Is nuclear power for Australia’s energy mix a viable solution?

Evidence/data for consideration

Prepared for the Inquiry into Nuclear Energy

by

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25 October 2024

Vogtle Nuclear Plant, Georgia, USA

Critical environmental factors that need to be included

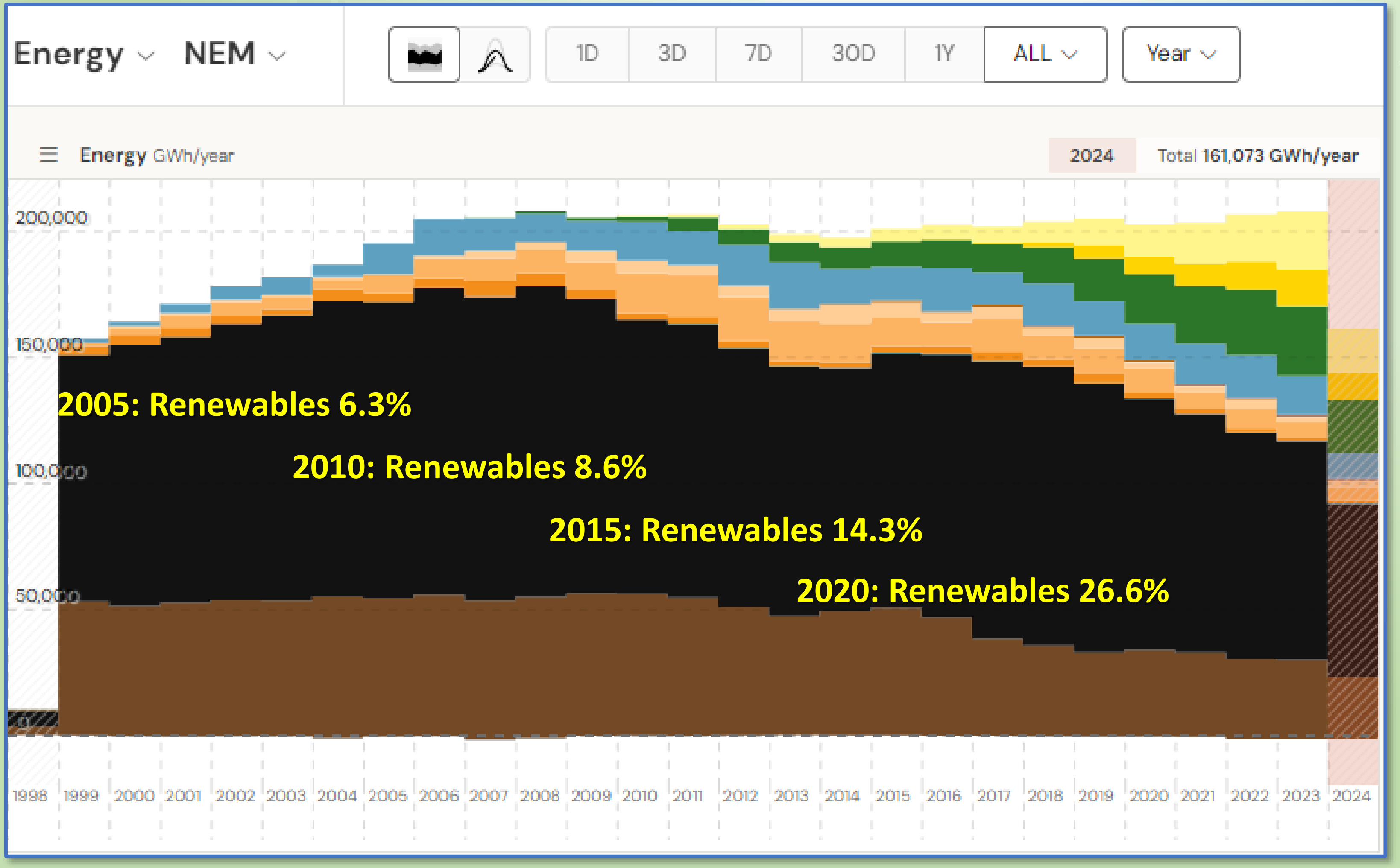
NEM’s historical and current energy mix

Expectations/scenarios for coal-fired generator closures & gas supply outlook

Global warming in the pipeline and consequences

Relentless and accelerating sea level rise (SLR)

National Energy Market's energy mix history



Source: https://explore.openelectricity.org.au/energy/nem/?range=all&interval=1y&view=discrete-time&group=Detailed

Calendar year 2023

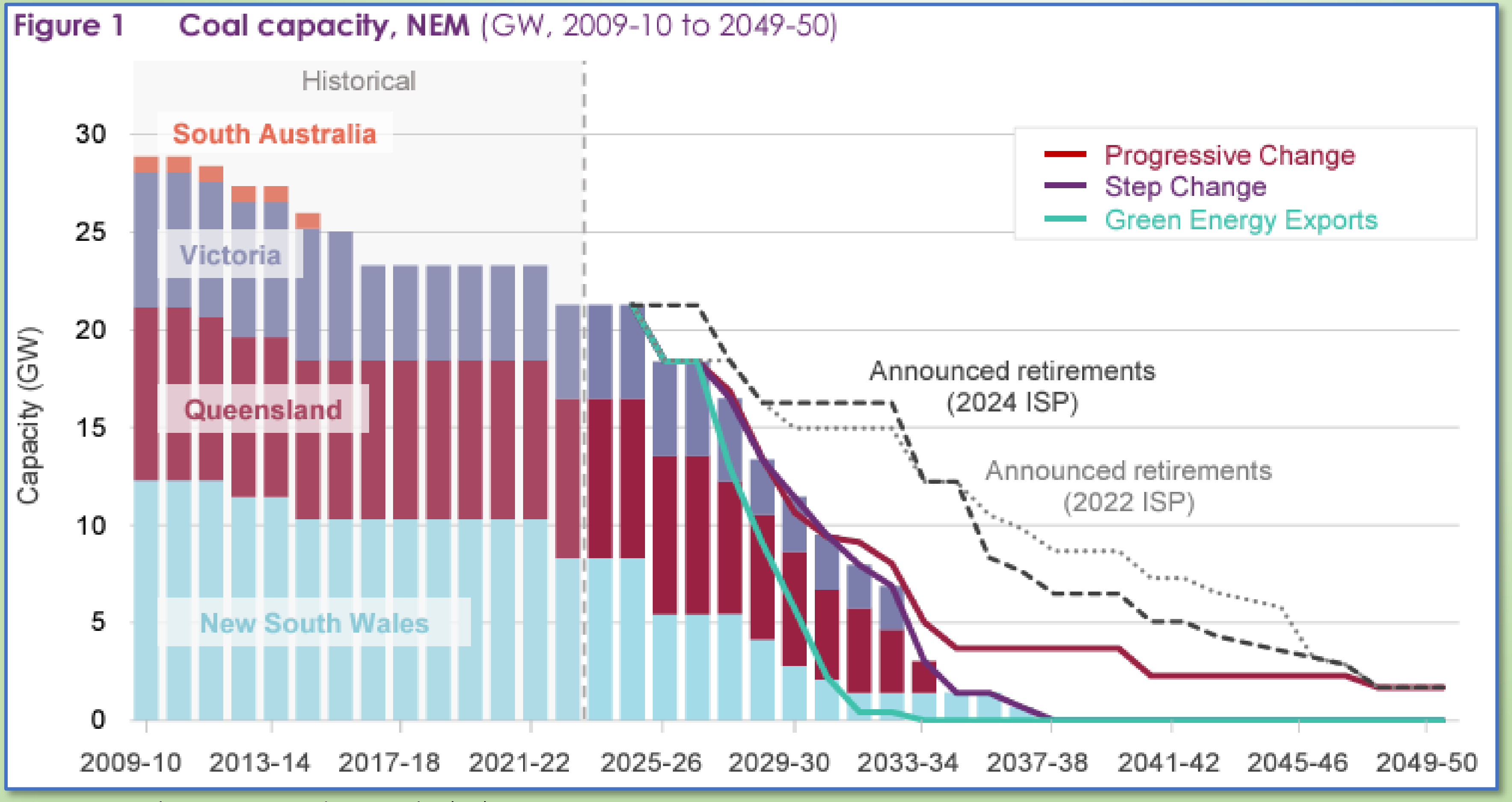
Solar (rooftop)	11.0%
Solar (Utility)	7.0%
Wind	13.2%
Hydro	7.3%
Battery (Discharging)	0.2%
Gas (Waste Coal Mine)	0.2%
Gas (Reciprocating)	0.09%
Gas (OCGT)	1.0%
Gas (CCGT)	3.2%
Gas (Steam)	0.3%
Distillate	0.02%
Bioenergy (Biomass)	0.08%
Bioenergy (Biogas)	0.04%
Coal (Black)	41.3%
Coal (Brown)	15.1%
Renewables	**38.6%**

Expected closures for coal-fired generators

NEM Region Site Name (state)	Commissioning Year(s)	Use-by Date Range (*for 40–50 year life*)	AEMO's Expected Closure Year	Capacity (*MW*)
Eraring (NSW)	1982–1984	2022–2034	2027 (2029)	4x 720
Callide B (QLD)	1988	2028–2038	2028	2x 350
Yallourn W (VIC)	1973 & 1982	2013–2034	2028	2x 360 + 2x 380
Vales Point B (NSW)	1978	2018–2028	2033	2x 660
Bayswater (NSW)	1985–1986	2025–2036	2033	4x 660
Gladstone (QLD)	1976	2016–2026	2035	6x 280
Loy Yang A (VIC)	1984–1988	2024–2038	2035	3x 560 + 1x 530
Tarong (QLD)	1984–1986	2024–2036	2037	4x 350
Mt Piper (NSW)	1992–1993	2032–2043	2040	2x 730
Kogan Creek (QLD)	2007	2047–2057	2042	1x 750
Stanwell (QLD)	1993–1996	2033–2046	2043–2046	4x 635
Loy Yang B (VIC)	1993–1996	2033–2046	2046	2x 535
Millmerran (QLD)	2002	2042–2052	2051	2x 440
Callide C (QLD)	2001	2041–2051	Not Disclosed	2x 460

Expected closure year: https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-planning-data/generation-information

AEMO's scenarios for coal power closures



Source: AEMO's *2024 Integrated System Plan* (*ISP*)

Coal retirements are occurring faster than announced dates, and may occur even faster than these forecasts. Ownership has become less attractive, with higher operating costs, reduced fuel security, high maintenance costs and greater competition from renewable energy in the wholesale market.

Precarious Lithgow LGA local coal supplies

Coal Mine	Angus Place	Invincible	Cullen Valley	Clarence	Springvale	Airly
Type	Underground Longwall	Open Cut	Open Cut	Underground Longwall	Underground Longwall	Underground Bord & Pillar
Operator	Centennial	Western Mining Solutions	Western Mining Solutions	Centennial	Centennial	Centennial
Production consent expires	**18 Aug 2024**	**31 Dec 2025**	**31 Dec 2025**	**31 Dec 2026**	**31 Dec 2028**	**31 Jan 2037**
Maximum allowable production	**4.0 Mt/y ROM**	**1.2 Mt/y ROM**	**1.0 Mt/y ROM**	**3.0 Mt/y ROM**	**5.5 Mt/y ROM**	**1.8 Mt/y ROM**
Status	C & M since 2015	Producing in 2023 & 2024	Limited production	Producing	Producing	Producing
Permitted export method	Via private road to MPPS	Road	Road	Mostly rail, by road up to 100 kt/y (east) & 200 kt/y (west)	Via conveyor to Western Coal Services, then to MPPS or Lidsdale Siding	Rail

Centennial has lodged a development application to extend the life of Angus Place Colliery called Angus Place West (APW) to extract up to 2.0 Mt/y ROM until **31 Dec 2042**. To date, no EIS has yet been made publicly available.

Australia’s east coast gas supply is in decline

Figure 8 Map of basins, major pipelines, and load centres

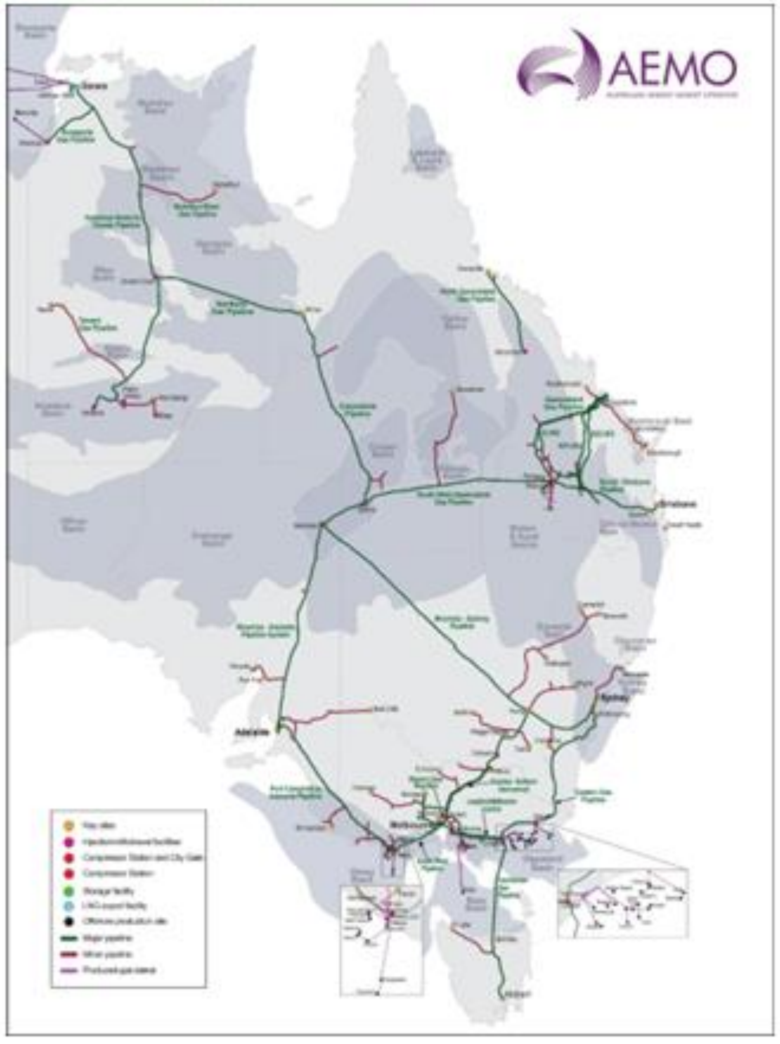
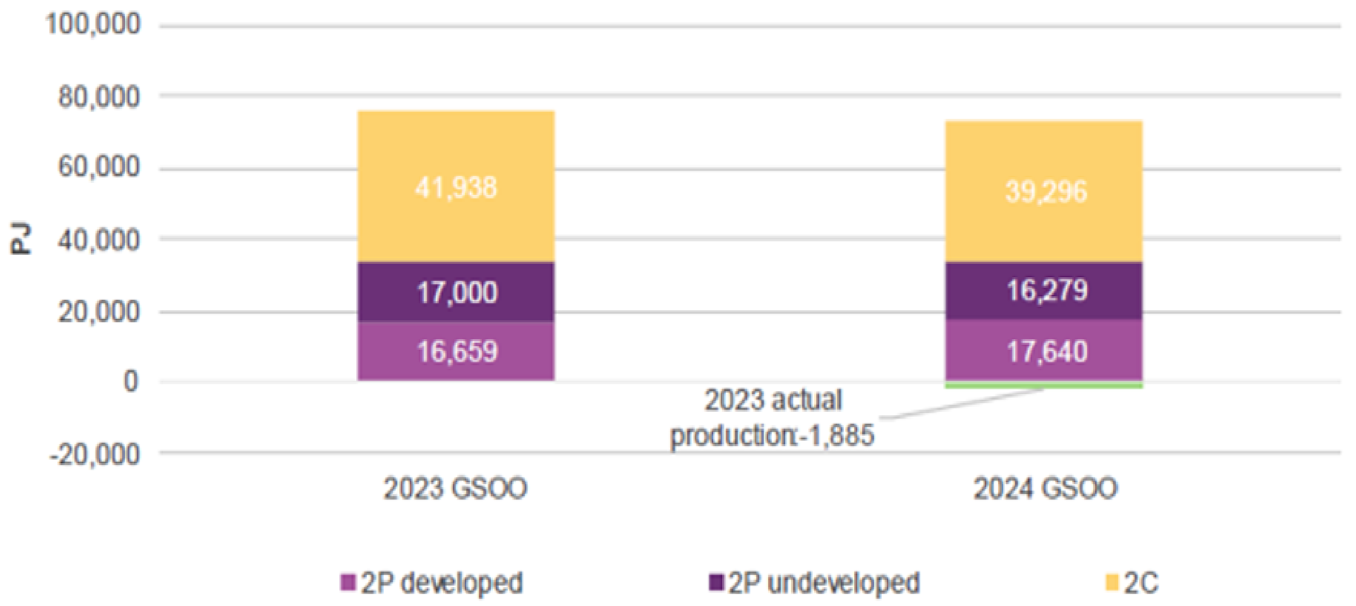


Figure 26 Reserves and resources reported in the 2023 GSOO and 2024 GSOO



Key Data (as at 31 Dec 2023):

- **2023 actual consumption: 1,885 PJ**
- **2P developed reserves: 17,640 PJ R/P = 9.4 years; plus**
- **2P undeveloped reserves: 16,279 PJ R/P = 8.6 years**
- **2C resources: 41,938 PJ these are less certain**

The 2P reserves estimate reflects statistically that there should be at least a 50% probability that the quantities actually recovered will equal or exceed the sum of estimated proved plus probable reserves. Source: *2024 Gas Statement of Opportunities*, AEMO, Mar 2024

Global gas production and top-10 producers

Natural gas (Gm^3)	2018	2019	2020	2021	2022	2023
World	3,845.3	3,964.0	3,866.2	4,043.7	4,048.6	4,059.2 (100%)
1. United States	840.9	928.1	924.8	944.5	993.4	1,035.3 (25.5%)
2. Russian Federation	669.1	679.0	638.4	702.1	618.4	586.4 (14.4%)
3. Iran	220.3	228.3	235.8	242.8	247.7	251.7 (6.2%)
4. China	161.4	176.7	194.0	209.2	221.8	234.3 (5.8%)
5. Canada	176.8	169.6	165.6	172.3	184.8	190.3 (4.7%)
6. Qatar	175.2	177.2	174.9	177.0	178.5	181.0 (4.5%)
7. Australia	127.4	146.1	145.7	147.9	154.2	151.7 (3.7%)
8. Norway	121.4	114.4	111.7	114.5	123.0	116.6 (2.9%)
9. Saudi Arabia	112.1	111.2	113.1	114.5	116.7	114.1 (2.8%)
10. Algeria	93.8	87.0	81.4	101.1	97.6	101.5 (2.5%)

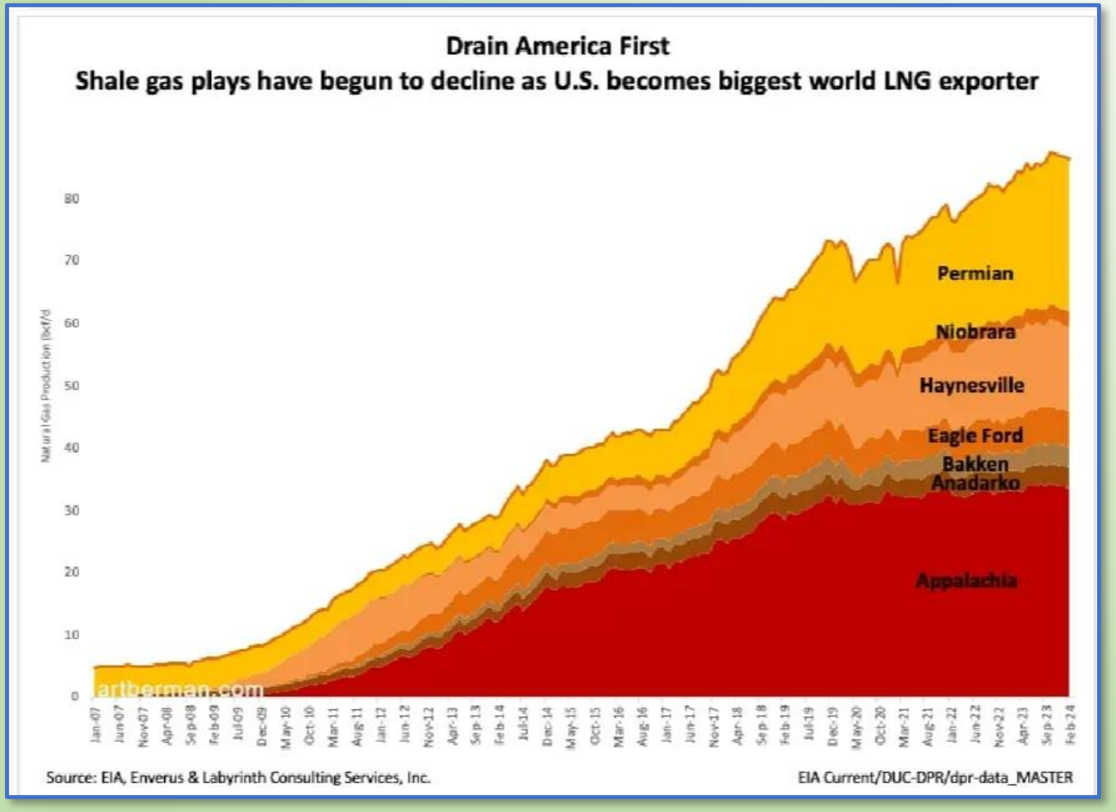
Excludes gas flared or recycled. Includes natural gas produced for Gas-to-Liquids transformation.

