Submission to the HoR Select Committee on Nuclear Power Generation in Australia

From:

Dr R.J Hill, Chair, SA&NT Division of ATSE

Former CSIRO Group Executive for the Divisions of Energy Technology, Mining and Exploration, Minerals (processing), Industrial Physics and Manufacturing

Prologue

A comprehensive discussion on the potential role of nuclear power in the achievement of Australia's Net Zero targets occurred at a half-day 'closed door' symposium entitled "Nuclear Energy and Net Zero" held at the National Wine Centre on Adelaide on 20 June 2024. A summary of these discussions was prepared, reviewed by the speakers at the Symposium and uploaded onto the Fellows section of the ATSE website in September, where it is available as background, in part, for this submission.

The Symposium speakers included the former Chief Scientists of Australia and South Australia, together with two independent experts in nuclear power generation and energy economics. As the fifth speaker at the Symposium, my focus drew upon my extension minerals-sector research and management experience in CSIRO. It highlighted the much smaller materials and thus environmental footprints of nuclear power generation versus other renewable sources and, as a consequence of this, its much lower biodiversity impacts, land access issues and full life-cycle costs.

In the submission below, I focus specifically on these relative footprints and draw out their impact on materials availability, supply line security, and the environmental and biodiversity impacts of the associated mining, processing, and waste disposal. The submission draws heavily upon the diagrams and graphs that were included in my presentation at the Symposium, rather than converting all of this information to text.

Summary

The massive increase in the global extraction and processing of the critical materials required for the expansion of renewables infrastructure to achieve the net zero emissions targets for 2050 will not be realized for even the first tranche of renewables infrastructure within the target timeframe. If Australian history is any guide, the large number of new mines, processing and manufacturing plants required for these critical minerals will have difficulty in getting social and environmental approvals. The alternative is to continue to rely indefinitely on other countries for all of this infrastructure, thereby transferring the environmental and social impacts to those countries.

In contrast, in a similar fashion to fossil fuels (but without the CO_2 emissions), nuclear power provides high-intensity, base load, synchronous, dispatchable electricity that has up to two orders of magnitude lower physical and biodiversity footprint than renewable technologies. If the deployment of nuclear power is optimally undertaken,

when applied in a whole-of-life systems analysis, many studies from overseas indicate that the benefit of nuclear power translate into a lower overall cost per kWh of electricity delivered. Part of this advantage comes from the fact that the lifetime of nuclear power reactors is much longer than renewable infrastructure, with some installations overseas operating continuously for more than 60 years.

Australia already has a world-class regulatory system for the uninterrupted safe operation of medical and research nuclear reactors (HIFAR and OPAL) at Lucas Heights since 1958. It also has the benefit of large domestic supplies of uranium ore and has one of the world's most geologically stable landmasses with the potential to provide very-long-term storage of any future waste produced by a civil nuclear power industry. Synergies between the development of a nuclear power industry and preparation for the establishment of AUKUS are also clear.

If nuclear energy is so expensive and takes so long to deliver, why are many countries committing to tripling their nuclear energy contribution (COPS28)? All large engineering projects routinely come in over budget and late, including Snowy 2.0, the NBN, and most airports and large freeway systems. If the legislative ban on nuclear power is removed and the market is allowed to operate, in 20 years nuclear power will have generated at least the level of impact of renewables that has been achieved over the past 20 years, with a much lower environmental and social impact.

To achieve its emission targets while remaining globally competitive, Australia would be wise to take the lead of other nations by commencing urgently the development of a domestic nuclear power industry.

Background

A 'renewables-only' pathway to achieving Australia's target of Net Zero emissions by 2050 has many significant challenges. Despite a massive investment over the past 20 years in Australia, including approximately $20B of private capital for domestic rooftop solar panels, batteries and electric vehicles, and a plethora of public sector grants and subsidies (also numbering in the tens of billions of dollars), the proportion of electricity generated from solar and wind infrastructure still provides only 32% of electricity generation in Australia and only 9% of energy usage overall.

The rate of expansion of the renewables contribution above these modest levels has stalled in recent years due to issues of cumbersome and expensive regulation and environmental approval for the setting aside of vast tracts of land to build the requisite transmission lines, solar panels, and wind turbines. There has also been push-back from landowners and indigenous communities who do not wish their land and amenity to be used for such purposes.

The contention that Australia is a "special case" for a renewables-only strategy and that it will become a "renewables superpower" can be dismissed on a number of fronts. Northern Africa, South Africa, China, and the lower States of America all have very significant insolation rates for most of the year. Many of these nations, presumably, are developing similar strategies to "cash in" in the renewables revolution. China is already in this situation by dint of its massive global monopoly on the production of solar panels, wind turbines, batteries and electric vehicles, so the chances of Australia breaking into this monopoly anytime soon is miniscule.

