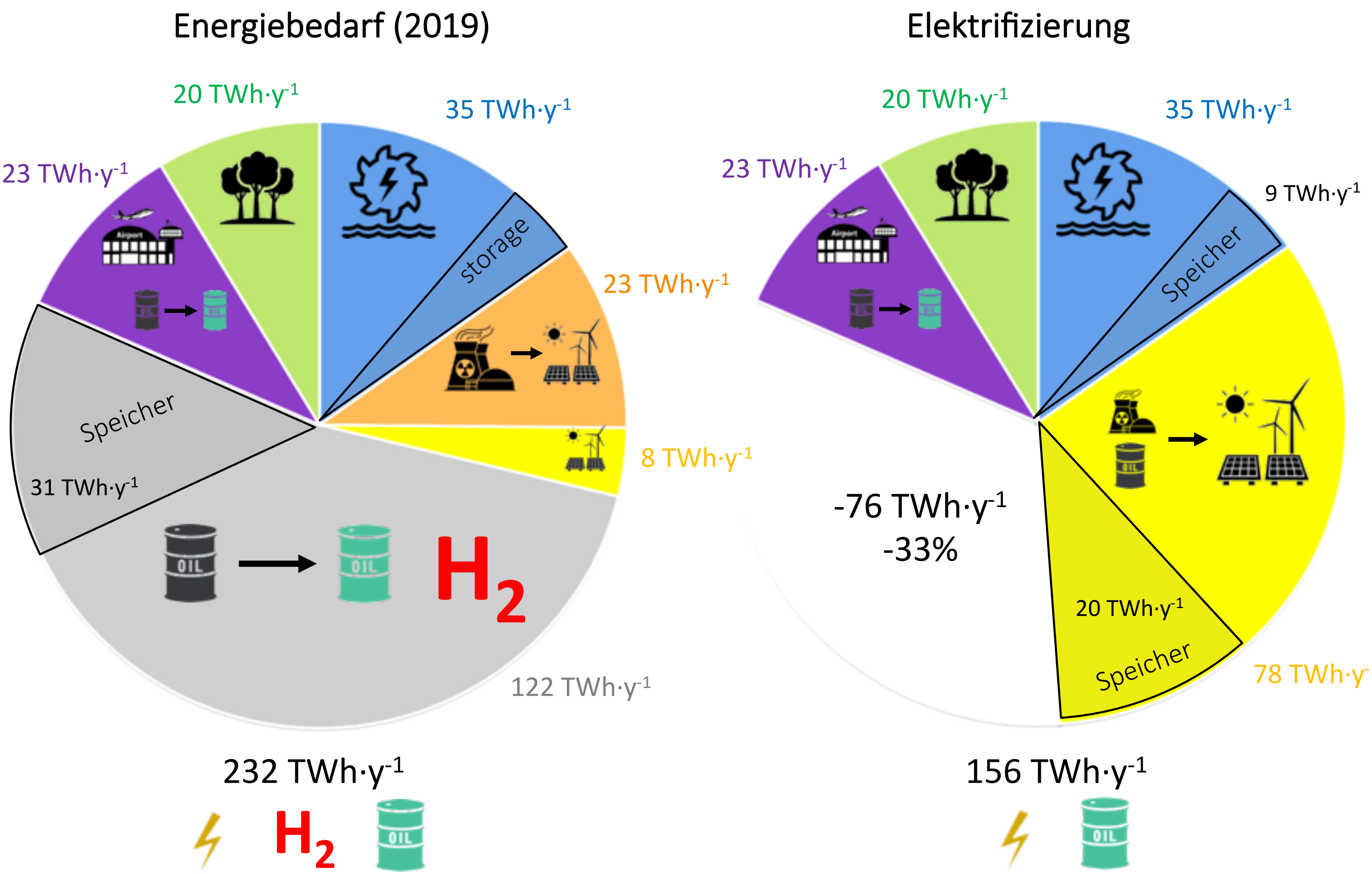
Die Schweizer Energiewirtschaft 2050

Produktion und Speicherung erneuerbarer Enbergie



Produktion und Speicherung erneuerbarer Enbergie

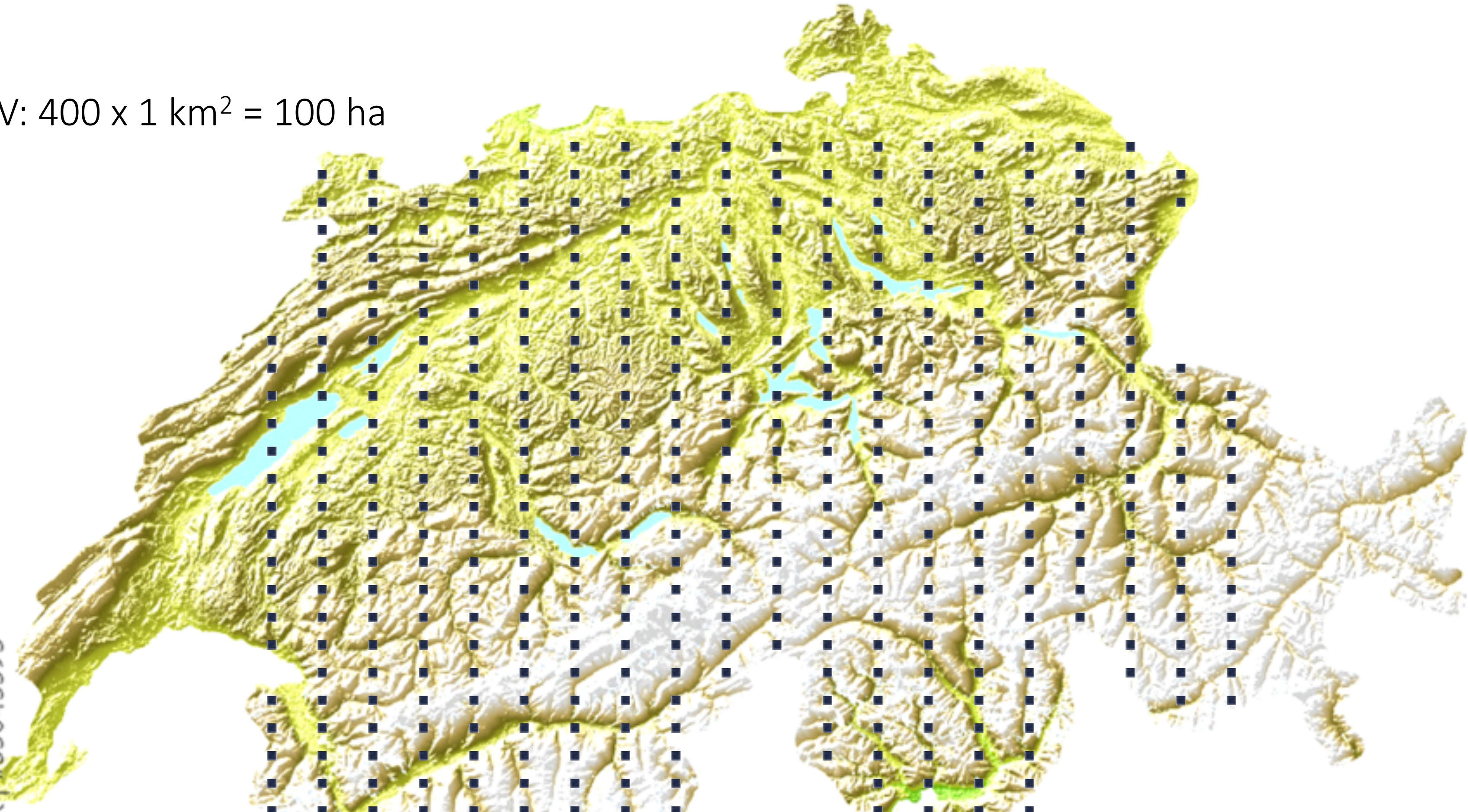
Die Schweizer Energiebedarf 2019

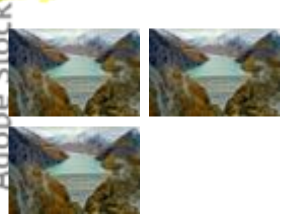


Ref.: SCHWEIZERISCHE GESAMTENERGIE STATISTIK (2019) Art.-Nr. 805.006.19 / 08.20 / 1200 / 860467013, Federal Office of Energy, Switzerland, https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/energiestatistiken/gesamtenergiestatistik.exturl.html/

