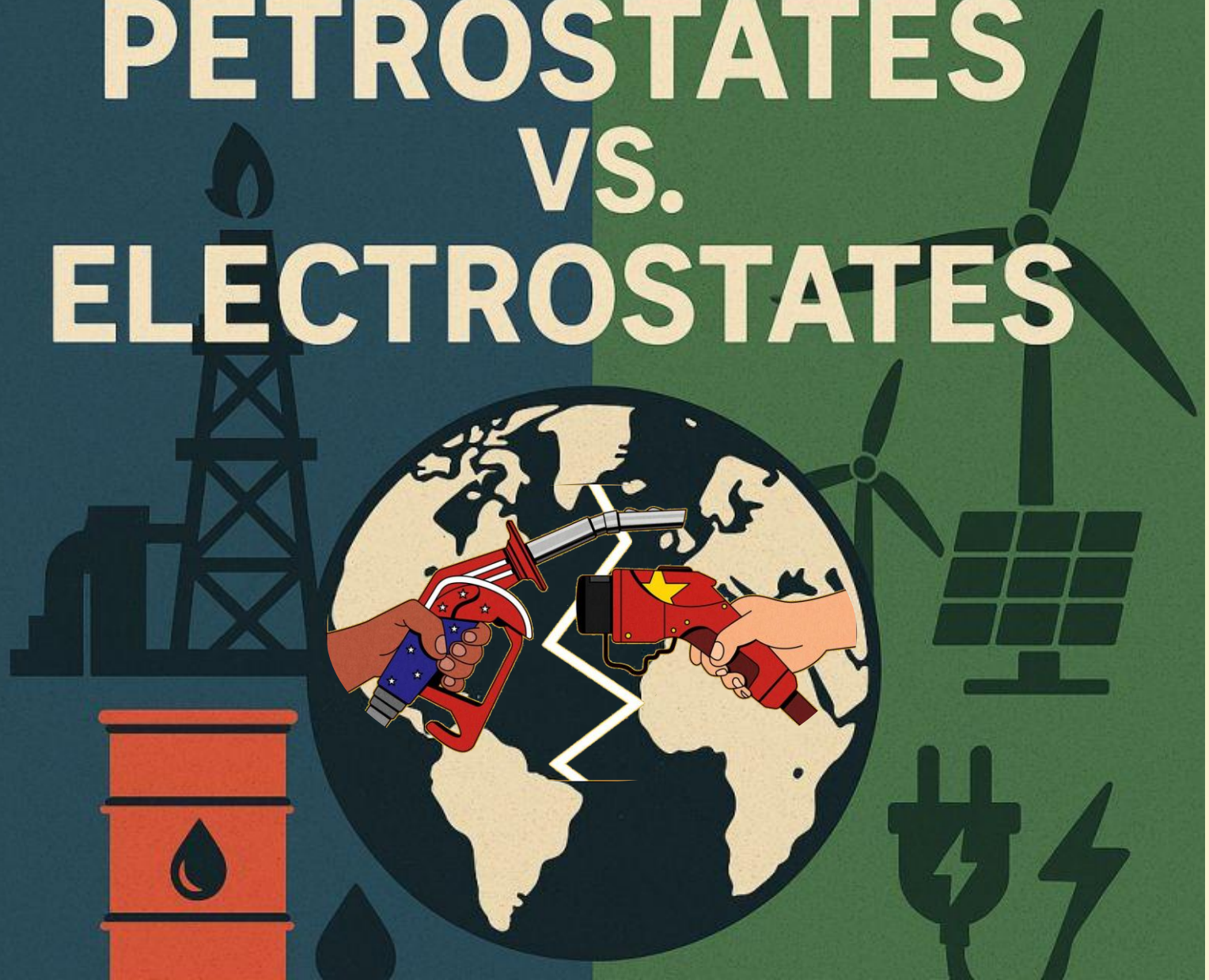
PETROSTATES VS. ELECTROSTATES

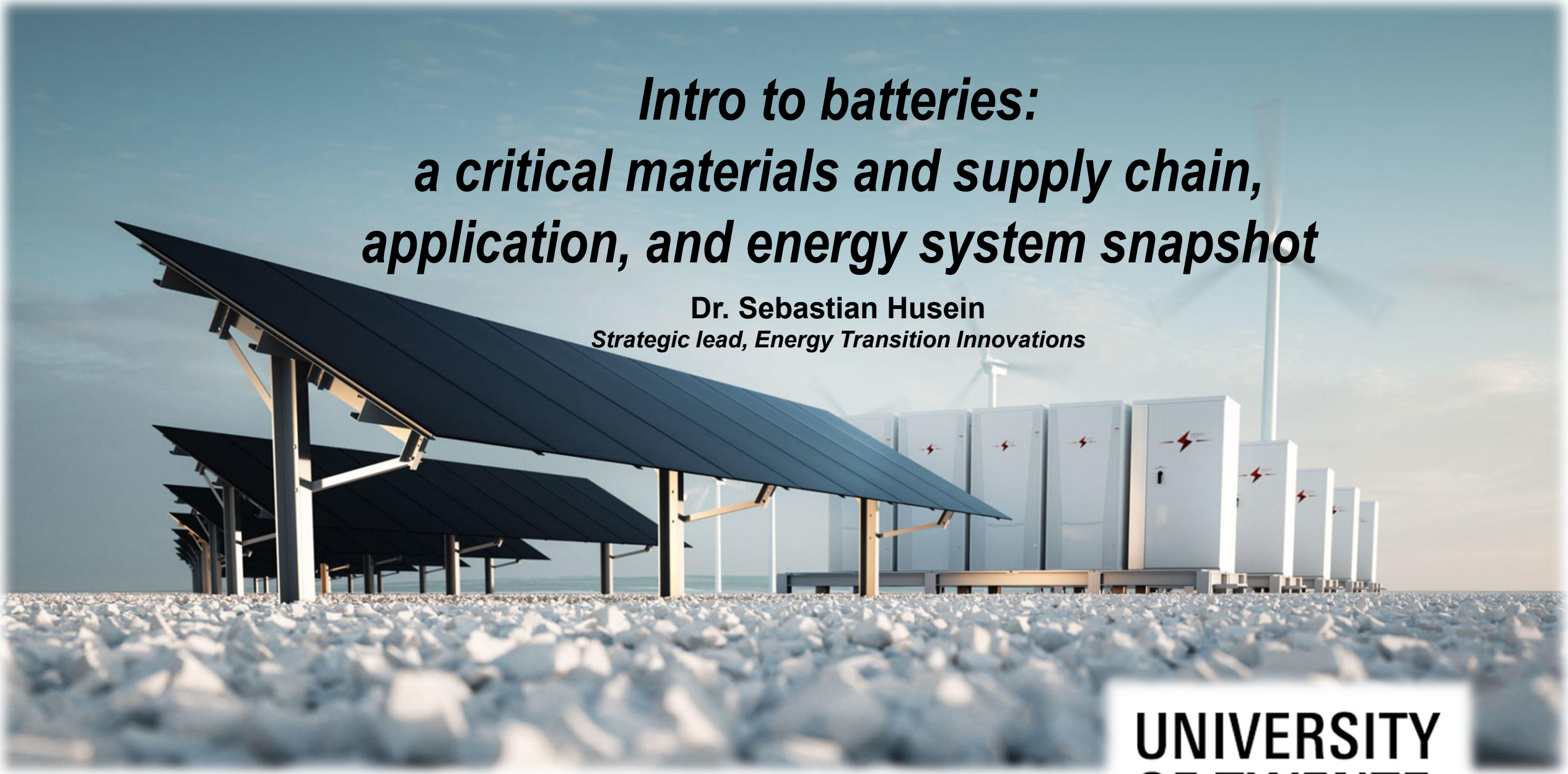


THE NEW JOULE ORDER

SECURITY-DRIVEN ENERGY TRANSITION



ECONOMICS-DRIVEN ENERGY TRANSITION



Intro to batteries: a critical materials and supply chain, application, and energy system snapshot

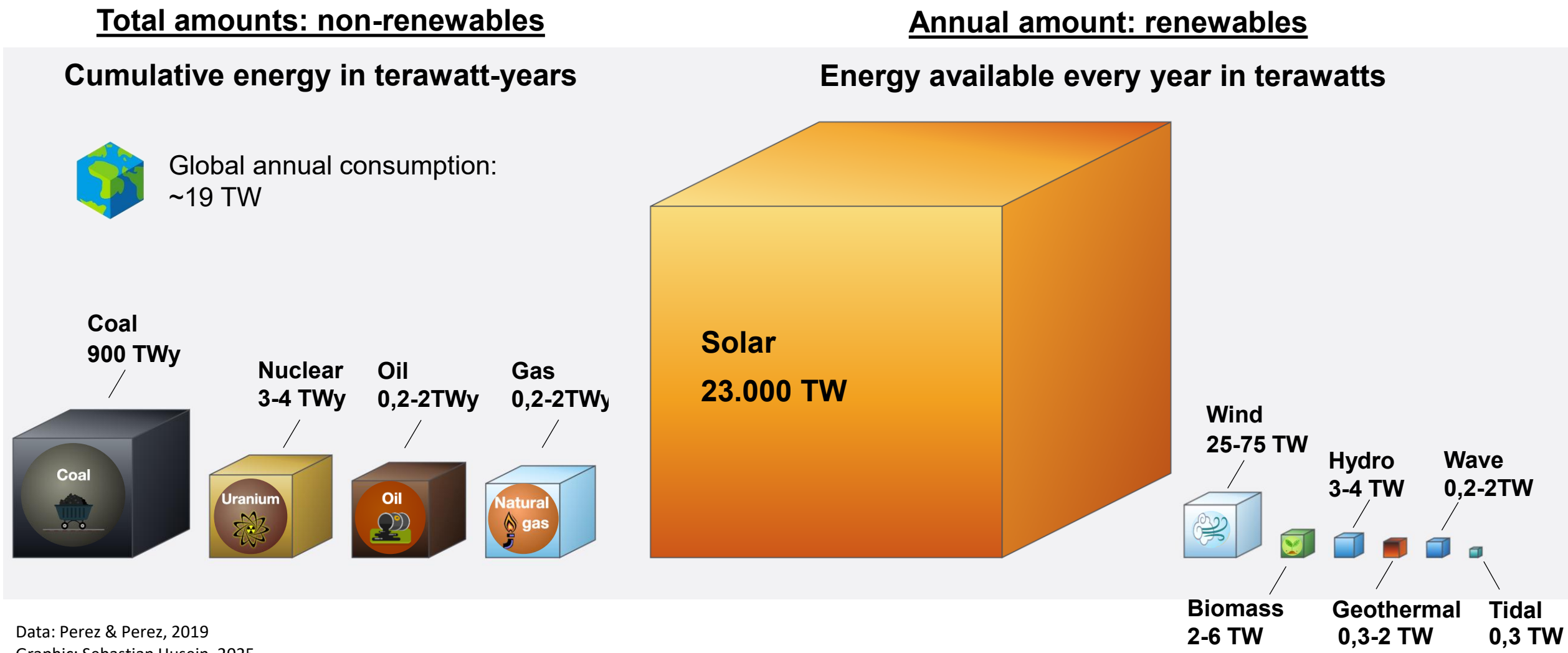
Dr. Sebastian Husein
Strategic lead, Energy Transition Innovations