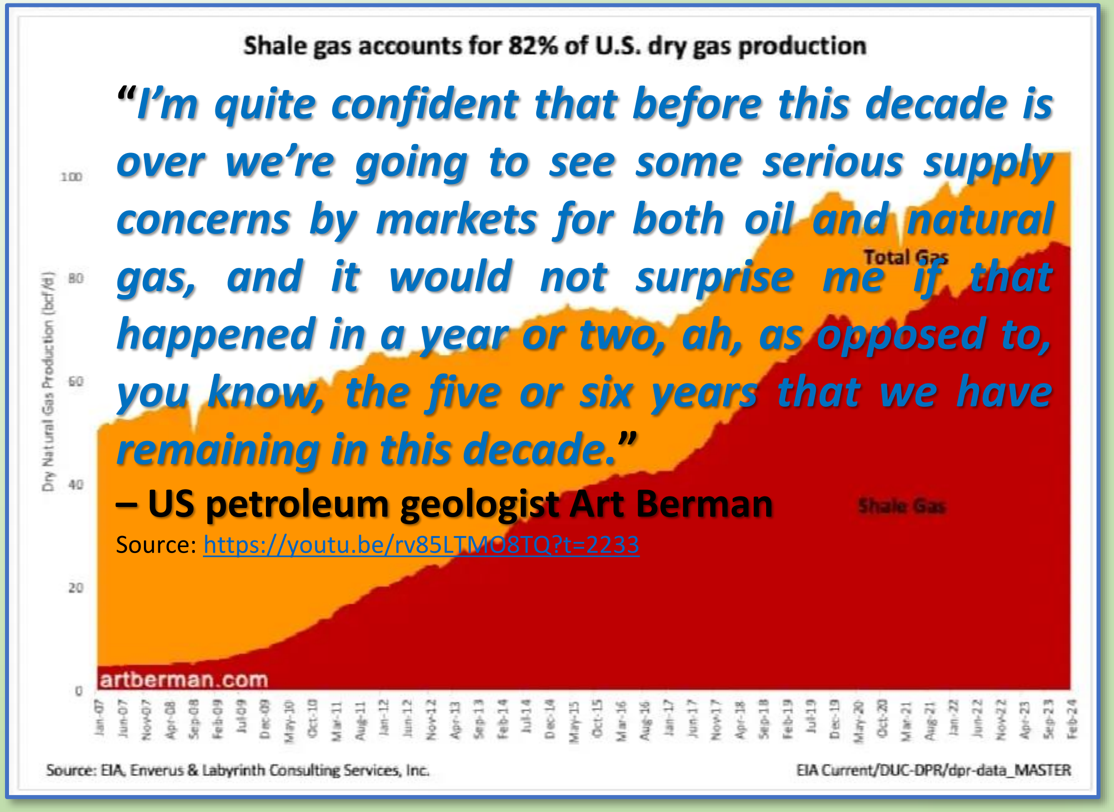
As far as possible, the data above represents standard cubic metres (measured at 15 °C and 1013 mbar), standardised using a Gross Calorific Value (GCV) of 40 MJ/m^3

Source: *Statistical Review of World Energy 2024*, Energy Institute

Australia is a minnow compared with USA and Russia

US shale gas production is now at a peak





"I'm quite confident that before this decade is over we're going to see some serious supply concerns by markets for both oil and natural gas, and it would not surprise me if that happened in a year or two, ah, as opposed to, you know, the five or six years that we have remaining in this decade."

– US petroleum geologist Art Berman

Source: https://youtu.be/rv85LTMO8TQ?t=2233

- **The US is the biggest producer of natural gas in the world and recently became the largest exporter of LNG.**
- **US shale gas plays have reached an apparent peak and may be starting to decline.**
- **At best, the rate of production growth is slowing.**

- **Any decrease in the growth of shale gas could become an acute problem because it accounts for 82% of US dry gas production.**
- **Expectations for future US shale gas production may be too high and that US gas reserves may be overstated.**

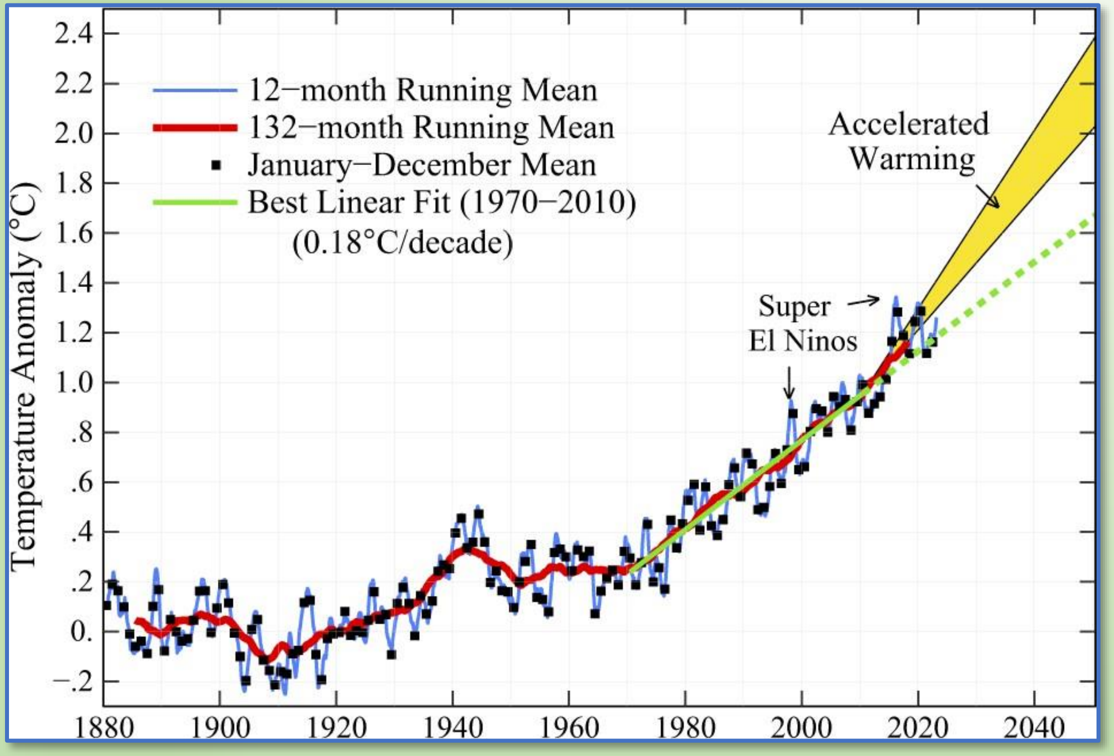
https://www.artberman.com/blog/draining-america-first-the-beginning-of-the-end-for-shale-gas/

NSW's *Climate Change (Net Zero Future) Act*

- **On 30 Nov 2023, both Houses of the NSW Parliament with multi-party support passed the *Climate Change (Net Zero Future) Act 2023*.**
- **The Act enshrines whole-of-government climate action to deliver net zero by 2050.**
- **It legislates:**
  - **guiding principles for action to address climate change that consider the impacts, opportunities and need for action in NSW;**
  - **emissions reduction targets for NSW:**
    - **50% reduction on 2005 levels by 2030;**
    - **70% reduction on 2005 levels by 2035;**
    - **Net zero by 2050.**
  - **an objective for NSW to be more resilient to a changing climate;**
  - **establishing an independent, expert Net Zero Commission to monitor, review, report on and advise on progress towards these targets.**

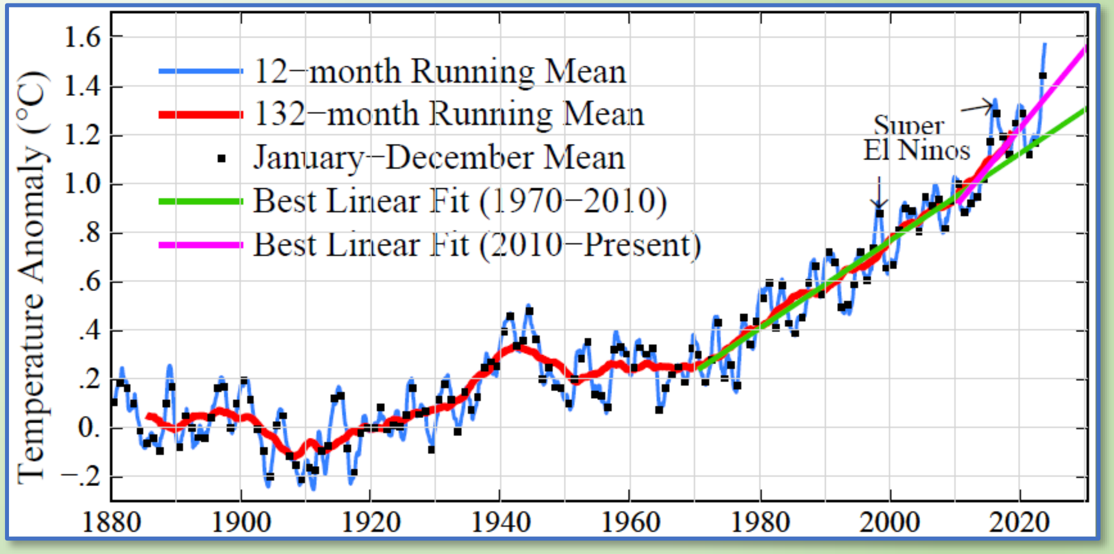
Source: https://www.energy.nsw.gov.au/nsw-plans-and-progress/government-strategies-and-frameworks/climate-change-net-zero-future-act-2023

Global warming in the pipeline



Global temperature relative to 1880–1920 baseline. The edges of the predicted post-2010 accelerated warming rate are 0.36 and 0.27 °C per decade.

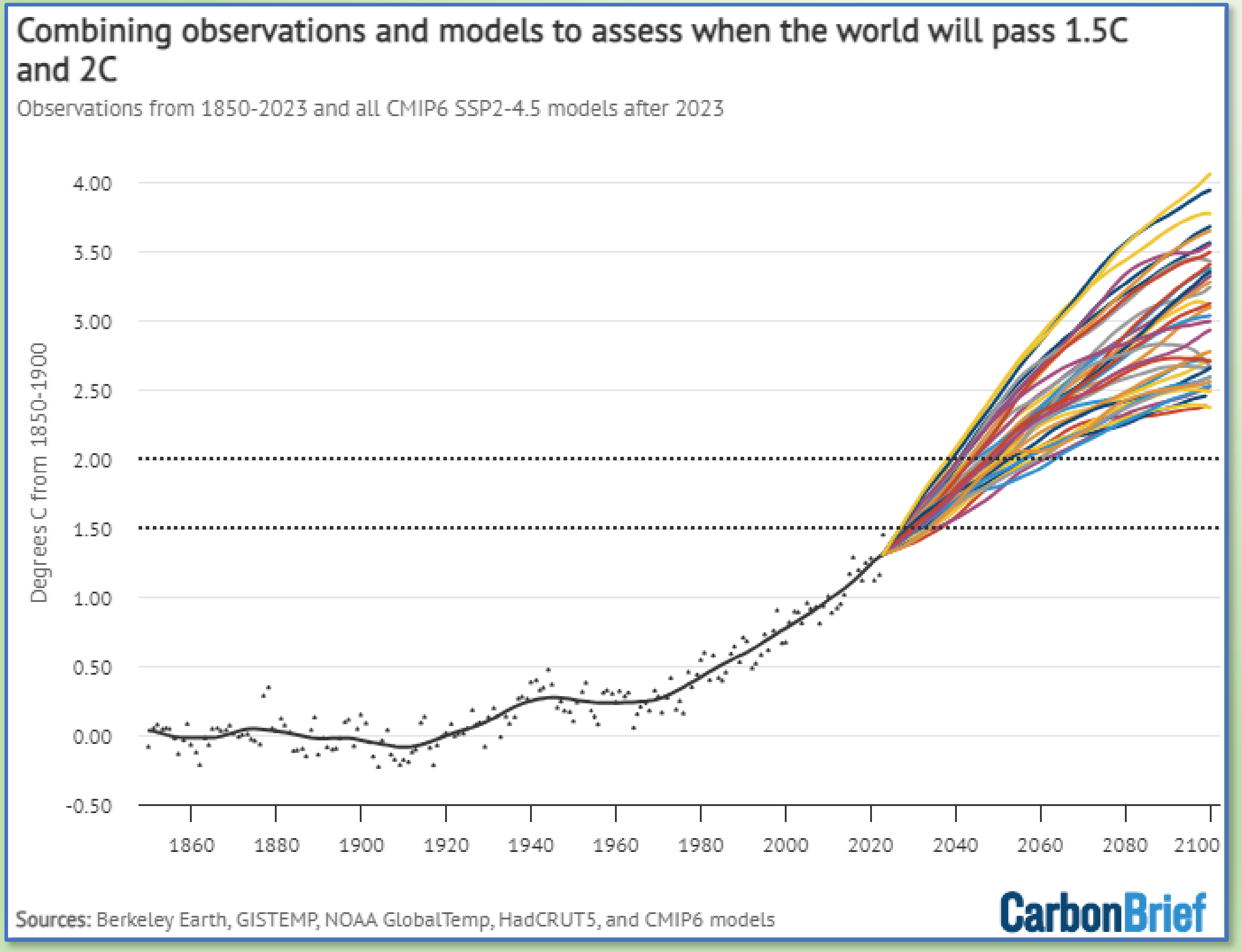
Source: *Oxford Open Climate Change*, Hansen *et al.* (2023), **Global warming in the pipeline**
https://academic.oup.com/oocc/article/3/1/kgad008/7335889



The unprecedented global warming of the past year gives the impression of a supergiant El Niño (see above), while, in fact, the El Niño was only of moderate strength.
The two large human-made climate forcings – greenhouse gases (GHGs) and aerosols – account for accelerated global warming. The growth rate of these two forcings accelerated in the past 15 years.

Source: Hansen *et al.*, 27 Jun 2024, **The World Will Cool Off – A Bit – and Other Good News!**
http://www.columbia.edu/~jeh1/mailings/2024/GlobalCooling.2024.06.27.pdf

Global Mean Surface Temperature trajectory



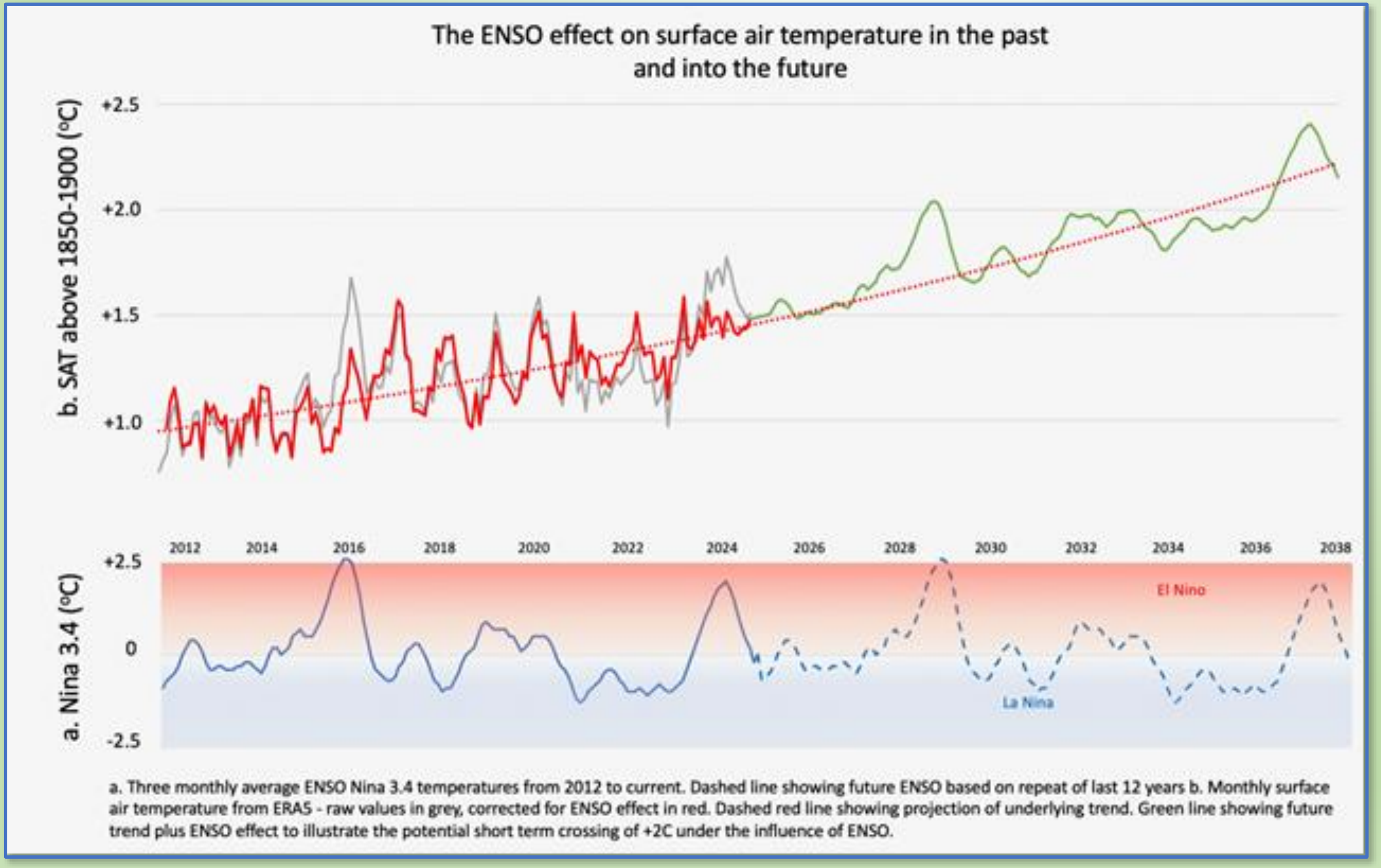
Source: https://www.carbonbrief.org/analysis-what-record-global-heat-means-for-breaching-the-1-5c-warming-limit/

Key takeaways:

- **The current longer-term (30-year average) composite GMST anomaly (relative to the 1850-1900 baseline) is +1.30 °C (Berkeley Earth dataset is warmest at +1.41 °C, NOAA GlobalTemp is coolest at +1.22 °C);**
- **Projected year of longer-term (30-year average) GMST +1.5 °C breach:**

GMST Dataset	50th %ile	5th %ile	95th %ile
Composite	**2030**	**2028**	**2036**
Berkeley Earth	2027	2025	2031
HadCRUTS	2030	2028	2036
NASA GISTEMP	2032	2029	2040
NOAA GlobalTemp	2033	2030	2041