Erneuerbare Energie Wandler und Speicher für die Elektrifizierung

PV: 400 x 1 km^2 = 100 ha





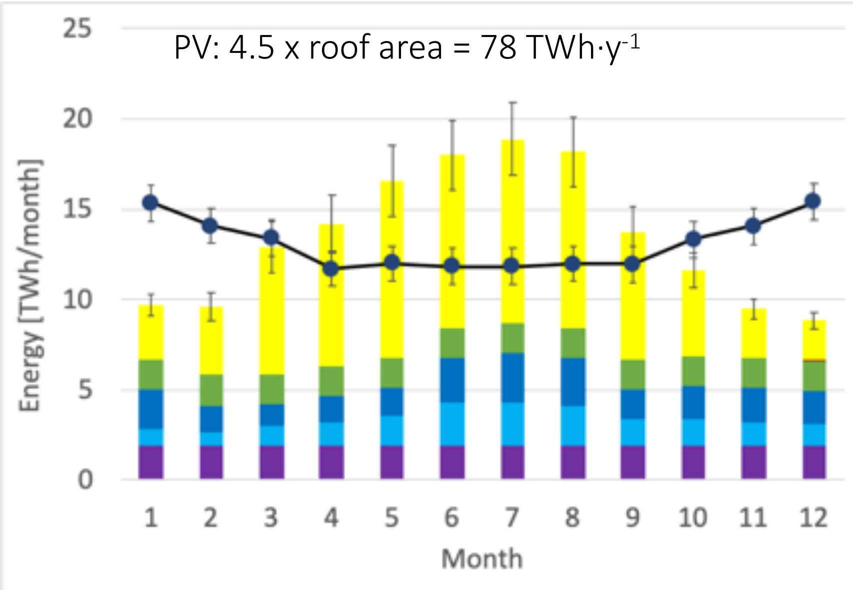
13 x Grande Dixence

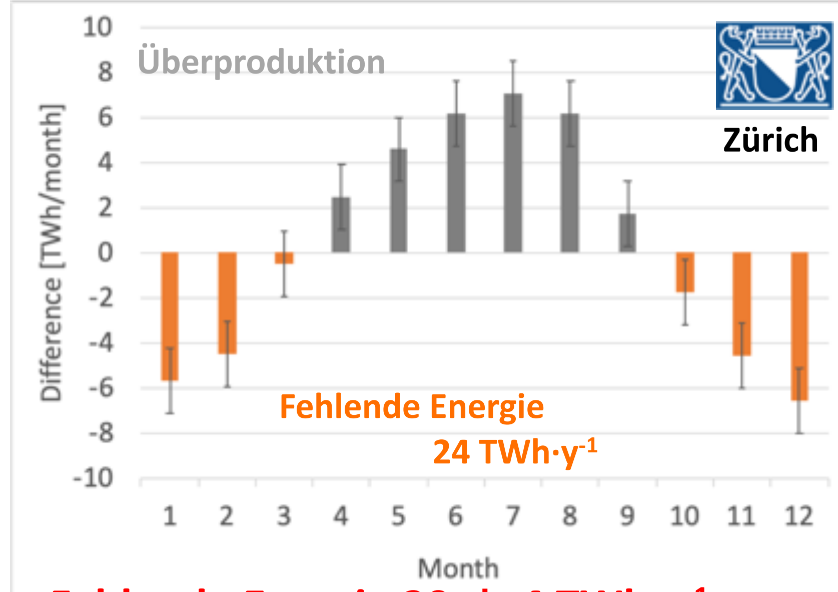
Produktion und Speicherung erneuerbarer Enbergie

Erneuerbare Energiewirtschaft

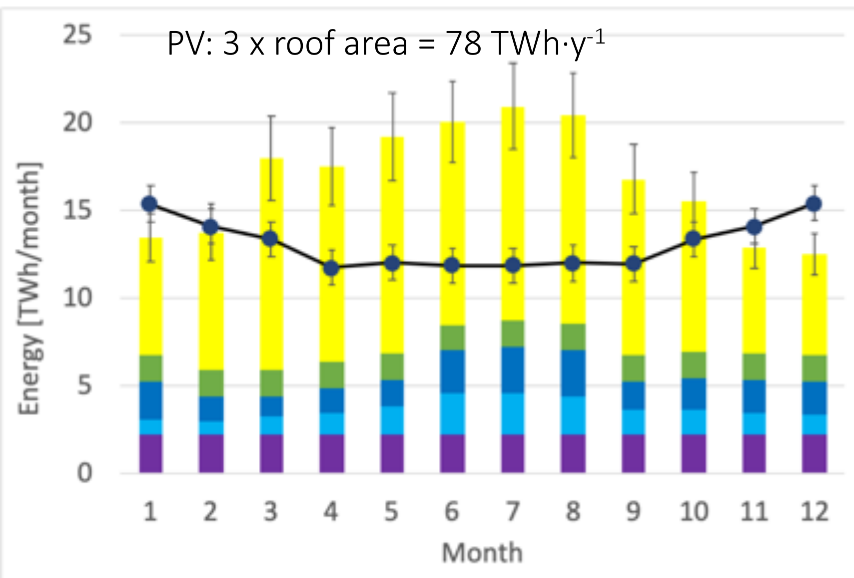
	Elektrizität 3669.-	Wasserstoff 5683.-	Syn. Öl 9712.-
23 TWh·y⁻¹	1 x 75 GWh 316.- 4 x		
121 TWh·y⁻¹, 47 TWh·y⁻¹	2 x 134 km² 150 GWh 642.- 9 x 1.5 TWh	6 x 480 GWh 2656.- 2 Mm³ 200 bar 25 x	12 x 920 GWh 6684.- 159 L 94 Mio.
Airport 23 TWh·y⁻¹			2 x 140 GWh 1212.- 14 Mio.
existierende PV, Biomasse, Wasserkraft 63 TWh·y⁻¹	1500.- 8 TWh·y⁻¹ 20 TWh·y⁻¹ 35 TWh·y⁻¹		

