

# Board of Governors General Conference

**GOV/INF/2012/12-GC(56)/INF/6**

Date: 15 August 2012

**General Distribution**

Original: English

---

## **For official use only**

Item 6(a) of the Board's provisional agenda

(GOV/2012/34)

Item 16 of the Conference's provisional agenda

(GC(56)/1 and Add.1)

# International Status and Prospects for Nuclear Power 2012

*Report by the Director General*

---

## **Summary**

- General Conference resolution GC(55)/RES/12 requested the Secretariat to update in 2012 its report on the International Status and Prospects of Nuclear Power (document GC(54)/INF/5, issued in 2010), which provides a comprehensive overview of the international status and prospects of nuclear power. This report responds to that resolution.



# International Status and Prospects for Nuclear Power 2012

*Report by the Director General*

## **A. Developments since 2010**

1. After two years of small declines, global nuclear power capacity first increased by 4 GW(e) in 2010 to 375 gigawatts (GW(e)) and then dropped in 2011 to 368 GW(e) after the accident at the Fukushima Daiichi nuclear power plant. In 2010, five new reactors were connected to the grid and one was permanently retired. In 2011, seven new reactors were connected but thirteen were permanently retired. Twelve of the thirteen retirements were directly due to the Fukushima Daiichi accident. The number of construction starts on new reactors increased in 2010 for the seventh year in a row to 16, but dropped in 2011 to 4.
2. Globally the Fukushima Daiichi accident is expected to slow the growth of nuclear power but not reverse it. In the Agency's 2011 updated low projection, global nuclear power capacity grows from 370 GW(e) today<sup>1</sup> to 501 GW(e) in 2030, down 8% from what was projected in 2010. In the updated high projection, capacity grows to 746 GW(e) in 2030, down 7% from 2010's projection.
3. Among countries introducing nuclear power, interest remains high. Of the countries without nuclear power that, before the Fukushima Daiichi accident, had strongly indicated their intentions to proceed with nuclear power programmes, a few subsequently cancelled or revised their plans, others took a 'wait-and-see' approach, but most continued with their plans. In September 2011, a nuclear power plant went into operation in the Islamic Republic of Iran.
4. The 2011 edition of the 'Red Book', *Uranium: Resources, Production and Demand*, jointly prepared by the Organisation for Economic Co-operation and Development's (OECD's) Nuclear Energy Agency (NEA) and the IAEA, estimated identified conventional uranium resources at less than \$130/kg U at 5.3 Mt U, a decrease of 1.4% compared to the 2009 edition. At the projected 2012 rate of consumption, the lifetime of 5.3 Mt U would be 78 years.
5. In December 2010, the Agency's Board of Governors approved the establishment of an IAEA low enriched uranium (LEU) bank to be funded by \$150 million in voluntary contributions. The Agency accepted an offer from Kazakhstan to host the bank. In February 2011, the agreement between the Government of the Russian Federation and the Agency that established a low enriched uranium (LEU) reserve in Angarsk, Russian Federation, entered into force. In March 2011, the Board of Governors approved a proposal for a 'Nuclear Fuel Assurance' by the UK, cosponsored by the

---

<sup>1</sup> 30 June 2012.

European Union (EU), the Russian Federation and the USA. In August 2011, the American Assured Fuel Supply became available in the USA. It comprises 230 tonnes of LEU with an enrichment of 4.95%.

6. In Finland, construction on the ONKALO underground rock characterization facility, a precursor to a spent fuel repository, reached its final disposal depth in 2010. Posiva, the nuclear waste management company, intends to submit the repository construction licence application in late 2012 and begin final disposal in 2020. The Swedish Nuclear Fuel and Waste Management Company (SKB) submitted a licence application in March 2011 for the construction of a spent fuel repository in Forsmark and estimates that final disposal could begin by 2025. The Council of the EU approved “Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste”, which established harmonized standards for all EU member countries and required them to establish national programmes and report on progress to the European Commission (EC) by August 2015 and every three years thereafter.

7. Technology advances were reflected in 2011 in the connection to the grid, in China, of the world’s first AP-1000. The 65 MW(th) (20 MW(e)) pool-type China Experimental Fast Reactor (CEFR) was also connected to the grid in 2011. In Argentina, site excavation started in 2011 for the 27 MW(e) prototype plant for CAREM, a small pressurized water reactor (PWR) with all primary components located inside the reactor vessel. South Africa’s plans for moving the pebble bed modular reactor (PBMR) into the construction phase were halted in 2010 as a result, among other things, of funding constraints in the wake of the global financial crisis. The project remains under a ‘care and maintenance plan’ to protect the intellectual property and assets involved.

## **B. Current Status of Nuclear Power**

### **B.1. Use of Nuclear Energy**

8. In 2011, nuclear energy produced 12.3% of the world’s electricity and 5.1% of the total primary energy used worldwide. Most electricity generation continues to be fuelled by fossil fuels.

9. Nuclear power has been used to produce electricity for public distribution since 1954, and nuclear power plants have since operated in 33 countries.<sup>2</sup> Currently, 30 countries operate 435 reactors, with a total capacity of 370 GW(e).<sup>3</sup> A further 62 units, totalling 59.2 GW(e), are under construction.<sup>4</sup> During 2011, nuclear power produced 2517 billion kW•h of electricity. The industry now has more than 14 700 reactor-years of experience.

10. The contribution of nuclear energy to total electricity generation varies considerably by region as shown in Table B-1. In 2011, the highest share of nuclear generated electricity was 25.7% in Western Europe. The lowest shares were 1.8% in the Middle East and South Asia and 0% in the Southeast Asia

---

<sup>2</sup> Argentina, Armenia, Belgium, Brazil, Bulgaria, Canada, China, Czech Republic, Finland, France, Germany, Hungary, India, Islamic Republic of Iran, Italy, Japan, Kazakhstan, the Republic of Korea, Lithuania, Mexico, Netherlands, Pakistan, Romania, the Russian Federation, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, Ukraine, the United Kingdom and the United States of America.

<sup>3</sup> These totals include 6 reactors in Taiwan, China, with a total capacity of 5018 MW(e).

<sup>4</sup> Unless indicated otherwise, all such statistics are as of 30 June 2012.

and the Pacific region. Globally, nuclear power's share of electricity generation has declined from 16% in 2002 to 12.3% in 2011.

TABLE B-1. Use (in EJ) and percentage contribution (%) of different types of fuel for electricity generation in 2011

Region	Thermal (a)		Hydro		Nuclear		Renewables (b)		Total	
	Use (EJ)	%	Use (EJ)	%	Use (EJ)	%	Use (EJ)	%	Use (EJ)	%
North America	30.2	63.0	2.6	15.6	9.6	18.8	1.0	2.6	43.4	100
Latin America	5.5	39.5	2.8	57.4	0.3	2.2	0.4	0.9	9.0	100
Western Europe	14.4	51.3	1.9	16.8	8.7	25.7	1.1	6.3	26.1	100
Eastern Europe	17.8	65.6	1.0	15.5	3.7	18.7	0.03	0.2	22.5	100
Africa	6.1	80.9	0.4	16.5	0.1	2.0	0.06	0.5	6.6	100
Middle East and South Asia	22.9	87.3	0.7	10.9	0.4	1.8	0.0	0.02	24.0	100
Southeast Asia and the Pacific	7.5	88.4	0.3	9.3			0.4	2.3	8.2	100
Far East	48.6	78.0	3.1	13.9	4.7	6.9	0.7	1.1	57.0	100
<b>Total</b>	<b>152.9</b>	<b>68.2</b>	<b>12.8</b>	<b>17.4</b>	<b>27.5</b>	<b>12.3</b>	<b>3.7</b>	<b>2.1</b>	<b>196.8</b>	<b>100</b>

(a) The column headed 'Thermal' is the total for solids, liquids, gases, biomass and waste.  
(b) The column headed 'Renewables' includes geothermal, wind, solar and tide energy.

## B.2. Available Reactor Technology

11. Of the commercial reactors in operation, approximately 82% are light water moderated and cooled reactors; 11% are heavy water moderated heavy water cooled reactors; 3% are gas cooled reactors; and 3% are water cooled and graphite moderated reactors. Two reactors are liquid metal moderated and cooled. Table B-2 indicates the numbers, types and net electrical power of currently operating nuclear power plants.