ENSO effect on GMST: past & feasible future

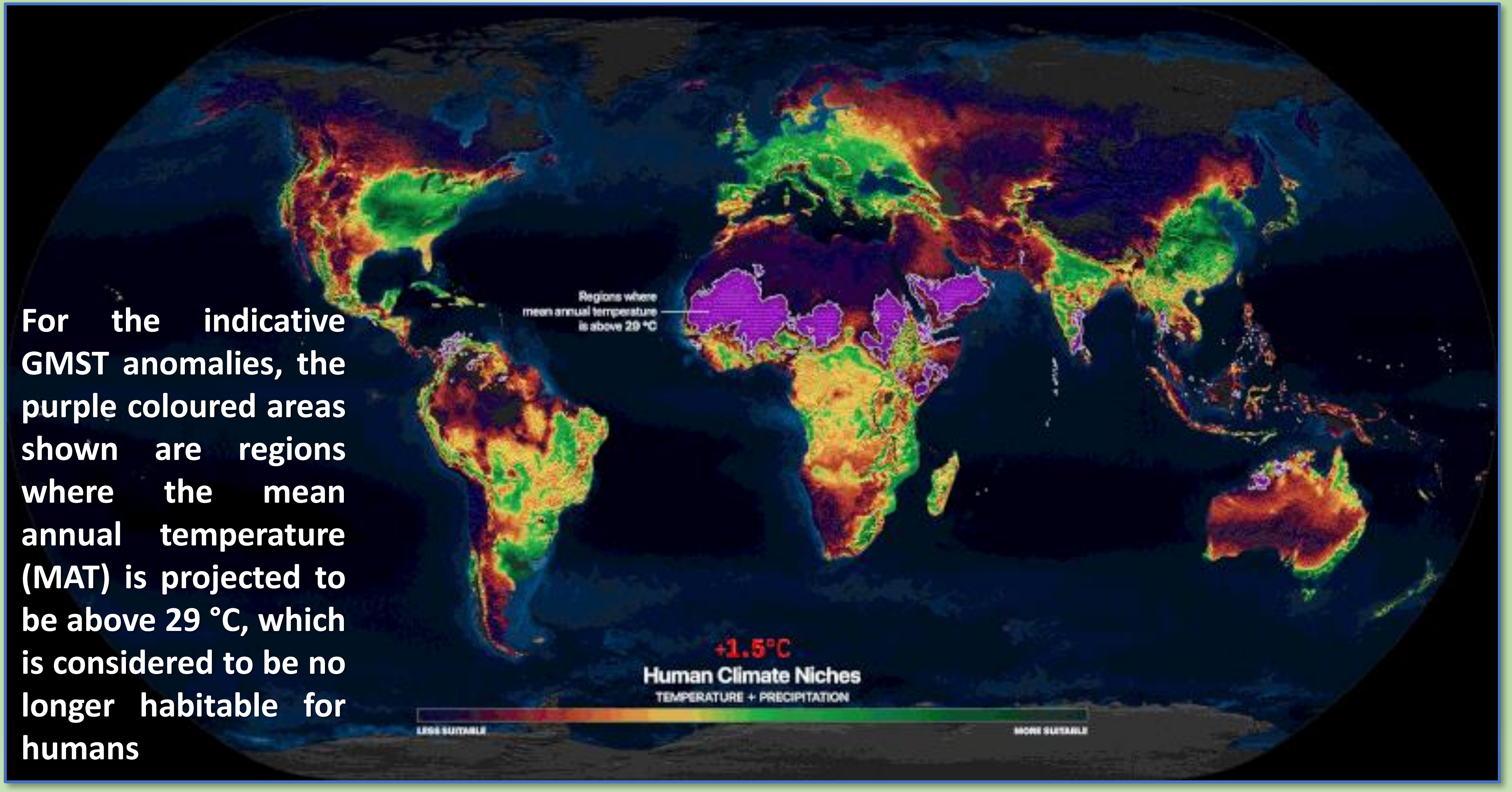


Source: https://x.com/EliotJacobson/status/1844730857170649288

- **Historic ENSO data in blue.**
- **Monthly surface air temperature (SAT) data in grey.**
- **The red line is the SAT corrected for ENSO.**
- **The red dotted line shows a gradually accelerating global warming trend.**
- **The current GMST is a little over +1.4 °C.**

Assuming continued GHG emissions coupled with existing & growing reinforcing feedbacks, the trend line crosses +1.5 °C in early 2026 and +2 °C in 2034.

Rising heat reduces ‘human climate niche’



For the indicative GMST anomalies, the purple coloured areas shown are regions where the mean annual temperature (MAT) is projected to be above 29 °C, which is considered to be no longer habitable for humans

Source: https://www.nature.com/articles/s41893-023-01132-6

Accelerating global mean sea level rise rate

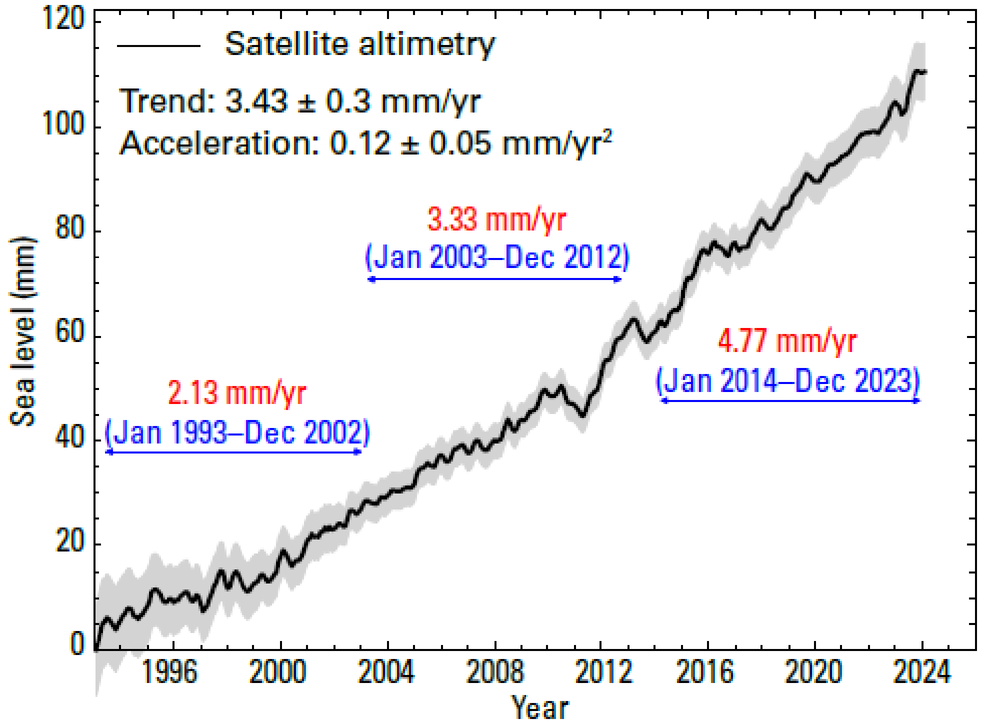


Figure 6. GMSL evolution between January 1993 and December 2023 based on satellite altimetry. The black line is the best estimate, and the grey shaded area indicates uncertainty. Red and blue annotations indicate the average rate of sea-level rise during three decades of the record as indicated.

Source: AVISO altimetry

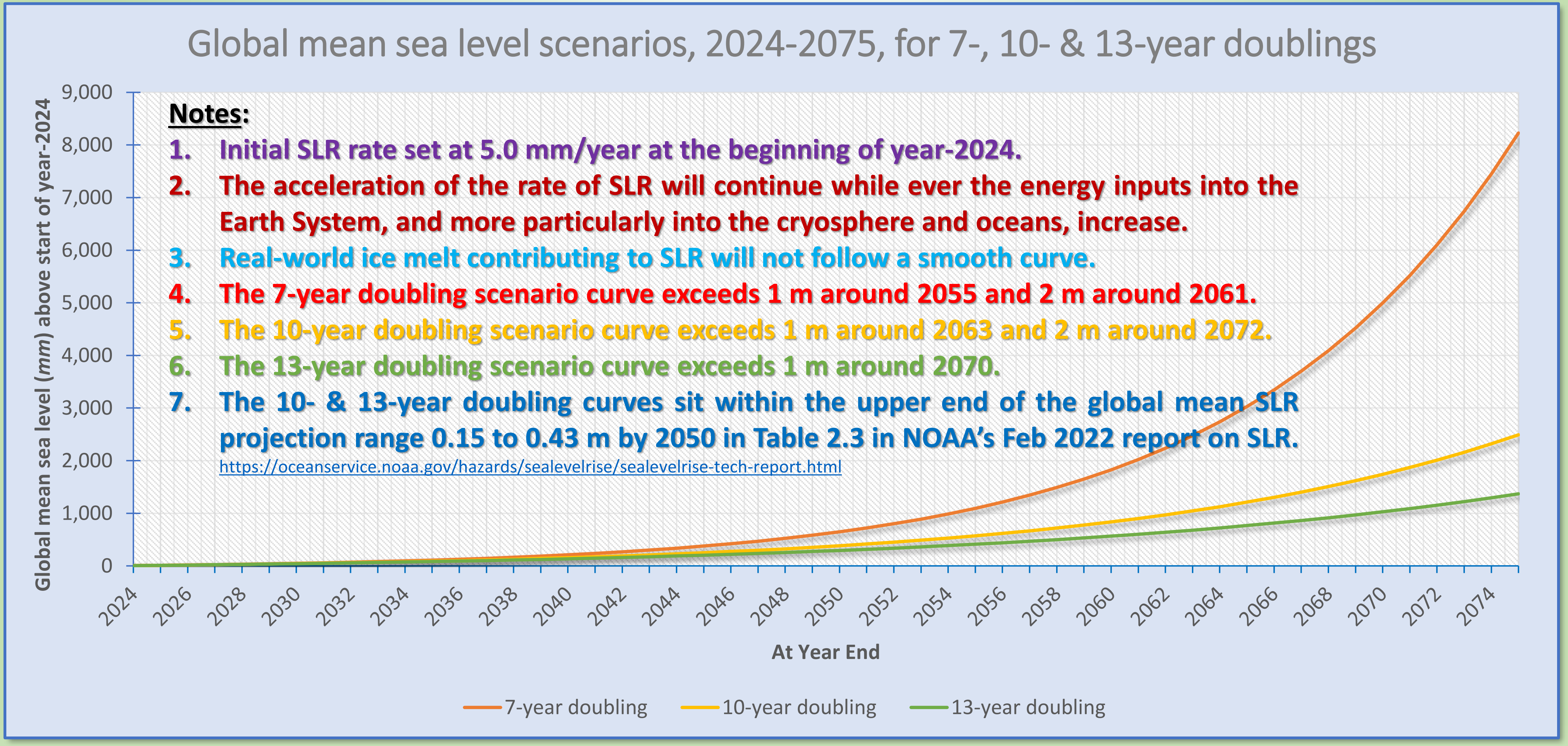
Source: https://library.wmo.int/records/item/68835-state-of-the-global-climate-2023

- **The World Meteorological Organization's recent report titled *State of the Global Climate 2023* indicates the sea level rise (SLR) rate of an average of 4.77 mm/year was observed over the period Jan 2014 through Dec 2023, with an acceleration at 0.12 ± 0.05 mm/y².**
- **The SLR rate doubling time has been around 18 years.**
- **This suggests the SLR rate is around 5.0 mm/year in year-2024.**
- In the scientific journal *Atmos. Chem. Phys.*, 16, 3761–3812, 2016, a paper by James Hansen *et al.*, titled **Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2°C global warming could be dangerous**, included (on page 3766):

  A sea level rise of 5m in a century is about the most extreme in the paleo-record (Fairbanks, 1989; Deschamps *et al.*, 2012), but the assumed 21st century climate forcing is also more rapidly growing than any known natural forcing.

- **Multi-metre SLR is highly likely before year-2100.**

Global mean sea level rise scenarios



Civil nuclear project delivery timeframes

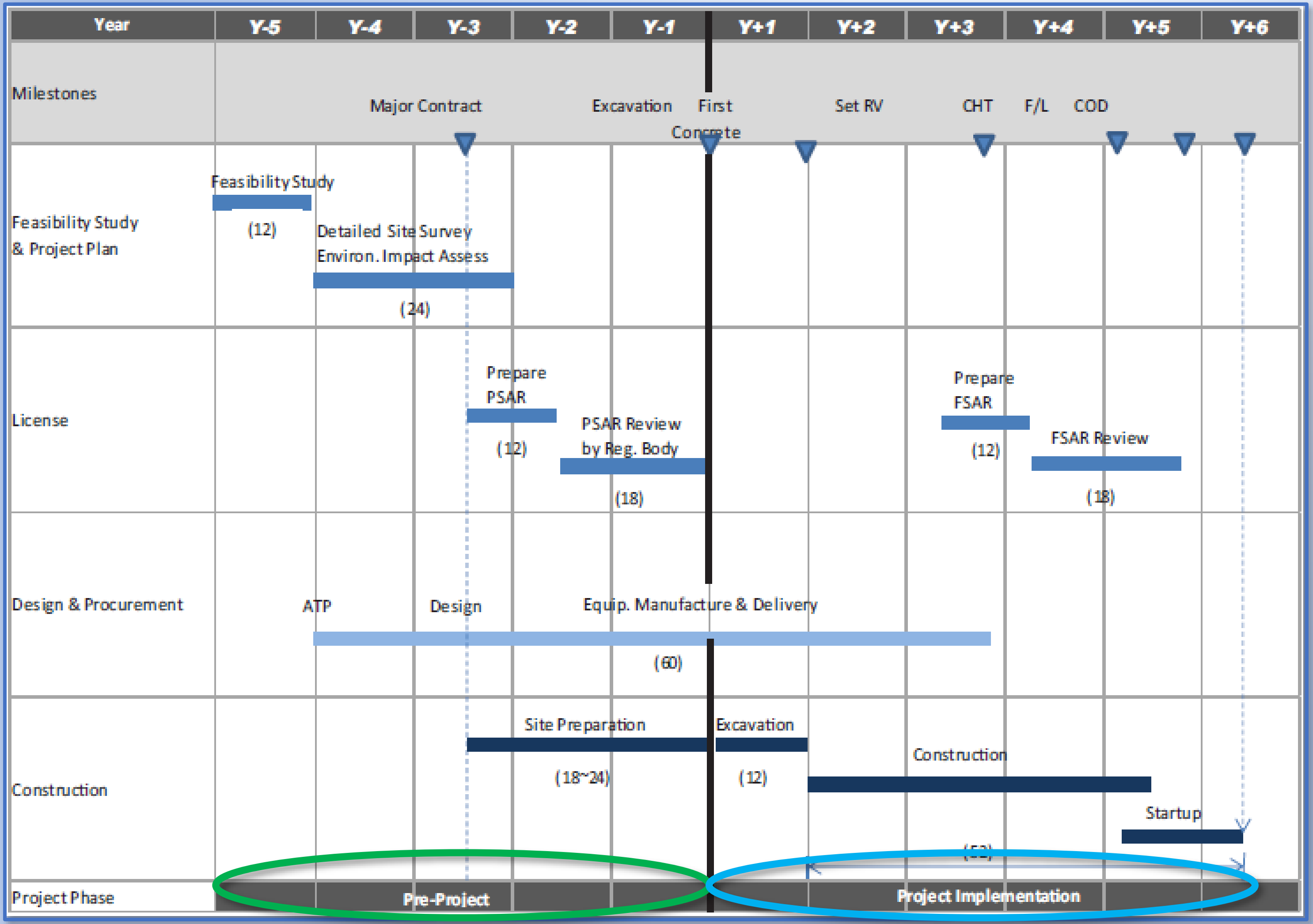
IAEA's suggested typical project delivery duration

Expected vs Real Duration from Construction Start to Grid Connection

12 recent civil nuclear project examples around the world

Hurdles for civil nuclear projects in Australia

IAEA's typical civil nuclear project duration



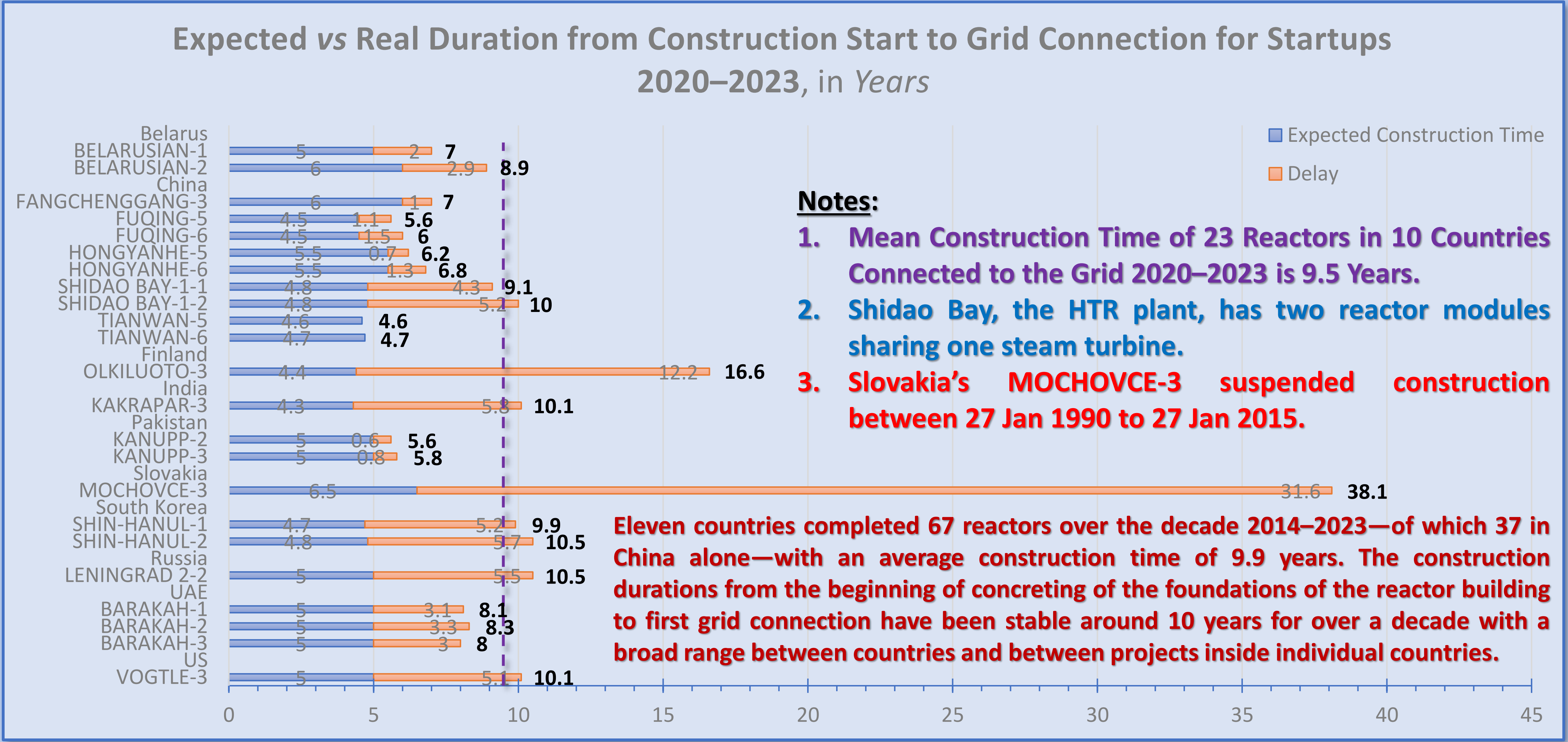
Source: IAEA Technical Report No. **NP-T-2.7**, *Project Management in Nuclear Power Plant Construction: Guidelines and Experience*

Civil nuclear power generator unit projects typically consist of two main phases:

1. **Pre-Project Phase; and**
2. **Project Implementation Phase.**

Note that the Pre-Project Phase, which includes activities for planning, an EIS, licencing, design, equipment procurements & site preparations (which are usually more difficult to observe because these activities are generally hidden from public scrutiny) require additional time, of the order of five years, BEFORE any onset of a Project Implementation Phase (i.e. first concrete pour milestone) can even begin.

