



SUMMER INSTITUTE
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Networks for Nuclear Innovation



A Magazine containing the results achieved in the Network for Nuclear Innovation projects during the WNU Summer Institute 2019



The work described in this Magazine was prepared during the final two weeks of the World Nuclear University Summer Institute 2019. It does not represent the position or the official views of World Nuclear Association, World Nuclear University or any of the companies to which the participants are affiliated with.

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FROM WORLD NUCLEAR UNIVERSITY PRESIDENT



Nuclear electricity generation is growing globally, but it needs to grow faster if the world is to meet future energy demand and mitigate the effects of climate change. The major goal that we have set to achieve by 2050 is to generate 25% of global electricity with nuclear power. Challenges in the technological, regulatory, economic, and social levels of our industry must all be addressed to achieve this growth. In such an international industry, this requires strong international collaboration. Networking is a vital component of international collaboration, and I am delighted to see the central role the Networks for Nuclear Innovation has played in this year's Summer Institute.

Fellows are selected to participate in the Summer Institute in part due to their ambition and enthusiasm for the future of nuclear. The Networks for Nuclear Innovation groups this year produced high quality reports with serious recommendations for diverse aspects of the nuclear future. Information does not respect national boundaries, and I anticipate that the innovative ideas generated during the NNI will be carried forward by the Fellows into their 39 countries. I support the endeavours of these future leaders, and fully believe in their future successes.

Agneta Rising
President
World Nuclear University

ACKNOWLEDGEMENTS

The first edition of the Networks for Nuclear Innovations (NNI) magazine was completed at the Summer Institute 2016. The main concept is to compile the ideas that emerge from the Fellows collaborative work in a publication that could inspire future innovations and serve as reference for the continuous development of important topics in the nuclear area.

We are extremely impressed by the efforts the Fellows and Mentors dedicated to finalize the text within the Summer Institute timeframe, at the same time they were preparing their impactful oral presentation.

We are grateful for the NNI Magazine Editor, Alina Constantin, who made sure all the pieces were correct and in place for its timely publication. The digital version of the NNI magazines can be found at: www.world-nuclear-university.org

Patricia Wieland
Head
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FOREWORD

This year the Summer Institute attracted 82 Fellows representing 39 countries. They bonded in Romania and then gathered in Switzerland, under the close guidance of their mentors, to intensively work on the dedicated projects of the programme – the Networks for Nuclear Innovation. The thematic chosen reflects actual aspects of nuclear industry, which are or have to be driven even more by innovation, to cope with the global context of climate change and accelerated digitalization.

The Fellows developed ideas, concepts and practical solutions to promote innovation in their area chosen while addressing the Sustainable Development Goals. The presentation of their results achieved, during the closing day of the Summer Institute, called for reflection, adaptability and international cooperation. Institutional changes needed, short term, mid-term and long term perspectives, economical aspects and implementation ways were carefully studied by the teams. Some of the messages derived are captured in this brief introduction, being in the same time an invitation for the reader to carefully consider each of the projects described, engage in dialogue and disseminate the most feasible proposals.

Innovative nuclear reactors, the Gen IV and the small modular reactors can be the ingredients of a nuclear renaissance, having increased safety capabilities and ability to target specific customer needs.

In order to encourage the development of Gen IV reactors, it is needed to collaborate at international to consolidate the fundamental features of Gen IV design and simplify the process of validation.

When communicated nuclear energy outside the industry, the Fellows highlighted how important is to come from the same shared values to the social and ethical level in order to be understood and build solid partnerships based on trust. This is key in gaining more acceptance for nuclear and going towards the goals of the Harmony programme.

Different aspects and criteria have to be considered when assessing the feasibility of a nuclear project, this being the base of creating openness and support, as every country has its own particularities. A forum for providing technical advice on feasibility studies and sharing of information has been proposed by one of the teams.

People are a company's most important resource. Even with the most expensive and safest equipment and systems, high-performing organizations shall invest in their people and culture to truly achieve their vision and mission. In order to maintain a proper organizational environment, favourable to development and progress, periodical checks and assessments of the organizational health and state of the culture in the organization have to be performed.

Another message strongly reinforced was that creating and maintaining a valuable and well prepared human capital is crucial for nuclear but has also to keep the pace with the technology infusing now all aspects of people's life. Organizations have to be aware and prepared to allocate the needed resources while having a sound and adaptive strategy. Governments, academia, and nuclear industry stakeholders can join efforts to create an internationally connected nuclear industry network where individuals possessing qualifications needed are much easier identified, as well as shortages or surpluses of particular skills.

We hope that the reader will enjoy the content and find value in it.
Yours sincerely,
Alina Constantin
Editor-in-Chief

RECOMMENDATIONS ON THE USE OF CLEAN HYDROGEN TO ACHIEVE DEEP DECARBONISATION

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Abstract

Among various Zero Emission Technology (ZET), Nuclear and Intermittent Renewables are considered as important to achieve deep carbonisation. The public and decision-makers have high expectations for Intermittent Renewables and its share is rapidly growing globally. According to OECD IEA, hydropower remains the largest renewable generation source, meeting 16% of global electricity demand by 2023, followed by wind (6%), solar PV (4%), and bioenergy (3%). The recent expansion of intermittent (or non-dispatchable) renewables, assisted by such policy tools as FIT (Feed-In-Tariff) or PTC (Production Tax Credit), is remarkable, but requires additional system costs for backup power, flexibility of power generating sources, storage/hybrid production and grid management, and does not necessarily translate to low gCO₂/kWh nor affordability. In some countries, operation and economics of conventional base-load power generating sources including nuclear power are threatened by increased share of intermittent renewables. However, complementary use of nuclear and intermittent renewables contributes to security (increased GHG emission reduction, increased domestic energy supply) and better economics for both since both are capital-intensive and a high capacity factor is required for economic operation. Looking beyond the complementary use of nuclear and intermittent renewables, there will be many technological (by use of ZET [Zero Emission Technology] and even NET [Negative Emission Technology]) and institutional innovations conceivable for deep decarbonization.

The work conducted for this project aimed to develop technological and institutional options to achieve deep decarbonization by 2050 with minimum cost burden to society. The present report demonstrates a new approach and provides recommendations on accomplishing carbon neutrality in OECD countries by 2050 using hydrogen storage for the most carbon-intense areas of human activity - energy production, industry and transport. The proposed hydrogen-based energy system includes diverse facilities, such as a very high temperature reactor (VHTR), Iodine-Sulphur (IS) conversion facility, electrolysis facility, compressed air storage and Brayton cycle gas turbine, ensuring grid stability, as well as price stability, which can be affected by the prompt ingress of intermittent renewables.

1. Introduction

At the G8 meeting in L'Aquila in 2009, leaders of the world's major industrialized nations agreed to achieve at least 50% reductions of GHG emissions by 2050. The UK is the first major economy that institutionalized by law a target to cut greenhouse gas emissions to net zero by 2050 and legislated to the end its contribution to global warming. Few years later, at the COP 21 in Paris in 2015, 195 countries adopted the first-ever universal, legally binding global climate deal to avoid

dangerous climate change by limiting global warming to well below 2°C. In order to accomplish the Paris Agreement, Sweden introduced a climate policy framework with a climate act. By 2045, Sweden is to have zero net emissions of greenhouse gases into the atmosphere.

Climate change is the biggest challenge that society faces today and urgent actions are required by the most developed countries in order to mitigate its effects for future generations. UK and Sweden have started to do more in these terms, however the biggest question is how to develop technological and institutional options to achieve deep decarbonisation with minimum cost burden to society. Succeeding in that will bring carbon neutrality in OECD countries by 2050. At the same time, that would help to achieve the SDG 7 (Sustainable Development Goals 7 - Affordable and Clean Energy) because our proposal will ensure access to affordable, reliable, clean, sustainable and modern energy, and SDG 3 (Good Health and Well-Being), SDG 13 (Climate actions) and SDG 11 (Sustainable Cities and Communities) because to achieve what we propose takes urgent action to fight climate change and air pollution (especially in the cities).

According to the OECDs Statistical Data Base, 89% of GHG emissions are produced by the Energy, Transport and Industry sectors, so focusing on those three sectors will definitely make changes in achieving decarbonisation. The purpose of this report is to propose to OECD policy makers a new approach on how to accomplish carbon neutrality in OECD countries by 2050. The aim of the new electricity system will be hydrogen production cells that will be used for hydrogen storage that will be used for energy production, industry and transport as needed. Hydrogen is the fuel of the sustainable future because it generates zero emissions and can be produced from low-carbon electricity or from carbon-abated fossil fuels. This report demonstrates that using hydrogen storage to achieve decarbonisation is possible with today's available technology and implementation of reasonable institutional options.

2. Energy

2.1. Overview

In order to achieve deep decarbonisation in the OECD countries, roughly 60% of electricity supply that today comes from coal, gas and oil should be replaced with renewables and nuclear power [1]. With the introduction of such a high percentage of renewables some kind of storage system is necessary in order to ensure grid stability. Our proposal is to use hydrogen storage.

2.2. Hydrogen Production Cells

The building blocks of this new electricity system are hydrogen production cells. Several of these hydrogen production cells are envisioned as a part of the new electricity system. The idea of the hydrogen production cell is to ensure network stability and reduce the price volatility at the time of a large ingress of renewable energy which is necessary in order to replace 60% of CO₂-intensive energy sources. It accomplishes these aims by storing energy when electricity supply is abundant (e.g. sunny and windy days) and produces electricity when electricity supply is scarce (e.g. days without wind).

The hydrogen production cell will contain a very high temperature reactor (VHTR) with accompanying Iodine-Sulphur (IS) conversion facility, electrolysis facility, compressed air storage (if available) and Brayton cycle gas turbine. The facility will be continuously powered by the VHTR and intermittently by the excess renewable energy or outside electricity from nuclear power when the electricity demand is low. The power will be used to produce hydrogen and fill up compressed air storage. Hydrogen storage will have two input streams of hydrogen: Hydrogen from curtailed or low-cost renewable/conventional electricity produced by electrolysis and hydrogen from the VHTR (very high temperature reactor) produced by Iodine-Sulphur (IS) cycle. Figure 1 presents schematic the hydrogen production cell.

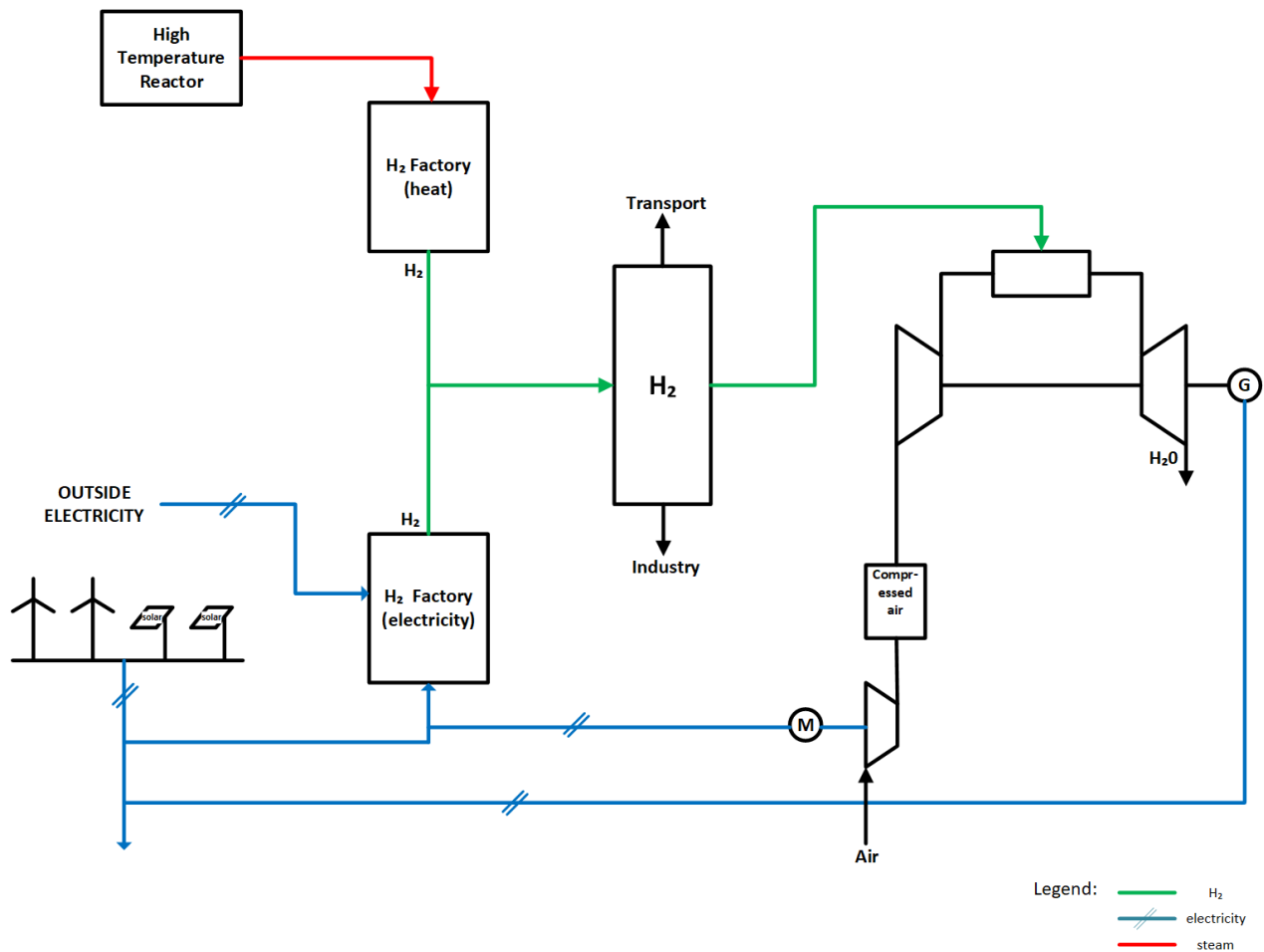


FIG. 1. Hydrogen Production Cell Schematic.

At the time of high demand the gas turbine will activate to support the electricity network. Stored energy in form of hydrogen and compressed air will be used.

The proposed system is practical: All the proposed components have been implemented on full or experimental scale and their further development is being actively pursued [2], [3], [4], [5].

The proposed system is economical if the externalities of fossil fuels are reflected in the price of fossil fuels: Utilization of VHTR reduces the price of produced hydrogen to under 28 US¢ /Nm³ by the year 2030 and 19 US¢ /Nm³ by the year 2050. This is twice the price of natural gas in Europe per generated power unit meaning that some support mechanism is needed [6], [7].

2.3. Additional Applications

The produced hydrogen will be distributed to the industry and transportation in order to facilitate decarbonisation in these sectors.

In order to guarantee the stable supply and reasonable cost of hydrogen, which is precondition for its acceptance in other sectors such as industry or transportation, a VHTR is an important component. This is because hydrogen produced by this method is cheaper [8] compared to hydrogen produced using only renewable energy and dispatchable.

3. Transport

3.1. Overview

The transport sector consists primarily of road, air, and water based transportation methods, which combined, accounted for almost one quarter of total global CO₂ emissions in 2016, a 71% increase on 1990 levels [9].

Road transportation is the most significant contributor to the sector's emissions. Figure 2 shows the global transport CO₂ emissions by sub-sector [9].

Given this, and projections of future global trade it is clear the road transport sector in developed countries has an important role to play, alongside other sectors, in providing technological and institutional innovations to reduce CO₂ emissions [10].

One such innovation is the use of Hydrogen powered vehicles throughout the road transport sector.

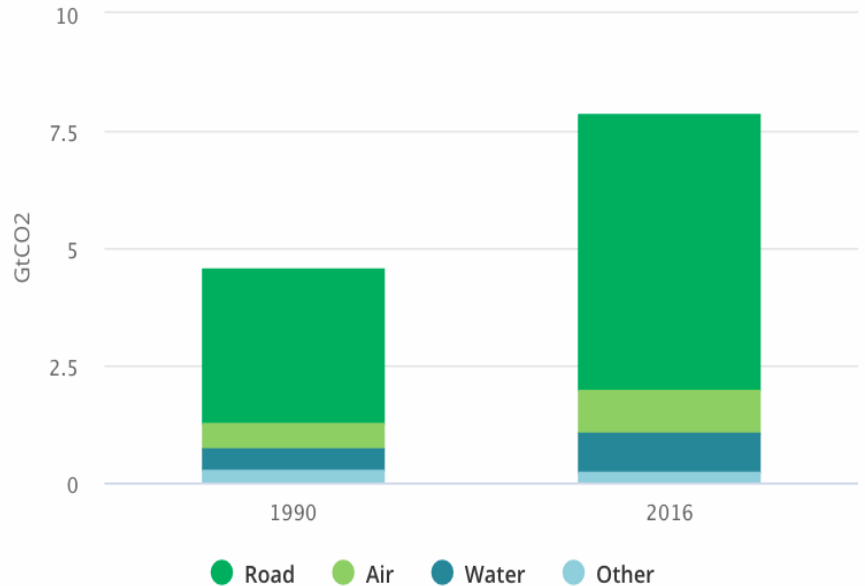


FIG. 2. Global Transport CO₂ Emissions by Sub-Sector.

3.2. Fuel Cell Electric Vehicles for Road Transport

The vast majority of road transport falls into 3 main categories: passenger cars, road freight vehicles (lorries), and public road transport (buses). The decarbonisation of these methods of transportation would account for the almost complete decarbonisation of the road transport sector. All of the above vehicles are compatible with Hydrogen and Fuel Cell technology.

Our proposal is based in the use of FCEVs (Fuel Cell Electric Vehicles), together with BEVs (Battery Electric Vehicles) in substitution of Internal Combustion Engines (ICE) or even Hybrid solutions to get deep decarbonization.

According to the Shell Hydrogen Study, the maturity, requirements, advantages, disadvantages and alternatives can be seen for each vehicle type as indicated in Table 1 [11].

TABLE 1. Factors in FCEVs of Various Types.

	Cars	Lorries	Buses
Market Maturity	Technology proven worldwide (Europe, North America, Asia) through prototypes/small fleets, first production vehicles in moderate numbers. Incentive schemes for passenger car purchase still necessary	Vehicles mostly in the USA (around 50), with individual examples in Germany/EU. Concepts and prototypes primarily for smaller lorries in urban areas with air quality issues, but also first concepts/prototypes for heavy goods vehicles.	Technology tried and tested in numerous small fleets worldwide (Europe, North America, Asia), larger projects with several hundred buses at the planning stage; currently only in publicly funded transport projects, studies on commercial use.

Requirements	Comparable to internal combustion engine vehicles in terms of equipment, performance, range; sufficiently dense hydrogen refuelling infrastructure.	Space-saving hydrogen storage; reliable supply; reduction in total cost of ownership.	Flexible, reliable use in scheduled services with short downtimes (for refuelling/charging); ideally no space and weight restrictions for passenger transport.
Advantages	Pollutant-free driving; range and performance close to petrol cars.	Higher efficiency, no air pollutants, low noise emissions.	Range 300 to 450 km, no public infrastructure needed for municipal buses, range still too short for coaches; no air pollutants, low noise emissions, little additional weight from hydrogen tanks.
Disadvantages	Still much more expensive than internal combustion engine cars; poor refuelling station infrastructure.	Expensive drive technology/fuel; still shorter range than diesel; low density of refuelling stations.	Vehicles still more expensive than the reference technology of diesel buses.
Alternatives	CO ₂ =0: BEV CO ₂ : ICE	CO ₂ =0: BEV CO ₂ : ICE diesel, LNG/CNG	CO ₂ =0: BEV CO ₂ : Gas buses, diesel hybrid buses

FCEVs together with BEVs are necessary to achieve a deep decarbonization of the transportation sector. Both make use of similar and complementary technologies suitable for different segments and customers. They are not competitive but complementary.

