# IEEE Webinar Written Responses

Q: ­Are the very small reactors predominantly water-based or other advanced reactors­

* *Very small reactors (~<30 MWth) are predominantly advanced reactors. A feasibility study funded by the Ontario Ministry of Energy on the Potential Deployment of Small Modular Reactors (SMRs) in Ontario (see* [*http://ontarioenergyreport.ca/pdfs/MOE%20-%20Feasibility%20Study\_SMRs%20-%20June%202016.pdf*](http://ontarioenergyreport.ca/pdfs/MOE%20-%20Feasibility%20Study_SMRs%20-%20June%202016.pdf) *) included 9 reactor concepts with a power range of 5 to 32.5 MWe. In that study, seven suitable reactors out of nine were Advanced Reactors.*

Q: ­Which type of reactor would be most immune to the disastrous results experienced at fukishima?­

* *Most new generation reactors are immune to the environmental releases that displaced many people from their homes at Fukushima. In Fukushima, the reactor cores melted because after the successful shutdown of the reactors, the low level decay heat produced by the active fuel increased the core temperature. When all available water in the plant evaporated, fuel melted. Most advanced reactors employ a number of measures (multiple barriers) to eliminate this to happen. Typically (1) decay heat is removed from the reactor core passively (i.e. without the use of pumps and active systems that require power and prone to malfunction), (2) excess heat is dumped to the environment air (so that safety systems will not run out of water), (3) advanced fuels (like TRISO fuel used in High Temperature Gas-Cooled Reactors) or coolant (molten-salt and lead) will retain fission products. Having said that, even the new generation water-cooled reactors (for example NuScale SMR) developed safety systems that will preclude Fukushima-type of accidents.*

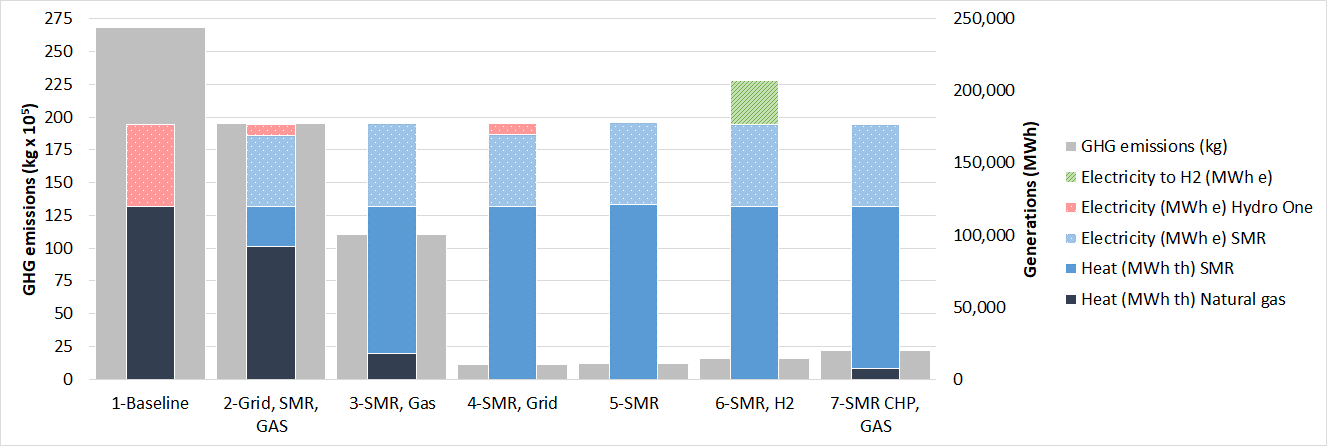
Q: ­is nuclear power considered renewable? if yes, what is the cost comparison to solar and wind power generation?­

* *Nuclear power is not considered renewable as it relies on uranium or plutonium as a fuel which is not a renewable resource. However, due to the small volume of fuel needed to produce large volumes of power, nuclear power is expected to be sustainable for a long time to come.*
* *In addition, it is useful to clarify that although not renewable power, nuclear is a clean source of energy. Like wind and solar panel, there are no emissions released during the operation of the reactor. Furthermore, because of the large volume of energy generated nuclear reactors are generally found to have lower emissions per KWh produced compared to wind and solar.*

Q: ­Economics: Have you done any analysis that demonstrates the relative ciost per kWe when the "ecpnomisc of many" beneifts are factored in (ie - compare a lareg reactor with a group of small reactors?­

