A Appendix 1. Country reports 2021

Australia

Australia remains a committed member of the Generation IV International Forum. We welcome the continuing expansion in the very-high-temperature reactor (VHTR) System Arrangement, and its Project Arrangements with the recent addition of the United Kingdom and the rejoining of Canada to the VHTR Materials Project Management Board (MAT PMB), as well as the further interest expressed by Russia.

We also support the development of stronger cooperation and collaboration within the molten salt reactor (MSR) system, initially through more coordinated programs of work under the existing memorandum of understanding (MoU) and then by the signing of an MSR System Arrangement and associated Project Arrangements.

Turning to national matters, Australia is investing more than half a billion dollars into building strategic international partnerships to make low-emissions technologies cheaper than high emitting alternatives. Australia has signed a letter of intent with the United Kingdom to establish a partnership on low-emissions solutions, which includes advanced small modular reactors (SMRs) that can use VHTR and MSR technologies.

Regarding the development of a national repository, on 11 August, the Minister for Resources and Water, announced his intention to make a declaration under the National Radioactive Waste Act that would confirm Napandee as the site for the National Radioactive Waste Management Facility. We are currently engaging in a public consultation process following that expression of intent.

The Australian government has no plans to lift the moratorium on nuclear energy in Australia. It recognizes that nuclear energy is a mature technology used to deliver reliable electricity in many countries, with virtually no greenhouse gas emissions.

Any decision to remove the current prohibition on nuclear power generation would require bipartisan agreement and wide-spread community support.

Australia continues to look at all emerging low-emissions technologies as they evolve over time, including nuclear energy, and to examine whether they are right for Australia

Australia acknowledges once again the GIF Secretariat and the GIF leadership team for their hard work and perseverance in developing and implementing virtual Experts Group and Policy Group meetings.

Canada

SMR activities and developments

Update on government policy and actions

Since the launch of Canada's SMR Action Plan, the government of Canada has continued to work with interested parties to advance this important initiative. The action plan is a pan-Canadian initiative with chapters submitted by more than 100 partner organizations from across the country. As of 31 December 2021, it includes 513 concrete actions which partners are taking to advance the development, demonstration and deployment of SMR technologies in Canada. Under the action plan, the government of Canada will establish an annual SMR Leadership Table, convening the Canadian nuclear family, from mining to production, as well as Indigenous Peoples.

The government of Canada has continued its engagement with Indigenous Peoples across Canada on SMRs, acknowledging that genuine, meaningful partnerships with Indigenous Peoples are critical components for Canada to capture the SMR opportunity. An Indigenous Advisory Council was created to enable a coordinated, Indigenous leadership voice from across Canada on the development of SMRs.

Under the *Hydrogen Strategy* for Canada, work is being conducted to explore the benefits and requirements of producing hydrogen with nuclear energy. Under the strategy, a working group was established in August 2021 dedicated to nuclear hydrogen, with the intention to advance the policy and technical work required to take actions on the strategy's recommendations.

In February 2021, The Premier of the Province of New Brunswick announced that the province is investing CAD 20 million (Canadian dollars) in ARC Clean Energy to support its SMR technology. These investments demonstrate strong support for New Brunswick's Advanced SMR Nuclear Energy Research Cluster, and in general for SMR R&D in Atlantic Canada.

In March 2021, Canada's Minister of Innovation, Science and Economic Development Canada, along with the Minister responsible for the Atlantic Canada Opportunities Agency, announced that the government of Canada is investing CAD 50.5 million in Moltex Energy Canada to help it develop a stable salt reactor – wasteburner reactor. This technology uses a waste to stable salts process that would use spent CANDU fuel. The federal government will also invest CAD 5 million in New Brunswick Power to help

it prepare its Point Lepreau generating station site for the proposed installation of SMRs designed by Moltex and ARC Clean Energy. In addition, an investment of CAD 560 000 is being made for a research center at the University of New Brunswick to support SMR development and deployment in the province.

In April 2021, the province of Alberta formally became a signatory to the 2019 MoU between the provinces of Ontario, Saskatchewan and New Brunswick, which established a framework for the deployment of nuclear energy by way of SMRs in each jurisdiction. These provinces have agreed to collaborate on the advancement of SMRs as a clean energy option to address climate change and regional energy demands, while simultaneously supporting economic growth and innovation. For Alberta, this poses an opportunity to reduce the province's greenhouse gas emissions, power its remote communities, and provide a form of economic diversification.

The government of Canada is committed to continuous improvement with respect to ensuring that safe solutions are in place for managing radioactive waste, including waste that may result from new and innovative nuclear technologies. For this reason, Canada launched an engagement process to modernize Canada's radioactive waste policy. The Department of Natural Resources (NRCan) undertook an extensive engagement process to hear the views and perspectives of interested Canadians on how they would like to see the radioactive waste policy modernized. NRCan, with the support of other federal departments and agencies having responsibility for radioactive waste, engaged with non-governmental organizations, Indigenous Peoples, industry, other levels of government and other interested Canadians. In parallel to the radioactive waste review, NRCan is also undertaking a review of nuclear liability limits.

Utilities, vendors and regulatory SMR updates

On 2 December 2021, Ontario Power Generation (OPG) announced that it will work with GE Hitachi Nuclear Energy (GEH) to deploy GEH's BWRX-300 boiling water SMR at the Darlington nuclear site. OPG and GEH will collaborate on SMR engineering, design and planning, preparing the licensing and permitting materials, and performing site preparation activities, with the goal of constructing Canada's first commercial, grid-scale SMR, expected to be completed as early as 2028.

Global First Power Ltd (GFP)'s application to the Canadian Nuclear Safety Commission for a license to prepare a site for a Micro Modular Reactor (MMR) completed its preliminary evaluation step and has moved on to formal license review. Considerations of siting alternatives has led to the identification of a preferred location at the Canadian Nuclear Laboratories (CNL) Chalk River site, owned by Atomic Energy of Canada Ltd. The proposed project includes an MMR high-temperature gas-cooled reactor (HTGR) to provide process heat to an adjacent plant via molten salt.

The Canadian Nuclear Safety Commission (CNSC) continues work to ensure its readiness for SMRs in Canada. The CNSC undertakes an optional preliminary step before the licensing process, which is called a vendor design review (VDR), to assess vendors' understanding of Canada's regulatory requirements and the acceptability of a proposed design. There are currently twelve SMR proposals in the VDR process - ten VDR service agreements in force between vendors and the CNSC, and two more under development. These vendors are ARC Nuclear, GE Hitachi Nuclear Energy, LeadCold Nuclear, Moltex Energy, NuScale, SMR (Holtec), StarCore Nuclear, Terrestrial Energy, U-Battery Canada, Ultra Safe, Westinghouse and X Energy.

Industry action on climate change and SMRs

In June 2021, Canadian Natural Resources, Cenovus Energy, Imperial, MEG Energy and Suncor Energy formally announced the Oil Sands Pathways to Net Zero Initiative. These companies operate approximately 90% of Canada's oil sands production. Working collectively with federal and provincial governments, the initiative's goal is to achieve net-zero greenhouse gas emissions from oil sands operations by 2050 to help Canada meet its climate goals. A key pathway to net zero, identified in this initiative, will be evaluating, piloting and accelerating the application of potential emerging emissions-reducing technologies, including SMRs.

Other activities and developments

Refurbishment of OPG CANDU reactors at Darlington is progressing well. unit 2 has been successfully refurbished and restarted. In June 2021, the Bellows severing of unit 3 was completed, which marked an important milestone in the unit 3 refurbishment project.

Bruce Power's unit 6 major component replacement (MCR) project continues to proceed on track. The MCR project focuses on the replacement of key reactor components in units 3-8, including steam generators, pressure tubes, calandria tubes and feeder tubes.