According to the specific requirements on weight and range for each method of transportation, FCEVs are particularly important for technologies where electrification, or the use of batteries, is not practical, such as long distance freight trains. Figure 3 shows [12] transport technologies most suited to either FCEVs or BEVs, as a function of vehicle range and weight.

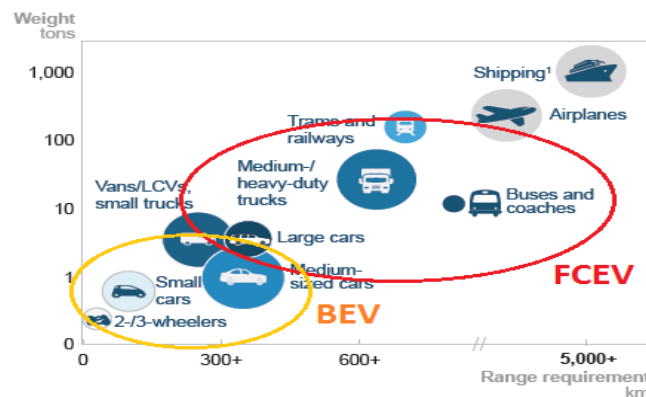


FIG. 3. FCEV and BEV Transport Technology Applicability.

Taking into account the current cost projections of FCEVs and BEVs, mainly for long range or heavy payloads, FCEVs become more competitive, due to the lower associated costs of adding hydrogen storage versus adding batteries. It is expected that by 2030, the cost of a typical powertrain with a 55 kWh battery, with a 300 km range will be comparable between BEV and FCEV [12]. With regards to future projections of technology range, it is estimated that the range to weight ratio of

FCEVs will, by 2030, bring the technology in line with comparable Internal Combustion Engine (ICE) vehicles available today [12].

According to the energy model of green H₂ production, the emissions of the whole FCEV lifecycle are comparable to those of BEVs running on green electricity [12].

3.3. Infrastructure

If hydrogen technology is to be deployed for the decarbonisation of the road transport sector in the future, significant additional infrastructure will be required.

3.4. Filling Stations

There are three different location solutions for hydrogen refuelling stations:

1. Integration into an existing refuelling station
2. New standalone facility
3. Mobile refuelling stations when a small amount of hydrogen is needed

Which of these are chosen depends on different priorities. Our proposal consists on integration into existing refuelling stations to preserve local jobs and capital assets. In case of new standalone facilities, the proposal includes greater possibility of standardization of key components and minimising of investments.

3.5. Transport of H₂

While transporting electricity over long distances can cause energy losses, pipeline transportation of hydrogen reaches almost 100% efficiency. This benefit makes hydrogen an economically attractive option when transporting clean energy at scale and over large distances.

Our proposal recommends the use of current gas transport pipelines to transport. Some experiences, as the H21 project [13] in which gas distributor company in Leeds concluded that it was possible technically and economically viable to decarbonise Leeds' gas distribution networks by converting them to 100% hydrogen.

4. Industry

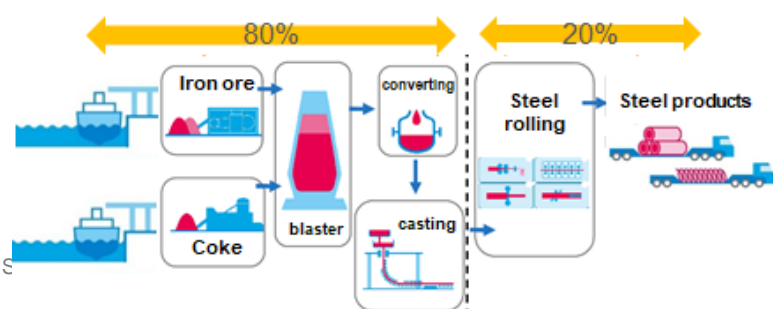
4.1. Overview

According to a United Kingdom CO₂ emission survey in the industrial sector, the primary emitter is the steel industry and secondary is the chemical industry [14]. So we propose a hydrogen-utilising decarbonisation solution for the steel and chemical industries.

4.2. Steel Industry

Iron and steel are key products for the global economy. The sector is the largest industrial emitter of and second largest industrial user of energy [15]. Although considerable improvements have been made in recent years, the iron and steel sector still has the technical potential to further reduce CO₂ emissions.

The steel making process is illustrated in Figure 4. First, steam the material coal to make a substance called "coke". Next, this coke, iron ore and limestone are put into a furnace called



"Blaster". What we have produced is the "crude iron" which is the raw material for steelmaking. Then, after various processes, it becomes a block called "a slab" and finally it becomes steel.

The coke is a mass of carbon, which is a substance represented by "C" in the elemental symbol. On the other hand, iron ore is represented by " Fe_2O_3 ". In the blast, the easy-to-burn coke burns, generating very high heat and raising the temperature inside the blast. Iron ore is melted by this heat. Furthermore, since coke is "C", it combines with oxygen "O" contained in iron ore to generate CO_2 and plays a role of removing oxygen from iron ore. This phenomenon is called reduction. This process can prevent the oxidation of iron ore and make strong iron.

The percentage of energy consumption in the entire steelmaking process is approximately 80% of the upper stroke including this blast furnace. If energy saving and CO_2 reduction proceed in this part, it can have a big impact on the CO_2 emissions of the entire steel industry.

To reduce CO_2 emissions in the "upper stroke" including blast furnaces, we propose two methods "Hydrogen reduction technology" and "Carbon dioxide Capture and Storage".

4.3. Hydrogen Reduction Technology

Hydrogen reduction technology is that replace part of the role of coke entering the blast furnace to Hydrogen (H). Hydrogen (H) is combined with oxygen "O" of iron ore " Fe_2O_3 " to make water (H_2O), and "reduction" is performed to remove oxygen from iron ore.

The steel industry is trying to use hydrogen produced by reforming the gas which is produced when coke is produced, as for "hydrogen reduction technology" [16]. On the other hand, we, the nuclear industry and the electricity industry, can supply hydrogen using technologies such as HGTR. In other words, collaboration between the steel industry and the nuclear industry are expected to achieve significant reduction of CO_2 emission in the steel industry (Figure 5).

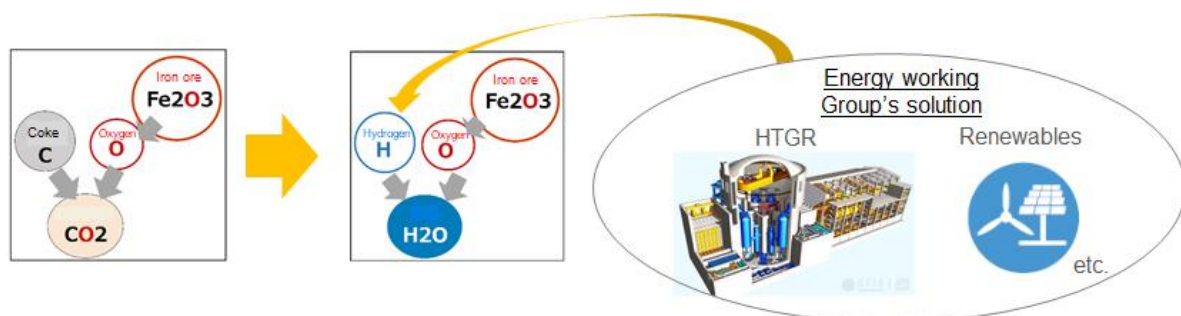


FIG. 5. Proposed Nuclear, Hydrogen and Steel Industry Solution.

4.4. Carbon Dioxide Capture and Storage

In order to burn with high heat, it is necessary to put coke into the blast furnace as well. But then, as mentioned above, CO_2 is generated by "reduction". Therefore, CO_2 is separated and recovered from the gas discharged from the blast furnace. This is Carbon dioxide Capture and Storage (CCS).

4.5. Chemical Industry

The chemical industry is the second largest CO_2 emission sector. The chemical industry consumes a large amount of fossil resources such as naphtha and ethylene as a

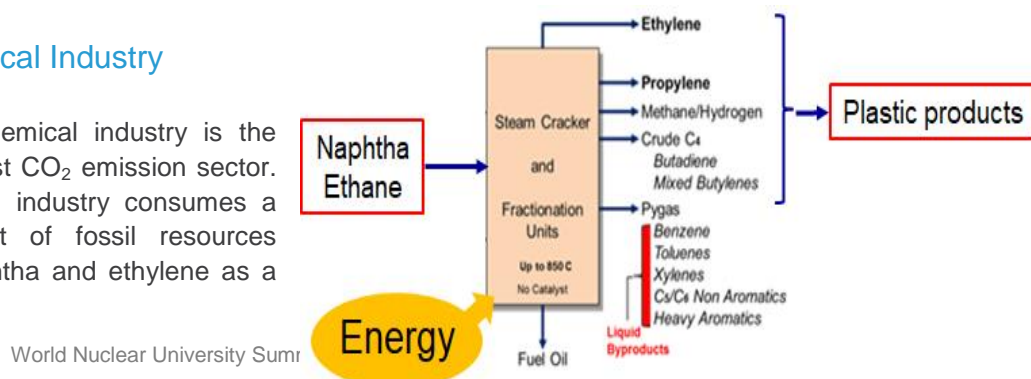


FIG. 6. Typical Plastic Production Process.

raw material for plastic products, and its impact on global warming due to CO₂ emissions is significant.

Ethylene, one of the raw materials for plastics, is produced by thermal decomposition of naphtha and ethane. Therefore, the production of ethylene requires a large amount of energy and emits a large amount of CO₂. Figure 6 illustrates the typical plastic production process.

CO₂ emissions can be reduced if plastics can be produced using CO₂ as a raw material instead of fossil resources. To reduce CO₂ emissions, we propose "Carbon dioxide derived Key Chemical Production Process technology".

This is a technology that produces plastics using CO₂ and hydrogen as raw materials, not fossil resources [17]. CO₂ is collected from thermal power plants, steelworks and factories, hydrogen production facilities using steam reforming etc. Hydrogen can be supplied by the nuclear industry and the electricity industry using technologies such as HGTR. In other words, collaboration between the chemical industry and the nuclear industry are expected to achieve significant reduction of CO₂ emission in the chemical industry. The proposed nuclear, hydrogen and chemical industry solution is presented in Figure 7.

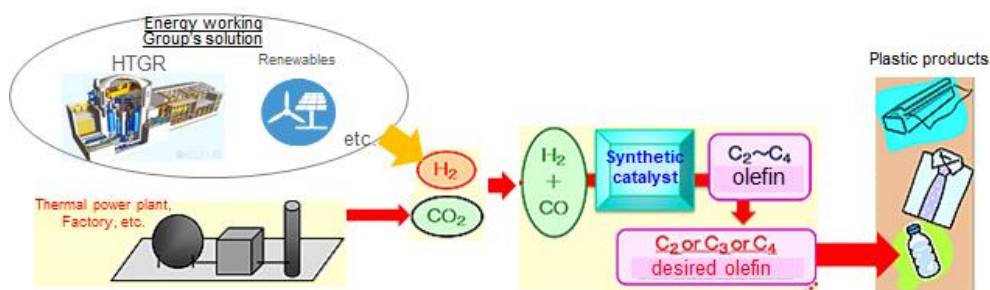


FIG. 7. Proposed Nuclear, Hydrogen and Chemical Industry Solution.

5. Institutional Recommendations

In order to implement the technical vision of the hydrogen society, and to achieve the required target of net zero greenhouse gas emissions by the 2050, innovative and deep institutional policies are needed. We propose comprehensive climate legislation supported by clear global budgetary commitments. Part of the legislation will apply immediately and include, among other proposals, the following main provisions presented in Table 2.

TABLE 2. Immediate term institutional provisions.

Provision	Short Description	Motivation
Hydrogen and clean energy education and research promotion.	Education about hydrogen, climate change, different type of clean energy production and importance of the environment conservation for the general public. Promotion of hydrogen research nationally and internationally (e.g. through OECD)	In order to achieve public acceptance of the proposed measures it is necessary to educate the public about the technology. Promotion of research of hydrogen technology is necessary in order to reduce cost and increase safety and availability of the technology.

Greenhouse gas tax for energy generation	Tax per released amount of greenhouse gas and current CO ₂ trading system reform (fixed and increased minimum CO ₂ €/ton price)	Include society/external cost into the price of generated energy; make hydrogen economically more attractive.
Government subsidy for hydrogen technology	Monetary support for development and introduction of hydrogen-based technologies.	Development of hydrogen-based society requires R&D and investment support that should be provided by the government.

Part of the legislation will apply in the middle to long term and include among other things the harmonized tax policy, the preferential treatment for low-CO₂ products and the ban on carbon combustion (Table 3).

TABLE 3. Mid / long term institutional provisions.

Provision	Short Description	Motivation
Harmonized tax policy	Harmonized tax policy in relation to hydrogen across the OECD.	In order to ensure equal development of the technology across the national borders a common tax policy is needed.
Preferential treatment for low-CO ₂ products.	Customs tariff should apply in relation to CO ₂ emission resulting from the manufacturing of the product.	Serves to increase economic competitiveness of hydrogen advanced and CO ₂ -low economies in comparison to countries that have not adopted low CO ₂ framework.
Ban on carbon combustion	Total prohibition on combustion of fossil fuels. Year when this measure will be introduced should be agreed and fixed long in advance.	This purpose of this policy is to create the sense of urgency and ensure introduction of CO ₂ -neutral technologies.

6. Evaluation

Sustainable development requires a long-term structural strategy for the global economic and social systems, which aims to reduce the burden on the environment and on natural resources to a permanently viable level, while still maintaining economic growth and social cohesion. Only development that manages to balance these three dimensions can be sustained in the long term. Concerns regarding such factors as social, economic and environmental impact have increased interest in the sustainability assessment of energy systems based on hydrogen [18].

International Energy Agency (IEA) Task 36 advances were used to increase the readiness level associated with the life-cycle framework for sustainability assessment of hydrogen energy systems by robustly combining harmonized life-cycle environmental (global warming, cumulative energy demand, and acidification), economic (LCOE) and social (fair salary, health expenditure, etc.) indicators [19].

Three sustainability dimensions are to be taken into account in carbon-intensive areas of industry, energy and transport. Since 2017 energy sector emissions increased by 2.6% and a further by 2.5% in 2018, following three years of decline. In the industry sector direct CO₂ emissions rose 0.3% to reach 8.5 GtCO₂ in 2017 (24% of global emissions), a rebound from the 1.5% annual decline during 2014-16. Transportation is responsible for 24% of direct CO₂ emissions from fuel combustion.

Decarbonizing the power, industry and transport sectors is a fundamental step to reduce emissions, especially in an increasingly electrified world [20].

Sustainability assessment of complex energy systems is encumbered by a need to consider a number of important while also competitive parameters reflecting three sustainability dimensions. These parameters are defined quantitatively as indicators to be used in the assessment. No single indicator can fully capture the complexity of an energy system. In this case structured methodologies for assessing energy sustainability are needed. IEA and the International Renewable Energy Agency (IRENA) in their studies [20], [21], provided a set of indicators helping to assess different areas of hydrogen energy systems use. Together, the indicators make up an accessible and comprehensive tracking framework that can help inform effective and well-coordinated policy-making.

Considering advantages and disadvantages of these methods in assessing sustainability of the proposed hydrogen-based energy system is complex, highlighting the need for additional elaboration. In addition to three sustainability dimensions proposed the infrastructure dimension is crucial for development. It provides the services that enable society to function and economies to thrive. This puts infrastructure at the very heart of efforts to meet the Sustainable Development Goals (SDGs) [22]. The proposal developed by the Network for Nuclear Innovation (NNI) Group 1 for sustainability assessment of energy systems involving hydrogen production combines suitable indicators developed by IEA and IRENA and supplements them with ones for infrastructure dimension providing the ground for sustainability enhancements. The assessment indicators for hydrogen energy systems are presented in Figure 8.

Sections	Our key indicators	Measure	Our weight proposal
Environmental	• CO ₂ emissions	CO ₂	10%
	• Share of low-carbon power generation	%	10%
	• Share of EV in new sales	%	5%
	• Energy savings, CO ₂ savings	%	8%
	• Energy consumption per GDP	Energy / \$	5%
Economic	• CAPEX	\$	10%
	• Discount rate	%	5%
	• Capacity factor	%	7%
	• Lifetime	years	5%
	• Performance, commodity prices	\$	5%
	• Operation & Maintenance cost	\$	5%
	• Development of Hydrogen and EV charging station	Yes No	5%
Infrastructural	• Integration of Transmission grid, Storage, Curtailment	Yes No	5%
	• Level of direct human work input	%	5%
Social	• Level of health expenditures	%	5%
	• Average salary in a Country	Salary / Average	5%

FIG. 8. Assessment Indicators for Hydrogen Energy Systems.

The set of indicators with proposed weighting can be used within the framework of multiple-criteria decision analysis tools to see the progress in the process of sustainability enhancement and gaps identification.

7. Conclusions

In the view of major environmental challenges facing humanity nowadays, the transformation of the global energy sector from fossil-based to zero-carbon by the second half of this century is evident and acknowledged on the international level. The present report demonstrates a new approach and provides recommendations on accomplishing carbon neutrality in OECD countries by 2050 using hydrogen storage for the most carbon-intense areas of human activity - energy production, industry

and transport. The proposed hydrogen-based energy system includes diverse facilities such as VHTR, IS conversion facility, electrolysis facility, compressed air storage and Brayton cycle gas turbine, ensuring grid stability, as well as price volatility, which can be affected by the prompt ingress of intermittent renewables. Technological and institutional recommendations developed are aimed at achieving targets stated in the SDG 3 (Good Health and Well-Being), SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). The progress on the way to successfully reach CO₂ burden free future can be assessed by means of indicators in each of sustainability dimensions, including infrastructure.

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PULSECHECK: A TOOL FOR PROMPT DIAGNOSIS OF ORGANIZATIONAL HEALTH AND CULTURE

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Abstract

An innovative tool (hereafter called PulseCheck) to promptly measure the health and culture of an organization was systematically developed as the final requirement of the 2019 Summer Institute at the World Nuclear University. The PulseCheck tool directly responds to the need of the nuclear industry (e.g., nuclear power plants, nuclear fuel cycle, research and development institutions, etc.) to standardise and simplify the mechanisms to assess the effectiveness of an organization. Although this tool was originally developed for the nuclear industry, and because it is people centred, it is sufficiently versatile for implementation in other industries with different economic and social factors. The metric associated with the PulseCheck tool is a comprehensive survey based on key attributes that were identified through extensive research and the collective experience of the authors. The output of the PulseCheck tool was categorized using six “*Essential Outcomes*” that are applicable to any organization: set direction, maximize competence, effective tool set, workforce engagement, cope with risk and sustainable results. Two main sets of indicators were then defined (i.e., Leadership and Team Effectiveness Indicators) to give a concise assessment of the health state of the organization. This assessment will provide the leadership and individuals in the organization valuable data to establish actions aligned not only towards improvement, but also towards further understanding of the reality of the organization’s health. In addition, a diagnosis of the culture in the organization was obtained by cross-linking the data obtained in the survey with well-defined culture “personalities” that have been described in the open literature. The PulseCheck tool goes one step further and allows leaders and top management to get insights in how the organization can drive a cultural change depending on its desire to have a certain type of culture, which at the end should be based on the organization’s values and vision.

