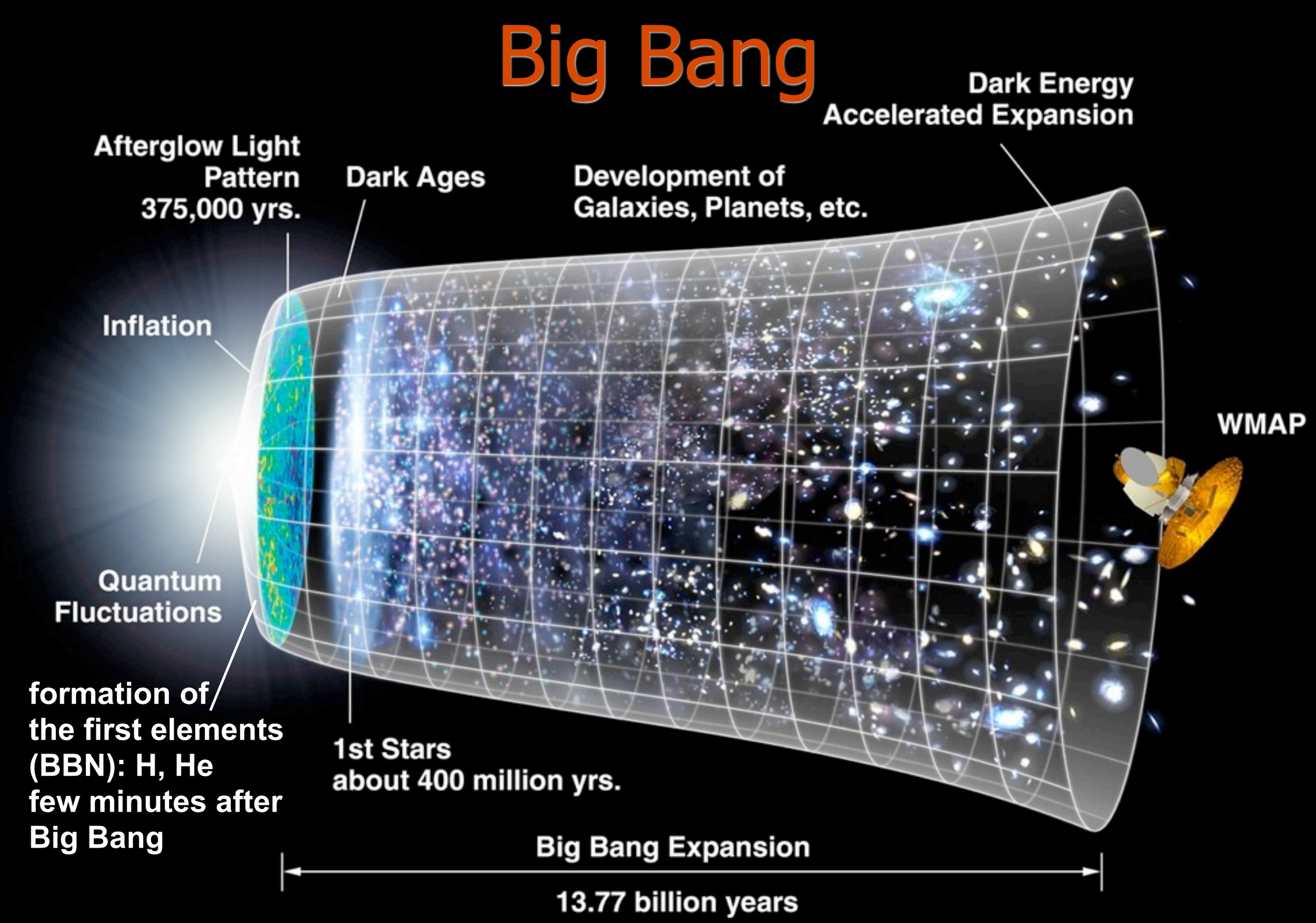
Hydrogen in the Universe
and
on Earth

an Astrophysical Point of View

Prof. Dr. Robi Banerjee
Hamburger Sternwarte
University of Hamburg

Big Bang


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
formation of
the first elements
(BBN): H, He
few minutes after
Big Bang
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years
NASA/WMAP Science Tea

Molecular Hydrogen in the Universe


HST: Orion nebula

HST: star formation region Tarantula Nebula in the Large Magellanic Cloud

HST: “Pillars of Creation” Eagle Nebula

ESA Herschel Telescope: Rosetta Nebula

Hydrogen on Earth?

atmosphere composition

- 78 % nitrogen
- 21 % oxygen
- ~ 1 % water vapor
- ...

surface/crust composition

- 71 % water (surface area)
- 60 % silicia (SiO_2)
- 16 % aluminia (Al_2O_3)
- 6 % lime (CaO)
- ...

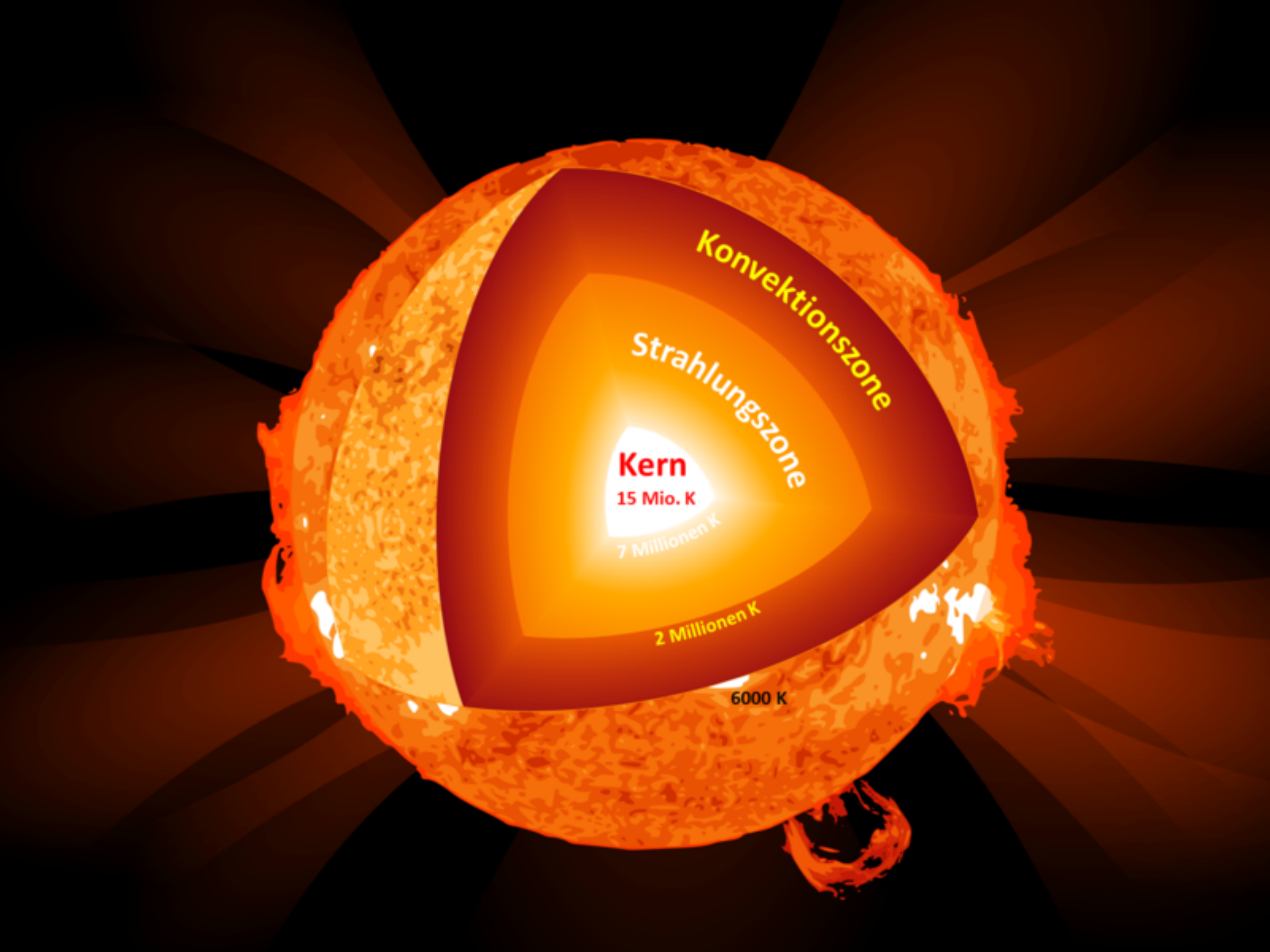
Hydrogen on Earth?