International update

Canada's Nuclear Cooperation Agreement (NCA) with ITER was ratified in May 2021. The NCA opens the door to Canada's participation in the ITER project, enabling Canadian entities to provide goods and services to ITER in line with Canadian nuclear non-proliferation policy. This follows from the previous MoU between Canada and ITER that aimed to identify the precise domains in which Canadian suppliers could export expertise and technologies on a commercial basis to the ITER project. Under Canada's non-proliferation policy, Canadian-supplied nuclear material, equipment and technology may only be transferred where Canada has concluded a bilateral NCA. Under the terms of the NCA, a coordination committee was established between Canada and ITER as the main mechanism to notify both parties about possibilities of cooper-

ative activities. The inaugural meeting of this coordination committee took place in November 2021. A working-level taskforce will explore specific areas of common interest, and discuss potential commercial and collaborative opportunities.

In June 2021, General Fusion announced that it intends to build and operate a fusion demonstration plant (FDP) at the UK Atomic Energy Authority's Culham Campus. General Fusion is the largest Canadian fusion energy company and among the leading private ventures pursuing a compact and economical fusion reactor. Construction of the FDP is anticipated to begin in 2022, with operations beginning approximately three years later. In July, 2021, General Fusion and CNL announced a partnership to develop tritium extraction techniques for use in commercial fusion power plants. Leveraging CNL's Canadian Nuclear Research Initiative, the organizations will identify the most promising approaches for managing tritium in fusion energy systems. In October 2021, General Fusion announced that it will open new headquarters, anchoring the company's operations in Canada.

In August 2021 the government of Canada signed an MoU with Romania on Civil Nuclear Cooperation, with the aim of employing the full breadth of Canada's nuclear supply chain to support Romania's refurbishment and new build civil nuclear projects. The MoU is a bilateral commitment that further strengthens government-to-government, industry-to-industry, lab-to-lab and regulator-to-regulator cooperation in nuclear energy development. Key areas of collaboration include CANDU refurbishments and new build, specifically related to Cernavoda units 3 and 4, SMRs, medical isotopes, supply chain integration, research and development, and best practices in waste management and decommissioning.

Canada's participation in GIF

Canada continues to participate in the supercritical supercritical-water-cooled reactor (SCWR) system with a current focus on materials and thermal hydraulics research to support development of the pressure-tube type small modular SCWR concept. In 2021, Canada re-joined the VHTR system, signing the GIF VHTR System Arrangement, and will be participating in the VHTR Materials Project. This is in addition to its current participation in the Hydrogen Production Project. Canadian entities continue their participation in the MSR Provisional System Steering Committee, and will work with other members on the future direction of MSR system collaboration.

China

Nuclear energy policy

On 3 September 2021, the operating license of the Qinshan nuclear power plant unit 1 was approved by the Ministry of Ecology and Environment to be extended to 30 July 2041. This decision will have a far-reaching impact on establishing a comprehensive nuclear operating license-extension system in China.

Nuclear energy development

By the end of 2021, there were 53 nuclear power units in operation in the Chinese Mainland, with an installed capacity of 54 646 gigawatts (GW), 20 nuclear power units under construction with an installed capacity of 21 356 GW. The total installed capacity is up to about 76 GW, ranking second in the world.

On 30 January 2021, unit 5 of Fuqing nuclear power plant, the world's first Hualong One reactor, entered commercial operation after 68 months of construction that began on 7 May 2015. It is the first Generation III nuclear power reactor completed as planned in the world. In addition, on 18 March 2021, unit 2 of the Karachi nuclear power plant in Pakistan, the first overseas Hualong One reactor, was successfully connected to the grid.

On 19 May 2021, President Xi Jinping and President Vladimir Putin witnessed the launching ceremony for units 7 and 8 of the Tianwan nuclear power plant and units 3 and 4 of the Xudapu nuclear power plant where four VVER-1200 reactors will be constructed.

On 17 June 2021, the first underground research laboratory for high-level radioactive waste began construction in Gansu Province, and will allow scientists to fully characterize the site's geology and determine its suitability for a high-level radioactive waste repository.

On 13 July 2021, the China National Nuclear Cooperation (CNNC) multi-purpose SMR demonstration ACP100 project, with a power generating capacity of 125 MW, began construction in Hainan Province. It will be the world's first commercial onshore SMR to start construction.

On 11 September 2021, China's first radioactive waste glassification facility was officially put into operation. It will convert hundreds of cubic meters of high-level radioactive liquid waste into a solid glass form, suitable for long-term storage and disposal.

On 9 November 2021, the nuclear heating commercial demonstration project, covering 4.5 million square meters and benefiting 200 000 residents, was put into operation in Haiyang city, Shandong province. It becomes the first city with zero-carbon heating in China, which fully demonstrates the innovative achievements and new prospects of the comprehensive utilization of nuclear energy.

On 20 December 2021, the high-temperature gas-cooled reactor – pebble-bed module (HTR-PM) demonstration project (unit 1) was connected to the grid successfully. It marks a substantial leap from laboratory to engineering application. At present, various tests are being carried out in an orderly manner to ensure unit 2's connection to the grid. Units 1 and 2 are expected to be in full commercial operation in mid-2022.

GIF activities in China

Sodum-cooled fast reactor (SFR): The China experimental fast reactor (CEFR) is preparing for material irradiation tests. CDFR's installation of the reactor vessel and its internals is undergoing and expected

to be finished by the end of this year. It is planned to start commissioning in the first half of 2022.

VHTR: The HTR-PM loaded its fuel on 21 August 2021 and reached first criticality on 12 September 2021. It was connected to the grid in 20 December 2021 and reached full power operation in 2022. The R&D in fuel and fuel cycle, as well as MAT PMB, is going as planned, and the computational methods validation and benchmarks Project Arrangement was signed, with preparations to join the Hydrogen Production Project Management Board still ongoing.

SCWR: The CSR 1000 fuel design has been improved with better hydraulic performance. A small SCWR CSR-150 reactivity control method has also been proposed. The first China technical meeting about two international, thermal-hydraulic benchmark exercises was held in May. A round-robin test has been organized focusing on obtaining reliable corrosion rate data and reaching agreement on a corrosion mechanism and materials testing standards.

Lead-cooled fast reactor (LFR): The China General Nuclear Power Group has launched and R&D Alliance on the lead-bismuth-eutectic (LBE) cooled fast reactor, and established a series of experimental facilities to develop key technologies. The budget for the China Initiative Accelerator Driven System (CiADS) project was approved by government, and its kick-off meeting was held in July 2021.