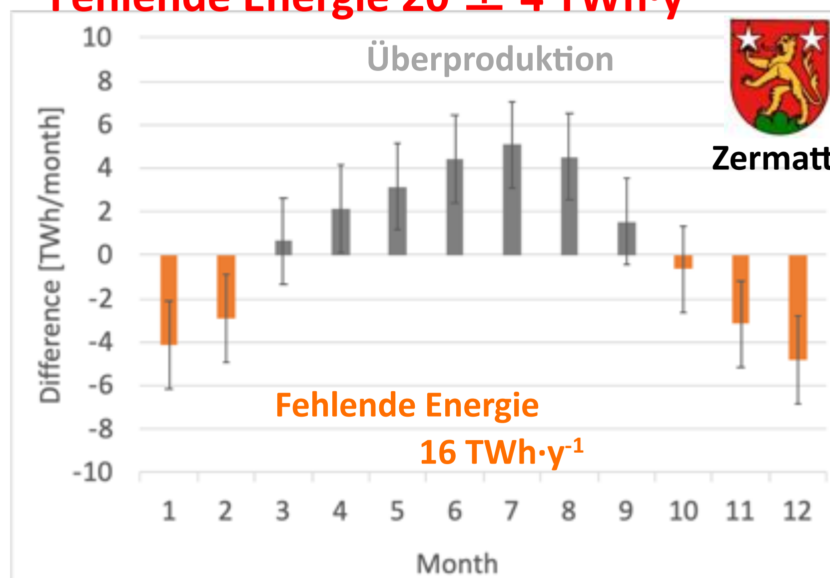
Saisonale Energiewirtschaft





Fehlende Energie 20 ± 4 TWh·y^{-1}

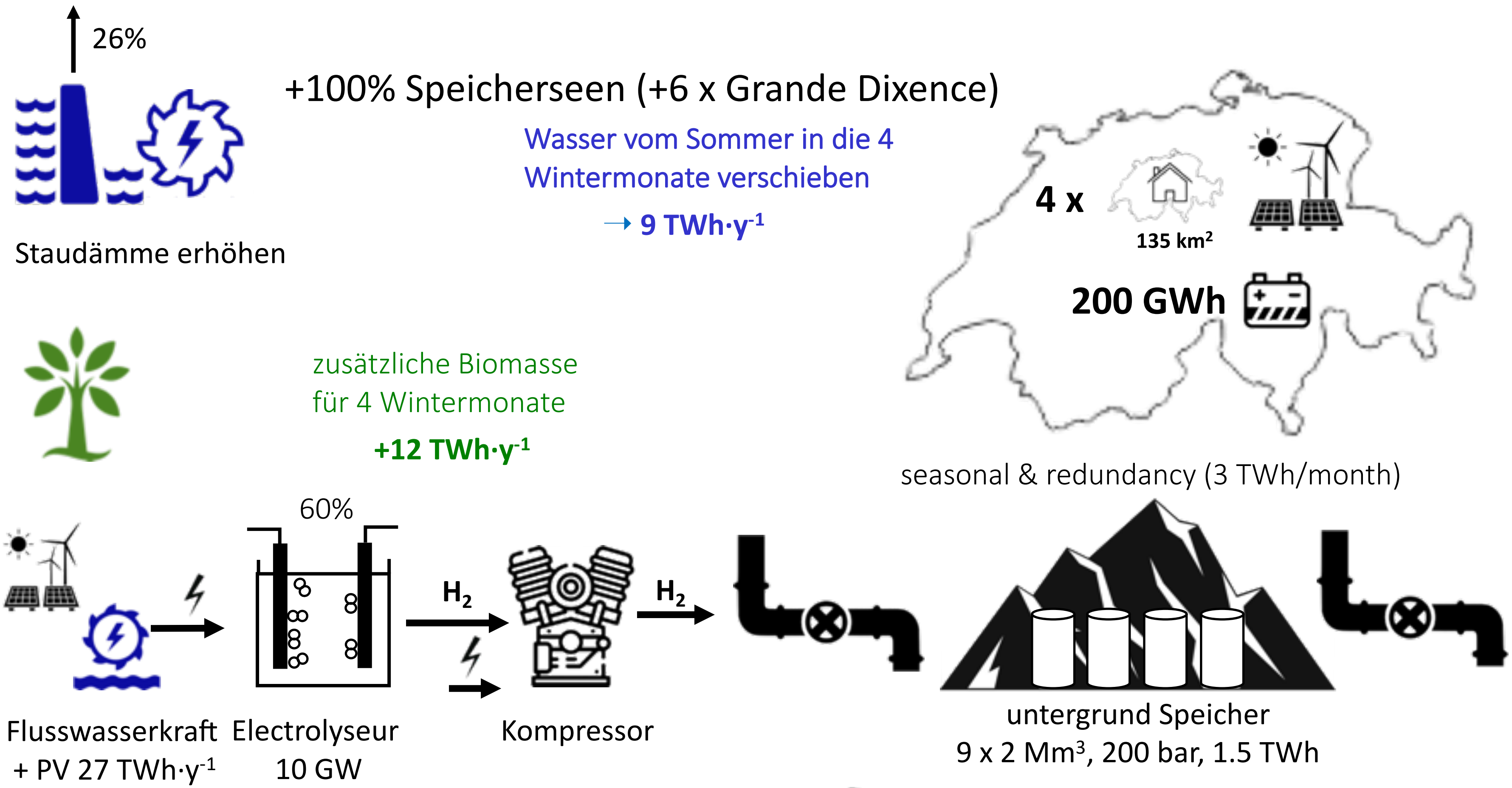


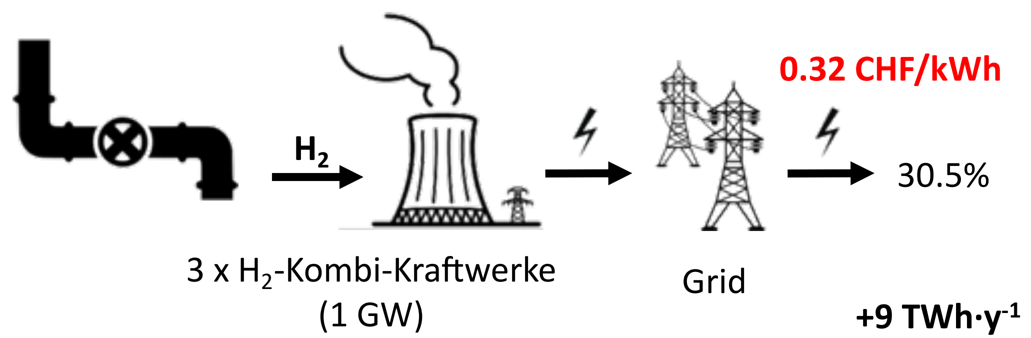


Ref.: https://solargis.com/maps-and-gis-data/download/switzerland
GLOBAL SOLAR ATLAS: https://globalsolaratlas.info/map?c=-7.013668,42.539063,2

■ Kerosin, ■ Biomasse, ■ Flusskraftwerk,
■ Wasserkraftwerk mit Speichersee, ■ Photovoltaik

