

Progress towards low-carbon electricity generation: a global view.

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“Energy is central to nearly every major challenge and opportunity the world faces today.” (United Nations)



<https://ourworldindata.org/about>



Our World in Data (OWID) is a free, non-profit website. “Our mission is to increase understanding of the world’s largest problems and drive informed action to solve them”

OWID is produced as a collaborative effort between researchers at the University of Oxford, & Global Change Data Lab, which owns, publishes, and maintains the website and the data tools. It is used by journalists, policymakers, scientists, teachers, and curious individuals worldwide

We’ve also made it easy to download and reuse the data (though note that most of this data comes from third-party providers such as the WHO, UN, and World Bank and is subject to their license terms).

The talk will cover -

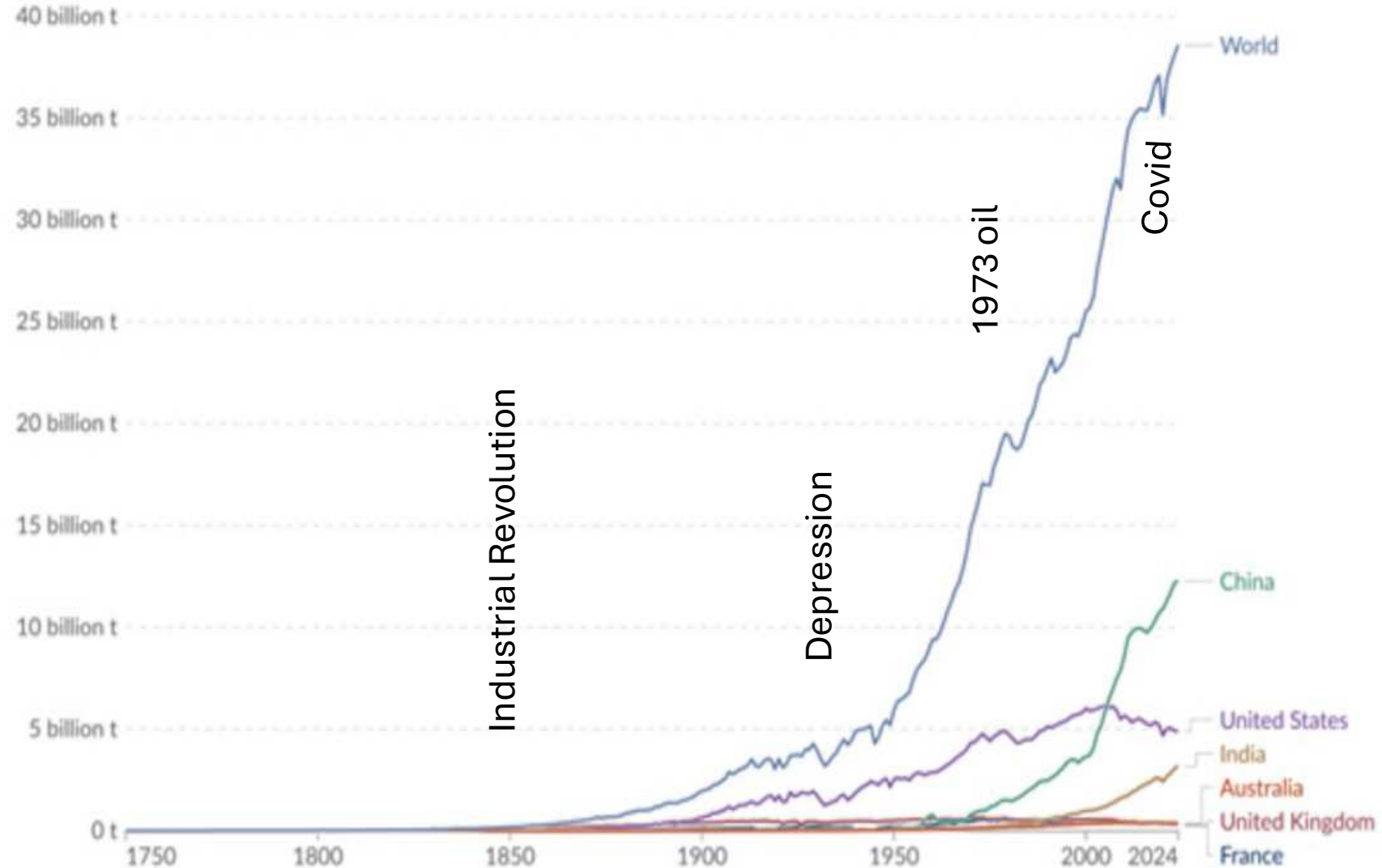
- The rationale for low carbon electricity
- Australia's efforts at low C have barely made a dint
- How might low C be done better?
- The German experience 2002-22
- Australia's integrated system program (*ISP*)
- What OWID informs about other energy in the mix

The rationale for employing low carbon electrification is to curtail anthropogenic CO₂ emissions

Annual CO₂ emissions

Carbon dioxide (CO₂) emissions from fossil fuels and industry. Land-use change emissions are not included.

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Data source: Global Carbon Budget (2025)

OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

There seems no end to the ongoing runaway increase in anthropogenic greenhouse gas emissions

Negligible in early industrial revolution

Takes off around 1850

Increased
8 x since 1950
2 x since 1998

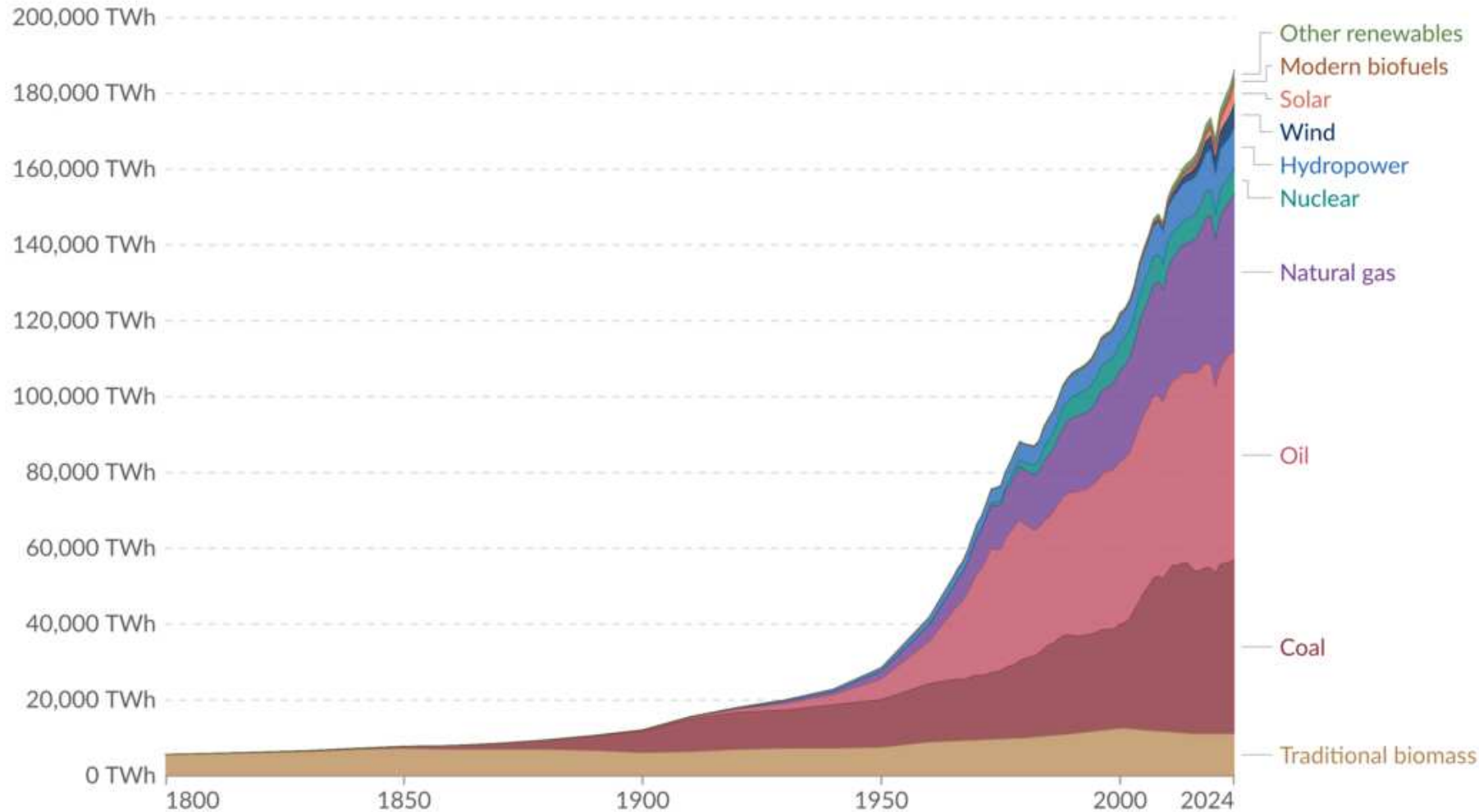
China (32%), USA & India main emitters

Australia, France, UK
~1% each

Global primary energy consumption by source

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Primary energy¹ is based on the substitution method² and measured in terawatt-hours³.



Data source: Energy Institute - Statistical Review of World Energy (2025); Smil (2017)

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Note: In the absence of more recent data, traditional biomass is assumed constant since 2015.

2025: More than 75% of total energy derived from combustion – fossil fuels and biomass

hydro since 1930's
nuclear since 1950's
wind/solar since 1990's

1. Primary energy Primary energy is the energy available as resources – such as the fuels burnt in power plants – before it has been transformed. This relates to the coal before it has been burned, the uranium, or the barrels of oil.

Primary energy includes energy that the end user needs in the form of electricity, transport and heating, plus inefficiencies and energy that is lost.

How to stop anthropogenic green house gas emissions?

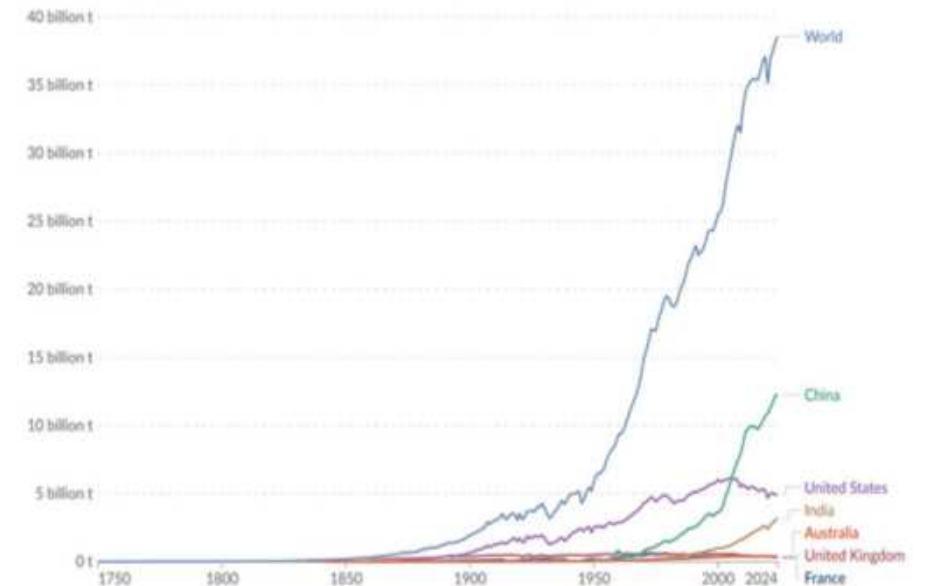
What has the World been doing to change course?