TABLE B-2. Current distribution of reactor types<sup>5</sup>

Country	PWR		BWR		GCR		PHWR		LWGR		FBR		Totals	
	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)	No.	MW(e)
ARGENTINA							2	935					2	935
ARMENIA	1	375											1	375
BELGIUM	7	5927											7	5927
BRAZIL	2	1884											2	1884
BULGARIA	2	1906											2	1906
CANADA							18	12604					18	12604
CHINA	13	10496					2	1300			1	20	16	11816
CZECH REP.	6	3766											6	3766
FINLAND	2	976	2	1760									4	2736
FRANCE	58	63130											58	63130
GERMANY	7	9496	2	2572									9	12068
HUNGARY	4	1889											4	1889
INDIA			2	300			18	4091					20	4391
IRAN, ISL. REP.	1	915											1	915
JAPAN	24	19284	26	24931									50	44215
KOREA REP.	19	17886					4	2785					23	20671
MEXICO			2	1300									2	1300
NETHERLANDS	1	482											1	482
PAKISTAN	2	600					1	125					3	725
ROMANIA							2	1300					2	1300
RUSSIA	17	12864							15	10219	1	560	33	23643
SLOVAKIA	4	1816											4	1816
SLOVENIA	1	688											1	688
SOUTH AFRICA	2	1830											2	1830
SPAIN	6	6057	2	1510									8	7567
SWEDEN	3	2816	7	6509									10	9325
SWITZERLAND	3	1700	2	1563									5	3263
UK	1	1191			15	8055							16	9246
UKRAINE	15	13107											15	13107
USA	69	67368	35	34097									104	101465
<b>WORLDWIDE<sup>a</sup></b>	<b>272</b>	<b>250289</b>	<b>84</b>	<b>77720</b>	<b>15</b>	<b>8055</b>	<b>47</b>	<b>23140</b>	<b>15</b>	<b>10219</b>	<b>2</b>	<b>580</b>	<b>435</b>	<b>370003</b>

a. Note: The worldwide totals include the following data from Taiwan, China: 2 PWRs totalling 1840 MW(e) and 4 BWRs totalling 3178 MW(e), for an overall total of 6 reactors and 5018 MW(e).

<sup>5</sup> As of 30 June 2012. Source: IAEA (PRIS).

12. The majority of operating reactors were designed in the late 1960s and 1970s and are not offered commercially today. Reactor designs increased gradually in size, taking advantage of economies of scale. Many of the earliest reactors, which started commercial operation in the 1950s, were 50 MW(e) or smaller. Currently operating reactors range in size from less than 100 MW(e) up to 1500 MW(e). The average reactor size in operation on 30 June 2012 was 851 MW(e).

13. Reactor technology available for use today is fundamentally based upon previous designs while taking into account (1) sixty year lifespans, (2) simplified maintenance — on-line or during outages, (3) easier and shorter construction, (4) inclusion of safety and reliability considerations at the earliest stages of design, (5) modern technologies in digital control and the human-machine interface, (6) safety system design guided by risk assessment, (7) simplicity, by reducing the number of rotating components, (8) increased reliance on passive systems (gravity, natural circulation, accumulated pressure, etc.), (9) addition of severe accident mitigating equipment, and (10) complete and standardized designs with pre-licensing.

14. Although the industry has historically pursued economies of scale, the deployment of small and medium sized reactors (SMRs) continues. “Small” means less than 300 MW(e). “Medium sized” means between 300 MW(e) and 700 MW(e). SMRs are being developed to be used in isolated areas or in small grids with limited interconnections such as exist in some developing countries, and to allow smaller investments so as to reduce financial risks. Small, transportable reactors have been proposed to allow power plants to be delivered as pre-constructed packages.

### **B.3. Human Resources**

15. The projected growth in nuclear power discussed in Section C.4 will require a growing workforce with the necessary skills. However, even in a number of countries with operating nuclear power plants, nuclear education and training have experienced declines, and even for their currently operating reactors, many countries face significant challenges to deal with expected attrition from the existing workforce. For the USA, the Nuclear Energy Institute’s 2011 *Nuclear Pipeline Survey* shows a potential 39% attrition rate over the next five years, equivalent to approximately 22 300 people. Similar figures are reported for Europe by the European Human Resources Observatory for the Nuclear Sector, which was created by the European Commission to track demand and supply for nuclear experts within the European Union. The OECD/NEA’s 2012 *Nuclear Education and Training: From Concern to Capability* notes that governments have recognized the challenge and Finland, France, Spain, the UK and the USA, among others, have undertaken surveys to identify current and future needs. Overall, while a number of national initiatives have been implemented to enhance educational capability, the response to human resources challenges has been variable, and a more consistent, international effort is still needed. In May 2011, the Agency initiated a Global Nuclear Power Industry Workforce Survey to get accurate estimates of the current numbers of personnel directly supporting nuclear operations. Data collection has been slow, and the survey has been kept open into 2012 in order to collect more data.

16. Countries introducing nuclear power face particular human resources challenges, and they will rely heavily on support from vendor countries for education and training for their first nuclear power plants. The Agency can encourage coordination of the services offered by vendors and through bilateral and multilateral arrangements, and can supplement their activities with workshops, review services, the validation and enhancement of educational programmes, and assistance with workforce planning and human resource development strategies. The USA recently provided a Nuclear Power Human Resources (NPHR) modelling tool to the Agency, to be shared with Member States, especially those considering introducing nuclear power. It estimates future human resources needs based on national plans. The Agency has also fostered regional educational networks in the Asian (ANENT),

African (AFRA-NEST) and Latin-American and Caribbean regions (LANENT). These provide a platform for collaboration and sharing best practices.

## **B.4. The Fuel Cycle, Waste and Decommissioning**

17. The fuel cycle is normally divided into front-end activities (mining, conversion, enrichment and fuel fabrication) to produce fuel assemblies for reactors and back-end activities to manage the spent nuclear fuel and the nuclear waste (including storage, reprocessing and waste disposal).

### **B.4.1. Front end**

18. The latest edition of the OECD/NEA–IAEA ‘Red Book’, *Uranium 2011: Resources, Production and Demand*, estimated identified conventional uranium resources at less than \$130/kg U at 5.3 Mt U, a decrease of 1.4% compared to the previous edition, *Uranium 2009: Resources, Production and Demand*. For reference, the spot price for uranium on 24 July 2012 was also \$130/kg U.

19. Uranium production in 2010, the most recent year reported in the Red Book, was 54 670 t U, a 6% increase over 2009. Production in Kazakhstan, the world’s largest producer, increased by 27%. Australia, Canada and Kazakhstan accounted for 62% of global production. These three countries, plus Namibia, Niger, the Russian Federation, the USA and Uzbekistan, accounted for 92%. Provisional figures indicate that final figures for 2011, when available, will show an increase over 2010 to about 57 230 t U.

20. Uranium consumption by the world’s nuclear power plants in 2010 was 63 875 t U. The World Nuclear Association (WNA) estimated that consumption dropped in 2011 to 62 552 t U in the wake of the accident at the Fukushima Daiichi nuclear power plant<sup>6</sup> but projected that it would rebound in 2012 to 67 990 U.<sup>7</sup> At the projected 2012 rate of consumption, the lifetime of 5.3 Mt U would be 78 years. This compares favourably to reserves of 30–50 years for other commodities (e.g. copper, zinc, oil and natural gas).

21. Unconventional uranium resources and thorium further expand the resource base. Unconventional resources include potentially recoverable uranium associated with phosphates, nonferrous ores, carbonatite, black shale and lignite, resources from which uranium is only recoverable as a minor by-product and uranium in seawater. In 2011, only a few countries (Chile, Finland, Jordan, Mexico, Peru, South Africa and Sweden) mentioned or reported unconventional uranium resources. Past estimates of potentially recoverable uranium associated with phosphates, non-ferrous ores, carbonatite, black shale and lignite are of the order of 10 Mt U. Worldwide resources of thorium have been estimated to be about 6 million tonnes. Although thorium has been used as fuel on a demonstration basis, its broader use would depend on the commercial deployment of thorium fuelled reactors, which is a gradual process.

22. Commercial scale plants to convert triuranium octaoxide (U<sub>3</sub>O<sub>8</sub>) to uranium hexafluoride (UF<sub>6</sub>) operate in Canada, China, France, Russian Federation, UK and USA. Smaller conversion plants operate in Argentina, Japan and Pakistan. Total world conversion capacity has remained constant at around 75 000 tonnes of natural uranium per year. Total current demand for conversion services is in the range of 59 000 to 65 000 t U per year.

---

<sup>6</sup> WNA World Nuclear Power Reactors & Uranium Requirements, 1 January, 2012 (<http://www.world-nuclear.org/info/reactors0112.html>) Accessed 7 May 2012

<sup>7</sup> World Nuclear Power Reactors & Uranium Requirements, April 2012 (<http://world-nuclear.org/info/reactors0412.html>) Accessed 7 May 2012

23. Total global enrichment capacity is about 65 million separative work units (SWUs) per year compared to a total demand of approximately 45 million SWUs per year. Commercial scale plants operate in China, France, Germany, Netherlands, Russian Federation, UK and USA. Smaller enrichment plants operate in Argentina, Brazil, India, the Islamic Republic of Iran, Japan and Pakistan.

24. Several proposals have been advanced in recent years to better ensure uninterrupted nuclear fuel supplies, particularly for countries introducing nuclear power. Most envision a central role for the Agency. In December 2010, the Agency's Board of Governors approved the establishment of an IAEA LEU bank to be funded by \$150 million in voluntary contributions pledged to the Agency. The Agency accepted an offer from Kazakhstan to host the bank and formal negotiations on a host State agreement began in 2012. In February 2011, the agreement between the Government of the Russian Federation and the Agency that established an LEU reserve in Angarsk, Russian Federation, entered into force. This reserve holds 120 tonnes of LEU and is located at the International Uranium Enrichment Centre. In March 2011, the Board of Governors approved a proposal for a 'Nuclear Fuel Assurance' by the UK, cosponsored by the EU, Russian Federation and USA. This introduced a draft 'Model NFA Agreement' by which a State supplying LEU or enrichment services could agree not to interrupt supplies to recipients that comply with international obligations and published export licensing standards. In August 2011, the American Assured Fuel Supply became available in the USA. It comprises 230 tonnes of LEU with an enrichment of 4.95%.