Short construction times are the exceptions



Notes:

1. Mean Construction Time of 23 Reactors in 10 Countries Connected to the Grid 2020–2023 is 9.5 Years.
2. Shidao Bay, the HTR plant, has two reactor modules sharing one steam turbine.
3. Slovakia’s MOCHOVCE-3 suspended construction between 27 Jan 1990 to 27 Jan 2015.

Eleven countries completed 67 reactors over the decade 2014–2023—of which 37 in China alone—with an average construction time of 9.9 years. The construction durations from the beginning of concreting of the foundations of the reactor building to first grid connection have been stable around 10 years for over a decade with a broad range between countries and between projects inside individual countries.

Source: *World Nuclear Industry Status Report 2023*, **Figure 14 · Delays for Units Started Up 2020–2022** and *WNISR2024*, **Figure 12 · Delays for Units Started Up, 2021–2023**

UAE's Barakah four reactor project

- **Initial feasibility investigations began with an *Energy Planning Study* in 2006, leading to the establishment of the UAE's *Nuclear Policy*, announced in 2008. The first reactor was expected to be operational in 2017, the second in 2018, the third in 2019, and the fourth in 2020. See Slide 6 at:** https://www.isoe-network.net/publications/pub-proceedings/symposia-thematic/policy-standards-and-regulation/national-regulations/3092-bilal2015-ppt-1/file.html
- **The IAEA's Power Reactor Information System (PRIS) provides information about commercial power reactor units throughout the world, but it doesn't include the prerequisite time required to plan these units (before the first concrete is poured). The PRIS data for the UAE's Barakah project includes:**

Reactor Unit Designation	Type	Model	Thermal Capacity (MW_{th})	Net Capacity (MW_e)	Construction Start Date	First Grid Connection Date	Commence Full Commercial Operations	Construct to Operate (*y; m; d*)
BARAKAH-1	PWR	APR-1400	3,983	1,337	19 Jul 2012	19 Aug 2020	**01 Apr 2021**	8; 08; 14
BARAKAH-2	PWR	APR-1400	3,983	1,337	15 Apr 2013	14 Sep 2021	**24 Mar 2022**	8; 11; 10
BARAKAH-3	PWR	APR-1400	3,983	1,337	24 Sep 2014	08 Oct 2022	**24 Feb 2023**	8; 05; 01
BARAKAH-4	PWR	APR-1400	3,983	1,310	30 Jul 2015	23 Mar 2024	**Pending**	9; 02; 26+

- **UAE has demonstrated it took more than 15-years to get its first reactor unit operational from scratch.**
- **Some estimates suggest the all up cost with finance is $US34 billion, or around AU$51 billion.**

Finland's OLKILUOTO-3 reactor project

- **The first licence application for the third unit was made in Dec 2000 and the date of the unit's entry into service was estimated to be 2010.**
- **In Feb 2005, the Finnish government gave its permission to TVO to construct a new nuclear reactor, making Finland the first Western European country in 15 years to order one.**
- **The PRIS data for Finland's OLKILUOTO-3 project includes:**

Reactor Unit Designation	Type	Model	Thermal Capacity (MW_{th})	Net Capacity (MW_e)	Construction Start Date	First Grid Connection Date	Commence Full Commercial Operations	Construct to Operate (*y; m; d*)
OLKILUOTO -3	PWR	EPR	4,300	1,600	12 Aug 2005	12 Mar 2022	**01 May 2023**	17; 08; 20

- **Finland has demonstrated it took more than 22-years to get its reactor unit operational from scratch.**
- **Experts have put OLKILUOTO-3's final price tag at around €11 billion, or over AU$17.5 billion.**

Source: https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=860

USA's VOGTLE-3 & -4 twin reactor project

- **In Aug 2006, Southern Nuclear formally applied for an Early Site Permit (ESP) for two additional units, and in Mar 2008, submitted an application for a Combined Construction and Operating License (COL).**
- **In 2006, Westinghouse said it could build an AP-1000 reactor for as little as US$1.4 billion. In Apr 2008, Georgia Power Company reached a contract agreement for two AP-1000 reactors designed by Westinghouse, owned by Toshiba.**
- **The PRIS data for USA's VOGTLE-3 & -4 twin reactor project includes:**

Reactor Unit Designation	Type	Model	Thermal Capacity (MW_{th})	Net Capacity (MW_e)	Construction Start Date	First Grid Connection Date	Commence Full Commercial Operations	Construct to Operate (y; m; d)
VOGTLE-3	PWR	AP-1000	3,400	1,117	02 Mar 2013	31 Mar 2023	**31 Jul 2023**	10; 04; 30
VOGTLE-4	PWR	AP-1000	3,400	1,075	19 Nov 2013	06 Mar 2024	**29 Apr 2024**	10; 05; 11

- **USA has demonstrated it took around 17-years to get VOGTLE-3 operational from scratch.**
- **Experts have put the Vogtle twin reactor final price tag at more than US$30 billion, or AU$44 billion.**
- **A similar twin reactor project for VC SUMMER-2 & -3 in South Carolina was abandoned in 2017 with estimated costs at around US$9.8 billion.**

China's HAIYANG-1 & -2 twin AP1000 project

- **Haiyang Nuclear Power Plant is located in Haiyang, Shandong province. It is the second site in China to house Westinghouse AP-1000 units, after the Sanmen Nuclear Power Station.**
- **Site preparation works began one month ahead of schedule, on 30 Jul 2008.**
- **The PRIS data for China's HAIYANG-1 & -2 twin Westinghouse AP-1000 reactor project includes:**

Reactor Unit Designation	Type	Model	Thermal Capacity (MW_{th})	Net Capacity (MW_e)	Construction Start Date	First Grid Connection Date	Commence Full Commercial Operations	Construct to Operate (y; m; d)
HAIYANG-1	PWR	AP-1000	3,415	1,170	24 Sep 2009	17 Aug 2018	**22 Oct 2018**	9; 00; 29
HAIYANG-2	PWR	AP-1000	3,415	1,070	20 Jun 2010	13 Oct 2018	**09 Jan 2019**	8; 06; 21

- **On 7 Jul 2022, construction began on HAIYANG-3, and HAIYANG-4 began construction on 22 Apr 2023. These are both a CAP1000 model, which is a Sino standardization of the Westinghouse AP-1000 design.**
- **Even the Chinese, with decades of nuclear power development experience, are demonstrating that nuclear power projects are requiring significantly more than a decade to get up-and-running from scratch.**

Japan’s Shimane Nuclear Power Plant

- **The Shimane Nuclear Power Plant is located in the town of Kashima-chou in the city of Matsue in the Shimane Prefecture. It is owned and operated by the Chūgoku Electric Power Company.**
- **Following the Mar 2011 Fukushima disaster, a decision was made to decommission SHIMANE-1. It was permanently shutdown on 30 Apr 2015, more than 41 years since it was first connected to the grid.**
- **SHIMANE-2 has been offline since 17 Jan 2012, undergoing inspections to meet new regulatory standards established in the wake of the Fukushima disaster. It is scheduled to restart in early Dec 2024.**
- **Chugoku Electric Power Company announced that it aims to start the operation of SHIMANE-3 by FY2031.**
- **The PRIS data for Japan’s SHIMANE-1, -2 & -3 includes:**

Reactor Unit Designation	Type	Model	Thermal Capacity (MW_{th})	Net Capacity (MW_e)	Construction Start Date	First Grid Connection Date	Commence Full Commercial Operations	Construct to Operate (y; m; d)
SHIMANE-1	BWR	BWR-3	1,380	439	02 Jul 1970	02 Dec 1973	**29 Mar 1974**	3; 08; 28
SHIMANE-2	BWR	BWR-3	2,436	789	02 Feb 1985	11 Jul 1988	**10 Feb 1989**	4; 00; 09
SHIMANE-3	BWR	ABWR	3,926	1,325	24 Oct 2006	**N/A**	**N/A**	**?**

- **If all goes to the latest plan, SHIMANE-3 will take more than 25-years to complete and begin operations.**

France's FLAMANVILLE-3 reactor project

- **Preparatory work for the reactor project began in summer 2006. The FLAMANVILLE-3 reactor was originally expected to cost €3 billion and be ready in four years.**
- **The process of loading fuel assemblies into the core of the FLAMANVILLE-3 reactor began on 8 May 2024 and has now been completed ahead of its start-up.**
- **The PRIS data for France's FLAMANVILLE-3 reactor project includes:**

Reactor Unit Designation	Type	Model	Thermal Capacity (MW_{th})	Net Capacity (MW_e)	Construction Start Date	First Grid Connection Date	Commence Full Commercial Operations	Construct to Operate (*y; m; d*)
FLAMANVILLE -3	PWR	EPR	4,300	1,630	03 Dec 2007	**Pending**	**N/A**	16; 10; 23+

- **France has demonstrated it will take more than 18-years to get FLAMANVILLE-3 reactor unit operational from scratch.**
- **Experts have put FLAMANVILLE-3's price tag currently at around €13.2 billion, or over AU$21 billion.**

Source: https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=860

China’s SHIDAO BAY-1 twin reactor project

- **In Nov 2005, China announced its intention to scale up the HTR-10 experimental reactor for commercial power generation. The first two 250 MW_{th} High-Temperature Reactor-Pebble-bed Modules (HTR-PM) were planned to be installed at Shidao Bay, and together drive a single steam turbine generating 200 MW_e.**
- **Originally to be started in 2011, the project was postponed after the Fukushima Daiichi nuclear disaster in Japan in March 2011. In 2009, it was planned to be finished in 2013.**
- **The PRIS data for China’s SHIDAO BAY-1 (SHIDAOWAN-1) twin reactor project includes:**

Reactor Unit Designation	Type	Model	Thermal Capacity (MW_{th})	Net Capacity (MW_e)	Construction Start Date	First Grid Connection Date	Commence Full Commercial Operations	Construct to Operate (*y; m; d*)
SHIDAO BAY-1	HTGR	HTR-PM	2x 250	200	09 Dec 2012	14 Dec 2021	**06 Dec 2023**	10; 11; 28

- **China has demonstrated it took more than 18-years to get its twin demonstration reactors designated SHIDAOBAY-1 (SHIDAOWAN-1) operational from scratch.**
- **The World Nuclear Association states that the cost of the demonstration HTGR was US$6,000 (AU$9,200) per kilowatt, three times higher than early cost estimates and 2-3 times higher than the cost of China’s larger Hualong reactors per kilowatt.**

Russia's floating twin small reactor project

- The project for a floating nuclear power station began in 2000, when the Ministry for Atomic Energy of the Russian Federation (Rosatom) chose Severodvinsk in Arkhangelsk Oblast as the construction site, Sevmash was appointed as general contractor. The Rosatom project is the first floating nuclear power plant intended for mass production. The initial plan was to manufacture at least seven of the vessels by 2015.
- The PRIS data for Russia's AKADEMIK LOMONOSOV-1 & -2 floating twin small reactor project includes:

Reactor Unit Designation	Type	Model	Thermal Capacity (MW_{th})	Net Capacity (MW_e)	Construction Start Date	First Grid Connection Date	Commence Full Commercial Operations	Construct to Operate (y; m; d)
AKADEMIK LOMONOSOV -1	PWR	KLT-40S 'Floating'	150	32	15 Apr 2007	19 Dec 2019	**22 May 2020**	13; 01; 08
AKADEMIK LOMONOSOV -2	PWR	KLT-40S 'Floating'	150	32	15 Apr 2007	19 Dec 2019	**22 May 2020**	13; 01; 08

- Russia has demonstrated it took **around 20-years** to get its twin reactor units operational from scratch.
- The initial estimate of around 6 billion roubles ($US\$_{2007}$232 million) grew to **at least 37 billion roubles as of 2015 ($US\$_{2015}$740 million)**. The Nuclear Energy Agency estimates energy costs an estimated **US$200/MWh.**

South Korea's SHIN-HANUL-1 & -2 project

- **The Hanul Nuclear Power Plant (originally the Uljin NPP) is a large nuclear power station in the North Gyeongsang Province of South Korea. The facility has six pressurized water reactors (PWRs) with a total installed capacity of 5,881 MW. The first went online in 1988. In the early 2000s it was the third largest operational nuclear power plant in the world and the second largest in South Korea. The plant's name was changed from Uljin to Hanul in 2013.**
- **On 4 May 2012, ground was broken for 2 new reactors, Shin ("new") Uljin-1 & -2 using APR-1400 reactors.**
- **The PRIS data for South Korea's SHIN-HANUL-1 & -2 twin reactor project includes:**

Reactor Unit Designation	Type	Model	Thermal Capacity (MW_{th})	Net Capacity (MW_e)	Construction Start Date	First Grid Connection Date	Commence Full Commercial Operations	Construct to Operate (y; m; d)
SHIN-HANUL-1	PWR	APR-1400	3,983	1,340	10 Jul 2012	07 Dec 2022	**31 Jul 2023**	10; 04; 28
SHIN-HANUL-2	PWR	APR-1400	3,983	1,340	19 Jun 2013	21 Dec 2023	**05 Apr 2024**	10; 09; 18

- **Despite decades of nuclear power development experience, South Korea is demonstrating that nuclear power projects are requiring significantly more than a decade to get up-and-running from scratch.**

UK's HINKLEY POINT C twin reactor project

- The Hinkley Point site was one of eight announced by the British government in 2010, and in November 2012 a nuclear site license was granted. On 15 Sep 2016 the UK government approved the project with some safeguards for the investment.
- The PRIS data for the UK's HINKLEY POINT C-1 & -2 twin reactor project includes:

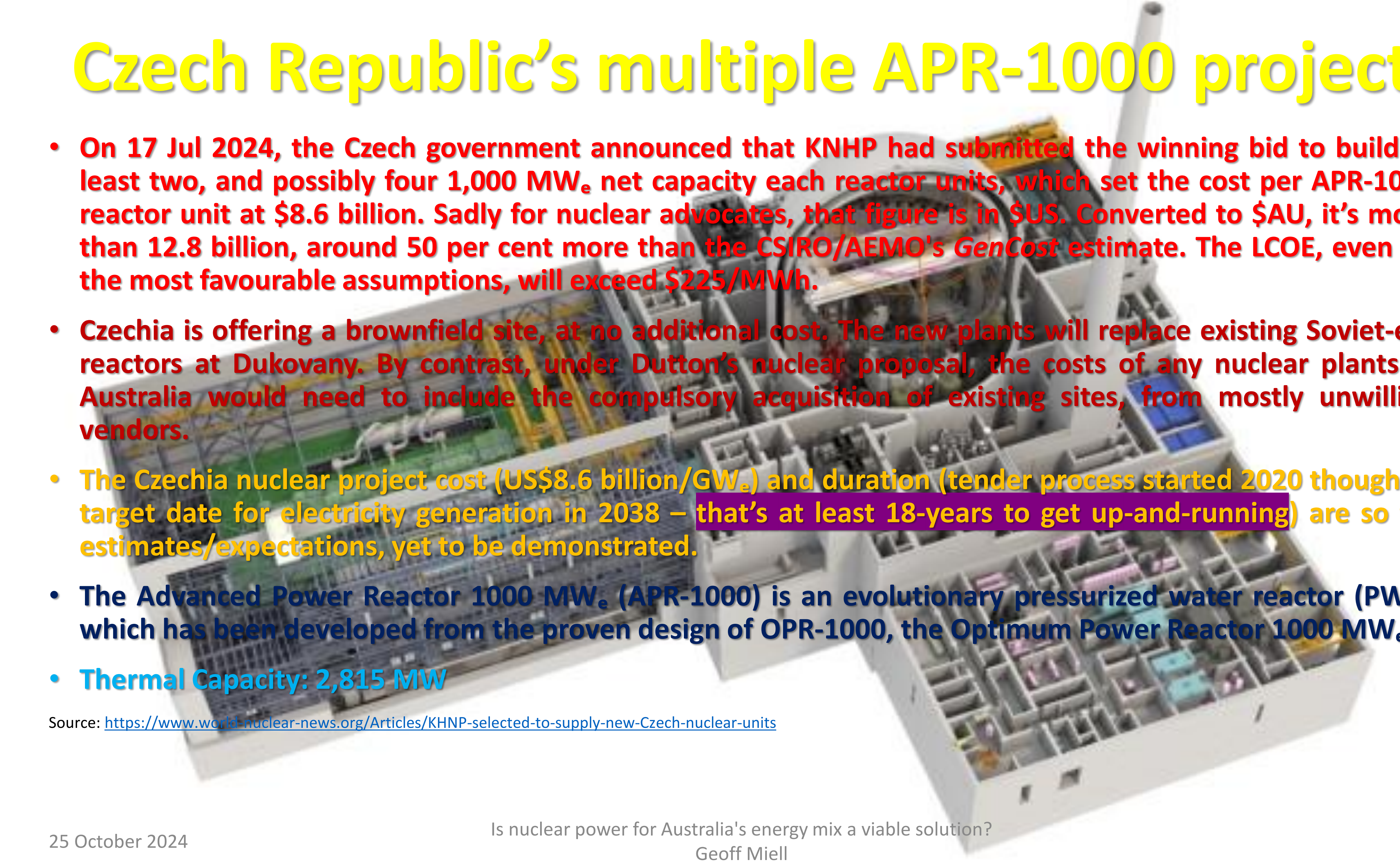
Reactor Unit Designation	Type	Model	Thermal Capacity (MW_{th})	Net Capacity (MW_e)	Construction Start Date	First Grid Connection Date	Commence Full Commercial Operations	Construct to Operate (y; m; d)
HINKLEY POINT C-1	PWR	EPR-1750	4,524	1,630	11 Dec 2018	N/A	N/A	?
HINKLEY POINT C-2	PWR	EPR-1750	4,524	1,630	12 Dec 2019	N/A	N/A	?

- The commissioning date for HINKLEY POINT C-1 is now expected for 2029–2031. This suggests that it will likely take at least 19-years to get the first of these twin reactors operational.
- Experts have put the HINKLEY POINT C-1 & -2 twin reactor project price tag currently at around £31–34 billion, or AU$58.3–63.9 billion.

Canada's Darlington New Nuclear Project

- The Darlington New Nuclear Project (DNNP) involves the site preparation, construction, operation, decommissioning and abandonment of up to four new nuclear reactors at the existing Darlington site, owned by Ontario Power Generation (OPG).
- OPG submitted an application for a site preparation licence to the Canadian Nuclear Safety Commission (CNSC) in 2006, followed by an environmental impact statement (EIS).
- In 2012, the Government of Canada issued its response report, agreeing with all recommendations directed to federal departments and determining that the DNNP is not likely to adversely affect the environment. The CNSC issued a 10 year site preparation licence to OPG.
- In Dec 2021, OPG announced its selection of the General Electric Hitachi BWRX-300 reactor for deployment at the DNNP site. The BWRX-300 is a 300 MW_e water-cooled, natural circulation small modular reactor.
- Based on the CNSC's and other federal authorities' comprehensive evaluation and assessment of OPG's documentation, CNSC staff recommend that the Commission determine that the deployment of up to four BWRX-300 reactors at the DNNP remains bounded by the original EA.
- Pending CNSC regulatory approval, the project will be ready for nuclear construction work to begin in early 2025. The first unit is expected to be in commercial operation by late-2029, with the rest of the units coming online by the mid-2030s. The DNNP, if it all goes to the latest plan, will have taken more than 22 years to get-up-and-running.

