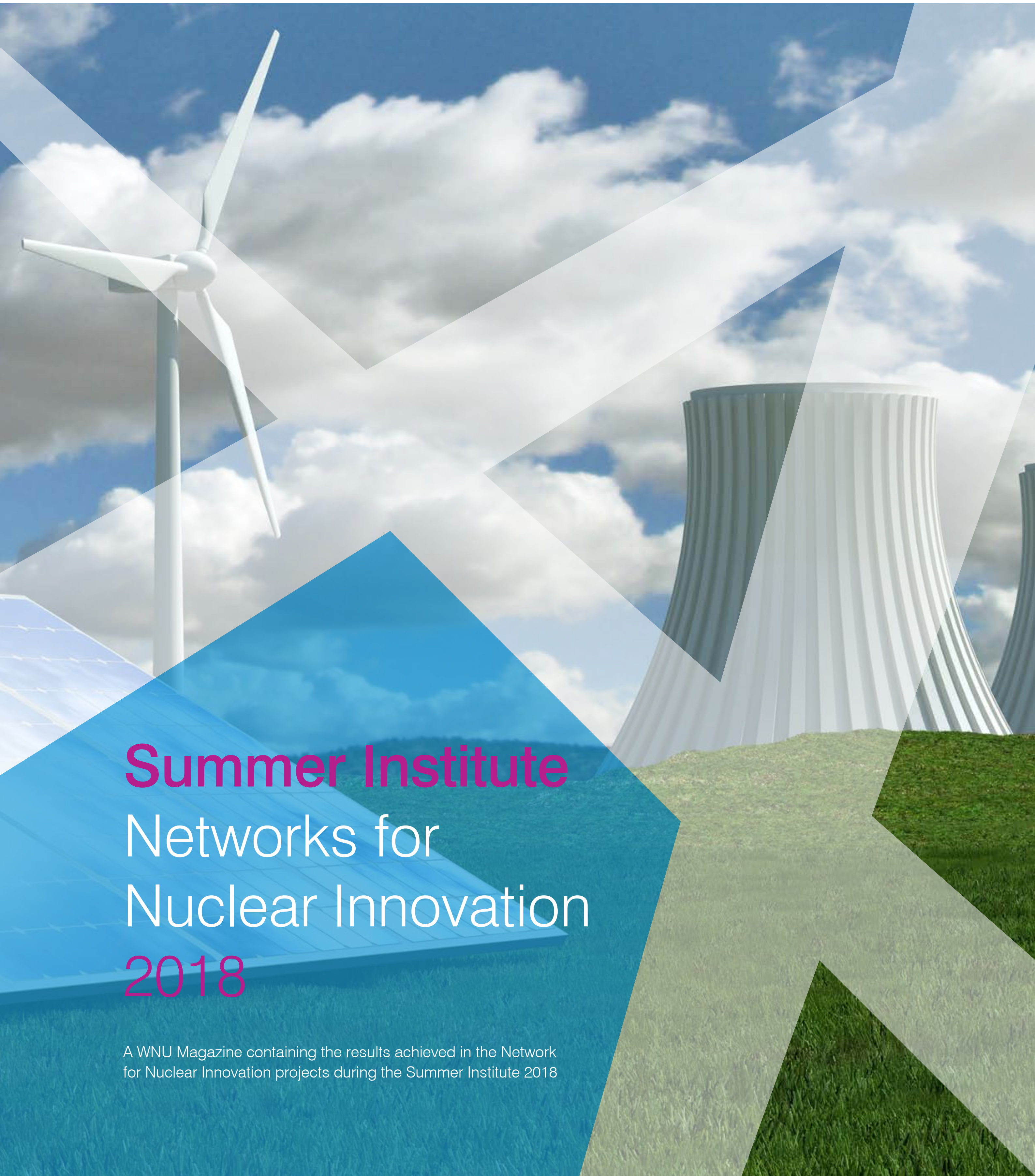

# Summer Institute

# Networks for Nuclear Innovation 2018

A WNU Magazine containing the results achieved in the Network for Nuclear Innovation projects during the Summer Institute 2018

# Contents

# From World Nuclear Association Director General

Our industry has won its place by focusing on value and achieving excellence both on the technology side and in relation to human capital. We need now more than ever to make our achievements sound for the whole world and enhance collaboration for a clean energy. And networking is a vital component in reaching these goals. Networking matters equally inside and outside the industry and the future leaders that we gather at the World Nuclear University become more aware to never underestimate the power of networks.

I always like to give the analogy between networking and chain reactions. You start local and become global. Everyone is only 6 handshakes away from a top influencer, which means by harnessing the power of networking you can have your voice heard, create impact and make a difference.

I am delighted to see the growing importance of the Networks for Nuclear Innovation projects in the Summer Institute and the impressive outcome the Fellows produce in such a short time interval. I would be even more delighted if I could follow each one of the Fellows to see how they bring forward to the industry their messages and innovative ideas. I fully support their endeavors and believe they will succeed in their mission.

Agneta Rising
Director General
World Nuclear Association

# Foreword

We live now in a world driven by continuous change and innovation is a key component of our future. When thinking about innovation, it can be associated with making ideas happen, solving problems, bring new technologies to life, create breakthrough. Innovation is the future delivered, staying relevant, adding value or anything that is new, useful and surprising.

Leaders and senior executives need now more than ever to understand their changing environment, challenge the assumptions and continuously innovate. Policymakers become increasingly aware that innovative activity is the main driver of economic progress and well-being as well as a potential factor in meeting global challenges. But innovation is needed at all stages and more and more talented, creative people want to work for innovative companies. Innovators want to be challenged and encouraged to create on a regular basis, so companies need now a culture of innovation to capture and retain the talents.

This publication aims at providing a glimpse into the results achieved and open the way for further thinking on the subjects addressed.

We hope that the reader will enjoy the content and find value in it.

Yours sincerely,
Alina Constantin
Editor-in-Chief

# Introduction

*"The Network for Nuclear Innovation at the Summer Institute is the most challenging leadership exercise I have participated in; not the subject in particular, but trying to streamline the vision of several future nuclear leaders was a great experience and showed how an international team is enriching."*

WNU SI Fellow

*"I recognized the WNU-SI is a really fantastic program for future leaders, though the Fellows are already mid-level leaders. I had great experiences somewhat different from IAEA training program which I had many times at KINGS. The 6 weeks passed by so fast, like a kaleidoscope."*

WNU SI Mentor

At the World Nuclear University Summer Institute our aim is to make a difference through working with industry's best and brightest for developing the nuclear leaders and instill their passion for innovation.

We challenge them to become every day their better versions and at the end of this intensive programme we are confident that they return to their companies more motivated and better equipped to create a bright future for the nuclear area.

Besides the dynamic lectures, interactive platforms, invited leaders presentations, field trips to nuclear and industrial facilities, working group activities and cultural events, the SI programme culminates with the group activity entitled Networks for Nuclear Innovation (NNIs). Each NNI is guided by mentors and mandated to create a piece of work of high quality to bring solutions to important global nuclear issues, built on the learning gained during the Summer Institute and benefiting from the multicultural and diverse technical backgrounds of the Fellows in the groups. WNU encourages the Fellows to actively participate in the growing network of 1132 Summer Institute Alumni in 84 countries, to collaborate beyond the Summer Institute, and eventually achieve the implementation of their NNI proposals.

In 2018, four topics were selected - addressing the integration of nuclear and renewables in the low carbon grid, leadership and employee development, nuclear communications in the 21$^{st}$ century and status and challenges related to small modular reactors – and the participants proved their hardworking by delivering outstanding results and presentations. They had the chance to gain a more in depth perspective on current matters that the nuclear industry is facing, as well as to contribute in a creative way to produce recommendations and possible solutions.

The Fellows in the Networks for Nuclear Innovations showed the grit to face challenges and to critically analyze complex issues. Whilst they had the freedom to present their own ideas, they have demonstrated the maturity to reach consensus in an international arena.

Well done!

Patricia Wieland
Head of the World Nuclear University

# NUCLEAR AND RENEWABLES INTEGRATION (NRI) IN LOW CARBON GRID

*In a world facing major societal and environmental challenges, issues related to the production and use of energy are becoming more and more important.*

*To improve the chances of humanity development, quality of life improvement, while preserving our natural environment, the next future energy mix must be reliable, eco-friendly and cost-effective. Nuclear-Renewables-Integration (NRI) systems meets such requirements. The deployment of NRI must be supported by incentive policies and is based on the development of smart grids and storage technologies adapted to the power capacity of nuclear power plants and mitigating the intermittency of renewable energies.*

*A study of the technical and economic feasibility of the NRI implementation is proposed in the case of two countries with very different power generation profiles: Nigeria and Republic of Korea. Based on a simple evaluation model that can be further improved, these examples show both the benefits of NRIs and the difficulties of managing such evaluations in search of an optimum balance between cost control, security of supply, and preservation of the environment and thus leading to enhanced quality of life.*

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***Keywords:*** *nuclear, renewables, integration, NRI, low carbon grid, sustainability, energy demand, climate change*

# Introduction

The world is now facing major challenges deriving from technology development and world's population growth. It is not only the developing world that is facing problems, striving to reduce poverty and maintain quality of life but also the developed countries are failing to control all technology developments and suffer from man-made problems.

Maintaining standards of living in the developed world and eliminating poverty worldwide will require massive quantities of energy and a massive increase in energy resources and exploitation. The energy demand is growing and applies to both, OECD and non-OECD countries. For the former, energy is required to at least maintain a good life standard. For the second, energy is needed to foster development and to reduce poverty. But ensuring energy growth has to go together with de-carbonization to face climate change threat and moreover, there are severe economic constraints for any low-carbon system.

In a low-carbon electricity system, the key primary energy sources are nuclear, hydro, biomass, wind and solar, each having their advantages and drawbacks. The reliability and dispatchability of energy at low cost and with low green-house gas (GHG) emissions can only be achieved with an integrated energy mix.

The purpose of this article is to propose a new approach on how to build a sustainable power generation mix, i.e. to find a way to achieve a cost effective, reliable and eco-friendly integrated power generation system which will involve sustainable energy generation, storage and multiple usage.

As the sustainable integrated energy system solution depends on the existing infrastructures and the state of development of a particular country, two cases were studied: Republic of Korea as an OECD country and Nigeria as a non-OECD country. For each case, a specific "nuclear-and-renewables-integration" (NRI) sustainable solution is proposed and associated with a proper solution for storage. Each NRI solution is evaluated technically and  economically to ensure its feasibility. This article demonstrates that any tailor-made NRI is smart and flexible enough to provide a sustainable solution which is still reliable, cost-effective and eco-friendly.

