Climate Change and the Role of Nuclear Power

Proceedings of an International Conference
Vienna, Austria, 7-11 October 2019

IAEA
International Atomic Energy Agency

CLIMATE CHANGE AND THE ROLE OF NUCLEAR POWER

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

PROCEEDINGS SERIES

CLIMATE CHANGE AND THE ROLE OF NUCLEAR POWER

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ORGANIZED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
IN COOPERATION WITH THE
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FOREWORD

Climate change is one of the most important issues facing the world today. Nuclear power can make a significant contribution to reducing greenhouse gas emissions (GHGs) worldwide, while at the same time meeting the increasing demands for energy of a growing world population and supporting global sustainable development. Nuclear power has considerable potential to meet the challenge of climate change by providing electricity, district heating and high temperature heat for industrial processes while producing almost no GHGs.

To address the challenges posed by climate change, and to achieve the goals established in the 2015 Paris Agreement Under the United Nations Framework Convention on Climate Change (UNFCCC), a significantly greater deployment of low carbon energy technologies is needed. Nuclear power has the potential to play a significant role in achieving these mitigation goals and, as a large scale, reliable, and concentrated source of energy, can also contribute to the broader economic and social dimensions of sustainable development. The potential role of nuclear power was also addressed in the 2018 Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5ºC.

The IAEA has an important role in improving the understanding of the potential contribution of nuclear power by providing interested Member States with guidance and assistance in deploying safe, secure and safeguarded nuclear technology and in formulating national energy strategies and policies. Supporting Member States in the attainment of the United Nations climate change targets and Sustainable Development Goals (SDGs) is thus closely aligned with the statutory objective of the IAEA, namely "…to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

To this end, the IAEA organized the International Conference on Climate Change and the Role of Nuclear Power, from 7 to 11 October 2019 in Vienna. This first of a kind topical conference served as a forum for exchanging science based information on the role of nuclear power in supporting the low carbon energy transformation needed to achieve climate change goals, and conducting objective discussions on the opportunities and challenges involved in the development of safe, secure and safeguarded nuclear technology. The major themes of the conference covered energy and climate change policies, implications for the power sector, environmental perspectives and potential roles of existing, evolutionary and innovative nuclear power systems, including the integration of nuclear/renewable energy systems. In addition to nuclear power's interim and long term contributions, some strategic and cross-cutting issues relating to public perception, regulations, markets and finance were addressed.

The conference was organized by the IAEA, in cooperation with the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA), with the participation of IAEA Member States and international partners, including leading international organizations involved with climate change and the UN SDGs, such as the UNFCCC, United Nations Department of Economic and Social Affairs (UNDESA), United Nations Industrial Development Organization (UNIDO), the United Nations Intergovernment Panel on Climate Change (IPCC), the International Energy Agency (OECD/IEA) and the World Nuclear Association (WNA).

These proceedings include a summary of the plenary and technical sessions and side events, as well as the full texts of the statements delivered in the opening, closing and high level plenary sessions of the conference, with all presentations and full papers, where submitted, available on-line as supplementary files.

The IAEA would like to express its appreciation to the members of the International Scientific Programme Committee and the Secretariat of the Conference for convening and organizing this conference. The IAEA officers responsible for this publication were W. Huang, A. Borio di Tigliole and S. Monti of the Department of Nuclear Energy.

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1. SUMMARY

1.1. INTRODUCTION

Climate change is one of the greatest challenges of the 21st century. In response to this global threat, the international community reached the landmark 2015 Paris Agreement Under the United Nations Framework Convention on Climate Change (UNFCCC) (the Paris Agreement) setting clear objectives to keep a rise in global temperatures in this century well below 2°C above pre-industrial levels, and to pursue efforts to limit the temperature increase even further, to 1.5°C. Taking urgent action to combat climate change and its impact is also one of the 17 UN Sustainable Development Goals (SDGs) adopted in 2015.

Current national pledges reflected in Nationally Determined Contributions (NDCs) under the Paris Agreement to curb greenhouse gas (GHG) emissions vary considerably in terms of ambition and scope and collectively fall short of the Paris Agreement 2°C target, let alone the 1.5°C target. In order to support the achievement of the Paris Agreement and SDGs and reach net zero emissions by 2050, all nations are called to scale up their ambitions and adopt concrete and realistic implemenation plans compatible with these goals.

Around 70% of the world's electricity currently comes from burning fossil fuels, according to the International Energy Agency.[1] By 2050, around 80% of all electricity will need to be low carbon to meet the Paris Agreement goal. Significantly greater and faster deployment of low carbon energy technologies, along with the phase-out of emission intensive sources, requires that all options be considered.

As a large scale, reliable, dispatchable, concentrated and low carbon energy source, nuclear power has contributed significantly in the past decades not only to GHG reduction but also to broader economic and social dimensions of sustainable development. The 442 nuclear power reactors currently in operation in 30 countries generated 10% of the world's electricity and one third of all low carbon electricity while avoiding approximately 2 Gt CO_2 every year. It has great potential to play a significant role in achieving climate change mitigation goals and supporting social and economic development in the transition to a global low carbon economy.

Maintaining active involvement in responding to the UN's climate change and sustainable development objectives is closely aligned with the statutory objective of the IAEA — "…to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". The dual challenges of climate change and sustainability reinforce the crucial role of "Atoms for Peace and Development".

Recognizing the right of Member States to choose nuclear energy as part of their energy mix, the IAEA has a unique role in enhancing the understanding of nuclear energy's contribution in addressing global issues. Two aspects of this role is providing its Member States with guidance and assistance for deploying nuclear technology and in formulating national energy strategies and policies.

In this context, the IAEA, in cooperation with the OECD Nuclear Energy Agency (OECD/NEA), organized the first International Conference on Climate Change and Role of

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[1] INTERNATIONAL ENERGY AGENCY, Global Energy and CO_2: Status Report 2019, OECD, Paris (2020), https://www.iea.org/reports/global-energy-co2-status-report-2019/emissions

Nuclear Power from 7 to 11 October 2019 to facilitate a comprehensive and inclusive discussion on the unique role of nuclear power in addressing climate change and sustainable development.

1.2. SUMMARY OF THE CONFERENCE

The conference explored the role of nuclear power in the mitigation of climate change and the achievement of SDGs, and identified major challenges and opportunities for the full utilization of nuclear energy, along with the options to address these challenges and make the most of the opportunities. In addition to the decision makers and officials from national governments and regulatory bodies, representatives of international organizations, industry and civil society participated in the conference, including those from non-governmental organizations and academic institutions. The IAEA welcomed and encouraged the participation of women, early career professionals and individuals from developing countries.

More than 500 participants, representing 79 countries and 18 international organizations, attended the conference. In addition to the heads and senior officials of the IAEA and OECD/NEA, a number of prominent and high level speakers from international organizations and IAEA Member States also attended the conference and delivered keynote speeches, including the Under-Secretary-General for Economic and Social Affairs at the United Nations Department of Economic and Social Affairs (UNDESA), Director General of the United Nations Industrial Development Organization (UNIDO), Director General of the World Nuclear Association (WNA), and senior government officials from Argentina, Bangladesh, Brazil, China, Egypt, France, Hungary, India, Mongolia, Morocco, the Russian Federation, United Kingdom and the United States of America. Heads of relevant international organizations such as the Executive Secretary of the United Nations Framework Convention on Climate Change (UNFCCC) and the Executive Director of the International Energy Agency (IEA) of the OECD, sent messages to the event.

The thematic topics of the conference included:

- Challenges and opportunities for existing nuclear power plants with respect to their contribution to the avoidance of GHG emissions;
- Factors necessary to support high rates of deployment, including for advanced nuclear power technologies, consistent with achieving climate change goals, including those established in the Paris Agreement, and SDGs, namely SDG 7 (“Ensure access to affordable, reliable, sustainable and modern energy for all”) and SDG 13 (“Take urgent action to combat climate change and its impacts”);
- The prospects for synergies between nuclear power and other low carbon energy sources.

The conference programme consisted of opening and closing sessions, high level plenary sessions, topical plenary sessions with invited keynote addresses, techical sessions with keynote addresses and panel discussions, side events, interactive e-poster/e-space and exhibitions. On the first day, in addition to the opening session, three high level plenary sessions were dedicated to the keynote addresses of the heads of international organizations and ministerial level officials from Member States. Subsequently, topical plenary sessions consisting of invited keynote addresses focusing on six topical themes were arranged, followed in each case by a technical session. Parallel sessions featured the presentations selected from submitted abstracts/papers. On Friday, one special plenary session on nuclear safety and security was arranged to highlight the importance of these topics. A special award session for winners of the visulization competition was also organized to recognize the value of the younger generation in combating climate change. The summary of the conference president, consisting of findings and recommendations, was presented in the closing plenary session at the end of the conference.

The poster/interactive content sessions used IT applications to improve communication and interactions, which complemented the more traditional approach to posters Exhibitions and side events presenting global trends and innovative nuclear technologies to help meet climate mitigation goals were held throughout the conference.

The 18 technical sessions with 125 oral presentations were grouped into six parallel technical tracks:

- Track 1: Advancing energy policies that achieve the climate change goals;
- Track 2: The increasing contribution of nuclear power to the mitigation of climate change, including synergies with other low carbon power generation sources;
- Track 3: Development and deployment of advanced nuclear power technologies to increase the use of low carbon energy;
- Track 4: Shaping the future of the nuclear industry in regulated and deregulated energy markets to address climate change;
- Track 5: Enhancing international cooperation and partnership in nuclear power deployment;
- Track 6: Public and non-nuclear stakeholders' perceptions of the role of nuclear power in climate change mitigation.

All presentations, posters and full papers, where submitted, are available in the on-line supplementary files on the publication's web page at www.iaea.org/publications. Selected papers, based on presentations within the different tracks, are included in this publication.

1.3. OBJECTIVES AND STRUCTURE OF THE PROCEEDINGS

Designed to be an output of this inaugural conference on climate change and the role of nuclear power, these proceedings are expected to serve as a source of information for a wide audience, including decision makers, regulators, experts, scholars, the public and other stakeholders from Member States and international organizations involved in the nuclear energy, climate change, environment, eocnomics and social developmentareas.

This publication contains the summary of the conference president, the major findings, challenges and conclusions from the topical plenary sessions, technical sessions and a special plenary session on nuclear safety and security. In addition, the opening session, executive summary, keynote papers (where available), summaries of the technical sessions and panel sessions, the summary of the eight side events and the closing session are included.

2. OPENING SESSION

2.1. OPENING PLENARY SESSION

2.1.1. President of the Conference — Welcome Address

Statement as provided, verbatim.

M. Chudakov
Deputy Director General and Head of the Department of Nuclear Energy
International Atomic Energy Agency
Vienna, Austria

Excellencies, ladies and gentlemen,

Welcome to Vienna and the International Atomic Energy Agency. It is my honour to serve as the President of the IAEA's first international conference on the topic of climate change and the role of nuclear power.

I am pleased to share this podium today with Mr Cornel Feruță , the Acting Director General of the International Atomic Energy Agency and Mr William Magwood, Director General of the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OCED/NEA). They will both address you in a couple of minutes.

Ladies and gentlemen, this is the first IAEA conference on this topic. But the topic itself is not new. Nuclear power has been providing low carbon electricity for decades. Today, we face not only climate change, but also the growing need for more energy and more and more electricity to enable socioeconomic development worldwide.

The conference will discuss how nuclear power can contribute to addressing this twin challenge.

Ladies and gentlemen, some 550 participants from 79 Member States and 18 international organizations are gathered here today. This shows the interest in this topic but also its timeliness.

After opening remarks by the IAEA Acting Director General and the OECD/NEA Director General, we will hear keynote speeches from the heads of the United Nations Department of Economic and Social Affairs, the United Nations Industrial Development Organization, the Intergovernmental Panel on Climate Change and the World Nuclear Association.

We will also hear messages from the heads of the International Energy Agency of the Organisation for Economic Co-operation and Development and the United Nations Framework Convention on Climate Change.

With us today are several ministers and high-level officials from Member States. They will elaborate on energy and climate policies for addressing the transition to low carbon energy.

Ladies and gentlemen, our purpose is to have an objective discussion about nuclear power, its contribution to curbing greenhouse gas emissions, its potential future role and the challenges it faces. The discussion will be based on science and facts.

During the week, we will talk about challenges and opportunities for the existing nuclear fleet to continue providing a significant contribution to the world's low carbon electricity.

We will discuss what is needed to speed up deployment of nuclear power, including advanced technologies like SMRs, to meet climate and sustainable development goals.

We will examine how nuclear reactors and renewables can be used together in hybrid energy systems, including energy storage, hydrogen production and many other non-electric applications of nuclear power.

And we will discuss energy policies and public perception of nuclear power's role in mitigating climate change.

We will also discuss nuclear safety and security aspects related to the operation of the existing fleet and the deployment of advanced reactors in a dedicated plenary session.

Importantly, we will hear from different countries about their strategies for the transition to low carbon energy systems. We will hear about their valuable experiences, how they are overcoming challenges, and what are their short and long-term plans.

As the President of the conference, I encourage all of you to actively engage in the discussions and contribute to the fruitful outcomes of the conference.

And now, it is with great pleasure that I invite Mr Cornel Feruță, Acting Director General of the IAEA, to give his opening remarks.

2.1.2. IAEA Acting Director General — Opening Address

Statement as provided, verbatim.

C. Feruță
Acting Director General
International Atomic Energy Agency
Vienna, Austria

Excellencies, distinguished guests, ladies and gentlemen,

I am very pleased to welcome you all to this IAEA International Conference on Climate Change and the Role of Nuclear Power.

I thank the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development for its cooperation in organizing this important event.

It is gratifying to see high level participants from IAEA Member States and from many partner organizations here today.

I believe this reflects international recognition of the gravity and scale of the climate emergency — as reflected in last month's UN Climate Action Summit — and a growing appreciation of the contribution that nuclear science and technology can make in addressing it.

Like all technologies, nuclear power brings benefits and risks. It has a good overall safety record. However, it is not always judged purely on the basis of scientific facts.

It is my hope that this conference will contribute to an informed consideration of nuclear power on the basis of facts and, possibly, help to dispel some misconceptions.

Ladies and gentlemen, around 70% of the world's electricity comes from burning fossil fuels, according to the International Energy Agency. By 2050, if climate change goals are to be met, around 80% of electricity will need to be low carbon. Making that transition will be a major challenge.

At present, nuclear power provides 10% of the world's electricity. But it accounts for one-third of all low carbon electricity generated today. That fact deserves to be better known.

The world will need to harness all low carbon sources of energy in order to meet the Paris Agreement goal of limiting the rise in global temperatures to well below 2 degrees Celsius above pre-industrial levels. Use of renewables such as wind and solar power will continue to grow.

However, nuclear power provides the steady and reliable stream of electricity needed to run and grow an advanced economy, and to enable developing countries to boost economic output and raise living standards.

Together with hydropower, nuclear is the only low carbon source of energy that can replace fossil fuels for 24/7 baseload power.

Nuclear power plants produce practically no greenhouse gas emissions or air pollutants during their operation. Emissions over their entire life cycle are very low.

The use of nuclear power reduces carbon dioxide emissions by about two gigatonnes per year. That is the equivalent of taking more than 400 million cars off the road — every year.

In some countries, nuclear power has been successfully integrated with other low carbon energy sources and serves as a flexible baseload backup to intermittent renewable sources.

It is difficult to see how the goal of reducing greenhouse gas emissions can be achieved without a significant increase in the use of nuclear power in the coming decades.

Ladies and gentlemen, a number of countries are considering introducing nuclear power, or expanding existing nuclear programmes, as part of their efforts to achieve sustainable development.

The IAEA does not attempt to influence countries' decisions either for or against nuclear power.

We help countries to make informed decisions by providing solid scientific data and analysis and offering planning tools. If countries opt for nuclear power, our role is to help them use it safely, securely and sustainably.

Some countries have successfully extended the operating lifetime of existing power plants to 60 years and see potential to extend it to as long as 80 years. The IAEA helps countries to share experience in this area.

It is essential that the most robust levels of nuclear safety are in place at every nuclear power plant in the world.

This is a national responsibility, as is the need to ensure that nuclear and other radioactive material is properly secured so that it does not fall into the hands of terrorists and other criminals.

However, effective international cooperation in these areas is vital. The IAEA provides the global platform for cooperation in nuclear safety and security.

We establish global nuclear safety standards and security guidance. We provide detailed practical assistance in many areas, from energy planning, as I mentioned, to plant site selection, legal and regulatory matters and technical training, all the way through to plant decommissioning.

The IAEA Milestones Approach helps countries that are considering or planning their first nuclear power plant to understand, and prepare for, the commitments and obligations associated with nuclear power.

We also work to ensure that the growing use of nuclear power does not lead to the proliferation of nuclear weapons by implementing safeguards in 183 countries.

Ladies and gentlemen, I believe that technological advances in the coming years will further improve the economic attractiveness and cost-effectiveness of nuclear power.

Advanced reactor designs with innovative safety features could play a key role in the accelerated replacement and expansion of the global nuclear fleet.

Small modular reactors could make nuclear power feasible for the first time on smaller grids and in remote settings, as well as for non-electrical applications.

Advances being made in several countries concerning the final disposal of high level radioactive waste may help to alleviate public concerns about the long term sustainability of nuclear power.

I expect that we will learn more about some of the remarkable technological innovations in the pipeline during the next few days.

Ladies and gentlemen,

In more and more parts of the world, climate change is already causing significant damage to the coastal and urban infrastructure, and to fragile eco- and agricultural systems.

This poses a threat to the livelihoods of farmers and entire communities, compromising food security and access to water, threatening harvests and enabling the spread of insect pests and disease.

Through our technical cooperation programme, the IAEA makes available non-power applications of nuclear science and technology to help countries address such problems.

For example, our scientists help to develop new varieties of food crops such as rice and barley that are tolerant of drought, and other conditions such as extreme temperatures and salinity, which are being exacerbated by climate change. We help countries and regions to use nuclear techniques to identify and manage limited water resources.

With specialist laboratories in Monaco and near Vienna, the IAEA helps countries to obtain reliable environmental data and devise accurate models to help predict future conditions. We launched international studies to help understanding of the effects of climate change on polar and mountainous regions. We support the analysis of scientific climate data in a way that is meaningful for policy-makers.

Ladies and gentlemen, I hope that this Conference will help to build public understanding of the advantages of nuclear power in addressing the climate crisis, one of the greatest challenges of our time.

The IAEA is committed to assisting our 171 Member States in making optimal use of nuclear science and technology in order to improve the well-being and prosperity of their people.

Let me conclude by thanking you all once again for your presence here today. I wish you a very successful Conference,

Thank you.

2.1.3. OECD/Nuclear Energy Agency — Opening Address

Statement as provided, verbatim.

W.D. Magwood IV
Director General
OECD Nuclear Energy Agency
Paris, France

Good morning.

Good morning to ministers, colleagues, friends, fellow citizens of the Earth. It is good to see all of you here, and to see so many familiar faces. As we come here together today, it is clear that we all have a very similar objective: we see a great need to transition the way we make and use electricity, a great need to address the concerns of people around the world about the climate. Where perhaps we disagree with some people is how to do that. But how to achieve that is really the principal question facing us around the world at this time.

The single most important issue in facing climate change is what is the right mix of technologies and methods that will enable us to be successful. I have said for many years that this is a very large and complex problem, and that when we take any solution off the table, we make finding a solution in the end that much more difficult. It does not mean that we know what the answers are today, but it means that because we do not know what the answers are, we need to keep our minds open. And that should be the advice for everyone. Because if we are truly serious about solving this problem all answers should be considered.

I want to start my presentation today by introducing the Nuclear Energy Agency because it is a much smaller organization than the IAEA in terms of the number of countries. We have 33 countries and all of them are also IAEA Member States. The NEA member countries are the ones with the largest concentration of expertise, knowledge and experience in the use of nuclear technologies. They come together under the framework of the OECD/NEA to try to solve very difficult problems that are challenging not really just to our member countries but the global community. We work in areas such as nuclear safety, stakeholder involvement, science, technology, economics and many other areas. We work together to try to find solutions. And we do this using a variety of mechanisms, including research projects, multinational initiatives, committee activities, and others; and we work together very closely with the IAEA in doing all that.

When COP21 concluded successfully, it was the most important initial step that we have seen in many years. Although I will not repeat here the details of this agreement because everyone is very familiar with them, I think it is worth highlighting that in order to meet the commitments of COP21 we have to do a lot of work. According to a recent OECD analysis, electricity related carbon emissions would need to decline 85% among OECD countries in order to meet these targets. This is very difficult, if you are familiar with the way electricity is made and operated around our member countries, because it requires very complex infrastructure and a lot of investment, and changing all that is not going to be easy.

When you look at what has been happening around the world, it looks clear that there are many activities under way: we have been watching in the US how coal has been abandoned in favour of gas, which has resulted in a drop in carbon emissions; in Japan we have seen the closure of nuclear power plants in the aftermath of the Fukushima Daiichi event, with the resulting increase in carbon emissions; France, which is a very interesting case, for quite a while has already met the Paris Agreement carbon reductions, producing an average of 40 g of CO_2 per kW·h. The reason for that is that France relies heavily on nuclear power, and this shows the contribution that nuclear power can make towards fighting this battle.

When we look around the world we see that electricity demand has been growing steadily. In many developed countries, OECD countries, the demand has been very flat but in developing countries the demand is rapidly increasing. This is something that deserves a great deal of attention to think about these issues. Obviously, there is going to be a large growth in the use of variable renewable energy around the world. This is not a bad thing, this is a good thing as it provides an opportunity for many countries to use electricity in a novel way that does not produce greenhouse gases, in a way that is very flexible. But it also has some consequences. Due to time, I will go very quickly over some NEA recent analyses that have highlighted some of the consequences of high levels of renewable deployment. In these analyses we have begun to focus on what is becoming to be well understood as the system costs of electricity.

Too often, when we look at the analysis regarding the cost of electricity, we look at simply the cost of electricity from a particular source, from a wind farm, from a nuclear power plant, from banks of solar panels. But the truth is that we have a look at the overall cost system, in terms of profile costs, which is the cost associated with the fact that in case renewables are not always available there is a cost due to backing up that supply; or when there are unexpected interruptions of supply. Of course, there is the cost of transmission and distributions that can be very expensive as more renewable resources are more widely used.

To give you some examples of the kinds of behaviour we are seeing in our analyses, in the case of 10% variable renewable penetration, which is something that we see today in many countries, we see a lot of variation in the residual demand, but it is very manageable by grid operators. In a case with high penetration of variable renewables, 75% in this case, you can see how exaggerated the curve of the residual demand is. The residual demand represents the demand that is not covered with variable renewables, and it shows what the system has to do to make up for when renewables are not available. We have talked to grid operators, and they said: “We don't know how to do this, we do not have the technology, we do not have the methods, we have no idea how this would actually work”. Now, does it mean that we should not expand the use of renewables? No, that is not the answer. But we need to recognize that there are costs that need to be absorbed. Those costs are represented on this chart: on the left you see the base case, which is pretty close to today’s cost of producing electricity; on the far left you see the cost to produce electricity as you expand the penetration of renewables in the system. You end up with almost double cost for the same electricity. Do we want to see electricity costs go up, while reliability goes down? At the same time we still have issues reducing emissions.

The report that we issued earlier this year, ‘The Cost of Decarbonisation’, makes very solid recommendations. The most important recommendation is to recognize these costs. Recognizing these costs is very important because this is the path to make rational decisions, the path to balance the grid in the appropriate way. We should invest in all low carbon technologies and we should also make sure we have an adequate transmission and distribution infrastructure. Economists also suggest that carbon pricing is one of the most cost effective manners to achieve decarbonization.

I will now make some bottom line points: to meet global electricity requirements all low carbon technologies can play a role, with their costs appropriately allocated. At the same time, electricity markets have to be modernized. This is probably the most difficult policy space we have ever encountered because reforming these markets is something that is political, technical and economic and, as such, very complex. We have to also recognize that while we will see a large deployment of variable renewables around the world, what the energy mix actually looks like in one country may be different from what works in another. What works in Norway may not work in Australia, what works in the United States of America may not work in Brazil. That is okay, but each country should be able to figure out what the right balance is for its economy and its circumstances. There is no one-size-fits-all effort and to the degree that we need large, low carbon capacity fast, nuclear may play a large role.

As you heard earlier, there are new technologies coming up. Baseload Small Modular Reactors (SMRs) are the ones I think are coming to us first. These are technologies that may take the place of traditional nuclear power plants around the world. They are characterized by low cost, high flexibility, high quality and even higher levels of safety that may perhaps allow the disappearance of off-site emergency preparedness. There are other types of new technology: distributed generation, mobile SMRs that are deployed for particular uses; micro-reactors, which is something that people have become very excited about; Generation IV reactors, which might be a little further out in the future in some cases but which people are pursuing very aggressively right now. All these technologies are now under consideration, now being developed, now going for regulatory approval and these could be game changers that could make a big difference going forward.

The folks that we see protesting outside are very passionate about the climate and I congratulate them for being passionate about the climate. But many of them project an image for climate action which is not really what many people want to see. Quite frankly, while riding a bike may be good for you, not everyone wants to ride a bike to work every day. Not everyone wants to take a sailboat to go from France to the United States of America: it might be a pleasant thing to do, but it does take a bit of time. As developing countries are looking to expand their infrastructure to pull people out of poverty, installing a few solar panels on top of a few houses is not what they are thinking about. I have talked about this with ministers from all over the world. I have talked to ministers in countries that want to maintain and even expand their industrial basis, and they want to have a reliable electricity supply that will support this. I have talked to ministers in countries that are trying to pull people out of poverty, and their first priority is to change the lives of the people: provide access to good clean water, have education, have lights to study at night. They care about the climate, but they care about these people more. If we tell them that the way to save the planet is to abandon them, they are not going to join this fight. This is a chart that the IEA put together that shows that in several countries around the world there are huge numbers of people without access to electricity or clean water. Are we to tell these people that they have to wait a long time, or that they cannot have that because we worry about the planet? That is not an acceptable answer.

People in OECD countries expect to maintain their current quality of life, including access to transportation, food options and the prospects for continuous economic expansion. Governments with manufacturing industry will want to keep those manufacturing industries alive and want them to prosper. Leaders in emerging economies want to reduce poverty, and it is essential that any action on climate change not be viewed as being in conflict with these aspirations. Nuclear power is not the only solution, but it is a solution where we can have our cake and eat it too. We can have expanded access to prosperity, expanded access to energy, and we can do that without damaging the environment. To me, this is a very important message to begin to talk about. This message can make climate action more powerful for people around the world. A vision that incorporates both renewables and nuclear energy together, I think is a good message, and one that can motivate countries around the world to work together.

Thank you very much.

2.2. HIGH LEVEL PLENARY OF THE INTERNATIONAL ORGANIZATIONS

Chairperson: M. Chudakov, IAEA

2.2.1. United Nations Department of Economic and Social Affairs — Keynote Address

Statement as provided, verbatim.

Z. Liu
Under-Secretary-General for Economic and Social Affairs
United Nations
New York, United States of America

Excellencies, distinguished participants, ladies and gentlemen,

I am very pleased to address this important conference shortly after the United Nations High-Level Week, which included the Climate Action Summit and the Sustainable Development Goals (SDGs) Summit.

I wish to congratulate the IAEA for convening this timely dialogue.

Four years have passed since both the 2030 Agenda for Sustainable Development and the Paris Agreement on climate change were adopted by world leaders. Significant momentum is growing across governments and all stakeholders to deliver on these agreements.

At the Climate Action Summit, 65 countries and major sub-national economies have committed to net zero emission by 2050.

Over 100 global companies delivered concrete actions to align with the Paris Agreement climate targets.

Millions of youth activists marched all over the world, pressing hard for immediate climate action.

Countries are also demonstrating their commitment to the SDGs through their Voluntary National Reviews and the concrete steps they are taking for implementation.

But this is not enough.

Looking around the world, hunger is on the rise. The rate of poverty reduction has slowed. Inequalities are increasing, and the negative trends in biodiversity loss and greenhouse gas emissions continue unchecked. Too many people remain vulnerable, including in small island developing states, least developed countries and landlocked developing countries.

We are not on track to meet the SDGs, or to keep the global temperature rise within 1.5°C above pre-industrial levels. We must step up, raise ambitions and scale up action.

Distinguished participants, the newly released Global Sustainable Development Report, prepared by an Independent Group of Scientists, reminds us that the need for action is urgent. We have limited time in which to bring about the transformation we need. The Report identifies six entry points to accelerate integrated actions. One of these is on energy decarbonization with universal access. In the UN Secretary-General's global call for a decade of action at the SDG Summit, energy, among a few other issues, is also recognized as the specific solution that link up and have impact across the 17 goals.

The global energy transformation must be accelerated to achieve both the 2030 Agenda and the Paris Agreement on climate change.

The Intergovernmental Panel on Climate Change Special Report showed that limiting warming to 1.5ºC is still possible. However, this requires rapid and far-reaching transitions in energy, along with land, industry, buildings, transport and cities. At present, however, we are far from realizing these visions.

Today, there are still 840 million people living in darkness. Three billion are without clean cooking facilities. At the same time, we are facing a 2 per cent annual increase in carbon dioxide emissions, with a record 37 billion tonnes being released in 2018 alone.

Modern renewables are increasing — but must be dramatically scaled up, especially in transport, heating and cooling. We must advance energy efficiency if we are to double energy efficiency improvements by 2030.

Ladies and gentlemen, how can nuclear energy help realize the objectives of the 2030 Agenda for Sustainable Development and the Paris Agreement on climate change? Let me share with you a few thoughts, drawing on existing analyses, including the 2019 Global Sustainable Development Report.

First, with low levels of greenhouse gas emissions, nuclear power contributes to emissions reduction today, and potentially in the future. Existing nuclear power plants have avoided approximately 1 to 2 gigatonnes of carbon dioxide equivalent per year when compared with gas or coal alternatives.

Will this climate dividend continue or expand into the future? That will depend on how countries evaluate nuclear power against renewables and other clean alternatives. It also depends on how countries decide to deal with existing nuclear power plants, as two-thirds of today's nuclear power plants in advanced economies are more than 30 years old.

Second, nuclear technology plays an important role in our society. It can be used to monitor pollution. It helps in the diagnosis and treatment of cancer and other major diseases. Radiation technology helps to prevent food from spoiling. It helps create new crop varieties, supporting climate change adaptation.

Third, nuclear safety remains a significant public concern, especially after the Fukushima accident and terrorism related fears. The long term management of nuclear waste is still an unresolved issue and needs to be addressed.

Lastly, the cost competitiveness of nuclear power will remain an important issue — as renewable energy has become increasingly more cost competitive than many conventional options. Few private investors are willing to go it alone, given the large capital costs. Government commitments and public acceptance will be a prerequisite for the development of new nuclear plants.

Excellencies, distinguished participants, readily available technological solutions already exist to make significant headway toward a zero emission future. And we have the roadmap: the 2030 Agenda for Sustainable Development and the Paris Agreement on climate change.

Science also tells us it is not too late.

We at the United Nations Department of Economic and Social Affairs are firmly committed to support an accelerated energy transition to realize a zero emission future:

First, we will strengthen coordination across the UN system, including reinforcing the secretariat for UN Energy.

Second, we will facilitate international cooperation, strengthen support for global dialogues on energy at the High-level Political Forum on Sustainable Development, and follow up the UN Decade on Sustainable Energy for All 2014–2024. We will continue to invest in the SDG 7 Technical Advisory Group.

Third, we will leverage the global conferences next year — on sustainable transport in Beijing, and on oceans in Lisbon — to catalyze further action.

Finally, we will continue to promote the synergies between climate action and the broader SDG agenda so as to scale up ambition and commitment in implementation.

I urge everyone to step up your efforts for a better future for all.

I wish you a fruitful meeting.

Thank you.

2.2.2. United Nations Industrial Development Organization — Keynote Address

Statement as provided, verbatim.

Y. Li
Director General
United Nations Industrial Development Organization,
Vienna, Austria

Excellencies, distinguished delegates, ladies and gentlemen,

It is a great honour and pleasure for me to join you at today's conference, which highlights once again the urgent need to take action on climate change.

I would like to thank the International Atomic Energy Agency for inviting me, and I am very pleased to share the experience of UNIDO, the United Nations Industrial Development Organization.

That climate change and sustainable development are the central challenges of our time has become clearer than ever before. This year, we experienced the hottest summer months in the Northern hemisphere. The years 2015 to 2019 were also the five hottest years ever recorded. Young people around the world are taking to the streets to remind us of the urgency of climate change.

Just over a week ago, I returned from the Climate Action Summit convened by the UN Secretary-General in New York. The Summit once again reminded us that if we continue on our current path, we face at least three degrees Celsius of global heating by the end of the century. This reminder is alarming, given that any temperature rise above 1.5 degrees will lead to major and irreversible damage to the ecosystems of our planet.

From the side of UNIDO, and in the implementation of our mandate of inclusive and sustainable industrial development, we see a very close connection between the central challenges of climate change and sustainable development.

It is clear that both challenges are directly linked and need to be addressed simultaneously and in a cross-sectoral way.

Inclusive and sustainable industrial development must be part of the solution. The positive effects on job creation, income generation, economic growth and social inclusion are evident. At the same time, industry plays an important role to address the climate challenge through a more sustainable use of resources, in particular through innovative and sustainable energy solutions.

Energy is a great integrator because it cuts across all economic sectors and lies at the heart of the core interests of all communities, industries and countries.

Today, industry accounts for more than a third of global energy consumption and for almost one quarter of the global greenhouse gas emissions. It will also be the sector to drive the growth of global energy demand over the next decades.

It is clear that we need a new energy paradigm that can reconcile economic growth with the sustainability for the benefit of future generations, and that industry must be part of such a paradigm change.

Ladies and gentlemen, the call for action is clear. Countries need to reduce greenhouse gas emissions, including emissions from industry.

But taking action on climate change still remains a daunting task, in particular due to lack of capacity, limited access to climate finance and suitable climate technologies, and the lack of awareness of the private sector on the need to take action.

The Nationally Determined Contributions that define the respective national reductions in greenhouse gas emissions under the United Nations Framework Convention on Climate Change outline solutions to support and realize the climate goals of the Paris Agreement.

These solutions are policies, technologies, best practices and other instruments available to industry, policy-makers and the international community.

The international scientific community has identified that there is a set of proven, market-ready energy technology options that can help us meet the climate goals. However, to achieve progress, it will be necessary to combine these technologies. And we need to support countries in adopting those technologies which are appropriate to their needs.

Given the need to increase awareness, UNIDO disseminates and implements existing best available technologies and practices for sustainable energy globally through knowledge-sharing, capacity building, investments, and partnerships.

I am pleased to note that, over the past decade, progress and innovation in clean energy technologies and industries have been quite impressive. Some emerging countries having shown leadership and long term vision in promoting technology innovation and entrepreneurship development.

However, a large number of countries are still lacking an inclusive and suitable industrial development strategy, the institutional capacity, and financial resources to play an active role in building technology responses to the challenge of climate change.

With different national priorities and socioeconomic constraints, countries require tailored solutions and strategies. So, to achieve the changes required at the necessary speed and scale, we need to intensify cooperation, collaboration, and lesson-sharing of best practices and past failures.

As we all move forward with the global climate change agenda, there is also a need for greater collaboration between public and private stakeholders, including financial institutions.

As the central coordinator of industrial development within the UN system, UNIDO has been among the strongest supporters for a closer engagement of the private sector in all areas of development, and we have witnessed the success of this approach.

The countries that have been more successful in improving the energy efficiency of their industrial sector are those that have also implemented a larger number of cooperative measures between government and industrial associations.

In other words, those countries where government and industry have come together to identify, discuss, negotiate and agree upon a win-win policy and technology solutions were more successful in advancing the sustainable development agenda.

Ladies and gentlemen, now that we have examined the importance of the private sector and particularly industry as part of the new energy paradigm, I would like to focus on three specific action areas.

For the deep decarbonization of industry, countries will have to significantly increase their energy efficiency and to progressively switch from carbon intensive to low carbon and carbon neutral fuels and energy sources.

From the industrial demand perspective, there are three action areas that I would like to highlight today: energy efficiency, innovation, and climate financing.

Energy efficiency is a key technology option to achieve greenhouse gas emission reduction targets.

Approximately 40 per cent of the greenhouse gas emission reductions needed by 2040 could be achieved through efficiency improvements in the supply and end-use of energy.

First, energy management systems are recognized as a best practice to ensure sustainable energy efficiency and continual improvement of industrial performance. UNIDO has spearheaded the development of the international standard ISO 50001. We support over 20 countries in setting up a national programme on energy management in industry.

Second, innovation is an essential part of technological development and of technology adoption. Shifting the energy infrastructure towards low carbon sources needs both local technologies and new local players brought to the market.

UNIDO recognizes that the transformation towards a sustainable future has to be driven by the efforts of innovators, entrepreneurs and of small and medium sized enterprises.

One of the UNIDO flagship programmes in this area, Global Cleantech Innovation, engages directly with the private sector and promotes business models for clean and sustainable energy solutions while accelerating their growth. Over the past eight years, the Global Cleantech Innovation Programme has supported more than 865 companies in eight countries.

Thirdly, mobilizing investment for the energy transition is an indispensable enabler. As an example in this area I would like to mention the Private Financing Advisory Network, PFAN, hosted by UNIDO. This is a global network that identifies investment ready clean energy proposals. It advises companies on their business development and searches for appropriate financiers. The PFAN hosted by UNIDO has been successful in supporting over 110 clean energy projects, thereby leveraging almost $1.5 billion of investment.

Ladies and gentlemen, now that I have given a few examples on how UNIDO supports industries in mitigating their greenhouse gas emission, let me recap by emphasizing the holistic scope of our technical support.

Selecting technologies that increase operational efficiency and fuel consumption have multiple benefits for industry: they reduce costs, mitigate emissions and increase competitiveness.

Adopting and promoting new climate friendly services and technologies requires innovation. Financing is the enabler that can accelerate the transition.

In addition to their efforts to reduce emissions, many countries also need support in adapting to climate change. From an industrial development perspective, we focus on increasing the resilience of the human environment. We need to consider how to climate-proof power systems and utilities to ensure supply even when climate related disasters would occur. This is particularly important for least developed countries and small island developing States.

Ladies and gentlemen, let me conclude by highlighting the importance of partnerships to boost climate change action and help countries meet their Paris Agreement targets.

We need to work together and help Member States deliver on their national designated contributions and on the Sustainable Development Goals of the 2030 Agenda.

We need commitment, speed and economies of scale in the changing patterns of international production, investment and technological innovation.

I welcome the discussion at this important conference exploring the climate impact and benefits of nuclear technologies. All technological solutions are needed to attain the United Nations climate change targets and Sustainable Development Goals!

I thank you for your attention and wish you a fruitful discussion.

2.2.3. Intergovernmental Panel on Climate Change — Keynote Address

Statement as provided, verbatim.

H. Lee
Chair
Intergovernmental Panel on Climate Change
Bonn, Germany

Nuclear power currently supplies about 11% of the world's electricity. Today's output is lower than it was a decade ago.

Ten years ago, when there was no Paris Agreement, when the world's global temperature was not as high as today's 1°C above pre-industrial levels, when the world did not have the benefit of having the IPCC's special report on 1.5°C, we did not know at that time the impact of global warming between 1°C, 1.5°C and 2°C and its policy implications.

Four years ago, in December 2015, at COP21 in Paris, the countries asked the IPCC to provide a special report on this very important aspect and the impacts of keeping this warming to 1.5°C as well as the comparable mitigation pathways to achieve that global warming.

One of the key conclusions, as was very often mentioned in this conference, as well as also before this conference, is that it is feasible to achieve limiting the warming to 1.5°C. Considering that the world has already experienced a 1°C warming, it is feasible to achieve limiting the warming to 0.5°C. It is feasible.

But a more important message is, limiting that warming to 0.5°C comes with opportunities for a clean economy, job creation, better jobs, innovation, and great potential for achieving sustainability.

We analysed 21 models globally available, and we came up with the conclusion that to limit global warming to 1.5°C, global net anthropogenic CO_2 emissions must reach net zero around 2050. But that must be accompanied by very deep reductions in non-CO_2 emissions as well.

Obviously, emission reductions on that scale require very rapid transitions in energy, industries and consumption. Emissions in all of these sectors must be virtually eliminated — net zero — within a few decades.

Achieving this will require a wide portfolio of mitigation options and a significant upscaling of investments in those options. The transitions required to realize these emissions reductions are clearly unprecedented in terms of scale but not necessarily in terms of speed.

The benefit of restricting warming to 1.5°C is lower risks to ecosystems, health, security, water supply, and economic growth.

Now, what are the implications for the energy sector transitions?

We have so much relied on fossil fuel energy systems during the last 100 years. Reducing energy sector emissions to zero by 2050 involves three broad strategies:

(1) Energy efficiency improvement;
(2) Increased electrification;

(3) Decarbonization of electricity supply.

We examined 21 models and those 21 models provided a total of 85 pathways consistent with 1.5°C.

We look at efficiency first.

Efficiency is reflected in the data of the primary energy supply.

Across these 85 pathways, 1.5°C implies that the median primary energy supply declines from 582 exajules in 2020 to 503 exajules in 2030 — in ten years — and then 581 exajules in 2050.

These projections are of course uncertain and the range increases as they go further into the future. For 2050 the range is 289–1012 exajules.

In short, over the next 30 years global primary energy supply could grow at a rate of 1.9%, or decline at a rate of 2.3% per year. The median projection is no growth of primary energy supply to 2050.

Stabilizing primary energy for the next 30 years while global population and income rise is possible only with significant improvements in efficiency of energy production, transformation, distribution and final use.

The electricity share of global energy use is projected to more than double.

It is generally known that electricity is more versatile than fossil fuels and, in most energy uses, more efficient.

Based on median values of the 89 1.5°C pathways, electricity share as a primary equivalent of total primary energy rises from 19% in 2020 to 43% in 2050.

As usual, the ranges across the pathways are very large over three decades, but in every case global electricity consumption rises. The rate of growth varies between 0.5% and 5% per year. This is the range.

Increased electrification reduces emissions only if the power comes from non-fossil sources.

The fossil fuel share of electricity generation declines from 63% to 22% in the next 30 years. This is the strong median result of 89 pathways.

The non-biomass renewables offset the decline of fossil fuel generation in most of the increased supply. Over the 30 years, their supply increases from 25 exajules to 137 exajules, an average annual growth rate of 5.9%.

In most 1.5°C pathways, nuclear power contributes to the decarbonization of the electricity supply over the next 30 years.

Based on, again, the median results of these 89 pathways, nuclear power increases from 11 hexajules in 2020 to 23 in 2050, an average annual growth rate of 2.5%.

There are large variations, however, in nuclear power between models and across pathways. The pathway with minimum nuclear power assumption anticipates output of only 3 hexajules in 2050 — about 30% of the 2020 output, while the pathway with maximum reliance on nuclear power estimates 116 hexajules of nuclear power that year, a tenfold increase from 2020.

One reason for this large variation is that the future development of nuclear can be constrained by societal preferences, assuming that narratives underly the pathways.

The second reason for the variation is the technological assumptions built into the models. For example, only 7 of 21 models we analysed include a vast small modular reactor designs as possible technologies.

In addition to electricity generation, nuclear energy contributes to mitigation of other greenhouse gas (GHG) emissions in many pathways. Nuclear power is an option in 6 of the 21 models used to generate the emissions pathways.

Clearly, 1.5°C pathways are consistent with everything from negligible nuclear power to a tenfold increase in nuclear power over the next three decades.

The opportunity exists. The challenge is, how much of the opportunity will you be able to capture? Time is critical, so the share of the opportunity you capture will depend on the speed at which nuclear technology can be deployed.

In summary, human activity has already led to a 1°C increase in the global average temperature.

It is still possible, though challenging, to limit the global average temperature increase to 1.5°C, the goal of the Paris Agreement.

To meet that goal will require that global net anthropogenic emissions be reduced to net zero by 2050, and that human induced emissions of other GHGs be reduced to zero shortly thereafter. The strategies for reducing emissions are robust and well known: very ambitious efficiency improvements, increased electrification, and decarbonization of electricity supply. The available models indicate that this can be done using widely different mixes of technologies including pathways with much greater and with very limited use of nuclear power.

In short, there is considerable potential as well as uncertainty for nuclear power.

Obviously, we do not and cannot know what technologies will be available over the next 30 years and how they will perform. The challenge to nuclear power is to be a cost effective alternative to other non-fossil technologies and to deploy nuclear power much faster than in the past.

I wish you success in meeting these challenges because the climate needs all the help it can get.

2.2.4. World Nuclear Association — Keynote Address

Statement as provided, verbatim.

A. Rising
Director General
Wold Nuclear Association
London, United Kingdom

Ladies and gentlemen

It is fantastic to be here at the IAEA, to have this climate change conference right now, and I thank Acting DG Feruță and DDG Chudakov.

It is absolutely the right time; it is an important meeting with factual and scientific content. I have seen the programme and gone through and looked at everything: it is excellent.

Over the course of this conference we will hear about future technologies. We have already heard about climate change. I will concentrate on what is happening now.

I come from the World Nuclear Association. I am representing the global nuclear industry. Many other organizations here are representing governments. It is, I think, timely and good to have industry talking about its experience and what the industry can do.

The World Nuclear Association has 184 members, in 43 countries. The global nuclear industry is committed to delivering what it needs to do to save our planet from climate change. Our technology is ready, our supply chain is ready and our people are ready.

But to achieve the targets, to have success, we also need support from governments; otherwise the nuclear option will maybe fade away or not deliver its full potential.

We see that nuclear is moving higher up on the agenda. I would like to give some examples as further evidence that nuclear is now central and included in all discussions on the issues of energy and climate.

One initiative that has been running for the last two years is Nuclear Innovation for a Clean Energy (NICE) Future, established by three governments — the USA, Canada and Japan — and now with many other governments supporting this programme. We will hear more about it later in the programme.

We have already heard today the views of the IPCC on the role of nuclear energy in combating climate change.

I should also mention that the UN Economic Commission for Europe (UNECE) has had its first nuclear session. They are working with the Sustainable Development Goals, especially on energy, and nuclear is also included here for the first time. And UNECE has had its flagship programme, ‘Pathways to Sustainable Energy’, where the nuclear industry is working together with the UNECE to contribute information on the technology options, specifically nuclear and also, in collaboration with UNECE, IAEA and OECD/NEA, the role of nuclear energy in sustainable development on entry pathways; so this is work that is ongoing.

The IEA has published earlier this year its first nuclear report in 18 years. The report, 'Nuclear Power in a Clean Energy System', launched in May this year, stated that a failure to invest in existing and new nuclear plants in advanced economies would have negative implications for emissions, for costs and for energy security.

The IEA report also concluded that strong policy support is needed to secure investment and there is a need to reform policies to ensure competition on a level playing field. In the view of the IEA, electricity markets should value the clean energy and energy security attributes of low carbon technologies, including nuclear power. Licensing processes should support new construction by not leading to project delays and cost increases that are not justified by safety requirements.

Also this year, the World Energy Council issued a scenario report on nuclear energy. In all of their scenarios nuclear energy increases. The report concludes that nuclear energy is one of the most cost effective sources of energy in many countries and that nuclear energy contributes to clean low carbon energy system stability, and this is not currently valued and compensated for because usually only generation costs are compared.

Mr Lee, the Chair of the Intergovernmental Panel on Climate Change has just given an important presentation in which he talked about how we need to have a rapid energy transition and we need also to have scalability.

Mr Lee mentioned that in the many scenarios reviewed by the IPCC, nuclear energy increased on average by two and a half times. He pointed out that the amount of nuclear in the scenarios ranged from negligible to a tenfold increase. I would like to pick the middle ground and talk about the representative middle of the road scenario. In this scenario nuclear increases five times. This is a scenario where there is minimal disruption to life; it is not that everybody has to use a solar powered sailing boat from Europe to the USA — there are the commonly used ways to travel. The scenario allows us to keep our modern lifestyle, but nuclear would have to do a lot more to electrify those new processes and systems. And of course then you need to have a lot more nuclear, increasing by five times; there would be roughly 25% nuclear in the generation mix by 2050.

A 25% nuclear electricity share, that is when we are looking to the future role of nuclear energy, but we see that today nuclear is already contributing. Nuclear energy is contributing a lot — specifically because it is low carbon and there are not so many low carbon options out there supplying so much electricity.

But how will the future look? I think that it was well expressed by Mr Lee. The future is an opportunity. It is not written, it is up to us and it is up to us to take action.

One example of a country that has already taken action is France. In the mid-1970s, France was heavily reliant on fossil fuels for its electricity generation, with only a little hydro and nuclear. From that point France decarbonized by building nuclear power plants. Now the electricity in France has been decarbonized, and that includes meeting a substantial growth in demand with even more nuclear energy.

Some might say "Oh, that was the 1970s and 1980s; we can't do this today!" Of course we can! We can do it again and we can do it even better.

Nuclear energy gives rapid, large scale, long lasting decarbonization — you do not have to build your plant again only a few decades later because these plants will most likely run for 80 years.

Today nuclear power plants have capacity factors around 80% as a global average. Interestingly, new reactors with only a couple of years of operating experience achieve capacity factors over 80%, as do reactors that are 45, 50 years old.

When you build a nuclear power plant you are building a very big machine with a large electricity output and it operates 24/7, irrespective of weather or seasons.

And then some might say “No, no, no, construction times are so long we cannot have nuclear energy”.

Of course we can! We need to check the facts. If we look at the 90 reactors that have started operating from 2000 to today, typically the construction time is five–seven years. But also, of those 90 reactors, 27% were built in less than five years. So nuclear is fast, it is rapid, it is scalable and it is long lasting.

