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PHOTOVOLTAÏQUE : AVANCÉES TECHNOLOGIQUES ET CONTRIBUTION À LA RÉDUCTION DES ÉMISSIONS DE CO2

CRP Formation continue Septembre 2023

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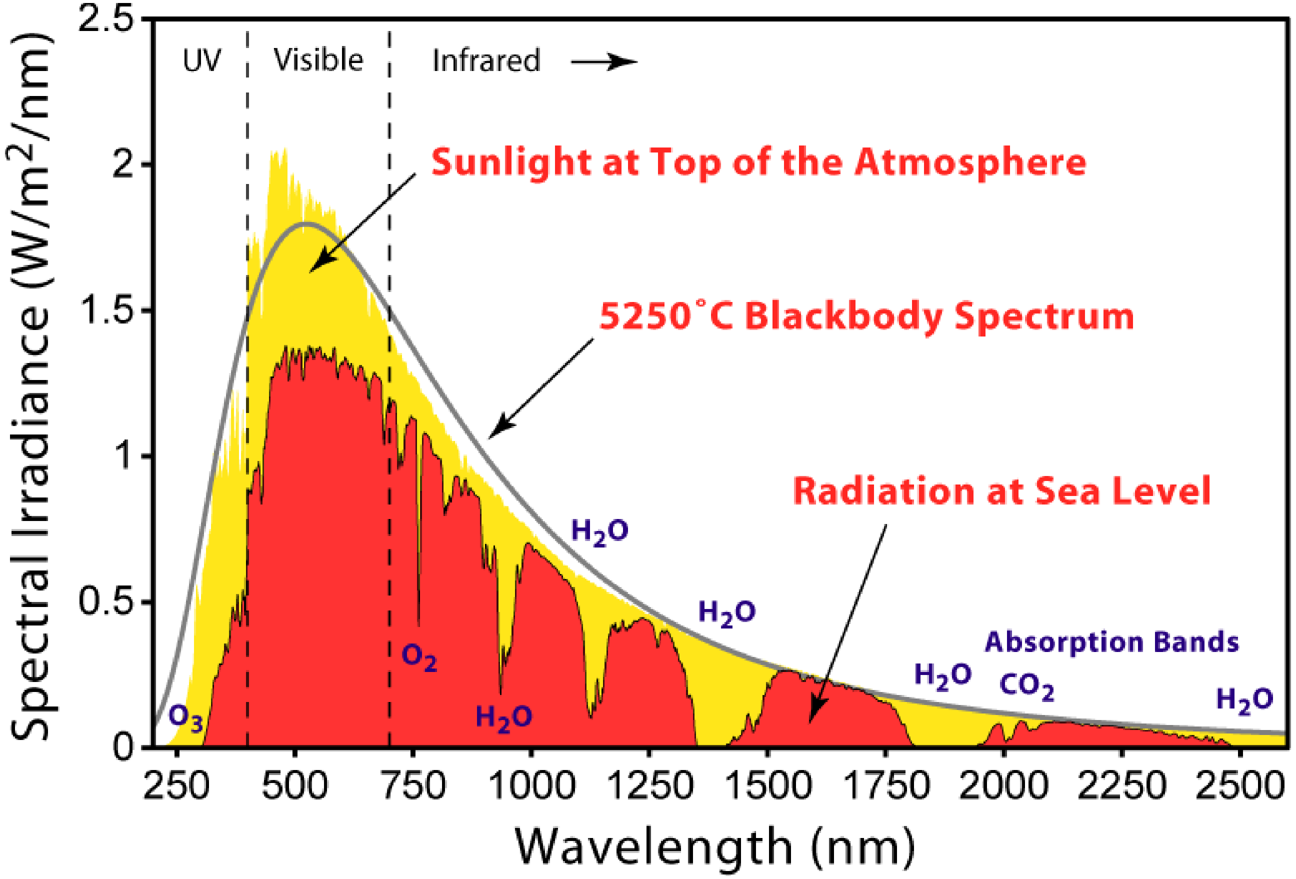
The basics of the sun and energy

Solar irradiance spectrum



- The mean **solar irradiance** is 1366 W/m² in outer space

The spectrum is referred to as **AM$_0$**.

- On earth: losses by absorption (18%) and by diffusion (10%)

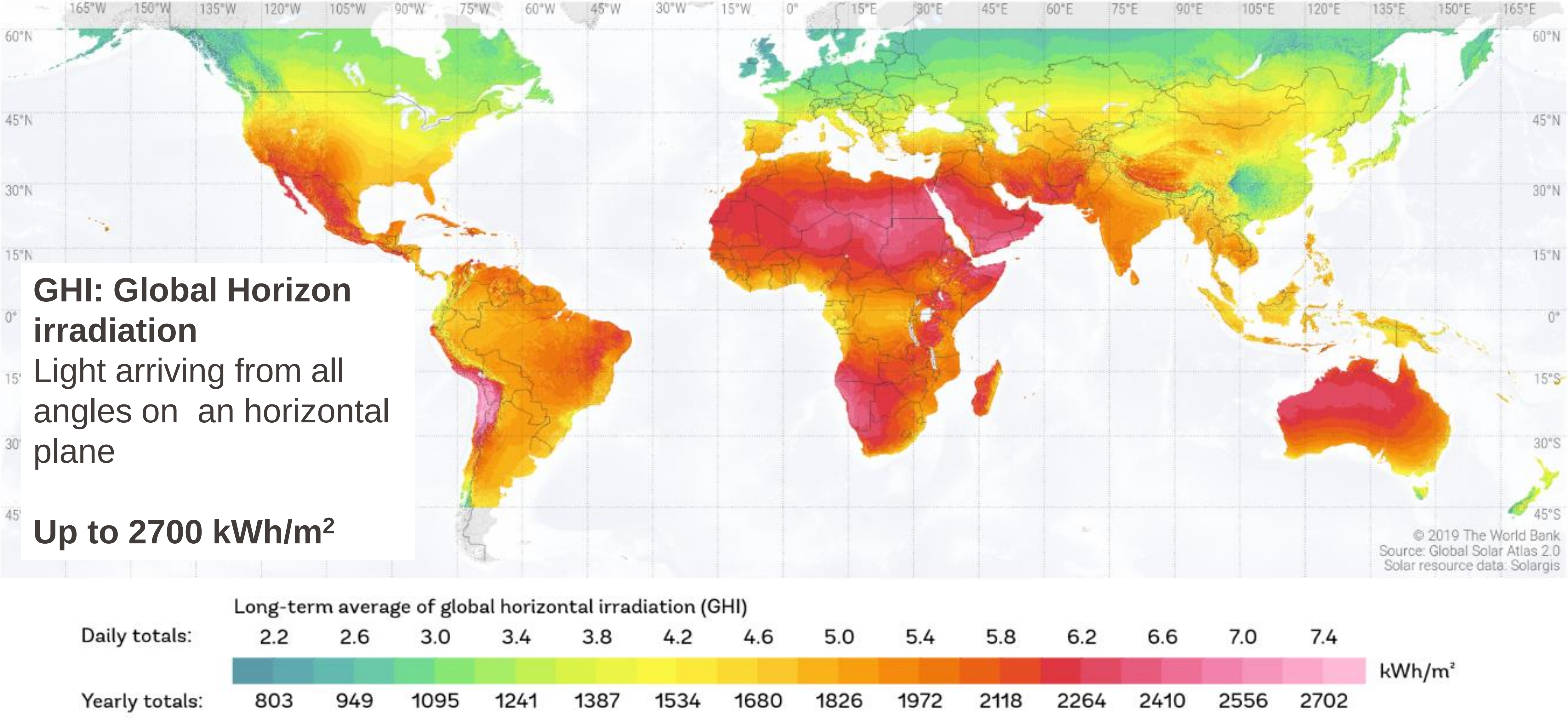
~ 970-1000 W/m²

Direct light around 90% of total "global" light

Solar spectrum crosses the earth atmosphere → absorption (water vapour, ozone, dust…) and Rayleigh scattering (diffusion… blue light is more scattered than red light).

SOLAR RESOURCE MAP

GLOBAL HORIZONTAL IRRADIATION



GHI: Global Horizon irradiation
Light arriving from all angles on an horizontal plane

Up to 2700 kWh/m^2

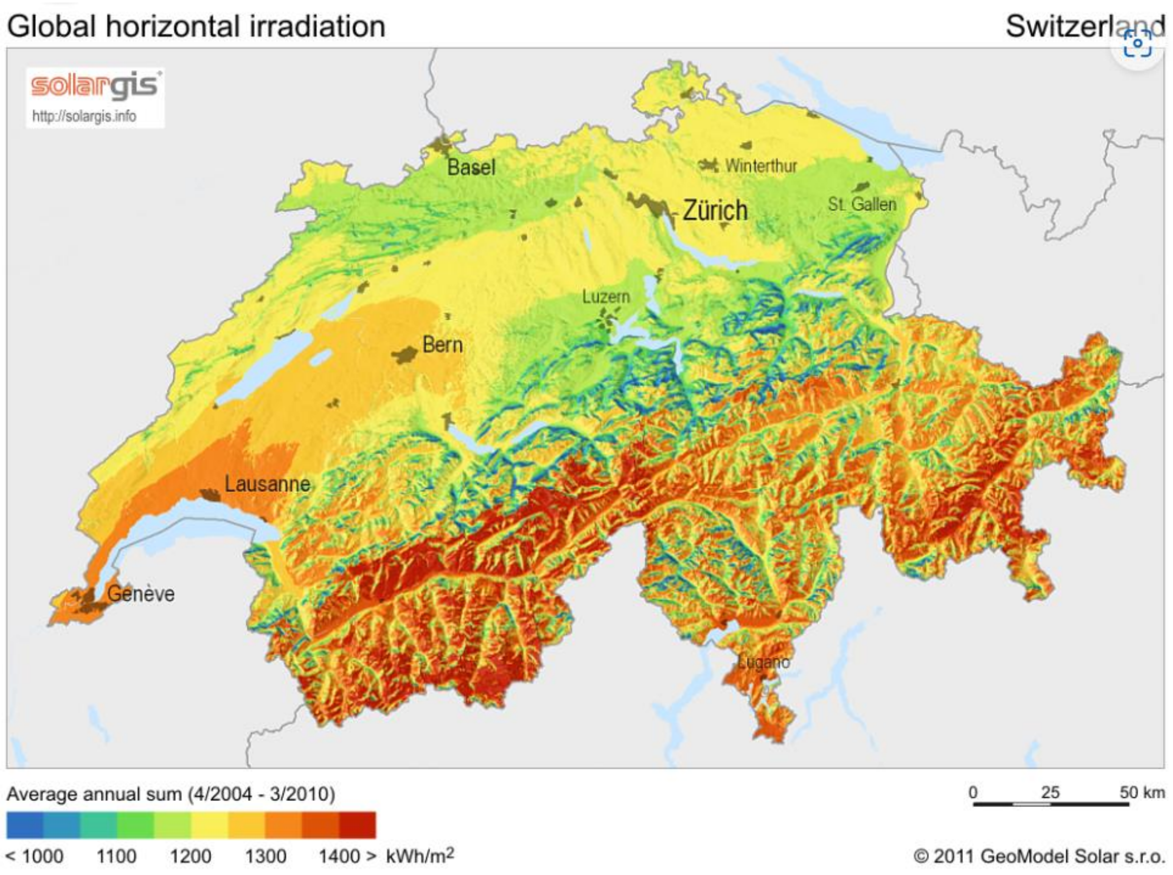
This map is published by the World Bank Group, funded by ESMAP, and prepared by Solargis. For more information and terms of use, please visit http://globalsolaratlas.info.

The basics of the sun and energy

Annual GHI in CH

One year in Switzerland:
1000-1500 full hours at intensity
1000 W/m^2

1000-1500 kWh/m^2/y



Almost the same as

1 barrel/m^2/year

1 litre of oil ~9-10 kWh chemical energy

1 barrel = 159 litres

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Fundamentals of PV

Basic design of a solar cell : p-n junction

→ Intrinsic (pure) semiconductor material (e.g. Si, CdTe,…)

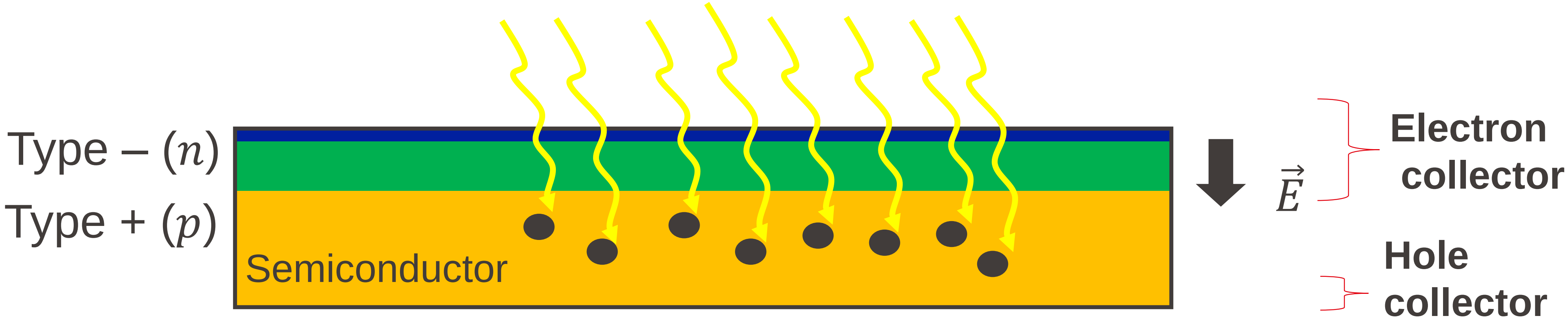
→ Doping with chosen impurities → becomes conductor with + (p) or – (n) charges transporting the current

→ If a p-zone is in contact with an n-zone → diffusion of charges and creation of an electrical field $\vec{E}$

→ Under light: absorption of photons if $h\nu > E_g$ (E_g: semiconductor bandgap)

→ Photons absorbed in p-zone transfer their energy to electrons (in n-zone to holes)

→ Photogenerated carriers move towards the junction and cross it



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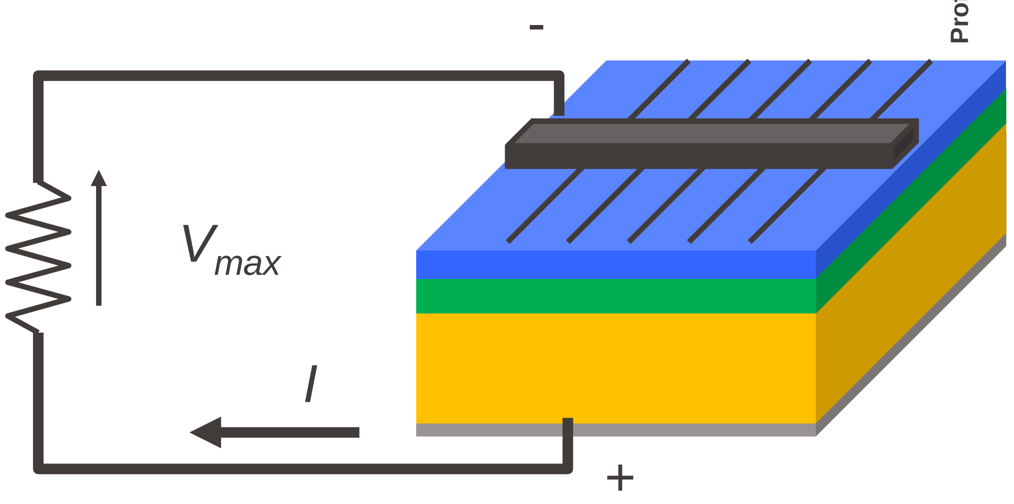
Fundamentals of PV