# Why NRI?

**Because it is reliable.** For a complete reliable energy system, specifically an electricity system in this case, there is a need for reliable baseload sources of electricity: crude oil, natural gas, coal, hydro, and nuclear and/or storage capacities. Renewable energy (RE) can only be considered reliable if they are associated with large storage capacities because of their low capacity factor: a maximum of 41% for new wind projects, an increase of only 15% in 12 years (Wiser and Bolinger, 2015). For solar, the average annual capacity factor hit 27% for the first time in 2016, with solar farms achieving average monthly capacity factors of only up to 35% in summer months (U.S. EIA, 2018a).  Putting intermittent energy sources in use can be expensive to implement into an already established infrastructure. Fossil fuels are still cheaper than many alternative fuels in many parts of the world. In fact, two energy production systems can be considered as reliable: the combination of RE and very large storage capacities or integration of RE with a reliable "base load" source of energy which decreases somewhat the storage needs. However, the choice to be made must also take into account environmental and financial criteria.

**Because it is eco-friendly.** With the exception of gaseous discharges from biomass, RE are non-polluting during operation and produce waste only during the construction and dismantling phases. Most of these waste products are inert and their management is achievable, with the exception of some composite, hazardous or high value-added materials whose disposal or recycling are not yet at industrial maturity (Larsen, 2009; IRENA and IEA-PVPS, 2016). Although nuclear power produces very much less quantity of waste, its high-level radioactive waste requires very specific storage operations and a reflection on the legacy left for future generations (Ojovan and Lee, 2015). The main environmental impact of RE lies in the extensive use of raw material and land (DOE, 2015) leading to potential public dislocations and ecosystem disruptions, and with the potential risk of rapid exhaustion of some rare materials. High electric grid penetration by intermittent power sources which have low capacity factors requires either the construction of back up baseload power sources or energy storage facilities (which have their own GHG emission intensity and natural resource consumption) (Dolan and Heath, 2012). Thus, NRI makes it possible to obtain the best results in avoiding GHG emission and biosphere pollution during operation. Such mixes optimize the use of land and natural resources according to the constraints, needs and ambitions of each country or region.

**Because it is cost-effective.** Based on the levelized cost of electricity (LCOE), Lazard (2017) and U.S. EIA (2018b) highlight the competitiveness of RE compared to nuclear power, whereas this somewhat contradicts with OECD-NEA (2018) estimations (**Figure 1**).

LCOE is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. It can be regarded as the average minimum price at which electricity must be sold in order to break-even over a reasonable portion of the lifetime of the project.

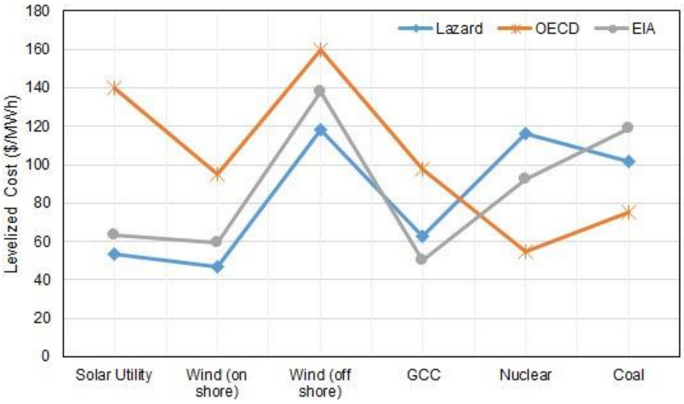


***Figure 1*** *Comparison of total system cost for generation technology (after Lazard (2018); OECD NEA, 2018; U.S. EIA, 2018b)*

The reasons for such a dispersion are closely related to the data considered in the LCOE calculation, which does not systematically take into account all the parameters that eventually influence LCOE such as subsidies, transmission cost, variability cost, geopolitical risk impact, environmental impact, social effects and employment effects.

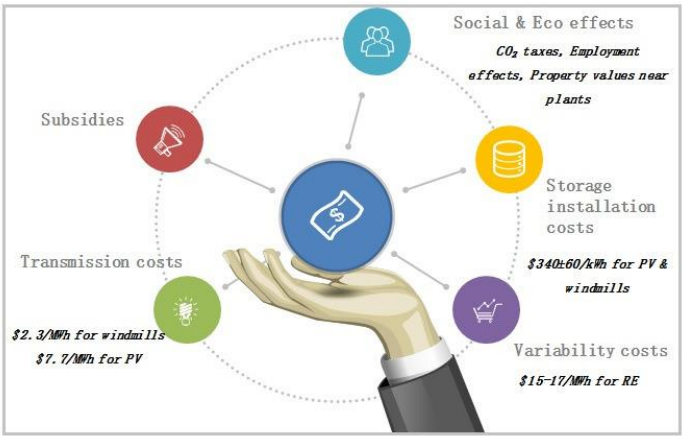


***Figure 2*** *Parameters to be integrated in the calculation of the LCOE for a more realistic perspective*

For example, the development of the transmission network for RE generates additional costs of up to US$ 2.3/MWh for windmills and up to US$ 7.7/MWh for photovoltaic (PV) installations (Siemens, 2013). In addition, the environmental cost shall be taken into account: e.g. assuming a price of US$ 95/t for $CO_2$ gives an additional cost of US$ 52/MWh for greenhouse gas damage in the case of coal power plants (Siemens, 2013).

One shall also consider the cost of storage that is mandatory for intermittent energies (according to Schmidt et al. (2017), US$ 340±60/kWh for PV solar panels and windmills once the first TWh is installed).

Finally, all these additional components lead to the definition of a more realistic and accurate LCOE value to compare the competitiveness of primary energy sources – giving access to a level playing field (LPF) for costs comparison.

Such calculation is beneficial to nuclear – insensitive to additional environmental, infrastructure and strategic costs – and to a lesser extent to RE for which grid costs can be high (**Figure 3**).

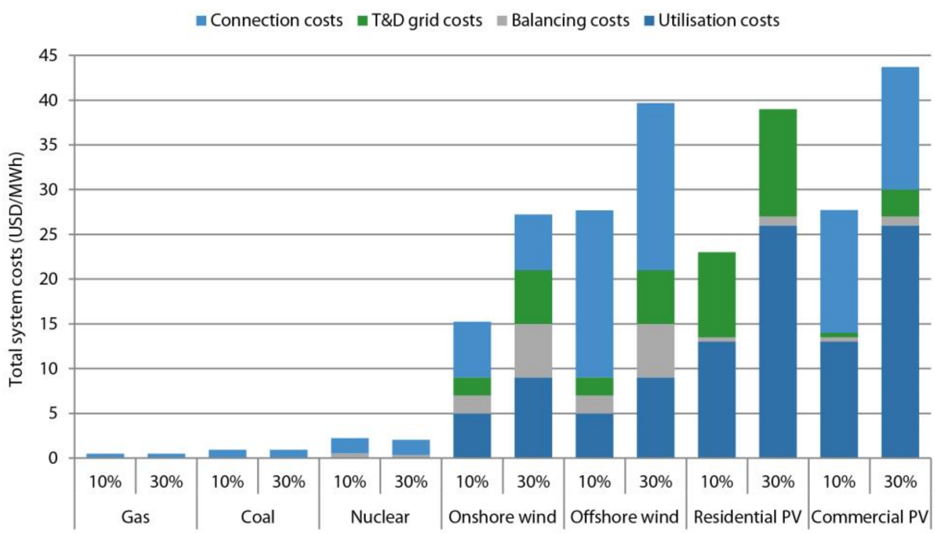


***Figure 3*** *Grid-level system costs for shares of 10% and 30% of RE generation (OECD NEA, 2018).*

Cost-effectiveness of an energy system relies on many conditions such as affordability, competitiveness, effective use of resources required for the installation of facilities, and profitability. When realistic LCOE is calculated, nuclear energy recovers competitiveness that was not obvious with the standard LCOE (**Figure 4**).

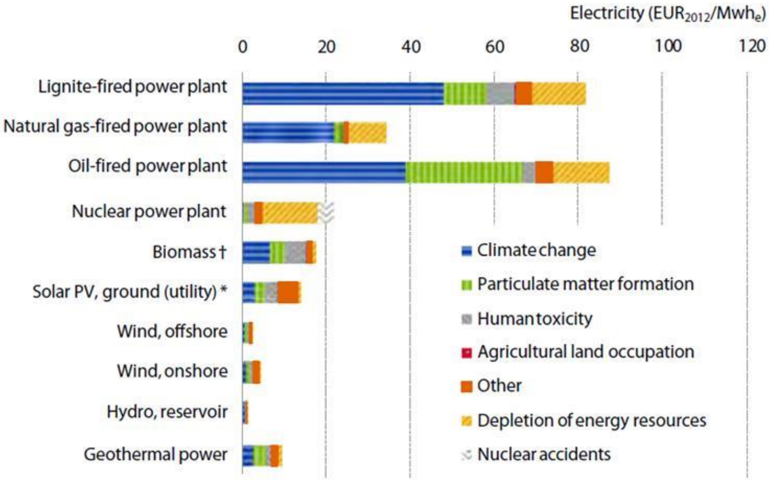


***Figure 4*** *Additional costs related to LCOE (Siemens, 2013)*

Consequently, to meet the growing and variable demand of energy in a sustainable way, the energy system requires the existence of a LPF in terms of cost-effectiveness evaluation and establishing an NRI energy system can be a feasible solution to achieve total low carbon system cost-effectiveness.

# Policy measures and technologies for NRI

The implementation of NRI requires both energy policies and technologies innovations: while energy policies provide the driving force for NRI, technology improvements give them a reality. Energy markets are very effective at reducing costs but they fail to comply with long-term vision of security of supply, environment preservation, and improvement of the quality of life. As examples, negative prices of electricity (caused, for example, by the Production Tax Credit, for some intermittent RE) and early closure of NPPs are sometimes consequences of deregulated markets in which the very low price of fossil fuels (or inadequate global subsidies to intermittent RE when the supply is already more than the demand) is short-term biasing the electricity policy in USA and other countries. In Japan, the high dependence of imported energy resources threatens the security of supply and the export import balance of the country. Different options could be used to prevent these detrimental effects.

To achieve NRI, some technological improvements are required: on one hand, RE – mainly wind and solar – require energy storage to smooth their unreliable intermittent generation (adjustment market has also othertools to smooth the generation like demand side management, hybrid production, curtailment of intermittent renewables etc). On the other hand, reliable nuclear energy cannot be operated in full load following mode like a gas turbine for economical and technical reasons. Due to its high capital cost, operation at constant full power is desired to reduce its LCOE. Hence, NRI requires storage, and a new grid infrastructure.