Czech Republic's multiple APR-1000 project



- On 17 Jul 2024, the Czech government announced that KNHP had submitted the winning bid to build at least two, and possibly four 1,000 MW_e net capacity each reactor units, which set the cost per APR-1000 reactor unit at $8.6 billion. Sadly for nuclear advocates, that figure is in $US. Converted to $AU, it's more than 12.8 billion, around 50 per cent more than the CSIRO/AEMO's *GenCost* estimate. The LCOE, even on the most favourable assumptions, will exceed $225/MWh.
- Czechia is offering a brownfield site, at no additional cost. The new plants will replace existing Soviet-era reactors at Dukovany. By contrast, under Dutton's nuclear proposal, the costs of any nuclear plants in Australia would need to include the compulsory acquisition of existing sites, from mostly unwilling vendors.
- The Czechia nuclear project cost (US$8.6 billion/$GW_e$) and duration (tender process started 2020 though to target date for electricity generation in 2038 – that's at least 18-years to get up-and-running) are so far estimates/expectations, yet to be demonstrated.
- The Advanced Power Reactor 1000 MW_e (APR-1000) is an evolutionary pressurized water reactor (PWR) which has been developed from the proven design of OPR-1000, the Optimum Power Reactor 1000 MW_e.
- Thermal Capacity: 2,815 MW

Source: https://www.world-nuclear-news.org/Articles/KHNP-selected-to-supply-new-Czech-nuclear-units

Hurdles for nuclear projects in Australia

- **HURDLE #1: Any government would need to gain sufficient control over both houses of the Australian Parliament, the House of Representatives and the Senate, to amend both the:**
  - ***Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth), Section 140A: No approval for certain nuclear installations;**
  - ***Australian Radiation Protection and Nuclear Safety Act (1998)*, where subsection 10(2) expressly prohibits the CEO from granting a licence for the construction or operation of any of the following nuclear installations: a nuclear fuel fabrication plant; a nuclear power plant; an enrichment plant; or a reprocessing facility;**
  - **and then set-up appropriate legislation and a regulatory body to oversee and license suitable nuclear power facility designs, constructions, operations, fuel and waste managements, decommissioning, *etc*.**
- **HURDLE #2: Overcome relevant state legislations prohibiting nuclear power generation facilities:**
  - **NSW: *Uranium Mining and Nuclear Facilities (Prohibitions) Act 1986 No 194*;**
  - **Victoria: *Nuclear Activities (Prohibitions) Act 1983*;**
  - **Queensland: *Nuclear Facilities Prohibition Act 2007*.**
- **HURDLE #3: Owners of Australian coal-fired power stations have indicated they have no interest in developing nuclear power generation, like apparently AGL Energy, EnergyAustralia, Origin Energy, and Alinta Energy. Energy executives, fund managers and investors do not think nuclear energy is financially viable in Australia.**
- **HURDLE #4: Former Australian Chief Scientist Dr Alan Finkel says: *"If we did large-scale* [nuclear power]*, I would imagine something approaching 20 years in Australia."*** https://www.smh.com.au/politics/federal/coalition-s-campaign-for-nuclear-energy-implausible-experts-say-20230821-p5dy2a.html

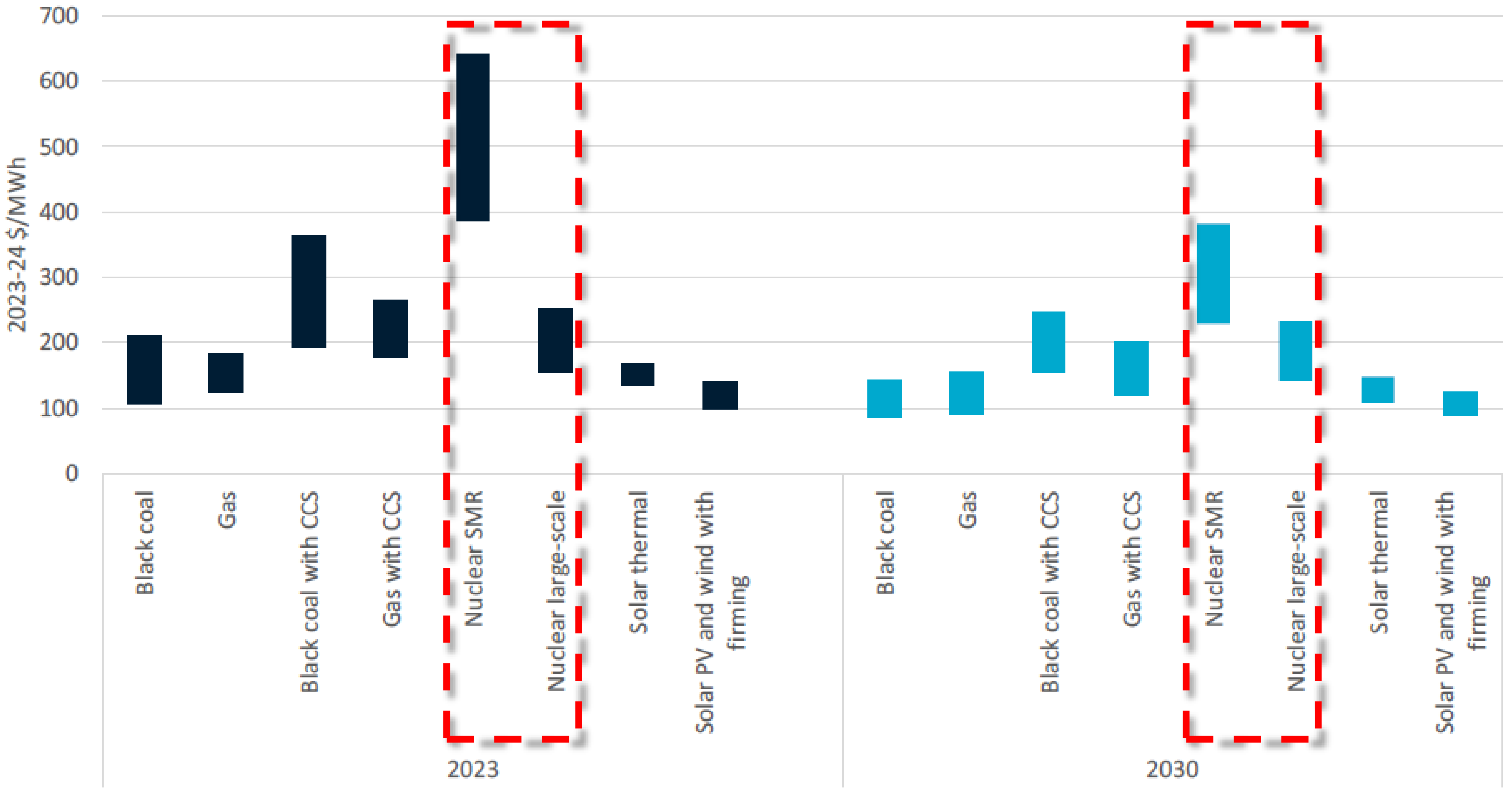
Levelised Cost of Energy (LCOE) & Capital Cost Comparisons

CSIRO/AEMO's *GenCost 2023-24*

Lazard's *LCOE+ v17*

IEEFA's *Nuclear in Australia would increase household power bills*

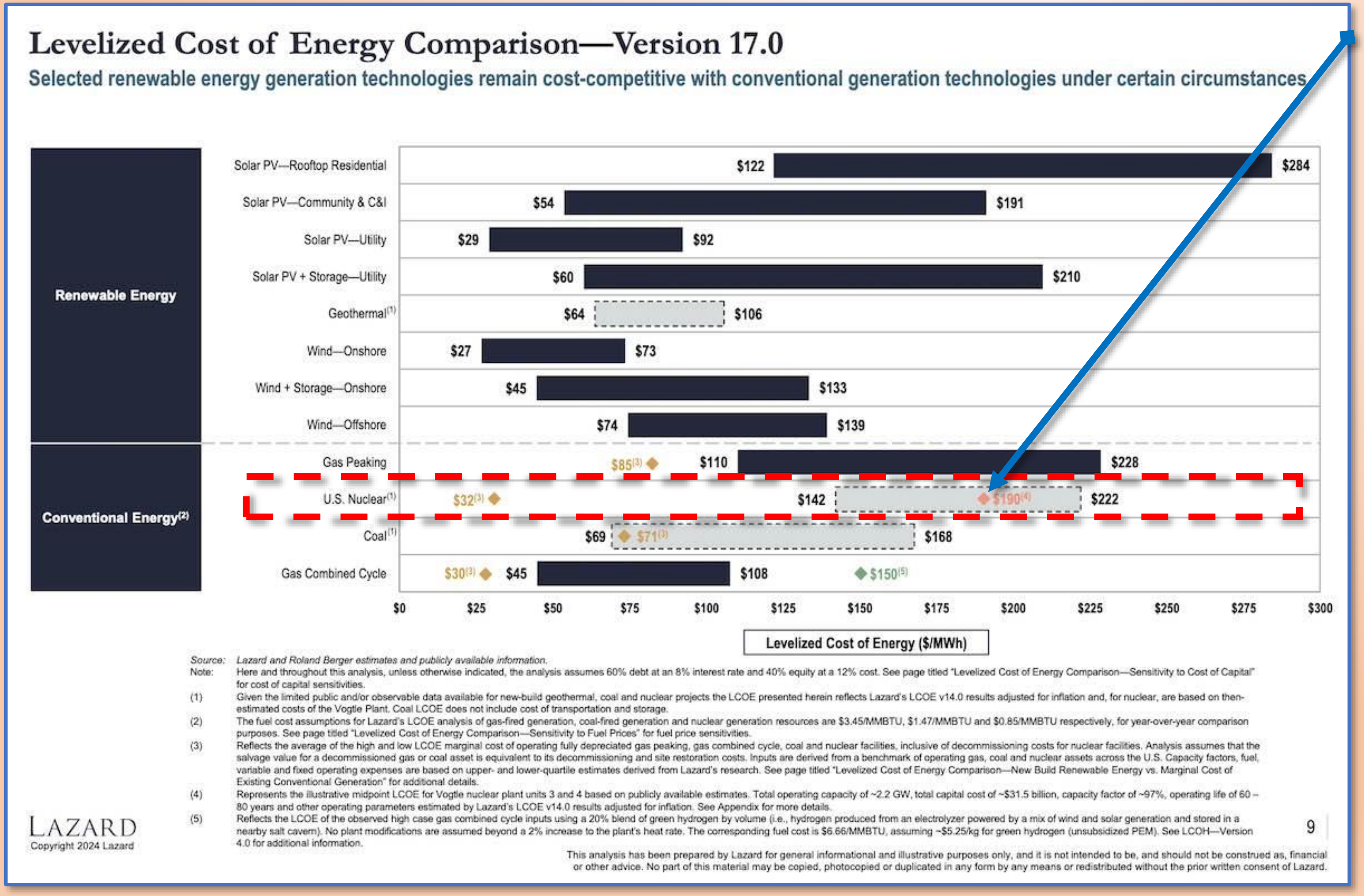
GenCost 2023-24: Nuclear is more expensive



ES Figure 0-3 Calculated LCOE by technology and category for 2023 and 2030

Source: https://www.csiro.au/en/research/technology-space/energy/gencost

Lazard's *LCOE+*: Nuclear US$142–222/MWh



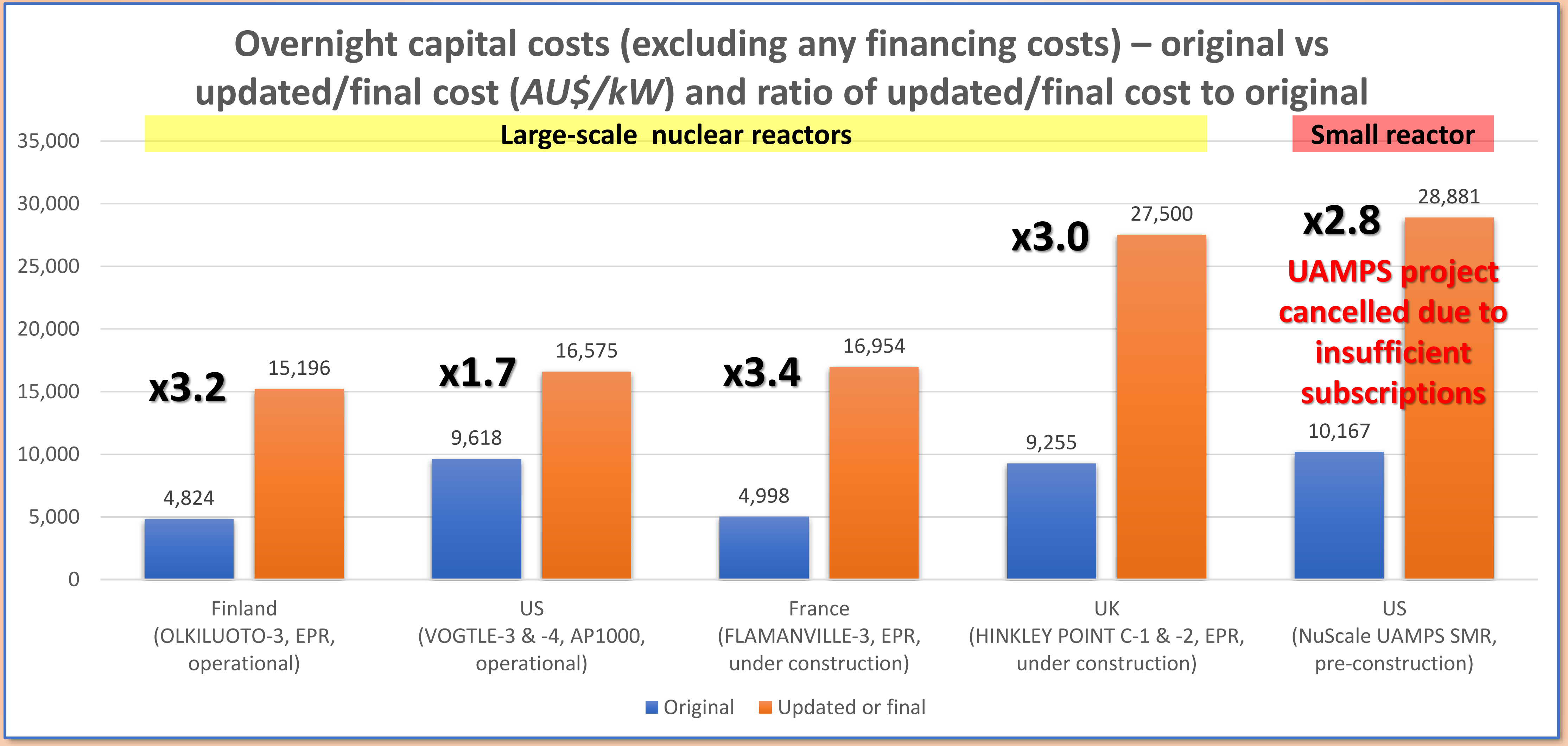
Source: https://www.lazard.com/research-insights/levelized-cost-of-energyplus/

A LCOE of US$190/MWh is illustrative for the Vogtle nuclear plant units 3 and 4, based on publicly available estimates, including a total operating capacity of ~2.2 GW, total capital cost of ~$31.5 billion, capacity factor of ~97%, operating life of 60–80 years and other operating parameters adjusted for inflation.

VOGTLE-3 & -4 LCOE: US$190/MWh ≈ AU$281/MWh

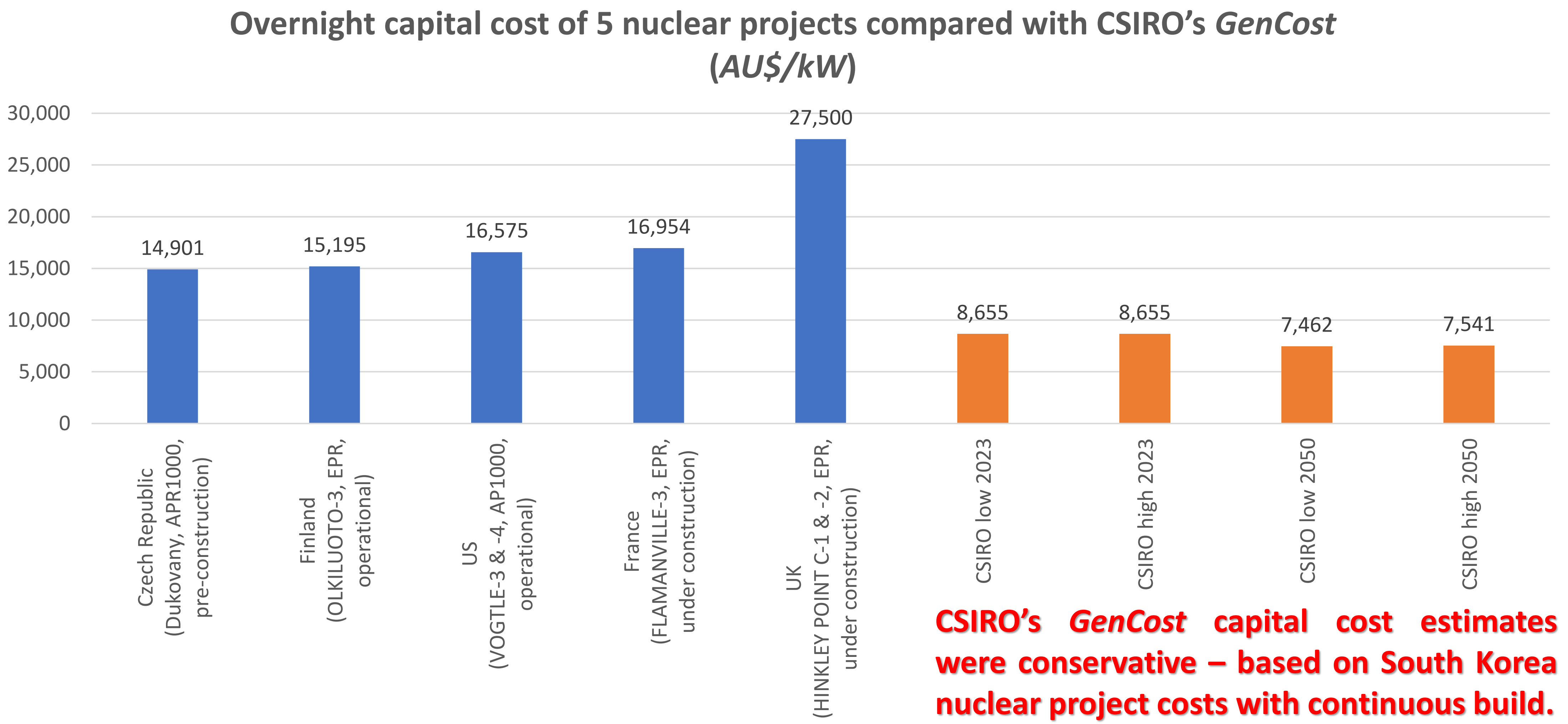
circa 2.5 times Australian 'firmed' wind + solar

IEEFA finds 5 recent project cost blow outs



Source: https://ieefa.org/resources/nuclear-australia-would-increase-household-power-bills

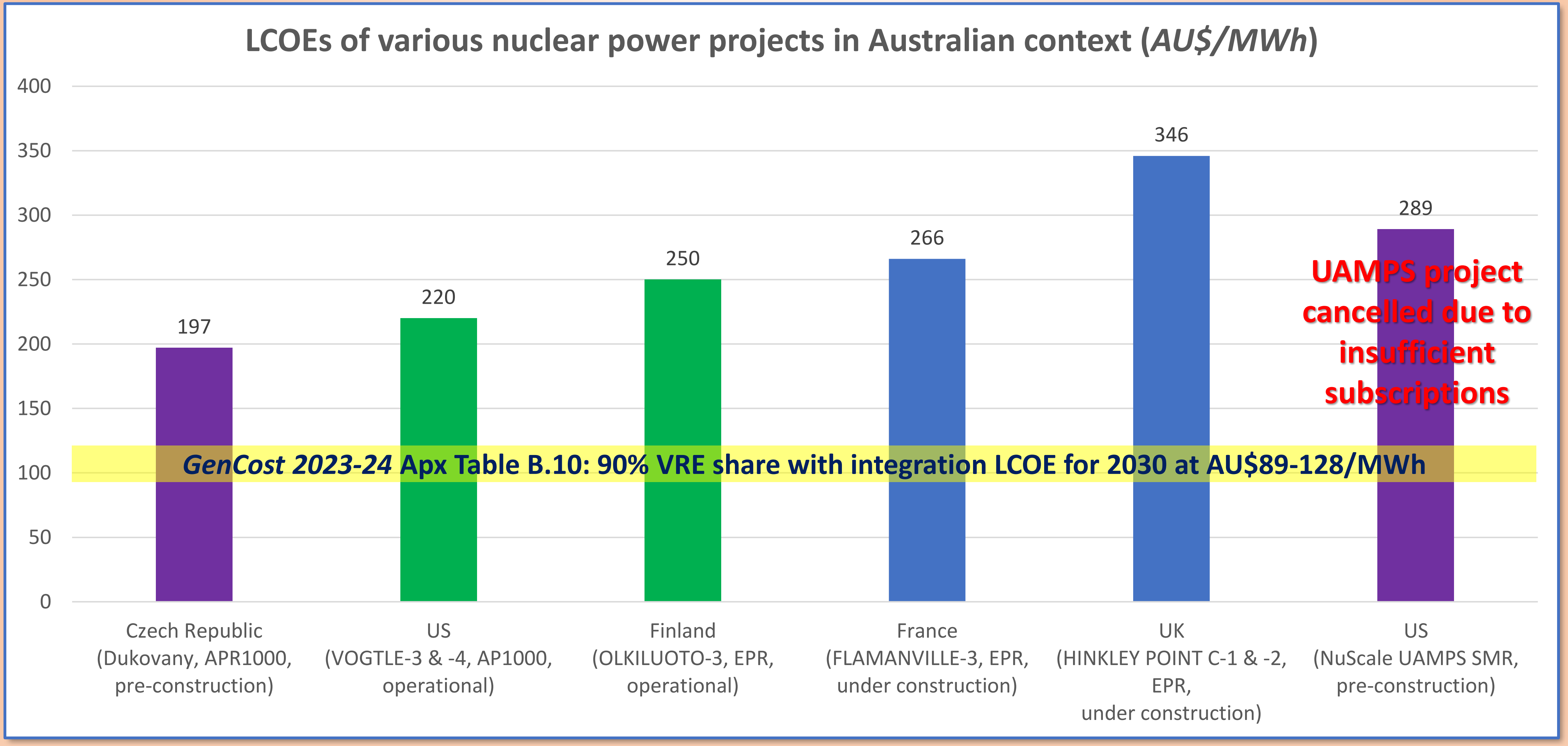
IEEFA compared 5 plant costs with *GenCost*



CSIRO's *GenCost* capital cost estimates were conservative – based on South Korea nuclear project costs with continuous build.