25. The world's capacity to fabricate fuel for light water reactors (LWRs), which use fuel with enriched uranium, is about 13 000 t U per year (of enriched uranium in fuel assemblies). The demand for such fuel is currently about 7 000 t U per year and expected to increase to about 9 500 t U per year by 2020. Fabrication capacity for natural uranium fuel for pressurized heavy water reactors (PHWRs) is about 4 000 t U per year; demand is about 3 000 t U per year.

26. Recycling provides a secondary nuclear fuel supply through the use of reprocessed uranium and mixed oxide (MOX) fuel. The current fabrication capacity for MOX fuel is around 250 t of heavy metal (HM). Worldwide, approximately 30 LWRs currently use MOX fuel.

#### **B.4.2. Back end**

27. Some countries see spent fuel as a waste product to be disposed of as high level waste (HLW). Others see it as a resource for reprocessing and potential reuse. Currently a market for reprocessing and reuse exists, but not for storage or disposal.

28. Because there are currently no operating disposal facilities for HLW, spent fuel inventories are growing, and much of this spent fuel will have to be stored for longer periods than initially intended, possibly longer than 100 years. In 2011, about 10 500 tonnes of heavy metal (HM) were discharged as spent fuel from all nuclear power reactors. The total cumulative amount of spent fuel discharged through December 2011 was approximately 350 500 t HM, of which about 240 000 t HM were stored. The rest had been reprocessed. Global commercial reprocessing capacity was about 4 800 t HM per year, spread across four countries, France, India, Russian Federation and the UK. In Japan, construction of the 800 t HM/year commercial reprocessing plant at Rokkasho was almost complete when work was suspended as a consequence of the earthquake and tsunami on 11 March 2011.

29. The countries that have made the most progress on disposal facilities for HLW are Finland, France and Sweden. In Finland, construction on the ONKALO underground rock characterization facility, a precursor to a spent fuel repository, reached its final disposal depth in 2010. Posiva, the nuclear waste management company, intends to submit the repository construction licence application in late 2012 and begin final disposal in 2020. In France, the national radioactive waste management agency Andra signed a contract in January 2012 for the design of its future deep geological repository, which is scheduled to start operation in 2025 in the Meuse/Haute-Marne region of eastern France. The

Swedish Nuclear Fuel and Waste Management Company (SKB) submitted a licence application in March 2011 for the construction of a spent fuel repository in Forsmark and estimates that final disposal could begin by 2025.

30. In the EU, in July 2011, the Council of the EU approved a Directive on spent fuel and radioactive waste management that established harmonized standards for all EU member countries and required them to establish national programmes and report on progress to the European Commission (EC) by August 2015 and every three years thereafter.

31. In addition to HLW associated with spent fuel, low and intermediate level waste (LILW) is generated throughout the fuel cycle. Treatment, conditioning and long term storage of LILW waste are mature technologies and are normally done at the nuclear facilities where the waste is generated. A number of countries already operate industrial scale LILW disposal facilities, and others are building them. But some countries with operating nuclear power plants have not yet been able to site and construct LILW disposal facilities, primarily due to a lack of political and public acceptance.

### **B.4.3. Decommissioning**

32. Once power reactors reach the end of their lifecycle, they are decommissioned. Decommissioning involves dismantling them in a controlled way and then managing and disposing of the resultant radioactive waste.

33. There are three basic options: immediate dismantling, long term safe enclosure followed by dismantling, and entombment, also called on-site or in-situ disposal. Entombment has generally been limited to small installations. The choice between immediate dismantling and long term safe enclosure depends on the availability of disposal facilities and uncertainty about their future availability, the availability of funds (which may not be available for reactors that were shut down earlier than planned or that were not required to accumulate such funds during their operating lives), projected costs (which decline as radiation levels drop and technology improves), concerns about jobs around shutdown reactors, the planned future use of the site (possibly for new reactors), the preferences of interested stakeholders and the applicable national laws, regulations and spent fuel management strategies.

34. As of December 2011, 124 power reactors were shut down. Of these, 16 had been fully dismantled, 50 were in the process of being dismantled, 49 were being kept in safe enclosure mode, 3 had been entombed, and 6 did not yet have specified decommissioning strategies.

### **B.5. Industrial Capacity**

35. The number of nuclear power reactors under construction peaked in 1979 at 233. It then dropped to between 30 and 40 for 1995–2005 but has since risen to 62 as of 30 June 2012 (Fig. B-1). The nuclear supply industry adjusted to the post-1980 decline largely through consolidation, particularly in North America and Europe. Conversely, the capabilities of China, India and the Republic of Korea have grown through localization and are expected to increasingly contribute to meeting the world's future need for nuclear construction expertise. This section highlights some recent developments to expand industrial capacity to respond to the projected growth in nuclear power reported in Section C.4.

36. The suppliers of heavy industrial equipment are in China, Czech Republic, France, Japan, Republic of Korea and Russian Federation. New capacity is being built by Japan Steel Works (JSW) and Japan Casting & Forging Corporation (JCFC) in Japan, by Shanghai Electric Group and subsidiaries in China, by Bharat Forge in India, by Doosan in the Republic of Korea, by Le Creusot in

France, by Plzeň in the Czech Republic and by OMZ Izhora and ZiO-Podolsk in the Russian Federation.

37. In Canada, the former, government owned reactor supplier Atomic Energy of Canada Limited was partially privatized in 2011. The nuclear power reactor supply and nuclear services portion of the company was sold to the engineering and construction group SNC-Lavalin and renamed Candu Energy Inc. The remaining portion of the company retained the AECL name and now focuses on research and development, design, engineering, specialized technology, waste management, and decommissioning. It continues to own and operate the Chalk River nuclear laboratories.

38. In China in 2011, the State Nuclear Power Technology Corporation (SNPTC) and Shanghai Nuclear Engineering Research and Design Institute (SNERDI), together with Westinghouse, completed the preliminary design of the Chinese Advanced Power Reactor (CAP-1400), also called the Large Advanced Passive PWR Nuclear Power Plant (LPP). This opens the possibility of China exporting this design with Westinghouse's cooperation.

39. The Republic of Korea is developing an exportable 1500 MW(e) advanced power reactor (APR+) and the EU-APR 1400 for the European market, (see para. 86), and, in the Russian Federation, the main reactor component supplier, OMZ, is doubling production capacity for large forgings at its Komplekt-Atom-Izhora facility to three or four pressure vessels per year.

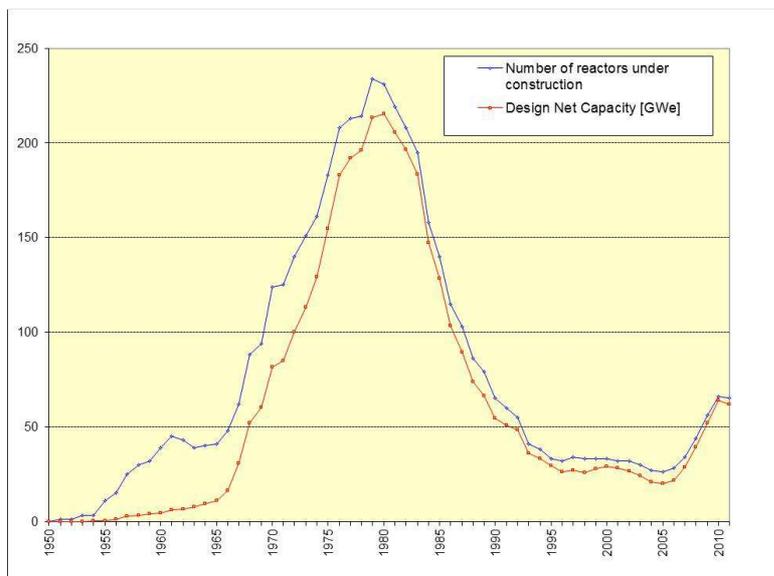


FIG. B-1. Number of reactors under construction (and total reactor capacity) from 1951 to 2010. Source: IAEA (PRIS).

## C. Prospects for the Future Application of Nuclear Energy

### C.1. Prospects in Countries already using Nuclear Power

40. Table C-1 summarizes available information on the expansion plans of countries currently operating nuclear power plants plus Lithuania, which has 43.5 reactor-years of operating experience but, since Ignalina-2 was shut down at the end of 2009, no operating reactors. The table is based on Member State presentations to the 2011 IAEA General Conference and other public expressions of their positions.

## C.2. Prospects in Countries considering the Introduction of Nuclear Power

41. Since the mid-2000s, developing countries have expressed a new or renewed interest in nuclear power. While the Fukushima Daiichi accident caused some countries to change their positions and some to take a ‘wait and see’ approach, interest continued among countries considering or planning for nuclear power introduction.

42. Table C-2 shows the number of countries at different stages of nuclear power consideration or development. Sometimes referred to as ‘nuclear newcomers’, some countries, such as Bangladesh, Egypt and Vietnam, have in fact been planning for nuclear power for some time. Others, such as Poland, are reviving the nuclear power option after plans had been curtailed when governments and public opinion changed. Countries such as Jordan and Uruguay are considering or planning for nuclear power for the first time. What they have in common is that they are all considering, planning or starting nuclear power programmes, and have not connected a first nuclear power plant to the grid.