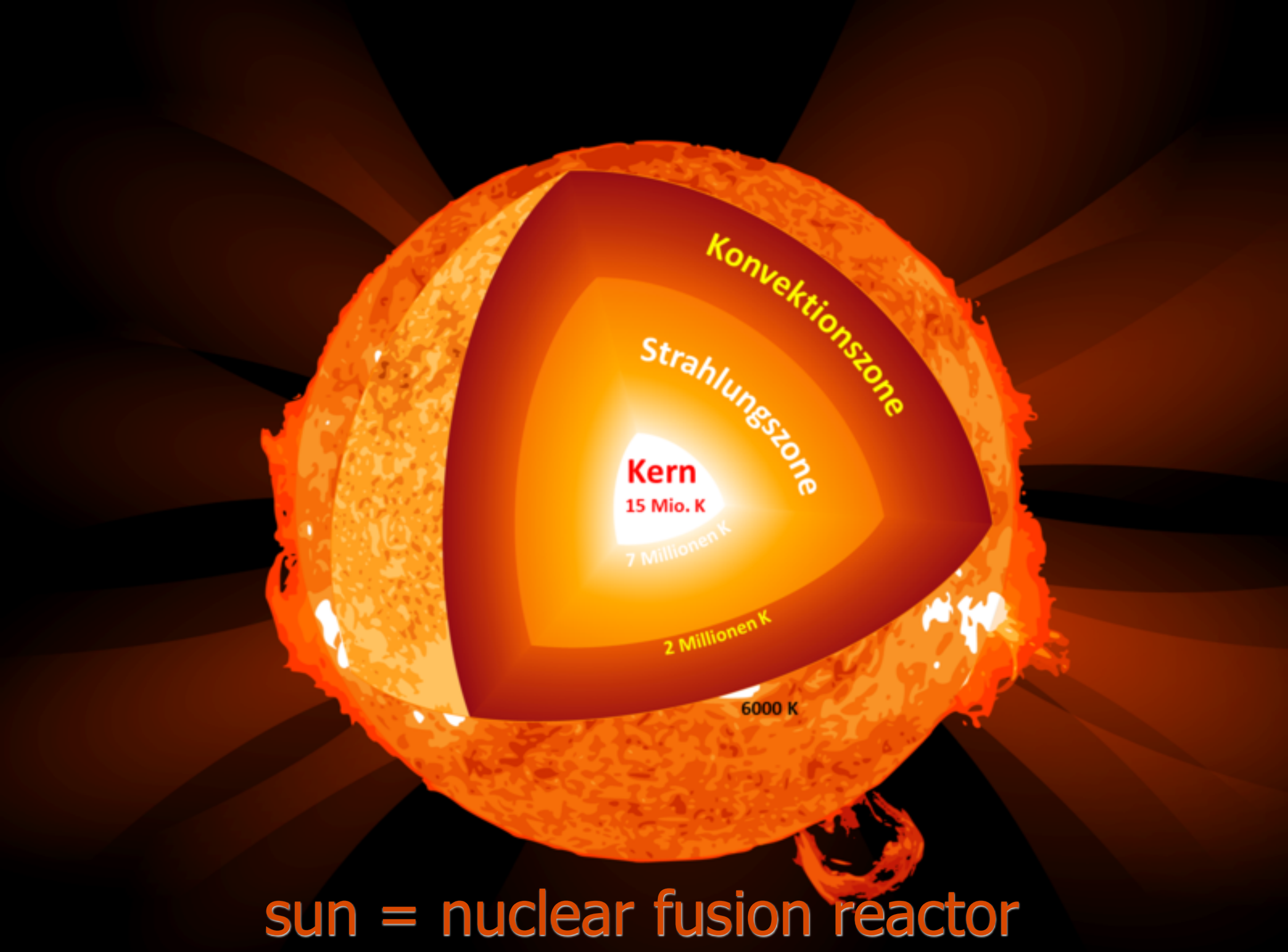
No free hydrogen

The Sun

The Sun

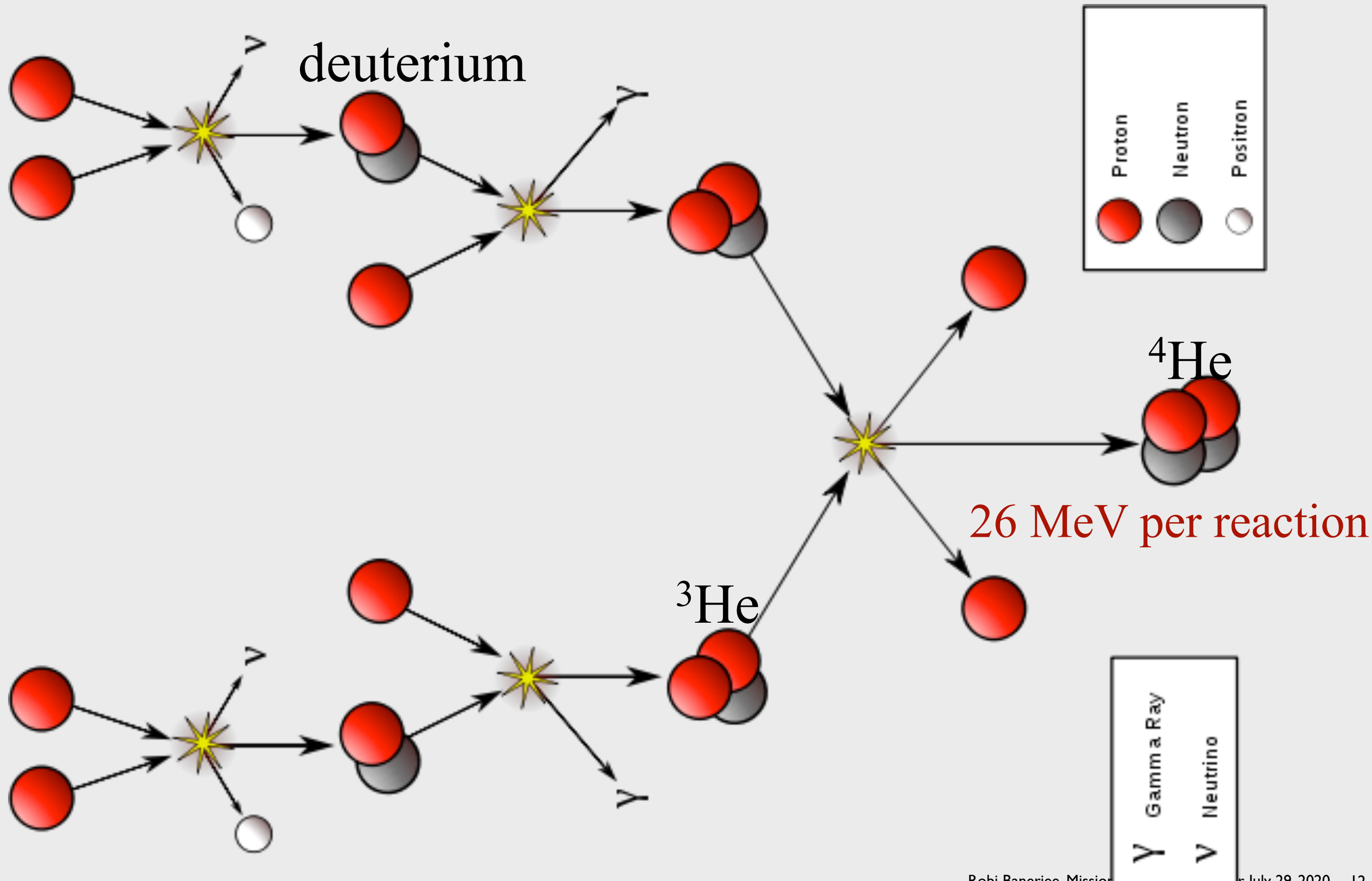
- 75 % hydrogen
- 24 % helium

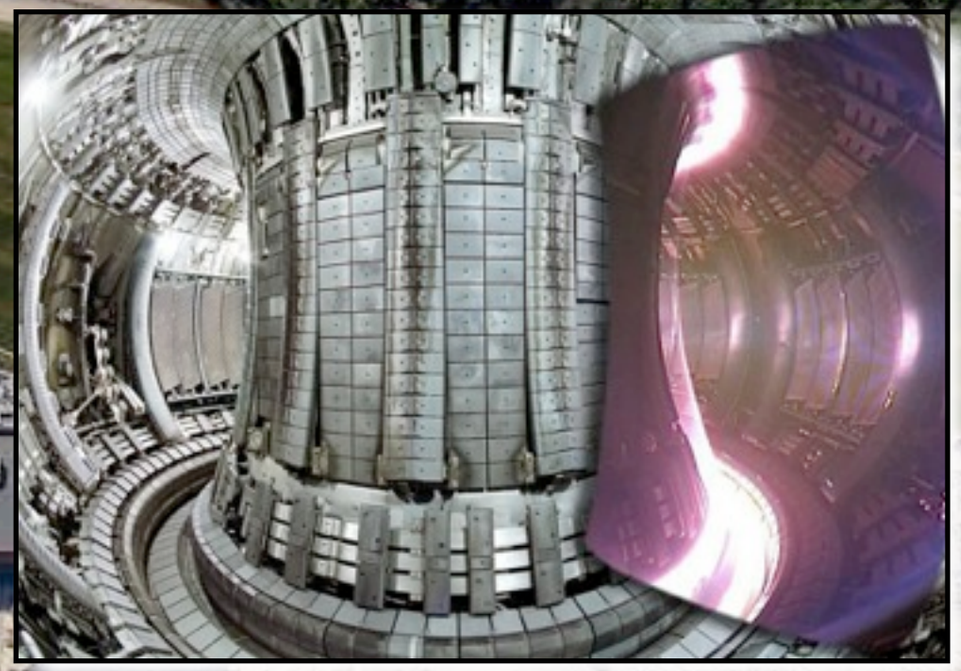

Konvektionszone
Strahlungszone
Kern
15 Mio. K
7 Millionen K
2 Millionen K
6000 K



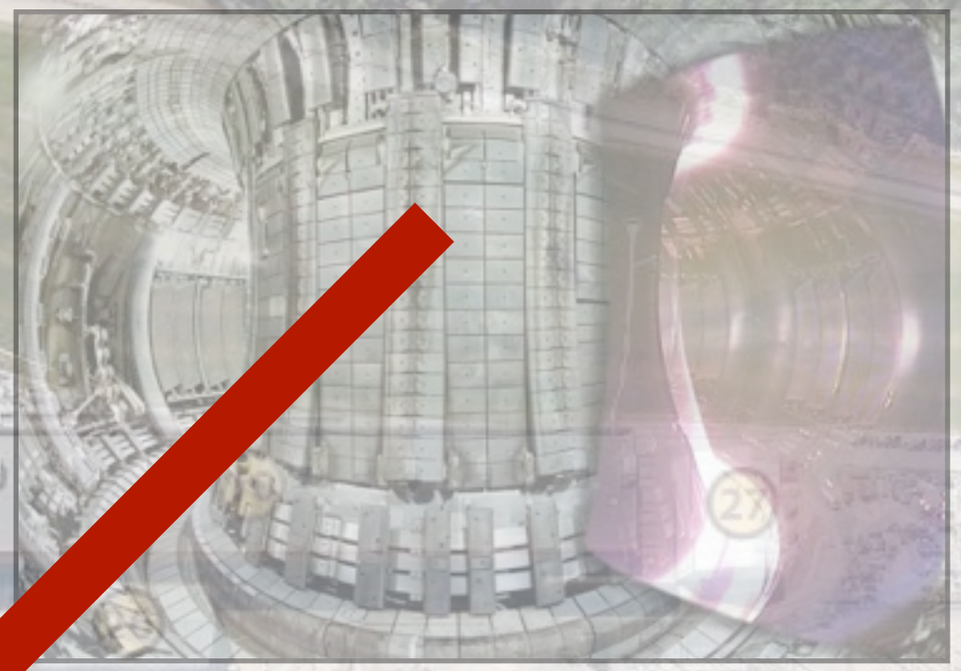
sun = nuclear fusion reactor

sun's energy generation





ITER start of assembly phase: 28.07.2020



ITER start of assembly phase: 28.07.2020

The Sun

- constant total power:

$$L_\odot = 3\times10^{26}\ \mathrm{W} = 3\times10^{14}\ \mathrm{TW}$$

- at Earth surface (distance ~ 150 Mio km)

$$L_\oplus \approx 1.74\times10^{17}\ \mathrm{W} \approx 174.000\ \mathrm{TW}$$

- per unit area: solar constant

$$\mathbf{s_\oplus = 1.36\ kW/m^2}$$

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- per unit area: solar constant

$$\mathbf{s_\oplus = 1.36\ kW/m^2}$$

- Sun generates **winds!**

low wind : $75\ \mathrm{W/m^2}$
(5 m/s)

strong wind : $10\ \mathrm{kW/m^2}$

World Demand of Energy

about 505 Exa Joule per year

≈ 140 Billion kWh / a

average power demand: ≈ 16 TW

The Sun

- at Earth surface

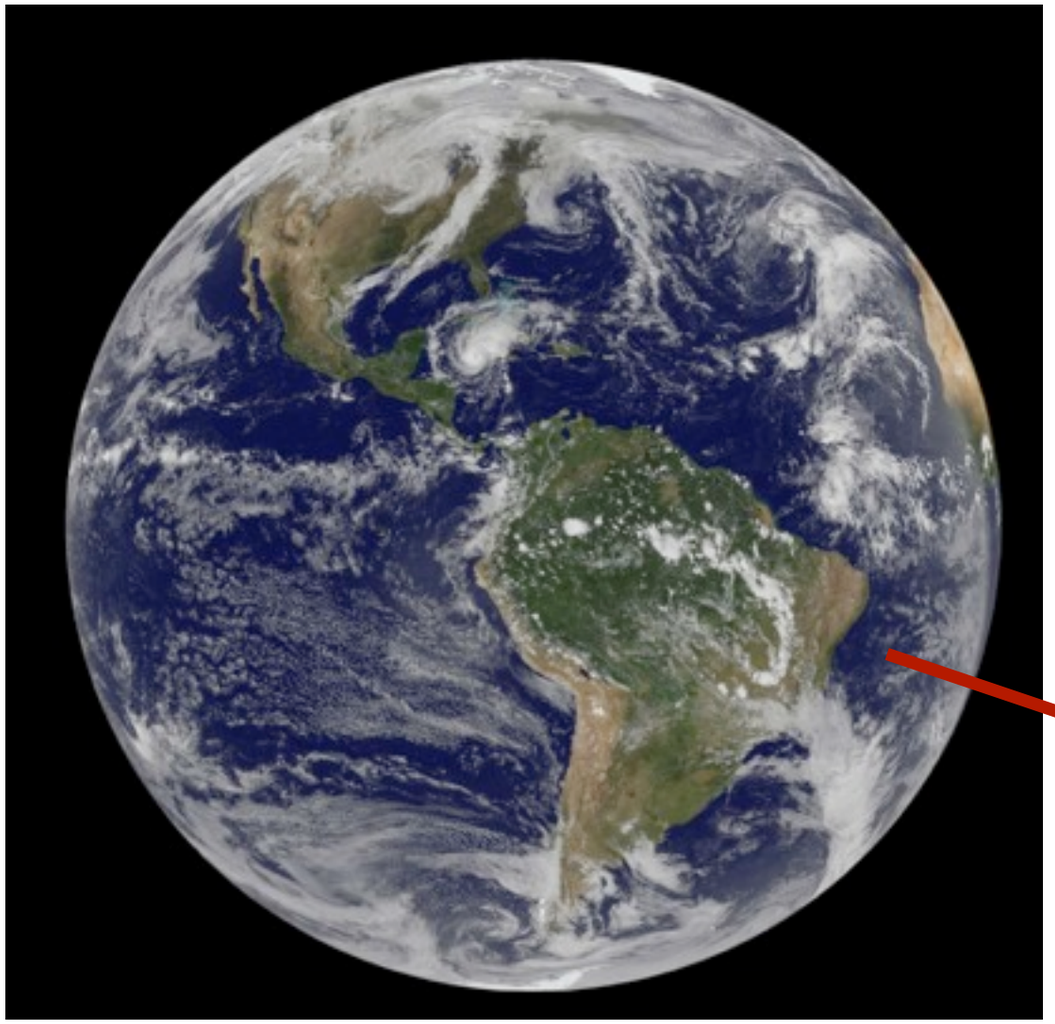
$L_\oplus \approx 1.74 \times 10^{17}\,\mathrm{W} \approx 174.000\,\mathrm{TW}$

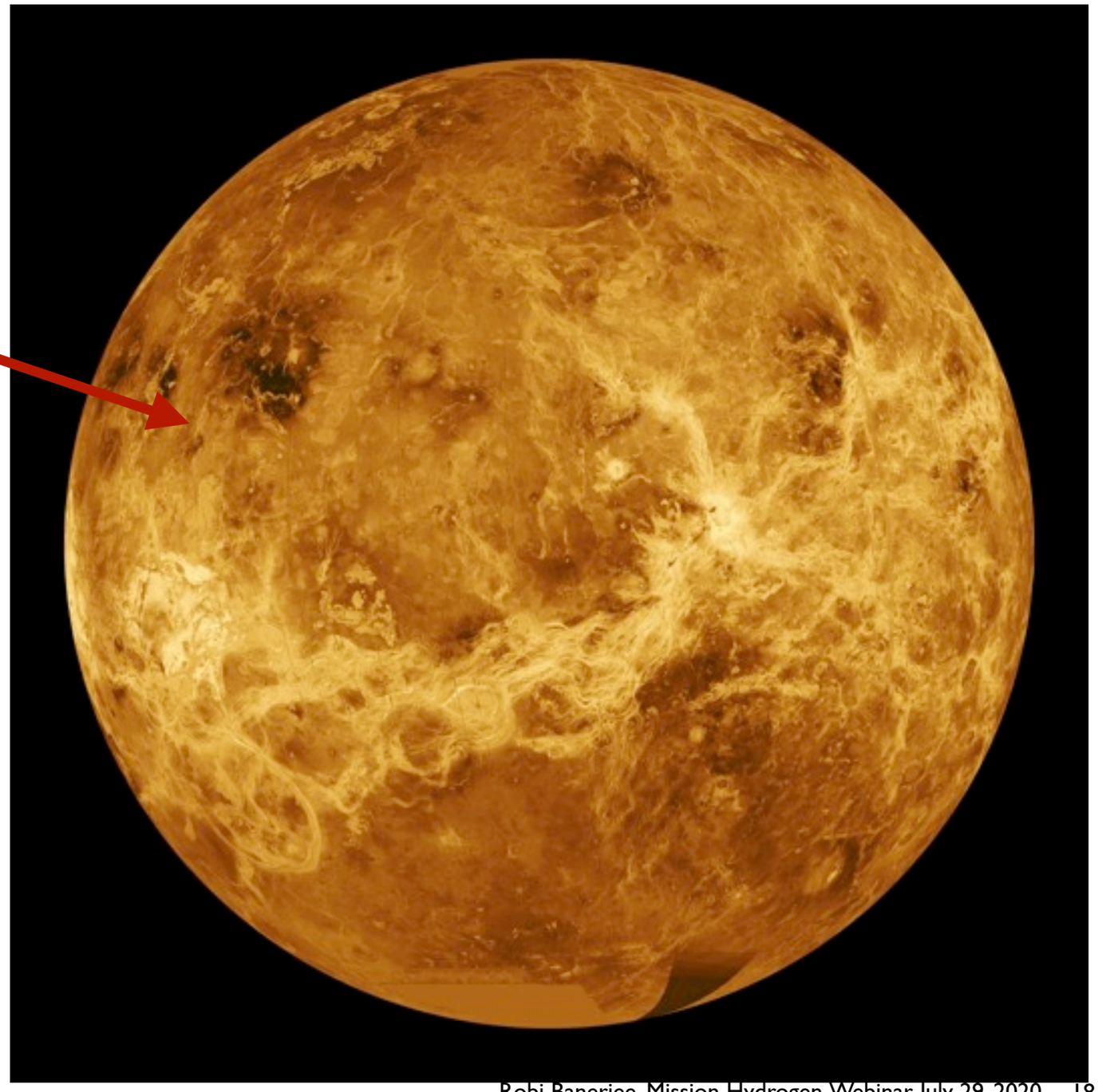
→ more than **10.000 times** world power demand!

→ less than **50 minutes** to supply the Earth's energy demand of an entire year!

Why use Sun's power?

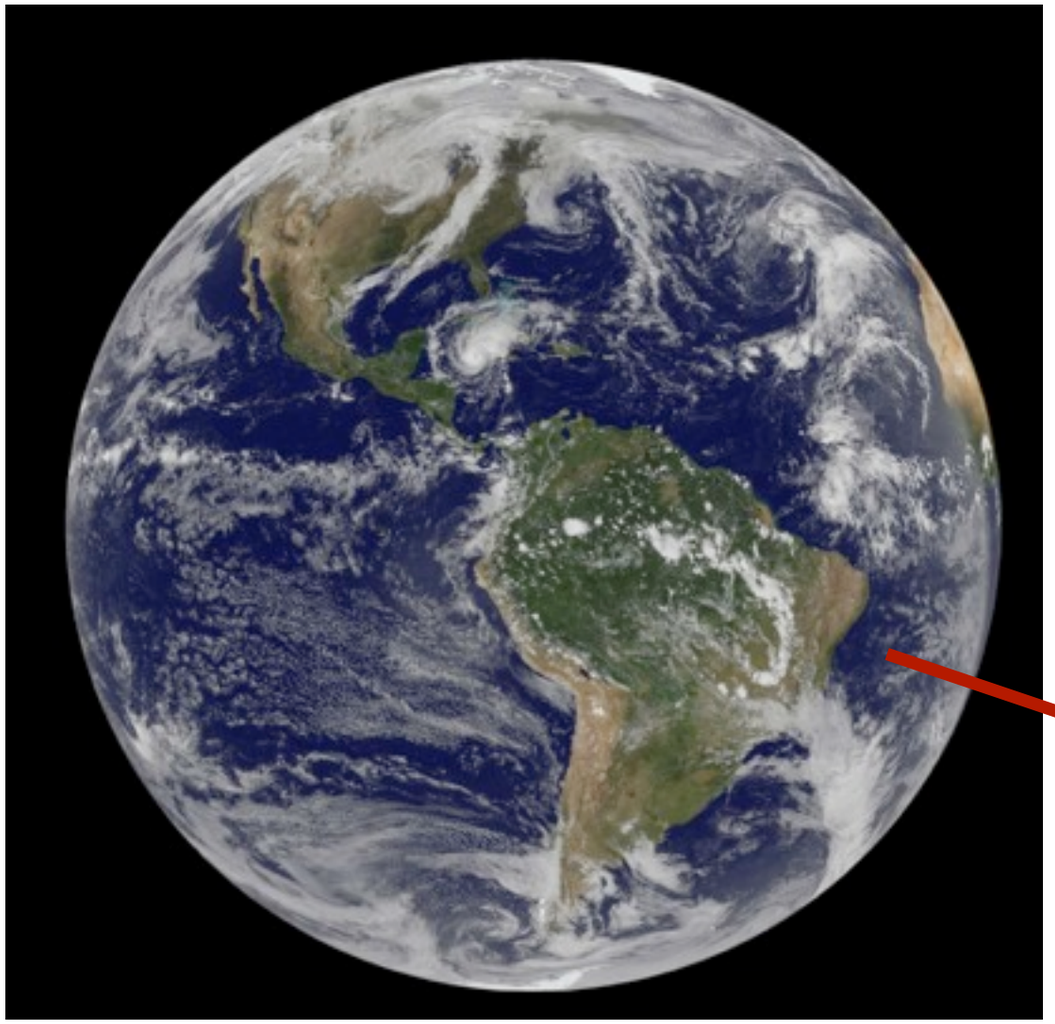
Why use Sun's power?