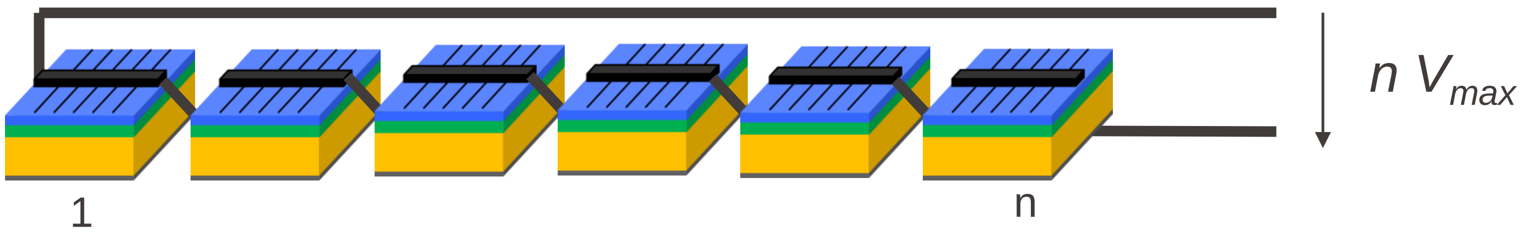
Extraction of current

Metallic contacts extract the current
(and/or transparent conductive contacts)

Useful power
dissipated on R_M



- Voltage depends on bandgap (Eg)
  - **~0.7 V for crystalline Si, 1.1 V for GaAs**
- Current depends on Eg and is proportional to the surface area
  - **typical ~ 40 mA/cm^2 c-Si, or 10 A for a 6" inch square cell**
- To get high voltage → connect cells in series



! If one cell is not illuminated
It will block the full chain !
Usually a «by-pass diode»
will protect a chain of cells

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Fundamentals of PV

First approximation : a basic solar cell can be seen as a p-n diode with a current source in parallel (current proportional to light intensity)

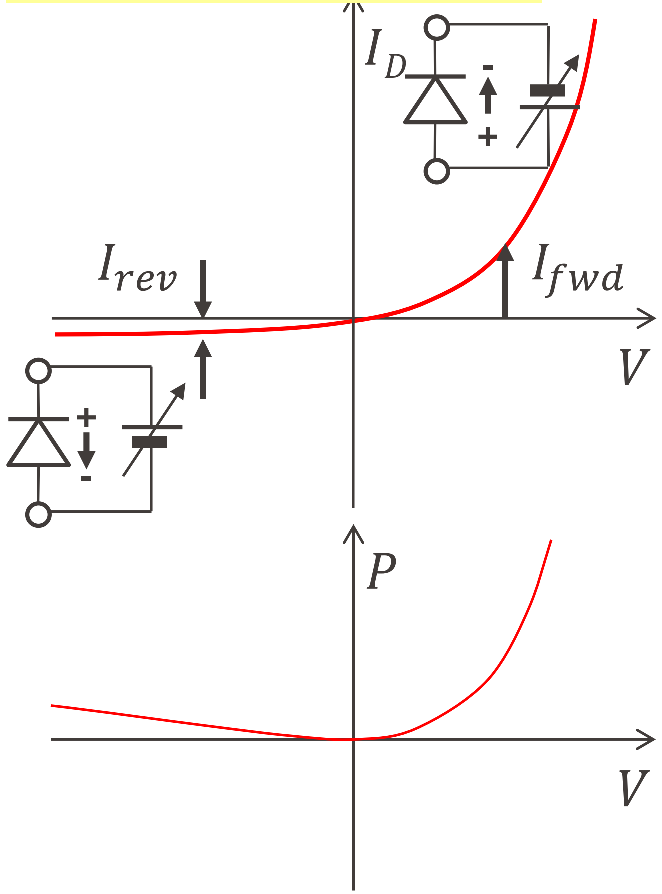
kT=
26 mV at 25°K
q= electron charge (+)
I_o= saturation current

Dark

$$I_D = I_0 \left[\exp\left\{ \frac{qV}{kT} \right\} - 1 \right] \quad (1.2)$$

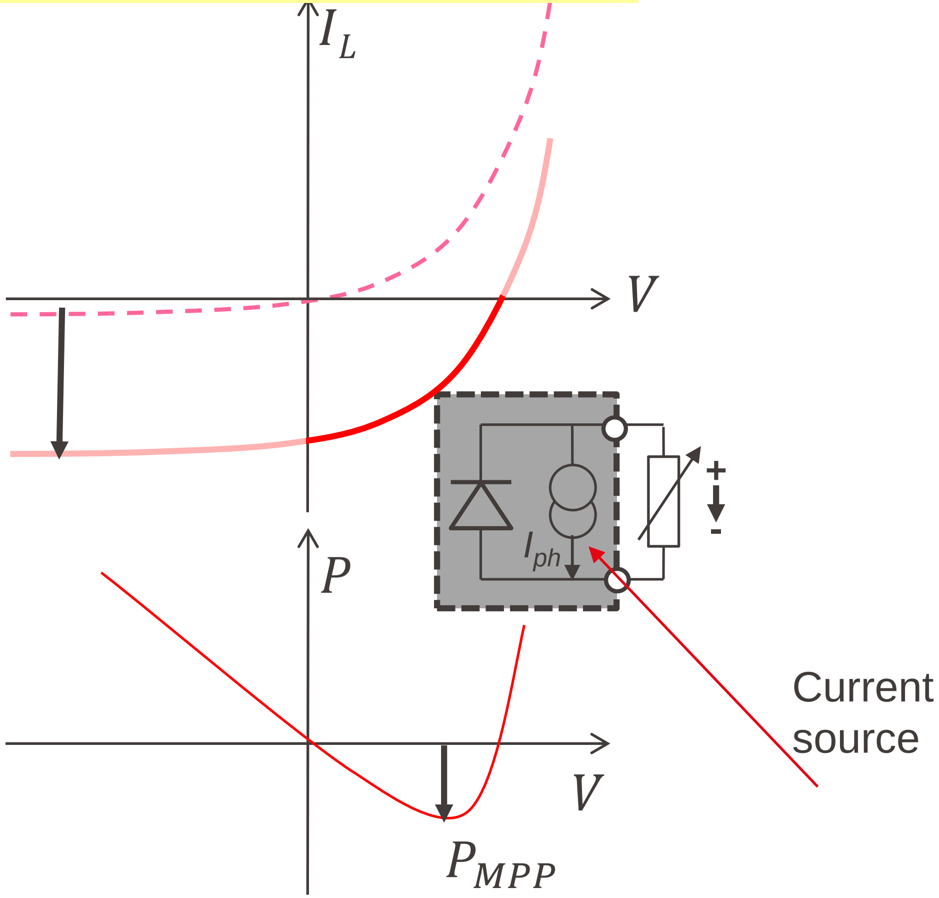
Illuminated

$$I_L = I_D - I_{ph} = I_0 \left[\exp\left\{ \frac{qV}{kT} \right\} - 1 \right] - I_{ph} \quad (1.3)$$



P= VI

consuming
sign convention
producing



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Fundamentals of PV

Measure power density delivered under ***standard test conditions*** (*STC*)
Cell or module at 25°C, spectrum AM**1.5G** (global, light passing at 48° in the atmosphere), light intensity 1000 W/m²

$$\eta_{STC} = \left.\frac{P_{MPP}}{P_{light}}\right|_{STC}$$

Efficiency at STC

Modules are sold according to **W or Wp** (=W peak output), with respect to 1000 W/m² (AM1.5G)

Example: 1 m² of a 20% module is rated at 200 Wp

Rule of thumb: in CH or Germany **1 Wp** of modules give **1 kWh** per year (corresponds roughly to 1000 hours of full sun → 1 W x 1000 h = 1 kWh)

- On a one axis tracking system in South Algeria, with bifacial modules 1 W → **3 kWh per year**

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Inverters

Inverters (including an MPPT): grid injection

An inverter is an electrical device that converts DC to AC current. **PV** inverters usually include an MPPT tracker.

Mounted inverters close to PV modules

SMA «sunny boy» 3kW inverter

ABB 5 MW inverter

$\eta = 98.6\%$

Module based electronics

- Entrance voltage into inverters up to 1000, or even 1500 V obtained by strings of modules (typically 30 to 50 modules in series)
- With mass manufacturing: large inverters down to low cost 4-10 cts/W
- Typical efficiencies 96-99%

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PV Technologies: an overview

Crystalline silicon
Mono and multicrystalline
Status: main market share (Mostly Mono)

Thin films
CdTe, CIGS, a-Si
Status: 3-5% market share (mostly CdTe)

III-V solar cells (GaAs based)
Space application

Market

Concentrator technologies

Status: failed market entrance
New innovative concepts

Other technologies
Organic-Polymer, Dye sensitized, nano-inorganic
Status: niche application, failed market entrance
Perovskite: R&D with challenges

Novel PV concepts
Quantum dots, intermediate band…
Status: attempt of demonstration

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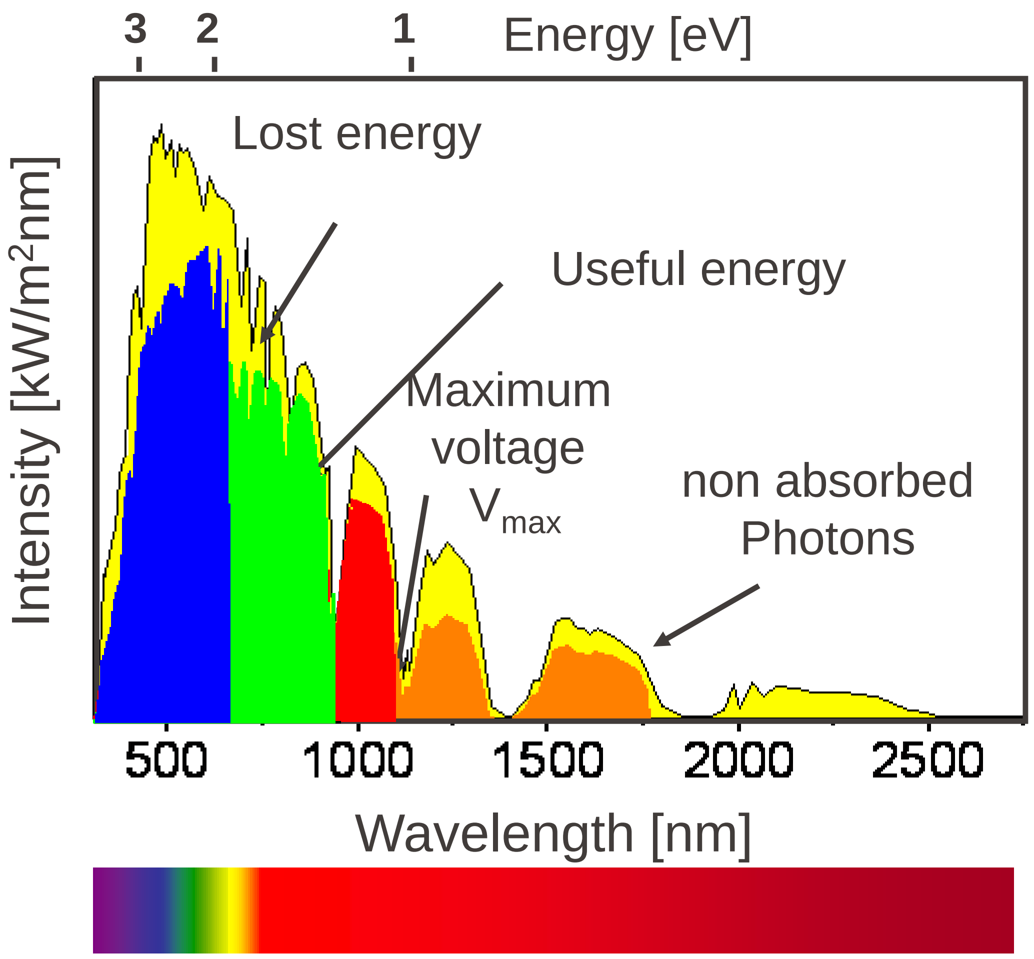
PV performance and its limits

Voltage and current

A ***semiconductor with a bandgap*** E_g absorbs only photon with $E>E_g$
e.g., photons below the wavelength λ corresponding to the bandgap

$$\lambda[nm] = \frac{1240}{E(\lambda)[eV]} \quad (1.6)$$



$V_{max} \leq E_g$ **The voltage is lower than the bandgap**

- Ge, E_g = 0.8 eV
- c-Si, µc-Si:H , E_g= 1.12 eV
- GaInAs, E_g = 1.3 eV
- a-Si:H, E_g = 1.7 eV

Compromise between current and voltage →
Efficiency limit for a "single Junction" ~31-33%

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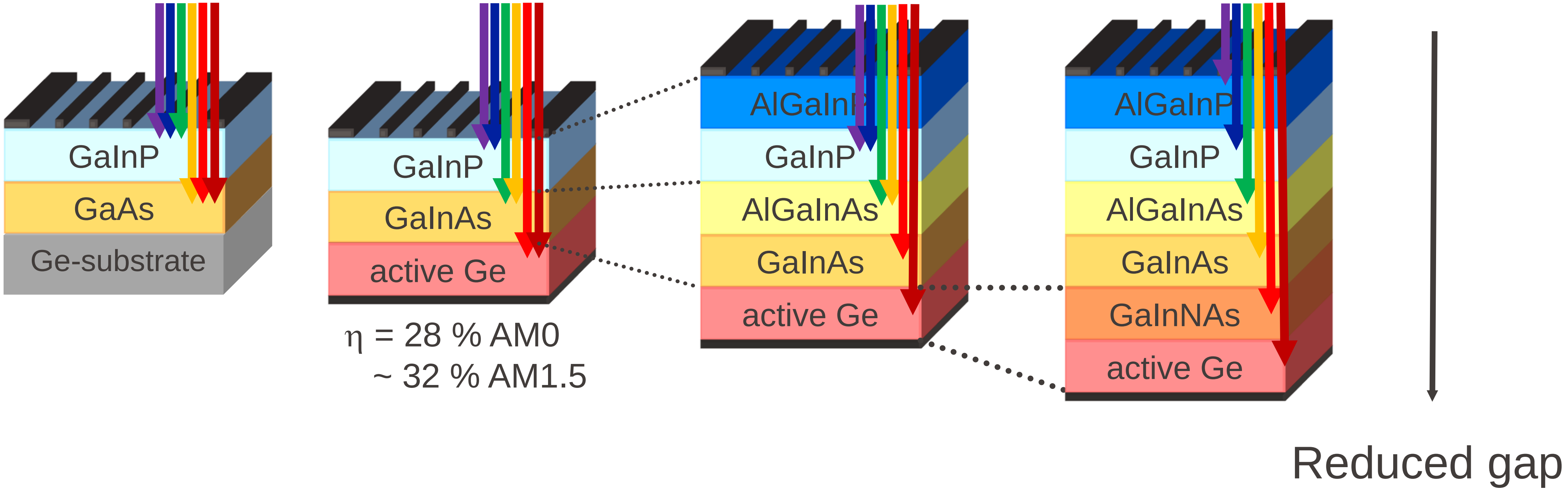
PV performance and its limits