TABLE C-1. Positions of countries with operating nuclear power plants plus Lithuania

Category	Number of countries
New unit(s) under construction with more planned/proposed	11
New unit(s) under construction but the policy for more units is not established	2
No units under construction but with plans/proposals for building new unit(s)	10
No units under construction, and currently no plans/policy for building new units	4
Firm policy not to build new units and/or for closure of existing units	4

TABLE C-2. Positions of countries without operating nuclear power plants<sup>8</sup>

Description of group	Number of Countries 2012	Number of Countries 2010	Number of Countries 2008
Considering a nuclear programme to meet identified energy needs with a strong indication of intention to proceed	14	14	14
Active preparation for a possible nuclear power programme with no final decision	6	7	7
Decided to introduce nuclear power and started preparing the appropriate infrastructure	6	10	5
New nuclear power plant ordered	3	2	0
New nuclear power plant under construction	0	1	1

43. Of the 29 countries considering or planning for nuclear power in 2012, 10 are from the Asia and the Pacific region, 10 are from the Africa region, 7 are in Europe (mostly Eastern Europe) and 2 are in Latin America.

<sup>8</sup> Two additional groups were included in previous editions of this publication but not in this edition because they did not add substantially to an understanding of the rising expectations for nuclear power among developing countries. One group included countries that were not planning to introduce nuclear power but were interested in considering the associated issues, but it proved difficult to characterize trends and there were wide fluctuations in the numbers from year to year. A second group included countries where an invitation to bid to supply a nuclear power plant had been prepared, but this proved problematic because of countries that were choosing to order plants through direct bilateral agreements rather than through bids.

44. Even after the Fukushima Daichii accident, some countries have taken concrete steps toward nuclear power introduction. In the United Arab Emirates (UAE), in 2011, the Emirates Nuclear Energy Corporation invited bids for uranium, conversion and enrichment for the fuel for the UAE's first reactors. In Turkey, the project company Akkuyu Nukleer Santral Elektrik Uretim filed applications for construction permits and a power generation licence. Belarus signed a contract with the Russian Federation for the construction of two reactors, and Bangladesh signed an intergovernmental agreement with the Russian Federation, also for two reactors. Vietnam signed a loan agreement with the Russian Federation regarding financing of its first nuclear power plant and announced its intention to undertake a similar agreement with Japan.

45. The Islamic Republic of Iran began commissioning of its first nuclear power plant at Bushehr in September 2011, which marked the commissioning of the first nuclear power plant in a 'newcomer' country in 15 years.

46. The rate at which new countries joined the list of countries operating nuclear power plants was fairly steady through the early 1980s as shown in Fig. C-1. Until the addition of the Islamic Republic of Iran in 2011, only three countries had connected their first nuclear power plants to the grid in the post-Chernobyl era — China, Mexico and Romania. The countries now planning for their first nuclear power plants are doing so after an experience gap of 15 years. Of the countries considering or planning for their first nuclear plant, 9 have explicitly expressed target dates for the first operation before 2030.

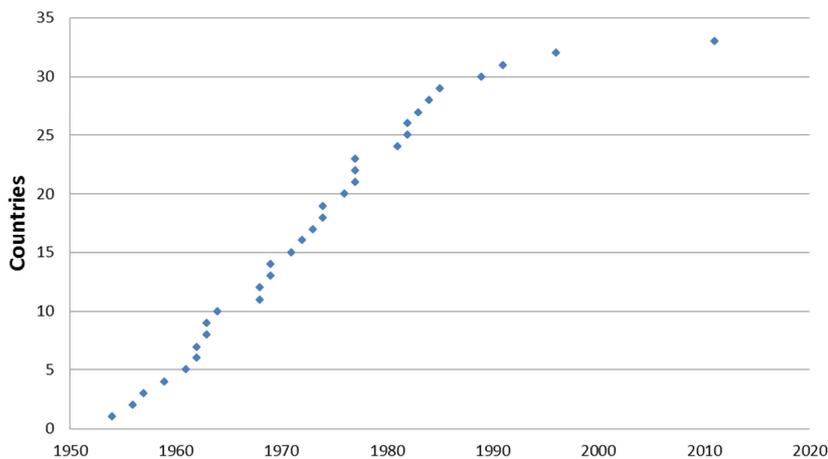


FIG. C-1. Number of countries operating, or having operated, nuclear power plants. Source IAEA (PRIS)

47. Overall, Tables C-1 and C-2 are consistent with trends reflected in the Agency's low and high projections described below, i.e. there remains substantial uncertainty in projections about nuclear power, and the growth in the use of nuclear power is projected to be driven more by expansion in established nuclear power countries than by countries starting nuclear power programmes. The 9 countries that have explicitly expressed target dates for the first operation before 2030 lie between the 7 countries in the Agency's low projection that would connect their first plant by 2030 and the 16 countries that would do so in the high projection.

### **C.3. Potential Drivers for the Introduction of Nuclear Power**

48. The key factors that have driven rising interest in nuclear power since about 2005, and the increase in construction starts shown in Fig. B-1, have not changed with the Fukushima Daiichi accident: growing energy demand, especially for electricity; volatile fossil fuel prices; environmental pressures and energy security concerns.

#### **C.3.1. Demand**

49. Global energy and electricity demands are set to grow for decades. No credible short or long term energy assessment indicates otherwise. A growing world population and development aspirations in the current developing world, where large parts of the population still lack access to electricity, translate into even faster growth rates for electricity than for total primary energy demand. All studies agree that most demand growth will occur in the developing countries.

50. The medium variant of the latest UN population projections estimates an additional 1.5 billion people by 2030 and another 1 billion by 2050, bringing the world's population to about 9.3 billion.<sup>9</sup> The World Bank projects average annual growth for the world economy of 3.1% up to 2015 and 2.5% between 2015 and 2030.<sup>10</sup> Developing countries will grow fastest. Based on these two main drivers of energy demand, the OECD's International Energy Agency (IEA) projects an increase in electricity demand from 21 300 TWh in 2010 to between 30 390 and 35 470 TWh by 2030 depending on environmental policies. Eighty per cent of the growth would occur in the non-OECD countries. Extending the analysis to 2050 results in an increase in electricity demand to between 37 660 and 46 190 TWh.<sup>11</sup>

#### **C.3.2. Fossil fuel prices and economics**

51. The volatility of international fossil fuel market prices around substantially elevated levels remains a major concern in the developed and developing world alike. For many energy import dependent developing countries, high fuel import prices drain their limited export revenue and hamper economic development. Given rising global energy demand and a reluctance of major producers to accelerate investment in exploration and additional production capacity, partly due to economic uncertainty, high global price levels for fossil fuels are unlikely to ease up soon.

52. The commercialization of large volumes of shale gas recently in the USA, however, has turned the tide of rising natural gas prices and upended the assumption that unconventional fossil resources are necessarily more expensive than their conventional counterparts. Shale occurrences are plentiful in many parts of the world, but their gas bearing nature varies greatly, making projections of commercially available shale gas highly uncertain. There is also uncertainty about public acceptance due to environment and health concerns about extraction using hydrofracking. As discussed in Section C.3.3, the use of shale gas also generates carbon dioxide emissions, and shale gas that leaks to the atmosphere is an even more potent direct greenhouse gas (GHG).

53. Economic development requires reliable affordable baseload electricity. Unlike fossil fuelled electricity generation, for nuclear power the cost of fuel accounts for only a few per cent of the cost of

---

<sup>9</sup> UNDESA (United Nations Department of Economic and Social Affairs). 2010. World Population Prospects. The 2010 Revision. [Online] Available from: <http://esa.un.org/unpd/wpp/index.htm>

<sup>10</sup> World Bank. 2009. Global Economic Prospects: Commodities at the Crossroads, [Online] Available from: [http://siteresources.worldbank.org/INTGEP2009/Resources/10363\\_WebPDF-w47.pdf](http://siteresources.worldbank.org/INTGEP2009/Resources/10363_WebPDF-w47.pdf)

<sup>11</sup> IEA (International Energy Agency). 2010. Energy Technology Perspectives 2010: Scenarios and Strategies to 2050. [Online] Available from: <http://titania.sourceoecd.org/vl=13668216/cl=27/nw=1/rpsv/~6673/v2010n11/s1/p1>

electricity. A doubling or tripling of uranium prices translates to only a 4–6% increase in generating costs. In contrast, for fossil fuelled generation, a doubling of fuel costs raises total generating costs by 40–70%. Thus price volatility is a greater concern for fossil fuelled electricity generation.

### C.3.3. Environment

54. On a life cycle basis, nuclear power emits only a few grams of GHGs per kWh. The full life cycle includes uranium mining, milling, conversion, enrichment, fuel fabrication, power plant construction and operation, reprocessing, conditioning of spent fuel, interim storage of radioactive waste and the construction of final repositories. Life cycle emissions from the nuclear power chain are comparable with the best renewable energy chains and at least one order of magnitude lower than fossil fuel chains, as illustrated in Figure C-2. Overall, the Intergovernmental Panel on Climate Change (IPCC) has estimated that nuclear power has the largest and lowest cost GHG reduction potential in the power generation sector (IPCC, 2007).<sup>12</sup>

55. Nuclear power’s very low GHG emissions and its high potential for reducing GHG emissions from the electricity sector contribute to increased interest in nuclear power. However, without a new comprehensive, binding long term international environmental agreement to replace the Kyoto Protocol, which was extended in December 2011 to at least 2017, not all investors in new nuclear power plants can be sure of benefitting financially from nuclear power’s low GHG emissions.