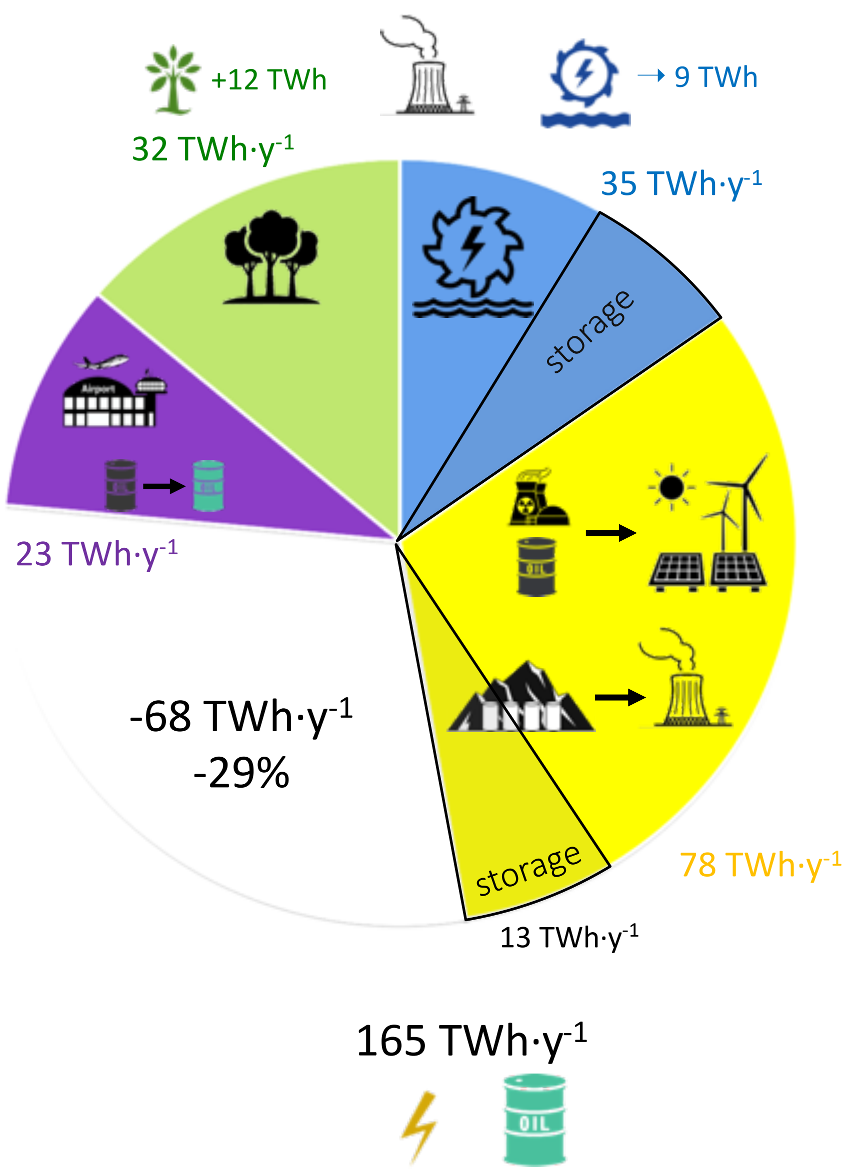
Energie autarke Schweiz

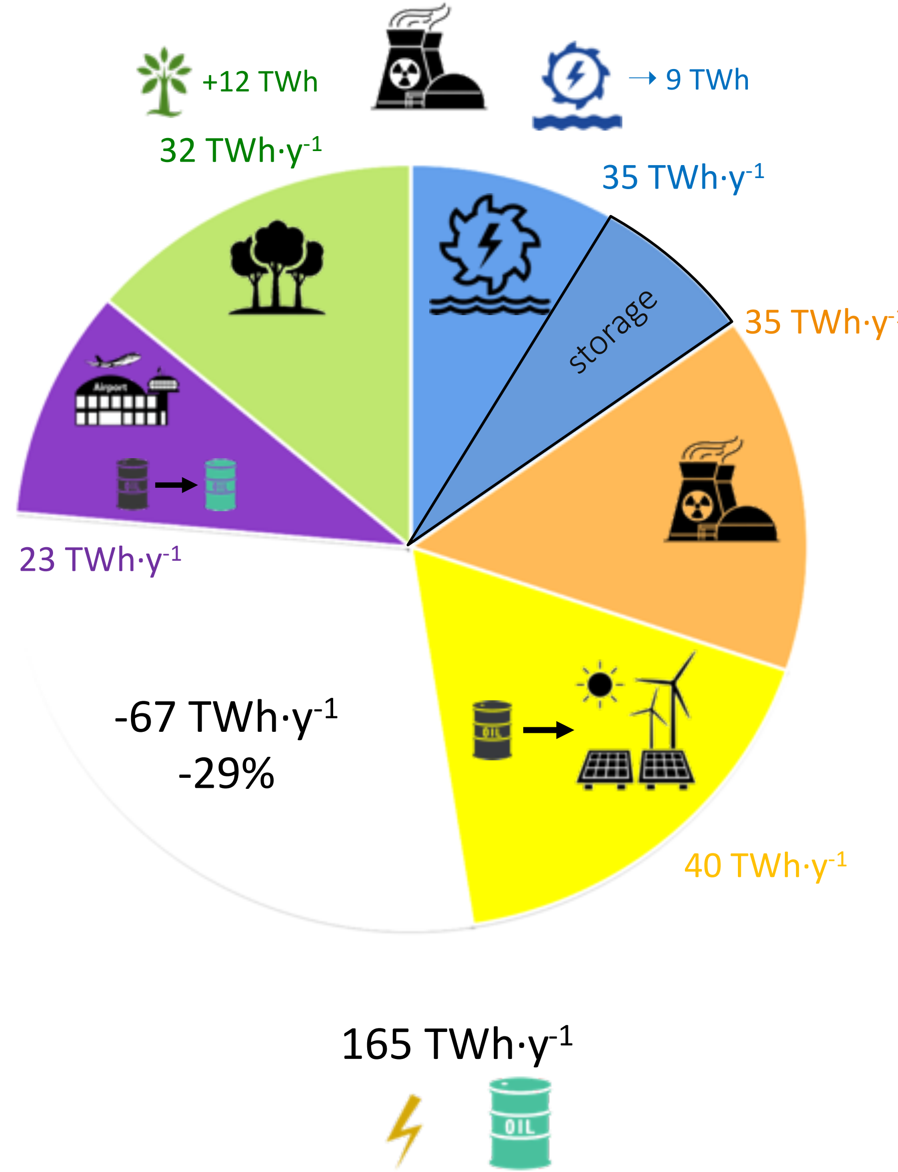




Produktion von Wasserstoff in den Sommermonaten für die Kombikraftwerke im Winter.

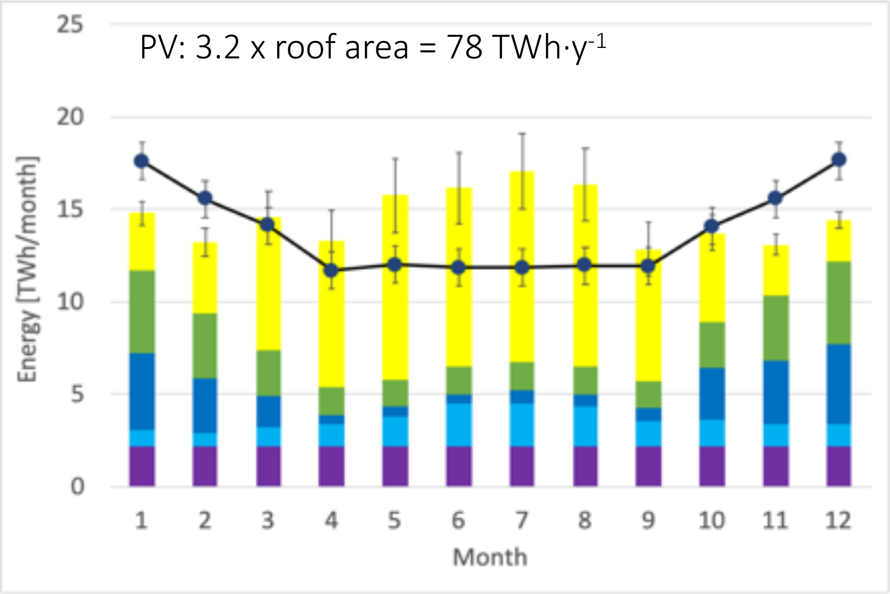
Energiewirtschaft mit Kombi- und Kern-Kraftweken

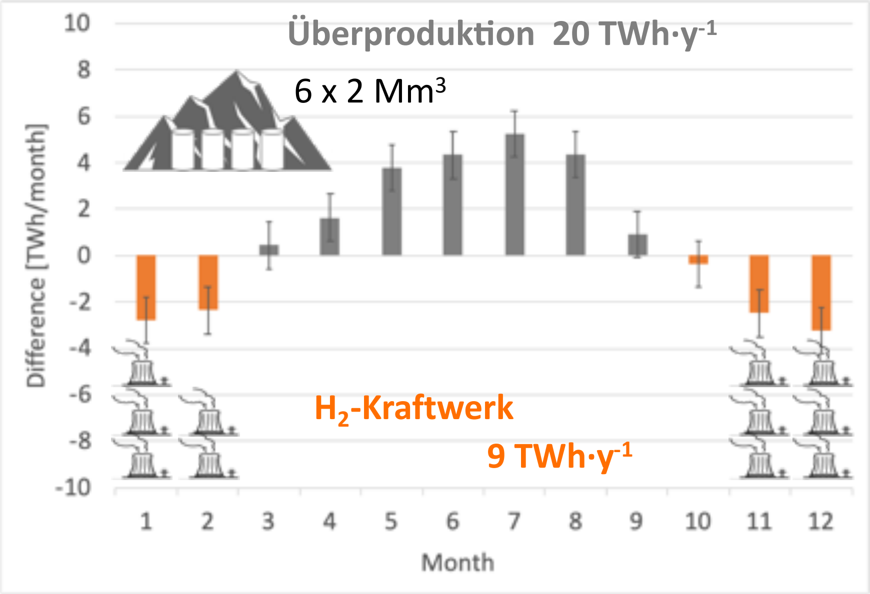


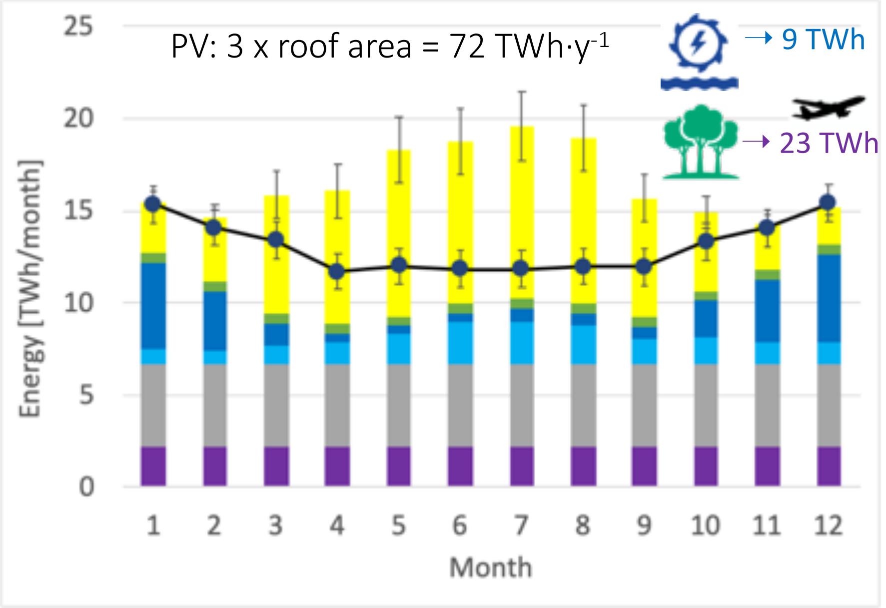


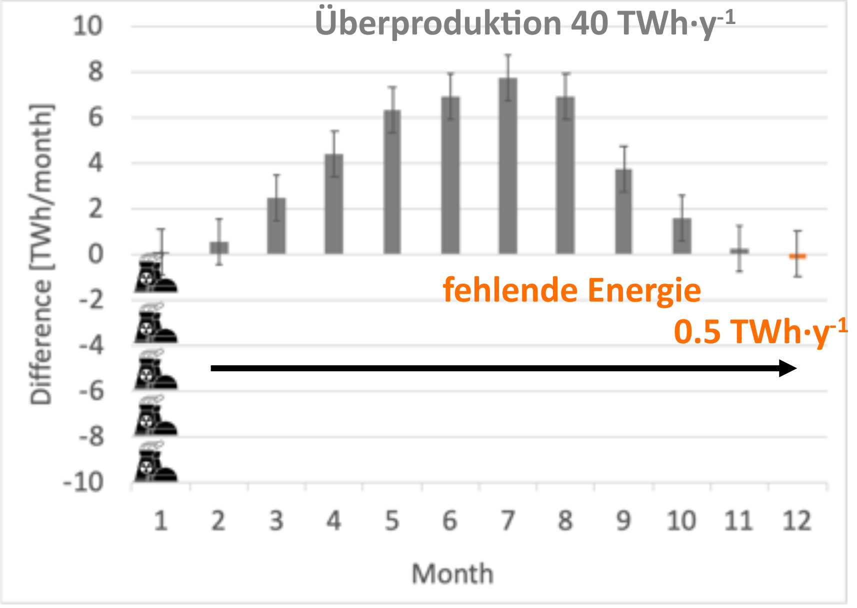
Ref.: SCHWEIZERISCHE GESAMTENERGIE STATISTIK (2019) Art.-Nr. 805.006.19 / 08.20 / 1200 / 860467013, Federal Office of Energy, Switzerland, https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/energiestatistiken/gesamtenergiestatistik.exturl.html/