* *There is a large body of work created related to the benefit of “economies of many” that SMRs are expected to benefit from. Below are a few references:*
* *IAEA, 2013, “Approaches for Assessing the Economic Competitiveness of Small and Medium Sized Reactors”, No. NP-T-3.7, Vienna.*
* *SMR Roadmap Economic and Finance Working Group Report:* [*https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf?x64773*](https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf?x64773)
* *M. Moore, 2017, “The Economics of Novel vSMRs in the North”, 37th Annual Conference of the Canadian Nuclear Society, 4-7 June 2017, Niagara Falls, Canada.*

Q: ­Could you please address pollution issue comparing SMRs vs fossil based plants ­

* *SMRs, and all nuclear technologies compare very favourably to fossil based plants in terms of pollution. Nuclear power generation does not produce any greenhouse gas or emit any CO2 during normal operations. The only emissions associated with nuclear are those required for the construction and eventual decommissioning of the plant at either end of its lifecycle. Page 7 of this WNA report will give you a summary of how these technologies compare in terms of lifecycle greenhouse gas emissions.* [*http://www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working\_Group\_Reports/comparison\_of\_lifecycle.pdf*](http://www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/comparison_of_lifecycle.pdf)
* *Here are some other early results looking at a microgrid at CNL. Scenario 1 gets electricity from the Ontario grid (low carbon) and heat from natural gas; this has the highest emissions (grey bars). Scenario 4 uses an SMR to produce all electricity and heat required; it has the lowest emissions.*
* 

Q: ­Can SMRs be used to replace peaker plants (typically Natural Gas fired plants now) or do they need to run constantly to provide baseline electricity?­

* *It is unlikely that SMRs can completely replace peaker plants (unless they are equipped with large quick-responding energy storage systems, such as battery storage). This is because SMRs cannot ramp power up and down at rates as fast as NG-fired plants. However, SMRs can reduce the load of peaker plants significantly by load following, albeit with some time lag. Equipped with fast responding energy storage system, SMRs can be peaker plants.*
* *For more information see the following paper:*

*Y. Ismail & B.P. Bromley, 2019, “Assessment of Small Modular Reactors (SMRs) for Load-Following Capabilities”, American Nuclear Society Winter Meeting.*

Q: ­Could SMR be a pebble-bed reactor?­

* *Yes. In fact one of the first SMRs built in China, the 200 MWe HTR-PM is a high temperature gas-cooled SMR with pebble-bed fuel core.*

Q: ­Thank you for the great presentation. I was curious how much the microreactors weigh that Metin mentioned (approximately)?­

* *Including shielding structures, it weight 35 to 45 tons.*

*Please see https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2017/power/Ananth19349.pdf*

Q: ­How, important is having a relaible unconstrained transmission grid to making the "hybrid Energy Grid" a reality?­

* *There are several types of hybrid energy systems. Some are based on a very closely coupled systems that would be located on a microgrid, others are decoupled systems that can operate over a large provincial grid.*
* *For more information please see* [*https://www.energy.gov/sites/prod/files/2016/06/f32/QTR2015-4K-Hybrid-Nuclear-Renewable-Energy-Systems.pdf*](https://www.energy.gov/sites/prod/files/2016/06/f32/QTR2015-4K-Hybrid-Nuclear-Renewable-Energy-Systems.pdf)

Q: ­Hi, I've heard there was a big initiative to develop fusion reactors, can you provide some information about this technology?­

* *Hello, there are many organizations around the world working to advance fusion reactor technology. A good summary of these efforts can be found here:* [*https://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-fusion-power.aspx*](https://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-fusion-power.aspx)

Q: ­What is predicted operational lifetime? How are they de-commissioned?

* *This varies substantially from reactor to reactor. Some are targeting only 20-30 year operating lives, whereas others are designed with the intention to run for as long as traditional CANDU plants (60+ years with refurbishment).*
* *As with traditional nuclear power in Canada, SMR vendors are working with the Nuclear Waste Management Organization (NWMO) to establish a final disposition pathway for their high-level waste. https://www.nwmo.ca/*

Q: What are the by-products/waste? How do we dispose of these?