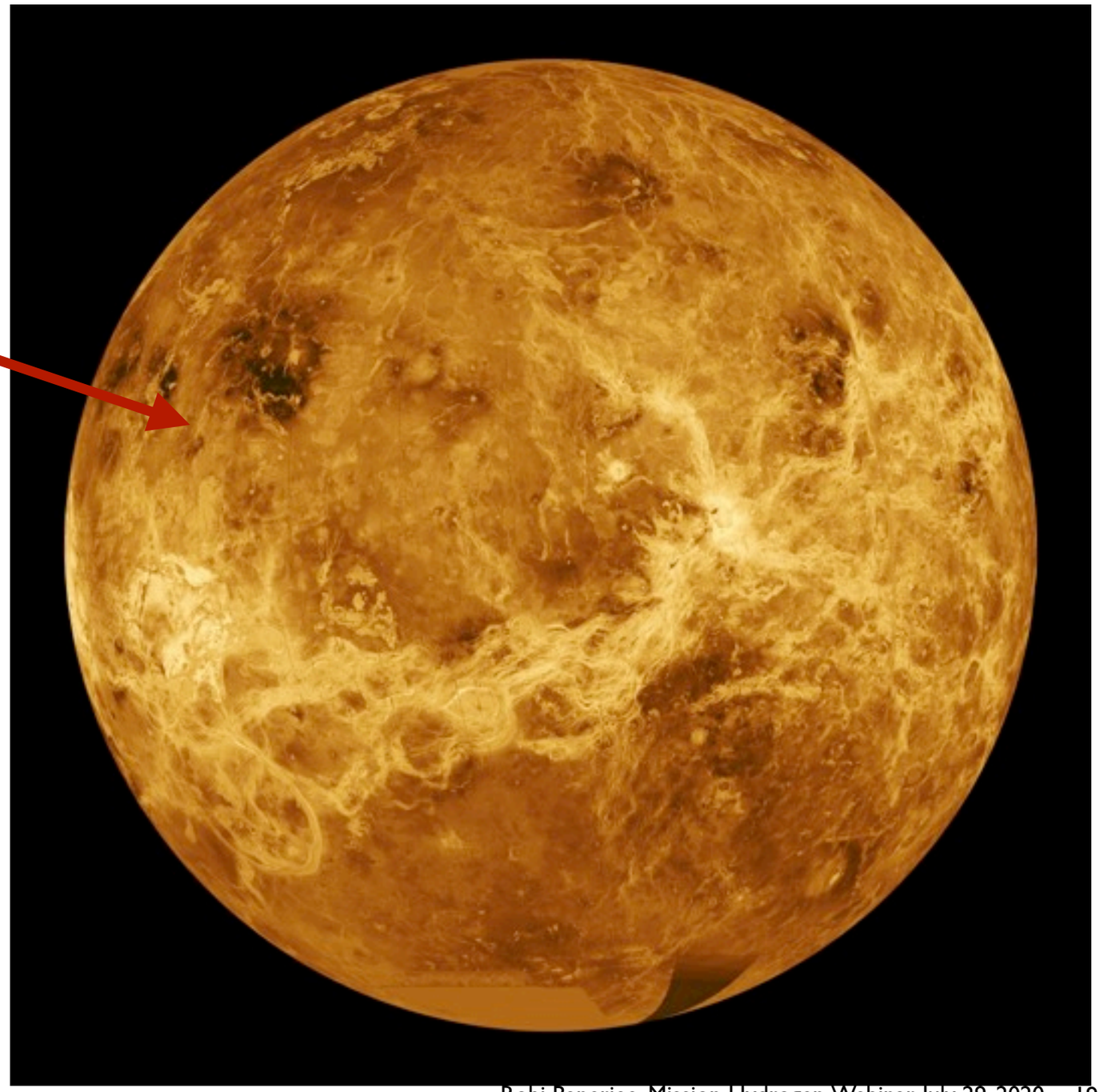




Venus' atmosphere:
96% CO_2

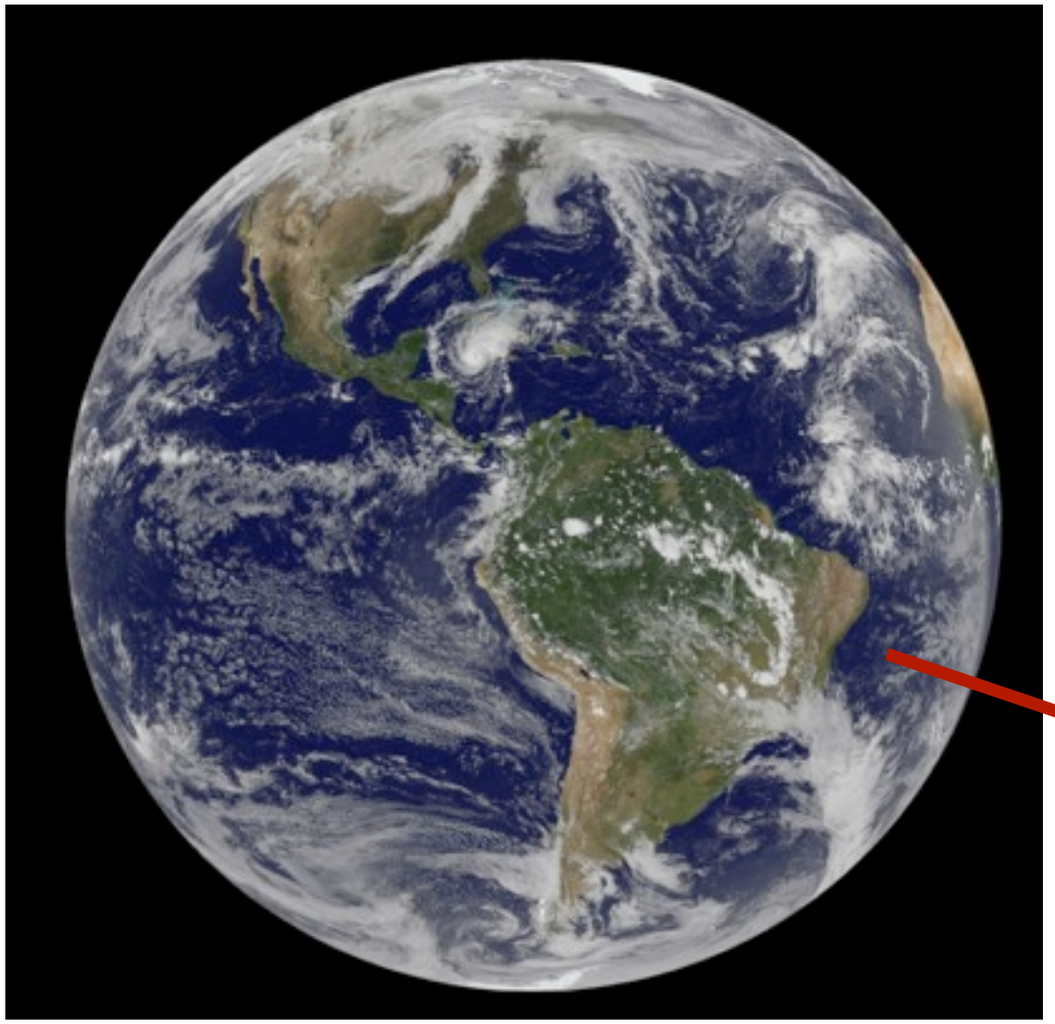
Why use Sun's power?

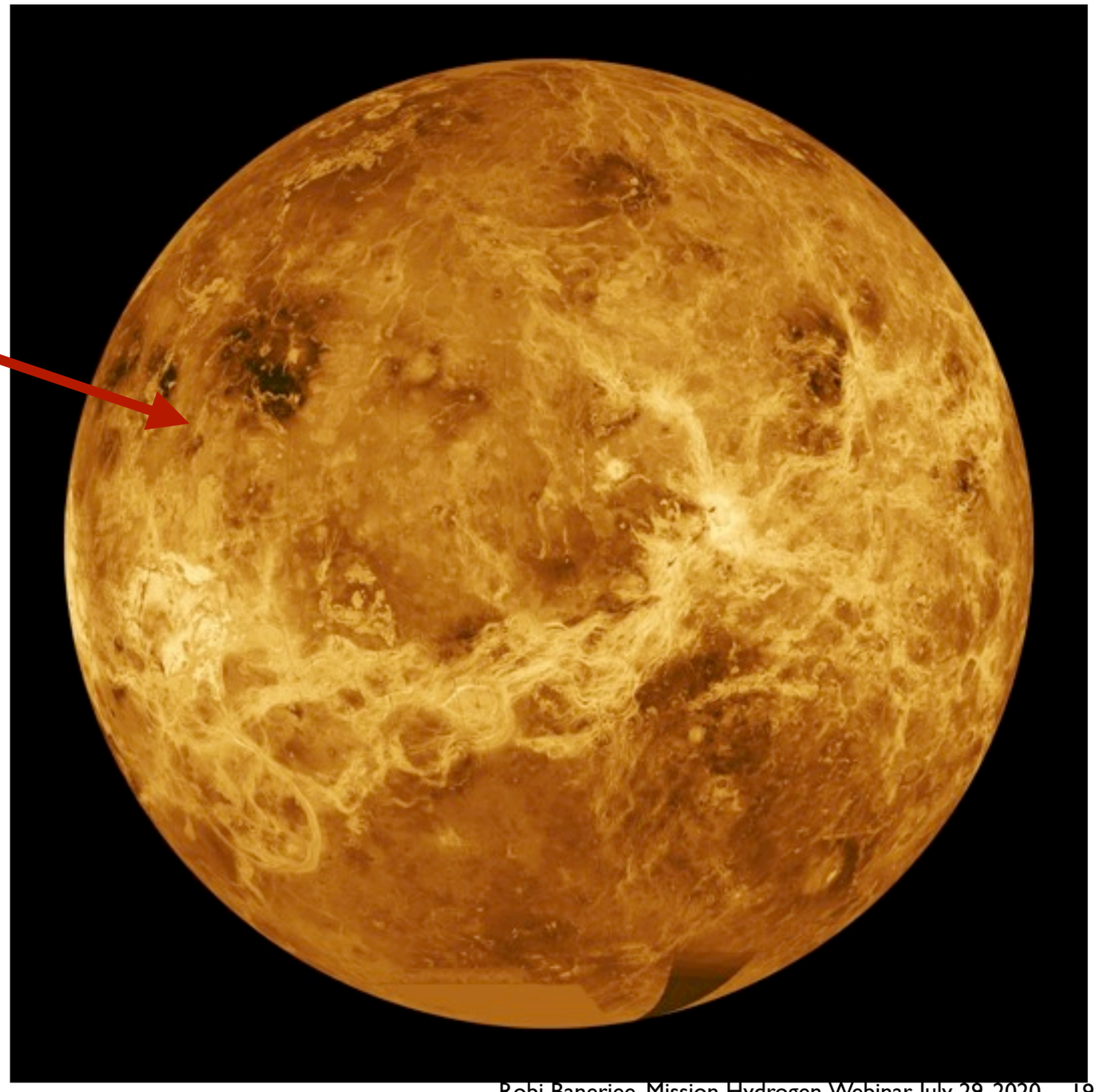




- anthropogenic climate change
- limited resources

Why use Sun's power?

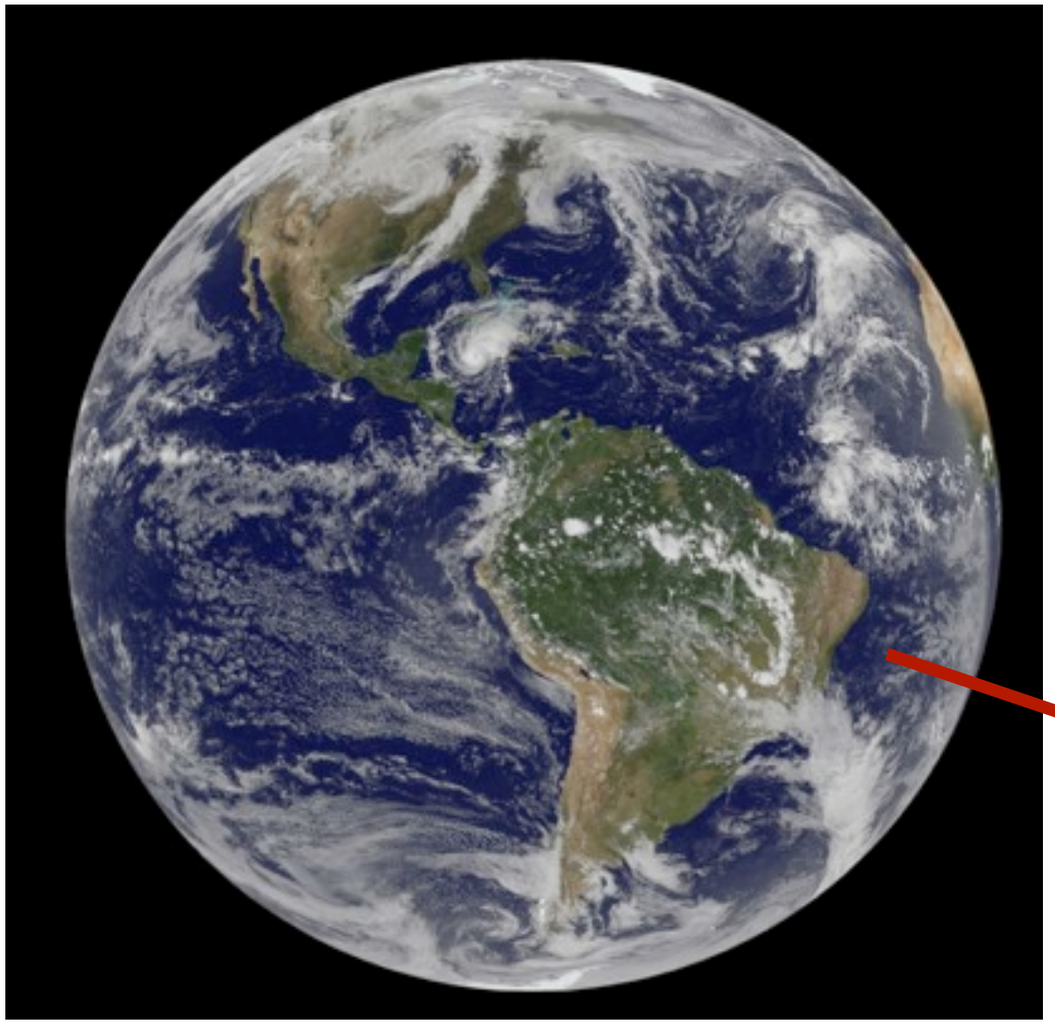


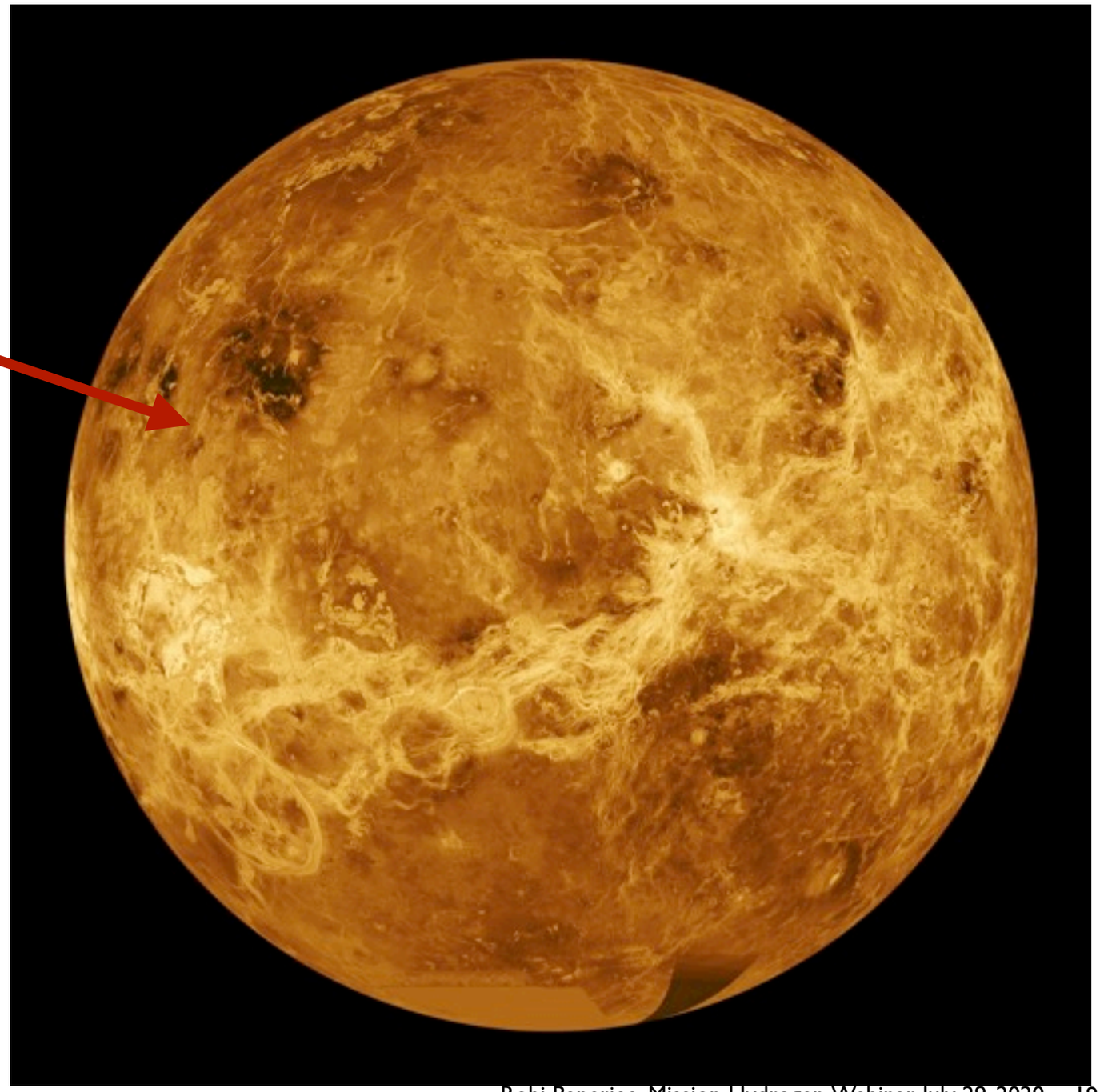


- anthropogenic climate change

- limited resources
- responsible handling

Why use Sun's power?