Increasing efficiency: tandem & multi-junction

tandem → triple-junction → 5-cells → 6-cells



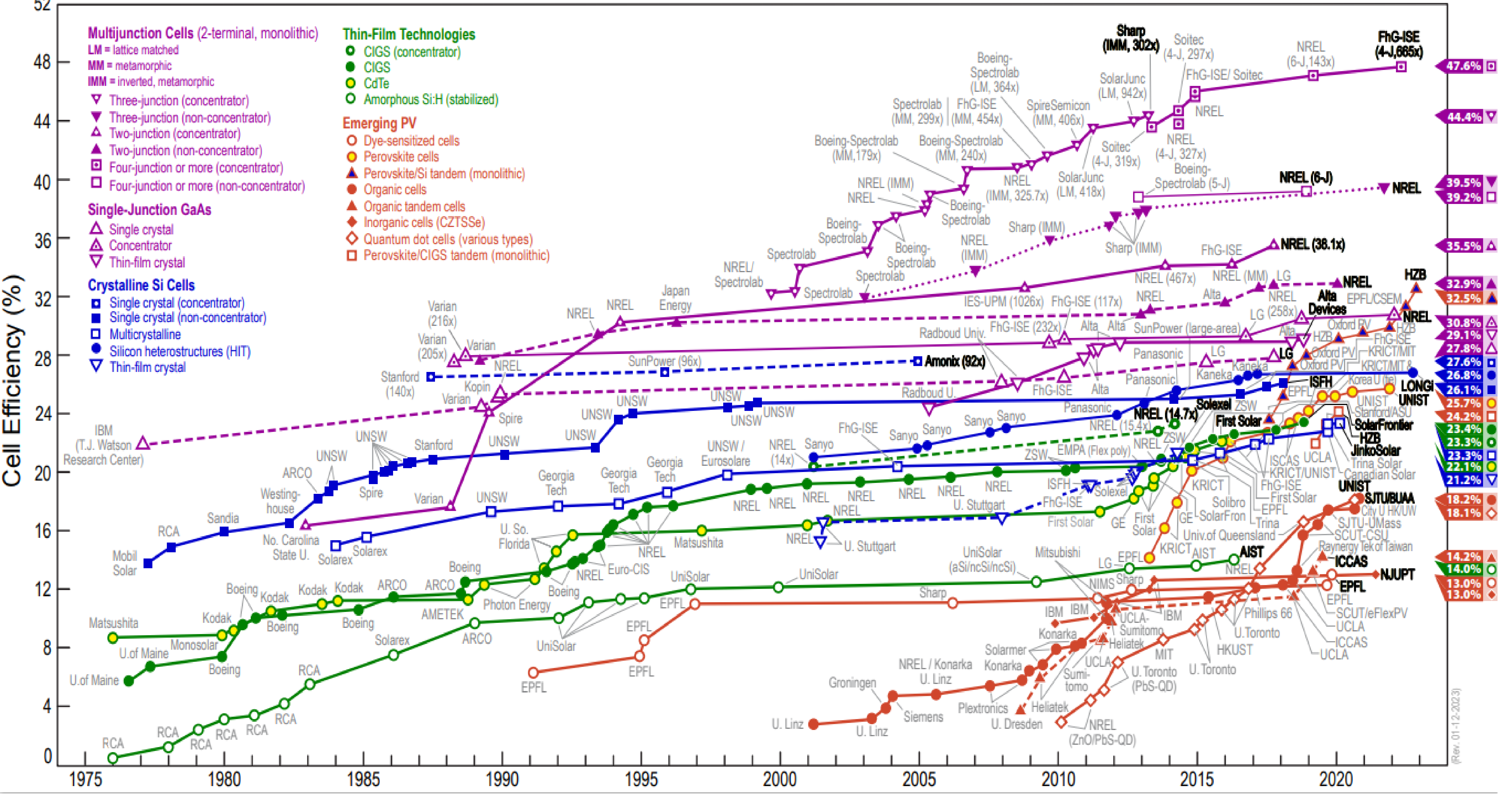
η = 28 % AM0
~ 32 % AM1.5

3-6 Junction Photovoltaic Cells For Space And Terrestrial Concentrator Applications
F. Dimroth et al. Proc 31st IEEE, 2005

Ultra-expensive (1000x more than standard Silicon solar cells)

Best Research-Cell Efficiencies

https://www.nrel.gov/pv/cell-efficiency.html



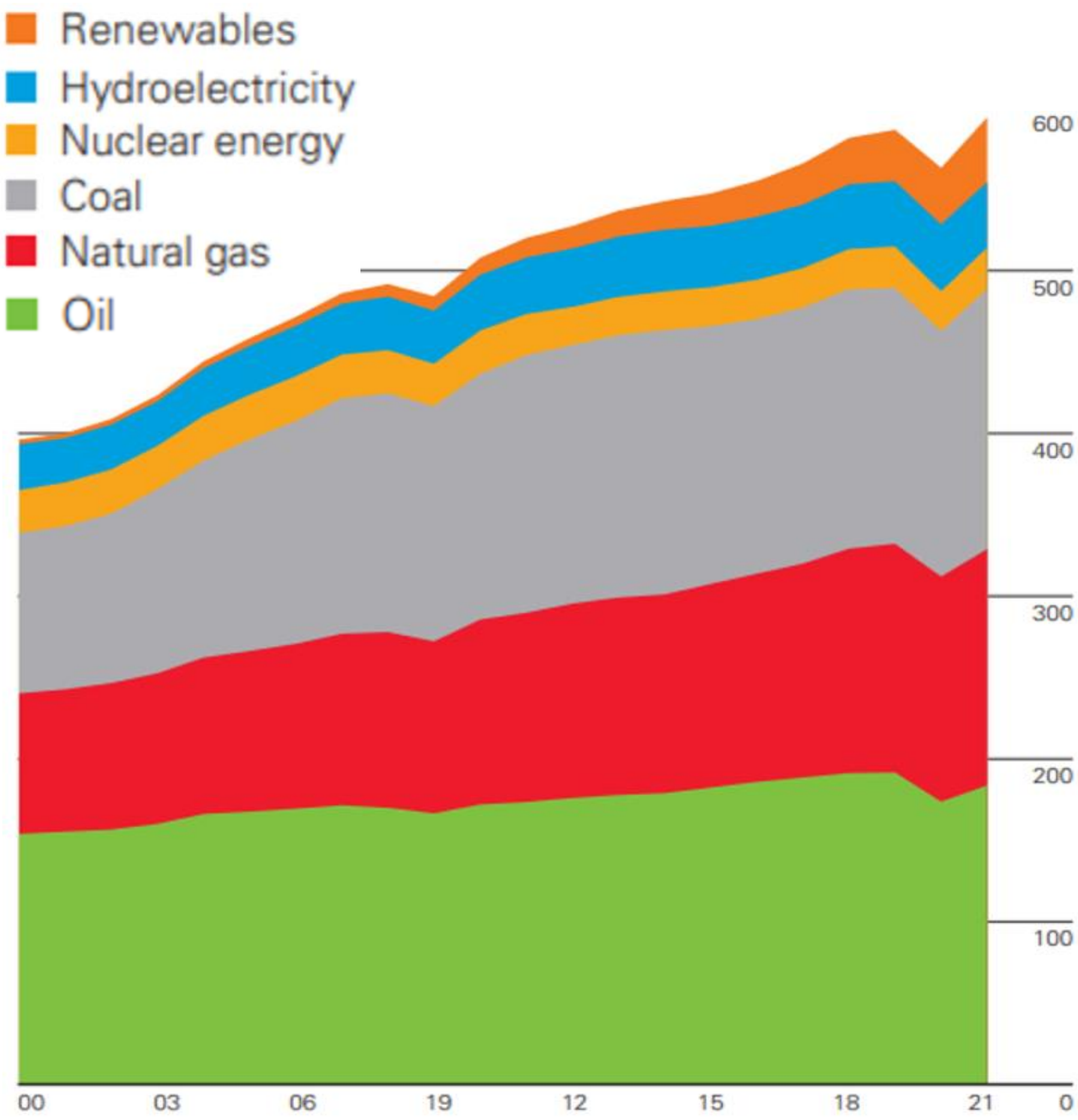
MESSAGE 1

A SEMICONDUCTOR OF HIGH QUALITY + 2 ASSYMETRIC CONTACTS → SOLAR CELLS

1 WATT OF SOLAR MODULE → 1-3 KWH PER YEAR

SILICON SOLAR CELLS = 97% OF THE MARKET

PRIMARY ENERGY CONSUMPTION



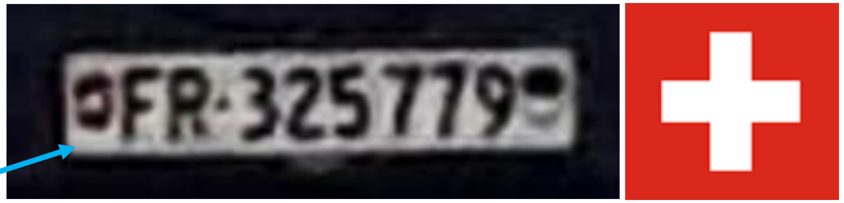
~ 166'000 TWh (CHF 320 TWh)

Still 80% fossile fuel

*Electricity in kWh of biomass, hydro, solar, nuclear wind taken multiplied by 2.5 to be shown as primary energy source

Statistical Review of World Energy 2022
IEA global energy review 2021


Fliegl
Fliegl
SAVARY TRANSPORT VESIN
avesco
FR 325779
MAKE DIESEL GREAT AGAIN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QUICK RULE OF THUMBS ESTIMATIONS

- With a 2% growth in primary energy need*
  → **250’000 TWh** in 2050

- **Strong electrification** of heating/mobility + biomass + rest electricity for H_2
  → **100’000 TWh** electrical production by 2050

Today:

28’000 TWh

In 2022*:

- hydro ~ 4300 TWh
- Nuclear 2600 TWh
- wind 2100 TWh
- Solar 1300 TWh

*according to BP accounting technique

*Global Electricity Review 2023 | Ember (ember-climate.org)

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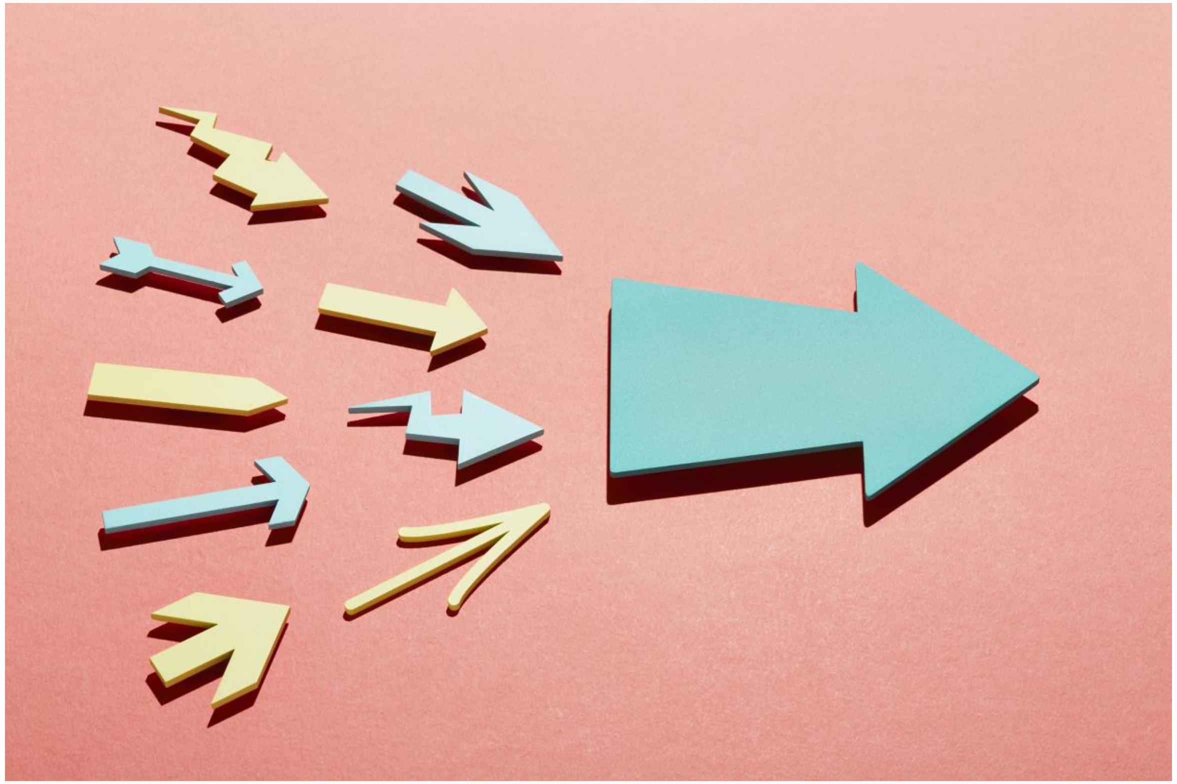
4 MAJOR OPTIONS FOR 100‘000 TWh ANNUAL ELECTRICITY PRODUCTION

1GW Nuclear → 8 TWh/year (8000 hours)
1GW solar → 1-2 TWh/year (1000-2000 hours)
1GW wind → 2-4 TWh/year (2000-4000 hours)

Which can be combined.....



a e.g. **40‘000 GW of Solar** and 15‘000 GW of Wind (+ Hydro + Biomass)

b 13’000 x 1 GW nuclear power plants

c Carbon sequestration

d Don’t care (or too late…)

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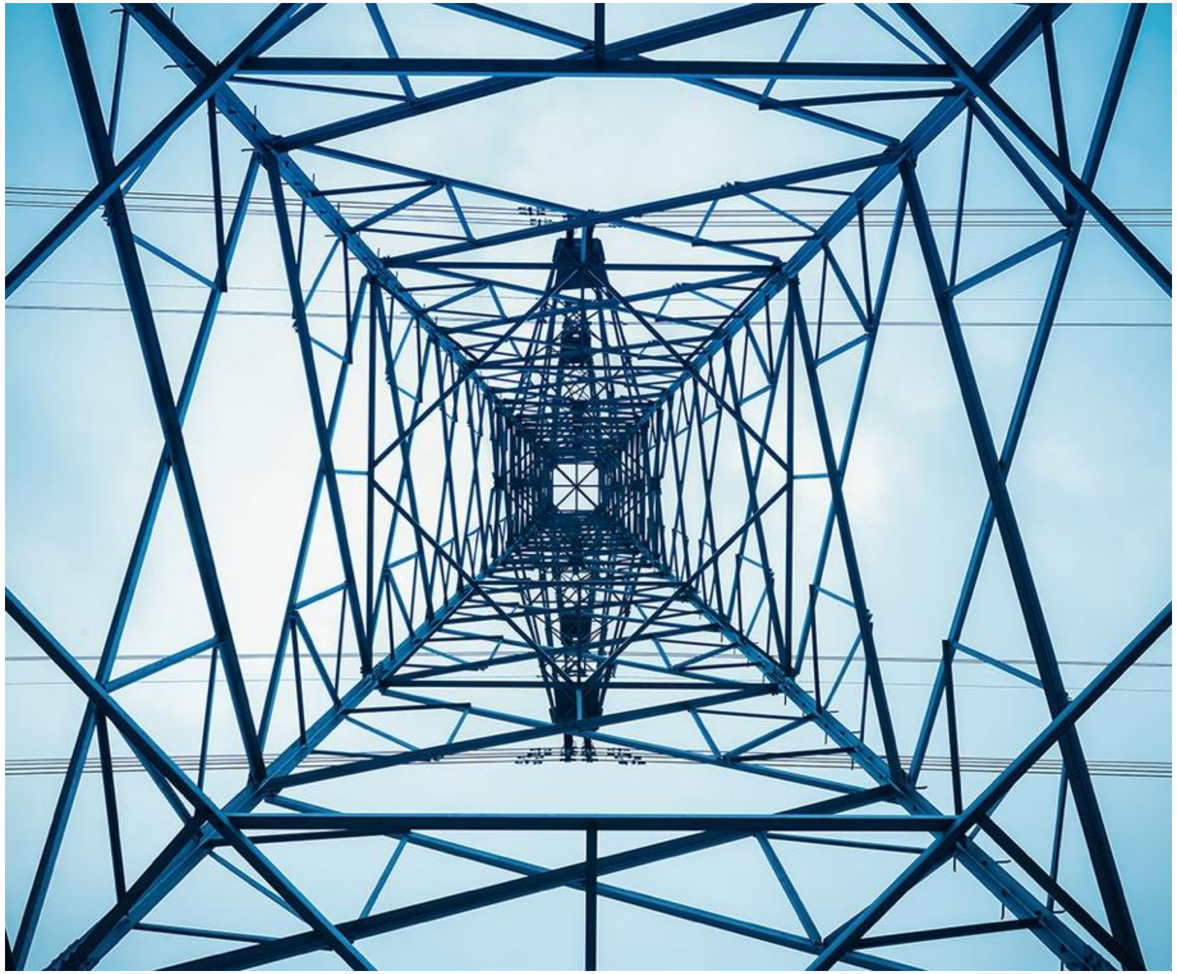
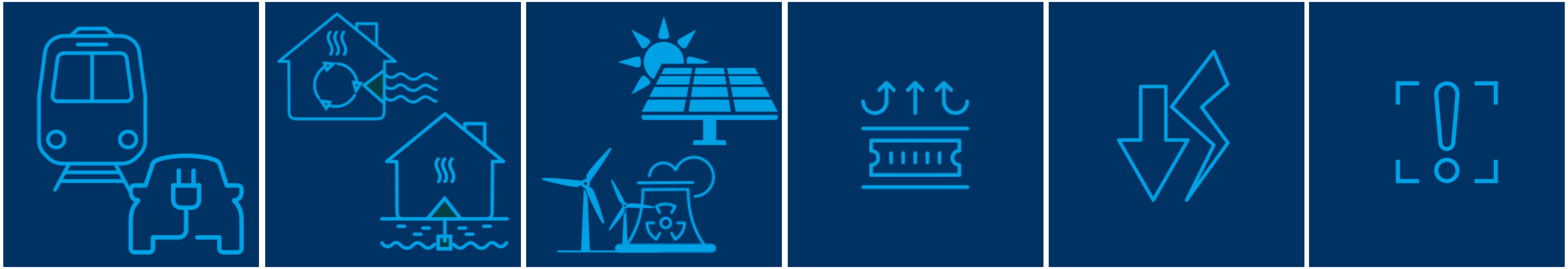
With massive wind and solar, eu grid can be balanced on an hourly/weekly basis but short-term storage (batteries mostly and pump storage) required



MAJOR TECHNOLGICAL ROUTES

Flexibility and **intelligence**



Public transport or **electric cars**
+
batteries

Heat pumps (air and geothermal)

Solar, Hydro, **Wind, Biomass** (Nuclear)

Insulation, efficiencey

Tracking losses

+ many small (but important)

+ H2 ….