What has been achieved?

What is it likely to achieve?

Annual CO₂ emissions

Carbon dioxide (CO₂) emissions from fossil fuels and industry. Land-use change emissions are not included.



Data source: Global Carbon Budget (2025)

OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

Since 1992 –

Adopted international protocols Kyoto '97; Paris '2015; Dubai 2023 UN IPCC COP

Legislated protocols & efficiency standards

DCCEEW legislated targets: net zero by 2050 (legislated in 2022)

Financial incentives

UN Environment Program Finance

National finance schemes -

- Consumer rebates
- Industrial Tax Credits
- Concessional public funds, Net Zero Fund

& disincentives

Sanctions, boycotts, disinvesting

Removing “explicit” subsidies from fossil fuel

Mandating carbon exposure as a Corporate risk, ESG

QANGO's (often with charitable & quasi-scientific status) –

SEC, CCA, CEFC, AEMO, ARENA, Net Zero Economy Authority

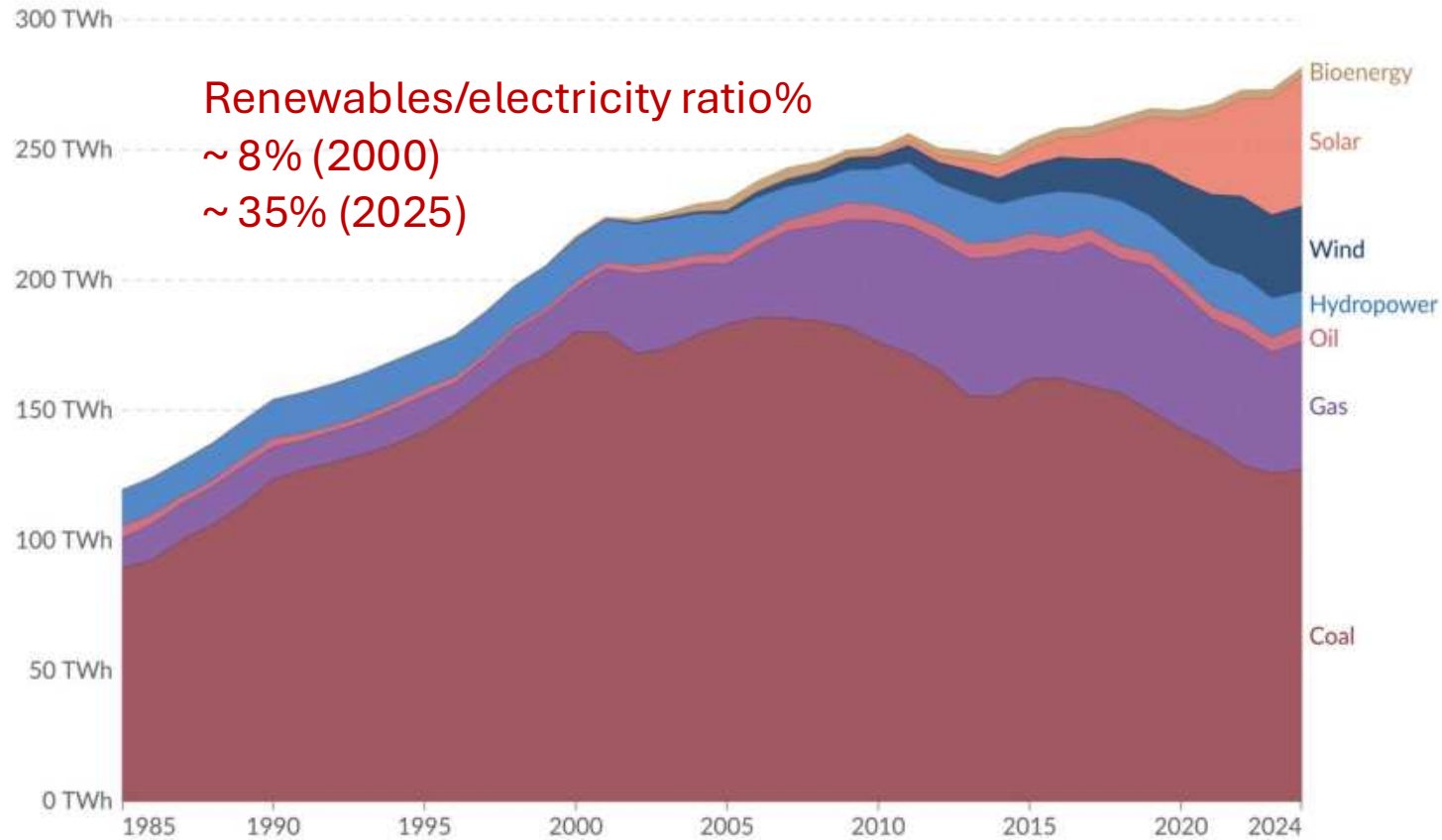
Australia is reducing, slightly, its CO₂ footprint

Australian electricity generation to date

Electricity production by source, Australia

Measured in terawatt-hours¹.

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Data source: Ember (2026); Energy Institute - Statistical Review of World Energy (2025)

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Note: "Other renewables" include geothermal, wave, and tidal.

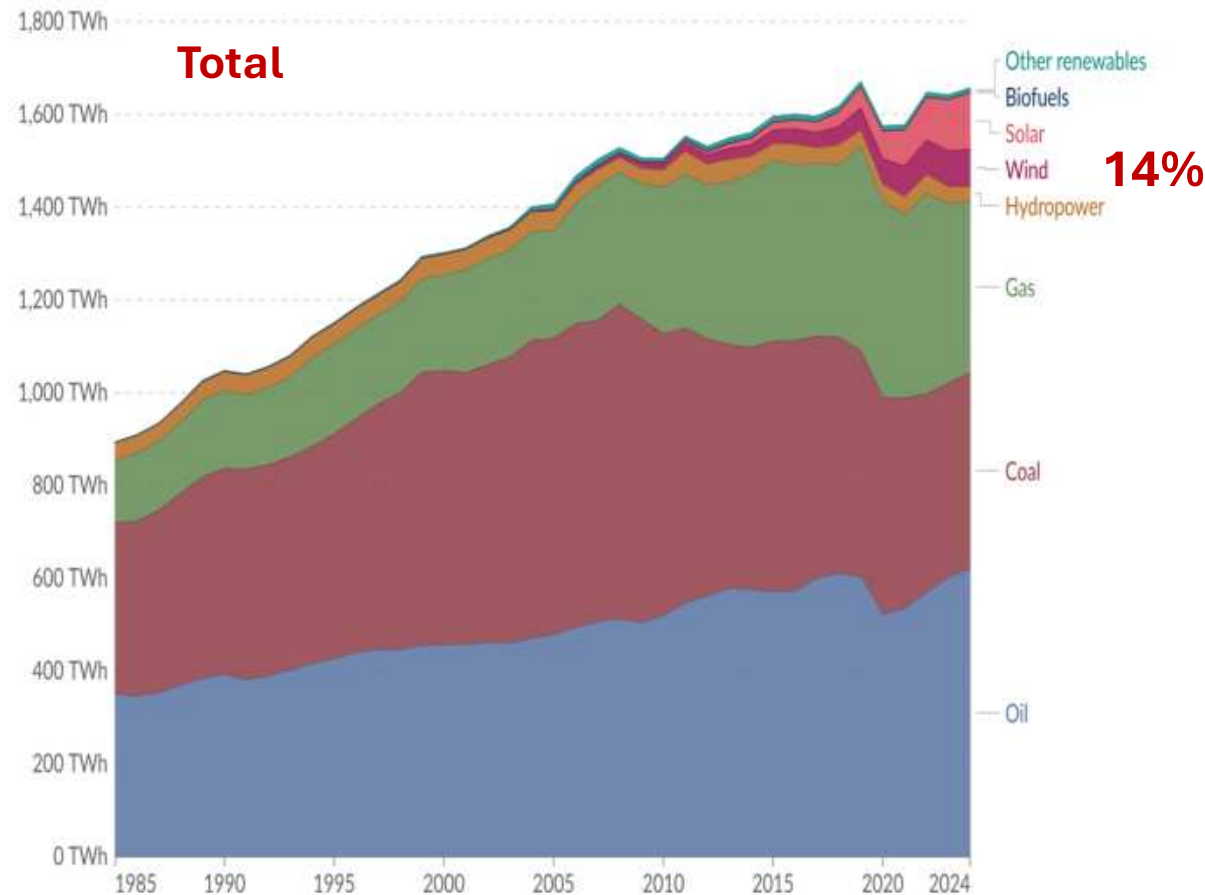
¹ Watt-hour A watt-hour is the energy one watt of power delivers for one hour. Since one watt equals one joule per second, a watt-hour equals 3600 joules of energy.

Total energy consumed by transport, construction, industry, mining etc is $> 5x$ electricity production

Energy consumption by source, Australia

Measured in terms of primary energy¹ using the substitution method².

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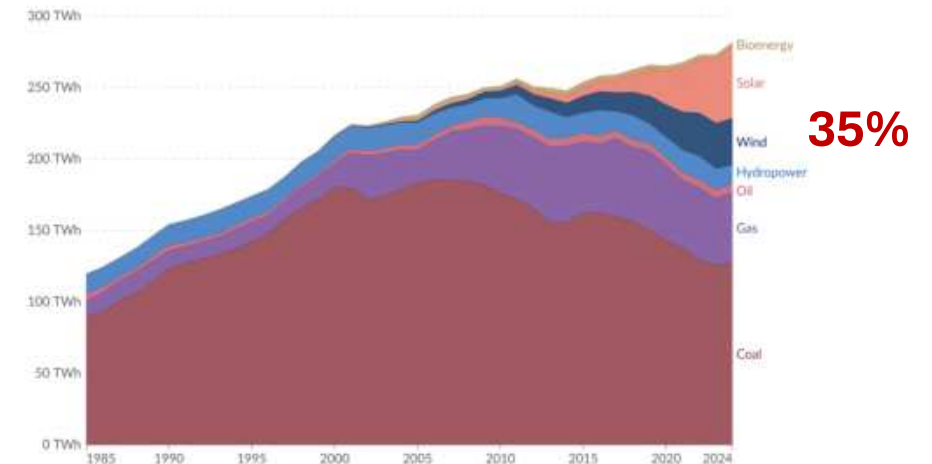


Electricity component

Electricity production by source, Australia

Measured in terawatt-hours¹.