Source: https://ieefa.org/resources/nuclear-australia-would-increase-household-power-bills

IEEFA's LCOEs for 6 nuclear projects & VRE



Source: https://ieefa.org/resources/nuclear-australia-would-increase-household-power-bills

Global nuclear fuel supply constraints

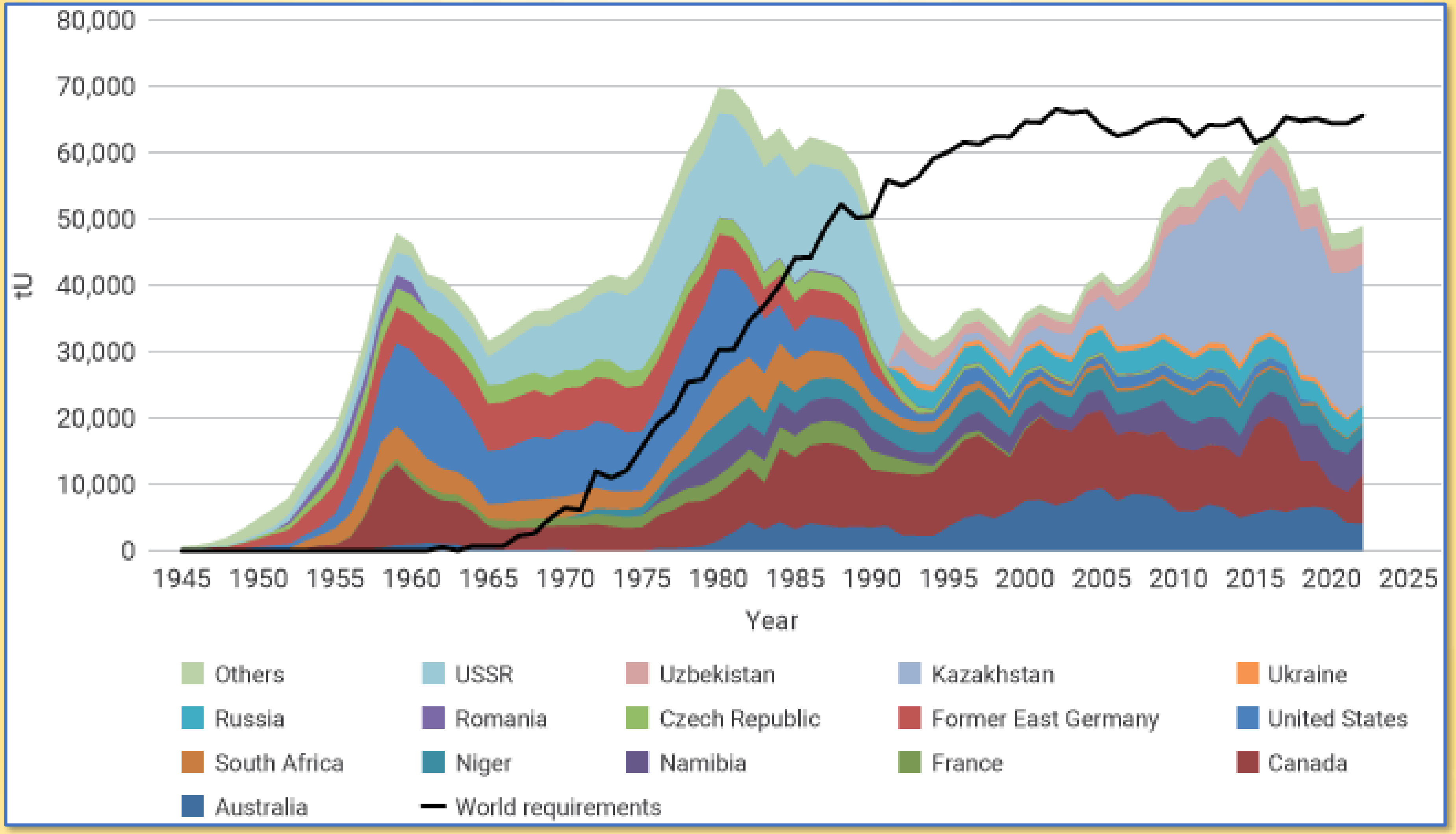
Global uranium ore production currently inadequate to meet world demand

Global high-grade uranium ores inadequate to sustain demand in longer-term

Thorium limitations

Limited nuclear fuel processing, enrichment and fabrication

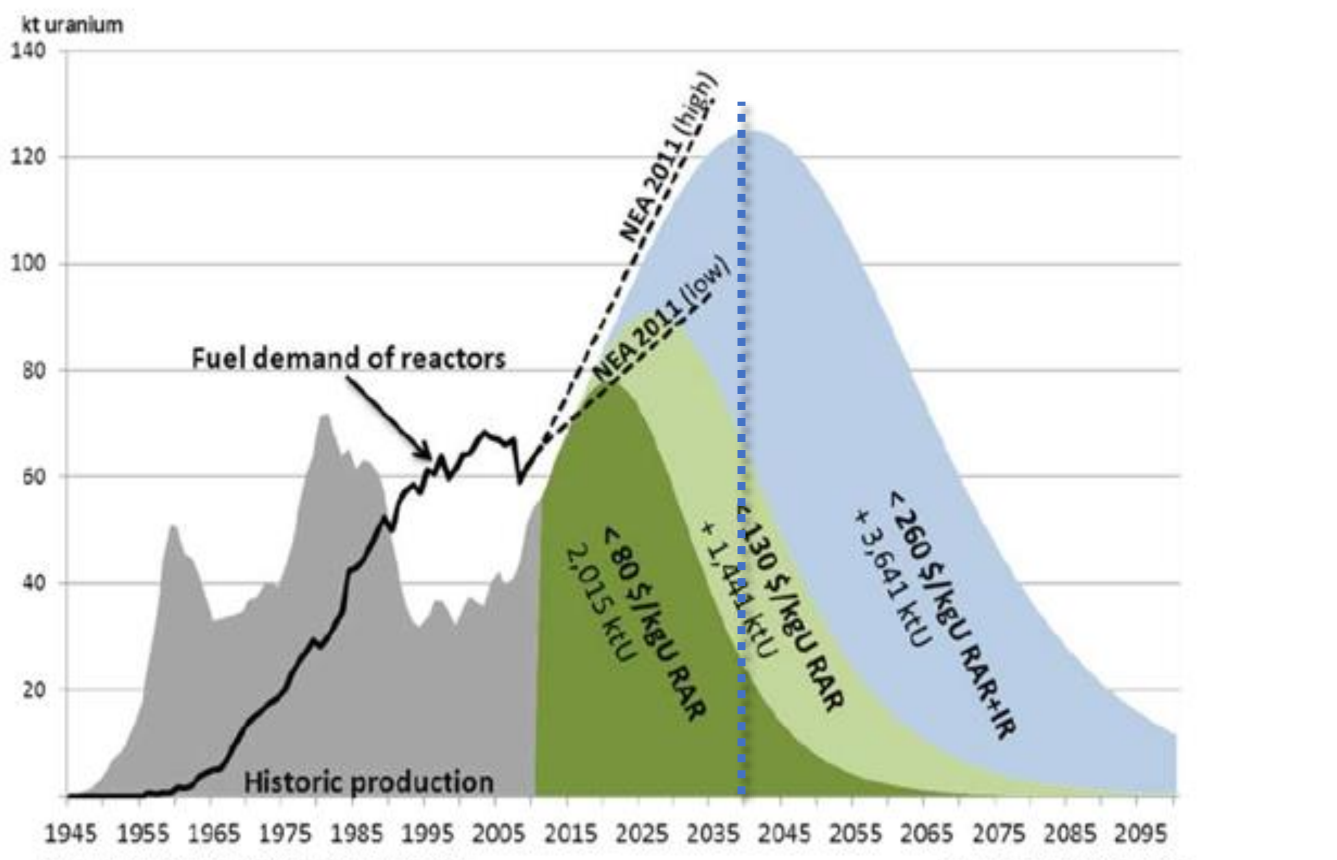
World uranium production & demand



Source: https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production

Uranium ore production & demand outlook

Figure 113: Historic and possible future development of uranium production and demand



Data source: NEA 2005, 2009, 2011, PRIS 2012, Calculations & Grafic: LBST

Source: https://energywatchgroup.org/wp/wp-content/uploads/2023/12/EWG-update2013_long_18_03_2013up1.pdf

- **The dark green area indicates the possible future uranium production from Reasonable Assured Resources (RAR) with extraction costs below $80/kgU, peaking around year-2020.**
- **The light green area indicates additional uranium (+ 1,441 kt RAR) that can be produced at a cost of $80–130/kgU, peaking around year-2030.**
- **The blue area shows the maximal amount of additional fuel (+ 3,641 ktU) that can be produced at costs below $260/kgU while also including Inferred Resources, peaking around year-2040.**
- **High-grade uranium ore supplies are unlikely to sustain a so-called "nuclear renaissance" in the longer-term.**

Thorium limitations

- **<u>Thorium lacks a fissionable isotope</u>: it is impossible to start any fission chain reaction purely on mined thorium, and therefore any nuclear system relying on thorium would be initially dependent on prior generation of fissile matter (extracted *from* uranium or bred *in* uranium systems).**
- **Today, the availability of fissile material (plutonium or enriched uranium) that arises from the well-established uranium/plutonium fuel cycle makes the implementation of thorium fuels feasible *in principle*, although the necessary economic drivers for devoting significant industrial resources to that end are not yet clearly established.**
- **The development of new fuels or new reactor concepts is a time- and resource-consuming process likely to span several decades. Any industrial application of thorium as a nuclear fuel would continue to require the input of fissile material from the existing uranium/plutonium cycle until the required amounts of ^{233}U could be produced to ultimately make the thorium cycle self-sustaining.**
- **If a thorium fuel cycle is pursued, an important factor governing the rate at which ^{233}U could be produced from the introduction of thorium/plutonium or thorium/uranium/plutonium cycles would be plutonium availability. The limitations imposed by fissile plutonium availability result in rather long transition periods between thorium/plutonium and thorium/^{233}U systems, which are likely to be of the order of many decades.**
- **The development of a fully self-sustaining thorium/^{233}U cycle would also require the development of industrial-scale reprocessing capabilities to recover ^{233}U from spent fuel, along with fuel fabrication facilities to prepare the material for re-use.**

Source: *Introduction of Thorium in the Nuclear Fuel Cycle: Short- to long-term considerations*, 2015, Nuclear Energy Agency

Uranium fuel enrichment classifications

- **Naturally occurring uranium is composed of three major isotopes:**
  - **uranium-238 (^{238}U with 99.2732–99.2752% natural abundance),**
  - **uranium-235 (^{235}U with 0.7198–0.7210% natural abundance), and**
  - **uranium-234 (^{234}U with 0.0049–0.0059% natural abundance).**
- **^{235}U is the only nuclide existing in nature (in any appreciable amount) that is fissile with thermal neutrons.**
- **Enriched uranium is a critical component for both civil nuclear power generation, and nuclear weapons.**
- **Uranium as it is taken directly from the Earth is not suitable as fuel for most nuclear reactors and requires additional processes, including enrichment, to make it usable (RBMK and CANDU designs are exceptions).**
- **Uranium fuel enrichment classifications include:**
  - **Low-enriched uranium (LEU) – lower than 20% concentration of ^{235}U, used in commercial LWR, the most prevalent power reactors in the world, where uranium is enriched to 3 to 5% ^{235}U. Slightly enriched uranium (SEU) has a concentration of under 2% ^{235}U.**
  - **High-assay LEU (HALEU) – is enriched between 5% and <20% concentration of ^{235}U, and is called for in many small modular reactor (SMR) and research reactor designs.**
  - **Highly enriched uranium (HEU) – has a 20% or higher concentration of ^{235}U. This high enrichment level is essential for nuclear weapons, and certain specialized fast neutron and naval reactor designs.**

Limited nuclear fuel processing/fabrication

- **Australia has a substantial (28%) global share of uranium reserves, but it has no conversion, enrichment and/or fuel fabrication processing/production capability. All Australian yellowcake (U_3O_8) production goes offshore for further processing elsewhere, including:**
  - **Conversion from U_3O_8 into uranium hexafluoride (UF_6);**
  - **Enrichment of UF_6 using gas centrifuge technology to the required enrichment level;**
  - **Fuel Fabrication where the enriched UF_6 is converted chemically to uranium dioxide powder, then pressed into ceramic pellets and sintered (baked) at high temperature. The pellets are then encased in metal tubes to form fuel rods, which are arranged into a fuel assembly ready for introduction into a reactor.**
- **The following countries are known to operate enrichment facilities: Argentina, Brazil, China, France, Germany, India, Iran, Japan, the Netherlands, North Korea, Pakistan, Russia, the United Kingdom, and the United States.**
- **The following countries are known to operate LWR fuel fabrication facilities: Brazil, China, France, Germany, India, Japan, Kazakhstan, South Korea, Russia, Spain, Sweden, UK, and the United States.**
- **Australia may well have control of its uranium reserves but not over any nuclear fuel processing, enrichment and fabrication necessary for facilitating operations of any nuclear reactors.**

High-Assay Low-Enriched Uranium (HALEU)

- Applications for HALEU are today limited to research reactors and medical isotope production. However, HALEU will be needed for many advanced power reactor fuels, and more than half of the small modular reactor (SMR) designs in development.
- HALEU is not yet widely available commercially. At present only Russia and China have the infrastructure to produce HALEU at scale. Centrus Energy, in the United States, began producing HALEU from a demonstration-scale cascade in October 2023.
- HALEU can be produced with existing centrifuge technology but requires a specific nuclear fuel cycle infrastructure and the development of new or modified regulations and licensing regimes. Moreover, new or modified transport containers will be required for the movement of the large quantities of HALEU required for the deployment of SMRs and advanced reactors.
- Establishing the supply chain to produce and deliver HALEU to customers will require significant capital investment. Governments will need to play a role initially until demand from the commercial market provides a sufficient signal to support private investment.

Source: https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/high-assay-low-enriched-uranium-haleu

- HALEU fuel production at large-scale appears to be a critical bottleneck for most civil SMRs.
- HALEU fuels require more energy for enrichment, incur higher fuel fabrication costs, potentially accelerate corrosion and embrittlement of pressure vessels, and potentially incur more onerous regulatory requirements and transport standards.

Some small modular reactor (SMR) developments

NuScale’s cancelled UAMPS project

Kairos Power’s Hermes & Hermes 2 Demonstration Program, preceding the KP-X

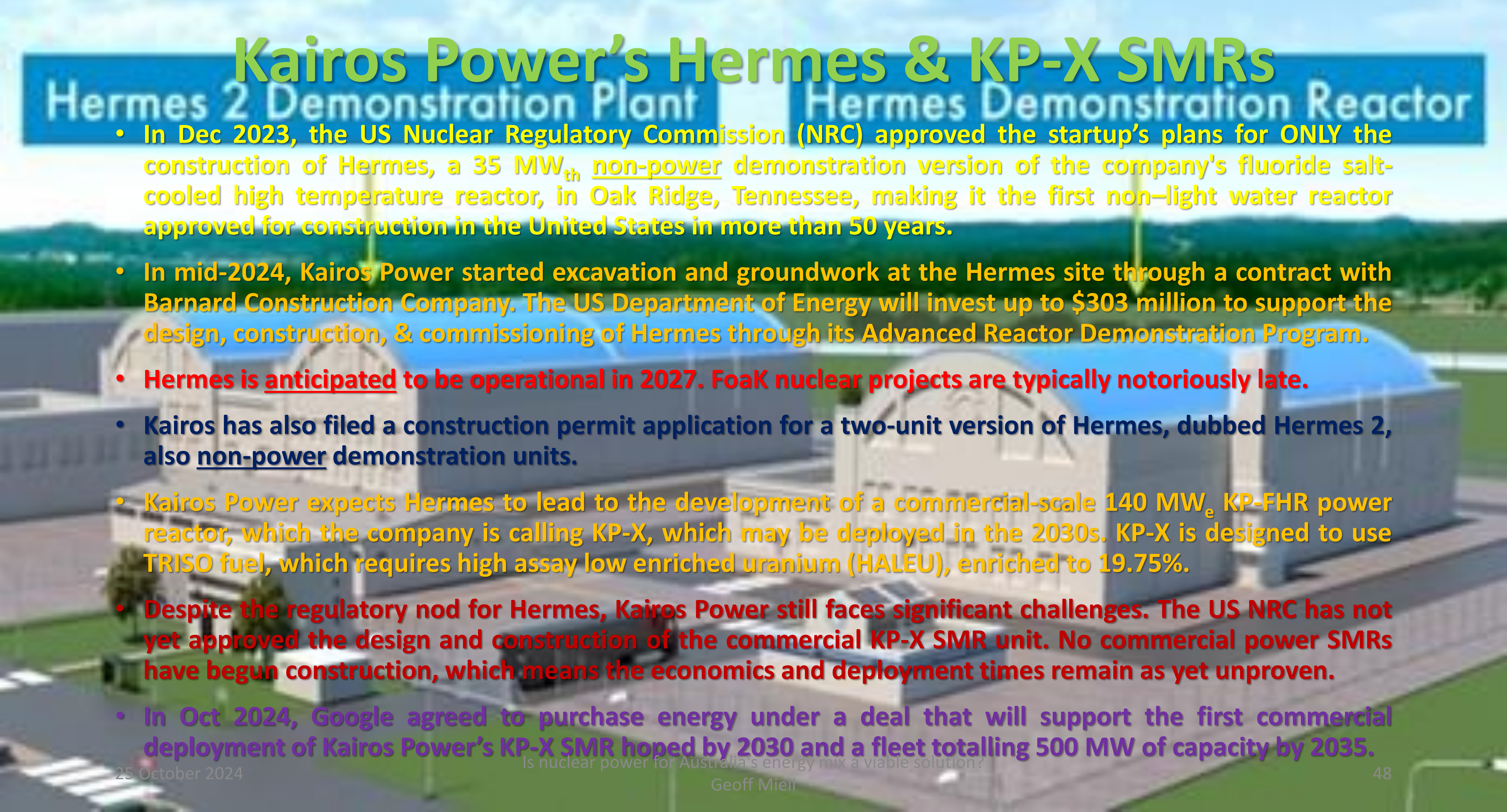
TerraPower's Natrium project

X-energy’s Xe-100 project

NuScale's cancelled UAMPS SMR project

- **NuScale's planned VOYGR™ small modular reactor (SMR) project has been in development since 2000.**
- **As originally envisaged, the VOYGR™ was designed to include 12 independent power modules, using common control, cooling and other equipment in a bid to lower costs, but it has changed repeatedly during the development process, with uncertain implications for the units' cost, performance and reliability.**
- **For example, the NuScale VOYGR™ power modules were initially based on a design capable of generating 35 MW_e, which grew first to 40 MW_e and then to 45 MW_e. When the company submitted its design application to the Nuclear Regulatory Commission in 2016, the modules' size was listed at 50 MW_e. Subsequent revisions have pushed the output to 60 MW_e, before settling at the current 77 MW_e. Similarly, the 12-unit grouping has recently been amended, with the company now saying it would develop a 6-module plant with 462 MW_e total generating capacity.**
- **NuScale projected that the first VOYGR™ module, once forecast for 2016, would come online in mid-2029 with all six modules online by 2030.**
- **This first-of-a-kind (FoaK) VOYGR™ reactor design posed serious financial risks for members of the Utah Associated Municipal Power System (UAMPS), which was the lead buyer.**
- **On 8 Nov 2023, NuScale and UAMPS announced they had mutually decided to terminate the project due to insufficient subscriptions to continue toward deployment.**
- **NuScale is currently the only US developer with a reactor design approved by the US Nuclear Regulatory Commission for a civil power SMR.**