1. Introduction

In today’s world, almost every organization (the Nuclear Industry is not an exception) is devoting a significant amount of effort, time and resources to develop a robust and reliable healthy environment to achieve success; nevertheless, it is recognized that “organizational health” is a complex and sometimes contentious concept that involves not only the working culture and employees’ engagement in their daily activities, but also the ability of the organization to align around a common vision, execute against that vision effectively, and reinvent itself through employee’s empowerment, innovation and creative thinking [1], [2], [3]. Based on the multidimensional aspect of this concept, measuring the organizational health is a complicated task that could involve a lot of resources, time and even complex data processing [4]. Therefore, our goal for the Network for

Nuclear Innovation project at the World Nuclear University Summer Institute 2019 (WNUSI2019) was to develop an *innovative and user-friendly tool* (i.e., PulseCheck Assessment Tool) that could be used at all levels of any company/industry to provide a fast and concise diagnostic of the health and culture status of the organization. The output of this tool would give a high level summary to the management/leadership team in order for them to set appropriate actions to either reinforce the existing healthy culture or to work towards improvement for a healthier and stronger organization on its way to excellence.

In this document, a high level summary of the actual PulseCheck assessment tool is covered, as well as the basic criteria used for its development and potential improvement. It is our expectation that this tool would be implemented in the nuclear industry, but also easily transferred to other industries with different economic and social factors.

2. How can we diagnose an organization and implement a sustainable change?

As fellows of the World Nuclear University Summer Institute and individuals with leadership positions in the nuclear industry, the authors recognized their responsibility to demonstrate the numerous benefits that nuclear science and technology currently has and can have in the future. It is clear that demonstrating these benefits starts with the performance of existing organizations in the industry; nevertheless, it is recognized that long-term performance depends on **Organizational Health**. Some of the questions that are addressed throughout this work are:

- How well is the leadership of your organization truly leading?
- How effectively do you and your colleagues work together?
- Is your organization's culture aligned with the vision set out by your leadership team?

It is recognized however, that assessing these and other aspects of an organization can be challenging, and more so to actually implement any long-lasting changes. Nonetheless, experience has shown the reward to be well worth the effort with studies demonstrating a strong correlation between organizational health and an organization's performance. Our PulseCheck assessment tool is intended to provide a simple and yet effective method to give an initial diagnostic of the overall organizational health and current working culture, allowing weakness or gaps to be identified and challenged using a set of improvement measures and actions.

2.1. The PulseCheck Framework: Organizational Health

As described before, *organizational health* is not defined by any one factor, but can be broken down into a number of essential outcomes [4], [5]. These essential outcomes are:



Set Direction: Leaders establish a clear vision and strategy and align their team around this common purpose setting up individual goals aligned with the vision of the organization and ensure expectations are clearly stated and communicated.



Maximize Competence: Leaders develop talent within the organization and foster a continuous learning attitude. The teams are recognized for being proficient in their specific focus area of expertise with all members clearly understanding their roles and responsibilities.



Effective Tool Set: Leaders provide an efficient tool set (e.g., software, procedures) to accomplish the required work while the team is well trained on these tools and uses them efficiently.



Engaged Workforce: Leaders engage the workforce and inspire them through communication and empowerment. This engagement builds and sustains trust and fosters a culture of continuous improvement through coaching and accountability. Teams work to build a positive atmosphere through mutual trust and respect.



Cope with Risk: Leaders make well-informed decisions, always considering the impacts of those decisions and potential actions to mitigate risks to the organization (i.e., a risk management approach is embedded within the strategic planning of the organization). Similarly, teams and individuals make informed decisions within their area of responsibility, communicating effectively and resolving conflicts efficiently.



Sustainable Results: Leaders drive the organization to a position in which strong performance is sustainable and driven towards continuous improvement with prompt actions taken to address performance declines. The team is always accountable for their results and individuals help each other in times of need – everyone is committed to the overall success of the team and the organization.

Each of these **Essential Outcomes** can be diagnosed via a set of indicators, which are broken down into leadership and team components. To assess the health of these indicators, their attributes were studied and survey questions were carefully drafted, with all responses using a linear scale of 1 to 5. A comprehensive definition of a ‘healthy organization’ was therefore defined. It is important to mention that for the purpose of this project, a survey was selected as the main metric for gathering information; however, other metrics could be used and integrated into the PulseCheck tool in the future. Once the responses of the survey were compiled, the risk level of each indicator was defined as high risk (coloured in red), medium risk (coloured in yellow) and low risk (coloured in green) for an easy-to-read assessment. The definition of the risk levels was defined on the percentage of answers that fit to a specific outcome/indicator: over 80% was considered low risk, between 65 and 80% was defined as medium risk and below 65% was considered high risk. The actual dashboard is depicted in Figure 1.

Organizational Health Dashboard			
The Dashboard below provides an assessment of the organizational health through both Leadership and Health Indicators. The understand each Outcome or Indicator, please click on the cell.			<div style="background-color: red; color: white; padding: 2px;">High Risk</div> <div style="background-color: yellow; color: black; padding: 2px;">Medium Risk</div> <div style="background-color: green; color: white; padding: 2px;">Low Risk</div>
Essential Outcomes	Leadership Health Indicators	Team Health Indicators	Feedback
Set Direction	Establish a Clear Vision and Strategy	Aligned on Common Purpose, Vision and Goals	
Maximize Competence	Develop Talent	Team Talent, Roles & Responsibilities are Clear	
	Foster a Learning Organization		
Effective Tool Set	Effective Implementation of Tool Set	Effective Use of Tool Set	
Engaged Workforce	Align and Engage Workforce	Positive Atmosphere of Mutual Trust and Respect	
	Inspire, Motivate and Communicate		
	Build and Sustain Trust		
	Coach and Foster Accountability		
Cope With Risk	Make Good Decisions and Manage Risk	Effective Decision-Making & Conflict Resolution	
Sustainable Results	Achieve Sustainable Results	Committed to Team Success	

FIG. 1. Screen Shot of the PulseCheck Dashboard for the Organizational Health Assessment.

2.2. The PulseCheck Framework: Culture Assessment

The culture of an organization can be described as ‘how’ the organization works to achieve their vision. While organizational health measures how effectively leaders and teams work and work together, the culture assessment determines the type of interactions and delivery mechanisms the organization uses to deliver the work. For the purpose of this project, the culture of the organization is considered in two dimensions:

- Dominant trigger for change - Individual decision-making, supervisor decision-making or leadership decision-making;
- Dominant control mechanism - Individual skills and knowledge, rules based and/or process based.

Based on the combination of these two dimensions, an organization can be described as having one of the nine culture “personalities” as depicted in Figure 2.

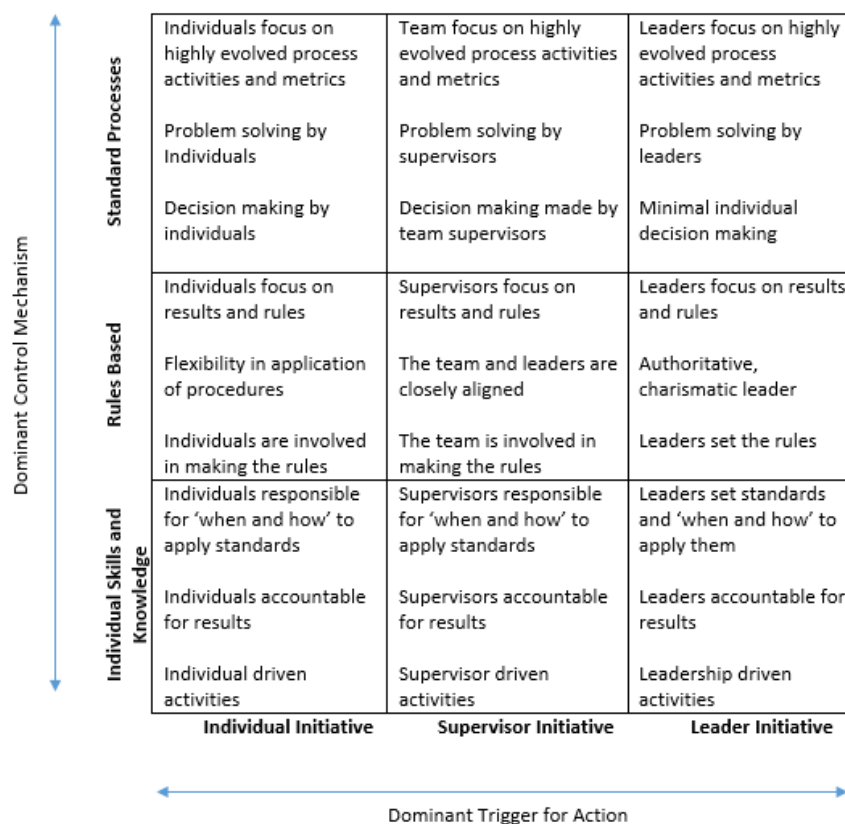


FIG. 2. The Nine Culture “Personalities” in an Organization and Their Relationship.

One aspect worth mentioning is that there is no ‘right’ culture for an organization; however there is usually a desire to create a certain type of culture based on the organization’s values. For example, a Nuclear Power Plant would typically be found to be highly process and supervisor or leadership driven (top middle or top right box in Figure 2) to achieve their goal of high reliability. In the opposite context, a consulting firm consisting of equal partners would likely fall into the bottom left box in Figure 2, with individuals responsible for driving their own results and being highly dependent on the skills and knowledge of individual partners.

One of the advantages of the PulseCheck Assessment Tool is that it can provide insights in how the organization can drive a cultural change based on where the organization is currently located in the culture “personality” matrix. Some parameters/considerations to move across the different culture “personalities” (Figure 2) can be summarized as follows [6]:

- **Transition from Leader Initiative to Individual Initiative – Move to the left in the culture “personality” matrix**
 - Increase leadership’s delegation of authority by: (1) lowering the prescriptiveness of instructions (“What do you think?” rather than “Do what I say”), (2) emphasizing feedback from your team and (3) delegating authority (i.e., decision-making power) to competent individuals at lower levels of the organization.
 - Shift accountability to lower levels of the organization: higher performance incentive weighting at lower levels of the organization.
 - Promote activities where individuals have an active participation at different levels of the organization – for example: (1) set at least once a year an innovation hackathon where individuals at every level in the organization can make suggestions to improve, (2) always promote a systematized team effort for root cause analysis when problems arise in the organization, etc.

Key Attribute - Empowering individuals: Increase flexibility and responsibility for individuals to make decisions on how and when they will achieve deliverables while holding them accountable for the outcomes.
- **Transition from Individual Initiative to Leader Initiative – Move to the right in the “personality” matrix**
 - Shift leadership style to more directive: (1) increasing the prescriptiveness of instruction (“Do what I say” rather than “What do you think?”), (2) emphasizing your monitoring capabilities (e.g., field presence, etc.), and (3) consolidating decision making in your hands by lowering delegation.
 - Move-up accountability: higher performance weighting incentive at the top of the organization.
 - Drive change activities at your own initiative in a top-down manner: (1) when problems arise engage in resolution more promptly and (2) lead initiative for improvement and innovation through gap analysis with strategies.

Key Attribute - Leadership Factory: Developing and deploying strong leaders at all levels
- **Transition from Individual Skills and Knowledge to Standard Processes – Move to the top of the “personality” matrix**
 - Drive standardization: (1) observe best shared unspoken processes/practices, (2) formalize them into procedures and (3) assure their enforcement (e.g., as a company grows it could be effective to select a single project management software for all the organization).
 - Increase discipline in following established rules for leaner operation

Key Attribute - Continuous improvement engine: Involving all employees in drive for performance and excellence.
- **Transition from Standard Processes to Individual Skills and Knowledge - Move to the bottom of the “personality” matrix**
 - Allow definition, by individuals or teams themselves, of the rules and standard by which they collectively want to work by.
 - Increase flexibility in the application of procedure: assure that the “why” is sufficiently spread and understood to let the team drive the action plan. Provide appropriate training (knowledge background) if necessary.

Key Attribute - Talent and knowledge core: Attracting and inspiring top talent to foster individual excellence.

3. PulseCheck of the Nuclear Industry – A Test Case

In order to demonstrate the use and versatility of the PulseCheck tool, the survey (i.e., metric for this study) was sent to the WNU Summer Institute 2019 Fellows. The main idea of this exercise was

not only to test the assessment tool, but also to have quick diagnostic of the health and cultural state of the nuclear industry (here represented by a diverse group that is coming from different sectors within the industry).

Approximately 30 Fellows responded to the survey showing that the overall risk of Organization Health in the nuclear industry is **medium** (dominating yellow colour in the dashboard shown in Figure 3 – left-hand side chart in the figure). In addition, two attributes under the Leadership Effectiveness Indicators were identified as high risk: *Develop Talent*, which belongs to the essential outcome “Maximize Competence”, and *Achieve Sustainable Results* which belongs to the essential outcome “Sustainable Results”. In reviewing the survey responses it appears that the high risk of the development talent indicator is related to poor hiring decisions within organizations (i.e., wrong expertise) while the high risk in achieving sustainable results was related to leadership actions in addressing declines in performance. It is important to mention that the data or the analysis was not categorized either by company, industry sector or country; therefore, further analysis is required to draw more specific conclusions about the survey. Individual responses showed a variety of results; however, those results won't be discussed in this document.

Organizational Health Dashboard				Cultural Assessment Dashboard			
The Dashboard below provides an assessment of the organizational health through both Leadership and Health Indicators. The understand each Outcome or Indicator, please click on the cell.			High Risk	The highlighted cell identifies the culture of your organization. By clicking another cell in the Culture Assessment Dashboard, you can identify strategies and approaches to transition and transform the characteristics of your organization to that culture.			
Essential Outcomes	Leadership Health Indicators	Team Health Indicators	Feedback				
Set Direction	Establish a Clear Vision and Strategy	Aligned on Common Purpose, Vision and Goals	<p>Focus on highly evolved process activities and metrics</p> <p>Problem solving by individuals</p> <p>Decision making by individuals</p> <p>Individuals focus on results and rules</p> <p>Flexibility in application of procedures</p> <p>Individuals are involved in making the rules</p> <p>Individuals set "the way it's done here"</p> <p>Individuals are accountable for results</p> <p>Relationship driven activities</p> <p>Focus on highly evolved process activities</p> <p>Problem solving by team</p> <p>Decision making made by team</p> <p>Focus on team based rules</p> <p>The team and leaders are closely aligned</p> <p>The team is involved in making the rules</p> <p>The team sets "the way it's done here"</p> <p>Team is accountable for results</p> <p>Careful selection of people by team</p> <p>Focus on highly evolved process activities</p> <p>Problem solving by leaders</p> <p>Minimal individual decision making</p> <p>Focus on activities</p> <p>Authoritative, charismatic leader</p> <p>Leaders set the rules</p> <p>Leaders set "the way it's done here"</p> <p>Leaders are accountable for results</p> <p>Careful selection of people by leaders</p> <p>Leadership sets out the vision and metrics but individuals are empowered to make decisions, solve problems and are ultimately held accountable for their area of responsibility. Move from authoritative managerial decision to a systemized root cause analysis process of accountable focus in teams. This has to be done in a ritualized manner (once or twice a year). Empowering individuals: Increase flexibility and responsibility for individuals by coaching, knowledge transfer and fostering a learning organization.</p>				
Maximize Competence	Develop Talent	Team Talent, Roles & Responsibilities are Clear					
Effective Tool Set	Effective Implementation of Tool Set	Effective Use of Tool Set					
Engaged Workforce	Align and Engage Workforce	Positive Atmosphere of Mutual Trust and Respect					
	Inspire, Motivate and Communicate						
	Build and Sustain Trust						
Cope With Risk	Make Good Decisions and Manage Risk	Effective Decision-Making & Conflict Resolution					
Sustainable Results	Achieve Sustainable Results	Committed to Team Success					

FIG. 3. Organization Health Dashboard – Overall Assessment of the Nuclear Industry based on 30 Responses from the WNU Summer Institute 2019 Fellows.

With the Cultural Assessment Dashboard (right-hand side of the chart in Figure 3), it was concluded that the nuclear industry is highly process driven (top row of matrix), with a high level of problem-solving and decision-making occurring at the supervisor level (middle column of matrix); however, individual responses varied significantly (not shown here). The described result is not a surprise considering the nature of the nuclear industry itself.

4. Conclusion

The main conclusions that can be drawn from the design of the PulseCheck Assessment Tool are the following:

- People are the company's most important resource. Even with the most expensive and safest equipment and/or systems, high-performing organizations shall invest in their people and culture to truly achieve their vision and mission.
- Measuring the organizational health and state of the culture in the organization (i.e., how the organization works to achieve its vision) represents an opportunity for the leadership team and for every individual in the organization to diagnose the organization itself and define actions to either reinforce behaviours or correct those that need to be improved.
- The PulseCheck Assessment Tool is a versatile tool to promptly check not only the state of organizational health but also the working culture in a particular organization. This tool

provides feedback and actions for improving organizational effectiveness and strategies for cultural transformation. Although this tool was designed for the Nuclear Industry, it can be easily implemented in other organizations.

- Because of organizational health and culture are quite extensive areas, a variety of metrics and dimensions can be considered and integrated into the PulseCheck tool. Moreover, the tool was conceived to be able to take data from other sources (e.g., peer reviews, managers in the field, etc.). This could constitute part of a future effort to further improve this assessment tool.

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BUILDING PARTNERSHIPS OF TRUST

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Abstract

The nuclear industry often relies on facts and figures to make the case for nuclear energy. However, the public remains wary of nuclear energy. Deliberate stakeholder engagement and two-way communication are needed to overcome this. In this project, three different types of nuclear facilities are analyzed to identify the values of these facilities and find stakeholders that share these values. Ideas for building partnerships of trust between the nuclear facilities and the stakeholders are then presented, concluding that the industry can think outside of the box in order to find valuable and long-lasting partnerships to improve the societal acceptance of nuclear energy.

1. Introduction

Negative public perception of nuclear energy remains a difficult challenge to overcome because of the “dread” that the technology evokes. A recent study in the US showed that there would be 40% more nuclear power plants if nuclear were fairly compared to other energy sources based on factual merits. Deliberate stakeholder engagement and two-way communication with the public are needed to overcome the public scepticism of nuclear energy [1].

The goal of the Harmony Programme, which is a global initiative led by the World Nuclear Association, is to provide at least 25% of electricity from nuclear by 2050 as part of a clean and reliable low-carbon mix [2]. Jeremy Gordon, the mentor for this project, says that, “*the industry has to reduce the remoteness of nuclear energy from people’s lives. Continuous transparent engagement based on aligned human values is key to building understanding and trust.*”

Science communication models mainly fall into two categories to explain the gaps between scientists and the public: (1) the information deficit model, which assumes the gaps are a result of a lack of information or knowledge; and (2) the engagement or dialogue model, which assumes the gaps are a result of lack of trust. Public understanding of science by itself does not increase sympathy for new technologies. Rather, genuine dialogue and engagement build support for new technologies through a sense of public ownership and by developing trust in scientists and tech developers [3].

“Decisions always involve both facts and values, whereas most science communication focuses only on facts. If science communication is intended to inform decisions, it must be competent with regard to both facts and values. Public participation inevitably involves both facts and values. Research on public participation suggests that linking scientific analysis to public deliberation in an iterative process can help decision making deal effectively with both facts and values.” — Thomas Dietz, Michigan State University [4].

Effective public engagement is built on trust through common values. Values are ideas that reflect a sense of right and wrong, principles and concepts that guide action in different situations and help set priorities. They form the basis of the character of an organisation. Nuclear facilities can find

common values with other groups of people in order to build partnerships of trust outside of the industry.