## Energy policies for NRI

● **Level Playing Field** is a country-dependent set of energy policies that leads to a sustainable energy system. Should the policies be biased to favor intermittent RE, the system will lose reliability. On the other-hand, if the policies become biased towards nuclear, the system might be able to respond to load demands but at an extra cost, as LCOE of very capital intensive nuclear is very sensitive to its Usage Factor (the less you use it, the more expensive it is, as every capital-intensive production means are when fuel accounts only for a small share of the generation price).

● **Carbon pricing or taxes** would efficiently capture the externality of environmental and societal damage caused by GHG emission (Perez-Arriaga, 2013) and encourage their decrease by promoting low emission technologies. According to Forsberg et al. (2017), a price of US$ 10/Mt$CO_2$ in the USA would avoid most of the early NPPs closures, increasing by only US$ 4.6/MWh the energy costs for final customers.

● **Direct financial support** adjusts markets behavior by explicitly giving an incentive to a certain technology (e.g. Feed-in Tariff, Contract for Difference, Zero Emissions Credit, and Clean Portfolio Mechanism).

● **Clean Capacity Mechanism** allocates a fixed amount of money to the plants capable of dispatching clean energy at any moment. Such mechanism balances the electricity mix accounting for the availability of clean energy.

● **Storage subsidies** will help NRI while remaining technologically neutral, as NRI requires storage capacities.

● **Demand shifting and peak shaving** merely consists on a scheme of hourly prices and incentives to big energy consuming industries based on statistical analysis of the demand pattern. This makes the demand more predictable and, in this way, helps the implementation of NRI.

### Energy storage technologies for NRI

● **Electro-chemical storage**. Batteries using four main technologies – Lithium-Ion, Lead acid, NaS and Redox Flow – are extensively used throughout all industries. Batteries can be fed by any source of electricity-generating technology and could be placed in any point on an already existing grid. Estimates of storage costs vary widely among references, from US$ 350 to US$ 150,000/MWh (World Energy Council, 2016; Forsberg et al., 2017). It would be important to consider the real-life expectancy of batteries due to their short end of life.

● **Thermal Storage** refers to different technologies with various efficiencies and technological maturity. Heat storage coupled to thermal power plants producing steam power has been a topic of interest with operational technical solutions since the 1920s in conventional industry and promising processes under development (e.g. packed-bed thermal energy storage or hot rock storage). Thermal storage could be heat storage in the reactor core of High-temperature engineering test reactor or heat storage from steam produced from certain types of NPPs. Again, the estimates vary widely depending on the sources and technologies used: from US$ 80 to US$ 15,000/MWh (World Energy Council, 2016; Forsberg et al., 2017).

● **Mechanical Storage** is mainly represented by two technologies: (i) pumped storage hydropower accounting for ≈95% of today global storage capacity and (ii) compressed air energy storage. These options are economic with a levelized cost of storage ≈7 times cheaper than electro-chemical storage (World Energy Council, 2016). But in case of pumped storage, they need specific geographical situation.

● **Chemical Storage (or co-generation), Energy Carriers.** Hydrogen production is not simply a way of storage: it can be transported economically and be used directly by some industries (e.g. transports) (Forsberg et al., 2017). Production price varies between US$ 40,000 and US$ 60,000/MWh. Ammonia and hydrocarbon productions are alternatives to hydrogen, the latter have the advantage of being usable by the transport industry without investment in the existing infrastructure.

For some storage technologies, available prospective costs have a strong uncertainty, with differences up to three orders of magnitude. Among other parameters, the different storage technologies have different level of maturity, storage time, output rate and resources consumption.

Thermal storage is a major asset for implementing NRI: for many existing reactors it may be possible to send up to 20 to 25% of steam output to storage when prices are low with little or no upgrade of the turbine-generator. For new plants, there is the option of diverting ≥70% of the steam to storage at times of low electricity demand and increasing the peak plant output by 25% or more (Forsberg et al., 2017). Also, electricity at times of excess capacity can be converted to high-temperature process heat usable by industries (e.g. Firebrick Resistance-Heated Energy Storage (FIRES) technology is deployable today). These technologies have the potential to address the challenge of electricity price collapse – when supply is too abundant with relatively low demand that impacts non-dispatchable wind and solar as well as Nuclear (Gas turbines on the other hand can just shut down with less effect on their resulting LCOE as it depends highly on gas consumption and less on initial investment).

## Case studies: NRI in Nigeria and South Korea

These case studies are dedicated to investigate the technical and economic feasibility of NRI implementation in an OECD country: Republic of Korea and in a non-OECD country: Nigeria. These are based on a critical analysis of the situation of the two countries and a model helping to optimization of a reliable, eco-friendly, and cost-effective mix. The “NNI4NRI” model developed is based on an excel calculation in order to provide some quantitative data for decision making. The model can be further refined, but was deemed sufficient for the purpose of the study.

**Figure 5** presents the profiles of countries considered for case studies. For each quantity, one value corresponds to the present state and the other to a projection. The analysis took into consideration the map of wind and sunshine, as well as the prospects up to 2050 for the evolution of the population and the energy demand of the two countries.

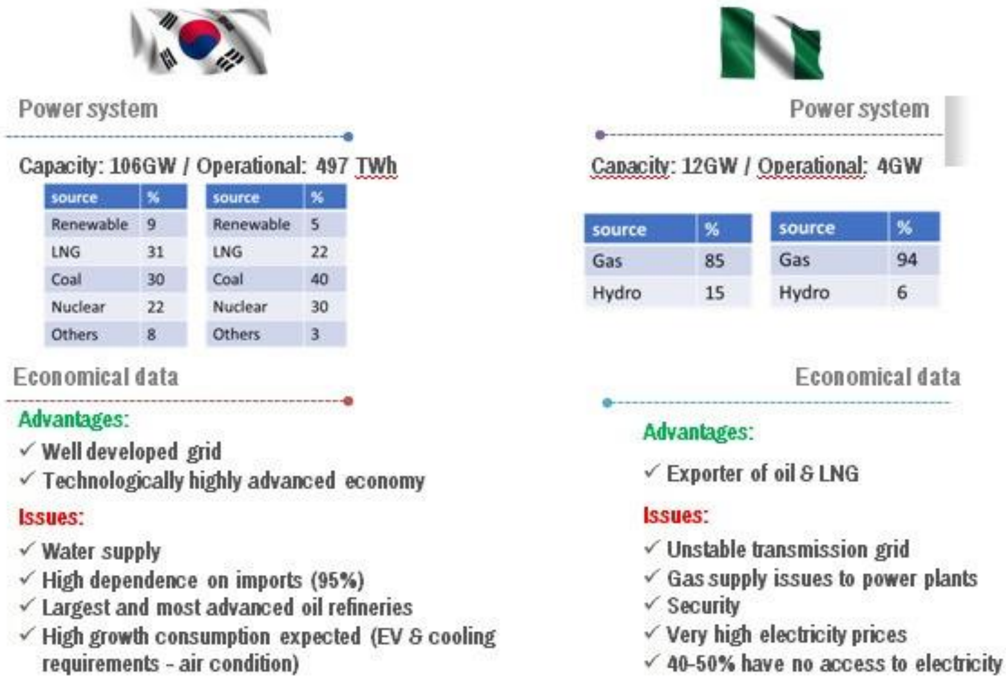


***Figure 5*** *Profiles of countries considered for case studies*

The sustainability of the energy system was assessed using the NNI4NRI Model implemented that evaluates the mix relevance with respect to the following three categories: Reliability (R), Eco-friendliness (EF), and Cost-effectiveness (CE). For each one, the following considerations were made:

● **Reliability**, measured between 0 and 100%, corresponds to the fraction of the energy consumption that can be reliably delivered on-demand, at any time. To cover this demand, the sum of base-load and dispatchable sources has been considered. The percentage of base-load is limited to 75% to take into account that an installed capacity of 100% base load does not provide 100% reliability due to its inability to follow load adequately. To carry out the calculation, each energy source and storage solution is given a score between 0 and 100 (**Table 1**). Combining storage capabilities with Nuclear and Renewables allows for a higher reliable energy system as this allows nuclear to compensate for the intermittency of the renewable sources. In other words, nuclear energy can be a reliable and dispatchable source of power for the society. This way, the statistical model is capable of showing the benefits of NRI.

● **Cost-effectiveness** is expressed as a normalized cost from 0 to 100%: 0% representing the most economical option (cheapest) and 100% representing the most expensive energy mix, according to literature data (Lazard, 2017; OECD-NEA, 2018). This cost is computed as the average of the different energy sources (**Table 1**) weighted with their energy share. Hence, cost-effectiveness is more focused on affordability.

● **Eco-friendliness** implies the evaluation of the different criteria (i.e. climate change, particulate matter formation, human toxicity, agricultural land occupation, depletion of energy resources, accidents) for giving an overall score (between 0 and 100%) to each energy source and storage solution (**Table 1**), assessing its impact on the environment.

***Table 1*** *Ranking used by NNI4NRI model to assess the reliability, eco-friendliness, and cost-effectiveness of energy sources and storage solutions*

| Energy source or storage solution | R (%) | EF (%) | CE (%) |
|---|---|---|---|
| Nuclear | 90 | 77 | 39 |
| Gas | 80 | 68 | 70 |
| Coal | 80 | 8 | 54 |
| Oil | 80 | 14 | 54 |
| Biomass | 80 | 83 | 66 |
| Hydro | 80 | 98 | 71 |

| Energy source or storage solution | R (%) | EF (%) | CE (%) |
|---|---|---|---|
| Wind | 41 | 95 | 68 |
| Solar | 27 | 87 | 100 |
| Batteries | 95 | 10 | 100 |
| Thermal | 95 | 60 | 10 |
| Pumped hydropower | 95 | 42 | 13 |
| Compressed air | 95 | 92 | 17 |
| Carriers (hydrogen) | 95 | 75 | 37 |

# Results and discussions

The current energy systems of Nigeria and South Korea were evaluated by the NNI4NRI model, the scores obtained as a result are presented in **Table 2**.

Model calculations clearly emphasize that (i) energy systems are country-dependant and must be adapted to country's requirements and resources, (ii) no sustainable energy system can rely on a single power source, and (iii) sustainability is ensured by smart integration between nuclear, storage and renewable sources.

Some improvements in reliability and cost-effectiveness (**Table 2**) could be expected for Nigeria by the deployment of the nuclear programme with sufficient storage associated with solar panels in the North of the country where sunshine is maximum and wind turbines in the center of the country where the wind conditions are the best. According the model, the energetic mix then could be: 55% of nuclear, 15% hydro, 10% biomass, 10% wind, 5% gas, 5% solar, and 10% storage composed half of carriers (hydrogen) and half of thermal storage (coupled with NPPs).

