

TRANSITION ÉNERGÉTIQUE, SOLAIRE ET ÉOLIEN: VÉRITÉS, CONTRE-VÉRITÉS ET NOUVELLES POSSIBILITÉS

FORUM DES PROFESSIONNELS DE LA CONSTRUCTION 2023

PRIMARY ENERGY CONSUMPTION



~ 168'000 TWh (CH 320 TWh)

2% annual growth driven by China and India

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 (BP)

Statistical Review of World Energy 2022, BP https://www.energyinst.org/__data/assets/pdf_file/0 004/1055542/EI_Stat_Review_PDF_single_3.pdf IEA global energy review 2021









QUICK RULE OF THUMBS ESTIMATIONS

- With a 1.5 % growth in primary* energy need (instead of 2%...)
 → 250'000 TWh in 2050
- Strong electrification of heating/mobility + biomass + rest electricity for H₂
 → 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

EPF

" csem

*according to BP accounting technique

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

4 MAJOR OPTIONS FOR 100'000 TWh ANNUAL ELECTRICITY PRODUCTION

Which can be combined.....

- a e.g. 40'000 GW of Solar and 15'000 GW of Wind (+ Hydro + Biomass)
 - 13'000 x 1 GW nuclear power plants
 - Carbon sequestration
- d Don't care (or too late...)

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





Michael Child, C. Breyer, et al. Renewable Energy 139 (2019) 80-101

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



MAJOR TECHNOLGICAL ROUTES FOR THE ENERGY TRANSITION



Flexibility and intelligence



HOW PV HELPS 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 for winter production/ reduce time to construction and opposition
- Wind could be transitionnal. In 2040, hydrogen import (partially through NH3 systems)



ALPINE WITH SNOW REFLECTION

F. Baumgartner et al. ZHAW

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







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 EPFL :CSEM

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»

STATUS 2023

Thanks to huge industrial effort by China (\rightarrow overcapacity, price war.... But good for the transition)

- Module price goes down to 12-15 cts/Watt (25 CHF/m2), inverters 3 cts
- For the same service it 20 cheaper to import Solar panels and inverters than to import oil....
- Windturbines price down to 40 cts/Watt
- Battery Packs price droping (even stationnary down to 200 CHF/kWh \rightarrow 5-6 cts to store 1 kWh)

In the big picture Wind and Solar for large park Are becoming so cheap (1.2-1.7 cts/kWh) that soon H2, or NH3 (easier for transport) will become a true alternative to natural gas

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 ? (according to Bloomberg. Enough for 100 million cars per year)

EPFL

CSem

China will have the capacity by 2025!

WORLDWIDE PRODUCTION OF SOLAR MODULES



ROW

North America

Europe

Asia

220 GW in 2022

Est > 450 GW in 2023 (n.b > 90% produced in China)

Switzerland ~ 1.1 GW in 2022 ~ 1.9 GW in 2023

EPFL = csem

PERSPECTIVES 2028

Industry expects 800–1000 GW annual production by 2028... (n.b. China has already enough produciton capacity \rightarrow module price goes down) (\rightarrow 25 000 GW 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) \rightarrow 400 years for 40'000 GW 1000 GW/Year (2028 ?) \rightarrow 40 years for 40'000 GW

✓ PV on the right growth path

- Wind needs to be pushed faster
- Batteries growing strongly



MESSAGE 1

TRANSITION IS NECESSARY, POSSIBLE AND COST EFFECTICE. NO DESPAIR, BUT ACTION !

IS THE ENERGY TRANSITION SUSTAINABLE?

- Material availability, extraction ?
- Energy Payback time?
- CO₂ emission (and others)?
- Biodiversity?









18





Volume 7, Issue 11, 15 November 2023, Pages 2408-2413

Commentary

Energy transition will require substantially less mining than the current fossil system

<u>Joey Nijnens</u>¹ $\stackrel{2}{\searrow}$ $\stackrel{1}{\boxtimes}$, <u>Paul Behrens</u>², <u>Oscar Kraan</u>¹, <u>Benjamin Sprecher</u>³, <u>René Kleijn</u>²

Show more 🗸

19



- 5 trillions per year health costs
- 4-7 millions death
- Climate warming
- (and Putin)



MATERIAL USAGE FOR ELECTRICAL NICO LITHIUM BATTERIES

kg/vehicle



EPFL = csem

MATERIAL USAGE: EXEMPLE CUPPER

PV: 1 TW/year at 3 Cu Tons/MW
Windturbines: 500 GW/year at 2 Tons/MW, with Al grid connection)
Electric cars: 80 millions cars at 60 kg Cu, with charging station

 \rightarrow 3 MT /year

 \rightarrow 1 MT/year

 \rightarrow 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!

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





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.