Sources

The sources for the figures and discussion in this submission were:

Net Zero Australia (UM, UQ, PU, nous): *Final modelling results* (April 2023)
https://www.netzeroaustralia.net.au/final-modelling-results/

The Economist: *How green is the energy revolution really?* (January 2024)

Energy Transitions Comm: *Material and Resource Requirements for the Energy Transition* (July 2023)

Scott Tinker: *Have you ever seen a lithium mine?* (October 2023)
https://www.youtube.com/watch?v=aTfwqvNuk44

Mark Mills: *The energy transition delusion - inescapable mineral realities* (SKAGEN conf. Jan 2023)

Ian G. Jones: *Mining for Net Zero: The impossible task* (2021)
https://www.youtube.com/watch?v=QFDhq0WxCiY

Michael Shellenberger: *Why renewables can't save the planet* (TEDxDanubia 1999) https://www.youtube.com/watch?v=N-yALPEpV4w

Simon Michaux: *Industrial transformation away from fossil fuels will not go as planned* (Oct 2023)) https://www.youtube.com/watch?v=iqjsPa8bUaA

ARENA: *Strategic priorities support the transition to low emission metals* (2024)

IEA: *The role of critical minerals in clean energy transitions* (2023)
https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-tarnsitions

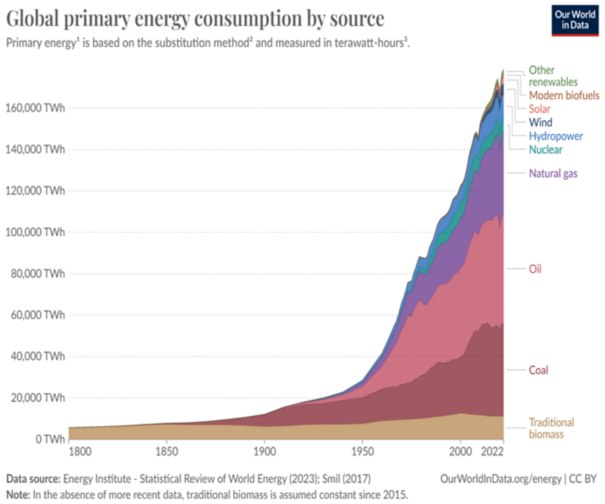
Australian Government, Department of Industry: *Australia's Critical Minerals List* (December 2023)

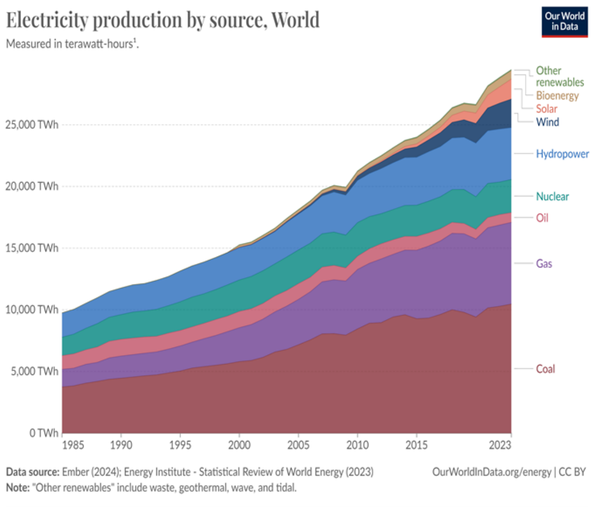
Geoscience Australia: *Mineral resources and advice* (2024)

Additional acknowledgements are provided in the footnotes to many of the diagrams.

Introduction

The Climate Council defines "Net Zero" as "*The phase-out of all fossil fuels and transition to renewable energy across all sectors of the economy*." This is a huge ask, as the following graphs and tables for the world as a whole indicate.





The situation for Australia is no less challenging (where "renewable" is taken as solar and wind since hydropower in Australia can no longer be scaled to meet the emerging demand.