South Korea can gain in eco-friendliness (**Table 2**) by maintaining the nuclear programme and adding to it some storage capacities. The north east of the country is favorable to the installation of wind turbines whereas a diagonal north east-south west is favorable to that of solar PV. NNI4NRI model's recommended mix was 60% nuclear, 25% hydro, 10% solar, 5% wind, and 12% storage composed half of carriers (hydrogen) and half of thermal storage (coupled with NPPs).

***Table 2*** *Evaluation by NRI4NNI Model of the current energy mix of Nigeria and Republic of Korea and calculation of the optimized mix*

| Country | R (%) | EF (%) | CE (%) |
|---|---|---|---|
| Nigeria (current) | 79.5 | 71.5 | 29.5 |
| **Nigeria (NRI mix)** | **83.7 (↗)** | **72.1 (≈)** | **49.0 (↗↗)** |
| Republic of Korea (current) | 82.1 | 39.7 | 49.9 |
| **Republic of Korea (NRI mix)** | **84.5 (↗)** | **74.8 (↗↗)** | **48.6 (≈)** |

# Concluding remarks

Facing major environmental challenges and its own expansion, humanity must reconcile a growing demand for energy with the preservation of its environment and natural resources. This necessarily involves the promotion of low emitting GHG energies. Integrated energy solutions – called NRI – involving Renewable Energy, Nuclear and energy storage (batteries, heat storage or chemical "storage" in the form of co-generation) can meet this need.

NRI systems exploit the complementarity between Nuclear and RE, erasing the intermittency of the latter and ensuring an economically efficient operation at full capacity of NPPs. The energy produced in surplus during periods of low demand or high mobilization of RE is stored for use as heat and redistributed during peak periods.

More than reliable, NRI provides dispatchable energy.

The development of NRIs requires the support of national energy policies looking for the implementation of a level playing field which recognizes non-market values and should use subsidies or levy.

Case studies were carried out to evaluate the technical and economical feasibility of the implementation of NRI (Nuclear, Renewables with Storage) systems in two countries with very different profiles – Nigeria and South Korea. The NNI team have concluded that benefits can be derived from such integrated mixes to achieve an improved reliability, cost-effective and environment friendly energy system, thus improving the quality of life for the two countries.

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The mentors would like to recognize the huge amount of work done, especially in researching through the different available reports, and trying to develop a computing tool aimed at weighing the benefits and costs of different scenarios. The group would also like to acknowledge the support and help received from the Summer Institute Alumni and Fellows who responded to the survey on the WNA issue paper on the level playing field.

# INNOVATIVE SOLUTIONS TO LEADERSHIP SUCCESSION PLANNING FOR NUCLEAR INDUSTRY

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*Leadership is an important aspect of achieving global safety and security in the nuclear industry. The success of the nuclear industry calls for organizations to ensure that their staff has the capabilities to implement safety standards under strong responsible leadership.*

*Our main objective is to understand the key issues in the nuclear industry surrounding attracting, retaining, and developing leaders.*

*We conducted a comprehensive survey of the 2018 WNU Summer Institute Fellows, analyzed their responses, and found trends and correlations in the data. The data we collected show three primary areas that are pivotal for leadership development but are not currently well utilized in the nuclear industry. They were: poorly executed and opaque succession planning, ineffective feedback and career development, and the perceived lack of opportunities within the industry.*

*We recognize that these are not isolated issues, nor can they be solved overnight by one individual. However, based on the responses and feedback from the WNU Summer Institute Fellows we have proposed a series of recommendations and suggestions to improve these processes. The WNU Summer Institute Fellows have committed to take these suggestions back to their organizations and work with their management to help implement them.*

***Keywords:*** *leadership, employee development, succession planning, career opportunities*

# Introduction

Strong organizations utilize talent to innovate and sustain growth for their business. The nuclear industry is having difficulty attracting, retaining and developing effective leaders. Why is this? What can be done about it? Is there more than just our technology that makes nuclear unique?

The WNU Summer Institute 2018 is composed of 59 highly motivated Fellows from the nuclear industry and from across the globe. The Fellows range in age from 22 to 45 and most have between 4 and 10 years in the nuclear industry. 37% of the Fellows are women. We are from a variety of backgrounds and industry sectors, but collectively we represent a crucial cross-section of motivation and potential. 52 Fellows responded to a comprehensive survey to identify the key challenges facing the industry in the areas of leadership and employee development. Approximately half of the Fellows directly supervise other employees, but almost all perform leadership roles such as project management.

We used the survey and the subsequent analysis of the data to identify trends and make recommendations to the industry. Our hope is that our recommendations have a real impact, and that the concerns of the Fellows are taken seriously. Their perspective, their stories, and their outlook should influence the way that the industry sees leadership and what it should do to improve it. The goals for these recommendations are to provide tangible, innovative solutions to leadership and employee engagement challenges.

## WE WANT QUALITY FEEDBACK AND PERFORMANCE REVIEWS ARE NOT EFFECTIVE, ESPECIALLY FOR WOMEN

A feedback mechanism used by many organizations is scheduled performance reviews. Performance reviews are intended to be periodic meetings of staff and supervisors where they get together and discuss an employee's performance. The content is usually a comparison of defined corporate objectives against the employee's performance. If the employee is lucky there will be some discussion of career development, usually in the form of some training to take place during the year. Is this practice effective? Does is actually improve performance? Results from our survey seem to indicate that it does not.

Respondents were asked to rate the perceived value of their performance reviews. 77% of respondents indicated that there was at least some value, but a staggering 17% said there was no value in performance reviews. Clearly there is considerable room for improvement. Sadly, there was a strong correlation of value of the performance review with gender. Female Fellows have been especially let down by performance reviews. In fact, not a single female Fellow ranked their performance review as of very high value and 35% of women ranked performance review as no value as compared to just over 5% for men.

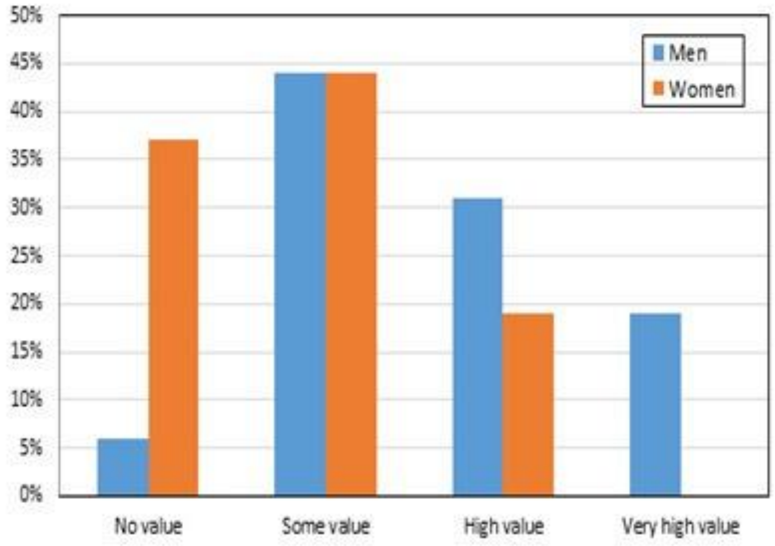



***Figure 1** Perceived Value of Performance Reviews among WNU Summer Institute 2018 Fellows*

Who is to blame for this trend? Is it the first line managers? Our survey suggests this is not the case with only 2% of respondents saying their managers are “not supportive” of their career development. We believe it is the process of performance review that is to blame. In their detailed feedback many respondents emphasized that the process of performance review is a checkbox exercise with no real feedback on their performance or their career development. Fellows were clear: they want constructive criticism and career planning.

To solve this issue, we suggest the nuclear industry take performance reviews seriously and stop focusing on easily quantifiable corporate deliverables. The focus should be on the employee’s development with evaluation of their performance being a secondary objective. Employee development should be the first and most prominent section on a performance review form rather than an afterthought at the end. How can companies expect their employees to be motivated and engaged if they don’t have a clear career goal to work toward? By shifting to a career development focus it will make succession planning easier as high potential candidates will self-identify and hidden, previously overlooked, talent may emerge. Criticism of employees should include behavioral improvement rather than just technical skills or completion of defined projects. As a final recommendation we suggest that employee development should also include a component of peer review, not just from peers in a similar role but other staff above or below an individual in an organization.

## WHERE ARE WE GOING AND HOW DO WE GET THERE?

Succession planning is an important tool for organizations to plan who will replace key staff in the event they leave, retire, or are promoted. Many organizations will identify employees they believe have the necessary leadership potential and skills for senior positions before those positions become vacant. This is especially important for upper management positions, which are critical for organizational success and cannot be left vacant.

We asked Fellows if their organizations assess or evaluate their leadership potential. The majority of respondents (71%) said that they did; but when asked if they received feedback on their leadership potential only 35% said they had. We also asked Fellows if their organizations had succession planning. Only half of the Fellows knew if their companies have a succession plan and only a quarter of Fellows knew where they fit in a succession plan. These points to a lack of top-down communication regarding leadership potential and succession planning even among a group of “high potential” individuals such as the WNU Summer Institute 2018 Fellows. If retaining high potential individuals is an issue for the industry, would it not make sense to inform employees of succession plans to assure they have a clear career goal to work toward? Furthermore, wouldn’t an organization like to know if an employee actually wants to fill the role they have been slated for? It seems like common sense, but the reality of the situation is this is not the case.


***Figure 2** Succession Planning among WNU Summer Institute 2018 Fellows*

In order to retain and develop successful leaders, succession planning and employee development needs to be adaptable, transparent, and provide two-way communication between employees and employers. To ensure this is carefully monitored we suggest that succession planning and employee development be a key performance objective for individuals and management.

Imagine a world where employees and companies have an aligned vision for succession planning and development, where people are engaged and working towards positions they are interested in. We believe staff turnover would be lower, staff engagement would be higher, and development paths would be clearer. Furthermore, because the training and motivation of the staff is improved, safety is increased as a byproduct.