An excellent example comes from the Netherlands, where radioactive waste is stored above ground at the Centrale Organisatie Voor Radioactief Afval (COVRA) for at least a hundred years. While looking for suitable storage space for artefacts that are not exhibited, museums and COVRA found each other. The favourable climate-conditioned COVRA storage buildings for radioactive waste have enough unused space to securely store the museums' artefacts. The storage space has been offered for free to the museums by means of a contract for a hundred years, forming a long-lasting partnership between the waste facility and the museums [5].

“How can we explain the long-term aspect of radioactive waste management in a way that people can relate to? Ask people how long we should preserve our cultural heritage such as the paintings of Rembrandt or Van Gogh. The answer is generally: “forever.” The link between the long-term preservation of art and the management of radioactive waste helps people to visualise and trust the concept of long-term management.” - Hans Codée and Ewoud Verhoef of COVRA, The Netherlands [5].

2. Survey

For this project, three different types of facilities have been selected to represent different parts of the nuclear fuel cycle and technology: medical centre with research reactor, nuclear power plant (NPP), and deep geological repository (DGR). A survey was conducted of World Nuclear University (WNU) participants. The goal was to better understand the values that leaders in the nuclear industry see that their facilities bring to society, and to collect ideas on what other organizations share these values. 48 WNU participants from 26 countries took part in the survey, with results presented in Figure 1. It is interesting to see that industry leaders share a variety of values around nuclear facilities, many of which align with the United Nations Sustainable Development Goals.

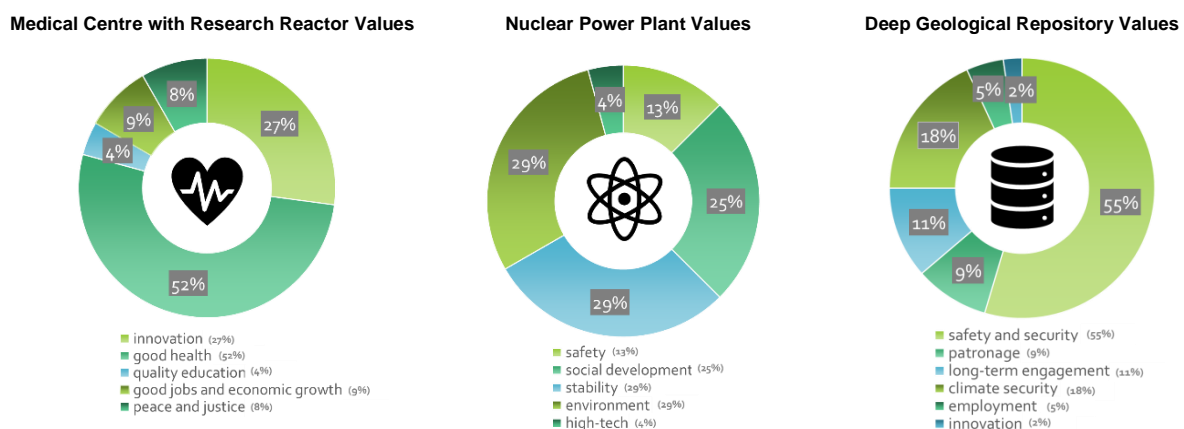


FIG. 1. Results of WNU survey on values for various nuclear facilities.

3. Case studies

The proposed approach is intended to implement a methodology for building trusting relationship links outside the nuclear industry's usual ecosystem of stakeholders. From the selection of three types of nuclear facilities and typical values that can be linked directly or indirectly with the activities there, this project identifies potential partners with whom to build partnerships of trust. For selected values, two to three case studies are presented per facility.

3.1. Medical Centre with Research Reactor

Medical centres with research reactors provide much value to society, which is often unseen, due to unfamiliarity with radiation technology. Some values (high-tech, innovation, health, accuracy, excellence, knowledge, education) and associated stakeholders are shown in Figure 2.

3.1.1. Value of Health

A medical centre with a research reactor is fully focused on producing radioisotopes, providing early diagnostics and targeted therapy in the field of oncology, cardiology and neurology. Hence, health is one of the major values, bringing advanced nuclear technologies also into the women's healthcare sector. The value of women's well-being is globally shared by women's health clinics, non-governmental organisations (NGOs), social media, social media influencers and mobile apps – just to mention some of them.

There is a lack of information in the public about early diagnostics and existing benefits of nuclear medicine. The topic of oncology is quite sensitive and is rarely discussed in the public space. Modern methods of nuclear medicine can diagnose cancer at the earliest stage and increase the patient's chances of survival. Moreover, the existing methods of nuclear medicine are some of the most effective in the treatment of cancer. In this case, it is important to choose the right channels for communication.

Some key relevant channels of communication with women in society are, for instance: apps, social networks, NGOs, and magazines. In partnerships with media platforms that share the values and ideals of women's health, content that will unobtrusively promote how important it is to pay attention to your health, including undergoing early diagnosis using nuclear medicine methods, could be prepared. The results of this activity should be to increase women's awareness of nuclear medicine methods, the need for timely diagnosis and the possibility to receive effective treatment of cancer. Partnerships of trust are furthermore created through common values of health between women's health organisations and nuclear medicine.

3.1.2. Value of Knowledge

As a way to preserve the workforce in nuclear medicine, a medical centre with research reactor is interested in educational activities. While disseminating knowledge across different layers of the educational system, the firm focus of the centre is/should be forming trustworthy relationships with the key stakeholders such as secondary schools and key supporting universities which share the same value of being a knowledge-spreading organization.

There are at least three strong communication channels in the educational community: teachers, fellows or classmates and informal or semi-formal organizations. All these channels are simultaneously social groups with at least one common feature: the desire to receive and share



FIG.2. Values and stakeholders for a medical centre with research reactor.

knowledge both within their group and between groups. Any activities aimed at these groups should be consistent with the core value and make a contribution to the ongoing process of knowledge spreading, not just on nuclear science, but on science in general.

In partnership with educational institutions (schools and universities), as well as organizations, associations, camp organizers, training programmes can be developed aimed at raising awareness in the subject area. For example, it may be possible to develop a teachers' programme aimed at raising awareness about the current situation in the medical scientific sector. Another example would be organizing camps for students who have decided to go into medicine and science.

Co-organizing educational programmes with other organizations that are also strongly committed to knowledge would build important partnerships within and trust among the broader science and education community.

3.2. Nuclear Power Plant

Nuclear power has many different values to different people; from stability and responsibility to teamwork and bravery. Some of these values, and matching stakeholders, are shown in Figure 3. Here we will examine how nuclear power plants can build partnerships of trust with organisations that share the values of happiness, innovation, and sustainability.

3.2.1. Value of Happiness

Theme parks, such as Walt Disney World and Universal Studios, have been attractive to people for a very long time. Especially in the emerging markets, they are popular and profitable [6]. Some challenges that they face include the rising cost of land and finding unique types of entertainment. It appears that, on one hand, the land surrounding an NPP is cheaper and less entertaining [7], and on the other hand, entertainment industries are looking for new opportunities to invest and evolve.

More importantly, they both share some mutual values. NPPs are committed to providing clean energy to make the world a better and happier place for human beings. Entertainment industries bring happiness to people as their main goal. Some of them are pursuing education in a fun way, as well. Both types of facilities are also committed to the safety of their visitors and the public.

Therefore, a cooperation between a NPP in the emerging market and an international entertainment firm could be established to build a nuclear power theme park jointly. There would be different themed zones, such as "adventures on a nuclear island," and educational movies and interactive museums. This could build the partnership of trust between the entertainment industry and nuclear power by commercial innovation and shared values to make a happier life for everyone.



FIG. 3. Values and stakeholders for NPPs.

3.2.2. Value of Innovation

The definition of innovation is “the introduction of something new”, whether a new idea, method or device. Although introduced in the 1960s, nuclear energy is still considered an innovative energy source. The nuclear industry is constantly working on innovative new ways to produce reliable and sustainable electricity. Innovation is also a key value for artists and designers, amongst others. The drive to create something new connects these two otherwise unrelated groups. Both groups could profit from a cooperation. Artists, designers or even architects could gain a huge canvas using the surface of the cooling tower or the whole NPP area. It would be a way to showcase their talents for the artists. By inviting creative people in and presenting them with the opportunity, the NPP could build a network with the creative community whilst also improving the looks of the otherwise quite bleak concrete buildings.

3.2.3. Value of Sustainability

Sustainability is something most organisations and companies strive for these days. In particular in Europe recycling, reusing and upcycling are more than mere concepts. By building trust within the growing community of sustainable organisations and companies, by exchanging ideas and cooperating also offsite the facility the sustainability of NPPs could be communicated to a broader audience.

For instance both Belgian NPPs are registered with the Eco-Management and Audit Scheme (EMAS) which is a European environmental management scheme and thus prove “that they work with an environmental management system that aims to continuously improve their environmental performance” [8]. EMAS registered organisations and other EMAS stakeholders can connect in an EMAS Club through a common interest for environmental best practices. EMAS Clubs are voluntary bottom-up initiatives. The participation in, and contribution to, such clubs by NPPs could lead to a valuable exchange of ideas and in connecting over the common value of sustainability [9].

3.3. Deep Geological Repository

A fundamental set of values that every DGR follows are long-term engagement and responsibility towards the public and future generations. Interestingly, many fields and organisations share these same values, two of which are analysed here. More values and stakeholders are shown in Figure 4.



FIG. 4. Values and stakeholders for a deep geological repository.

3.3.1. Value of Social Responsibility

Seed collections need to be stored at constant low temperature and low moisture and to be guarded against loss of genetic resources in order to avoid loss of biodiversity during regional or global crises. Worldwide, many gene banks hold collections of food crops for safekeeping. Yet many of these are vulnerable, exposed not only to natural catastrophes and conflict, but also to avoidable disasters, such as lack of funding or poor management [10]. The loss of a crop variety can be irreversible for humankind. A global seed vault could be added in DGR projects. Seeds and crops could be brought by gene banks and safely stored in the DGRs. By doing so, a strong and trustful relationship between the nuclear facility and the gene banks can be established.

3.3.2. Value of Long-Term Engagement

People are commonly looking for ways to ensure the safe and secure deposition of their most valuable belongings and artefacts. In Switzerland a client can rent a deposit box of starting at 10 litres and as high as 20,000 litres for a yearly cost from \$60 up to \$10,000 [11] in a bank. Former Swiss military bunkers are transformed to storage sites for the safe and secure holding of valuable items and computer data [12]. A possible collaboration between DGRs, banks and private vault owners can be established in order to create a robust partnership of trust between these parties.

In both cases (i.e. gene/seed banks and bank vaults), DGRs offer a remote location with no visible entrance, in a geologically stable area with ideal and continuously monitored air conditions which serve as an additional barrier for the long term preservation of the deposits. They would be guarded, secured and protected via a series of barriers and the stored material wouldn't be damaged even under the most unfavourable natural or man-made disasters. Furthermore, the stored deposits can be retrieved by their owners without significant effort. Undoubtedly, the long-term partnership between DGRs and the proposed stakeholders spans centuries and represents the ultimate insurance policy for the world's food supply and heritage/wealth preservation.

4. Conclusion

In this work, a series of new collaboration channels between selected nuclear facilities and various stakeholders are proposed. The aim of this project was to explore possible long-lasting, strong and innovative relationships of trust between the nuclear sector and other organisations outside this industry in a meaningful and non-traditional way. By pooling knowledge, skills and political capital, a group of stakeholders could steer a decision in a way that a single group could not do alone. When an issue or opportunity arises, it is too late to build relationships, so they need to be built in advance. Women's organisations, NGOs, schools and universities, international entertainment firms, artists, banks and plant breeders are only a few examples of new partners which share key values and visions with the nuclear sector. Such a network of trust can work as a foundation for increasing the chances of achieving the Harmony Goal leading to a sustainable future.



Seeking common values and unique stakeholders for the future of nuclear technology

The members of the team are pictured here with an important personal value in their native language (from top left to bottom right): Rotem Daudee (*safety*), Sophie Missirian (*openness*), Christina Raith (*communication*), Lenka Kollar (*progress*), Isidro Amadeo Baschar (*teamwork*), Xiaoyu Guo (*responsibility*), Egor Kvyatkovskiy (*truth*), Andrei Tomescu (*engagement*), Jeremy Gordon (Mentor - *fair play*), Denis Kovalev (*health*), Irina Manina (*happiness*), and Dionysios Chionis (*humbleness*).

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A RISK MITIGATION & COMMUNICATION TOOL TO SUPPORT HARMONY PROGRAMME

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Abstract

Global warming is one of the main challenges to whole world and human kind. In order to mitigate its effects, while maintaining development, power generation through sustainable technology is one of the solutions. Nuclear power can provide large base load units and will help in generating jobs by powering big industries. To achieve this, World Nuclear Association (WNA) has suggested the Harmony programme as 25 % of electricity need of world in 2050 should be supplied through new nuclear power construction. This goal can be fulfilled by following various innovative ideas which are required in every field to accelerate nuclear power plant construction.

One of the key components is conduction of feasibility studies (FS) in time bound manner. As per initial review finding of feasibility studies, for developed nuclear nation and newcomer countries, completion period of pre-feasibility study and feasibility study are varying during project execution. In addition, construction is getting delayed due to various regulatory issues and un-accounted reasons which may have been prevented through risk identification and mitigation measures during preparation of feasibility study.

A comparative analysis of FS for South Korea as an expanding country and Uganda as a new comer country has been carried out. One of the main purposes of this study was to identify, with the help of innovative tools, key areas where more emphasis is needed in NPP project development. Furthermore, this identification helps to visualize the connection of the key areas with the stakeholders. Finally, an International Forum under the umbrella of already existing international nuclear organizations such as IAEA, WNA and OECD/NEA was proposed to support countries in key aspects of FS by the use of innovative tools. This forum will provide the opportunity to create and maintain sustainable FS network of multicultural expert team with highly knowledgeable professionals from nuclear industries including fellows from WNU, employees deputed from members' country and young students.

1. Introduction

As a result of human and natural factors, different parts of the worlds have continued to experience the consequences of global warming [1]. To mitigate the occurrence of global climate change conditions, a number of countries have taken measures to adopt clean energy technologies to reduce on greenhouse gas emissions.

Due to the increasing demand for clean energy, the World Nuclear Association [2] developed the Harmony Programme in line with the International Energy Agency's 2 degrees Celsius scenario

with a goal for the global nuclear industry to produce 25% of global electricity by 2050 [3]. Therefore, realizing the Harmony goal requires the global nuclear industry to ensure a generation of 1000 GWe from new nuclear capacity.

In order to build a new nuclear power plant on schedule and in budget, a good enough (Pre) Feasibility Study (FS) is mandatory. However, during the activities of World Nuclear University Summer Institute 2019 (WNU SI 2019) Nuclear Network for Innovation (NNI), it was established that FS have often been carried out in a perfunctory manner and solely as a routine process. This has seen a number of nuclear projects fail and/or delayed in both new comer and expanding countries.

During the WNU SI 2019 NNI, a comparative analysis of FS for South Korea as an expanding country and Uganda as a new comer country has been carried out and a feasible approach which streamlines the FS process has been developed and recommended to the developers of the nuclear projects.

2. Purpose and scope of feasibility study

In order to implement a successful nuclear project, a feasibility study is mandatory as it plays a critical role to communicate to stakeholders about the risks and opportunities. Therefore, it should be prepared based on a proactive approach, country specific and should be practical. The questions that were raised during pre-FS should be qualitatively answered in FS process with scientific background. The goal of FS is to provide a structured and comprehensive assessment on country's readiness for nuclear new-built project [4]. Unlike the already made structure of feasibility study indicated in [4], the WNU SI 2019 NNI has identified the need for a structured and country specific feasibility study process. The scope of the structured made feasibility study process has been divided into four consecutive phases analogous to the medical examination process indicated in Figure 1. For each phase, there are key focus topics that cover the 15 issues indicated in IAEA report NG-T-3.3 [4] in a logical manner. The results of the studies of the "first checkup" phase are the input for next "blood pressure" phase studies, and similar for other phases.

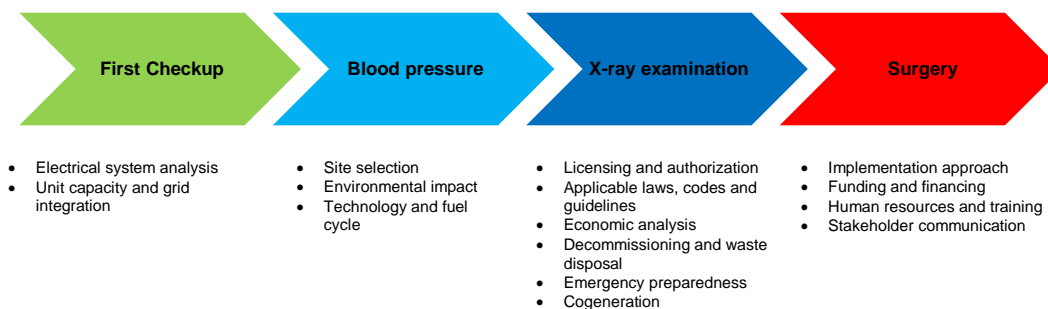


FIG. 1. Analogy to medical examination.

A comparison between South Korea, as an expanding country and Uganda, as an emerging country was carried out by our working group to identify the focused areas to mitigate the risks, provide a better understanding of the feasibility study process in a simple and logical way and to guide in the allocation of the available resources during the implementation of the nuclear power program. During this study, different tools were explored for identification of different risk portfolios based on analysis of available information related to the feasibility studies of above-mentioned two countries. Subsequently for each risk, different mitigation measures were also identified. The details are given in next section.

3. Background of two countries

a. South Korea

The Republic of Korea has become one of the leading industrial and technological superpowers. Despite relatively late adoption of nuclear energy, South Korea undertook an ambitious development of domestic reactor design, OPR-1000, which has been iteratively improved by the engineering branch of Korea Electric Power Corporation (KEPCO). Based on the national self-reliance policy introduced in 1985, the entire supply chain of nuclear power plant development and licensing is now streamlined and allocated to domestic organizations. In addition, several top-tier universities and research institutes ensure knowledge transfer to the industry, under the framework of a comprehensive nuclear energy promotion plan.

Nowadays, South Korea operates 24 nuclear reactors, which account for about 30% share of the total electricity mix, whilst four other reactors are under construction and more are in planning. After the Energy Transition Policy [5] was announced by the new Government in 2017, the key objective shifted to expansion of renewable energy sources (about 47 GW by 2030). The driving factors behind the policy are, on one hand, cutback of greenhouse gases (GHG) and particulate matter emissions, and on the other hand, reduction of dependency on foreign resources.

b. Uganda

The government of Uganda has expressed interest to develop nuclear power for electricity generation to meet the National Development goals for social economic transformation by 2040 [6], [7]. The projected energy demand by 2040 is 42,000 MW for which the energy resources have to be critically analysed [7]. The maximum potential that Uganda can generate, when all the available resources are exploited is 7,400 MW [8]. In order to meet the projected energy demand by 2040, nuclear energy has been identified to play a significant role in the energy mix.

Nuclear energy being a big undertaking, it is essential for them to conduct thorough FS for identification of relevant infrastructure issues and subsequent decision for planning short term and long-term goals to resolves these issues. Currently, Uganda is concluding Phase 1 of the IAEA milestone approach.

4. Results for the comparison of two countries in feasibility study

The best method for carrying out the comparison study is the development of a risk matrix with a traffic light concept. The input to the visual risk matrix (Table 1) is the FS database where the evaluation of importance of each FS topic and subtopics is done and where risks and mitigation measures for each item are collected and managed. In addition, key stakeholders for each topic are listed in the database.