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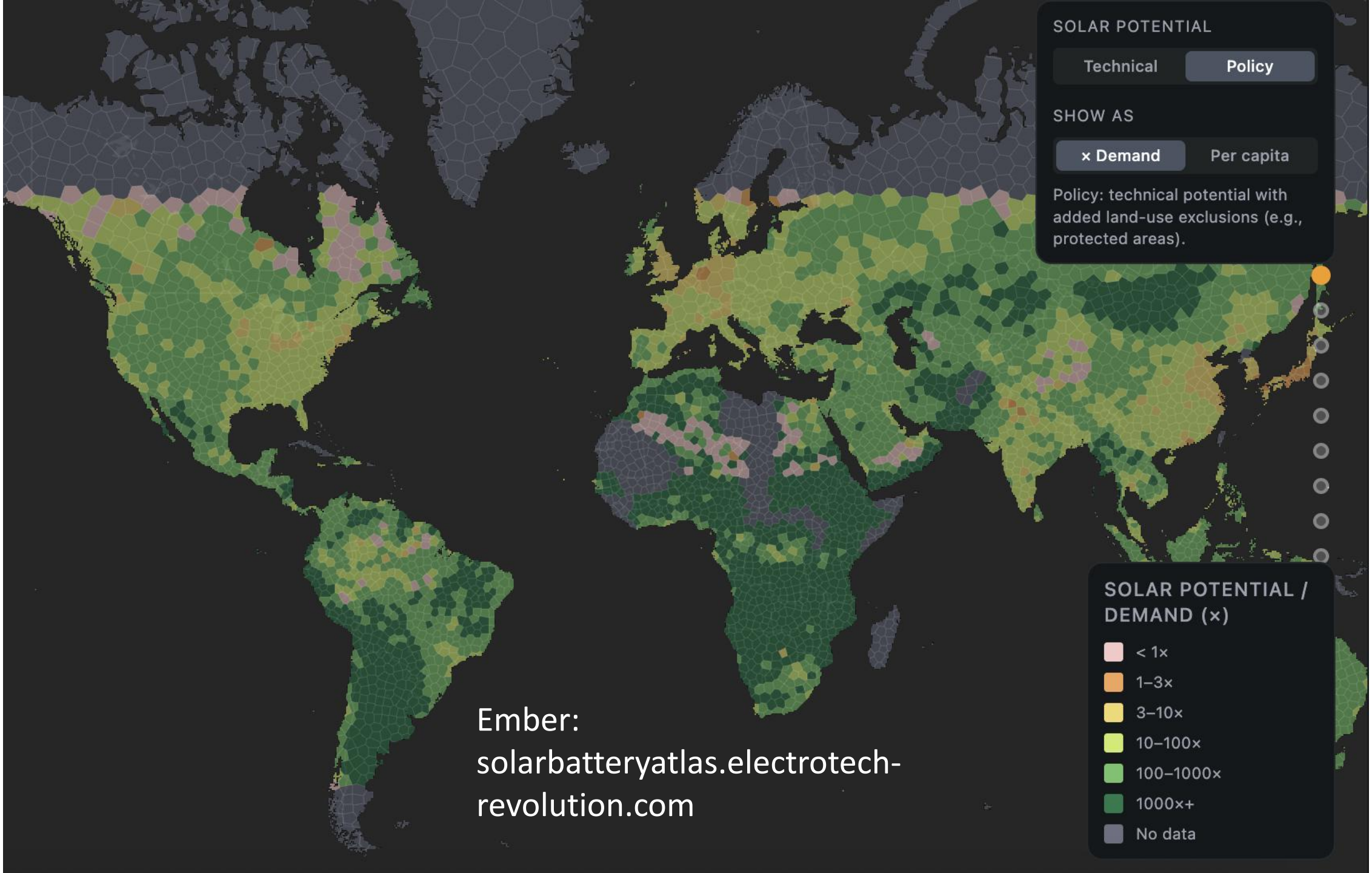
UNIVERSITY OF TWENTE. | BATTERY CENTRE

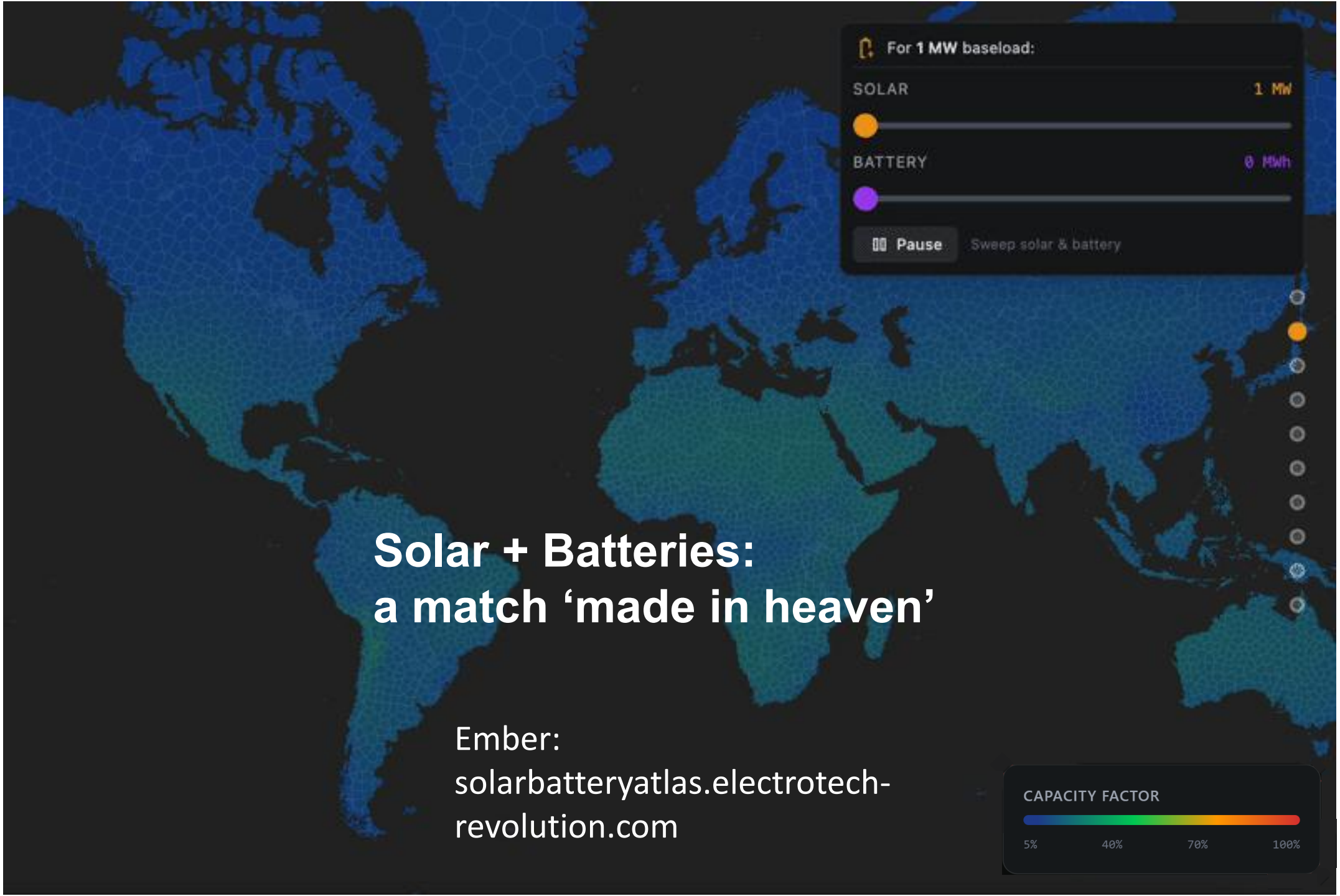
s.s.t.husein@utwente.nl
utwente.nl/energy

Comparing energy source amounts



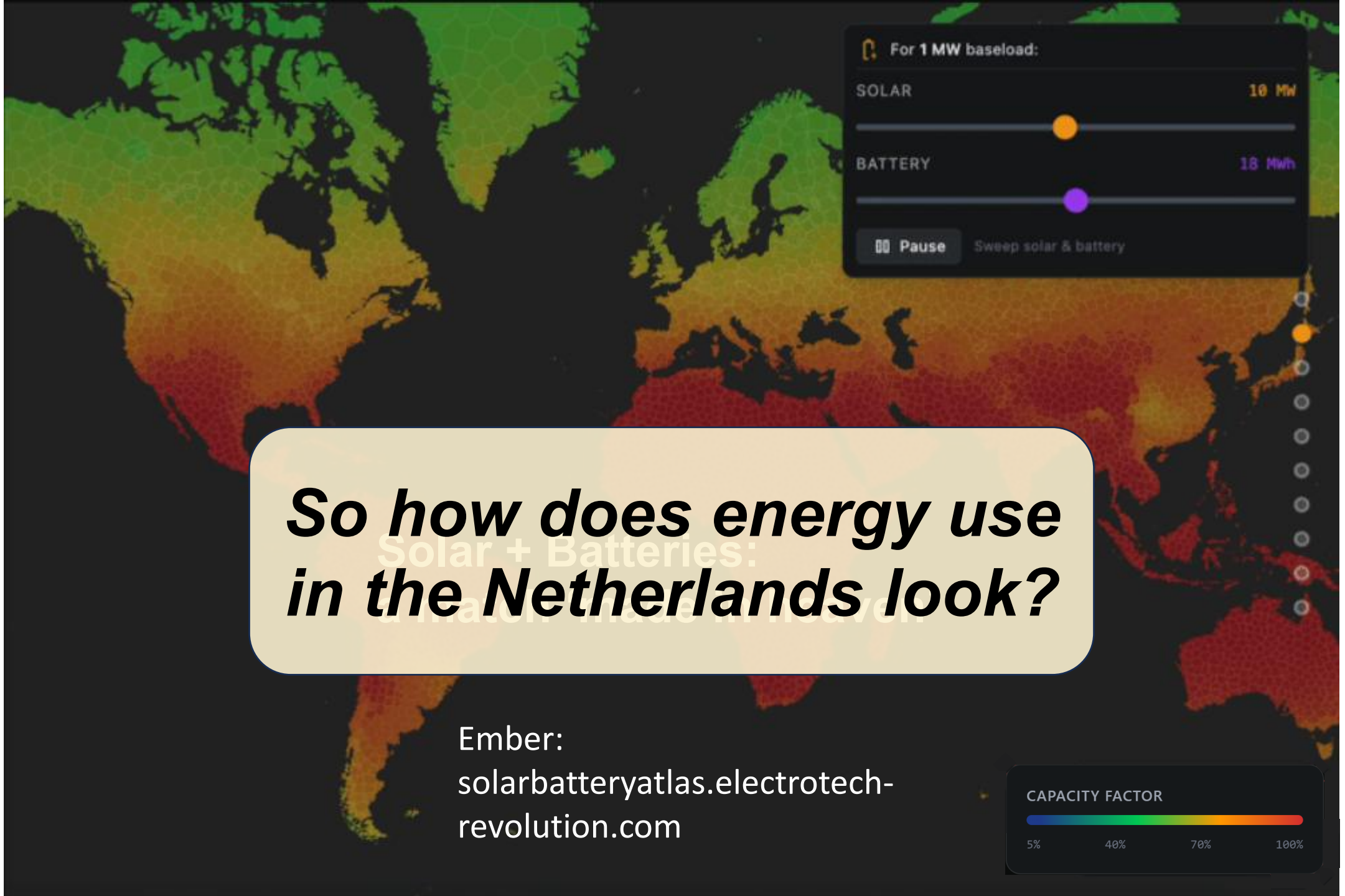
Data: Perez & Perez, 2019
Graphic: Sebastian Husein, 2025


SOLAR POTENTIAL
Technical
Policy
SHOW AS
× Demand
Per capita
Policy: technical potential with added land-use exclusions (e.g., protected areas).
SOLAR POTENTIAL / DEMAND (×)
< 1×
1–3×
3–10×
10–100×
100–1000×
1000×+
No data
Ember:
solarbatteryatlas.electrotech-revolution.com



Solar + Batteries: a match ‘made in heaven’