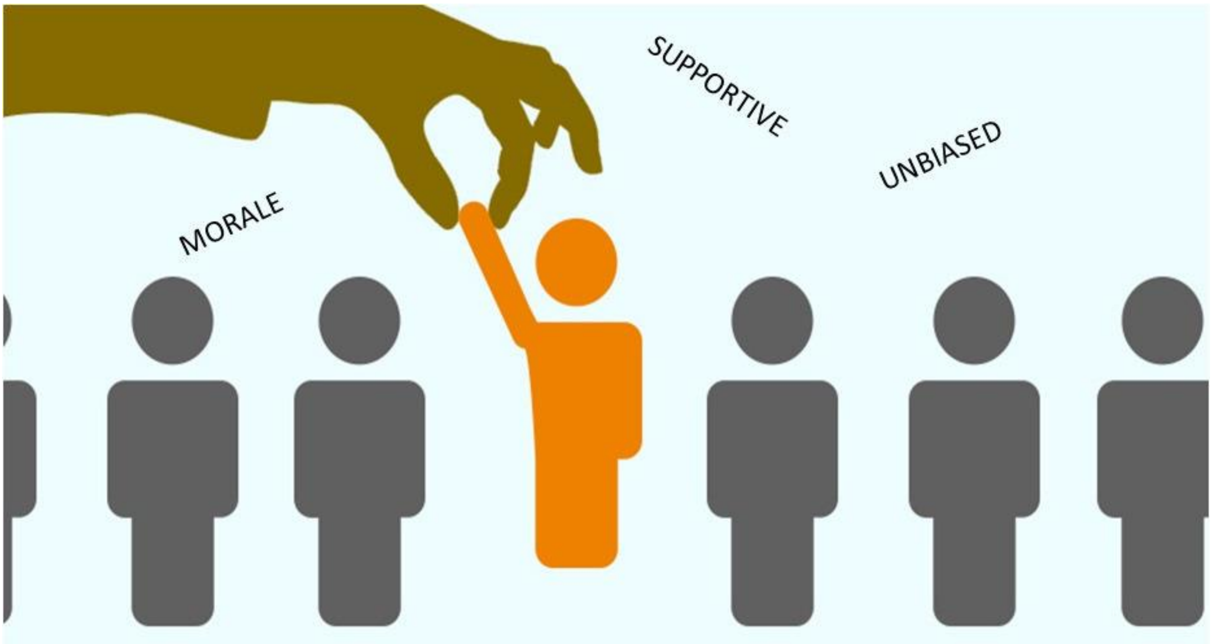
## YOU SAY OPPORTUNITIES ARE OUT THERE …BUT WHERE ARE THEY?

If the nuclear industry truly wants to grow and retain employees it needs to be proactive and find out what is causing people to join the industry and what is causing them to leave. Our survey results show that people are joining the industry for many reasons, the most prominent of which is attraction to nuclear technology. Other factors include more traditional reasons such as opportunities, wages, and job security. A surprising result is that the third most cited reason for why people joined the industry was moral or environmental reasons. This suggests that messaging from the nuclear industry is effective. We will admit that our survey did not identify clear ways to attracting new people but what is evident is that some people are attracted to it.

When asked what frustrates them about the nuclear industry many Fellows said slow bureaucratic processes, but when asked why they would leave the industry the top answer was lack of opportunities. Is this perceived lack of opportunities a reality or is it a reflection of poor succession planning and professional development? Regardless of the cause, how can the nuclear industry possibly expect to retain effective leaders if a group of high potential leaders doesn't see opportunities for advancement and growth?

Without opportunities in an industry they are passionate about, Fellows suggest they would seek opportunities elsewhere. Our survey shows that 23% of Fellows are planning to leave the nuclear industry in the next 5 years and 27% have already applied to positions outside the industry. Our interpretation is that Fellows are not leaving because they want to but rather because they feel they have to. What is driving this trend?

The common perception of younger employees is that they prefer to be mobile and are not as loyal as their older counterparts. When asked if millennials in the workforce were loyal to their company only 1% of CEO's responded yes while 82% of the millennials in the same study said they were. Our survey confirms this finding with 63% of Fellows either "agreeing" or "strongly agreeing" to the statement "I would prefer to stay at my current company and progress through leadership rather than move organizations or industries". So how can the nuclear industry match the desires of the Fellows with its own needs?



One suggestion we had was for companies to provide an independent internal recruitment agency. This would help staff advance and develop within a given organization. In other words, businesses could make the most use of the employees that they have rather than spend money headhunting and training new staff.

To complement this, companies could initiate a shadowing program as part of succession planning and employee development so staff can gain experience, trail new jobs and see what opportunities exist in their organizations. A spinoff benefit of this could be that it results in staff gaining mentors and/or sponsors.

A final suggestion is to create a rotational development program for new leaders that includes applied on-the-job training in leadership and management. Such rotations exist for entry level positions but as staff move into management they are forced to learn through. Job rotations for leaders would help them gain a breadth of experience from leaders within their own company or across the industry.

# Concluding remarks

The data we collected showed three primary areas that are pivotal for success of key leaders but are not currently well utilized. They were: poorly executed and opaque succession planning, ineffective feedback and career development, and the perceived lack of opportunities within the industry. These are not isolated issues, nor can they be solved overnight by one individual. In fact, we believe they are interconnected and caused by ineffective communication and a lack of organizational transparency. Issues of this nature can only be solved by open and honest collaboration between all parties. The industry needs to have transparent two-way communication when it comes to performance review and succession planning. We believe this could help address the perceived lack of opportunities in the industry.

For going further, each member of our NNI team has committed to presenting our findings and associated recommendations to our companies. Recognizing that each organization has its own needs, we expect these to be tailored for optimal results. We have also committed to learn from each other and gather the best practices in the industry to have the largest impact on the industry as a whole.

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**Acknowledgment.** We would like to thank our mentors, Mr Amir Shahkarami and Mr Tae-ryong Kim, for their support throughout our Networking for Nuclear Innovation project. We would also like to send a special thanks to all the 2018 Fellows in the WNUSI who provided valuable insights and stories which were pivotal to our success. We are especially indebted to everyone involved with the WNU Summer Institute, who have been so supportive and worked actively to provide us with suitable working atmosphere to develop as global leaders.

# CHANGING THE CONVERSATION. STORIES FROM THE NUCLEAR COMMUNITY

*The nuclear industry has lost its voice and it is time to reclaim it. The consequences of not doing so will permit negative headlines, falsities and low public opinion to impede the growth of nuclear. Unlike past communication efforts which relied on engineers and experts to convey facts about nuclear, this project aims to retake the narrative by telling the stories of those working in the nuclear community.*

*The stories come from the perspective of eight diverse professionals working in the nuclear industry. Their first-hand accounts aim to convey that the values of a cleaner environment, better healthcare, making nuclear more secure and improving economic development are the same as those held by the non-nuclear community.*

*Through this innovative approach using emotion versus facts, the project concludes that trust can begin to be established between both communities. This is the first step in a long-term effort aimed at changing the perspectives of people and reclaiming the positive message about nuclear and its boundless benefits.*

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**Keywords**: *nuclear communication, nuclear stories, positive messages, nuclear community*

# Introduction

Since the Fukushima Daiichi accident in 2011, the nuclear community has lost its voice. The optimistic narratives hailing the dawning of a “nuclear renaissance” have been replaced by headlines announcing premature nuclear reactor closures, the cancellation of new reactor constructions, economic struggles and public opinions turning against nuclear. Whatever
the cause, the nuclear community’s positive message has largely been muted. As a result, the world is missing a vital message highlighting the countless benefits of nuclear power.
Past efforts to convey a more positive nuclear message have relied on using nuclear engineers and experts to project facts and figures demonstrating that nuclear energy is safe, reliable and cost effective – it’s the “smart” thing to do.

Communications experts are increasingly suggesting that this is not the most effective approach. By contrast, this project aims to change the conversation by taking a new and innovative approach with a focus on emotions, honest stories and shared values – nuclear is the “right” thing to do. As it turns out, those on both sides of the nuclear argument hold common aspirations. These values include preserving the environment, fostering economic growth and development and most importantly, creating a better life for all generations (Adams, 2018). Why not nuclear to enable these?

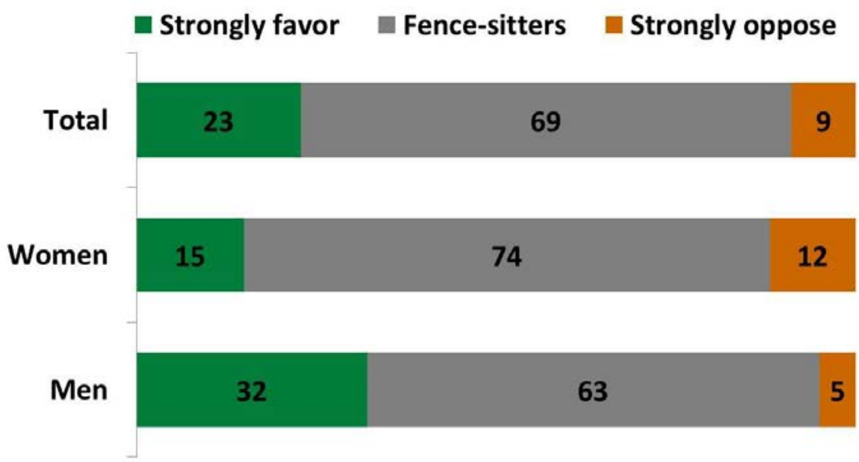
Our Group represents the diversity of the world, coming from 13 countries and representing women, expectant-mothers and parents. We are global citizens that work in the nuclear industry. Most of us did not set out to work in the nuclear field but unique experiences drew us in, and kept us in. Our project aims to share these personal stories through a series of short videos. The videos demonstrate why we chose nuclear, how we benefited from it, why we are not afraid of it and why we all work towards making it safer. Through our stories, we aim to share our first-hand experiences of the positive aspects of nuclear, address common concerns and fears, and establish trust with our audiences so that they may consider embracing the nuclear industry like we do.

# The rationale of our project

We acknowledged that our project is set in the context of communications in the 21st century. This not only offers a variety of tools by which we can transmit our message, but also necessitates an innovative approach to cut through distraction and attract the attention of our desired audience. The Group also recognized that the nuclear narrative is saturated by many common misunderstandings about nuclear, as well as genuine concerns and fears. Which ones do we address, and how?

Moreover, as this graph of U.S. public opinion on nuclear shows, the majority of people have no strong view about nuclear. We must be careful how we talk to them as they could be pushed to either end of the scale. How should we best communicate with these people? This was our challenge.