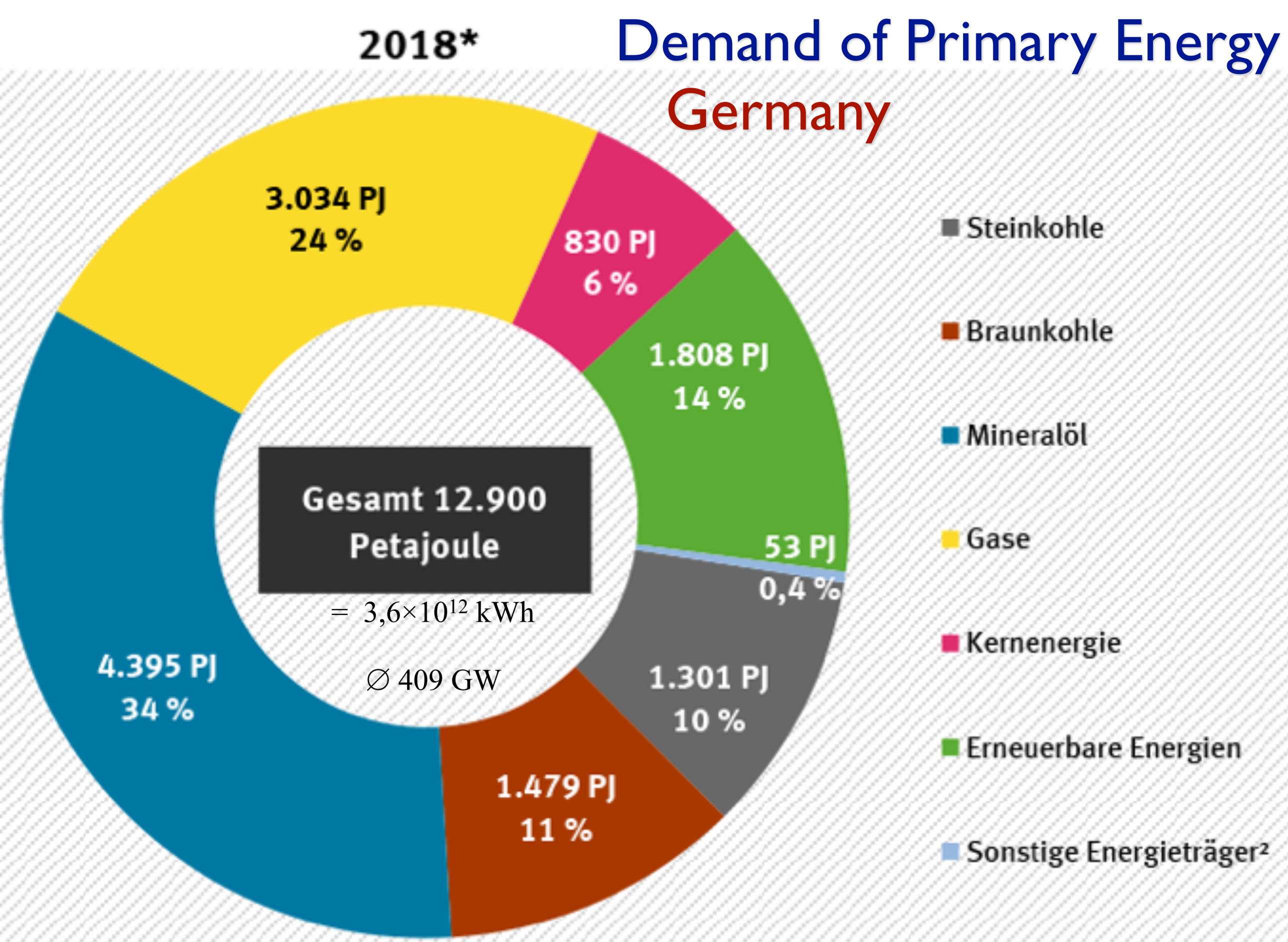




- anthropogenic climate change

- limited resources
- responsible handling
- improvement of quality of live

Demand of Primary Energy
Germany



DESERTEC-EUMENA

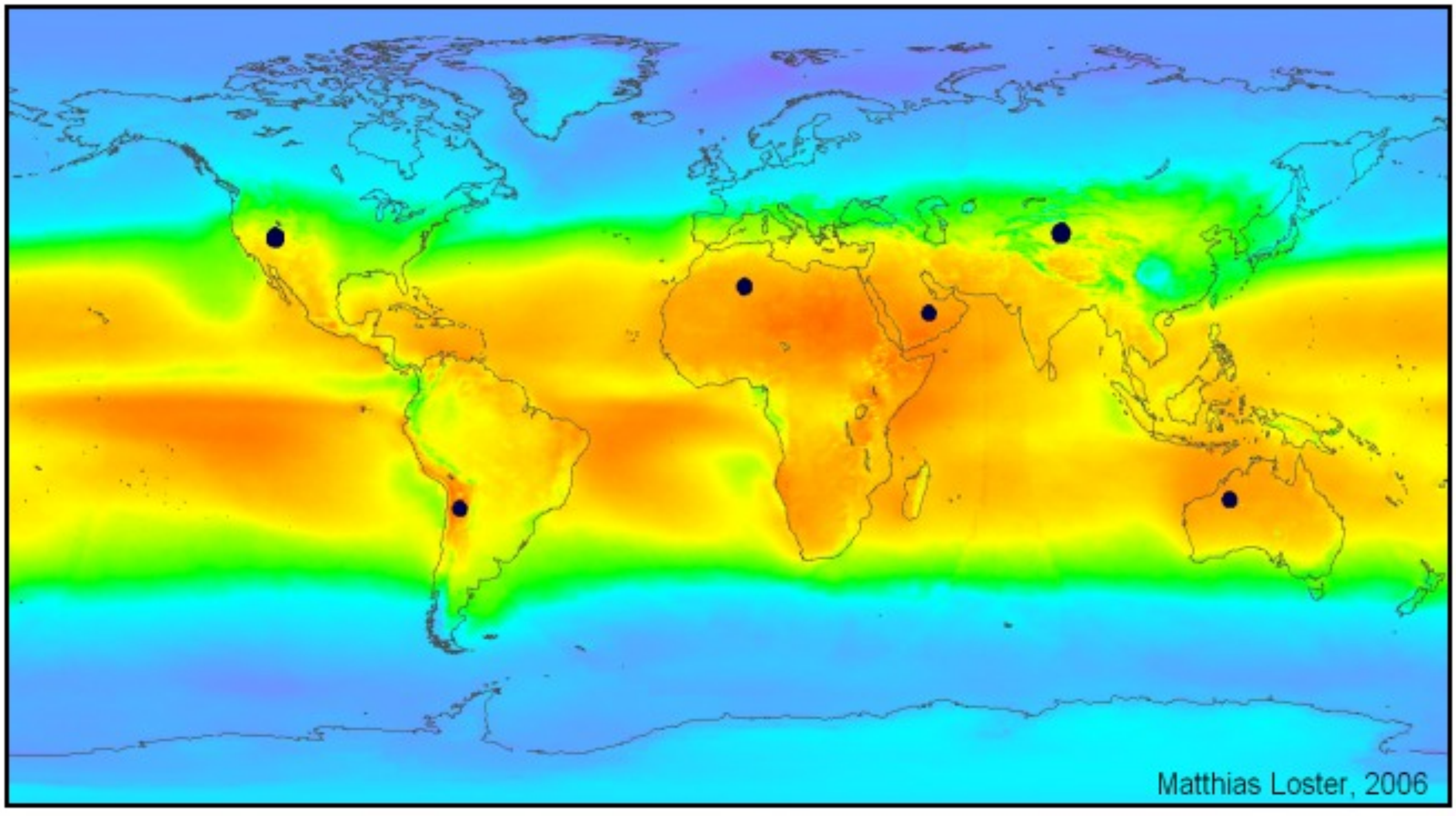
- Concentrating Solar Power
- Hydro
- Photovoltaics
- Biomass
- Wind
- Geothermal

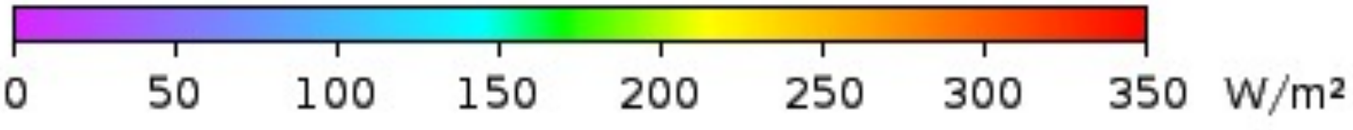
DESERTEC FOUNDATION

CSP collector areas for electricity

- World 2005 90.000 km²
- EU-25 2005 16.000 km²
- MENA 2005 3.025 km²
- TRANS-CSP Mix EUMENA 2050

Direct Solar Power



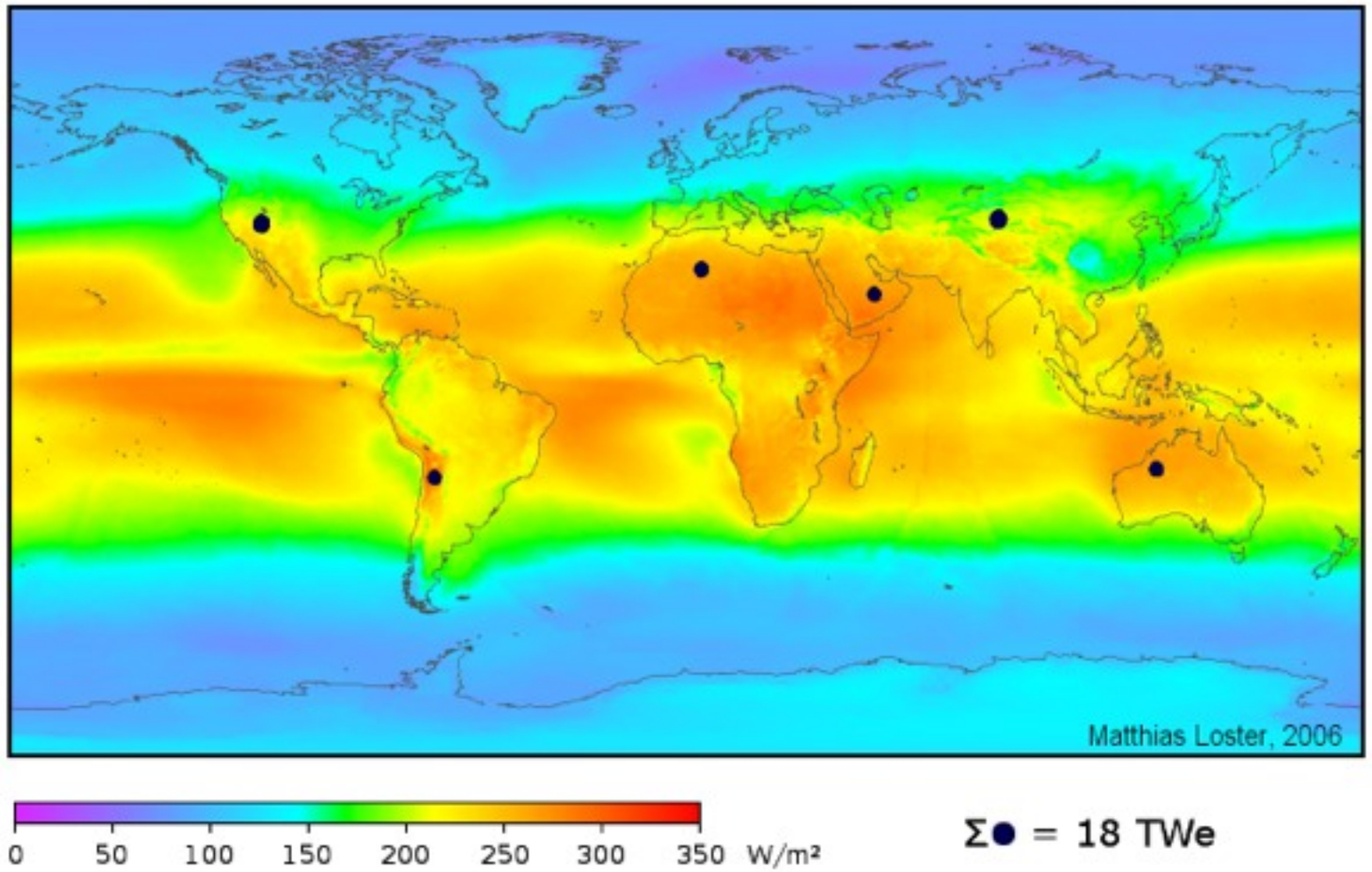


Σ● = 18 TWe

Direct Solar Power

- average global solar power:

  ~ 165 W/m²



installed facilities*:

- ~ 456 GW for hot water (*China*: 325 GW)
- ~ 4,8 GW solar heat power plants (*Spain*: 2,3 GW, *USA*: 1.7 GW)

*Source: Renewables 2017, Global Status Report REN21

PS10 & PS20

Solar Thermal Power Plants

11 + 20 MW

Sevilla, Spain

Noor Solar Plant
up to 2 GW 2020

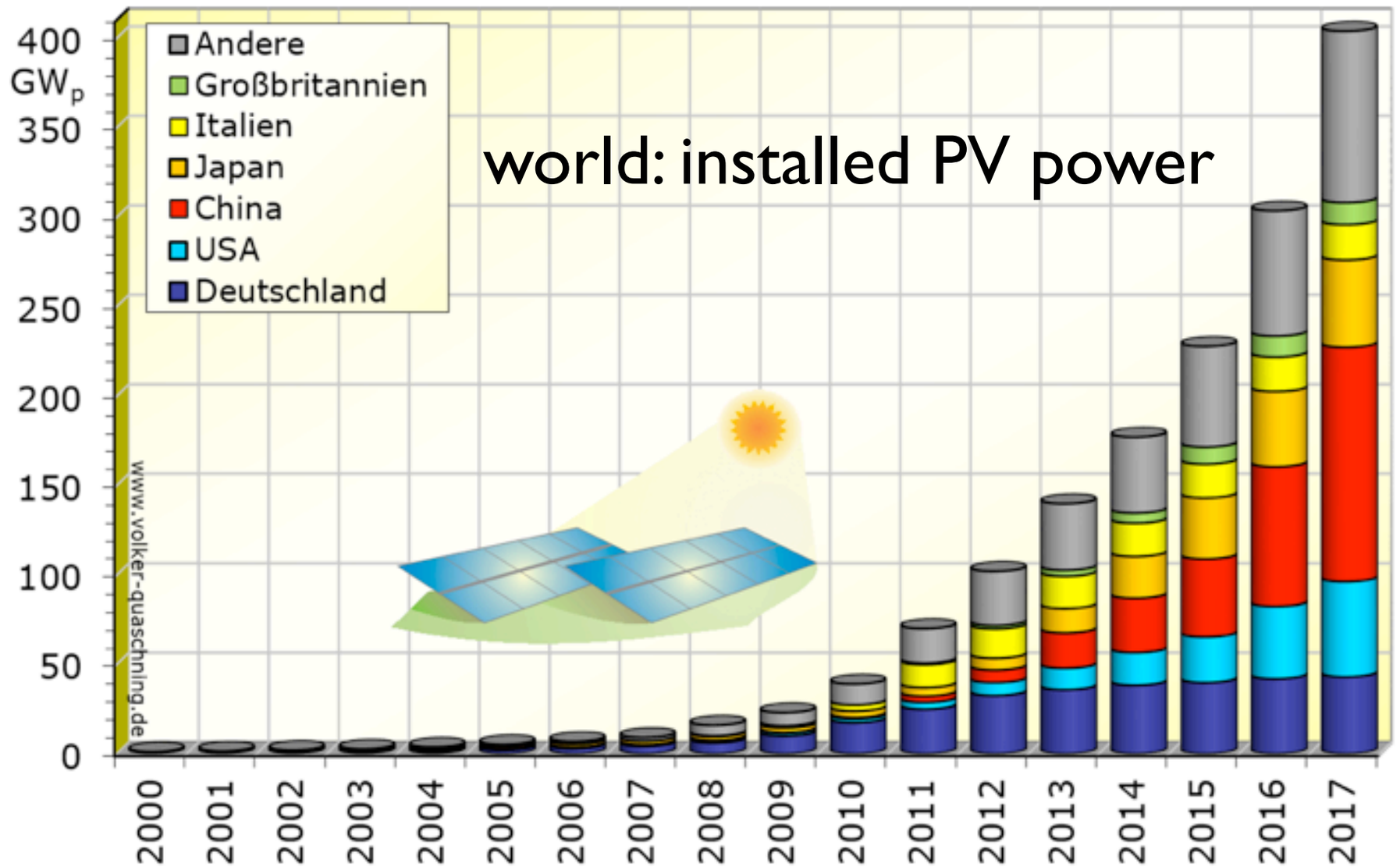
Quarazate, Morocco

Photovoltaics

Photo electric effect
(Albert Einstein 1905, Nobel price 1921)