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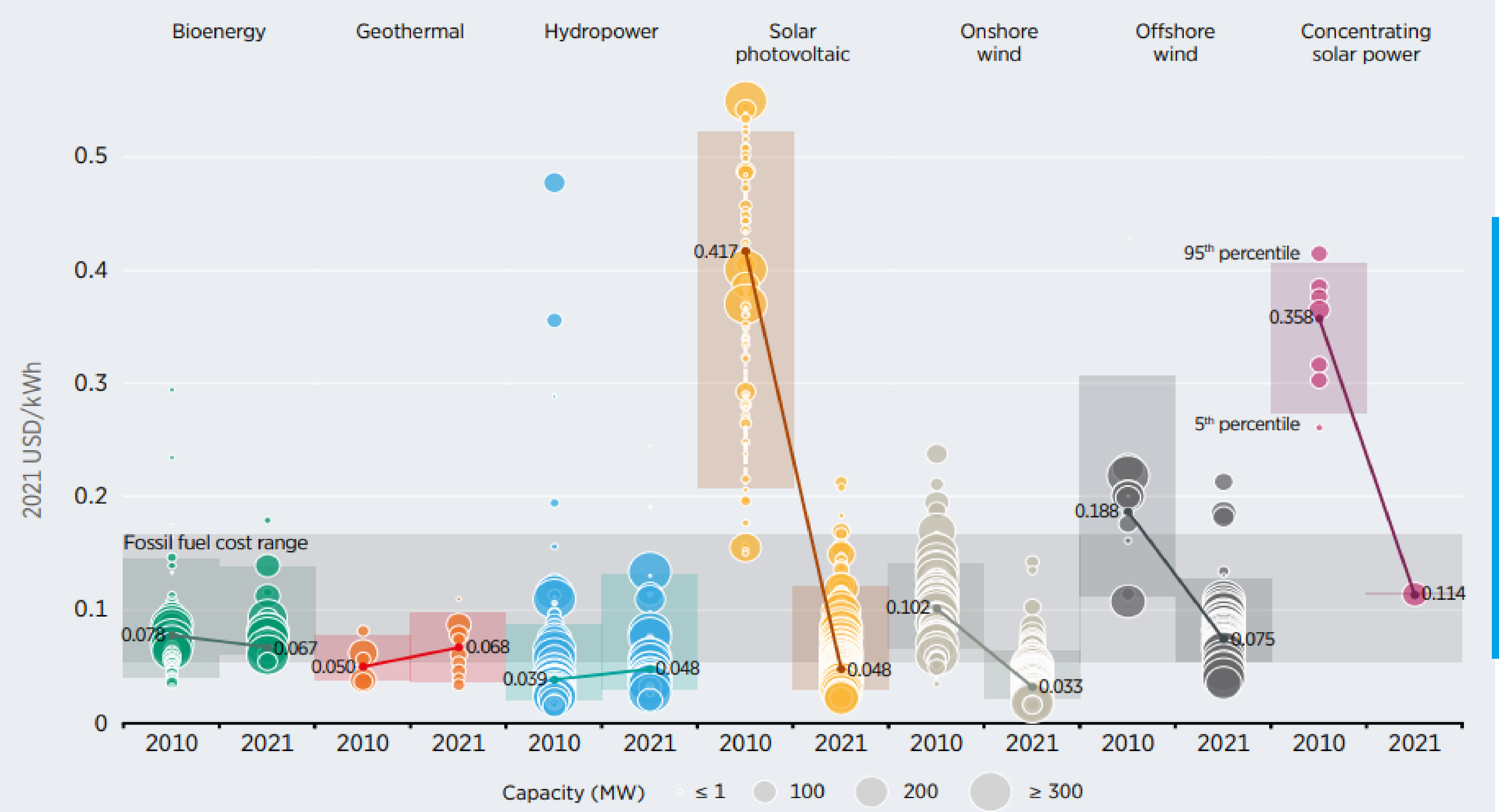
LEVELISED COST OF ELECTRICITY (LCOE)

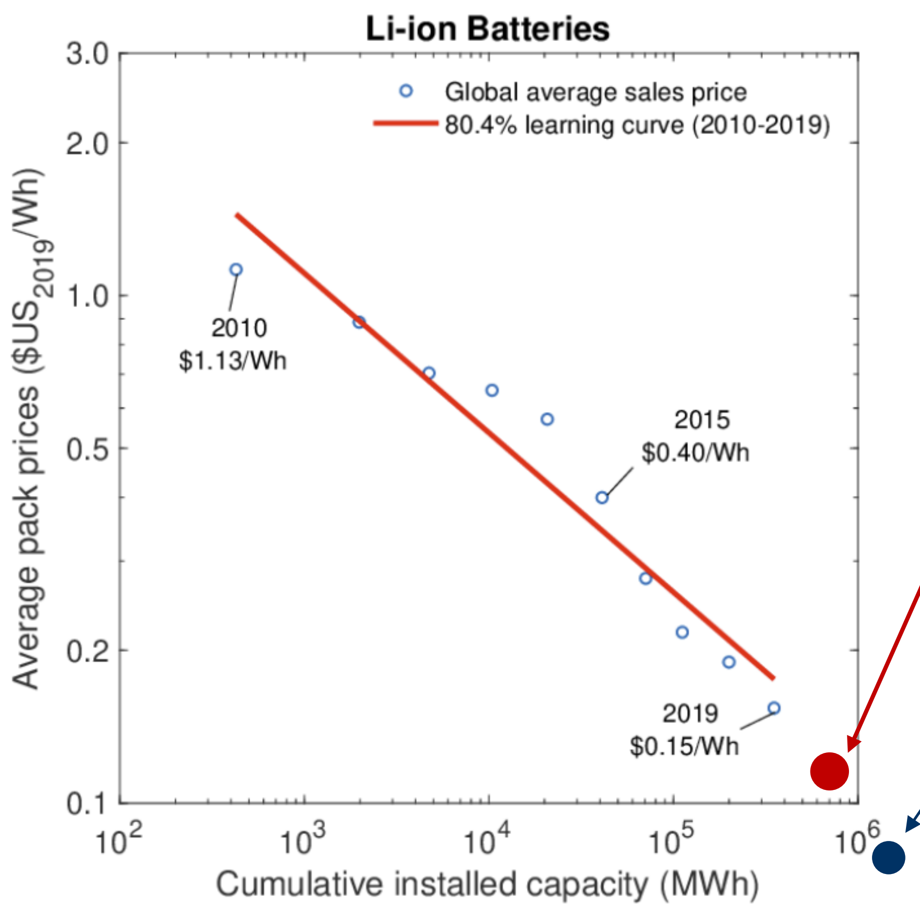
In ten years wind and solar large parks (bi-facial + 1 axis tracking) well below LCOE of fossile fuels



Source: IRENA report «Renewable power generation costs in 2021»

STORAGE STIMULATE BY THE AUTOMOTIVE MARKET

Automotive Battery learning curve



Cost Dynamics of Clean Energy Technologies, Glenk et al.

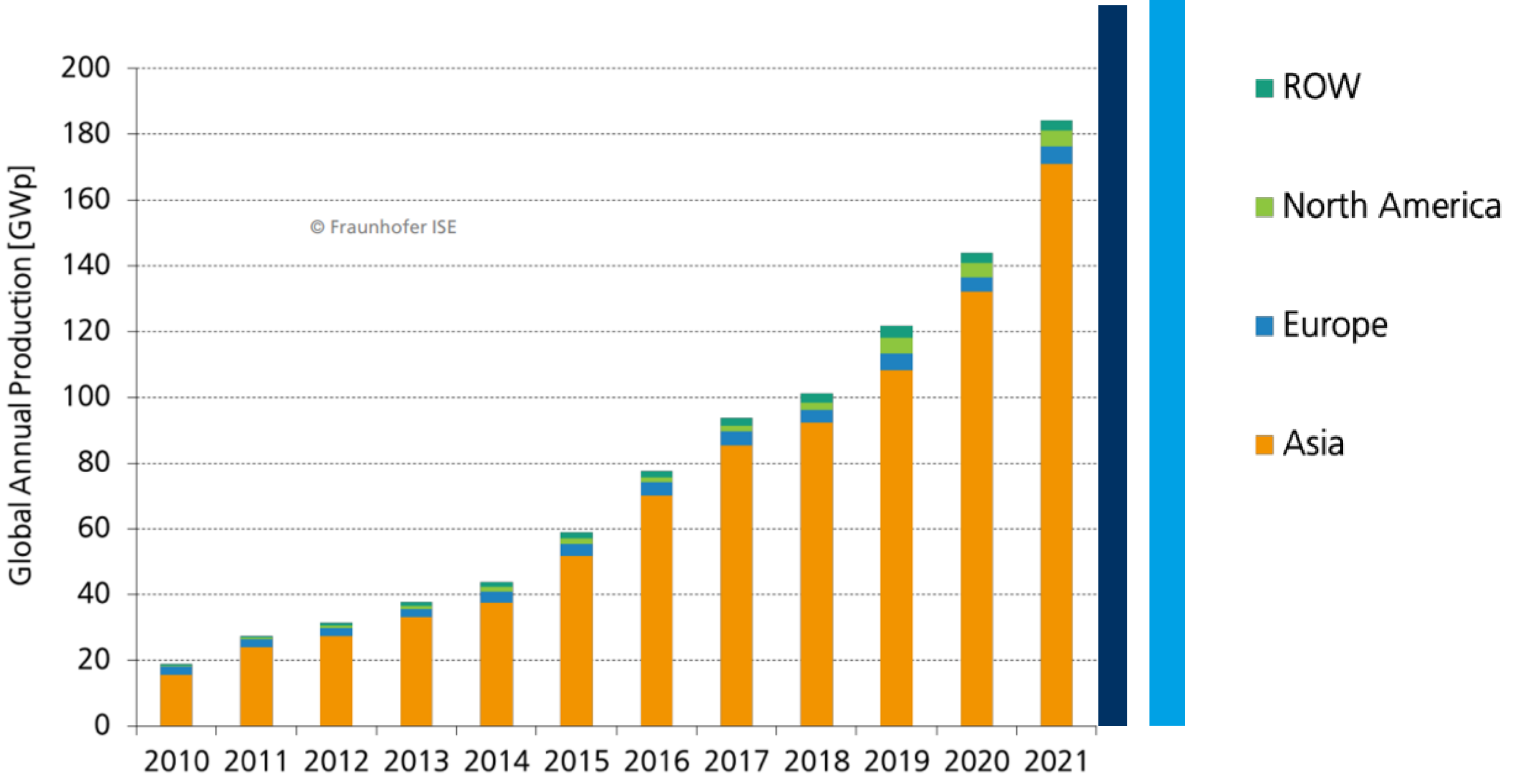
Today automotive battery pack at 120-150 $ /kWh

"We expect the price of an average battery pack to be around $94/kWh by 2024 and $62/kWh by 2030"
Bloomberg NEF (before the Ukraine War)
Tesla announcements

700 GWh Li-Ion produced in 2022

4700 GWh annual battery production by 2030 ?

WORLDWIDE PRODUCTION OF SOLAR MODULES

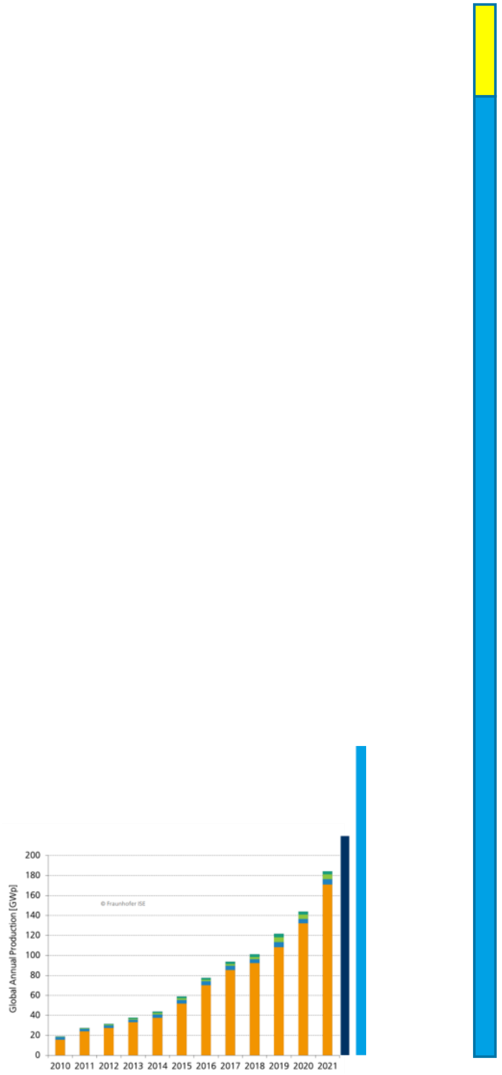


Data: Until 2020 IHS Markit; IEA 2021. Graph: PSE 2021; Date of data: 31-July 2022

220 GW in 2022

- Est 350 GW in 2023 (n.b > 90% China)

PERSPECTIVES 2028



Industry expects 800–1000 GW annual production by 2028…
(→ > 25 TW installed by 2050 ....)

Could even grow to 2000–3000 GW/year in „agressive scenarios“ (CO2 capture, high Power to gas fraction, Desalination)

100 GW/Year (2018) → 400 years for 40’000 GW
1000 GW/Year (2028 ?) → 40 years for 40’000 GW

✓ PV on the right growth path
✓ Batteries growing strongly

- Wind needs to be pushed faster

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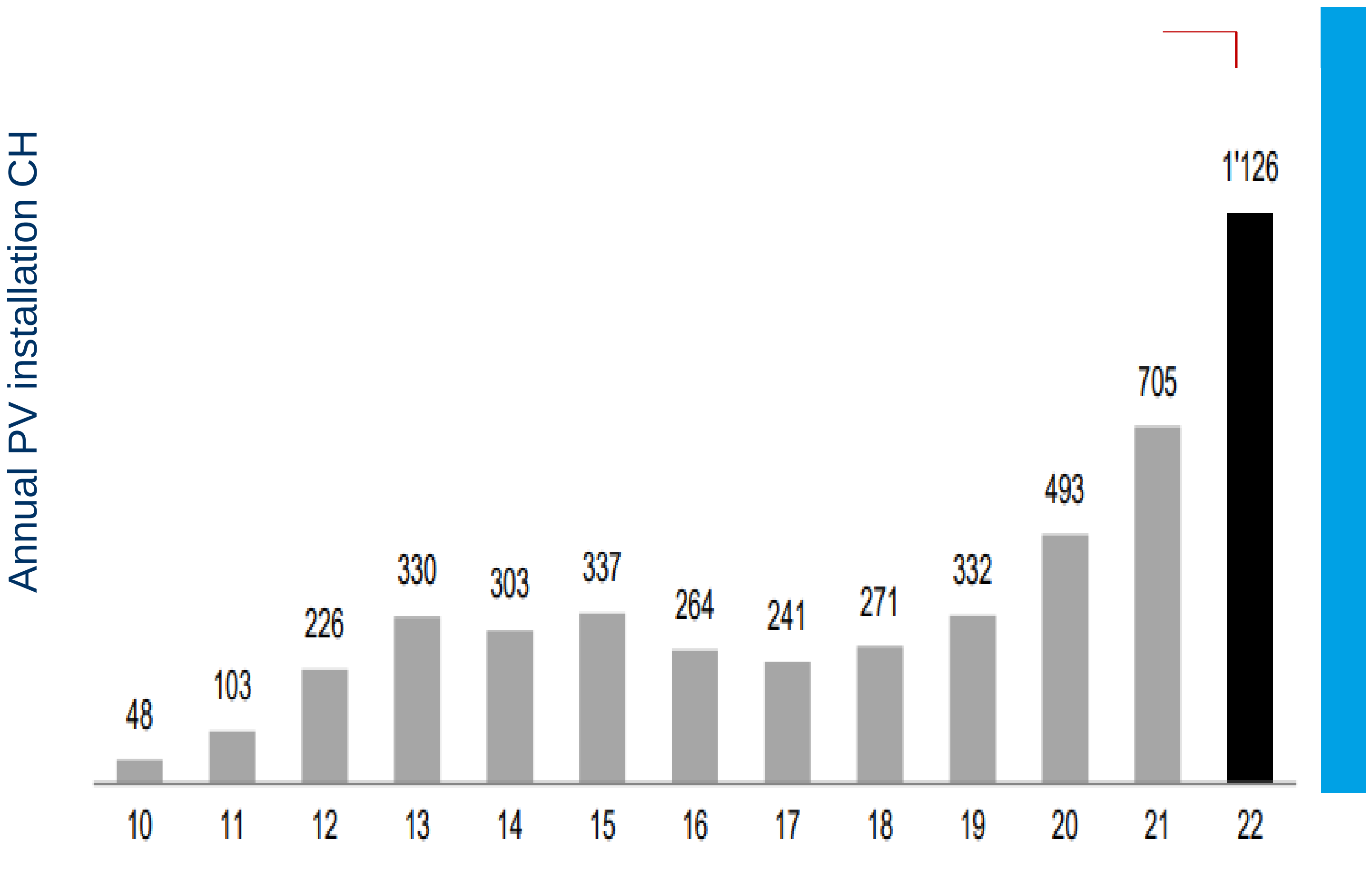
MESSAGE 2

TRANSITION IS NECESSARY, POSSIBLE AND COST EFFECTICE.
NO DESPAIR, BUT ACTION !
HUGE UPSCALING IS/WAS NECESSARY !