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Data source: Ember (2024); Energy Institute - Statistical Review of World Energy (2025)

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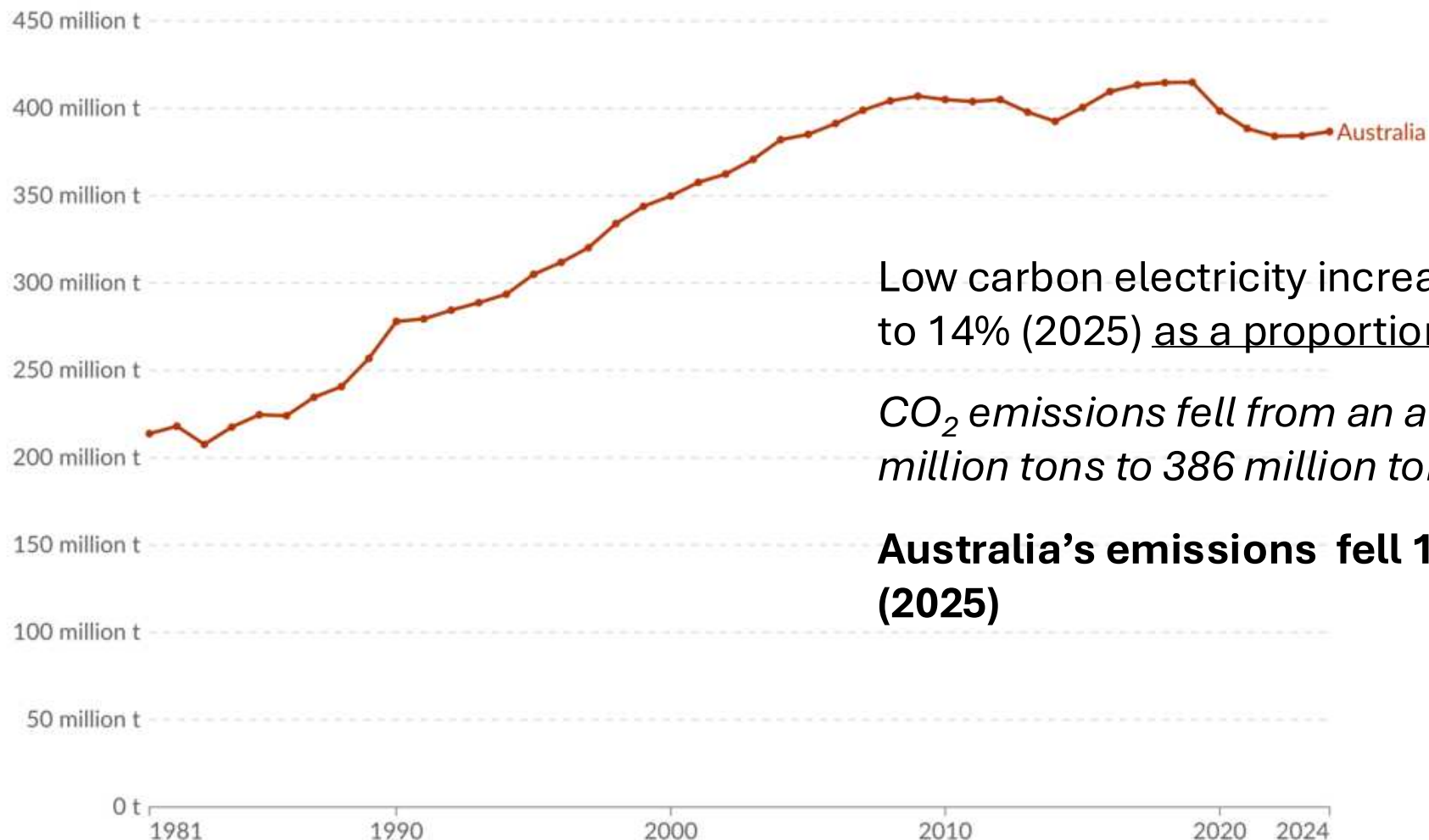
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1. Watt-hour A watt-hour is the energy one watt of power delivers for one hour. Since one watt equals one joule per second, a watt-hour equals 3600 joules of energy.

Annual CO₂ emissions peaked in Australia in 2019



Carbon dioxide (CO₂) emissions from fossil fuels and industry¹. Land-use change emissions² are not included.



Low carbon electricity increased from 3.5% (2000) to 14% (2025) as a proportion of total energy

CO₂ emissions fell from an annual peak of 415 million tons to 386 million tons (2025).

Australia's emissions fell 1.1% (2019) → 1% (2025)

Data source: Global Carbon Budget (2025)

OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

.... but at what cost to reduce 0.1%?

How many \$ spent & lost? to achieve 14% renewables?

Still 68% to go to reach 82%.

What price to essential industries, sovereignty and security?

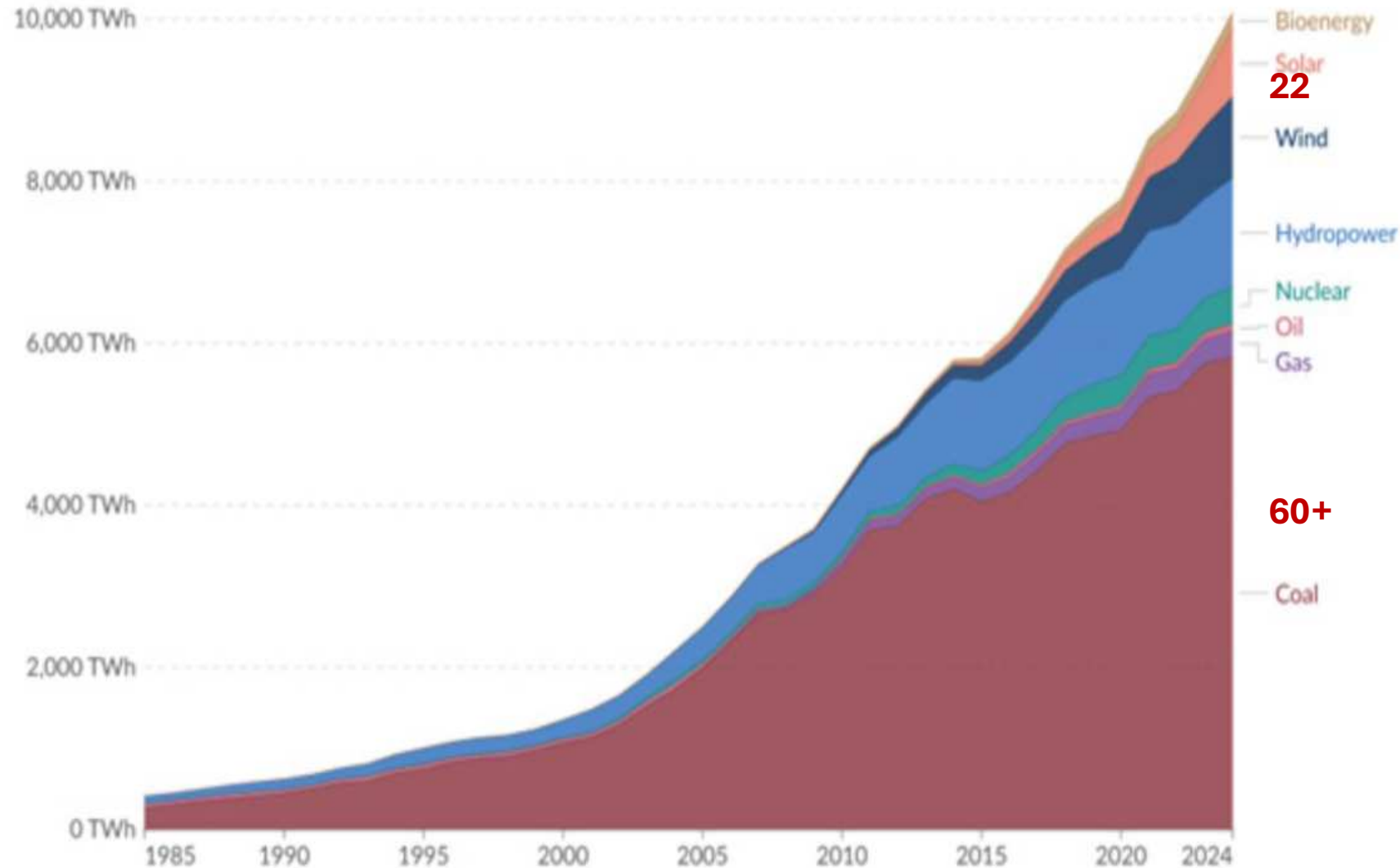
- ☐ *Adding to the cost of electricity*
- ☐ Adding **33-50%[^]** to inflation index
- ☐ *losing industries, skills, employment*
 - Paper (Visy)
 - Plastic
 - Fertiliser (Orica)
 - Mn (Gupta)
 - Fe smelting (Gupta)
- ☐ *Propping up energy intensive Al smelting for how long?*

- ☐ *Grid instability; less abundance*
- ☐ Environmental degradation
- ☐ Social division
- ☐ Uncosted short lifespan, *recycling* issues
- ☐ *Compromised security*
 - Build reliant on a country that has a history of economic coercion
- ☐ *Undermined sovereign capability*

[^] Rippling effect from increased energy prices

Electricity production by source, China

Measured in terawatt-hours.



Data source: Ember (2026); Energy Institute - Statistical Review of World Energy (2025)

Note: "Other renewables" include geothermal, wave, and tidal.

OurWorldinData.org/energy | CC BY

China remains the world fossil fuel (and also electricity) superpower

Its electricity mix is not different from the World's

Electricity

RE growing very fast 22%,
fossil fuels > 60%, & *not reducing*

Nuclear 4.6%

Total energy

Renewables 16%

Coal 53%

Coal 56% of world's consumption, not reducing

How might low C be done better?

