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The Committee Manager
Standing Committee on Environment and Planning
Victorian Parliament House, Spring Street
EAST MELBOURNE VIC 3002

24 February 2020

Re: Inquiry into potential benefits to Victoria from nuclear power industry

Dear Committee:

Nuclear Economic Consulting Group (NECG)[1] makes this submission into the Victoria Environment and Planning Committee inquiry into potential benefits to Victoria in removing prohibitions enacted by the Nuclear Activities (Prohibitions) Act 1983.

I. Summary

NECG strongly recommends that the Victorian Government:

- Remove prohibitions on nuclear power in the Nuclear Activities (Prohibitions) Act 1983;
- Develop and implement state policies and administrative capability to support nuclear power generation and other nuclear fuel cycle activities; and
- Consider ways to promote or support the nuclear power industry.

Nuclear power is a proven, mature, large-scale, carbon-free, reliable, dispatchable, base-load electricity generation option that is, and will continue to be, essential to a carbon-free electricity sector.

1 https://nuclear-economics.com/

Nuclear power may be a useful option for Australia to address the energy trilemma (i.e., maintain a reliable electricity system with affordable electricity prices while reducing or eliminating carbon emissions) in the electricity sector.

Victoria may have a role in this critical national effort.

If Victorian prohibitions of nuclear power industry activity remain in place, it will be difficult to have a real, fact-based debate about the costs, benefits, and other issues related to nuclear power and nuclear fuel cycle activities. It will also constrain Victoria's options to promote clean growth strategies.

II. NECG

NECG is a management and economic consulting firm. NECG experts[2] combine consultancy experience with extensive real-world operational and corporate leadership. NECG experts have worked in the nuclear industry and on nuclear projects around the world at all stages.

We apply in-depth analysis to complex economic, business, regulatory, financial, geopolitical, and other challenges related to the nuclear industry. Our work is based on analytical rigor and objectivity informed by real-world industry experience.[3]

NECG's work is informed by extensive experience in the electricity industry (including project development, technology development, and financing), in electricity industry restructuring, and in assessing the impact of electricity reform on the nuclear power industry.

III. Submission

Nuclear power is a proven, mature, large-scale, carbon-free, reliable, dispatchable, base-load electricity generation option. Nuclear power is, and will continue to be, an essential part of a clean energy strategy. Nuclear power can help meet electricity system reliability/resilience requirements, provide power needed for economic growth, and achieve climate protection objectives.

The world needs to move away from combustion-based electricity generation to reduce greenhouse gas emissions responsible for global climate change and to reduce air pollution responsible for persistent health hazards and mortality.

Nuclear power provides a powerful and effective option to help shift away from combustion-based electricity generation. In developed economies, nuclear power can enable a shift away from existing combustion-based electricity generation and toward a cleaner overall generation mix. This is particularly relevant for Australia, given its heavy dependence on coal-fired

[2] See https://nuclear-economics.com/expertise/

[3] See https://nuclear-economics.com/resources

generation. In developing economies, nuclear power can help meet electricity demand growth with less reliance on new combustion-based electricity generation.

Including nuclear power as an electricity generation option for Victoria will:

- Provide a powerful and effective option to decarbonize the electricity sector;
- Provide a scalable means to meeting evolving and future electricity grid demands;
- Provide new jobs from investment in nuclear power and nuclear fuel cycle activities;
- Reflect Australia's leading global role in uranium production;
- Facilitate a national debate on nuclear power that is based on rational economic, environmental, public policy, and other measures, rather than on political issues; and
- Encourage developers of potential nuclear power and/or nuclear fuel cycle facilities to consider Victoria as an option for project investment.

A. Global Nuclear Power

Nuclear power has more than 60 years of power generation experience in multiple countries. According to International Atomic Energy Agency data[4] through the end of 2018:

- 450 nuclear power reactors, with a combined net capacity of 396 GW(e), were in operation;
- 55 nuclear power reactors, with a total capacity of 57 GW(e), were under construction;
- Nine new nuclear power reactors, with a total capacity of 10,358 MW(e), were completed and connected to the grid;
- Construction began on five new nuclear power reactors, with a total capacity of 6,339 MW(e);
- Nuclear electricity generation was 2,563 TWh, a 2.4% increase from 2017;
- Nuclear electricity was about 10% of total world electricity production; and
- Nuclear power has almost 18,000 cumulative reactor-years of global operating experience.