ANNUAL SWISS PV MARKET IN MW: NEW INSTALLATION



Source: Swissolar/internal data

End 2022: 4.2 GW installed
~6. % of annual CH electricity consumption of 2022

1.5 GW more in 2023 ?

Min > 1.7–2 GW year
For scenarios with **50 GW** solar

A factor 1.7 to 2 two slow.
But 20x better than 12 years ago

Confederation targets ~ 35-40 GW

HOW TO SOLVE THE «WINTER PROBLEM» IN CH – 1/2

- Put more quickly more photovoltaics everywhere and curtail (easy)
- Put more PV on facades and in the alps (less easy but useful)
- Increase some dams height/new dams, optimise for Swiss autarcy not costs
- More wind/ reduce time to construction and opposition

HOW TO SOLVE THE «WINTER PROBLEM» IN CH – 2/2

- Renovate buildings and introduce efficiency everywhere
- Do not stop safe nuclear powerplants too early
- Store biomass and wastes, use for district heating/electricity in Winter, store heat in Summer for winter, geothermal for winter
- Rely on EU grid, supply and assets (e.g. close to 300 GW gas which could turn to hydrogen, strong wind growth). Import/export will/should continue
- Reduce consumption for a few critical weeks in Winter (e.g. maintenance of industrial assets, reduction of heating,),….
- Build peakers gas/hydrogen turbines, with short operation time (only a few weeks per year) and store clean fuels...

ALPINE WITH SNOW REFLECTION

- Bi-facial PV systems
  - **Up to 3 times more energy** in Winter seasons. (and up to ~ 3 times the price).
  - Would speed up installation and energy security

F. Baumgartner et al. ZHAW

Greniols park: simulation by enemies

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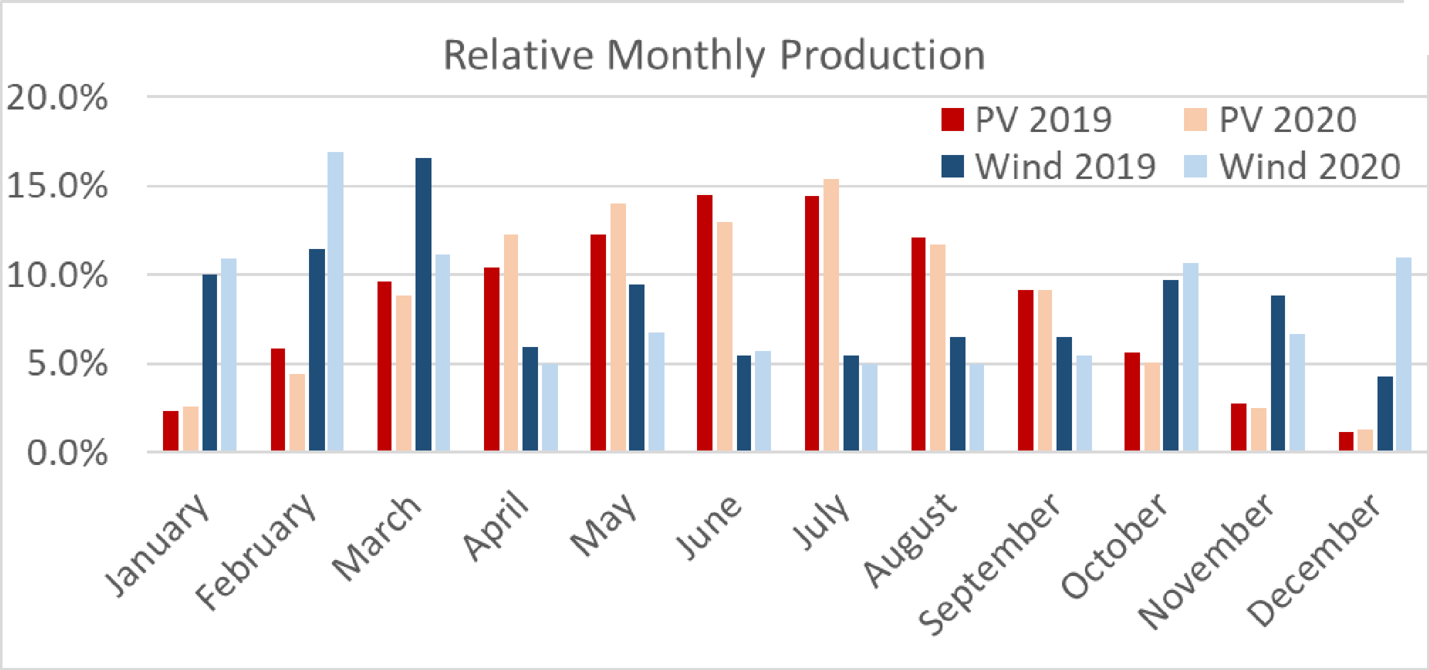
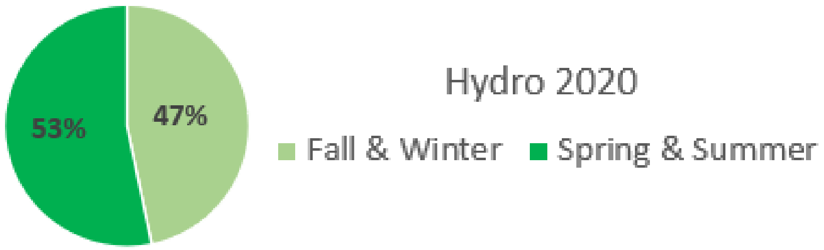
WIND AND SOLAR: ALSO COMPLEMENTARY IN CH

Strategic
for winter electricity: reduced „summer to winter-storage



Source: 2020 electricity generation in Switzerland – ENTSO-E



Swiss National Congress for Wind Energy 2022, M. Cauz et al.
A study by Marine Cauz, Phd Student of EPFL- PV-lab, working with Planair

IS THE ENERGY TRANSITION SUSTAINABLE?

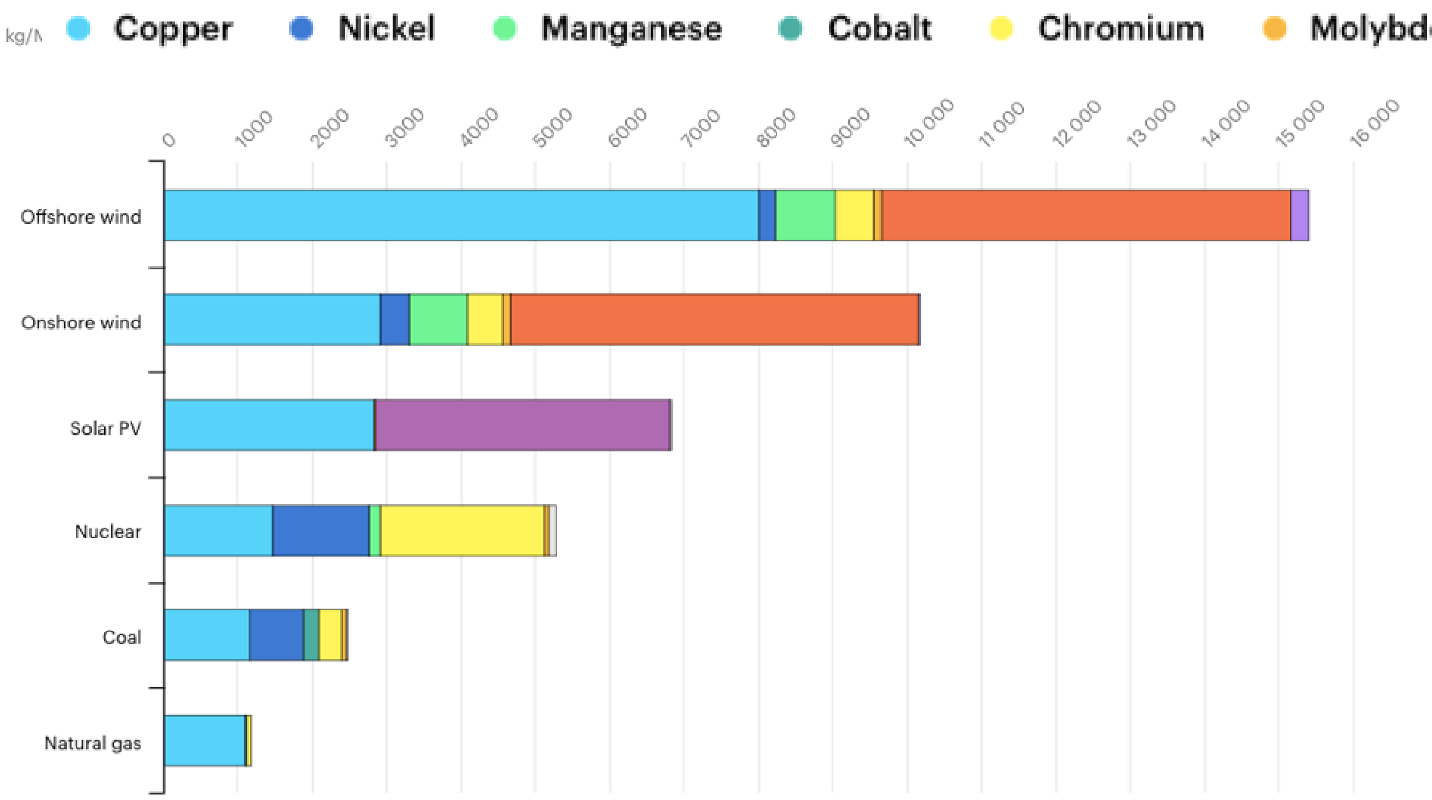
- Material availability, extraction ?
- Energy Payback time?
- CO_2 emission (and others)?
- Biodiversity?

Spoiler:

YES

but

MATERIALS EXTRACTION



Minerals **for renewable is a small fraction of total mining.** Impact much less than current status (in particular fossile fuel and coal extraction brings huge issues and pollution)

“an emerging perspective in the US public discourse argues that a buildout of renewable electricity would exacerbate supply risks, mining intensity, and import dependence. This paper’s findings challenge such assertions.”

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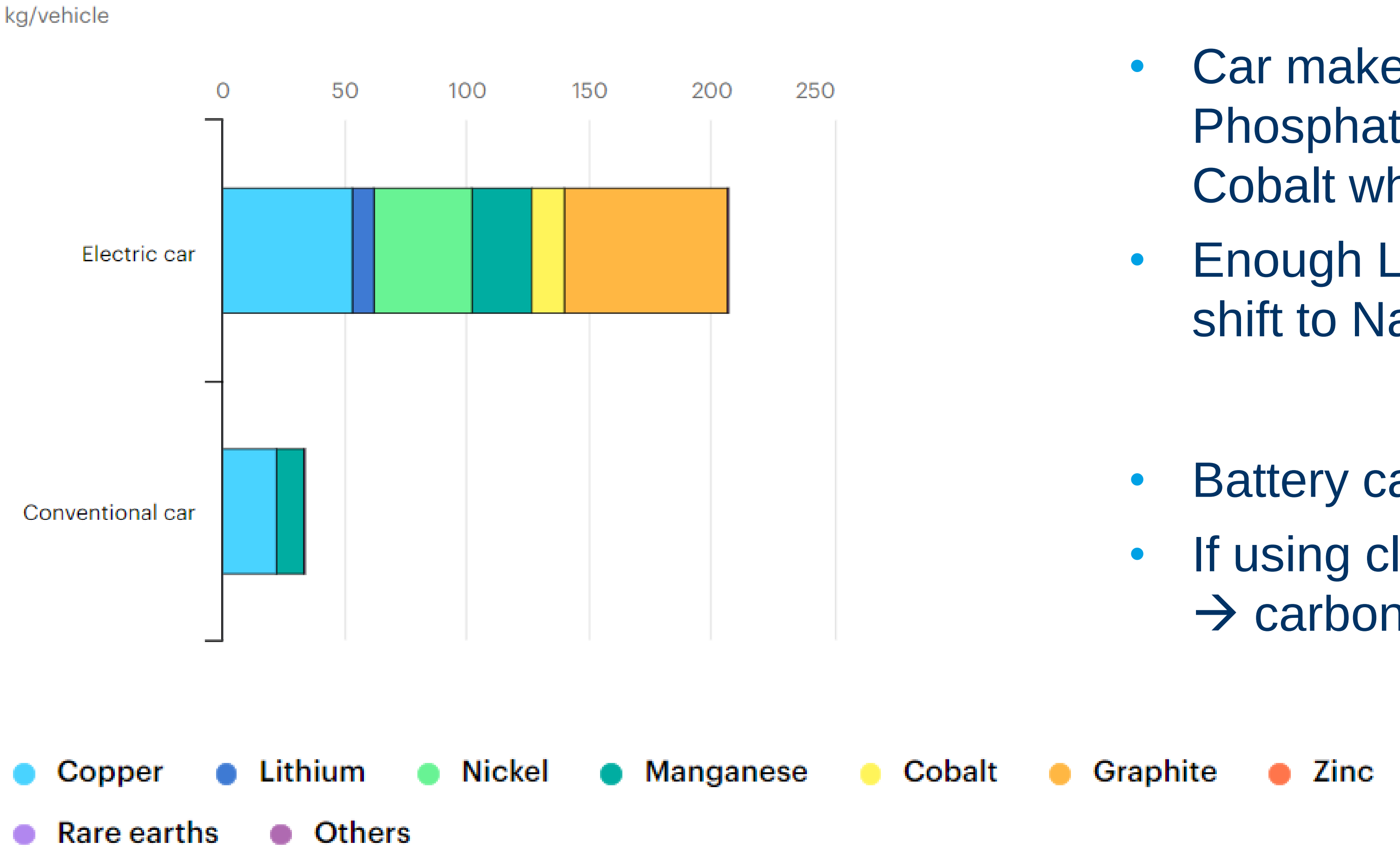
MATERIAL USAGE FOR ELECTRICAL NICO LITHIUM BATTERIES



- Car makers can shift to Lithium Iron Phosphate batteries. Heavier but no Ni and Cobalt which are the most critical.
- Enough Li for > 2 billions cars, and possible shift to Na-Ion

- Battery cars of 70 kWh CO_2 emission ~ 5 T.
- If using clean electricity in 30'000 km
→ carbon neutral!

As for all mining possible local problems, and good practice required!!