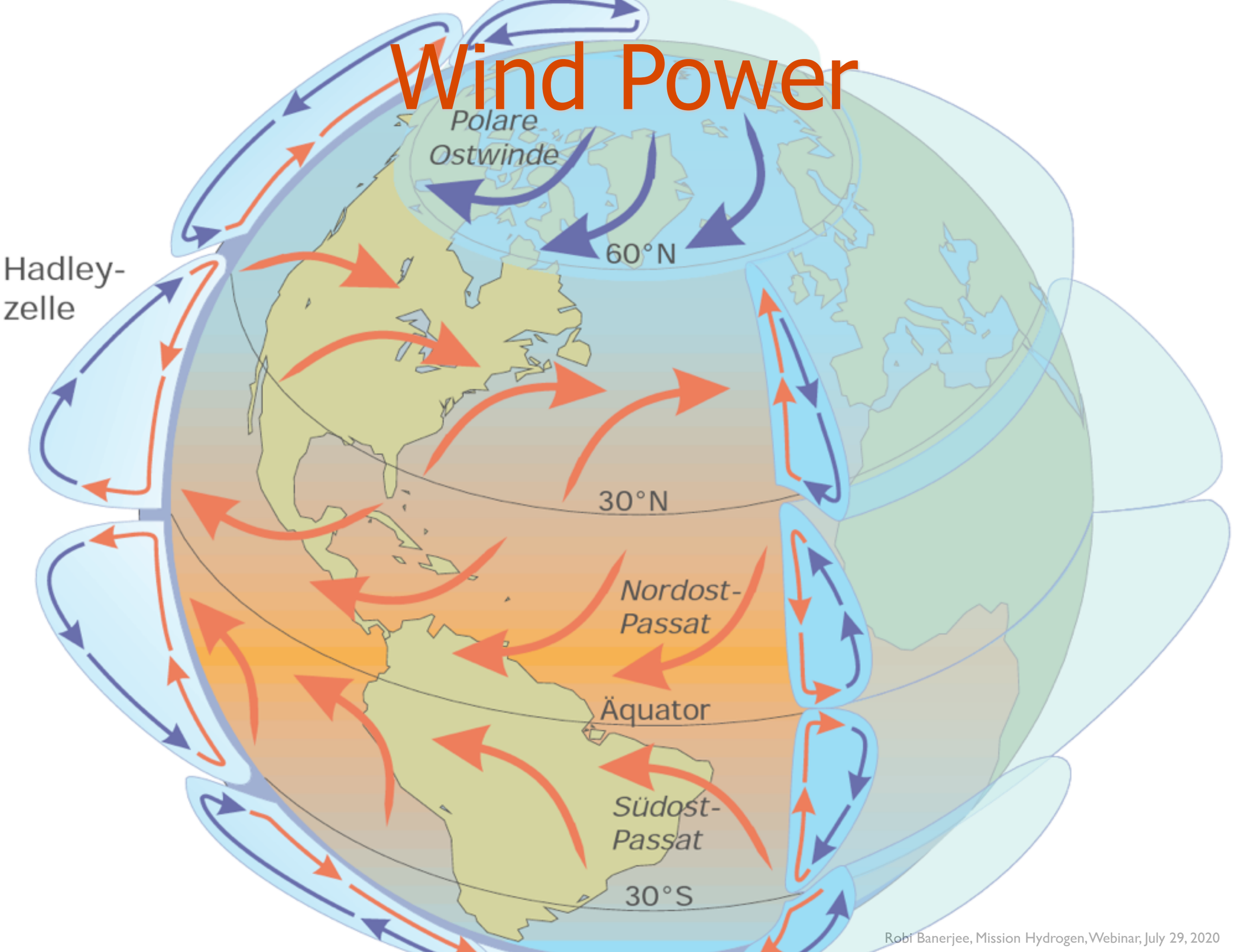
- electric power generation
  also at lower intensity

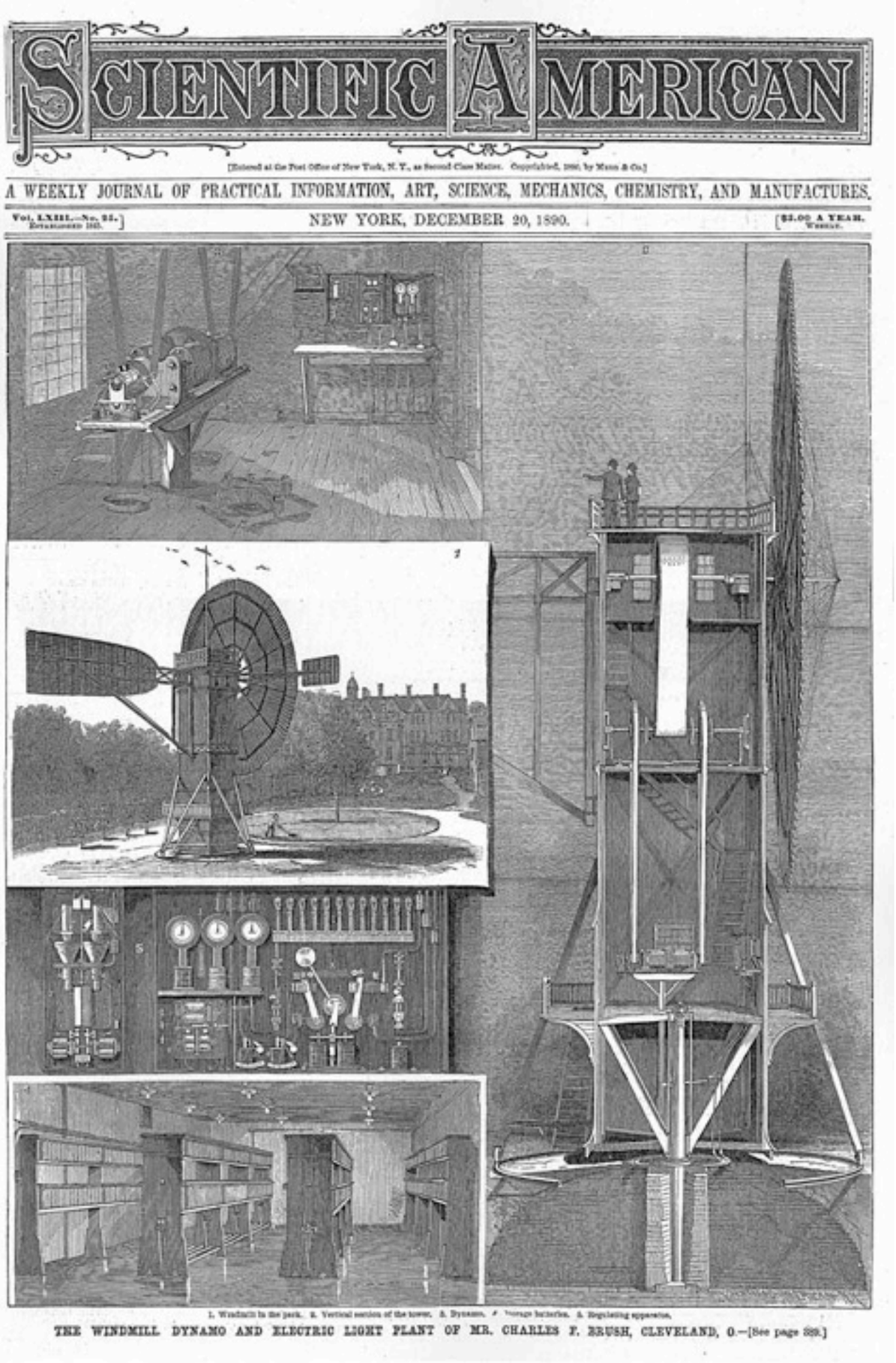
- efficiency
  ~ 20%

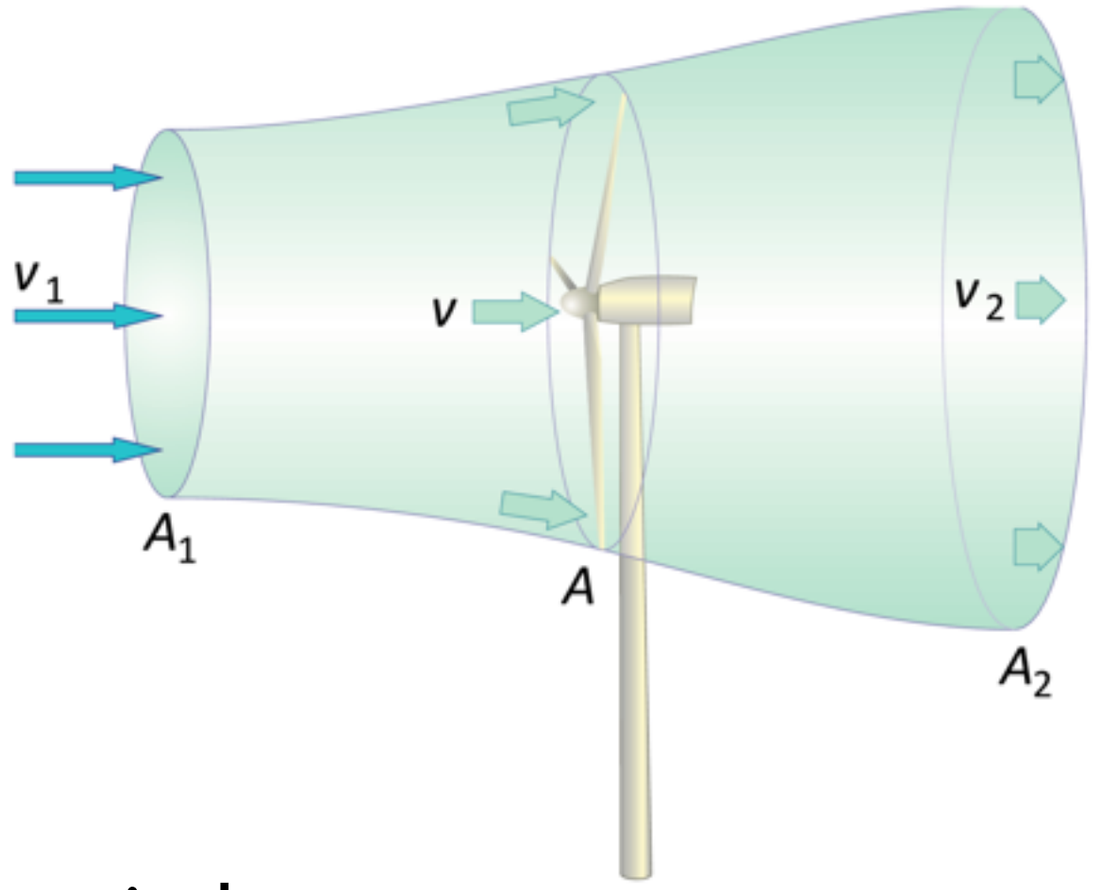


world: installed PV power

Wind Power


Polare
Ostwinde
60°N
Hadley-
zelle
30°N
Nordost-
Passat
Äquator
Südost-
Passat
30°S





wind power density:

$$\propto v^3$$

$$c_{P,Betz} = \frac{16}{27} \approx 0{,}593$$

Wind power by Charles Brush in 1888

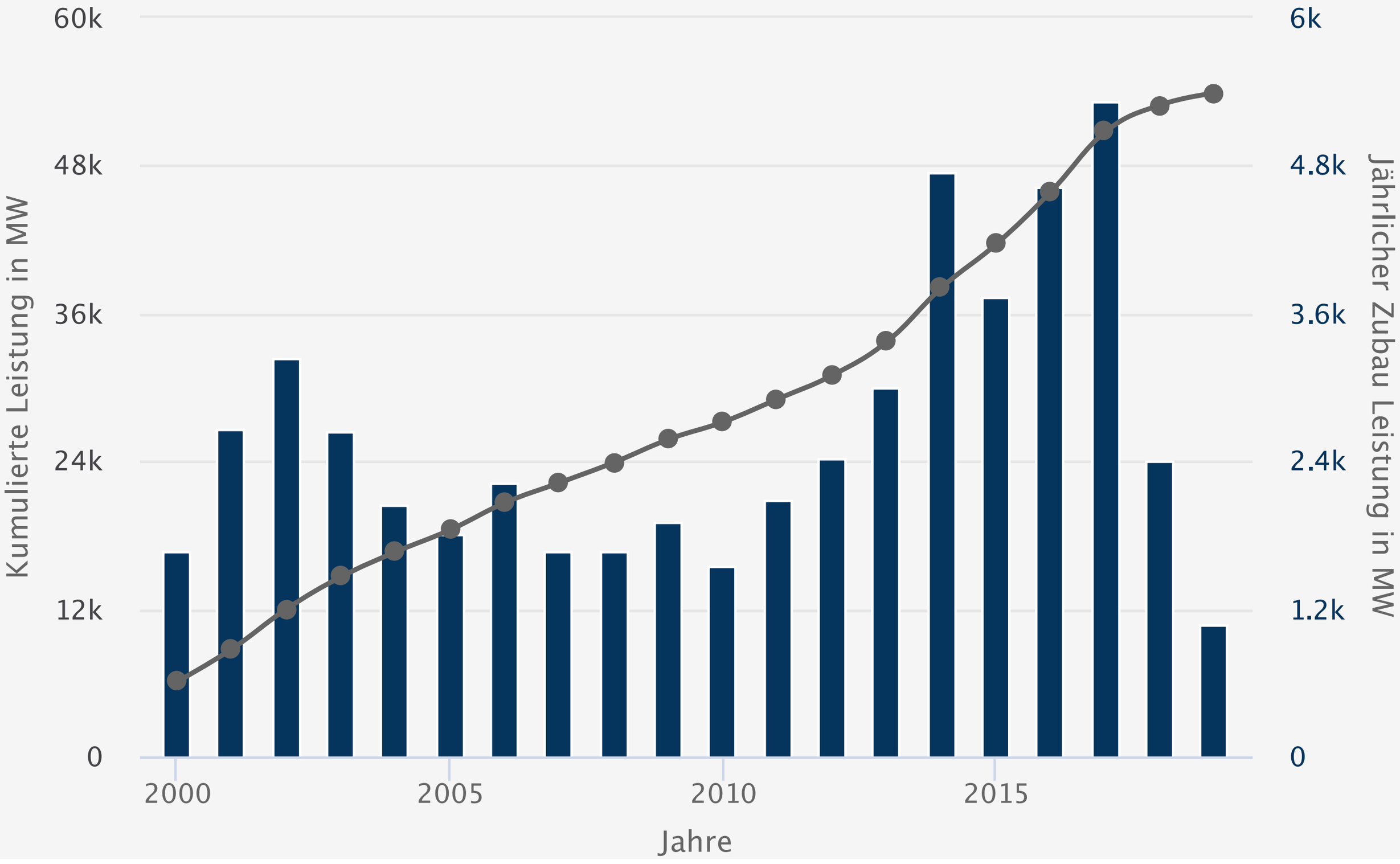
Veja Mate, Nordsee, ca. 400 MW

Stößen-Teuchern ca. 177 MW

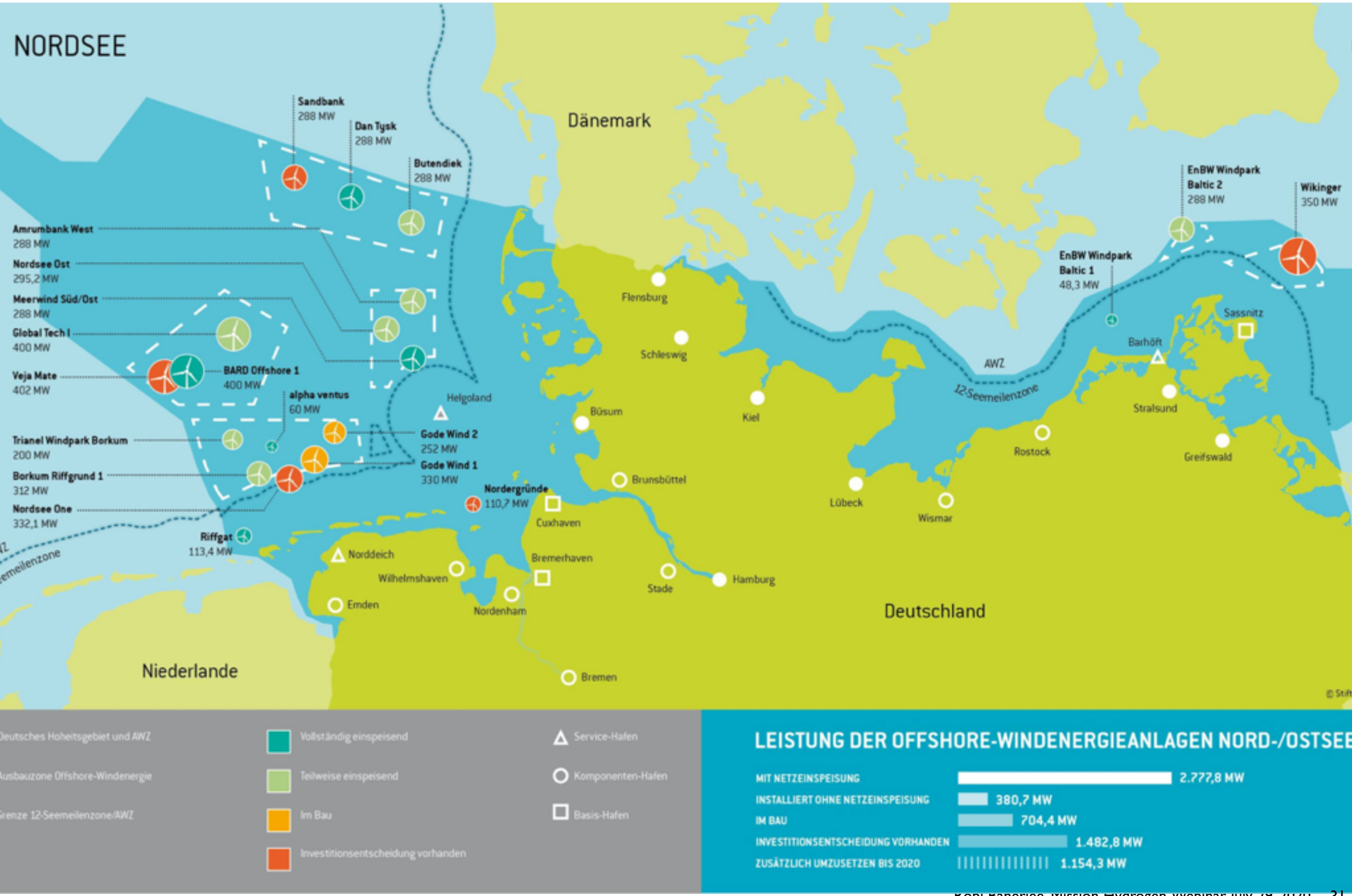
Stand: 31.12.2019

BWE
Bundesverband WindEnergie

Germany: onshore wind power 2019: 54 GW



Germany: offshore wind power 2015: 2.8 GW



Germany: offshore wind power 2017: 5.4 GW

LEISTUNG DER OFFSHORE-WINDENERGIEANLAGEN NORD-/OSTSEE

MIT NETZEINSPEISUNG	
INSTALLIERT OHNE NETZEINSPEISUNG	0 MW
IM BAU	780 MW
INVESTITIONSENTSCHEIDUNG VORHANDEN	1.520 MW

Germany: offshore wind power 2019: 7.5 GW

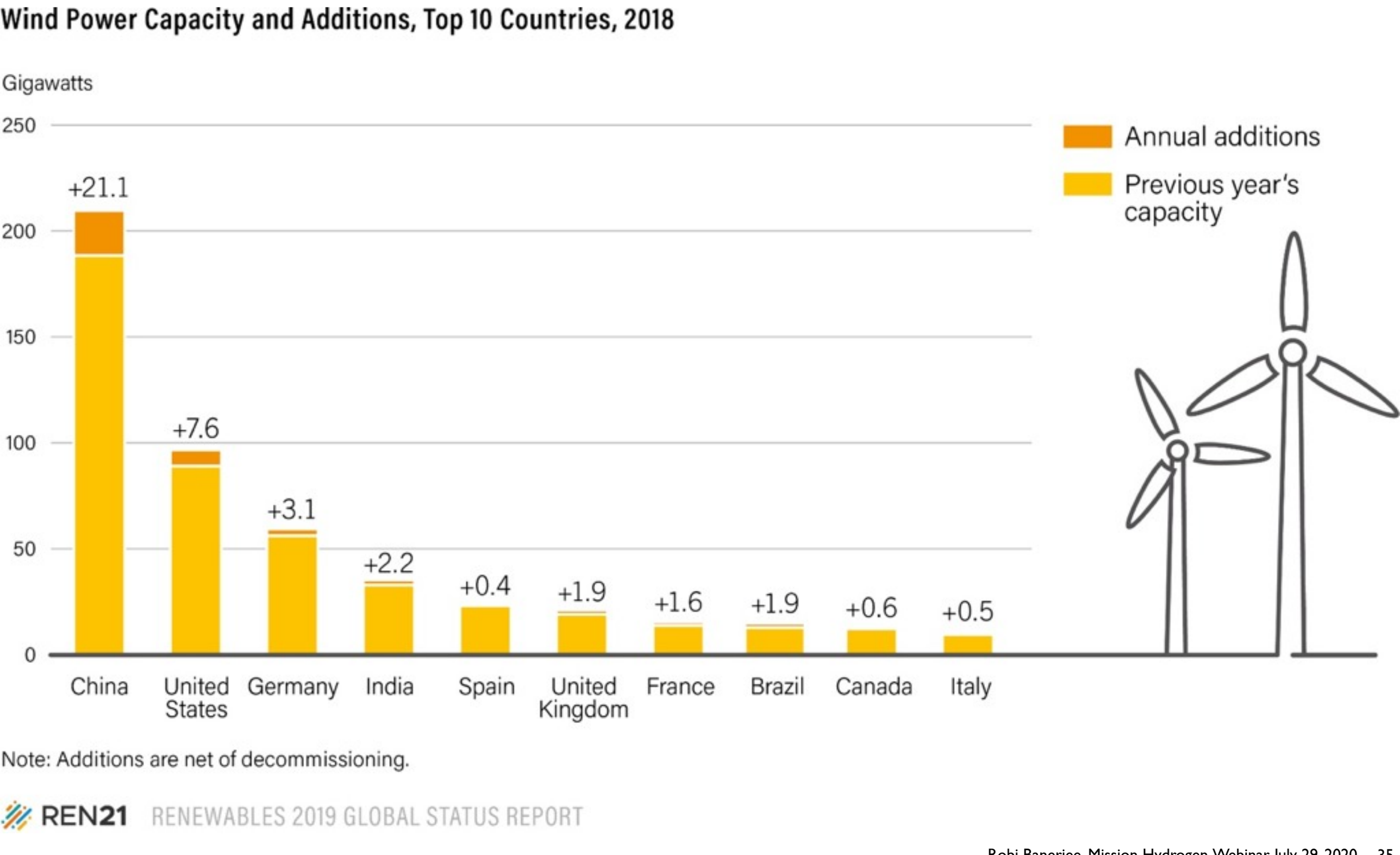
Germany: offshore wind power 2019: 7.5 GW

2020: no new power plants

potential: > 400 GW

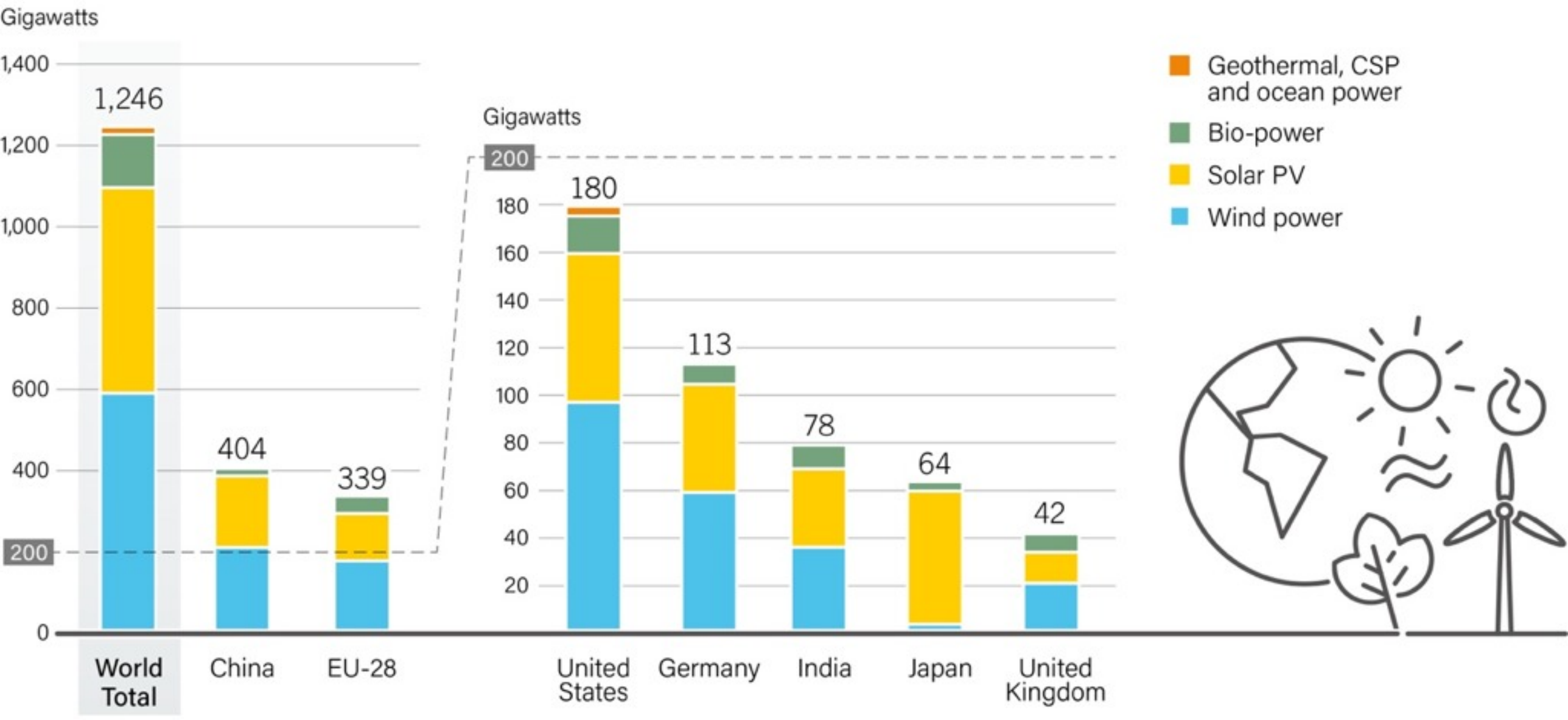
but: limited to max. 20 GW by law!

Wind Power


Wind Power Capacity and Additions, Top 10 Countries, 2018
Gigawatts
250
200
150
100
50
0
+21.1
+7.6
+3.1
+2.2
+0.4
+1.9
+1.6
+1.9
+0.6
+0.5
China
United States
Germany
India
Spain
United Kingdom
France
Brazil
Canada
Italy
Annual additions
Previous year's capacity
Note: Additions are net of decommissioning.
REN21
RENEWABLES 2019 GLOBAL STATUS REPORT

Total Renewable Power

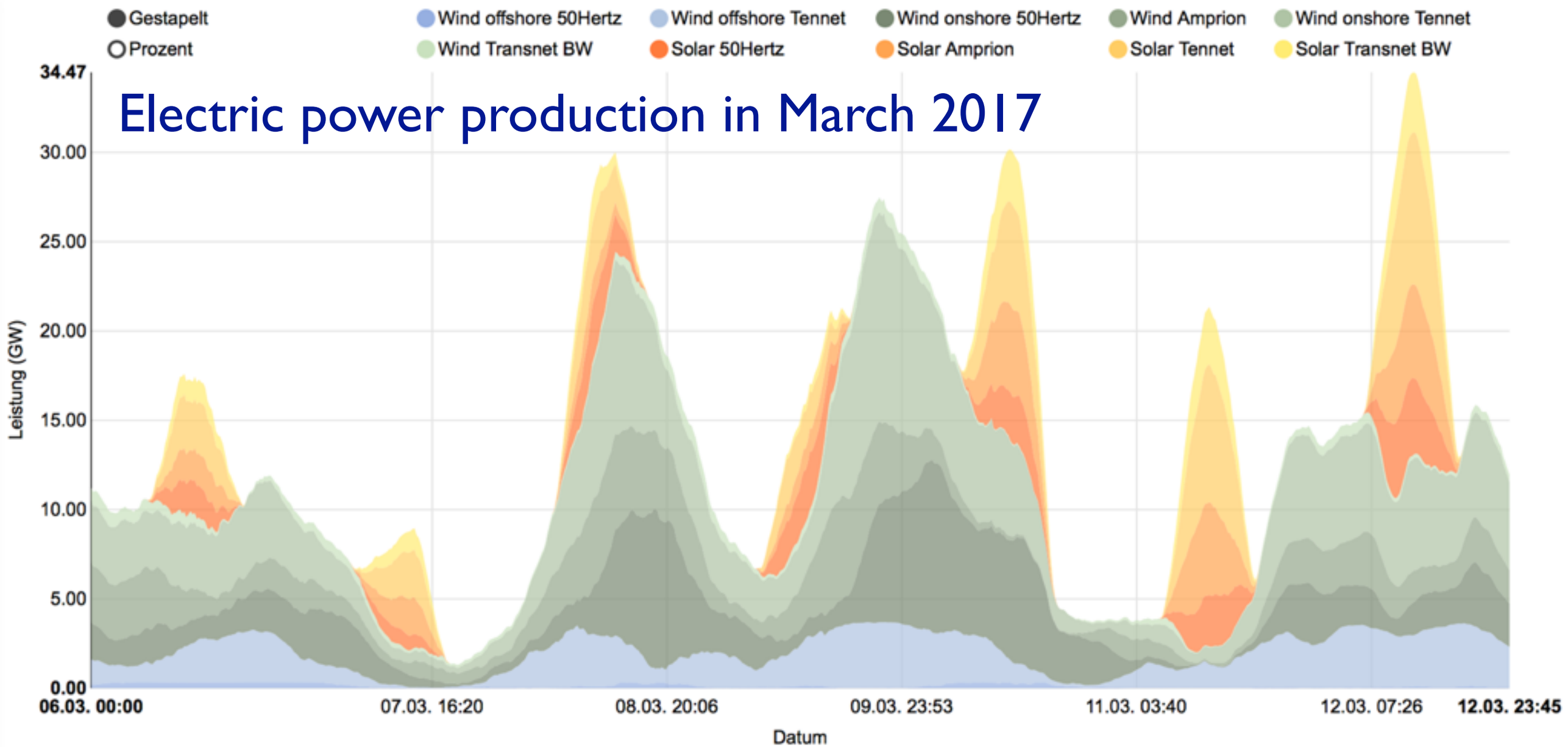
Renewable Power Capacities in World, EU-28 and Top 6 Countries, 2018



Note: Not including hydropower.

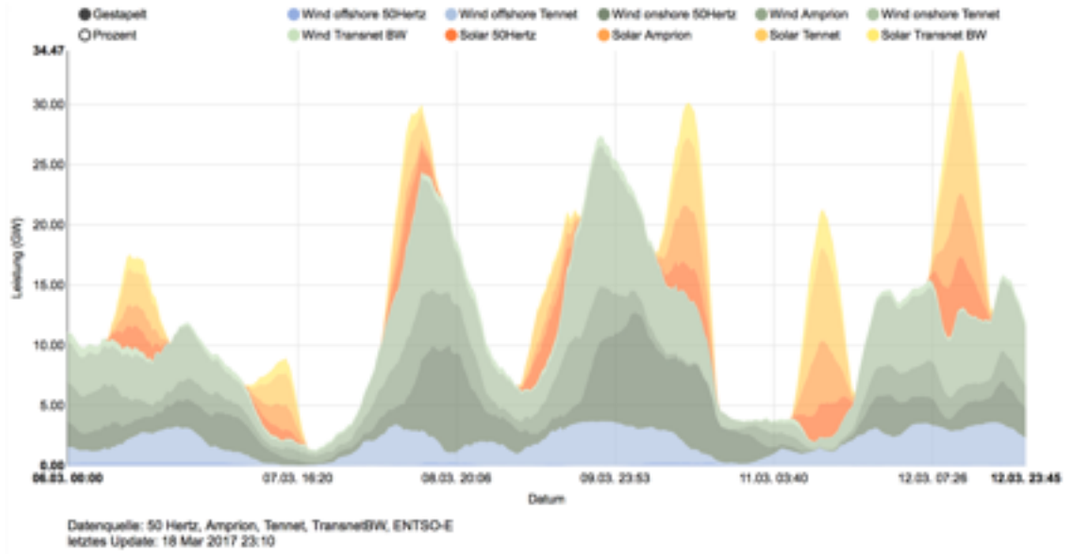
REN21 RENEWABLES 2019 GLOBAL STATUS REPORT