A lot of reactors have come on-line since 2016 and many more will before the end of 2020; we expect 47 in total. It is important to note that these 47 reactors are based on 20 designs: the smallest one 35 MW(e), the largest one 1720 MW(e). Nine of these designs were built for the first time. These reactors are being built in 11 countries, two of which are newcomer countries.

It is absolutely crucial that we have more newcomer countries, and it is a very important and professional support that the IAEA provides in assisting countries and supporting them in what they need for their infrastructure development because we all support newcomer countries to get access to clean, reliable and affordable electricity for their people.

The global nuclear industry has set a harmony goal to supply 25% of global electricity before 2050. That is roughly 1000 GW of new nuclear capacity. We will need this additional nuclear generation to make possible a cleaner, reliable energy mix for all of us.

You might think this is a hard task. And it is, it is ambitious, but it is also feasible.

Over the 20 years leading up to 2014, we were adding an average of 5 GW of new nuclear capacity per year. In 2015, it doubled, and we have been around this level since — that is, 10 GW(e) per year.

We can say the nuclear industry has been able to double its new build rate. But to meet the Harmony Goal we will need to double and even triple that build rate again. This the industry cannot do on its own; here is the opportunity for governments, and in fact also requirement for governments, to give policy support.

If governments do this, it will be possible. In the mid-1980s the nuclear industry was adding more than 30 big reactors per year.

The Harmony Goal programme is the framework of action that the nuclear industry is working on and this is to reach out to key stakeholders, to understand the options and potential of nuclear and what needs to be done to make use of this potential.

We urgently need to create a level playing field. Nuclear energy has to be treated on an equal basis with other generation options and recognized for its value as a reliable and resilient low-carbon energy provider.

This is an important target; yes it is a very important target requiring action now. Dozens of well-performing reactors around the world are at risk of early closure because of the failing markets.

In many countries governments have left it to the markets to sort all the complex issues related to energy and climate policy. Markets will not sort out these things. They have to be sorted out by governments putting the right frameworks in place.

As IAEA Acting Director General Feruţă said, nuclear delivers 24 hours a day, seven days a week. But the plants are not getting paid for the reliable nature of their supply. And that is why very productive and beneficial reactors might have to close down.

We need to increase decarbonization and we need to increase electrification at the same time. We need electric vehicles, we need to have heat, industrial processes and desalination — all these things need more electricity, and it will have to be clean, low carbon electricity.

Sweden was the fastest in the world in terms of adding nuclear capacity per capita. In combination with hydro it has very low carbon electricity. And trains are low carbon because they all run on electricity. But it is not possible to add more trains to meet demand because there are insufficient electricity supplies to power them. There is not enough electricity. And yet Sweden still plans to close down two reactors soon.

When looking at the costs of different electricity generation technologies, the levelized cost of electricity provides a good comparison, a fair comparison. According to data from the IEA and OCED/NEA, nuclear is one of the cheapest options.

But the levelized costs do not include system costs, which you should also include. This was already mentioned in the presentation by the OECD/NEA's William Magwood.

The system costs are low for nuclear, if not the lowest, whereas when you see the balancing costs, and utilization costs and other grid costs for the wind and solar you will see that they add quite a lot of cost to society. China is investing in nuclear energy. China is also very advanced in solar PV and wind. When considering levelized costs of electricity, their nuclear, even today, is one of the cheapest options. And then if you add system costs nuclear comes out as even more competitive. We do need all the renewables as well, but we should look at the whole cost each incurs.

We also need to create harmonized regulatory processes. We need to provide a more internationally consistent, efficient and predictable nuclear licensing regime and to facilitate significant growth of nuclear capacity and also timely licensing for innovative designs.

The variety of national regulatory requirements causes many drawbacks for the entire nuclear industry, including developers, vendors, operators and even regulators themselves. This results in increased costs and reduced predictability in project execution.

This is very important, particularly for small modular reactors, if we are going to bring nuclear energy to new countries. Airplanes can land in different countries even if they are designed in one country. We need an analogous system where you do not need to relicense everything when you move across borders.

We also need to create an effective safety paradigm. We should focus on the genuine public wellbeing — the health, environmental and safety benefits of nuclear have to be appreciated and better valued, especially when compared to other energy sources. When you look at the safety of different forms of electricity generation, nuclear is the one with the lowest fatalities per energy produced.

We can put in perspective the service nuclear does in the electricity system with other sectors, such as transport. The world's transport system is responsible for a lot of dangerous gaseous emissions, including carbon dioxide. Nuclear generation avoids the emissions of more than 2 500 000 tonnes of carbon dioxide yearly, compared to coal fired generation. That is equivalent to removing 400 million cars from the world's roads and keep them off the roads.

Nuclear reactors are the low carbon backbone of the electricity system that operates in the background day in and day out, often out of sight and out of mind. They are the silent giants we rely on, daily.

Nuclear energy and nuclear technologies meet Sustainable Development Goal 7 — Ensure access to affordable, reliable, sustainable and modern energy for all — and Sustainable Development Goal 13 — Take urgent action to combat climate change and its impacts.

I would also like to mention one thing in addition; it was from the Ministry of Energy in the United Arab Emirates, where the World Energy Congress was hosted just over a month ago. They said "Yes, we know that nuclear energy will give us low carbon electricity. But it's not only that, it will give us jobs — interesting jobs — and a lot of economic growth. Thanks to what we are doing in the UAE we now see that our companies in the supply chain are getting to 'nuclear quality' — they have stepped-up in order to be suppliers to the nuclear projects. And now they have the quality to act on the world stage and export. So they see significant economic development".

So I am now turning to you, we have now been able to double the number of reactors that we are putting onto the grid, but we now need to triple from here. We need governments to take this opportunity, make use of the support the IAEA is giving, make use of all the information and experience there is in the nuclear industry.

As I said, the supply chain is ready, and governments must take action to allow the nuclear industry to deliver the Harmony Goal, to enable the world to meet the climate challenge.

Thank you very much.

2.2.5. International Energy Agency — Keynote Address

Statement as provided, verbatim.

F. Birol
Executive Director
International Energy Agency
Paris, France

Ladies and gentlemen,

Thank you very much for giving me the opportunity to share with you the International Energy Agency's views on energy, nuclear energy in particular, and climate change. We at the IEA are very fortunate experts, because we have all the energy data at our fingertips; make our judgements, recommendations, analysis based on data.

When we look at the last year, 2018 energy data, we see a few interesting points: number one, global energy demands last year increased the strongest in the last ten years, about 2.3%, a very strong growth. More importantly, electricity demand increased even two times higher than the energy demand. This is an ongoing trend, and we expect this trend to continue and the growth of electricity is very, very pertinent and much higher than energy demand. As such, we believe electricity is the future.

But coming back to 2018 again, despite the growth in renewable energies, in solar, wind and others, we saw last year global emissions increased and reached a record high; 2018 global CO_2 emissions reached a record high. And as such a key message for me is that there is a growing and dangerous disconnect between the climate ambitions reports, meetings, government intentions and what is happening in the real life. More and more reports, stronger ambitions, more speeches — like mine here — and we saw that the emissions still do increase.

Therefore, we believe, and we believe very strongly at the IEA, that we have to look at all clean energy technologies, to make the most of those options. Renewable energies, solar and wind, are definitely important parts of this picture, but we also think that the nuclear power, carbon capture, utilization and storage, and other clean energy technologies are important. In that context we have very recently prepared a report on nuclear energy, many of you may know — and I hope you know — looking at the current set of play in nuclear power at its importance in terms of climate change and also electricity security and what are the recommendations for the governments around the world. And our numbers show that today nuclear power is the second largest clean electricity source for all renewals put together. And in the advanced economies, in the developed economies, it is number one, with about an 18% share of total electricity generation.

But, ladies and gentlemen, when we look at the future, we have all the reasons to be worried from a nuclear point of view and also from a CO_2 emissions point of view. The nuclear fleet around the world today is ageing, and we do not see a major new activity in most of the developed countries. Even lifetime extensions are becoming a major challenge. Our numbers show that without changing the policies of advanced economies, this 18% share in total electricity generation will go down sharply to 6%. And, as such, reaching our climate targets will be even more difficult.

We think there is a role for governments, those governments especially which take climate change and electricity security seriously, to provide support for the existing power plants, providing the framework conditions for lifetime extensions, and also for all the countries around the world to look at the new technologies, such as SMRs. SMRs, small modular reactors, are very promising technologies and they can be of great help for developed and developing countries to meet their growing electricity demand.

To finish, dear colleagues, we believe the challenge of climate change is a great one, a difficult one, especially when we look at the numbers today for CO_2 emissions and in the energy sector. We need all technologies to be part of the game. I know that some of us like this technology, others favour another technology, but we do not have the luxury to pick out our favourite technologies. The time is not for boosting our own egos, but to reduce the CO_2 emissions, and here we need nuclear power together with other great technologies. Thank you very much.

2.2.6. United Nations Framework Convention on Climate Change — Keynote Address

Statement as provided, verbatim.

P. Espinosa
Executive Secretary
United Nations Framework Convention on Climate Change
Bonn, Germany

Presented by
I.F. Vladu

Mr. Chair,

Your Excellency Mr. Liu Zhenmin, Under-Secretary-General for Economic and Social Affairs, Mr. Li Yong, Director General of the United Nations Industrial Development Organization, Prof. Hoesung Lee, Chair of the IPCC, Ms. Agneta Rising, Director General of the World Nuclear Association,

Your excellencies, distinguished delegates, ladies and gentlemen.

Unfortunately, Ms. Patricia Espinosa, the Executive Secretary of the UNFCCC Secretariat, could not be here with you today. On her behalf, I would like to thank the IAEA for this opportunity to address you and deliver her opening remarks.

Mr. Chair.

We live a climate emergency. This is a fight for our lives. This is a fight we must win. Business as usual is no longer an option. Everywhere, people demand more vigorous and quick action to stop climate change. Everyone wants a sustainable future. Everyone wants to live on a clean, green and healthy planet. It is our responsibility to listen to them. And achieve results.

We have very little time left. The window to act is closing fast, though 2019 and 2020 give us a chance, which could be the last.

To stop runaway climate change, to avoid more weather disasters, to avoid more suffering, nations need to use all options at their disposal to update their climate action plans under the Paris Agreement by 2020.

We need these plans to be much more ambitious than they are now. Because we are going in the wrong direction. We need to adapt to a changing climate. We need to stabilize the global temperature rise at 1.5°C.

But we are on route to an increase of more than double. And this means an uncertain future for humanity.

What is the conclusion? We need more climate ambition. And we need it now.

Your conference provides an opportunity to advance. You can help those nations willing to do so to consider or strengthen their use of nuclear power.

Nuclear is a mature, low carbon energy source which already contributed to reducing emissions. Nuclear energy can help limiting global warming at 1.5°C. But this, according to the IPCC, would require doubling the nuclear energy supplied in 2050 as compared to 2020.

The greenhouse gas (GHG) emissions and health risks of nuclear power are low, land requirement is lower than that of other energy sources, but the deployment of nuclear power is constrained.

Good work has been done to remove deployment barriers, but more is needed.

You need to address the high costs, risks of accidents and of proliferation, the long term storage of nuclear waste and social opposition.

We need your help to boost climate action throughout the world and to have that action reflected in the next round of Nationally Determined Contributions and Long term Low Emission Development Strategies, which are due next year.

For that to happen, we must harness the energy, momentum and ideas from all people at all levels. We must work to find solutions together.

On behalf of the Executive Secretary of the UNFCCC Secretariat, I wish you a successful conference!

2.3. OUTCOMES OF THE IAEA 2018 MINISTERIAL CONFERENCE ON NUCLEAR SCIENCE AND TECHNOLOGY — KEYNOTE ADDRESS

Chairperson: M. Chudakov, IAEA

Statement as provided, verbatim.

N. Mokthar
Deputy Director General and Head of the Department of Nuclear Sciences and Applications
International Atomic Energy Agency
Vienna, Austria

Distinguished guests, ladies and gentlemen, colleagues.

It is a pleasure for me to join you today to address this important conference. Climate change is one of the most serious issues facing the entire world today. This week you will discuss how using nuclear power as a source of energy can help mitigate the effects of climate change. Today I would like to highlight how nuclear science can provide tools to monitor climate change and provide solutions for adaptation to its effects.

In November 2018, the first IAEA Ministerial Conference on Nuclear Science and Technology concluded with the adoption of a Ministerial Declaration that stated: "10. *We recognize* the importance of the IAEA's work in nuclear power applications, non-power applications of nuclear science and technology as well as in nuclear safety to monitor environmental changes to ecosystems and to assist Member States…in adapting to climate change impacts and in mitigating climate change as a global challenge".

It is useful to think of nuclear and isotopic techniques as precision tools that allow precise measurements. This ability to monitor changes in our surroundings to such an accurate level allows scientists to provide the key information decision makers need to monitor and protect their natural resources.

In terms of monitoring the climate, a lot of our monitoring work is done through our four environment laboratories, three of which are located in Monaco, by the sea, and one, our Terrestrial Environment Laboratory, here in Austria.

To help Member States better understand the amount of carbon being released into the oceans and atmosphere, the IAEA has recently developed a precise carbonate reference material. Its use in laboratories is improving the accuracy of emission measurements, and can therefore help Member States better estimate and manage their emissions. It is clear that the amount of CO_2 in the atmosphere is rising — and by examining the isotopic ratios of the carbon we can also identify its precise origins.

The increased carbon levels are also having a significant effect on the oceans, as the oceans absorb about a quarter of the CO_2 emitted by human activities every year. This is resulting in increasing ocean acidification. We can use our tools to study it and the effects it has on socially and economically important seafood. We can show that when acidity levels increase, decalcification occurs and many species struggle, and reproduce less successfully. Some marine species absorb more metals and toxins, grow more slowly and need more food to survive. The contaminants they absorb can move up through the food chain, and ultimately arrive on our tables too. We now know that marine species that are stressed or run down by these changing conditions are more susceptible to illness, just like humans!

Our laboratories train experts around the world on the use of various techniques that help us understand these long term effects of ocean acidification, and enable a rapid and precise identification of various harmful toxins in marine species. It is this kind of information that can support many seafood safety monitoring initiatives worldwide.

Another important aspect is the development of tools to monitor the Earth's freshwater resources, which are precious and limited, and under stress. Most of the water we use is hidden underground. Knowing how much is being extracted and how quickly it is being replenished, or affected by pollution, is essential to appropriate water management policies. Isotopic techniques can map global groundwater resources and reveal the exact age of the water stored there. This information helps water managers to calculate groundwater extraction and replenishment rates.

In an important project in the Sahel region of Africa, for example, the IAEA assisted 13 Member States to produce the first-ever broad overview of groundwater availability and quality in this water stressed areas. Similar large scale multinational initiatives have been undertaken in Latin America, where groundwater isotopic data have been integrated into hydrological maps. These tools inform managers where to place appropriate water management efforts, and where supplies are vulnerable to pollution. Likewise in the Asia–Pacific region, isotopic tools are allowing authorities to assess and manage deep groundwater resources, as climate change has begun to affect more traditional sources.

How will climate change influence water supplies in the coming years? It is difficult to say precisely, but we can use models to make projections. And here at the Agency we develop and promote a range of isotopic tools to enable scientists to predict future scenarios on water availability. The IAEA has a huge store of water isotope data from our continuous global water monitoring programmes, many of which have been running for over 60 years. By making use of these long term records, the Agency has developed an Isotope-enabled Water Balance Model. The model has been successfully tested in the Nile River basin and is able to give better estimates of available water resources. Scientists and researchers are working to further extend the forecast component of this model right now.

Ladies and gentlemen

It has always amazed me just how versatile nuclear science is. It is operating everywhere behind the scenes to make lives better. Of course, it is operating in our research reactors and power stations. But it is also at work on our farms and food supply chains, keeping crops, animals and food safe, and even helping us maintain the health of the soil itself. And it is in this area of food and agriculture that I will briefly mention some of the work we are doing in terms of adaptation to climate change.

One of the continual challenges humankind faces is producing more food for growing populations, while using fewer resources, in changing climatic conditions. The IAEA supports a range of adaptive activities in the agricultural sphere: namely, plant breeding, soil and crop management, livestock production and insect pest control. In fact, we operate five laboratories dedicated to these five specific areas, right here in Austria, that provide a global venue for training and the latest research into techniques that can help countries adapt to the issues that face them.

Crop adaptation to climate change is essential for food security. We use a technique called plant mutation breeding in which radiation is used to induce beneficial mutations. This method has allowed the development of high yield crop varieties that are more resistant to harsher conditions, such as drought, heat, wind, hail, frost and salinity. There are thousands of such crops now being grown all over the world, with new varieties being developed all the time in Member States as conditions change. Today, for example, we are working with Bangladesh on rice, in Namibia on drought resistant chick peas, in Kuwait on barley in the desert, and many more. Billions of people depend on these adapted varieties — and the work in this sphere is becoming even more important as populations increase.

As weather patterns change, so does the distribution of insect pests that attack crops and livestock, and we use the sterile insect technique, a method by which billions of males are irradiated, so that when they are released and mate with wild females, no offspring are produced. This has led to the successful suppression of many dangerous and economically devastating insects such as the tsetse fly and fruit flies. Just recently, Senegal reported a 98% suppression of the tsetse fly in a target region. In 2017, the Dominican Republic reported that it had stopped an economically devastating outbreak of the Mediterranean fruit fly. Nuclear techniques work! And today a lot of attention is focusing on developing the technique to target the mosquito, one of the most dangerous and pervasive vector insects of them all.

I hope I have been able to give you a glimpse today of the work that is being done. There are a hundred more adaptation stories I could tell you about soil health, animal health, and food security, and just how extraordinary and important nuclear techniques are in terms of monitoring the climate and adaptation to climate change, but my time with you today is up.

But please do find the time to browse the Agency's website where you will find excellent information on our work in nuclear energy. Also take a look at the nuclear sciences and applications and technical cooperation pages. There really is a world of nuclear experiences to be enjoyed there!

Thank you.

2.4. HIGH LEVEL PLENARY SESSION OF MEMBER STATES

Chairperson: M. Chudakov, IAEA

This section provides the oral plenary presentations made by Argentina, Bangladesh, Brazil, China, Egypt, France, Hungary, India, Mongolia, Morocco, Russian Federation, United Kingdom and USA. Additional material relating to the presentations is provided in the on-line supplementary files which can be found on the publication's individual web page at www.iaea.org/publications.

2.4.1. Argentina — Keynote Address

Statement as provided, verbatim.

J. Gadano
Deputy Secretary of Nuclear Energy
Undersecretariat of Nuclear Energy
Argentina

Good afternoon. I am Julian Gadano, the Argentine Deputy Secretary of Nuclear Energy since 2015 and the President of Nucleoeléctrica Argentina (the operator of the Argentine nuclear power plants) since 2019. Today, I am pleased to be here in order to present a broad overview about the role nuclear power can have to mitigate the huge crisis of climate change and present the argentine situation and the work locally done on the subject.

INTRODUCTION: CLIMATE CHANGE AND THE NEED FOR NUCLEAR ENERGY

Argentina acknowledges climate change is one of this century's major problems: the demand for accessible, safe and clean electric energy is currently increasing more than ever and while electricity consumption continues to rise, air pollution and greenhouse gas effect emissions must fall. It is clear that the energy industry is changing faster than ever and that there are plenty and complex challenges in the energy sector to be solved under the big transition that has to be done into diversified energetic matrixes. Argentina understands that the new technological improvements within the digital era are currently altering the supply and demand regarding the energy sector, implying new consumption patterns, and the need to develop creative partnerships, optimization methods and new industrial standards.

With a more complex energetic market scenario, an evolved behaviour of energy customers and a more globalized and integrated world, there is an unavoidable requirement for innovation, entrepreneurship and flexible business models. This need is extremely important in order to adapt to the altered market demands, to force existing players to reexamine the way they operate and to drive them into low carbon solutions.

CURRENT DILEMMA

In this regard, to supply the growing demand for reliable, affordable and clean electricity, countries will urgently need to work towards the implementation of different types of low-carbon energy sources to work together and deliver energetic supply non-stop. The main controversial issue regarding this point implies that energy production coming from fossil fuels is currently increasing faster than clean energy. Coal and fossil fuels have very high environmental costs and are the ones raising the plant's temperature causing climate change. At the same time, nuclear comprised 17.5 per cent of global electricity in 1994, and this number has gone down to 10.5 per cent in 2016.[2] These figures reflect that in the long run nuclear power is declining regarding absolute terms. Clean, low-carbon, energy production has been on the decline during the last 3 decades: since 1995 it has gone from 37% to 32%.[3]

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[2] ENVIRONMENTAL PROGRESS, Global outlook. http://environmentalprogress.org/global-crisis

[3] ENVIRONMENTAL PROGRESS, Energy and the Environment. http://environmentalprogress.org/energy-and-environment

NECESSARY AND URGENT SOLUTION

These figures present a worrying challenge because global warming has to be slowed down, and to achieve that goal there is a requirement to turn today's 32% of low carbon power into 100% and as quickly as possible[4].

In this sense, considering the current scenario and figures, and that the deployment of Renewable sources alone cannot add up quickly enough to decarbonize at the rate we need (due to intermittency) there is an urgent need for the deployment of nuclear energy.

THE NEED FOR NUCLEAR ENERGY

In the first place, only nuclear power can provide clean, reliable energy without enhancing global warming and being a 24/7 support for renewable sources. Secondly, nuclear uses the least amount of natural resources and produces the least amount of waste. Thirdly, investments in nuclear power plants are long term: its useful life can last for 60+ years.

ARGENTINE SITUATION. GREENHOUSE GAS EMISSIONS

In this sense, it is important to make explicit the situation in which Argentina is at the moment and the main figures that reflect the local scenario.

Argentina created in 2015 a Secretariat dedicated to Environment and Sustainable Development. Its objective is the implementation of environmental public policies and its management within the country and the National Administration.

This Secretariat has developed a National Greenhouse Gases Stocktaking[5], which posts the emitted and absorbed gases into the atmosphere during a whole calendar year. It includes only the emission and absorption sources for which there is the necessary information available to carry out the evaluation, according to the quality principles of the Intergovernmental Panel on Climate Change[6]. The most recent figures regarding this locally developed instrument of measurement are the following.

In 2014, Argentina emitted 368 Mt CO_2 eq, with 52.5% of the emissions coming from the energy sector, followed by 39.2% coming from the agricultural sector, the industrial processes with 4.5% and finally the residual handling with 3.8%[7]. The following main local climatic trends in Argentina, which affect the natural systems as well as the human activities, were identified:

- Annual average temperature increase in the whole country.

4 ENVIRONMENTAL PROGRESS, Global outlook. http://environmentalprogress.org/global-crisis

5 Self-translated from Spanish: Inventario nacional de GEI (Gases de Efecto Invernadero).

6 The Intergovernmental Panel on Climate Change is an IO established for the first time in 1988 by two UN organizations: the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) and later ratified by the UN General Assembly through resolution 43/53. Its mission is to provide scientific assessments about the information (scientific, technical and socioeconomic) regarding the current Climate Change risk caused by human activity, its potential environmental and socioeconomic consequences and the possible options to adapt to those consequences or mitigate its effects. It is presided by Hoesung Lee.

7 National Greenhouse Gases Stocktaking (2017), p.12. https://inventariogei.ambiente.gob.ar/resultados and https://inventariogei.ambiente.gob.ar/files/inventario-nacional-gei-argentina.pdf

- Hydric stress due to the temperature increase, mostly in the north and west regions of the country.
- Increased frequency of extreme precipitations and floods, in the northeast and centre regions of the country.
- Temperature increase in the Patagonia and Cuyo regions, with retreat of the glaciers.
- Increment of the river flow rates and the frequency of floods, affecting the maritime littoral region and the River Plate's coast.
- Retreat of the rivers and projected water crisis in Mendoza, San Juan, and Comahue[8].

ARGENTINE ACTION PLAN

The Argentine action plan, that is already being carried out by the national government, consists of the following.

In the first place, the idea consists in finding the points of interaction between the increasing energy demand and the energy supply, and in this sense, design and implement the following mitigation measures.

(1) Firstly, energy efficiency.
Regarding efficiency in home applications, efficient water heaters, heat pumps, water-saving devices, street lightning, residential lighting and thermal insulation in buildings.
(2) Secondly, renewable energy.
By implementing solar water heaters, electricity generation from non-conventional renewable resources connected to the grid, generation of distributed electricity and off-grid electricity generation.
(3) Thirdly, fuel.
By mixing with biofuels
(4) Last but not least, large scale generation.
By deploying nuclear, hydroelectric generation, as well as substituting fossil fuels with natural gas for electricity generation and improving the efficiency of thermal power stations.

These four pillars are being constantly monitored and under continuous revision, are being boosted with appropriate funding and are carried out through a participatory process in which the national cabinet of climate change, national ministries, provincial governments, NGOs, academia and the private sector are being jointly involved.

THE ARGENTINE NUCLEAR SECTOR

Some of the more relevant characteristics of the sector are:

- Firstly, Argentina has more than 60 years of the peaceful uses of nuclear energy.
- Secondly, Argentina has the capacity to run the entire fuel cycle.

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[8] National Greenhouse Gases Stocktaking (2017), p.5. https://inventariogei.ambiente.gob.ar/files/inventario-nacional-gei-argentina.pdf

- Furthermore, Argentina is an exporter country of nuclear technology (reactors, radioisotopes). For example, Argentina exports to Peru, Algeria, Egypt, Australia, Holland and India.
- In this sense, the nuclear cluster is one of the most sophisticated technological industry in Argentina and is constantly expanding.

NPPs OPERATING IN ARGENTINA

Currently, the operative nuclear power plants in Argentina are three and add up 1790 MW of power. The NPPs Embalse and Atucha II use natural uranium technology and heavy water, while Atucha uses slightly enriched uranium and heavy water.

In 2019, the 3 NPPs are working simultaneously, and are representing 9% of the total energy generation.

Within the Energy Plan of the Secretariat of Energy for 2030, the aim is to increase the nuclear generation to represent 11% of the electric generation in the country. This is going to be carried out with the startup of the IV (fourth) Argentine NPP based on PWR technology in 2028, and with the completion of the CAREM Small Modular Reactor prototype in 2022.

MAIN ACCOMPLISHMENTS IN CLIMATE CHANGE POLICY

To continue, I would like to remark on the main accomplishments in climate change policy that Argentina has made during the last period:

- In the first place, the executive is working on a National Law Project that establishes the necessary objectives in order to address climate change as a National State policy.
- In 2015, Argentina signed COP21.
- At the same time, Argentina has created the first National Cabinet for Climate Change.
- What is more, under the Argentine Presidency of G20, the Climate Sustainability Working Group was created.
- Finally, the climate risk maps system, a very important tool for this purpose, was created.

With the points above, Argentina strongly believes that the need for nuclear energy is essential to reverse climate change without ignoring the new increasing demands for clean, reliable and affordable energy. Nuclear generation — a 24/7 source of energy — is essential in order to supply the increasing energetic demand that the 21st century is calling for, but in a clean, sustainable and affordable way. In this regard, it is key to state that the incorporation of nuclear energy into energy matrixes specifically targets the Sustainable Development Goals 7[9] and 13[10]. In this framework, it is important to remark that the International Energy Agency (IEA) and the Nuclear Energy Agency (OECD/NEA) state that in order to achieve the necessary

[9] UNITED NATIONS, Sustainable Development Goals. SDG 7: Affordable and Clean Energy. Retrieved from https://www.un.org/sustainabledevelopment/energy/

[10] UNITED NATIONS, Sustainable Development Goals. SDG 13: Climate Action. https://www.un.org/sustainabledevelopment/climate-change-2/

production to supply the increasing energy demand, nuclear energy generation must more than double globally by 2050 — reaching 930 GW of total installed capacity[11].

CONCLUSION

As a conclusion, it is important to remark the urgent need to join forces towards policymaking. In the light of the new global climate agreements, new policies are definitely needed. Argentina believes in the power of technology as a solution to climate change in energy provision to boost energy efficiency. Argentina emphasizes that governments and policymakers have to take initiative and responsibility to enable new possibilities, new solutions, new alternatives for the energy sector, new ways of providing energy such as the deployment of small modular reactors.

We are under a crisis, climate change is an actual crisis, and this time we have the determinant responsibility not to fail in mitigating this crisis in effective ways. Once and for all. We owe that to next generation and now we have run out of time. We cannot fail now. In this sense, since nuclear is a baseload, reliable, affordable and safe source of power, Argentina believes in the peaceful uses of the atom to combine rapidly with renewables, diversifying matrixes and cutting emissions. Starting today.

[11] IEA and OECD/NEA, Technology Roadmap: Nuclear Energy 2015 edition. Retrieved from https://www.oecd-nea.org/pub/techroadmap/techroadmap-2015.pdf

2.4.2. Bangladesh — Keynote Address

Statement as transcribed, verbatim.

M.A. Zafar
Ambassador and Permanent Representative of Bangladesh
Vienna, Austria

Good afternoon.

At the outset, let me express our delegation's sincere appreciation to the IAEA and its staff, in particular the Department of Nuclear Energy under your leadership Mr. President, for making excellent preparations for this conference.

Mr. President.

Bangladesh is one of the most vulnerable countries to the adverse impacts of climate change. The country is experiencing progressively significant climate change impacts that are affecting national economy and development as well as lives and livelihoods of the people. Approximately 40 million people in the coastal areas of Bangladesh are under the direct threat of displacement from a 1°C rise of global temperature from the pre-industrial level. Climate change will threaten the significant achievements Bangladesh has made over the last decades in improving economic, social and environmental aspects and poverty eradication and welfare of its people, and the path towards achieving the SDGs.

Mr. President.

Climate change poses a significant risk to the economic development of Bangladesh. The economic losses due to climate change in Bangladesh over the past 40 years were at an estimated $12 billion, which is depressing the GDP annually by 0.5 to 1 per cent. According to a World Bank (WB) report of 2018, 134 million people, or 82 per cent of the population of Bangladesh, are at risk of declining living standards through loss of productivity and income as a result of erratic climate change.

In the face of such grave scenario, Bangladesh is putting greater efforts to meet the adaptation needs with its limited resources. Despite being a climate vulnerable developing country, Bangladesh has pioneered among its peers in establishing a climate fund entirely from its own resources to combat climatic adversities. With an allocation of $420 million from the revenue budget of the Government, a Climate Change Trust Fund (CCTF) was established in 2009 to implement the projects undertaken in line with the Bangladesh Climate Change Strategy and Action Plan (BCCSAP). Already 687 government projects have been awarded from the Trust Fund. Among those, 313 projects have been successfully completed. For the last two decades, the country had to spend more than $10 billion for addressing climate change. Recently Bangladesh has developed a Country Investment Plan (CIP) for Environment, Forestry and Climate Change sectors, which provides a strategic framework for national and international investments in these sectors in coordination with the relevant stakeholders for implementation.

Mr. President.

The IAEA has a significant role in dealing with climate change challenges, which was duly recognized during the Ministerial Conference on Nuclear Science and Technology held last year.

I recall that the Conference also recognized that a good number of the Member States considers nuclear power as a low carbon energy source that contributes to mitigate the impact of climate change and to the achievement of their Sustainable Development Goals. In this context, may I add that Bangladesh is one of those countries.

In this context, I also recall the 10th Ministerial Meeting of the Forum for Nuclear Cooperation in Asia (FNCA), held in Tokyo in December 2009. The Ministerial meeting recognized that the case studies conducted under the FNCA framework on the assumption of including nuclear power in the Clean Development Mechanism (CDM) under the United Nations Framework Convention on Climate Change (UNFCCC) had been quantitatively shown to be beneficial. Thus, FCNA would promote, both domestically and internationally, the inclusion of nuclear power in crediting mechanisms in the post-2012 international framework on climate change.

Mr. President.

Bangladesh strongly believes that nuclear energy provides access to clean and reliable energy, contributing to mitigating the negative impacts of climate change. My country therefore took the decision to introduce nuclear power in its national energy mix back in 2010. In the same year, Bangladesh prepared its first Power System Master Plan 2010, which was later revised in 2016. At this critical juncture, the issue of climate change was given due consideration. We found nuclear energy to be a safe, environment-friendly and economically viable source of electricity generation, which is also reflected in the Intergovernmental Panel on Climate Change (IPCC) Special Report published last year. According to our Master Plan, by the year 2041, 9% of the total electricity for the country, or 12 000 MW, will be nuclear power. This path will not only secure the required energy for our sustainable growth, but will also help us to successfully fulfil the voluntary and conditional commitments we made under the Paris Agreement.

You are aware that Bangladesh started the physical construction of the Rooppur Nuclear Power Plant, the first NPP of the country, in 2017. By now, casting of first concrete of both Unit 1 and Unit 2 have been done, Core Catcher for both the units have been installed and all necessary construction works are going in full swing strictly following the fixed schedule. Rooppur NPP is likely to generate 1200 MW electricity from unit 1 by the year 2023 and another 1200 MW from unit 2 by 2024.

Mr. President.

Climate change is a global phenomenon that goes beyond national borders. It is an issue that needs to be addressed through collective efforts and innovative solutions not only at the national level but also in the local and regional plane. The Paris Agreement calls for a coordinated and combined effort in local and regional level to ensure effective climate action in a sustainable manner.

Bangladesh believes that the effective implementation of the Paris Agreement is a collective responsibility for shared prosperity. Climate finance is a key to this end. All countries must work hard to set a new collective quantified goal from a floor of $100 billion per year, including transparency of climate finance. Climate financing should be need-based and developed countries need to come forward to provide accessible, adequate and predictable climate finance to the developing countries as agreed upon in Paris. LDCs and the climate vulnerable countries should receive particular attention in this regard.

Mr. President.

In conclusion, I would like to underline that nuclear power can contribute significantly in reducing global greenhouse gas emissions. At the same time, it can help to tackle increasing energy demands and provide support for achieving Agenda 2030, particularly Goal 7, as energy is essential for economic growth, especially for the developing countries and improved welfare of their peoples. We, therefore, urge the Agency and fellow Member States to make best use of nuclear power, along with new innovations and technology, to make continued contribution towards that direction.

I thank you.

2.4.3. Brazil — Keynote Address

Statement as transcribed, verbatim.

R. Danilow
General Coordinator
Ministry of Energy and Mines
Brazil

Good afternoon.

I would like to start by thanking the IAEA for the invitation and the opportunity to be speaking here in such a rich environment about subjects that are very important for Brazil.

Also thank all participants for their interest of watching our panel.

My goal today is to present Brazil's energy and power sector, how we think long term planning, including our expectations for our energy transition. Naturally, the focus will revolve around nuclear power generation.

So, one of the greatest challenges Brazil has in the energy sector, is to keep pace in expanding the energy supply to supply energy for an ever-growing demand. Our reality is one where energy demand follows closely the GDP growth and for instance in the power sector, we expect demand to rise by 3.6% per year until 2027.

Brazil has started its energy transition a few decades ago, when we decided to explore our potential for hydro power plants and for bio-fuels. Today, our stock capacity is of nearly 85% of non-emitting energy sources. Unfortunately, hydro power expansion is almost achieving its limits of available sites, and also there is discussion on environmental issues for new hydro power plants in more isolated regions.

When you take a broader view, the energy sector as a whole, is also quite clean. We have almost half of our energy consumption in Brazil from clean, renewable energy sources.

And this is very significant for us, especially when we compare ourselves to other countries. The energy mix until 2027 is expected to be even cleaner and achieve a share of 48% of renewable energy.

Our minister has been stating quite often that all our efforts in the policy arena will be guided by these policy axes. We need to attract investment, to expand supply in the energy and so we need to create and attractive investment environment. We estimate that we need $370 billion investment in the oil, gas sector and the power sector. A third of which is for the power sector.

And talking about the future, I move on the next topic of the presentation about energy planning. We have two main instruments to elaborate our planning.

The first one is the 10-year energy expansion plan. This is released once a year. Its main goal is to disseminate information. The expansion supply for the next 10 years is mainly done by projects for investments have already been made. So, what we try with this instrument is to align information from the markets and so investors are better informed to have greater efficiency in their decision making for future projects. The second instrument is the national energy plan that is released every 5 years. It is quite different from the first one because it has a 30-year time horizon and is a policy tool to provide subsidies and open a discussion with the society for more strategic policy decisions.

After the plan is published we set up a task force and we analyse several different scenarios with different future paths that we can take and so this action plan that is set up after the plan's publication is a huge dialogue with society so we can choose our objectives and our targets for the next decades.

The graph shows our expected power matrix for 2027 in relative terms. There is a lot of information that can be extracted from here, but the message I want to give you first is that we can expect our power sector to remain clean until the end of the next decade.

Notice that almost all non-emitting sources will increase their participation in the energy mix and this is due mostly to the market behaviour because these are the most cost competitive sources. The exception here are hydro power plants; as I mentioned, we currently have a limited number of sites available for new plants, and although they will continue to grow, they will not do so at the same pace.

About electricity generation, we expect to have to deliver 40% more electricity in 2027 than we did 2 years ago and we intend to do so by increasing by 6% points the share of renewables. And regarding nuclear specifically this rise that you see is due to the new nuclear power plant Angra 3 that we want to be delivered by 2026.

All of this puts us in the positive situation where we can continue to expand our energy supply without compromising our expected economic growth and without compromising our environmental sustainability.

This is a graph of the CO_2 emission per capita relating only to energy use. But also we do not want to get stuck in a comfort zone, we want to be even cleaner. And Brazil has set out Nationally Determined Contributions for the Paris agreement to reduce its greenhouse gas emissions. In the energy sector, in the power sector we have some targets that relate to increasing the share of renewables not only by hydro power plants but also the use of bio-fuels in the power and the transportation sector, increase the use of wind, solar but also nuclear power plants.

And finally, we intend to obtain gains in the use of electricity, efficiency gains.

We move on to the final part of the presentation about nuclear power generation. First I present the two nuclear power plants that we have: Angra 1 and Angra 2. They have been operating for quite some time and they both together have installed capacity of 2 GW and represent 2.6% of Brazil's power generation. The third plant of this complex, Angra 3, as I mentioned, is a project that has been under construction with physical progress of nearly two-thirds but is for the moment on hold for a set of reasons.

We have a presentation here in this conference on Wednesday by Electronuclear. That is a company that has been developing this project, so there you can have more information and details about it. But the message is, the federal government has set this project as a priority infrastructure project. We are now in a big effort from government, together with Electronuclear, to remodel the business model and to define a private partner to resume construction in 2021 and deliver it on-line in 2026. We estimate the investment to be \$3.7 billion until then.

This is very modest scenario, especially when compared to some other countries which have much larger nuclear energy programmes. And we want to move forward, we want to expand our share with nuclear and we have the means now we are aware of the benefits. Regarding the means to achieve such a larger plan, we believe that Brazil has a set of special conditions for it, in the sense that we have national uranium reserves; they are the 5th or 6th largest natural reserves in the world. Only 30% of our area has been prospected. We have the knowledge of the entire chain of treatment of the fuel and we have currently operating nuclear power plants. As far as we know, only a few other countries have this set of conditions.

Future nuclear power plants should be discussed with society in the national energy plan that I have mentioned, and we are now even more aware of the benefits of this energy source. First again, because we have national uranium reserves that will provide for a stable supply and less volatility in costs. We have another benefit in that we have an increasing need for base load power plants, especially because hydro plants are now close to their limit and we have an increasing share of wind and solar. A third benefit is that it uses a relatively small area and can be close to load centres, as opposed to hydro, wind and solar they are very site specific. And lastly, it is a non-emitting energy source.

Although we are in the process of discussing this scenario with society, we are still elaborating the national energy plan, so, unfortunately, I cannot give any more, or many more details about it just yet. We are considering all these benefits, realizing the importance for the country, for strategic purposes. For the energy transition, it is certainly a very positive scenario.

This is the message I had for today.

Thank you.

2.4.4. China — Keynote Address

Statement as provided, verbatim.

K. Zhang
Chairman
China Atomic Energy Authority
Beijing, China

Distinguished President, Acting Director General Feruţă, Director General Magwood, dear participants, ladies and gentlemen.

Good afternoon. I am privileged to meet you in this beautiful October in the capital of music, Vienna. We are here to talk about the crucial topic of 'Climate Change and the Role of Nuclear Energy'. This conference is held exactly after the UN Climate Action Summit, which demonstrates that the IAEA and its member countries are taking practical actions to achieve sustainable development and tackle climate change. On behalf of CAEA, I would like to congratulate on the opening of this conference and extend our gratitude to the thoughtful preparation by the IAEA.

Climate change is a common challenge for human society. The rising temperature and melting ice sheet will lead to disastrous consequences to our ecosystem and survival. The 2019 UN World Economic Prospect shows that with more frequent extreme weathers in the past twenty years, climate related disasters have caused more than $2245 billion of economic loss, an increase of 151%. To tackle global climate change and protect the planet Earth we are all depending on, the UN has approved the Paris Agreement in COP21. The agreement aims to control global temperature rise within 2°C in this century and within 1.5°C compared with pre-industrial levels. Despite that some countries still have different views to the agreement, strengthening international cooperation and tackling global challenge are the common wish of the international community.

China has always been an active player in the global efforts of combating climate change. It approved the UNFCCC in 1992 and the Paris Agreement in 201. The national governance strategy for the new era proposed by President Xi Jinping has claimed that we will propel eco civilization and green development and build a clean, low carbon, safe and efficient energy system. Chinese government believes that the lucid water and lush mountains are invaluable. We are constantly reducing the use of fossil fuels and developing green power. By 2018, the carbon emission per unit GDP in China had decreased 45.8% from the 2005 level. That is the equivalent of reducing carbon dioxide emissions by 5.26 billion tonnes. In the same year, the share of non-fossil fuel in primary energy consumption increased to 14.3%, and forest stock increased by 4560 km^2 from the 2005 level. Chinese government has promised that by 2030, the carbon emission per unit GDP will decrease by 60 to 65% compared with 2005. Moreover, the share of non-fossil fuels in primary energy consumption will be increased to 15% in 2020 and 20% in 2030.

Nuclear energy is a clean, low carbon and efficient base-load energy. It plays a very important role in the UN 2030 Sustainable Development Agenda, and helps China to ensure energy supply, optimize energy mix, and tackle climate change. At present, China mainland has 47 nuclear power units in operation, with a total installed capacity of 48.73 GW. Another 11 units are under construction, with an installed capacity of 12.18 GW. Supported by a complete industrial system, China has developed mature technology and nourished abundant talents in nuclear fuel production, equipment manufacturing, project construction, waste disposal and technology application. We are exploring diversified application of nuclear energy to secure energy supply, optimize energy mix, tackle climate change, reduce greenhouse gas, and deal with pollution.

Following the idea of innovative, coordinated, green, open, and shared development, China has explored a unique path of nuclear energy development. Here, I would like to review China's development and share our experience and practices in the safe, healthy and sustainable development of nuclear energy.

First, build confidence. China honors its commitment in the Paris Agreement. Despite the changing global environment of nuclear energy development in recent years, China's policy to develop nuclear energy in a safe and efficient way is unwavering. We have made relentless efforts to save energy and reduce emissions. In 2018, nuclear energy contributed 286.5 billion kw·h of electricity, accounting for 15.83% of non-fossil fuel electricity. That is the equivalent of reducing 88.24 million tonnes of standard coal, 230 tonnes of carbon dioxide, 750 000 tonnes of sulphur dioxide, and 650 000 tonnes of nitrogen oxide. This year, our government has approved another four 1000 MW nuclear power units, demonstrating the crucial role of nuclear energy in China's sustainable development.

Second, give priority to safety. Following the "rational, coordinated, and balanced" nuclear safety strategy, China prioritizes safety at all times. It implements the nuclear safety law, improves safety standards, conducts safety reviews, improves safety awareness, and nourishes a safety culture. Through technological innovation, China improves the inherent safety of nuclear facilities. Meanwhile, China values nuclear security capacity and has constructed the largest, most advanced, and best equipped nuclear security demonstration centre in the Asia–Pacific region. It has invited the IAEA to provide consultancy on physical protection and pushed forward low enrichment conversion of reactors both at home and abroad. Furthermore, China is strengthening the nuclear emergency system. The capacity of emergency rescue has been enhanced, emergency drills and training are held on a regular basis, and public communication activities in nuclear emergency are promoted.

Third, build sound infrastructures. China has a closed cycle technology path for nuclear fuel and constantly improves the overall efficiency of the nuclear fuel sector. It actively builds a modern, market-oriented, professional and international nuclear fuel cycle, and has the capacity to construct multiple units simultaneously. It is also developing large uranium mines in an eco-friendly way to improve uranium supply. Moreover, China is strengthening decommissioning and radwaste management. It actively builds low and medium level radioactive waste disposal sites, as well as high level radioactive waste disposal labs.

Fourth, focus on talent training. China has established a system that enables colleges, research institutes and enterprises to communicate and corporate. In China, more channels are identified for personnel training and more efforts are made to enhance the professional skills of talents. By June 2019, 72 colleges in China had nuclear engineering majors, among which 47 universities have schools for nuclear related majors. Every year, more than three thousand undergraduate students are enrolled to study nuclear engineering. Meanwhile, to help developing countries train nuclear talents, CAEA cooperated with the IAEA and set up the Chinese Government Scholarship for atomic energy. In the last two years, China has helped more than 70 Masters and doctoral students from developing countries in Asia and Africa to learn nuclear engineering.

Fifth, enhance global cooperation and communication. Following the sharing spirit and win-win cooperation, China carried out technology communication with advanced nuclear countries and shared its experience with developing countries. Since its reform and opening-up, China has cooperated closely with Russia and France and constructed major projects like Daya Bay and Tianwan NPPs. With bilateral and multilateral platforms, China shares its practices and experience of HPR1000 and HTR in terms of equipment manufacturing and project construction. It is also cooperating with other countries on the Gen IV advanced nuclear technology and nuclear fusion research reactors. All these efforts will improve the economics and safety of nuclear energy and explore new solutions for sustainable development. Furthermore, China follows the belt and road initiative and strengthens its cooperation with Asian, European, African, and Latin American countries to provide new solutions to nuclear energy and technology applications. China also attaches importance to communication and cooperation with the IAEA and fulfills its responsibility of nuclear non-proliferation. It provides technical support to other developing countries and protects their rights of using nuclear energy for peaceful purpose.

Dear colleagues, ladies and gentlemen.

In today's world, multi-polarization, economic globalization, social informatization and cultural diversity are gaining momentum. But meanwhile, climate change, energy security and other issues are becoming prominent. To realize the 2030 SDGs and let nuclear energy contribute to tackling climate change and energy crisis, China will work with other countries and international organizations on the following aspects.

First, build a community of shared future of the nuclear sector. Nuclear energy development is relevant to the common interests of humankind and no country can develop alone. Only by working together can we effectively combat climate change, protect the ecosystem, prevent nuclear proliferation and achieve the 2030 SDGs. Only with consultation, mutual contribution, and shared development can we develop a nuclear community of shared future and realize the vision of “atoms for peace and development”.

Second, explore a new scenario of nuclear energy sustainable development. Nuclear energy is one of the greatest discoveries in the twentieth century. Nuclear power development can bring clean, low-carbon and green energy supply. Its diversified applications can deliver benefits to our survival and development. Therefore, we should expand nuclear technology application, strengthen radwaste disposal, and seek new solutions of decommissioning and high-level radioactive waste disposal. With joint efforts, we will transform the landscape of nuclear energy development.

Third, safeguard nuclear safety and security. Nuclear safety and security are the lifeline of nuclear energy development. The lesson we learn from the Fukushima accident is that once an accident happens, it will threaten the development of the global nuclear energy sector. Against the backdrop of escalating terrorism, strengthening nuclear security and combating terrorism has become a common wish of the international society. Therefore, we need to be aware of those potential risks, shoulder our national responsibility and global obligations, improve our nuclear safety and security to prevent any potential danger.

Fourth, improve public acceptance of nuclear energy. Public acceptance is very crucial for all countries when making nuclear energy plans. While we are improving the economy and safety of nuclear energy, we should also enhance public communication and science popularization. In this way, we will dispel the fear to nuclear energy and change people’s negative attitude, which will create a very favorable communication environment for the sustainable development of nuclear energy.

Ladies and gentlemen.

To tackle climate change and build a green, low-carbon and sustainable nuclear energy system, we need nuclear energy to play its indispensable role. China is willing to make joint efforts and common progress with other countries and promote the safe, healthy, and sustainable development of nuclear energy. China will contribute more to the UN SDGs and the global fight against climate change.

Thank you.

2.4.5. France — Keynote Address

Statement as provided, verbatim.

F. Jacq
Chairman
Alternative Energies and Atomic Energy Commission
Paris, France

Ladies and gentlemen.

I am pleased to speak today in front of you as the representative of the French authorities at this international conference.

GENERAL CONTEXT

First of all, I wish to reaffirm France’s determined commitment to the fight against climate change.

As long as it is not obvious for all of us, it will be necessary to repeat it:

— The latest IPCC reports confirm the inexorable warming of our planet and its potential ecological as well as societal impacts and the reinforcement of extreme phenomena.
— They also indicate that a major cause for this is the massive human production of greenhouse gases, in particular carbon dioxide resulting from the use of fossil fuels for energy production purposes.

Thus, the commitment to the fight against climate change must be a priority for us.

This commitment must guide political, economic, industrial and technical choices in the decades to come.

For this, all the possible solutions must be implemented:

— Reducing energy consumption is key to achieving the objectives of the Paris Agreement. Particular effort must be made to aim for a rapid reduction in the consumption of fossil fuels;
— The reinforcement of the modes of production of carbon-free energies like renewable energies and nuclear energy for the countries which choose them;
— The development and deployment of storage technologies, and optimized network management is a major factor.