The IAEA projects that a doubling of current nuclear power capacity by 2050 is needed to achieve Paris Agreement objectives. Nuclear electricity generation is already a key factor in

[4] See 2019 Edition of IAEA RDS-1, "ENERGY, ELECTRICITY AND NUCLEAR POWER ESTIMATES FOR THE PERIOD UP TO 2050" - https://www.iaea.org/publications/13591/energy-electricity-and-nuclear-power-estimates-for-the-period-up-to-2050

achieving lower carbon dioxide emissions in many countries including France, the UK, USA, Switzerland, Ukraine, Russia, Spain, Finland, Sweden, and South Korea.

In contrast, Germany's failure to meet its climate goals[5] is in large part a result of the politically motivated closure of its nuclear electricity generation. Germany's politically-driven shift from nuclear power to renewables has led to increased use of coal-fired generation, to a need for more natural gas from Russia, and to the highest power prices in Europe.[6]

Existing fleets of operating nuclear power plants in China, India, Russia, the European Union, and other countries are growing as new nuclear power projects are developed and placed into operation. In the UK, new nuclear power plants are being built to replace older nuclear power plants that will be decommissioned over the next 5-10 years.

At the same time, multiple countries are developing nuclear power for the first time, including:

- Bangladesh, with a 2-reactor nuclear power plant (Roopur) under construction;
- Belarus, with a 2-reactor nuclear power plant (Ostrovets) under construction;
- Egypt, with a 4-reactor nuclear power plant (El Dabaa) under development;
- Turkey, with a 4-reactor nuclear power plant (Akkuyu) under construction; and
- UAE, with a 4-reactor nuclear plant (Barakah) under construction, with the first unit to be started up soon.

Twenty-eight countries are interested in introducing nuclear power and an additional 20 countries have expressed interest in nuclear power.

Multiple Africa, Middle Eastern, and Asian countries are considering nuclear power programs and have participated in some nuclear infrastructure related IAEA activities, and have participated in IAEA-supported technical cooperation projects on energy planning.[7]

B. Nuclear Power Technology

1. Current nuclear technology

Most nuclear power capacity in operation, under construction, and under development in the world is based on large light water reactor (LWR)[8] and pressurized heavy water reactor

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5 See https://www.bloomberg.com/graphics/2018-germany-emissions/

6 See https://www.cleanenergywire.org/news/german-households-and-industry-pay-highest-power-prices-europe

7 See International Status and Prospects for Nuclear Power 2017 (https://www-legacy.iaea.org/About/Policy/GC/GC61/GC61InfDocuments/English/gc61inf-8_en.pdf)

8 Light water reactor technology includes pressurized water reactors and boiling water reactors.

(PHWR) technology. These proven reactor designs are in use and operating today and are ready for immediate deployment.

The more than 18,000 reactor-years of operational experience at hundreds of nuclear power plant in tens of countries has resulted in an extensive knowledge base and nuclear know-how in the industry. This deep and wide global nuclear power experience has led to improvements and modifications to existing reactors, to better operating procedures, to a deeply entrenched nuclear safety culture, to a large international group of nuclear power operators and experts, and to new reactor designs (e.g., large Generation III or III+ LWR reactors).

The nuclear power industry has developed sophisticated measures related to cyber-physical security. Moreover, new security requirements continue to emerge to meet the demands created by digitizing safety instrumentation and control and systems, the convergence of internet and communications technologies and operational technologies (ICT – OT), new reactor designs, and grid modernization efforts.

Nuclear power plants typically have redundancy measures and industrial control systems are not connected to the internet, making them less vulnerable to remote access intrusions that can have cyber-physical consequences. Also, nuclear power may make an electricity system easier to defend from cyber and/or physical attacks as compared to multiple units of distributed electricity generation resources that have less rigorous cyber-physical security systems.