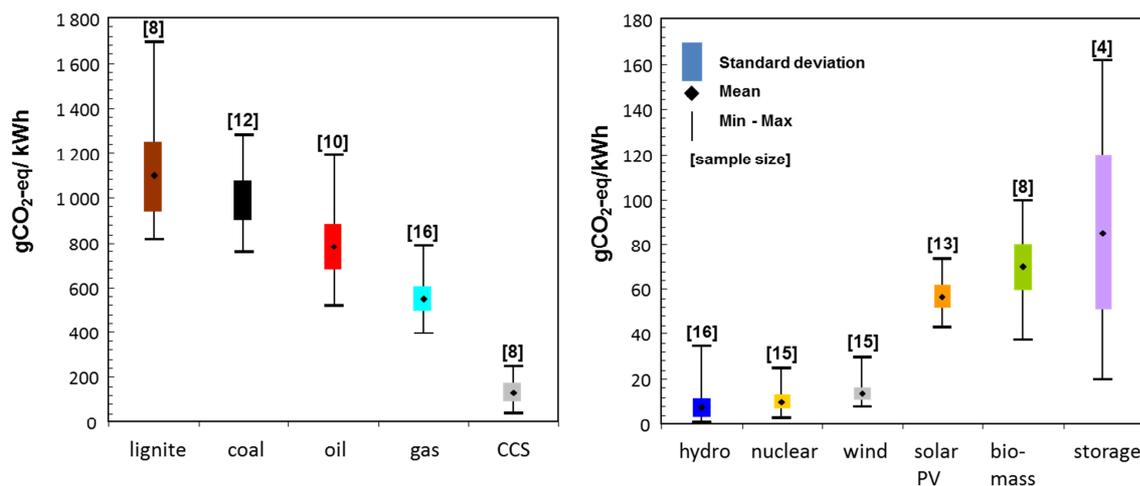


FIG. C-2. Life cycle GHG emissions of different electricity generating options. Note the scale of the right panel is one order of magnitude lower than the left panel.

56. In addition to its very low GHG emissions, nuclear power does not emit any noxious gases during operation that create air pollutants like nitrogen oxides (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>) and particulate matter emissions that cause harm to human health and are responsible for poor urban air quality and regional acidification.

### C.3.4. Energy security

57. Technology, fuel and energy source diversification and strategic storage have long been the principal pillars of energy supply security. Nuclear power enhances supply security when it is part of a

<sup>12</sup> IPCC, 2007: *Climate Change 2007: Mitigation. Contribution of WGIII to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

country's energy mix and, in most countries, nuclear expansion would increase diversity in the electricity sector.

58. Uranium resources are both extensive and geographically diverse as described in Section B.4. Identified conventional uranium resources recoverable at less than \$130/kgU are sufficient to last about 78 years at the projected 2012 consumption rate. Resources at higher costs and in additional categories, e.g. 'prognosticated and speculative resources', add to the estimated resource base. And reprocessing, recycling and the deployment of fast breeder technology would increase the longevity of all resource categories by a factor of 60 to 70.

59. The energy density of nuclear fuel is much higher than fossil fuel, so smaller volumes are required, which makes it easier to establish strategic inventories. In practice, the trend over the years has been away from strategic stocks toward supply security based on a diverse well-functioning market for uranium and fuel supply services. But the option of relatively low cost strategic inventories remains available for countries that find it important.

60. The long service time of nuclear power plants and their stable generating costs for baseload generation are additional aspects of energy security.

#### C.4. Projections in the Growth of Nuclear Power

61. The Agency publishes annually two updated projections for the global growth in nuclear power: a low projection and a high projection. The 2011 updates allow for the effects of the Fukushima Daiichi accident. In the updated low projection, the world's installed nuclear power capacity grows from 370 GW(e) today<sup>13</sup> to 501 GW(e) in 2030, down 8% from what was projected in 2010. In the updated high projection, capacity grows to 746 GW(e) in 2030, down 7% from 2010's projection. Table C-3 shows that projected growth is greatest in the Far East. Other regions with substantial nuclear power programmes are Eastern Europe and the Middle East and South Asia.

TABLE C-3. Estimates of nuclear electricity generating capacity

Region	2010	2020		2030		2050	
		Low	High	Low	High	Low	High
North America	113.8	119	126	111	149	120	200
Latin America	4.1	6.4	6.4	9	18	15	60
Western Europe	122.9	93	126	83	141	60	170
Eastern Europe	47.4	66	80	82	108	80	140
Africa	1.8	1.8	1.8	5	16	10	48
Middle East and South Asia	4.6	13	22	30	53	50	140
South East Asia and the Pacific	0	0	0	0	6	5	20
Far East	80.6	130	164	180	255	220	450
<b>World total</b>	<b>375.3</b>	<b>429</b>	<b>525</b>	<b>501</b>	<b>746</b>	<b>560</b>	<b>1228</b>

62. Figure C-3 compares the Agency's projections to those of the OECD's IEA and the WNA. The IAEA's low projection, the IEA's current policies scenario and the WNA's reference scenario all use similar 'business as usual' assumptions and produce comparable results. The high scenarios from the organizations are also comparable, as are the low nuclear scenarios of the IEA and WNA.

<sup>13</sup> 30 June 2012

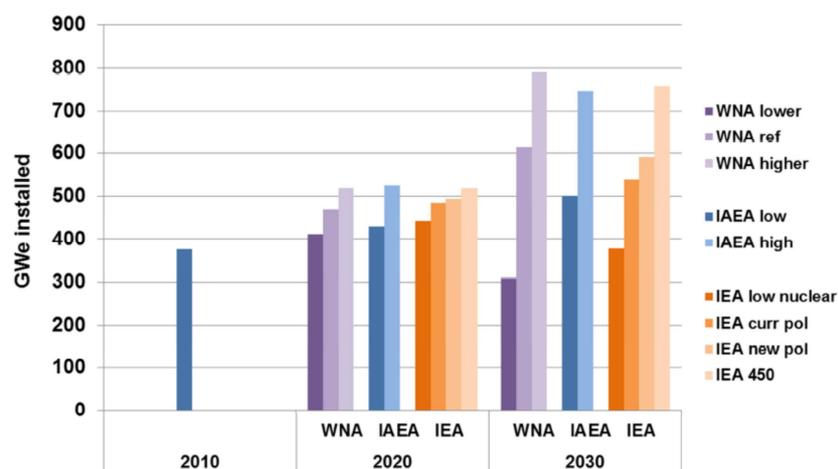


FIG. C-3. Comparison of nuclear power projections by the IAEA (blue), the WNA (purple)<sup>14</sup> and the IEA (orange)<sup>15</sup>. “450” designates a scenario in which the atmospheric concentration of GHGs is limited to 450 parts per million.

63. The *Global Energy Assessment* (GEA), which was released by the International Institute for Applied Systems Analysis, the GEA coordinator, at the UN Conference on Sustainable Development in June 2012 (‘Rio+20’), also presents various future energy scenarios that include nuclear power. The GEA scenarios are based on one economic development scenario but three different groups of energy system transformations. The group GEA-Supply (GEA-S) rapidly scales up all supply-side options. GEA-Efficiency (GEA-E) emphasizes efficiency improvements throughout the energy system and solutions, including life-style changes, to limit energy demand. GEA-Mix (GEA-M) is a combination of GEA-S and GEA-E. Within these groups, the GEA developed 60 alternative pathways that portray multiple sensitivity analyses. Figure C-4 shows the ranges of nuclear power for the three groups over time. Most of the GEA analyses were completed before the Fukushima Daiichi accident, and the lower ends of the nuclear capacity ranges result from sensitivity analyses that purposely exclude nuclear power by 2100. However, the low nuclear trajectories have also been interpreted as possible consequences of the accident.

### C.5. Non-Electric Applications

64. Non-electric applications include hydrogen production to, first, upgrade low quality petroleum resources such as oil sands while offsetting carbon emissions associated with steam methane reforming; second, support large scale production of synthetic liquid fuels based on biomass, coal, or other carbon sources; and, third, serve directly as a vehicle fuel, most likely for light duty plug-in hybrid hydrogen fuel cell vehicles. Nuclear energy can also be used in the petroleum industry for extracting bitumen using steam-assisted gravity drainage (SAGD) or oil shale retorting.

65. Figure C-5 illustrates the benefits of cogeneration of electricity and heat, and the figure is in principle applicable to other non-electric applications such as seawater desalination and hydrogen production. There are currently 79 reactors operating in a cogeneration mode, and the potential for applying this technology more widely appears promising. The more the development of nuclear power plants and nearby industrial and other facilities can be coordinated such that the other facilities exploit waste heat from the nuclear power plants, the greater the benefit of the power plant and the more profitably it can be run. In addition, where seawater is available but fresh water is scarce, seawater

<sup>14</sup> *The Global Nuclear Fuel Market: Supply and Demand 2011–2030*, WNA, London, 2011.

<sup>15</sup> *World Energy Outlook 2011*, OECD-IEA, Paris, 2011.

desalination might provide both potable water and cost-effective industrial water for the nuclear power plant itself.