Ember: solarbatteryatlas.electrotech-revolution.com



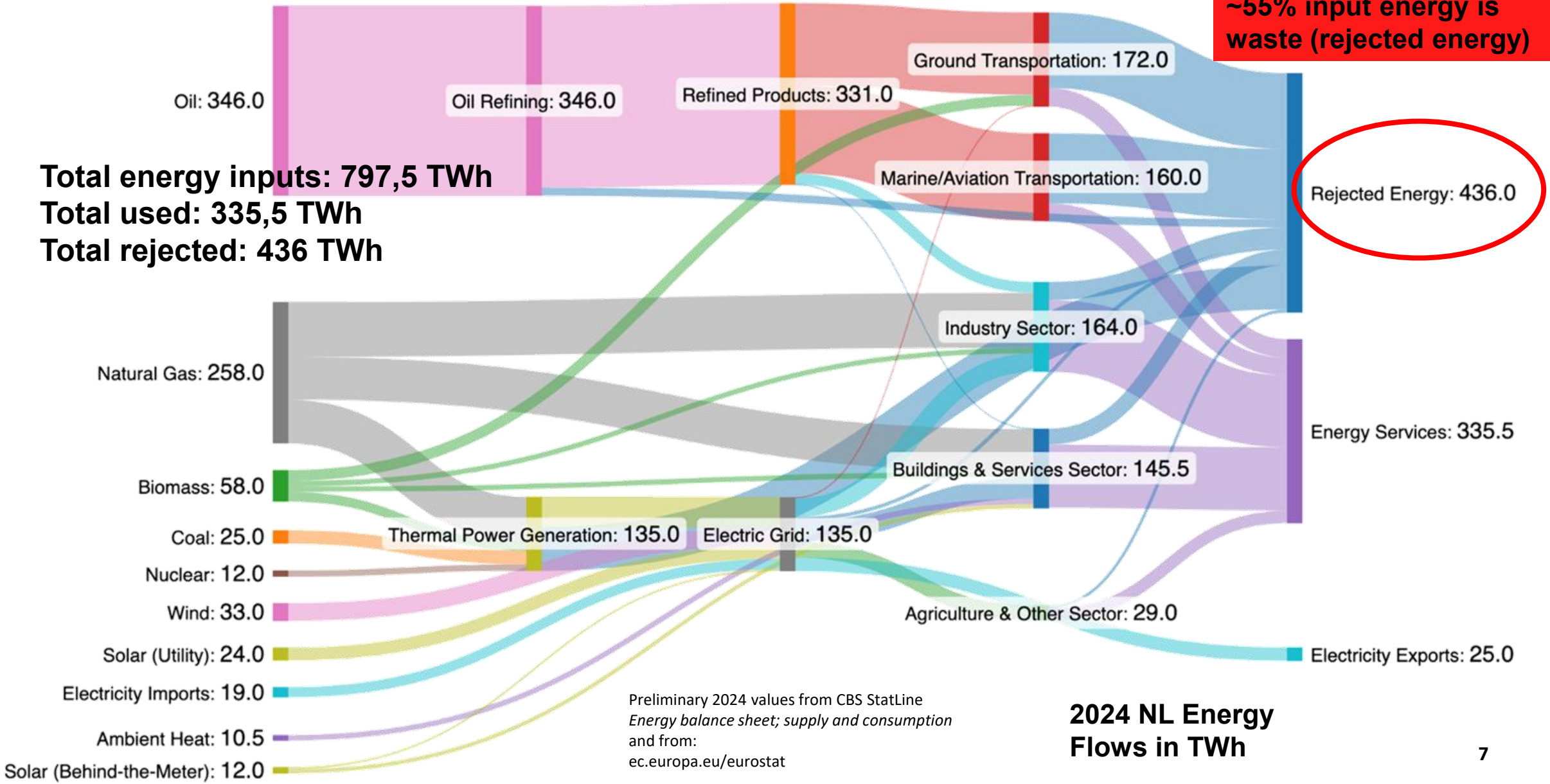
So how does energy use in the Netherlands look?

Ember:
solarbatteryatlas.electrotech-revolution.com

NL Energy Flow (TWh): still a large electrification potential

~55% input energy is waste (rejected energy)

Total energy inputs: 797,5 TWh
Total used: 335,5 TWh
Total rejected: 436 TWh

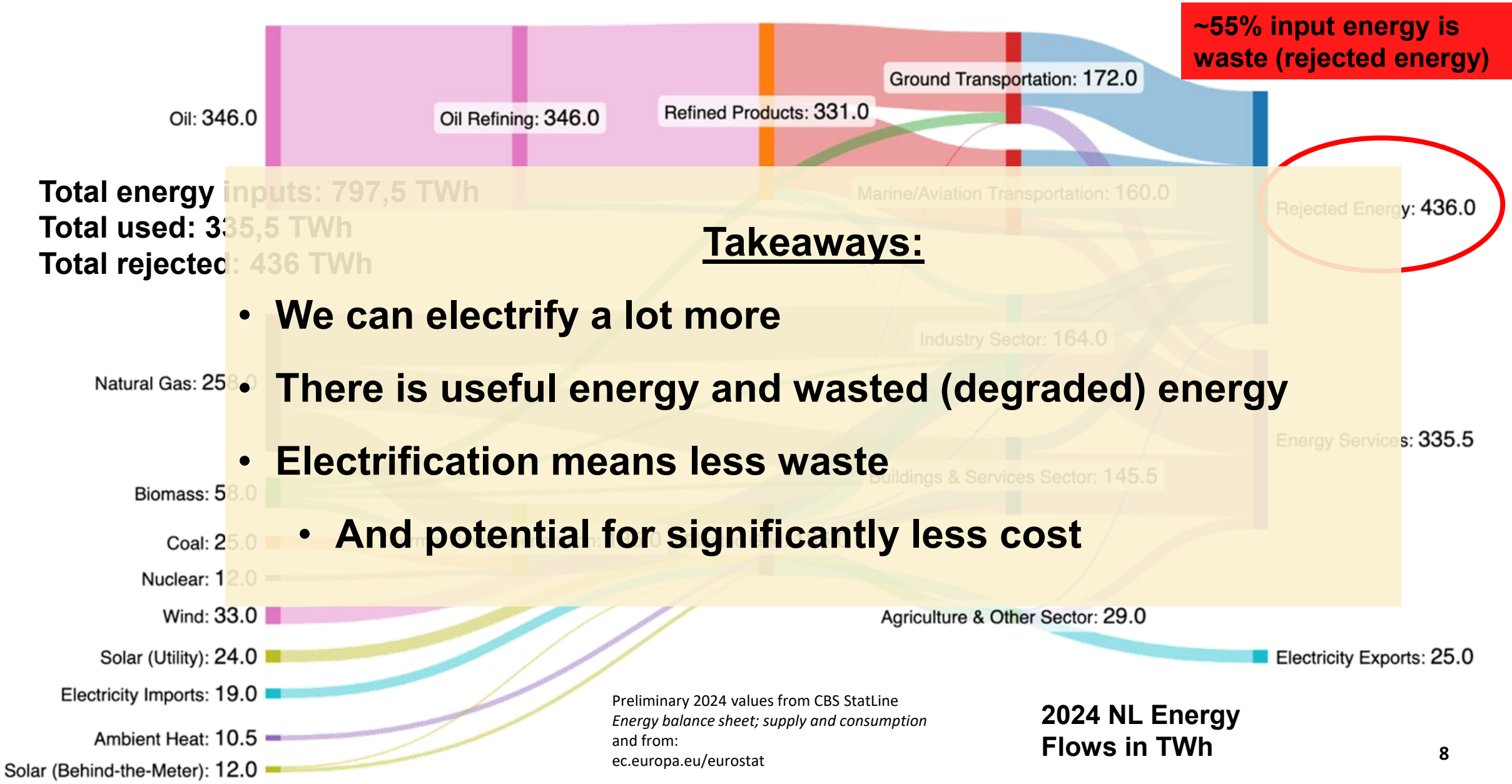


Preliminary 2024 values from CBS StatLine
Energy balance sheet; supply and consumption
and from:
ec.europa.eu/eurostat

2024 NL Energy Flows in TWh

NL Energy Flow (TWh): still a large electrification potential

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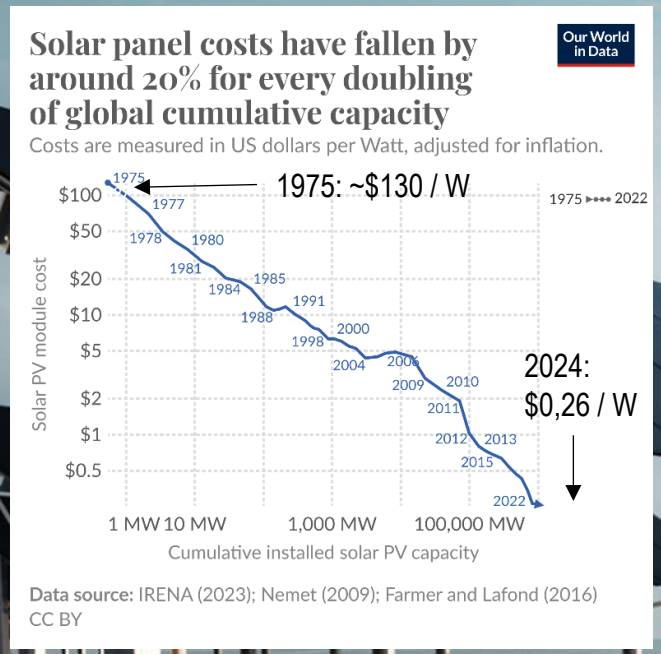
Takeaways:

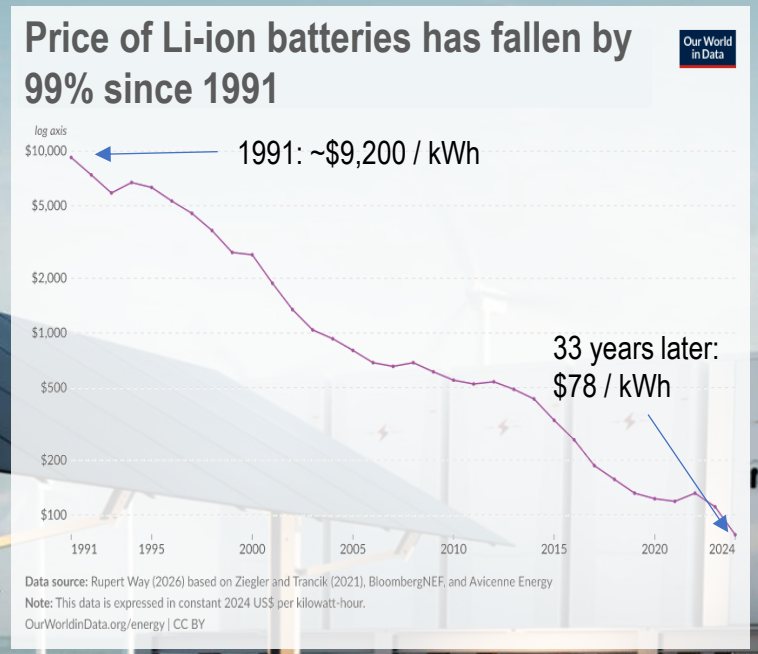
- **We can electrify a lot more**
- **There is useful energy and wasted (degraded) energy**
- **Electrification means less waste**
  - **And potential for significantly less cost**

Preliminary 2024 values from CBS StatLine
Energy balance sheet; supply and consumption
and from:
ec.europa.eu/eurostat