Kairos Power's Hermes & KP-X SMRs



- **In Dec 2023, the US Nuclear Regulatory Commission (NRC) approved the startup's plans for ONLY the construction of Hermes, a 35 MW_{th} non-power demonstration version of the company's fluoride salt-cooled high temperature reactor, in Oak Ridge, Tennessee, making it the first non–light water reactor approved for construction in the United States in more than 50 years.**
- **In mid-2024, Kairos Power started excavation and groundwork at the Hermes site through a contract with Barnard Construction Company. The US Department of Energy will invest up to $303 million to support the design, construction, & commissioning of Hermes through its Advanced Reactor Demonstration Program.**
- **Hermes is anticipated to be operational in 2027. FoaK nuclear projects are typically notoriously late.**
- **Kairos has also filed a construction permit application for a two-unit version of Hermes, dubbed Hermes 2, also non-power demonstration units.**
- **Kairos Power expects Hermes to lead to the development of a commercial-scale 140 MW_e KP-FHR power reactor, which the company is calling KP-X, which may be deployed in the 2030s. KP-X is designed to use TRISO fuel, which requires high assay low enriched uranium (HALEU), enriched to 19.75%.**
- **Despite the regulatory nod for Hermes, Kairos Power still faces significant challenges. The US NRC has not yet approved the design and construction of the commercial KP-X SMR unit. No commercial power SMRs have begun construction, which means the economics and deployment times remain as yet unproven.**
- **In Oct 2024, Google agreed to purchase energy under a deal that will support the first commercial deployment of Kairos Power's KP-X SMR hoped by 2030 and a fleet totalling 500 MW of capacity by 2035.**

TerraPower's Natrium SMR project

- On 28 March 2024, TerraPower applied for a construction permit to the US Nuclear Regulatory Commission (NRC) for its Natrium reactor to be built in Wyoming, with hopes of receiving approval in time to begin construction and have the reactor online in 2030. However, the Natrium design has not yet been approved by the NRC yet.
- Russia's invasion of Ukraine has caused the only source of commercial HALEU fuel, necessary for the Natrium design, to be no longer a viable part of the supply chain, delaying the project by at least 2 years.
- TerraPower has begun construction on its 345 MW_e Natrium sodium-cooled fast reactor demonstration project near Kemmerer, Wyoming. Initial construction activities will be limited to non-nuclear site features, with nuclear construction to begin after the US NRC approves TerraPower's nuclear construction permit application for the Natrium design.
- The Natrium design is one of two awardees in the US Department of Energy's Advanced Reactor Demonstration Program (ARDP). X-energy's Xe-100 reactor design is the other. ARDP is set to disburse $3.2 billion over seven years, with the partner companies providing matching funds.
- Alongside its 345 MW_e reactor, the facility is planned to have a molten salt-based energy storage system that can achieve power output of 500 MW for more than five and a half hours.
- TerraPower plans to begin construction in 2025 on the facility's energy island, including steam turbines and other power generation equipment, and hopes to begin construction in 2026 on the nuclear island containing the reactor and related systems.

X-energy's Xe-100 SMR project

- **The Xe-100 SMR is an 80-MW_e high-temperature, gas-cooled reactor that can be scaled into a four-pack 320 MW_e power plant and up to a 960-MW_e plant with 12 units. It uses a pebble bed TRISO fuel system (uranium particles encased in graphite) and relies on helium as a coolant.**
- **With federal US government support, X-energy is currently developing an initial Xe-100 plant at Dow Inc.'s manufacturing site on the Gulf Coast of Texas. The company was one of two selected by the Department of Energy's Advanced Reactor Demonstration Program (ARDP) for funding.**
- **On 16 Oct 2024, tech giant Amazon announced new partnerships with Dominion Energy and X-energy to develop and deploy 5 gigawatts of nuclear energy to power needs across the USA over the next 15 years. X-energy will receive support for developing an initial 320 MW_e project with Energy Northwest in Washington state; and Dominion has a memorandum of understanding with Amazon to advance SMR development in Virginia.**
- **The gap between the hype about SMRs and industrial reality continues to grow. The nuclear industry and multiple governments are doubling down on their financial and political investments into SMRs. So far, the harsh reality does not reflect those efforts: with no regulatory design certifications for civil <u>power</u> reactors, and no constructions in the west, SMR power projects continue to be delayed or canceled.**
- **The only real world recently operational civil small reactor examples are China's SHIDAO BAY-1 twin demonstration reactors & Russia's AKADEMIK LOMONOSOV-1 & -2 on a floating barge at the Arctic port of Pevek, which appear to thoroughly undermine claims that SMRs could be cheaper and faster to deploy.**

High-Level nuclear waste

- **High-level radioactive wastes are the highly radioactive materials produced as a byproduct of the reactions that occur inside nuclear reactors. High-level wastes take one of two forms:**
  - **Spent (used) reactor fuel when it is accepted for disposal**
  - **Waste materials remaining after spent fuel is reprocessed**
- **Spent nuclear fuel is used fuel from a reactor that is no longer efficient in creating electricity, because its fission process has slowed. However, it is still thermally hot, highly radioactive, and potentially harmful. Until a permanent disposal repository for spent nuclear fuel is built, licensees must safely store this fuel at their reactors.**
- **Because of their highly radioactive fission products, high-level waste and spent fuel must be handled and stored with care. Since the only way radioactive waste finally becomes harmless is through decay, which for high-level wastes can take hundreds of thousands of years, the wastes must be stored and finally disposed of in a way that provides adequate protection of the public for a very long time.**
- **High-level wastes are hazardous because they produce fatal radiation doses during short periods of direct exposure. For example, 10 years after removal from a reactor, the surface dose rate for a typical spent fuel assembly exceeds 10,000 rem/hour – far greater than the fatal whole-body dose for humans of about 500 rem received all at once. If isotopes from these high-level wastes get into groundwater or rivers, they may enter food chains. The dose produced through this indirect exposure would be much smaller than a direct-exposure dose, but a much larger population could be exposed.**

High-Level nuclear waste decay rates

A Comparison of the Thermal Power and Radioactivity of Spent Fuel and High-Level Waste

Time since discharge of spent fuel (years)	Thermal power for Spent Fuel (watts/MTHM)*	Thermal power for High-Level Waste (watts/MTHM)*	Radioactivity for Spent Fuel (Ci/MTHM)*	Radioactivity for High-Level Waste (Ci/MTHM)*
10	1200	1000	410,000	320,000
100	290	110	42,000	35,000
1,000	55	3.3	1,800	130
10,000	14	0.47	480	42
100,000	1.1	0.11	58	21
1,000,000	0.39	0.15	21	10

***MTHM = metric tons of heavy metal originally charged to the reactor**

The curie (symbol Ci) is a non-SI unit of radioactivity originally defined in 1910. It is currently defined as 1 Ci = 3.7×10^{10} decays per second. In 1975 the General Conference on Weights and Measures gave the becquerel (Bq), defined as one nuclear decay per second, official status as the SI unit of radioactivity. 1 Ci = 3.7×10^{10} Bq = 37 GBq

Source: Table 1 in https://www.iaea.org/sites/default/files/21404640216.pdf

Additional nuclear industry historical & current data

National nuclear power program startups & phaseouts, 1954–mid-2024

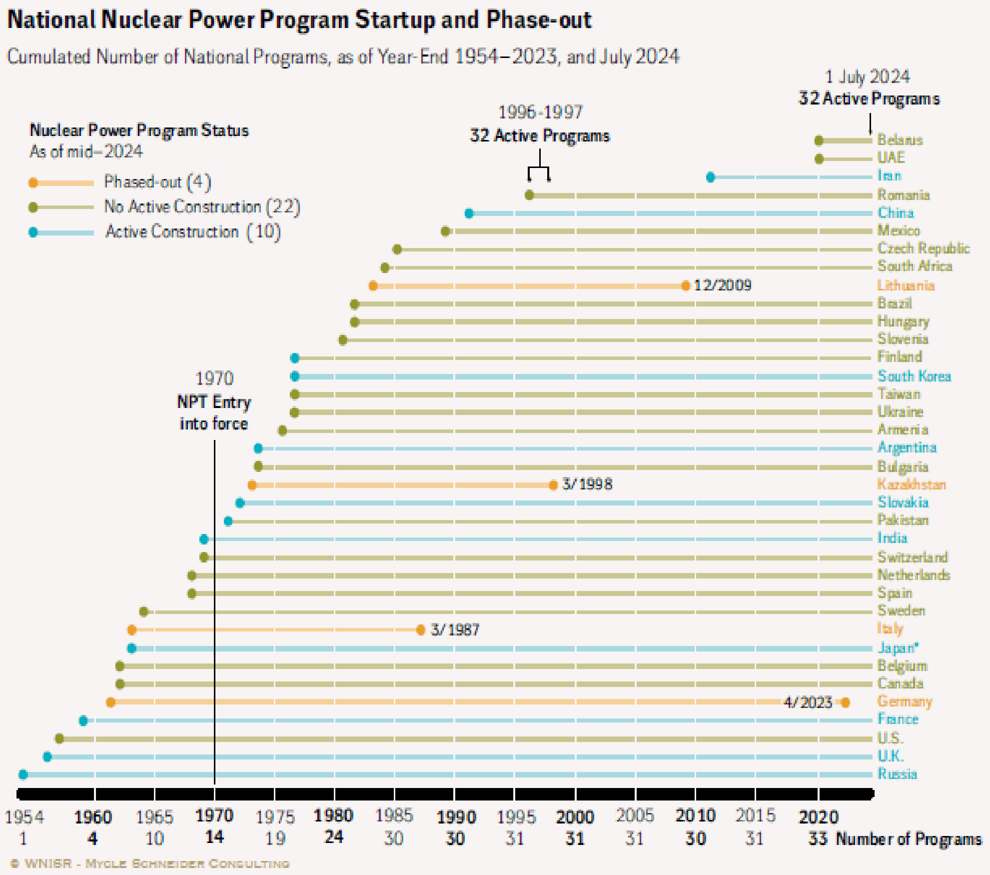
Global nuclear electricity production, 1985–2023

Nuclear reactors under construction, as at 20 Oct 2024

Nuclear reactor projects abandoned, since 1970

National program startups & phaseouts

Figure 1 · National Nuclear Power Programs Development, 1954–2024



Sources: compiled by WNISR, with IAEA-PRIS, 2024

Source: *World Nuclear Industry Status Report 2024*

Nuclear Power Program Status

(as of mid-2024):

- Phased-out: 4 countries
- Active Programs: 32 countries
- No Active Construction: 22 countries
- Active Construction: 10 countries

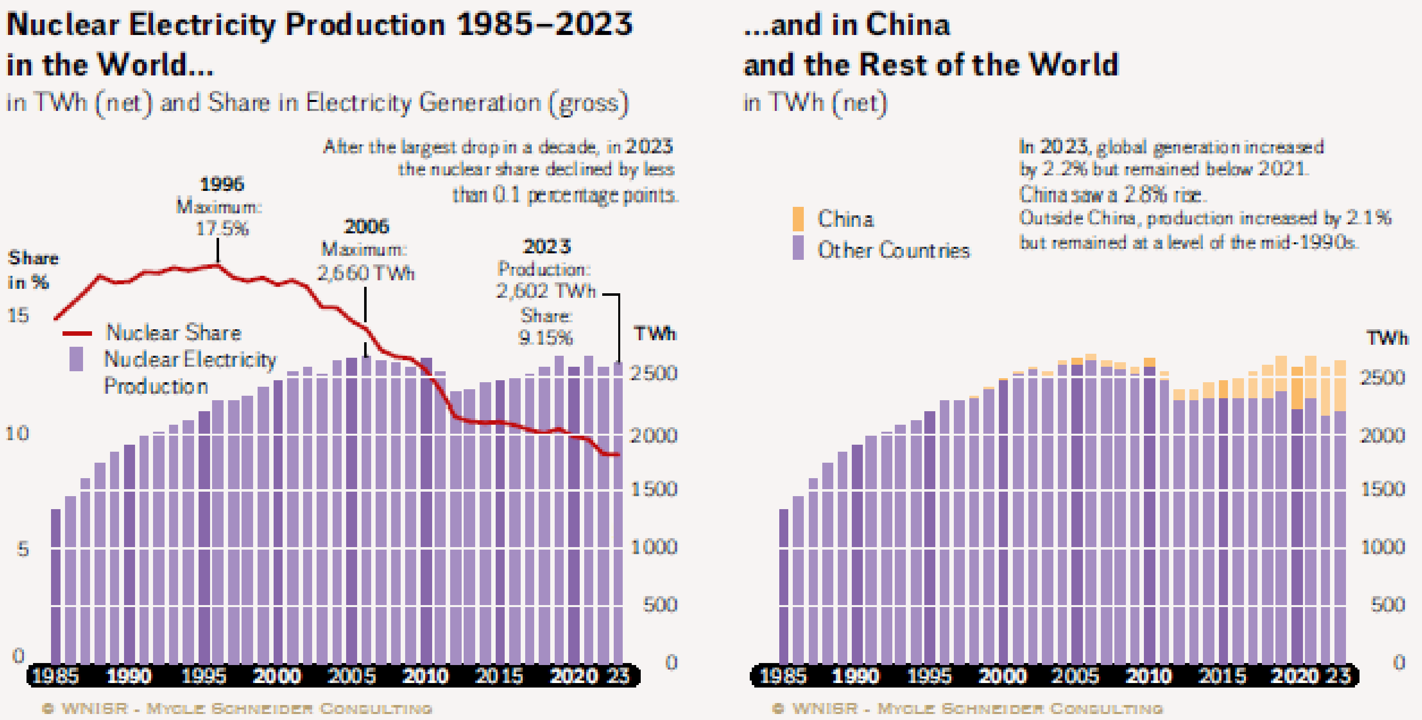
Age of the World Nuclear Fleet

(as of mid-2024):

- Reactor age 0–10 years: 74 units
- Reactor age 11–20 years: 28 units
- Reactor age 21–30 years: 37 units
- Reactor age 31–40 years: 142 units
- Reactor age 41–50 years: 105 units
- Reactor age 51 years & over: 22 units
- Mean age 32 years for: 408 units

Global nuclear electricity production

Figure 2 · Nuclear Electricity Generation in the World... and China

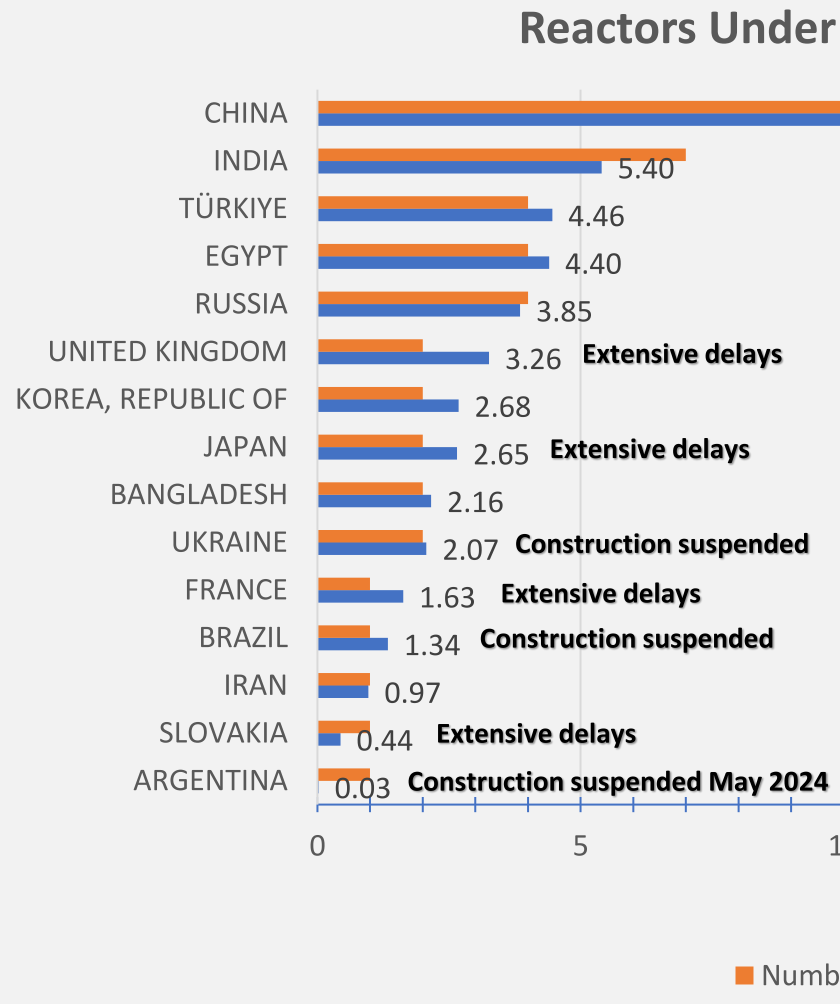


Sources: WNISR, with IAEA-PRIS and Energy Institute, 2024

Note: IAEA-PRIS production data for the years 2022 and 2023 does not include Ukraine (data unavailable). Net nuclear production for Ukraine for those years represented 59 TWh and 49 TWh respectively according to the Energy Institute's "Statistical Review of World Energy" dataset.[24] The total number is thus based on IAEA-PRIS plus the production figure for Ukraine from the Energy Institute.