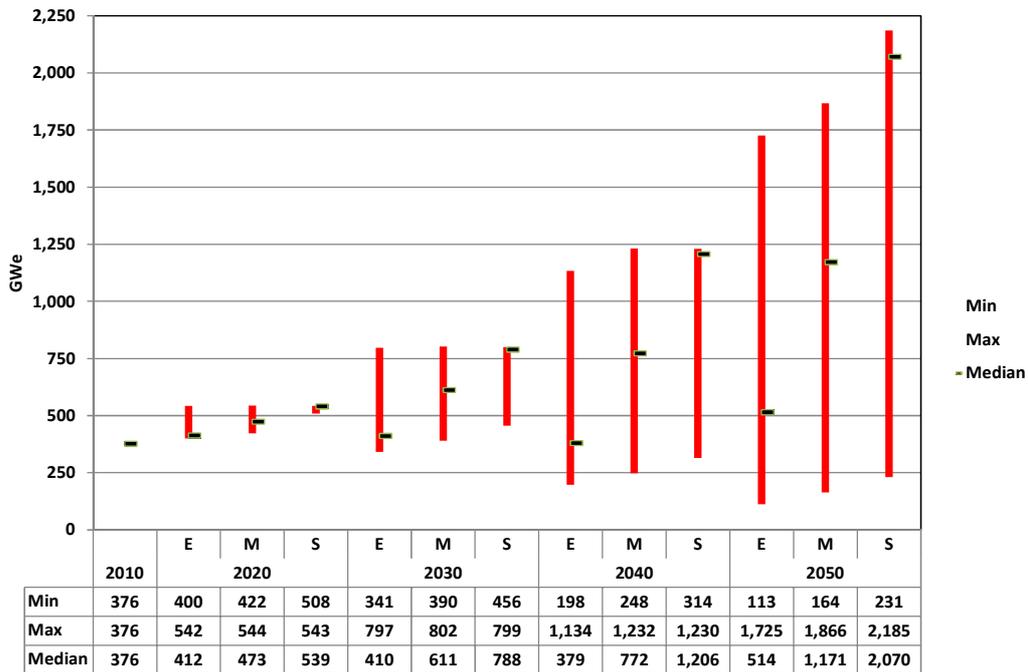


FIG. C-4. Nuclear power developments across GEA-S, GEA-E and GEA-M. (Source: GEA, 2012).

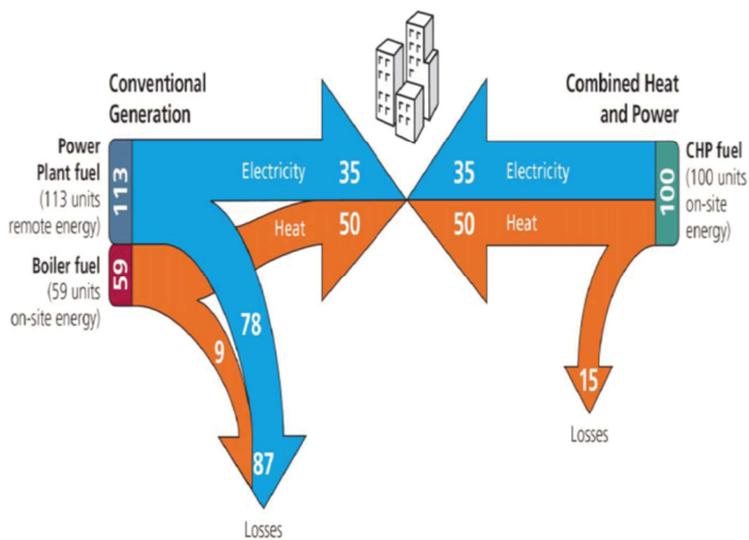


FIG. C-5. Primary energy savings due to cogeneration compared to conventional separate energy production.

## **D. Challenges for Nuclear Expansion**

### **D.1. Financing**

66. Compared particularly to natural gas fired power plants, nuclear power plants are relatively expensive to build and relatively inexpensive to operate. They share this ‘front-loaded’ cost structure with other technologies with low carbon emissions such as hydropower, wind power and solar power.

67. Nuclear power’s high upfront capital costs, its long lead times for planning, licensing and construction, and its cost sensitivity to interest rates all pose financing challenges. Other things being equal, nuclear power is therefore a more attractive investment if financing is available that can wait for longer term returns (which is more characteristic of governments than private industry) and where financial risks are lower due to more predictable electricity demand and prices, stable market structures and strong political support.

68. Partly for these reasons, most of the 62 reactors under construction around the world are financed directly by government owned utilities that have strong government support, access to resources, and good credit ratings that allow more affordable borrowing and easier access to the international credit market. This includes those countries where current and projected expansion in nuclear power is centred, China, India, Republic of Korea and Russian Federation.

69. Privately owned utilities that are large and have strong balance sheets are participating in building and financing a smaller number of new reactors, usually as partners in coalitions. The Olkiluoto-3 and Fennovoima projects in Finland are examples of cooperative models, combining corporate finance and project finance, where ownership and funding are shared among municipalities, local utilities, industrial electricity consumers and strategic partners.

70. Developments in the UK and USA reflect the importance of predictability and stability to private investors. Most new reactors in the USA have been proposed in US states with regulated electricity markets, where some costs can be billed to the utilities’ customers even during construction and where regulation increases the predictability of electricity prices. To increase private investment in nuclear power in the UK, investors are exploring mechanisms, such as ‘contracts for difference’, and the government is proposing legislation, both of which are designed to increase price predictability.

71. For countries starting nuclear programmes, the sources of financing are partly or fully in the countries supplying the nuclear power plants. The UAE’s four new reactors are being financed by the UAE Government and a Korean consortium led by the Korea Electric Power Corporation. In Turkey the project company is co-owned by Turkey and the Russian Federation, and the costs of construction, operation and decommissioning will be fully financed by the Russian side. In Bangladesh, Belarus and Vietnam, agreements also specify that the bulk of the financing will come from the Russian Federation.

72. None of the projections shown in Figure C-3 in Section C.4 requires nuclear power to expand much faster than the rest of the electricity supply sector as a whole, so investment requirements will not be significantly out of step with the overall sector. The challenges of scaling up the current financing arrangements in expansion centres like China, India, Republic of Korea and Russian Federation will likely be fewer than the challenges of ensuring the predictability of electricity demand, prices, and strong political support that are important to encouraging private investment in some other countries.

## D.2. Safety and Reliability

73. Since March 2011, discussions on nuclear power plant safety have been dominated by the need to identify and apply the lessons learned from the accident at the Fukushima Daiichi nuclear power plant.

74. The IAEA Ministerial Conference on Nuclear Safety was convened in June 2011 to discuss an initial assessment of the accident, to consider the lessons that needed to be learned, to help launch a process to enhance nuclear safety throughout the world and to consider ways to further strengthen the response to nuclear accidents and emergencies. Many Member States have carried out reviews as part of national safety assessments (often called ‘stress tests’) and have committed to completing any remaining assessments promptly and implementing any necessary corrective action.

75. The preliminary insight gained from the accident was the need for regulators and operators of nuclear power plants worldwide to review and strengthen, as needed: (a) protective measures against extreme hazards like tsunamis; (b) power and cooling capabilities in the event of severe accidents; (c) preparations to manage severe accidents; and (d) the design bases of plants, i.e. the assumptions about a predetermined set of accidents to be taken into account.

76. Although there are lessons yet to be learned, action plans applying the accident’s preliminary lessons have been developed at both the national and international level. The IAEA Action Plan<sup>16</sup> on Nuclear Safety defines a programme of work to strengthen the global nuclear safety framework. It was adopted by the General Conference in September 2011 and defines 12 main actions.

77. Operationally, the level of nuclear power plant safety around the world remains high, as indicated by safety indicators collected by the Agency and the World Association of Nuclear Operators. Figure C-6 shows the total number of unplanned scrams, including both automatic and manual scrams, per 7 000 hours of critical power reactor operation. This indicator monitors performance in reducing the number of unplanned total reactor shutdowns and is commonly used to indicate progress in improving plant safety. As shown in Figure C-6, there have been significant improvements in the last decade, although not as dramatic as those in the 1990s. Nevertheless, the gap between the best and worst performers is still large, and room for continued improvement exists. The increase from 2010 to 2011 is related to the high number of scrams triggered by the March 2011 earthquake in Japan.

## D.3. Public Perception

78. Public acceptance of nuclear power in different countries and localities reflects how perceived benefits compare with perceived risks. In the aftermath of the Fukushima Daiichi accident numerous public opinion surveys were conducted, including two large multi-country surveys with similar questions about whether respondents supported or opposed nuclear power<sup>17</sup> or viewed nuclear power favourably or unfavourably<sup>18</sup>. Approval rates varied greatly across countries and regions, from almost total rejection in some countries to initial steep drops in approval rates followed by rebounds to pre-Fukushima levels in others<sup>19</sup>. In many countries with operating reactors, polls also found differences

---

<sup>16</sup> <http://www.iaea.org/newscenter/focus/actionplan/>

<sup>17</sup> IPSOS (Ipsos Social Research Institute). 2011. Strong global opposition towards nuclear power. [Online] Available from: <http://www.ipsos-mori.com/researchpublications/researcharchive/2817/Strong-global-opposition-towards-nuclear-power.aspx>

<sup>18</sup> Gallup. 2011. Impact of Japan Earthquake on Views about Nuclear Energy: Findings from a Gallup Snap Poll in 47 Countries by WIN-Gallup International. [Online] Available from: [http://www.nrc.co.jp/report/pdf/110420\\_2.pdf](http://www.nrc.co.jp/report/pdf/110420_2.pdf). [Accessed 2012-04-26]

<sup>19</sup> IPSOS (Ipsos Social Research Institute). 2012. After Fukushima; Global Opinion on Energy Policy. [Online] Available from: <http://www.ipsos.com/public-affairs/sites/www.ipsos.com/public-affairs/files/Energy%20Article.pdf>

between opinions about existing reactors, which were viewed favourably, and new reactors, which were viewed less favourably.