- **Increase efficiency**
- **Is using less energy a way forward?**
- **Geological CO₂ sequestration**
- **Geothermal?**
- **Adopting new/ newer technologies: e.g.,**
 - **Off planet solutions**

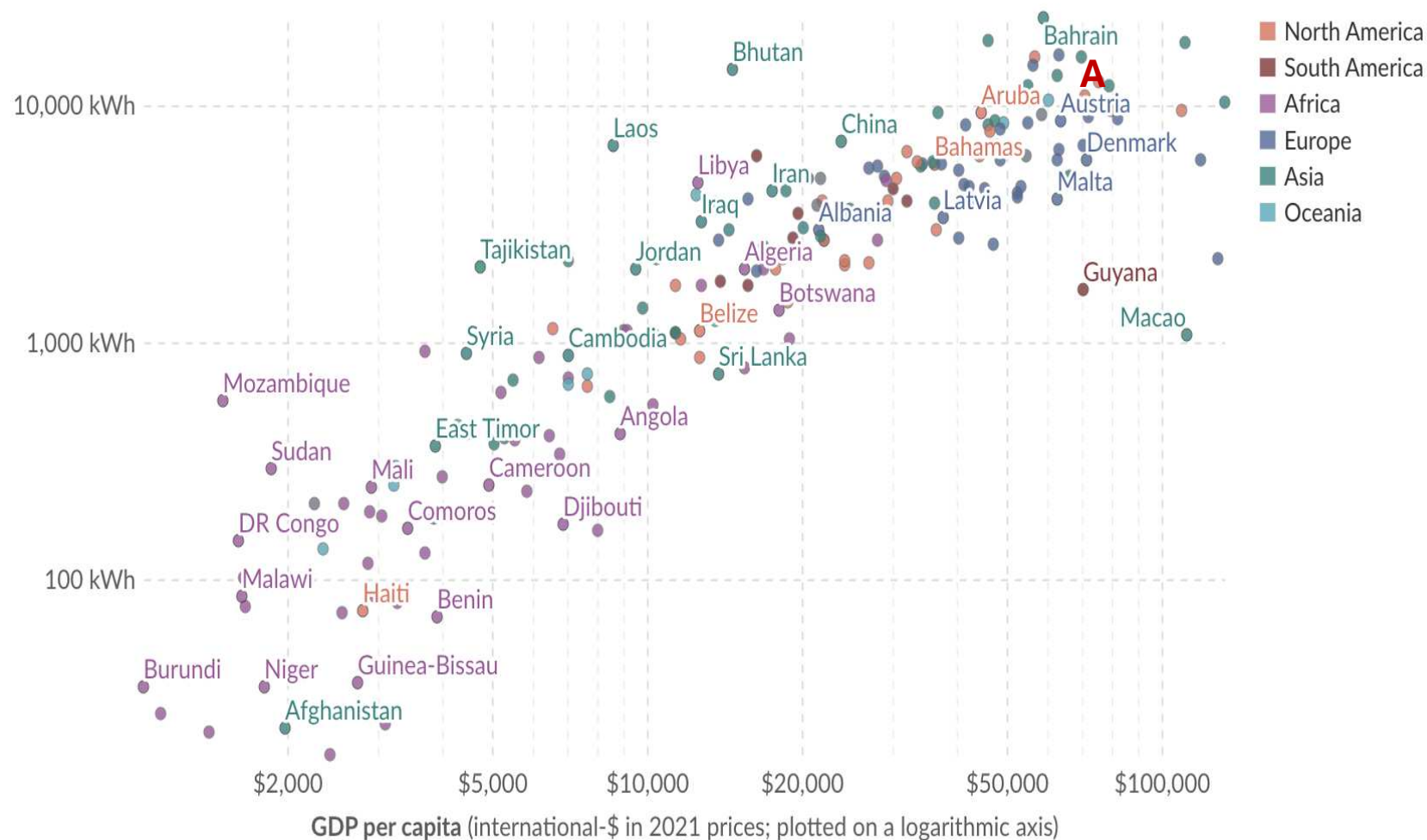
**\$-rich
nations
don't use
less energy.**

Per capita electricity generation vs. GDP per capita, 2024

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Average annual electricity generation per capita, measured in kilowatt-hours¹ per person. Gross domestic product (GDP) per capita is adjusted for inflation and differences in living costs between countries.

Per capita electricity generation (kilowatt-hours; plotted on a logarithmic axis)



Data source: Ember (2026) and other sources

OurWorldinData.org/electricity-mix | CC BY

Note: GDP data is expressed in international-\$² at 2021 prices.

Use less Energy?

❖ one wishes

Efficiency/ tech gains

❖ huge gains → more use

CO₂ sequestration (Moomba SA, WA)

❖ 20%?

Geothermal

❖ volcanic

❖ hot rock (SA)

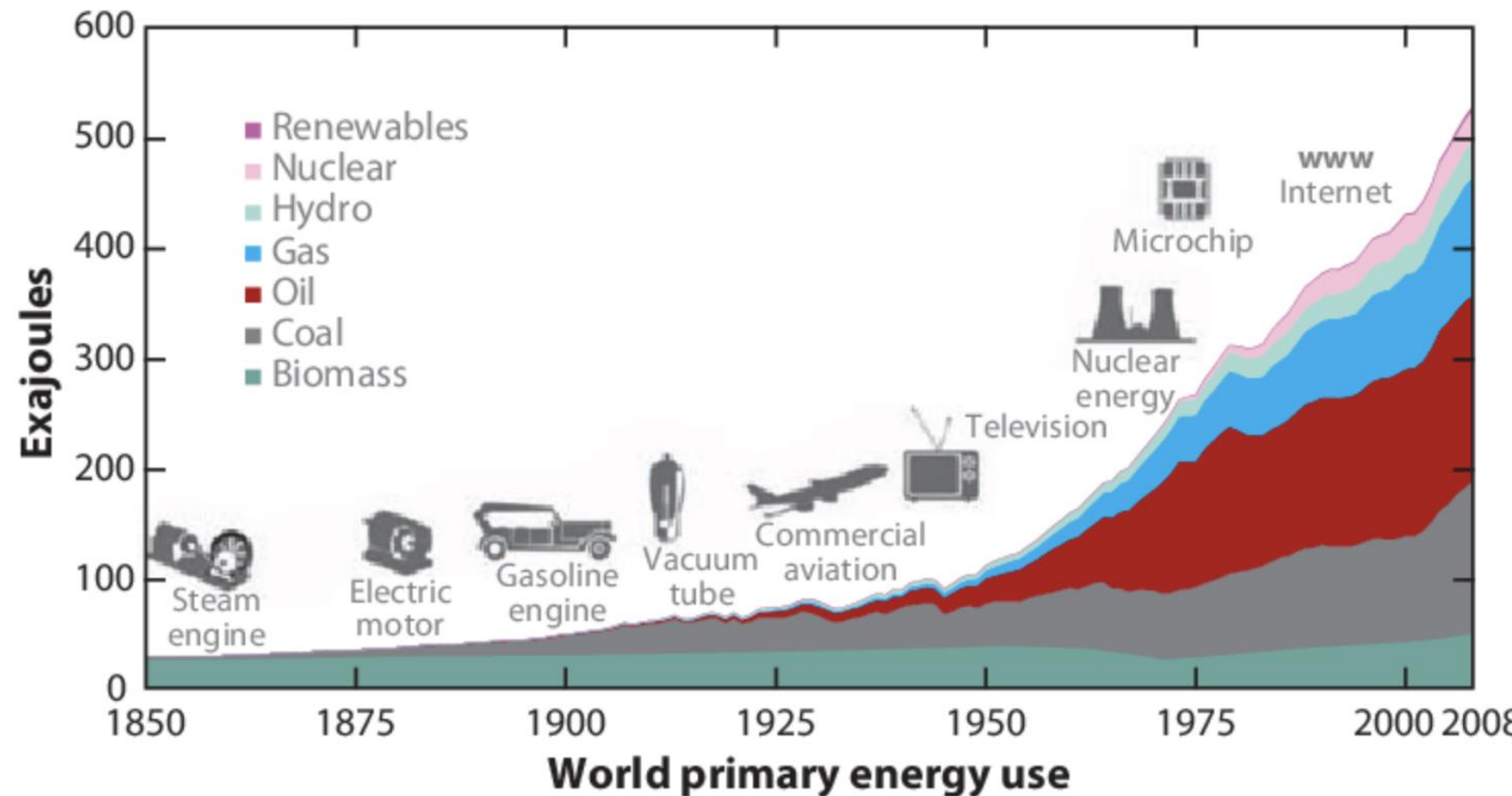


Figure 2

Figure 2 Evolution of primary energy sources, shown as absolute contributions by different energy sources. Biomass refers to traditional biomass until the most recent decades, when modern biomass became more prevalent... [Expand](#)

**The Germany 2002-22 (Lars Schernikau) with
58% renewable electricity (Australia 35% RE)**

Germany's "Energiewende" 2002-22

Lars Schernikau

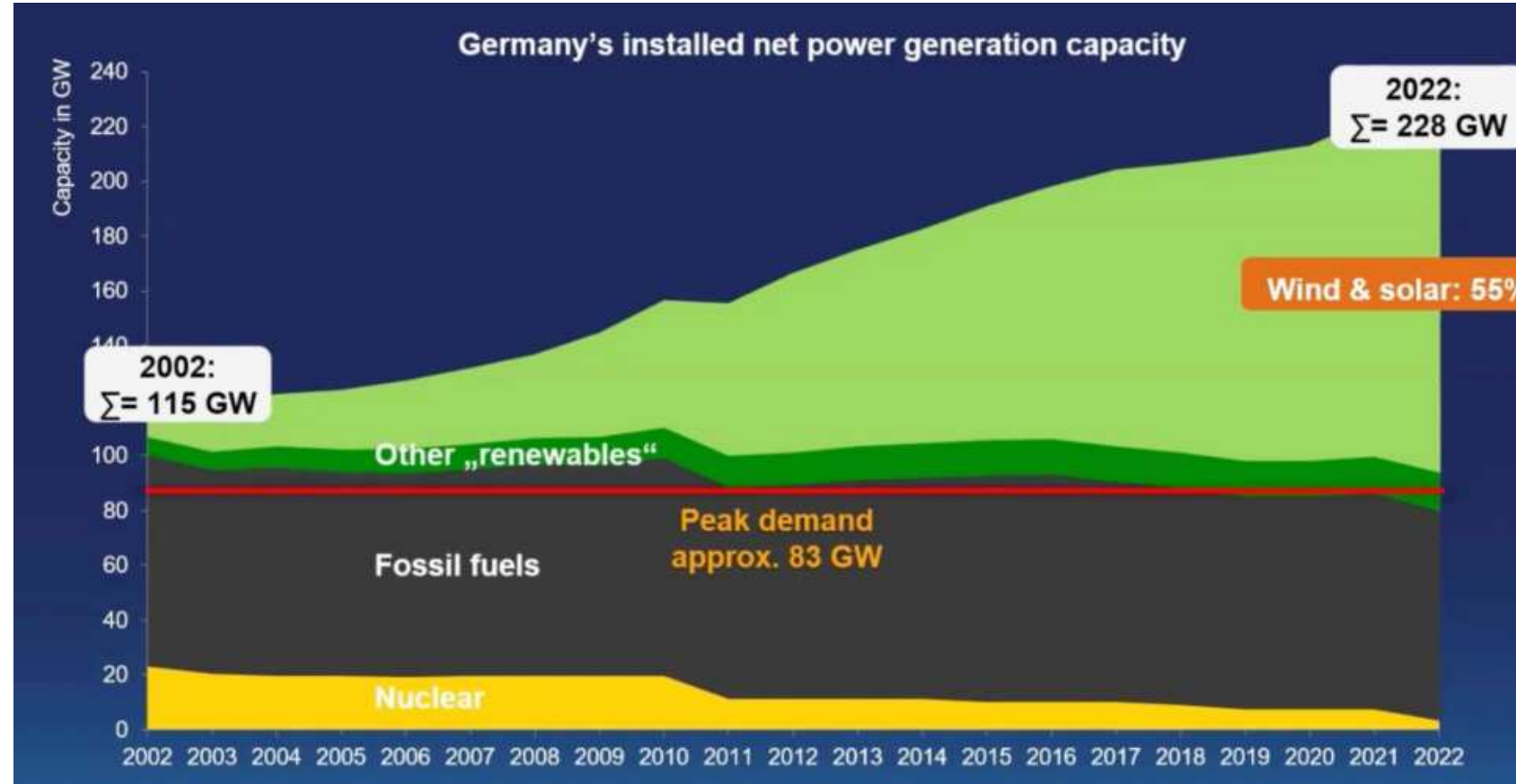
Capacity (GW)

Points to note about these real data

- massive overbuild for unchanging peak demand
- 20GW nuclear mothballed 2011-2023
- addition of renewable capacity; BESS; *interconnectors*; still reliant on FF.