* *Nuclear waste is typically broken out into three categories: low-level waste (LLW), intermediate-level waste (ILW), and high-level waste (HLW).* 
  + *LLW: Short lived reactivity, can be handled easily with simple precautions*
  + *ILW: Higher radioactivity, often consists of used reactor core components, resins, and filters.*
  + *HLW: Spent nuclear fuel. Requires careful management over a long time period.*
* *The disposition requirements for each of these waste types is different, with higher level waste requiring more substantial controls and precautions. Ultimately, HLW in Canada will be dispositioned by the NWMO (https://www.nwmo.ca/)*

Q: ­How many more years to commercialization?­

* *Designs based on existing nuclear technologies are targeting the late 2020s for commercialization. More advanced designs that use new technologies are targeting the early and mid 2030s for commercialization. Ultimately, the speed at which commercialization happens will largely depend on government and private investment to help vendors overcome technical and regulatory hurdles.*

Q: ­What is your prediction for first commercial use of SMR

* *As a representative of CNL, I cannot name a specific company in answering this question, however it is commonly accepted that water-cooled SMRs are the most likely technologies to reach the market first, as they are generally using existing proven technology in a new way, rather than trying to use entirely novel coolants or materials.*

Q: ­Do we have competition in SMR's from the Americans?­­

* *Yes, we have very strong competition from the Americans in this field. The US Department of Energy (DOE) has a number of substantial funding programs to help accelerate the deployment of SMRs in the US.* [*https://www.energy.gov/ne/initiatives/funding-opportunities/industry-foa-awardees*](https://www.energy.gov/ne/initiatives/funding-opportunities/industry-foa-awardees)
* *These programs, and the US’s robust supply chain make them a very appealing country for demonstration projects and commercial deployment.*

Q: ­Are we to understand that SMRs do not have an equivvalent LOCA risk?

* *Yes. LOCA (Loss Of Coolant Accident) scenarios are typically associated with high pressure coolant pipe breaks. In new generation water-cooled reactors, the connected pipes are either completely eliminated or reduced to much smaller numbers – thereby eliminating or significantly reducing LOCA possibility. Most advanced reactors (lead, sodium, molten-salt) operate at pressures close to atmospheric conditions. Hence, they are not likely to experience pipe breaks caused by high internal pressures. If the reactor vessel cracks (say due to material degradation), the coolant may leak, but the leak will be slow, detected early and managed, rather than resulting in a rapid loss of coolant if it was under high pressures*.

Q: ­How would you get sufficient and skilled operating personnel to live at the proposed remote sites

* *There are many different SMR operating schemes. One that is of particular interest for remote sites is a remote operation, which has the majority of operators working in a different geographic location. This can be achieved through a number of design choice that lead to simpler and more automated operations.*

Q: ­The micro reactors seem ideal as a power source for large container ships. Has this market been considered­­­

* *This is a good application of microreactors, but hindered by the licencing of a nuclear power plant in different jurisdictions. If the microreactors receive public and international acceptance and be as common as aeroplanes in the future, it is likely that we will see them powering large container ships. However, this will not likely be one of the early applications of microreactors*.

Q: ­What is the size of the SMR to be built at Chalk River?­

* *The Micro Modular Reactor (MMR) is 15 MWt with a 5MWe output. https://usnc.com/mmr-energy-system/*

Q: ­What are the main hurdles, especially non-technical, to deploying SMRs in Canada?

* *The most substantial hurdles to deployment in Canada are financial and political/social. Demonstrating a new reactor technology is expensive, and many private investors are reluctant to put money into technologies that may not yield a return for ten or more years. It is unlikely that SMRs will succeed in Canada without funding from Provincial and Federal governments. This funding will only materialize if it is politically viable to do so. This means that the nuclear industry needs to work hard to communicate with Canadians from all walks of life to answer their questions and concerns around nuclear technology, explain the risks and the benefits in an open manner, and try to build public acceptance of these new reactors.*

Q: ­Please comment on the life cycle costs for energy, both capital operating costs?­­

* *As with many large infrastructure projects. The lifecycle cost of an SMR varies based on the SMR technology and the deployment location. SMRs are also sensitive to economic factors such as the discount rate achieved because they are capital intensive projects with operations and fuel commonly accounting for less than 50% of the total life cycle cost.*
* *For more information see SMR Roadmap Economic and Finance Working Group Report:* [*https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf?x64773*](https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf?x64773)

Q: ­How should the nuclear industy deal with those "Anti Nuclear Cancel Culture" forces who ignore science to push their misinformation on social media­