2. New nuclear power technology

The nuclear power industry is in the process of a potential shift away from large LWR and PHWR technology, while building on global experience and lessons learned.

There is growing interest in developing new small and advanced reactor designs that may provide additional benefits due to standardized, factory-built designs with modular construction and deployment.

These new small and advanced reactors should be available for deployment towards the end of this decade.

These new reactor designs may have shorter construction periods, advanced safety features, and capability to meet new applications for nuclear power (e.g., mining, remote communities, district heating, industrial applications, desalination, and hydrogen production).

These small and advanced reactors may also provide a secure autonomous power supply for national security sites.

Some advanced reactor designs can use radioactive waste from the current generation of nuclear power as fuel.

New small and advanced reactor technology approaches also focus on increasing security through reactor and power plant design features.

C. Role of Government is Important

For nuclear power to be a viable option, Australia must develop and implement the necessary nuclear laws and treaties; enhance nuclear safety regulator capability to oversee development, construction, and operation of power reactors; adopt appropriate electricity market structures; and put other administrative infrastructure in place.

While most of these activities will be a part of an Australian Federal Government effort, there is a role for Victoria and other state governments.

Relying on the short-term electricity market to deliver nuclear power investments may not work. Nuclear power has a unique mix of high upfront capital investment, zero carbon emissions, long operating life, low operating cost, and multiple public goods (e.g., energy security, energy diversity, clean baseload energy) that may not be compensated in the electricity market.

There is a role for out-of-market incentives and mechanisms to provide additional revenue and revenue certainty to nuclear power plants, including carbon taxes, long-term contracts, tax credits, and other out-of-electricity-market mechanisms.[9]

Other countries are dealing with the issues related to nuclear power in electricity markets, and NECG recommends that Victoria assess this experience, including:

- **Ontario, Canada** - Ontario has an electricity market, but relies on administrative resource planning and supply contracting[10] to determine the development of generation resources.[11]

  Using this approach, Ontario entered into contracts to support the refurbishment of the Bruce nuclear power plant units to extend operating life to 60 years or longer; closed all coal-fired power plants; and achieve low electricity sector carbon emissions.

- **Great Britain –** Great Britain has one of the earliest electricity markets, but also has a strong commitment to nuclear power. Great Britain concluded that the electricity market would not deliver new nuclear power investments.

  The electricity market, supplemented by a package of out-of-market incentives for new nuclear investments that resulted in the new Hinkley Point C nuclear power project. Today, regulated nuclear power plants are being considered, as is an aggressive program to promote the development of small modular reactors.

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9 A comprehensive set of actions to help nuclear power is presented in the American Nuclear Society Toolkit (http://nuclearconnect.org/wp-content/uploads/2016/02/ANS-NIS-Toolkit-V2.pdf) . While some of these tools are unique to the U.S., there are multiple ideas that could be applied in Victoria.

10 A recent report on Ontario electricity contracts is at http://www.ieso.ca/-/media/Files/IESO/Document-Library/contracted-electricity-supply/Progress-Report-Contracted-Supply-Q1-2019.pdf?la=en

11 See http://www.ieso.ca/Learn/Ontario-Power-System/Electricity-Market-of-Tomorrow

- **U.S.** - About half of the U.S. nuclear fleet is regulated or government-owned, with the other half converted into merchant power plants as a part of the electricity market reform and restructuring.

  While the regulated and government-owned nuclear plants lower total system costs for utility owners, the merchant nuclear plants have difficulty covering cash generating costs in the short-term electricity markets.[12] [13]

  Out-of-market approaches have been implemented to keep merchant nuclear plants from early retirement in U.S. states, including New York, Illinois, Connecticut, New Jersey, and Ohio. These states provide additional revenue linked to the value of zero-carbon nuclear electricity to supplement electricity market revenue.

  Georgia, South Carolina, Florida, and other states adopted utility regulatory policies to facilitate new nuclear power projects.

- **Japan** - Japan is restarting its fleet of nuclear power plants and undertaking electricity industry reform and restructuring. Japan examined global experience with nuclear power in restructured and reformed electricity industries to develop multiple market design features and out-of-market activities aimed at maintaining the long-term economic value of nuclear power.[14]

D. Benefits of nuclear power

1. Nuclear power has zero carbon emissions

Nuclear electricity is generated without any emissions of carbon or other air pollutants.