Euratom

Nuclear energy policy

On 15 September, the President of the European Commission, Ursula von der Leyen, delivered her second State of the Union address in the European Parliament. Ms von der Leyen focused on Europe's recovery from the coronavirus crisis with the main drivers focusing on health preparedness, the Next Generation European Union (EU) financial program, and making Europe (and the world) greener, more digital and more socially just. On climate regulation and finance, the European Commission has introduced the "fit for 55" package. This is a set of proposals to make the EU climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030 (compared to 1990 levels), setting in stone the goals of making the EU the world's first climate-neutral continent by 2050.[1]

The inclusion of nuclear in the EU Taxonomy for sustainable activities regulation has been the subject of intense debate. Although nuclear energy is consistently acknowledged as a low-carbon energy source, opinions differ notably on economic aspects and on the potential impact on other environmental objectives, such as the long-term impact of nuclear waste. The European Commission requested that the Joint Research Centre (JRC) draft a technical report on the "do no significant harm" aspects of nuclear energy, which was delivered in March 2021. The Commission also mandated a review of this report by the experts of Article 31 of the Euratom Treaty (radiation protection and waste management), as well as by the SCHEER Scientific Committee on Health, Environmental and Emerging Risks. The Commission performed the analysis of the results of this consultation in accordance with the Communication on a Strategy for Financing the Transition to a Sustainable Economy published in July 2021. A complementary Climate Taxonomy Delegated Act draft covering nuclear and gas (not covered in the first EU Taxonomy Delegated Act) was prepared and will be finalized in early 2022. The document emphasizes adopting state-of-the-art and advanced technologies.[2]

Budget

The regulation establishing the Research and Training Programme of the European Atomic Energy Community for the period 1 January 2021 to 31 December 2025 was adopted on 10 May 2021.[3] The program defines a single set of objectives for indirect actions (co-funded research and innovation projects) and direct actions (the research program implemented by JRC). The aim of the regulation is to pursue nuclear research and training activities with an emphasis on the continuous improvement of nuclear safety, security and radiation protection, as well as to complement the achievement of Horizon Europe's objectives.[4] These objectives include that of the JRC, as the formally recognized Euratom implementing agent for the Generation IV International Forum (GIF), continuing to facilitate and coordinate the contribution and participation of the Euratom community in GIF's research and training activities. The contribution to GIF activities under the scope of the Euratom program is focused on safety, radiation protection, safeguards and non-proliferation research and training activities specific to Gen-IV systems.

EU member states agreed on an overall budget of EUR 1 382 million, of which EUR 583 273 million will be dedicated to indirect action for nuclear fusion. The multi-annual financial framework dedicated to nuclear fission research includes EUR 26 639 million for indirect actions and EUR 532 328 million for direct actions. The budget for 2021-2025 represents a decrease compared to the previous exercise. Appropriate measures will be introduced to cope with the reduced resource availability.

1. See: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en.

2. See: https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en#nuclear.

3. See: http://data.europa.eu/eli/reg/2021/765/oj.

4. See: https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en.

Council Regulation (Euratom) 2021/100 of 25 January 2021, establishing a dedicated financial program for the decommissioning of nuclear facilities and the management of radioactive waste, and repealing Regulation (Euratom) No. 1368/2013,[5] was adopted. The scope of this new Instrument encompasses the Nuclear Decommissioning Assistance Programme for the dismissed nuclear power plants in Bulgaria and Slovakia, managed by the Directorate-General for Energy (DG ENER), and the operational Decommissioning and Waste Management Programme (D&WMP) of the JRC's obsolete facilities, managed by the JRC. The JRC is also tasked with fulfilling a knowledge management and dissemination role based on its own and collated experiences.

Research activities

Under the new Euratom Research and Training Programme, the Research & Innovation Work Programme 2021-22 was published on 1 July. The 49 eligible proposals received will be evaluated, and 30 projects will be launched by June 2022 for a total budget of around EUR 100 million of the total Euratom contribution to co-funded projects (indirect actions). This total includes an amount dedicated to actions addressing Generation IV advanced systems, with five proposals received.

The active involvement of JRC and Euratom representatives in GIF Steering Committees, working groups and task forces continues. There are significant contributions from JRC and EU member states to all of the six systems. In particular, the JRC contributes to the Risk and Safety and Proliferation Resistance and Physical Protection Working Groups ((RSWG and PRPPWG); and to the Advanced Manufacturing and Materials Engineering and Non-Electric Applications of Nuclear Heat Task Forces (AMME-TF and NEaNH TF). Moreover, the JRC is involved in 11 of the 13 indirect actions on Generation IV stemming from the previous Euratom Research and Training Programme. Support to the development of advanced nuclear systems remains a strategic component of JRC nuclear research in spite of the incompatibly with decreasing resources.

The Strategic Research and Innovation Agenda (SRIA) of the Sustainable Nuclear Energy Technology Platform (SNETP) was adopted in July 2021. SNETP is the largest nuclear stakeholder association in Europe, counting more than 100 major players. The SRIA emphasizes the important role of nuclear technologies and applications to achieve the decarbonization goals of the EU, deployed along the three pillars of SNETP: 1) the Nuclear Generation II and III Alliance (NUGENIA), with a focus on light water reactors; 2) the European Sustainable Nuclear Industrial Initiative (ESNII), with a focus on fast neutron reactors; and 3) the Nuclear Cogeneration Industrial Initiative (NC2I), focusing on high-temperature reactors and their applications. The document focuses on relevant challenges and the R&D needed to tackle them in the context of overall nuclear fission technologies and the specific aspects of each SNETP pillar; cross-cutting challenges with common R&D orientations are also highlighted.[6]

France

Nuclear energy policy

The French President Emmanuel Macron in October 2021 unveiled a five-year investment plan entitled "France 2030". The plan aims at fostering innovation. Decarbonizing French industry is one of the main targets. The plan includes a focus on SMRs, with a consortium led by Electricité de France (EDF) developing a 340 MWe SMR called NUWARD™. Its conceptual design development phase is ongoing until 2022. The consortium initiated a roadmap of technical discussions with the regulator in order to prepare the review of the Safety Options' Report in 2023.

Energy mix scenarios

French grid operator, Réseau de Transport d'Électricité (RTE, or the "Electricity Transmission Network"), released a report In October 2021 presenting six scenarios for the French energy mix, allowing France to achieve the aim of carbon neutrality by 2050. The scenarios consider different shares of nuclear and renewables. The report presents the main conclusions regarding consumption, energy mix evolution, economy, technologies, the environment and general considerations.

Status of the French fast reactor program

Regarding the SFR, digital simulation of the behavior of SFR subassemblies under irradiation is progressing, with the development of a methodology that couples thermal-hydraulics and thermal-mechanics computation. The comparison with the Japanese coupled calculation on the Joyo subassembly shows good agreement in computed deformation and temperature distribution.

Regarding the MSR, a one-week bootcamp has been held, gathering 70 people from the French Alternative Energies and Atomic Energy Commission (CEA), EDF, Orano, Framatome and the Institut de Radioprotection et de Sûreté Nucléaire (IRSN), as well as French start-ups. Strategy, scientific and organizational aspects were addressed.

Regarding facilities, the decision has been made to invest in experimental loops devoted to severe accident experiments (on both Gen-II, III and Gen-IV technologies). Commissioning a facility is scheduled in 2026. The facility will be broadly open for international cooperation.

5. See: https://eur-lex.europa.eu/eli/reg/2021/100/oj.

6. See: https://snetp.eu/wp-content/uploads/2021/09/SRIA-SNETP-1.pdf.

Japan

The government of Japan has outlined a "Carbon Neutral Policy" with the objective of decreasing carbon emissions by 46% in 2030, as compared with 2013, and reaching carbon neutrality by 2050.

According to a Cabinet Decision on the Sixth Strategic Energy Plan: the Advisory Committee for Natural Resources and Energy began its deliberations in October 2020, and a draft was presented on 21 July 2021. After amendments based on public and other comments, the Sixth Strategic Energy Plan was approved by the Cabinet on 22 October 2021.

For the stable use of nuclear power, the following points have been addressed:

- Restart of operation with safety as the top priority: launch of the restart acceleration task force, bringing human resources and knowledge together, and maintaining and improving technological capabilities;
- Measures for spent nuclear fuel: promotion of construction/utilization of interim storage facilities and dry storage facilities, etc. to increase storage capacity; and technology development for reducing the volume and harmfulness of radioactive waste;
- Nuclear fuel cycle: efforts towards the completion and operation of the Rokkasho Reprocessing Plant through a public and private partnership, obtaining the understanding of the relevant municipalities involved and international society, and through further promotion of plutonium-thermal (mixed oxide [MOX] fueled) power generation;
- Final disposal: steady implementation of literature surveys in two municipalities of Hokkaido, and commencement of surveys in as many areas as possible across Japan;
- Efforts in relation to various challenges in proceeding with long-term operation while ensuring secured safety: Fulfilling conservation activities and considering various issues depending on the individual roles of the public and private sectors;
- Public understanding: interactive dialogue, in regions where electricity is consumed, and easy-to-understand, polite public relations/public hearings.