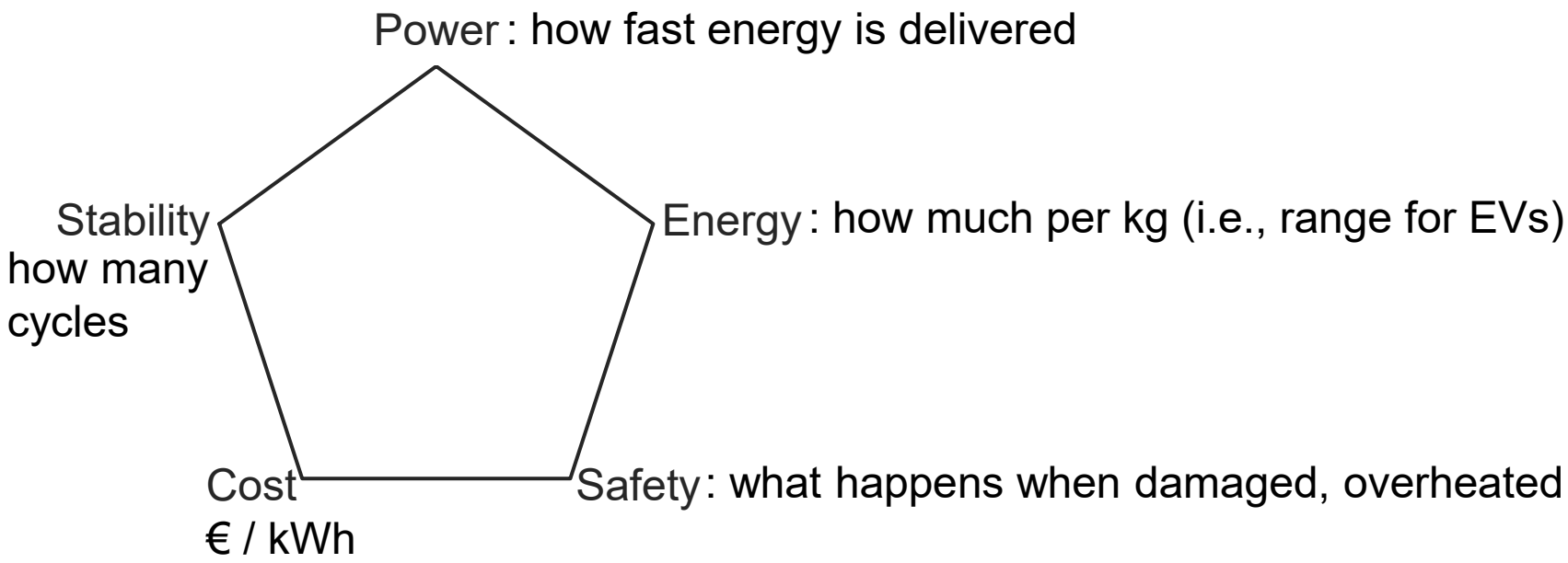
2024 NL Energy Flows in TWh

Cost reductions in solar and batteries



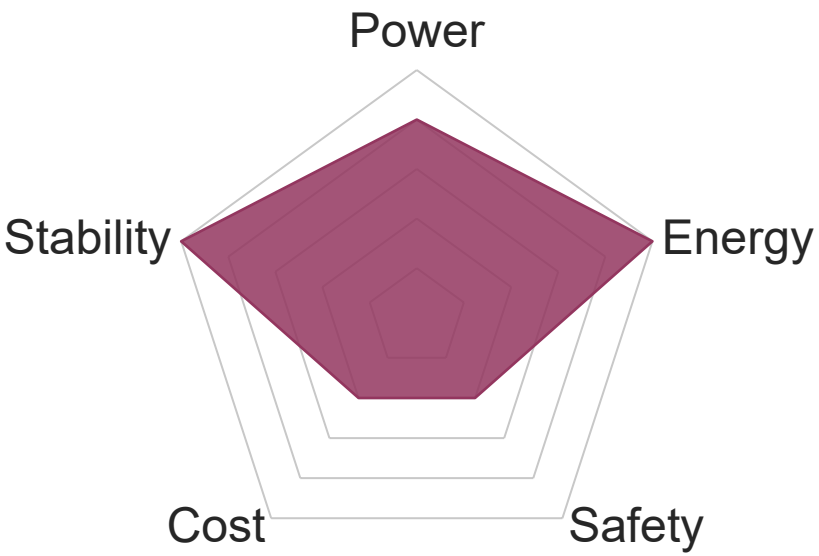


Five metrics for batteries



Five metrics for batteries

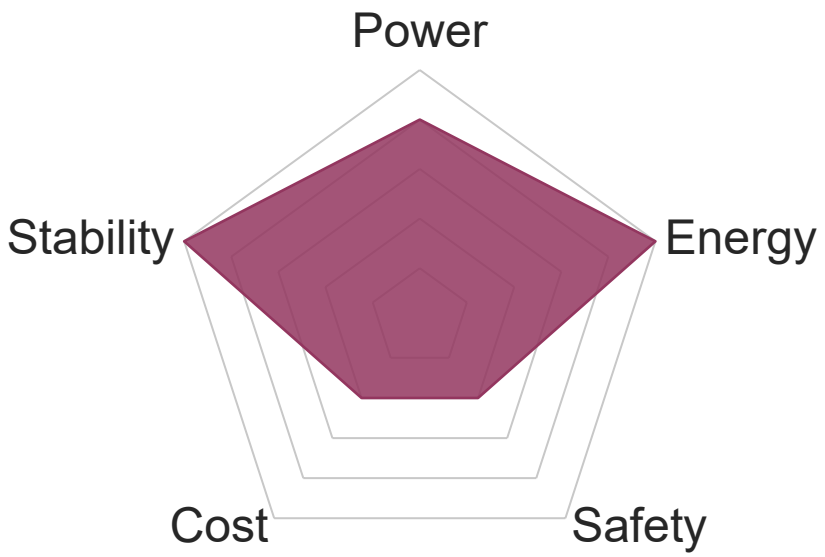
Nickel manganese cobalt (NMC)



Source: Houache et al. (2022), "On the Current and Future Outlook of Battery Chemistries for Electric Vehicles: Mini Review".

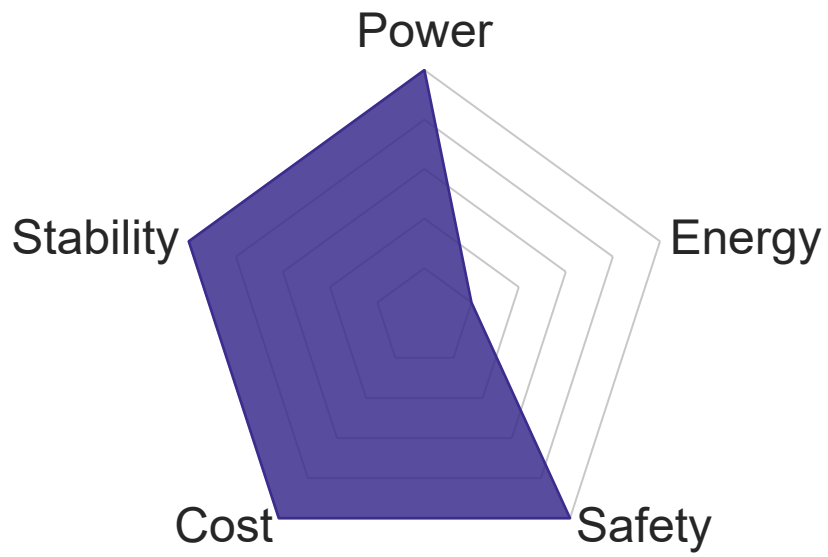
Five metrics for batteries

Nickel manganese cobalt (NMC)



Higher-end & high-performance vehicles

Lithium iron phosphate (LFP)

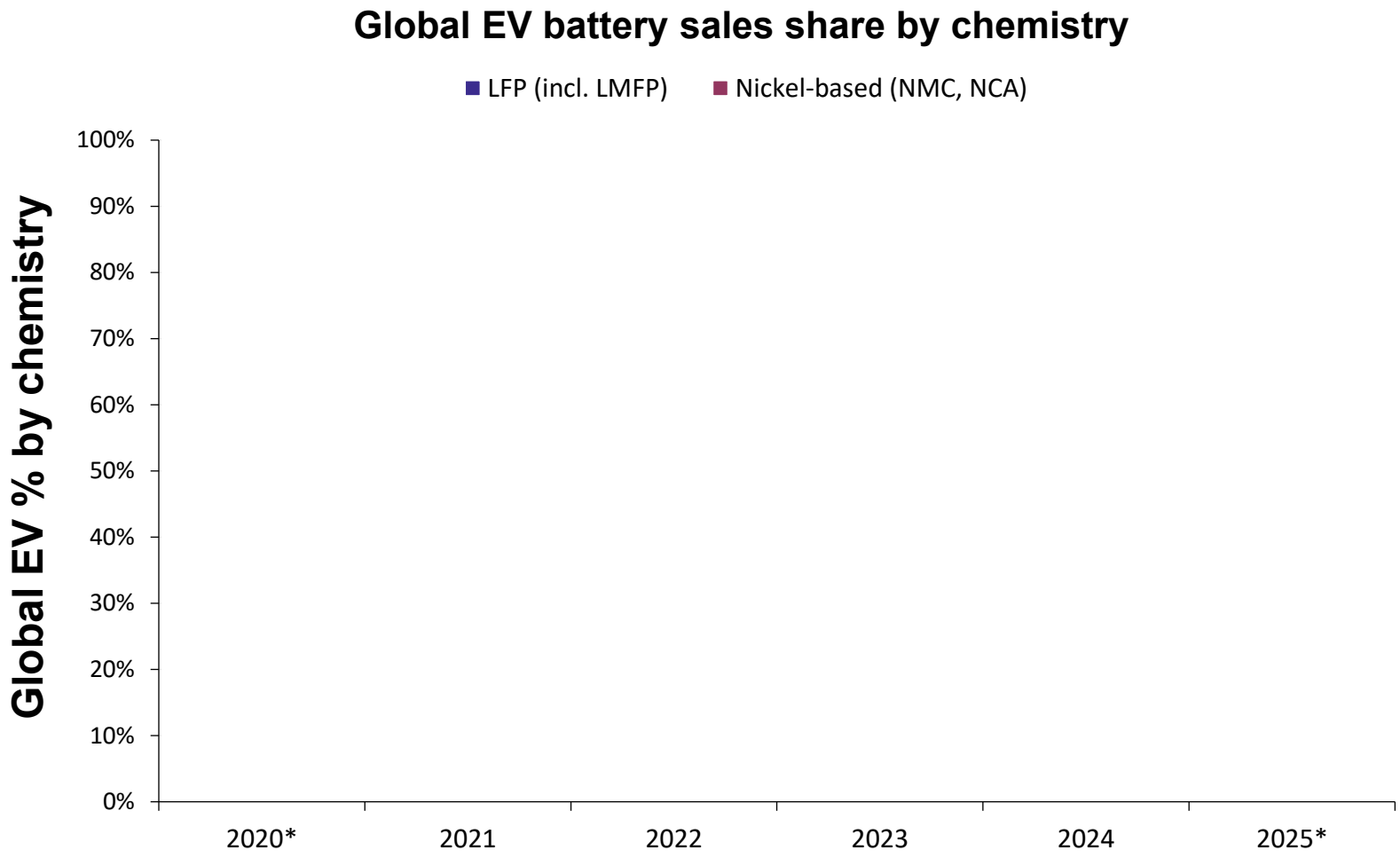


Entry-level & heavy-duty vehicles

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Source: Houache et al. (2022), "On the Current and Future Outlook of Battery Chemistries for Electric Vehicles: Mini Review".

LFP: niche to majority in five years

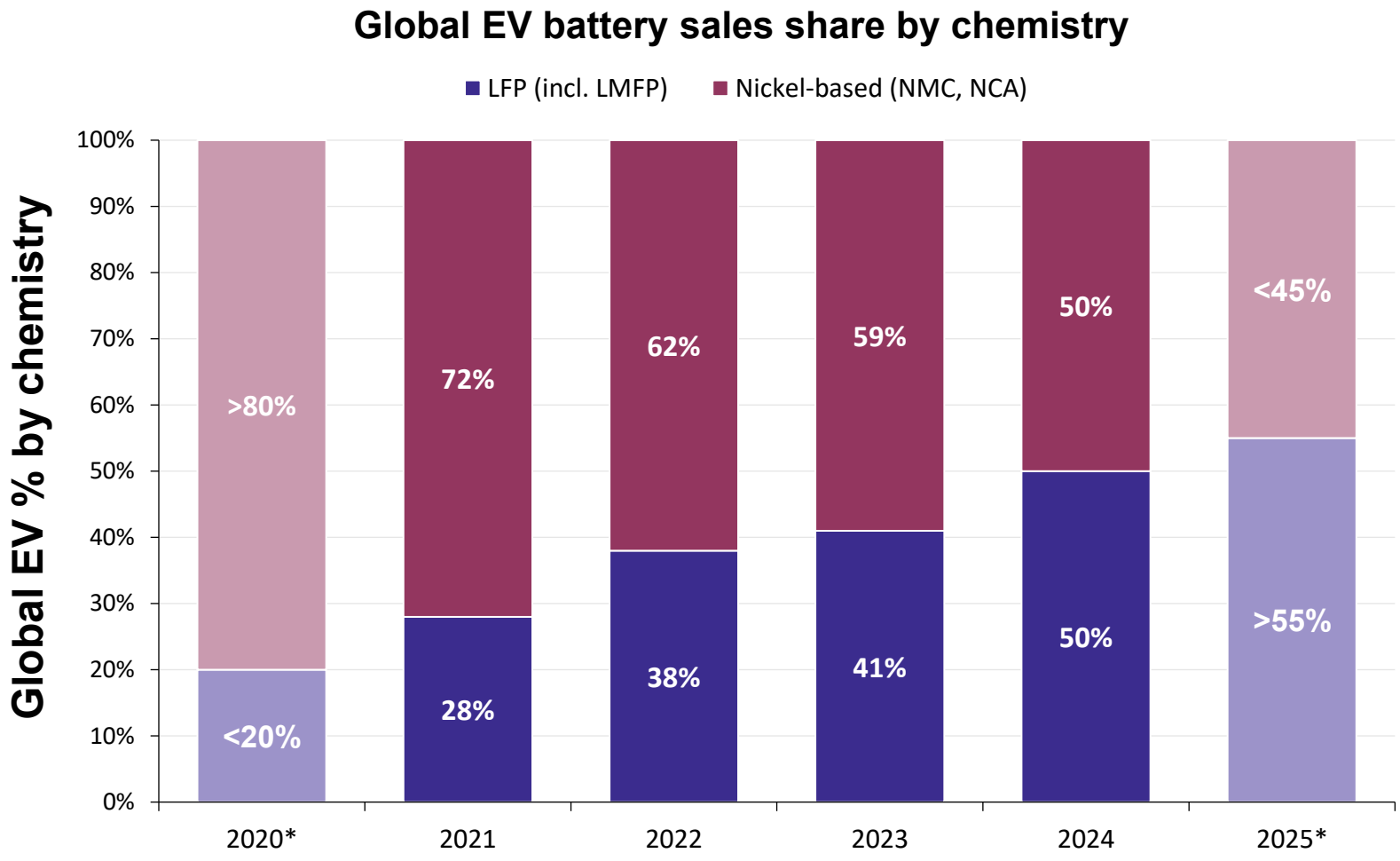


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LFP: niche to majority in five years

- 2020: under 20% LFP
- 2024: half
- 2025: over 55%
- Driven by China
  - 81% LFP in 2025
  - EU still >85% NMC

- Why the switch?