Total lifecycle carbon emissions of nuclear power are comparable with, or lower than, the total lifecycle carbon emissions of solar and wind energy.

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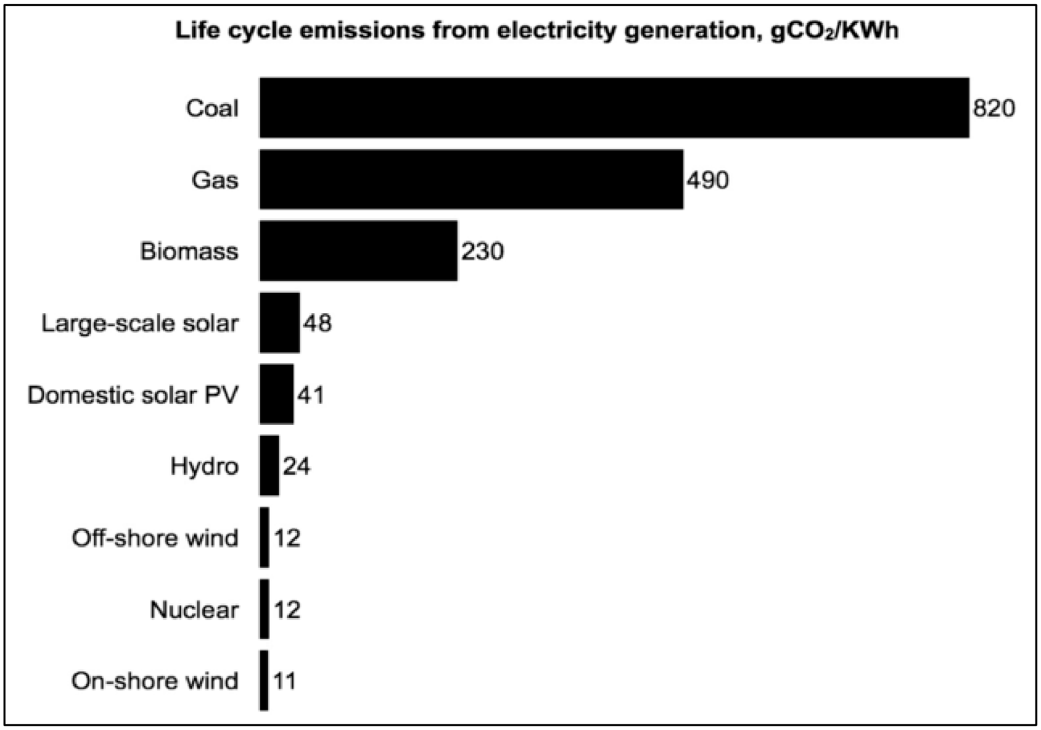
[12] See Economic and Market Challenges facing the U.S. Nuclear Commercial Fleet (https://nuclear-economics.com/wp-content/uploads/2017/10/2017-09-Market-Challenges-for-Nuclear-Fleet-ESSAI-Study.pdf)

[13] See NECG Commentary #21 (https://nuclear-economics.com/21-market-failure/)

[14] See NECG Commentary #26 (https://nuclear-economics.com/26-japan-nuclear-power-and-electricity-reform/)



Source: Intergovernmental Panel on Climate Change Life Cycle Assessment

The ability of nuclear power to generate large amounts of clean electricity is an important tool in global efforts to curb greenhouse gas emissions.

Nuclear power is now, and is likely to remain, the primary generating technology to replace combustion-based electricity generation to reduce the dumping of carbon and other pollutants into the air.

2. Nuclear power plants are reliable

Nuclear power plants can operate all the time, without interruption due to a lack of sun, wind, or rainfall. Other low or zero-carbon electricity generation options (e.g., solar and wind) have intermittent output that:

- May not be available when needed to meet system demand (i.e., resulting in high market prices and/or bulk power system shortages);
- May generate more power than needed to meet system demand at times (i.e., leading to negative spot market prices and complications for grid management); and
- Creates the need for additional infrastructure (e.g., transmission lines and storage) to manage the electricity system.