For the promotion of R&D, making the most of the private sector's ideas and wisdom, by 2030, the development of a fast reactor will be steadily promoted by utilizing international cooperation. The SMR technology will be demonstrated through international cooperation; and component technologies related to hydrogen production at a high-temperature gas-cooled reactor (HTGR) will be established. R&D on nuclear fusion will also be promoted through international collaboration, such as through the ITER Project.

The Nuclear Energy X Innovation Promotion (NEXIP) program is ongoing.

Several types of reactors (LWR, SMR, SFR, HTGR, MSR) are being proposed from the private sector. The government financially supports this program, and the Japan Atomic energy Agency (JAEA) offers technical support.

In terms of LWRs, 9 units have restarted, 7 units certified and 11 units are under examination under a new nuclear regulation.

The High Temperature Engineering Test Reactor (HTTR), the JAEA's 30 MW experimental HTGR, restarted operation on 30 July 2021. While the HTTR was not severely damaged after the great earthquake of 2011 in Japan, regulatory requirements were enhanced in view of the lessons learned from the accident at the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi Nuclear Power Station. After a five-year safety review by the Nuclear Regulation Authority, in conformity with new regulatory requirements, the JAEA obtained permission to restart the HTTR without significant reinforcement. The JAEA will carry out the safety demonstration tests by using the HTTR under the framework of an OECD/NEA project. Also, the JAEA has plans to conduct various tests to confirm safety, core physics and the thermal-fluid characteristics, as well as fuel performance. Furthermore, a demonstration plan for hydrogen production by the HTTR is under discussion.

The experimental reactor, Joyo, has been approved for the development of a large production of medical radioisotopes, which is seen as essential to Japan's growth strategy from the perspective of economic security, and several billion yen is expected to be allocated in the budget for the fiscal year 2021. Additionally, plans are underway to build a new research reactor in Tsuruga.

Korea

Nuclear power in Korea

A total of 24 nuclear power reactors (21 pressurized water reactors [PWRs) and 3 CANDUs) were in operation as of October 2021, providing 160 184 GWh of electricity that corresponds to 29% of the total electricity production in Korea. The installed nuclear capacity of these 24 reactors accounts for 17.7% (23 250 MWe) of the total capacity. Two PWRs, Shin-Kori units 5 and 6, are under construction. Shin-Hanul unit 1 was recently permitted to operate, but Shin-Hanul unit 2 is still waiting for permission to operate.

Nuclear energy policy and R&D in Korea

The goal of Korea's national energy policy has changed, with the portion of power generation from renewable energy sources increasing to 20% by 2030, and the share of nuclear and coal-based electricity production gradually reducing. During 2021, the Korean government established the 2050 Carbon Neutrality Committee under the direct control of the President of Korea. The committee presented the nationally determined contribution (NDC) by 2030 as a 40% reduction compared to 2018 emissions.

The government still supports both the export promotion of nuclear power plants, R&D activities relevant to enhancing nuclear safety and nuclear dismantling and disposal technology. Remarkably, in April 2021, the national assembly, the government, industry, academia and research institutes have gathered together to prepare a plan for the development of an innovative SMR. It was an official, new movement to develop an innovative SMR in Korea. The Korea Hydro & Nuclear Power Co. and the Korea Atomic Energy Research Institute announced the cooperative development of an LWR-based SMR by 2028.

Sodium-cooled fast reactor

As for SFR developments, current SFR R&D activities focus mainly on obtaining the technical feasibility of SFR technologies, coupled with pyro-processing to support back-end fuel cycle activities as an alternative option for domestic spent nuclear fuel management. In September 2021, a commission was established to examine the adequacy of pyro-processing and the SFR technology. A further R&D program to develop pyro-processing and SFR technologies will be planned just after the commission's decision by the end of this year.

SFR development is also focusing on the new SMR market in near future. The dedicated SFR project granted by the Korean government started in early 2021, and is focused mainly on the development of an SFR-based SMR that facilitates global export towards a market expected in the middle of 2030s. The ongoing SFR project consists of three groups of common and necessary technologies, which are dealing with a set of sodium experimental capabilities, advanced modeling and simulation, and innovations in metal fuel technologies. The specific R&D areas include multi-physics analyses methods coupling fluidic characteristics with thermal-structural behaviors, the uncertainty quantification methodology in the field of reactor core thermal hydraulics, high-fidelity advanced instrumentation technologies for practical applications and sodium-free annular metal fuel technologies.

Very-high-temperature gas-cooled reactor

In early 2019, the Korean government announced its national plan for the hydrogen economy, which centers on two axes of hydrogen-powered vehicles and the hydrogen fuel cell. Hydrogen demand in the 2040s is expected to reach 5.26 million tons per year. Nuclear hydrogen production using VHTRs was evaluated as one of the possible clean hydrogen production technologies.

A project, called "Very High Temperature System (VHTS) Key Technology Development", was launched in April 2020 to develop the performance evaluation technologies of design and analysis codes, and the performance verification technologies of high-temperature materials. In addition, a sub-project of VHTS key technology development, called "Development of essential technologies for hydrogen production coupled with VHTS", was launched in April 2021. This sub-project focuses on the development of coupled technologies between the very high-temperature system and high-temperature steam electrolysis (HTSE) hydrogen production. Hydrogen production tests will be completed with a 6 kWe HTSE module using high-temperature steam from the very high-temperature helium loop.

Russia

The generation of electricity by nuclear power plants in Russia in 2020 reached 215.74 billion kilowatt-hours. This is an absolute record in the country's nuclear power industry since Soviet Union times. According to Concern Rosenergoatom forecasts, in 2021, it is expected that Russian nuclear power plants will generate electricity at the level of 218 billion kWh.

In early June 2021, the first unit of the Belarusian nuclear power plant was put into commercial operation, and the construction of the second unit of this plant will be completed by the end of the year. In May 2021, China launched the construction of the units 7 and 8 of the Tianwan nuclear power plant, as well as units 3 and 4 at the Xiudapu nuclear power plant. In June 2021, the construction of the fifth unit of the Kudankulam nuclear power plant in India also began. In March, work started on the third unit of the Akkuyu nuclear power plant in the Republic of Türkiye.

Manufacturing of equipment for China's CFR-600 fast neutron reactor is underway and progressing well.

Rosatom has signed an agreement with the Russian Republic of Yakutia for the construction of a low-power, ground-based nuclear power plant, based on the SMR RITM-200, in Ust-Yansky Ulus. Four units are to be constructed, and a license for the construction has been obtained.

Rosatom's first wind power plant (WPP) – Adygeyskaya – with a capacity of 600 MW, has been commissioned. Another wind farm – Kochubeevskaya in Stavropol – is under construction.

The optimization of competitiveness for the BN-1200M project has been completed and a recommendation has been received from Rosatom's Scientific and Technical Councils on its construction as the 5th unit of the Beloyarsk nuclear power plant.

A full-scale industrial production of mixed uranium-plutonium oxide fuel for the BN-800 fast neutron reactor has been put in place at FSUE GHK. In 2020, the first reloading of the BN-800 reactor core with MOX fuel (one third of the core) was successfully completed, confirming the possibility to provide the full fuel supply for the BN-800 reactor. In the same year, the first batch of BN-800 fuel assemblies was manufactured with MOX fuel from highly-radioactive plutonium dioxide extracted from the VVER reactor's spent nuclear fuel (SNF).