Australia: Total energy

Source	2022 share (%)
Renew	8.9
Gas	27.1
Oil	36.5
Coal	27.5

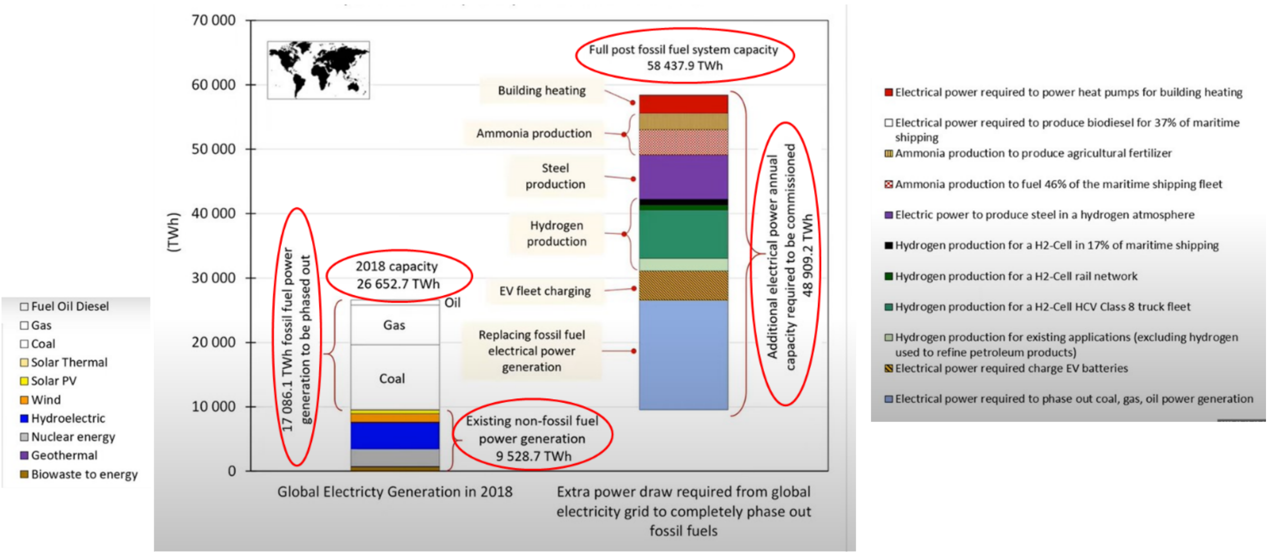
Source: DCCEEW (2023) Australian Energy Statistics, Table C https://www.energy.gov.au/energy-data/australian-energy-statistics/data-charts/australian-electricity-generation-fuel-mix

Australia: Electricity only

Source	2022 share (%)
Renew	32
Gas	19
Oil	2
Coal	47

Source: DCCEEW (2023) Australian Energy Statistics, Table C https://www.energy.gov.au/energy-data/australian-energy-statistics/data-charts/australian-electricity-generation-fuel-mix

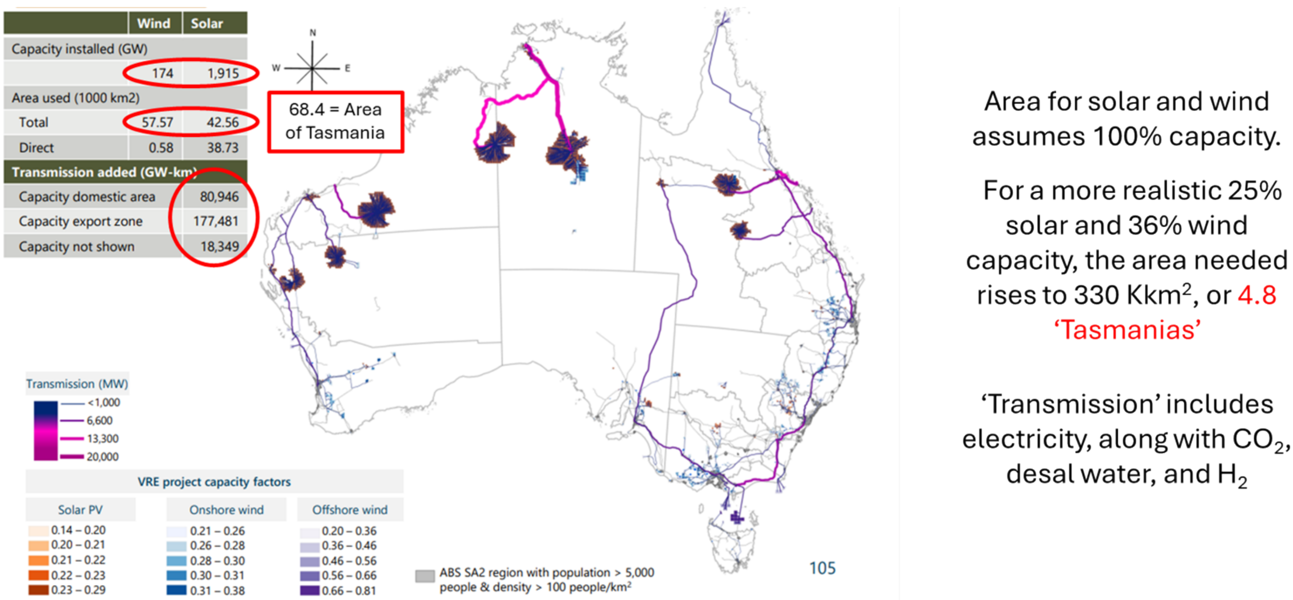
The next figure underlines the magnitude of the task when it is realized that not only does coal and gas have to be replaced by renewables, but also all EV fleet charging, hydrogen, steel and ammonia production, and all building heating. The full task is for a new 48,909 TWh of power from renewables, when the current non-fossil fuel production is just 9,528 TWh. In other words, we have to increase renewables' contribution by a factor of 5 times, just to replace the existing energy usage worldwide. Given that hydropower (the blue segment of the left hand column) cannot be scaled significantly, this factor is really around 10 times. Add to this the massive increase in energy usage as world standards of living increase, and the difficulty of the challenge becomes clear.