From Table 1, for countries having mature nuclear industry technology such as South Korea [9], [10], there are only a few risks to consider when implementing an N-th nuclear power programme. With many experiences gained through nuclear program implementation, they have developed their technology, project management and human resources skills [11]. On the other hand, emerging countries in the nuclear industry have the opposite situation including several challenges.

Summary Sheet (Table 1) has also driven us to highlight different viewpoints as below:

1. The electric system analysis

South Korea : How to well-control electricity demand and supply being connected to price.

Uganda : How to overcome the absolute electricity shortage soon.

2. The market analysis

South Korea : How to increase energy security and green energy percentage.

Uganda : How to establish the sustainable base load energy resource.

3. The economic viability analysis

South Korea : How to promote productivity and efficiency with the best energy mix.

Uganda : How to build up the nuclear infrastructure with optimum and best investment.

4. The national development plan, economic

South Korea : How to increase national wealth with NPP export expansion.

Uganda : How to make a quantum jump in national industry through NPP.

How to complete nuclear technology self-reliance.

TABLE 1. Comparison of main factors, risks and communication stakeholders.

South Korea		Factors		Uganda		
Risk	Stakeholder			Risk	Stakeholder	
Energy Policy Change	Government	●	Electrical system analysis	●		
		●	Unit capacity and system integration	●		
		●	Site and supporting facilities	●	Improper site selection	Government
		●	NPP technology and fuel cycles	●		
		●	Environmental impact of the project	●		
Delays in reviewing	Regulator	●	National participation	●		
		●	Licensing and authorization	●		
		●	Economic analysis	●	Cost estimation difficulty	Government
		●	Emergency preparedness and response	●		
		●	Applicable laws, codes and guidelines	●	Absence of applicable laws	Regulators
Public acceptance	Public	●	Decommissioning	●		
		●	Stakeholder communication for transparency	●	Multi-stakeholder involvement	Government
		●	Project implementation approach	●	Inadequate experience	Government Vendors
		●	Funding and financing	●	Big reliance on foreign fund	Government
		●	Organization, human resources and training	●	Inadequate knowledge, experience	Government Vendors

Legend: ● low risk, ● medium risk, ● high risk

The high risks in South Korea are energy policy change coming from alteration of political party, licensing delay and public acceptance. To minimize political risks, it is needed to make a decision, not on governmental level, but on the level of congress or parliament. For the public acceptance, continuous efforts are necessary to change public perception about nuclear safety with promoting advantages of nuclear and good practices on radioactive waste management [12], [5].

The high risks for Uganda include the lack of applicable laws, codes and guidelines. The appropriate development of a regulator is essential for preparing guidance documents in Uganda. The funding and financing is a great challenge (red) for Uganda. One of the recommendations would be the government to get involved and support in identifying the project financing means.

This brief analysis leads us to a good conclusion. This tool can be effectively developed for other countries through mutual support through an international forum. The paragraphs below are for explaining the general idea and modalities required for the proposed forum.

5. International Feasibility Study Forum

In light of the above, a critical prerequisite for the success of the Harmony programme has been identified in this NNI project. As demonstrated by Uganda's case, developing countries now experience an imminent need for base-load electricity supply in order to facilitate future growth and industrial development. Nuclear power may accomplish this target, while being environmentally friendly.

In order to successfully establish nuclear programmes in developing countries, knowledge sharing and assistance are required. In particular, in the area of Feasibility Study, which is really the cornerstone of any new nuclear project. This support can be effectively done by establishing an International Forum under the umbrella of already existing international nuclear organizations such as

IAEA, World Nuclear Association and OECD Nuclear Energy Agency covering the following main activities listed below:

- Platform for member countries.
- Supporting countries in key aspects of FS such as identification of risk and its mitigation, and effective communication with all the stakeholders by the use of the tools developed before.
- Sharing of lessons learned.
- Professional training.
- Create and maintain sustainable FS network of multicultural expert teams with highly knowledgeable professionals from nuclear industries including fellows from WNU, employees deputed from member' countries and young students.

6. Conclusion

The Feasibility Study is an important tool for communication, risk management and mitigation of undertaking a nuclear power project and for facilitating the implementation of the harmony programme. Due to the increasing demand for electricity, energy security and the need to reduce on greenhouse emissions among others, a number of countries are embarking on nuclear power programmes while others are considering expanding their nuclear industry. However, the nuclear power programme being a complex business, adequate care must be taken to ensure that the risks that might significantly impact the project causing delays, increasing the cost, causing rejection of the programme, among others should be considered. In this study, a diagnostic approach has been proposed to avoid project delays, reduce on the project time and to provide timely feedback to the respective stakeholders. This is to ensure that the project is implemented within time schedule and for the 25% share of nuclear in the energy mix to be realized by 2050. A forum for providing technical advice on Feasibility Studies and sharing of information has been proposed in this study. Despite our efforts to ensure that project delays are mitigated, more attention is needed by countries to ensure optimization of resources during project implementation and that the right decisions are made by the relevant stakeholders.

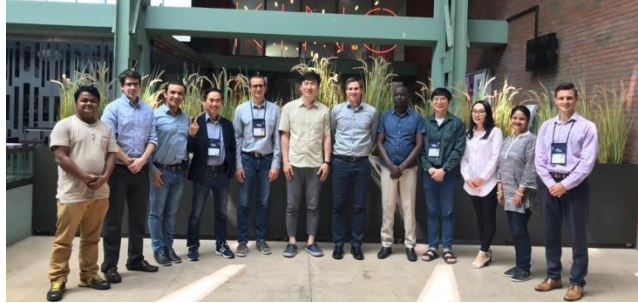
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POWERING THE WORLD BY 2040 – AN UNTAPPED MARKET FOR A CUSTOMER-DRIVEN ENERGY SOLUTION USING SMALL MODULAR REACTORS

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Abstract

The United Nations “Sustainable Development Goals” set ambitious targets to improve standards of living and protect the environment in all countries, but especially so in developing non-OECD (Organization for Economic Co-operation and Development) countries where the demand for electricity is expected to double by 2040. Many of these sustainability goals can be effectively achieved through an affordable, reliable, and readily deployable energy solution. In this study, we propose an energy solution that specifically targets the customer needs in the non-OECD countries using a Small Modular Reactor (SMR) design and an innovative delivery model to minimize risk of deployment.

The specific customer needs can be met through proposed functional requirements for the SMR, with detailed technical requirements to be defined through a follow up technology verification process. This study proposes a business model of “energy-as-a-service”, to make the nuclear case competitive. Licensing strategy is also presented for this business model. Finally, a case study based on the Philippines current energy needs is presented, showing how such an energy solution can apply.

1. Introduction

United Nations studies on demographics and economic growth predict large population increases in many developing countries by 2050, with the global population reaching 9-10 billion. At the same time, rapid economic growth and industrialization is predicted to raise standards of living and per capita energy consumption, especially electricity with consumption expected to double by 2050 [1]. This poses urgent development challenges of electricity demand, water supply, fuel poverty levels, and pollution.

A snapshot of today shows approximately 1 billion people who currently have limited or no access to electricity, and 2.7 billion without access to “clean cooking” facilities with dramatic health consequences [2]. As of 2017, three out of ten people did not have a safely managed drinking water supply [3]. Fuel poverty remains an issue in every country including OECD economies where for example approximately 15% of households in France struggle with fuel affordability [4]. In addition to long-term climate change concerns driven by greenhouse gases emissions, it is estimated that 2.9 million premature deaths per year are due to air pollution and emissions are likely to keep increasing without significant efforts. These issues are at the core of the United Nations Sustainable Development Goals (UN SDG) and are especially of concern for non-OECD countries.

Solutions to date have focused on advanced economies providing aid or proposing designs that are based on already developed infrastructure and local knowledge rather than customer needs.

Focusing on the customer side, the fulfillment of these needs requires *energy, provided affordably, reliably, when and where needed*. We believe that the choice of energy source is technology-neutral and primarily driven by the above factors. “Affordability” from the point-of-view of the customer translates to minimal need for highly specialized personnel (associated training, wages, etc.), light infrastructure requirements (little or no need for grid improvements, roads, etc.), and price of energy. “When and where needed” translates as quick deployment of energy production capabilities in a scalable fashion, at the required location (including remote areas). “Reliability” translates as a high capacity factor of the energy production facility approaching 100% thus eliminating economic losses due to brownouts.

In remote areas and many non-OECD countries, these needs are only partially fulfilled by diesel generators, intermittent renewables, and biomass. The purpose of this work is to prepare a solution that far exceeds these competing options and opens up a whole new untapped energy market by using existing SMR designs harnessing nuclear energy. In the following sections, we develop an applicable business model, contracting, and licensing framework. We then provide technical boundary conditions for a Small Modular Reactor (SMR) to fit these customer needs. Finally, a market case-study of the Philippines is presented as a potential ideal early customer of this energy solution.

2. Requirements

2.1. Potential market

There is a potential market of thousands of islands, arctic, or mountain communities disconnected from large grids. In addition, there are numerous mine sites or factories, remote communities, desalination plants and other high energy intensive needs, as well as temporarily occupied facilities such as research stations that also would be prime markets for reliable, cheap energy. In remote areas and many non-OECD countries, these needs are only partially fulfilled by diesel generators, intermittent renewables, and biomass. The purpose of this work is to prepare a solution that far exceeds these competing options and opens up a whole new untapped energy market by using existing SMR designs harnessing nuclear energy. In the following sections, we develop an applicable business model, contracting, and licensing framework. We then provide technical boundary conditions for a Small Modular Reactor (SMR) to fit these customer needs. Finally, a market case-study of the Philippines is presented as a potential ideal early customer of this energy solution.

2.2. Market competition

Table 1 identifies the competing electricity sources in remote areas. The primary competitor is small diesel generators and oil power plants up to approximately 2 MW where fuel is either shipped in or flown in. Based on anonymized estimates of comparable SMR technologies [5], a target actual delivery price of less than 60 \$/MWh is believed to be achievable with a solid delivery model. This allows significant room for profit margin up to 20% compared to the Levelized Cost of Electricity (LCOE) of diesel generators at 240 \$/MWh. The high reliability of an SMR is the principal advantage over Solar or Wind options, but advantages also include even lower costs for maintenance and construction.

TABLE 1. Technical and economic characteristics of classical energy solutions compared to the proposed solution.

Requirement	Indicator	Diesel generators	Solar PV/Wind	Traditional nuclear	Our SMR solution
Affordable	Price (\$/kW installed)	500	1500	10000	-
	LCOE [6] (\$/MWh)	240	250	145	< 60
Reliable	Capacity factor (%)	≈ 100	10-30	≈ 82 [7]	≈ 100
Low-infrastructure	Grid requirement	No	No	Yes	No
Quick deployment	Mean delivery time	1 month	months	5-20	1 month
Scalable	Mean size of a unit (MWe)	≈ 0.2	≈ 0.1	≈ 1000	0.1 - 10

2.3. Commercial model

Given the requirement for rapid deployment in countries with potentially no nuclear experience, it is necessary to build a new commercial model differing from the traditional one where nuclear reactors were delivered along with multi-year training schemes for local regulators and operators/employees.

We propose an innovative approach similar to the strategy used by some of the most successful IT (Information Technology) innovators. For this SMR strategy, the service provider warrants the delivery of energy and offers the customer a simple cost structure paying for use of the product as a service. In this approach, the customer only pays for the energy actually delivered – “energy-as-a-service” – but does not own or operate the infrastructure. Regulatory considerations are also handled by the energy provider company operating the reactor rather than by the customer. Such an approach limits the need for costly training of the local operators/employees and regulators. This model is based on the well-established contracting strategy of Build, Own, and Operate (BOO) by which the liability fully lies with the energy provider.

Regarding nuclear security and safeguards, the reactor and its fuel remain the property of the energy provider company. Remotely monitored devices prevent tampering and immediately send alerts if disrupted. This potentially eliminates the need for any nuclear waste management framework in the host country. However, some regulatory challenges are to be expected and will be discussed below.

2.4. Technical requirements

Considering the demands for an affordable, quickly deployable and scalable energy production system, which can be deployed in locations with limited infrastructure, we derive the following minimal technical boundary requirements for our product:

- A low power per unit allows for small-sized units with inherent cooling and safety features, which can thus be quickly deployed and moved across the world, without grid requirements or expensive site-preparation.
- A small footprint of the unit allows for modularity by deploying multiple units to a single site to quickly increase the amount of power delivered.

- The energy supplied can be either electricity, or heat that can be used in a local desalination plant, district heating, process heat, etc.

There are currently a range of existing SMR designs, such as the SAFE reactor design by NASA [8], the eVinci reactor designed by Westinghouse [9] or the MMR™ reactor by Ultra Safe Nuclear Corporation [10]. These reactors share various common features, such as the use of heat pipes to remove the core power (hence minimal moving parts and maintenance), long-lived cores and inherently-safe cores with passive decay heat removal systems. The small size of the core makes it much simpler to passively remove the core decay heat compared to conventional nuclear power plants.

2.5. Regulatory strategy

The main regulatory challenge is the potential for unique country-specific regulatory requirements to obtain a license for site preparation, construction and operation of the SMR. The existing legal regime in some countries requires nuclear waste to be disposed of in the country of operation. An exception to this rule will need to be sought long term before SMR end of life to take advantage of central waste disposal facilities and expertise. There are strong existing precedents for this type of agreement such as the Russian agreement with Turkey and Iran to return all spent fuel to Russia for disposal.

Licensing will be addressed on a country-specific basis with a graded approach using Canada's SMR licensing roadmap as a model [11]. Once the regulatory precedent for SMRs is established, it is expected that specific SMR exceptions will apply due to the "inherently safe" designs and due to the size and design representing a much lower risk compared to conventional power reactors. It is expected that by first licensing the SMR design in a country with a strong regulatory regime will make subsequent licensing around the world much more straightforward, where only residual gaps are addressed.

The key to the licensing strategy is the technology validation of the inherently safe design through features such as passive cooling, containment of radiation and passive safety systems. This also includes the emergency planning for accident scenarios and the emergency planning zone to be reduced to the footprint of the facility. From an economic perspective, spent fuel should be shipped back to the country of origin. However, should that not be acceptable due to political or regulatory requirements, a spent fuel interim storage would be built locally after the end of reactor life.

3. Country case study: Philippines

The following is a worked example of how this energy solution would work for the Philippines as an ideal early adopter of the SMRs.

3.1. Country profile and market

The Philippines is an archipelago made up of 7,641 islands in Southeast Asia, and a total population of 101 million growing annually by 1.72%. It has the region's third largest economy with a GDP of \$305 billion in 2016 [12]. The energy demand is forecasted to grow from 33.1 MTOE in 2016 to 91.0 MTOE by the year 2040. A steady increase in energy exports show that the current indigenous energy production has been unable to meet increasing energy demands [13]. In light of this, the Philippines' Department of Energy has incorporated the creation of a nuclear power programme in the Philippine Energy Plan 2017 – 2040 although there is yet to be a definite national position with respect to nuclear power. There is also a plan for increased installed capacity for renewables to at least 20 GW by the year 2040 [13]. Moreover, 8.5 million Filipinos have no access to clean drinking water [14].

The Philippines has three main energy grids for each of the three island groups in Luzon, Visayas and Mindanao and in 2016, had a total capacity of 20 GW. Several islands have small independent grids which supply electricity primarily generated using diesel and oil. The total installed capacity for these grids is 316 MW [15]. These micro-grids tend to be unstable and have inadequate generation capacity thus making scheduled and unplanned blackouts common occurrences.

Furthermore, an estimated 800,000 households are without electricity. The total off-grid demand amounted to 209.9 MW in 2015.

As an example, Siquijor is an island province in the Visayas islands group with a total of approximately 17,500 households composed of 96,000 people (2015 census) on an area of roughly 340 km² [16]. Approximately 25% of these households have no access to electricity, while the remaining 75% have access largely to 14 MW of unreliable and expensive imported diesel-based electricity. Even with recent capacity increases, Siquijor cannot meet current and forecasted energy demands beyond 2040. To compensate in the short-term, the local supplier rents diesel modular generator sets but there remains an immediate need for an upgrade to the distribution system and a medium-term need for grid modernization [12]

3.2. How can SMR provide a solution

Small island grids in the Philippines powered by SMRs in the MW range can reduce the dependence on expensive imported fossil fuel generation while maintaining the availability of power and grid reliability;

- A total of 3 nuclear reactors with a capacity of 5 MWe are needed to fully displace diesel generators powering an island such as Siquijor. By 2040, with the island projected to need a total capacity of 190 MW, a total of 38 such nuclear reactors will need to be deployed;
- For the whole Philippines, the expected off-grid capacity by the year 2040 is about 2 GW which will entail the deployment of 400 nuclear reactors of 5 MWe capacity;
- The Philippines also has a clean water demand of approximately 0.5 billion m³, which the projected nuclear reactor units could help provide through desalination.

4. Conclusion

The current approach for conventional large nuclear power plants is not adapted to customer requirements in emerging markets, where the largest increases in electricity demand will take place by 2040. If nuclear energy is to power the lives of a significant fraction of the world population, it is necessary to change its paradigm. People are looking for cheap energy, delivered to them in a quick and reliable way. We propose a unique energy solution that addresses these needs by offering “energy-as-a-service” to remote customers in the shape of an easily transportable, very-small scale modular nuclear reactor. Various reactor designs, which may fulfill the associated technical requirements are currently available on the market. The combination of a high demand and a low energy output per unit will allow mass production of the reactors and thus a significant “economy of numbers”.

This product could revolutionize the energy market with thousands of potential customers around the world, both in emerging economies (remote islands, rural communities without access to the grid) and in developed countries (remote mines, industrial sites). A preliminary study indicates that in the Philippines alone, the market for small-scale off-grid electricity could be around 2 GW, which would translate to 400 to 2000 reactor units.

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STUDY OF “4 HARMONIZATION PROGRAMME” FOR ACHIEVING INTERNATIONAL COOPERATION IN GENERATION IV REACTORS

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Abstract

According to International Atomic Energy Agency (IAEA), an accessible, affordable, and sustainable energy source is fundamental to the development of modern society. Current scenarios predict a global demand for primary energy 1.5-3 times higher in 2050 as compared to today, and a 200% relative increase in the demand for electricity. The harmony program aims for at least 25% of world energy to be produced by nuclear to reduce the carbon footprint impact on the environment.

Generation IV International Forum (GIF) is seeking to develop more economical, sustainable and safe nuclear reactors, from their fuel cycles to decommissioning and waste treatment, and thus meet the world's energy needs. Research on the fourth-generation reactors is therefore needed for the realization of this programme. GIF proposed 6 reactor types as the future nuclear technologies which have clear advantages and technological advancements compared to reactors in use today, along with meeting the goals listed in this paper. There are breakthrough possibilities in the development of new generation nuclear reactors, where the life-time of the nuclear waste can be reduced to some hundreds of years instead of the present time-scales of a hundred thousand years.

The International Atomic Energy Agency has initiated an International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) in the year 2000. The main objective of INPRO is to help the world community to ensure that clean and safe nuclear energy is available to contribute in fulfilling the energy needs in the 21st century in a sustainable manner.

This paper analyses the technology, results, applications, and limitations of the GIF nuclear reactors. Also, review the use of nuclear energy for nonelectric applications especially in areas such as seawater desalination, hydrogen production, district heating and other industrial applications.

1. Introduction

With an ever-growing population of the earth and the aspiration of 10 billion people to better living conditions, there is no doubt today that demand for energy will continue to grow. However, a continuation of the current energy mix will be detrimental to the environment, and in particular to the global warming of our atmosphere. Demand for a safe, clean and efficient energy supply will therefore increase during this time too. Today, more than 400 nuclear power plants are in operation worldwide. They provide a large share of the Carbon Dioxide (CO₂)-free power supply. To continue to capitalize this advantage, new nuclear energy systems will be needed in the future.