In 2022, it is planned to load the next batch of BN-800 MOX fuel assemblies, which will completely transfer the core of the BN-800 reactor to this type of nuclear fuel.

Construction work at the site of the multi-purpose fast neutron research reactor MBIR is continuing at a good pace. In 2021, construction and installation works are 10-15% ahead of schedule.

The reactor vessel was manufactured at the Atommash factory. An intermediate slab was installed at the base of the reactor shaft, on which the installation of related equipment has begun.

In July 2021, the international consortium agreement was signed that legally formalized the relations of the first key participants of the consortium, and fixed the rights and obligations of participants for the use of the MBIR reactor resource after reactor commissioning.

Rosatom is open to international partners' accession to the International Research Center Consortium.

Rosatom has begun to shape the appearance of a new technological platform in Russia for nuclear generation in the horizon after 2030 – two-component nuclear energy with a closed nuclear fuel cycle. It will multiply the available fuel supply and solve issues related to the management of SNF.

In June of this year, the construction of a nuclear power unit with a fast neutron reactor, BREST-300, was launched in Seversk, in the Tomsk region. For the first time in the world, a nuclear power plant with a fast neutron reactor and facilities for a closed nuclear fuel cycle will be constructed at the same site. This is, without exaggeration, a milestone for the global nuclear power industry.

Mr Mariano Grossi, Director General of the International Atomic Energy Agency (IAEA), and other partners took part in the ceremony in virtual mode. The construction of the fuel fabrication and refabrication module has been completed, and the stage of installation of technological equipment has begun. For nitride fuel, the characteristics of fuel readiness for a burnout level of 6% have been fully confirmed. This research continues and results have been obtained for the burnout of 9%, and assemblies are being prepared to achieve a burnout of 12%, which is the most economically justified level for the BREST-300 reactor. Research for the BREST-300 SNF reprocessing cycle has been completed. It is has been proven that C-14 is exuded at the level of 99.9%.

A side event was held at the IAEA General Conference to demonstrate the success of this breakthrough project and to start organizing international partnerships based on the new technological platform mentioned above.

Rosatom has joined work recognizing nuclear energy as a "green" source of power and promoted nuclear energy as such at the 2021 United Nations Climate Change Conference in Glasgow.

New "developments for the future" in the nuclear industry are being carried out within the framework of the Russian state approved integrated program entitled "Development of equipment, technologies and scientific research in the field of nuclear energy use in Russia for the period up to 2024". The program includes research on two-component nuclear power, the development of an experimental infrastructure, thermonuclear and plasma technologies, new materials and technologies for advanced energy systems, and reference (baseline) nuclear power plant power units, including low-power nuclear power plants and VVERs with spectral regulation.

As part of GIF work, Rosatom is considering the possibility of signing the System Agreement on molten salt reactors, as well as additions to Project Agreements on "Improved Fuel and Safety and Operation of fast sodium neutron reactors".

A project agreement has been signed on the equipment projects and the SFR energy conversion unit, and a project agreement on thermal hydraulics and safety is being prepared as part of the work on supercritical reactors. In 2021, Mr A.V. Moiseev, a representative from Russia, was elected Chair of the interim System Steering Committee for the LFR.

In September 2021, Kuzina Yu.A., from the Institute of Physics and Power Engineering in Russia, held a webinar on "Experimental R&D in Russia in support of fast neutron reactor projects".

South Africa

Nuclear new build program

Following the issuance of a non-binding request for information (RFI) in June 2020 for 2 500 MW of nuclear energy, the Department of Mineral Resources and Energy received twenty-five responses globally from nuclear technology vendor companies. The assessment of received responses, which culminated in a consolidated report, was completed in March 2021 and it showed that there is a strong interest from nuclear technology vendor companies for delivery of the South African nuclear new build program, which is envisaged to comprise conventional nuclear power plants and SMRs.

In August 2020, the Department of Mineral Resources and Energy submitted a Determination under Section 34 of the Electricity Regulation Act of 2008 for 2 500 MW of nuclear energy to the National Electricity Regulator of South Africa (NERSA) for concurrence. The public consultation process was thereto undertaken in February 2021. In August 2021, NERSA issued a concurrence under Section 34 of the Electricity Regulation Act of 2008 for 2 500 MW of nuclear energy to be procured. The NERSA concurrence came with a number of suspensive conditions, which the department is currently engaged in a process to address.

Subject to Cabinet approval, discussions are ongoing to revive research and development of the Pebble Bed Modular Reactor Programme in line with the government policy position as stated in the Nuclear Energy Policy of 2008. R&D work is expected to consolidate all previous efforts, including work progress by Eskom for advanced high-temperature reactor technology development.

Koeberg long-term operation

Eskom's implementation of the Koeberg Long-Term Operation Programme is continuing as planned and is subject to the National Nuclear Regulator (NNR) Act, 1999 requirements. The Koeberg nuclear power plant reaches its 40-year end-of-design life in 2024, and in January 2021, Eskom submitted a formal application to the NNR to extend the operating license of the Koeberg nuclear power plant for another 20 years until 2044. It is anticipated that Eskom will submit a safety case for long-term operation to the NNR by July 2022.

Strengthening the regulatory framework for long-term operation of nuclear installations in South Africa, the Minister of Mineral Resources and Energy gazetted regulations in March 2021 in terms of Section 36 of the NNR Act, 1999, on long-term operations of nuclear installations.

Multi-purpose reactor project

In September 2021, the Cabinet favorably considered the project initiation report and approved the setting up of the multi-purpose reactor project to replace the SAFARI-1 research reactor by 2030. The prefeasibility report has been completed by the South African Nuclear Energy Corporation and has undergone an independent gateway review, following which the project has entered the feasibility stage and is planned to be completed by mid-2023. This will include an RFI, site licensing, environmental impact assessment and concept design, as well as communication and stakeholder engagement activities to be initiated in 2022.

Centralized interim storage facility

The Republic of South Africa, through the National Radioactive Waste Disposal Institute, and with oversight by the Ministerial Steering Committee, is implementing a centralized interim storage facility project for off-site storage of SNF. The pre-feasibility report for the centralized interim storage facility project has been submitted to Cabinet and noted. The project is currently in the feasibility phase and is planned for commissioning in 2030.

Radioactive Waste Management Fund Bill

The Radioactive Waste Management Fund Bill, aimed at collecting funds through the polluter pays principle for management of SNF, is at an advanced stage of drafting, with the bill currently being consulted via different Cabinet clusters with the aim of obtaining Cabinet approval to publish the bill for public comment soon.

National Nuclear Regulator Act Amendment Bill

On 12 May 2021, Cabinet approved the publication of the National Nuclear Regulator Act Amendment Bill for public comment, which was done in June 2021. The act has been amended to, among others, strengthen issues of nuclear security and give effect to enforcement powers for nuclear inspectors. The department aims to complete all of the necessary work to approach Cabinet so as to obtain approval for the bill to be tabled in Parliament soon.

Switzerland

GIF activities

The operation of the Paul Scherrer Institute (PSI), where most of GIF research activities are taking place, were maintained at all times in spite of the COVID-19 pandemic.

On the MSR research side, the major focus is on safety, without a particular preference for a specific MSR concept. However, the fast reactor option is being considered as a reference system and chloride salt as the potentially most promising salt type for fuel cycle simplicity. During 2021, studies related to the breed-and-burn fuel cycle in the molten chloride fast reactor were ongoing at PSI.