Simon Michaux (2023) https://www.youtube.com/watch?v=iqjsPa8bUaA

The next figure shows the results of Net Zero Australia Project (NZAP), a 12-month collaborative project between the University of Melbourne, the University of Queensland and Princeton University, for its middle of the range "E+2050 model". This model involved "nearly full electrification of transport and buildings by 2050, renewable rollout rate almost unconstrained, and a lower cap on underground carbon storage". It showed that the area of land that needed to be devoted to solar and wind electricity generation and transmission would be around 330Kkm^2, or 4.8 times the area of Tasmania. Like the models from the Australian Energy Market Operator (AEMO), the NZAP ignored any contribution from nuclear energy, but it did include the production of hydrogen.

The area required for electricity generation does not count the area required for the replacement of all energy exports of the country, a scenario that NZAP estimated would require some $7-9 trillion of investment.



https://www.netzeroaustralia.net.au/final-modelling-results/

The low intensity and low capacity factors (25-30%) of solar cells and wind farms (versus around 80-90% for nuclear) translates into a massive physical footprint, both in terms of land area needed, and the resultant environmental impact. For example, the world's largest PV project (just 2GW) at Dhafra in the Abu Dhabi desert occupies 20 km^2 (see next figure).

2GW Al Dhafra Solar PV project (2023), 4M modules and 20 sq km in the Abu Dhabi desert.
https://www.adpv2.ae/solar-project

Recently, Atlassian co-founder Mike Cannon-Brookes's *SunCable*, proposed building an (up to 6GW, but it is not clear if this assumes 100% capacity) solar farm and battery storage facility in the Australian Outback. If completed (in 2030), it would be one of the largest renewable energy projects in the world. Unfortunateltely, it will occupy a land area of 127 km^2, and one wonders if social and financial approval will eventuate.

For comparison, a 1GW wind farm would require 900 turbines operating at 36% capacity, which would occupy a similar land area, given the need to ensure non-interference between the turbines.

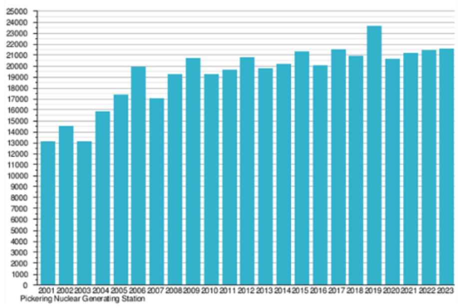
On the other hand, various modules of the 3.3 GW Pickering Ontario, nuclear reactor have been operating since 1971 and over the past 20 years have yielded capacity factors of up to 87% (see figure below). The total area of land, including the exclusion zone, is merely 2.4 km^2, less than 2% of the *SunCable* proposal.

Commissioned: 1971-86

Total land area: 2.4 km^2

Total Nameplate: 3.11 GW (6 units)