When compared to renewable energy options, nuclear power is superior in terms of availability.

Nuclear power plants are refueled every 18 to 24 months and can easily store nuclear fuel reloads on-site to avoid potential geopolitical or natural hazard-related disruptions.

In contrast, fossil fuel plants are heavily reliant on complex fuel delivery supply chains that are susceptible to fuel supply disruptions that impact generation output, electricity market prices, and system reliability / security.

3. Nuclear power plants are dispatchable

Dispatch refers to the process of turning power output up or down when needed. Dispatch of power plants by markets or system operators is used to meet the varying daily, weekly, and annual demand for electricity. Demand refers to the total amount of electricity needed to supply utility customers at any point in time.

Economic dispatch of generators, including those in the Australian electricity market, is based on short-run marginal cost (SRMC). Power plants with a low SRMC are dispatched (i.e., turned on) first, with higher-SRMC units dispatched as needed to meet additional demand. In electricity markets, the SRMC of the last unit dispatched determines the spot market price.

Nuclear power plants have a marginal cost of zero (i.e., it costs no more to operate these plants at full capacity than to have them sitting idle; all costs are fixed).[15] Nuclear power's low SRMC makes these plants the first generators to be turned on to meet demand and typically leads to nuclear power plants operating at full output between refueling outages.

Fossil fueled power plants have higher SRMC due to the cost of fuel, so that fossil fueled power plants are dispatched after nuclear power. Fossil-fueled power plants are also used for load-following (i.e., turning output up or down to meet varying net demand for electricity).

Renewable electricity generation options (e.g., solar and wind) are not dispatchable[16] and even lead to an increased need for load-following operation that may lead to an increase in fossil-fuel power plant emissions.

Despite their typical operation as base load generators[17] due to economics, nuclear power plants have exceptional load following capability.[18] In France and some other countries, nuclear power plants operate to follow varying daily, weekly, and annual demand and to provide frequency

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[15] See NECG Commentary #2 (https://nuclear-economics.com/nuclear-power-short-run-marginal-cost/) and NECG Commentary #3 (https://nuclear-economics.com/nuclear-base-load/)

[16] Some renewable generators can be turned off when generating (i.e., when the sun is shining or the wind is blowing), but these generators cannot be turned on when not generating (i.e., when the sun is not shining or the wind is not blowing).

[17] Base load also refers to the lowest annual demand for power during a year. This base load demand level must be met during the entire year and nuclear power is typically used to meet this base load demand.

[18] See NECG Commentary #12 (https://nuclear-economics.com/12-nuclear-flexibility/)

control[19]. New small and advanced reactor designs are may provide even greater load-following capability.

Nuclear power will be an increasingly important carbon-free option to balance the grid and provide frequency control in a decarbonized world where there is an increase in intermittent, non-dispatchable, renewable generation.

4. Nuclear electricity is affordable

Nuclear power plants generate power over a much longer time horizon at a total lifetime cost that is at or below the cost of other available options.[20]

When the emission externalities of combustion-based generation and the total system cost impact of renewable energy options are properly reflected, nuclear electricity is very competitive. Nuclear power has the potential to lower total system costs compared to other generating options.[21]

The economics of nuclear power are attractive when the costs and benefits of these nuclear power plants are considered on a time scale consistent with the operating life of the nuclear power plants themselves (i.e., 60 to 100 years of operation, which far exceeds the asset life of solar, wind, or even gas-fired projects).

5. Nuclear power is relatively new technology

Combustion of fossil fuels and low-intensity power from wind, running water, and sunlight have been used for most of human civilization.

In contrast, nuclear fission was not discovered until the late 1930s; the first nuclear power plants were not built until the 1950s; and the first large-scale commercial nuclear power plants were not built until the 1960s.

It is an amazing feat of science and engineering that many of first large-scale commercial nuclear power plants designed and built in the 1960s and 1970s (i.e., Generation II nuclear power plants) are still operating today and can operate for decades longer.