The SFR research studies are also focusing on reactor safety in order to define design improvements. The Horizon-2020 ESFR-SMART project, coordinated by the PSI and devoted to safety of one of the Gen-IV systems was prolonged by one year to address delays in experimental works resulting from COVID-19. Two project proposals related to SFR safety assessment, with significant participation on the part of the PSI, have been submitted to Euratom.

On the materials research side, a focus has been set on the development of new analytical tools for high-temperature materials. It includes the preparation of a laser and infrared-based equipment to measure the thermal conductivity of tubular silicon carbide (SiC) composite materials. This also represents an extension of a former approach using a unit based on thermocouples and a central heating wire. It is part of a running PhD thesis on the micro/macro-structure analysis of the SiC composite, based on X-Ray tomography and the connection to the measured conductivity values trough finite element method (FEM) models. In addition, a new synchrotron-based tomography analysis method, delivering a significantly increased resolution and contrast that not only shows the pores but also the fibers in the composite, is being developed. This will enable an extension of the thermal conductivity model by the interfaces between the matrix and the fibers.

A milestone has also been reached with the integration of the PSI creep data in the Materials Handbook.

Switzerland (Mr Manuel Pouchon) co-chaired the biannual VHTR Materials PMB virtual meetings in September 2021, and delivered an update on the Swiss situation and Gen-IV related materials research.

Switzerland, represented by Mr Pouchon, regularly participates in GIF AMME-TF meetings, which will potentially have some implications for the materials/components of Gen-IV reactors.

Finally, a new PhD thesis focusing on the basic mechanisms of irradiation induced creep has started at PSI. This study is based on the measurement of diffusion coefficients in unstrained, strained and strained plus

irradiated samples. This thesis will help to develop the corresponding creep model, which is not well understood today. Knowledge of the mechanism will lead to a better understanding of the materials behavior under intense radiation and high temperatures. These conditions are typical for Gen-IV systems.

Politics and regulation

The Swiss government has confirmed its strategy to reach net-zero CO_2 emissions in 2050.

The new "Energy Research Masterplan of the Federal Government", for the period 2021-2024, was released in November 2020. It clearly states the need to maintain expertise in the nuclear energy field in Switzerland and maintains nuclear energy research as an important component, also explicitly underlining research on Gen-IV reactors. The support to nuclear energy research is also integrated into the research strategy of the ETH Board, the strategic management body of federal polytechnic schools and research institutes.

The Swiss Federal Nuclear Safety Inspectorate (ENSI) has released new guidelines, in particular concerning the requirement for a geological waste repository. ENSI continues to systematically update and adapt these guidelines to the IAEA requirements.

A two-week IAEA Integrated Regulatory Review Service (IRRS) mission took place in Switzerland from 18-29 October 2021.

Operation of Swiss nuclear power plants and waste management

The dismantling of the Mühleberg/boiling water reactor (BWR) is advancing quickly and according to plan.

The Leibstadt BWR reactor has undergone an extensive revision, including the replacement of the main reactor circulation pumps, in spite of the COVID-19 crisis. The plant was restarted at the beginning of December 2021, with about a one-month delay in scheduling.

Other reactors are in operation and running at nominal power.

Nagra, the company in charge of realizing the final repository for nuclear waste in Switzerland, has almost completed all deep drillings (one is still ongoing) to acquire detailed information on the geology of the three possible locations for a geological waste repository. The results of these studies are meant to determine the detailed geological differences between the possible sites and back up the final choice for the location of the repository, which should be announced at the end of 2022. Nagra published a detailed report on the state of knowledge and research at the end of 2021 as requested by the Swiss regulation. The safety authorities (i.e. ENSI) will evaluate the report during 2022.

Nuclear-power-related research in Switzerland

The focus of the Nuclear Energy and Safety Division (NES) at PSI is to deliver a strong contribution to the education of the next generation of nuclear experts, scientific support for the safe operation of LWRs, delivery of the scientific basis for the assessment of deep geological repositories' safety and the technology monitoring, including research work on Gen-IV concepts.

Three new professors with leading functions in NES have been appointed and will contribute to know-how conservation in nuclear engineering and associated fields (radiochemistry, high performance computing, modeling and data science, energy system analysis) in Switzerland. They are also actively participating in the Swiss Master Course in Nuclear Engineering at the two polytechnic schools (i.e. ETHZ and EPFL).

In spite of the non-association of Switzerland to the HORIZON-Europe research initiative, PSI researchers are nevertheless actively participating at many consortia. Their participation will be financed directly by Switzerland's State Secretariat for Education, Research and Innovation.

United Kingdom

Nuclear energy update

The United Kingdom was the lead on the *Pathways to net zero using nuclear innovation* publication for the Nuclear Innovation: Clean Energy (NICE) Future Initiative on the occasion of the 2021 Clean Energy Ministerial.

The UK government has also confirmed its decision to adopt the UK Climate Change Committee's Sixth Carbon Budget in full, thereby setting a new target to cut UK carbon emissions by 78% by 2035.

In the second quarter of 2021, low-carbon sources generated 53.1% of the United Kingdom's total electricity generation. Renewables accounted for 37.3% and nuclear 15.8%. These figures were lower than last year, driven by lower wind speeds, a decrease in solar and hydro generation due to weather conditions and outages at all but one of the UK's nuclear power plants.

Plans continued to establish the Regulated Asset Base (RAB) model to fund new nuclear projects at a low cost of capital, saving consumers money.[7]

The UK government aims to bring at least one large-scale nuclear project to the point of a final investment decision by the end of this Parliament, subject to clear value for money and all relevant approvals.

7. According to the UK government: "The Nuclear Energy (Financing) Bill will introduce a Regulated Asset Base (RAB) model as an option to fund future nuclear projects. A RAB model is a tried and tested method, typically used in the UK, to finance large scale infrastructure assets such as water, gas and electricity networks. Under this model a company receives a license from an economic regulator to charge a regulated price to consumers in exchange for providing the infrastructure in question." See: www.gov.uk/government/news/future-funding-for-nuclear-plants.

In December 2020, the UK government announced the start of formal negotiations on Sizewell C, and those negotiations are ongoing.

A new GBP 120 million Future Nuclear Enabling Fund is to provide targeted support in relation to barriers to entry for advanced nuclear technologies. Further details of how this fund will operate will be published in 2022, alongside details of a roadmap for deployment that takes into account value for money.

This new fund is also supported by the existing Advanced Nuclear Fund of up to GBP 385 million to invest in the next generation of nuclear energy. Including up to GBP 215 million for SMRs and up to GBP 170 million for an R&D program to deliver an advanced modular reactor by the early 2030s.

The Generic Design Assessment (GDA) was opened in May 2021 to advanced nuclear reactors.[8] Rolls-Royce (as part of the UKSMR consortium) have stated their intention to make an application to enter the GDA.

COP26 update

The UK COP26 Presidency convened the Climate and Development Ministerial on 31 March 2021. The COP26 President emphasized the need for partners to come together around practical solutions. He reiterated that steps that would be taken today were in support of the COP26 Presidency's stated goals of cutting emissions to keep 1.5 degrees in reach, facilitating greater action on adaptation, mobilizing finance for climate action and coming together to make the COP26 negotiations a success.

The UK Presidency continued to work with countries, institutions, civil society and others on issues and actions in the run up to COP26.

UK GIF membership update

The UK is continuing to present project proposals for engagement with the GIF SFR and VHTR Project Arrangements and will be seeking formal agreement from the other partners to join these arrangements as soon as possible. A big thank you to all those coordinating this approval process and the hard work supporting the United Kingdom's wider engagement with GIF's exciting agenda.