Many nations, both emerging and industrial, therefore believe that increased use of nuclear energy will be needed to secure clean energy supplies. That's why they have teamed up for a Generation IV research and development programme to meet this challenge. Generation IV covers

the entire system of nuclear energy, from extraction to disposal, including nuclear reactors and the nuclear fuel cycle. This work will focus on the six reactor systems selected from more than 130 concepts under the Generation IV programme and how to address the technology in order to know its availability at Industrial Level. The work will show whether the systems still meet today's requirements and why they lag behind the 2000 timetable. Section 2 of this study speaks about the history and the current status of the Gen-IV technology and the nuclear reactor types that were proposed at the beginning of 2000. Section 3 contains the goals of the technology and the areas that were categorized.

An evaluation assessment is reflected in section 4, in order to know which technology is more suitable at the industry level from the proposed technology that was described. Within section 5 can be found the proposal of this study in order to achieve the international harmonization level and enhance the cooperation between existing organizations to achieve the commercialization of Gen-IV technology.

2. Background

2.1. History

The Generation IV research and development programme is an initiative launched in 2000. The goal is to advance research on nuclear energy systems that are needed after 2030 and that differ significantly from Generation III systems. The Generation IV International Forum (GIF) was established to develop and implement the program [1].

Figure 1 contains the latest information on a status of GIF system arrangements and memoranda of understanding the system development timelines as defined in the original roadmap in 2002 and in the 2013 update.

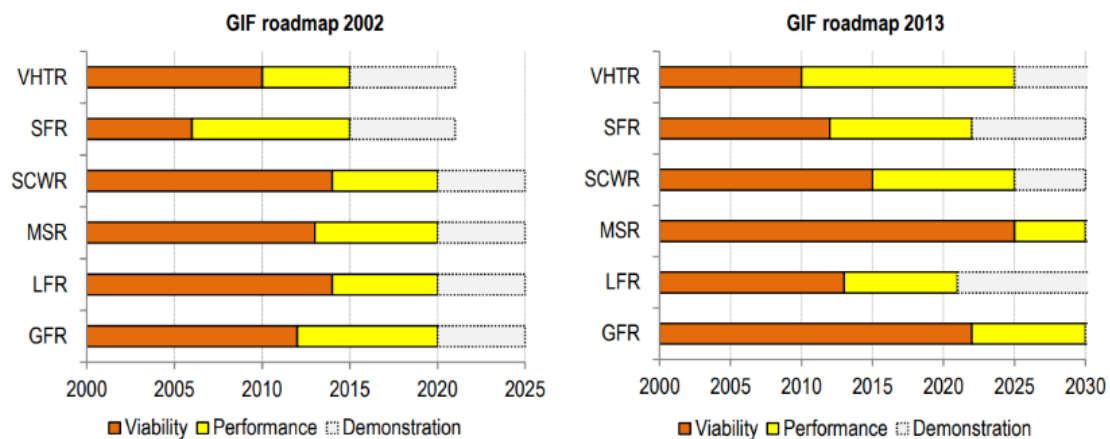


FIG. 1. System development timelines as defined in the original roadmap in 2002 and in the 2013 update.

The GIF formulated the development goals with 8 criteria, with several levels of sub-goals [2]. With these development goals, a worldwide survey was launched, in which more than 100 reactor concepts were submitted. Out of these, 6 systems were selected for follow-up: Gas-Cooled Fast Reactor (GFR), Lead-cooled Fast Reactor (LFR), Molten Salt Reactor (MSR), Sodium-cooled Fast Reactor (SFR), Supercritical-Water-Cooled Reactor (SCWR) and Very-High-Temperature Reactor (VHTR). The Technology Roadmap Update in 2013 has confirmed the choice of these six systems [3].

2.2. Current social-economic situation and environment

The ambitious technical goals of the Gen. IV programme can be divided into the following four policy objectives: (1) sustainability, (2) efficiency, (3) safety and reliability, (4) Proliferation barriers and physical self-protection.

On the basis of these political objectives, it is also easier to assess whether the provisions of the year 2000 are still up to date. Sustainability is generally a bigger issue than it was in 2000, especially for the topics of final disposal and fuel cycle. The energy market is more competitive than ever; with the development of renewable energies and state intervention, it is more important than ever to be able to offer energy at competitive prices. Safety continues to be a big issue at Nuclear Power Plants (NPPs).

The importance of reliability has greatly increased as a result of the expansion of renewable energies (wind / solar) and their unreliable feed-in and has also become more important from an economic point of view. At a time when global political turmoil and the threat of terrorism are on the rise, these goals are more relevant than ever. The targets set in 2000 are still applicable today, and some of them even meet the needs better than foreseen in 2000.

3. Goals of Generation IV

Eight technology goals have been defined for Generation IV systems in four broad areas which are sustainability, economics, safety and reliability, and proliferation resistance and physical protection.

These ambitious goals are shared by a large number of countries as they aim at responding to the economic, environmental, and social requirements of the 21st century. Table 1 lists the generation goals of Generation IV.

TABLE 1. Generation IV goals.

Goals for Generation IV nuclear energy systems	
Sustainability-1	Generation IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and provides long-term availability of systems and effective fuel utilization for worldwide energy production.
Sustainability-2	Generation IV nuclear energy systems will minimize and manage their nuclear waste and notably reduce the long-term stewardship burden, thereby improving protection for the public health and the environment.
Economics-1	Generation IV nuclear energy systems will have a clear lifecycle cost advantage over other energy sources.
Economics-2	Generation IV nuclear energy systems will have a level of financial risk comparable to other energy projects.
Safety and Reliability-1	Generation IV nuclear energy systems operations will excel in safety and reliability.
Safety and Reliability-2	Generation IV nuclear energy systems will have a very low likelihood and degree of reactor core damage.
Safety and Reliability-3	Generation IV nuclear energy systems will eliminate the need for offsite emergency response.
Proliferation Resistance and Physical Protection	Generation IV nuclear energy systems will increase the assurance that they are very unattractive and the least desirable route for diversion or theft of weapons usable materials, and provide increased physical protection against acts of terrorism.

4. Evaluation assessment

After some two years' deliberation and review of about one hundred concepts, late in 2002 GIF announced the selection of six reactor technologies which they believe represent the future shape of nuclear energy. These were selected on the basis of being clean, safe and cost-effective technology, which means of meeting increased energy demands on a sustainable basis, while being resistant to diversion of materials for weapons proliferation and secure from terrorist attacks.

In addition to selecting these six concepts for deployment between 2010 and 2030, GIF recognized a number of International Near-Term Deployment advanced reactors available before 2015.

Tables 2 and 3 contain the specifications and fuel cycles of those six reactor technologies.

TABLE 2. Specifications of 6 Gen-IV reactor technologies [4].

Type	Neutron spectrum	Coolant	Temperature (°C)	Pressure	Size (MWe)	Use
Gas-cooled fast reactors	fast	helium	850	high	1200	electricity & hydrogen
Lead-cooled fast reactors	fast	lead or Pb-Bi	480-570	low	20-180 300-1200 600-1000	electricity & hydrogen
Molten salt fast reactors	fast	fluoride salts	700-800	low	1000	electricity & hydrogen
Molten salt reactor - advanced high-temperature reactors	thermal	fluoride salts	750-1000		1000-1500	hydrogen
Sodium-cooled fast reactors	fast	sodium	500-550	low	50-150 600-1500	electricity
Supercritical water-cooled reactors	thermal or fast	water	510-625	very high	300-700 1000-1500	electricity
Very high temperature gas reactors	thermal	helium	900-1000	high	250-300	hydrogen & electricity

TABLE 3. Fuel cycle of 6 Gen-IV reactor technologies.

Type	Fuel Cycle	Fuel
Gas-cooled fast reactors	Closed, on site	U-238+
Lead-cooled fast reactors	Closed, regional	U-238+
Molten salt fast reactors	Closed	UF in salt
Molten salt reactor - advanced high-temperature reactors	Open	UO ₂ Particles in prism
Sodium-cooled fast reactors	Closed	U-238 & MOX
Supercritical water-cooled reactors	Open (Thermal) / Closed (Fast)	UO ₂
Very high temperature gas reactors	Open	UO ₂ prism or pebbles

+: with some U-235 or Pu-239

For the evaluation assessment of the current status of the proposed technology; the following aspects are forecast regarding the research conducted, with technical, safety and non-proliferation considerations taken into account.

Though demonstration of those six concepts are planned to start from 2015 or 2020, those technical roadmaps were updated in 2013 to reflect the latest status of development and difficulty. Current technical situation of Gen IV is shown in Table 4. MSR and GFR are in the validity phase; validation of basic concepts and solving basic technical issues. The other four types are in the performance phase; evaluation of processes, phenomena, material and components in engineering scale or prototype scale. Especially, SFR and HTR (lower temperature than VHTR) type technologies are much more developed than others because of the experiences of construction and operation of reactors. There is no type which is reached in demonstration phase; detail design of system, License acquisition, construction and operation of reactors for implementation reactors which are industrial level.

TABLE 4. Technical situation of Gen IV reactors.

Type	Status & Challenges	Construction & Operation
MSR	<ul style="list-style-type: none"> • Baseline concepts: MSFR, AHTR • No system arrangements have been signed • Main R&Ds: liquid salt physical chemistry and technology 	-
GFR	<ul style="list-style-type: none"> • The finalization of the design of a small experimental reactor • The decision on launching the licensing process for the experimental reactor. 	-

SCWR	<ul style="list-style-type: none"> Start of design studies for a prototype Main R&Ds: Component tests, Qualification of computational tools and candidate materials, and Out-of-pile & in-pile tests for fuel assembly 	-
VHTR*	<ul style="list-style-type: none"> The construction and operation of HTR-PM Main R&Ds: Main Thermal hydraulic safety experiments, Qualification of UCO-TRISO fuel, new grades of graphite for VHTR use, and Ni alloys for high temperatures 	(HTR) Peach Bottom 1, Fort St Vrain, THTR, HTTR, HTR-10, HTR-PM600
SFR	<ul style="list-style-type: none"> Constriction of demonstration reactors Main R&Ds: Enhanced safety, advanced fuel development, used fuel handling, and economic evaluation, etc. 	BN-600, BN-800, CEFR, PFBR, Phenix, SPX, EBR-II, Fermi, Monjy Joyo
LFR*	<ul style="list-style-type: none"> Lead-cooled experimental reactor starts in 2020 Preparing for higher-temperature designs Main R&Ds: materials corrosion, a lead chemistry management, and fuel development 	(Pb-Bi cooled) experimental reactor, submarine reactors,

* Not only to generate electricity, but also another potential of the reactors is investigated (i.e. generating hydrogen, industrial utilization of thermal, desalination of seawater) [3], [5].

Table 5 contains the safety features assessment for the six types of reactors of Generation IV. From the safety aspects in the table, it could be listed that the VHTR has clear inherent safety features, with no possibility of an off-site emergency. There are already several prototype projects in the world.

Although the SFR has some risk of positive reactivity insertion, it has enough safety margins. Besides, SFR has the prototype project and in China and Russia. SCWR has mature technology accumulation, which makes it easier during R&D, and the engineering safety features are proven.

LFR is a similar concept to the SFR, which will be some of reference. What's more, Lead has much better physical and chemical characteristics than Sodium, which means the LFR could have better safety features. The MSR and GFR has very good safety concept but has no any engineering experience, both of their safety needs to be proved in the future.

TABLE 5. Safety features assessment [6], [7], [8].

TYPE	Inherent features	Passive systems and Emergency
VHTR	<ol style="list-style-type: none"> 1. Elimination of core melt and radioactivity release 2. Plutonium breeding and minor actinide burning 	<ol style="list-style-type: none"> 1. Passive and inherent design features 2. Passive decay heat removal 3. Unnecessary off-site Emergency 4. Prototype project
GFR	<ol style="list-style-type: none"> 1. Lack of accident analysis 2. Fuel breeding and/or actinide management 	<ol style="list-style-type: none"> 1. Fully passively safe GFRs are possible 2. Lack of engineering experience
SFR	<ol style="list-style-type: none"> 1. Reducing the radiotoxicity and actinide management 2. Operation in normal pressure with significant safety margins 3. Positive reactivity insertion might result in core damage 	<ol style="list-style-type: none"> 1. Passive shutdown mechanism under R&D 2. Prototype project
LFR	<ol style="list-style-type: none"> 1. High thermal inertia and negative reactivity feedback of lead systems 2. No loss of primary coolant 3. Low chemical activity of Lead 4. Full actinide recycling 	<ol style="list-style-type: none"> 1. Strong natural circulation characteristics 2. Passive decay heat removal systems 3. Reducing the requirements for off-site emergency
MSR	<ol style="list-style-type: none"> 1. Negative temperature and void feedback coefficients 2. The absence of in-core reactivity reserve 3. Minimization of radiotoxic nuclear waste 	<ol style="list-style-type: none"> 1. A maximum of passive devices to cool the fuel 2. Passive draining of the core fuel into passively cooled geometrically noncritical tanks 3. Lack of engineering experience
SCWR	<ol style="list-style-type: none"> 1. Conservative design with high reliability and availability 2. Proven technology and quality assurance 	<ol style="list-style-type: none"> 1. Automatic depressurization system 2. Gravity-driven core flooding system 3. Passive moderator cooling system

Table 6 contains the rank categories in terms of safety that was used to categorize the technology. On the other hand, Table 7 points out the description of the proliferation issues of these technologies.

In fact, it is difficult to predict and compare Gen IV technologies in terms of proliferation risk. Currently, there is already an excellent international mechanism for non-proliferation for all the existing civil nuclear facilities, which definitely will be used for the Gen IV nuclear energy. For the breeding reactors, the risks of proliferation maybe higher during the reprocessing process, but it can be managed well under the current non-proliferation mechanisms.

TABLE 6. The safety rank

RANK	TECHNOLOGY
Demonstration	VHTR, SFR
Performance	SCWR, LFR
Viability	MSR, GFR

TABLE 7. Proliferation issues [3],[7]

TYPE	DESCRIPTION
VHTR	Proliferation resistance
GFR	Risks in proliferation
SFR	Risks in proliferation
LFR	Risks in proliferation
MSR	No approach dedicated to liquid-fuelled reactors
SCWR	Proliferation resistance similar to BWR

At the end of the evaluation assessment, it was found that the VHTR is the most viable technology to apply at the industry level. The evaluation shows that the technology has satisfied the early viability phase in the development project; as the developers have experience in construction and operation for high temperature reactors gained through their research and development programmes. It was learned that each country has a different VHTR concept and design; but at the same time has the additional application of the generation of hydrogen. It could be said that the high temperature is one of the challenges that needs to be studied more, in order to create a more mature technology.

5. Proposal

In order to encourage the development of Gen IV reactors, international collaboration is needed to consolidate the fundamental features of Gen IV design and simplify the process of validation. Based on the above investigation and discussion, NNI-6 group initiated a proposal called “4 Harmony” to achieve the target of harmonization with different international working groups to enhance the level of cooperation.

Many potential initiatives and projects were projected for Gen IV reactors; IAEA conducted the International Programme Innovative Nuclear Reactors Fuel Cycles (INPRO) programme and Generic Reactor Safety Review (GRSR) service; by the other side Organisation for Economic Co-operation and Development/ Nuclear Energy Agency (OECD/NEA) had Multinational Design Evaluation Programme (MDEP) evaluation programme; and World Nuclear Association (WNA) performed the Cooperation in Reactor Design Evaluation and Licensing (CORDEL) workgroup. GIF is an international specific forum that joins information about Generation IV reactors. Different organizations use different systematic languages but at the end, they are working in the development of Gen-IV technology.

A harmonization programme could be a good solution to join the existing organizations that are working in Gen-IV technology for the current development and deployment programs. The 4 Harmony initiative includes 4 levels and Figure 2 contains the main structure of the initiative.



FIG. 2. The 4 Harmony Programme structure.

The first one is Academic Training including neutronics, thermal hydraulics, materials, construction, and operation. It is required more human power who can understand deeply the knowledge and the development of the Gen IV technology. The World Nuclear University Summer Institute can be a good place to gather and spread the seed of knowledge.

The second level is Industrial consultant. An International Cooperation Convention among different consultants should be established to assist and support the design and regulation.

The third level is an international committee consisting of IAEA, NEA, WNA and GIF; they will work together to make a judgment on the limitations of the new design. A new design beyond the existing six concepts can get international recognition. This effort could strengthen the confidence of the industry and encourage more and more companies to invest in the Gen-IV areas.

The long-lasting goal is that one international Gen-IV cooperation agency will emerge to implement the common guideline based on consensus and common values for the design technology.

Figure 3 represents a flow chart process to develop an International Cooperation programme; it proposes the junction and international cooperation between organizations. After the selection of the evaluation assessment, this proposal could be applied to know the availability and capability of the technology at industry level. Harmonization with International Standards is a key point in the development of GIF if it is pursued, it could open a channel for International Standardization and regulation which is an important benefit. INPRO project will judge the capability and sustainability of the fuel cycle process of the design proposal, based also on the criteria of GIF. After this, it

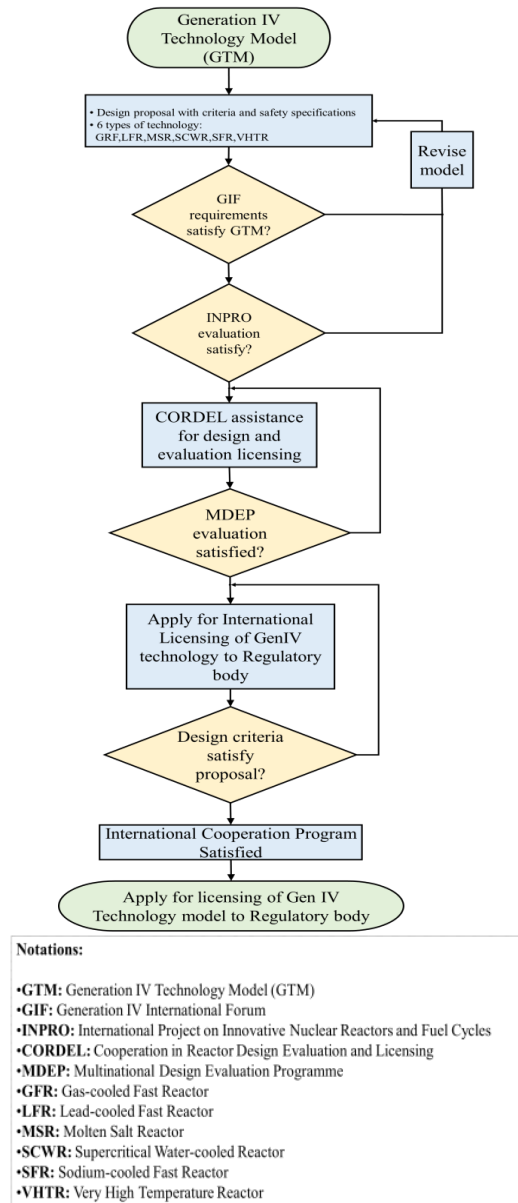


FIG. 3. Development process for international

will pass the results to MDEP. MDEP could be a strategy for proposing international guidelines that could contain the general criteria for design and safety specifications.

MDEP could be a system controller in this process because it could develop innovative approaches to evaluate the resources and knowledge of national regulatory authorities reviewing new reactor designs. At the end, the final information could support the submission documentation to the National Regulatory Authority for License; it that way the reactor model could be commercialized.