I.e., a transition + **addition** of wind/solar-BESS

Economic stagnation characterised by high energy costs & weak private sector demand; manufacturing is going offshore



Why FF is required to stabilise the grid?

The grid is an extremely complex piece to kit which must balance electricity input and demand

Balancing voltage and frequency deviation requires millisecond responses. A minor deviation will shut the grid down if not instantly corrected. E.g. Spain/Portugal; South Aust

Firming maintains the balance with a spinning turbine. This is inherent with FF or nuclear turbines

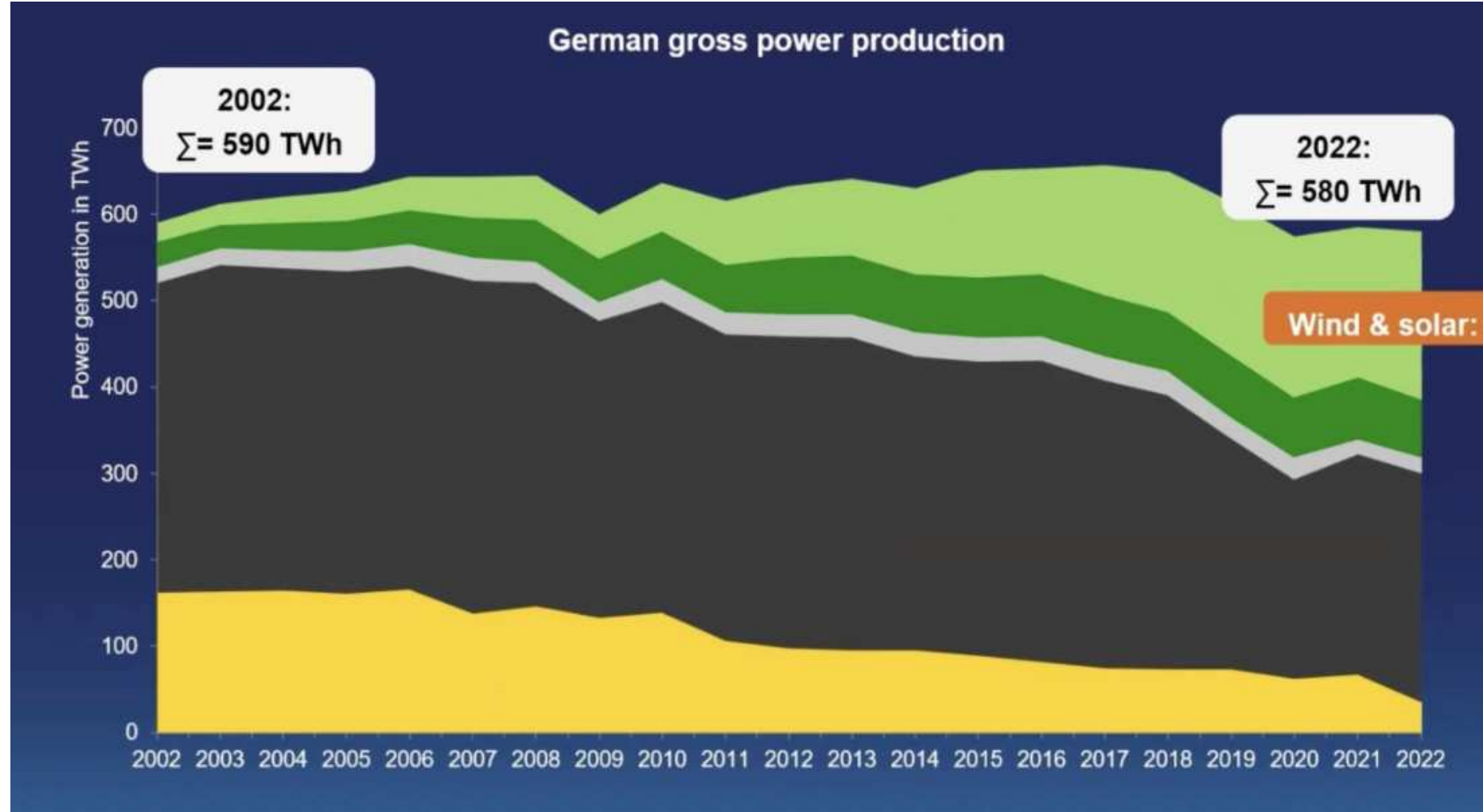
Hence the requirement for gas.
BESS* is too short term

*Battery+inverter will work for 2h

*Snowy2 hydro for 12d

Germany 2002-22 from Lars Schernikau

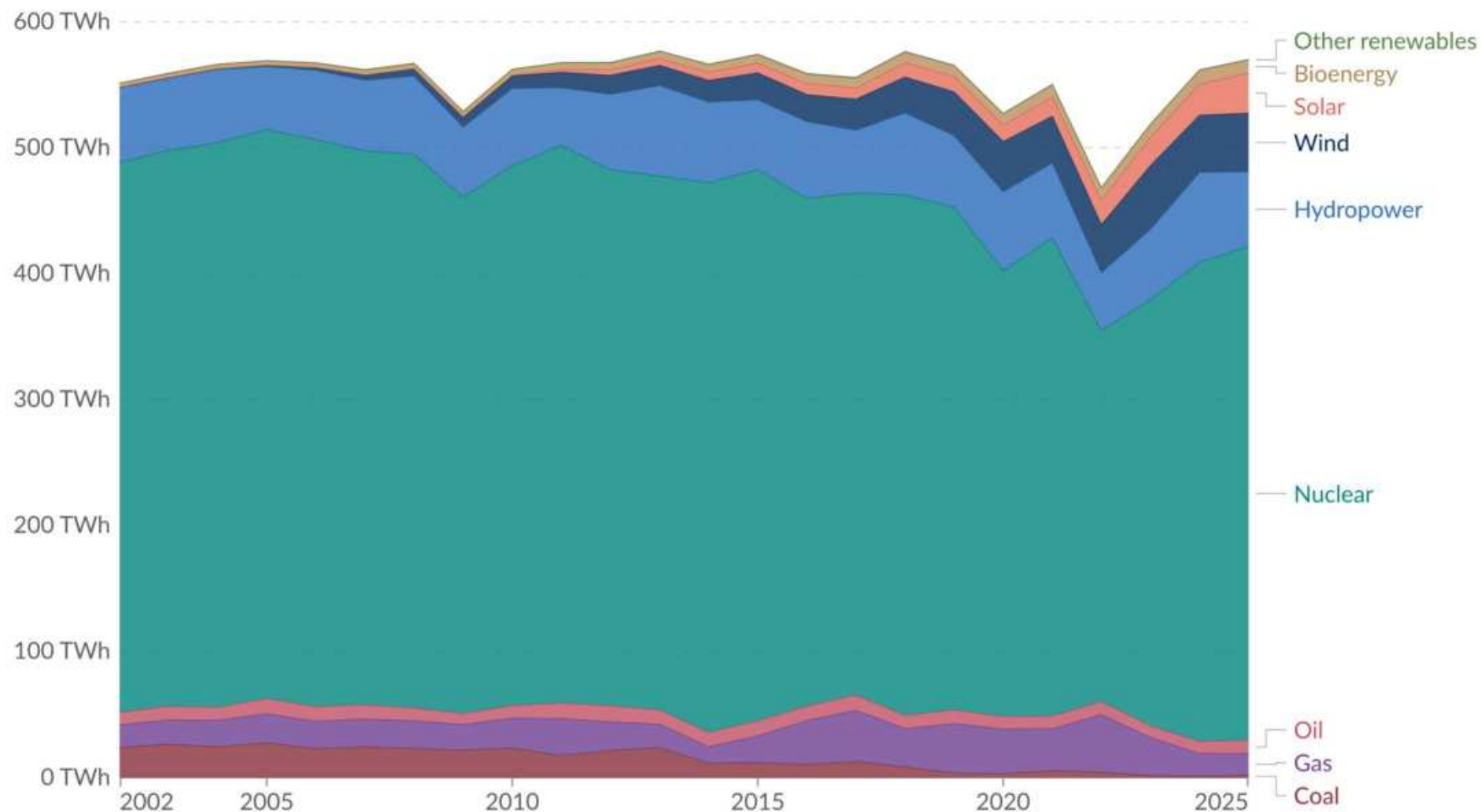
Electricity Production
(TWh) by source



Electricity production by source, France

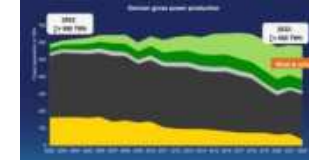
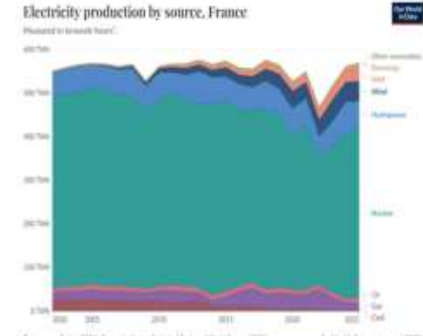
Measured in terawatt-hours¹.