*Figure 1 Public opinion on nuclear in U.S. (from Bisconti Research Inc.)*



# Initial Brainstorming – Preparing the Plan

Our first brainstorming session aimed at identifying different methods to attract the attention of our audience. Several proposals were identified including the use of: video, infographics, books, webtoons, tourism/site visits, social network services, games, toys, etc. It was also proposed that the Group utilize the “Chain Reaction” approach to spread our message to a wider and more influential audience, including a celebrity who would be willing to champion our positive nuclear messages. The Group held a second brainstorming session where the key target audiences where identified along with qualities each demographic would likely find appealing about nuclear. The result was the following:

• Youth (11-19 y): friendly, secure for them, reliable power in their devices
• Active Workforce (20-60 y): safe, not destructive, economic powerful, jobs, clean environment, fresh air, backup, clean and profitable growth
• Seniors (>60 y): future of grandchildren/children, economic, clean environment, nuclear application/medicine

The Group also invited Mr Gaston Meskens, a sociologist who works extensively with civil society and environmental groups to give his insights on how to focus our messages. Based on his advice, the Group narrowed the values identified in the second brainstorming exercise to one per age category. These single values would form the basis of distinct messages created for each age group, albeit, still able to resonate with the other age categories. The values identified were:

• Youth: Power your Devices
• Active Workforce: Clean Environment and Development
• Seniors: Healthcare

With the target audience and key values established, the Group turned to selecting the method to transmit our messages. In our considerations, the Group recalled the statistics indicating that the more informed people felt about nuclear energy, the more likely they were to be in favour of it. Consequently, the Group aimed to select mediums and methods to transmit them that could draw the attention of a large audience. A final brainstorming session selected a combination of videos and infographics to do this and opted to share them with the public using various social media platforms like Twitter, Facebook, Kakao etc. The Group also established a hashtag - #WhyNotNuclear which would be used to generate interest in the videos and infographic, with a goal to begin trending. Social media was selected for its ability to rapidly and efficiently reach a wide global nuclear audience. Lastly, the Group decided that it needed to corroborate the values we identified for each age group.

Recognizing that there was no time to conduct a focus group outside the project, the Group opted to use the 59 WNU Fellows as its focus group. During the presentation of our plan, the Group requested the Fellows to play the roles of youth, active work force and seniors. The Fellows where then asked to shout out the words they believed captured the target audiences beliefs about nuclear. The answers were recorded and the subsequent analysis validated our identified values.

# Back to the Drawing Boards – Engaging our Imagination

Following the Groups presentation of its plan, it became apparent that our intended approach lacked innovation. As the Group sat around the table, a spontaneous discussion began. We commented on how diverse we were and began asking each other how we got involved in the nuclear industry. By accident, we discovered many touching and poignant stories among us. Such stories came from the perspective of two pregnant women deeply involved in this area, Fellows with close friends and family benefiting from nuclear medicine, and people touched by the Chernobyl and Fukushima accidents. This unexpected and emotional discussion made us realize that our stories about how nuclear positively affected our lives should be our messages.

It was thus decided that we would communicate our messages through our experiences. We came to appreciate that emotions are what shape opinions, motivate people to take action, and ultimately change peoples' minds. We concluded that if we wanted to send a message that would impact our audiences, we needed emotions to be a fundamental part of our speech. We therefore chose stories which captured our passion, beliefs and life experiences with an aim to demonstrate in a relatable manner that we hold the same values as those outside the non-nuclear community. Our videos would aim to communicate with the audience how we feel about nuclear and live it through our daily lives. To us, the key was to be authentic so as to successfully transmit to others the passion that moves us every day and give the audience a reason to trust beyond our nuclear stories.

Our decided path forward was to create videos of our stories with an aim to reach the audience through our personal experiences rather than facts which can be easily found on the Internet. The videos would be supported by simple infographics which capture a still image of the storyteller and accompanied by a brief caption of their key message. These videos and the associated infographics would be sent over social media.




## Target Audience

In recognition of the limited timeframe for this phase of the project, the Group reviewed the stories and concluded that the messages in the videos likely resonate the most with women and mothers. This was seen as a positive first step as research has consistently demonstrated that this democratic holds the most negative views towards nuclear (NEA OECD, 2010). The videos and stories, however, are also likely to resonate with the 20-60 year old age category.

The stories are also targeting the non-nuclear community, which refers to anyone that does not work in the nuclear industry. This community further comprises of people considering themselves opposed to nuclear, indifferent to nuclear, or potentially swayed to either side based on the prevailing narrative.


## Results and recommendations

In our presentation of the plan, the Group conducted a focus group of the 59 WNU Fellows to gauge their views on nuclear from the perspectives of the three target audiences. In our final presentation, we shared the videos of our stories with the same group of Fellows. Noting the caveat that the videos now only targeted women and mothers, the same Fellows were asked to comment on whether they believed the videos would resonate with the narrowed target audience. There was broad support for our "stories" method. Fellows agreed that an emotional versus factual approach resonated well, however expressed some concern about using social media as a means to transmit the message. Some concerns included fear of reprisal from one's organization if sharing a nuclear message over social media and preventing the message from appearing like propaganda. These concerns will be noted and incorporated into the next phase of this project, although in general, most agreed that sharing personal stories and values can transcend these concerns.

This project represents the first phase of a long-term outreach and communications campaign aimed at changing the conversation about nuclear. In sharing our personal stories about why we believe in nuclear, we aimed to begin building trust between ourselves (the nuclear community) and our audience (the non-nuclear community). It is hoped that this initial campaign will begin the process of getting people in the non-nuclear community to either discover nuclear or re-think their views towards it. We hope our stories demonstrate what members of both communities value, such as the environment, health and the well-being of our families, stand to benefit from nuclear.

This initial phase did not intend to change negatives views about nuclear, but rather to reset the conversation, peak curiosity and make people more willing to engage in future dialogue about nuclear. After all, for someone to continue to listen, they need to be given something to relate to (Pelletier, 2015). Based on this, this project makes the following recommendations:

**Recommendation 1:** It is recommended that focus groups be established to ask direct questions about nuclear energy. The focus groups should aim to gauge peoples understanding of nuclear, capture their key concerns or views, and obtain their recommendations on what can be done to improve the image of nuclear energy. The focus groups should be conducted in multiple countries and include all age categories. The results of the focus groups would represent useful data on the values, fears and opinions most prevalent in the non-nuclear community and can be used to inform a more dedicated and effective communication campaign.

**Recommendation 2**: It is recommended that future communications campaigns target a wider audience, namely Youth (11-19 y), Active Workforce (20-60 y) and Seniors (>60 y). The Group acknowledges that the project's short timeline as well as the stories selected limited the Group's message to a narrower audience of women and mothers. Going forward, personal stories that resonate with youth and seniors can be developed and distributed in the same manner as the current videos. The Group recommends continuing the use of stories as they give a deeper meaning behind the message being delivered.

**Recommendation 3:** It is further recommended that the nuclear industry re-engage in funding stakeholder outreaches, including the above-recommended focus groups. A successful communications strategy must include all relevant stakeholders, including the nuclear industry. All need to be partners in building trust and greater understanding about nuclear.

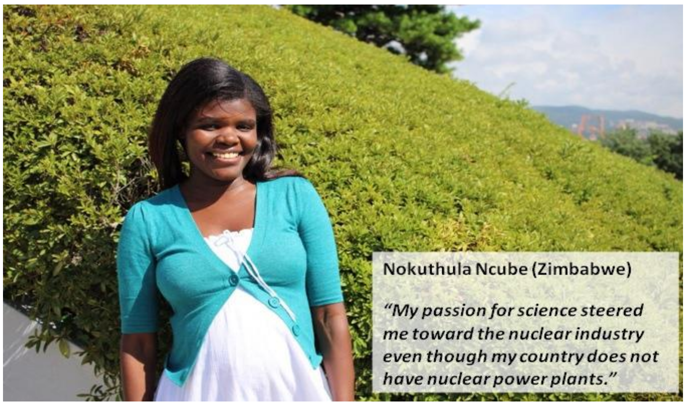
**Recommendation 4:** It is recommended that a professionally produced set of videos are created and distributed through social media. It is suggested that a hashtag (e.g. #whynotnuclear) is used to connect the various posts relating to this communications campaign. Consideration should be given to whether this is most effective from personal social media accounts, corporate / industry group accounts, or both.

# Concluding remarks

When first confronted with the challenge of how to change the nuclear narrative, the Group turned to the comfort of using facts combined with a solid message. The Group believed that this method would convince a wider audiences to change their negative perceptions about nuclear. It did not take long for us to realize that a more effective method would be to attract the public's attention through emotions. We came upon this revelation during a group discussion which revealed some compelling and emotive stories amongst our diverse group. Personally moved by many, the Group recognized that they could be used to similar effect if communicated to a smaller, non-nuclear audience. Moreover, the Group felt the stories represented a more innovative and engaging method to begin establishing trust with a skeptical, scared or even hostile audience. In doing so, it is hoped that non-nuclear communities can begin to consider accepting nuclear as a benefit that promotes the things they value most, such as a clean environment, economic development and a better future for their families.

We recognize that the expectations may be ambitious but the Group believes that this is a bold and innovative way to change the conversation about nuclear. This approach focuses not only on establishing a meaningful message, but communicating it in an engaging and authentic manner. By sharing our true stories, the Group hopes to connect with people and influence their thoughts and feelings about nuclear on a personal rather than expert level. We hope that this becomes the new strategy for nuclear global communications in the 21st century. So, now that we have shared our stories, what are yours?



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**Acknowledgment.** We would like to thank our two mentors, Ms Janice Dunn Lee and Mr Humberto Werdine, who gave us the encouragement, guidance and direction to be creative, innovative and successful.
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# A MARKET-DRIVEN ASSESSMENT TO INFORM THE DEVELOPMENT AND DEPLOYMENT OF SMALL MODULAR REACTORS

*An innovative market-driven assessment methodology has been developed to compare Small Modular Reactor (SMR) designs and alternative energy options against market needs. Three markets have been investigated; Mature, Industrial and Remote/Emerging.*

*Twenty-one criteria for energy source deployment have been defined and weighting factors for each market type assigned based on broad market considerations by a multidisciplinary team.*

*Three SMR designs and two alternative energy options have been evaluated using the assessment methodology and recommended solutions have been suggested in order to inform the future direction of the nuclear industry. Recommended solutions include innovations in the financing, design and regulatory regimes.*

***Keywords:** small modular reactors, mature market, industrial market, remote/ emerging market, market-driven assessment*

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# Introduction

Maintaining and growing the global energy market over the coming years creates many opportunities for investment. To maintain the existing market share for nuclear, the International Energy Association World Energy Outlook for 2017 indicates that US$ 426 billion will need to be spent from 2017-2025, and an additional US$ 674 billion from 2026-2040 (IEA, 2017). When considering changes to energy policy that call for a significant reduction in carbon emissions, the potential for investment in nuclear power solutions improves even more (over US$1 trillion over each time period). A large proportion of this increasing energy demand will be from developing states, which will likely comprise of a large amount of remote and industrial energy needs. One of the major roadblocks for constructing new nuclear power plants is the high capital investment requirements for large, high output facilities. Small modular reactors (SMRs) look to solve this issue by reducing the up-front capital requirements and leveraging modular manufacturing techniques. Although these innovations help to improve the financial picture for nuclear power, they alone are not enough. Many of the SMR designs under development in the market today are based on existing large reactor technologies but may not have been developed in response to the full spectrum of market needs.