The GIF Economic Modelling Working Group (EMWG) report, covering financing of nuclear energy, was released in August. We would like to thank Fiona Reilly, Co-Chair of the EMWG, for her work leading this white paper, which identified barriers to private sector investment and provided recommendations on the changes required to remove these barriers. This report will help realize the potential of advanced nuclear systems to meet the wider world energy demands and the decarbonization agenda in a flexible manner, and alongside other low-carbon energy production.

The United Kingdom has joined the interim Non-Electric Applications of Nuclear Heat Task Force (NEaNH) and looks forward to working with other task force members on taking this work forward across all six GIF technologies.

Public perception

"Sciencewise" is a program set up to assist UK government policymakers in conducting public dialogue to inform their decision making on science and technology issues. The UK government is working with Sciencewise to deliver a number of virtual 'public dialogue' events in order to explore views around modular nuclear technologies (SMRs and AMRs). The outputs from this project were published in August 2021.

International collaboration

The United Kingdom was the lead on the *Pathways to net zero using nuclear innovation* publication for the NICE Future initiative on the occasion of the Clean Energy Ministerial 2021.

This publication brought together policy perspectives on nuclear innovation's role in helping countries achieve their decarbonization goals.

Regulation and Generic Design Assessment

Generic Design Assessment (GDA) is the process carried out by the Office for Nuclear Regulation (ONR) and the Environment Agency to assess the safety, security and environmental protection aspects of a nuclear power plant design.

The GDA provides confidence that the proposed design is capable of being constructed, operated and decommissioned in accordance with the standards of safety, security and environmental protection.

UK Government funding since 2017 has enabled the ONR to shape multilateral and bilateral cooperation towards practical deliverables, common regulatory positions and harmonization on key technical regulatory expectations that are aligned with the UK regulatory framework.

In May 2021, the United Kingdom opened the GDA to advanced nuclear reactors.[9]

Research and development

In July 2021, the UK government launched a "call for evidence", inviting views on the UK government's preference to explore the potential of HTGRs to enable an AMR demonstrator by the early 2030s and support net zero by 2050.[10]

The Call for Evidence closed on 9 September 2021 and found no significant, additional evidence to materially change the outcome of the government's underpinning analysis.

8. See section entitled "Regulation and Generic Design Assessment" on page 91, and www.onr.org.uk/new-reactors/.
9. See: www.gov.uk/government/publications/entry-to-the-generic-design-assessment-for-advanced-nuclear-reactors.
10. See: www.gov.uk/government/publications/advanced-modular-reactors-amrs-technical-assessment.

As a result, the AMR RD&D Program will focus on HTGRs with the ambition for this to lead to a HTGR demonstration by the early 2030s, at the latest. The scope of the program is being developed.

United States

Nuclear energy continues to be a vital part of energy development strategy to put the United States on a path to net-zero emissions by 2050. The US Department of Energy (DOE) is aggressively working to revive, revitalize and expand nuclear energy capacity as we appreciate a historic period of unified congressional support for nuclear energy. The US Office of Nuclear Energy (NE) is leading the effort to move new and innovative advanced reactors, SMRs and microreactors from the conceptual and development stages into the commercial energy sector. The NE executes its mission through investments in research and development efforts with national laboratories, US universities and industry technical organizations, as well as through partnerships with the US industry and commercial stakeholders to develop and demonstrate advanced reactor technologies and designs.

The following summary briefly highlights some of the activities supported by the DOE-NE in 2021 to accelerate the development and deployment of advanced reactor technologies.

Advanced Reactor Demonstration Program

Recognizing the importance of advanced reactors meeting the Nation's energy security and climate change goals, the Advanced Reactor Demonstration Program (ARDP) was initiated in fiscal year 2020 to develop federal and US nuclear industry partnerships in the construction and demonstration of domestic advanced nuclear reactor designs that are safe and affordable to build and operate. The ARDP directly addresses advanced reactor development, demonstration and deployment through two focused pathways: advanced reactor demonstration and risk reduction for future demonstration.

Advanced reactor demonstration pathway

The goal of the advanced reactor demonstration pathway is to realize the construction and operation in the US of two innovative reactor designs within a seven-year time period, following the initiation of the awards. The NE selected two projects to be supported through the demonstration pathway, and cost-shared cooperative agreements for the two reactor projects were completed in early 2021. The two designs that are to be built and operated by calendar year 2028 under this pathway are:

Natrium by TerraPower, LLC: Natrium is a 345 MWe SFR that leverages decades of development and design undertaken by TerraPower and its partner, General Electric-Hitachi. The high operating temperature of the Natrium reactor, coupled with a molten salt thermal energy storage system, will allow the plant to provide flexible electricity output that could complement variable renewable generation technologies such as wind and solar. In November 2021, Team Natrium announced its intent to site the demonstration reactor at the Naughton coal plant site in Kemmerer, Wyoming. By demonstrating the Natrium reactor at a retired coal plant, TerraPower will not only take advantage of the existing energy infrastructure that is in place, but also the workforce. This project will leverage innovations from the concentrated solar power, tunneling and combined cycle gas turbine industries, and intends to utilize the latest advanced construction and manufacturing methods to bring thousands of jobs back to the area. Also, given the potential synergies between Natrium and the DOE Versatile Test Reactor (VTR) project, stakeholders from both projects have developed an MoU to facilitate collaborations between the two projects, with the intent of optimizing technology development cost and schedule for both efforts.

Xe-100 by X-energy, LLC: The Xe-100 is a 100 MWe pebble-bed high-temperature gas-cooled reactor that is ideally suited to provide flexible electricity output, as well as process heat for a wide range of high-temperature industrial heat applications, such as desalination and hydrogen production. The reactor will be fueled by TRISO pebbles, providing a robust safety profile. The demonstration is currently planned to be sited at the Hanford, Washington reservation on land leased to the US utility, Energy Northwest. X-energy is working with an affiliated local utility, Grant County Public Utility District, to become the owner/operator of the plant so as to provide electric power to their service district.

Risk reduction for future demonstration pathway

The goal of the risk reduction for future demonstration pathway is to support potential future demonstration of additional advanced reactor technologies through cost-shared, competitively awarded projects that are designed to maximize the utility of the results across the nuclear energy industry. The DOE NE selected five projects to aid advanced reactor developers in resolving technical, operational and regulatory challenges to enable future demonstration of a diverse set of advanced reactor designs. The risk reduction projects support the development of safe and affordable advanced reactor technologies that can be licensed and deployed over the next 10 to 14 years. The five projects selected for award are:

- Hermes Reduced-Scale Test Reactor by Kairos Power, LLC: Kairos Power will design, construct and operate its Hermes reduced-scale test reactor, which is intended to lead to the development of their commercial-scale fluoride salt-cooled high temperature reactor concept. The NE is working to complete this cooperative agreement in the near term.
- eVinci™ Microreactor by Westinghouse Electric Company (WEC), LLC: WEC will advance the design of a heat pipe-cooled microreactor which uses TRISO fuel for operation. In December 2021,

the cooperative agreement for the WEC award was finalized, and project activities were initiated.

- BWXT Advanced Nuclear Reactor (BANR) by BWXT Advanced Technologies, LLC: BWXT Advanced Technologies will develop a commercially viable transportable microreactor with the design focused on using TRISO fuel particles to achieve higher uranium loading and an improved core design. The NE is working to complete this cooperative agreement in the near term.
- Holtec SMR-160 Reactor by Holtec Government Services, LLC: The Holtec-led project will support early-stage design, engineering and licensing activities to accelerate the development of Holtec's light water-cooled SMR design, and is the only water-cooled design supported through the ARDP. In November 2021, the cooperative agreement for the Holtec award was finalized, and project activities were initiated.
- Molten Chloride Reactor Experiment by Southern Company Services Inc.: The Southern Company Services-led project will support the design, build and operation of the Molten Chloride Reactor Experiment (MCRE) at Idaho National Laboratory (INL). In the first year of the project, the team will focus on completion of the MCRE conceptual design to support development of safety and environmental compliance documents. In September 2021, the cooperative agreement for the Southern Company Services award was finalized, and project activities were initiated.