Source: IEA, Global EV Outlook 2024 (2021) and 2025 (2022-2024) charts, World bars: share of battery capacity of new EVs sold, excl. 2/3-wheelers; nickel-based = low- + high-nickel NMC and NCA. *2020 and 2025 (lighter bars) are IEA report statements: 2023 LFP was "more than double" 2020; 2025 LFP "over 55%" (GEVO 2026). Licence: CC BY 4.0.

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Chemistry impacts manufacturing

LFP safety

- Larger cells
- Cells ~~→ Modules →~~ Packs

- Pack energy density (LFP) vs. Pack energy density (NMC)

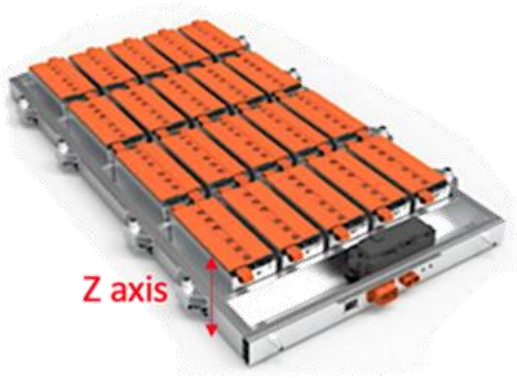
- Chemistry + manufacturing

But also…

- Patents, Ni price (Russia & Ukraine), Chinese subsidies (range), and range anxiety

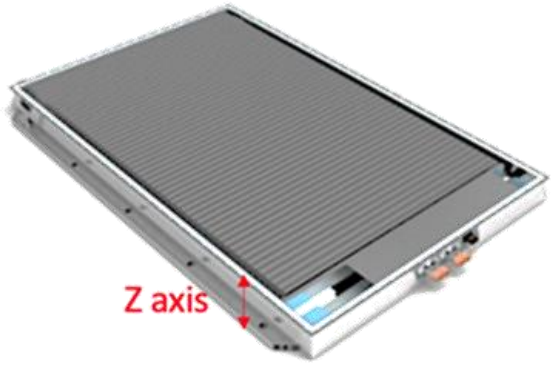
But:

- EU EVs are still >85% NMC
  - Long-term contracts with S. Korea



Low space utilization

Battery pack with modules



High space utilization

Battery pack without modules

Volta Foundation: next gen battery pack design (2020)



LG Energy Solution

SAMSUNG

SK on

Where do materials come from?

Cathode active material

Li ion batteries

Where it's done:

Who owns it:

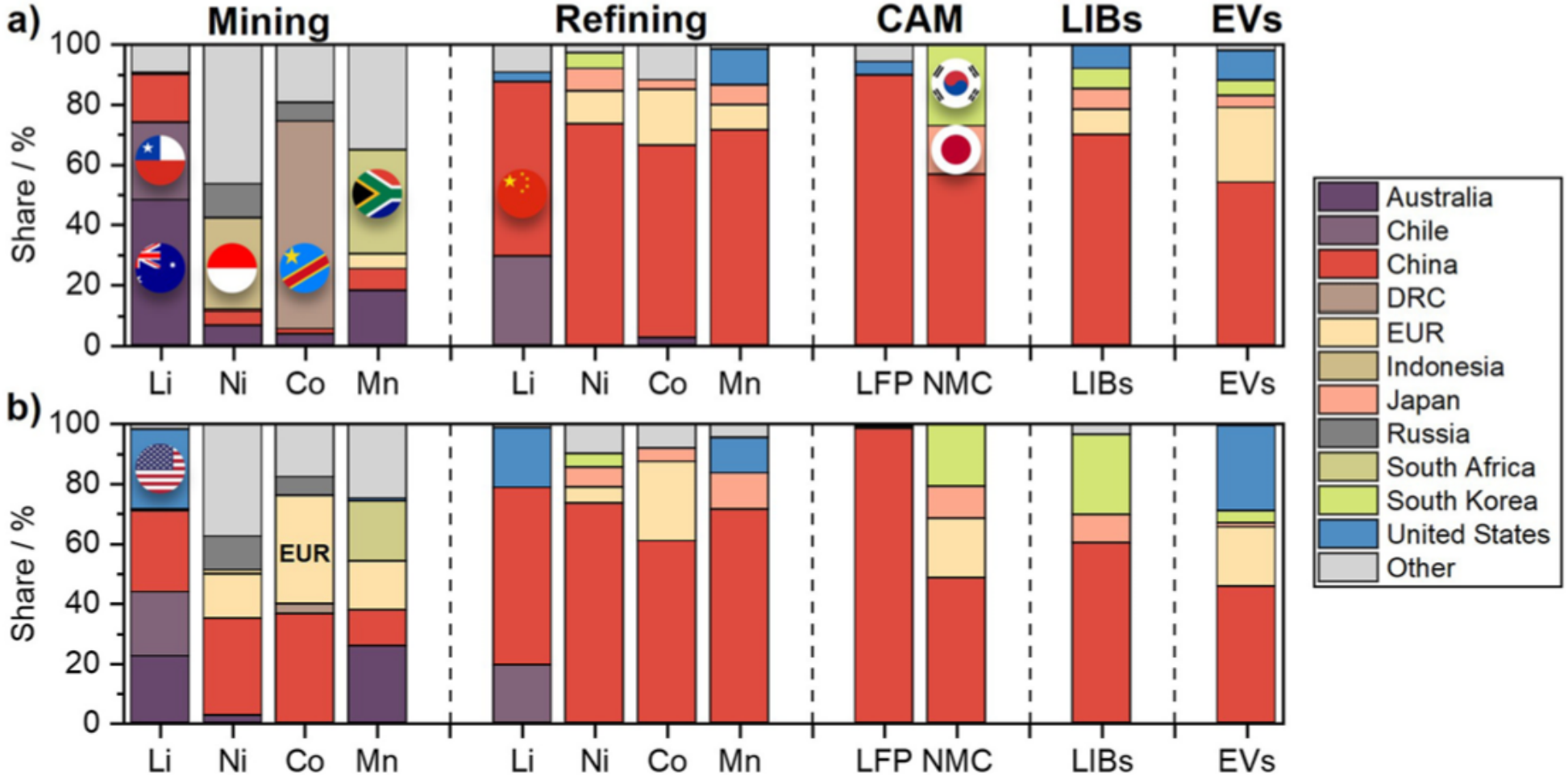
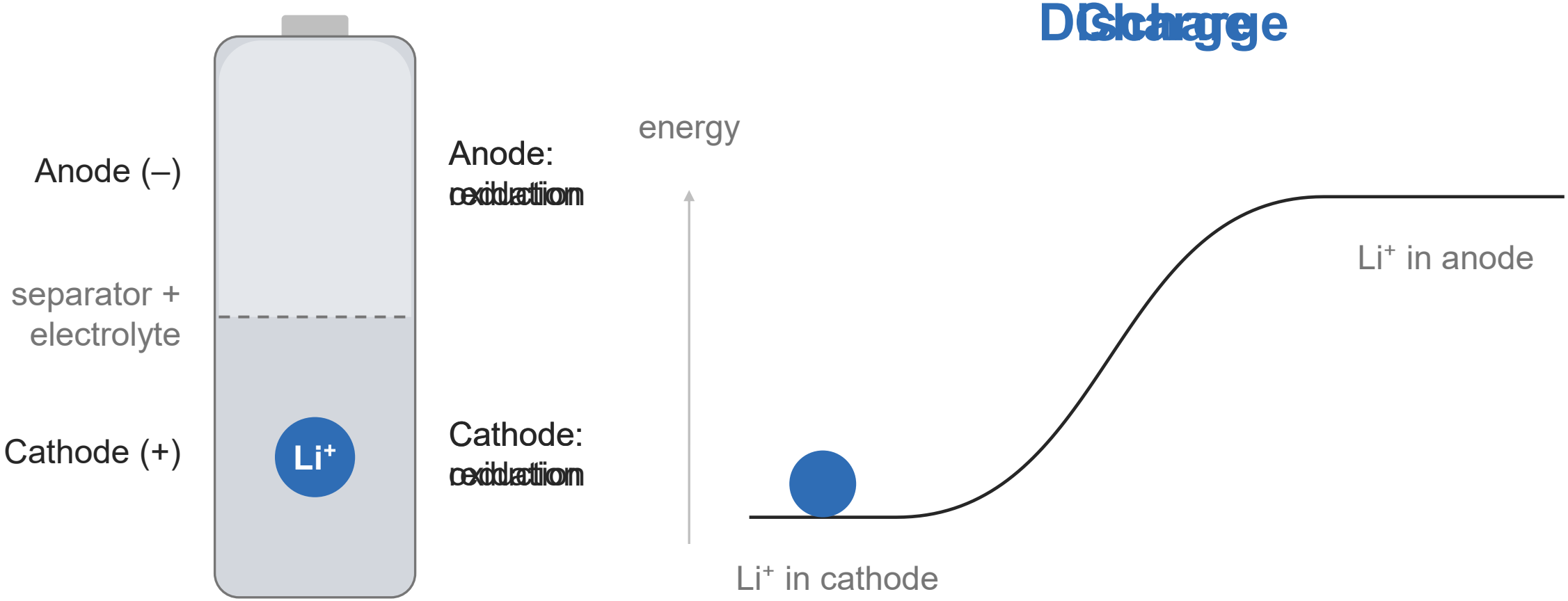


Fig. 1. a) Geographical distribution (revisualized from Cheng et al.) [29], and **b)** Ownership distribution of the LIB supply chain.

T. Greitemeijer et al., "China's hold on the lithium-ion battery supply chain: Prospects for competitive growth and sovereign control." (2025) J. Power Sources Advances

Battery Fundamentals:
the components & what they do, in brief

Charging = pushing lithium uphill



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Three components and the five metrics



Anode — Power, Energy

Stores the lithium when charged. Sets how fast you can charge.

Electrolyte — Safety, Stability

Transports the ions. Sets safety and operating temperature range.

Cathode — Energy, Cost

Provides the lithium. Sets most of the voltage and the cost.

This is a very simplified view. In real cells, there are trade-offs in the metrics.

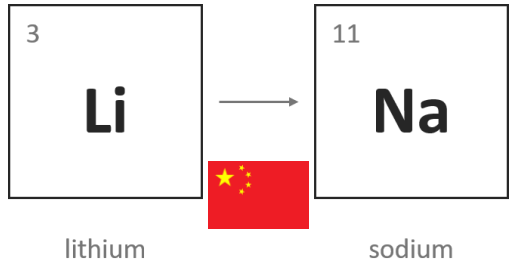
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What's coming in the next years (what's here…)

Cathode	Manganese added to LFP (LMFP)	Energy
	Sodium-ion cathodes	Cost
Anode	Hard carbon for sodium-ion	Cost
	Silicon blended into graphite	Energy
Electrolyte	Semi-solid now, solid-state later	Safety, Energy

*Shirley Meng group estimates

Sodium ion batteries: swap the chemistry, keep the factory



What's coming in the next years (what's here…)

Cathode

Manganese added to LFP (LMFP) — Energy

Sodium-ion cathodes — Cost

Anode

Hard carbon for sodium-ion — Cost

Silicon blended into graphite — Energy

Electrolyte

Semi-solid now, solid-state later — Safety — Energy

But we're only 1%-2% of the way for 2050:

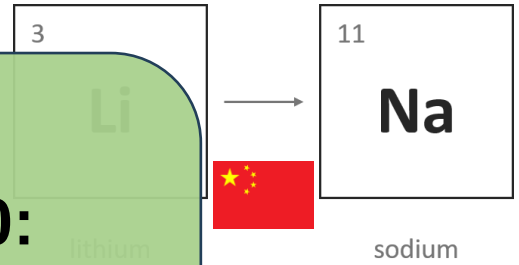
200-300 TWh batteries needed in 2050*

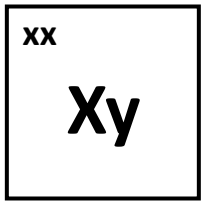
vs.

a few TWh on the road or as stationary storage today

*Shirley Meng group estimates

Sodium ion batteries: swap the chemistry, keep the factory





Metal air? LiS? Flow batteries?