6. Conclusion

After reviewing the original proposal of Gen IV and its background, we conclude that Gen IV is not a reactor type, but gives the direction of reactor technology development. Gen IV should meet goals from the aspects of sustainability, economics, safety & reliability, non-proliferation.

Safety and proliferation features of Gen IV are related to the current technical situation. Each type needs to be improved in technological challenges but a deep understanding is needed and supporting evidence before relying on only technical point to build high safety and non-proliferation reactors.

Before the implement of Gen IV NPP, international cooperation is essential on Research, Operation, Regulator, Human resource, etc. It was proposed the "4 Harmony" initiative has the potential to strengthen the connection between existing international organizations and working groups.

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CHANGE. CONNECT. CONVINCED.

Innovative Communication Strategies to Nuclear Waste Management

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Abstract

Although the nuclear industry has demonstrated a safety record for several decades, the management, transport and disposal of radioactive waste is still one of the most controversial aspects of the nuclear fuel cycle today. However, the barrier in nuclear waste management is not a technical one, but rather a matter of communication with stakeholders. Indeed, most current communication strategies are not adapted to their target audience and the intended messages are not properly understood by the majority of the civil society. This NNI report delivers a general overview on waste management options with the purpose of addressing the main questions and prevailing issues among the stakeholders. The report concentrates on providing an innovative communication strategy aimed to shift public perception of nuclear waste management and to increase public trust and acceptance of nuclear energy as a whole. Our message is mainly addressed to decision makers (government) but also to the civil society (public and non-governmental organizations). The objectives of our communication strategy are threefold: share consistent and trustful information, share responsibility and share transparency. Three different audiences were identified as the key decision makers for whom the communication needs to be optimized, including schoolchildren, civil society and nuclear industry employees. Some measures have also been proposed to evaluate the effectiveness of the communication channels when implementing the communication strategy. This project will contribute to shifting public perception of nuclear waste management, therefore increasing public trust and acceptance of nuclear energy.

1. Introduction

Like all industries, the generation of electricity produces waste. Nuclear waste emits radiation and it needs to be managed safely and effectively. With the development of nuclear industry, the quantity of radioactive waste that we need to manage is increasing, but this remains **extremely low** compared to other forms of energy production and to the industry in general. Although the nuclear industry has demonstrated a safety record for several decades, the management and disposal of radioactive waste is still one of the most controversial aspects of the nuclear fuel cycle today [1]. However, the barrier in nuclear waste management is **not technical**, but a matter of **communication with stakeholders**.

This report presents a general overview on waste management options and provides the audience with an innovative communication strategy aimed to **shift public perception** of nuclear waste management and to **increase public trust and acceptance** of nuclear energy as a whole. The report is addressed to decision makers (government) as well as to the civil society (public and NGOs).

2. Nuclear waste management

2.1. What is nuclear waste?

Compared to other energy producers that externalize the costs of their waste on the society and environment, the nuclear industry is the only one that takes **full responsibility for all its waste**. Nuclear waste includes spent (burnt) fuel and operational waste from the nuclear power plants, waste from spent fuel recycling (when performed), waste from dismantling (decommissioning) nuclear installations, waste from nuclear medicine, agriculture, industry and research. Radioactive waste is normally classified as low, intermediate and high levels, according to the amount and types of radioactivity and consequently the demands in managing it [1]. The most difficult type of waste to manage is high-level/long-term waste arising from nuclear power generation. Nevertheless, high-level/long-term waste represents only a **very small fraction** of the total amount of nuclear waste and has been handled, transported, and stored for many decades virtually **without incident**, and certainly without harm to anyone. The cost of managing and disposing all nuclear waste is very small (less than a tenth of the total electricity bill).

2.2. How does nuclear compare to other electricity generation sources?

Compared with fossil energy sources and other renewable sources such as wind, hydro or biomass, nuclear power plants are amongst the **lowest greenhouse gas emitters** over the whole lifecycle. Nuclear energy is **sustainable** and can decisively contribute to fulfilling the goals of sustainable development. Lifecycle emissions of natural gas and coal generation are 15 and 30 times greater than nuclear respectively [2]. In addition, fossil fuel and biomass waste pollution from fine particles alone, not to mention climate change effects driven by CO₂ emissions, are estimated to kill almost 9 million people every year [3], that is a little more than the whole population of Switzerland.

In addition to greenhouse gas emissions, each electricity generation technology produces other types of wastes that need to be managed, such as non-recyclable silicon in solar panels, fiberglass in wind turbines, coal ash from coal power plants etc. Figure 1 compares all solid waste volume with energy generation technology

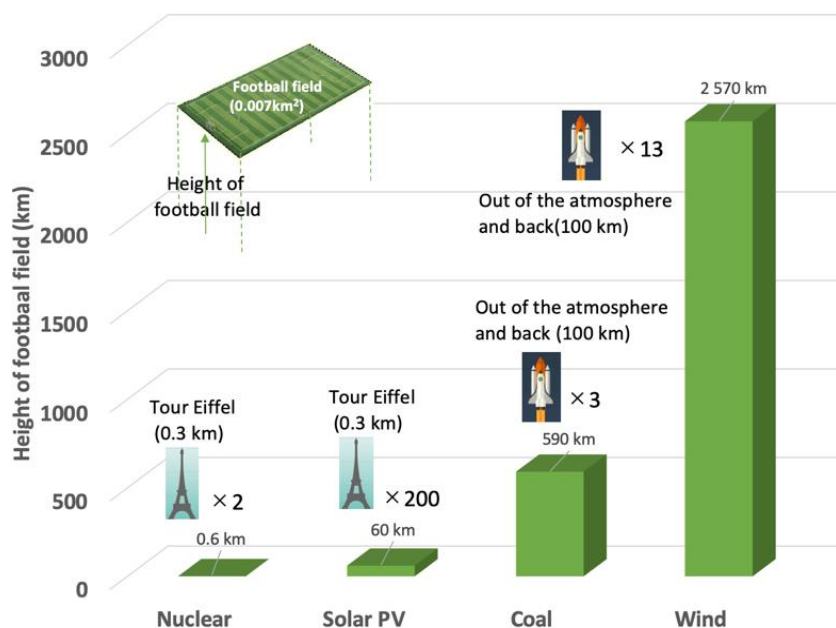


FIG.1. Comparison of cumulative waste volume by energy type in 2050.

[4]¹. The figure shows the cumulative waste volumes that each technology would produce if they generated a tenth of the global electricity demand (~2500 TWh) for the next 30 years till 2050. Solar photovoltaics produces around 100 times more waste volume than nuclear, whereas wind and coal ash volumes are higher by a factor of 1000 compared to nuclear.

2.3. What are the current options in waste management?

Low and intermediate level waste is generated at all stages of the fuel cycle and constitutes the large majority of the total nuclear waste. It has a low radioactive content, making it suitable for disposal in near surface facilities, currently in operation in many countries. To minimize the required space, treatment or conditioning processes such as incineration, compaction and physical transforming are currently used before disposal, reducing waste volume up to a third of the initial one [5].

Temporary storage facilities for the high-level nuclear waste already exist. The spent fuel from reactor can be recycled for recovering the valuable materials from it, or it can be safely stored and finally disposed without reprocessing (Fig. 2). With technology advancing, the spent fuel can actually be used as new fuel in 4th generation reactors, allowing a **substantial increase in sustainability**.

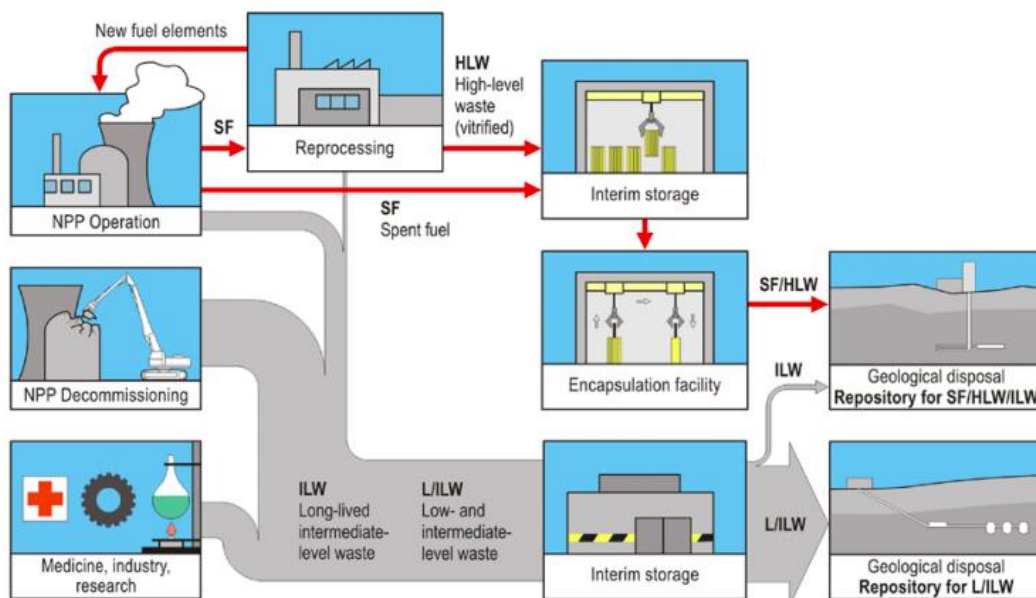


FIG. 2. Current options in radioactive waste management [6].

As an alternative to long-term storage, uranium can be separated from spent fuel by a chemical process, as some countries have already safely demonstrated at an industrial scale for decades. The material recycled in this way is used again as nuclear fuel, recovering even more energy. Another advantage of recycling is the significant reduction in the volume of high-level waste to about one-fifth [7]. Moreover, the level of radioactivity of the waste is decreasing to only a tenth of the initial value [8].

Other technologies for recycling of spent fuel have been demonstrated on a small scale and could be adapted for future types of nuclear fuels if necessary. Transmutation is another option that

¹ Data were compiled from the following sources:

- GHENAI, C., Life Cycle Analysis of Wind Turbine, Ocean and Mechanical Engineering Department, Florida Atlantic University USA
- Radioactive Waste in Perspective, OECD-NEA Report (2010)
- <https://www.wind-watch.org/faq-size.php>
- <https://brightstarsolar.net/common-sizes-of-solar-panels/>
- <https://www.wholesalesolar.com/blog/how-long-do-solar-panels-last/>
- <https://www.solarpowerrocks.com/solar-basics/how-much-electricity-does-a-solar-panel-produce/>
- <https://www.nagra.ch/en/volumesen.htm>

can transform long-lived radioactive elements into significantly shorter-lived elements by burning them using an advanced 4th generation nuclear reactor. The goal is to have waste that becomes radiologically harmless in only a few hundred years, while reducing the footprint of the geological disposal and improving social acceptance [9].

2.4. What about transportation?

The proper transportation of nuclear materials and radioactive wastes is very important for the sustainability of nuclear industry. Transport of radioactive wastes has an **excellent safety record** (more than 44 000 shipments of high-level waste since 1962). No container with highly radioactive material has ever been breached or leaked [10]. As the most exposed part of the nuclear fuel cycle, transport becomes the focus of numerous social protests. The safety of transportation is accomplished by the concept of **defense in depth**: a combination of strict regulatory systems, specialized companies with rich experience, reliable operation procedures, and very solid containers providing mechanical integrity and radiation shielding, even under extreme accident conditions [11].

2.5. How does long-term storage work?

The long-term effects of high-level radioactive wastes make it necessary to ensure the safety of the waste storage facility for several tens of thousands of years. Many options have been investigated, but nowadays the scientific community agrees on the **deep disposal in a geological repository**. This confines long-lived/high-level radioactive waste in stable rock deep under the ground and isolates it from humans and natural environment on the ground [12]. A **multi-barrier system** combining deep underground "natural barriers" (such as rock, salt or clay) with "engineered barriers" consisting of several protective layers (such as steel or concrete) is commonly used [13]. The idea of such multiple barrier systems is shared internationally. Several nations have been working on deep geological repositories, among which Finland, Sweden, France and the United States are the most advanced. In most countries, waste is stored so that it is readily retrievable from repositories.

Any potential site is assessed to ensure safety and suitability in terms of technical, environmental and socio-economic aspects. The site should be able to safely contain and isolate the waste over the very long term, as demonstrated by a series of mechanical and geochemical analyses. In addition, the site should be located in a region where the overall impact on society is acceptable and beneficial effects are enhanced. The communication strategy accompanying the site selection is essential and early stakeholder engagement is key to its success.

2.6. How do we transfer the knowledge to future generations?

Since nuclear projects last many years and involve numerous stakeholders in different phases, there is a constant work of knowledge transfer, in order to guarantee the preservation of what is known [14]. As the greatest number of grid connections of power reactors were in 1984 [15], slowing down until the 21st century, it is of great importance that the experienced professionals continue to transfer to the new generation the accumulated knowledge in order that the industry can maintain its technical excellence, given the undergoing renaissance of the nuclear industry in the last years.

3. Developing an innovative communication strategy

The overall motivation of this report is contributing to **shifting public perception** of nuclear waste management and to increasing **public trust and acceptance** of nuclear energy, since the majority of the public perceives nuclear waste disposal as one of the major problems affecting nuclear industry. A better communication strategy will help defining the target audience and consistently articulating the message, so that all the stakeholders share the same mental model. Understanding the audience allows directing the efforts more precisely, and with the alignment of nuclear industry employees, board and other stakeholders, it will be easier to get the message across [16]. In this sense, Figure 3 shows the step-by-step actions for developing an innovative communication strategy plan for nuclear waste management.

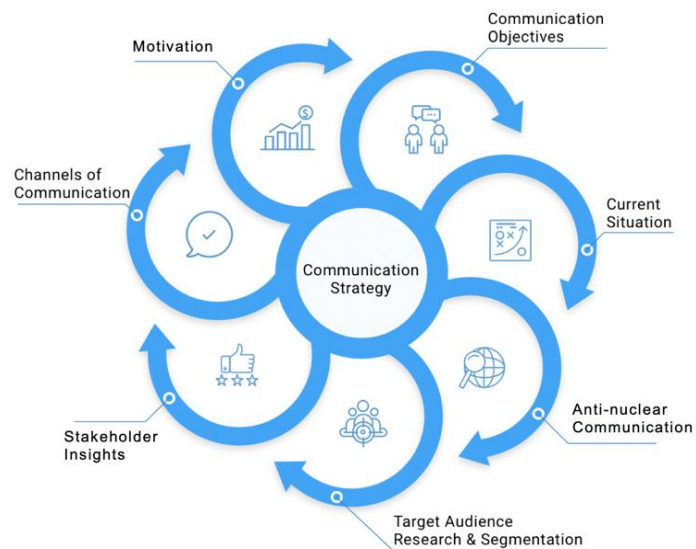


FIG. 3. Communication strategy plan (adapted from [16]).

The public communication can be approached in various ways but the message always needs to be clear and understandable. The people with more knowledge and better understanding of nuclear energy will be more open to accept and support the building of radioactive waste management disposal in their surroundings.

3.1. Communication objectives

The objectives of this communication strategy are to **share consistent and trustful information, share responsibility and transparency**. Sharing information is related to knowledge exchange and knowledge management. Being transparent while sharing the information builds trust and acceptance, and it is vital in the nuclear industry. The trust increases during the time, step-by-step, after a lot of engagement with stakeholders. The other objective is to share the responsibility, in the sense that all stakeholders (civil society and government) must be committed to the waste management issues and be prepared to respond adequately and quickly to the demands of society.

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3.2. Current situation

The current anxiety and objection of public stem mainly from a **lack of confidence** and of a clear vision to the future and of the decision-making process. Most countries have already been operating communication programmes dedicated to waste management. However, these programmes are intended to only provide information via websites, seminars and field tours.

The Nuclear Energy Agency recommends **adequate public participation** in all programme stages [17]. By doing so, the public ensures that they can influence the program and that the outcomes are reflecting their expectations. However, many countries are not fully satisfying with this recommendation and this brings out serious setbacks to the process.

The nuclear industry in general is **not sufficiently active** in sharing with the public its responsibilities and its confidence in the safety of nuclear waste management. At the same time, the public is not intensively involved in the decision-making process to reflect their expectations and concerns related to waste management.

3.3. Anti-nuclear communication

The public perception of the nuclear industry has been shaped by its association to military activities (nuclear weapons tests) and the three high-profile accidents that the industry has experienced (Three Mile Island in 1979, Chernobyl in 1986, and Fukushima in 2011). Less serious incidents resulting in small radioactive releases from operating plants have strengthened these perceptions. The strong activity of **anti-nuclear groups and organizations**, together with audience-driven **media reports** and apocalyptic movies, have exacerbated the sentiment that all “artificial” radiation and nuclear waste are extremely dangerous and have terrifying consequences on human health and the environment.

While these statements can easily be addressed and disproved with fact-based science, it is difficult to change the people’s perception when faced with an anti-nuclear communication strategy focused on **fears and emotions**. Very strong imagery associating nuclear waste with desolate fields devoid of life, movies about the occurrence of horrible genetic mutations and cancers or even acrobatic events aimed at penetrating the sites of nuclear repositories are all part of a unified strategy conveying the message that nuclear waste is not safe. On the other hand, most antinuclear activists **avoid scientific confrontation** and often respond with half-truths or false misconceptions. The typical anti-nuclear rhetoric demands for **absolute guarantees** that a future nuclear incident cannot ever occur, without properly quantifying the consequences of such an event on public health and environment, and putting this into perspective with respect to natural radiation levels and other accepted risks.

4.1. Target audience and communication channels

Three different audiences were identified as the key decision makers for whom the communication needs to be optimized. The first group are **schoolchildren** at the age of 10 to 18. These are future decision makers in the long term, and are the most unbiased group of the population and hence more open minded to receive information. The second group is the **civil society** - the decision makers in the short term and hence a crucial group. The biggest obstacle for this group is that a large majority of them already have a firm opinion on matters, and convincing them with facts that go against their principles is more difficult. The third and final group is the people within the **nuclear industry** itself, i.e. the employees. Although the work force in the nuclear industry has some general ideas on nuclear waste management, the industry itself appears to be complacent on the issue. It is vital that people working in nuclear put the back-end of the nuclear cycle (decommissioning and waste management) on the same pedestal as building new power plants.

In order to identify the communication channels adapted for different audiences, the following formula was used: *Identify audience -> identify key message -> identify reason to believe -> identify the appropriate channel*. The following tables summarize the key communication messages and channels for each target audience.

TABLE 1. Key messages to be addressed to the target audience.

Target Audience	Schoolchildren	Civil society	Nuclear industry employees
Key Messages	Waste is normal: all electricity generation technologies produce waste; Nuclear industry produces the least amount of waste per unit of energy produced		Waste management is as important as new builds.
Engagement	Focus on medium / long term impacts	Focus on short term impacts	Pro-active rather than reactive
Reason to believe	Proven process: nuclear waste has been managed and transported safely for decades. All information and processes regarding waste management are transparent and easy to access and in consultation with the public.		Confidence in the regulatory processes, the safeguards and design, and the entire fuel life cycle management.

TABLE 2. Communication channels and content.