* *There will always be detractors and critics of nuclear energy, but the nuclear industry has struggled in the past to defend itself in the public forum. In the past two decades, this has begun to change, with a new generation of professionals entering the workforce, concerned about the effects of climate change and curious about nuclear technology. To support this development, it is essential that the nuclear industry finds ways to coordinate its messaging. Organizations like the Canadian Nuclear Association* [*https://cna.ca/*](https://cna.ca/)*, the North American Young Generation in Nuclear* [*https://naygn.org/*](https://naygn.org/)*, and Women in Nuclear* [*https://womeninnuclear.com/*](https://womeninnuclear.com/)*, are doing excellent work in this area and I would recommend checking them out.*

Q: ­Some designs have refuelling at mid-life, is this risk more than those that are fuelled for life. Any comments?­

* *Not sure what risk is allude here. It is possible that there is increased risk of proliferation and the possibility of mechanical failure during refuelling (operational risk), but these are manageable as in current reactor fleet.*

Q: ­What Canadian companies are the major players in product components for SMRs?

* *Since there are no SMRs currently in operation, there are no existing major players in SMR component production, however, Canada has a very well established nuclear supply chain, which would likely be able to produce any new components required in relatively short order once SMRs start getting built. https://www.ocni.ca/membership-directory/*

Q: ­Would an expanded PR program help to reduce the misinformaton about the "primordial fear" of nuclear energy plants?­­

* *Yes, I cannot stress enough how important it is for the nuclear industry to increase its engagement with the public. There will always be detractors and critics of nuclear energy, but the nuclear industry has struggled in the past to defend itself in the public forum. In the past two decades, this has begun to change, with a new generation of professionals entering the workforce, concerned about the effects of climate change and curious about nuclear technology. To support this development, it is essential that the nuclear industry finds ways to coordinate its messaging. Organizations like the Canadian Nuclear Association* [*https://cna.ca/*](https://cna.ca/)*, the North American Young Generation in Nuclear* [*https://naygn.org/*](https://naygn.org/)*, and Women in Nuclear* [*https://womeninnuclear.com/*](https://womeninnuclear.com/)*, are doing excellent work in this area and I would recommend checking them out.*

Q: ­IS there any SMR design that matches temperature to provide only industrial process heat (no electrical power)?­

* *Any SMR design could do this. Producing electrical power is not an essential facet of an SMR, it is achieved by ‘attaching’ a steam generator or similar system to the nuclear plant. If only heat was required, the developer could alter their design accordingly.*

Q: ­How Hydrogen SMRs are compared to nuclear SMRs?

* *I believe was is being referred here is hydrogen produced using heat and electricity from and SMR vs. steam-methane reforming. Currently the proven/commercial technology for producing hydrogen with nuclear reactor is electrolysis which utilizes electricity from an SMR but not heat. Although this is a reliable method of clean hydrogen production, currently it does not complete economically with steam-methane reforming due to currently low natural gas prices and a relatively low cost of carbon.*
* *Under development are other clean hydrogen techniques such as high-temperature electrolysis, and several thermo-chemical processes. These processes utilize the high-temperature/high-quality heat produced by a nuclear reactor to improve the efficiency of the process. We are optimistic that these processes will lead to a clean & cost competitive alternative to steam-methane reforming in the future.*

Q: ­Can the units respond quickly to follow the changes in electrical load? Can they respond at the 4 second rate?­

* *Power levels for SMRs can be typically varied between 100% and 50%, although lower values of 15% to 20% are possible in some systems. Power ramp rates of 2%/min to 5%/min are possible, with some design concepts achieving ramp rates as high as 10%/min.*
* *The reactors would most likely need to be coupled with another quick responding technology (i.e. battery storage, fly wheel, etc) to achieve a response rate of 4 seconds.*
* *For more information see the following paper:*

*Y. Ismail & B.P. Bromley, 2019, “Assessment of Small Modular Reactors (SMRs) for Load-Following Capabilities”, American Nuclear Society Winter Meeting.*

Q: ­What is the refueling frequency? 20 years? How much spare fuel is needed onsite?­

* *This varies for each design. This article gives some information based on the most common designs.* [*https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx*](https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx)
* *Spare fuel is not kept on site usually. Shipments are planned so that fuel arrives ‘just in time’ for refuelling.*

Q: ­Is there technology to make nuclear batteries to store power?­

* *No magic bullet that exists. There are many energy storage technologies that a nuclear battery can be coupled with (as mentioned above: flywheel (mechanical storage, small amount of energy), battery, molten-salt, pumped hydro, compressed air or steam, ammonia and hydrogen to name a few. The appropriate energy storage system will be a function of the location, application and availability of energy storage systems.*