MATERIAL USAGE: EXEMPLE CUPPER

PV: 1 TW/year at 3 Cu Tons/MW → **3 MT /year**

Windturbines: 500 GW/year at
2 Tons/MW, with Al grid connection) → **1 MT/year**

Electric cars: 80 millions cars at
60 kg Cu, with charging station → **4.8 MT/year**

~ 8-9 MT out of 25 MT /year processed today

→ market pressure and possible bottlenecks, but not fundamental, and…

- Materials can be saved (improved designs), additional/improved mining and recycling.
- As for other less used materials (e.g. rare earth, Ag for photovoltaics, Cobalt for batteries), alternative solutions always exist!

DURABILITY OF PV ? MANY IMPROVEMENTS!

1st major improvement

Siemens silicon recrystallation process 200 kWh/kg of Si in 2000!!!

Today:

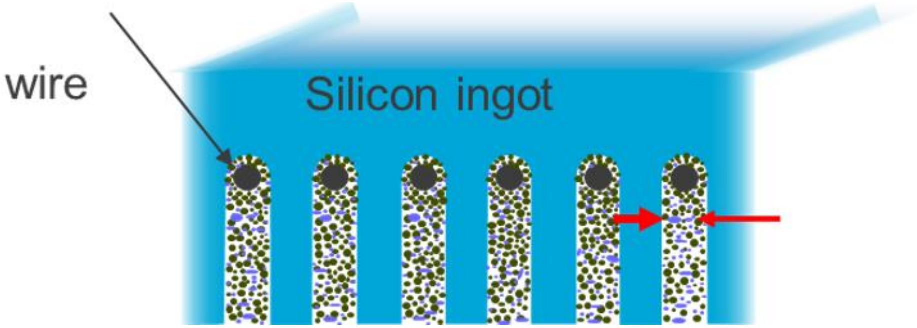
Can make 10 tons of silicon per run,
tubular filaments, cold reflected coated walls.

Only 40-45 kWh/kg.

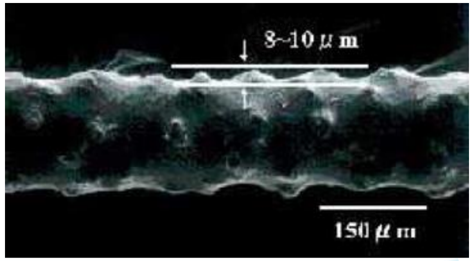
DURABILITY OF PV

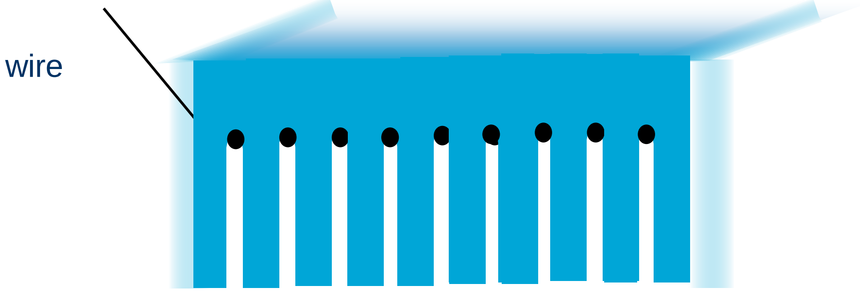
2nd major improvement

Wafer sawing



Yesterday, multi-wire sawing, SiC particles
→ 200 microns lost Si





Today, diamond wires for mono c-S
→ 50 microns lost Si (36 microns wire)
→ 80 % more wafers than 5 years ago!

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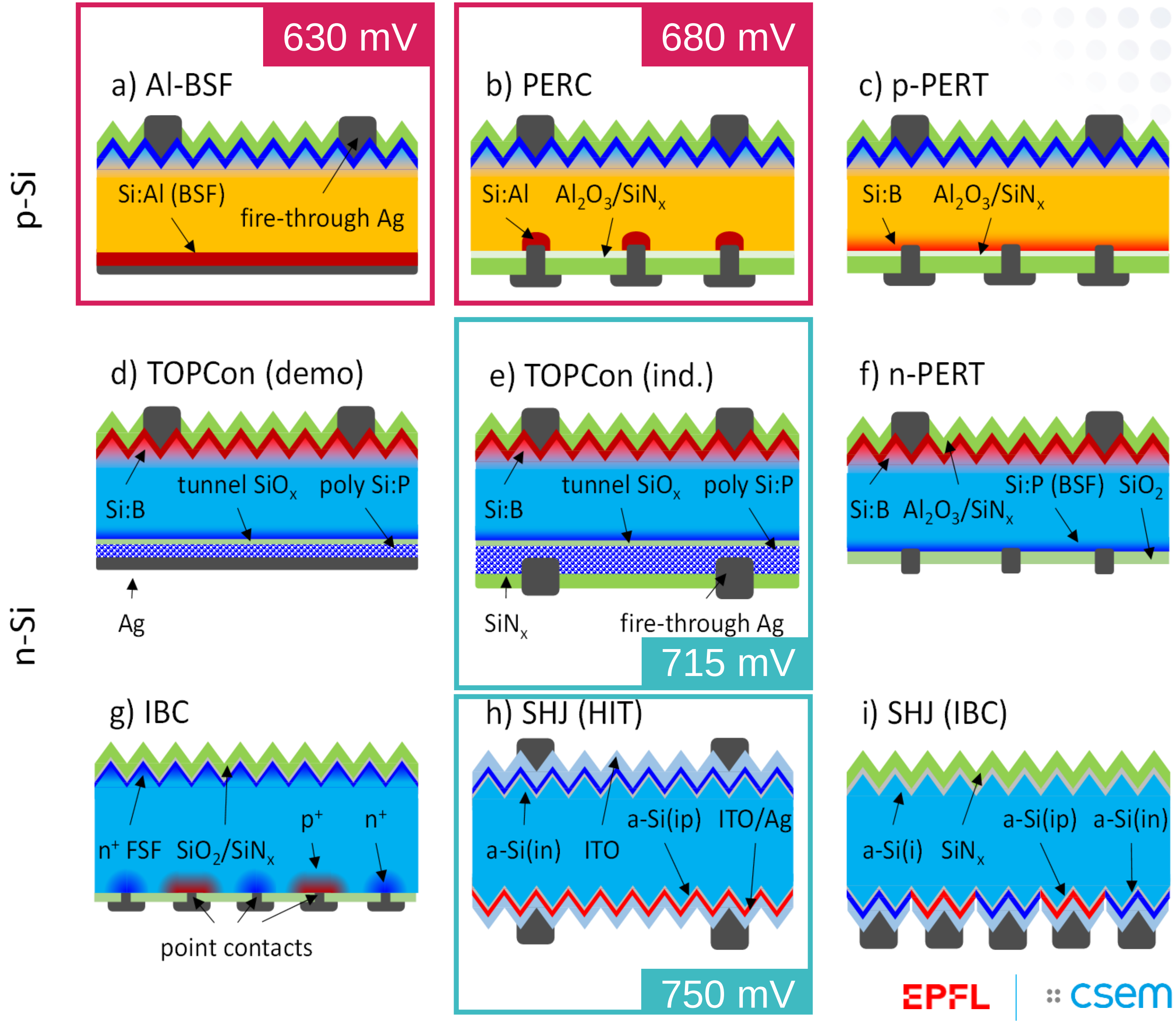
DURABILITY OF PV

3rd major improvement technologies

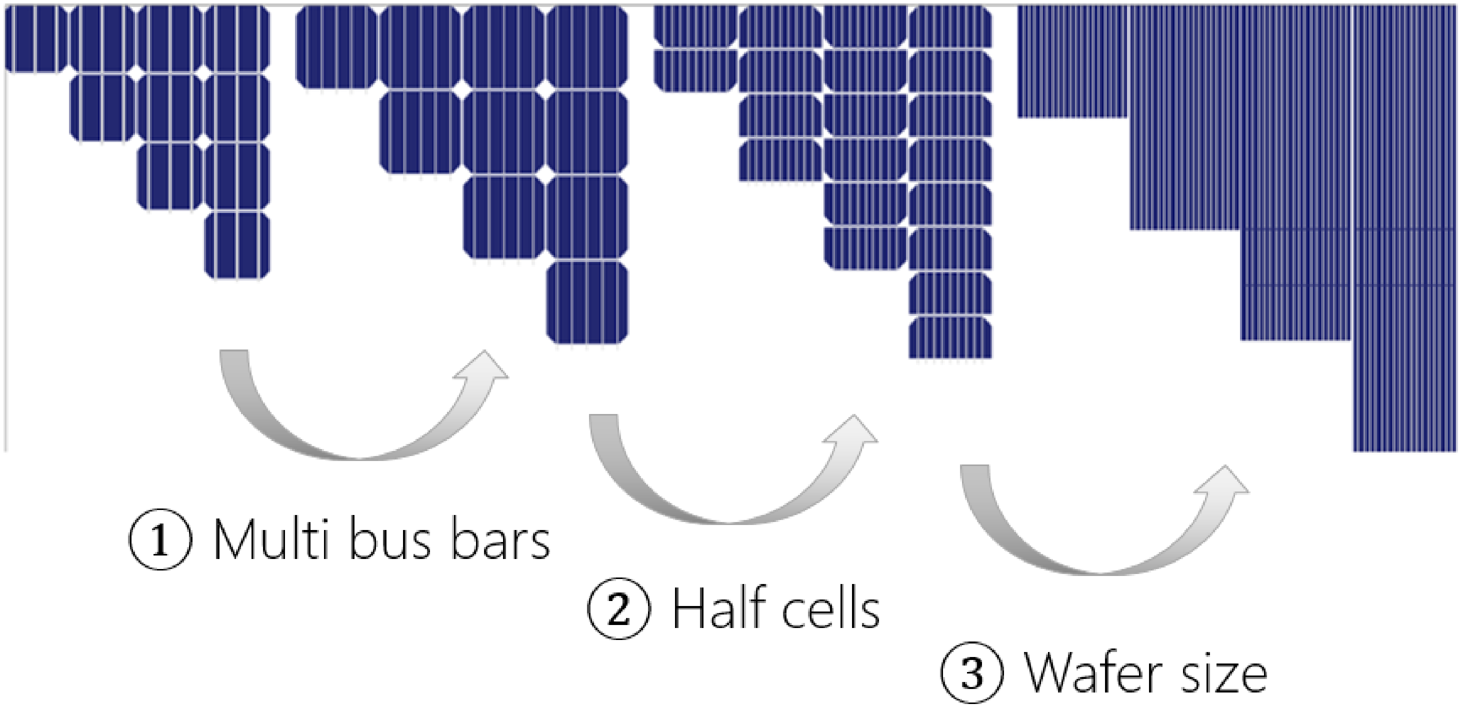
The various types of silicon technologies:

More and more Voltage !!



Ballif/Haug et al. Nat. Rev Materials 2022

4th improvements
modules design

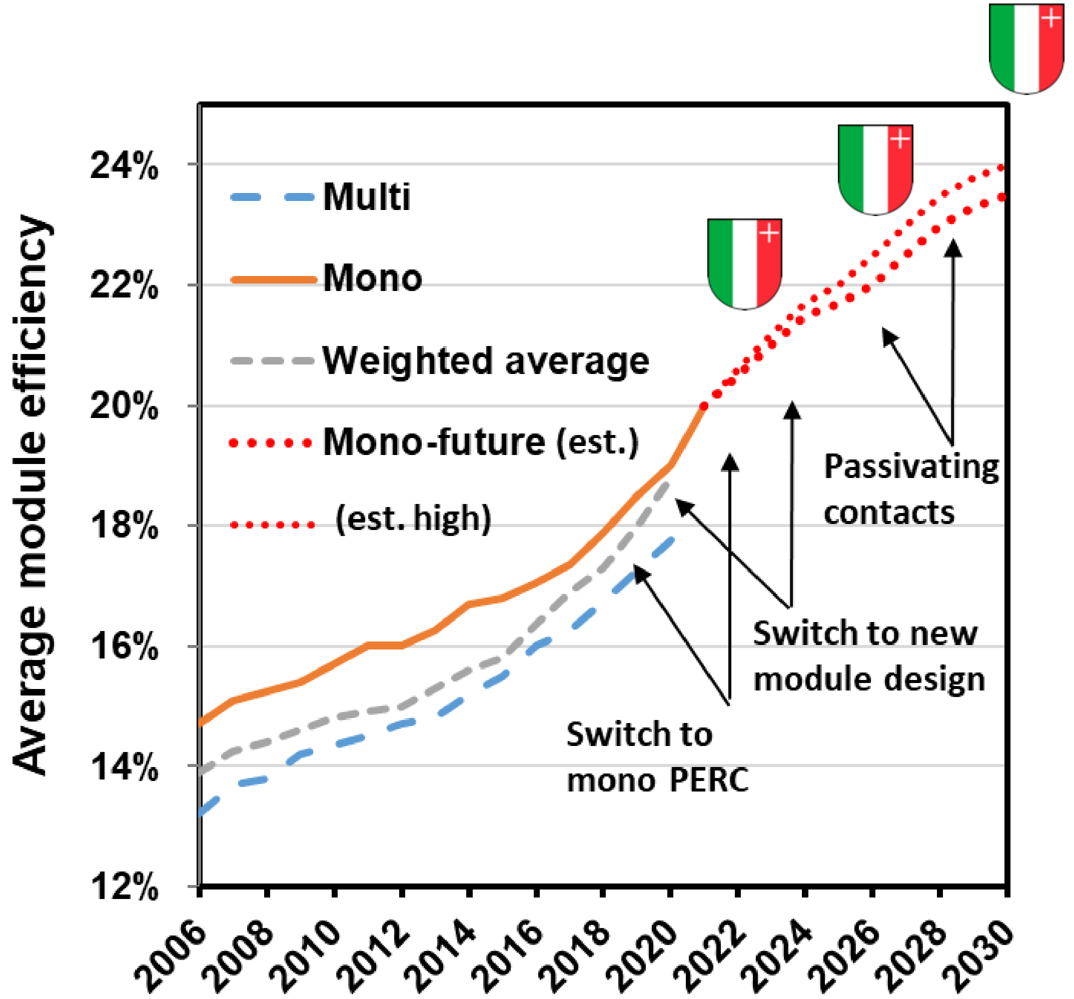


0.5–1.5% absolute efficiency gain

1) More bubars: reduce losses in siliver fingers (+ 0.1-1% relative)
2) Half-cells: less losses in cupper ribbon interconnects (+ 2% relative)
3) Larger cells: less empty area, less edges per area (up to 21 x 21 cm2 cells) (+ 0.5-1% relative)
4) Larger modules: less spacinga the edge (+ 1-2% relative for 700 W modules)