Schoolchildren	Civil society	Nuclear industry employees
Media: Emotion-focused advertisement campaigns highlighting the benefits of nuclear and nuclear waste management. Use all media channels available including written, broadcast, as well as social media. Employ specialized companies with expertise in public communication campaigns.		Incentives for employees to be more engaged in discussions with the public and media through direct contact and social media, in parallel to the official communication channels.
Entertainment: Board games /Video games / Smartphone App - subconsciously giving a more positive image of nuclear.		
Virtual reality tours of geological repositories (because some are not accessible due to distance or regulatory restrictions)		Increased international cooperation within the industry for sharing of best practises between the various countries.
School field trips , school science workshops, summer camps	Technical visits to repositories	Compulsory technical visits to repositories for employees in the industry
Display the waste amounts created by each technology in your generation mix along with the electricity bill - just like a carbon footprint for flying. Provide the option to choose your electricity mix depending on waste generation.		Give more importance to the back-end in the WNU curriculum - lessons about waste management in different countries.
Tools: fitness band with dosimeter showing the real-time radiation in daily life, so that one has a better idea of the exposed doses - such as higher doses while flying, while travelling in Kerala (India) or the Swiss Alps. Visible dosimeters in public places (stations, city centres) showing the background radiation.		
	Hotline - to address fake news or wrong viral information, Call Centre (Q&A)	More technical information for the employees, in the form of lectures about waste management. Simple take-away messages addressing public concerns.
	Public forums with anti-nuclear NGOs to actively address their concerns. Engage open-minded influencing environmentalists to shift their perception from anti-nuclear to pro-nuclear using climate-change based evidence	
Address the idea of confirmation bias - for example through a game - to show how certain mental models influence our decisions, how we are influenced by the media etc.		
Running competition on site of repository – organize events to increase public engagement within the repository sites.		

Among the highlights of the proposed communication strategy, some focus on **sharing information** in a clear and simple way, including familiarizing the public with the background radiation through the use of portable dosimeters on fitness bands, promoting entertaining games or stimulating nuclear industry employees to get more engaged in public discussions. Other channels aim at **sharing responsibility** about the consequences of energy-related waste, such as including the volume of CO₂ produced per type of energy in the electricity bill or running advertisement campaigns on the sustainability of nuclear energy compared to fossil fuels and some renewable energies. Finally, other channels focus on **sharing transparency** through engaging field trips or events centered around waste facilities, virtual reality tours or public discussions with antinuclear NGOs.

When these communication channels are implemented, it is important to evaluate the effectiveness of the communication with the targeted audiences. There are many evaluation tools, such as online surveys, face-to-face surveys, stakeholder interviews, case studies, social media monitoring, etc. Different evaluation methods can be used depending on the type of activity, the stage of implementation, or the resources available for evaluation [18].

4. Conclusion

Lack of confidence in nuclear waste management and negative public perception have been a major concern since the start of use of nuclear energy. The current communication strategies are not well understood by a large portion of the population. This NNI group focused on developing an

innovative communication strategy to shift this negative perception and increase the public trust, targeted for school children, civil society, and nuclear industry employees as the key stakeholders in the decision-making process related to nuclear waste management. A step-by-step communication strategy plan has been proposed to identify and analyse the project objectives, current situation, research on anti-nuclear communication activities, as well as to develop innovative communication channels for the targeted audiences. Some measures have also been proposed to evaluate the effectiveness of the communication channels when implementing the communication strategy.

This project will open the door for effectively communicating nuclear waste management with the public, and thus gaining more trust and support from the public.

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HUMAN RESOURCES DEVELOPMENT FOR FUTURE NUCLEAR POWER PLANTS

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Abstract

The Harmony Programme envisions an increase of 1000 GWe nuclear capacity by 2050. This increase in capacity coupled with advancement in technological innovations in the nuclear power industry provides an opportunity for socio-economic advancement and flexible workforce.

Harmony Resources is a fictional company focused on revolutionizing how the international nuclear power industry approaches human capital development. Harmony Resources achieves this mission leveraging the coordinated regulatory process envisioned by the Harmony Programme and implementing innovative technologies. By analyzing the impacts of future Industry 4.0 (I4.0) technologies on new nuclear power plant staffing demands, Harmony Resources has proposed three products that the nuclear energy industry can implement to succeed in the future. These products include using innovative technologies to expand recruitment of nuclear professionals, a standardized nuclear power-related education system, plant-specific gap training, and a database of globally available, appropriately trained professionals that is accessible to the international nuclear power industry.

This white paper provides a strategy for implementers to prepare the workforce for the new nuclear power industry.

1. Introduction

The Harmony Programme is a global initiative of the nuclear industry that provides a framework for action to provide at least 25% of electricity via nuclear power by 2050 as part of a clean and reliable low-carbon mix [1]. The Programme is a framework for action to help the nuclear industry reach out to key stakeholders to remove barriers for growth by addressing three objectives (Figure 1).



FIG. 1 The three objectives of the Harmony Programme [1].

The nuclear power industry will need to build 1000 GWe of new nuclear capacity by 2050 to meet the Harmony goal, increasing the workforce by one million new nuclear workers [1]. Experts estimate that a lack of well-prepared professionals leads to a substantial annual profit loss for the global economy. Current human resource development is geared towards the past norms of the nuclear power industry, and as a result, will need to adapt to the nuclear power plant of the future. One vision for the nuclear power plant of the future exploits the benefits of I4.0 to reduce costs throughout the nuclear lifecycle [2]. I4.0 blurs the differences between the work of people and the work of machines resulting in improved information management and decision-making [3].

The nuclear power plant of the future will require a highly skilled, mobile workforce. Current licensing and operating schemes at nuclear plants are heavily specialized, even between nuclear plants of similarly designed reactor types. This requires significant re-training of individuals relocating to a different plant. In the United States for example, the Crystal River Nuclear Plant and the Davis Besse Nuclear Plant are both Babcock & Wilcox PWRs. When the Crystal River Nuclear Plant was permanently shut down, a licensed control room operator wanting to use his/her skills at Davis Besse would require years of re-training and license certification at the Davis Besse plant. This process is not only inefficient, but very costly for the operating company (so much so that many United States utilities require contractual obligations to stay with the company for several years after completing licence training or else pay penalties to the company upon leaving). In addition, this process can create significant career setbacks for specially trained individuals since they essentially “start over” if they move between nuclear sites. This risk can decrease interest of future professionals to join the nuclear field, and it also leaves the global nuclear community at a constant risk of losing valuable knowledge and experience.

Harmony Resources believes a revolutionized approach to human capital development is necessary for the future success and relevancy of nuclear power in the energy sector. We aim to redefine the needs and expectations for human capital in the field of nuclear energy by focusing on revolutionizing three key aspects of the current nuclear energy workforce structure.

This approach involves:

- standardizing the nuclear power-related education system and recruitment for nuclear professionals,
- facilitating an internationally mobile nuclear power workforce, and
- providing an international database of available and qualified individuals to aide nuclear energy stakeholders to easily identify the right talent worldwide.

This paper provides a strategy to best position the nuclear industry workforce to meet the Harmony Programme goals by leveraging a future harmonized regulatory process and implementation of I4.0 capabilities.

2. Human resources development for future nuclear power plants

In an I4.0 focused Nuclear Power Plant (NPP), organizational structures will be decentralized and become more flexible. We predict a transition a combination of large scale nuclear plants and small modular reactors, spread over an increased area, but operated and maintained remotely through network systems, with minimal human interface. I4.0 will change the career landscape as workers may be expected to work remotely on systems globally and deploy minimal staff to physical stations [4].

This new approach will require a workforce with a different skill set than traditional nuclear plant workers. Workers will be expected to have basic knowledge in big data, information technology, data analysis, and decision making. Technology adoption causes significant short-term labor displacement, but in the longer run, it creates a multitude of new jobs opportunities and increases demand for existing ones.

Figure 2 depicts the predicted skill transition required for Industry 4.0 [4].

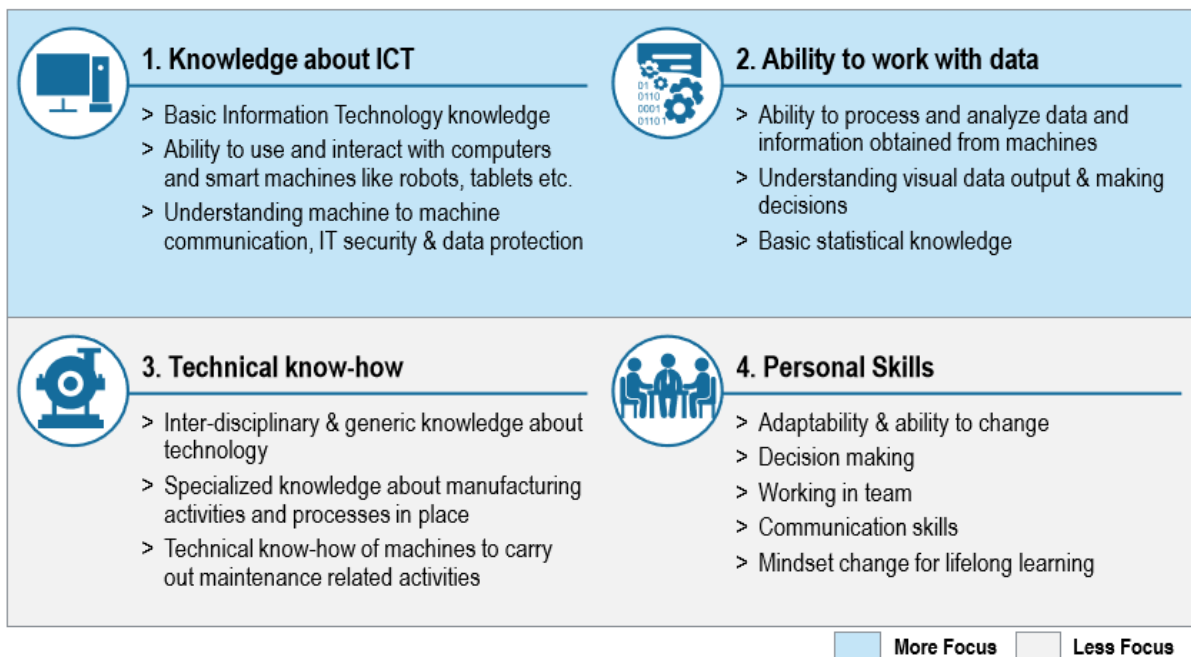


FIG. 2. Predicted skill transition required for Industry 4.0 [4].

Substantial workplace transformations means approximately 15% of the workforce will need to transition to other occupations, as more tasks will become automated. Also with modernization new occupations will be created, trends predict up to 9% by 2030 and up to 15% by 2050 [5]. This extensive transformation represents an opportunity to integrate and prepare the new workforce for critical stages of nuclear design, manufacturing, and construction through a standardized education and training for future and existing workforce.

2.1. Standardized Education System and Recruitment

Today, many countries show a keen interest in nuclear power development while others are exploring creating a national nuclear programme for the first time. It is critical for the nuclear industry to understand how to reach the local communities to expand the talent pool of available nuclear professionals.

Before entering the nuclear business, people must have access to the appropriate level of education and training to perform competently. Since the industry does not have a standardized education system, the traditional recruitment method has been to find suitable personnel after graduation from university. The scope of training required varies by countries and companies. Furthermore, with the integration of innovative technologies in the future NPP, training and education will also be required for the existing professionals to understand this new technology.

Harmony Resources proposes a standardized international education system for the nuclear power industry by utilizing technologies such as artificial intelligence, virtual reality (VR), big data, and cloud computing. Figure 3 shows the schematic of four sub-programmes of the standardized education system. Tier 0 targets kids aged 12 to 15 to raise awareness of nuclear related concepts. Tier 1 targets high school students to develop skilled workers, then Tier 2 targets university students to develop a more tailored curriculum. Tier 3 prepares existing professionals for changing technologies as a result of I4.0.

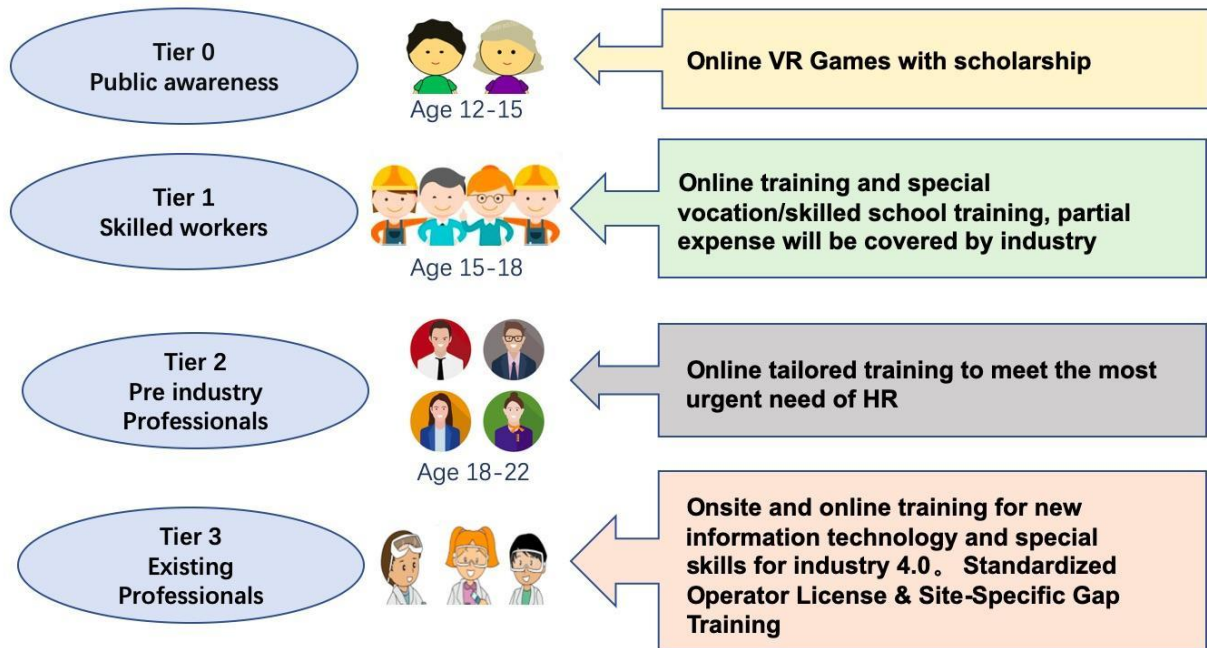


FIG. 3. Schematic of four sub-programmes of the standardized education system.

Harmony Resources believes that with the cooperation of and investment from government, academia, and industry, we could create appropriate programs focused on increasing public awareness of nuclear power as a career. It is crucial to target future talent, as well as existing professionals, by providing more tailored education and training courses to the individual's need to reduce the training time as well as increase the cost efficiency for the readiness of the nuclear project. Figure 4 shows the proposed smart education pipeline of the standardized education system. The Smart Training System uses I4.0 technology to provide a tailored training program to the general public as well as future and current employees who need proper training to be a competent professional for the nuclear industry.

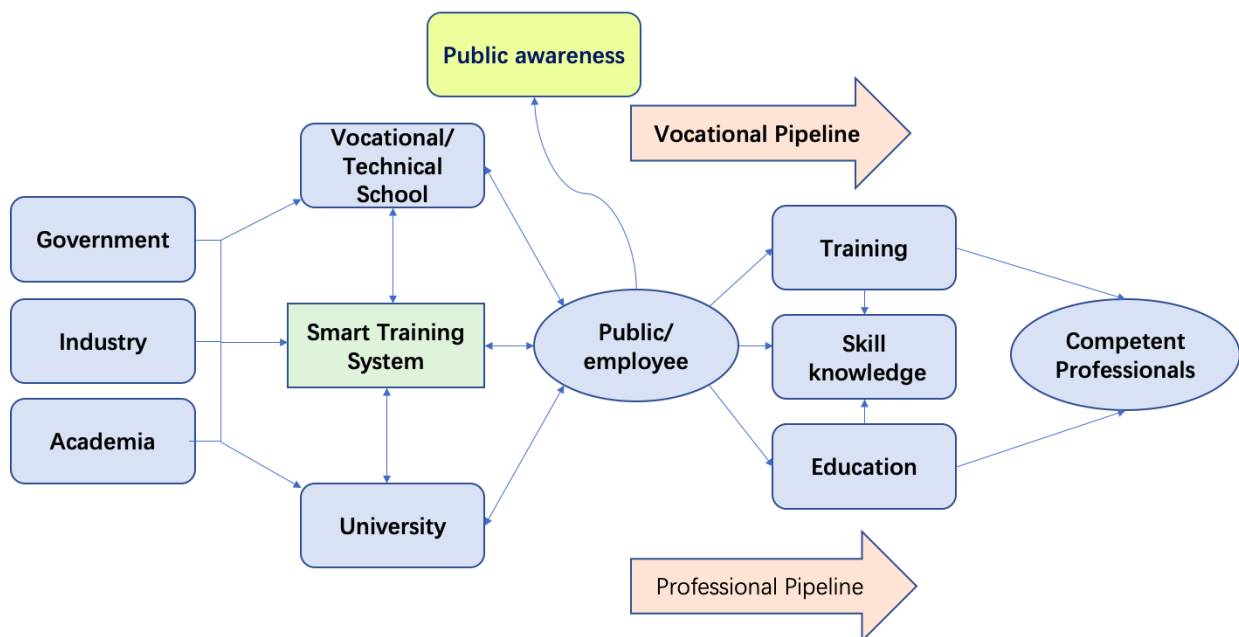


FIG. 4. Stakeholders in the proposed standardized education system.

2.2. Global Mobility

(a) Standardized Licensed Operator Training

The 448 nuclear reactors currently operating worldwide fall into six major reactor design types: pressurized water reactor, pressurized heavy water reactor, boiling water reactor, gas-cooled reactor, light water graphite reactor, and fast neutron reactor [6]. Current Licensed Operator programs at nuclear plants are heavily individualized, even between nuclear plant operators of similarly designed reactor types, requiring significant re-training of individuals relocating to a different plant. Standardized Operator License training provided through the aforementioned international training program would increase the available workforce and global mobility of operators.

(b) Plant-Specific Gap Training

Harmony Resources also supports an internationally-accepted plant-specific Gap Training strategy aimed at eliminating costly re-training and supporting global mobility. Much like the current approach to pilot's license transfers between countries, Gap Training for Licensed Operators would address only the plant-specific differences and conclude with a Gap exam to ensure high standards of knowledge and safety are maintained. This gap training would reduce training time from several years to only months, or possibly weeks, depending on the similarity of technology. By using the proposed international virtual training program, the process would be streamlined even more by not requiring individuals to be on-site or fit into a physical training course schedule before gap training can begin.

(c) Workforce evaluation and improvement

Harmony Resources understands the value of an internationally connected nuclear industry network. In the future, a database of individuals possessing qualifications needed for areas of Nuclear Design, Nuclear Construction, and Nuclear Operation will allow organizations to not only find needed staff, but to help identify shortages or surpluses of particular skills. Using advanced database technologies, the industry will have access to a global picture of available talent. We can dynamically understand the current and future needs and trends of various fields around the world, enhance the effectiveness and pertinence of personnel training, proactively manage knowledge and experience transfer, and better meet the development needs of nuclear I4.0.

3. Conclusion

Harmony Resources envisions that the ideas outlined in this white paper will be coordinated by an international organization comprised of government, academia, and nuclear industry stakeholders. The strategies outlined in this white paper provide tangible benefits to the nuclear power industry.

These benefits include:

- access to the nuclear power community through education and training regardless of location,
- standardized licensing and site-specific gap training to facilitate the global mobility of the workforce,
- increased interest in NPP careers and career progression opportunities due to mobility between plant sites,
- reduced costs for re-training and better access to an experienced workforce, and
- access to database of nuclear power professionals to recruit and train for the roles that are anticipated in the future.

Implementation of the human resources framework outlined above will align the nuclear industry for the changing environment and necessary workforce growth expected of the Harmony Programme by 2050, ensuring the nuclear power as a reliable and sustainable energy source of the future.

Are you ready to join us 4 future nuclear?



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