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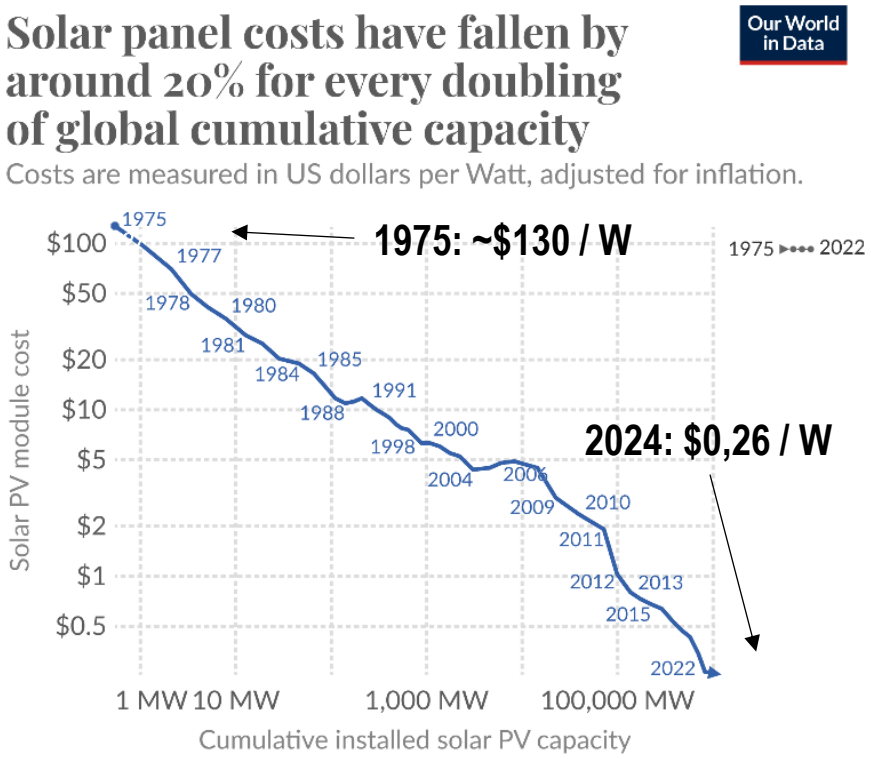
"Only 1 in 200 projects are on budget, on time, and actually deliver the promised benefits"

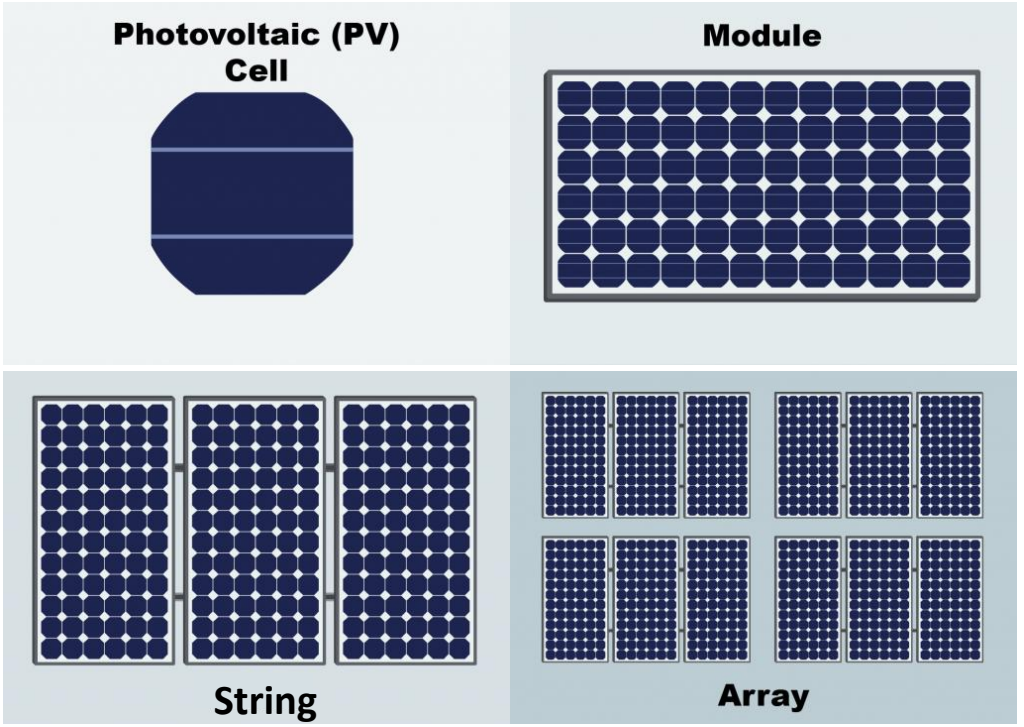
- Analysis of >60.000 global projects, Prof. Bent Flyvbjerg

Flyvbjerg, B., & Gardner, D. (2023). *How big things get done: The surprising factors that determine the fate of every project, from home renovations to space exploration and everything in between*. Signal.**

Modularity for scalability and cost learnings

- Wind: doubled installed capacity 6x in 20 years
- Solar: doubled 10x in 20 years

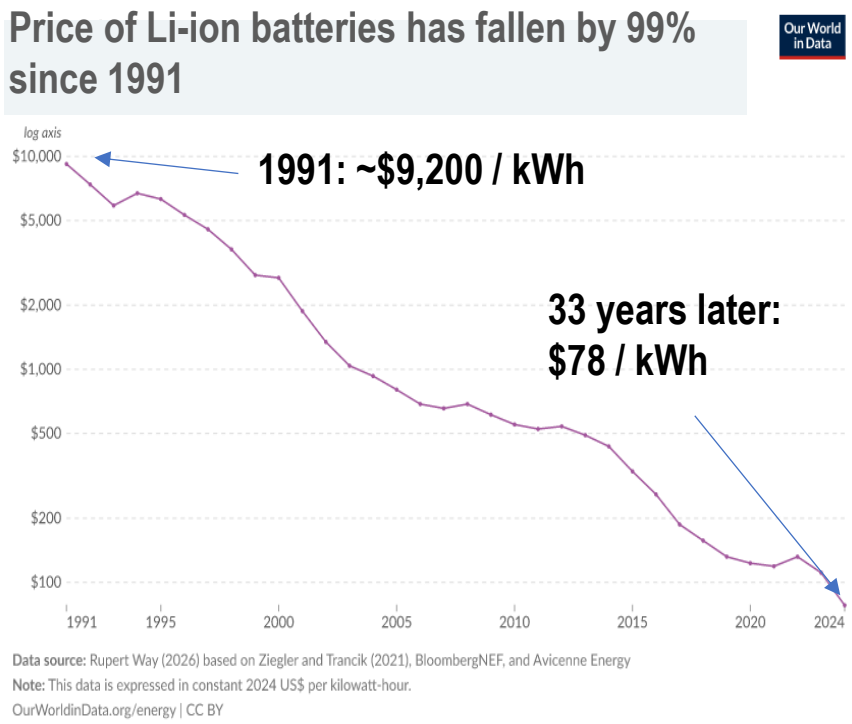


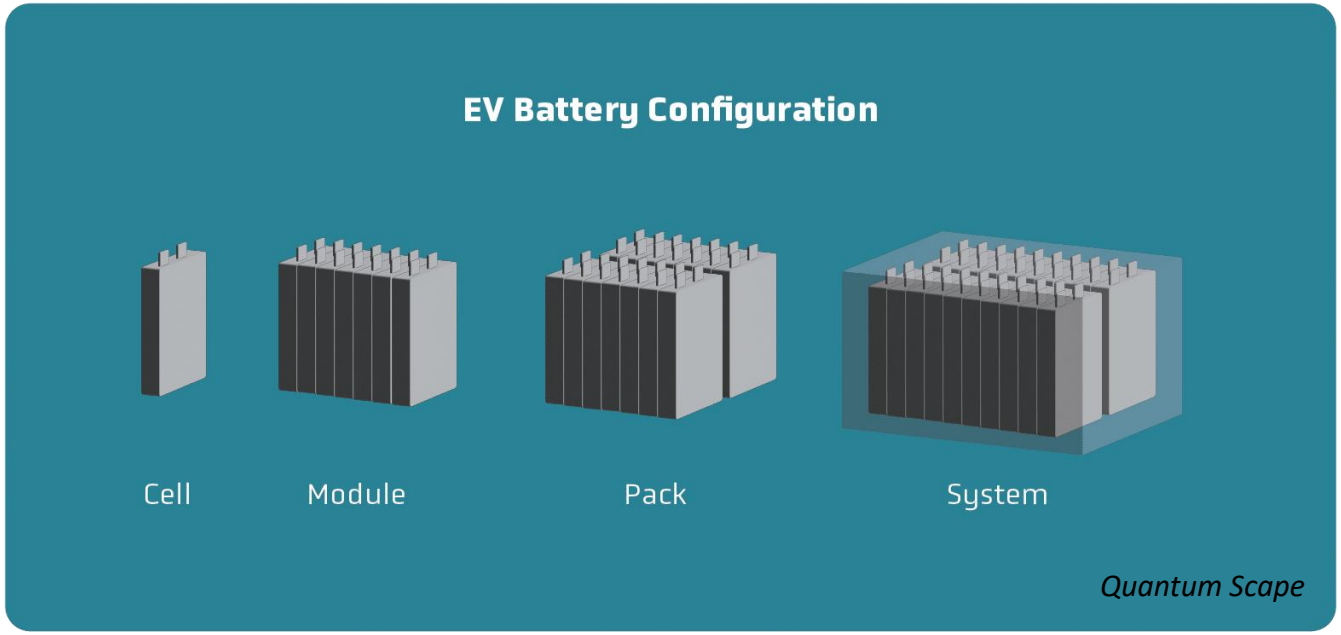


University of Central Florida, Florida Solar Energy Center

Modularity for scalability and cost learnings

- Wind: doubled installed capacity 6x in 20 years
- Solar: doubled 10x in 20 years
- Batteries: doubled 6x in 10 years

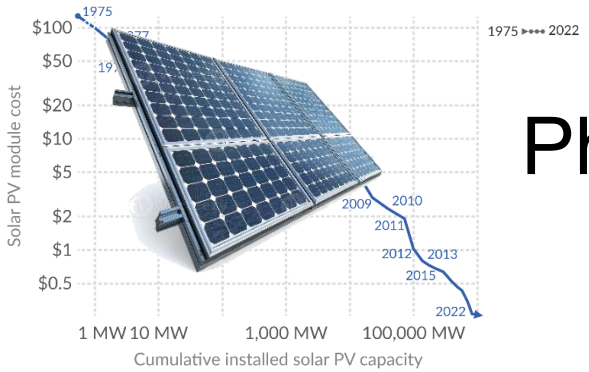




Solar panel costs have fallen by around 20% for every doubling of global cumulative capacity

Our World in Data

Costs are measured in US dollars per Watt, adjusted for inflation.