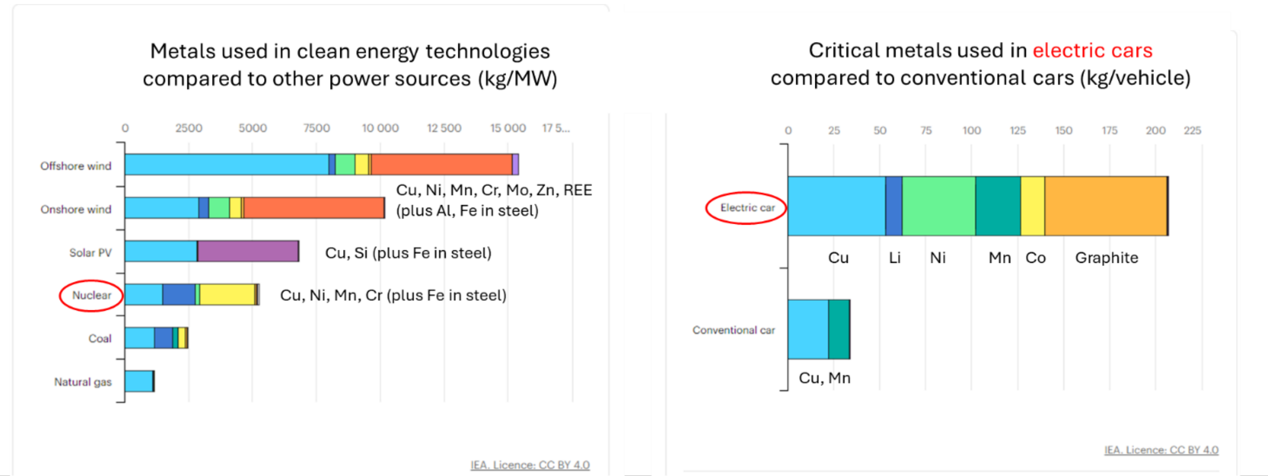
Capacity factor: 73.85% (lifetime)
87.07% (2019)



With smaller footprints the environmental and social impacts are much lower

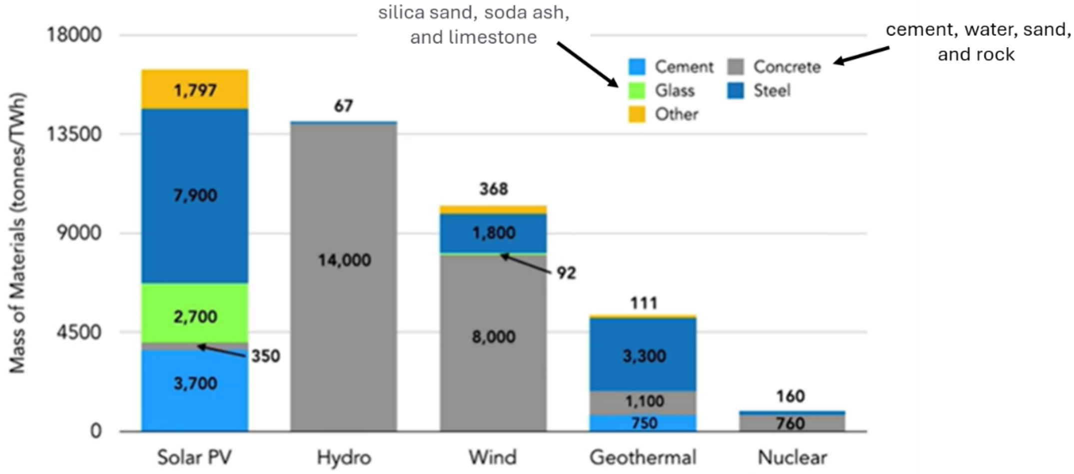
Materials requirements

The critical minerals needed for 1 MW of power from various sources is provided in the figure below. The requirements for nuclear are approximately 30% of those for offshore wind and about 70% of solar PV. Electric cars use much more of these minerals than a conventional car.



Source: IEA The Road of Critical Minerals in Clean Energy Transitions
https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

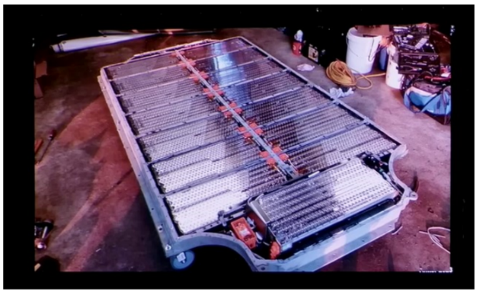
The conventional materials of construction requirements per TWh for various energy production systems is also dramatically higher (by about 16 times) for solar PV than for nuclear, once again highlighting the large numbers of individual units required for a given level of power production.



The effect of low energy intensity on the materials requirement for renewables is again evident

Michael Shellenberger: Why renewables can't save the planet https://www.youtube.com/watch?v=N-yALPEpV4w

Replacement of units is an issue for infrastructure with a more limited-service lifetime, especially if they cannot be economically recycled. If they cannot be recycled, then new resources must be mined and used for new construction each time the infrastructure fails. There is currently no effective recycling mechanism for solar cells or for defunct turbine blades, as the following graphic from the US shows.