All these dimensions are necessary in a global approach of decarbonized energy systems.

NEED FOR AN INTERNATIONAL APPROACH

In the context of climate change, national actions are not sufficient: the fight against global warming must involve commitments and cooperation at an international scale.

This is the meaning of what could be built in the context of the Paris Agreement in 2015. We are extending it here at the IAEA today, as we have done at the Climate Summit in New York last September and will do at the COP25 next November in Chile.

These steps should allow us to collectively define the solutions to be implemented at the political, technical and financial levels.

France has set itself the objective of achieving carbon neutrality by 2050. It is also actively involved in building an international coalition, a coalition that has been joined by Chile, Japan and Italy during the French presidency of the G7 at Biarritz.

Recently, at the Climate Summit in New York, the French President also stressed the need to increase efforts as regards funding these actions. He recalled on this matter that France would double its contribution to the Green Climate Fund.

ENERGY TRANSITION IN FRANCE

France, whose electricity production is already largely decarbonized thanks to its nuclear power generation fleet, is firmly in line with an energy transition approach.

The reduction of French energy consumption is indeed a priority to meet our general commitments in terms of energy transition and climate, in accordance with the French Climate Plan launched in 2017. France is implementing ambitious measures in this direction, particularly in the fields of transport and construction. A law dedicated to transport, discussed in recent months, sets ambitious measures to reduce the use of private cars, and is accompanied by increased resources for public transport. With regard to buildings, a plan for the energetic renovation of buildings presented in 2018 aims to end the 'thermal sieves' in 10 years with 4 billion euros dedicated, by accompanying more specifically low-income households and making information more reliable on the energetic performance of housing. The 'energy and climate law' currently being adopted completes this plan with several measures that will help speed up the renovation of heat sieves.

- In addition, a special effort will be made to reduce the consumption of fossil fuels;
- The last four coal fired power plants will be closed by 2022;
- No new power plant using fossil fuels will be authorized;
- Coal and oil will no longer be used for residential heating after 2028.

Renewable energies will be massively developed and 32% of energy consumption will come from renewable sources in 2030 in France, in line with the commitments made at the level of the European Union.

With regard to its electricity production, an essential element since decarbonization will partly be based on the electrification of uses, France is seeking to diversify its production resources by increasing its share of renewables, which will have to increase from 20% of the electricity mix today to 40% in 2030. This will result in a reduction of the nuclear share, from about 75% today to 50% in 2035.

FOCUS ON THE NUCLEAR ENERGY TRANSITION IN FRANCE

France confirms its choice to continue in the nuclear path, while having a balanced energy mix allowing the elimination of carbonized energies.

Nuclear power appears as a safe, proven and sustainable option, which, together with renewable energies, will form the basis of the French electricity mix.

In this perspective, taking full advantage of nuclear energy implies resolutely engaging in an ambitious innovation and R&D policy; this is the direction taken by France and I want to mention some examples:

- France confirms its commitment to invest in tomorrow's nuclear research tools, such as the Jules Horowitz Irradiation Reactor, which will particularly benefit the Agency's Member States, in particular through the ICERR programme of access to nuclear facilities;
- France is working on the back end of the fuel cycle, aiming to consolidate its position as a historic leader in the field. France is positioning itself in the field of small modular reactors, with the development of an SMR innovation called Nuward, in the framework of a partnership between EDF, Technicatome, CEA and Naval Group, open to international cooperation.

NUCLEAR/RENEWABLE COMPLEMENTARITY AND ENERGY SYSTEM INTEGRATION

The climate emergency is such that all decarbonized solutions must be mobilized at the earliest in substitution of fossil energies. Thus, nuclear power and renewable energies must not be opposed but participate jointly in the development of carbon-free mixes, electrical mixes, but also energy systems as a whole. Electricity generation from nuclear and renewable sources, combined with deployments of energy storage and conversion systems and management of energy networks, can contribute to the development of decarbonized electricity mixes, but also provide solutions for hydrocarbon-free transport (batteries, hydrogen, synthetic fuel). These integrated systems will benefit from the rise of digital technologies in the interest of optimization (artificial intelligence, management of large volumes of data, cybersecurity). In these areas too, an innovation policy and ambitious R&D are needed.

CONCLUSION

In conclusion, France is convinced that nuclear energy, like other carbon-free energies, has its full place in the fight against climate change as a substitute for carbon-based energy sources.

However, nuclear energy will have to adapt and integrate into new energy systems that are more diversified and more flexible, which will allow us, combined with greater energy efficiency, to achieve the carbon neutrality objectives that we have set.

To make progress in this direction, international cooperation is key, and international energy agencies, in particular the OECD Nuclear Energy Agency and the IAEA, will have to play their part to tackle this pressing issue that is climate change.

2.4.6. Hungary — Keynote Address

Statement as provided, verbatim.

P. Kovács
State Secretary Responsible for the Maintenance of the Capacity of the Paks NPP
Paks, Hungary

The Hungarian nuclear programme is widespread. In Hungary, the currently operating nuclear power plant is the Paks Nuclear Power Plant which has 4 units of 500 MW(e) each. It was built in the 1980s and has an operating licence until the mid-2030s. Nuclear energy plays a crucial role in the Hungarian electricity system. In 2018, Paks Nuclear Power Plant generated half of the electricity generation and one third of the electricity consumed in Hungary. The annual load factor of Paks 1 is above 90%; no other power plant has an annual load factor as high in Hungary.

We also have research and training reactors, like the Budapest research reactor, which is a light-water cooled and moderated tank-type reactor with beryllium reflector, with 10 MW(th) capacity. It is ideal for neutron research and irradiation; it is also used for isotope production. Our training reactor is located at the Campus of the Budapest University of Technology and Economics; it is a pool-type reactor with 100 kW nominal thermal capacity.

Additionally, we have a well-developed system for radioactive waste management (the company responsible for this is PURAM). Hungary operates a geological repository for low- and intermediate-level radioactive waste in Bátaapáti and extensive work has been carried out for the site selection for a deep geological repository, intended to be used for long-term storage of high-level waste and spent fuel assemblies.

Besides its crucial role in electricity generation, nuclear energy also helps Hungary to avoid GHG emissions. The total GHG emissions of Hungary (all sector included such as transport, industry, etc.) in 2017 would have been almost 10% higher if nuclear power were to be replaced by natural gas fired power plants. Additionally, without nuclear power in the country, the CO_2 emissions of the electricity generation sector would be 50% higher (even if we replace nuclear with natural gas, and not coal). If we replaced nuclear generation with lignite, the Hungarian CO_2 emissions from electricity generation would double.

In reality, to avoid GHG emissions in the electricity generation sector we have only a few options. Low-carbon generation can come from nuclear and renewable energy. To decarbonize, one should combine these technologies with energy efficiency measures also. If we look into the European electricity sector, it becomes clear that nuclear and renewables (mainly hydro) together are the key to achieve low carbon electricity generation.

Even though our main focus now is on decarbonization, ensuring the security of electricity supply is of the same importance and securing electricity supply is the responsibility of the governments. The Hungarian electricity consumption, along with system load has a growing tendency, while the Hungarian conventional power plants are ageing. By 2033, about 2500 MW generation capacity will be closed, while the electricity system load is expected to grow by 1000 MW. To secure the electricity supply imports are also available, the Hungarian interconnection capacity is outstanding, we are well connected with our neighbours. Hungary has a 30% import share of consumption on an annual basis, but as a monthly average it is regularly higher than 40%, and on a daily basis it is even higher.

We are facing the challenge that the conventional power plants are ageing, and not only in Hungary, but across Europe as well. Many of them will reach the end of their lifetime quite soon. We have to also think on the availability of the future source of our import capacity. How will we replace them? Emission neutral options are only if we replace the ageing conventional power plants with renewables and nuclear capacity. But 'renewables only' cannot be the solution as they come with many challenges to the electricity system. If we think that supply security is equally important, nuclear generation is a must-have in the long-run.

Growing electricity demand, ageing conventional power plants and the penetration of non-dispatchable capacity bring new challenges for the electricity system. Reserve power plants have been started more and more frequently in the last 1.5 years, and we expect this tendency to continue. This is also why we need new power plants that are weather-independent and generate electricity reliably. We believe that base-load electricity capacity is needed for economic development. Without the maintenance of the Hungarian nuclear capacity, the consumption in Hungary cannot be met on the long-run in a low-carbon way.

As a result of the decarbonization objective and the need for security of electricity supply, Hungary decided to carry out the Paks II project. New units on the site of the Paks Nuclear Power Plant have been on the agenda since the 1980s. In 2009, the Hungarian Parliament made a decision-in-principle to start the preparations for the new nuclear units. According to the National Energy Strategy 2030, the nuclear capacity maintenance is one of the main tools to achieve a secure, low-carbon, efficient and competitive electricity system. Therefore, Hungary decided to implement the Paks II. project, which includes the construction of two WWER-1200 type, 3+ generation units, with 2 × 1200 MW(e) nameplate capacity. The new units will have improved active and passive safety systems, load-following capability and high availability factor.

2.4.7. India — Keynote Address

Statement as provided, verbatim.

A. Kakodkar
Former Chairman
Atomic Energy Commission
Mumbai, India

INTRODUCTION

The solution that would enable the world to credibly and viably address the global threat of climate change is still eluding us. At the same time, nuclear energy, perhaps the only source of clean and abundant base load energy, which at one stage seemed to grow rapidly, has slowed down at a time when a large part of the world is aspiring to better their quality of life and is yet to reach the necessary level of energy consumption. Although, there is awareness on the inevitability of nuclear energy in meeting the climate change threat in a cost-effective manner, universal acceptance of this reality is eluding us.

Obviously, the approach to the resolution of the tangle between sustainable development of the world at large and the existential threat to the world as a whole, needs a deeper look. Several new developments are currently being worked upon. We also need to look at the projected timelines related to progression of the potential climate change threat and implementation of the new solutions to combat it. A set of solutions, that can be deployed on an adequate enough scale before it is too late, is the need of the hour. We need these solutions not just in the context of electricity but also to address the total energy needs in a holistic way.

India is a large country on a rapid economic growth path with the largest additional energy needs as compared to any other country. How India sustainably addresses her growing energy needs is thus a matter of interest both locally as well as globally.

ROLE OF NUCLEAR IN ADDRESSING THE THREAT OF CLIMATE CHANGE

The IPCC Special Report on Global Warming of 1.5°C has clearly brought home the fact that the climate change threat is real, far more serious than any other threat seen so far and that the window to deal with it is closing very fast. The report projects that on current trends, warming will reach 1.5°C above pre-industrial times between 2030 and 2052 and that staying below 1.5°C in 2100 will require cuts in GHG emissions of 45 per cent below 2010 levels by 2030 and to net zero by 2050. The recent UNDP publication NDC Global Outlook Report 2019: The Heat is On suggests that:

(1) The road to limiting global temperature rise to 1.5°C or below would require unprecedented efforts by both governments and businesses throughout the world.
(2) The impacts of climate change have been growing, often with terrifying results, ranging from wildfires, droughts, flooding, and hurricanes to sea-level rise, ocean acidification to the melting of the permafrost.
(3) A path exists to 1.5°C, but the window for achieving it is closing fast.
(4) The race against climate change is one we can and must win.

It is now clear that the challenge of emission cuts of 45% of 2010 levels by 2030 and reaching net zero by 2050 has to be met with technologies that are ready for deployment. Although our search for new technologies should be ongoing, they are unlikely to be available for deployment at the required scale within the available timeframe. Impact of climate change has started manifesting — leading to social concerns which might over time transform into unrest. Youth led global climate strikes could well be a precursor.

Expanding energy access and economic opportunity for billions of people that constitute a larger part of humanity and take their HDI to high levels remains an as yet unfulfilled global development agenda. Today that seems to be severely constrained by the climate change threat. An Interdisciplinary MIT Study released in 2018, The Future of Nuclear Energy in a Carbon-Constrained World and an IAEA report Climate Change and Nuclear Power 2018 clearly bring out that in most regions, serving projected load in 2050 while simultaneously reducing emissions to net zero, will require a mix of electrical generation assets that is different from the current mix. Nuclear power can make a vital contribution to meeting climate change targets while delivering the increasingly large quantities of base load electricity needed for global economic development. Without nuclear contribution, the cost of achieving deep decarbonization targets increases significantly. The least-cost portfolios thus include an important share for nuclear, the magnitude of which significantly grows as the cost of nuclear drops.

Post-Fukushima, about 50 new nuclear power reactors are under construction in fifteen countries. Only three countries (Bangladesh, Belarus and the UAE) among them are new entrants to the use of nuclear power. According to a World Nuclear Association report on Emerging Nuclear Energy Countries (updated January 2019), about 30 countries are considering, planning or starting nuclear power programmes. While there are a large number of emerging economy countries with growing energy needs, their adopting nuclear power option to combat climate change risks would depend on their concerns related to nuclear power being addressed adequately. There is thus interest in nuclear power among emerging nuclear energy countries but perceived risks and barriers to deployment of nuclear energy are holding them back. These barriers essentially relate to issues regarding finance, safety, used fuel management and nuclear proliferation.

WHAT INDIA CAN OFFER

A nuclear energy system that can address these issues successfully should therefore be of small or medium size that is cost competitive, has a proven track record of safety, leads to low spent fuel arising with greater stability and has low proliferation risk. We need such a readily implementable system. The 220 MW(e) Indian PHWRs — powered with LEU–Th fuel — would appear most promising in this context. More than a dozen reactors with consistent high-performance track record are operational today. In fact, one of them, the first unit of Kaiga Atomic Power Station, holds the world record for longest uninterrupted run of 962 days. The specific capital cost ($/MW(e)) of these reactors manufactured in India is better than large light water reactors. With LEU–Th fuel, the burnup goes up by a factor of eight as compared to PHWRs running on natural uranium, while being well within the limits of present-day technology. Thermo-physical properties of thorium enable better fuel performance — in reactor as well as in storage. Low temperature moderator within the core, smaller core size, thorium-based fuel all contribute to better safety performance. Thorium contributes to proliferation resistance that uranium fuelled systems cannot achieve. Quick deployment is possible as everything is proven and fuel qualification through irradiation can be readily done.

With mixed oxide fuel containing thorium and LEU (~12–15% U-235), we can get comparable utilization of mined uranium in almost every reactor system in commercial service today.

PHWRs are the best in this regard. With (Th–LEU) fuel, proliferation concerns relating to spent fuel are largely addressed making long term storage as well as recycle (prompt or deferred) more acceptable. ThO_2 matrix brings in safety advantages in the reactor and in fuel storage.

While PHWRs are readily deployable, an Advanced Heavy Water Reactor (AHWR) with Th–LEU MOX fuel has also been designed and developed. The reactor system is essentially a new configuration with existing well-known technologies that in addition to the advantages stated above, virtually eliminates the possible adverse impact in the public domain as a result of reactor operation. The configuration also enables a robust design against external as well as internal threats, including insider malevolent acts. Design and engineering of the reactor is ready for taking up construction immediately.

The operating fleet of nuclear reactors in India currently comprises of 22 reactors delivering 6780 MW of electricity. Another 9 reactors totalling a capacity of 6700 MW(e) are under construction. The Government of India has recently approved construction of 12 more reactors with a total capacity of 9000 MW(e). Together this would amount to a total generation capacity of 22 480 MW(e). We also hope that a number of additional power plants that are expected to be set up through collaboration with other countries, including further domestic addition, should enable reaching the target of 63 GW(e) by the year 2032.

CONCLUDING REMARKS

From the above narration it is clear that the threat of climate change is at our doorsteps. We need to quickly set up an implementation plan to combat this threat. Nuclear clearly has to be an important part of that solution. We have to find ways of dealing with this challenge based on readily implementable technologies. Some of the credible ways of doing so have been brought out.

While electricity generation is a large contributor to greenhouse gas emission, we should also remember that decarbonization of the energy sector as a whole needs to address not just electricity production but also other energy use forms. Leveraging biomass, use of high temperature heat and/or electricity to produce non-fossil hydrogen, capture of CO_2 and its use for production of value added products including fuel are some of the areas where abundant solar and nuclear energy serving as a primary energy source can completely transform the global energy scenario to non-fossil energy use with assured development for all.

2.4.8. Mongolia — Keynote Address

Statement as provided, verbatim.

T. Namsrai
Minister of Environment and Tourism of Mongolia
Ulaanbaatar, Mongolia

Good afternoon Chair Mr Chudakov and distinguished delegates and speakers and all participants joining this conference. I am very glad to attend this conference and would like to express my kind appreciation to the IAEA for organizing an international conference on this critical topic, which will deliver very informative and important perspectives on climate change.

I will present the current situation with climate change in Mongolia including: State Policy on Climate Change and Overview of Nuclear Energy Development in Mongolia.

The climate of Mongolia is harsh and continental due to its unique geographical location in the centre of the Eurasian continent, high above sea level, and surrounded by high mountains. The country has four distinct seasons, large temperature fluctuations and little precipitation. About 85% of the annual precipitation is recorded during the months of April to September. The annual mean temperature has increased by 2.24°C between the year 1940 and 2014. About 77% of Mongolian territory has been affected by desertification and land degradation, and the permafrost area has shrunk more than twice during the last 40 years. Peatland has been reduced by half in the last 50 years. The total lake area was reduced by 8%, and 838 lakes have dried out. Some 80% of livelihood is dependent on climate. For example, as you can see, the permafrost covered approximately 63% of the Mongolian territory in continuous and discontinuous forms in 1971. But the percentage changed to 29.3% in 2016.

Regarding natural disasters, the graph shows the frequency of extreme hydrometeorological events in Mongolia, which increased five times in 2015 compared to 1989. The second graph shows long term variations of short and long lasting extreme atmospheric events in Mongolia.

I would like to give you some information on the key policy documents and legal framework on climate change. Mongolia joined the United Nations Framework Convention on Climate Change in 1993, the Kyoto Protocol in 1999 and the Paris Agreement in 2016, which provide the international legislative basis for climate change policies and strategies.

Although there is no special law on climate change in Mongolia, there are other laws which support climate change related issues and activities. In other words, the climate change issues are reflected in related laws and programmes of Mongolia. However, policies and a legal framework on climate change are being considered in Mongolia. For example, the law on air, law on energy, law on forests, green development policy, sustainable development vision 2030 and the national action programme on climate change all reflect Mongolia's adaptation and mitigation needs.

Mongolia's Sustainable Development Vision 2030 (SDV-2030) was adopted by Parliament in February 2016 to implement UN sustainable development goals as reflected in national social and economic characteristics and long-term social policies and to tackle environment issues and climate change.

The goals of SDV-2030 include:

- To become one of the leading middle-income countries by per capita income.
- To have a diversified sustainable economy.
- To eradicate income inequality and have a majority of its population with average and higher levels of income.
- To maintain Mongolia's pristine natural environment and sustainable ecology.
- To promote sustainable democratic governance.

Therefore, promoting green and sustainable environmental development is one of the main issues in this document — for example to reduce greenhouse gas emissions, to adapt to climate change, to increase the quality of water, etc.

As I mentioned before, Mongolia adopted a green development policy in 2014. This document relates to policies in which resources are developed efficiently without impacting the ecosystem and with reduced gas emissions and waste. Both the strategic objectives and means to implement them include solutions to address climate change.

The National Action Programme on Climate Change (NAPCC) was approved by Parliament in 2000 and upgraded in 2011. It has two phases.

The first phase was implemented from 2011 to 2016 and the second phase started in 2017 and will continue until 2021. The main goals of the programme are to ensure environmental sustainability, the development of socioeconomic sectors adapted to climate change, the reduction of vulnerabilities and risks, and mitigation of GHG emissions as well as to promote economic effectiveness and efficiency and implement 'green growth' policies. The implementation of the NAPCC will help Mongolia create the capacity to adapt to climate change and establish a foundation for green economic growth and development. The NAPCC includes both adaptation and mitigation strategies and measures for key socioeconomic sectors of the country.

Successful implementation of the SDV-2030 and NAPCC will make a great contribution to decrease GHG emissions and increase carbon absorption.

The Ministry of Environment and Tourism is responsible for ensuring the implementation of UNFCCC and many other environmental conventions and agreements and cross-cutting coordination. Within the framework of the UNFCCC, the following steps have been taken:

- Initial national communication (1st November 2001).
- Submission on NAMAs (28th January 2010).
- Second national communication (10th December 2010).
- National Action Program on Climate Change (6th January 2011).
- Technology Needs Assessment (2013).
- Intended Nationally Determined Contributions INDC (September 2015).
- Submission on first Biennial Update Report (BUR, 2017).
- GCF readiness support (2017).
- Third national communication (May 2018).

Currently, we have started a project to develop the fourth national communication. The National Adaptation Plan project started this year, to be completed by 2022 with UNEP. We also established a National Climate Change Committee this year, including members of all relevant sectors which are key to ensuring the successful implementation of the UNFCCC at national level.

As to GHG emissions in Mongolia, these have been divided among sectors for energy, agriculture, waste and industrial processes, and product use. Total GHG emissions in Mongolia in 2014 were 34 gigatonnes of CO_2. This represents a 70% increase from 1990 when it was 21 Gt CO_2. GHG emissions in 2014 from the energy sector accounted for 50% of national emissions. The second largest share of emissions was from the agricultural sector at 48%. The two main sources of national emissions were energy and agriculture for all the years of the inventory. Mongolia's INDC country set of specific measures intended as nationally determined contribution was submitted to the UNFCCC in 2015. Then we ratified the Paris Agreement in 2016. The expected mitigation impact is a 14% reduction in greenhouse gas emissions excluding land use change and forestry by 2030 compared to projected emissions under a business as usual scenario. We have a target of specific renewable energy by 2020 to be increased by 20% and by 30% by 2030.

Mongolia is a developing country without nuclear power plants. Economic development has been limited by harsh climate, scattered population and sizeable expanses of unproductive land. Infrastructure and transport are not well developed. Mongolia's primary source of energy is coal, which accounted for 96% of GHG emissions in 2015. Models suggest that GHG emissions for energy consumption could increase 2.3 times between 2010 and 2030 with energy production increasing 2.1 times. The share of clean energy production is general targeted by increasing renewables and energy efficiency. Energy related supply goals were included in SDV-2030 with the share of power supplied by domestic sources will be 100% by 2030. The share of renewable energy will be 30% by 2030.

We are developing our new NDC with more ambitious targets. In our new NDC the production of GHG from the energy sector will be reduced by 29% by 2030. This involves increasing renewable capacity, reducing electricity transmission losses, develop combined heat and power plants and technology improvements such as supercritical combustion technology.

Nuclear energy would be one potential source of energy for Mongolia in the future. The Parliament approved the state energy policy of Mongolia in 2016:

- Phase 1 (2016–2020): To increase renewable energies to 20% of total energy, providing preparation work of using nuclear energy.
- Phase 2 (2021–2025): To increase renewable energies to 25% of total energy complete preparation work of using nuclear energy.
- Phase 3 (2025–2030) to increase renewable energies to 30% of total energy start using nuclear energy.

State policy in nuclear energy approved in 2009 envisaged:

- Introduction of nuclear technology.
- Exploitation of radioactive minerals.
- Peaceful use of nuclear energy as electricity supply.
- Ensure nuclear and radiation safety.

As with some other countries, nuclear development has stagnated following the Fukushima accident. In 2016, the Parliament approved the SDV-2030 which envisaged starting to use nuclear energy in 2030. Parliament also approved an action plant for 2016–2020. This included expansion of programmes related to radioactive minerals, to undertake research on NPPs, to establish a centre for public awareness, to provide centres for cancer treatment. The government at this time focused on assessing the infrastructure needed for nuclear power using the IAEA's 19 Milestones. Although we have no nuclear facilities, we are using nuclear technology in health, agriculture, water, industry and environment. Mongolia has substantial uranium resources. Currently no uranium is being produced in Mongolia. There are currently eight deposits on which feasibility studies have been completed, Mongolia is carrying out preparatory work in order to commercialise radioactive minerals.

Although the issue of developing new energy resources has been discussed, it has been an ongoing issue due to lack of finance and insufficient framework. Besides renewable energy resources such as solar and wind it is of crucial importance for us to settle this issue of developing new energy sources that can be environmentally friendly as well. In order to do that we need to take some actions, such as

To develop and broaden energy sources, including nuclear, to achieve updated NDC targets and to ensure energy security

To increase nuclear techniques and technology to tackle climate change, for environmental monitoring of heavy metals in soil and water, and to enhance border and customs control.

To improve economic growth by integrating the objectives of main national level policies and mechanisms including positive planning and finance and budgeting, which is not yet properly established.

To develop the NDC implementation plan to support implementation of sector policies.

To identify potential sources of funding.

To strengthen the capacity at all levels and provide policy makers with scientific information to mitigate and adapt to climate change.

2.4.9. Morocco — Keynote Address

Statement as provided, verbatim.

K. Mrabit
Director
Moroccan Agency for Nuclear and Radiological Safety and Security (AMSSNuR)
Rabat, Morocco

Presented by T. Mefek

My presentation will cover five points: the national context of nuclear energy in Morocco; the INIR mission conducted in Morocco in 2015; the role of the regulator AMSSNuR; its main achievements; and the challenges and conclusions. Morocco has ratified all the international binding instruments, the last one being the Nuclear Safety Convention in May 2019. Morocco has adopted a nuclear safety, security and safeguards law in 2014 on the basis of which the nuclear regulatory body was established.

As to the national context, we do not have any nuclear power plants, but we have a research reactor of 2 MW power, and nuclear applications are dominated by the medical field, the industrial field and some applications in transport. Concerning energy in Morocco, we are importing more than 90% of our needs from outside. We are importing fuel and electricity and by 2018 we imported more than 9% of our electricity from Spain and Algeria. There are projects for connections with Portugal and Spain in the future. Many activities are under development and the main growth rate of electricity consumption in the last 10 years has been 10.5% a year. Electrical capacity by 2010 was 6 GW and by 2030 it will be more than 26G W. The Government of Morocco has established a strategy to develop renewables. By 2010 they represented 10% of overall capacity and by 2030 their share will be 52%. Morocco started to think about a nuclear option in the early 1980s and this option is still open for after 2030. Morocco undertook a study to select and qualify a site — a coastal site 300 km south of Casablanca and it was qualified under IAEA auspices from 1984 to 1994. Another study was done to update the first one and in 2009 the government created a national committee (CRED) to evaluate the status of National Nuclear Infrastructures and established a documented strategy for a nuclear power option. In 2015, we invited an INIR mission which made 17 recommendations and four suggestions, and we are working now on an integrated working plan (IWP) which will be presented to the IAEA in November 2019.

The five main INIR mission recommendations discussed here are:

(1) Nuclear safety: To develop a plan for establishing a national policy and strategy for nuclear safety — by ratifying the Nuclear Safety Convention. We have responded to this recommendation.
(2) Management: To develop plans for the implementation of Integrated Management Systems 'IMS' in key organizations — we are working on it.
(3) Radiation protection: We are working to identify how the existing radiation protection program will be expanded to address the requirements related to a nuclear power plant.
(4) Regulatory framework: We are working to develop a detailed plan to include all the regulations to be developed, reviewed, revised, or superseded in order to ensure that an adequate regulatory framework will be in place to complete the Phase 2 activities.
(5) Human resources: We are working on the development of a national human resource strategy involving all the key organizations and taking account of the likely timescales for implementation of the nuclear power programme.

The regulatory body, AMSSNuR, was created in 2016 and we have drawn up a strategic plan for 2017-2021. Our mission is to ensure the protection of the public, society and the environment against the risks associated with the uses of ionizing radiation. Our vision is to become an independent, credible and transparent regulatory body by 2021. We are guided in this objective by values such as independence, objectivity, rigour and transparency.

We have six strategic objectives. The most important is to upgrade the national regulatory framework. The others are: to enhance the level of nuclear and radiological safety and security; to develop and implement the national nuclear security system and the emergency response plan; to develop and maintain human and organizational capacities; to establish and implement a transparent and reliable communication policy with respect to stakeholders and the public; and to strengthen regional and international cooperation.

We have a roadmap. The first stage, from 2016–2017, was to ensure a smooth transition following the creation of AMSSNuR; the second, from 2018–2019, was to strengthen the level of safety and security, and we have undertaken many activities in this regard; and the third from, 2020–2021, is to conduct external evaluations: IRRS, IPPAS, ISSAS, EPREV and to prepare the strategic plan 2022–2026.

We have begun capacity building based on the four pillars concept developed by the IAEA: education and training; human resource development; knowledge management; and knowledge networks.

The main achievements in 2017–2019 include: the development of 17 regulations in nuclear safety, security and safeguards; drafting and submitting to the government nine of these regulations, one of which deals with the safety of nuclear installations; and we are working on five others. We will complete all 17 regulations by 2020.

We have developed and submitted to the government national policies on nuclear safety of radioactive waste management and spent fuel. We have started a programme of authorizations; authorizations granted by AMSSNuR up to August 2019 totaled 2162. These are dominated by the medical sector (69%). Our colleagues are working on a review and assessment to computerize authorizations and to simplify procedures.

We have also established a national inspection programme covering the research reactor and all the regions of Morocco. This programme is dominated by medical applications. We have established a national strategy for public information and communication. We organized seven regional meetings with the public, we developed media communications, digital communications and corporate and emergency communications.

Concerning the National Strategy for Nuclear Safety and Security Education and Training, we used the IAEA methodology based on four phases. We are now in phase two and we have identified 8000 persons to be trained. We have created a national committee to govern and follow up implementation of this national strategy.

Regarding national, regional and international cooperation, we have agreements with the Departments of Energy, Health, Interior and High Education. We participate in IAEA activities — GNSSN, RCF, FRNBA, ANNuR, IGTLN. We have agreements with the European Union and with some senior regulators. We are working on the establishment of workshops and training, and in the past three years we organized 64 workshops. Last year we organized a School of Radiological Emergency Management, in collaboration with the IAEA. We organized the Third International Regulators Conference on Nuclear Security from 1 to 4

October 2019 in Marrakech. By the end of 2019, we will organize two more large events — a Regional School of Nuclear and Radiological Leadership and a National Workshop on Nuclear Safety Culture.

We are also working on our integrated management system. We have mapped and identified management processes, core processes and support processes and this is part of our continuous contact with stakeholders to understand their expectations and requirements. We have developed a manual for the integrated management system, which includes AMSSNuR's policies, processes, procedures and records.

Concerning human resources development, we started with 17 people and now have more than 60. And by the end of 2019 we will have more than 90. We are encouraging gender equality, aiming to have 50% of women in our staff. The average age of our staff is 35 compared with 42 in 2016. We are recruiting from the university and also from experienced people who worked before in the nuclear sector. Of the 64 workshops we organized in the past three years, 74% were focused on nuclear safeguards and security, 20% on nuclear safety and 11% on radiological safety and environmental monitoring. These were organized with the IAEA (54%), the EU (13%) and the United States of America (11%). AMSSNuR supported 16% of all training efforts.

The challenges for 2020 are to implement the integrated management system; continue to strengthen the nuclear safety and security culture; and to achieve the updating of the regulatory framework. In 2021, we will request the IAEA to conduct external reviews, in particular IRRS, EPREV and IPPAS. By 2022 we will start implementing the new Strategic Plan for 2022–2026.

To conclude, we have responded to all of the INIR recommendations concerning the regulatory component and AMSSNuR activities, especially with respect to human resources, the integrated management system, public information, and international cooperation. We are developing regulations relating to nuclear safety, security and safeguards. We have developed a radioactive waste policy and strategy and a nuclear safety policy. We have made good progress in implementing AMSSNuR's Strategic Plan 2017–2021. We have made continuous improvements to enhance safety and security leadership and to strengthen national, regional and international cooperation.

2.4.10. Russian Federation — Keynote Address

Statement as transcribed, verbatim.

V. Artisyuk
Councilor, Adviser to Director General
State Atomic Energy Corporation "Rosatom"
Moscow, Russian Federation

Mr Chairman, distinguished participants.

It is my great honour to deliver the keynote address to this high-level international conference that focuses on the role of nuclear power in combating climate change. I am Vladimir Artisyuk — Councilor and adviser to the Director General of the State Atomic Energy Corporation "Rosatom". Our State owned corporation possesses national nuclear competences in a broad spectrum of nuclear technologies and plays leading roles in worldwide nuclear development for peaceful purposes in cooperation with the International Atomic Energy Agency and through several dozens of bilateral agreements. Rosatom has been leading in nuclear power plant constructions internationally, thus helping newcomer countries to secure access to clean and affordable energy, as it is formulated in the UN Sustainable Development Goals.

Russia acknowledges climate change as a global threat with global consequences that are affecting the whole of humanity and brings new challenges to energy supply and global security. Russia is a party to the Paris Agreement of 2015 that aims at holding the global increase in the global average temperature to well below 2°C above pre-industrial level through limiting greenhouse gas emissions.

According to International Energy Agency data of 2016, Russian contribution to global CO_2 emission is about 4%. Russia is among the main emitters, in 5th position after China, USA, EU and India. About 75% of greenhouse gas emissions come from the power generation sector, oil and gas production, metallurgy and transport.

It is a matter of fact that in Russia, the power sector's specific emission has been decreasing. In 2018 it was reduced by 37.2 g CO_2-eq /kW(th) compared to 2000 and by 79.7 g CO_2-eq /kW(th) compared to 1990. Currently, the specific emission is at the level of 293.4 g CO_2-eq /kW(th), less than half of the world average of 800 g CO_2-eq /kW(th).

The relatively low specific emission of the Russian power sector is explained by the fact that the fraction of coal in electricity generation is relatively low, about 15%. In contrast, the fraction of natural gas which has the lowest carbon footprint among fossil fuels is about 50%. The share of carbon free electricity in 2018 was 38.3%, consisting mainly of hydro (17.1%) and nuclear power (18.3%).

The Russian nuclear power sector has a long history and has accumulated significant experience in reliable and safe operation not only of power generating reactors but of all kinds of facilities in the nuclear fuel cycle. It is noteworthy that Russia had the first nuclear power plant connected to the grid in June 1954, thus starting the era of peaceful nuclear power. This year we celebrated the 65th anniversary of this ground-breaking event. Currently, Russia operates 36 reactors dominated by the well-proven WWER technology, the Russian pressurized water reactor technology. In 2016 the first Generation 3+ reactor in the world, a WWER-1200 reactor which has both active and passive safety systems, was put into operation. This reactor system is considered the reference for a large number of countries embarking on nuclear power programmes under bilateral cooperation agreements with the Russian Federation. In December this year, the first floating nuclear power plant in the world will produce electricity in the remote area of the Russian North-East. Russia is the only country that operates a fleet of icebreakers with nuclear propulsion. A new generation of Russian icebreakers is being equipped with an integral small modular reactor, RITM. Six such reactors have been already manufactured so we have in fact a serial production and this experience will be used in the construction of new RITM-based floating and on-land nuclear power plants.

To combat climate change, various approaches have been introduced. Along with the introduction of renewable energy, the Circular Carbon Economy approach also offers the potential to develop new energy systems based on innovation and technologies that utilize all energy sources. One of the key features of nuclear power is that it is an essentially circular industry that has the potential to reuse uranium and other heavy metals accumulated in the spent fuel of current power reactors. Incorporating fast reactors as part of the nuclear energy system provides the firm basis for minimizing radioactive wastes and achieving a system in which the radioactivity of wastes deposited in deep geological repositories is at a level comparable to that of the natural uranium extracted for nuclear fuel production. Russia is the only country in the world that has a significant experience in commercial operation of fast reactors. The first sodium cooled fast reactor was commissioned in the Soviet Union in Kazakhstan in 1973, the second one in 1980, the third one in 2015. This demonstrates that Russia maintains the competence to build fast reactors which offer the chance to have almost unlimited fuel resources required for the sustainable development of global nuclear power.

Though policy makers worldwide are still reluctant to put nuclear power on the list of green energy sources, the wind is beginning to change. In 2018, in the report of the Intergovernmental Panel for Climate Change (IPCC-2018), there was a clear message that in order to meet the goals of the Paris Agreement in terms of keeping the global warming within 1.5°C, the share of nuclear power in the energy mix has to increase by factors between 2 and 6, depending on the scenario. That can be achieved only by joining forces in recognizing the role of nuclear power. That is why we consider the International Conference on Climate Change and the Role of Nuclear opening today at the IAEA as a meaningful step towards a sustainable future.

In conclusion, let me stress that the Russian Federation is ready to establish any form of partnership to share its vision and experience and promote nuclear power to secure access to affordable and clean energy and preserve the planet for our children, grandchildren and many, many further generations to come.

I thank you very much for your attention.

2.4.11. United Kingdom — Keynote Address

Statement as provided, verbatim.

J. Loughhead
Chief Scientific Advisor
UK Department for Business, Energy and Industrial Strategy
London, United Kingdom

Excellencies, ladies and gentlemen.

It is with great pleasure that I address the conference today at such a critical time for mitigating climate change.

There is no doubt that climate change is one of the most profound global challenges we face. The decisions we make in the next few years will affect the future of our planet for generations to come. The UK has a proud tradition of climate leadership but recognizes that a step change in action is needed in our own country and across the world. That is why this conference is so timely, and we thank the IAEA for convening it.

On the 27th June, the UK government became the first major economy to set a legally binding target to achieve net zero greenhouse gas emissions by 2050.

We have made Clean Growth one of four ‘Grand Challenges’ to make the UK a world leader in emissions reductions whilst being a hub for jobs, investment and exports in new low-carbon sectors. We will continue to build on our strengths in areas such as nuclear innovation, offshore wind, smart systems, battery storage and green finance but in parallel drive efficiency of energy use and to ensure more sustainable consumption.

Our commitment to clean growth involves supporting the attainment of the UN Sustainable Development Goals, including those related to climate change and other environmental pressures. The UK continues to increase spending on climate related funds and innovation funds, to help low and middle-income countries respond to the challenges and opportunities of climate change.

That is why the UK, in partnership with Italy, has bid to host COP26 in 2020. COP26 will be a great opportunity for the UK, and us all, to showcase our efforts to tackle greenhouse gas emissions, to meet UNFCCC targets and rise to the challenge of climate change.

We believe that nuclear has an important role to play in decarbonizing energy systems. Electricity demand in the UK is likely to grow significantly by 2050 as other sectors of the economy, such as transport and heat, are electrified. To meet increasing electricity demand whilst meeting our ambitious net-zero target, there will need to be a substantial increase in low-carbon generation.

The technologies currently available to provide large-scale constantly generating, low-carbon power by 2050 are nuclear and gas with carbon capture, usage and storage (CCUS). Therefore, a significant increase in their capacity, alongside renewables, is likely to be required to meet increasing demand as well as our climate targets, if nuclear can reduce its costs. Nuclear must ensure that it delivers value for money for consumers in a competitive energy market.

Economics is a growing issue for nuclear energy with significant competition following the latest UK auction for offshore wind which cleared at £39.65 MW/h, a 30% reduction since 2017. To address competitiveness, we have taken an innovative partnership approach with the UK civil nuclear sector, which we call our Nuclear Sector Deal. The Deal drives joint action alongside industry to meet agreed objectives, including cost reductions of 30% for new build projects and 20% for decommissioning.

Nuclear is an important part of the UK's energy mix: it provides around 40% of the UK's low carbon electricity. Our first new build project in a generation at Hinkley Point C will provide 7% of the UK's total electricity requirements, powering nearly 6 million homes with low carbon energy. In order to address the issue of cost, we are currently looking at innovative new funding models for new build projects. Therefore, we are currently considering the Regulated Asset Base (RAB) model as a sustainable funding mechanism which aims to attract private finance and reduce the cost of capital for nuclear new build projects. We are currently engaging with a range of stakeholders on this proposal.

Alongside tackling the economic challenges of currently available nuclear reactors, the sector is rapidly advancing with innovative small and advanced modular reactors. These are another opportunity for nuclear to help meet our net-zero targets which the UK welcomes. Therefore, we are actively supporting SMR and AMR innovation through the UK's Nuclear Innovation Programme and wider policy framework.

This support includes:

- Up to £44 million for an R&D competition for next generation AMRs.
- Up to £12 million to help our nuclear regulators build capability to take future licensing decisions on small and advanced modular reactors, recognizing that there may be different licensing considerations to current reactors.
- Up to £20 million for an advanced manufacturing and construction programme to help innovate and demonstrate manufacturing techniques for modular nuclear.
- We are also considering an up to £18 million award to support further design and development of a UK SMR by a consortium led by Rolls-Royce.

Each of these points underline the UK's commitment to supporting the opportunity of small and advanced reactor innovation as a way of generating low carbon energy and reaching our net-zero target.

We are keen to seek out the best and most talented minds to tackle climate change. Our Equality, Diversity and Inclusion Strategy is proactively developing new pipelines to attract and retain a diverse workforce through supporting local apprenticeship schemes and sharing of best practice and tools across the nuclear sector.

Mindful of our responsibilities to future generations, we have also launched consent-based processes to identify a location for a geological disposal facility for our higher activity radioactive waste and we plan to consult stakeholders on a new radioactive waste and decommissioning policy next year.

In the IAEA context, the IAEA has an important role in improving the understanding of the potential contribution of nuclear power by providing interested Member States with guidance and assistance for deploying safe, secure and safeguarded nuclear technology and in formulating national energy strategies and policies. The UK is a strong supporter of the IAEA and its invaluable work in this regard.

The UK also supports the Technical Cooperation Fund and nuclear applications laboratories, which play an important role in contributing to climate related science and technology development. These spin-offs are a good thing and support the social capital of nuclear.

To end, we are delighted to host a side event in the margins of this important conference entitled ‘Advanced Nuclear Innovation and Climate Change: UK Perspectives’ taking place Thursday at 17:30 in M2, followed by a reception. This event will be a chance for attendees to learn more about the UK’s position on advanced nuclear innovation from policy and regulatory perspectives as well as the potential of nuclear co-generation. I would like to invite your participation for what promises to be a stimulating panel discussion.

Thank you.

2.4.12. United States of America — Keynote Address

Statement as provided, verbatim.

S. Jaworowski
Chief of Staff, Senior Advisor
Office of Nuclear Energy, United States Department of Energy
Washington, D.C., United States of America

Thank you.

I am pleased to be here to talk about the important role that nuclear energy can play in a clean energy future and what the USA is doing to help advance nuclear energy technologies to best enable this future.

As you know, nuclear energy is the best source of reliable, baseload clean energy. In the USA, nuclear power accounts for 55 per cent of our clean energy. It protects our air quality by generating electricity without harmful pollutants like carbon dioxide, nitrogen oxide, sulphur dioxide, particulate matter or mercury.

Beyond these benefits, nuclear power is the most reliable and most efficient source of electricity, operating around the clock at a more than 90 per cent average capacity factor. That is more than two times the capacity factor of intermittent clean sources. In fact, according to the U.S. Energy Information Administration, during our 2019 polar vortex, U.S. nuclear power plants operated at 99.7 per cent capacity.

In addition, nuclear power has created powerful local economic benefits in the USA. An HIS Markit Report reveals that with nuclear in the energy mix, the USA's current diverse electricity portfolio lowers the average retail price of electricity by 27 per cent and reduces the variability of monthly consumer electricity bills by around 22 per cent. This study also found that losing this generation diversity would cause a decline in U.S. gross domestic product by $158 billion; a loss of one million jobs; and $845 less in disposable income annually per household.

Finally, nuclear is powerful. Just one uranium fuel pellet creates as much energy as one ton of coal, 149 gallons of oil or 17 000 cubic feet of natural gas. A single nuclear power reactor generates enough electricity on average to power 755 000 homes without emitting any greenhouse gases. That is more than enough to power a city the size of Philadelphia.

ADMINISTRATION SUPPORT FOR NUCLEAR ENERGY

The Trump Administration is 'All-In' on nuclear energy. Early in his term, President Trump ordered a review of U.S. nuclear energy policy to "help us find new ways to revitalize this crucial energy resource". The Administration's plans include development of advanced nuclear reactor and fuels technologies that are crucial for the future of the U.S. nuclear power sector.

To carry out our ambitious goals, the Administration nominated Dr. Rita Baranwal as Assistant Secretary for Nuclear Energy at the Department of Energy. Dr. Baranwal, the first woman to lead the Office of Nuclear Energy, is overseeing a broad portfolio to promote advanced nuclear research and development. She has more than 20 years of experience in the nuclear field and is well suited to manage our private–public partnerships to deploy advanced nuclear technologies.

New construction is ongoing in the USA. The Administration is supporting the construction of two new Westinghouse AP1000 reactors at the Vogtle nuclear power plant in Georgia. Westinghouse AP1000 technology is the most advanced, high powered light water reactor system licensed by the Nuclear Regulatory Commission.

In addition, DOE is supporting the siting of the nation's first small modular reactor, designed by NuScale Power, with a goal of operation at the Idaho National Laboratory by 2026. Since 2013, under a private–public partnership, DOE has supported the design and licensing of the NuScale Power SMR, which recently cleared phases 2 and 3 of the regulator's design certification process.

Beyond SMRs, DOE is working with the Department of Defense to demonstrate and deploy microreactors potentially as early as 2023. These smaller, transportable reactors could provide clean energy to remote communities, for microgrid applications, and for emergency services. Some of the microreactors in development are under two megawatts in size — small enough to replace diesel generators in remote locations with emissions-free power at a fraction of the cost.

To help with long term operation of the existing fleet of nuclear power plants, the Department's Light Water Reactor Sustainability Program is conducting research to develop to improve the economics and reliability, sustain the safety, and extend the operation of the current fleet. Through the Department's Accident Tolerant Fuels program, industry is developing new fuels that are intended to directly and substantially further enhance fuel reliability and safety, leading to improved economics for nuclear reactor operations.

We have several initiatives to support the development and commercialization of next generation reactor technologies.

We recently established the National Reactor Innovation Center to speed up the licensing and commercialization of advanced reactors. Led by INL, the NRIC provides a platform for companies to assess the performance of their reactor concepts through testing and demonstration.

The NRIC builds on the success of our GAIN initiative that was created to build private-public partnerships that can leverage the expertise and facilities at our national laboratories to help bring innovative nuclear concepts to reality.

We are proceeding with plans to build a Versatile Test Reactor that would use high energy neutrons to speed up the testing of advanced fuels and materials needed by both new reactor designs and our existing fleet.

We have already restarted the Transient Reactor Test Facility at Idaho National Laboratory to better examine fuel performance under simulated accident conditions. The facility is preparing to test the accident tolerant fuels that will increase performance in today's reactors.

Also in the fuels area, DOE is developing pathways to provide small amounts of high assay, low enriched uranium, or HALEU, to U.S. industry for testing of their advanced reactor designs. HALEU allows for smaller plant sizes, longer core life, and a higher burnup of nuclear fuel. We are also working toward long-term solutions by demonstrating the ability to enrich uranium to HALEU levels using advanced centrifuge machines.

NUCLEAR REIMAGINED

Besides lower costs and greater efficiencies, the new advanced reactors being developed in the USA have broader benefits that will provide a range of options to solve non-electric challenges. Many of the advanced reactor designs produce process heat and steam that can be used in homes and public buildings; they could even support other industries like agriculture or food processing.

In transportation, SMRs could provide power to charge electric vehicles or power a rail line. During off-peak hours, such an SMR could put its excess capacity toward hydrogen generation.

Finally, DOE is developing advanced integrated energy systems, with SMRs providing flexibility to ramp production up and down in cooperation with renewable generation.

NUCLEAR INNOVATION CLEAN ENERGY (NICE) VISION

Working internationally, the USA is a lead country, together with Canada and Japan, of the Nuclear Innovation Clean Energy (NICE) Future initiative that was launched in May 2018 under the Clean Energy Ministerial initiative. We are joined by six other countries and 14 partner organizations.

The initiative recognizes that there is no one-size-fits-all solution to energy production. It fosters collaboration among clean energy supporters to explore diverse solutions, including nuclear energy as an option, for the development of clean, integrated, and reliable energy systems.

The innovations that the NICE Future initiative is working on include: integrated nuclear renewables systems, desalination for drinking water, process heat, flexible electricity grids, hydrogen production and energy storage, advanced smart designs, and nuclear waste reduction.

Also under the Clean Energy Ministerial, the USA is participating in the C3E Technology Collaboration Program, which aims to advance women's participation in the clean energy field. In this program, members are sharing experiences on domestic efforts that aim to strengthen recruitment, retention, and advancement of qualified women in clean energy. Members agree that bringing this greater gender diversity into the clean energy sector can bring in more diverse views that can help foster innovation and technology advancement.

INTERNATIONAL FRAMEWORK FOR NUCLEAR ENERGY COOPERATION (IFNEC)

This November, Secretary Perry is hosting several IFNEC week events in Washington in support of IFNEC's goal: exploring mutually beneficial approaches to ensure the use of nuclear energy for peaceful purposes proceeds in a manner that is efficient and meets the highest standards of safety, security and non-proliferation.

There will be a Reliable Nuclear Fuel Services Working Group meeting, a Steering Group and Executive committee meeting, and a global ministerial conference on 'Bringing the World SMRs and Advanced Nuclear'. Conference panels will include near-term deployment opportunities, forward thinking financing options, and revolutionizing the regulatory environment.

OFFICE OF NUCLEAR ENERGY OUTREACH

Finally, one of our biggest global challenges to the greater use of nuclear energy is public opinion. That is why DOE is meeting with individuals and stakeholders around the USA to hold conversations about important nuclear energy issues.

Late last year, we started an activity we call the Millennial Nuclear Caucuses. The activity was kicked off by Energy Secretary Rick Perry and young people representing multiple nuclear energy organizations. Now, we travel the country and internationally to talk nuclear. In fact, we are working with the IAEA, the International Youth Nuclear Congress and the United Nations Nuclear Young Generation organization to hold a Millennial Nuclear Caucus here on Tuesday evening and we hope you can attend.