6. Nuclear power plants can be large

Nuclear power plants operating today are typically large, with most nuclear power plants having an output of 1,000 MWe or greater. Sellers and buyers of nuclear power plants moved to larger

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19 See https://www.powermag.com/flexible-operation-of-nuclear-power-plants-ramps-up/

20 See OECD NEA 2015- Projected Costs of Generating Electricity - 2015 Edition (http://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015)

21 See OECD NEA 2019 - The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables (https://www.oecd-nea.org/ndd/pubs/2019/7299-system-costs.pdf) and OECD NEA 2018 - The Full Costs of Electricity Provision (https://www.oecd-nea.org/ndd/pubs/2018/7298-full-costs-2018.pdf)

plant sizes to capture economies of scale. Spreading fixed investment and generating costs over the larger output from a larger nuclear power plant lowers the cost of generated power.

For countries with large and well-developed electricity systems, large nuclear power plants are a viable option to provide reliable competitive electricity.

7. Nuclear power plants can also be small

Countries with smaller or less-developed electricity systems may need smaller-sized nuclear power plants.

Small and advanced reactors may have competitive costs due to a range of beneficial attributes. These cost savings may result in lower capital costs and make these small and advanced nuclear power plants easier to fund.

These small and advanced reactors may be added in smaller increments to meet growing power demand, enabling innovative financing techniques to be applied, with initial nuclear units starting commercial operation (i.e., generating profits) before later additional units begin construction.

8. Nuclear power plants are compact

Nuclear power plants generate vast amounts of power, but even the largest nuclear power plants in terms of power output have a small site footprint.

Nuclear power plants use less land and material per unit of electricity generation than any other generating technology.

This is different from wind and solar that would require extremely large amounts of land to build a wind or solar power plant that has a capacity level (i.e., during periods when the intermittent wind or solar generator is operating) comparable to a nuclear power plant.

Nuclear plants are favored from an energy intensity and energy density perspective.

9. Nuclear power plants have long operational lives

The first large-scale commercial nuclear power plants (i.e., Generation II technology) were conservatively designed to operate for about 40 years, but many of these nuclear power plants remain in operation today, more than 40 years since they were placed into operation.

Some existing nuclear power plants have obtained regulatory approvals to operate for 80 years and nuclear safety regulators are currently examining the potential for existing nuclear power plants to operate for longer than 80 years.

The long operating lives of nuclear power plants are achieved through continual capital investment to replace aging components and to update systems to modern standards. An “old” nuclear power plant, in total years of operation, is up to date because of continual capital investment and modernization.

New nuclear power plants are designed to operate for a minimum of 60 years and are likely to see operation for 80 or 100 years.

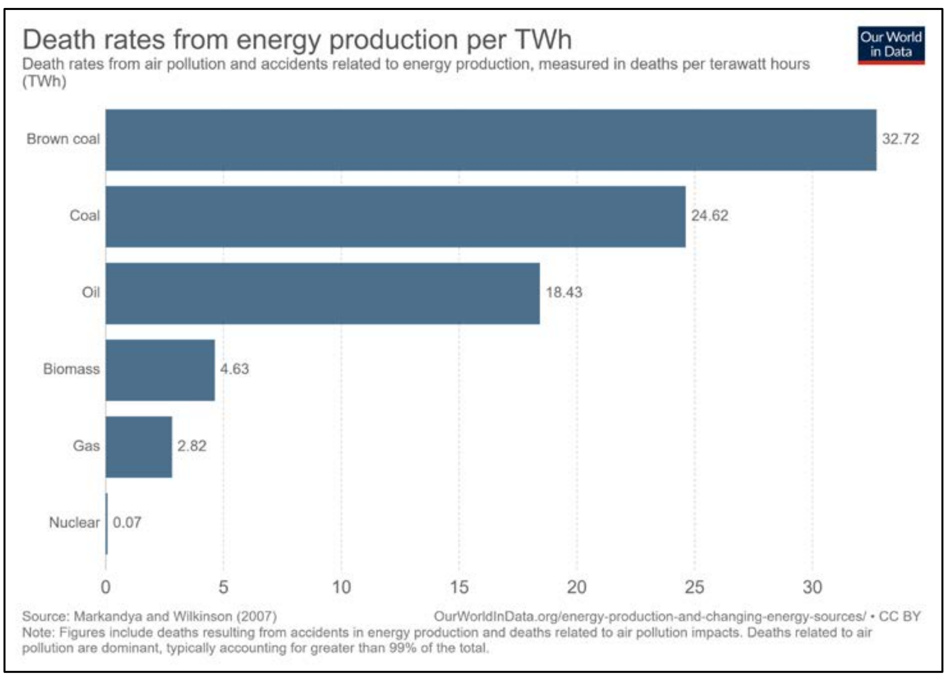
A recent IEA report[22] recommends that countries should authorize "lifetime extensions of existing nuclear plants for as long as safely possible."