The battery floor of an EV.
90% of Li batteries are not recyclable and need to be replaced every 8-12 years

Hail-damaged solar cells for landfill
Solar panels need replacing after 20-30 years

January 9, 2020: wind turbine blades being buried in the Casper WY Regional Landfill.
Around 8,000 wind turbine blades need to be removed and disposed of every year in the US. Credit: Benjamin Rasmussen, Getty images

More discussion about 'decommissioning' and replacement of renewable infrastructure in needed!

Relative CO_2 emissions for various sources of renewable electricity are also revealing. When one takes the whole-of-life gCO_2eq / kWh it becomes clear that the oft-quoted operating emissions do not provide anywhere near the full story. The following graphic shows that the median emission from nuclear power is similar to those from wind, ocean tidal and wave power. It is also around 25% of the total emissions from solar PV and about a third of that of geothermal. Most of the emissions arise from the mining, processing and manufacturing cost of the infrastructure which is, of course, much larger for those systems with a lower intensity and larger footprint.

Technology	Min.	Median	Max.
Coal – Pulverised coal	740	820	910
Gas – combined cycle (CO, H_2, CH_4)	410	490	650
Biomass – Dedicated	130	230	420
Tesla 3 Li-ion battery pack	30	110	200
Solar PV – Utility scale	18	48	180
Solar PV – rooftop	26	41	60
Geothermal	6.0	38	79
Concentrated solar power	8.8	27	63
Hydropower	1.0	24	2200
Wind Offshore	8.0	12	35
Nuclear	3.7	12	110
Wind Onshore	7.0	11	56
Pre-comm. ocean tidal and wave	5.6	17	28

Not all figures include the impacts of all phases of the life cycle.

Aerial view of WA's Kemerton Li(OH) plant. Image: Albemarle.

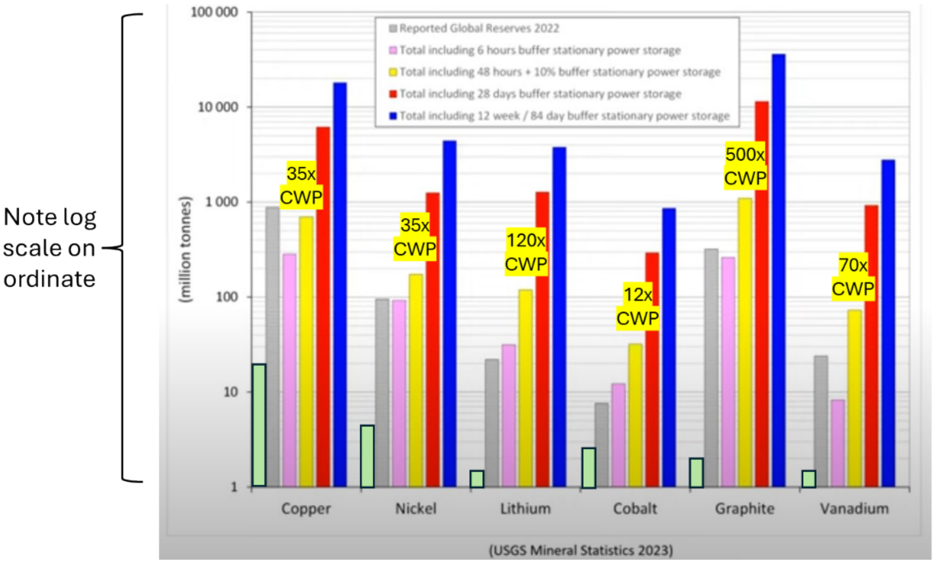
https://en.wikipedia.org/wiki/Life-cycle_greenhouse_gas_emissions_of_energy_sources

What conclusions can we make from these comparisons?

Relative to nuclear power:

1. The much lower energy density of renewables means than their aerial footprint is very large, and so:
2. Renewables require much greater quantities of materials of construction per TWh, many of which are 'critical' metals.
3. Renewables have short(er) operational lives and cannot be recycled efficiently, so they must be rebuilt continuously from primary resources.

What quantity of some of these critical metals is required to phase out fossil fuels compared to currently identified resources? The light blue histogram bars in the following diagram designate the current world production of each of the metals, and the grey bars are the reported global reserves in 2022. The pink, yellow, red and blue bars represent various models for the required renewables, based on the additional storage capacity required to cater for increasing levels of backup reserves (see the key).