Erneuerbare Energie und Kraftwerke (165 TWh·y^{-1})



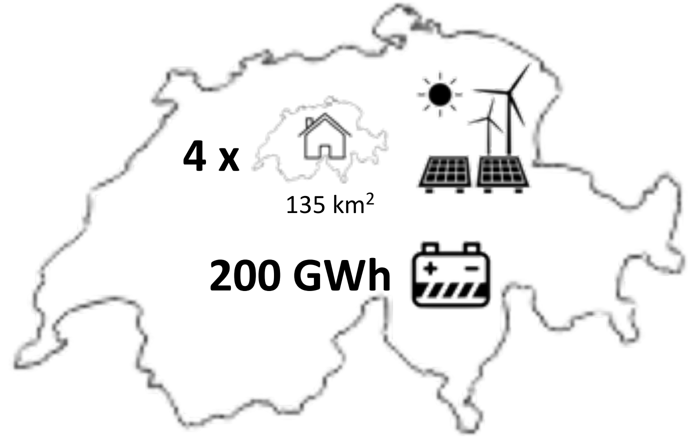


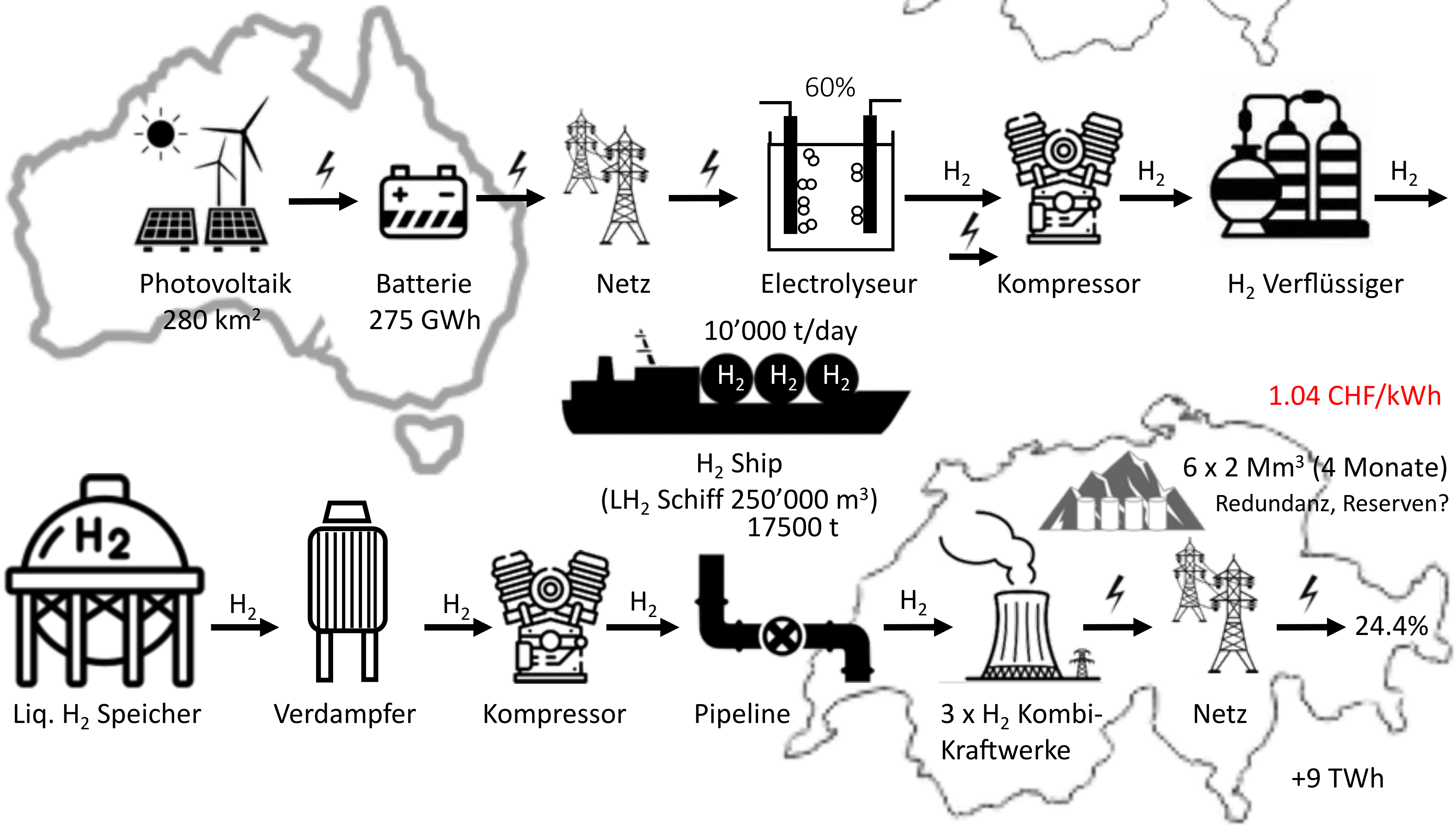




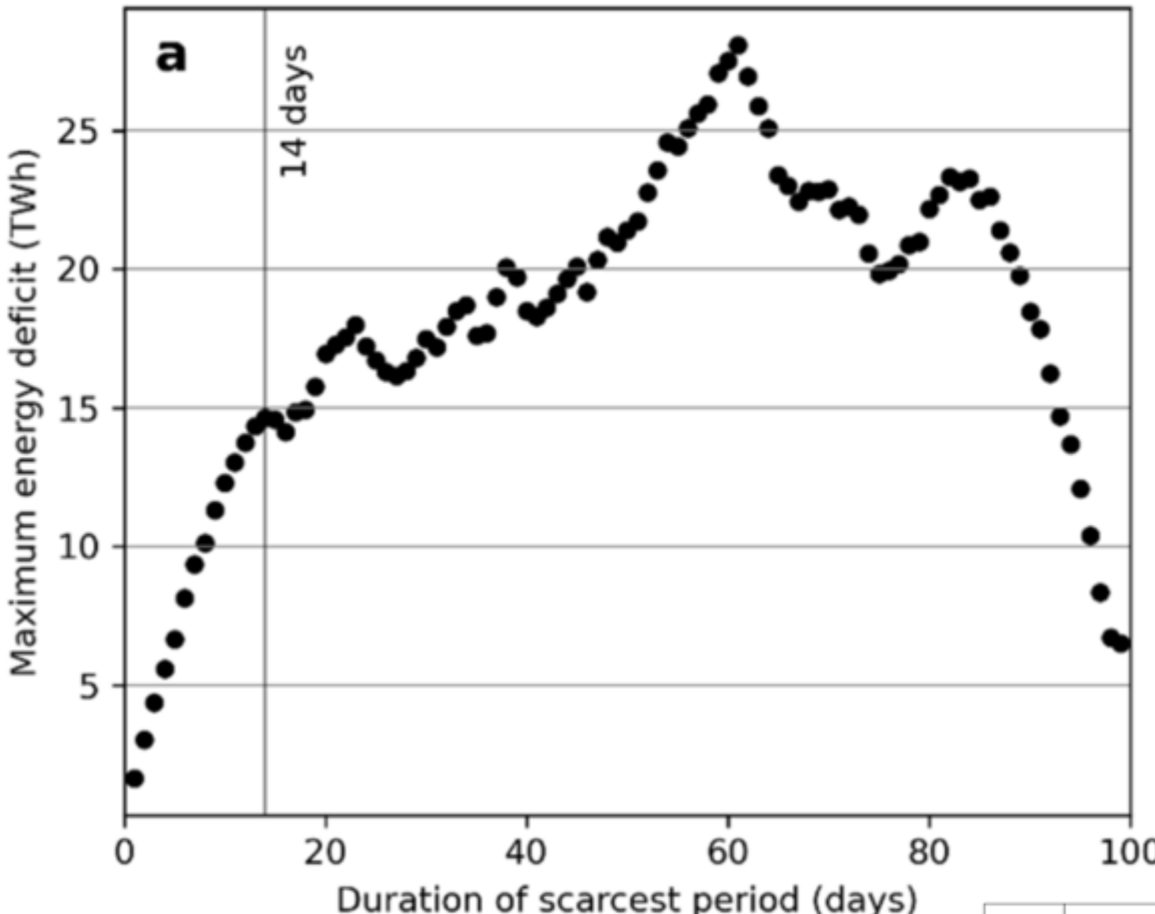
Wasserstoff produziert in Australien

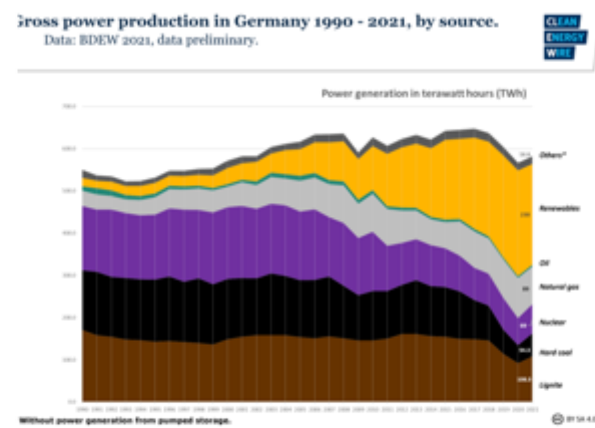
Wasserstoff Import für die Kombikraftwerke während 4 Monaten zur Produktion von Elektrizität und Wärme.