Source: *World Nuclear Industry Status Report 2024*

Nuclear reactors under construction



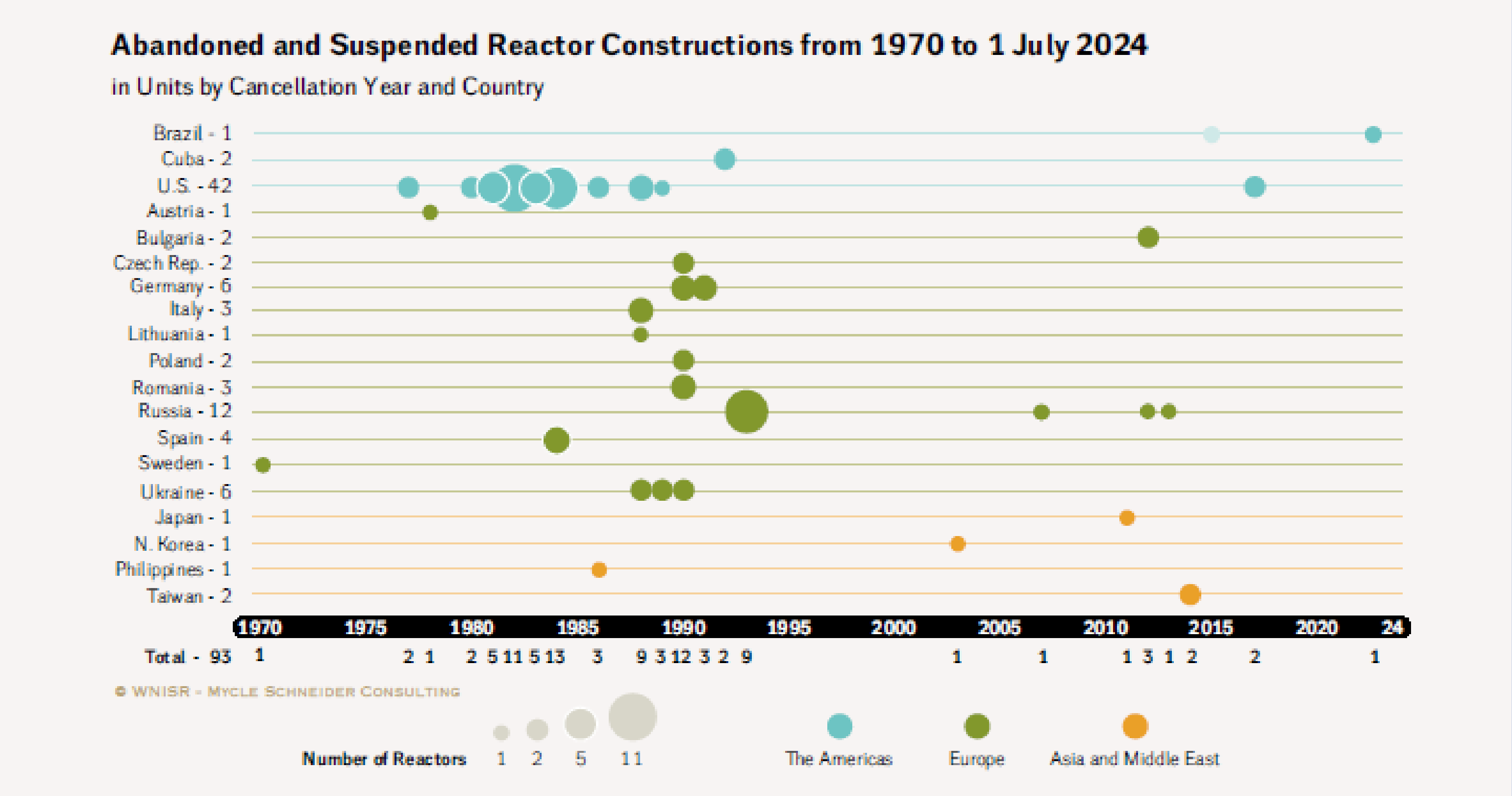
Notes:

1. **Total number of reactors under construction: 63**
2. **Total net electrical capacity under construction: 66.100 GW_e**
3. **China has by far the most reactors (29 units) under construction in the world.**
4. **Russia is largely dominating the international market as a technology supplier, for seven different countries, including four each in China, India, Egypt and Türkiye, two in Bangladesh, and one each in Iran and Slovakia. It is uncertain to what extent these projects will be impacted by the various layers of sanctions imposed on Russia following the invasion of Ukraine.**

Source: https://pris.iaea.org/PRIS/WorldStatistics/UnderConstructionReactorsByCountry.aspx

Nuclear reactor projects abandoned

Figure 15 · Cancelled or Suspended Reactor Constructions



Sources: Various, compiled by WNISR, 2024

Note: This graph only includes constructions that had officially started with the concreting of the base slab of the reactor building. Many more projects have been cancelled at earlier stages of construction/site preparation.

Source: *World Nuclear Industry Status Report 2024*

- **Of the 807 reactor constructions launched since 1951, at least 93 units in 19 countries had been abandoned or suspended, as of 1 Jul 2024. This means that 11.5%—or one in nine—of nuclear constructions have been abandoned.**
- **Experience shows that having an order for a reactor, or even having a nuclear plant at an advanced stage of construction, is no guarantee of ultimate grid connection and power production.**

The Coalition's nuclear proposal so far…

- **On 19 Jun 2024, the Coalition announced seven locations, located at power station sites that have closed or are scheduled to close, where they propose to build nuclear power plants:**
    1. **Liddell Power Station, New South Wales;**
    2. **Mount Piper Power Station, New South Wales;**
    3. **Loy Yang Power Stations, Victoria;**
    4. **Tarong Power Station, Queensland;**
    5. **Callide Power Station, Queensland;**
    6. **Northern Power Station, South Australia (SMR only); and**
    7. **Muja Power Station, Western Australia (SMR only).**
- **A Federal Coalition Government will initially develop two establishment projects using either small modular reactors or modern larger plants such as the AP1000 or APR1400.**
- **The Coalition promises: *"They will start producing electricity by 2035 (with small modular reactors) or 2037 (if modern larger plants are found to be the best option)."***

Source: https://www.liberal.org.au/latest-news/2024/06/19/australias-energy-future

- **On 23 Jun 2024, on ABC TV's *Insiders* program, Ted O'Brien MP said multiple reactor units could be located at each nominated site. How many reactors/capacities & costs are not yet specified.**

See the *YouTube* video from time interval **0:05:22** at: https://www.youtube.com/watch?v=ioLayZmJtBU

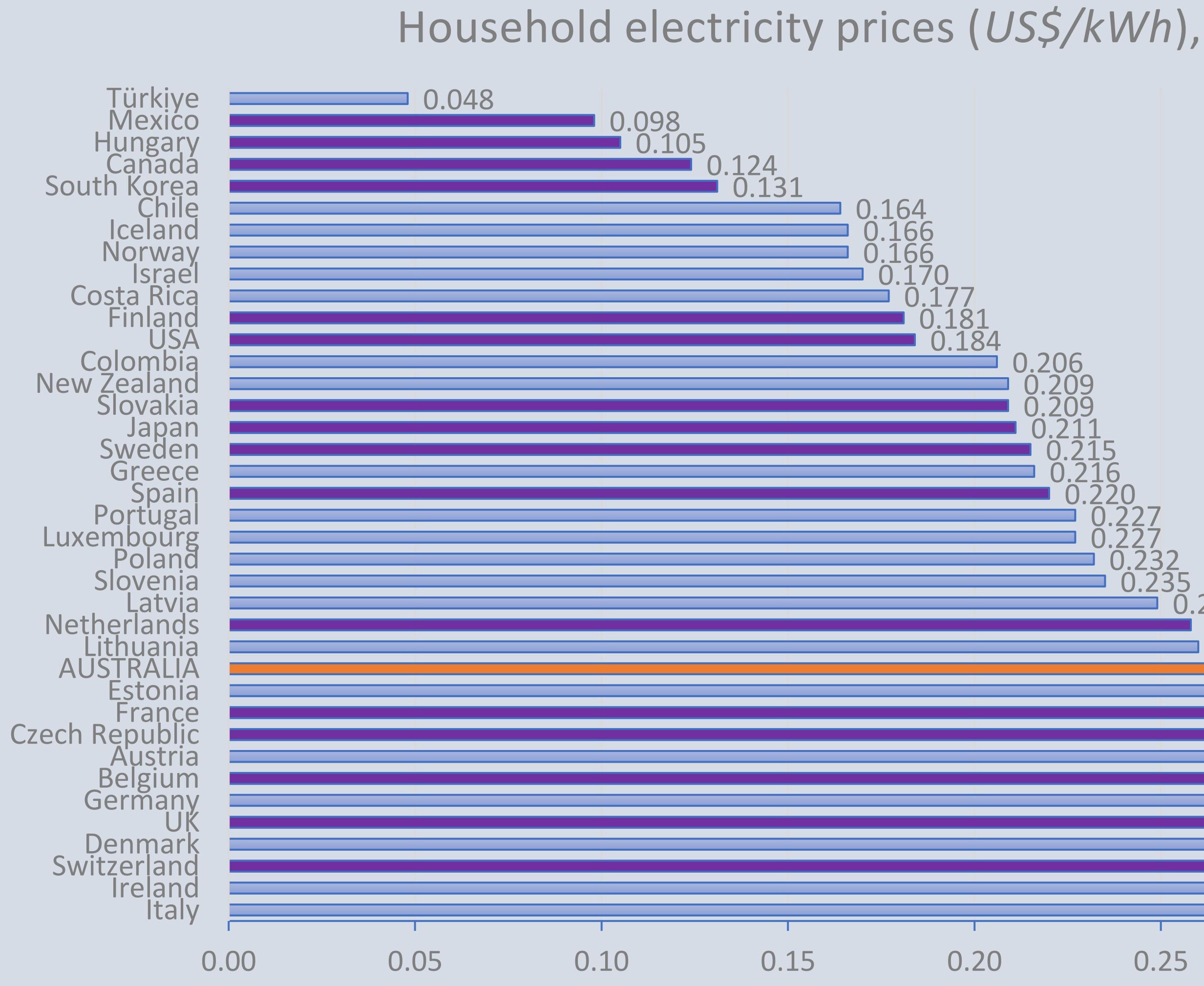
Water consumption for nuclear plants

- In the UK, the seawater withdrawal requirement for a 1600 MW_e nuclear unit is about 90 cubic metres per second (7.8 GL/d).
- That means direct once-through wet cooling is out of the question for the Coalition's nominated six inland sites, given the long distances from coastlines and high elevations above sea level.
- For recirculating or indirect wet cooling, where a power plant does not have abundant water, it can discharge surplus heat to the air using recirculating water systems which mostly use the physics of evaporation. In the UK, the water requirement for a 1600 MW_e nuclear unit with natural draft cooling towers is about 2 cubic metres per second (173 ML/day).
- Mechanical draft cooling towers have large axial flow fans in a timber and plastic structure. The fans provide the airflow and are able to provide lower water temperatures than natural draft towers, particularly on hot dry days. Such cooling towers give rise to water consumption, with up to 3.0 litres being evaporated for each kilowatt-hour produced, depending on conditions.

Source: https://world-nuclear.org/information-library/current-and-future-generation/cooling-power-plants

- For example: 3.0 litres/kWh x 1,460,000 kW x 24 hours/day = 105.12 ML/day
- For perspective, the 2x 730 MW capacity Mt Piper Power Station's daily water demand is around 40 ML/day on average and 54 ML/day when the plant is operating at full capacity.
- Thus, large-scale (i.e. GW-range) nuclear power plants are substantially thirstier than equivalent capacity coal-fired power plants.

OECD household electricity prices

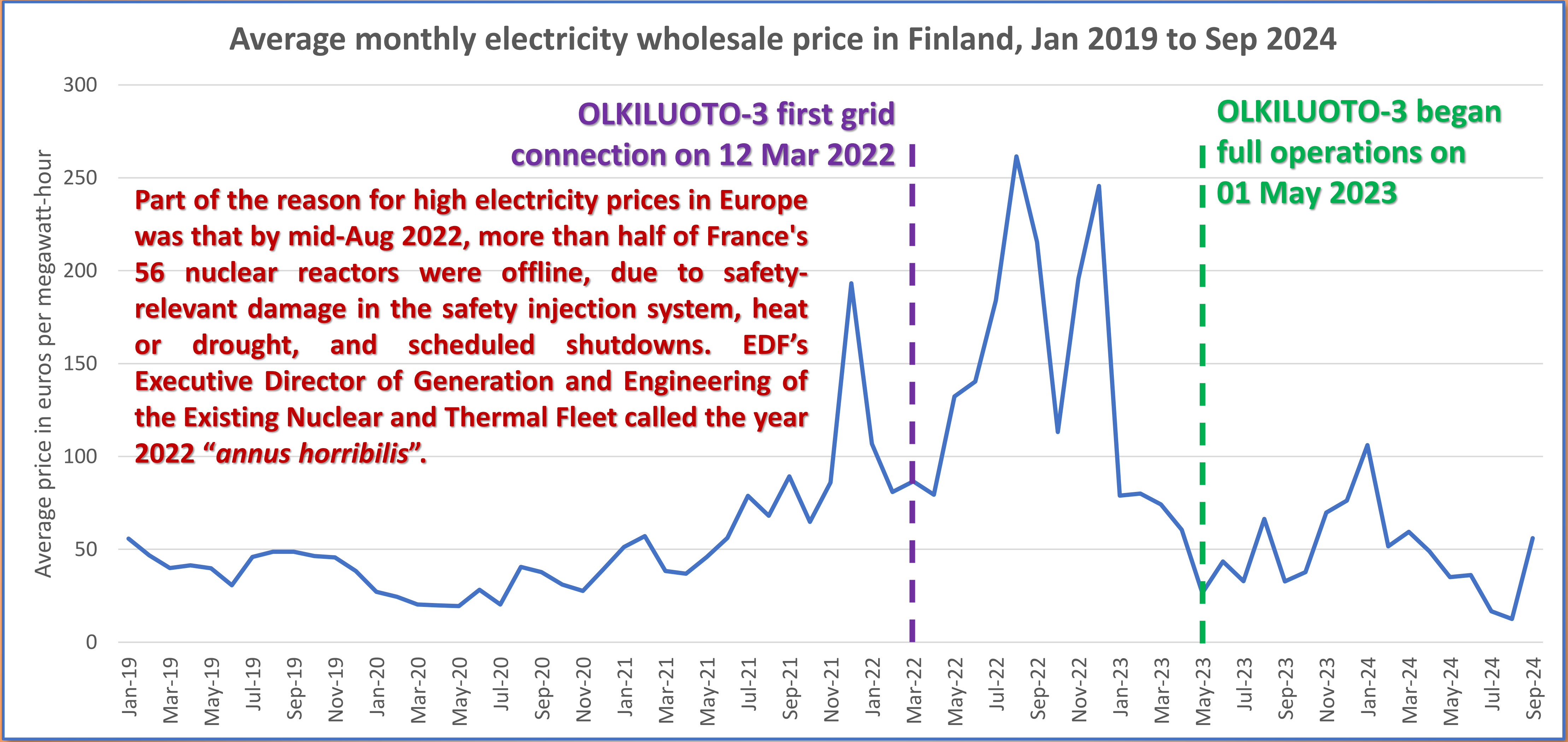


Notes:

1. **OECD countries shown with purple bars include nuclear power generation in their respective domestic energy mixes.**
2. **Household electricity prices range from the cheapest in the world, Iran (at US$0.002/kWh), through to the most expensive, Bermuda (at US$0.458/kWh).**

Source: accessed 25 Oct 2024 https://www.globalpetrolprices.com/electricity_prices/

Average monthly electricity prices in Finland



Source: https://www.statista.com/statistics/1271437/finland-monthly-wholesale-electricity-price/

Conclusions

Overwhelming evidence/data indicates that nuclear technologies:

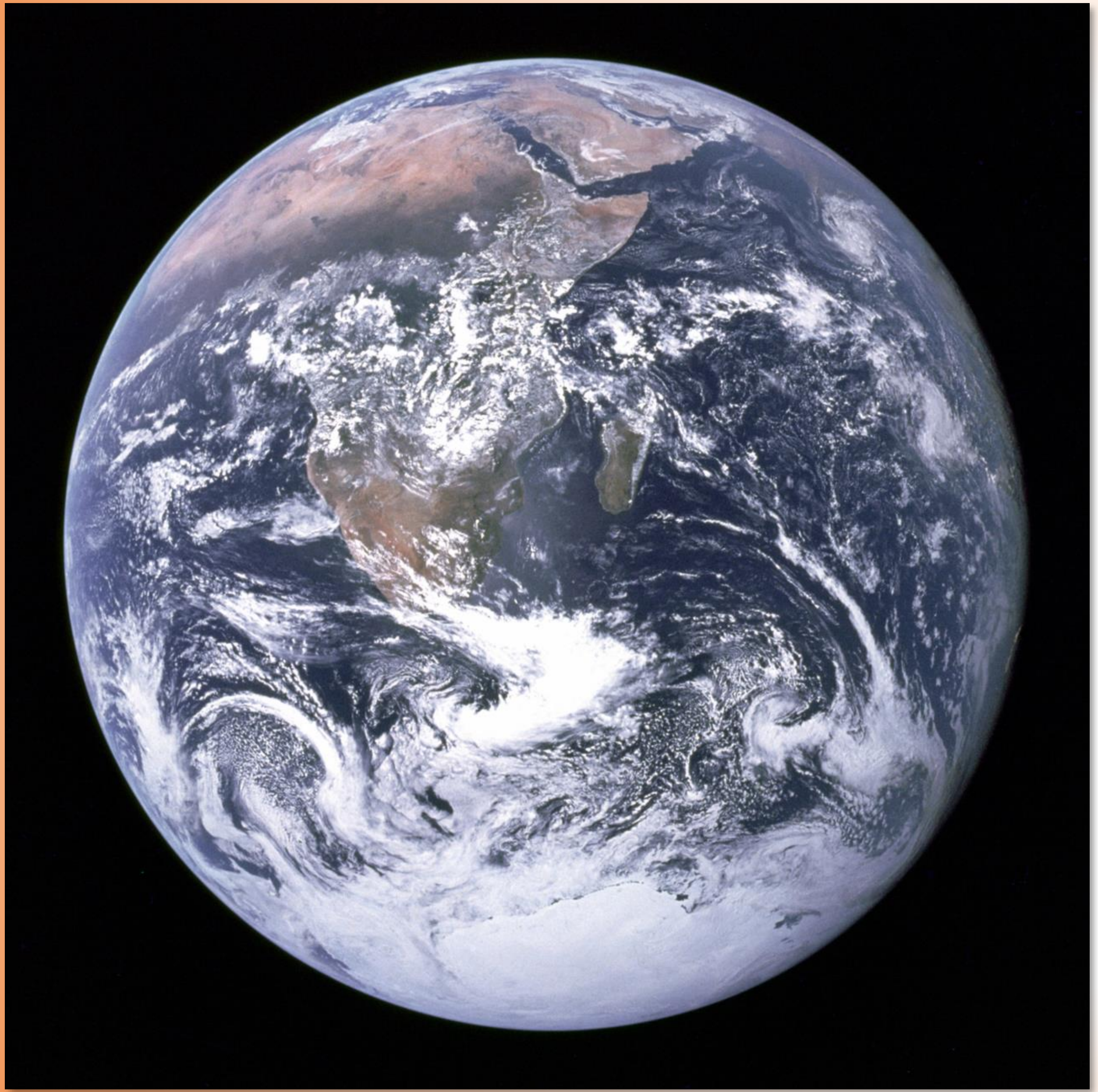
1. **Are too slow to deploy (likely mid-2040s at the earliest for any possible operational nuclear reactor(s) in Australia);**
2. **Are too expensive (almost double to six times the cost of 'firmed' renewables, per *GenCost 2023-24*, Lazard's *LCOE v17*);**
3. **Use finite fuels inadequate to sustain long-term a so-called "nuclear renaissance" (see the Energy Watch Group's 2013 report titled *Fossil and Nuclear Fuels – the Supply Outlook*, Figure 113: Historic and possible future development of uranium production and demand); and**
4. **Leave behind a toxic waste legacy that will long outlast any energy benefits gained (an intergenerational issue).**

Nuclear technologies cannot save us!

Ponder this…

- **Most, if not all ageing, increasingly unreliable and increasingly more expensive to run coal-fired generators will likely be closed by 2038. What would keep the 'lights on' in Australia while we wait 20+ years (NOT 10-12 years that the Coalition are promising) for any prospective nuclear generator units to become operational? That's the urgent conversation Australia needs to have.**
- **Emeritus Professor Ian Lowe's commentary was published in *The Saturday Paper* on 10 Aug 2024 (edition 512) headlined Dutton’s nuclear lies. Ian Lowe wrote:**

> ***“The whole proposal is really a smokescreen. It is designed to hide the reality that a Coalition government would keep burning coal and gas for decades. There is also no plan to deal with the radioactive waste that nuclear reactors would produce, needing to be stored for geological time. The 2015 Nuclear Fuel Cycle Royal Commission, held in South Australia, estimated a storage facility would cost an eye-watering $41 billion. Peter Dutton’s nuclear plan is a farce. No part of it is real, plausible or sincere. As a proposal, it is probably the most dishonest ever put before the Australian electorate.”***



There is only one planet we have to live on

– There is no planet B!

The Blue Marble, The Earth seen from Apollo 17 on 7 Dec 1972, NASA/Apollo 17 crew