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Buyers' remorse:

- Ursula von der Leyen (2026) “*a strategic mistake for Europe turning its back on a reliable affordable (nuclear power) source of low emissions power*”
- Friederich Merz (2026) “a serious strategic mistake” ...need (to rely on) coal as a buffer, interconnectors, and SMR's in the future”



Australia's East Coast integrated system plan (ISP)

As of 2025-

- has reduced Australia's CO2 emissions by 0.1% of world emissions;
- renewable only 14% total
- A RE ambition of 82+% of total energy (= Net Zero) by 2050

The Eastern Australian grid (AEMO's 2024 plan)

Points to note in the modelling –

- demand $\leftrightarrow$!
- 6 x overbuild –
 - Roof top solar
 - Utility solar
 - Wind
 - CER storage firming
 - Utility storage BESS
 - Snowy2 firming
 - gas “firming”

It's a long way to net zero

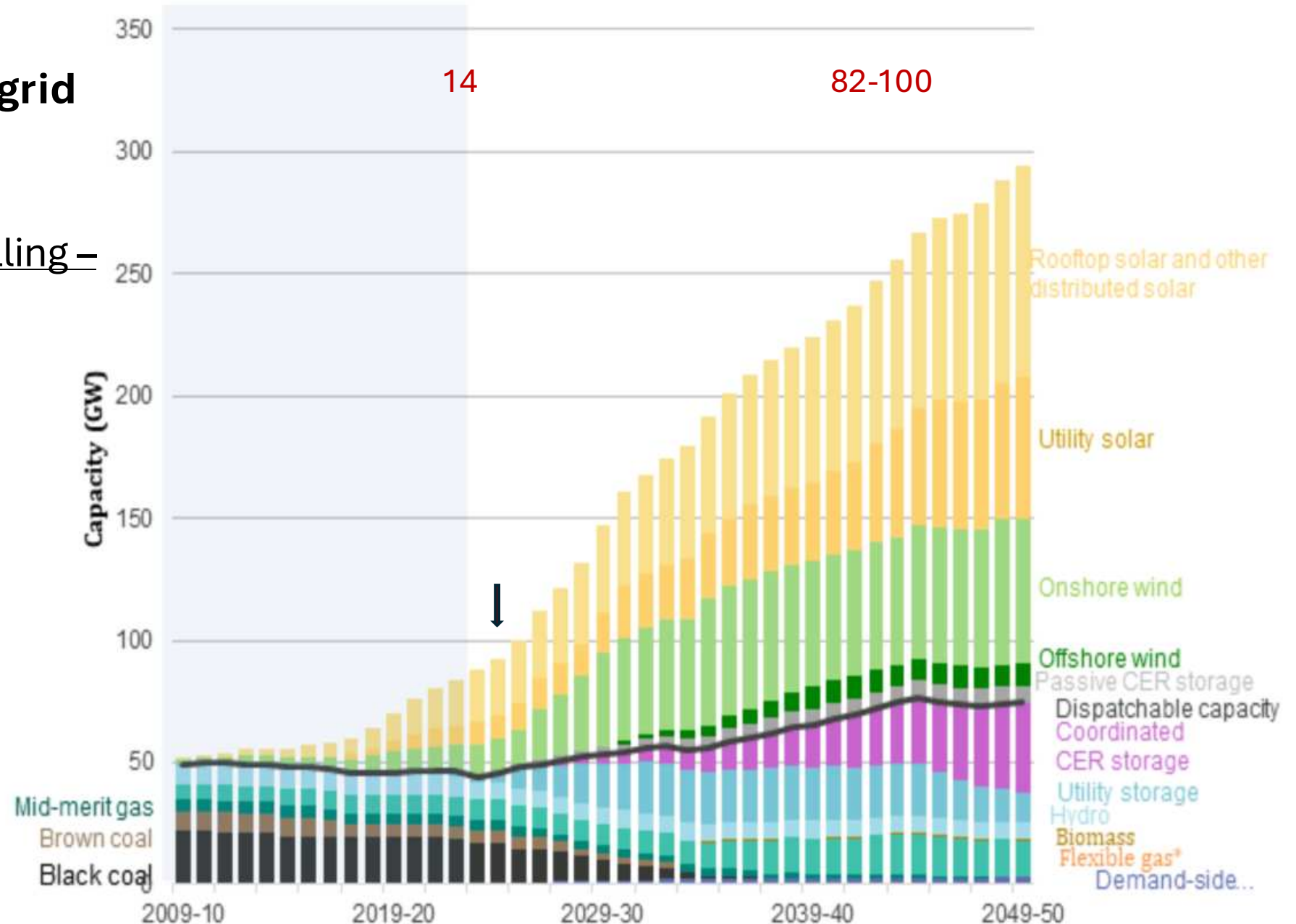


Figure 8: 2024 Integrated System Plan: Report Charts version 1.0 (figure 2)

AEMO's ISP footprint

- 7% of our land
- 5-20x > coal
- 200-5000 fold > nuclear
- loss of agricultural land
- *compulsory acquisition* of farms
- loss of some pristine forest and biodiversity

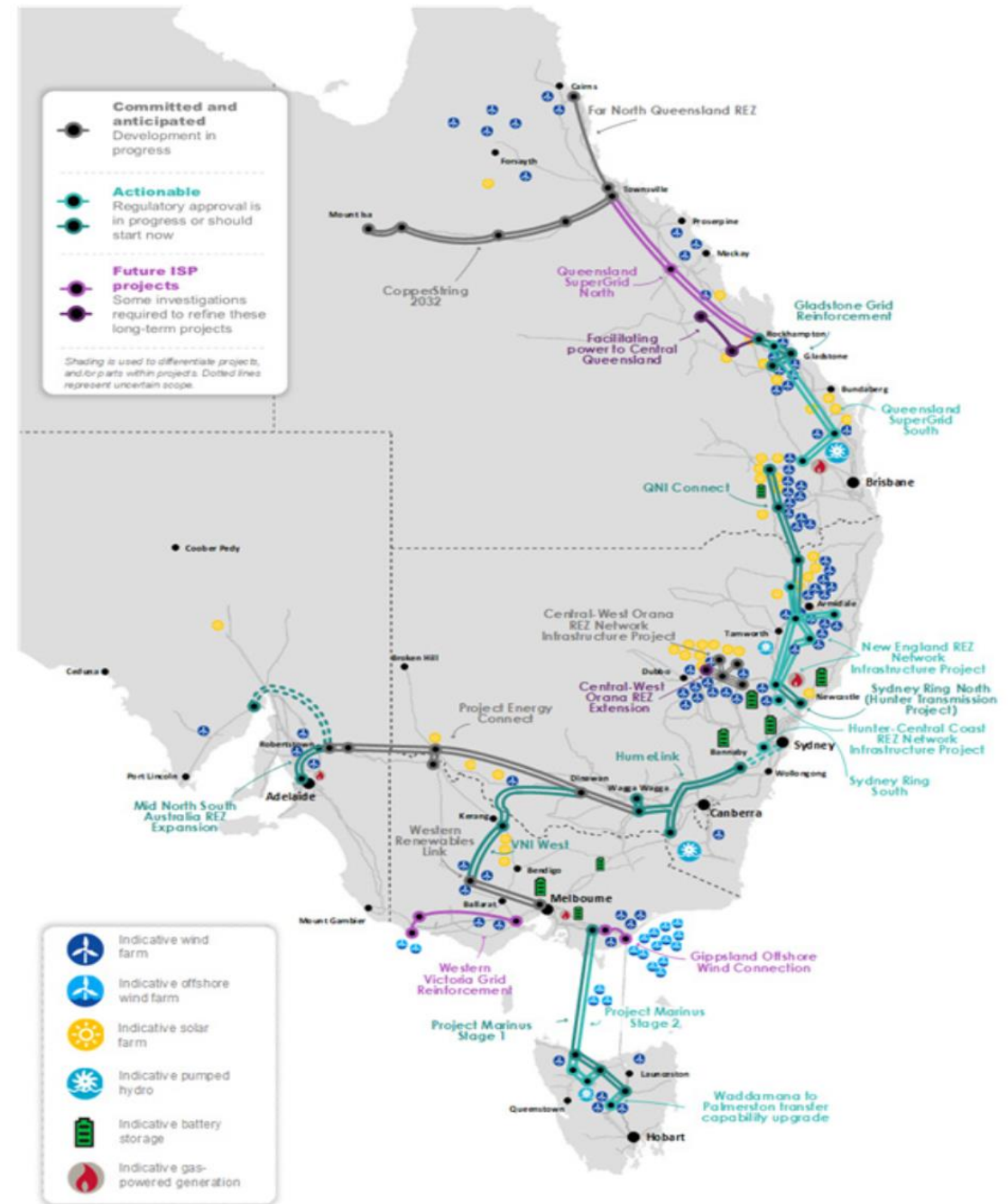


Figure 9: 2024 Integrated System Plan: Report Charts version 1.0 (figure 3) in Data

GenCost costing of the ISP

GenCost is a collaboration between CSIRO & AEMO. It is *opaque & incomplete, biased, and as Jennie George says “constrained by the requirement to deliver Labor’s legislated 2030 targets”* .. Past President Federal ALP (17/7/26)

The ISP costing -

- Excludes invisible ‘off-budget’ costs
- Is principally informed by RE accountants (RG, MK) and by billionaires (SHaC, MT) rather than energy engineers

The ISP design consulted -

- civil engineers (AURECON) ; ^onuclear ^othermal engineers
- RE enthusiasts (most prominently SG*)

SG stated in **sworn deposition** to the
Federal Government’s **House Select Committee on Nuclear Energy**
“China has **no** domestic fossil fuel industry” ... (12/12/2024)

The Eastern Australian grid (AEMO's ISP) \$ costings

3 published cost predictions 2025

Range < 500B to 9 Trillion

- GenCost \$156 billion annualised to 2050
- non-Govt costings \$594 billion (Frontier Economics 2025)
- \$7-9 trillion to 2060 (Netzeroaustralia 2025: Princeton U, UQ, UMelb collab.)

Unpublished costs

Invisible off budget (CIS, curtailment) \$1 trillion? (Robert Gottliebse 2026)

Curtailment costs
increase with overbuild

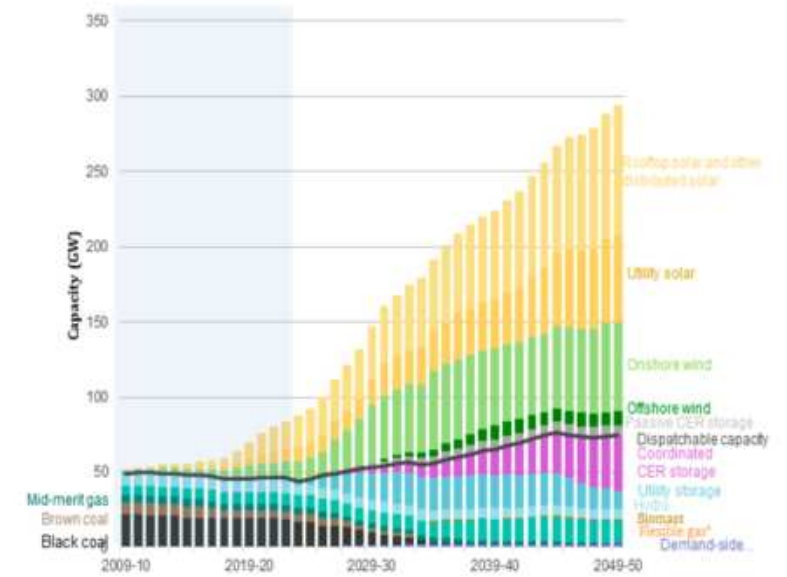


Figure B: 2024 Integrated System Plan: Report Charts version 1.0 [Figure 2]

The reality

Power bills are up 40% since 2023

CSIRO now says.. *“Investing in fossil fuels could cut electricity costs by 5 per cent but shatter climate targets”* SMH 15th July

What else can be done with the energy generation mix to mitigate CO₂?