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

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





Si:B n-Si Ag g) IBC n⁺ FSF SiO₂/SiN_y

p-Si

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







- 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



PURIFIED SILICON USAGE PER WATT FOR SILICON PV MODULES



From 17 to 2 g/W in 2022 in 20 years thanks to:

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

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 per W of modules electricity required



PV MODULE CO₂ FOOTPRINT



Made with:

EU electricity 400 gCO₂/W

China coal electricity ~600 gCO₂/W

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 O CELLS

Reported

< 300 gCO₂/W

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



EPFL

" CSem

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 $CO_2/W \rightarrow 3$ GT
 - 40 TW of PV at 300 g CO₂/W \rightarrow 12 GT
 - 2 billions batteries of 50 kWh at 60 kg CO₂/kWh → 6 GT
 - Systems, grid update.... \rightarrow 6 GT

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



Using a few percent (\sim 3%) of our remaining carbon budget is required to build the objects and infrastructure that will save on CO₂



MESSAGE 2.

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



PHOTOVOLTAICS AND ENERGY SYSTEMS IN NEUCHÂTEL

CONTRACTS WITH OVER 40 COMPANIES ALONG THE CHAIN







:: CSem

2800 M² OF INFRASTRUCTURE AND 120 PEOPLE.....



PRODUCTION FORECAST AND PREDICTIVE MAINTENANCE FOR ENERGY ASSETS WITH CSEM AI

Wind-Log[™] ■BKW

Machine learning from Big data sets and physical knowledge of systems

Applicability

- Wind Hydro
- Solar
- Heat pumps
- Cooling
- Batteries





BATTERY RESEARCH ACTIVITIES: FROM MATERIALS TO SYSTEMS

Cell

modelling

SoX estimators

based on EIS

Validation vs.

measurements

Coatings and Interfaces





- Thin-film coatings
- Wet coatings
- Interface functionalization

Solid-state electrolytes



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

Cell/module testing



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

Post mortem analyses



- Opening
- Imaging
- Modelling



-

es BMS prototyping



- CMS concept
- Active balancing
- EIS integration



- Frequency regulation
- Power trading optimization
- V2G analysis

35

NOT ALL BATTERIES ARE SAFE.... EXCEPT AT CSEM



CUSTOMER AND PARTNER NETWORK



NEW ORGINAL SMARTWIRE TECHNOLOGY AND SILICON HETEROJUNCTION PROCESSES AT GW LEVELS



- Developped with CSEM/EPFL
- SWISS MEYER BURGER only solar cell producer in Europe with > 1 GW
- Multi GW planned
- All R&D, product development and part of production equipement made in Switzerland

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



CELLS ABOVE 30%? FOR THE FIRST TIME PEROVSKITE/SILICON TANDEM SOLAR CELL BY EPFL/CSEM





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

CSEM Upscaling ongoing And 29.6% certified on 25 cm² Innosuisse

Xin Yu Chin et al. Science, 2023

Turkey et al. Artuk et al.



Sahli et al. Nature materials 2018



DEEP-TECH CLEAN



Octopus II: A key tool from an IMT start-up for high efficiency c-Si cells and bottom cells

Metrology for cell and modules

PASAN SA, Neuenburg

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

New Production lines in Thun

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











:: 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

> hftu Höhere Fachschule Luzern

Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra

ETAT DE FRIBOURG STAAT FREIBURG

Swiss Federal Office of Energy SFOE







Prix solaire Suisse 2019 With support of RÉPUBLIQUE ET CANTON DE NEUCHÂTEL



47





































8 climacy

New high performance costaffordable solutions for Roof or indsutrail building A new company in Bussiny (see talk this afternoon)



Private house Neuchâtel

Courtesy L.E. Perret-Aebi



Private garden Neuchâtel



INNOVATION IN SWITZERLAND



• Deployable PV systems







Agrivoltaics on the move

insolight







VOLTIRIS



Integrated PV to reach the Stratosphere







Light weight customized ultrareliable modules







Strateole: PV solutions for stratospheric balloons









Multiple Applications For terrestrial PV

EPFL «CSem

.... THE T-TOUCH SOLAR CONNECT

METED

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

New York

MESSAGE 3.

AMAZING EVERYTHING YOU CAN DO WITH SOLAR AND CLEANTECH.... SO MUCH HAPPENS IN SWITZERLAND, WITH MANY OPPORTUNITIES

THANKS FOR YOUR ATTENTION

Schweizerische Eidgenossenschaft

Confédération suisse Confederazione Svizzera Confederaziun svizra

 Swiss National Science Foundation



EPFL

You want to sponsor our activiti Dont's hesitate to contact us !

christophe.ballif@csem.ch Christophe.ballif@epfl.ch

MORE CLEANTEC

Climacy



Energy Systems : reduce consumption & increase local renewable production

SMART HEATING

SMART BOILER

HABITAT & JARDIN 2023

S **Č** L A R S P L I T



Install The application will allow you to follow the lifferent stages of the installation of the sola panels at all times

Next

THE APP FOR INSTALLERS

SOLARSPLIT is a mobile application that brings together and supports users in the process of installing and crowdfunding their solar panels.

APP STORE PLAY STORE



Probably the Cleanest Car Ever!

For a Circular Economic Model Worldwide.





QUALITY GAS ANALYZERS

Best in Class Real Time Gas Inference Analyzers









:: CSeM







CONTROLLED REFRIGERATION

Make the management of your refrigeration installations easier and more flexible



NOVATON CORPORATE PROFILE CLEAN TECHNOLOGIES, POSITIVE AQUACULTURE