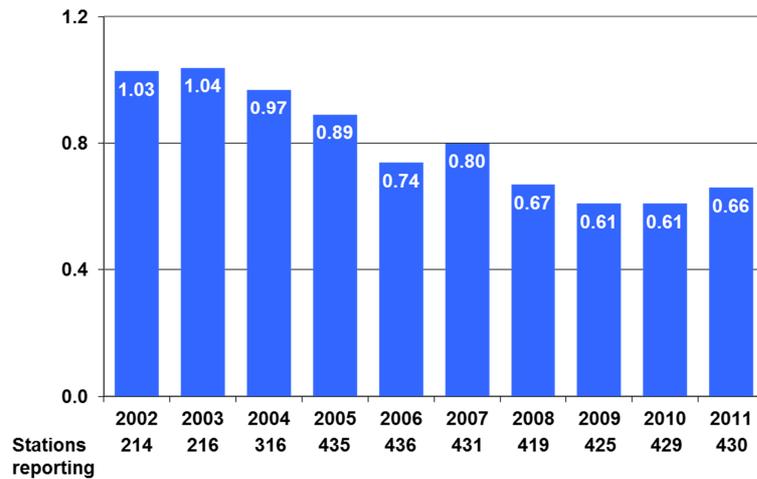


FIG. C-6. Total number of unplanned scrams, including both automatic and manual scrams, that occur per 7 000 hours of critical power reactor operation. Source: IAEA (PRIS).

79. The poll results underline the importance of providing transparent accessible information on the consequences of the accident, preparations for future accidents, and all the risks and benefits of nuclear power and other energy alternatives. Also important is strong stakeholder involvement, including local governments, emergency services, regulators, unions and community organizations. Finally, a better public understanding of radiation and of the radiation exposure continually encountered in everyday life is fundamental to a balanced view of the health impacts of nuclear power.

#### **D.4. Spent Fuel and Waste Management and Disposal**

80. As summarized in Section B.4, there are currently no operating disposal facilities for HLW, and spent fuel inventories are therefore growing. All spent fuel is initially stored under water in storage pools at reactor facilities for between 9 months and several decades, depending on the storage capacities of the pools. If the fuel is to be reprocessed, it is transported to a reprocessing facility and stored there in buffer storage pools before being fed into the process. Fuel not destined for reprocessing remains stored in the original reactor storage pools or is transported to separate ‘away from reactor’ (AFR) fuel storage facilities. Despite their name, the AFR facilities may be either on a part of the reactor site or at other dedicated sites. Currently there are around 120 operating commercial AFR spent fuel storage facilities around the world, most of them being dry storage facilities at reactor sites.

81. The challenge is to accelerate progress on building HLW disposal facilities and expand AFR storage to accommodate the increased spent fuel inventories and extended storage times described in Section B.4. The countries that have made the most progress on final disposal are Finland, France and Sweden where facilities are scheduled to begin operation in 2020–2025. For other EU countries, as noted in Section B.4, the Council of the EU approved a Directive in July 2011 that required all EU member countries to establish national programmes on spent fuel and radioactive waste management and report on progress to the EC by August 2015 and every three years thereafter.

#### **D.5. Relationship between Electricity Grids and Reactor Technology**

82. The maximum size for a new power plant, if grid stability problems are to be avoided, is generally considered to be about 10% of the existing grid. Twelve of the 29 countries considering or

planning for nuclear power have grids of less than 5 GW(e), which would make them too small, according to the 10% guideline, to accommodate most of the reactor designs on offer without improved international grid interconnections. Although many designs below 600 MW(e) are in development, commercial availability is limited. Grid issues may also limit technology options for countries with grids smaller than 10 GW(e).

## **E. Development of Reactor and Fuel Cycle Technology**

### **E.1. Light water reactors (LWRs)**

83. Light water reactors (LWRs) dominate new construction. Fifty-four of the 62 units currently under construction are LWRs.

84. The 26 reactors under construction in China include the European Pressurized Reactor (EPR), the AP-1000 by Westinghouse, and indigenous PWR designs such as CNP-600, CPR-1000 and CAP-1400. The China National Nuclear Corporation has also developed a CNP-1000 plant incorporating experience from the design, construction and operation of the Qinshan and Daya Bay nuclear power plants. The first two units began commercial operation in 2010 and 2011 at Ling'ao. The Shanghai Nuclear Engineering Research and Design Institute (SNERDI) is developing the CAP-1400/1700 Advanced Passive Plant based on AP-1000 passive safety technology.

85. Japan operates 4 advanced boiling water reactors (ABWRs) and was building 2 more until the accident at the Fukushima Daiichi nuclear power plant. Construction was indefinitely suspended. Japan has a programme to develop the 1638 MW(e) ABWR-II with expected economies of scale relative to current ABWRs. Commercial introduction of the ABWR-II is foreseen for the latter half of the 2010s. Japan also has programmes to develop a high performance advanced boiling water reactor (HP-ABWR) and a high performance advanced pressurized water reactor (HP-APWR). Both are on the order of 1800 MW(e). A European version of the APWR, the EU-APWR, is also under development and will be assessed for compliance with the European Utility Requirements.

86. In the Republic of Korea, 11 OPR1000 units are in operation and 1 is under construction. Based on the OPR1000 design, Korea Hydro & Nuclear Power Company has developed an advanced power reactor APR1000 and, for further economies of scale, an APR1400. APR1400 units are under construction at Shin-Kori-3 and -4 and are planned at Shin-Ulchin-1 and -2 and Shin-Kori-5 and -6. Four APR1400s have been ordered by the UAE. A European version of the APR1400, the EU-APR1400, is being developed and will be assessed for compliance with the European Utility Requirements. Design work has begun on the APR+, an advanced PWR of 1500 MW(e).

87. In France, AREVA Nuclear Power has designed the 1650 MW(e) European Pressurized Water Reactor (EPR), which meets the European Utility Requirements. Four are under construction in China, Finland and France. In partnership with E.ON, AREVA is developing the 1250 MW(e) KERENA design, an advanced BWR with passive safety systems, and, in a joint venture with Mitsubishi Heavy Industries, it is developing the 1150 MW(e) ATMEA-1 design, an advanced PWR with active safety systems.

88. Westinghouse in the USA has developed the AP-1000 design, which received design certification in 2006. Four AP-1000 units are currently under construction at the Sanmen and Haiyang sites in China. The US Nuclear Regulatory Commission (NRC) is reviewing both GE-Hitachi Nuclear Energy's ABWR and Toshiba's ABWR for design certification renewal. It is reviewing AREVA's US-EPR, Mitsubishi's APWR and GE-Hitachi Nuclear Energy's ESBWR for design certification.

89. In the Russian Federation, Atomenergoproekt/Gidropress is designing evolutionary WWER plants with power levels ranging from 300 MW(e) to 1800 MW(e). Two WWER-1000 (V-320) units and five WWER-1200 (NPP-2006) units are under construction. There are two WWER-1000 (V-320) units operating in China (Tianwan-1 and -2), two in the Czech Republic (Temelin-1 and -2) and one in the Islamic Republic of Iran.

## **E.2. Small and medium size power reactors (SMRs)**

90. Currently, 131 SMRs operate in 26 countries, with a total capacity of 58.9 GW(e). Of the 62 reactors under construction, 14 are SMRs. Approximately 45 innovative SMR concepts are at some stage of research and development.

91. Argentina is developing the CAREM reactor, a small, integral type pressurized LWR design with all primary components located inside the reactor vessel and an electrical output of 150–300 MW(e). Site excavation started in September 2011 for a 27 MW(e) CAREM prototype plant.

92. In France, the DCNS Company is developing Flexblue, a small modular underwater design of 50–250 MW(e) based on the French water cooled marine propulsion reactor.

93. The Republic of Korea's system integrated modular advanced reactor (SMART) design has a thermal capacity of 330 MW(th) and is intended for seawater desalination. Standard design approval is expected from the national Nuclear Safety Commission by the end of 2012.

94. The Russian Federation is building two 35 MW(e) KLT-40S barge-mounted reactors to be used for cogeneration of electricity and process heat. The KLT-40S is based on the commercial KLT-40 marine propulsion plant and is an advanced variant of the reactor that powers nuclear icebreakers. The 8.6 MW(e) ABV-6M is in the detailed design stage. It is an integral pressurized light water reactor with natural circulation of the primary coolant. The 8.6 MW(e) RITM-200, currently in the detailed design phase, is an integral reactor with forced circulation for nuclear icebreakers.