Current world production (CWP)

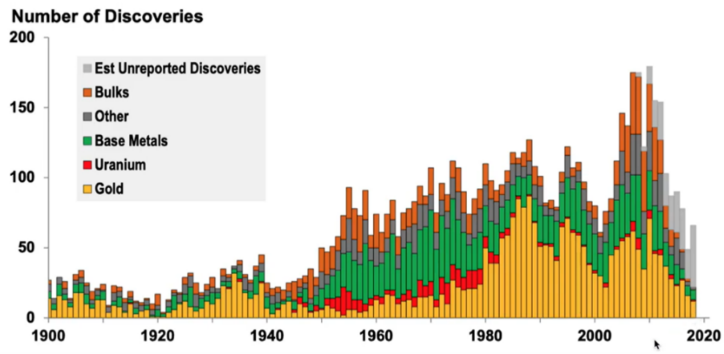
The IEA's estimate of the need for "*6x more mineral inputs to hit net zero globally by 2050*" seems to a massive UNDERestimate

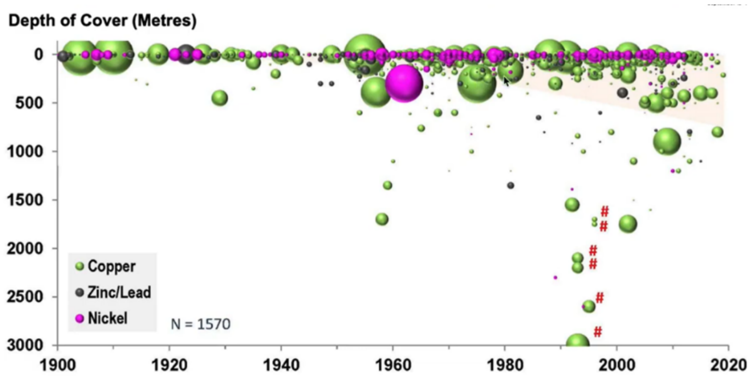
Amended from Simon Michaux (2023) https://www.youtube.com/watch?v=iqjsPa8bUaA

The yellow model includes just 48 hours of storage capacity plus a 10% buffer and has been selected as a middle-of-the-road case for comparisons against current world production (CWP) rates. The yellow box above the histogram for each metal shows the multiplier relative to CWP. The best-case scenario is for cobalt for which the world will need 12 times CWP. The worst-case scenario is graphite, where we will need 500 times CWP. In the case of copper, the multiplier is 35 times CWP. Indeed, it has been suggested that to support the renewables revolution we will need to discover mine and process more copper than has been undertaken in the history of humanity

Because of the low or nonexistent recycling rates of many of these metals, the same need for resources will be repeated every 15-25 years (the lifetimes of batteries, turbines and solar panels).

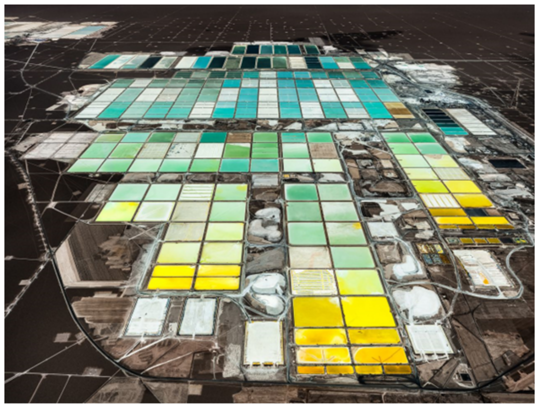
Unfortunately, discovery rates of metal resources have been declining over the past decade, ore grades are decreasing and they are being found at ever increasing depth and are smaller in size (see figure below). All of this contributes to increased costs of extraction, processing, CO_2 emissions and environmental impact. The average time from discovery to full mine production is around 16 years, so we can't just turn on the metals tap overnight, even if we knew where the new resources were located and had approval for their extraction. Furthermore, the need for this increased production comes at a time when global investment in exploration and mining is slowing.