To engage an even younger generation about nuclear technologies, DOE is supporting a collaboration between the American Nuclear Society and Discovery Education to develop a nuclear science curriculum for students of all ages. The curricula will include lesson plans, career profiles, and a virtual field trip to a nuclear power plant.

We are also reaching out to Congressional leadership and staff with learning lunches where experts present and answer questions from the audience.

Lastly, we are developing videos and infographics to provide more information about the Department's nuclear energy activities on our website.

CLOSING

I would like to close by saying that exciting innovations are just around the corner for nuclear, and even more in the not so distant future. Together, with renewed vision and action, we can enable a brighter future. We can and must take advantage of emissions-free nuclear in new and innovative ways to accelerate progress toward a thriving, cleaner world.

Thank you for inviting me to speak.

3. SUMMARIES OF THE PLENARY SESSIONS

3.1. TRACKS 1 AND 4: ENERGY POLICIES AND FINANCIAL INSTRUMENTS TO STIMULATE LOW CARBON INVESTMENTS

3.1.1. Track 1: Advancing energy policies that achieve the climate change goals

There is a consensus in the international scientific community that the impacts of climate change are manifest and increasing in intensity. Maintaining the operation of the current nuclear fleet of nuclear reactors is critical in meeting climate change objectives. However, developing new nuclear projects is risky for investors, mainly because they often lack loan guarantees and encouraging policy incentives. Thus, governmental action and international cooperation are critical drivers to nuclear development.

The session participants discussed the role of nuclear power and other low carbon technologies in the transition towards decarbonized energy systems and recognized the need to deploy low carbon options swiftly. Strong commitments from governments and clarity on long term policy objectives are essential. However, participants recognized a general lack of interest and climate policy incentives to support investments in low carbon projects.

Challenging market conditions and specific risks inherent to each phase of nuclear development have led to a lack of competitiveness with regard to alternative options, including natural gas (in particular in the USA) or renewable energy sources such as solar and wind. Specific policy support to mitigate such risks faced by nuclear developers is thus required. Preserving the operation of the existing fleet of reactors is a priority, as is support to the commercial deployment of small modular reactors (SMRs) and other advanced reactors.

3.1.2. Track 4: Shaping the future of the nuclear industry in regulated and deregulated energy markets to address climate change

Meeting the targets of the 2015 Paris Agreement requires the immediate and radical transition of the energy and electricity sectors to low carbon technologies. This represents a significant challenge for all IAEA Member States, but is also a unique opportunity for the development of nuclear energy. Nuclear power must be one of the pillars of a decarbonized energy system, together with renewables and energy storage. Decarbonizing the electricity sector without nuclear power would be much more expensive, or even impossible.

Construction costs and the lead time of recent nuclear projects have shown different outcomes in different areas of the world. Thus, lowering these costs and reducing the lead time of new nuclear power plants (NPPs) are essential to foster the competitiveness of nuclear power.

Securing financing emerged as one of the major challenges for new NPPs. While different financing and contracting structures are possible, it is essential to mitigate the overall project risk by allocating it to the entity more suited to bear it.

Governments have an important role to play at all stages of nuclear power development.

Financial institutions focusing on development and sustainable funds are playing an increasing role in financing energy projects worldwide. Access to these investments could ease the financing of nuclear projects. However, despite contributing to several UN Sustainable Development Goals, nuclear power is generally not considered as part of green or sustainable activities.

Competitive electricity markets are not providing the needed signals for investment in low carbon technology, in particular for dispatchable plants. Clear, effective and technologically neutral policies, together with appropriate market designs providing more certainty for investors in low carbon technologies, are needed to effectively achieve the transition to a low carbon system.

3.2. TRACKS 2 AND 3: NUCLEAR POWER TODAY AND TOMORROW

3.2.1. Track 2: The increasing contribution of nuclear power in the mitigation of climate change, including synergies with other low carbon power generation sources

The session explored the current status and future developments in the nuclear power industry, highlighting the integration of energy from renewable sources such as hydro, wind and solar. Two issues missing in the discussion of the economics of nuclear power are: the system cost of intermittent renewables; and social and environmental externalities. Government support to nuclear power is justified based on these issues.

In the case of Brazil, nuclear power paired with renewable energy sources, has played a key role in the country's hydrothermal transition. The potential of SMRs, such as NuScale, to provide applications in addition to energy was also discussed. These applications included areas such as hydrogen production, desalination, oil refining, and load following. The ability of SMRs to meet immediate energy demands in a short amount of time due to flexible operation is a unique feature that could also play a role in many energy markets. It was noted that government support was critical in ensuring that nuclear power continue to contribute to a low carbon future. Main points:

- Renewables and nuclear power can work together to provide low carbon energy.
- SMRs can provide flexibility in operation and siting, and further may also provide non-power applications, such as hydrogen production, heat supply to industry and desalination.
- In order for nuclear power to continue to contribute to a low carbon future, government support is critical.

3.2.2. Track 3: Development and deployment of advanced nuclear power technologies to increase the use of low carbon energy

The session focused on understanding the challenges related to deployment of new and advanced nuclear power technologies in order to reduce greenhouse gas (GHG) emissions at each stage of the nuclear fuel cycle. The closing of the nuclear fuel cycle is important for the sustainability of nuclear power, and the use of reprocessed or depleted uranium will also support the reduction of CO_2 emissions arising from mining along with a reduced footprint of ultimate waste coming out of the NPP. The performance and sustainability of the nuclear industry are improved by the use of innovative designs and SMRs that could not only provide a dispatchable power supply, but could also replace ageing fossil fuel power plants.

Designing innovative reactors which are different from existing technology requires a different strategic roadmap, a different time horizon and a completely different approach. Co-existence of nuclear power with the variety of renewable energy sources in a cost effective and efficient manner is paramount for successful deployment of advanced reactors in current and future energy mix scenarios. Advanced reactors that incorporate non-electrical applications such as district heating, hydrogen production and desalination, some of which require high temperatures which could be achieved using advanced high temperature reactors, could facilitate further decarbonization of the energy sector. Time is of the essence and if advanced reactors are to play a significant role in GHG reduction, the required time to deploy the technology will have to be reduced. Main points:

- A closed nuclear fuel cycle will improve the sustainability of the nuclear industry and contribute to a further reduction of emissions from the fuel cycle.
- The energy sector will have a considerable share of intermittent and variable renewable energy within decentralized energy systems. Innovative reactor designs could help in the proper assimilation of more flexible offerings of nuclear power in the future energy mix.
- The implementation of non-electrical applications, including high temperature applications, could be achieved with advanced reactors and can contribute to GHG reduction in the non-electricity energy market, which is largely not accessible with the current nuclear offerings.
- It is important to have social acceptance of the new technology with a proper assessment of risk; public acceptance is vital for the early deployment of new technologies.

3.3. TRACKS 5 AND 6: PARTNERSHIPS AND ENGAGEMENT

3.3.1. Track 5: Enhancing international cooperation and partnership in nuclear power deployment

The session explored the fundamental role of international cooperation and partnerships to scale up nuclear power deployment to address the challenge of climate change. Partnership opportunities and successful examples were discussed, including intergovernmental cooperation under the Nuclear Innovation: Clean Energy Future Initiative and the Flexible Nuclear Campaign (both under the Clean Energy Ministerial[12]) and the cooperation framework provided by the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC).

Emerging market opportunities are driving new opportunities for cooperation between the nuclear power and low carbon energy technology sectors, and in non-electric energy applications, such as hydrogen for use in transportation and industry. However, the session also highlighted the need to foster additional cooperation and partnerships to better align financial flows, and facilitate access to financing mechanisms, with transformative climate action, and to ensure that nuclear technologies — particularly advanced options — are properly evaluated in large scale scientific assessments, such as those of the Intergovernmental Panel and Climate Change (IPCC), which are instrumental in guiding the policy processes of the UNFCCC and other bodies. Main points:

- There is no one size fits all solution for the successful deployment of nuclear power. A range of partners and cooperation mechanisms is needed depending on the local investment and institutional framework, resources, infrastructure and technology, among other factors.

[12] The Clean Energy Ministerial (CEM) is "a high-level global forum to promote policies and programs that advance clean energy technology, to share lessons learned and best practices, and to encourage the transition to a global clean energy economy" (http://www.cleanenergyministerial.org/about-clean-energy-ministerial).

- New cooperation opportunities are emerging around nuclear power's potential to support large scale, renewable deployment and integration, changing patterns of electricity demand, and the development of non-electrical applications of nuclear energy.
- Partnerships can bring together stakeholders from the intergovernmental climate policy process and stakeholders from the science, engineering and technical communities to improve understanding of the potential of nuclear technologies to contribute to mitigation.

3.3.2. Track 6: Public and non-nuclear stakeholders' perception of the role of nuclear power in climate change mitigation

This session examined the causes for the public's over-estimation of the risks associated with radiation exposure and nuclear power, resulting in nuclear power's exclusion from future energy planning and markets. Myth based perceptions and fixed world views prevent nuclear power's contribution to a low cost energy mix that demonstrably can achieve the decarbonization goals that mitigate climate change.

Dialogue with the public based upon listening and empathetic, audience tailored communication help to correct perceptions through a fact based understanding of the benefits (climate change mitigation and energy security) and the risks that are inherent in any energy production technology. Research on communication suggests that business models need to be adapted to align the technology with the predominant world views that value inclusive decision making, affordability and community scale/community owned nuclear power solutions. Collaboration is needed to demonstrate to decision makers that nuclear power is an essential, low cost component in the energy mixes that facilitate carbon neutrality. Main points:

- Start an empathetic dialogue now with the public to encourage a fact-based understanding of the risks inherent in all energy systems, emphasizing nuclear power's benefits, to help dispel myths about radiation exposure's public health consequences.
- Enhance the acceptance of nuclear power by adapting business models to reflect world views that emphasize inclusive decision making, affordability, community scale/community owned nuclear power solutions.
- Collaborate in energy modelling to adapt policy to build a marketplace that grants nuclear power its role as an indispensable component in the energy mixes that facilitate carbon neutrality at the lowest cost.

3.4. SPECIAL SESSION: NUCLEAR SAFETY AND SECURITY

The session shared the experiences of nuclear programmes in several Member States and the links with their national climate change goals. The full range of nuclear programmes, from new build within embarking countries to established operational programmes, and safely operating ageing fleets, were discussed. The importance of nuclear safety and security from an IAEA viewpoint was also discussed.

It is widely accepted that safety and security underpins the sustainable development of nuclear power. The establishment and maintenance of appropriate infrastructures, consistent with IAEA safety standards and security guidance, are critical for nuclear power programmes. A robust regulator, with a focus on enabling regulation, is a key part of this infrastructure.

4. PLENARY SESSIONS

4.1. TRACKS 1 AND 4: ENERGY POLICIES AND FINANCIAL INSTRUMENTS TO STIMULATE LOW CARBON INVESTMENTS

Chairpersons: J. Gadano (International Framework for Nuclear Energy Cooperation)
M. Takada (UNDESA)

4.1.1. Track 1: Advancing energy policies that achieve the climate change goals

Invited Speaker — American Nuclear Society

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This paper was not available for publication but the full presentation is included in the on-line supplementary files, for reference, and can be found on the publication's individual web page at www.iaea.org/publications.

4.1.2. Track 1: Advancing energy policies that achieve the climate change goals Invited Speaker — United Nations Industrial Development Organization

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This paper was not available for publication but the full presentation is included in the on-line supplementary files, for reference, and can be found on the publication's individual web page at www.iaea.org/publications.

4.1.3. Track 1: Advancing energy policies that achieve the climate change goals Invited Speaker — Électricité de France

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It is both a privilege and a pleasure for me to share some of my thoughts and convictions with you concerning the critical issues of climate change, nuclear power, and public policy. All are of increasing urgency, and each calls for immediate action.

There is no 'pause' setting for climate change. The conclusions of the Paris Accord and its goal of limiting global warming to no more than 2°C must no longer be viewed as luxuries, but as compelling necessities.

Scientific evidence is growing: climate change is accelerating. Its impacts will be felt more intensely, and sooner than anticipated.

Few now doubt that climate change is under way. Its effects are already keenly felt. Wildfires rage in the USA, Canada and the Russian Federation. Category 5 hurricanes occur at three times previous rates. A summer heatwave scorches Europe. Severe drought plagues India and Australia. The Arctic ice cap is melting, as are glaciers around the world.

Science confirms: recent progress in climate models shows global heating that is more intense, and accelerating faster than expected. Warming has already risen by 1°C. It will hit 2°C by 2040. If we do not step up decarbonization efforts at once, it will reach 3°C by 2050. And 2050 is right around the corner, especially for the energy and electricity sector.

A warming of 3°C would mean major disruptions to local climates, landscapes, and lifestyles. Here are just a few examples from the IPCC:

- The number of those subject to food shortages in certain regions would increase by more than 500 million due to declining crop yields.
- Nearly three-quarters of the world's population would be affected by extreme heat waves — particularly deadly for vulnerable populations.
- Two-thirds of the world's population would be affected by increasingly intense droughts of up to four months or longer.
- Permafrost would melt, tropical forests die out, and temperate forests would radically transform, accelerating the extinction of numerous species.

The current 1°C warming is already forcing adaptations. At EDF, for instance, we have already invested hundreds of millions of euros to prepare our facilities and networks for rising temperatures.

A temperature of +3°C would mean doing much, much more. We must ask ourselves whether all countries, especially emerging nations, would be capable of managing such rapid warming, or the resulting systemic changes and challenges. What does 'adaptations' mean when part of your country is under water?

I do not see ‘collapsology’ as a viable alternative. Rather, I am convinced that we can and must act quickly to shift into high gear in the fight against global warming. This means facing certain realities head on.

We are lagging behind in the fight against climate change.

In 1987, when the Rio Earth Summit was held and the Brundtland Report was published, fossil fuels made up 81% of the global energy mix. Thirty years later, in 2017, after Kyoto, after the Paris COP, after all the work done to promote energy efficiency and a renewable revolution led by wind and solar power, fossil fuels still made up 81% of the mix.

This shows just how complex it can be to reduce carbon emissions, especially for emerging countries faced with meeting the dual challenges of energy access and economic development. It is also a reminder that in order to tackle climate change, we must make use of carbon-free technologies in concert rather than substituting one for another. The renewable energies rolled out thus far have merely served to offset the decline in nuclear’s share of the mix.

We have almost used up the carbon budget if we are to meet the Paris target. We are left with a clear choice: either every new dollar invested in energy is used towards decarbonized sources, or we must offset investment in fossil fuels with major emission reductions. If this is indeed the case, we cannot currently afford the exclusion of any carbon-free technologies.

It has become increasingly clear — and widely documented — that we cannot win the climate change fight without nuclear power. This simple statement may be an ‘inconvenient truth’ to some, but becomes more evident to others with every passing day.

We know what it will take to limit global warming to 2°C.

The science is clear on this too. We must firstly stop the increase of carbon emissions as soon as possible. Secondly, make electricity carbon neutral by 2050 (by 2040 for industrialized countries) and from then on, mostly carbon negative. Thirdly, achieve complete carbon neutrality by 2050 in industrialized countries and by 2060 at the global level, principally as a consequence of a massive electrification of buildings, transport and industry. Under this scenario, with warming below 2°C, decarbonized electricity would become the primary source of energy in 2050, according to the IEA.

I would like to seize this opportunity to thank Fatih Birol for his courageous stance in favour of nuclear energy expressed in the recent report published by the IEA.

Demand for electricity would then rise across the globe, with a huge increase coming from emerging countries in addition to a substantial uptick from industrialized nations. The European Commission’s most recent scenarios for Europe show electricity demand rising by between 35 and 75% by 2050, in spite of major efforts to promote energy efficiency.

In the absence of nuclear power generation, it is becoming clearer every day that any known roadmap for meeting such demands is unrealistic.

Renewable energies are set to play a key role in ensuring that supply keeps pace with rising demand. In an under 2°C gain scenario, the IEA estimates that new capacities of wind and solar generation installed each year must increase by a factor of three as compared to the current rate. Without nuclear, an even faster renewables growth rate is required, posing the real risk of renewables running up against the limit of their potential capacity, as highlighted in the recent report of DENA, the German Energy Agency.

All of these reports make one thing crystal clear: to meet the challenge of climate change, we will need to leverage the complementarity of nuclear power, renewables *and* energy efficiency. We can no longer consider fighting climate change without the asset of nuclear generation. The clock is ticking. In the absence of nuclear, emissions will not decrease, or will do so much too slowly. Where nuclear power is rolled out, emissions sharply decline. As underlined in a recent World Bank report, the biggest decrease in emissions was achieved during the 1980s in France, directly attributable to the country's nuclear electricity programme. Emissions were cut by 4.5% per year. We must ramp up every effort that allows nuclear to make its full contribution — and do so without further delay.

Forging public policies in line with our climate challenge will first of all require a commitment by governments to one key issue: visibility.

The role of governments is key as energy investments have never been as dependent as now upon decisions taken by nations. According to the IEA, 85% of energy sector investments are currently directly or indirectly dependent on the State. In the electricity sector, it is 95%, even though half the world's electricity is generated in markets open to competition. Visibility can be achieved by focusing on three priorities: planning, incentivizing, and support

PLANNING

First, long term visibility is improved when energy policy objectives are prioritized and clearly identified: climate, economy, and security of supply. All too often, targets focus on means — this or that technology for instance, rather than actual end goals. This is one source of the harmful 'stop-and-go' patterns in regulation.

Next, costs come down when there is industrial continuity, when first-rate expertise is maintained within the industrial ecosystem, and when series effects and standardization kick in to lower costs. This is crucial for nuclear power. This is actually crucial for all of the technologies we will need for energy transition.

INCENTIVIZING

The first task is to guarantee adequate investment. Greater magnitudes of uncertainty lead to volatility, and for a capital-intensive sector like ours, this means less investment and more risk to security of supply. This is especially true in power markets that are open to competition: their market design must be adaptive, and long term contracts used for all types of generation.

Secondly, there must be incentives for extending the service life of existing nuclear plants. As the recent IEA report on nuclear clearly showed, keeping existing plants in service is vital to climate protection, as well as the most competitive way to produce electricity that is carbon-free, dispatchable and, as demonstrated in France, flexible. Now is the time to create a regulatory framework within these countries that ensures proper remuneration of existing nuclear over the longer term. This means a framework that guarantees adequate remuneration for capital previously invested, as well as for the continued safe operation of existing plants.

Thirdly, effective signals must be provided for investment in new nuclear. These signals must limit the cost of capital by design, through intelligently sharing risk between operators, builders, suppliers, consumers and the State. This can make a huge difference for capital intensive projects like nuclear power plants. We can, and must, innovate in terms of contract engineering to ensure that all major industrial projects, including new nuclear, are of benefit to our overall energy and climate policies.

If energy transition leads to a greater inequality of benefit, it will eventually be rejected by citizens, as illustrated in the Yellow Vest movement in France.

One means to avoid this is a constant focus on minimizing costs. We cannot devote hundreds of dollars per tonne of CO_2 to what might be obtained for a few tens of dollars. This is the primary guarantee of fairness. It is then equally important to identify which populations are most affected by transition, and provide support to the most vulnerable among them.

Lastly, acceptance of the energy transition will depend on the concrete benefits for citizens in terms of growth and jobs. Here, the ability to develop and maintain local industries will be essential. Anywhere future technologies are developed and produced becomes an opportunity for future economic growth and jobs. Nuclear power is a driving force for industrial development and the creation of skilled jobs.

Industry players must do their share, with the public good in mind.

We must continue to drive innovation, improve technological performance, and lower related costs. Industrial players too have a role in ensuring the success of nuclear through first choosing an adapted design that meets the highest safety standards; second adopting an industrial organization that optimizes construction projects and keeps lead times in check; third maintaining and developing skills across the entire value chain; fourth innovating and conducting R&D to improve performance and prepare the reactors of the future, such as SMRs.

Given their expertise in technologies, technical systems and related challenges, industrial firms can further help by making sure that energy systems are considered holistically, with the public good always taken into account.

We must pay more attention to evolving consumer expectations, and to their desire to be treated more like stakeholders. This is the only way we will continue to earn our 'license to operate'. It is time for us to bolster our corporate social responsibility and expand our focus on shareholder value to include stakeholder value, as the Business Roundtable recently encouraged us to do.

The time to protect the climate is now. As you know, Jacques Chirac, our former President, had declared in Johannesburg in 2002 "Notre maison brule et nous regardons ailleurs", "Our house is burning down and we're blind to it". We will not rise to the challenge without nuclear.

Public policies must quickly deliver the visibility required for nuclear to do its share in protecting our climate and promoting economic and industrial growth.

Rising to the challenge of climate change will also require greater international cooperation. Nuclear can and should lead the way. It is a source of sovereignty. It is inherently collaborative. The IAEA and WANO are key institutions here, each in its own area. International cooperation on norms and technical and safety standards is more important than ever for the future of nuclear. It is the way forward if we are to continue to innovate, notably with SMRs, and to attract the best talent.

As a public utility dedicated to serving the general interest, let me re-affirm EDF's long-standing commitment to tackling climate change and upholding the role of nuclear with conviction.

4.1.4. Track 4: Shaping the future of the nuclear industry in regulated and deregulated energy markets to address climate change

Invited Speaker — OECD/Nuclear Energy Agency

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This paper was not available for publication but the full presentation is included in the on-line supplementary files, for reference, and can be found on the publication's individual web page at www.iaea.org/publications.

4.1.5. Track 4: Shaping the future of the nuclear industry in regulated and deregulated energy markets to address climate change
Invited Speaker — China National Nuclear Corporation

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Ladies and gentlemen, good morning! It is my great pleasure to be here and join the discussions on 'Climate Change and the Role of Nuclear Power'. On behalf of the China National Nuclear Corporation, I would like to take the opportunity to share our views and opinions on 'The Active Role of Nuclear Energy in Pushing Global Energy Transition'.

1. IMPORTANCE OF NUCLEAR ENERGY FOR CLIMATE CHANGE

Climate change is a global challenge to be dealt with that requires common efforts of all nations affected. In response to climate change, the UN General Assembly approved the UNFCCC (United Nations Framework Convention on Climate Change) in 1992. The ultimate goal is to keep greenhouse gas concentrations at a stable level. The Paris Agreement, reached in 2015 at the Paris Climate Conference, aims to keep global temperature rise in this century below 2ºC above pre-industrial levels, and even further to 1.5ºC.

Clean energy transition is crucial in combating climate change. With progress in technology, the world is entering an age of clean energy with less dependence on fossil fuels. The share of natural gas, nuclear energy, solar power, wind power and hydropower in energy production and consumption is increasing rapidly. In some countries, clean energies take 60% of the energy mix. However, hydropower is highly restricted by regional resources and wind and solar power also have natural constraints. They can hardly be main power producers without a breakthrough in energy storage technology. Also, nuclear power has been demonstrated to be an important option in replacing coal fired power. Based on these factors, nuclear power is an important baseload power source which avoids price fluctuations and grid safety risks from renewable energy. Nuclear energy will still be an integral part of the future energy mix.

By the end of June 2019, 451 nuclear power units were in operation in 31 countries and regions, with a total installed capacity of about 400 GW, accounting for 10% of global power generation. Nuclear power and hydropower contributed 90% of low carbon electricity over the past 50 years. Despite the impact of the Fukushima accident, the proven Gen III nuclear technologies are building more global confidence. Meanwhile, many emerging economies are planning for nuclear power, the developed countries need to replace decommissioned plants, and the global community is calling for less emissions. All these facts give us confidence that nuclear power will continue to prosper globally in future.

2. ACTIONS OF CHINA AND CNNC

China is committed to tackling climate change. In 2014, President Xi Jinping proposed the new energy strategy of "promoting revolutions on energy supply, consumption, regulations and technology, and encouraging international cooperation". Over the past five years, with the joint efforts of the Chinese Government and society, tremendous changes have been made in China's energy structure. The past three years have witnessed the fastest growth of clean energy in China. China now ranks first in installed capacity of hydro, wind and solar power, as well as nuclear power construction. The Chinese Government has promised to cut carbon emissions per unit GDP by 60% to 65% from the 2005 level by 2030. China plans to increase the share of non-fossil energy in primary energy consumption to 15% by 2020 and 20% by 2030.

Nuclear power is playing an increasingly important role. By the end of June 2019, there were 47 nuclear power units in operation in the China mainland, with an installed capacity of nearly 50 GW, ranking third in the world. All units have maintained a good operational record, and no accident above level II has occured over 30 years. There are also 11 units under construction, with an installed capacity of 12 GW, ranking first in the world. In 2018, nuclear power generated about 300 billion kW·h of electricity in China, accounting for 4.2% of national power generation. We are fully confident that in the next 10 years, we can expect 6 to 8 units/per year to be constructed. Nuclear energy will play a bigger and more active role in China.

CNNC is the only company in China, and also among the few in the world, with a complete nuclear industrial chain. Our business scope covers uranium mining and enrichment; fuel fabrication; nuclear power research and design; plant construction and operation; spent fuel disposal; and nuclear technology application. In recent years, CNNC has made remarkable progress in nuclear power development. We are open to cooperation and has constructed PWR nuclear power plants from France, CANDU from Canada, WWER from Russia, AP1000 from USA and our own HPR1000. We are also promoting the localization of equipment supply and have built up the capacity to manufacture equipment for 8 to 10 units every year. At present, more than 85% of key equipment and materials of the HPR1000 can be produced in China. As to the ability of plant engineering and construction, CNNC is capable of constructing various reactors, including PWRs, fast breederr, HTRs, etc. The historical record is more than 30 units under construction simultaneously. Summarizing:

- CNNC is committed to developing Gen III nuclear power technologies. China is one of the leading developers of Gen III technology and has more than 10 Gen III nuclear power units in operation or under construction. HPR1000 projects designed by CNNC are proceeding smoothly. The global demo project of HPR1000, Fuqing 5, has entered into commissioning stage and will achieve power production by the first half of 2020. Four HPR1000 units, both at home and abroad, will be completed on time or ahead of schedule, making HPR1000 the only Gen III technology built without delays.
- CNNC is committed to nuclear technology innovation. In today’s world, nuclear technologies are progressing fast, especially in the areas of small modular reactors (SMR), special purpose reactors, nuclear waste transmutation and treatment. In response to new changes, CNNC actively engages in innovation process, such as development of ATF and other advanced fuels, HTR, fast breeder reactor, nuclear fusion technology, and spent fuel disposal, etc. CNNC constantly drives innovation in nuclear technology, and our SMR is expected to start construction next year.
- CNNC is committed to the diversified application of nuclear energy. CNNC has expanded its products from power generation to district heating, hydrogen production and water desalination, which meets different demands of users. The HTR developed by China can supply industrial heat above 750°C and is expected to have a broad application in hydrogen production. The demo project of 200 MW HTR will be in operation by 2020, laying a solid foundation for further commercial applications. In addition, CNNC is developing the pool-type, low temperature heating reactor in northern China to replace the fossil fired heating system.
- CNNC is committed to global nuclear energy cooperation. CNNC is working with Belt and Road countries on nuclear power, uranium resources, nuclear fuel, nuclear technology applications and other fields of nuclear industry. We are engaged in the international fusion research programme of ITER and provide technical services,

equipment supply, installation and construction. We are also cooperating with some major players such as Russia, France, EU and USA in different areas to promoting the technology of the industry. In future, CNNC will continue to enhance the international cooperation and try to contribute more to nuclear energy development worldwide.

3. WORKING TOGETHER FOR A BRIGHT FUTURE OF NUCLEAR ENERGY

To combat climate change, nuclear energy is still irreplaceabe and common efforts of the industry are indispensable. Hereby, I would like to emphasize the following three points.

First, we should build consensus and strengthen confidence of nuclear energy development. At present, global nuclear industry is moving out of the shadow of Fukushima accident. However, some countries tend to abandon nuclear power and sharply drop its proportion in energy mix, and developed countries witnessed sluggish growth of nuclear power. Except for several units in Finland, France, the USA and the UK, no other nuclear power units were built in North America and EU for about 30 years. Over the same period, however, about 100 units were built in developing and emerging economies. We should also notice that in the next 10 to 20 years, the world will see a peak of NPP decommissioning and life extension. Maintaining stable and sustainable development is essential for nuclear power to play its role in the energy mix. Therefore, governments and the global nuclear community should strengthen confidence and maintain the momentum and stable investments for nuclear power development, so that nuclear energy could contribute more to tackling climate change.

Second, we need continuous innovation to resolve the bottlenecks of nuclear energy development. Nuclear energy has formed a complete and mature industrial system, but it also faces obstacles and constraints due to its sensitive nature. Through innovation, we can effectively resolve challenges and obstacles, and lay a foundation for the safe and efficient development of nuclear energy. What is equally important is to improve the economics of nuclear power. Nowadays, project delays and budget overruns are very common in the global nuclear energy sector. In order to improve the economics and competitiveness of nuclear power, we need to take effective measures, learn from feedbacks, upgrade technology and management, optimize system design, reduce the cost of key equipment and shorten the construction time. Meanwhile, safety management must be improved, so that safety requirements are met in every aspect of design, construction, operation and management. In this way, we can ensure a high level of safety and push forward nuclear energy development. In the HPR1000 project in Pakistan — Karachi 2 and 3 — CNNC has adopted a package of innovative construction methods which has shortened the construction time by 7 months.

Third, we should strengthen cooperation and address common challenges. One thing unique about nuclear energy is that every stakeholder will suffer the pains and share the losses of any wrongdoings of the industry. That means we need all-round cooperation to address common challenges. Insightful, sustainable and systematic plans are essential to address people's concerns over nuclear safety, radiation protection, environmental impact, radwaste treatment and spent fuel disposal. Open and transparent communication is invaluable to gain the public's trust and expand common ground. Moreover, international technology cooperation is becoming even more important to optimize and upgrade nuclear energy technology to make it safer and more competitive.

Climate change is a global challenge. But the challenge may be an opportunity to create a new era of nuclear energy development. CNNC is willing to work with all countries to take the chance to promote the safe and efficient development of nuclear energy, and contribute to the global efforts of pushing energy transition and mitigating climate changes.

4.1.6. Track 4: Shaping the future of the nuclear industry in regulated and deregulated energy markets to address climate change

Invited Speaker — ESG Policy Challenge: Is there any Space for Nuclear? ROSATOM

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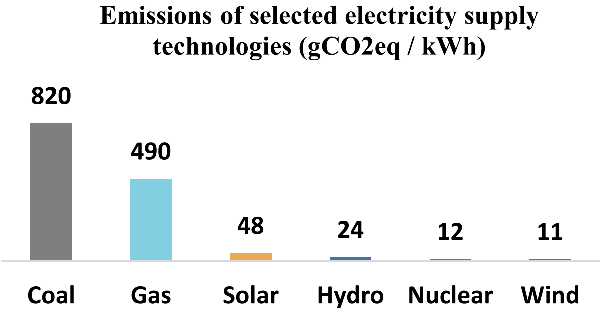
The climate issue is one of the cornerstones of the UN sustainable development agenda, and it appears to have become a significant game changer for various areas. These changes are now observed both in corporate strategies aimed at 'green' business performance, as well as in the public sector, when state policy and international regulations establish specific requirements regarding ESG performance. Since 2015, when the UN Sustainable Development Goals (SDGs) and the Paris Agreement within the United Nations Framework Convention on Climate Change (COP21) were adopted, the new sustainability requirements and criteria are being elaborated to define 'sustainable' and 'non-sustainable' activities.

In this regard, nuclear energy is still suffers in tough debates. On the one hand, as shown in the



Source: IPCC

above figure, we cannot ignore an evident positive impact of nuclear energy for meeting the CO_2 reduction challenge with the second lowest result of greenhouse gas emissions of 12 g CO_2/kW·h after wind which is No. 1 with 11 g CO_2/kW·h[13]. A recent International Energy Agency report — Nuclear Power in a Clean Energy System — asserts that there is no chance to fulfill CO_2 emission reduction commitment by 2040 without nuclear energy[14]. Together with IEA, the EU Technical Expert Group on Sustainable Finance Taxonomy Technical Report (Taxonomy Technical Report) outlines the "evidence on the potential substantial contribution of nuclear energy to climate mitigation objectives was extensive and clear"[15].

On the other hand, there are strong voices against nuclear energy being recognized as a part of sustainable energy mix. Beside political reasons, the main arguments for this refer to the risk of causing "potential significant harm to other environmental objectives, including circular

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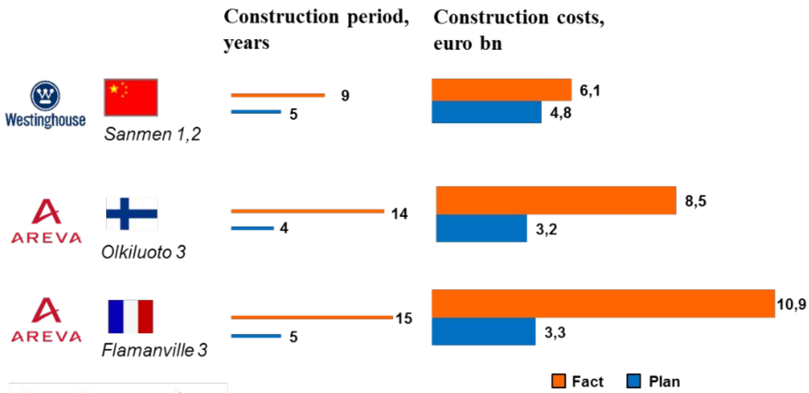
[13] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Bonn (2014).

[14] INTERNATIONAL ENERGY AGENCY, Nuclear Power in a Clean Energy System, OECD, Paris (2019).

[15] EU TECHNICAL EXPERT GROUP ON SUSTAINABLE FINANCE, Taxonomy Technical Report (2019). European Commission, Brussels (2019).

economy and waste management, biodiversity, water systems and pollution" (see footnote 15), i.e. Do No Significant Harm (DNSH) criteria as named in the Taxonomy Technical Report.

Undoubtedly, the nuclear industry is one of the most complicated industries and is traditionally subject to discussions of its pros and cons, with lots of biases. We cannot deny DNSH risks as well as well-known cases of NPP construction delays and capital cost overruns (see, for example, the figure below) that do not raise investors and debtors appetite for nuclear projects. These risks are inherent in most large scale technological projects, such as airport construction



Source: Rosatom analysis

or a new aircraft production launch, for example. However, these projects normally are supported by national and international infrastructure development programmes, export credit agencies (ECA), international grants, etc.

Such support is provided both to develop these large infrastructure projects, as they result in a significant impact for further economic development for the whole country, and also considering multiplied effects, such as additional orders for local industries, long term backlog, workplaces, state income tax, etc. According to the latest calculations made by Deloitte and FORATOM in 2019, the overall impact of the nuclear sector on the European GDP totals €507.4 billion in 2019, more than a half trillion Euro, translating into 3–3.5% of the EU GDP. Every Euro of direct impact of the nuclear industry on the EU GDP will generate a total of €4.9 in EU GDP. In terms of job creation, the EU nuclear industry's provides 6088 jobs per 1 GW of installed capacity, that is 3 times more than the wind sector's impact of 1805 jobs per 1 GW and about 17 times higher than the impact of the EU hydro industry with 361 jobs per 1 GW[16].

However, we see that the majority of development banks do not include NPP construction projects in their lists of infrastructure development projects priorities. The range of sustainable finance options does not include nuclear energy in its list of basically sustainable sectors, which would potentially deprive access to favourable terms of sustainable financing for nuclear energy in the future. These additional boundaries may hamper long term development of nuclear programmes.

At the same time shutdowns of existing NPPs seems to be not an explicitly efficient investment decision as a sharp decline in nuclear would mean a substantial increase in investment needs for other forms of power generation and for the electricity network in general. According to the IEA's 2019 report Nuclear Power in a Clean Energy System, a decision for the full decommissioning of the existing NPP fleet would cost around $1.6 trillion for advanced economies over the next two decades. In addition to this, roughly $1.2 trillion more would be

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[16] DELOITTE FORATOM, Economic and Social Impact Report (2019).

needed to invest in renewables-based generating capacity, together with $700 billion in network upgrades to integrate the larger renewables fleet. This decision to phase out all nuclear energy will cost $3.5 trillion for advanced economies in comparison with the two times less cost of $1.5 trillion investment to stay on track with nuclear according to the World Energy Outlook Sustainable Development Scenario[17].

Such dramatic differences in investment demand for the nuclear phase-out scenario would cause not only additional costs for the country, but also result in additional pressure on public budgets. For instance, Germany, which has denied its nuclear future in 2011, has now one of the highest electricity prices in Europe of almost 30.5 eurocent/kW·h due to substantial price hikes of 25% in 2010–2013 with level of CO_2 emissions practically staying unchanged. It is worth mentioning that in the last few months several European countries such as Sweden, Finland, UK, Hungary and Poland have stated their support for further development of nuclear power generation, performing pragmatic, economic-based reasons for such a decision.

Meanwhile, despite the large scale direct and indirect benfits from NPPs, none of the nuclear project financing deals have been awarded an official, 'green' label in 2018. However, several financial researchers in their green and sustainable financial reviews do classify nuclear project financing as "non-green by compliance with a high exposure to clean energy".[18] In 2018, the amount of green and sustainable financing reached $261 billion ,with 22% of this sum allocated to power utilities and energy, with only $9.2 billion financing nuclear projects (mostly projects in Finland, Switzerland, Japan, China).[19] Nevertheless, a positive trend can be noticed with "non-green by compliance" financing allocated to nuclear projects doubling in the past three years, taking into account only $5.2 billion in 2016. There are also some examples of successful, sustainable-linked loans deals in the nuclear sector, such as EDF in late 2018 which closed a sustainability loan amounting to 4 billion euros linked to achieving certain ESG performance indicators.

The sustainability compliance criteria of financial institutions are still quite diverse today. Each bank defines its own list of priority sustainable or green sectors and particular companies for its credit portfolio, together with screening black list exemptions. For example, the KLP fund, which is the largest government pension fund of Norway with $80 billion of assets, investigates such negative screening criteria as human rights, environmental damage, cases of corruption and unethical behaviour. Based on these criteria, KLP currently excludes such companies as Enel, KEPCO and Petrobras. The bad news is that such screening black list policies result in limitations of accessible financial sources, but the good news is that the sustainability trend is becoming mandatory, with financial institutions being in the forefront of these developments. Thus, certain rules will be drawn down.

Efforts to develop the Taxonomy of Sustainable Finance initiated by the European Commission in January 2017 is a serious step towards establishing a general regulatory framework to define principles of sustainable financing. The Taxonomy Technical Report published in June 2019 is to become the building block for further development of the sustainable finance regulatory framework and specific compliance criteria for borrowers. Most probably, the results of the Taxonomy Technical Report will become a basis for a common regulatory framework not only in Europe, but also for Asian and Middle East financial markets. The fact of non-inclusion of

[17] INTERNATIONAL ENERGY AGENCY, World Energy Outlook, OECD, Paris (2018).
[18] BLOOMBERGNEF, BLOOMBERG L.P.
[19] CLIMATE BONDS INITIATIVE, Green Bonds: State of the Market 2018 (2019).

the nuclear energy sector into the list of sustainable activities may be treated as a signal by some market players. However, despite the non-inclusion of the nuclear activities due to potential significant harm risk, the Taxonomy Technical Report recommends “more extensive technical work to be undertaken on the DNSH aspects of nuclear energy in future to consider if nuclear energy could be included in the Taxonomy at further stages” (see footnote 15).

The OECD Arrangement on officially supported export credits (Arrangement) serves as a good example of regulatory adjustments for specific sectors when considering financing. This Arrangement is quite similar to the Taxonomy as it outlines the basic requirement and limitations for financial organizations, including national ECAs, which provide subsidized financing and insurance for significant export projects. Beside general requirements, the Arrangement identifies specific sectors, such as aircraft, rail infrastructure, nuclear, renewables, etc., to require additional assessments of the environmental and social impact and risks in accordance with the World Bank Safeguard Policies and IFC Performance Standards. In case of compliance with these requirement, the project may be qualified to obtain favourable export financing terms, which include long term loans for each specific industry, for example 12 years for the aircraft industry and 18 years for nuclear in comparison with a maximum of 10 years of standard terms. A similar approach should be followed for nuclear and other complex sectors in further elaboration of the Taxonomy.

The modern VUCA world does not accept boundaries or blacklisting; it is all about transparency, opportunities, challenges and partnership. In this way, instead of considering nuclear energy as non-green or non-sustainable there should be developed specific criteria to ensure safety and risk mitigation fulfillment to open sustainable financing sources for the nuclear sector.

According to UN forecasts, by 2050 the world population will increase by 25% from 7.7 to 9.7 billion[20], causing energy demand to at least double. It is also noteworthy that over 1 billion people today are deprived of access to electricity. Taking into account the global CO_2 reduction challenge and the search for an efficient, sustainable energy mix, we strongly believe that nuclear energy cannot be excluded from the strategic future scenario. In this way, the strategic goal for the nuclear community is to ensure safety and a low risk profile, together with open dialogue with all the stakeholders making the nuclear industry truly welcomed and favourable all over the world.

[20] UNITED NATIONS, World Population Prospects, UN, New York (2019).

BIBLIOGRAPHY

BLOOMBERGNEF, Bloomberg L.P.

CLIMATE BONDS INITIATIVE, Green Bonds State of the Market 2018 (2019).

DELOITTE FORATOM, Economic and Social Impact Report (2019).

EU TECHNICAL EXPERT GROUP ON SUSTAINABLE FINANCE, Taxonomy Technical Report, European Commission, Brussels (2019).

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Bonn (2014).

INTERNATIONAL ENERGY AGENCY, Nuclear Power in a Clean Energy System, OECD, Paris (2019).

INTERNATIONAL ENERGY AGENCY, World Energy Outlook, OECD, Paris (2018).

UNITED NATIONS, World Population Prospects, UN, New York (2019).

4.2. TRACKS 2 AND 3: NUCLEAR POWER TODAY AND TOMORROW

Chairpersons: A. Omoto, Japan
D. Nicholls, South Africa

4.2.1. Track 2: The increasing contribution of nuclear power in the mitigation of climate change, including synergies with other low carbon power generation sources

Invited Speaker — Nuclear and renewables: Decarbonization in a collaborative model — Electronuclear–Eletrobas Termonuclear

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Comparing the costs of different power generation technologies has become one of the main arguments used by proponents of specific sources and those seeking to find the best approach to plan the expansion of electrical systems. However, this approach, taken alone for public energy policy making, is far from simple and can lead to unwanted and unexpected results.

How much does it cost? It seems like a simple question. However, when it comes to competing power generation technologies, it is an extremely challenging question. Generation costs include many variables: capital, fuel, location, waste disposal, environmental impact, interconnection, reliability, intermittency, and other external and systemic costs. No two technologies are alike.

System costs are often divided into the following four broadly defined categories of profile costs (also referred to as utilization costs or backup costs), balancing costs, grid costs and connection costs [1]:

- Profile costs refer to the increase in the generation cost of the overall electricity system in response to the variability of VRE output.
- Balancing costs refer to the increasing requirements for ensuring the system stability due to the uncertainty in the power generation (unforeseen plant outages or forecasting errors of generation).
- Grid costs reflect the increase in the costs for transmission and distribution due to the distributed nature and locational constraint of VRE generation plants.
- Connection costs consist of the costs of connecting a power plant to the nearest connecting point of the transmission grid.

The external costs are based upon the sum of three components: climate change damage costs associated with emissions of greenhouse gases (CO_2 and others); damage costs (such as impacts on health, crops, etc.) associated with other air pollutants (NOx, SO_2, NMVOCs, PM_{10}, NH_3); and other non-environmental social costs for non-fossil, electricity generating technologies. Environmental and social externalities are highly site specific and so results will vary widely even within a given country according to the geographical location.

For decades, analysts have come up with an approach that attempts to integrate some of the key cost variables of generation technologies. It is called the levelized cost of electricity (LCOE), meeting internal costs, including Capex and Opex, until a new plant is connected to the grid [2]. LCOE analysis [3] provided evidence on three key points:

- Despite recent high cost projects in Western countries, most new nuclear plants have an LCOE comparable to any other generation source, including most variable renewable energy (VRE). LCOE meets all costs, including Capex and Opex, until a new plant is connected to the grid; andar
- The LCOE for VRE did not take into account the system costs that consumers would be required to pay, such as network upgrades to accommodate generation far from consumer centres, low VRE predictability balancing and frequency control and backup and/or storage of electricity to compensate for this variability.
- LCOE analysis does not include environmental and social externalities such as waste disposal, greenhouse gas and air pollution, material resources and land use. Excluding marginal externalities, LCOE contradicts a central point for the consideration of clean energy technologies, which is the very impact of these externalities.

Using LCOE to compare generation costs has become widespread practice. However, the approach based on comparisons of LCOE associated with different generation technologies, or any other measure of total life cycle production costs per MW·h provided, does not take into account different system costs, effectively treating all generated MW·h, regardless of source, as a homogeneous product, i.e. a commodity, governed by a single price.

The criticism is technical and the fundamental objection is that cost does not measure value. Power generation occurs at different times and in different places, having different values at each moment and in each place. It would be like saying that a car costs a lot more than a bicycle, so we should all buy bicycles. Nevertheless, this disregards the fact that the car and bicycle are providing different services.

Analysing the OECD/NEA study on the costs of decarbonization [1], COSTES [4] gave us some powerful insights:

- Setting a price for carbon as an external cost seems obvious: $35 per tonne of emitted CO_2 is considered sufficient to eradicate it from all scenarios. This is not so far from the $20 already considered by some countries. The sooner this is achieved, the better, since everyone agrees that there is an urgent need to decarbonize the energy system.
- Ideally, policies should be developed to ensure that system costs are well analysed and allocated to the source that generates them. The concept of "Equivalent Firm Power" [5] was proposed, according to which any VRE source should guarantee its production with storage for which it would be responsible. In any system, this would be very difficult to implement.
- The adequacy of most existing electricity markets may be questioned. The order of merit could be justified in the past, when all sources had comparable LCOE and were fully exposed to the market. Electricity markets today produce situations where prices are zero and there are no longer economic signals consistent with an increasing share of VRE.
- In a market where any form of electricity generation is dealt with on its own merits, without any subsidies or priority rights, there will be a need for very clear new regulations. With a high share of VRE, existing markets will be very volatile and will pose high risks to any long term investment and financing. How can policies be designed to attract investment in this situation?
- There is clear evidence that in addition to hydroelectric power with large reservoirs, nuclear is the only low carbon dispatchable technology, and it is essential, along with variable renewable energy, to obtain a decarbonized electrical system. The cost–benefit ratio for the consumer leads to a balanced system where the value of nuclear energy and

the VREs themselves are not destroyed by excessive participation by the latter. Rather than developing public policies that set targets for VRE participation, which will require network capacity, flexibility and infrastructure, would it not be preferable to set carbon generation targets first and then identify which electrical system would provide the best cost–benefit?

When considering the facts about the types of technology, their costs, including external and system costs; public acceptance; and by assessing the potential for higher electricity prices, policy makers could create the market conditions and rules to find an appropriate path.

Nevertheless, there are other important subjects for decision makers to take into account:

- In order to accommodate a high share of VRE, the system must develop not only transmission and distribution networks but also incorporate new technologies that do not yet exist to accommodate the fluctuations that VRE generation entails. These costs may be taken into account, but what about the risks associated with these future technologies? And the reliability of such a system and its resilience?
- Material resources used to generate electricity is an issue scarcely analysed. It is a matter of energy and power density [6]. In essence, VRE has, in most areas, a limited load factor: to achieve the same generation in GW·h, VRE needs around three times more capacity than any dispatchable source and would require a lot of storage capacity with a limited load factor. Low energy density VRE implies more building materials (cement, concrete, steel, for example) and more land use for a given life cycle energy generation; which policy provides the most efficient way to use the resources the planet can offer?
- Another issue to consider is the acceptability of a given scenario. While existing nuclear power generation is generally well accepted, new nuclear power can be a challenge. What about a comparatively large VRE deployment and its impact? What about the acceptability and feasibility of distribution/connection requirements?

A cost effective, low carbon system would probably consist of a sizeable share of VRE, and at least an equally sizeable share of dispatchable zero carbon technologies, such as nuclear energy and hydroelectricity with large reservoirs. A complementary amount of gas fired capacity would provide additional flexibility, alongside storage, demand side management and the expansion of interconnections. The Brazilian system seems to be going in that direction, already having some of these attributes.

The Brazilian electricity system is unique for its extremely high contribution of renewable sources, thanks to intense use of a huge hydropower potential, started since the beginning of the twentieth century. As of 2018, renewable energy accounted for 85% of the installed capacity. Hydropower accounts for 64% and 'new renewables' (small hydro, wind solar and biomass) for 22%. Thermopower provides the remaining 14% (including 2% nuclear) [7]. This system, however, is called 'hydrothermal transition' since the beginning of the 21st century.

Hydrothermal transition is what happens when the expansion of an electricity system with a predominantly hydropower source requires an increasing thermopower contribution, either by hydro potential depletion or loss of auto-regulation capacity due to stored water volume reduction in reservoirs, or both simultaneously, which is effectively what is happening in Brazil.

The hydrothermal transition began to take place in Brazil in 2000, when the growth rate of the thermopower became higher than the growth rate of hydro. This is a consequence of the growth rate of the volume of water in the reservoirs becoming much less than the growth rate of hydropower installed until the late 1980s. Brazil realized this painfully in 2001, facing a supply crisis due to reduced reservoir levels with limited thermopower availability. Since then, thermopower has been successfully increased, facing without crisis reservoir levels lower than the 2001 crisis. From 2000 to 2018, thermopower installed capacity more than doubled, from 6% to 14%. On the other hand, reservoir storage capacity increased only 5%, indicating that the effects of hydrothermal transition will accelerate over the next years.