Data source: IRENA (2023); Nemet (2009); Farmer and Lafond (2016)
CC BY

Photovoltaics

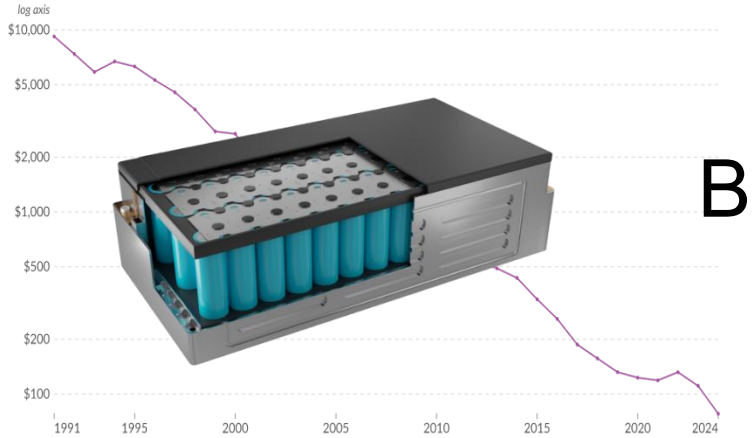
≠

Green H_2



Price of Li-ion batteries has fallen by 99% since 1991

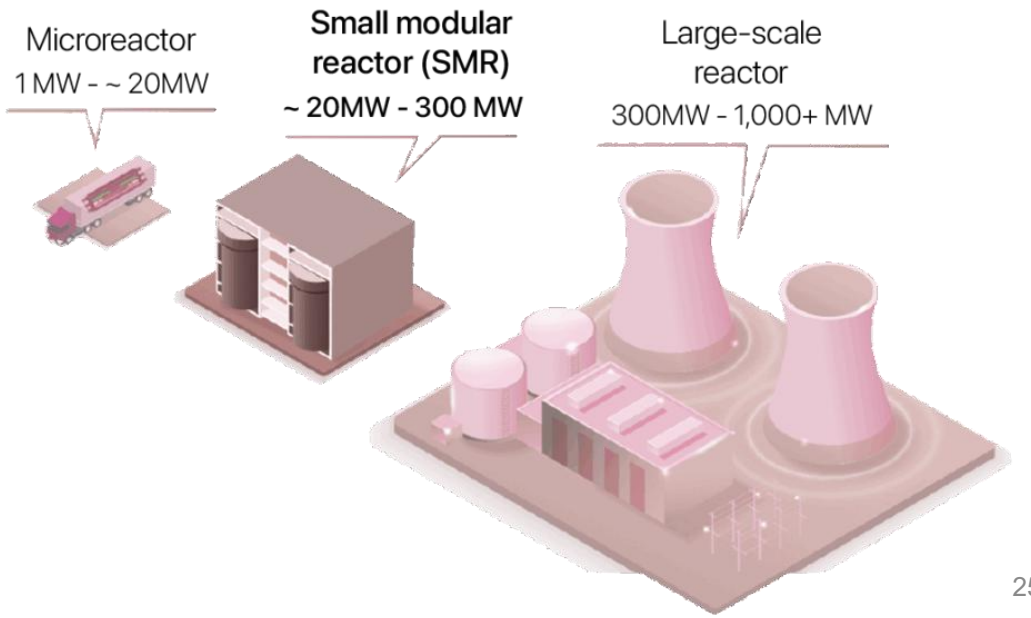
Our World in Data



Data source: Rupert Way (2026) based on Ziegler and Trancik (2021), BloombergNEF, and Avicenne Energy
Note: This data is expressed in constant 2024 US$ per kilowatt-hour.
OurWorldinData.org/energy | CC BY

Batteries

Nuclear



Further reading for Energy Transition perspectives

Carlyle reports by Jeff Curie & James Gutman:

(a) *The New Joule Order* (March 2025)

(b) *The New Martial Plan* (July 2025)

Eye on the Market report by Michael Cembalest, J.P. Morgan

(c) *Fighting Words: The Energy Transition in 2026*

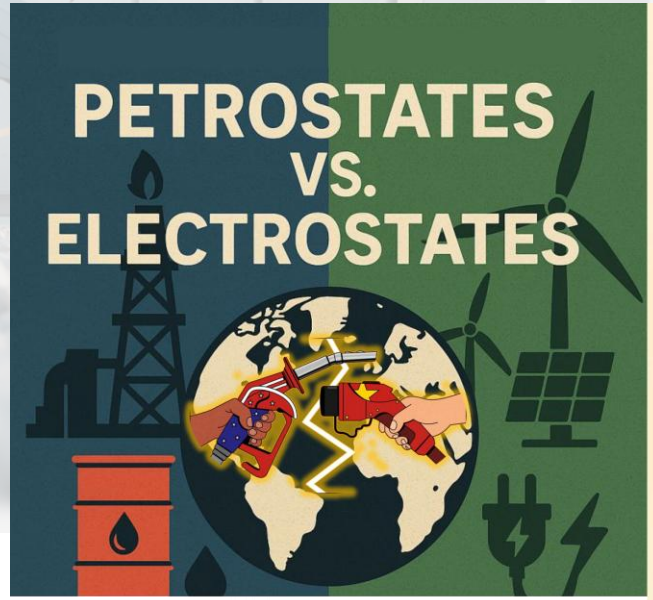
(d) *How Big Things Get Done by Bent Flyvbjerg*

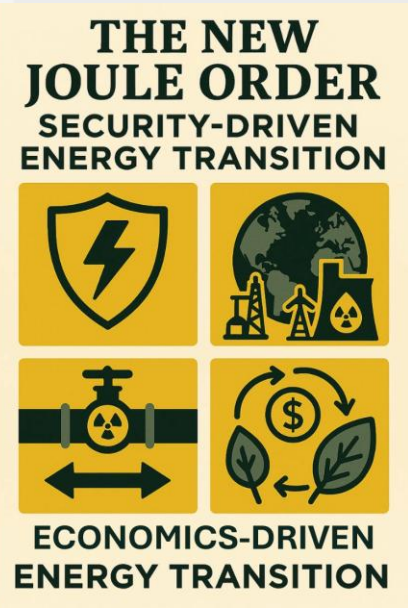
<u>The New Joule Order</u>:

1. **Resilience & Energy Security**
2. **Economics**

…

3. **Sustainability as a bonus**





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Appendix

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Photovolatics

Batteries

≠ H_2

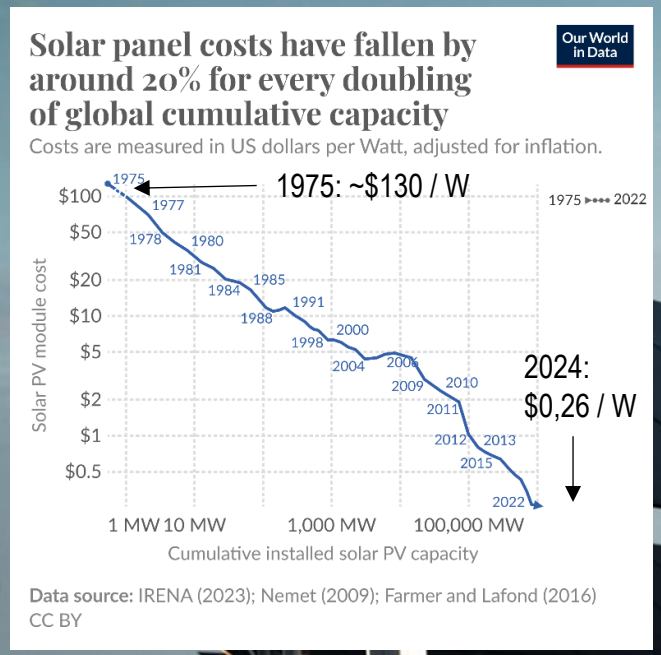


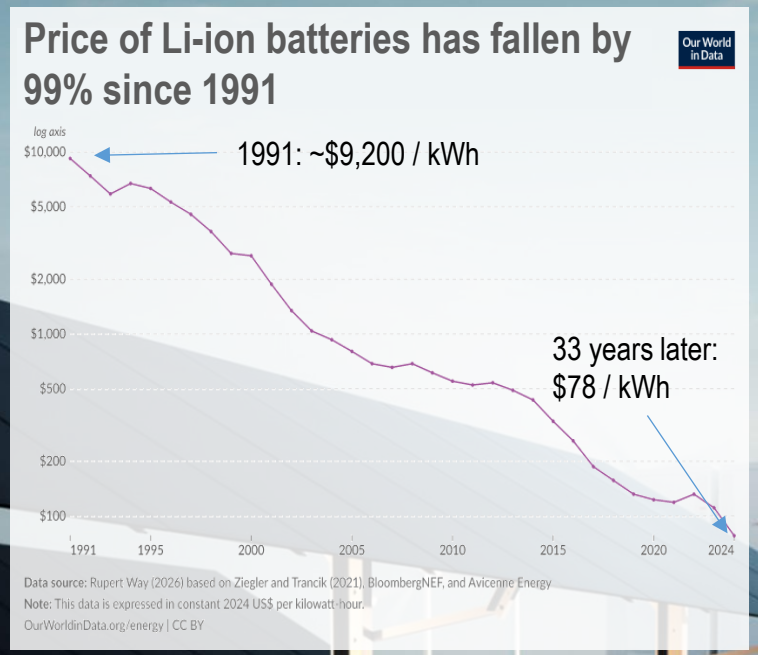
- PV and batteries have dominant, standardized architectures (c-Si; Li-ion variants), which enables massive global scale and automation.
- Electrolysers are industrial machines (AEL ≠ PEM ≠ SOEC ≠ AEM) with no shared manufacturing base and low production volumes.
- Materials don’t scale down in cost (Ir, Ti, Ni, ceramics) → hard floors that PV/battery materials don’t have.
  - PEM, SOEC materials must survive harsh environments, so highly restricted materials choices
  - AEL uses less scarce materials, but is then performance limited (lower current densities, etc.)
- Efficiency improvements don’t shrink Balance Of Systems (BOS), which stays expensive (water treatment, compression, safety systems).
- LCOH is dominated by electricity, so even cheap stacks can’t overcome the €/MWh limit.

Terminology

- BOS: accounting for everything in the system that isn’t the core device (electrolyzer)
- c-Si: crystalline silicon
- Li-ion: lithium ion (e.g., NMC and LFP batteries)

Economies of scale



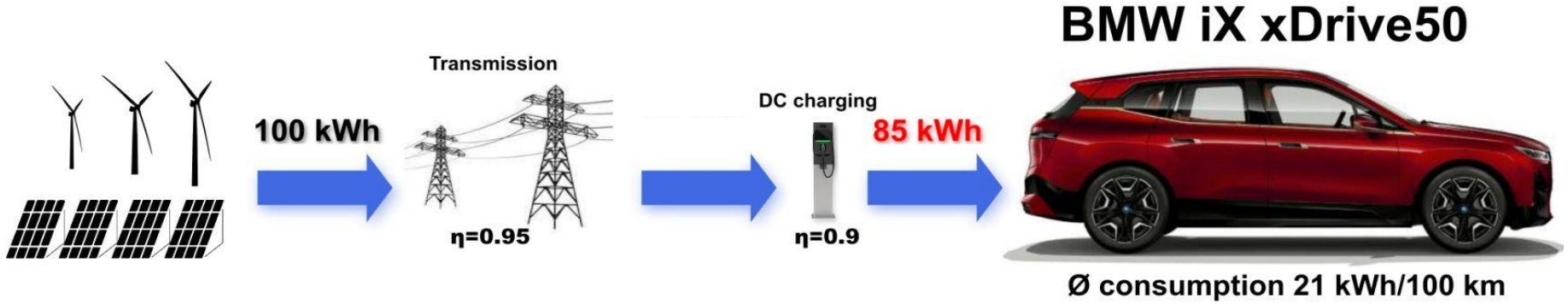


Time to install 1 GW of solar (global total):

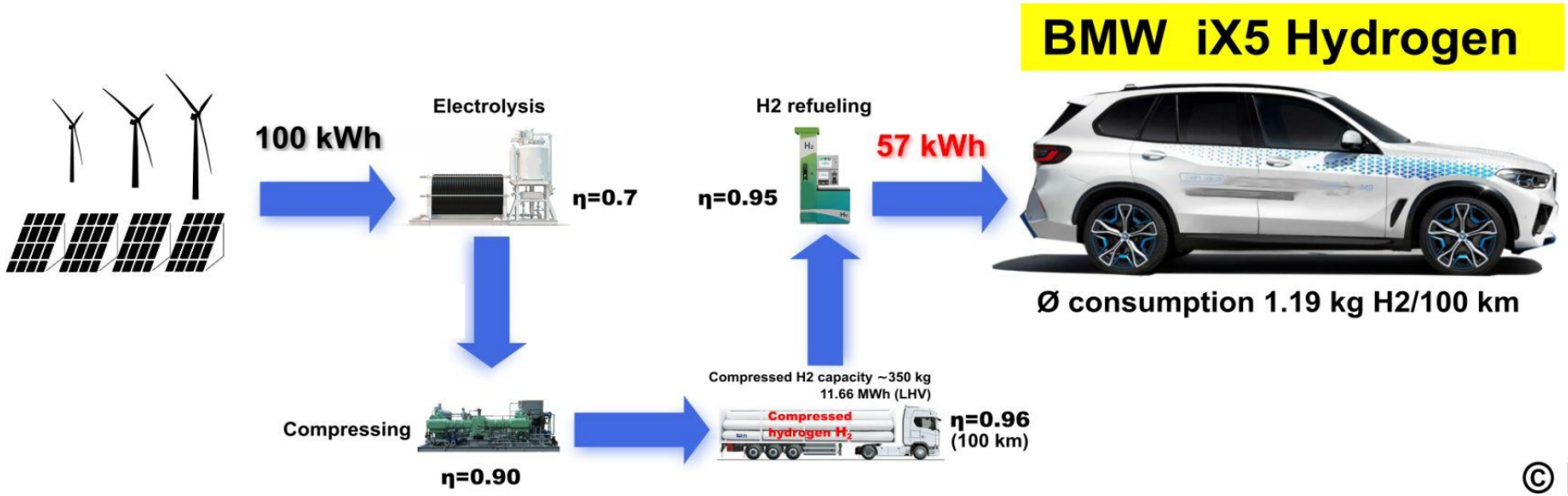
- **2004: 1 year**
- **2010: 1 month**
- **2016: 1 week**
- **2024: <1 day**