The work described in this article looks to explore how the requirements and needs in three distinct types of market dictate where SMR companies and designers should focus their efforts to ensure maximum market penetration. This is accomplished through the development and application of a qualitative methodology to evaluate energy solutions against the needs of these markets.

The information gathered here is by no means an in-depth analysis but is informed by the knowledge and opinions of a multidisciplinary team. As the contributors come from a variety of backgrounds including regulatory, reactor design, engineering, operations, public policy and research, it presents a balanced picture from a broad spectrum of stakeholders.

# Types of markets considered

To categorize the various types of market conditions that exist (or may exist in the future), the following market definitions have been devised.

**Mature Market** – represents existing electricity grids in developed nations that typically have a high population as well as a high level of energy consumption. It contains diverse sources of electricity generation sources that must have high levels of reliability and energy quality to meet the needs of consumers. It can be either regulated or de-regulated and is typically interconnected with neighboring regions to allow for importing and exporting electricity. A mature market has well established supply chains and there is reliable transmission of electricity from generators to consumers.

**Industrial Market** – is one in which power plants supply energy beyond pure electrical generation in order to support industrial needs (low population density, high energy consumption). Power plant energy can be used for desalination, process heat, district heating and hydrogen production applications by supplying high temperature water and/or steam, alongside electricity.
This ‘cogeneration’ results in significantly improved thermal efficiencies and benefits industry by enabling cheaper and more reliable energy.

**Remote/Emerging Market** – is an area or state with a demand of electricity or other secondary requirement (heat, potable water) which cannot be fulfilled in a cost-effective or a sustainable manner due to geographical (unavailability of natural resources, land span) or socio-economic (population, public perception, infrastructure status) reasons. A developing or emerging market is one that is pursuing a reliable energy solution in a comparatively smaller capacity (low population density, low energy consumption) but where the demand is expected to increase.

# Methodology

The fundamental approach taken in this assessment methodology looked at what each of the market areas deem to be most important when selecting a power generation solution. The 21 criteria that were selected for evaluation can be found in **Table 1**. Due to the inclusion of nuclear in the potential options, there are key factors that need to be taken into account such as safeguards and exclusion zoning. Although they may not be directly applicable to other technologies, they were included in the scoring as they will ultimately impact the decision-making process. As the importance of each of the criteria will vary from market to market, weighting factors were applied to each of the 21 criteria for each of the markets. In addition to these considerations, each of the markets have absolute needs that must be met so a “Go, No-Go” gate was also introduced into the concept. For example, there are countries that have put energy policies in place to exclude certain technological solutions and therefore those types of power generation solutions should not receive a score.

Addressing each market type, each power generation solution is scored to demonstrate how it meets the needs of each market utilizing the following formula:

$$\text{Decision Score (DS)} = \prod_{j=1}^{m} g_j \sum_{k=1}^{n} W_k S_k$$

where:

m denotes the number of "Go or No-go" (GoN) factors;

$g_j$ is the logic value (0 value means "No-go", and 1 value represents "Go") assigned to the $j^{th}$ GoN factor;

n is the number of evaluation criteria,

$W_k$ is the weighting factor (ranging from 0 to 4, where 0 is no importance, 1 is low importance, 2 is moderate importance, 3 is high importance and 4 is critical importance) assigned to the $k^{th}$ evaluation criterion for a given market;

$S_k$ is the score (ranging from 0 to 4, where 0 is ‘does not meet requirements’, 1 is ‘meets few requirements’, 2 is ‘means some requirements’, 3 is ‘meets most requirements’ and 4 is ‘fully meets requirements’) that each solution type earned for every market scenario regarding the $k^{th}$ evaluation criteria; and

DS is the final score for each power generation solution being considered in the market.

Five potential energy solutions were then subjected to the assessment methodology. These were: one integral-PWR SMR of approximately 50 MWe , one High-Temperature Gas-Cooled Pebble-Bed SMR (henceforth referred to as 'HTGR SMR') of approximately 50 MWe (IAEA, 2016a), one graphite-moderated high-temperature SMR (henceforth referred to as 'vSMR') of approximately 4 MWe (IAEA, 2016b), on-shore wind (approximately 3 MWe per unit) and a gas turbine unit (approximately 50 MWe). Due to the fact that there is insufficient information on the financial picture for SMR designs, and the fundamental approach being applied in this analysis, the capital cost, Levelized Cost of Electricity (LCOE) and Return on Investment (ROI) criteria were ignored. As the intent of this assessment is to inform the designs of SMRs based on market needs, ignoring the financial considerations helps to prevent analyzing issues that are already well-known in the industry. The key here is to design SMRs to achieve maximum market penetration and then find ways to improve the cost aspect of producing them.

# Results and discussions

For all markets, the best scores were obtained for the vSMR and Wind options, as shown in **Figure 1**. The Remote/Emerging market obtained the highest scores, illustrating that the potential of SMR deployments are higher for this market.

For all markets, High Safety and High Security were determined to be critical criteria. All energy options considered were deemed to ‘meet most of’ or ‘fully meet’ these criteria for all markets; hence High Safety and High Security are not considered distinguishing factors between markets nor energy options.

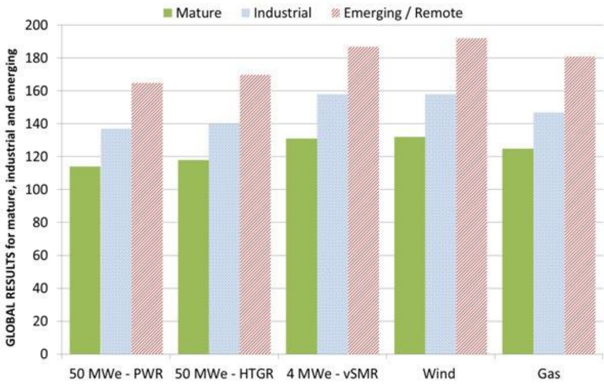


***Figure 1*** *Assessment Methodology Results for All Markets and Energy Options*

**Mature Markets** – As seen in **Table 2**, the best overall score in meeting the criteria of Mature Markets was achieved by Wind despite significant inherent disadvantages pertaining to High Reliability and Low Land Use. This is due to significant advantages inherent to renewable technology such as High Regulatory Alignment, High Security, Higher Public Perception, Lower Technological Design Risk, Low Construction Risk and Low Decommissioning & Waste Complexity. According to the resultant Decision Scores, SMRs can be competitive with other sources of energy. The main advantage of SMRs over Wind and Gas is High Reliability, due to the variable nature of the weather and the political/economic risks of a stable gas supply respectively.

However all three SMR options score less than Wind or Gas in one ‘moderately important’ criterion for Mature Markets; Low Decommissioning / Waste Management Complexity.
The low scoring of SMRs against this criterion is an inherent disadvantage of nuclear technology and is currently being addressed via numerous approaches across the nuclear industry.
Within the three SMR options, the vSMR better meets the criteria of Mature Markets mainly due to advantages of small size and modularity, which enable better scores for High Flexibility, High Scalability, Low Refueling Requirements, Low Land Use and Low Construction risk.

***Table 1*** *Criteria definitions*

| Parameter | Evaluation Criteria |
|---|---|
| 1 - Low Up-front Capital Investment | Engineering, Procurement, Construction (EPC) cost<br>Project management cost |
| 2 - Low LCOE (Levelized Cost of Electricity) | Electricity per total lifetime cost (predicted) |
| 3 - High ROI | Construction period<br>Possibility of cost overruns |
| 4 - Low Supporting Infrastructure Costs | Requirement of additional infrastructure (ie grid, fuel lines)<br>Compatibility with the existing infrastructure (ie grid) |
| 5 - High Flexibility of Power Output | Ability to provide multi-use (ie process heat, desalination)<br>Ability to load-follow |
| 6 - High Scalability of Power Output | Ability to increase the generation units/modules as required<br>Cost of introducing additional units |
| 7 - High Reliability of Power Output | Energy capacity factor<br>Ability to operate as a base load supply<br>Outage durations |
| 8 - Low Technological Design Risk | FOAK or not?<br>Is the technology is in existing market or has it adopted/based on a proven technology? |
| 9 - Low Construction Risk | Is there any existing supply chain?<br>Possibility of construction delays<br>Complexity of supply chain |
| 10 - Low Transportation Complexity | Size of the modules/parts<br>Ability of providing transportation for components/spare parts and fuel |
| 11 - Easy Maintenance | Requirement of maintenance frequency and duration<br>The complexity of maintenance work |
| 12 - Low Decommissioning / Waste Management Complexity | The complexity of the management practices required for waste related operations (ie processing/disposal)<br>The necessity of conducting such procedures for waste management |
| 13 - High Safety | Possible risk for human, environment in a case of accident/leakage<br>The advancement/reliability of the techniques that have deployed to avoid/minimize such a risk |
| 14 - High Security | The use of design-based-threat analysis to implement security systems<br>Requirement of specific safeguards or additional security assurances<br>The availability of security measures (active & passive) |
| 15 - Low Refueling Requirements | Frequency of fueling<br>Complexity of refueling operations |
| 16 - High Alignment to Energy Policy | Dependency on the national/regional energy policies |
| 17 - Positive Public Perception | Requirement of public acceptance<br>Existing general public perception on power source |
| 18 - Low Environmental Impact | Impact to during material production, construction, operation, maintenance and decommissioning |
| 19 - High Regulatory Alignment (Safeguards) | Requirement to fulfill high regulatory standards<br>Complexity of licensing procedures |
| 20 - Low Land Use and Exclusion Zoning | Use of land/size of the plant<br>Requirement of declaring emergency zones/security zones |
| 21 - Low Human Resources Capability Requirements | Staffing needs<br>Requirement of specific skills for employees |

***Table 2*** *Mature Market Results*

| CRITERION | 50 MWe PWR | 76 MWe HTGR | 5 MWe HTGR | Wind | Gas |
|---|---|---|---|---|---|
| 4 - Low infrastructure costs | 3 | 3 | 4 | 3 | 1 |
| 5 - High flexibility | 6 | 6 | 6 | 2 | 8 |
| 6 - High scalability | 6 | 4 | 8 | 8 | 4 |
| 7 - High reliability | 8 | 8 | 8 | 0 | 6 |
| 8 - Low technological design risk | 3 | 3 | 2 | 4 | 4 |
| 9 - Low construction risk | 4 | 4 | 6 | 8 | 8 |
| 10 - Low transportation complexity | 6 | 6 | 6 | 6 | 8 |
| 11 - Easy maintenance | 2 | 4 | 6 | 6 | 6 |
| 12 - Low decommissioning / waste management complexity | 6 | 6 | 6 | 8 | 8 |
| 13 - High safety | 12 | 16 | 16 | 16 | 12 |
| 14 - High security | 12 | 12 | 12 | 16 | 12 |
| 15 - Low refuellingrequirements | 3 | 3 | 4 | 4 | 1 |
| 16 - High alignment to energy policy | 6 | 6 | 6 | 8 | 4 |
| 17 - Positive public perception | 8 | 12 | 12 | 12 | 12 |
| 18 - Low environmental impact | 9 | 9 | 9 | 9 | 6 |
| 19 - High regulatoryalignment (safeguards) | 12 | 8 | 8 | 16 | 16 |
| 20 - Low land use and exclusion zoning | 6 | 6 | 9 | 3 | 6 |
| 21 - Low Human Resources | 2 | 2 | 3 | 3 | 3 |
| **FINAL RESULTS** | **114** | **118** | **131** | **132** | **125** |