A similar situation happened earlier in Canada. In the early 1960s, hydropower contribution to Canadian electric system was at a level equivalent to that in Brazil in 2000. This contribution decreased in the 1970s and 1980s, stabilizing in the 1990s around 50–60%. At the same time, the share of coal and nuclear in Canada rose, with the remainder filled by gas and oil and a small but growing share of new renewable sources.

Hydrothermal transition requires a long term strategy for diversification of primary sources of electricity generation. The role of new renewables in a Brazilian hydrothermal transition nowadays is much more important than was in Canadian transition, decades ago. The installed capacity of these new sources increased spectacularly from almost 0% in 2000 to 22% in 2018. New renewables have unique competitive advantages in Brazil for two complementarities: wind–hydro (high wind in dry season) and wind–solar (high wind in high insolation places). This allows low cost storage of intermittent energy in hydro reservoirs, saving water and increasing the capacity of hydroelectric make regulation of demand.

This strategy of diversification of sources can also be observed in many other countries and is most marked in those countries where national energy resources are very scarce, such as Japan and the Republic of Korea. More recently, countries have gone through a rapid economic growth process, such as India and China, are also seeking greater diversification. The Canadian and Brazilian cases arouse particular interest due to the starting point: a large hydropower contribution. The transition starting point of other countries is an electricity system with very large fossil fuel contributions.

Nuclear power will play a key role in diversification strategies for energy transitions directed to decarbonized systems. Although it reliably produces large quantities of low carbon, dispatchable energy, it faces issues of public acceptance in many countries. However, nuclear power remains an economically viable option to meet severe carbon constraints, despite the economic challenges for some new reactor projects.

The cost advantage of nuclear power is not in its plant level costs, although they are quite competitive. It lies in its general benefits to the electrical system. VRE's plant level costs have fallen dramatically, but its overall system costs are not accounted for as production is aggregated over a limited number of hours. All of these factors must come into play in the decisions of each country.

Electricity markets are evolving and nuclear energy is following this evolution to meet future requirements: Small modular reactor (SMR) development is a promising response. Nuclear energy is well placed to take on these challenges in a collaborative mode, working together with all other forms of low carbon generation, in particular VRE, to achieve the ambitious decarbonization targets most countries have set for themselves.

Nuclear power is a reliable partner of VRE through a collaborative model. A technical complementarity could be achieved through the development of greater flexibility in reactor operation in order to optimize VRE variable power production. A systemic complementarity could be achieved through innovative technologies in fields like co-generation, heat and hydrogen production, demand management or interconnection of ultra large power grids. Last but not least, strategic complementarity is needed for building the future decarbonized energy mix.

REFERENCES

[1] OECD/ NUCLEAR ENERGY AGENCY, The Costs of Decarbonization: System Costs with High Shares of Nuclear and Renewables, OECD/NEA, Paris (2019); available at http://www.oecd-nea.org/ndd/pubs/2019/7299-system-costs.pdf.

[2] GUIMARAES, L., The Levelized Cost of Electricity and its Impact on Energy Transition, CEIRI NEWS (2019); available in Portuguese at https://ceiri.news/o-custo-nivelado-da-eletricidade-e-seu-impacto-na-transicao-energetica/.

[3] INTERNATIONAL ENERGY AGENCY AND OECD/NUCLEAR ENERGY AGENCY, Projected Costs of Generating Electricity, OECD, Paris (2015); available at https://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf.

[4] COSTES, P., Viewpoint: Studying the cost of decarbonization, World Nuclear News (2019); available at http://world-nuclear-news.org/Articles/Viewpoint-Studying-the-cost-of-decarbonisation.

[5] HELM, D., Cost of Energy Review, British Institute of Energy Economics (2017); available at http://www.biee.org/wpcms/wp-content/uploads/Cost_of_Energy_Review.pdf.

[6] SMIL, V., Power Density: A Key to Understanding Energy Sources and Uses, MIT Press, Cambridge (2016).

[7] EMPRESA DE PESQUISA ENERGÉTICA, Decennial Energy Expansion Plan 2027 (2018); available in Portuguese at http://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-decenal-de-expansao-de-energia-2027.

4.2.2. Track 2: Current Status and Future Developments in the Nuclear Power Industry of the World

Invited Speaker — University of Ontario Institute of Technology

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STATISTICS ON ELECTRICITY GENERATION IN THE WORLD

Figure 1 shows the impact of the Electrical Energy Consumption (EEC) on Human Development Index (HDI) for all countries in the world, and Fig. 2 the main sources of global electrical energy generation [1]. Therefore, considering rapid changes in climate, possible catastrophic events such as powerful hurricanes, melting ice-caps in mountains, changes in solar activity, etc., countries should not rely on unreliable renewable sources such as hydro, wind, solar, and marine unless there is a significant backup with reliable energy source(s) independent of Mother Nature such as nuclear and thermal. It should be noted that, usually, NPPs operate at about 100% of installed capacity, providing reliable basic power to the grid.

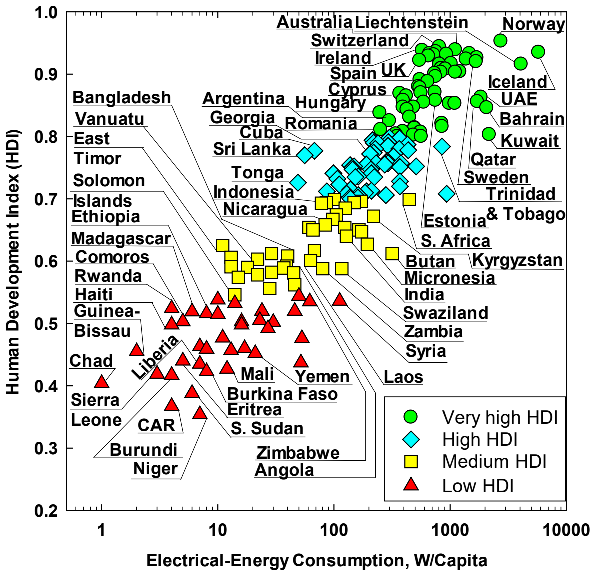

FIG. 1. Impact of EEC on HDI for all countries in the world [1].

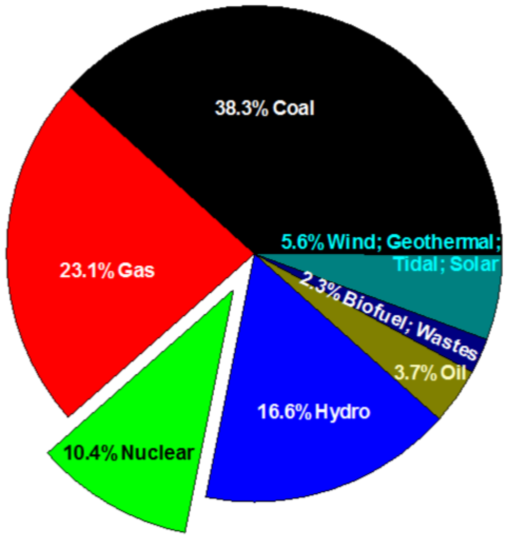

FIG. 2. Electricity generation in the world: population 7659 million; EEC 372 W per capita; HDI 0.728 or HDI Rank 98 [1].

Despite advances in thermal power plant design and operation worldwide, they are still considered as environmentally 'unfriendly' due to significant carbon dioxide emissions and air pollution as a result of the combustion process. In addition, coal fired power plants produce significant amounts of slag and ash, and other greenhouse gases such as SO_2, which contribute to acid rains.

MODERN NUCLEAR POWER REACTORS AND NUCLEAR POWER PLANTS

Nuclear power is often considered to be a non-renewable energy source like fossil fuels, such as coal and gas [2]. However, nuclear resources can be used for a significantly longer time than some fossil fuels, and in some cases almost indefinitely, if recycling of unused or spent uranium fuel, thoria fuel resources, and fast neutron spectrum reactors are used. The major advantages of nuclear power are: (1) concentrated and reliable source of almost infinite energy, which is independent of weather conditions; (2) high capacity factors are achievable, often in excess of 90% with long operating cycles, making units suitable for continuous baseload operation; (3) essentially negligible operating emissions of carbon dioxide and relatively small amounts of wastes are generated compared to alternate fossil fuel thermal power plants; (4) a relatively small amount of fuel is required compared to that of fossil fuel thermal power plants; and (5) NPPs can supply relatively cheap electricity for recharging of electrical vehicles during the night hours as they usually operate on full load (capacity) 24/7. As a result, nuclear power is considered as the most viable source for electricity generation within the next 50–100 years.

Current statistics of all world nuclear power reactors connected to electrical grids are listed in Tables 1 and 2 and shown in Figs 3 and 4. Analysis of the current statistical data on nuclear power reactors shows that 31 countries in the world have operating nuclear reactors (among these countries, 18 plan to build new reactors and 13 do not plan to build new reactors) and 5 countries which do not have nuclear power reactors (Bangladesh, Belarus, Egypt, Turkey, and the United Arab Emirates) are working towards introducing nuclear energy.

TABLE 1. NUMBER OF NUCLEAR POWER REACTORS CONNECTED TO THE ELECTRICAL GRID AND FORTHCOMING UNITS AS PER DECEMBER 2019 [1-5] AND BEFORE THE FUKUSHIMA DAIICHI EARTHQUAKE AND TSUNAMI DISASTER [6]

No.	Reactor type (reactor details)	No. of units		Installed capacity (GW(e))		Forthcoming units	
		As of Dec. 2019	Before Mar. 2011	As of Dec. 2019	Before Mar. 2011	No. of units	GW(e)
1	Pressurized water reactors (PWRs) (largest group of nuclear reactors in the world – 66%)	299 ↑	268	287 ↑	248	75	82
2	Boiling water reactors (BWRs) or Advanced BWRs (2nd largest group of reactors in the world, 16%; ABWRs were the first Generation III+ reactors put into operation in 1996–1997))	71 ↓	92	71 ↓	84	6	8
3	Pressurized heavy water reactors (PHWRs) (3rd largest group of reactors in the world, 11%; mainly CANDU-reactor type)	48 ↓	50	24 ↓	25	8	6
4	Advanced gas cooled reactors (AGRs) (3%) (UK, 14 reactors) (these CO_2 cooled reactors will be shut down in the near future and no more will be built).	14 ↓	18	8 ↓	9	1*	0.2*
5	Light water cooled, graphite moderated reactors (LGRs) (3%)	13 ↓	15	9 ↓	10	0	0

No.	Reactor type (reactor details)	No. of units		Installed capacity (GW(e))		Forthcoming units	
		As of Dec. 2019	Before Mar. 2011	As of Dec. 2019	Before Mar. 2011	No. of units	GW(e)
	(Russian Fed, 11 RBMKs and 4 EGPs; these pressure channel BWRs will be shut down in the near future and no more will be built again)						
6	Liquid metal fast breeder reactors (LMFBRs) (Russian Fed., SFRs – BN-600 and BN-800 (see Fig. 2))	2 ↑	1	1.4 ↑	0.6	3	0.6
Total		447 ↑	444	400↑	378	94	97

Notes: Arrows mean decrease or increase in the number of reactors.

LGRs and ACRs (CO_2 cooled) will be shut down and no more will be built; Data include 37 reactors in Japan, 28 of which are not in service as of December 2019.

*Forthcoming reactor is a helium cooled reactor — High Temperature Reactor Pebble-bed Modular (HTR-PM) (China).

Table 3 lists current activities in various countries worldwide on new nuclear power reactors. Analysis of the data in Table 3 clearly shows that China and the Russian Federation are the frontrunners in new nuclear builds in their countries and abroad. And it is not a big surprise, because both governments provide significant and long term support with funding for nuclear power R&D and their nuclear vendors, especially, to build NPPs abroad plus credits and other incentives for foreign countries, which would like to introduce nuclear power.

TABLE 2. NUMBER OF NUCLEAR POWER REACTORS CONNECTED TO THE GRID BY COUNTRY (RANKED BY REACTOR INSTALLED CAPACITIES) AS PER DECEMBER 2019 [1–5] AND BEFORE THE FUKUSHIMA DAIICHI EARTHQUAKE AND TSUNAMI DISASTER [6]

No.	Nation	No. of units (PWRs/BWRs)		Installed capacity (GW(e))		Changes in number of reactors from March 2011
		As of Dec. 2019	Before Mar. 2011	As of Dec. 2019	Before Mar. 2011	
1	USA	96 (64/32)	104	100	103	↓ Decreased by 8 reactors
2	France	58 (58/-)	58	63	63	No changes
3	China	47 (45/-/2[3])	13	45	10	↑ Increased by 34 reactors
4	Japan[5]	37 (15/22)	54	36	47	↓ Decreased by 17 reactors
5	Russian Fed.	36 (21/-/13[1]/2[2])	32	28	23	↑ Increased by 4 reactors
6	Korea, Rep. of	24 (21/-/3[3])	20	23	18	↑ Increased by 4 reactors
7	Canada	19 (-/-/19[3])	22	14	15	↓ Decreased by 3 reactors
8	Ukraine	15 (15/-)	15	13	13	No changes
9	Germany	7 (6/1)	17	10	20	↓ Decreased by 10 reactors
10	Sweden	8 (5/3)	10	9	9	↓ Decreased by 2 reactors
11	UK	15 (1/-/14[4])	19	9	10	↓ Decreased by 4 reactors
Total		362 (251/58/13[1]/2[2]/24[3]/14[4])	364	350	331	↓ Decreased by 2 reactors, but installed capacity increased by 19 GW(e)

Notes: Arrows mean decrease or increase in the number of reactors.

[1] No. of LGRs; [2] LMFBRs; [3] PHWRs; and [4] AGRs.
[5] As per December of 2019, only nine reactors were in operation.

TABLE 3. CURRENT CONSTRUCTION ACTIVITIES WORLDWIDE ON NEW NUCLEAR POWER REACTORS (FIRST SIX COUNTRIES/NUCLEAR VENDORS SHOWN) [1]

No.	Country/Nuclear vendor	Countries anticipating new builds (No. of possible units)
1	China/Various vendors (supported by government)	China (21+1?*), Pakistan (3), Romania (2), UK (2). Total: 28+1?
2	Russian Fed/Rosatom nuclear power activities supported by the Russian government)	Russian Fed. (4+3?), Belarus (2), Finland (1), Iran, Islamic Rep. (2), Hungary (2), India (1), China (2), Turkey (4), Egypt (4?), Bangladesh (2), India (1). Total: 21+7?
3	USA/Westinghouse, GE	China (2), USA (4+2?), Taiwan (2?). Total: 6+4?
4	Korea, Rep. of/Various vendors	UAE (4), Korea, Rep. of (3). Total: 7
5	India/Various vendors	India (6). Total: 6
6	France/Areva	China (1), Finland (1), France (1), UK (2). Total: 5

* ? : "Commercial start date — indefinitely" (Nuclear News, 2019).

The last several years, especially 2018, were very important for the nuclear power industry of the world. As such, the Russian Federation put into operation a number of Gen-III+ WWERs (PWRs) and the SFR–BN-800 reactor in 2016 and continue to lead the SFR technologies in the world. China put into operation many reactors/NPPs, including the world's largest Gen-III+ PWR–EPR (Areva design) with the amazing installed capacity of 1660 MW(e). In addition, several AP-1000 reactors (Westinghouse design), also a Gen- III+ design, were put into operation in China for the first time in the world. In general, Gen-III+ reactors/NPPs have installed capacities from 1000+ to 1660 MW(e), enhanced safety, and can reach slightly higher thermal efficiencies up to 36–37% (38%) compared to those of Gen-III reactors/NPPs.

The year 2019 and following years will be also very important because a unique GCR — a helium cooled reactor — High Temperature Reactor Pebble-bed Modular (HTR-PM) should be put into operation in China.

Figure 3 shows the impact of major NPP accidents within last 50 years on new builds. Analysis of the data in this figure shows that we might face a very significant drop (up to 3 times) in a number of operating nuclear power reactors somewhere between 2030 and 2040 (see Fig. 4). Even with higher rates of new nuclear capacity addition, we will have a tangible decrease in a number of operating reactors.

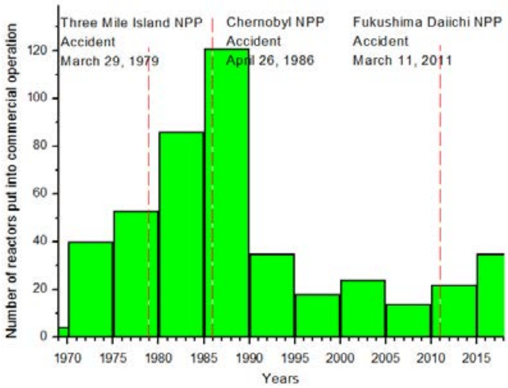

FIG. 3. Number of nuclear power reactors of the world put into commercial operation from 1969 versus years as per November 2018.

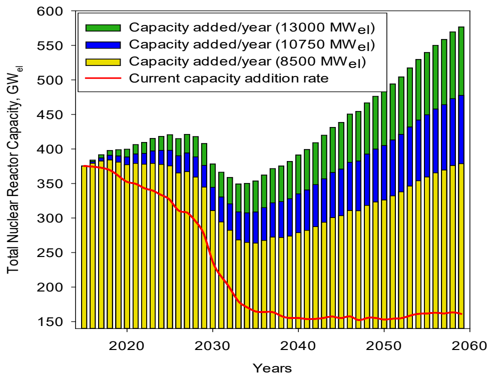

FIG. 4. Possible scenarios for future of nuclear power; based on 45 years in service and adding new reactors at a rate of ~21 reactors every 5 years (red line).

CONCLUSIONS

Nuclear power is, in general, a non-renewable source unless fuel recycling, thoria fuel, and/or fast reactors are adopted, which means that nuclear resources can be used significantly longer than some fossil fuels. Currently, this source of energy is considered as the most viable one for baseload electrical generation for next 50–100 years. However, all current Generations II, III and III+ NPPs, especially, those equipped with water cooled reactors, are not competitive with modern thermal power plants in terms of thermal efficiency. Therefore, new generation NPPs must have thermal efficiencies close to those of modern thermal power plants, i.e. within the range of, at least, 40–50%, and incorporate improved safety measures and designs.

REFERENCES

[1] PIORO, I., et al., Current Status and Future Developments in Nuclear-Power Industry of the World, ASME J. of Nucl. Eng. Radiat. Sci. **5** 2 (2019) 27 pages; Free download from https://asmedigitalcollection.asme.org/nuclearengineering/article/doi/10.1115/1.4042194/725884/Current-Status-and-Future-Developments-in-Nuclear.

[2] PIORO, I.L., Ed., Handbook of Generation IV Nuclear Reactors, Elsevier–Woodhead Publishing, Duxford (2016) 940 pages; available from https://www.gen-4.org/gif/jcms/c_9373/publications.

[3] Nuclear News, Reference Special Section, American Nuclear Society, March (2019) 33–65.

[4] http://www.world-nuclear.org/; accessed 5 Dec. 2019.

[5] https://pris.iaea.org/pris/; accessed 5 Dec. 2019.

[6] Nuclear News, Reference Special Section, American Nuclear Society, March (2011) 45–78.

4.2.3. Track 2: The increasing contribution of nuclear power in the mitigation of climate change, including synergies with other low carbon power generation sources

Invited Speaker —NuScale Integrated Energy Systems, NuScale Power

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1. SMR INTEGRATED ENERGY SYSTEMS (IESs)

It is becoming widely recognized that nuclear power must be a major component of strategies to combat climate change because it offers the greatest potential for reduced carbon emissions in the electricity sector. Both the Intergovernmental Panel on Climate Change (IPCC) (https://www.ipcc.ch/sr15/) and the International Energy Agency (IEA) propose a significant increase in nuclear power to achieve carbon emission reduction goals on a global scale. However, nuclear power can also play a major role in reducing carbon emissions beyond the electricity sector to include the industrial and transportation sectors. Hence the interest in integrated energy systems (IESs). Figure 1 illustrates IES applications considered in a series of NuScale studies conducted with universities, industry and national laboratory collaborators.

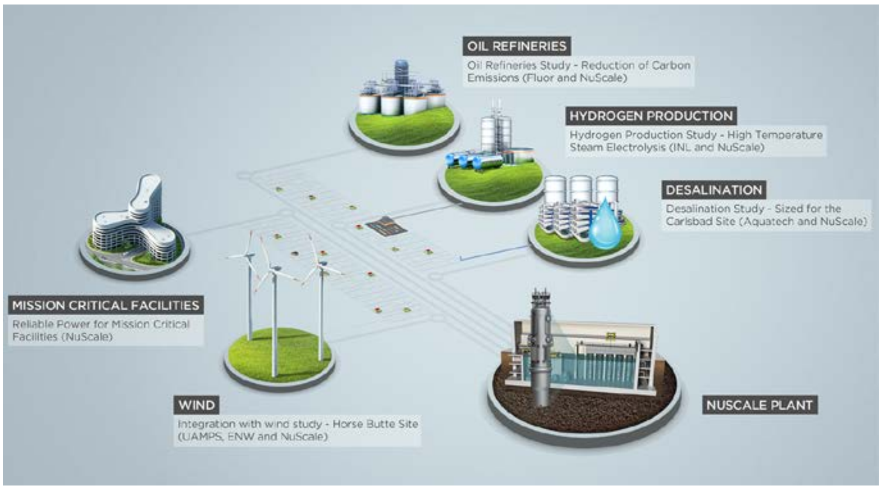

FIG. 1. Applications of the NuScale Integrated Energy System.

The studies include flexible power operations, hydrogen production, process heat and power for oil refineries, and water desalination.

An IES can incorporate SMRs that provide either fixed baseload power or flexible power operations. As a result, the operating strategy for a nuclear IES will depend on the type of SMRs incorporated into the system. For example, an SMR that operates solely at a fixed maximum power for baseload electricity production would likely choose to operate its fuel at a higher linear power with a tighter margin to the design limit. Also, a baseload SMR would not be designed to provide significant steam turbine bypass capability since its primary focus is maximizing electric power production. In contrast, an SMR intended for flexible power output would operate with a greater margin to fuel limits to permit relatively rapid changes in power output in order to match variable loads. It would also provide a means for up to 100% of the main steam to bypass the turbine for use in process heat applications. Natural circulation SMRs, such as the NuScale design, fall into the latter category of flexible power SMRs.

It is interesting to note that the economic value of flexible nuclear power operation will likely grow with the increased penetration of renewable energy sources. Energy imbalance markets (EIMs) are currently forming in the USA to balance supply and demand in grids with significant variable power generation [1]. An EIM is a voluntary market that provides a sub-hourly economic dispatch of participating resources for balancing supply and demand every 5 minutes. EIMs that include nuclear power load following plants may offer a premium for carbon-free power when wind and solar are not available or to stabilize the grid (i.e. generator frequency hunting). By their nature, EIMs indirectly encourage the development of nuclear powered IESs. If flexible power SMRs are providing power to an EIM primarily when renewables are not available, or to perform frequency hunting to keep the grid stable, what should their role be during their 'reduced power hours?' An energy optimized IES that incorporates a flexible power SMR offers an interesting solution. It can ensure economic and full utilization of the SMR power output, while providing carbon free electrical and thermal power to industrial processes. It has the potential to address humanitarian needs like increased availability of clean water and reduced carbon emissions in the transportation and industrial sectors. The following sections describe the operational flexibility of the NuScale SMR and some of its proposed IES applications.

2. OPERATIONAL FLEXIBILITY

Efficient use of an SMR based IES will require some level of operational flexibility, particularly in remote locations where the SMR is the only source of power generation for both industrial and residential power. The multi-module design of a NuScale plant, which comprises up to 12 highly robust NuScale Power Modules (NPMs) offers significant operational flexibility for IES applications. A key feature of the design is that each NPM has the capability to bypass 100% of its steam output to its condenser or to an industrial process (e.g. hydrogen production or industrial heat). By simply adjusting the valve position on the steam turbine, the NPM electrical power output can increase from 12 MW(e) (20%) to 60 MW(e) (100%) in 27 minutes or reduce power from 100% to 20% in 10 minutes. In this mode, the thermal power (200 MW(th)) of the NPM remains constant. This permits the transition from electrical power production to thermal power production for industrial processes in a relatively seamless manner. This same feature allows for rapid load following, which for example, may be required to offset the variability of output from wind farms [2]. The NPM also has significant thermal power maneuverability through the motion of control rods. NPM thermal power can increase from 20% to 100% in 96 minutes by control rod motion. This is adequate for load following solar farms and industrial processes that vary slowly over hours to days.

3. REDUCING CO_2 EMISSIONS AT OIL REFINERIES

NuScale Power teamed with the Fluor Corporation to conduct a preliminary technical and economic assessment to evaluate the feasibility and desirability of using NuScale power modules to support oil recovery and refining processes, thus reducing the overall carbon footprint of these industrial complexes and preserving valuable fossil resources as feedstock for higher value products [3]. As part of the study, an economic assessment was performed for the case of a representative refinery sized to process 250 000 barrels/day of crude oil. The cost differential between using nuclear generated electricity and heat relative to the reference scenario of using natural gas was calculated for a variety of natural gas prices and potential CO_2 tax penalties. The result is shown in FIG. 2. Based only on operating costs, the 10 module

NuScale plant is competitive with the reference case for natural gas prices as low as \$5/MBtu, even with no CO_2 tax. The capital investment for the NuScale plant can be recovered in 25 years if the natural gas cost exceeds \$9.5/MBtu without a carbon tax, or \$7.5/MBtu with a \$40/MT CO_2 penalty. While such gas prices exceed current prices in the USA, they are well below prices in many other countries. By providing both process steam heat and electrical power, a 10 module NuScale plant would reduce CO_2 emissions from the refinery by approximately 40% or roughly 200 MT/h.

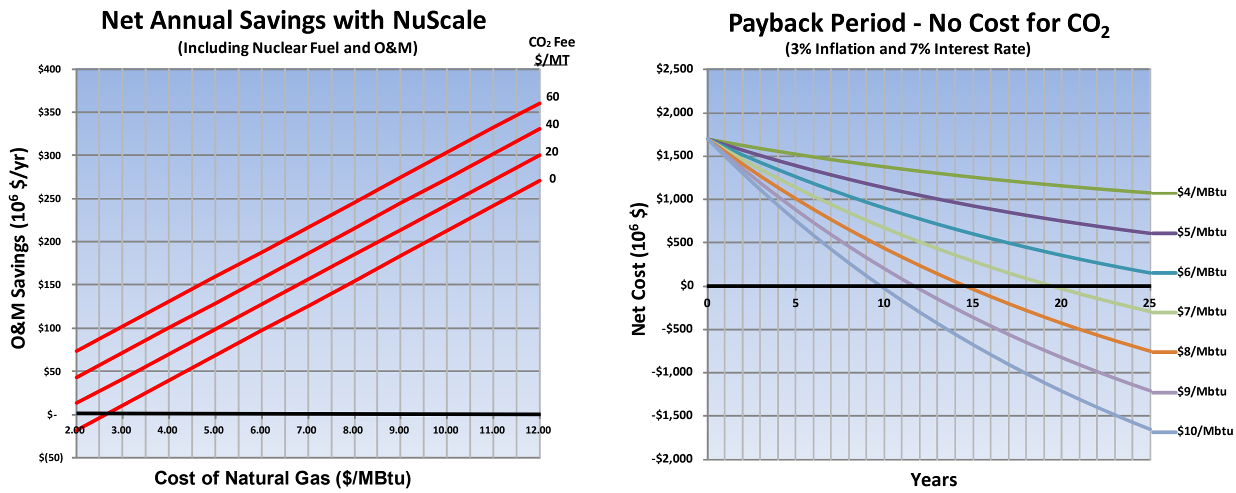

FIG. 2. Economic analysis of coupling a NuScale 10 module plant to a 250 000 barrel/day oil refinery.

4. HYDROGEN PRODUCTION

Given the low cost of natural gas, steam–methane reforming is the most common method of producing hydrogen in the USA. It requires combustion of roughly 10–15% of the methane in the feed stream to generate the heat and steam necessary to split the remainder of the methane. Consequently, the resulting emission of CO_2 is a concern. Alternatively, electrolysis can dissociate water or steam into a clean source of hydrogen and oxygen. High temperature steam electrolysis (HTSE) is an emerging technology and is ~40% more efficient than conventional water electrolysis. NuScale teamed with researchers at the Idaho National Laboratory (INL) to study the technical and economic feasibility of producing hydrogen using the HTSE process coupled to a 6 module NuScale plant [4]. Figure 3 illustrates the hydrogen production process analysed for this study.

Based on the analysis performed by INL, it was determined that a 6 module NuScale plant implementing 50 MW(e) modules would produce approximately 190 MT of hydrogen and 1500 MT of oxygen per day. Of significant interest was the result that only 1.15 MW(e), or only 2.4% of the total power output was required to raise the steam outlet temperature from 300ºC to 800ºC at the mass flow rates required for the HTSE process. With regard to the impact on the transportation sector, a single 60 MW(e) module (i.e. NPM updated power rating) could produce enough hydrogen to power roughly 70 000 fuel cell vehicles.

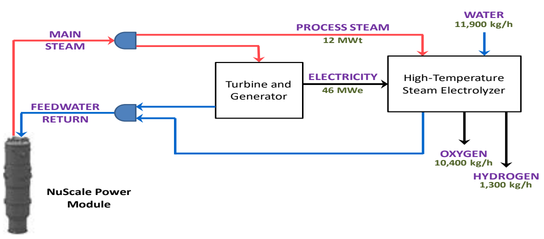

FIG. 3. Hydrogen production using steam and electrical power from a NuScale Power Module.

5. CONCLUSIONS

This paper briefly examines the role of flexible power SMRs in (IESs). As the penetration of renewables increases, the need for systems that can balance and stabilize the grid using carbon-fee power will become increasingly important as reflected in the emerging EIMs. An energy optimized IES that incorporates a flexible power SMR can ensure full utilization of the SMR power output, while providing economic, carbon-free electrical and thermal power to industrial processes. Working within an EIM, it can also serve to balance and stabilize the grid. NuScale studies that examine the potential for hydrogen production for fuel cell vehicles and other industrial applications yield promising results. One 60 MW(e) NPM could power ~70 000 fuel cell vehicles. Similarly, the proposed coupling of a NuScale plant to a 250 000 barrel per day oil refinery predicted a 40% reduction in CO_2 emissions. As the fundamental structure of the electric power market changes, innovative nuclear power must be prepared to meet the challenges.

REFERENCES

[1] MAIZNER, E., Letter to Bonneville Power Administration Stakeholders: “EIM Participation”, Department of Energy BPA, Portland, Oregon, 20 June 2019. https://docisolation.prod.fire.glass/?guid=5883b49a-7229-4bda-4269-1b0385523cfd

[2] INGERSOLL, D.T., et al., “Can nuclear power and renewables be friends?”, Proceedings of ICAPP, 3–6 May 2015, Nice (2015) Paper 15555.

[3] INGERSOLL, D.T., et al., “NuScale energy supply for oil recovery and refining applications”, Proceedings of ICAPP 2014, 6–9 April 2014, Charlotte (2014), Paper 14337.

[4] INGERSOLL, D.T., et al., “Extending nuclear energy to non-electrical applications”, 19th Pacific Basin Nuclear Conference, 24–28 August 2014, Vancouver, Paper PBNC2014-209.

4.2.4. Track 3: Development and deployment of advanced nuclear power technologies to increase the use of low carbon energy

Invited Speaker — Generation IV International Forum

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1. ROLE OF ADVANCED REACTORS FOR FUTURE POWER GENERATION

As the world's population is expanding and seeking improved standards of living, global demand for energy is inexorably going to increase. However, the existing energy generation mix will not properly address the global concerns over greenhouse gas emissions, air pollution and depletion of fossil resources. An increased use of clean, safe, and affordable energy sources is required.

The Generation IV International Forum (GIF) promotes nuclear energy as a key pillar towards sustainable and low carbon energy mixes. Advanced nuclear energy systems and innovative applications of nuclear technologies can provide solutions underpinning economic growth and supporting environmental stewardship in both the electrical and non-electrical sectors. Alongside distributed electricity generation systems with large shares of intermittent renewables (e.g. solar photovoltaic and wind), advanced nuclear technologies offer a reliable, decarbonized and dispatchable power generation source for the future.

Generation IV systems offer additional features in terms of performance and sustainability compared to existing concepts. The use of high temperature coolants such as helium, liquid metals, liquid salts, or supercritical water offers additional design flexibility, allowing a significant increase in thermal efficiency, while also broadening industrial heat applications that can substantially displace fossil fuel usages. Advanced reactors provide dispatchable power supply and are able to complement variable power generation from renewables. Furthermore, some of the Generation IV systems make it even possible to enhance uranium utilization by a factor of up to 100 when deployed with an advanced fuel cycle. Recycling fissile materials paves the way to long-lasting fission reactors fueling.

2. GENERATION IV INTERNATIONAL FORUM

GIF is a multinational cooperative endeavor set up to carry out the research and development required to establish the feasibility and performance capabilities of next generation nuclear systems. It was established in January 2000 by 9 countries, and now has 14 members[21], all of which are signatories of the founding document, the GIF Charter, and 12 of which have acceded to the Framework Agreement and are actively participating in joint R&D activities.

[21] Argentina (non-active member), Australia, Brazil (non-active), Canada, China, Euratom, France, Japan, the Republic of Korea, Russian Federation, South Africa, Switzerland, United Kingdom and United States of America.

In its Technology Roadmap, GIF has defined four goal areas to move nuclear energy forward into what is being named 'fourth' generation (see Fig. 1): safety and reliability; proliferation resistance and physical protection; economic competitiveness; and sustainability.

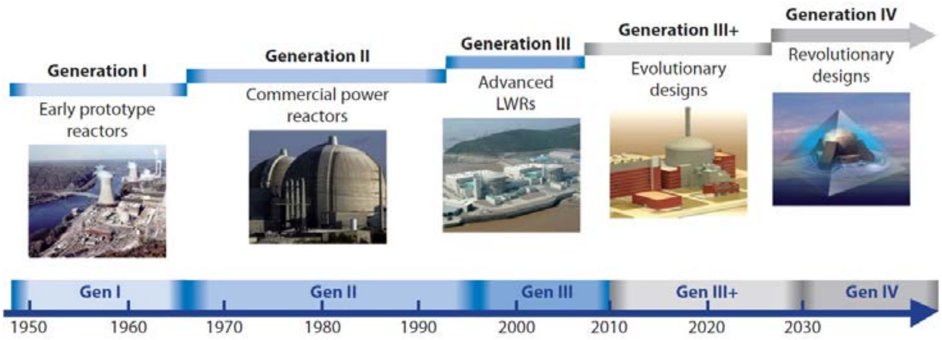

FIG. 1. The four generations of reactor designs.

The Technology Roadmap has also described the R&D work required to achieve these goals and enable the deployment of Generation IV energy systems. A Generation IV nuclear energy system includes the nuclear reactor and its energy conversion systems, as well as the associated fuel cycle technologies.

Closing the nuclear fuel cycle is a major component for achieving the sustainability goal. Fissile material can be recovered from spent fuel to produce new fuel. Currently, almost 95% of the spent fuel from light water reactors can be reused as reprocessed uranium and mixed oxide fuel. With advanced fuel cycles using fast spectrum reactors and extensive recycling, it may be possible to breed fissile fuel from fertile material, and thus produce as much fissile material as the reactor consumes, or even more if needed. This would also reduce the footprint of ultimate waste geological repositories.

Advanced separation technologies for Generation IV systems are being designed to avoid separation of sensitive materials, and include other features to enhance proliferation resistance and incorporate effective safeguards.

The Technology Roadmap has clearly outlined the potential of combining different reactors in 'symbiotic' fuel cycles, for example, combining thermal reactors and fast reactors, to accommodate transition periods. This has led, among other things, to a portfolio of Generation IV systems rather than a single system. GIF also considers that a large share of existing nuclear plants are going to be operating in the decades to come; advanced reactors can be combined with those existing reactors in order to address evolving market requirements.

2.1. The six GIF systems

In its early years, GIF ran a multi-criteria analysis to identify the most promising concepts against the four goal areas previously defined. Six systems (see Fig. 2) were selected, amongst nearly 100 concepts:

- Gas cooled fast reactor (GFR), with a closed fuel cycle.
- Lead cooled fast reactor (LFR), with a closed fuel cycle.
- Molten salt reactor (MSR), with thermal and fast neutron concepts and a closed fuel cycle.
- Sodium cooled fast reactor (SFR), with a closed fuel cycle.

— Supercritical water cooled reactor (SCWR), with fast and thermal neutron concepts (although designs with fast neutron spectrum are no longer developed by GIF), and an open or closed fuel cycle.
— Very high temperature reactor (VHTR), with thermal neutrons and an open fuel cycle.

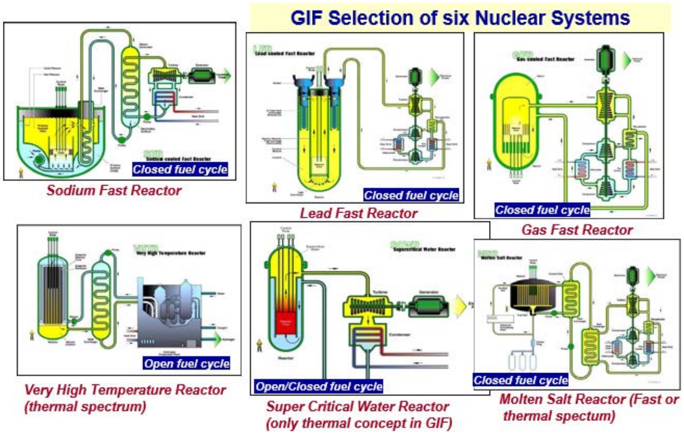

FIG. 2. The six GIF systems, four of which use a closed fuel cycle and a fast spectrum.

2.2. International collaboration

The involvement of GIF members in Generation IV system R&D as of 2019 is presented in Fig. 3.

SFR			●	●	●	●	●			●	●	●
VHTR	●	●	●	●	●	●			●	●	●	●
LFR			Planned Oct 2019		●	●	●			●		●
SCWR		●	●		●		●					●
GFR				●	●							●
MSR	●	●		●			●		●	●		●

● : signatory of System Arrangement
● : signatory of Project Arrangement
● : signatory of MoU

FIG. 3. GIF member involvement in Gen IV systems R&D.

The 2018 update of the Technology Roadmap confirmed the selection of these six systems and reassessed their Technology Readiness Level (TRL). The SFR and LFR concepts are clearly the most advanced among the four fast spectrum GIF systems.

3. INNOVATION FOR ADVANCED REACTORS: WHAT IS ON GIF'S AGENDA?

Generation IV systems are aimed at improving sustainability, economic competitiveness, safety and reliability, proliferation resistance and physical protection through innovations. Special topics are now on the agenda of the GIF. They are presented below.

3.1. GIF initiatives for technical innovation

Technologies dealing with modular construction, advanced concrete solutions, innovative fuels and materials, and 3-D printing are being investigated by designers of advanced reactor systems. To better understand the impact of cross-cutting technologies on R&D activities, the GIF launched a feasibility study on Advanced Manufacturing and Materials Engineering in 2017.

Experimental data are required, to validate simulation tools and to reduce uncertainties, provided by modern R&D infrastructures. GIF launched a task force on R&D infrastructures to identify existing key facilities, potential gaps, and facilitate access to such facilities within the international community. This aims at sharing expertise and costs as well.

3.2. GIF initiatives for safety standards

Sharing operational feedback and best practices is a way to reach the long term objective of international safety standards with a unified and stable licensing process. A dedicated GIF Task Force works on developing safety design criteria (SDC) and guidelines (SDG) for the design of the next SFR generation. GIF also cares about helping regulators become familiar with the technical characteristics of Generation IV systems. This approach is being extended to other Generation IV systems. Exchanges with the IAEA and experts from the OECD/NEA Working Group on the Safety of Advanced Reactors (WGSAR) are contributing to the development of international safety standards and requirements for advanced reactors.

White Papers on the safety of GIF systems are regularly updated along with the GIF safety basis report. The GIF Integrated Safety Assessment Methodology was developed as a technology-neutral toolkit to evaluate the safety characteristics of all Generation IV systems.

GIF will continue to engage with regulatory authorities and technical support organizations (through the WGSAR for instance) with the goal of reaching in the long term a harmonization of requirements and a better understanding of licensing application and costs.

3.3. GIF initiatives with the private sector

In some countries, especially in the USA, interest froms the private sector for advanced and innovative reactors is a positive signal. It is an outstanding opportunity to attract young, skilled and motivated scientists and engineers. GIF intends to develop a cooperation between R&D bodies and the pivate sectors. There is great interest in small modular reactor concepts around the world, some of them being close to Generation IV concepts. GIF is currently exploring the way to establish a win–win relationship with the private sectors for deployment of Generation IV systems.

3.4. Flexibility of the Generation IV systems

Considering the increasing share of renewables, Generation IV systems must be flexible for integration into low carbon electricity grids. There is also agreement that co-generation and hybrid systems should improve the economics. Flexibility requirements have to be considered as part of the R&D.

GIF categorized the flexibility into three genres, referring to criteria proposed by the Electric Power Research Institute: operational flexibility considers maneuverability, ramp rates, minimum power level, frequency control, island mode and fuel flexibility; deployement flexibility deals with scalability, siting requirements, modularity; and product flexibility considers the possible non-electrical applications such as co-generation and heat applications.

A survey of Generation IV systems flexibility was carried out by the GIF Economic Modeling WG in 2019, in order to collect evidences on the capabilities of Generation IV systems in terms of flexibility and to review R&D needs to foster these flexibility capabilities as well as cost reduction opportunities. The six GIF systems show enhanced flexibility capabilities, even if not all the systems have validated these claim by multi-dimensional physics calculations. As regards operational flexibility, they should offer up to 10%/min ramp rate. Product flexibility is ensured, since all concepts have the capability of providing both heat and electricity. All concepts plan to operate at much higher temperatures than current reactors, enhancing their ability to support industrial applications. Regarding deployment flexibility, all systems show scalable concepts and are amenable to factory fabrication, but there may be some limitations for large capacity units. In general, zoning requirements are similar to current reactor technologies, with a few concepts targeting significantly reduced emergency planning zones.

The R&D requirements identified were correlated with the technological maturity of Generation IV systems: more specific R&D has been identified for systems with past experience (SFR and VHTR). Opportunities for cross-cutting R&D across the systems has also been identified (e.g. advanced instrumentation and advanced materials).

4. CONCLUSION

Further progress is under way to increase the technology readiness level of the six Generation IV systems. GIF is continuing with its endeavour to foster collaboration between its members on R&D topics, on experimental facility sharing and on common safety standards. New areas have recently turned up, with increasing interest from the private sectors for advanced reactors, generally advanced small modular reactors, and with the impact of increasing the share of renewables, inducing flexibility requirements. All these topics show promising further opportunities.

Clean, innovative and advanced nuclear technologies can play a significant role in simultaneously furthering economic growth and effective environmental stewardship. The Generation IV International Forum calls on policy makers to acknowledge the real contribution that nuclear energy is making today to the mitigation of carbon emissions from the power sector, and to consider supporting the deployment of advanced reactors and innovative applications of nuclear technologies, including heat applications, to further accelerate the decarbonization of the world’s energy mix in the coming decades.

4.2.5. Track 3: Development and deployment of advanced nuclear power technologies to increase the use of low carbon energy

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In Canada, nuclear energy generates approximately 15% [1] of the total electricity mix, and more than 60% [2] in the province of Ontario. Like many countries, the Canadian fleet of reactors is ageing; some have already undergone refurbishment, while others are nearing the original designed lifetimes and refurbishments are scheduled to be completed in the next 10 years. To maximize the lifetimes of existing assets, new research was needed to expand data sets and refine models for material and component performance. That is why CNL established the Centre for Reactor Sustainability (CRS), which encapsulates all of our capabilities and facilities related to reactor life extension and drives research projects and activities that have a significant impact on the life and daily operations of nuclear power plants. For example, through the Candu Owners Group, CNL's Fuel Channel Life Management Program has been a critical point for the CANDU reactor industry, providing firm scientific evidence that the plants are safe to operate right up to their scheduled refurbishment dates.

Building on decades of experience serving the Canadian utilities, CNL is expanding its ability to tackle the nuclear materials, fuels and engineering issues challenging the global light water reactor fleet. By looking outside and drawing in disruptive technologies and ideas, CNL is delivering solutions that enable lower operating costs; more efficient material testing; and deployment of advanced and accident tolerant fuels. CNL's industry centric approach to research and development ensures that government and private funding is fully leveraged for real-world impacts, improving the economics of clean energy production.

Looking to the future, an industry led, pan-Canadian roadmap was convened to consider the development and deployment of small modular reactors (SMRs) in Canada and globally [3]. The roadmap emphasizes the importance of first of a kind demonstration projects to gain experience in design, licensing, construction and operation; and the value of CNL in providing a fully equipped platform for demonstrating advanced reactor technologies. CNL's ambition to demonstrate the commercial viability of SMRs is well under way. An invitation to host an SMR on a CNL managed site was launched in 2018, and SMR proponents are currently engaged at various stages in the evaluation and negotiation process.

Whether the need is applying life extension expertise to different reactor designs than the domestic CANDU reactor or hosting the testing/demonstration of an advanced reactor design, CNL is retooling its capabilities to support reactor operations into the future to ensure available low carbon power.

REFERENCES

[1] INTERNATIONAL ENERGY AGENCY, Nuclear Power in a Clean Energy System, OECD, Paris (2019).

[2] Ontario's System-Wide Electricity Supply Mix: 2018 Data, https://www.oeb.ca/sites/default/files/2017-supply-mix-data.pdf

[3] CANADIAN SMALL MODULAR REACTOR ROADMAP STEERING COMMITTEE, A Call to Action: A Canadian Roadmap for Small Modular Reactors (2018).

4.2.6. Track 3: Development and deployment of advanced nuclear power technologies to increase the use of low carbon energy

Invited Speaker — Advanced nuclear energy in a low carbon power system: European Energy Research Alliance

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This paper was not available for publication but the full presentation is included in the on-line supplementary files, for reference, and can be found on the publication's individual web page at www.iaea.org/publications.

4.3. TRACKS 5 AND 6: PARTNERSHIPS AND ENGAGEMENTS

Chairpersons: M. Betti, Joint Research Centre of the European Commission
Suryantoro, Indonesia

4.3.1. Track 5: Enhancing international cooperation and partnership in nuclear power deployment

Invited Speaker — The Nuclear Innovation: Clean Energy Future Initiative — United States Department of Energy

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1. A NEW INITIATIVE IS BORN

With the launch of the multi-governmental Nuclear Innovation: Clean Energy Future (NICE Future) initiative at the 9th Clean Energy Ministerial (CEM) in Copenhagen in May 2018, a new ministerial level discussion on clean energy that included nuclear energy was born. The NICE Future initiative envisions clean energy systems that take advantage of emissions-free nuclear energy in new and innovative ways to accelerate progress toward clean energy goals. Nuclear energy provides one-third of the world's emissions-free electricity. Solar, wind, and nuclear are all emissions-free, but of these only nuclear energy provides clean electricity 24/7, and it has the smallest footprint. Recognizing that there is no one size fits all solution to the energy mix of each country, the NICE Future initiative was launched to show interested CEM members a range of options to consider for their clean energy systems relevant to their own domestic and international priorities.

2. MINISTERIAL LEVEL DISCUSSIONS AT THE MAY 2019 10th CLEAN ENERGY MINISTERIAL IN VANCOUVER

The NICE Future initiative had a strong first year of activities, establishing the foundations for a successful work stream under CEM. The IAEA conference audience will be debriefed on discussions from the ministerial on how new and emerging clean energy breakthroughs can accelerate progress toward clean air goals. Discussions at CEM10 focused on how nuclear energy related breakthroughs, such as flexible advanced nuclear, small reactors, or next generation designs, when paired with renewable energy, have the potential to further accelerate cost-effective emissions reductions and boost renewables while providing reliable, affordable energy, including to remote regions where energy access has been difficult. These technology approaches can also solve key global problems, like providing potable water for desalination, industrial process heat, and hydrogen for production and energy storage. Discussions at CEM10 also included emerging studies, flexibility needs in future low emissions energy systems, and innovative technical solutions for current nuclear reactors (which already operate flexibly in some markets) and advanced reactors.

Exciting new work featured at CEM10 included:

— The launch of a high profile and accessible book for policy makers from the NICE Future initiative, titled ‘Breakthroughs’, featuring stories to spark the imagination and challenge pre-conceptions of power systems for the future.
— Engaging visual exhibits of the integrated energy systems profiled in the ‘Breakthroughs’ book.
— The launch of new analysis by the International Energy Agency (IEA) and OECD Nuclear Energy Agency (OECD/NEA) on the importance of nuclear power alongside other clean energy sources in meeting clean energy goals.
— Discussion by environmental non-governmental organizations (NGOs) in support of a new CEM campaign on “flexible hybrid nuclear-renewable energy systems”.

The initiative highlighted that breakthroughs will:

— Expand the efficiency of nuclear and renewables integration.
— Create more integrated and flexible systems that are enabling to both technologies, with the potential to support an expansion of renewable energy.
— Create new, economic applications for excess emissions-free energy.
— Create energy storage options for advanced transportation technology (including hydrogen).
— Provide energy access to remote areas.

3. GOALS

The NICE Future initiative helps policy makers understand the technology options that could be available to them, from today’s large light water reactors to the small modular reactors (SMRs) and other novel designs that will soon reach commercial markets. The initiative offers information on technical feasibility, economics and financing, and perspectives from a number of communities and stakeholders that will be helpful for governments considering the roles that nuclear can play in their clean energy futures.