This approach has a lower cost than building new nuclear power plants and is economically feasible when nuclear power plant output has an appropriate value (i.e., the economic value of clean electricity and other attributes are reflected in price of nuclear electricity).

10. Nuclear power is safe

Nuclear power has proven to be one of the safest electricity generation technologies in use today by far.

Even when the estimated deaths from the very few nuclear accidents (e.g., Three Mile Island, Chernobyl, and Fukushima Dai ichi) are included, nuclear power has a lower death/MWh than any other generation source. See chart below.[23]



22 See IEA "Nuclear Power in a Clean Energy System" May 2019 (https://www.iea.org/publications/nuclear/)

23 Source: https://ourworldindata.org/grapher/death-rates-from-energy-production-per-twh

11. Nuclear power internalizes waste management and decommissioning costs

In most countries, nuclear power decommissioning and radioactive waste disposition costs are included in the cost of nuclear electricity generated. Current approaches to nuclear waste management (e.g., dry cask storage, underground repositories, etc.) are feasible and proven.[24]

In contrast, fossil fuel electricity generation continues with the centuries-long practice of freely dumping carbon dioxide and other air pollution emissions into the air. Likewise, coal-fired generators dispose of toxic coal ash waste in surface ponds that sometimes overflow and that leach toxic compounds into the groundwater.

The same holds true for solar panels, with little assessment of panel disposition costs and few environmentally-sound decommissioning and waste disposition approaches.

Similar concerns are presented by wind turbines, which may have no funding for decommissioning when the wind turbine is no longer operational and few options to dispose of non-metallic blades and other items.[25]

12. Nuclear power is scalable

Nuclear power plants can add a significant amount of generating capacity by building multiple large nuclear power plants with few constraints due to fuel delivery or location.

Nuclear power is the only zero-carbon electricity generation source that can be scaled up to meet demand.

The early nuclear fleet build experience in France shows that nuclear generation capacity can be built quickly to meet a large portion of a country's electricity production.[26]

More recent experience in China confirms that it is feasible to deploy nuclear power in a large and rapid manner, while maintaining a high degree of safety.[27]

As noted above, new small and advanced reactors may offer significant and important scalable applications to accommodate demand growth in smaller systems with smaller increments of nuclear power capacity.

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24 See NECG report on Review of Jacobs MCM Report Commercial Model done for South Australian Joint Parliamentary Committee on Findings of the Nuclear Fuel Cycle Royal Commission for more detailed discussion of this topic (https://nuclear-economics.com/2016-11-11-south-australia-mnr-necg-final-report-appendices-2/)

25 See https://www.npr.org/2019/09/10/759376113/unfurling-the-waste-problem-caused-by-wind-energy

26 See IAEA note on "The French Experience in Nuclear Energy: Reasons for Success" (https://nuclear-economics.com/iaea-french-nuclear-experience-31060498/)

27 See http://english.www.gov.cn/atts/stream/files/5d6ddd5dc6d0cc300eea7734

IV. Conclusion

NECG strongly recommends that the Victorian Government:

- Remove prohibitions on nuclear power in the Nuclear Activities (Prohibitions) Act 1983;
- Develop and implement state policies and administrative capability to support nuclear power generation and other nuclear fuel cycle activities; and
- Consider ways to promote or support the nuclear power industry.

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Respectively submitted,

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Edward Kee

CEO, Nuclear Economics Consulting Group