Q: ­Are there any procedures in place for the disposal / recycling of moderator and coolant elements?­

* *Not currently, there are researchers at CNL and other laboratories working on this challenge, but their results are not published at this time.*

Q: ­Where does Canada stand on the world scale with the development of nuclear technology?­

* *Canada is a “Tier 1” nuclear nation. We were the first country in the world to achieve nuclear fission outside of the United States and developed our own reactor technology (CANDU), which has been exported around the world. Our supply chain is among the most robust in the modern world and our regulatory agency is the ‘gold standard’ by which other regulators are measured. Russia and China have made early gains in developing SMR technologies, but Canada is seen by most SMR vendors as a key market for demonstration and commercialization in the Western World.*

Q: ­Is the structure of normal PWR completely the same with Small PWR? (including steam generator, pressurizer and so on)­

* *With “Small PWR”, I understand a PWR-type SMR. A PWR SMR structure includes all major PWR components (steam generator, pressuriser, heat transport pump and reactor vessel) in one large reactor vessel, hence eliminating all pipes connecting these components. This configuration eliminates Loss of Coolant Accident possibility.*

Q: ­OKLO in the USA is certified for building I believe. They are a micro reactor that uses spent fuel. Is that possible with CANDU spent fuel as well?­

* *Yes, there are several technologies that could recycle spent CANDU fuel. The most prominent in Canada is probably Moltex https://www.moltexenergy.com/*

Q: ­Is anyone taking a reactor from a nuclear submarine and moving it to a on-land generation system?­

* *Yes, Rolls Royce in UK has nuclear submarine experience and developing a PWR-type SMR, presumably using their nuclear submarine reactor experience. Recently France started to develop an SMR concept – the leading design company has many years of submarine nuclear reactor experience.*

Q: ­Is spent fuel stored onsite?­

* *Interim storage of spent fuel for traditional reactors is onsite yes, but this has not been finalized for SMR designs at this point.*

Q: ­What are the Canadian Standards for the installation of SMRs?­

* *Canadian Nuclear Safety Commission (CNSC) regulates the use of nuclear energy and materials in Canada (see link* [*https://www.cnsc-ccsn.gc.ca/*](https://www.cnsc-ccsn.gc.ca/)*). Canadian Standards Association (CSA) also provides standards for QA, manufacturing, inspection and maintenance requirements of operating nuclear reactors.*

Q: ­How small can they be made? Can we foresee a single-home consumer product shipped by Amazon?

* ­*The smallest fission reactor I have seen is NASA’s kilower (KRUSTY) reactor.* [*https://www.cnsc-ccsn.gc.ca/*](https://www.cnsc-ccsn.gc.ca/)*. This reactor is developed for space applications and can generate 5 kW (heat) power. This size of reactor can potentially be shipped, but unlikely to be a consumer product for other (mostly proliferation) reasons. Very small reactors leak (waste) neutrons and, hence, have to use highly enriched fuel. Hence they would be proliferation concern and not likely be an Amazon item ☺.*

Q: ­seeing how much physical security that current NPPs have, is it realistic that SMRs could be left unattended?­

* *It is unlikely that SMRs could ever be left completely unattended, but with advancements in remote monitoring and operational technologies, staffing levels could be significantly reduced. Potentially, the reactors could function with only a few technical staff on site and a small security presence.*

Q: ­What is the best achievable ramp up and ramp down rates achievable for a 100 MW SMR­

* *Power levels for SMRs can be typically varied between 100% and 50%, although lower values of 15% to 20% are possible in some systems. Power ramp rates of 2%/min to 5%/min are possible, with some design concepts achieving ramp rates as high as 10%/min.*
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Q: ­Are there extra challenges in developing microreactors that would be useful for remote communities?

* *Public acceptance, remotely-monitored autonomous operations and cyber security are few challenges that will have to be addressed.*

Q: ­Are SMR's intended for baseload or peaking applications. Thank you, and great presentation.­

* *SMRs can be operated in different ways. They likely will be used to provide baseload power. But can also provide peaking power. This may be achieved through slower ramp up and ramp down of the reactor for daily/seasonal peaks (this has been routinely practiced in France for many years) while coupling with energy generation/storage technologies that can provide quick minute to minute/second to second response.*
* *We see SMRs are part of the solution, but in many use cases they perform best when coupled with other technologies in such a way that both technologies strengths can be highlighted and there limitations addressed through synergies.*