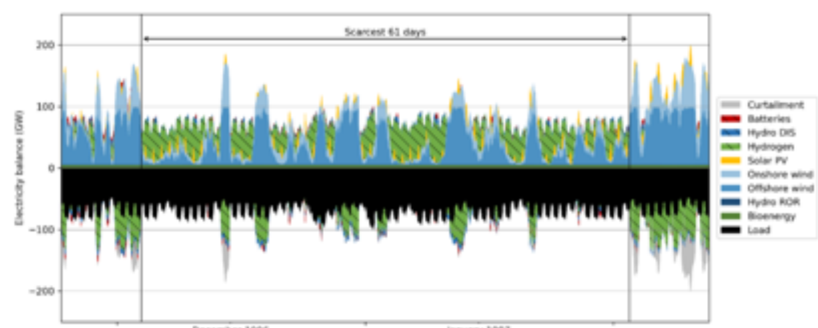




Erneuerbare Energie und Speicherung (Stromlücke)



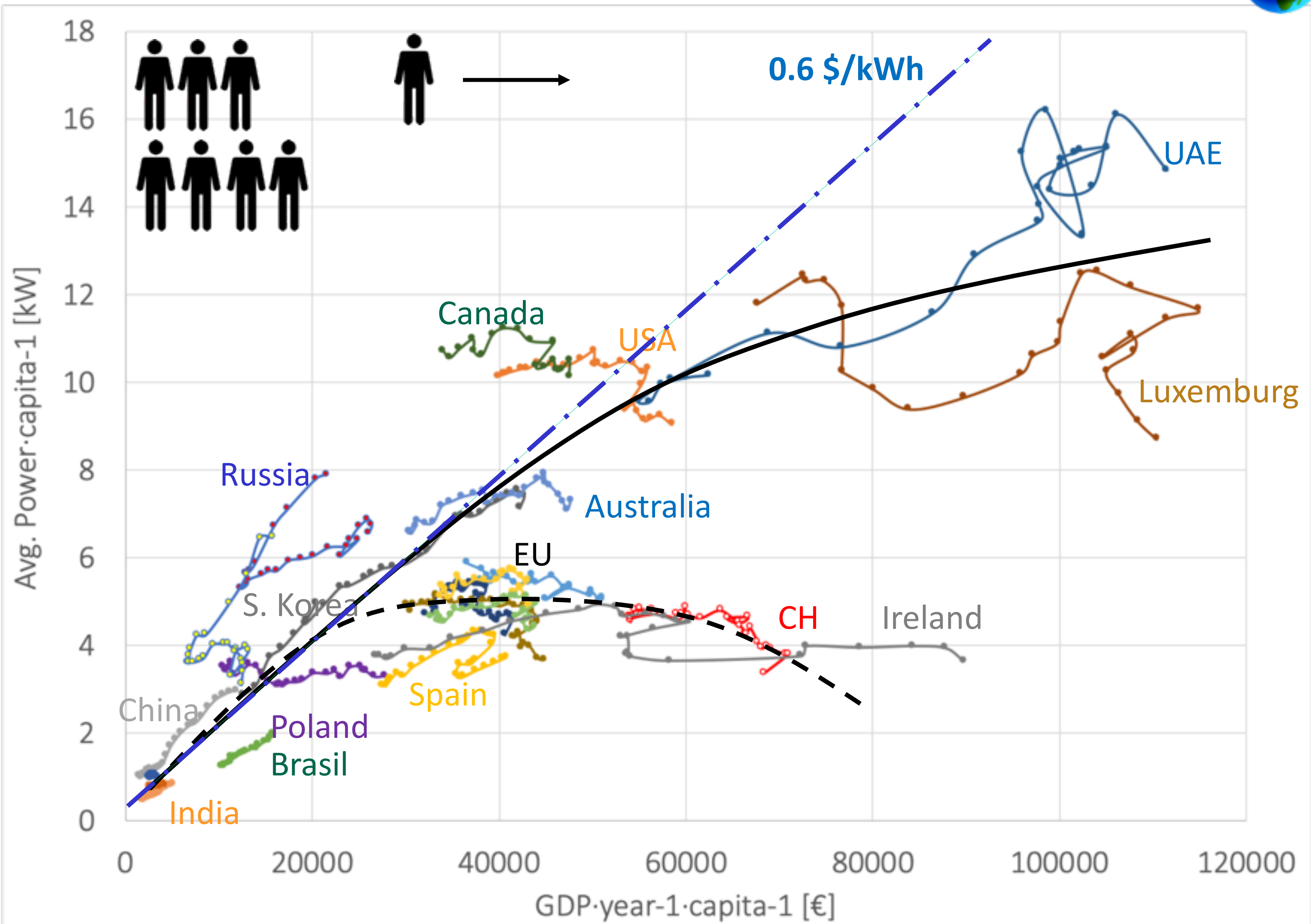




Ref.: Oliver Ruhnau, and Staffan Qvist,"Storage requirements in a 100% renewable electricity system: extreme events and inter-annual variability", Environ. Res. Lett. 17 (2022) 044018, https://doi.org/10.1088/1748-9326/ac4dc8