It is not just
CO₂.

There is the
massive
physical
footprint

Mining requirements of electricity sources, including gas

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Measured in kilograms of material per gigawatt-hour (GWh) of electricity generated. Rock includes mined coal and the amount of rock that has to be mined for the extraction of minerals. The amount of gas that is extracted per unit of electricity is also shown for context, although not directly comparable to other sources.

Metals and minerals Rock Gas extracted

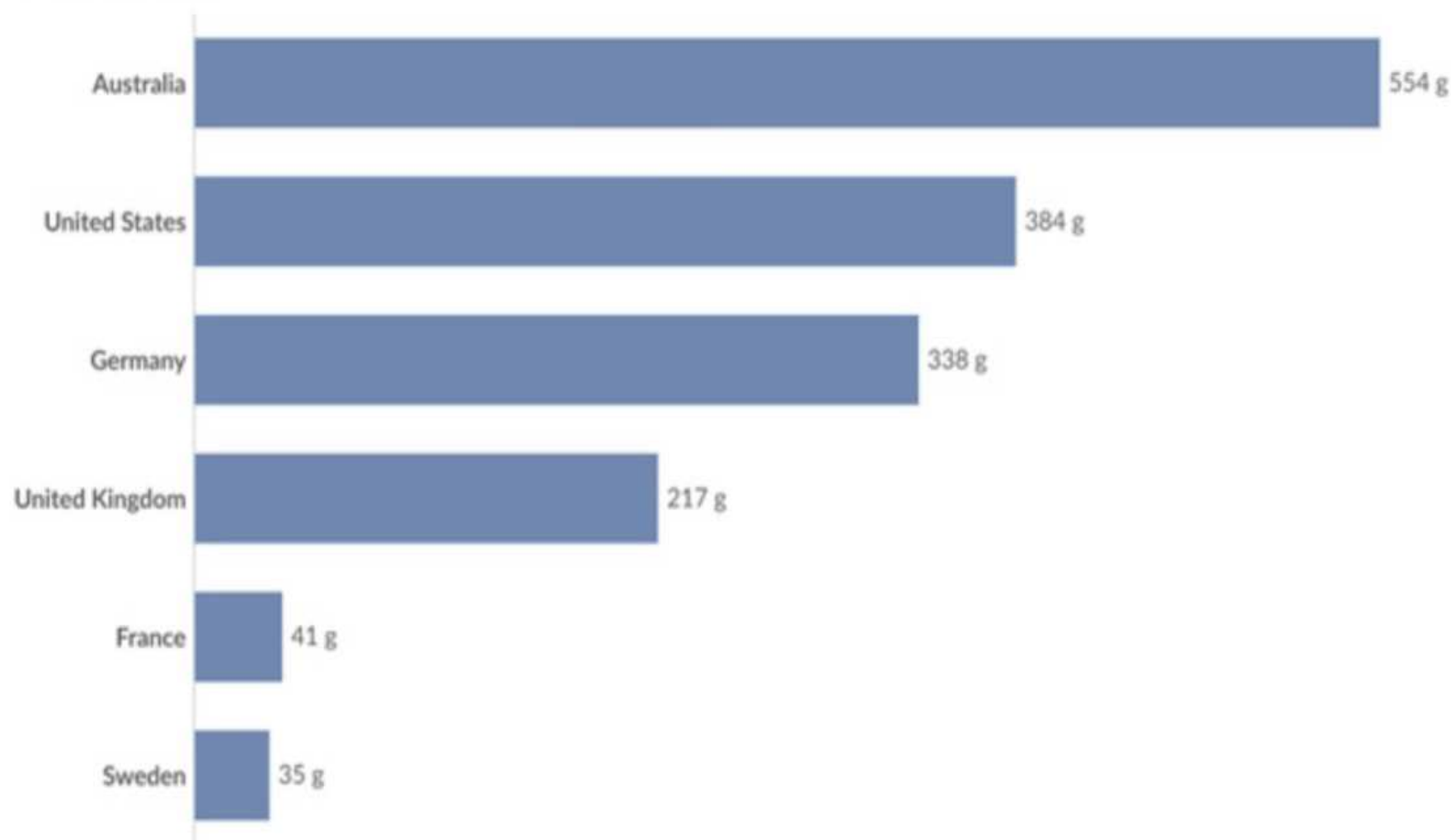


Data source: Seaver Wang et al. (2024). Updated Mining Footprints and Raw Material Needs for Clean Energy.
OurWorldinData.org/metals-minerals | CC BY

Lifecycle carbon intensity of electricity, 2024

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Measured in grams of carbon dioxide-equivalents emitted per kilowatt-hour of electricity generated. Emissions are estimated on a lifecycle basis, including upstream, supply chain and manufacturing stages, and cover all greenhouse gases.



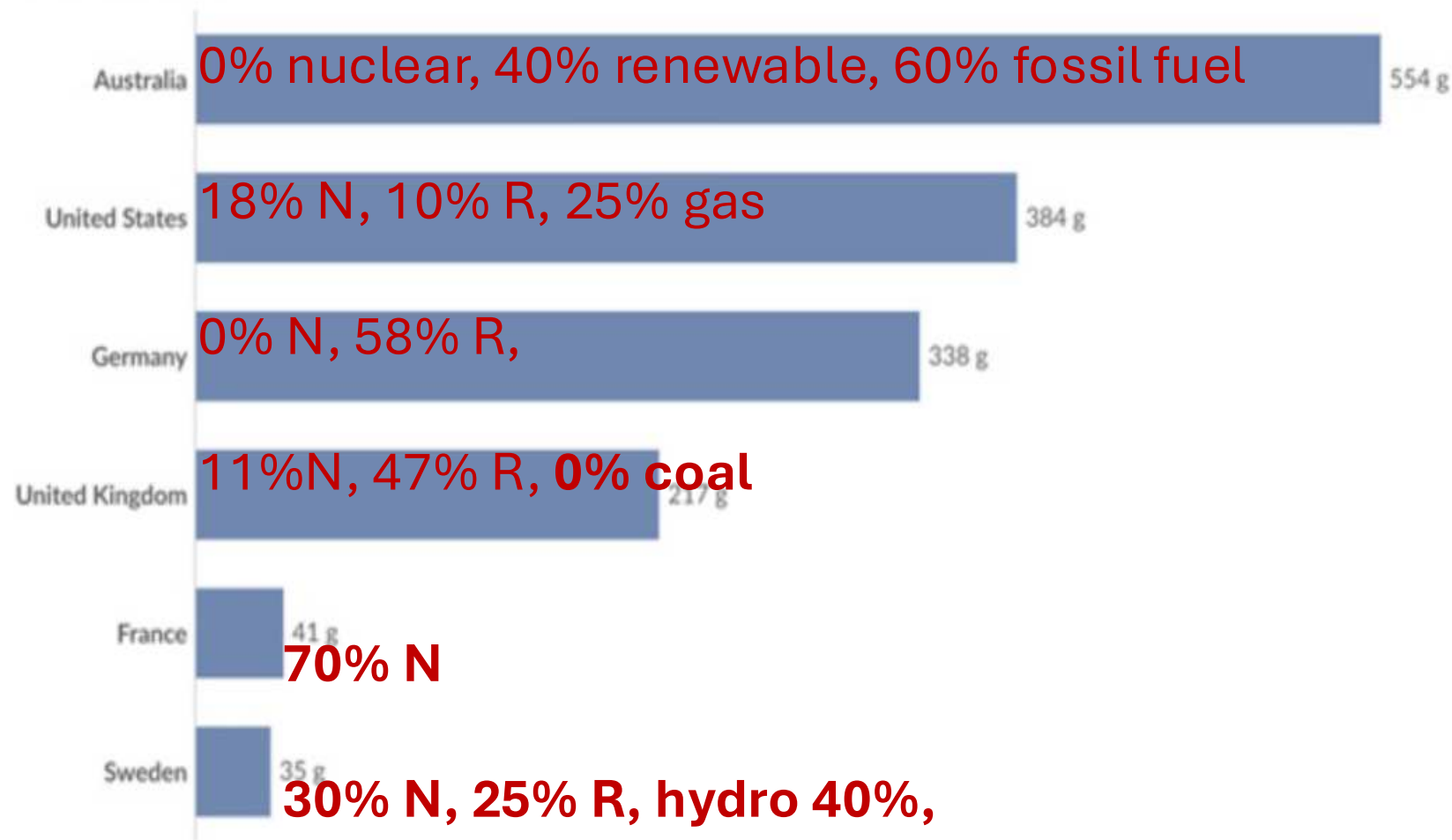
Data source: Ember (2026)

OurWorldinData.org/energy | CC BY

Lifecycle carbon intensity of electricity, 2024

Measured in grams of carbon dioxide-equivalents emitted per kilowatt-hour of electricity generated. Emissions are estimated on a lifecycle basis, including upstream, supply chain and manufacturing stages, and cover all greenhouse gases.

Perhaps nuclear
should be in the mix?