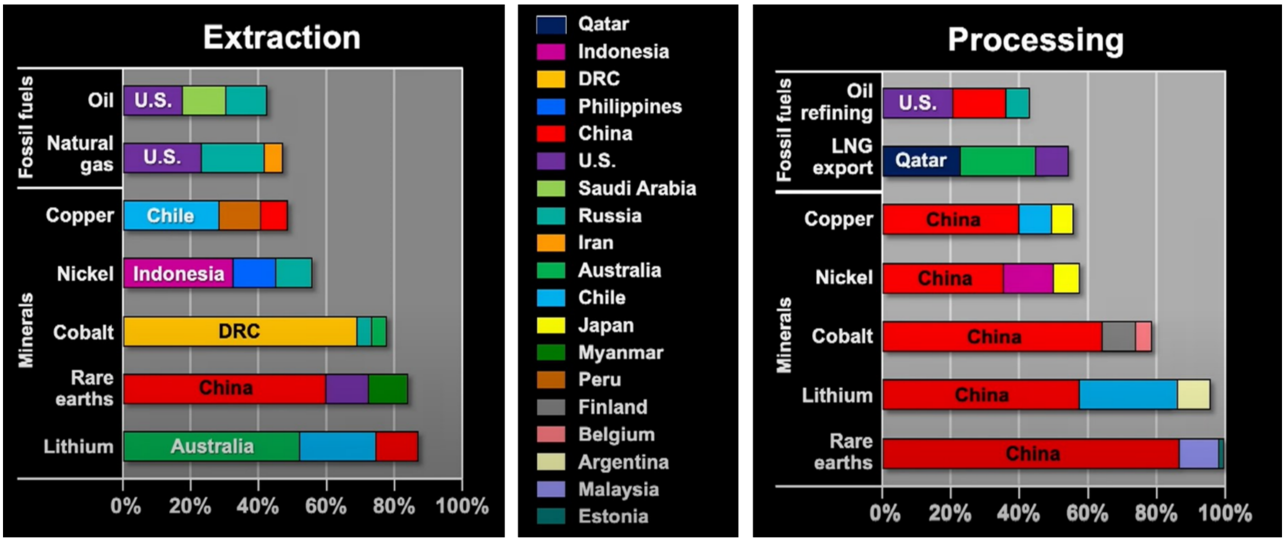
The following figure provides just two examples of the major impact that mining (left – BHP Cu mine) and processing (right- Li precipitation ponds) have on the landscape and hence biodiversity and the environment. Multiple this 100-fold to get an image of the global impact in achieving Net Zero. The recent example of the overturning of approvals for a tailings dam for gold in NSW points to another of the difficulties in expanding the mining and processing of these critical minerals

BHP's Escondida Cu Mine, Chile
(3.9km long, 2.7km wide, 645m deep)
https://www.mining.com/bhp-billiton-expects-significant-increase-in-copper-production-at-escondida-mine-in-chile/



Li evaporation 'ponds', Salar de Atacama, northern Chile
https://www.euronews.com/green/2022/02/01/south-america-s-lithium-fields-reveal-the-dark-side-of-our-electric-future

Finally, in the figure below, extraction (left) and processing (right) of these critical minerals are 'dangerously' concentrated in a few countries, with Australia (with the exception of lithium and uranium) becoming reliant on just a few countries for its supply chains.



Scott Tinker https://www.youtube.com/watch?v=aTfwqvNuk44

Conclusions

- There seems to be little awareness or acknowledgment in the general community of its huge dependency on minerals, whether for the renewables revolution or otherwise.
- There is no path to Net Zero using solar and wind energy without a LOT more mining and mineral processing to meet the massively increased demand for all renewable energy materials.
- Current mineral reserves are not adequate to resource the metal production required to manufacture even one generation of renewable technology units.
- New economic deposits must be found quickly, but they are becoming harder to find, are more complex, have lower grades, and occur at greater depth.
- There is a huge environmental and social cost in producing the metals we need for this green revolution, and very few economic recycling options.
- On the other hand, nuclear power has a much lower materials requirement than renewables, due largely to its higher energy density, which leads to an environmental footprint that is at least 20 times less than solar or wind.
- The lifetimes of nuclear power reactors are up to 3 times higher than solar and wind, meaning that replacement costs and materials requirements are equivalently lower.
- Although not covered in the discussion above, nuclear reactors can be located at decommissioned coal-fired power station sites that are already on the national grid without the need for tens of thousands of new transmission lines to bring the electrons from their remote locations.
- The emerging Small and Medium Reactor (SMR) technology has opened the door for bespoke location of these smaller unit next to their end-use location. The recent contracts by Google, Microsoft et alia to use SMRs for their increased need for energy to drive AI is but one example of how these

reactors can deliver real advantages. They are anticipating delivery of these units by 2035.

- Australia has safely operated 3 nuclear reactors since 1958; 10MW *HIFAR* (1958-2007), 100kW *Moata* (1961-2009) and 20MW *OPAL* (2007-present)
- The *HIFAR* reactor was built by UK firm Head Wrightson Processes Ltd between 1955 and its commissioning in 1958. The *OPAL* reactor was designed, built and commissioned by Argentinian company INVAP S.E. Contract signed in 2000 and the reactor opened in 2008.
- Australia has sites for low/'moderate' level radioactive waste storage at Sandy Ridge WA (operating), and at Kimba SA (overturned on appeal by the court) and proven technology (*SYNROC* - Ansto) for conditioning and storage of intermediate or high-level liquid wastes.
- Australia has 1/3rd of the global resources of uranium (and produces 10% of global usage).

R J Hill, 31 October 2024