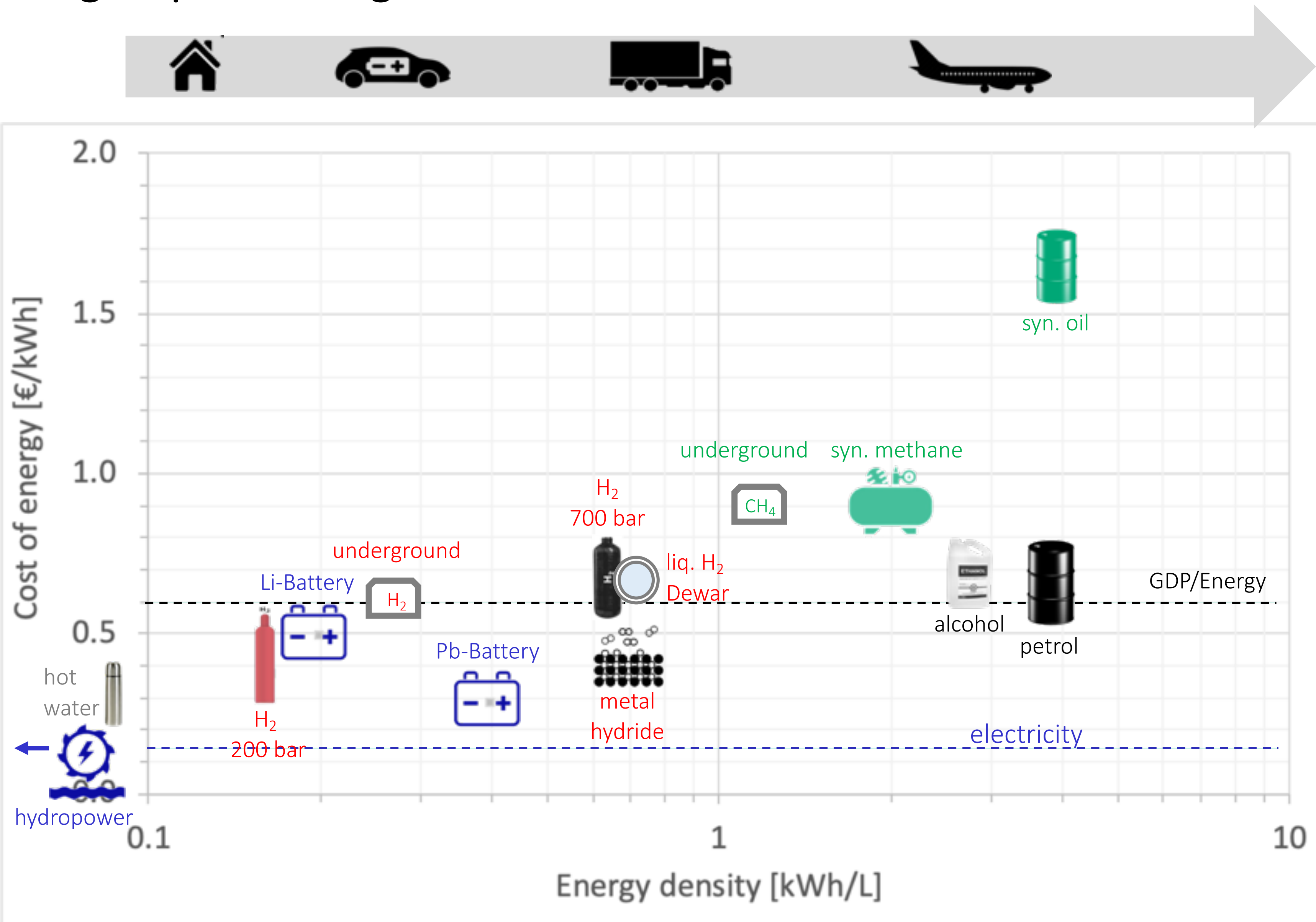
Energie und Wirtschaft

Produktion und Speicherung erneuerbarer Enbergie



Ref.: https://ourworldindata.org/grapher/energy-use-per-capita-vs-gdp-per-capita

Energie Speicherung



Erneuerbare Energie für die Welt

Albanese vows to transform Australia into clean energy 'superpower'

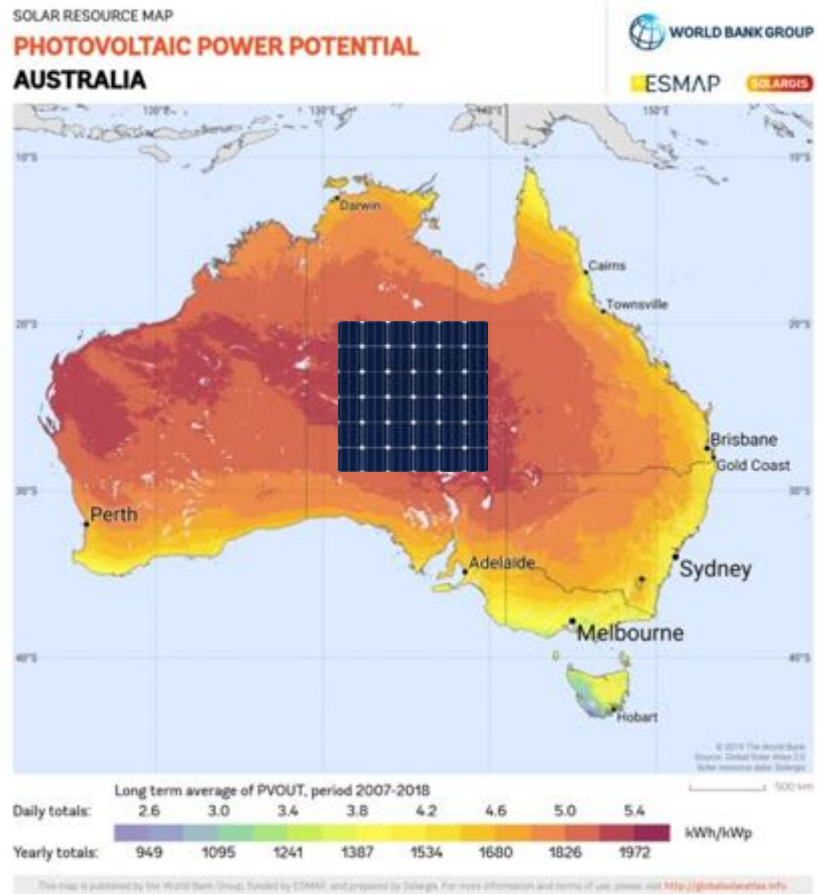
Incoming Australian prime minister Anthony Albanese has promised to make the nation a "renewable energy superpower" in the wake of Labor's federal election victory at the weekend.