Nuclear energy can be integrated with other clean energy technologies in many ways to create a thriving, emissions-free economy. An expanding suite of nuclear technologies can help tackle challenges, such as rapidly scaling-up clean power in the developing world, providing flexible support for variable renewables, bringing energy access to remote communities, and decarbonizing processes that are vital to economic progress including manufacturing, hydrogen production, water desalination and district heating (Figs 1–3; photos courtesy of Third Way: https://advancednuclearenergy.org/blog/nuclear-reimagined).

FIG. 1. Nuclear technology integrated with solar photovoltaics and wind turbines to provide both electricity and clean drinking water.

FIG. 2. A micro-reactor used to provide heat to an Arctic village.

FIG. 3. Nuclear technology integrated with solar photovoltaics and wind turbines to power a modern data centre.

4. INNOVATIVE OPTIONS, MANY CHOICES

Technology areas of high interest to the initiative for their transformational roles include:

Integrated nuclear-renewables	Desalination for drinking water	Process heat	Flexible electricity grids	Hydrogen production and energy storage	Advanced, smart designs, e.g. SMRs, Gen-IV	Nuclear waste reduction

Four topical focus areas of the initiative are:

1. Exploring innovative applications for advanced nuclear systems both electric and non-electric.	2. Engaging policy makers and stakeholders regarding energy choices for the future.
3. Pooling experience on economics, including valuation, markets structure, and ability to finance.	4. Communicating nuclear energy's role in clean integrated energy systems and developing the nuclear workforce of the future.

5. KEY ACCOMPLISHMENTS

The NICE Future initiative has:

- Established a dialogue on the different roles nuclear energy can play in clean energy systems of the future.
- Engaged nuclear and non-nuclear experts and policy makers in a discussion on how nuclear energy supports broader clean energy goals. Webinars, workshops, and coordination with other CEM initiatives have promoted this dialogue.
- Developed and disseminated resources to inform policies and planning.
- Developed reports to provide plain language briefings for policy makers on the roles that nuclear can play in the clean energy mix.
- Built partnerships and worked with different stakeholder groups.
- Worked with nongovernmental groups, including youth and women engaged in clean energy advocacy, to share information with the public.

To conclude, the NICE Future initiative discussions have engaged individuals from nearly 35 countries and 80 organizations in transformational discussion on the potential roles for nuclear energy in clean energy systems. We invite the attendees at the conference to get to know this initiative.

4.3.2. Track 5: Enhancing international cooperation and partnership in nuclear power deployment

Invited Speaker: Can nuclear energy be a competitive climate change option today? Lessons from recent world experience — LucidCatalyst

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To manage climate change, we need to reduce carbon dioxide emissions from the global energy system to near zero by mid-century. Meanwhile, global energy demand might double from current levels. All credible studies have concluded that to have a serious chance of success, we will likely need all the low carbon solutions we have available to us. In order to meet the Paris climate treaty's more ambitious goal of limiting global temperature rise to 1.5ºC this century, world carbon dioxide emissions would need to be cut 50% by 2030 and entirely by 2050. To achieve this historically unprecedented societal shift, most of the IPCC scenarios along with numerous other expert projections call for not only the massive expansion of renewable energy, but also major investments in nuclear energy, carbon capture and storage, negative emissions technologies, and for research evaluating geoengineering options.

However, some question whether nuclear energy can, or should, play a substantial role in decarbonizing the global energy system. The costs of US and European projects have been high and progress slow, and recent schedule delays and cost overruns at nuclear projects in the Southeastern USA, as well as Finland and France, have further supported these doubts.

Are the financial and timing risks of a major nuclear expansion program simply too high? Should we wait for new technologies to emerge? Or is there a way to deploy today's nuclear technology rapidly and affordably to help us address climate change in time, even as we develop complementary nuclear technologies?

It is widely believed that new current generation (sometimes called 'Generation III+') nuclear energy plants are too expensive to compete with other zero carbon options like wind and solar, much less with coal and gas plants. However, many nuclear projects around the world are being built today at a 50 to 80% lower capital cost than current and recent projects in the USA and Europe. (see Fig. 1).

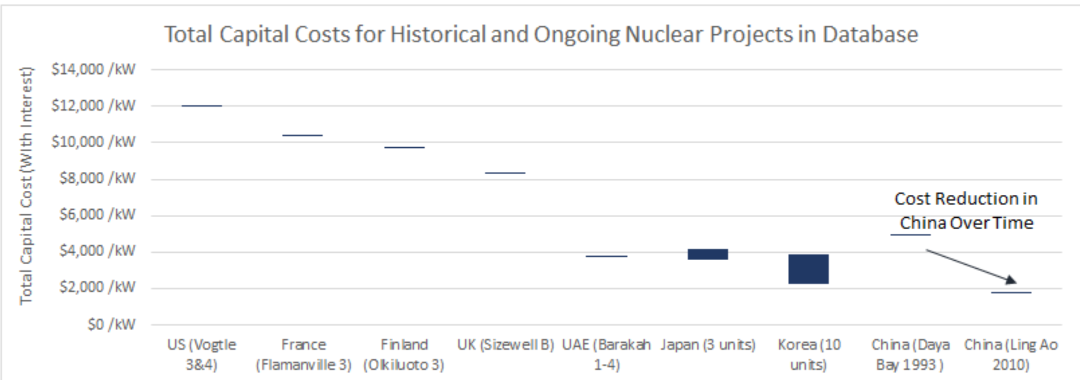

FIG. 1. Overnight capital costs of nuclear plants recently built or under construction. Source: ETI, endnote iii, from reported data.

At this cost level, nuclear is highly competitive with both fossil fuel sources of electricity as well as many renewable sources, as Fig. 2 shows.

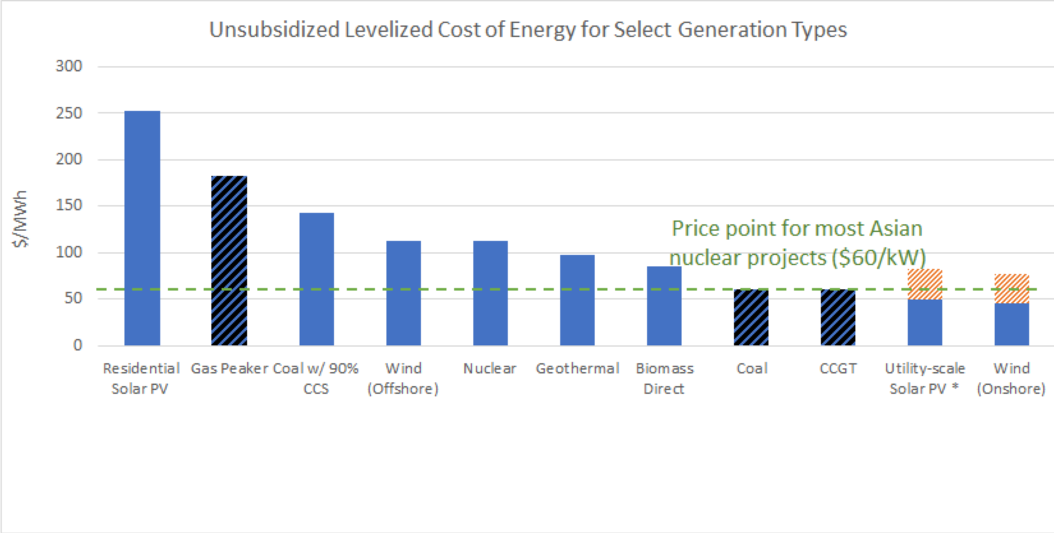

*FIG. 2: Total cost of electricity production with capital and operating costs included. *Reflects Lazard's cost estimate for a "PV Plus Storage" unit. These costs are assumed to be the same for wind. Source: Lazard, 2017. https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf.*

A recent study commissioned by Energy Technologies Institute (ETI 2018)[22] found that the gap between most and least expensive nuclear project costs is due principally to best in class industrial practice, labour productivity and a strategy to build the same design repeatedly, while maximizing learning between units. The cost reductions had very little to do with lower labour rates, build quality or rigour of safety regulation.

These best practices are not country specific. They can be transferred globally and improved to further reduce cost and build times. Historical examples of this include the successful, and relatively low cost, nuclear new build programmes in both the USA and France (see Fig. 3).

A significant part of the higher costs can be indirectly traced back to inexperience and first of a kind (FOAK) projects. Building something for the first time or doing it in a country for the first time (or after a prolonged pause) makes it very hard to implement best practices and high labour productivity — two of the big cost drivers according to the study — throughout the project.

Achieving cost reduction will require significant, internal transformation of the nuclear industry and this must be supported by public policy and continuing RD&D.

[22] https://www.eti.co.uk/news/cost-drivers-identified-to-support-investment-in-new-nuclear-power-and-its- role-in-the-uks-future-low-carbon-energy-system

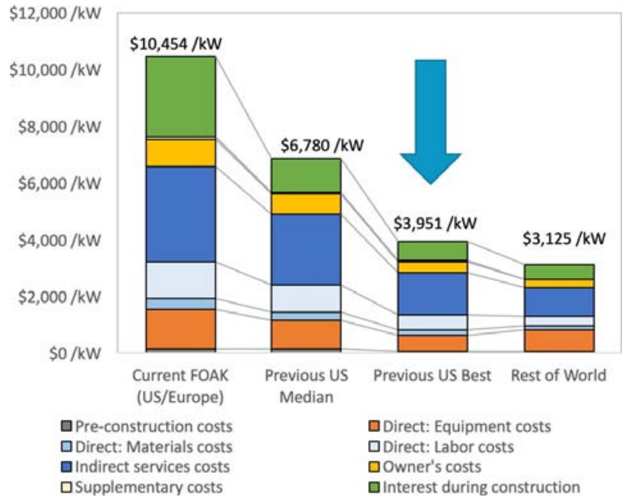

FIG. 3. The USA built a large number of cost effective nuclear plants in the past (source: ETI 2018).

The next generation of advanced reactor technologies (often called Gen IV) can further improve nuclear energy's cost effectiveness, but those technologies will require the same level of commitment to cost reduction as the Gen-III industry.

While these cost reduction initiatives will not address all the barriers to global nuclear energy expansion, they will make nuclear a far more viable option for decarbonization, and as a result, our decarbonization efforts significantly more efficient.

4.3.3. Track 5: Enhancing international cooperation and partnership in nuclear power deployment

Invited Speaker: Enhancing international cooperation and partnership in nuclear power deployment: Multilateral partnership mechanisms — United Nations Framework Convention on Climate Change

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This paper was not available for publication but the full presentation is included in the on-line supplementary files, for reference, and can be found on the publication's individual web page at www.iaea.org/publications.

4.3.4. Track 6 — Public and non-nuclear stakeholders' perception of the role of nuclear power in climate change mitigation
Invited Speaker: Chernobyl Tissue Bank, Imperial College London

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1. INTRODUCTION

The latest science on climate change makes sobering reading. There is a suggestion that our oceans may absorb less CO_2 than had been originally predicted. This, coupled with the physical fact that progressively less CO_2 will be absorbed by the oceans as the sea temperature rises, suggests that the targets set for reducing carbon emissions may be too low. In addition, the drive for Westernization in the less developed world means that the demand for energy will continue to rise. A recent International Energy Agency report [1] states that if the current energy policies in the Westernized countries do not change, solar and wind would need to see unprecedented growth in their deployment to meet climate change targets. Even if this were to occur, the evidence from countries such as Germany is that moving to an energy system that relies more on renewables does not necessarily lead to a decrease in CO_2 emissions.

Politicians are more likely to respond to the demands for a better life from their voters, rather than taking the long term view of preserving an inhabitable planet for the future. There is a drive in the developed countries of the world to move towards electric vehicles, but the electricity required to charge these when the population wishes, i.e. at night, will need to be found. Solar and wind power cannot be relied upon to provide the baseload required for this when the population wants it, which means that there will be pressure to return to 'quick and dirty' energy production by burning fossil fuels.

So how do we manage to square this circle? The only reasonable answer seems to be to build more nuclear power plants, and quickly, before it is too late to put the brakes on global warming. Solar and wind can play their part, but the simple fact is that both of these methods of power production are much less 'energy dense' than nuclear and depend on the vagaries of the climate. Even the majority of the 'green' environmental think tanks now admit that the best way forward would be with a mix of nuclear, wind and solar technologies.

Why then have we seen large increases in solar and wind, but a significant decrease in the use of nuclear? A large part of this has been due to public acceptance/rejection of the differing technologies, although we are now starting to see some resistance to the siting of yet more on-shore wind farms. If we accept that the only way to stand a reasonable chance to meet the GHG reduction targets that we have agreed upon is to increase nuclear energy production, how can we achieve this?

Firstly, in order to drive social acceptance of the technology, we have to address some of the unconscious biases around nuclear power. These stem from a confusion between nuclear weapons and nuclear power and primarily from a misunderstanding of the real health effects of exposure to low doses of radiation from a nuclear power plant accident. One consequence of the Fukushima Daiichi accident in 2011 is that there was significant engagement between scientists who had studied the effects of low dose radiation exposure with environmentalists and the media. This has facilitated channels of discussion and has led to many environmentalists questioning their longheld beliefs about nuclear power.

So, what are the facts about health effects and radiation? In the case of radiation, it is a toxin that is unavoidable as the planet we live on is inherently radioactive. All life on Earth is exposed to low dose radiation. The majority of each individual's annual dose of radiation comes from radon, which is generated from the rocks that comprise the crust of our planet. A smaller amount (14%) comes from artificial sources — mainly medical exposures, with a very small amount (1%) coming from the nuclear industry as a whole, including atmospheric testing of atomic weapons [2]. The average dose received by the majority of individuals from background radiation is around 2.4 mSv/a, which can vary depending on the geology and altitude where people live — ranging between 1 and 10 mSv/a, but can be more than 50 mSv/a. The highest known level of background radiation affecting a substantial population is in Kerala and Tamil Nadu states in India where some 140 000 people receive doses which average over 15 mSv/a from gamma radiation, in addition to a similar dose from radon. Comparable levels occur in Brazil and Sudan, with average exposures to many people of up to about 40 mSv/a. Taking the individual average dose of 2 mSv/a, someone who lived to the age of 80 would have accumulated 160 mSv of radiation from natural sources during their lifetime [3]. There is a general assumption that a toxin that comes from the natural world is somehow less toxic than the same toxin that is human-made — we see the same pattern in the pharmaceutical world, where some believe that therapeutic agents that are sourced from nature are somehow different from exactly the same chemical made by industry.

As with all toxins, health risks are related to dose to the individual. In the case of radiation, health effects can be divided into two components: high doses to the individual result in deterministic health effects, whereas low doses result in stochastic risks. Deterministic effects are directly related to dose and can be observed within a short time after exposure and can be seen in a small population size. Stochastic risks are not related directly to the dose but to the probability of a health effect occurring. Determination of the risk requires a large population to be exposed and a long period to have elapsed post exposure. The lower the dose of radiation, the longer the time period is likely to be before a final determination of risk can be obtained. The principal stochastic effect of radiation exposure is the risk of cancer.

There are inherent problems with assessing an effect that takes a long time to become apparent. We know that the frequency of disease is affected by a number of factors. General health and well-being can be affected by income and social status, education, the physical environment, social support networks and, most importantly, access to good healthcare, which will have a direct effect on how disease incidence is recorded and are subject to change over time [4].

If we wish to attribute a change in the incidence of disease to a specific factor, in this case radiation, studies have to be designed to account for changes in any of the areas given above over the period of the study. Properly conducted epidemiological studies, with identification of any confounding factors that cannot be controlled for, are therefore key to understanding how disease profiles change over time and attributing likely cause to the effect observed.

2. WHAT DOES EPIDEMIOLOGY TEACH US ABOUT THE HEALTH EFFECTS OF RADIATION?

2.1. The Life Span Study

The primary source for information on the health risks of radiation is the Life Span Study (LSS) that followed the atomic bombs in Hiroshima and Nagaski. One commonly held misconception is that this study is associated with high doses of radiation only. However, 45% of the study participants received doses of less than 5 mGy and only 5% received doses higher than 1 Gy [5]. The most important stochastic health effect associated with radiation exposure is the increase in cancers, both in leukaemia and solid cancers. There is a strong correlation with dose and effect, with the attributable fraction of leukaemias and solid cancers being 86% and 48% in those who received doses in excess of 1 Gy, and 45% and 11%, respectively, in those who received doses higher than 0.005 Gy. However, contrary to what many expect, less than 1000 excess cancers (98 of 315 leukaemias and 853 of 17488 solid cancers) have occurred in this cohort over a 54 year period. It can therefore be concluded that the risk of exposure to low dose radiation is small and that below a dose of 100 mSv attribution becomes increasingly difficult.

The LSS cohort's exposure to radiation is different from the type of exposure to the general population associated with a nuclear power plant accident, where exposure is primarily due to ingestion of the volatile isotopes released, e.g. ^{131}I and ^{137}Cs, rather than whole body exposure from external gamma rays. Therefore, there may be inherent errors in using LSS data to infer likely effects of exposure from a nuclear power plant accident.

2.2. The Chernobyl accident

The health effects of the Chernobyl accident have been the subject of many international studies, and several reports by the United Nations Scientific Commission on the Effects of Atomic Radiation (UNSCEAR). The UNSCEAR report of 2008 states the following: Among early responders, 134 were exposed to doses higher than 1 Gy, and 28 of these died as a result of their exposure with a few weeks to months after the accident. A further 19 have died since, but many of these deaths were associated with smoking, drinking, driving cars, and other ordinary activities.

There has been a considerable increase in thyroid cancer in those who were exposed to ^{131}I from fallout that resulted in the consumption of contaminated milk and foodstuffs. The increase was first reported in two letters to Nature in 1992 [6, 7]. Initially, the increase was met with disbelief as the latency was very short (four years). The increase is restricted to those exposed as children, with the youngest at exposure showing the highest risk.

However, as with the LSS, correct attribution of these cases individually to radiation is difficult. There is a pool of subclinical thyroid cancers in the population that come to light when that population is subjected to screening and the incidence of spontaneous thyroid cancer increases with age. A recent White Paper from UNSCEAR [8] suggests that the attributable fraction is likely to be 25% (with a range of between 0.07 and 50%). It has been estimated by some that exposure to ^{131}I may eventually result in an excess 16 000 thyroid cancer cases [9]. Young onset thyroid cancer is associated with a 1% mortality rate over about 50 years [10]. We can therefore predict about 160 deaths from these 16 000 cases.

The World Health Organization (WHO) [9] estimated that there may be 4 000 further cases of cancer in the workers involved in the cleanup of the Chernobyl reactor site, who received higher doses than the local population. However, 33 years after the accident there has been no observed increase in solid cancers in these workers. There is a report of a slight increase in one form of leukaemia in one group of workers, but the numbers are small, and the increase is not significant and restricted to only one of the four groups under study. There is considerable discussion whether these cases are attributable to radiation exposure or some other cause.

Contrary to the impression created by dramatizations, the dose absorbed by six million residents of the contaminated areas of Belarus and Ukraine was the equivalent of one whole body CT scan (10 mSv) but spread out over 20 years [9]. Even those who were evacuated from Chernobyl received about three times as much — or the equivalent of five years of background dose for people living in the USA.

The largest health effect has been on the mental health of the exposed population. This is not due to the biological effect of the interaction of radiation with biological tissues, but rather due to the inability to appropriately frame the risk, leading to a psychological fear of radiation. Since mental health plays a considerable role in physical health, the perpetuation of this fear is likely to result in physical health consequences.

2. HOW DO WE RESET THE PUBLIC UNDERSTANDING OF RADIATION RISK?

It is necessary to study large populations to identify small additional radiogenic cancers with confidence. Theoretically, a population of 1 billion individuals would be needed to detect a statistically significant risk of cancer at a dose of 1 mSv. The study would need to be effectively a life span study, as we know from other studies that the risks of solid cancers remain elevated throughout life. Such a study would not be feasible even in the absence of uncertainties around dosimetry and confounding factors.

Before we embark on such a study, do we really need to know precisely the effect of radiation on health at these low levels? Many other factors, such as socioeconomic status, lifestyle factors such as air pollution, alcohol and obesity would appear to have a greater effect on our health. For example, being exposed to air pollution in a city such as London results in an increased mortality of 2.8% when compared to a smaller, rural city such as Inverness, whereas exposure to 200 mSv or 100 mSv as a liquidator at Chernobyl results in 1% and 0.4% increased mortality [11]. It should be noted that the mortality figures for the liquidators rely on the estimates of cancer cases provided by WHO being correct. WHO estimated 4000 excess cancer cases — some 30 years later, no deaths attributable to the radiation have yet been identified in the liquidator cohorts. Being severely obese (BMI>40) potentially results in between 4 and 10 years of life lost compared with between 1.3 and 5.2 years of life lost for atomic bomb survivors who were within 1500 metres of the hypocentre and received whole body doses >1Gy. When the whole exposed cohort in the LSS is considered, the average loss of life expectancy is four months [11].

The health effects of low dose radiation exposure have been exaggerated by some, and the resulting fear of radiation may be leading us to decide energy policy based on urban myths rather than scientific facts. It is impossible to go through life without risk, and we must learn to measure, compare and manage risks to survive as individuals and also as a species.

By rejecting nuclear power as a source of low carbon energy, because of our lack of perspective on its real risk, we expose ourselves to the much greater health risks posed by climate change. The inability to mitigate climate change is a risk not just to our species, but to all species on this planet.

We need to get over our fear of nuclear and embrace a technology that offers a stable power source for all, and a solution to climate change — before it is too late!

REFERENCES

[1] INTERNATIONAL ENERGY AGENCY, Nuclear Power in a Clean Energy System, OECD, Paris (2019), https://webstore.iea.org/nuclear-power-in-a-clean-energy-system

[2] WORLD NUCLEAR ASSOCIATION, Nuclear Radiation and Health Effects, WNA, London (2018) https://www.world-nuclear.org/information-library/safety-and-security/radiation-and-health/nuclear-radiation-and-health-effects.aspx

[3] MCLEAN, A.R., et al., A restatement of the natural science evidence base concerning the health effects of low-level ionizing radiation, Proc. Biol. Sci. **284** (2017) 1862. pii: 20171070.

[4] WORLD HEALTH ORGANIZATION, Health Impact Assessment, WHO, Geneva https://www.who.int/hia/evidence/doh/en/ accessed 14/9/19.

[5] DOUPLE, E.B., et al., Disaster Med Public Health Prep. **5** (2011) S122–S133; doi:10.1001/dmp.2011.21.

[6] KAZAKOV, V.S., DEMIDCHIK, E.P., ASTAKHOVA, L.N., Thyroid cancer after Chernobyl, Nature (London) **359** (1992) 21.

[7] BAVERSTOCK, K., EGLOFF, B., PINCHERA, A., WILLIAMS, D., Thyroid cancer after Chernobyl, Nature (London) **359** (1992) 21–22 (Reply).

[8] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, Evaluation of Data on Thyroid Cancer in Regions Affected by the Chernobyl Accident, 2017
https://www.unscear.org/docs/publications/2017/Chernobyl_WP_2017.pdf

[9] CARDIS, E., et al., J. Radiol. Prot. **26** 2 (2006) 127–140
DOI: 10.1088/0952-4746/26/2/001.

[10] VAISMAN, F., TRONKO, M.D., TUTTLE, R.M., Clinical presentation and clinical outcomes in Chernobyl-related paediatric thyroid cancers: What do we know now? What can we expect in the future? Clin. Oncol. (R. Coll. Radiol.) **23** (2011) 268–275.

[11] SMITH, J.T., Are passive smoking, air pollution and obesity a greater mortality risk than major radiation incidents? BMC Public Health **7** (2007) 49
https://bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-7-49

4.3.5. Track 6: Public and non-nuclear stakeholders' perception of the role of nuclear power in climate change mitigation

Invited Speaker: Historical learning rates for nuclear power and the implications for future SMRs — The Breakthrough Institute

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1. INTRODUCTION

Early studies of cost trends for nuclear power found that the technology had experienced positive learning [1], meaning construction costs decreased with increased firm experience. More recent analysis has found negative learning however, or forgetting-by-doing, where costs increase as firms or countries gain experience [2, 3]. Nuclear power was not alone in experiencing negative learning rates. Rubin et al. (2015) found that onshore wind and natural gas combined cycle plants also experienced negative learning over specific time periods [4]. For nuclear power, a limitation of past studies has been cost data availability, with most studies focusing on the US and more recently France. Both countries appear exceptional in different ways with regard to nuclear power costs, but neither has been building significant new capacity in recent decades, calling into question the relevance of these learning rates for future energy system modelling and scenario planning.

Here we analyse new data from over 350 reactors in eight countries to calculate country specific learning rates [5]. An analysis of historical learning rates puts bounds on what is possible with traditional large scale LWR technology, but many expect that a move toward the modular fabrication of entire reactors could accelerate learning further [6]. Others are concerned that economies of scale may outweigh the benefits of learning-by-doing. We perform a simplistic model to show that with modest SMR learning rates, smaller reactors could become cost competitive with large-scale bespoke reactors after a few hundred units.

2. METHODS

In its simplest form, the learning rate is defined as how much the cost of a technology declines with each doubling of experience, usually measured by installed capacity for energy technologies. Equation (1) defines the standard experience curve, and the associated learning rate can be calculated with Eq. (2).

$$Y = ax^b \tag{1}$$

$$LR = 1 - 2^b \tag{2}$$

For our data, we calculated the cumulative installed nuclear capacity at the time econstruction began on each reactor [7]. For six countries we have complete cost histories, including overnight capital costs for all commercial reactors. For the UK, we only have costs for reactors completed before 1980, representing their first fleet of gas cooled reactors, and our German data are limited to the western part of Germany. We fit experience curves to each country to calculate the learning rate. We exclude reactors with capacities less than 100 MW as these tend to be expensive, early demonstration reactors, which can lead to an overestimation of commercial learning if they are included.

To explore the trade-offs between economies of scale and accelerated learning through modularization, we created a simple model comparing the costs of a 1000 MW reactor with a 50 MW and 2 MW reactor, assuming faster learning rates but higher initial costs. We assume the 1000 MW starts with first of a kind (FOAK) costs of $5500/kW and experiences a learning rate of 1%. For the smaller reactors we look at learning rates ranging from 5 to 20% and initial costs 1.25 times – 2 times the 1000 MW reactor. We calculate the capacity of small reactors you would need to build to break-even on costs with the 1000 MW reactor.

3. RESULTS

For the historical data, we found a large range of learning rates, shown in Table 1, from significant learning in the UK at 27% to negative learning in the USA at –49%. It becomes clear that the USA was a significant outlier in terms of negative learning. France and the Republic of Korea both saw positive learning over their complete nuclear history.

TABLE 1. LEARNING RATE CALCULATED BY FITTING EXPERIENCE CURVES TO FULL COST HISTORIES IN EACH COUNTRY.
The data for the United Kingdom includes reactors completed before 1980, the only information publicly available. Negative rates indicate that reactors became more expensive with cumulative installed capacity

Country	Learning rate (%)
United Kingdom (Pre-1980)	*27*
Rep. of Korea	*12*
France	*4*
Canada	–6
Japan	–15
Western Germany	–19
India	–20
USA	–49

Looking at future deployment, we could expect to see modest learning even for large LWRs in the range of 0–5% with standardized designs, as in the case for the Republic of Korea or France. However, assuming that SMRs have faster learning but higher initial costs, they could become cheaper than a large LWR after enough units are built. Our calculation finds that the number of SMRs needed to break-even on cost is more sensitive to initial costs than to learning rates (see Table 2). For example, if the 50 MW SMR starts at 50% higher costs compared with the 1000 MW reactor, you would need to build 22 GW (or 440 units) before they reached cost parity with a 5% learning rate, but with a 10% learning rate you would only need to build 14 units to reach cost parity. With global nuclear capacity expected to increase by several hundred GW to meet climate change mitigation targets, there would likely be sufficient volume to see this kind of learning. However, this simplistic model does not incorporate other benefits of factory fabrication such as reduced construction duration that could further reduce costs.

TABLE 2. CUMULATIVE CAPACITY (GW) OF SMRs CONSTRUCTED BEFORE THEY BREAK-EVEN ON COSTS WITH A 1000 MW REACTOR.

Column labels are learning rates for the 50 MW SMR, and row labels are the FOAK cost multiplier for the SMR compared with the 1000 MW reactor. A base cost of $5500/kW for the 1000 MW reactor is used, with a 1% learning rate

a. 50 MW SMR

	5%	10%	15%	20%
1.25×	1 GW (20 units)	0.2 GW (4 units)	0.1 GW (2 units)	<0.1 GW (<2 units)
1.5×	21.9 GW (440 units)	0.7 GW (14 units)	0.3 GW (6 units)	0.2 GW (4 units)
1.75×	290 GW (5860 units)	2.1 GW (42 units)	0.5 GW (10 units)	0.3 GW (6 units)
2×	>1000 GW	5.6 GW (112 units)	1 GW (20 units)	0.4 GW (8 units)

b. 2 MW microreactor

	5%	10%	15%	20%
1.25×	19 MW (10 units)	5 MW (3 units)	4 MW (2 units)	3 MW (<2 units)
1.5×	401 MW (201 units)	20 MW (10 units)	8 MW (4 units)	6 MW (3 units)
1.75×	5.4 GW (2700 units)	61 MW (31 units)	17 MW (9 units)	9 MW (5 units)
2×	>10 GW	161 MW (81 units)	31 MW (16 units)	14 MW (7 units)

The economic impacts of learning rates can be significant. For example, building 10 GW of our 1000 MW baseline unit would cost $54 billion, whereas building 10 GW of the 50 MW at just a 5% learning rate would only cost $50 billion, even assuming it starts out 25% more expensive. With the 2 MW microreactor, assuming it starts at 50% higher cost than the 1000 MW reactor, the total cost of the first 10 GW (5000 units) would be $47 billion. With a 10% learning rate, the total cost would drop to $27 billion, or an average capital cost of $2700/kW. Learning rates in the range of 10–30% are not uncommon for other energy technologies, including wind turbines of a similar capacity to microreactors, up to large gas turbines [4].

4. CONCLUSIONS AND FUTURE WORK

Our analysis of historical learning rates demonstrates that relying on US data alone provides an underestimate of learning for nuclear technologies, which could be particularly significant for economic modelling of future energy systems. In addition, our simple model of future SMR costs illustrates that accelerated learning could significantly reduce costs with significant deployment. However, further work is needed to put realistic bounds on these estimates. As it stands, many Western countries have seen large FOAK costs for new reactors larger than 1000 MW, with little to no learning. On the other hand, some SMR developers are promising FOAK costs lower than those for large scale reactors, meaning that any learning would make them a better bet than large scale reactors.

REFERENCES

[1] CANTOR, R., HEWLETT J., The economics of nuclear power: further evidence on learning, economies of scale, and regulatory effects, Resour. Energy **10** (1988) 315–335.

[2] GRUBLER, A., The costs of the French nuclear scale-up: A case of negative learning by doing, Energy Policy **38** (2010) 5174–5188.

[3] COOPER, M., Policy challenges of nuclear reactor construction, cost escalation and crowding out alternatives, Inst. Energy Environ. Vermont Law 5 http://www.ises.org.il/assets/files/News/20100909_cooperStudy.pdf (2010, accessed 26 November 2013).

[4] RUBIN, E.S., et al., A review of learning rates for electricity supply technologies, Energy Policy **86** (2015) 198–218.

[5] LOVERING J.R., YIP, A., NORDHAUS, T., Historical construction costs of global nuclear power reactors, Energy Policy **91** (2016) 371–382.

[6] ROULSTONE T., How to make nuclear power affordable, Mod. Power Sys. 11 January 2018.

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Power Reactor Information System, The Database on Nuclear Power Reactors, IAEA, Vienna.

4.3.6. Track 6: Public and non-nuclear stakeholders' perception of the role of nuclear power in climate change mitigation

Invited Speaker: Status of Electricity Sector Decarbonization — Qvist Consulting Limited

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1. INTRODUCTION

When attempting to find a solution to a difficult problem, perhaps the most effective approach is to see if someone else has already found a solution to the same problem. However, this type of approach has so far rarely been considered when it comes to the greatest challenge currently facing humanity, that of rapidly eliminating the emissions of greenhouse gases that are changing the climate. Energy and climate policy are primarily, with few exceptions, determined on a national level. It is therefore of value to see what national policies or technology approaches have achieved success in terms of decarbonization while simultaneously allowing for economic development. In all serious decarbonization plans published to date, electricity plays a major and often dominant role. (1) All existing fossil fuelled electricity generation must be phased out and replaced by low carbon sources. (2) Low carbon electricity supply must expand further to power large parts of the economy that currently runs on fossil fuels. Thus, when the world now takes on the daunting task of decarbonization, is it sensible to ask:

- Are any nations or larger regions already successfully and reliably powered (for electricity) by low carbon energy sources?
- If yes on (1), how was this done, how long time did it take, and at what cost?

This paper provides a short overview and categorization of successful electricity sector decarbonization to date, thereby giving at least a partial answer to the important questions posed above.

2. THE ELECTRICITY DECARBONIZATION STORY SO FAR

If we define 'successful' historical electricity sector decarbonization as one which achieves an annual average life cycle emissions rate below 50 $gCO_{2\text{-eq}}$ per kW·h of electricity consumed, approximately 20 countries or major regions have so far achieved this target. Using data from Refs [1–4], these successfully decarbonized supply systems can be grouped in the following categories:

- Decarbonized due to energy poverty ('Poor'):
  Poor developing nations with low per capita production and consumption of electricity (<4000 kW·h/year per capita).
- Decarbonized due to fortunate local conditions ('Lucky'):
  Sparsely populated, small-population countries with extraordinarily abundant domestic hydroelectric and/or geothermal resources, which together supply more than half of all electricity generation and consumption.
- Decarbonized through energy policy ('Replicable):
  Energy-rich regions which have decarbonized using an (at least partially) replicable

strategy, where hydroelectricity and geothermal sources combined provide less than half of total electricity generation.

The dividing line between groups 1 and 2 has been drawn at 4000 kW·h per year per capita (~450 W of consumption per person on average). After industrialization has run its course, a developed country typically registers annual electricity consumption per capita well above 4000 kW·h. The OECD average today is about 8700 kW·h/year per capita (~1000 W) [1, 2].

The dividing line between categories 2 and 3 is based on the extent to which other countries and regions can derive any learning from their experience. For any type of low carbon energy source, local conditions to some extent determine the ease and cost with which it can be expanded. However, hydroelectric power and conventional geothermal energy uniquely depend on local conditions in a way in which no other currently available low carbon energy sources do.[23] If a nation or region lacks large rivers that can be dammed with hydroelectric power plants, or lacks a sufficiently high geothermal temperature gradient, these sources simply cannot be developed. Thus, even though the electricity supply systems of, for example, nations like Iceland and Norway satisfy very high electricity demand completely by low carbon power, their experience of developing local hydroelectric and geothermal power is of no practical value as inspiration for any other country or region that is not similarly geographically blessed.

The regional potential for wind[24] and solar power naturally depends on the quality of the wind and solar resource base, but these sources can in principle be utilized anywhere on Earth. Nuclear energy can in principle be utilized anywhere on Earth with few geographical restrictions.

The main characteristics of these groups are defined in TABLE 1.

[23] Wave and tidal power are also geographically constrained to countries and regions with suitable coasts or waters.

[24] Offshore wind power is naturally constrained to countries and regions with large bodies of water, either very large lakes or ocean coasts. When bundling offshore and onshore wind power into the single category of 'wind power', there is no geographical restriction that would prohibit some wind power utilization anywhere on Earth.

TABLE 1. GROUPING OF ELECTRICITY SUPPLY SYSTEMS WITH ANNUAL EMISSION RATES LOWER THAN 50 g CO_2-eq/kW·h [1–3]

Category	1. Energy-poor	2. Lucky	3. Replicable
Example of countries or regions	Democratic Republic of the Congo, Costa Rica, Ethiopia, Paraguay, Tajikistan, Namibia, Zambia, Nepal, Mozambique, Uruguay, Kyrgyzstan, Albania	Iceland, Norway, New Zealand South Island, Tasmania	Sweden, France, Ontario (Canada), Switzerland
Primary means of grid electricity generation	Typically a few large hydroelectric dams	Mainly hydroelectricity, with varying contributions from geothermal	Combination of nuclear energy and hydroelectricity
Average share of electricity generation from geographically limited domestic sources (hydro + geothermal)	95%	98%	32%
Average share of nuclear energy	0%	0%	50%
Average share of electricity from wind and solar sources	2.5%	0.5%	7%
Approx. group-average electricity consumption (Average watt per capita)	120	4000	1000

The proposed categorization and the dividing lines between groups are also shown in Fig. 1.

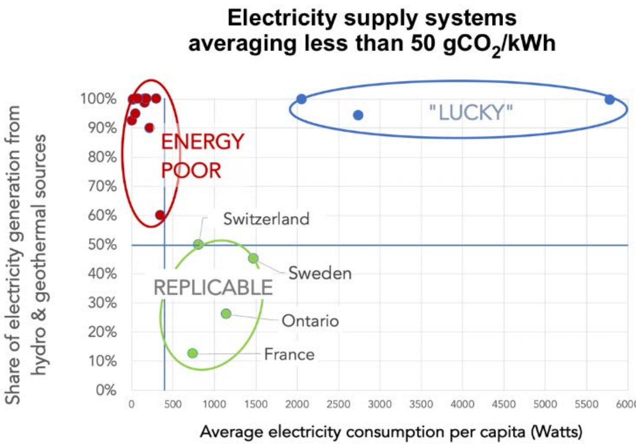

FIG. 1. Graphical representation of existing low carbon electricity supply systems [1–3].

3. CONCLUSIONS

So far, successful and *replicable* decarbonization of electricity supply has always been based on combinations of nuclear energy and renewable energy, primarily hydroelectric power. In the four countries and regions that so far have successfully decarbonized without primarily relying on fortunate local circumstances (meaning less than 50% hydro and geothermal energy), the fraction of electricity supply is shown in Table 2.

TABLE 2. ELECTRICITY SUPPLY SHARE IN THE 'REPLICABLE' GROUP IN 2018 [1]

Country/region	Hydroelectric	Nuclear	Wind + solar
Sweden	38%	42%	11%
France	11%'	72%	7%
Ontario	26%	60%	9%
Switzerland	50%	37%	3%

Three countries or regions (Iceland, Norway and the South Island of New Zealand) have so far managed to supply a high level of electricity consumption entirely with renewable energy. In all these cases, essentially all power comes from hydroelectric and geothermal power.

Countries not blessed with abundant hydroelectric power that have adopted '100% renewable electricity' supply strategies have so far failed to fully decarbonize their electricity supply sectors. The most well-known example is Germany, which maintains electricity sector emission levels nearly eight times higher than what is defined as 'decarbonized' in this paper. Even after a decade of dedicated national policies and heavy investments in its 'Energiewende' programme, the emissions intensity of German electricity supply remains significantly higher than the European Union average [5].

No country has so far achieved a low emissions electricity supply system through the expansion of wind or solar power alone.[25] On a national level, Uruguay is the only country with a significant annual share of variable renewable electricity (>25%) that also qualifies as a low carbon supply system according to the definition in this paper (<50 $gCO_{2\text{-eq}}$/kW·h). However, Uruguay already qualified before any expansion of variable renewable energy occurred, having its 'cleanest' production years ever in 2000–2003 with 100% hydroelectricity. The wind power expansion of recent years has, however, *significantly* helped to limit the use of fossil fuels during dry years in the hydroelectric sector.

Based on available experience and statistics, the most successful electricity decarbonization strategy is one that is balanced and technology neutral, and that combines renewable energy sources and nuclear energy.

[25] Some highly interconnected regions are achieving electricity production emission levels that approach those defined as low carbon in this paper. However, since they are typically small parts of much larger interconnected systems, they cannot be treated as stand-alone examples of supply systems. One example is the US state of Vermont, which now imports significantly more than half of all electricity consumed, but its in-state generation is indeed fully low carbon. Another example is heavily wind powered Scotland, which is a net exporter of electricity to the larger overall UK market.

REFERENCES

[1] BRITISH PETROLEUM, BP Statistical Review of World Energy 2019, BP, London (2019).

[2] WORLD BANK, World Development Indicators, World Bank, Washington, DC (2019).

[3] INTERNATIONAL ENERGY AGENCY, Carbon Intensity of Electricity Generation, OECD, Paris (2015).

[4] TOMORROW, ElectricityMap (www.electricitymap.org) (2019).

[5] ENERDATA, Emissions Intensity in the Electricity Sector in the G20 (2018).

4.4. PLENARY SESSION: NUCLEAR SAFETY AND S ECURITY

Chairpersons/moderators: L. Heikinheimo (Finland)
J. Lentijo (IAEA)

4.4.1. Keynote Address: United Arab Emirates

Statement as provided, verbatim.

H. Alkaabi
Ambassador and Permanent Representative of the United Arab Emirates to the IAEA
Vienna, Austria

Good morning, ladies and gentlemen.

I am very pleased to speak at this Plenary Session on a very critical and universal topic: Nuclear Safety and Security. This is a significant topic for all of us, across borders, and as a collective society.

What we have seen over the course of this week is overwhelming evidence to support the urgent need for the increased use of clean energy in order to limit and ultimately reduce carbon emissions.

Nuclear energy continues to be among the top policy choices for governments around the world in addressing climate change and energy needs. It is a proven energy source that does not emit high levels of CO_2 and can meet the large scale energy demands of growing industries and economies.

Though nuclear energy is indeed a promising solution for an era that faces global warming, nuclear programmes must be developed and managed in an effective and responsible manner. This can only be done taking into account the core principles of nuclear safety and nuclear security.

In the case of my country, the United Arab Emirates, the decision to embark on a nuclear power programme was taken in 2008, when it became clear that energy demand was rising rapidly. The government commissioned nationwide energy studies that concluded nuclear power was the most economically attractive and cost competitive baseload option. This was in line with the Government decision to diversify energy sources and increase the contribution of clean energy, including through aggressive development of renewables such solar energy.

Nuclear technology, to be deployed successfully, has to take into account the special circumstances surrounding the use of such sensitive technology. Those include ensuring highest safety and security standards are met.

It is for this reason that the UAE's Nuclear Policy of 2008 was developed clearly outlining six core principles, which specifically included the country's commitment to the highest standards of nuclear safety and security. Also, as key elements of the national policy, the UAE would cooperate with the International Atomic Energy Agency and other Member States in order to benefit from decades of international experience and to ensure complete compliance with international standards and best practices.

An important element in the responsible approach to ensuring nuclear safety and security was to have nuclear institutions that have deeply-rooted concepts of safety and security culture. The establishment in 2009 of both the UAE's nuclear regulator — the Federal Authority for Nuclear Regulation — and owner organization — Emirates Nuclear Energy Corporation — followed this approach and would later boast a robust strategy for effective implementation to support these principles.

Because the UAE closely followed a well-structured Roadmap that it had developed to implement its programme, construction of the first of four nuclear reactor units at Barakah was possible in 2012. To date, the construction of Unit 1 is now complete, with Unit 2 close behind, and the overall completion of all four units stands at 93%. The four APR-1400 Units at Barakah are expected to supply up to 25% of the UAE's electricity needs, once fully in operation, helping the UAE to achieve its national targets of clean energy.

Throughout the buildup of its nuclear programme, the UAE subscribed to all international instruments in nuclear safety and security, and continues to take active part in the peer review process of their conventions, strengthening national and global efforts in these domains.

The UAE has put a great emphasis on ensuring that we have a robust nuclear safety and security regulator, armed with best international expertise in the field.

In the midst of this process, the Fukushima Daiichi accident happened in 2011, just as the UAE was getting ready to issue its first construction licence for the first two units.

The Government had already at the time taken an important policy decision at the startup of the programme, namely safety first. It is this strong policy commitment that has led to numerous actions and specific compliance with nuclear safety and lesson learned measures.

The UAE took action to improve its programme in the aftermath of the Fukushima Daiichi accident and has undergone a number of stress tests to ensure that the nuclear plant and operator is fully ready for the safe operation of the Barakah NPP. We have hosted a number of IAEA peer review missions in the area of nuclear safety, most recently piloting an Integrated Nuclear Infrastructure Review Service (Phase 3) in 2018 and concluding a follow-up Emergency Preparedness Review mission just last month.

A number of the 12 major IAEA peer review missions received by the UAE have also covered the area of nuclear security, including physical protection and the accounting for and control of nuclear material. We concluded a Comprehensive Safeguards Agreement, and an Additional Protocol, with the IAEA to ensure that its nuclear programme is safe and secure.

A final element in streamlining a nuclear programme with the highest standards of nuclear safety and security is to ensure that the programme is sustainable. To achieve this, a country must invest heavily in the development and retention of nuclear expertise. Human resource development has indeed been a top priority in the UAE programme. With strong capacity building efforts, the UAE has been successful in developing a strong cadre of young and skilful expertise. Just last month, the UAE graduated 53 reactor operators, including women.

All these measures, conducted openly and transparently, have also included the engagement of the public in the UAE. Open forums hosted by nuclear stakeholders aim to ensure a broader understanding of the programme, and have resulted in high public acceptance rates. Strong confidence continues in the nuclear programme and its stakeholders in the UAE, who will continue to take on the responsibility of managing a nuclear sector that can address the growing energy needs of the country.

A decade later, the UAE has already an established strong safety and security infrastructure, a robust independent regulator and operator that is committed to the highest standards of safety and security. This has been reviewed and confirmed by international experts and through the IAEA's numerous independent assessments.

Ladies and gentlemen, when it comes to looking for solutions to combat the threat of climate change, the UAE continues to consider nuclear energy to be a valuable option. But this solution is one that must be implemented with careful planning and complete adherence to the highest standards of nuclear safety, security and non-proliferation.

As we approach the commissioning of the first nuclear reactor unit in the UAE, we continue to believe that a strong safety and security infrastructure is the cornerstone of a successful nuclear deployment.

It is therefore with clear, efficient and responsible strategies for implementing clean energy systems, including nuclear, that we can address the challenge of climate change successfully.

Thank you.

4.4.2. Keynote Address: Bridging the Gap, EDF, United Kingdom

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This paper was not available for publication but the full presentation is included in the on-line supplementary files, for reference, and can be found on the publication's individual web page at www.iaea.org/publications. A summary of the presentation is provided below.

M. Hartley described how the UK was bridging the gap between an ageing reactor fleet coming off-line and new build reactors being commissioned. He also talked about the UK approach of enabling regulation, which the UK Office for Nuclear Regulation defines as a constructive approach with duty holders and other relevant stakeholders to enable effective delivery against clear and prioritized safety and security outcomes.

4.4.3. Keynote Address: China’s Practice and Experience in Enhancing Nuclear Safety and Security

Statement as provided, verbatim.

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1. CHINA’S NUCLEAR POLICY AND DEVELOPMENT STATUS

China has always been an active player in the global efforts to combat climate change, and is constantly decreasing the use of fossil fuels and developing green energy. As a clean, low carbon, highly efficient and baseload energy, nuclear energy plays a crucial role in the UN 2030 Agenda for Sustainable Development. It also helps China to ensure energy supply, optimize its energy mix and tackle climate change.

Up till now, China has 47 nuclear power units in operation with a capacity of 48.73 GW, 11 units under construction with a capacity of 12.18 GW. Boasting mature technology and abundant talents, China has developed a complete nuclear industrial chain, from nuclear fuel production, equipment manufacturing, project construction, and waste disposal to technology application.

The Chinese Government is committed to reducing the carbon dioxide emissions per unit of GDP by 60–65% compared with 2005 levels by 2030. In 2018, China’s nuclear power generation amounted to 286.5 TW·h, accounting for 15.83% of China’s non-fossil fuel energy generation. This is equivalent to avoiding the combustion of 88.24 million tonnes of standard coal and the emission of 230 million tonnes of carbon dioxide, 750 000 tonnes of sulphur dioxide and 650 000 tonnes of nitrogen oxides.

2. CHINA’S VIEW ON NUCLEAR SAFETY AND SECURITY

China has always regarded nuclear safety as an important national responsibility, and integrated it into the entire process of nuclear energy development and utilization. It has always developed the nuclear industry subject to considerations of safety, implemented regulations in accordance with the strictest standards, and adapted to the new requirements of the nuclear industry. China’s nuclear industry has always developed in line with the latest safety standards and maintained a good safety record, pursuing an innovative driven path of nuclear safety with Chinese characteristics.

As an important advocate, promoter and participant in building a fair, collaborative and mutually beneficial international nuclear security regime, China has done a good job in ensuring its own nuclear security, fulfilled its international obligations, and promoted bilateral and multilateral cooperation on nuclear security. From 2010 to 2016, China’s presidents attended four Nuclear Security Summits. Following the ‘rational, coordinated, and balanced’ nuclear security approach, the Chinese Government continuously improves its nuclear security legislation and regulation, increases the inputs to nuclear security capacity building and technical R&D. Meanwhile, China established the Center of Excellence on Nuclear Security in cooperation with the USA in 2016, accepted the International Physical Protection Advisory Service (IPPAS) mission organized by the IAEA in 2017, and successfully completed the MNSR Conversion Projects in Ghana and Nigeria from 2017 to 2018.

3. BRIEF INTRODUCTION TO THE SNSTC/COE

In order to further enhance the security of nuclear materials and facilities and ensure the stable and healthy development of nuclear energy, the State Nuclear Security Technology Center (SNSTC), affiliated to the China Atomic Energy Authority (CAEA), was established with the approval of the Chinese central government. Its functions are categorized into four parts: personnel training and education; equipment test and certification; technical research and development; as well as support to government management.

During the Nuclear Security Summit in Washington in April 2010, China and the USA agreed to establish a 'Center of Excellence' (COE) on nuclear security. Under the agreement, the centre, located in Fangshan District, Beijing, is run and administered by China, while the USA will provide nuclear security equipment. The construction of the COE was kicked off in December 2013 and completed in December 2015. It has been in operation since March 2016.