National Reactor Innovation Center

The ARDP also provides support for the National Reactor Innovation Center (NRIC). The NRIC was authorized by the Nuclear Energy Innovation Capabilities Act (NEICA) of 2017 and was formally established in 2019. The mission of NRIC is to enable and accelerate the development and demonstration of advanced reactors by harnessing the unique capabilities of US national laboratories. In July 2021, the NRIC announced a cost-shared partnership with a team led by General Electric Hitachi to develop three advanced construction technologies that together can reduce the cost of new nuclear build by more than 10%. The project team will leverage promising technologies from other industries that have not been tested within the context of nuclear energy. These include:

- vertical shaft construction, a best practice from the tunneling industry that could reduce construction schedules by more than a year;
- Steel Bricks™, modular steel-concrete composite structures, much like high-tech LEGO® pieces, which could significantly reduce the labor required on site;
- advanced monitoring, coupled with digital twin technology, which can create a 3-D replica of the nuclear power plant structure.

These technologies can be applied to a variety of advanced reactor designs to significantly improve the economics of bringing advanced reactors to market.

Advanced reactor regulatory development

The Advanced Reactor Regulatory Development program, funded through the ARDP, coordinates with the US Nuclear Regulatory Commission (NRC) and industry to address and resolve key regulatory framework issues that directly impact the critical path to advanced reactor demonstration and deployment. Since 2019, the DOE-NE has supported the development of an industry-driven proposal to the NRC for risk-informed and "right-sized" license application content for advanced reactors to reduce regulatory uncertainty and support near-term demonstrations and deployments. In August 2021, this license application content guide was submitted to the NRC for review and potential endorsement. A decision by the NRC on endorsement of the content guide is expected in 2022.

Advanced reactor concepts-20

The DOE-NE selected three awards to support the development of designs that could have a significant impact on the energy market in the mid-2030s or later. In 2021, the cooperative agreements for all of the three advanced reactor concepts-20 (ARC-20) awards were finalized, and project activities were initiated. The three projects selected are:

- Inherently Safe Advanced SMR for American Nuclear Leadership by Advanced Reactor Concepts, LLC: The Advanced Reactor Concepts award will support the development of a 100 MWe pool type SFR design.
- Fast Modular Reactor Conceptual Design – General Atomics: The General Atomics award will support development of a 50 Mwe gas-cooled fast modular reactor.
- Horizontal Compact High Temperature Gas Reactor by the Massachusetts Institute of Technology (MIT): The MIT award will support the development of a modular integrated gas-cooled high temperature reactor.

Versatile test reactor

The versatile test reactor (VTR) project, formally launched in February 2019, is a critical part of the US effort to modernize its nuclear R&D user facility infrastructure. The VTR will provide a leading-edge capability for accelerated testing and qualification of advanced fuels and materials in support of the next generation of nuclear reactors.

Following issuance of the Draft VTR Environmental Impact Statement (EIS) for public review and comment on 31 December 2020, the DOE made revisions and created a comment response document. The subsequent Final VTR EIS has been prepared and will be issued in early calendar year 2022. The Final VTR EIS retains the INL as the VTR's preferred location and examines all environmental factors to support the DOE's final decision. The final decision, known as the Record of Decision, can be issued 30 days after the Final VTR EIS is published. The DOE is working with Congress to ensure that the VTR is appropriately funded in fiscal year 2022 and in a manner that reflects the administration's prior-

ity for the advanced reactor demonstration projects and the need to sustain VTR progress on critical systems in order to deliver the critical capabilities that the VTR will provide to support long-term nuclear energy innovation.

Clean hydrogen generation

The NE, in collaboration with other DOE offices, has been working to further the integration of hydrogen production processes with nuclear power plants, including high-temperature steam electrolysis (HTSE). In the past year, the DOE launched the Energy Earthshots Initiative to accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade. The first Energy Earthshot – Hydrogen Shot – focuses on reducing the cost of clean hydrogen. In support of the Hydrogen Earthshot, the DOE issued an RFI on viable hydrogen demonstrations, including specific locations, which can help lower the cost of hydrogen, reduce carbon emissions and local air pollution, create good-paying jobs and provide benefits to disadvantaged communities. The DOE also recently announced USD 20 million in funding to demonstrate technology that will produce clean hydrogen energy from nuclear power.

Fiscal year 2022 congressional budget request

In May 2021, the DOE released its FY22 Congressional Budget request, which seeks a record USD 1.8 billion for the NE. This is a historic level of commitment by the Biden-Harris Administration, and it clearly recognizes the role new reactors could play in helping to combat climate change, as well as the need for investments to deploy new technologies to market. The FY22 request includes nearly USD 700 million to help drive innovative US advanced reactor technologies to market within the decade. It includes USD 245 million to support the demonstration of two US reactors[11] in the near future and USD 305 million to support the maturation of additional reactor designs.[12] The request also supports further development of microreactor and SMR technologies.

In the summer of 2021, the DOE-NE received FY22 Congressional Marks from the House and Senate. The Congressional marks also emphasized the importance of advanced reactors in meeting our climate change goals, and provided strong support for advanced reactor development and demonstration programs. Both marks provided USD 245 million for the two ARDP demonstration projects, USD 55 million for the NRIC, USD 15 million for advanced reactor regulatory development, and they included funding for the Advanced Reactor Technologies program, advanced SMR RD&D, TRISO fuel and graphite qualification and the ARDP Risk Reduction awards. Both marks also provided support for a new program, which would ensure the availability of high-assay low-enriched uranium to support advanced reactor demonstration needs. The next step in the budget process requires the House and Senate to resolve any discrepancies via conference prior to finalizing the FY22 appropriation.

Infrastructure Investments and Jobs Act

The Infrastructure Investments and Jobs Act was signed into law on 15 November 2021. The act includes more than USD 62 billion[13] for the DOE to help transition the United States to a clean energy economy, and that includes leveraging the nation's largest single source of clean power—nuclear energy.[14] The act includes USD 6 billion to start a Civil Nuclear Credit program, where owners or operators of commercial US reactors can apply for certification, and competitively bid on credits to help support their continued operations and avoid premature retirements due to financial hardship. The DOE plans to seek public feedback to help set up the program and could start awarding its first credits to US nuclear power plants as early as this fall. The new legislation also allocates USD 8 billion to demonstrate regional clean hydrogen hubs, including at least one hub dedicated to the production of hydrogen with nuclear energy. Initial selections could be awarded before the end of the year. The DOE currently supports four clean hydrogen demonstration projects at commercial nuclear power plants across the country which are also part of the Department's Hydrogen Shot goal[15] to reduce the cost of hydrogen to USD 1 per 1 kilogram in one decade. Finally, the act provided USD 2.477 billion to support the two ARDP demonstration projects.

11. See: www.energy.gov/ne/articles/us-department-energy-announces-160-million-first-awards-under-advanced-reactor.
12. See: www.energy.gov/ne/articles/infographic-advanced-reactor-development.
13. See: www.energy.gov/articles/doe-fact-sheet-bipartisan-infrastructure-deal-will-deliver-american-workers-families-and-0.
14. See: www.energy.gov/ne/articles/5-fast-facts-about-nuclear-energy.
15. See: www.energy.gov/eere/fuelcells/hydrogen-shot.