MAY 23, 2022 DAVID CARROLL

MARKETS & POLICY | POLICY | SUSTAINABILITY | AUSTRALIA

Anthony Albanese is promising an end to the "climate wars".
Image: Facebook

space, solar intensity, shifted season



20 TW as H_2 $(1000\ km)^2$

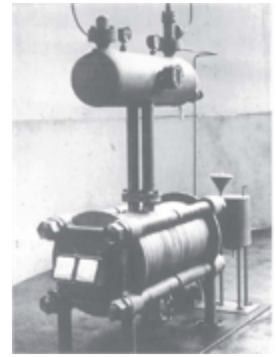
18 GW as H_2 $(30\ km)^2$

Wasserstoff Geschichte

1912

First H_2 ICE 1807
Francois Isaac de Rivaz

Hydroelectric plant Gampel 1898



Ewald Zdansky 1949

Alkaline Electrolyzer 4MW, 1980
Giovanola, Lurgi, IHT

PV, Electrolysis, Car, Stove
Markus Friedli 1991

Hydrogen Storage 1997
in Monthey

H_2YDROPOLE 2001

Ratrac MH & ICE 2004

H_2 FC Street sweeper
Hy.move 2009

Energy self sufficient house 2016

PEM Fuel cell 2017

Hyundai H_2 trucks 2020

DASH MH-FC Storage
System 2021

Wirtschaftsgeschichte: Alfred ESCHER

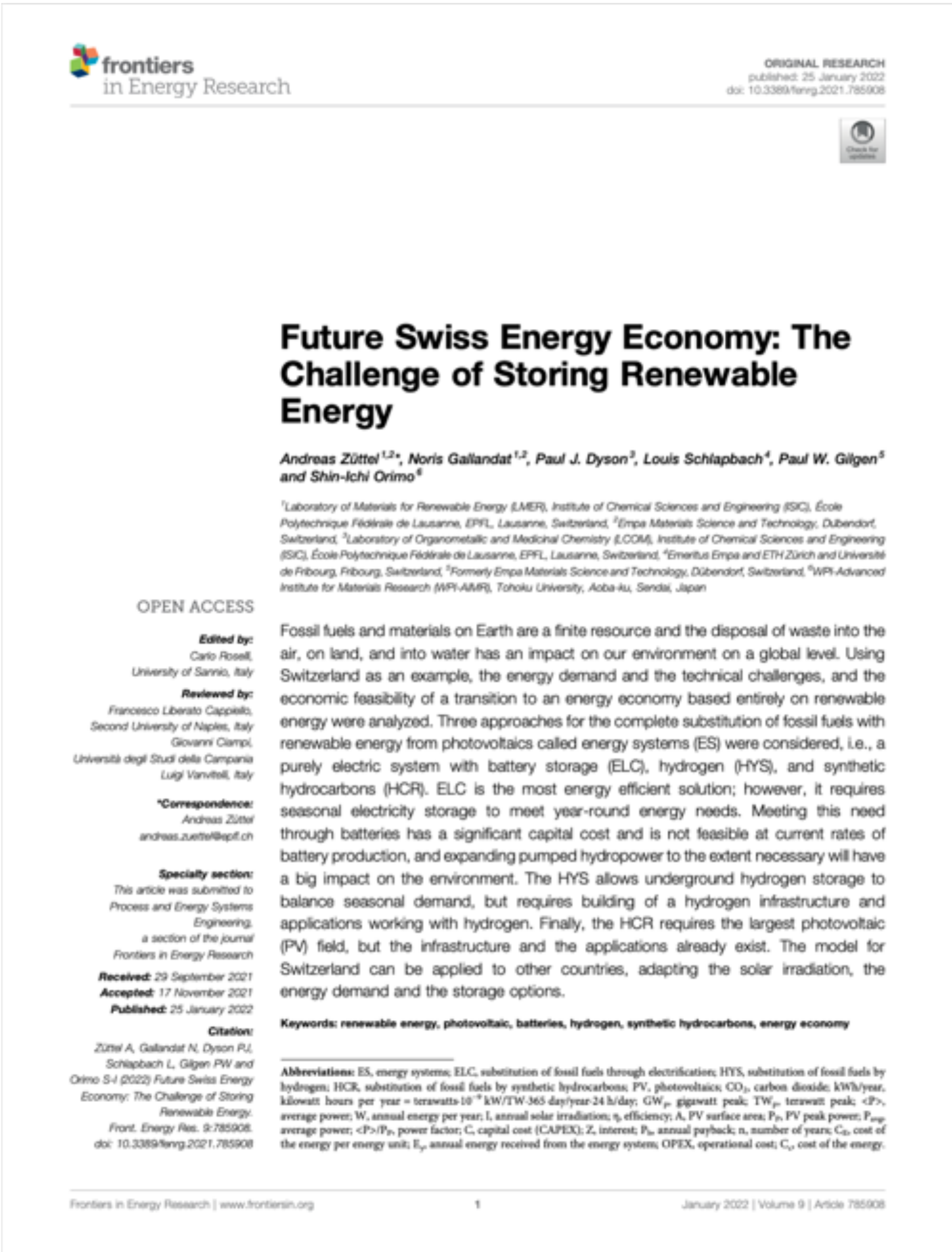
Train station Zürich 1889

Kreditanstalt 1873 (Credit Suisse)

Johann Heinrich
Alfred ESCHER
20. 2. 1819
- 6. 12. 1882, Zürich

ETH Zürich 1858 - 1864

Gotthard Tunnel, Göschenen, 1871–1882, 180 (+10%)
Gotthard base tunnel, 1999-2016 12'200 Mio (+21.3%)



frontiers in Energy Research

ORIGINAL RESEARCH
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Future Swiss Energy Economy: The Challenge of Storing Renewable Energy

Andreas Züttel[1,2]*, Noris Gallandat[1,2], Paul J. Dyson[3], Louis Schlapbach[4], Paul W. Gilgen[5] and Shin-Ichi Orimo[6]

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Fossil fuels and materials on Earth are a finite resource and the disposal of waste into the air, on land, and into water has an impact on our environment on a global level. Using Switzerland as an example, the energy demand and the technical challenges, and the economic feasibility of a transition to an energy economy based entirely on renewable energy were analyzed. Three approaches for the complete substitution of fossil fuels with renewable energy from photovoltaics called energy systems (ES) were considered, i.e., a purely electric system with battery storage (ELC), hydrogen (HYS), and synthetic hydrocarbons (HCR). ELC is the most energy efficient solution; however, it requires seasonal electricity storage to meet year-round energy needs. Meeting this need through batteries has a significant capital cost and is not feasible at current rates of battery production, and expanding pumped hydropower to the extent necessary will have a big impact on the environment. The HYS allows underground hydrogen storage to balance seasonal demand, but requires building of a hydrogen infrastructure and applications working with hydrogen. Finally, the HCR requires the largest photovoltaic (PV) field, but the infrastructure and the applications already exist. The model for Switzerland can be applied to other countries, adapting the solar irradiation, the energy demand and the storage options.

Keywords: renewable energy, photovoltaic, batteries, hydrogen, synthetic hydrocarbons, energy economy

Abbreviations: ES, energy systems; ELC, substitution of fossil fuels through electrification; HYS, substitution of fossil fuels by hydrogen; HCR, substitution of fossil fuels by synthetic hydrocarbons; PV, photovoltaics; CO_2, carbon dioxide; kWh/year, kilowatt hours per year = terawatts·10^{-9} kW/TW·365 day/year·24 h/day; GW_p, gigawatt peak; TW_p, terawatt peak; <P>, average power; W, annual energy per year; I, annual solar irradiation; η, efficiency; A, PV surface area; P_P, PV peak power; P_{avg}, average power; <P>/P_P, power factor; C, capital cost (CAPEX); Z, interest; P_a, annual payback; n, number of years; C_E, cost of the energy per energy unit; E_y, annual energy received from the energy system; OPEX, operational cost; C_c, cost of the energy.

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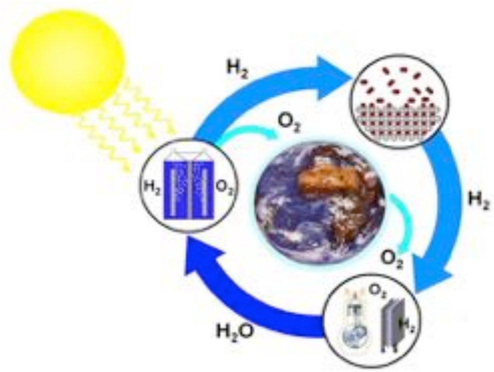
Andreas ZÜTTEL, Noris GALLANDAT, Paul J. DYSON, Louis SCHLAPBACH, Paul W. GILGEN, Shin-Ichi ORIMO, “Future Swiss Energy Economy: the challenge of storing renewable energy”, Frontiers in Energy Research: Process and Energy Systems Engineering, 9 (2022), https://doi.org/10.3389/fenrg.2021.785908

Produktion und Speicherung erneuerbarer Enbergie

15th INT. SYMPOSIUM HYDROGEN & ENERGY

22. - 27. January 2023
Seeblick Höhenhotel, Emmetten, Switzerland



http://hesymposium.ch/

SUBJECTS

- Hydrogen production
- Hydrogen storage
- Fuel Cells
- Batteries
- Synthetic fuels
- Theory & modelling
- Applications

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Berend SMIT, Switzerland
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Klaus LACKNER, USA
Allan WALTON, England
Heena YANG, Korea
Björgvin HJÖVARSON, Sweden
Sabrina SARTORI, Norway
Robert SCHLÖGEL, Germany

PROGRAM

	Su	Mo	Tu	We	Th	Fr
09:00						
12:00		Lunch				
14:00	Recept.			social event		depart.
17:00						
18:00	Din.	Dinner	Dinner	Dinner	Conf. dinner	
21:00		Poster	Poster			

inv. lec. inv. talk, talk

LOCATION

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REGISTRATION

Conference fee CHF 1350
incl. conference facilities, internet, proceedings and social event, excursion, coffee breaks, lunch, dinner, conference dinner, beverages at poster sessions.
Remote fee CHF 250

Registration online:
http://hesymposium.ch/
Registration and abstract submission:
before 1st December 2022

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Born 22. 8. 1963 in Bern, Switzerland. 1985 Engineering Degree in Chemistry, Burgdorf, Switzerland. 1990 Diploma in Physics from the Unversity of Fribourg (UniFR), Switzerland. 1993 Dr. rer. nat. from the science faculty UniFR. 1994 Post Doc with AT&T Bell Labs in Murray Hill, New Jersey, USA. 1997 Lecturer at the Physics Department UniFR. 2003 External professor at the Vrije Universiteit Amsterdam, Netherlands. 2004 Habilitation in experimental physics at the science faculty UniFR (www.unifr.ch). President of the Swiss Hydrogen Association „HYDROPOLE" (www.hydropole.ch). 2006 Head of the section "Hydrogen & Energy" at EMPA (www.empa.ch) and Prof. tit. in the Physics department UniFR. 2009 Guest Professor at IMR, Tohoku University in Sendai, Japan. 2012 Visiting Professor at Delft Technical University, The Netherlands, 2014 Full Professor for Physical Chemsitry, Institut des Sciences et Ingénierie Chimiques, Ecole Polytechnique Fédérale de Lausanne EPFL (www.lmer.epfl.ch), Switzerland. 2017 Co-Foundert of GRZ Technologies Ltd. (www.grz-technologies.com). 2020 Member of the Swiss Academy of Technical Science (SATW, https://www.satw.ch)

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HTL Burgdorf

MSc Physics
PhD Physics
Habilitation
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President

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Member

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Club Energie Suisse
Club Energia Svizzera
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SCS Swiss Chemical Society
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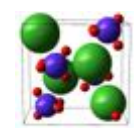
SPS swiss physical society
Member

Int. Symposium
Hydrogen & Energy
2007



Borohydrides
2000

MH Storage
2004

grz TECHNOLOGIES

Start Up Company
2017 Grolley (FR)
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