Ballif/Haug/Boccard et al.
Nat. Rev Materials 2022

PERMANENT INCREASE IN THE MODULE EFFICIENCY

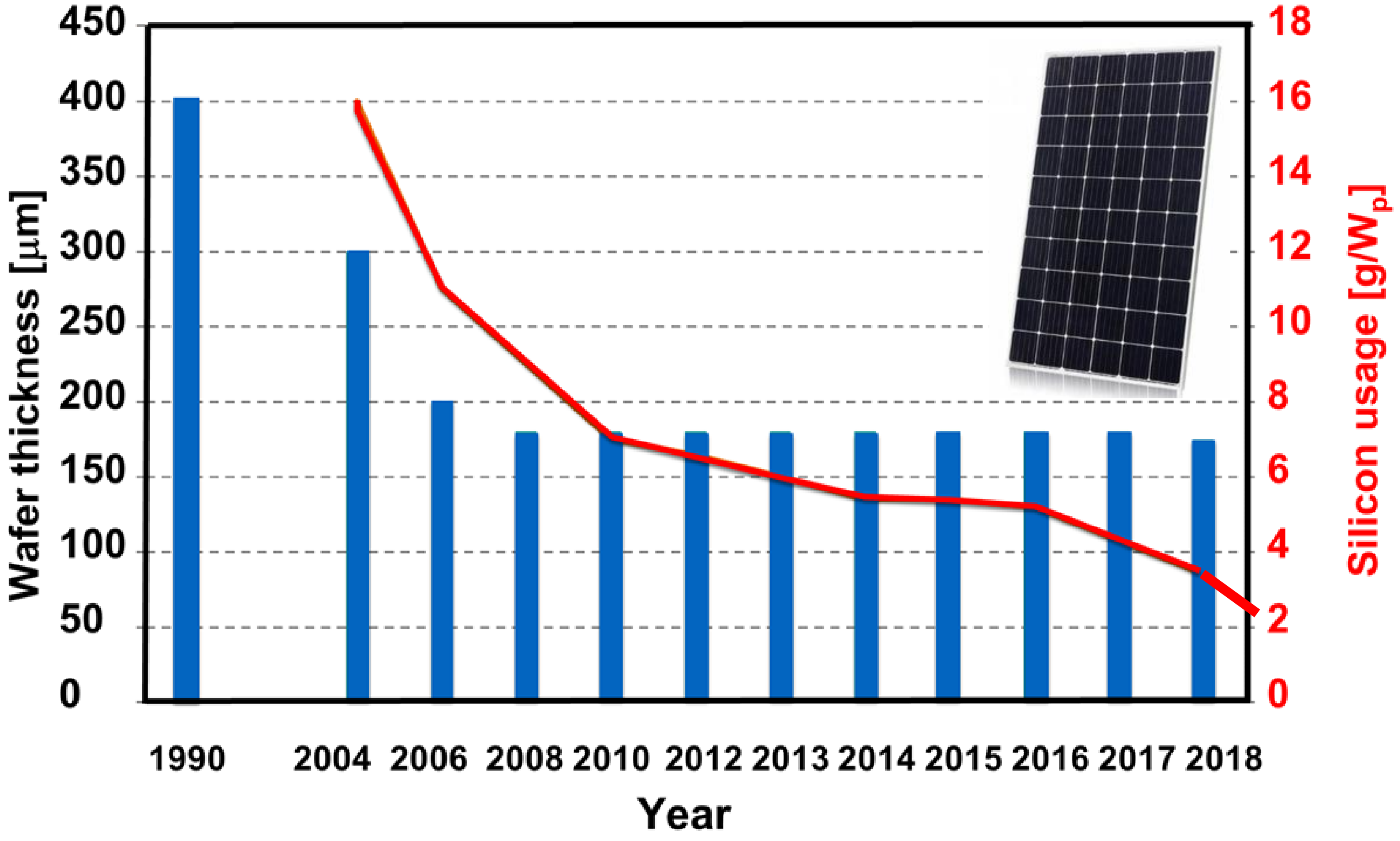


- 0.4-0.5% gain per year
- Todays average cells at 22.5-23.5%, modules at 20.5-21% average
- Efficiency will further increase → practical limit at 24–25%

Reduces all other material costs/usage per W

Haug, Ballif et all. Nat. Rev. Materials 2022

PURIFIED SILICON USAGE PER WATT FOR SILICON PV MODULES

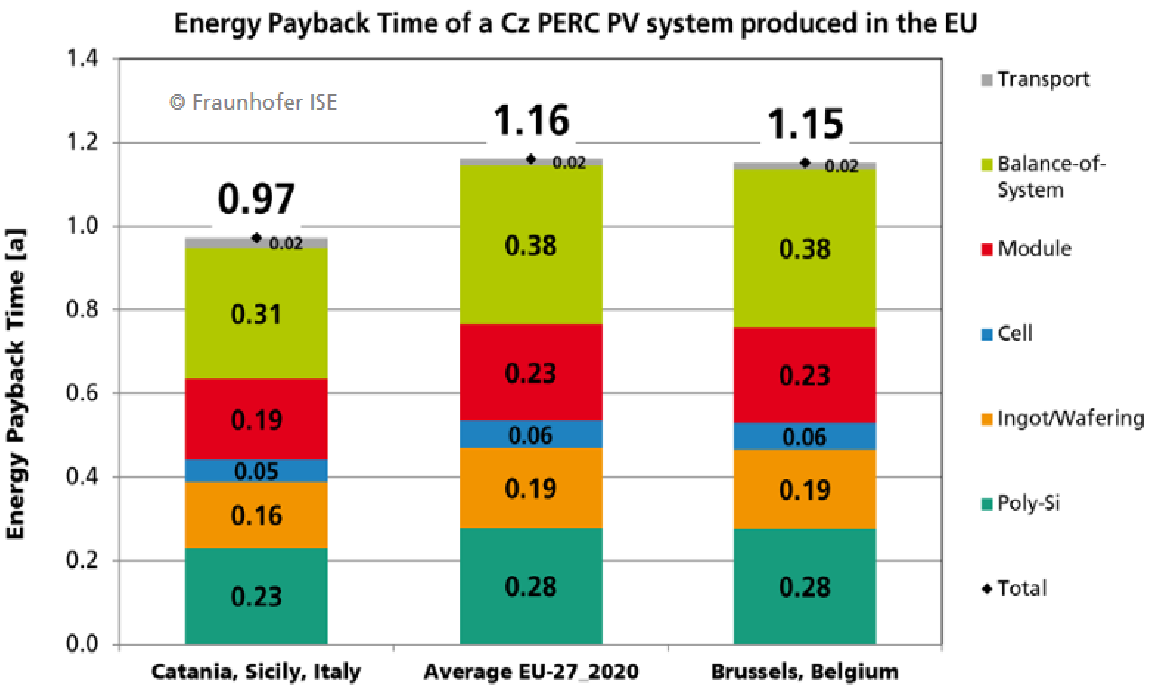


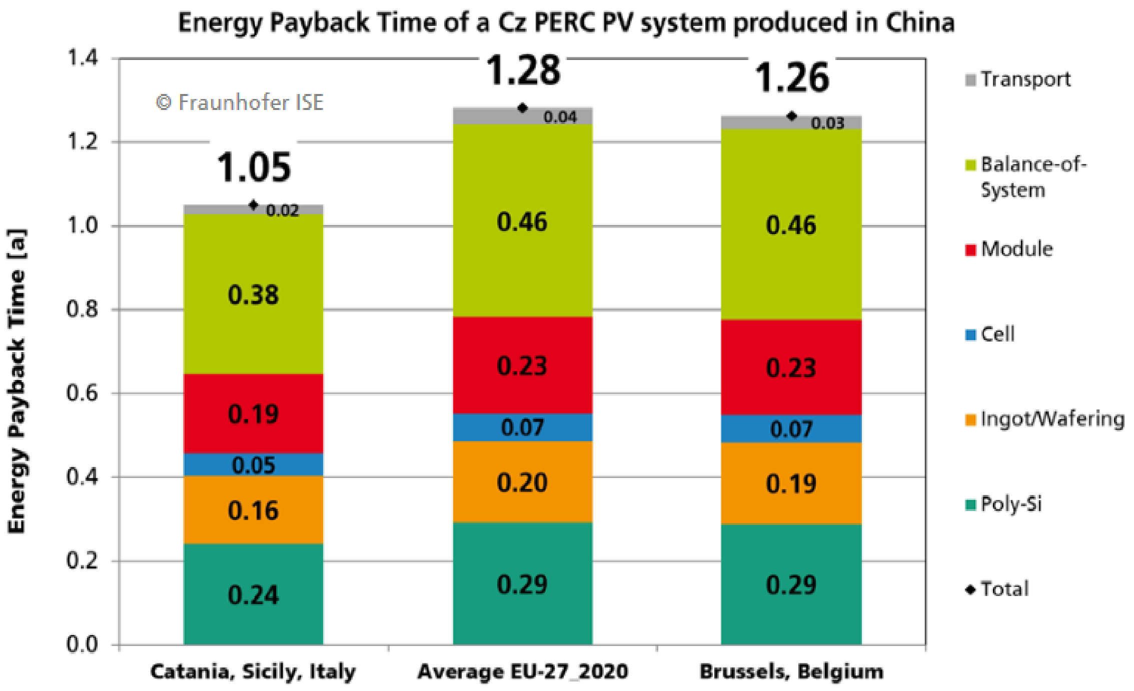
From 17 to 2.1 g/W in 20 years thanks to:

- Improved processes (poly-si)
- Diamond wire sawing
- Thinner wafers
- Efficiency increase

Haug, Ballif et all. Nat. Rev. Materials 2022, source Fraunhofer ISE, PSE)

ENERGY PAY-BACK TIME (EPBT) OF SILICON PV ROOFTOP SYSTEMS: STRONG IMPROVMENTS





A typical PV system will give back the energy required for fabrication in 1 year.

Module around 60–65% of the total.

Full module: currently around 0.5–0.6 kWh/W electricity required

Source: Fraunhofer report 2021
A. Barrou et al. CSEM, 2021-2022

PV MODULE CO_2 FOOTPRINT

Made with:

EU electricity	400 gCO_2/W
China coal electricity	~670 gCO_2/W
Reported	< 300 gCO_2/W

powered by Q.ANTUM DUO

Q CELLS modules earn further low-carbon certification for French tenders

Hanwha Q CELLS GmbH, the German subsidiary of one of the largest solar cell and module manufacturers in the world, Hanwha Q CELLS Co., Ltd, has received on March 14 a Certisolis carbon footprint (CFP) certification of 300 kgeq/CO² /kWc in France for its high-efficiency Q.PEAK DUO module series.

APRIL 1, 2019 Q CELLS

A comparative life cycle assessment of silicon PV modules: Impact of module design, manufacturing location and inventory – ScienceDirect 2021, Muller et al.

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KEEPING A SMALL FRACTION OF OUR EMISSIONS FOR THE ENERGY TRANSITION

- With the key elements of the energy transition (simple estimates)
  - 15 TW of Wind at 200 g CO_2 /W → 3 GT
  - 40 TW of PV at 300 g CO_2 /W → 12 GT
  - 2 billions batteries of 50 kWh at 60 kg CO_2/kWh → 6 GT
  - Systems, grid update…. → 6 GT

Estimated total (with current good practice)
→ **27 GT** ~3% remaining in the 1000 GT remaining for a +2°C scenario

Using a few percent (~ 3%) of our remaining carbon budget is required to build the objects and infrastructure that will save on CO_2

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MESSAGE 3.

YES, A LITTLE MORE MINING, CO2 AND LOCAL IMPACT ON LANDSCAPE (E.G. WIND, SOLAR) TO SAVE THE WORLD !

BUT IT IS MUCH, MUCH LESS DAMAGING THAN TODAY'S SYSTEM ! THE REST IS THE PROBLEM

or

PHOTOVOLTAICS AND ENERGY SYSTEMS IN NEUCHÂTEL

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2800 M^2 OF INFRASTRUCTURE AND 120 PEOPLE……

Technology infra-structure Platforms

Coatings and thin film devices fabrication	Cells Pilot lines	Modules R&D lines	Polymers coumpounding/ extrusion	Batteries fabrication and storage testing	Data /AI energy management

Reliability and accelerated aging tests

Metrology and characterization

- Heavy PV testing (damp heat, TC, Hail, UV)
- Hevy battery testing

CONTRACTS WITH OVER 40 COMPANIES ALONG THE CHAIN

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SMART GRID ACTIVITY PORTFOLIO

Digital Energy

Networks

- Flexibility services from distributed ressources
- Inverter control
- Code generation for multi-vector optimization

Renewables

- Anomaly detection and diagnostics
- PV system modelling
- High-resolution PV forecasting

- ✓ Intelligent valves
- ✓ Improved COP of heat pumps
- ✓ Better distric heating

Batteries

- Multi-service battery system
- Model-based state estimation

Buildings

- Building model identification
- Prosumer optimization
- Individual tenant billing

PRODUCTION FORECAST AND PREDICTIVE MAINTENANCE FOR ENERGY ASSETS WITH CSEM AI

Digital Energy

Machine learning from Big data sets
and physical knowledge of systems

Applicability

- Wind (software used no by Proxima Solutions)
- Hydro
- Solar
- Heat pumps
- Cooling
- Batteries

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BATTERY RESEARCH ACTIVITIES: FROM MATERIALS TO SYSTEMS

Batteries

Coatings and Interfaces

- Thin-film coatings
- Wet coatings
- Interface functionalization

Solid-state electrolytes

- Polymer solid state
- Ceramic solid state
- Integration and stabilization in cell

Cell modelling

- SoX estimators based on EIS
- Validation vs. measurements
- Simulations

Cell/module testing

- Technological screening
- Ad-hoc testing protocols
- Second-life testing procedures

Post mortem analyses

- Opening
- Imaging
- Modelling

BMS prototyping

- CMS concept
- Active balancing
- EIS integration

System-level analyses

- Frequency regulation
- Power trading optimization
- V2G analysis

A LEAN PROCESS TO MAKE HIGH EFFICIENCY CRYSTALLINE SILICON SOLAR CELLS

2005 — UNIVERSITÉ DE NEUCHÂTEL

First high efficiency solar cells

Swiss Electric Research award 2007

19.2%

2008

Creation Roth and Rau Switzerland

2009 — EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Hosting and transfer of technology to Roth&Rau Switzerland

22-23 %

2011

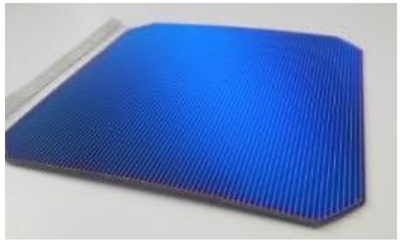
Meyer Burgers Acquires Roth&Rau

MEYER BURGER

2013 — csem

Industri-alisation phase

22-23 %



2017

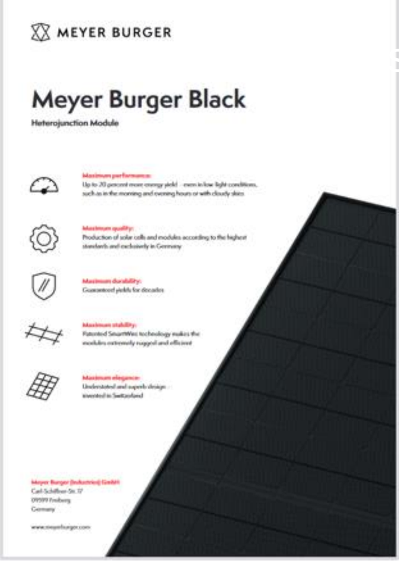
Large scale demonstrator

First production lines and tools sold

cea

2022 — csem

Becoming the Leading EU cell and module manufacturer



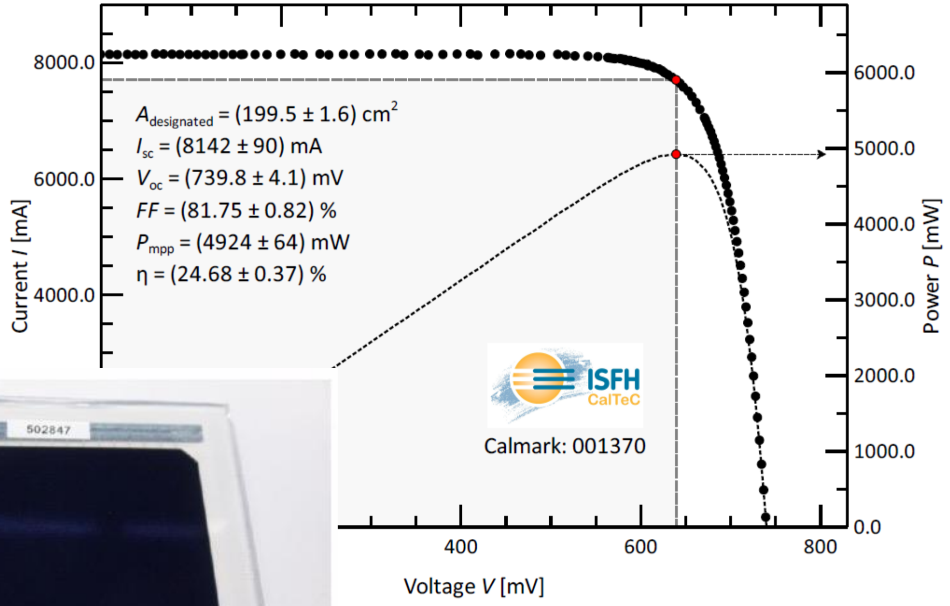
NEW ORGINAL SMARTWIRE TECHNOLOGY AND SILICON HETEROJUNCTION PROCESSES

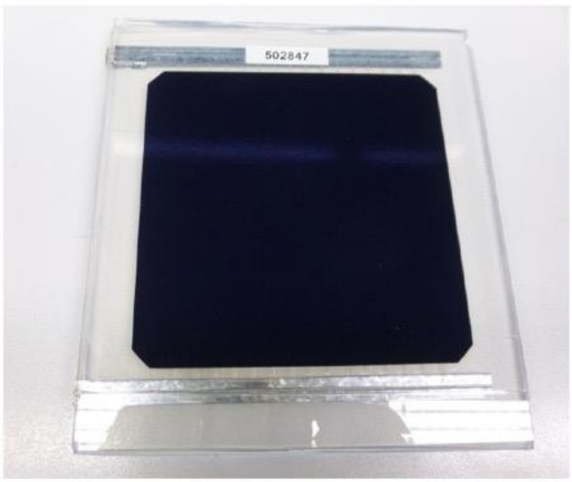
- developped with CSEM/EPFL
- Multi GW planned production
- Strong growth of Meyer Burger
- only solar cell producer in Europe with > 1 GW

promote EU products, with EU cells when possible. Support rebuilding a supply chain …