*Table 3 Industrial Market Results*

| Criterion | 50 MWe PWR | 76 MWe HTGR | 5 MWe HTGR | Wind | Gas |
|---|---|---|---|---|---|
| 4 - Low infrastructure costs | 6 | 6 | 8 | 6 | 2 |
| 5 - High flexibility | 3 | 3 | 3 | 1 | 4 |
| 6 - High scalability | 6 | 4 | 8 | 8 | 4 |
| 7 - High reliability | 16 | 16 | 16 | 0 | 12 |
| 8 - Low technological design risk | 9 | 9 | 6 | 12 | 12 |
| 9 - Low construction risk | 6 | 6 | 9 | 12 | 12 |
| 10 - Low transportation complexity | 6 | 6 | 6 | 6 | 8 |
| 11 - Easymaintanance | 3 | 6 | 9 | 9 | 9 |
| 12 - Low decommissioning / waste management complexity | 9 | 9 | 9 | 12 | 12 |
| 13 - High safety | 12 | 16 | 16 | 16 | 12 |
| 14 - High security | 12 | 12 | 12 | 16 | 12 |
| 15 - Low refuellingrequirements | 9 | 9 | 12 | 12 | 3 |
| 16 - High alignment to energy policy | 6 | 6 | 6 | 8 | 4 |
| 17 - Positive public perception | 4 | 6 | 6 | 6 | 6 |
| 18 - Low environmental impact | 6 | 6 | 6 | 6 | 4 |
| 19 - High regulatoryalignment (safeguards) | 12 | 8 | 8 | 16 | 16 |
| 20 - Low land use and exclusion zoning | 6 | 6 | 9 | 3 | 6 |
| 21 - Low Human Resources | 6 | 6 | 9 | 9 | 9 |
| **FINAL RESULTS** | **137** | **140** | **158** | **158** | **147** |

**Industrial Markets** – As seen in **Table 3**, the best overall scores were achieved by the vSMR and Wind options, with the two larger SMR options scoring lowest, and Gas in the middle. The GoN criteria were identified as High Reliability and High Regulatory Alignment. However, for some industrial applications, there may be additional GoN considerations; if a particular function is required (such as high temperature steam provision), then some SMR designs will be significantly more favorable due to co-generation capabilities and Wind would likely not be a feasible option. Furthermore, although Wind scores favorably, it does not meet all GoN requirements due to poor reliability, and therefore cannot be considered a viable option if deployed independently. Deploying Wind coupled with energy storage would not be economically viable at present given the technological status of energy storage options.

All three SMR options scored poorly on Low Design Risk and Low Construction Risk. These are some areas in which the nuclear industry should focus on in order to improve competitiveness of SMRs for penetration into Industrial Markets. Examples may include innovative financial approaches to risk management and innovations in SMR designs. For the vSMR option, three of the four GoN criteria are met, with the exception of High Regulatory Alignment, therefore it is proposed that solutions in this arena be progressed to better address the industrial market needs with SMRs.

**Remote/Emerging Markets** – As with Industrial Markets, **Table 4** shows that the best overall scores were achieved by the vSMR and Wind options, with the two larger SMR options scoring lowest and Gas in the middle. The GoN criteria were identified as High Flexibility, Low Design Risk, Low Construction Risk, Low Transportation Complexity, Positive Public Perception and Low Environmental Impact.

*Table 4 Remote/Emerging Market Results*

| Criterion | 50 MWe PWR | 76 MWe HTGR | 5 MWe HTGR | Wind | Gas |
|---|---|---|---|---|---|
| 4 - Low infrastructure costs | 9 | 9 | 12 | 9 | 3 |
| 5 - High flexibility | 12 | 12 | 12 | 4 | 16 |
| 6 - High scalability | 6 | 4 | 8 | 8 | 4 |
| 7 - High reliability | 12 | 12 | 12 | 0 | 9 |
| 8 - Low technological design risk | 12 | 12 | 8 | 16 | 16 |
| 9 - Low construction risk | 8 | 8 | 12 | 16 | 16 |
| 10 - Low transportation complexity | 12 | 12 | 12 | 12 | 16 |
| 11 - Easymaintanance | 3 | 6 | 9 | 9 | 9 |
| 12 - Low decommissioning / waste management complexity | 9 | 9 | 9 | 12 | 12 |
| 13 - High safety | 12 | 16 | 16 | 16 | 12 |
| 14 - High security | 12 | 12 | 12 | 16 | 12 |
| 15 - Low refuellingrequirements | 9 | 9 | 12 | 12 | 3 |
| 16 - High alignment to energy policy | 9 | 9 | 9 | 12 | 6 |
| 17 - Positive public perception | 8 | 12 | 12 | 12 | 12 |
| 18 - Low environmental impact | 12 | 12 | 12 | 12 | 8 |
| 19 - High regulatoryalignment (safeguards) | 12 | 8 | 8 | 16 | 16 |
| 20 - Low land use and exclusion zoning | 2 | 2 | 3 | 1 | 2 |
| 21 - Low Human Resources | 6 | 6 | 9 | 9 | 9 |
| **FINAL RESULTS** | **165** | **170** | **187** | **192** | **181** |

Remote markets do not identify High Scalability and Reliability as critical criteria, however these are critical in Emerging applications, hence the weighting factors are modified appropriately here. Due to these distinguishing factors, the SMRs will have higher reach in Emerging Markets rather than Remote Markets.

The results show that Wind and the vSMR option are more competitive because of their comparatively smaller capacities and less complexity. It is therefore recommended that the nuclear industry focuses on smaller power SMR designs, and investigates the optimum power vs. cost in order to maximize competitive advantage; this optimization study is dependent on a large number of complex variables and may be an evolutionary process during early SMR deployments.

# Solutions and next steps

**Innovation in Financing Approach** – To raise capital for building SMRs, it is recommended to leverage the collective support of both the industry as well as the public. This is a deviation from the traditional approach of securing large contributions from the government.

This is only possible as a result of the lower capital requirements for SMRs which are on the order of US$100 million as opposed to the multibillion-dollar requirement for traditional reactors. This can be accomplished through the issuing of government-backed bonds - or the establishment of some other investment vehicle - that provides a guaranteed return on investment. Through these means, not only will people feel invested in the successful deployment of SMRs but it will indirectly influence the public perception of nuclear as they become more educated on the subject and talk to others. Entering into partnerships with key stakeholders can also help to bolster localized support when entering into remote or emerging markets (indigenous or otherwise). A similar approach is being followed in Canada for raising capital on large hydro-electric projects.

**Innovations in Design** – Modularizing the internal components (sub-modules) of the SMRs will improve its maintenance simplicity as the components can be replaced in a plug-n-play manner. This also enforces the capability to standardize the sub modules which will lead to an economical and consistent supply chain for parts. SMRs can play a vital role as a multipurpose generator to produce additional resources such as heat, potable water and hydrogen for other needs in all types of markets. Integrated SMR systems with these additional benefits will enhance the market preference for SMRs significantly. Instead of designing a number of application specific SMRs, it will be more beneficial to focus on developing multipurpose SMR systems as integrated solutions. The option of integrating applications for radio-isotope production and material research if an SMR design can facilitate a high neutron flux (higher than $5\times10^{13}$ n/cm$^2$/s) (IAEA, 2003) and a feasible mechanism to yield it. Also, using reprocessed fuel as a primary fuel should be explored further as a long-term advancement.

**Innovations in Regulation** – As determined in the Results and Discussion, High Regulatory Alignment is an influential factor for SMR adoption. Current regulations were determined to be a barrier for technical adoption since SMRs cannot compete with the economies of scale for large Nuclear Power Plants and the regulatory experience is limited for new designs. The existing performance based approach with a single license is sufficient for regulatory approval of prototype SMRs; however, innovative regulatory frameworks are required to increase the rate of technology adoption. The ideal regulation for SMRs would be the optimization of performance based and prescribed regulations. As implemented for the transport of radioactive materials, the implementation of design certificates will reduce the licensing burden and allow for new market participants in the industrial and emerging markets. Vendors would seek design certification from the competent authority demonstrating that the prescribed equipment meets physical design and safety requirements. Potential operators would include the design certificate in their license application to the regulatory body as part of the licensing basis. Industry, government, and regulatory bodies should be actively engaged in regulatory research to determine opportunities for prescribed requirements in regulation for the issuance of SMR design certificates. Governments and national authorities should be actively engaged with the IAEA to establish specific safety requirements to create a credible methodology for the international design of SMR technologies similar to the successful implementation of the Regulations for the Safe Transport of Radioactive Materials.

Among the next steps proposed are the following:
• Market-Driven Assessment Methodology Improvements
  o As more details become available, a more defined and scientific weighting methodology should be used to increase
  granularity
  o Refine criteria ensuring proper weight is given to each criterion mentioned
  o Consider separating Remote and Emerging Markets in the analysis, due to differences in High Scalability and High Reliability requirements
• Investigate Emerging Markets and limiting the transmission distance losses (and associated significant costs)
• Account for the impact of distribution costs (infrastructure and losses) in the LCOE for remote/small grids and emerging Markets
• Consider assessing combined solutions through the assessment methodology, such as SMR + Wind or SMR + Storage

# Concluding remarks

The nuclear industry should focus on understanding the key market needs and innovate/design accordingly. The results indicate that the vSMR is best positioned to meet the needs of the markets assessed, and can be competitive with alternative energy options. Innovation across the industry, government, finance and regulation is needed to enable successful development and deployment of SMRs on a meaningful scale.

# References

IAEA, 2017 - World Energy Outlook 2017
IAEA, 2016a - IAEA Advanced Reactors Information System (ARIS)
IAEA, 2016b - Advances in Small Modular Reactor Technology Developments
IAEA, 2003 - Manual for Reactor Produced Radioisotopes (IAEA-TECDOC-1340)

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