Since 2016, the COE has organized over 120 workshops and training courses for around 3600 personnel from Chinese regulatory bodies and nuclear facility operators. Through cooperation with the IAEA and other partners, around 20 regional and transregional workshops have been held with over 1000 participants from more than 50 countries.

During the 63rd IAEA General Conference, the IAEA and CAEA signed a Collaborating Center Designation Agreement on 10 September 2019. SNSTC and CIAE (China Atomic Energy Institute) as CAEA's technical institutes, were collectively designated as IAEA Collaborating Centre on Nuclear Security Technologies. The four year agreement provides for collaboration between CAEA and the IAEA in research, development, testing, and training on nuclear security detection and physician protection technologies.

4. CONCLUSION

China stands ready to join hands with other Member States of the IAEA to construct a stronger defence of nuclear safety and security, ensure sustainable development of nuclear energy and play a more important role in addressing global climate change. China always supports the IAEA's central role in international cooperation and exchange in areas of nuclear security and safety and encourages the IAEA to help more developing countries to improve nuclear security capacity and promote nuclear safety level. China will continue to share knowledge, experience and good practice on nuclear safety and security with other Member States via its platforms like SNSTC/COE.

4.4.4. Keynote Address: Nuclear Power and Future Aspects: Case of Pakistan

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This paper was not available for publication but the full presentation is included in the on-line supplementary files, for reference, and can be found on the publication's individual web page at www.iaea.org/publications. A summary of the presentation is provided below.

A. Parvez talked about his experience in Pakistan and also gave his view regarding the economics of nuclear power and aspects of public perception. He also explained the role of the Pakistan Centre of Excellence for Nuclear Security.

4.4.5. Keynote Address: IAEA

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This paper was not available for publication but the full presentation is included in the on-line supplementary files, for reference, and can be found on the publication's individual web page at www.iaea.org/publications. A summary of the presentation is provided below.

S. Mallick gave a brief presentation on the importance of nuclear safety and security from an IAEA viewpoint and indicated that international cooperation on global nuclear safety and security, and national provisions for nuclear safety and security, have continued to be strengthened over recent years. Safety and security are integral parts of the use of nuclear and radiation technologies and is key to making these technologies sustainable. The IAEA safety standards and the Nuclear Security Series represents an international consensus of what constitutes a high level of safety or security. The IAEA peer review and advisory services help Member States to assess how their practices and frameworks compare to those recommended in the IAEA safety standards and security guidance documents. These services are held on request and help Member States improve their level of nuclear safety and security.

5. SUMMARY OF TECHNICAL SESSIONS

During the conference, the session chairs were requested to provide a summary of each session. Each of the parallel technical sessions consisted of presentations followed by a discussion. The following section is a compilation of edited summaries provided by the chairpersons. The IAEA appreciates their contributions.

5.1. TRACK 1: ADVANCING ENERGY POLICIES THAT ACHIEVE THE CLIMATE CHANGE GOALS

5.1.1. Parallel Technical Session 1a: Implementation of the climate change goals from a global perspective

Chairpersons: F. Vladu, UNFCCC
M. Deinert, USA

The summaries of presentations and discussions in Session 1a are given below.

H. Schneider (Switzerland): 'Nuclear energy in the Article 6 of the Paris Agreement'.
The paper provides an interpretation of the Paris Agreement's legal framework on international cooperation mechanisms and examines the conditions for eligibility of nuclear power projects. Nuclear power appears to be best suited for Article 6.2 (mitigation focused, bottom-up decentralized approach to international exchange; it does not require many United Nations Framework Convention on Climate Change (UNFCCC) rules) and Article 6.8 (holistic, non-market mechanisms for mitigation, adaptation, eradication of poverty). It seems less suited to Article 6.4 (top-down, requires strong rules and moderation from the UNFCCC). The negotiation process is seen as an opportunity to place nuclear power in the debate.

E. Morales (Uruguay): 'Nuclear shares in power and final energy consistent with 1.5ºC scenarios — Considerations for national climate strategies'.
The paper provides an analysis of the role of nuclear power in the context of detailed decarbonization scenarios and a shift towards electrification of energy use. A review of multiple Intergovernmental Panel on Climate Change (IPCC) median 1.5ºC scenarios provides various pathways to meet future electric demand, drawing on large shares of nuclear and renewable energy sources (at least 30% and 40%, respectively). Demand-side management decreases the amount of power generation needed from storage capacity to prevent curtailing demand (from 15 000 GW·h down to 3000 GW·h)

A. Van Heek (IAEA): 'Opportunities for small nuclear power plants by the recurring submission mechanism of the Paris Agreement'.
A doubling of nuclear capacity is projected to 2050. Small and medium size reactors (SMRs) meet new market requirements, require less grid size and lower financing requirements. They may thus constitute a viable alternative to ageing nuclear capacity and suitable solutions to meet growing electricity needs. However, the deployment of innovative reactor designs will be optimized if aligned with the recurring mechanism of national commitment declarations formulated by the Paris Agreement. The Agreement also provides the opportunity to set targets for the deployment of SMRs beyond 2030, in alignment with long term national plans for climate action. Supporting R&D policies need to be designed accordingly.

H. Turton (IAEA): 'Nuclear power and climate change: Scenario perspectives to 2050'.

The paper provides a comprehensive review of climate scenarios and highlights the increasing role of nuclear electricity in the context of deep decarbonization strategies. By 2050, scenarios compatible with limiting global warming to 1.5°–2°C achieve 80–90% low carbon electricity generation. For future nuclear power output, the scenarios cover a wide range, from a complete phase-out up to a ten-fold increase. Very low emissions scenarios (<10 Gt CO_2) feature an average of 8 PW·h of nuclear generation — more than triple today's level. More broadly, 90% of scenarios compatible with 1.5–2°C exceed the IAEA's low nuclear projection for 2050, and 60% exceed the high projection. Most scenarios show that nuclear power and renewables are generally complementary, with solar and wind accounting for at least 30% of total generation. Conducive market and policy conditions will be needed to capitalize on the large mitigation potential of nuclear power identified across the scenarios.

N. Davydova (Russian Federation): 'Nuclear energy may help to overcome the restrictions on economic growth posed by climate change mitigation policies'.
The transition to a post-industrial era may impede economic growth in developing economies. The deployment of renewables entails an extensive network investments, adding to the cost of electricity ($830–$1170/kW of wind capacity; $1170–$1700/kW of solar capacity; $1170–$2170 of transmission and distribution (T&D) costs per kilowatt installed). It is argued that under current conditions, at $1850/kW, nuclear power is most suited to centralized systems. The goal of halving per capita greenhouse gas (GHG) emissions can be met with a combination of nuclear power (40%), fossil fuels (40%) and solar power (20%).

M. Deinert (USA): 'Beyond LCOE: Quantifying co-benefits and the value of resilience in power systems'.
There is a need to reconsider the valuation of energy systems and shift the conversation from solely technical to more goal oriented and social considerations. The yearly cost of power outages is estimated at $20–$50 billion, while overall infrastructure losses are around $337 billion, most of it uninsured. There is thus an intrinsic value to the resilience of energy infrastructure. Statistical evidence suggests that in 30 years almost all coastal zones in the USA will be affected by hurricanes. Recent extreme weather events in the USA highlight the degree of resilience of various energy types of infrastructure. Nuclear power appears more resilient to extreme events compared with other energy infrastructures. For example, the impact of Hurricane Sandy on nuclear power plants was two times lower than the impact on petroleum infrastructures, while Hurricane Harvey did no damage to nuclear power plants. Hurricanes Irma and Maria proved particularly damaging to T&D systems in Puerto Rico.

5.1.2. Parallel Technical Session 1b: Perspective of countries with ongoing nuclear power programmes

Chairpersons: C. van Drunen (Canada)
A. Kumar (India)

The summaries of presentations and discussions in Session 1b are given below.

M. Chyzhenko (Ukraine): ‘Contribution of nuclear power to the avoidance of GHG emissions in Ukraine’.
The Ukraine climate strategy to 2050 is to reduce emissions by 31–34% compared with 1990 levels. Revisions to Nationally Determined Contributions (NDCs) may have to be even more ambitious than in the current 2050 strategy. Energy efficiency improvements alone will not be enough to reach the goal. Nuclear power is at the core of Ukraine’s mitigation strategy in which fossil fuels gradually decrease to 15% by 2035. At €18.6/kW·h, nuclear costs are much lower than renewable energy costs. According to the long term strategy, nuclear will avoid 80 Mt of CO_2 emissions.

A. Kumar (India): ‘Role of nuclear power in reduction of greenhouse gas emissions — The Indian scenario’.
Greenhouse gas emissions in India, notably stemming from electricity production, have increased from 100 to 2500 Mt CO_2 since 2000. The emission intensity of GDP is set to rise by 33–35% by 2030 compared with the 2005 level. At 1100 kW·h per capita, electricity consumption in India remains very low, and is only a third of the world average. Nuclear power (6.78 GW of installed capacity) currently supplies 2% of electricity needs, equivalent to the projected share in 2027. Additions to nuclear power totalling 2800 MW will come on-line around 2022–2023. Between 2020 and 2030, nuclear power plants may help save 453 Mt of CO_2 emissions. India also has very great ambitions in terms solar and wind deployment. By 2027, other low carbon sources in the power mix will include solar (23% of total generation), wind (16%) and hydro (11%). Overall, the renewable installed in 2027 may reach 237 GW.

M. Crozat (USA): ‘Economics and policies shaping the role of nuclear energy in the USA’.
In the last ten years, sizeable changes have occurred in the power sector in the USA. While coal generation has collapsed, nuclear operators have been able to maintain a stable production level. At 92.3% capacity factor, the US nuclear fleet remains high performing, avoiding 28 Mt CO_2 every year. Wholesale electricity prices in the 2000s were around $60/MW·h, making nuclear power very profitable. However, the recent decline in wholesale electricity prices has led to a decrease in market prices, down to $28–36/MW·h recently (set by natural gas plants). US nuclear generation costs peaked in 2012, but then dropped by 20% thanks to improved plant efficiency. The nuclear sector in the USA is facing a wave of premature closures: nine units shut down operations since 2013 and more shutdowns are being announced, to the detriment of climate mitigation. In the absence of national policy, five States are taking action to preserve 13 950 MW of nuclear capacity. States and regional coalitions have set their own clean energy goals and developed an approach in coordination with pledges from operators. A continuum of innovations, with bipartisan support, including advanced non-LWRs and SMRs, can stimulate the development of nuclear in the USA. However, new market designs, beyond existing rules, and adequate policy frameworks are needed.

C. van Drunen (Canada): ‘Nuclear power: Sustaining current contributions and facilitating future pathways’.
Ontario announced a coal phase-out in 2014, with expected annual savings of CAN $4.4 billion in environmental and health costs (and an 80% decrease in emissions). Other than hydro,

nuclear power offers the most cost competitive, low carbon option for electricity generation. CANDU reactors provide 15% of national electricity, including 60% of Ontario's low carbon electricity. Key drivers of the energy transition include the refurbishment of existing nuclear assets and innovation to maintain safe, competitive and reliable operation of nuclear assets. An industry-led, pan-Canadian SMR roadmap suggests that SMRs offer a significant potential for cost savings, for displacing coal, and generating on-grid and off-grid power and heat in industry. Other off-grid applications include power supply to remote communities and mines — these remote communities usually rely on expensive diesel generators ($500/MW·h). The Canadian Nuclear Laboratories' SMR initiative, shaped by the Roadmap, is meant to build confidence. With a 3% change in the cost of capital for a 300 MW first of a kind SMR, the levelized cost of energy can vary by 30%. SMR projects generally rely on private financing. However, stakeholder cooperation can reduce costs. The first SMR is to be hosted in 2026.

5.1.3. Parallel Technical Session 1c: Planning tools to support the preparation and update of NDCs (near term) and LEDs (mid term)

Chairpersons: M. Nyasapoh (Ghana)
H. Turton (IAEA)

The summaries of presentations and discussions in Session 1c are given below.

M. Nyasapoh (Ghana): 'Nuclear power contribution towards a low carbon electricity generation for Ghana'.
This presentation provides a scenario analysis based on the MESSAGE modelling framework, with IAEA financial and technical support. An integrated approach combining nuclear power and renewables can deliver low carbon energy for Ghana's industrial and economic aspirations, but requires a long term commitment.

G. Borsatto (Brazil): 'Energy demand and supply analysis to contribute to climate change challenge achievement using IAEA methodology and tools'.
The paper provides a model based analysis of the potential contribution of nuclear power to national climate mitigation efforts. A scenario assumes the construction of new power plants, resulting in a 41% reduction of CO_2 emissions by 2050.

R. Muradyan (Armenia): 'Creation of energy policies in Armenia that achieve climate change'.
The proposed modelling framework combines a model based approach and a statistical analysis to capture key determining factors of a national strategy. Armenia's cost effective mitigation strategy rests on a low discount rate (6% or less) and the implementation of strong measures for demand-side management. It also suggests that nuclear construction around 2030 would make a competitive option, provided that its commissioning can be achieved in a timely manner.

M. Kukharchuk (Ukraine): 'Assessment of the potential role of nuclear energy in Ukrainian climate change mitigation strategies'.
The paper draws on the MESSAGE modelling framework and includes a detailed representation of the nuclear fuel cycle. Scenarios are presented depicting long term outcomes for nuclear development based on various assumptions on nuclear construction costs and extent of climate objectives. Low nuclear capital costs (under \$4700/MW) or high carbon taxes (above \$50/t of CO_2) would favour strong deployment of nuclear energy, thereby supplying up to 75% of electricity generation by the end of the century. If these conditions are not met, the long term contribution of nuclear electricity to Ukraine's climate objectives may be in the order of 10–20%.

5.1.4. Parallel Technical Session 1d: Regional perspectives: The case of the EU

Chairpersons: E. Proust (European Nuclear Society)
A. Van Heek (IAEA)

The summaries of presentations and discussions in Session 1d are given below.

M. Constantin (Romania): 'Nuclear power development in Romania in the context of future energy market and climate change policies'.
In Romania, the contribution of nuclear energy to climate policy objectives is being consolidated by the life extension of the first two units of the Cernavoda nuclear power plant and the continuation of investment in the third and fourth units. For the longer term, efforts are being made for significant innovation in the form of the implemention of the ALFRED LFR demonstrator. Nuclear and vRES are seen as green energy pillars which can work together in systems with significant storage capacities. To accommodate the ambitious expansion of vRES with baseload operation of CANDU nuclear units, a 1000 MW(e) project for hydro-pumping-based energy storage was approved by the Government in 2014.

Ž. Tomšić (Croatia): 'Possible role of SMR in Croatian low carbon development strategy'.
The long term planning horizon of the Croatian low carbon development strategy in the electricity and heating sectors from 2015 to 2050 was analysed using the hourly chronological model in PLEXOS. In particular, the possible role of the NuScale SMR was investigated. The cost per megawatt is initially higher due to their smaller size, but capital expenditures for each SMR become lower with added volume due to factory learning effects.

E. Proust (European Nuclear Society): 'The important role of nuclear power in a low carbon world: The view of the European Nuclear Society's High Scientific Council'.
To achieve an effective and reliable solution for electricity generation, an appropriate balance between dispatchable and intermittent installed generating capacity is needed. The penetration of intermittent renewable energy should not exceed 40–50% of a country's required installed generating capacity. Given the massive investments that will be required to realize the radical transformation indicated by the IPCC SR15 report, it is of paramount importance to implement long term frameworks that provide stability and confidence for investors in all low carbon power technologies.

A. Gerse (Hungary): 'Towards a low-carbon electricity supply in Central Eastern Europe: Modelling the role of nuclear power plants'.
The carbon dioxide emissions from the electricity sector in the Central European region have been modelled in the Antares model of the French electricity transmission system operator RTE. Due to the nuclear phase-out in Germany, the share of low carbon electricity generation will decrease by one half from 2017 to 2025. However, if the planned new investments in Slovakia, Hungary, Romania and Poland are completed, the nuclear generation capacity could almost compensate for this loss by 2030.

B. Picamal (FORATOM): 'Nuclear power in Europe — Where to?'
The European Commission confirms that nuclear will form the backbone of a carbon free European power system, together with renewables, in its communication 'A Clean Planet for All', outlining the European Union's strategic long term vision for reaching a climate neutral economy by 2050. In a Foratom commissioned study, Deloitte quantified the economic impact of the nuclear sector on jobs and the economy, including 1.3 million jobs annually and a €576 billion annual contribution to the EU GDP.

5.1.5. Parallel Technical Session 1e: Perspective of countries with longer-term prospects

Chairpersons: G. Güngör (Turkey)
B. Magne (IAEA)

The summaries of presentations and discussions in Session 1e are given below.

G. Güngör (Turkey): 'The role of nuclear energy in transition pathways of the Turkish energy sector'.
The growing economy and heavy dependence on imported fossil fuels shifted the focus to energy security and, to a lesser extent, to climate change mitigation. Turkey is currently constructing its first NPP. Studies show that nuclear can contribute to climate change mitigation together with renewables, which have great potential, under a range of capital costs.

V. Watcharasuragul (Thailand): 'Dissemination of how nuclear energy can support Thailand's 4.0 policy'.
Thailand has adopted a new long term energy policy in 2015 which aims to introduce new technologies in several key areas. Nuclear is not yet considered in the associated energy plan (Power Development Plan, PDP). Current activities focus on public participation in future energy technology choices, which would offer decision makers insights into public opinion on nuclear power and its role in the future energy mix of Thailand.

R. Fahmy (Egypt): 'The significant role of nuclear energy in tackling climate change'.
Egypt's electricity is generated mainly from fossil fuel plants (92%), responsible for 31% of the carbon emissions in North Africa. With rapid electricity demand growth to support development, emissions are contining to rise rapidly. Egypt aims to implement a low carbon energy system with the goal of producing 20% of its electricity from the planned NPP by 2030. Egypt considers that this will support the electrification of one of its most carbon intensive sectors and, along with energy efficiency measures, reduce significantly the carbon footprint of its economy.

D. Musyoka (Kenya): 'Nuclear power's contribution to Kenya's nationally determined contributions'.
Kenya has great potential for geothermal and wind power, but its plans also include the construction of the first large coal plant. To avoid rising emissions and maintain its NDC commitments, the country is looking at nuclear as an alternative. Another strong reason for considering a future NPP is the planned completion of electrification in the country, with 28% of the population to be covered with this action, further raising interest in low carbon energy availability that can be achieved with nuclear power.

I. Ennison (Ghana): 'The role of nuclear power in the mitigation of Ghana's long term greenhouse gas emissions'.
Ghana started consideration of nuclear power in 2007, at the height of a power shortage crisis, as well as implementation of the IAEA Milestones approach; Nuclear is currently considered in the framework of the ambitious development plan for Ghana 2057, but detailed planning for introducing nuclear is yet to be done.

5.2. TRACK 2: THE INCREASING CONTRIBUTION OF NUCLEAR POWER IN THE MITIGATION OF CLIMATE CHANGE, INCLUDING SYNERGIES WITH OTHER LOW CARBON POWER GENERATION SOURCES

5.2.1. Parallel Technical Session 2a: NPP long term operation

Moderator: F. Dermarkar (Canada)

The summaries of presentations and discussions in Session 2a are given below.

A. Goicea (FORATOM): 'The importance of long term operation of the existing EU nuclear fleet'.
The presentation focused on the benefits of the long term operation (LTO) of nuclear plants, e.g. as a decarbonization driver, providing economic advantages, meeting regulations, reducing EU energy import dependency, and providing firm capacity to the electricity system. This was followed by a discussion on the challenges facing LTO in the EU and what could be done at the EU level to support it.

S. Bernhoft (USA): 'Overview of the Electric Power Research Institute's research for long term operations'. The presentation identified what was needed for safe, reliable and economical LTO, such as identifying the ability to detect and manage plant ageing, modernization of the existing fleet, and continued support to grid stability. The need for global innovative knowledge capture and transfer of ageing management operating experience were highlighted, and important questions were raised to help define the issue. An example of knowledge capture through Electric Power Research Institute (EPRI) U on the subject of protective coating ageing degradation mechanism and the use of distance learning, hands-on training and computer based training as methods of knowledge transfer was discussed. EPRI's vision for an app for ageing management using a digital mobile platform allowing for in-field use was discussed. The audience was challenged to think of the types of operating experience that would need to be shared globally and the best ways to achieve that.

A. Al Mazouzi (France): 'Innovation for safe and competitive nuclear energy as a low carbon energy source in the long term'.
This presentation reported on Électricité de France's (EDF's) innovation push on technologies, system and business model to support nuclear challenges such as fleet performance and extending the life of the fleet. An overview of the Nuclear of the Future Initiatives provided details on the research and innovation programme in partnership with academics and industries to improve the competitiveness and attractiveness of the nuclear sector. The future initiatives were shown to relate to continuous safety improvement, digital solutions for operations and maintenance, advanced solutions for building, manufacturing and repairs or flexibility beyond 2030. There were detailed examples of innovation in civil engineering, manufacturing and repair, and plant operation and maintenance

S. Rátkai (Hungary): 'MVM Paks NPP contribution to carbon free electricity production in the Hungarian electricity mix'.
The presentation reported on the Paks Nuclear Power Plant's contribution to carbon free electricity production in Hungary by first providing an overview of the current electricity generation and LTO work to date. A review followed of how license renewal was implemented and the importance of a technical basis. Ageing management programmes, condition assessments of SSCs, and time limited ageing analysis were all conducted to support the technical basis of LTO of the Paks units to secure its contribution in a very low expected carbon mix in Hungary into 2030.

M. Knutson (Canada): 'Sustaining and expanding nuclear electrical generation in Ontario'. This presentation reported on nuclear refurbishment projects currently under way in Ontario, where ten reactors are planned to be refurbished, providing 40+ years of clean, low cost energy to the people of Ontario with strong community support. The author spoke about Ontario Power Generation's nuclear refurbishment projects currently under way and how coordination with other operators in the province was essential to develop Ontario's nuclear refurbishment schedule and identify peak trade demands between the sites. The project's status was detailed, identifying the challenges and successes, followed by the application of lessons learned. The report closed with the identification of the engineering issues faced by the project.

5.2.2. Parallel Technical Session 2b: Flexible operation and hybrid energy systems

Moderator: S. Bragg-Sitton (USA)

The summaries of presentations and discussions in Session 2b are given below.

S. Feutry (France): 'Renewables and flexible nuclear alliance for a low carbon electricity generation'.
The presentation highlighted that flexible operation (FlexOp) is more cost effective, but requires modifications in the mechanical design of the unit, introduces a new core control mode, and requires trained operators. It offers a low carbon alternative to fossil fuel fired capacity and saves fuel when the market price is low. It does not have an impact on the fuel integrity nor on the plant lifetime or on the maintenance. It was stated that the future of FlexOp includes variability of several units at the same time, other flexibility levers such as storage, and scenarios studies with increasing use of renewables in the total energy mix.

S. Pustovalov (Russian Federation): 'New opportunities of existing nuclear power plants for climate change mitigation'.
This presentation explained that waste heat from NPPs can be used for heating water for district heating (up to 100 km), distillation desalination and greenhouses through CO_2 heat pumps. This allows a reduction in the consumption of fossil fuels in the global energy system, reducing CO_2 emissions and increasing total revenues.

C. Fazio (EC/JRC): 'Nuclear in future energy mix. Research needs from a European perspective'.
This presentation detailed the expected nuclear capacity to 2050 in the EU: LTO €50 billion (10–20 years) and new build €350–450 billion. It was explained that expected future nuclear use was foreseen for transmutation, H_2 production, district heating, other industrial processes and optimization of the share between nuclear and increasing renewables at the EU level. Finally, it was mentioned that introducing Generation IV in the future energy mix (SMRs, molten salt reactors, very high temperature reactors, liquid metal and gas fast reactors) will require innovative technologies and materials, new regulations and new methods of deployment.

F. Reitsma (IAEA): 'Potential of hybrid energy systems based on SMRs and renewables for energy supply and security'.
This presentation detailed IAEA support in the field of SMR development and highlighted the development objectives, which include better affordability, a shorter construction time, a wider range of users, site flexibility, reduced CO_2 production and integration with renewables. Currently, China, Argentina and the Russian Federation are constructing SMRs while the Republic of Korea and the USA are undergoing licensing reviews for their first models. The SMR/hybrid energy systems facilitate effective integration of renewables, overcoming the challenges of intermittency and transmission constraints because they provide system flexibility. The current technical and deployment challenges for SMRs were highlighted.

N. Haneklaus (Germany): 'Nuclear-renewable hybrid energy systems — IAEA activities'.
The presentation noted that while producing clean electricity was easy, grid stability was challenging. It focused on the activities by Aachen University to offer solutions to overcome these challenges, particularly collaborative initiatives in the field of load following capabilities of German NPPs, nuclear-renewable hybrid energy systems and flameless calcination.

S. Bragg-Sitton (USA): It was noted that maximizing energy utilization, generator profitability, grid reliability and resilience through novel systems integration and process design were the key elements for potential future energy systems. Studies are continuing to demonstrate the feasibility of light water reactors producing hydrogen which could provide a second source of revenue, provide energy storage for later electricity production and/or provide opportunity for grid services, reserves and grid regulation.

5.2.3. Parallel Technical Session 2c: Large deployment of evolutionary nuclear power plants

Chairpersons: A. Bychkov (Russian Federation)
T. Jevremovic (IAEA)

The summaries of presentations and discussions in Session 2c are given below.

M. Shohag (Bangladesh): ‘A comprehensive study on the national power system master plan of bangladesh incorporating nuclear power in the energy mix considering climate change and country’s development goal’.
This report stated that Bangladesh is using nuclear in its energy mix to reduce dependence on imported energy and help maximize its green baseload energy as it develops its energy and power infrastructure to meet its long term economic goals. It was emphasized that nuclear is a viable option for a green energy mix for those countries that are more vulnerable to climate change consequences and whose renewable options are limited. Nuclear power poses economic challenges and health and environmental risks, but climate change mitigation, as well as energy security and the non-climate environmental and socioeconomic benefits that nuclear power provides are reasons for Bangladesh to introduce and expand nuclear power in its grid.

H. Turton (IAEA): ‘Accelerating deployment of low carbon power for 1.5°C’.
The deployment rates for nuclear power and other low carbon electricity generation technologies will need to increase significantly — at least three-fold — to achieve the low carbon power mixes described in the IPCC’s scenarios that limit the global temperature increase at 1.5°C. In comparison, the deployment of solar and wind will need to increase by about 30-fold. Increases in industrial material capacity can support a substantial increase in nuclear power deployment, and thus economic and industrial capacity and material availability are unlikely to preclude nuclear power from playing a substantial role in IPCC envisioned climate change mitigation.

J. Seo (Republic of Korea): ‘Korean experiences on delivering Generation III Advanced Light Water Reactors — APR1400’.
This presentation reported that the APR1400 unit successfully demonstrated the process of constructing and commissioning a first of a kind (FOAK) plant, undergoing extensive commissioning tests, advanced safety demonstrations, and commercial performance (since December 2016). The schedule of the APR1400 units was affected by the Fukushima Daiichi accident, but construction was still completed without an undue impact on costs. Major lessons learned that contributed to the successful deployment of this plant include the necessity of close relationships and well-established supply chains for the FOAK equipment to maintain a good schedule and rigorous verification of plant control systems prior to plant operation for successful steady state and transient tests.

5.3. TRACK 3: DEVELOPMENT AND DEPLOYMENT OF ADVANCED NUCLEAR POWER TECHNOLOGIES TO INCREASE THE USE OF LOW CARBON ENERGY

5.3.1. Parallel Technical Session 3a: Advanced reactor deployment for electric and non-electric applications

The summaries of presentations and discussions in Session 3a are given below.

J. Reyes (USA): 'Nuclear-renewable hybrid energy systems — IAEA activities'.
This presentation described the resilience features of a new SMR developed by NuScale Power and how this design can be adapted to environmental impacts resulting from climate change. NuScale has significant resilience features that enable the plant to support critical infrastructure and grid recovery, if needed. These features are: (a) minimal water consumption; (b) no AC or DC power needed for safety; (c) island mode, black-start and off-grid operating capabilities; (d) site boundary emergency planning zone; and (e) highly reliable, long term power for critical facilities. A full NuScale plant would include 12 modules to produce a total of 720 MW(e). The plant design is in the final phases of design certification review by the US Nuclear Regulatory Commission.

A. Schweikert (USA): 'Scale matters: Ending global electricity poverty provides new opportunities for SMR and MMR technologies'.
This report presented a high resolution assessment of electricity poverty performed using satellite imagery data. 'Electricity poverty' is defined as any region (30 arc second) where there is measured ambient population but no visible night-time light (undetected by satellite imagery). The total estimated population living in areas without visible night-time light is approximately 1.7 billion. This assessment is useful for determining the potential for SMRs and micromodular reactors as sustainable power options in developing regions of the world.

X. Liu (China): 'Deep-Pool Low-Temperature Heating Reactor (DHR)'.
The DHR is a pool, light water cooled reactor with a thermal power of 400 MW that operates under low temperature and atmospheric pressure. It is a new approach for district heating supply intended to contribute to combating climate change due to its low carbon features. As it has large margins in its operating parameters and adopts advanced safety features, a small heat-supply reactor can avoid severe accidents and practically eliminate the risk of large scale radiation release. It is therefore suitable to be built near the user community and would replace old coal boilers.

L. Alkawass (Austria): 'Nuclear-SMR for reliable electricity system and climate change mitigations in Lebanon'.
This presentation discussed an evaluation of the Lebanese electricity sector and the need for an effective energy transition to a secure energy supply over the long term. At the same time it should address climate change commitments through the increased penetration of low carbon energy sources, including nuclear energy, to maintain sustainable baseload power. Due to the economic situation, weak national power grid, topographical characteristics and demographic distribution, marine based SMRs would be a suitable technology for Lebanon. The evaluation found that two SMR power stations might replace 19 of the 23 ageing operating fossil fuel power plants (which have low capacity factors and high production costs of electricity), hence reducing CO_2 emissions by electricity generation by 66%.

T. Nishihara (Japan): 'Japan's HTGR programme and potential for reduction of CO_2 emission'.

This presentation highlighted the potential synergy between nuclear energy, specifically high temperature gas reactor (HTGR) technology, and renewable energy (RE) as a hybrid system to contribute to reducing CO_2 emissions and thus address climate change. The Japan Atomic Energy Agency (JAEA) proposes the integration of the GTHTR300C with RE to meet grid demands. To address the variability of RE power generation over long time scales (such as hourly or daily), the GTHTR300C can adjust the ratio of power generation and hydrogen production by coolant inventory control and reactor/intermediate heat exchanger (IHX) bypass flow rate control. JAEA estimates that 27 HTGR systems (300 MW(e) each) can provide 20% reduction in CO_2 emissions in Japan.

5.3.2. Parallel Technical Session 3b: Greenhouse gas reduction in the nuclear fuel cycle

Chairpersons: A. Bychkov (Russian Federation)
S. Monti (IAEA)

The summaries of presentations and discussions in Session 3b are given below.

J. Guidez (France): 'What is the interest of new type of reactors to improve the fight against global warming?'.
This presentation highlighted the critical role nuclear power generation is already playing today as one of the lowest emitters of CO_2 during electricity generation. The notion was also introduced of EROI ('energy returned on invested'), which is the ratio between the usable energy produced by the installation during its running time and the energy necessary for its construction. Since nuclear power performs the best in this measure, this means that it is the energy source that also 'reimburses' most quickly the CO_2 emitted during the construction of facilities. J. Guidez then highlighted the potential of advanced reactors and innovative fuel cycles to reduce the impact even further, while also providing flexibility and servicing the energy market beyond electricity generation

Y. Lin (China): 'Exploration progress and models on green type of sandstone-hosted uranium resources for nuclear energy development in China'. The presentation explored progress and models of a new CO_2 negative uranium mining and extraction process. Sandstone hosted uranium deposits can be considered a green type of uranium resource due to in situ mining technology using $CO_2 + O_2$ agents developed in China. For the production of 1 t of yellowcake, 14 t of CO_2 are consumed (instead of producing CO_2). This is environmentally friendly and contributes to reduced CO_2 emissions. The resources and the proposed extraction process are thus key to a sustainable nuclear future.

N. Haneklaus (Germany): This presentation introduced the concept of energy neutral mineral processing to support climate change mitigation. Ore grades worldwide are depleting rapidly while the demand for mineral commodities is constantly rising. The majority of mineral processing operations today are powered by burning fossil fuels. A number of primary ores, such as phosphate rock, gold, copper and rare earth ores contain considerable amounts of accompanying by-product uranium and other critical materials, such as rare earth elements. Energy neutral mineral processing seeks to recover this unconventional uranium during primary ore processing and use it to fuel an NPP. Energy neutrality is reached if the energy produced from the extracted uranium is equal to or larger than the energy required for primary ore processing (and all the supporting processes). The extraction of uranium also leads to cleaner products and lower contamination by naturally occurring radioactive material in waste streams.

P. Paviet (USA): 'Why is the back end of the nuclear fuel cycle important for greenhouse gas reduction?
The presentation focused on arguments why the back end of the nuclear fuel cycle is important for greenhouse gas reduction. Although it is widely recognized that nuclear energy is a mature technology and a low carbon electricity source, it is important to ensure long term sustainability and potentially also reduce the CO_2 emissions associated with uranium mining. Different fuel cycle scenarios were studied. The evaluation shows that recycling U/Pu and/or U/TRU in fast and/or thermal reactors can provide a domestic supply of nuclear fuel for fast and thermal nuclear reactor systems while ensuring low carbon power supply and minimizing the use of uranium natural resources.

5.3.3. Parallel Technical Session 3c: Challenges associated with the rapid deployment of new innovative technologies

Chairpersons: J. Guidez (France)
F. Reitsma (IAEA)

The summaries of presentations in Session 3c are given below.

N. Haneklaus (Germany): This presentation explained that hydrogen is already used in several applications, especially in the petrochemical and chemical industries. The importance of hydrogen in several fields where decarbonization is difficult was highlighted, as for example transportation, and that this had led to increased interest. Methods of producing hydrogen with nuclear reactors were also explained, including the interest in hydrogen as energy storage, especially for intermittent and variable renewable energies.

L. Shasko (Canada): 'Creative disruption for clean nuclear energy and GHG emission reductions'.
The main obstacles to the public acceptance of nuclear energy are cost and social acceptance. 'Disruptive improvements' based on sustainability would be necessary in the near future to be able to resolve these problems. These could be obtained by collaboration with private or startup companies. To support new advanced reactor technology, liaison with educational institutions to increase knowledge, better understanding and increased trust may be an important element.

A. Moskvin (Russian Federation): 'Hydrogen energy perspectives'.
Discussing the many challenges being faced today because of growing energy demand and also with CO_2 emission reduction, the presentation proposed a resolution of these challenges involving hydrogen. The Russian Federation has identified hydrogen as an important market and Rosatom expects the share in the global energy market to be 10% by 2050. Rosatom invites cooperation with partners to build the required global hydrogen supply chain, especially for transportation and aspects such as storage. The example of the Russian/Japan hydrogen export pilot project was given.

C. Ni (China): 'Developing nuclear energy heating to reduce carbon emissions in north China'.
This presentation described the development of nuclear energy heating applications to reduce carbon emissions in north China. Currently, severe smog and CO_2 emissions are caused by coal heating, and the LANDSTAR 1 reactor is being developed to provide 200 MW(th) without any emission problems. Some of the simplifications and advanced safety features are highlighted as the reactor operates in natural convection and provides superheated steam (240°C) for industry, or hot water (90–120°C) for district heating. A project is under development for the city of Jamasi (2.35 million habitants), with construction estimated to take about 37 months. The public acceptance for the project is positive.

J. Arima (Japan): 'Opportunities and challenges for nuclear innovation in Japan'.
This presentation described the multiple requirements for nuclear power in Japan in the years to come. Clearly, new systems with increased safety are important, but also a major requirement is to reduce the cost of energy which is higher for developed countries. Innovative nuclear systems would be very useful in resolving these challenges. Collaboration (as in the USA, promoted by US DOE) between the government and private sectors could fuel this innovation. The biggest challenges remain the negative public acceptance of the nuclear industry and the weak support of politicians/or government.

5.4. TRACK 4: SHAPING THE FUTURE OF THE NUCLEAR INDUSTRY IN REGULATED AND DEREGULATED ENERGY MARKETS TO ADDRESS CLIMATE CHANGE

5.4.1. Parallel Technical Session 4a: Cost reduction potentials of nuclear new builds

Chairpersons: P. Lion (Russian Federation)
V. Alexeeva (IAEA)

The summaries of presentations and discussions in Session 4a are given below.

A. Roulstone (UK): 'Meeting the UK's 2050 de-carbonization targets for electricity generation: The contribution of nuclear energy'.
This presentation reported on the contribution of nuclear to reach the zero net emission target for the energy sector in the United Kingdom by 2050. It was noted that all three main options currently envisaged for decarbonization (renewables, nuclear and carbon capture and sequestration) face significant challenges. Cost of construction, funding and the availability of new sites are the key issues identified in the UK for future nuclear projects. Four main recommendations were identified in a recent report by the UK Energy Technologies Institute to reduce construction costs of large nuclear reactors: (1) A series of standard reactor designs should be built in sequence; (2) the design should be completed in detail before the start of construction; (3) construction should be undertaken by a consistent group of strategic contractors and suppliers, and (4) multiple units should be built on each site. Finally, SMRs and Advanced Modular Reactors may also have the potential to reduce costs even if more research is still needed.

K. Gogan (UK): 'Can nuclear energy be a competitive climate change option today? Lessons from recent world experience'.
The presentation provided insights into the cost breakdown and drivers of nuclear projects, based on a comprehensive report from the UK Energy Technologies Institute. It was noted that the construction costs of new nuclear plants differ significantly across countries: recent FOAK projects in the USA and Western Europe show high costs, while several examples in other parts of the world are characterized by 50–80% lower costs. Low costs do not depend on the country or technology, or on the safety requirements. Continuity, a ready design, standardization, competitiveness and depth of the supply chain, experienced project delivery organization and efficient interaction with safety authorities are all key factors for a successful nuclear project. Evidence was provided of cost reductions achieved in the past by building a second unit at the same nuclear site. The conclusion was that there are well characterized pathways to lower and potentially achieve very low costs.

J.G. Devezeaux (France): 'The renewal of the French nuclear fleet: A key to achieve the EU 2050 decarbonization goals'.
The presentation reported on an analysis of the European power system up to 2050 performed by the French Nuclear Energy Society (SFEN). The study concluded that a combination of nuclear power and renewables would achieve EU carbon emission targets at minimal cost and that nuclear remains an essential backbone of the EU electricity system. The potential for the long term operation of existing nuclear power plants remaining the most economical way to produce electricity was emphasized. SFEN is confident that it is possible to reduce construction costs of nuclear new builds by 30–50% in France, thus achieving a final generation cost of €60–70 MW·h. Optimizing the design and construction methods, reshaping the supply chain, committing to a large scale programme and decreasing the market uncertainties and the cost of capital are the key elements to achieve these targets.

J. Lovering (USA): 'Historical learning rates for nuclear power and the implications for future SMRs'.
The presentation analysed a comprehensive data set of over 350 nuclear power plants built in 8 countries. While in some countries (UK, Republic of Korea and France) learning rates have been positive, in others construction costs have increased with time. The conclusion was that historical learning rates in nuclear have been lower than those in other industries and there is little scope for achieving significant learning rates, at least for large power plants. On the other hand, SMRs, which are factory fabricated and assembled on-site, could achieve learning rates in line with those of other industries. Achieving such accelerated learning could significantly reduce construction costs, with significant deployment, and make the SMR competitive with large nuclear reactors

N. Han (China): 'Challenges and measures of new build NPP construction in China'.
This presentation included a comprehensive overview of the nuclear programme in China, including current challenges and countermeasures taken by the nuclear industry. After a period of rapid development in 2005–2010, when about 32 units were built and new Generation III technology introduced, the Fukushima Daiichi accident marked a slowdown in nuclear construction, with government policy focusing on safe and efficient development of nuclear power. Major challenges for the Chinese nuclear industry are to reduce construction duration and construction cost in an environment of rising labour costs and more stringent safety and environmental requirements. Reduced feed in tariffs for nuclear generation also adds to this challenge. It was noted that the ability of having specialized construction teams able to gather experience from different projects and the adoption of new technologies (modular construction, use of digital techniques as well as automation and standardization of construction procedures) have been essential factors in reducing the risks and costs of new builds.

5.4.2. Parallel Technical Session 4b: Financing sources for new nuclear projects

Chairpersons: M. Kray (USA)
M. Cometto (IAEA)

The summaries of presentations and discussions in Session 4b are given below.

P. Murphy (IAEA): 'Alternative contracting and ownership approaches for new nuclear power plants: IAEA-TECDOC-1750'.
The presentation reported on a recent IAEA study on project structure, contracting arrangements and financing of new nuclear projects. Several alternative approaches and structures for financing nuclear plants were presented which underlined the major role that governments have in the process. Reducing the risks of the project and allocating them to a more suitable entity is a key aspect in making the project viable. In this context, SMRs can provide a significant advantage over larger plants. In developing countries regional cooperation can also prove helpful in overcoming some of major challenges. Finally, drawing from the examples of Akkuyu an Barakah, the presentation discussed the main characteristics of BOOT and turnkey models. Finally, more innovative options for financing were discussed: (1) phase financing; and (2) considering nuclear as critical infrastructure.

E. Teplinsky (USA): 'Development financial institution financing for small modular reactor (SMR) projects: A mechanism to address climate change crisis and meet sustainable development goals by facilitating SMR deployment in the developing world'.
The presentation described the importance of nuclear power in addressing climate change and achieving the UN's Sustainable Development Goals. However, large nuclear power plants may face difficulties in developing countries due to a mix of technical (insufficient grid size and access to cooling water) and economic factors (high capital requirements and lack of project financing mechanisms). It was also noted that development finance institutions (DFIs) such as the World Bank are currently heavily involved in financing energy projects in developing countries, but do not finance nuclear projects. SMRs could potentially address some of the financing challenges of large reactors and overcome some of the obstacles from DFIs. The presentation concluded by urging DFIs to shift their policy stand toward nuclear and to provide financing for nuclear projects, in particular to SMRs.

K. Kallemets (Estonia): 'Achieving 33 GW(e) annual newbuild with startup model and financing in SMR deployment industry'.
Concern was expressed about the future of nuclear power in Europe, with potential shutdown of several existing units and insufficient new build projects, which could create a problem of security of supply. The large size of a nuclear project as the main reason to explain the large cost escalation and the construction delays observed in many new nuclear projects in Europe and the USA was highlighted. SMRs, which are less complex projects and therefore require smaller capital outlays and are characterized by a lower financial risk, could be a solution for nuclear power in Europe. It was indicated that startup financing could also be a way to significantly broaden the pool of investors in nuclear.

F. Dassa (France): 'Nuclear and climate: The necessary evolutions of the market design'.
Several countries are following the example of Europe and some regions in the USA in opening electricity markets to competition. However, fully competitive markets inherently fail to provide sufficient market signals to invest in low carbon technologies and ultimately cause a risk for the security of electricity supply. A reform of market designs with the adoption of long term contracts for all low carbon generation technologies is a possibility. Examples of such novel market arrangements can be found in Brazil, Canada and the UK.

M. Martini (OECD): The presentation described the recent trends in investments for sustainable development and gave an overview of the financial products currently available. In Europe, Australia and Canada, assets under sustainable framework and green bonds constitute a sizeable fraction of the total investments in the energy sectors and are growing rapidly. Potentially sustainable finance unlocks access to capital and could provide for lower capital cost for sustainable technologies. The presentation also focused on the recent initiative on the sustainable finance taxonomy promoted by the European Commission. This initiative is aimed at defining which economic activities can be considered environmentally sustainable and thus have access to sustainable financing. A final decision on the eligibility of nuclear power has not yet been taken.

5.5. TRACK 5: ENHANCING INTERNATIONAL COOPERATION AND PARTNERSHIP IN NUCLEAR POWER DEPLOYMENT

5.5.1. Parallel Technical Session 5a: Multilateral partnership mechanisms

Moderator: S. Jaworowski (USA)

Session 5a comprised an interactive panel discussion on international cooperation in low carbon energy deployment. The panellists included representatives from Energy for Humanity, the IAEA, the International Renewable Energy Agency (IRENA), and the World Nuclear Association (WNA), and the moderator was S. Jaworowski (USA). The panel reflected on lessons from recent partnerships in the deployment of nuclear power or other low carbon energy technologies, and discussed how governments, international organizations and others can facilitate cooperation across the low carbon energy sector.

L. Angelino (IRENA): 'International cooperation and partnerships: Experience from IRENA';
W. Huang (IAEA): 'Enhancing international cooperation and partnerships in low carbon power deployment — The IAEA's role'.
These speakers outlined the ways in which their organizations are active in building partnerships to support their Member States reach their energy and development objectives. The aims of these partnerships range from supporting long term energy planning and knowledge management to capacity building and infrastructure development, through to implementation and deployment. L. Angelino highlighted examples such as the Global Geothermal Alliance, the Small Island Developing States' Lighthouses Initiative and the IRENA Coalition for Action, which seeks to establish common ground for collaboration between developers of different technologies: wind, solar photovoltaics, hydro and geothermal.
W. Huang drew attention to the importance of partnerships across agencies of the UN, such as with the UN Department of Economic and Social Affairs, for coordinating efforts to address the climate change and sustainability agenda. He noted the IAEA's ongoing efforts to engage with a broader audience, including environment ministries on the potential of nuclear power. He also reminded the audience of the IAEA's role in multilateral and bilateral partnerships related to the non-energy applications of nuclear technology, such as in medicine and agriculture. New opportunities for cooperation between renewables and nuclear power — including in the planning and deployment of hybrid energy systems — were also discussed.

J. Cobb (UK, WNA): 'Multi-lateral partnership mechanisms'.
With regard to industry cooperation, low carbon technologies are often competing for recognition and investment and are sometimes pitted against one another by national policy, echoing a similar message from IRENA. The presentation recommended a focus on inter-industry partnerships that can provide mutual benefits to different forms of low carbon energy, including in influencing climate policy. Also discussed was collaboration within the nuclear industry, noting that cooperation is already central to any nuclear power project, given the range of partners and suppliers involved. Looking forward, the WNA has established the Harmony Goal and programme, which provides a focus for collaboration among the WNA's 180 members.

K. Gogan (UK, Energy for Humanity): The presentation provided further examples illustrating the potentially wide range of stakeholders — from industry, government, NGOs, academia — who will need to cooperate in the low carbon energy transition, as well as the need for partnerships to be demand (market) driven and to evolve. Changing energy markets create opportunities to engage with new partners, for example in non-electrical applications, and capitalize on new entrepreneurial approaches and business models. Also highlighted was an example of how shared goals on climate change action, combined with an open and measured approach from the nuclear sector, enabled organizations representing nuclear power, renewables and carbon capture sector to cooperate to achieve common policy outcomes, without the initiative being obstructed by traditional opponents of nuclear power.

5.5.2. Parallel Technical Session 5b: Experiences and perspectives on cooperation

Chairperson: A. Metelitsa (UNIDO)
A. Borio Di Tigliole (IAEA)

Session 5b comprised presentations from Argentina, China, North Macedonia, and the USA reflecting on experiences and perspectives on cooperation across different aspects of nuclear power, including innovation and deployment, sustainable information and knowledge management, and the importance of a robust and transparent system for nuclear safety and security.

B. Carpinelli (Argentina): 'Nuclear energy as a solution to climate change analyzed in terms of the new global market demands: The importance of nuclear projects cooperation and the international organizations role'.
The presentation addressed the importance of cooperation in nuclear projects and the role of international organizations in the context of global climate and market demands. Also highlighted was how the urgent need for climate action necessitates increasing the use of nuclear power, and how cooperation and partnerships supporting the development of innovative technologies and commercial models, as well as financing, can contribute to the goal of reducing NPP investment costs and construction times. Argentina is seeking to capitalize on a bilateral partnership with China to expand the use of nuclear power, as well as collaborating in international forums facilitated by the International Framework for Nuclear Energy Cooperation (IFNEC), the Generation IV Forum (GIF), the OECD Nuclear Energy Agency and the IAEA.

B. Li (China): 'Current status of nuclear power development and nuclear safety in China'.
The presentation approached the topic of cooperation with a focus on safety. The paper illustrated the growing importance of nuclear power to China's energy system and the strong and successful institutional focus on safety. China's activities to maintain and improve nuclear power plant safety explicitly embed cooperation with international, regional and domestic partners, including the IAEA, OECD/NEA, regulators, plant operators, suppliers and users. Mr. Li acknowledged the important role of technical support, particularly for 'embarking countries', including in regulator training and during regulatory reviews and safety inspections. Mr. Li and Ms. Carpinelli agreed on the value of the Argentina–China bilateral cooperation on nuclear power as an important mechanism for sharing best practices in safety and other areas.

E. Zaveckas (USA): 'Harnessing international support for nuclear power deployment: challenges and opportunities'.
This presentation explored the challenges and opportunities in garnering international support for the deployment nuclear power. In order to maximize support for nuclear energy, it is critical to ensure confidence in the international regulatory mechanisms that govern the development and deployment of new power plants. While recognizing the value of the assistance provided under the IAEA's Milestones approach, the speaker raised a concern that the voluntary nature of IAEA assistance, relying on requests from Member States based on self-assessment, risks the possibility that a nuclear power plant may be designed, built and become operational in non-compliance with the IAEA's nuclear safety standards. To address this challenge, the speaker recommended strengthening the IAEA approach with additional information sharing on new projects and cooperation with regional organizations — for example, the Organization for Security and Co-operation in Europe (OCSE) and the International Energy Agency of the OECD — to add additional layers of accountability and potential enforcement options.