Transportation & Storage



- strong local/regional dependence
- highly fluctuating

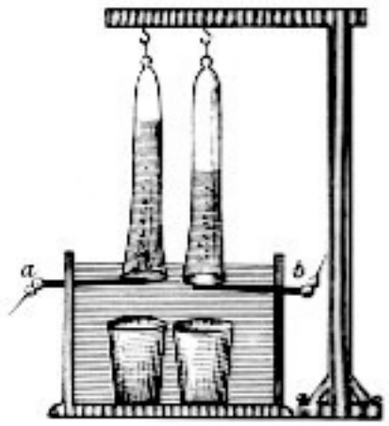
Transportation & Storge



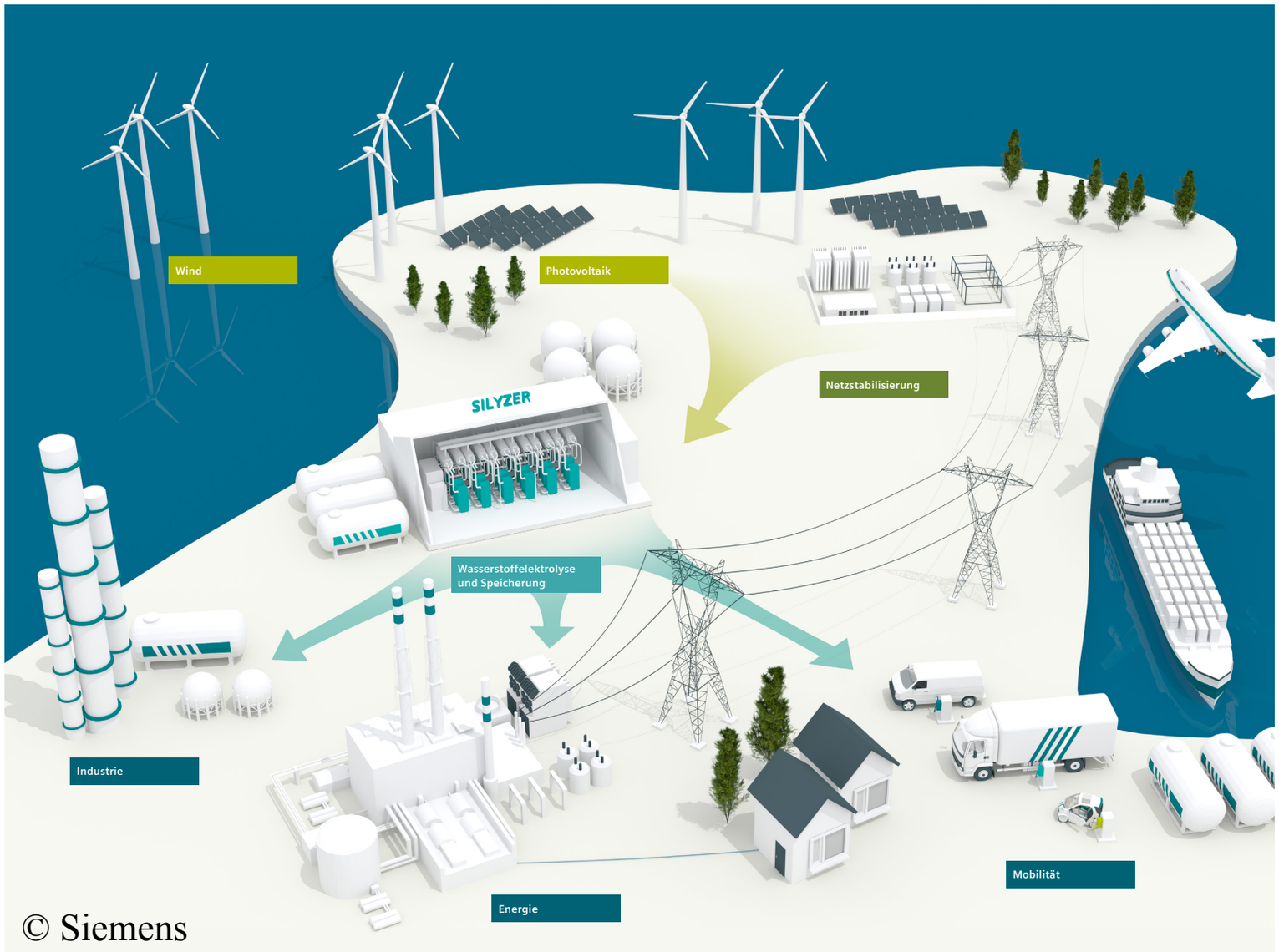
deenergiesed electrical power
~ 4,5 TWh (2015)
~ 3,7 TWh (2016)

Bundesnetzagentur

Power to Hydrogen



Johann Wilhelm Ritter 1800



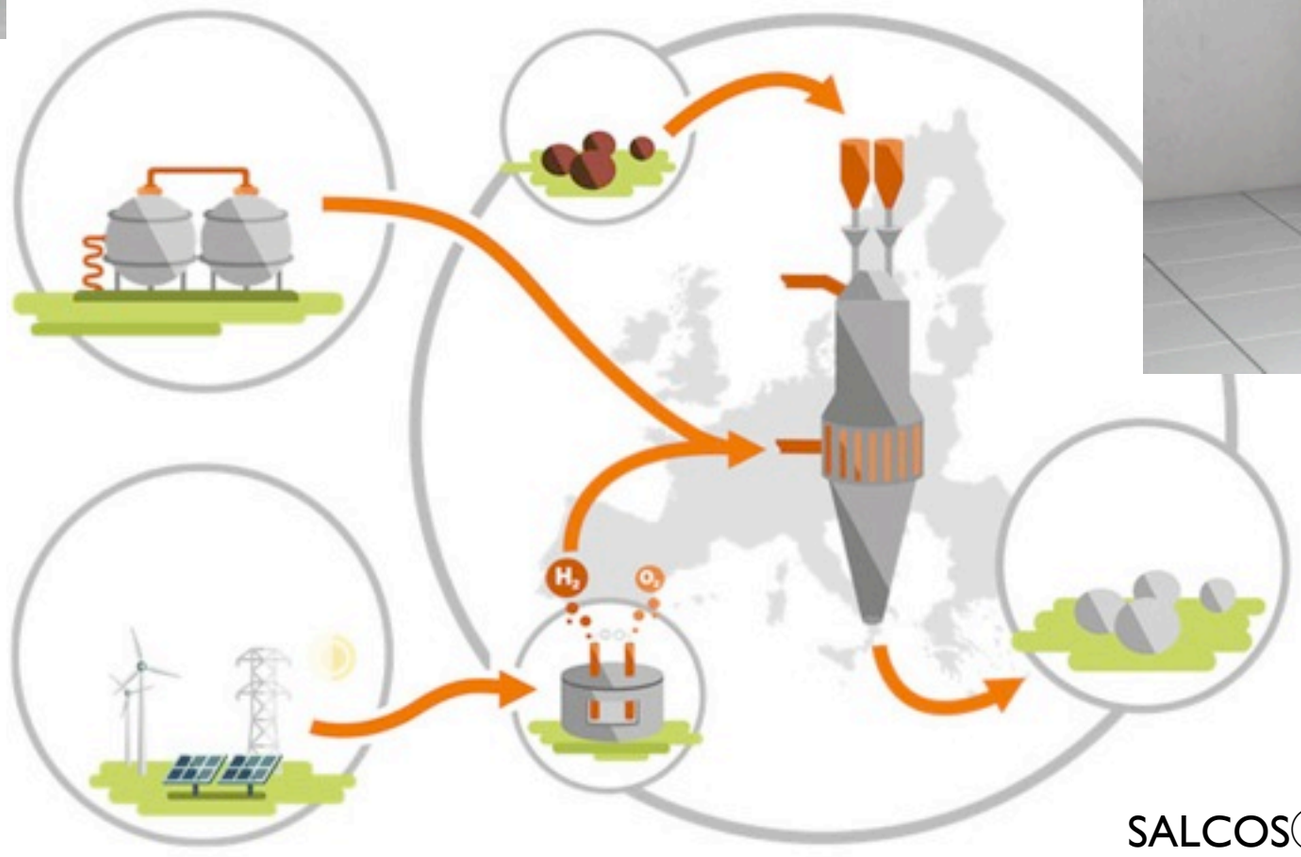
© Siemens

- flexible: storage / mobility / heat
  ⇒ *sector coupling*
- highest energy density: 33 kWh/kg
- possible storage & transportation in gas pipelines (limited by law: max. 5%)

sector coupling

mobility

heating



CDA
up to 82%

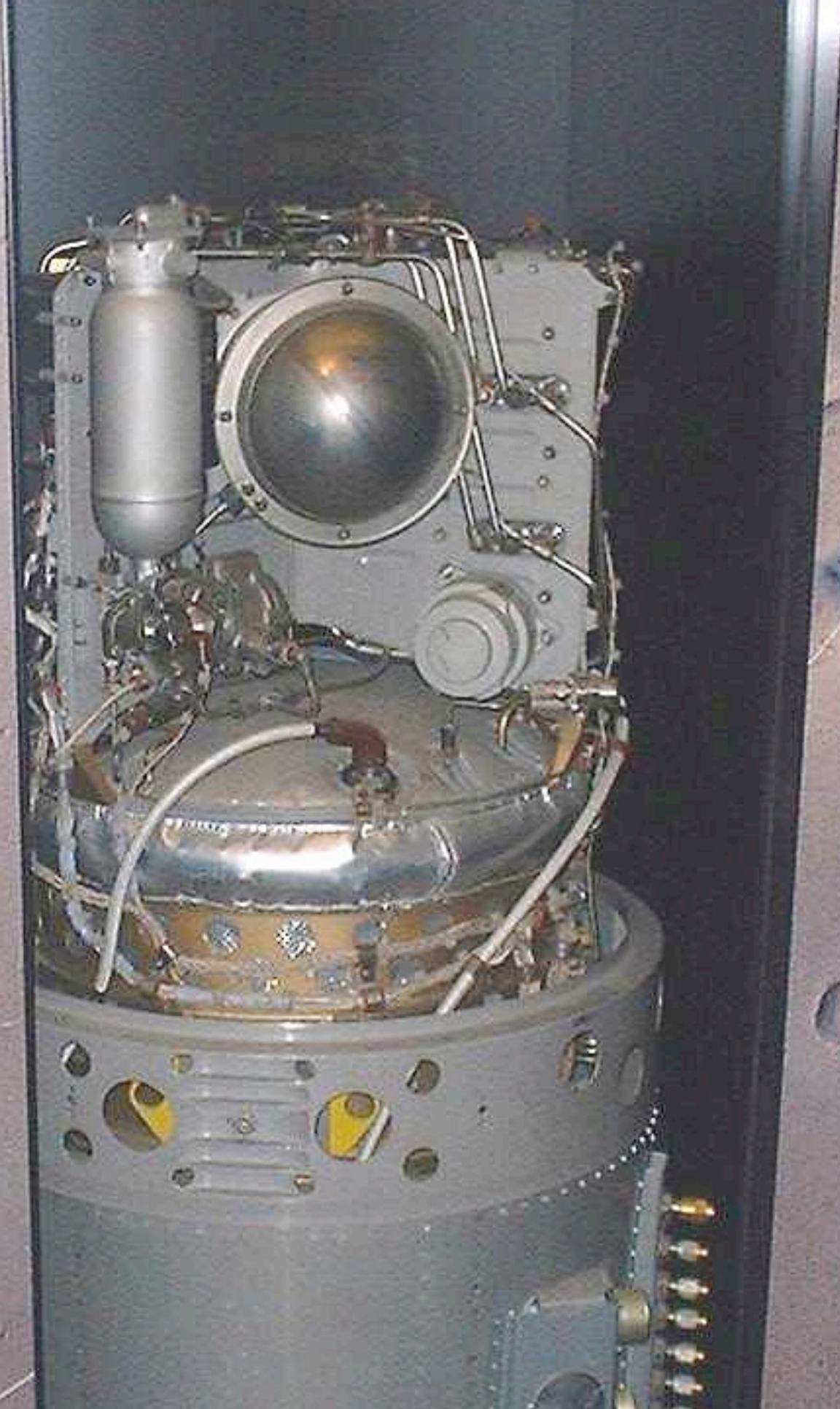
industry

SALCOS®

On Earth we live in houses which are supplied with electricity and running water. In space we must generate our own electricity and, for long missions, produce our own water. The type of fuel cell displayed here was used on the Apollo missions to the Moon. The cell uses hydrogen and oxygen to generate electricity and drinkable water.

Astronaut Michael J Bloomfield moves a water container in the Destiny module of the International Space Station, soon after a delivery of supplies by the Space Shuttle *Atlantis* in April 2002.

Fuel cells produce electricity and water through the chemical reaction of hydrogen and oxygen. The idea was first employed by Sir William Grove in the nineteenth century. In the 1960s, NASA developed the work of another English scientist, Francis Thomas Bacon.
In building the fuel cells for the Gemini and Apollo spacecraft.

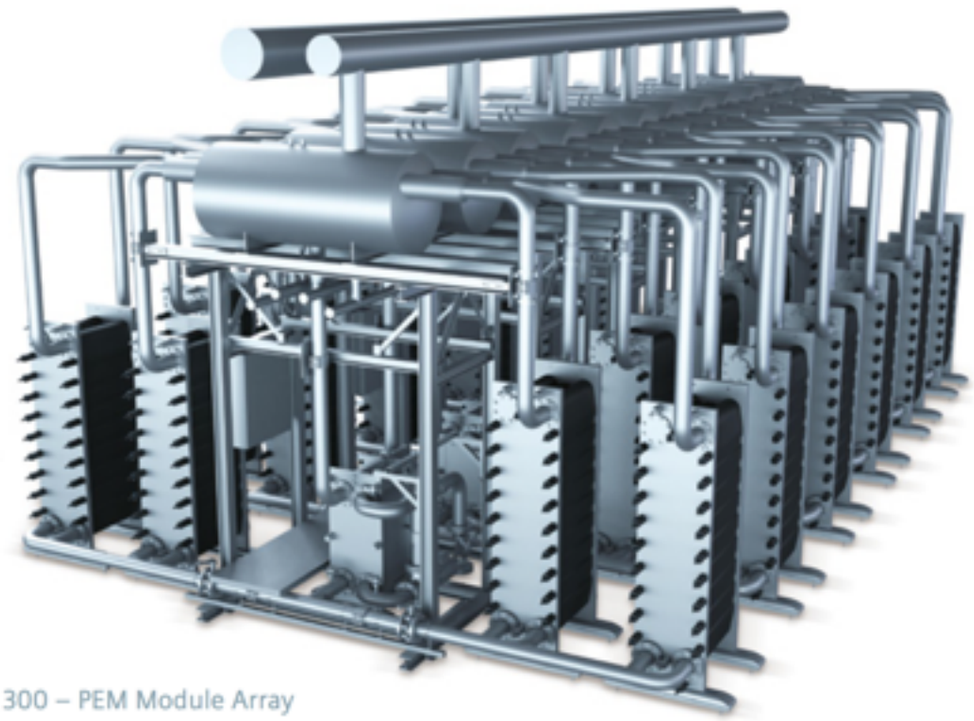


examples: storage

Picea from HPS

- up to 3000 kWh
- 300 bar gas bottles

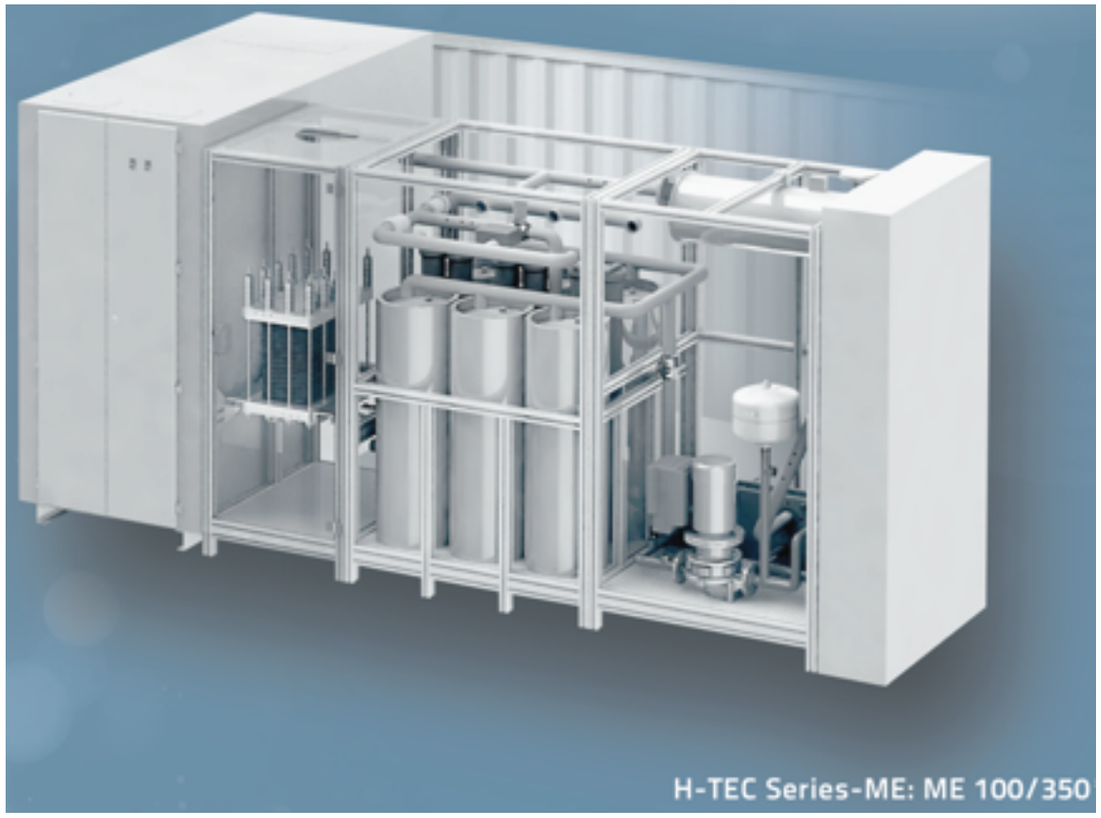
examples: MW electrolysers



SILYZER 300 – PEM Module Array

SIEMENS Silyzer 300 (PEM)

- 100 – 2000 kg/hour
  (~ 5 – 100 MW)



H-TEC ME 100/350 (PEM)

- 100 kg/day (4 kg/h)