Solar has doubled 10x in 20 years.
Wind has doubled 6x in 20 years.
Batteries: doubled 5x in last 8 years

Comparing battery electric vs. hydrogen fuel cell electric cars

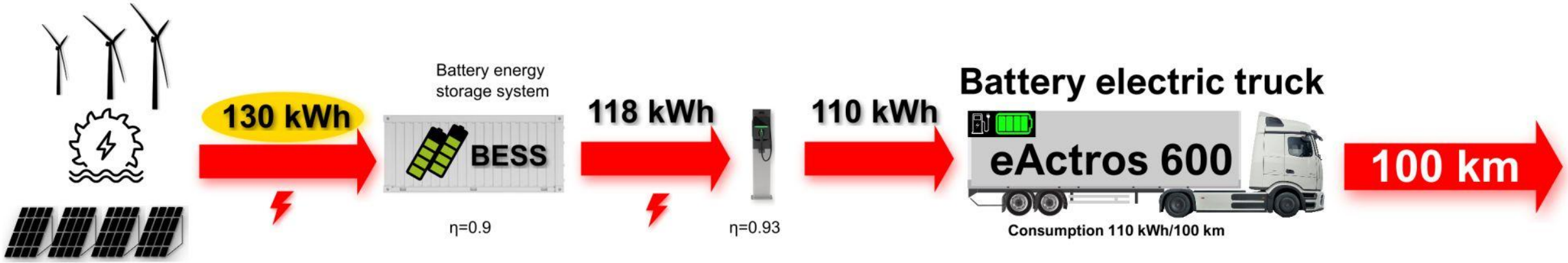


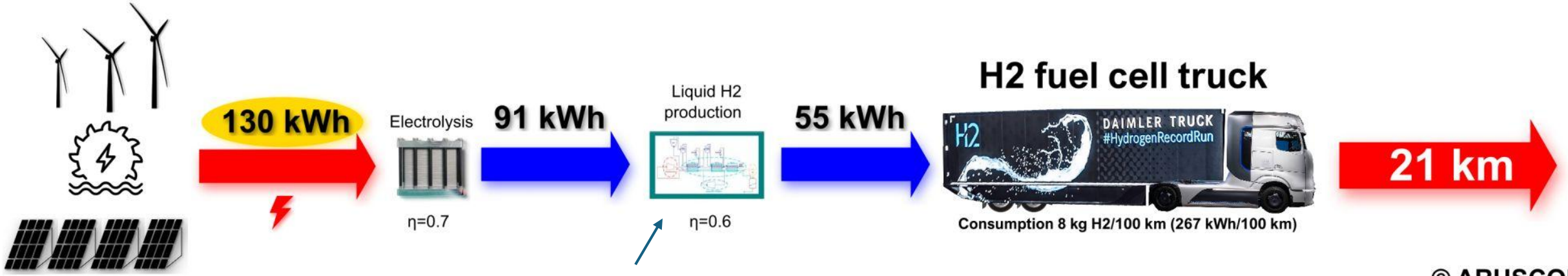
Factor 2,8 difference



© Michael Sura

But what about trucks?





Volumetric (per litre) energy density of liquid H_2 > compressed gas H_2
Hence, fits transport logistics better. But has low efficiency (η) and suffers from boiloff

© ARUSCON

Comparing heat pumps vs. hydrogen for home heating

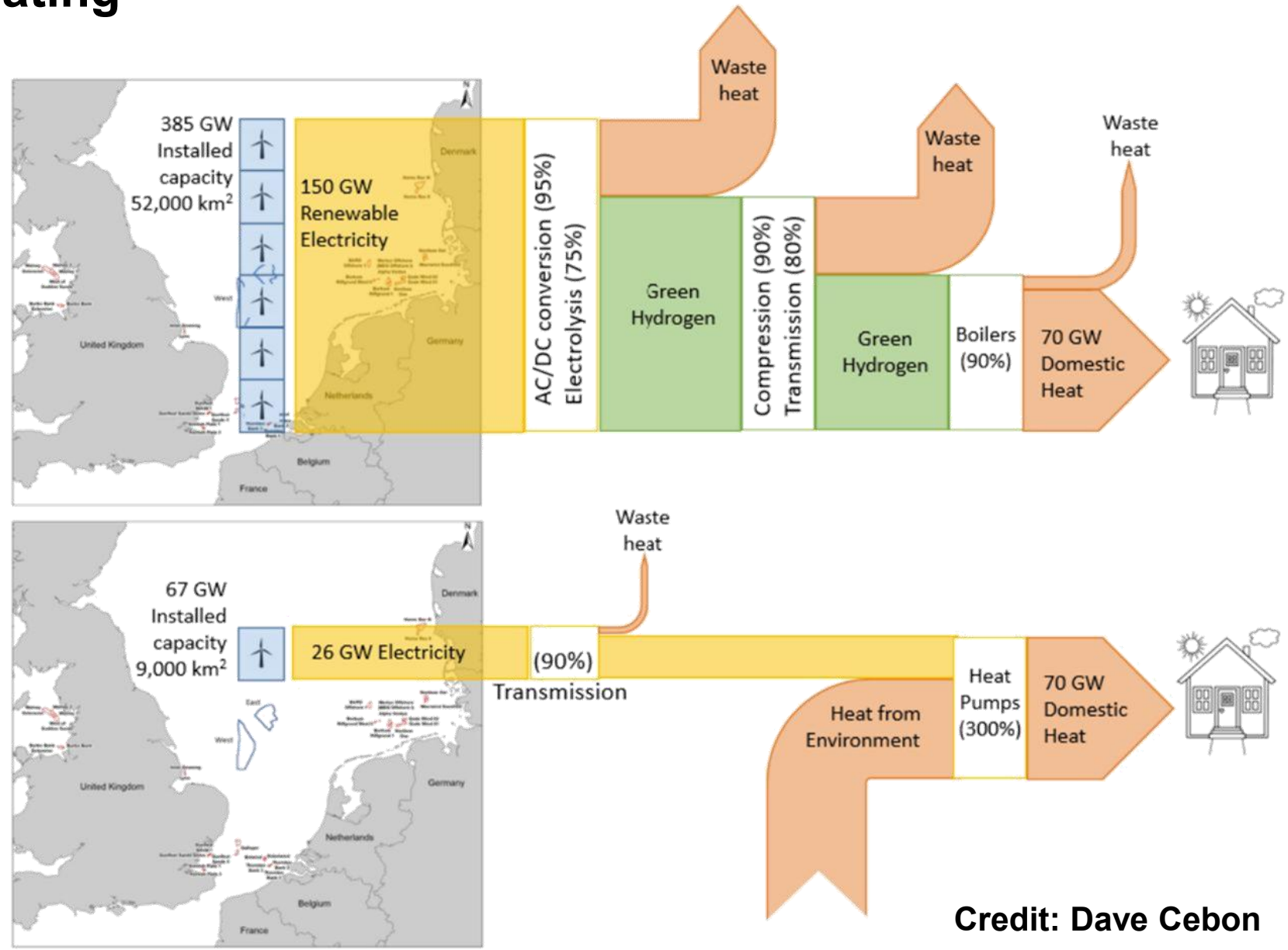
Comparison for heating all UK homes (about 3,5x homes more than NL)

Arrow colors:
Yellow = electricity
Green = hydrogen
Red = heat

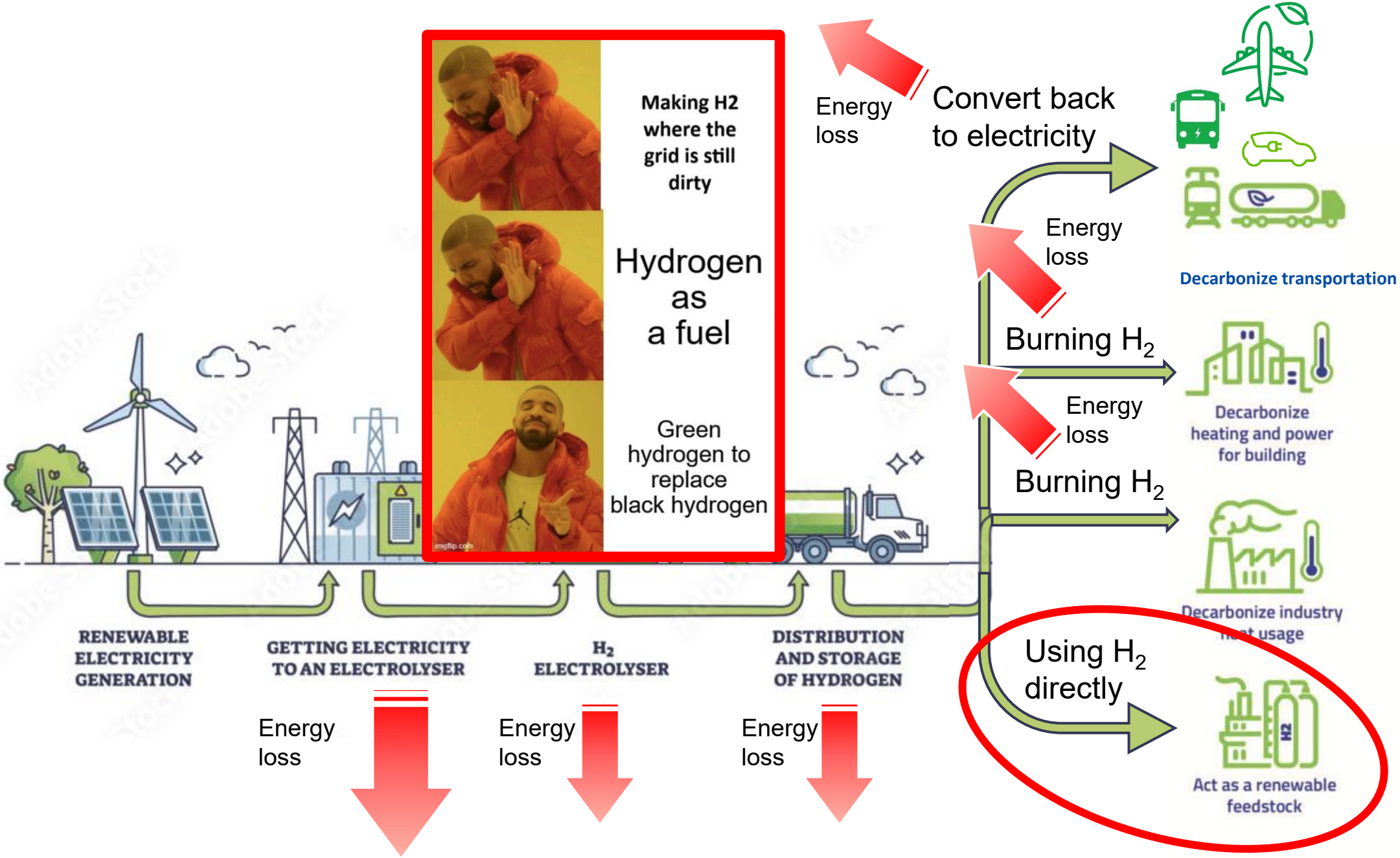
Blue boxes are to scale, showing how much area the wind farms covers

Electrolysis: ~75%. Boilers: 90%. ∴ H_2 heating ~70%
Heat pump: 300%+
5x more kWh needed for H_2

>54 independent scientific studies all conclude H_2 for home heating will play no significant role



Credit: Dave Cebon


Making H2 where the grid is still dirty
Hydrogen as a fuel
Green hydrogen to replace black hydrogen
Energy loss
Convert back to electricity
Energy loss
Decarbonize transportation
Burning H_2
Energy loss
Decarbonize heating and power for building
Burning H_2
Decarbonize industry
Using H_2 directly
Act as a renewable feedstock
RENEWABLE ELECTRICITY GENERATION
GETTING ELECTRICITY TO AN ELECTROLYSER
H_2 ELECTROLYSER
DISTRIBUTION AND STORAGE OF HYDROGEN
Energy loss
Energy loss
Energy loss