M. Sejmenova-Gichevska (North Macedonia): ‘Nuclear information management related to climate change: Correlation between energy indicators for sustainable development and INIS knowledge organization system’. Cooperation and partnerships related to information and knowledge management were discussed. The presentation outlined the Energy Indicators for Sustainable Development (ESID) and International Nuclear Information System (INIS) domains and taxonomy, focusing on their linkages with climate change. International partnerships play a key role in information collection and dissemination, as well as communicating energy issues and promoting institutional dialogue.

5.6. TRACK 6: PUBLIC AND NON-NUCLEAR STAKEHOLDERS' PERCEPTION OF THE ROLE OF NUCLEAR POWER IN CLIMATE CHANGE MITIGATION

Chairpersons: R. Whittleston (United Kingdom)
C. Nahon (France)

5.6.1. Parallel Technical Session 6a: National insights into public perception

The summaries of presentations and discussions in Session 6a are given below.

L. Alkawass (Austria): 'Lebanese public opinion on nuclear power'.
This presentation reported on a web based survey developed to assess public opinion on the Lebanese national energy strategy and the possible introduction of nuclear power in Lebanon. It was noted that in order for Lebanon to realistically consider a nuclear power programme in the future, it would have to take into account the results of the survey, which indicated a need to strengthen the public's nuclear knowledge through education, outreach programmes and effective media coverage.

Y. Anpilova (Ukraine): 'Nuclear energy and public opinion in Ukraine'.
This presentation discussed nuclear energy and public opinion in Ukraine, a country heavily dependent on nuclear energy. It was noted that public opinion on nuclear power is changeable and easily influenced. Surveys in Ukraine show a direct correlation between being informed about the benefits of nuclear power and the public's favourable attitudes.

H. Cheerathadayan (India): 'Environment, nuclear power and people's movement: India's triangular dilemma'.
This presentation reported on the obstacles facing India's nuclear power infrastructure, focusing on the country's need for nuclear power, the environment and climate change, and the implications of public perception of nuclear power projects.

M. Ritonga (Indonesia): 'The role of teachers on forming people's perception on nuclear energy in Indonesia'.
This presentation reported on the importance of the role of teachers in forming public perception of nuclear power in Indonesia. There was a need for teachers to be supported by the Ministry of Education and Culture to develop suitable curriculums, be appropriately trained, and have access to reference materials on nuclear power.

S. Roth (Sweden): The presentation discussed public communication at the back end in Sweden, with a focus on local perception of spent nuclear fuel and waste management. It was noted that there has been 40 years of research and development in Sweden on the back end, which needs a combination of siting, a technical solution, and public trust and acceptance.

5.6.2. Parallel Technical Session 6b: Strategies and initiatives on channels of communication

Chairpersons: F. Puente Espel (Mexico)
A. Stott (IAEA)

The summaries of presentations and discussions in Session 6b are given below.

L. Shasko (Canada): 'Innovating the bridge building elements of 'reluctant acceptance'.'
The presentation reported on the concept of 'reluctant acceptance', which explores acceptance of nuclear power framed in the context of climate change risk. It allows survey respondents an option to express objections to nuclear power while also recognizing a reluctant acceptance of it in light of the competing threat of climate change. The potential was noted for the reluctant acceptance concept to be widened to support a more robust, two sided conversation on nuclear power and climate change. Doing so may open new channels of communication with stakeholders on their perception of the role of nuclear power in climate change mitigation.

C. Grundy (UK): 'Dialogue study public perception for advanced nuclear technologies including SMRs and AMRs'.
This presentation highlighted the importance of societal awareness of developments in nuclear power technologies in achieving the UK's goals of ensuring sustainable, affordable and low carbon energy for decades to come. Public bodies have identified principles, adopted strategies and signed concordats with recommendations for public engagement, including: committing to best practice; valuing the core principles of trust; clarity; dialogue and consultation; and encouraging and supporting the nuclear workforce to engage with the public and act as ambassadors for the industry.

E. Langegger (Austria): 'The Nuclear4Climate Initiative: Lessons learned from grassroots campaign'.
This presentation reported on the design, kick-off, activities and future of the Nuclear4Climate campaign which was initiated by the French Nuclear Society in 2014. The campaign produces position papers with key messages and communication activities on social media and with video production. Nuclear4Climate has been presented at each COP climate conference since its launch, with side events, booths and engagement with different stakeholder groups.

L. Beltran (Mexico): This presentation focused on the shared socioeconomic pathways framework, its application to the energy sector, and its utilization in a particular geographical location, namely Mexico. The framework consists of a narrative outlining broad characteristics of the global future and country level population, GDP, and urbanization projections.

5.6.3. Parallel Technical Session 6c: Novel approaches to nuclear communication

Chairpersons: G. Thomas, (United Kingdom)
L. Berthelot (IAEA)

The summaries of presentations and discussions in Session 6c are given below.

C. Ringenbach (France): 'The climate collage: Original and effective way to explain climate change widely for non-scientific people'.
The presentation discussed the 'Climate Collage' game, which is described as a fun, participatory and creative workshop on climate change. It is an educational tool based on collective intelligence and emphasizing the cause–effect links between the various components of climate change. The workshop explains how the climate functions and the consequences of its disruption, and highlights the complexity of climate change, while enabling players to develop their own complete picture of climate change.

N. Davydova (Russian Federation): 'Public involvement in the discussion on nuclear energy, the environment and climate change: The case of the ROSATOM Public Council's Project "Green Square".'
This presentation reported on the Rosatom Public Council's Project 'Green Square', which serves as a platform for public involvement in the discussion on nuclear power, the environment and climate change. It was noted that science education and, in particular, on the environment, can form an ecological culture, reduce radiophobia, and increase public awareness of nuclear power.

S. Rasmeni (South Africa): 'Addressing the public perception on the role of nuclear power in climate change reduction through educational awareness and collaboration'.
Effectively communicating science to a variety of audiences remains an obstacle to the public acceptance of nuclear technology. The presentation offered ways of communicating science through different public platforms, including by building partnerships between science and social science communities to address perceptions.

B. Kugelmass (USA): 'True Reversal of Climate Change Requires Nuclear Energy'.
The presentation discussed how solving climate change requires far more than the total elimination of annual greenhouse gas emissions. The complete decarbonization of electricity, agriculture, transportation, building heat, and industrial sectors may reduce the rate at which we accumulate heat, but it will have no impact on the previous emissions that already, and will continue to, cause the majority of radiative forcing. A pathway was proposed towards global scale removal of greenhouse gas and a description provided on how deploying nuclear energy at scale can power the transition to a global carbon negative economy in a way that aligns short term individual economic motivations with long term environmental preservation.

6. SUMMARY OF SIDE EVENTS

6.1. SIDE EVENT 1: NUCLEAR FOR CLIMATE CHANGE: CHINA'S SOLUTION

This side event was organized by the China Atomic Energy Authority (CAEA), China National Nuclear Corporation (CNNC) and Tsinghua University. The purpose of the event was to:

- Emphasize the importance of nuclear power in China's efforts against climate change;
- Introduce the latest innovations in China to facilitate achievement of climate change goals;
- Focus on the High Temperature Reactor (HTR), pool-type heating reactor and other reactor technologies;
- Demonstrate China's determination to continuously improve design and construction abilities and cooperate with other Member States.

6.2. SIDE EVENT 2: MILLENNIAL NUCLEAR CAUCUS

The Millennial Nuclear Caucus (MNC) side event was held to stimulate the interest of young professionals in careers in the nuclear field and to encourage the peaceful uses of nuclear energy, technology and applications to achieve significant future carbon emission reductions. The event was co-organized by the U.S. Department of Energy (USDOE), the U.S. Mission to the International Organizations in Vienna (UNVIE) and the IAEA. The event proceedings were supported by the International Youth Nuclear Congress (IYNC), the United Nations Nuclear Young Generation (UNNYG) Mentoring Programme and Women in Nuclear (WiN–IAEA). Young professionals met at the MNC to explore nuclear power's role in carbon free energy production and innovation, and the importance of international collaboration in achieving global decarbonization goals.

Moderated by the IYNC, panellists from the Czech Republic, Japan and Kenya shared perspectives on the 'Importance of Nuclear for the Future of Clean Energy', emphasizing nuclear power and hydropower as the foundations of low carbon electricity production.

The UNNYG Mentoring Programme and WiN–IAEA designated 15 lead networkers who met with young professionals during the speed networking session and shared stories of their career and academic trajectories. In addition, the challenges and opportunities in the field were highlighted,as were the motivations to work towards a clean energy future.

6.3. SIDE EVENT 3: LOW CARBON ENERGY SYSTEMS BASED ON NUCLEAR AND RENEWABLES — INTERNATIONAL EXPERTISE AND NATIONAL BEST PRACTICES

Nuclear energy is a low carbon, economically competitive, reliable and flexible source of power production. These characteristics make nuclear energy and renewables complementary in a low carbon energy mix.

In this side event, four speakers presented state of the art scenario modelling and national best practices. J.H. Keppler, from the Division of Nuclear Technology Development and Economics at the OECD/NEA, provided insights into the relative costs of different low carbon energy mixes based on different shares of nuclear and variable renewables. L. Heikinheimo, from the Finnish Ministry of Economic Affairs and Employment, H.E. Ambassador H. Alkaabi from the Permanent Mission of the United Arab Emirates to the International Organizations in Vienna, and J.-J. Coursol from Electricité de France presented their national cases.

6.4. SIDE EVENT 4: IAEA–POWER INVEST: INSIGHTS INTO THE COSTS AND BENEFITS ATTACHED TO INVESTMENTS IN THE POWER SECTOR

PowerInvest is an iLecture based interactive session providing insights into the costs and benefits attached to investments in the power sector. The exercise involved the side event participants. Each participant played the role of a consulting firm (E-Planning, Inc.) advising the 'Government of Ladonia', Ministry of Energy and Petroleum on the development of a robust, cost-efficient, environmentally friendly and low carbon energy mix which would fulfill Ladonia's increasing demand for electricity over the next decades while generating a positive social and economic impact.

During the session, participants were asked to read Ladonia's country profile and then to suggest a power mix for the country. A simulator was used to assess the impact of participants' decisions:

- Who was able to meet the country's future electricity needs? To keep the lights on, 24 hours a day, 7 days a week.
- Who managed to generate electricity at the lowest cost? With the lowest carbon content?

The side event provided an opportunity to present the IAEA tools, frameworks and publications that could be used to support cost–benefit analyses of investments in the power sector.

6.5. SIDE EVENT 5: THROUGH THE CLIMATE LENS: GROWING SUPPORT FOR A TECHNOLOGY INCLUSIVE APPROACH

Governments and organizations around the world are acknowledging that we must achieve zero net carbon emissions by 2050 if we are going to avoid the most catastrophic effects of a warming planet. To do this, we cannot afford to leave a single low carbon option off the table. This includes existing and advanced nuclear reactors. A panel hosted by Third Way highlighted perspectives from Japan, UK and USA, as well as from the United Nations and environmental organizations, including how their position on nuclear power has evolved in the context of the climate crisis.

6.6. SIDE EVENT 6: CAPACITY BUILDING IN SUPPORT OF SDGs ON ENERGY AND CLIMATE

This side event brought together panellists from the three international organizations (IRENA, UNIDO and the OpTIMUS community) providing and supporting capacity building for energy planning on one side, and three receiving countries (Argentina, Ghana and Philippines) on the other side. It was noted that through a comprehensive capacity building programme, the IAEA develops and maintains energy system analysis tools and assists Member States enhance local expertise so that countries are able to elaborate their sustainable development strategies. In this effort, the IAEA cooperates with other international organizations and initiatives.

UNIDO elaborated on its programmes of support through subregional energy centres in Africa, the cooperation of countries, and the development of harmonized energy policies. It emphasized the importance of self-funding of the centres that offer services and knowledge development to national experts. A positive experience was shared by Ghana, where energy planning activities are conducted by several State-run commissions/agencies and are already providing support to other countries through, for example, hosting fellowships and helping utilities in the development of master plans.

Through its partnership and country support department, IRENA is looking to generalize national experiences and make them relevant at the regional and global levels. The support programme starts with a scoping mission to identify areas of interventions so that tailor-made activities can be designed and conducted. The collaboration between IRENA and the IAEA has been coordinated through a Practical Arrangement Letter. The outcomes of joint actions have already been apparent in several countries.

Representatives of Argentina and Philippines discussed the importance of following up external capacity building events, the creation of institutional memory and knowledge transfer ine national entities, and the need for continuous education.

The OpTIMUS community representative outlined five governing principles of the energy planning process:

(1) National ownership (achieving broad consensus on strategic objectives and plans and empowering relevant authorities to implement plans).
(2) Coherence and inclusivity (ensuring that strategic decisions taken in the energy sector are consistent with broader economic, social and environmental goals, including SDGs and NDCs under the Paris Agreement).
(3) Capacity (defining the priority of capacity building activities which strengthen the capability of national institutions to take the lead on strategic energy planning).
(4) Robustness (promoting the use of models, analysis and decision support tools that have strong technical and economic foundations, and are capable of dealing with rapidly changing circumstances in the energy sector).
(5) Transparency and accessibility (promoting open access to, and reviewing, planning inputs and encouraging the accessibility of planning outputs to key stakeholders).

6.7. SIDE EVENT 7: INFOGRAPHICS — IAEA DATA VISUALIZATION CHALLENGE

This side event included the demonstrations of winning submissions developed for the IAEA Data Visualization Challenge by teams from around the world, followed by a panel discussion with the winners and experts from the IAEA. The members of the winning teams discussed the data and technology used for their visualizations, explained the main messages of their infographics and how they are related to the theme of the conference.

The IAEA Data Visualization Challenge was a first of a kind competition organized by the IAEA on the development of creative data visualizations, and was organized as part of the conference. During the competition participating teams from around the world submitted projects demonstrating the role of nuclear power in climate change mitigation.

For the purpose of the competition, data visualization was defined as the visual representation of data that effectively communicates information. The following guidelines were given to the participating teams:

- The best data visualizations rely on less text and are intuitively designed.
- Submission formats could include, but were not limited to, interactive data visuals, posters, apps, videos, etc.
- Submissions could be interactive, dynamic, or static.

Submissions were evaluated on the basis of the following criteria:

— *Innovation and creativity:* The submitted work was expected to be an innovative, original work combining rich visuals (which should be given primary attention) and background text or speech (for videos and other dynamic representations) providing necessary explanations and context.
— *Logic:* The depth of thinking and research behind the visualization and logical structure of its arguments.
— *Message:* Strength of the message conveyed by the visualization.
— *Data:* The relevance, quality and reliability of the data on which the visualization is based. Transparency regarding the assumptions and the ways the data was processed.

The IAEA received nine submissions from different Member States to participate in the challenge. The Selection Committee, consisting of the Scientific Secretaries of the conference and the IAEA staff involved in data visualization activities, noted the high quality of the submissions received and thanked all participants of the Data Visualization Challenge for their contributions. After careful consideration, the Selection Committee chose the following three submissions as the winners of the Challenge:

— E. Varseev and I. Andriushin (Rosatom Tech, Russian Federation).
The award was given for the innovative dynamic representation of international energy and economy statistics, placing nuclear power in the context of economic development, electricity consumption and CO_2 emissions.
— H. Jung (Chungnam National University, Republic of Korea).
The award was given for creative visualization of the role of nuclear power in generating clean electricity, while using PRIS data, with NPPs represented as 'planets' and clean electricity generation as 'trees'.
— M. Ho (Canada).
The award was given for the clear and informative representation of the role of nuclear power in climate change mitigation, including country level statistics for CO_2 emissions avoided, NDCs and the share of nuclear in total energy generation using a variety of sources.

All of the winners were invited to the side event to present their projects and participate in the panel discussion with IAEA staff. The panel consisted of six members: three representatives of the winning teams and three IAEA staff members.

The points discussed during the panel discussion included the efficiency of data visualizations as a way to create trust with the public; specifically, that transparent and factual visualizations can help narrow the gap between the expert community and broader audiences. The participants noted that professionals usually have outreach only in their circle, while data visualizations permit broadening of the audience. Additionally, interactivity was identified as a key feature of data visualizations: professionals and broader audience interested in the topic often do not have enough time to study it in detail — visualizations help users to receive and process information. Another part of the panel discussion was devoted to data science, machine learning and deep learning . There was broad agreement that these new research areas were highly promising in analysing data in the nuclear area and making connections with sustainable development topics.

6.8. SIDE EVENT 8: ADVANCED NUCLEAR INNOVATION AND CLIMATE CHANGE — UK PERSPECTIVES

The UK Side Event was a panel discussion on the potential for advanced nuclear innovation to contribute to the UK's 2050 Net Zero target. The event presented policy, regulatory and academic perspectives on advanced nuclear. The Environment Agency's (EA) presentation summarized the Generic Design Assessment (GDA) process and the changes that had been made to accommodate new nuclear projects. The EA also outlined the work that is currently being carried out on regulating and supporting the development of advanced nuclear technologies (ANTs).

The Department for Business, Energy and Industrial Strategy (BEIS) presented the UK Government's work on decarbonizing energy, drawing emphasis to the UK's legally binding commitment to Net Zero emissions by 2050. The Advanced Modular Reactor (AMR) Feasibility and Development Project Competition was also discussed in this section of the event. The Royal Society's presentation focused on nuclear co-generation, outlining the wider use of new nuclear to decarbonize space heating, desalination, process heating, hydrogen production and synthetic fuels.

The consensus of the panel was that advanced nuclear technologies are needed to decarbonize energy (electricity, transport and heat) in the UK and regulatory frameworks are being put in place to support their development. Questions from the audience generally focused on prospective timetables for the GDA process and FOAK product delivery. The replies were consistent with UK policy — a GDA takes around four years, subject to the timing and quality of the document submitted. An FOAK SMR could realistically be expected to be completed in the early 2030s, subject to the right financing and policy frameworks being in place. The panellists were also asked to discuss nuclear financing, for which BEIS highlighted the regulated asset base consultation, which is being considered as an alternative model. The key messages from the event remained the UK's commitment to Net Zero 2050 and the work being done to facilitate ANTs in the UK's civil nuclear sector.

7. CLOSING SESSION

7.1. PRESIDENT OF THE CONFERENCE

Closing statement as provided, verbatim.

M. Chudakov
Deputy Director General and Head of the Department of Nuclear Energy
International Atomic Energy Agency
Vienna, Austria

Excellencies, ladies and gentlemen,

I would like to thank you for your participation in the International Conference on Climate Change and the Role of Nuclear Power, which has taken place this week here in Vienna, organized by the IAEA, in cooperation with the OECD Nuclear Energy Agency.

As the first of its kind conference focusing on climate change and the role of nuclear power, it drew broad interest from the international community, with the IAEA welcoming more than 500 participants from 79 Member States and 17 international organizations.

There were also close to 1100 downloads of the conference app to devices. This demonstrates the recognition of the international community of the significance and importance of this topic.

This is also reflected in the number of oral and poster contributions that we received over the past year in preparation for this event: 120 papers were received, 84 of which were presented orally and 36 contributed as posters or e-posters.

During the conference, we had nine plenary sessions, including a high level session for the international organizations and two for Member States. There were 18 parallel technical sessions which addressed 6 topical areas with presentations by 125 speakers. Eight side events were organized by Member States, non-governmental organizations and the IAEA Secretariat.

Heads of international organizations, namely the OECD Nuclear Energy Agency, the United Nations Department of Economic and Social Affairs, the United Nations Industrial Development Organization, the Intergovernmental Panel on Climate Change, the World Nuclear Association, the International Energy Agency of the Organization for Economic Co-operation and Development, and the United Nations Framework Convention on Climate Change, agreed on the importance of considering every option in the climate change dialogue, pointing out that if any technology is taken off the table, finding the solution to the problem becomes more difficult. This is true, particularly if economic growth without damaging the environment is the goal.

Thirteen IAEA Member State representatives from Argentina, Bangladesh, Brazil, China, Egypt, France, Hungary, India, Mongolia, Morocco, Russian Federation, UK and USA gave keynote speeches and elaborated on energy and climate policies in view of the transition to low carbon energy systems. Representatives included ministers and high level officials with expertise in the environment, energy, nuclear power and safety.

As I said before, the conference addressed six topical areas. Let me summarize the key findings for each one of them:

Regarding the topic on advancing energy policies for the climate change goals the main outcomes are as follows.

Some Member States, both high and low income States, are already facing severe impacts from climate change and bearing significant related social and economic losses. Adequate regulatory measures and more climate resilient energy infrastructures are needed.

A regional approach integrating national markets and domestic capacities, as well as the deployment of smaller nuclear units, is often seen as a means to improve nuclear viability and the ability to finance new projects.

Some Member States may not be able to integrate large nuclear projects in the immediate future, due to existing grid size, lack of domestic demand, or affordability. For these countries, SMRs could be an effective option.

Moving on to Track 2, on the increasing contribution of nuclear power in the mitigation of climate change, including synergies with other low carbon power generation sources, we heard the following.

The long term operation of NPPs has been undertaken in various countries, allowing for opportunities to engage new staff, the local community, supply chains and provide innovative solutions. Innovation is key to enabling the safe, reliable and cost competitive long term operation of NPPs.

Additional challenges include a reliable supply chain, long term retention of knowledge, evolving regulatory requirements and market frameworks that need to recognize the inherent economic and environmental benefits of nuclear energy.

Flexible operation of nuclear power has been proven, providing low carbon energy in a cost effective manner. SMRs can and will also provide this flexibility.

Hybrid energy systems, integrating current and new nuclear power technologies with renewables, offer flexibility in the production of electricity and heat for industrial applications.

In Track 3, related to the development and deployment of advanced nuclear power reactors, participants highlighted the following key findings.

High temperature reactors represent a near term deployable solution to enhance nuclear hydrogen production. This is an additional opportunity to decarbonize the energy sector.

Small modular reactors offer additional flexibility to accommodate intermittent renewables and are a better fit for countries with smaller electricity grids. They could also play an essential role in reducing greenhouse gas (GHG) emissions, replacing ageing fossil fuel power plants and providing district heat.

Advanced nuclear power technologies can significantly reduce greenhouse gas (GHG) emissions through non-electric applications, such as district heating and hydrogen production.

Track 4 was devoted to shaping the future of the nuclear industry in regulated and deregulated energy markets. The key findings of this track are as follows.

Decarbonizing the electricity sector tenfold by 2050 in a cost effective manner while maintaining security of supply requires additional efforts. These include recognizing and allocating system costs to the technologies that cause them, encouraging investment in all low carbon technologies, and implementing carbon pricing.

The construction costs of recent large nuclear projects show varying outcomes in different areas of the world due to different factors. Recent cost overruns and scheduling delays of projects occurred where there was a lack of recent experience in construction and a need to rebuild a supply chain. However, in other regions of the world evolutionary NPPs were built on time and on budget.

Competitive electricity markets are attracting fewer investments in any new form of dispatchable electricity generation, particularly low carbon technologies. Energy policies and market designs that efficiently favour investments in dispatchable low carbon technologies are key to decarbonizing electricity production.

Development financial institutions have shown a very limited interest for large nuclear projects so far, mainly because the current framework of financing for green and sustainable projects excludes projects perceived as being non-sustainable, such as nuclear, and only then evaluates the project.

Let us now move to Track 5, which focused on enhancing international cooperation and partnership.

Recent successful deployments of nuclear and other low carbon power generation plants indicate that a range of different partners and cooperation mechanisms are needed. There is no one size fits all solution.

Partnerships among international organizations, including the IAEA, will continue to play an important role in driving low carbon action by building capacity in sustainable energy planning and knowledge management.

Turning to Track 6, public and non-nuclear stakeholders' perception of the role of nuclear power in climate change mitigation, the conclusions were as follows.

Nuclear power is generally a subject that attracts a high level of public attention and scrutiny. This makes it more challenging to convey the importance of nuclear power in mitigating climate change. Ideas were highlighted for clarifying misperceptions, including efforts by several countries to improve public knowledge and perceptions of nuclear. It is essential to focus on educating students about the value of low carbon energy, including nuclear power.

Also underscored was the importance of understandable messages, trusted sources of information and other advocates in delivering a factual nuclear power narrative. Such advocates would include the climate community and environmental organizations. It was recognized that efforts in this direction are already under way.

Turning to the session on nuclear safety and security, the following points were made.

The commitments to, and ongoing implementation of, the highest levels of safety and security, consistent with IAEA safety standards and security guidelines, throughout the life of the power plants, are critical to all countries pursuing nuclear power for peaceful purposes. Avoidance of complacency is key to maintaining high levels of nuclear safety and security.

International cooperation in global nuclear safety and security, and national provisions for nuclear safety and security, have continued to be strengthened over recent years.

The nuclear industry continues to undergo comprehensive safety reassessments and takes measures to strengthen plant safety and security, improve regulatory oversight and enhance emergency preparedness and international collaboration.

The IAEA has played an indispensable role in facilitating these processes, including when ageing plants go into long term operation.

Ladies and gentlemen, what were the highlights of this week?

For the energy sector, global energy demand has increased, as has electrification, and both are projected to continue increasing.

Emissions in all sectors will need to be eliminated to meet the climate goals. Action is urgently needed, making use of all possible technologies to reduce emissions and rapidly move to the decarbonization of the energy sector. In most scenarios nuclear power contributes to the decarbonization of electricity supply in order to achieve climate goals by 2050.

The historical evolution of primary energy sources clearly shows that the work in front of us is very challenging. At the time of the Rio Earth Summit in 1987, fossil fuels represented 81% of the global energy mix. Thirty years later, in 2017, despite efforts to promote energy efficiency and to deploy renewables, the share of the global energy mix of fossil fuels remained unchanged, with CO_2-equivalent emissions increasing in 2018.

Also taking into account the expected growth in world population and energy demand, it was confirmed that in order to decarbonize the energy sector, nuclear power had a significant role to play.

Ladies and gentlemen, the role of governments is of critical importance. Long term strategies and planning are key to reducing uncertainties and volatility in the energy sector, particularly in deregulated markets. Well targeted incentives can be used to increase the production of carbon-free, dispatchable and flexible electricity generated by nuclear power.

The nuclear industry has a role to play by introducing innovation at all levels, reducing construction times and costs and making new nuclear power systems competitive with other baseload energy sources. By accelerating the development and deployment of innovative nuclear systems, nuclear power will become more sustainable and flexible for integration with other carbon-free energy sources and for non-electrical applications.

The important role of the IAEA to facilitate international cooperation was also highlighted, working with its Member States and multiple partners worldwide to support them in the safe, secure and peaceful use of nuclear power.

The future of nuclear power deployment can be constrained by societal preferences; thus, it is increasingly important to engage with the public and non-nuclear stakeholders. All energy generating technologies have risks and benefits. However, perceptions and awareness of hazards are disconnected from scientific evidence. New and effective communication channels will need to be utilized, with evidence based risks presented in an understandable way.

Ladies and gentlemen,

The past week has been an exciting opportunity to explore the role of nuclear power in climate change mitigation. I would like to express my heartfelt thanks to our Scientific Programme Committee for organizing the conference and evaluating and reviewing the scientific contributions. Likewise, I would like to thank all those who contributed papers, presentations and posters. Please allow me to thank all Track Leaders of our Technical Tracks and the Chairpersons and Moderators of the Technical Sessions.

I also want to thank our scientific secretaries, Huang Wei, Andrea Borio di Tigliole and Stefano Monti, as well as Jessica Callen, Martina Neuhold and Sanjai Padmanabhan who have all worked professionally to make this conference a success.

I wish you an enjoyable remaining stay in Vienna and a safe journey home.

I declare that this International Conference on Climate Change and the Role of Nuclear Power is now closed.

7.2. CONCLUSIONS OF THE CONFERENCE

The main message from the conference was unambiguous. To meet climate goals and implement more sustainable energy systems, there is an urgent need to take strong action, making use of all available low carbon technologies, including nuclear power. The four illustrative model pathways identified by the Intergovernmental Panel on Climate Change (IPCC) to achieve the climate goals by 2050 would require a substantial increase in nuclear power capacity compared with present day levels. Without a significant increase in the share of nuclear power in the energy mix, climate goals will not be met by the agreed deadlines.

The historical evolution of primary energy sources clearly shows that the work to be done by all parties committed to the energy transition is very challenging. As recalled by the President of the conference, at the time of the Rio Earth Summit in 1987, fossil fuels represented 81% of the global energy mix. Thirty years later, in 2017, despite efforts to promote energy efficiency and to deploy renewables, share of fossil fuels in the global energy mix remained unchanged, with greenhouse gas (GHG) emissions increasing in 2018.

In perspective, the task could be even more daunting. Global energy demand has increased, as has electrification, and both are projected to continue increasing. Emissions in all sectors will need to be dramatically reduced to meet the climate goals. At the conference it was reported that the IPCC analysed 21 models from around the world and came to the conclusion that to limit global warming to 1.5°C, global net anthropogenic CO_2 emissions must reach net zero around 2050. But that must be accompanied by very deep reductions in non-CO_2 emissions as well. Action is urgently needed, making use of all possible technologies, to reduce emissions and rapidly move to the decarbonization of the entire energy sector.

In most scenarios for achieving climate goals, nuclear power contributes substantially to this deep decarbonization by 2050 and beyond. To make this a reality, the conference recognized that all efforts which allow nuclear power to be exploited to its full potential need to be implemented. At the same time, the highest standards in safety, security and non-proliferation already reached by the nuclear industry need to be maintained and continuously strengthened.

Innovation at all levels is at the heart of these efforts. The findings of the conference include the need: to implement innovations in the current nuclear fleet to extend the life of NPPs; to reduce construction time and costs of new nuclear installations; to develop new financial mechanisms that favour private and public investments in nuclear projects; to accelerate the development and deployment of advanced nuclear technologies such as SMRs and fast reactors; to adapt current and future nuclear technologies for integration with other carbon free energy technologies and, in particular, variable renewable energy sources; and to more widely use nuclear power for non-electrical applications such as co-generation, district heating, hydrogen production and general industrial applications.

However, as mentioned above, time is critical. Therefore, nuclear power’s share of the anticipated new cleaner energy systems will depend on the speed at which nuclear technology can incorporate these innovations and advanced nuclear concepts become commercially available. More generally, there is a need to deploy current and innovative nuclear power technologies much faster than in the recent past.

The role of governments is of paramount importance. Long term strategies and planning are key to reduce uncertainties and volatility in the energy sector, particularly in deregulated electricity markets. Well targeted incentives can be used to provide support for the long term operation of existing power plants, increase the production of carbon free, dispatchable and flexible electricity generated by nuclear power, and facilitate the development and deployment of advanced technologies like SMRs and nuclear hydrogen production, which can be of great help for developed and developing countries to meet their growing energy demand.

The nuclear industry has a role to play by reducing construction times and costs and making new nuclear power systems competitive with other baseload energy sources. By accelerating the development and deployment of innovative nuclear systems, nuclear power will become more sustainable and flexible for integration with other carbon free energy sources and for non-electrical applications.

The private and public sectors must work together to facilitate access to credit and secure financing solutions for new nuclear projects. From this viewpoint the conference noted that advanced reactors are increasingly attracting private sector investments for their development. This is an interesting new trend and opportunity which, however, requires a different strategic roadmap, a different time horizon and, in some cases, a different approach with respect to the existing nuclear technologies.

As stressed by the President of the conference, the future of nuclear power deployment can be constrained by societal preferences. Thus, it is increasingly important to engage with the public and non-nuclear stakeholders. There is a need to start a dialogue with the public to communicate a fact based understanding of the inherent risks of all energy systems, presenting the benefits of nuclear power, and to realistically communicate the potential public health consequences of radiation exposure. New and effective communication channels will need to be utilized, with evidence based risks presented in an understandable way.

Finally, the conference highlighted the important role of international organizations and initiatives to facilitate and intensify multinational cooperation and promote collaboration, as well as share best practices and lessons learned, including past failures.

All the international organizations participating and contributing to the conference — the Nuclear Energy Agency of the Organization for Economic Co-operation and Development, the United Nations Department of Economic and Social Affairs, the United Nations Industrial Development Organization, the Intergovernmental Panel on Climate Change, the World Nuclear Association, the OECD International Energy Agency, and the United Nations Framework Convention on Climate Change — have recognized the urgent need for quickly decarbonizing the energy sector and accelerating the transformation in electricity production, industry, building, transportation and cities in order to attain United Nations climate change targets and Sustainable Development Goals. They have also acknowledged that nuclear power plants have already played an important role in decarbonization by avoiding approximately 1 to 2 gigatonnes of carbon dioxide equivalent per year, when compared with gas or coal alternatives. As a virtually carbon free energy source that is reliable, dispatchable and increasingly flexible, nuclear power has significant opportunities for greater deployment in the coming years but also faces challenges. Safety, above all after the Fukushima Daiichi accident, and long term management of nuclear waste remain a public concern. Cost competitiveness of nuclear power and the need for large capital investments are also important issues, particularly as renewable energy has become increasingly more cost competitive than many conventional options. As a consequence, and as highlighted in many technical sessions of the conference, government commitments and public acceptance will be a prerequisite for the development of new nuclear power plants.

The IAEA has been called on to support Member States and multiple partners worldwide to accelerate and expand the safe, secure and peaceful use of nuclear power for sustainable development and climate change mitigation. In doing so, it is also requested to develop new approaches, for instance to promote partnerships with organizations that have not traditionally supported nuclear power.

8. CONTENTS OF THE SUPPLEMENTARY FILES

The on-line supplementary files for this publication can be found on its individual web page at www.iaea.org/publications. For ease of reference the content is organized in the following folders.

1. Presentations

1.1. Monday – High level Plenaries

1.1.1. Opening Session

1.1.2. Member States

1.1.3. International Organizations

1.2. Tuesday

1.3. Wednesday

1.4. Thursday

1.5. Friday

2. Papers

3. Posters

ANNEX I.

CONFERENCE STATISTICAL DATA

Organized by	IAEA Department of Nuclear Energy (NE)	
Location	HQ, M Building	
Cooperating organization	OECD/NEA	
Total No. of participants and observers	526 (33% female, 67% male)	
Total No. of officially designated participants:	382 (Member States) and 80 (organizations)	
Total No. of observers:	64	
No. of Member States	79	
No. of organizations represented:	17	
No. of statements or presentations and others:	Sessions Side events Presentations/Speakers E-poster presentations Posters	29 (incl. opening and closing) 8 131 6 35
Scientific Secretaries (IAEA):	W. Huang (NEPK) (Lead Scientific Secretary) A.B. Di Tigliole (NE) Stefano Monti (NENP)	
Scientific, administrative support (IAEA)	A. van Heek (NEPK) M. Khoroshev (NEPK) J. Callen (NEPK)	
Conference coordination (IAEA)	M. Neuhold (MTCD) S. Padmanabhan (MTCD)	
Technical Cooperation Coordination	C. Henrich (TCEU)	
Conference website:	https://www.iaea.org/atoms4climate	

No. of participants by Member State: 382

Argentina	6	Jordan	5	Slovakia	2
Armenia	2	Japan	10	Spain	1
Australia	2	Kenya	4	Serbia	2
Austria	13	Kuwait	1	Sri Lanka	4
Belgium	1	Lebanon	3	Sweden	5
Bangladesh	4	Libya	3	Switzerland	2
Brazil	6	Lithuania	1	Syrian Arab Republic	1
Canada	8	North Macedonia	1	Tajikistan	1
Chile	4	Malaysia	5	Thailand	1
China	44	Mexico	8	Tunisia	1
Croatia	1	Malawi	1	Turkey	1
Cuba	1	Montenegro	3	United Arab Emirates	8
Cyprus	1	Mongolia	5	Uganda	2
Czech Republic	3	Morocco	2	United Kingdom	18
Egypt	15	Myanmar	1	Ukraine	5
Estonia	3	Nepal	4	Uruguay	1
Ethiopia	1	Netherlands	6	United States of America	25
Finland	1	Nigeria	4	Venezuela	2
France	18	Norway	1	Yemen	2
Germany	2	Pakistan	2		
Ghana	6	Panama	1		
Greece	7	Philippines	3		
Holy See	3	Korea, Republic of	3		
Hungary	5	Romania	6		
India	10	Russian Federation	18		

Indonesia	5	South Africa	5	
Iran, Islamic Republic of	2	Saudi Arabia	3	
Ireland	3	Senegal	1	
Iraq	6	Singapore	1	
Italy	1	Slovenia	3	

No. of participants by organization: 80

VCDNP (The Vienna Center for Disarmament and Non-Proliferation)	8	UNIDO (United Nations Industrial Development Organization)	4
EPRI (Electric Power Research Institute)	1	UNDESA (UN Statistics Division)	3
IRENA (International Renewable Energy Agency)	1	EC (European Union)	5
IPCC (Intergovernmental Panel on Climate Change)	2	ENS (European Nuclear Society)	8
WNA (World Nuclear Association)	5	IAEA (International Atomic Energy Agency)	25
FORATOM (European Atomic Forum)	2	OECD (Organization for Economic Co-Operation and Development)	1
ENEN (European Nuclear Education Network Association)	4	NEA/OECD (Nuclear Energy Agency of the Org. for Economic Co-operation and Development)	4
WINS (The World Institute for Nuclear Security)	1	UNFCCC (United Nations Framework Convention on Climate Change)	1
		OPEC (Organization of the Petroleum Exporting Countries)	2

ANNEX II

LIST OF PAPERS

Track	Paper	Presenter	Country	Paper Title
1	004	G. Güngör	Turkey	The Role of Nuclear Energy in Transition Pathways of Turkish Energy Sector
5	005	M. Sejmenova-Gichevska	North Macedonia	Nuclear Information Management Related to Climate Change: Correlation between Energy Indicators for Sustainable Development and INIS Knowledge Organization Systems
6	006	L. Alkawass	Austria	Lebanese Public Opinion on Nuclear Power
1	007	H. Turton	IAEA	Nuclear Power and Climate Change: Scenario Perspectives to 2050
6	009	Y. Anpilova	Ukraine	Nuclear Energy and Public Opinion in Ukraine
2	010	S. Sayed Ahmed	Egypt	The Global Warming and the Mitigations of Climate Changes
2	012	S. Pustovalov	Russian Federation	New Opportunities of Existing Nuclear Power Plants for Climate Change Mitigation
2	013	R. Menya	Uganda	Regulatory Infrastructure for Launching the First Nuclear Power Plant in Uganda
3	015	Luqman Hasan Nahari	Indonesia	Nuclear Energy Industrial System Concept for Reducing Carbon Emissions in the Face of Climate Change
1	016	M. Chyzhenko	Ukraine	Contribution of Nuclear Power to the Avoidance of GHC Emissions in Ukraine
1	017	E. F. Morales Rodríguez	Uruguay	Nuclear shares in Power and Final energy Consistent with 1,5 °C Scenarios – Considerations for National Climate Strategies
2	019	N. Haneklaus	Germany	Nuclear-Renewable Hybrid Energy Systems – IAEA Activities
1	021	L. Ferreira da Silva	Brazil	New Perspectives for the Brazilian Energy Sector
6	022	M. Try Agung Saputra Ritonga	Indonesia	The Role of Teachers on Forming People's Perception on Nuclear Energy in Indonesia
5	023	E. Zaveckas	United States of America	Harnessing International Support for Nuclear Power Deployment: Challenges and Opportunities

Track	Paper	Presenter	Country	Paper Title
2	024	M.B. Shohag	Bangladesh	A Comprehensive Study on the National Power System Master Plan of Bangladesh Incorporating Nuclear Power in the Energy Mix Considering Climate Change and Country's Development Goal
1	025	C. Manda	Malawi	A Review of the Contribution of Nuclear Power Plans Towards Malawi Energy Poverty and Climate Change Mitigation Goals: A Development Country Perspective
1	026	H. Schneider	Switzerland	Nuclear Energy in the Article 6 of the Paris Agreement
1	027	O. Dudkin	Ukraine	Achieving the Climate Change Goals through Nuclear Energy Development: Ukrainian Experience
2	028	E. D. Greaves	Venezuela, Bolivarian Republic of	Worldwide Reforestation Programme Powered by Molten Salt Reactors: Case Study from Venezuela
1	029	O. Agbenorku	Ghana	The Introduction of Nuclear Power to Ghana's Energy Mix and its Implications on Climate Change
1	030	V. Watcharasuragul	Thailand	Dissemination of How Nuclear Energy Can Support Thailand 4.0 Policy
1	031	M. Constantin	Romania	Nuclear Power Development in Romania in the Context of Future Energy Market and Climate Change Policies
5	032	B. Carpinelli	Argentina	Nuclear Energy as a Solution to Climate Change Analyzed in Terms of the New Global Market Demands, the Importance of Nuclear Projects Cooperation and the IOs Role
1	034	R. Fahmy	Egypt	The Significant Role of Nuclear Energy in Tackling Climate Change
3	035	L. Alkawass	Austria	Nuclear-SMR for Reliable Electricity System and Climate Change Mitigation in Lebanon
1	036	M. A. Nyasapoh	Ghana	Nuclear Power Contribution Towards a Low-Carbon Electricity Generation for Ghana
3	037	J. N. Reyes, Jr.	United States of America	Adapting Nuclear Power for Climate Change
3	040	M. Varvayanni	Greece	Preliminary Study of Large Commercial Ships Nuclear Propulsion Capability Using Small Modular ADS

Track	Paper	Presenter	Country	Paper Title
2	041	Z. M. Ihsan	Indonesia	How Environmentally Friendly and Economic is Different Method of Electrical Load Following in Nuclear Power Plant
3	043	J. Guidez	France	What is the Interest of New Type of Reactors to Improve the Fight Against Global Warming?
6	044	A. Ioannidou	Greece	The Role of Higher Education Institutions in Changing Public Perception of the Role of Nuclear Energy in Climate Change
4	045	A. R. M. Roulstone	United Kingdom	Meeting the UK's 2050 De-carbonization Targets for Electricity Generation: The Contribution of Nuclear Energy
1	047	Ž. Tomšić	Croatia	CHP SMR as Solution for Zero Carbon Development Strategy for Croatia
2	048	M Abdelaziz	Egypt	Proposed Investigation on the Replacement of Coal and Fossil Energy by Nuclear Power Related to its Impact on Climate Change
1	049	E. Meneses Ruiz	Cuba	Evaluation of Adaption Options for the Cuban Energy System to Climate Change and Extreme Weather
1	050	M. B. Alsous	Syrian Arab Republic	Strategic Study of the Syrian Energy Supply Alternatives for the Period 2020–2050 Including GHG Statistics
1	051	N. G. Davydova	Russian Federation	Nuclear Energy May Help to Overcome the Restrictions on Economic Growth Posed by Climate Change Mitigation Policies
2	052	S. Feutry	France	Renewables and Flexible Nuclear Alliance for a Low Carbon electricity Generation
6	053	C. Ringenbach	France	The Climate Collage: Original & Effective Way to Explain Climate Change Widely for Non-Scientific People
1	056	T. T. Naing	Myanmar	The Role of Nuclear Power and Climate Change in Myanmar
1	061	V. K. Aerattukkara	India	Role of Nuclear Power in Reduction of Greenhouse Gas Emissions – Indian Scenario
2	064	S. K. Rasmeni	South Africa	Effects of Climate Change on the Evolution of the Zambezi River Basin: Implications to South Africa's Hydropower Generation and Electricity Crisis

Track	Paper	Presenter	Country	Paper Title
4	065	K. Kallemets	Estonia	Achieving 33gwe Annual Newbuild With Startup Model and Financing in SMR Deployment Industry
1	070	G. Borsatto	Brazil	Energy Demand and Supply Analysis to Contribute to the Climate Change Challenges Achievement using IAEA Methodology and Tools
5	072	B. Li	China	Current Status of Nuclear Power Development and Nuclear Safety in China
3	074	I. Khamis	IAEA	The Role of Nuclear Hydrogen Production in a Low-Carbon Economy
3	075	C. Ni	China	Developing Nuclear Energy Heating to Reduce Carbon Emissions in North China
2	076	D. Subbotnitskiy	IAEA	Service Benefits: Potential Role of SMRs in Isolated Northern Areas for Climate Change Mitigation
1	077	G. Pourabedin	Iran, Islamic Republic of	Suggesting the National Measurement, Reporting and Verification (MRV) System for Iran
3	079	Z. Li	China	Exploration Progress and Models on Green Type of Sandstone-Hosted Uranium Resources for Nuclear Energy Development in China
3	080	T. Jevremovic	IAEA	Innovative Nuclear Energy Systems: Sustainable Solution for Energy Security and Climate Change Concerns
6	081	N. Davydova	Russian Federation	Public Involvement in the Discussion on Nuclear Energy, the Environment and Climate Change: The Case of the ROSATOM Public Council’s Project “Green Square”
1	083	A. Schweikert	United States of America	Beyond LCOE: Quantifying Co-Benefits and the Value of Resilience in Power Systems
3	086	X. Liu	China	Deep-pool Low-temperature Heating Reactor (DHR)
1	088	E. Elmoujarkach	Saudi Arabia	The Impact of Adding Two Nuclear Reactors to Saudi Arabia National Grid in Reduction of Carbon Dioxide Emissions
2	089	E. Börcsök	Hungary	Sustainable Nuclear-Renewable Hybrid Systems: A Case Study for Hungary

Track	Paper	Presenter	Country	Paper Title
3	090	W.-S. Chung	Korea, Republic of	A Holistic Model for Environmental Impact Assessment of Nuclear Power Generation in Korea
1	091	W. Allison	United Kingdom	Understanding the Place of Nuclear in the Science of Energy
3	092	A. Schweikert	United States of America	Scale Matters: Ending Global Electricity Poverty Provides New Opportunities for SMR and MMR Technologies
4	095	J. McBride	United States of America	Drivers of Historical Nuclear Construction Costs
6	096	L. Shasko	Canada	Innovating the Bridge Building Elements of ‘Reluctant Acceptance’
3	097	L. Hurlbert	Canada	Creative Disruption for Clean Nuclear Energy and GHG Emission Reductions
2	101	J. T. Seo	Korea, Republic of	Korean Experiences on Delivering Generation III Advanced Light Water Reactors – APR1400
4	105	E. Teplinsky	United States of America	Development Financial Institution Financing for Small Modular Reactor (SMR) Projects: A Mechanism to Address Climate Change Crisis and Meet Sustainable Development Goals by Facilitating SMR Deployment in the Developing World
1	106	U. F. Ahmad	Nigeria	Nuclear Power: Essential for Sustainable Development
1	107	R. Muradyan	Armenia	Creation of Energy Policies in Armenia that Achieve the Climate Change
3	109	B. N. Karkera	India	Ocean-Contained-Nuclear-Farms Integrated with Global-Free-Gravity Transportation for Restoring Climate-Health to the Best Condition of Stone-Age Period
1	114	M. Kukharchuk	Ukraine	Assessment of the Potential Role of Nuclear Energy in Ukrainian Climate Change Mitigation Strategies
6	115	C. Grundy	United Kingdom	Dialogue Study Public Perception for Advanced Nuclear Technologies including SMRs and AMRs
6	116	B. Kugelmass	United States of America	True Reversal of Climate Change Requires Nuclear Energy

Track	Paper	Presenter	Country	Paper Title
1	117	A. van Heek	IAEA	Opportunities for Small Nuclear Power Plants by the Recurring Submission Mechanism of the Paris Agreement
2	118	F. Reitsma	IAEA	Potential of Hybrid Energy Systems Based on SMRs and Renewables for Energy Supply and Security
3	119	F. Reitsma, N. Haneklaus	IAEA	Energy Neutral Mineral Processing to Support Climate Change Mitigation
2	121	H. Turton	IAEA	Accelerating Deployment of Low Carbon Power for 1.5 °C
1	122	D. Musyoka	Kenya	Nuclear Power Contribution to Kenya's Nationally Determined Contributions
1	123	E. Proust	European Nuclear Society	The Important Role of Nuclear in a Low-Carbon World: The View of the European Nuclear Society's High Scientific Council
1	127	N. A. Basri	Malaysia	CO_2 Emission in the Energy Sector in Malaysia – An Overview
1	128	A. Goicea	FORATOM	Nuclear Power in Europe – Where To?
6	129	H. Cheerathadayan	India	Environment, Nuclear Power and People's Movement: India's Triangular Dilemma
6	133	V. Faudon	France	The Nuclear4Climate Initiative: Lessons Learned from Grassroots Campaign
1	134	A. El-Sadat	Egypt	Optimum Planning of Nuclear Power Plants Integration in Egyptian Grid for Minimizing the CO_2 Emissions
4	135	J.-G. Devezeaux	France	The Renewal of the French Nuclear Fleet, a Key to Achieve the EI 2050 Decarbonization Goals
3	138	A. Moskvin	Russian Federation	Hydrogen as a Key Solution for the Global Energy Environment
1	139	Á. Gerse	Hungary	Towards a Low-carbon Electricity Supply in Central Eastern Europe: Modelling the Role of Nuclear Power Plants
2	141	C. A. B. Dath	Senegal	Small Uranium Mines in the SMR Development Era with Focus on African Contexts: From Economic to Sustainability Analyses

Track	Paper	Presenter	Country	Paper Title
6	142	S. K. Rasmeni	South Africa	Addressing the Public Perception on the Role of Nuclear Power on Climate Change Reduction Through Educational Awareness and Collaboration
1	143	I. Ennison	Ghana	The Role of Nuclear Power in the Mitigation of Ghana’s Long Term Greenhouse Gas Emission
3	144	J. Liou	Austria	Nuclear Renaissance: A Roadmap to Deploy Small Modular Reactors in Developing Countries
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