BEYOND STANDARD CELLS: THE TUNNEL BACK-CONTACT CELL

World record single-cell laminate with tunnel-IBC + SmartWires®:





✓ 24.7 % efficiency

First 60-cell tunnel-IBC module in glass/backsheet configuration:

MEYER BURGER

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

These activities are supported by SFOE in the frame of the project "SIRIUS" (2021-2024E)

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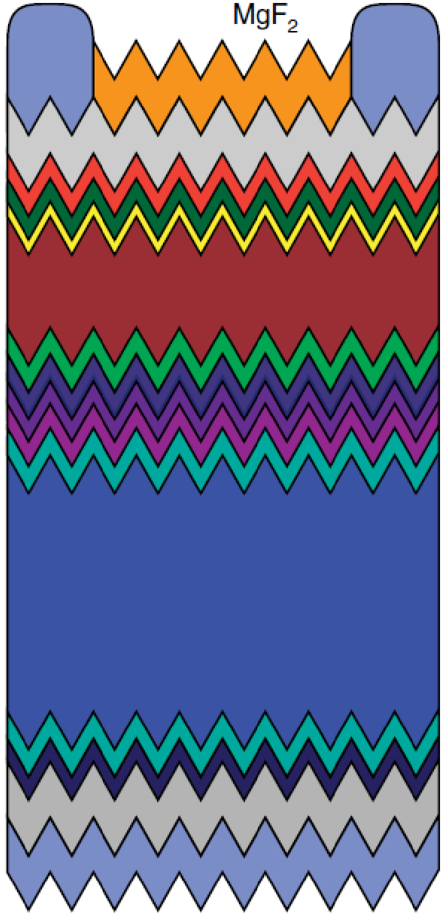
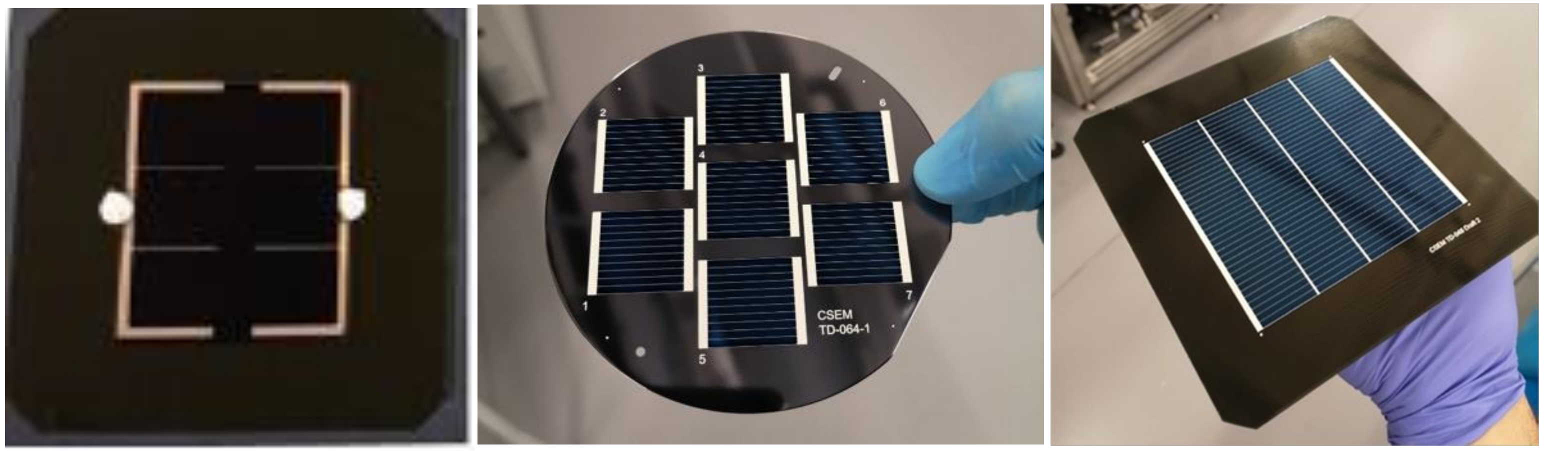
CELLS ABOVE 30%?
PEROVSKITE/SILICON TANDEM SOLAR CELL



Sahli et al. Nature materials 2018



EPFL PV-lab/CSEM
first time WR > 30%
Certified > 31.3%*

CSEM
Upscaling ongoing
And 29.6% certified on 25 cm^2

Possibly extend the learning curve,
But a lot of work/research to make stable device !

Xin Yu Chin et al. Science (2023)
Turkey et al.
Artuk et al.

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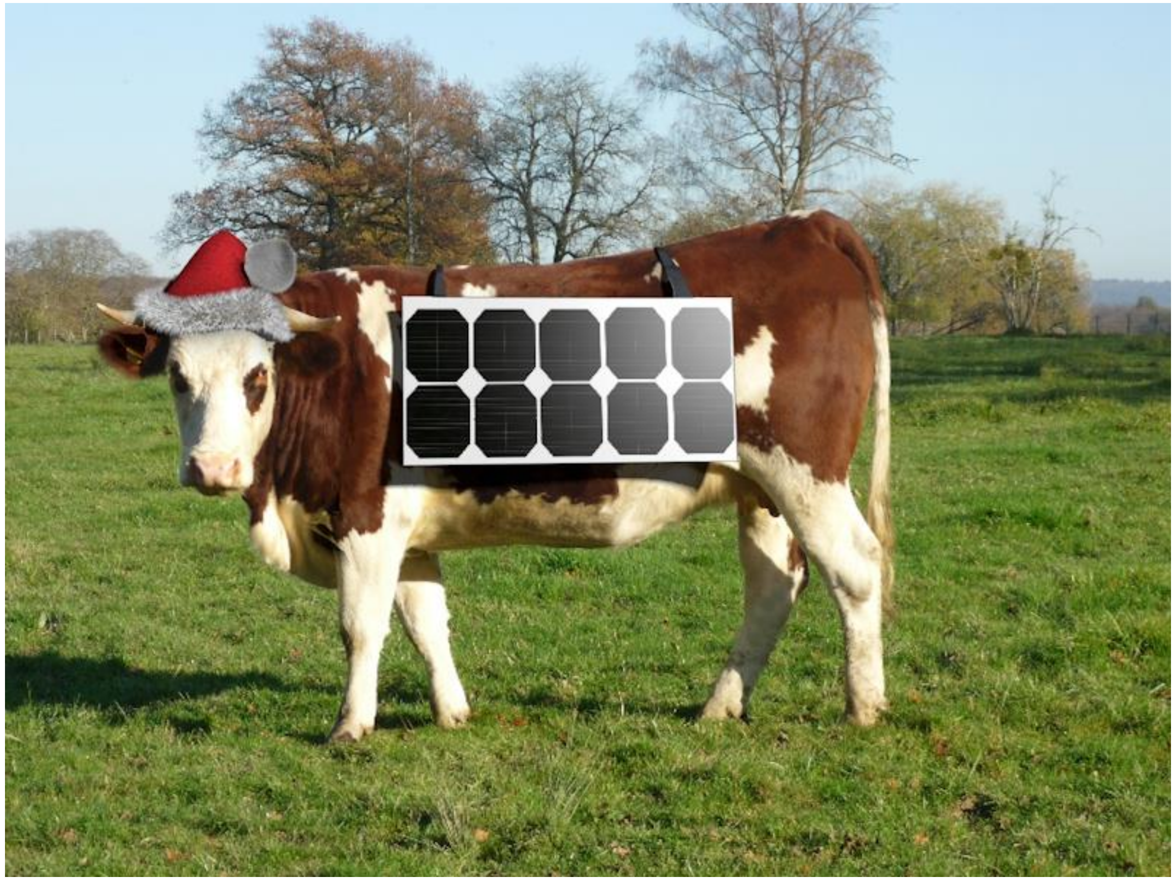
SWITZERLAND, SENSITIVE TO ACCEPTANCE IN RURAL AND URBAN ENVIRONMENT

Sensitive to aesthetics



Neuchâtel, maison des associations, Swiss Solar Award 2015 «renovation category»

Over 20’000 “Megaslates” systems installed (3S solar solution), fast ramping up of Swiss production

Prix solaire
Suisse 2015

Elegance and architecture
Transforming building and cities

CSEM as pioneer of transformative technologies for PV panes

Based on low cost c-Si modules, ….

White PV panels, together with Solaxess

SOLAXESS
WHITE & COLOR SOLAR TECHNOLOGY
csem

Ecuvillens
One of the
Terra-cotta tones

With ISSOL, Solstis,
Userhuus, SFOE

Soutien des Service de
l’énergie et des biens
culturels de Fribourg

Prix solaire
Suisse 2018

hflu Höhere Fachschule Luzern

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

ETAT DE FRIBOURG
STAAT FREIBURG

Schweizer
Solrif®

csem

Prix solaire
Suisse 2019

With
support
of

ne.ch
RÉPUBLIQUE ET CANTON DE NEUCHÂTEL

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z & Rettung


Schutz & Rettung

SOLAXESS
WHITE & COLOR SOLAR TECHNOLOGY
3S Solar Plus
csem

Private house
Neuchâtel

Courtesy L.E.
Perret-Aebi

Private garden
Neuchâtel

Courtesy L.E.
Perret-Aebi

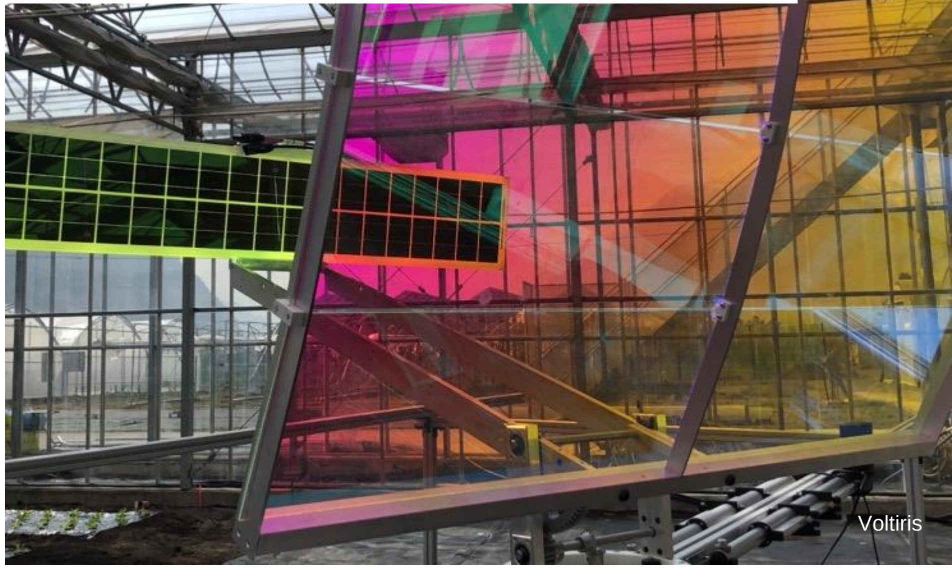
compáz
csem

INNOVATION IN SWITZERLAND: OF COURSE DHP (GR)

- Deployable PV systems

insolight

Agrivoltaics
on the move



hiperion
MAX SOLAR POWER

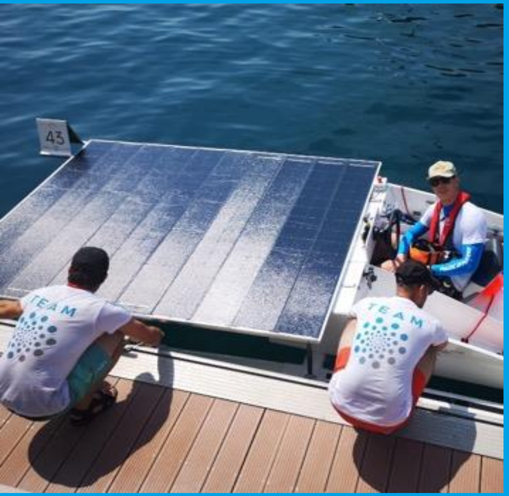
csem

Integrated PV to reach the Stratosphere

SOLARSTRATOS TO THE EDGE OF SPACE

csem

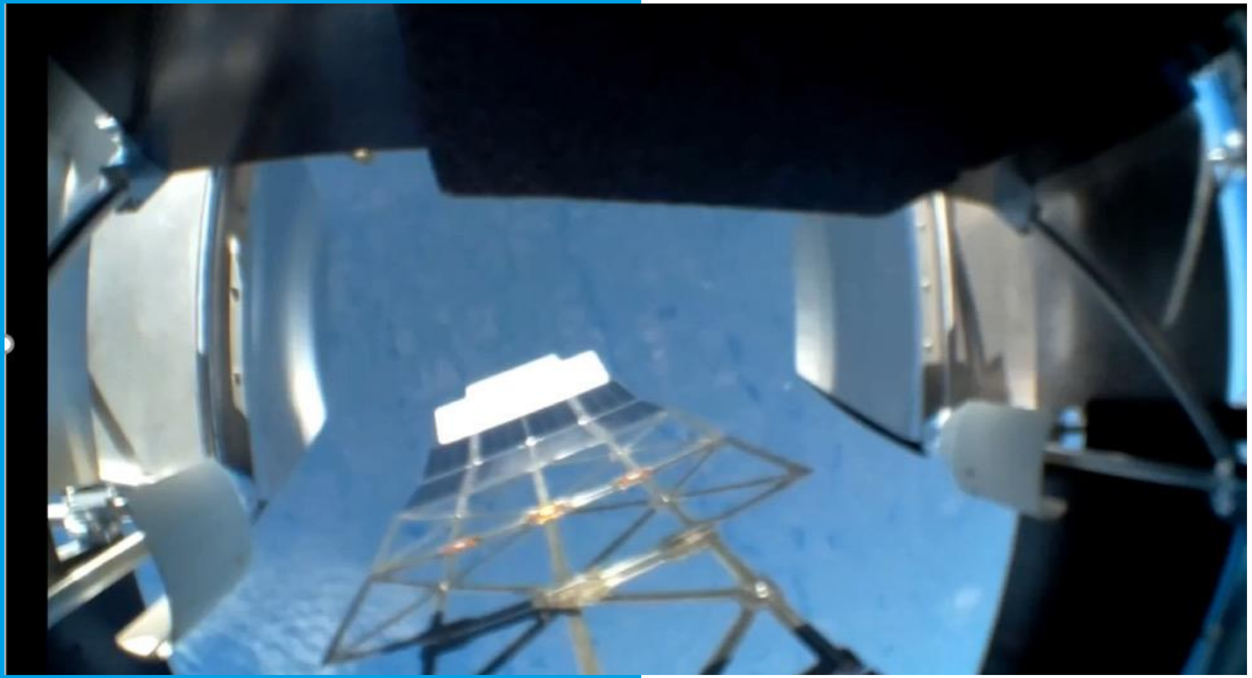
Light weight customized ultra-reliable modules




SWISS
swiss
airtainer

Strateole:
PV solutions for stratospheric balloons

Deployable lightweight structures and PV modules qualified in stratosphere!



Multiple Applications
For terrestrial PV

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.... THE T-TOUCH SOLAR CONNECT

Solar dials developped by CSEM,
production fully ramped-up by CSEM

MESSAGE 4.

AMAZING EVERYTHING YOU CAN DO WITH SOLAR AND EVEN MORE WHAT THEY CAN DO IN NEUCHÂTEL !

THANKS FOR YOUR ATTENTION

And let‘s take part together to changing the world for the best !

christophe.ballif@epfl.ch

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

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SIG