95. In the USA, four integral pressurized water SMRs are under development: mPower, NuScale, Westinghouse's SMR and Hi-SMUR 140. The mPower consists of 2–6 180 MW(e) modules. Its design certification application to the US NRC is planned for 2013. NuScale Power envisages a nuclear power plant of up to twelve 45 MW(e) modules. Its design certification application is also planned for 2013. The Westinghouse SMR is a conceptual 225 MW(e) design incorporating passive safety systems and proven components of the AP-1000. Development has also started on a more recent SMR design, the Holtec Inherently Safe Modular Underground Reactor (Hi-SMUR 160), a 160 MW(e) reactor that relies on natural convection, thereby eliminating the need for coolant pumps and dependence on external power sources.

## **E.3. Heavy water reactors (HWRs)**

96. There are 47 HWRs in operation and 5 under construction. There are two types: the pressure tube type and the reactor vessel type. Except for Atucha-1 in Argentina, all operating HWRs are the pressure tube type. Of the 5 under construction, all but Atucha-2 are also the pressure tube type.

97. In January 2011, the Canadian Nuclear Safety Commission (CNSC) completed the pre-project design review for the ACR-1000, making it the first advanced nuclear power reactor to have completed such a design review by the CNSC. The ACR-1000, being developed by Candu Energy, uses very high component standardization and slightly enriched uranium to compensate for the use of light water as the primary coolant. The CNSC is currently conducting the pre-project design review for the 700 MW(e) Enhanced CANDU-6 (EC 6) design. Candu Energy is also developing a CANDU supercritical water cooled reactor (CANDU-SCWR).

98. In India, the Nuclear Power Corporation of India Limited (NPCIL) has developed an evolutionary 700 MW(e) HWR. Four are currently under construction. The Bhabha Atomic Research Centre (BARC) is finalizing the design of a 300 MW(e) advanced heavy water reactor (AHWR), which will use thorium-based fuel, passive safety systems, heavy water moderation and boiling light water coolant in vertical pressure tubes.

#### **E.4. Gas cooled reactors (GCRs)**

99. There are 14 advanced gas cooled reactors (AGRs) and 1 magnox reactor in operation, all in the UK.

100. In China, an industrial scale modular demonstration plant called the high temperature reactor – pebble bed module (HTR-PM) is at an advanced stage of development. An owner company has been established, and components such as the primary system pressure vessels, steam generators, reactor internals and helium blowers are being manufactured. The site has been prepared, and first concrete will be poured once approval is received from the authorities.

101. The Republic of Korea is developing hydrogen production capabilities through the Nuclear Hydrogen Development and Demonstration (NHDD) project. An R&D project to develop the key technologies for producing hydrogen using the very high temperature reactor (VHTR) is under way. It focuses on coupling the VHTR and the sulphur-iodine thermochemical process; high temperature metal and graphite material data; the high pressure sulphur-iodine process; TRISO fuel manufacturing and qualification; and computer code and design methods.

102. In South Africa, the pebble bed modular reactor project was abandoned in 2010. The company Pebble Bed Modular Reactor (Pty) Limited still exists and will be maintained until at least 2013. Its current role is to maintain the project's intellectual property and develop appropriate strategies for future customer and supplier engagement.

103. In the USA in February 2012, the Next Generation Nuclear Plant Industry Alliance Limited announced its selection of the AREVA high temperature gas cooled reactor (HTGR) concept as the best design for the next generation of nuclear plants. The Alliance's member companies intend to cooperate in designing, building and operating HTGR technology. AREVA's concept is a prismatic fuelled HTGR of about 625 MW(th) per module.

#### **E.5. Fast reactors (FRs)**

104. There are 2 fast reactors in operation, China's 20 MW(e) experimental fast reactor (CEFR) and the Russian Federation's 560 MW(e) BN-600. Two more are under construction in India and the Russian Federation.

105. The CEFR is a pool-type sodium cooled fast reactor (SFR). China is also developing CFR-1000, a 1000 MW(e) SFR demonstration plant using MOX fuel.

106. Under its European Strategic Energy Technology Plan (SET-Plan), the European Commission recently defined a two-track technological pathway for developing fast reactors. The first track is for an SFR, and the second is for lead cooled and gas cooled fast reactors as longer term alternatives. The related demonstration and implementation programme, the European Sustainable Nuclear Industrial Initiative, foresees development of the French SFR prototype ASTRID and two demonstration plants, ALFRED and ALLEGRO, for lead cooled and gas cooled technologies respectively. The programme is also supported by a fast-spectrum subcritical irradiation facility, MYRRHA, in Belgium.

107. India is building a 500 MW(e) prototype fast breeder reactor (FBR) at Kalpakkam, Commissioning is planned for early 2013. The Indian programme foresees the construction of several

FBR units around 2020-2025 and the development, after 2025, of fast reactors with metallic fuel and higher breeding ratios.

108. Japan has been developing the 1500 MW(e) Japan sodium cooled fast reactor as part of its Fast Reactor Cycle Technology (FaCT) project, and the Republic of Korea is carrying out a broad R&D programme in support of the 600 MW(e) SFR KALIMER.

109. The Russian Federation is building BN-800 on the site where BN-600 currently operates. BN-800's commissioning phase is scheduled to begin in 2014. The Russian Federation recently launched a new programme to develop an advanced SFR (BN-1200), the lead cooled BREST-OD-300, the lead bismuth eutectic cooled SVBR-100, the related fuel cycles, and the new multipurpose research sodium cooled fast reactor MBIR.

## **E.6. Nuclear Fuel Cycle and Supporting Technology Developments**

110. New aqueous and non-aqueous spent fuel reprocessing technologies for LWRs are being investigated, which would make it possible to significantly decrease waste generation. To test and optimize the technologies under development, work is being conducted to establish pilot industrial demonstration facilities.

111. For HLW disposal, development work is under way to investigate suitable sites and specific engineered barriers and to perform safety assessments and implement the technology for encapsulation and disposal.

## **F. Cooperation relating to the Expansion of Nuclear Energy and Technology Development**

112. The Generation IV International Forum (GIF), through a system of contracts and agreements, coordinates research activities on six next generation nuclear energy systems selected in 2002 and described in *A Technology Roadmap for Generation IV Nuclear Energy Systems*. The six are gas cooled fast reactors (GFRs), lead cooled fast reactors (LFRs), molten salt reactors (MSRs), sodium cooled fast reactors (SFRs), supercritical water cooled reactors (SCWRs) and very high temperature reactors (VHTRs). They represent a variety of reactor, energy conversion and fuel cycle technologies. Depending on their respective degrees of technical maturity, these systems are expected to become available for commercial introduction between 2015 and 2030 or beyond. GIF currently has 13 members.<sup>20</sup>

113. The Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) has 37 members.<sup>21</sup> INPRO has four projects: (1) National Long-Range Nuclear Energy Strategies, (2) Global Nuclear Energy Scenarios, (3) Technical and Institutional Innovations and (4) Policy and INPRO Dialogue Forum.

---

<sup>20</sup> Argentina, Brazil, Canada, China, Euratom, France, Japan, the Republic of Korea, South Africa, Switzerland, Russian Federation, UK and USA.

<sup>21</sup> Algeria, Argentina, Armenia, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, the Czech Republic, Egypt, France, Germany, India, Indonesia, Israel, Italy, Japan, Jordan, the Republic of Korea, Kazakhstan, Malaysia, Morocco, the Netherlands, Pakistan, Poland, the Russian Federation, Slovakia, South Africa, Spain, Switzerland, Turkey, Ukraine, USA, Vietnam and the European Commission.

114. INPRO and GIF coordinate activities through a joint action plan that covers cooperation in the following areas: general information exchange, synergies in evaluation methods (focusing on proliferation resistance, safety and economics), cooperation in topical studies (including, inter alia, non-electric applications, SMRs and human resources), global dialogue between nuclear technology holders and users and joint activities, e.g. the second joint IAEA/INPRO/GIF workshop on safety aspects of sodium cooled fast reactors, held in November 2011. As part of the joint action plan, the Agency participates as an observer in the GIF Policy Group and as a member in GIF Working Groups.

115. The membership of the International Framework for Nuclear Energy Cooperation (IFNEC) has grown to 31 participating<sup>22</sup> and 30 observer countries and 3 observing international organizations, including the Agency. IFNEC currently has two working groups, one on infrastructure development and another on reliable fuel services.

116. The Multinational Design Evaluation Programme (MDEP) was launched in 2006 by the US NRC and the French Nuclear Safety Authority (ASN). As of April 2012, MDEP membership includes national regulatory authorities from 11 countries.<sup>23</sup> MDEP pools the resources of these 11 nuclear regulatory authorities to, first, cooperate on safety reviews of specific reactor designs and, second, explore opportunities for harmonizing regulatory practices. MDEP has five working groups: on the EPR, the AP1000, mechanical codes and standards, digital instrumentation and control (I&C), and vendor inspection cooperation.

---

<sup>22</sup> Argentina, Armenia, Australia, Bulgaria, Canada, China, Estonia, France, Germany, Ghana, Hungary, Italy, Japan, Jordan, Kazakhstan, Kenya, Republic of Korea, Kuwait, Lithuania, Morocco, Netherlands, Oman, Poland, Romania, Russian Federation, Senegal, Slovenia, UAE, Ukraine, UK and USA.

<sup>23</sup> Canada, China, Finland, France, India, Japan, Republic of Korea, Russian Federation, South Africa, UK and USA.