Data source: Ember (2026)

OurWorldinData.org/energy | CC BY

Physical footprint (tons of rock and mineral)/ 10⁵ TWh electricity favours nuclear

Mining requirements of electricity sources, including gas

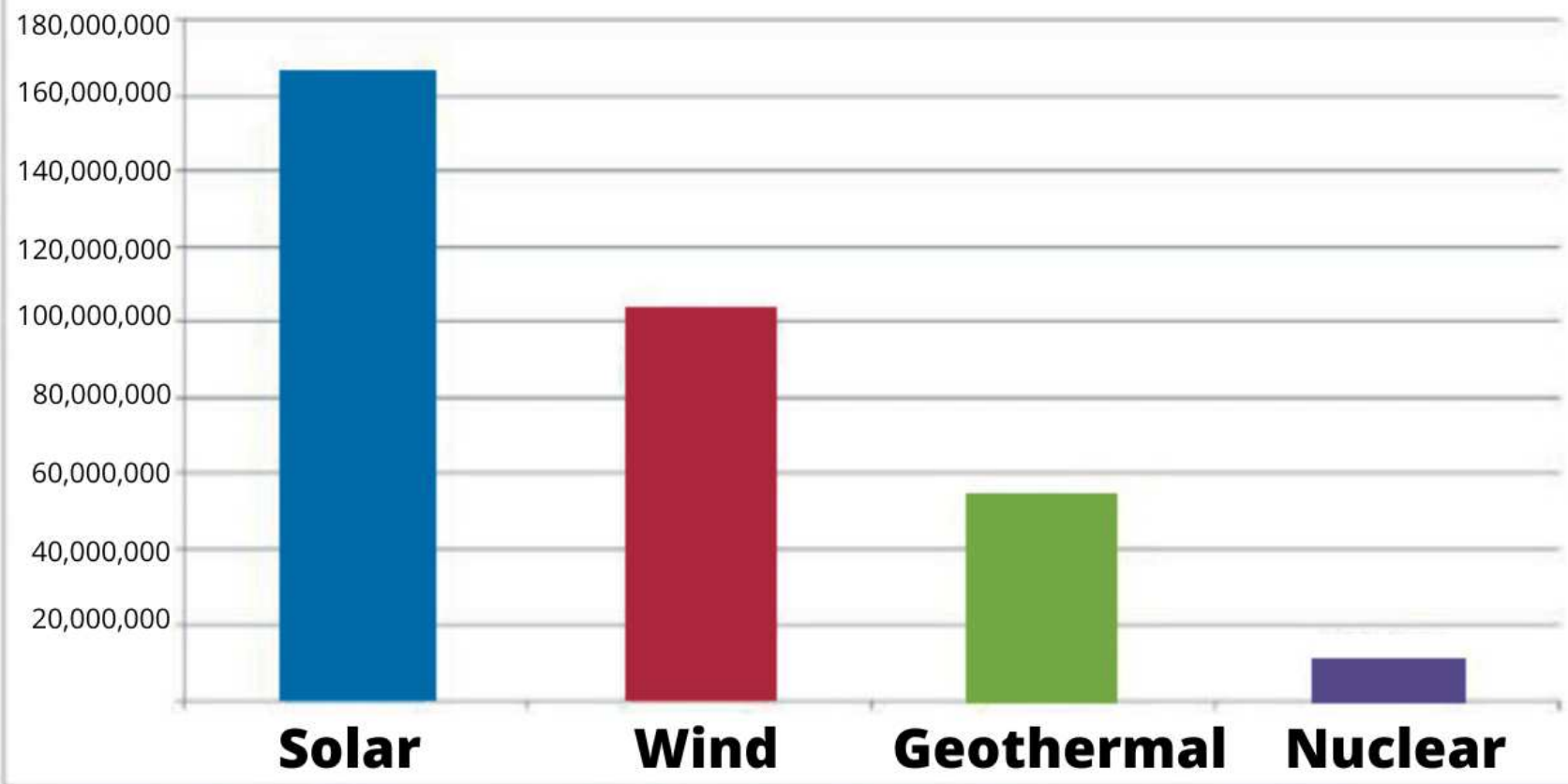
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■ Metals and minerals ■ Rock ■ Gas extracted



Data source: Seaver Wang et al. (2024). Updated Mining Footprints and Raw Material Needs for Clean Energy. OurWorldInData.org/metals-minerals | CC BY

Total tonnage required to build 10,000 TWh generation capacity

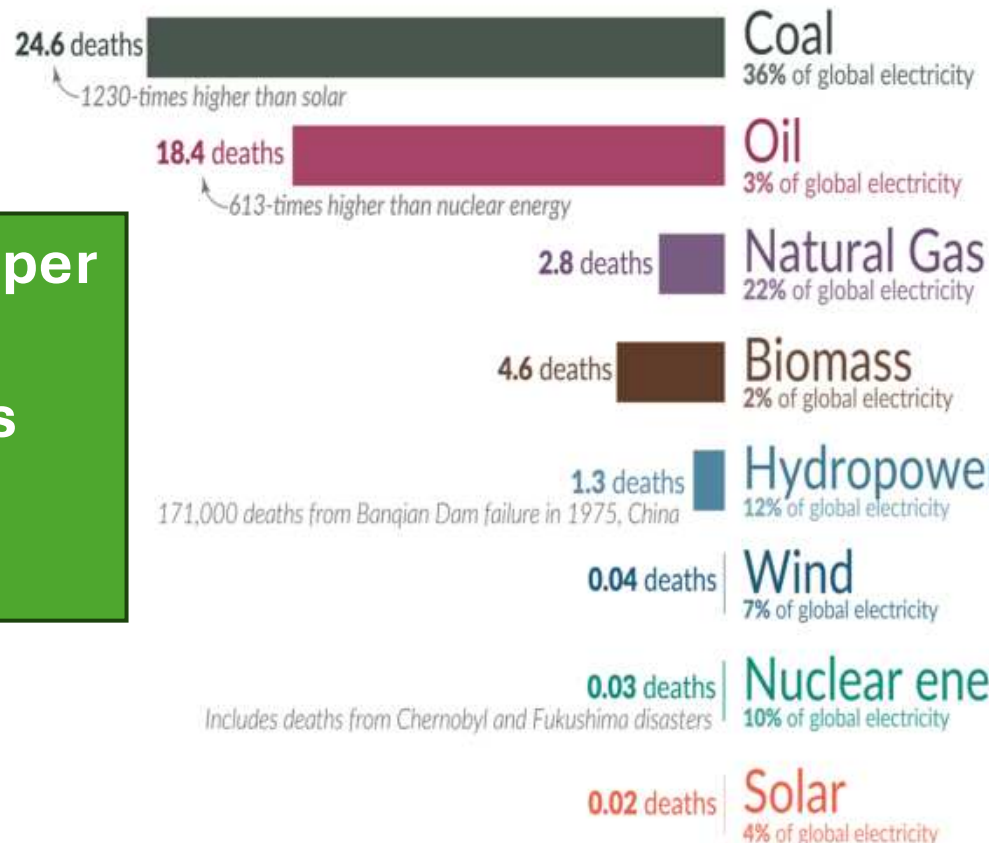


Source: Quadrennial technology review / Chapter 10: Concepts in integrated analysis / September 2015 / www.energy.gov

What are the **safest** and **cleanest** sources of energy?

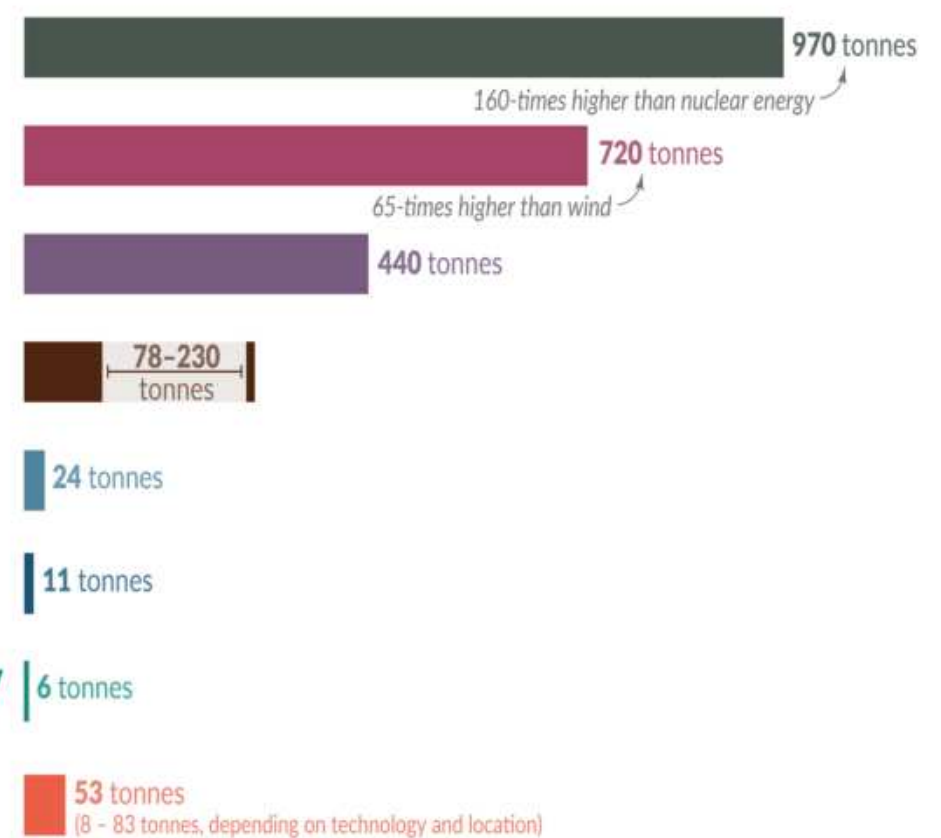
Death rate from accidents and air pollution

Measured as deaths per terawatt-hour of electricity production.
1 terawatt-hour is the annual electricity consumption of 150,000 people in the EU.



Greenhouse gas emissions

Measured in emissions of CO₂-equivalents per gigawatt-hour of electricity over the lifecycle of the power plant.
1 gigawatt-hour is the annual electricity consumption of 150 people in the EU.



Safety (deaths) per TWh energy strongly favours nuclear

Death rates from fossil fuels and biomass are based on state-of-the art plants with pollution controls in Europe, and are based on older models of the impacts of air pollution on health. This means these death rates are likely to be very conservative. For further discussion, see our article: OurWorldinData.org/safest-sources-of-energy. Electricity shares are given for 2021.

Data sources: Markandya & Wilkinson (2007); UNSCEAR (2008; 2018); Sovacool et al. (2016); IPCC AR5 (2014); UNECE (2022); Ember Energy (2021).

More about N

- ❖ Australia is the *only* G20 country banning N-for peaceful use
- ❖ *News flash*: Australia will export 100 GW U_r to India
- ❖ 38 countries signed the Declaration to Triple Nuclear Energy (COP 28)
- ❖ 440 existing NPP in 31 countries provide ~10% of world's electricity
- ❖ On safety, there was **no increase** in birth defects, *spontaneous* miscarriages, cancers in people living next to a nuclear reactor, or even post-Fukushima or Chernobyl (UNSCEAR, WHO, NIH)

Conclusions



Loire River : 4 of 56 nuclear plants in la France

- **Reliable, affordable energy is the lifeblood of any advanced nation and should be a right for developing countries.**
- Myth 1. Renewable wind, solar, BESS are achieving their targets –
 - Kyoto CO₂ commitments
 - Reliable affordable energy
- Myth 2. Renewable wind, solar, BESS is cheapest for Australia
- Myth 3. Renewable wind, solar, BESS is good for the environment
- Myth 4. Nuclear is unsafe, costly
- ***There is too much misinformation.***
Leaders have not been truthful about what is achievable regarding anthropogenic CO₂ emissions

thank you for your listening and your curiosity



questions
welcome



“For democracies to survive, leaders must be truthful about what is achievable regarding CO₂ emissions, or for that matter about any other uneasy fact”