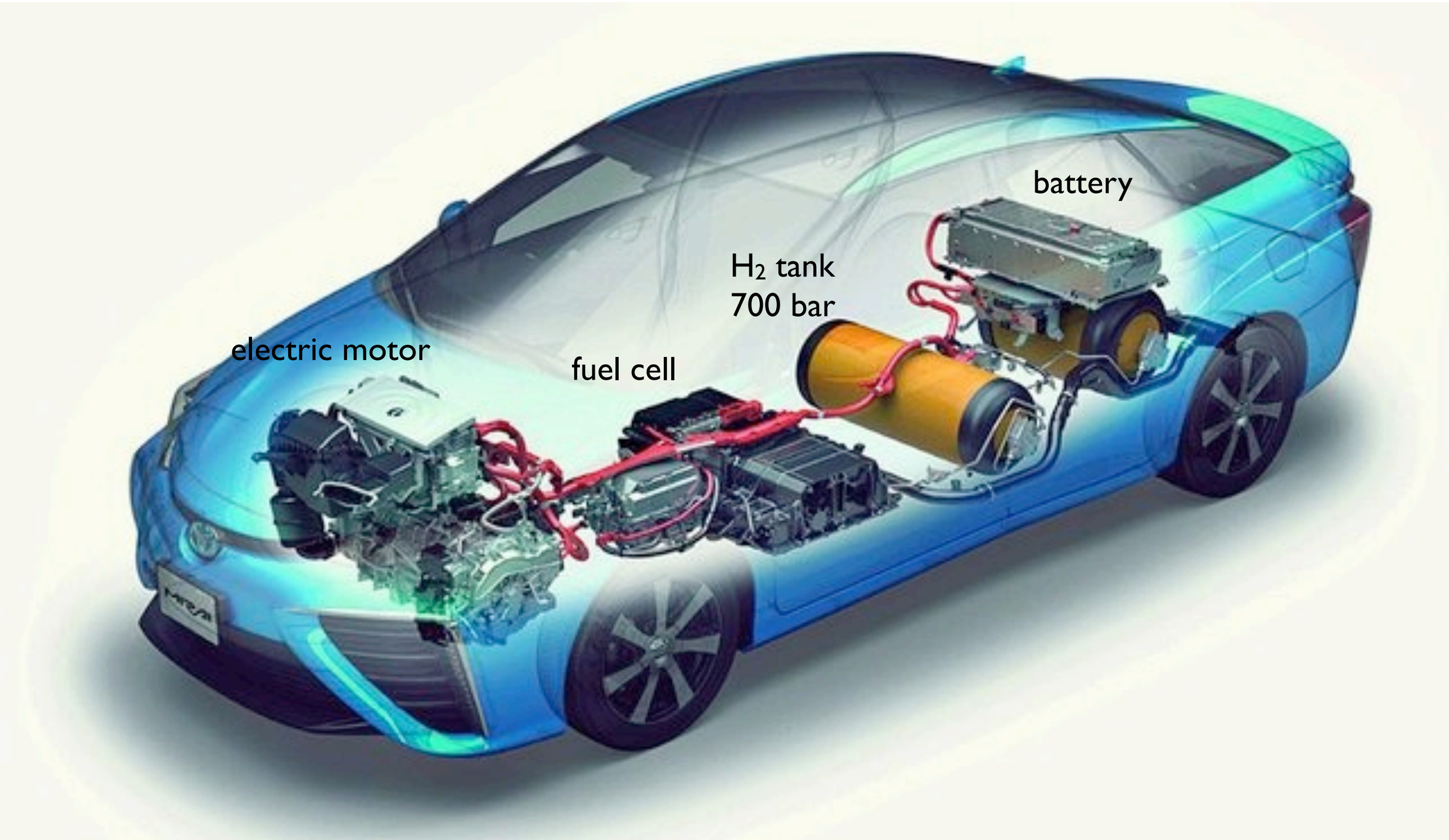
Hydrogenics

- > 1.5 MW

e.g. Mobility

car era started electric!

Fuel Cell Cars



Toyota Mirai, Fuel Cell Vehicle

Fuel Cell Cars

The Telegraph, Andrew Crowley

Fuel Cell Cars

- no CO_2 emission
- no exhaust … just water
- no combustion residues
- no stench
- very quite

- very simple engine
- efficient torque throughout
- no/simple gear
- much better acceleration
- …

The Telegraph, Andrew Crowley

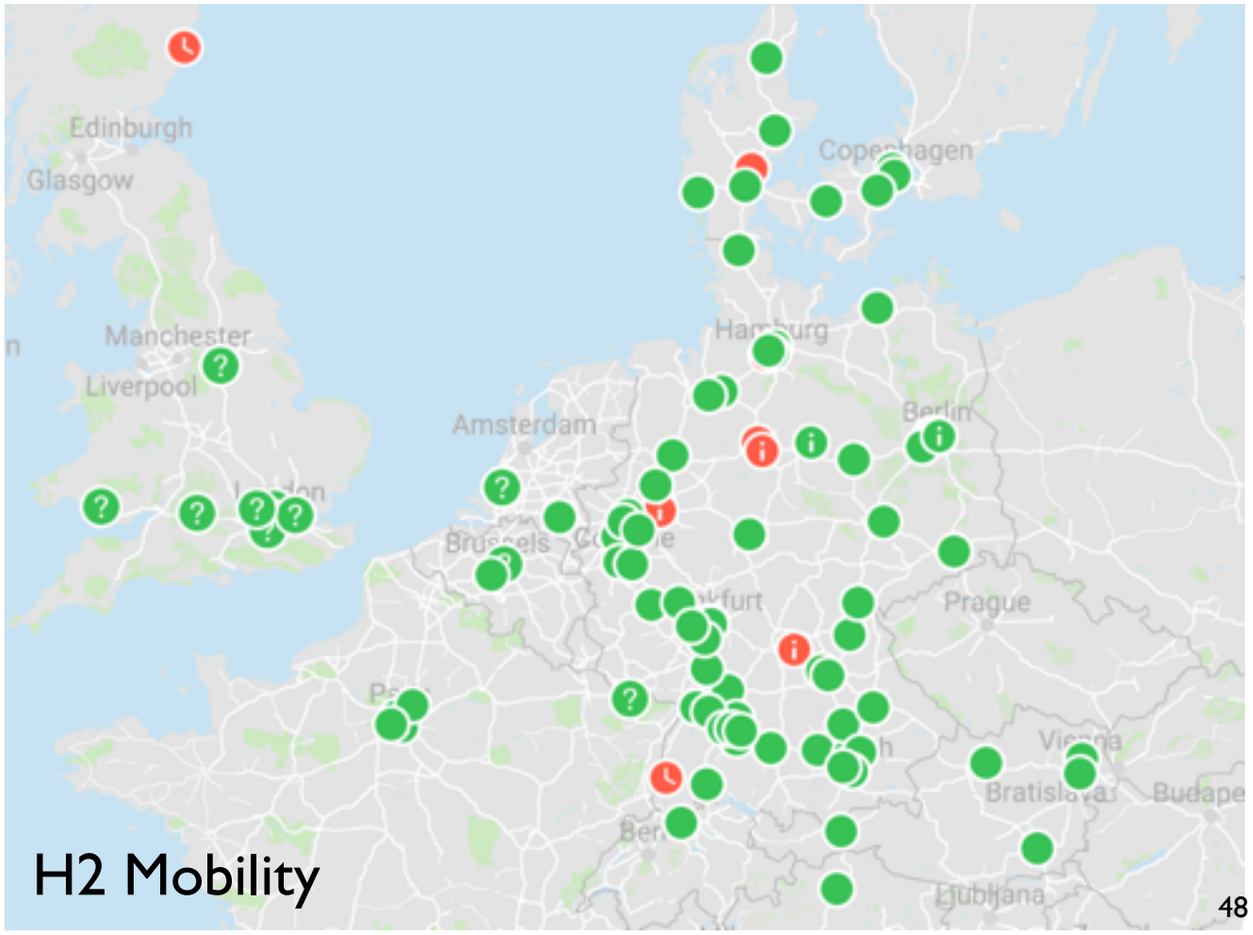
Mobility & Transportation

- Fuel cell cars (e.g., Toyota MIRAI, Hyundai NEXO/ix35)
- standard fuel nozzle (e.g. , WEH H70)
- standard pressure for cars (700 bar) and trucks (350 bar)
- about 120 H_2 stations in Europe (ca. 85 in Germany, 100 by 2020)

- Japan 2020: 160 H_2 stations
  40.000 cars

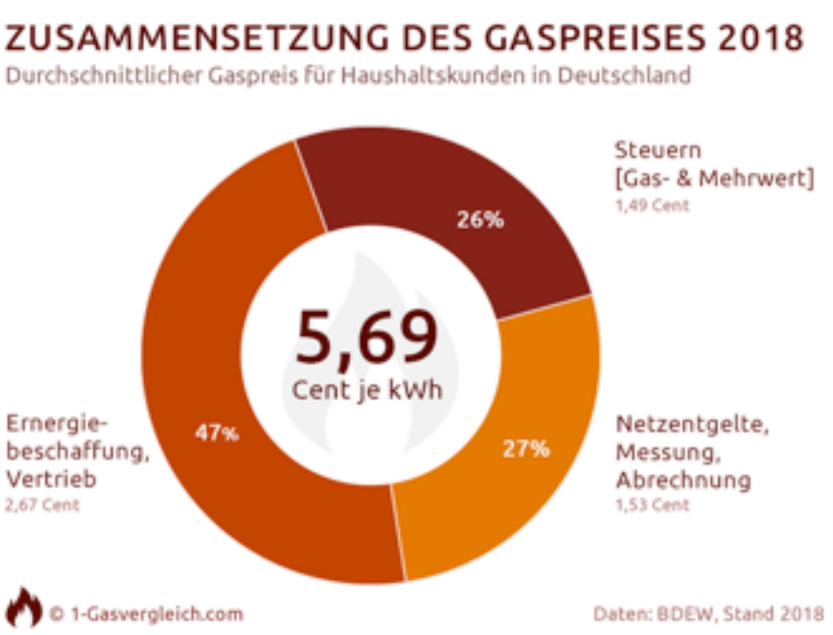
- Trucks: e.g. Nikola Motor

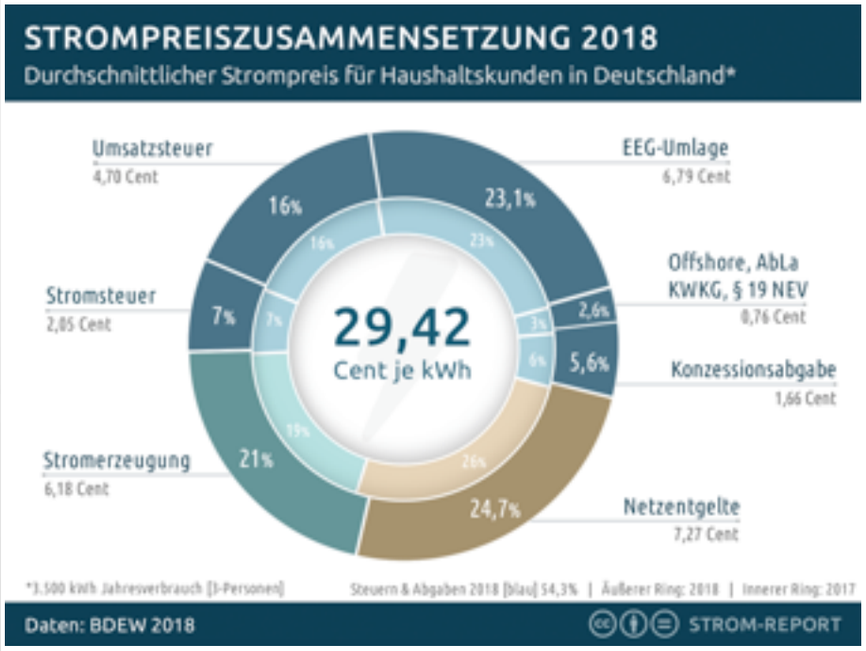
- Local trains: e.g. Alstom ‘Coradia’



Mobility & Transportation

Big problems: taxes/subsidies





natural gas	gasoline	electric power
5 - 7 ct/kWh	12 - 16 ct/kWh	**~ 30 ct/kWh**
53%, 1.1 x production	63%, 2.7 x production	80%, 5 x production

H_2 Initiatives

MISSION: HYDROGEN

NOW
Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie

H2 Süd
DIE WASSERSTOFF INITIATIVE BAYERN & BADEN-WÜRTTEMBERG

DWV
Deutscher Wasserstoff- und Brennstoffzellen-Verband

FCH
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

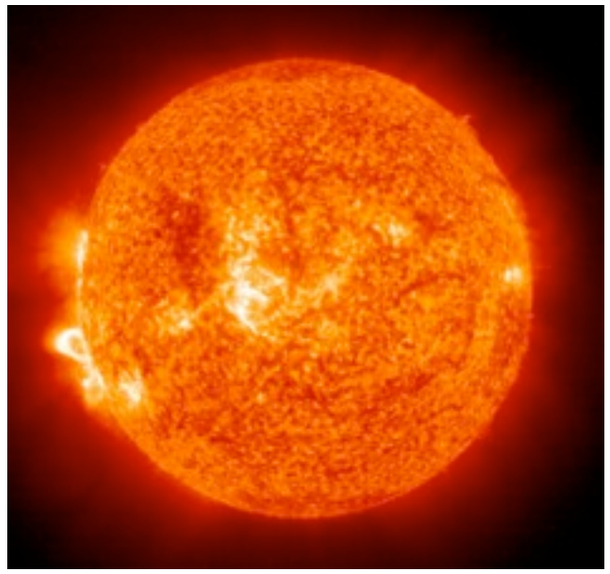
NORDIC HYDROGEN CORRIDOR
Co-financed by the European Union
Connecting Europe Facility

Hydrogen Europe

HYDROGEN INITIATIVE
AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

HyLAW

Summary



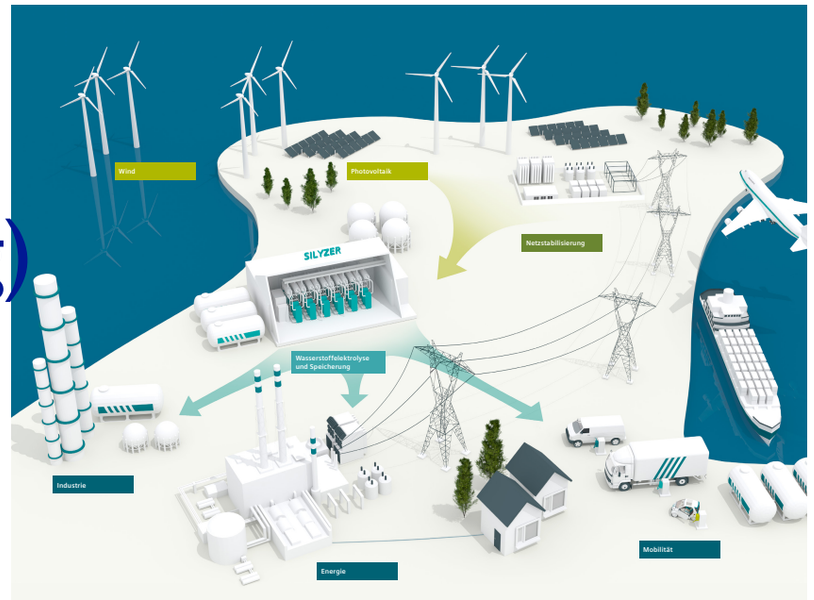
Everything started of with ***hydrogen***!

- renewable energy source *exists*:
  the **sun**

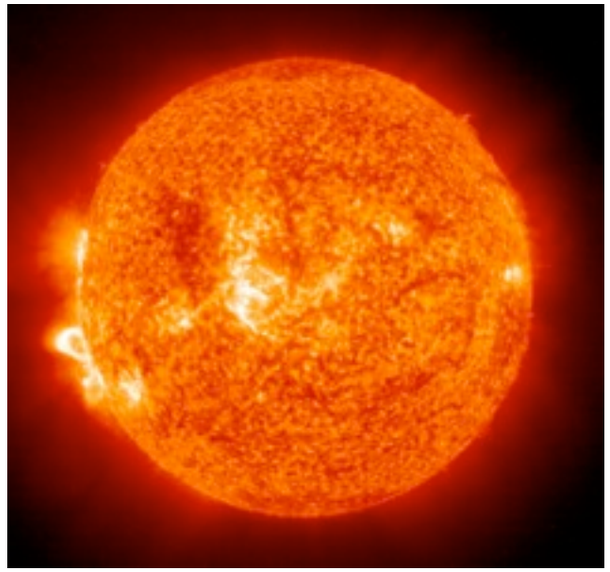
- the technology to tap it *exists*:
  wind power, solar thermal, PV, ...

- H_2 is the most *efficient* to store and transport renewable energy (sector coupling)

- the technology to utilise it *exists*
  and is ready for the mass market:
  electrolyser, fuel cells, storage tanks,
  cars, trucks, ...



Summary



Everything started of with ***hydrogen***!

- renewable energy source *exists*:
  the **sun**

- the techno
  wind powe

let's do it again!

- H_2 is the most *efficient* to store and transport renewable energy (sector coupling)

- the technology to utilise it *exists*
  and is ready for the mass market:
  electrolyser, fuel cells, storage tanks,
  cars, trucks, ...