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SUMMARY AND CONCLUSIONS

THE WORLD NUCLEAR INDUSTRY

STATUS REPORT 2016

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TABLE OF CONTENTS

ANNEXES

TABLE OF FIGURES

TABLE OF TABLES

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Executive Summary and Conclusions

Key Insights in Brief

The China Effect

- Nuclear power generation in the world increased by 1.3%, entirely due to a 31% increase in China.
- Ten reactors started up in 2015—more than in any other year since 1990—of which eight were in China. Construction on all of them started prior to the Fukushima disaster.
- Eight construction starts in the world in 2015—to which China contributed six—down from 15 in 2010 of which 10 were in China. No construction starts in the world in the first half of 2016.
- The number of units under construction is declining for the third year in a row, from 67 reactors at the end of 2013 to 58 by mid-2016, of which 21 are in China.
- China spent over US$100 billion on renewables in 2015, while investment decisions for six nuclear reactors amounted to US$18 billion.

Early Closures, Phase-outs and Construction Delays

- Eight early closure decisions taken in Japan, Sweden, Switzerland, Taiwan and the U.S.
- Nuclear phase-out announcements in the U.S. (California) and Taiwan.
- In nine of the 14 building countries all projects are delayed, mostly by several years. Six projects have been listed for over a decade, of which three for over 30 years. China is no exception here, at least 10 of 21 units under construction are delayed.
- With the exception of United Arab Emirates and Belarus, all potential newcomer countries delayed construction decisions. Chile suspended and Indonesia abandoned nuclear plans.

Nuclear Giants in Crisis - Renewables Take Over

- AREVA has accumulated US$11 billion in losses over the past five years. French government decides €5.6 billion bailout and breaks up the company. Share value 95 percent below 2007 peak value. State utility EDF struggles with US41.5 billion debt, downgraded by S&P. Chinese utility CGN, EDF partner for Hinkley Point C, loses 60% of its share value since June 2015.
- Globally, wind power output grew by 17%, solar by 33%, nuclear by 1.3%.
- Brazil, China, India, Japan and the Netherlands now all generate more electricity from wind turbines alone than from nuclear power plants.

Chernobyl+30/Fukushima+5

- Three decades after the Chernobyl accident shocked the European continent, 6 million people continue to live in severely contaminated areas. Radioactive fallout from Chernobyl contaminated 40% of Europe's landmass. A total of 40,000 additional fatal cancer cases are expected over the coming 50 years.
- Five years after the Fukushima disaster began on the east coast of Japan, over 100,000 people remain dislocated. Only two reactors are generating power in Japan, but final closure decisions were taken on an additional six reactors that had been offline since 2010-11.

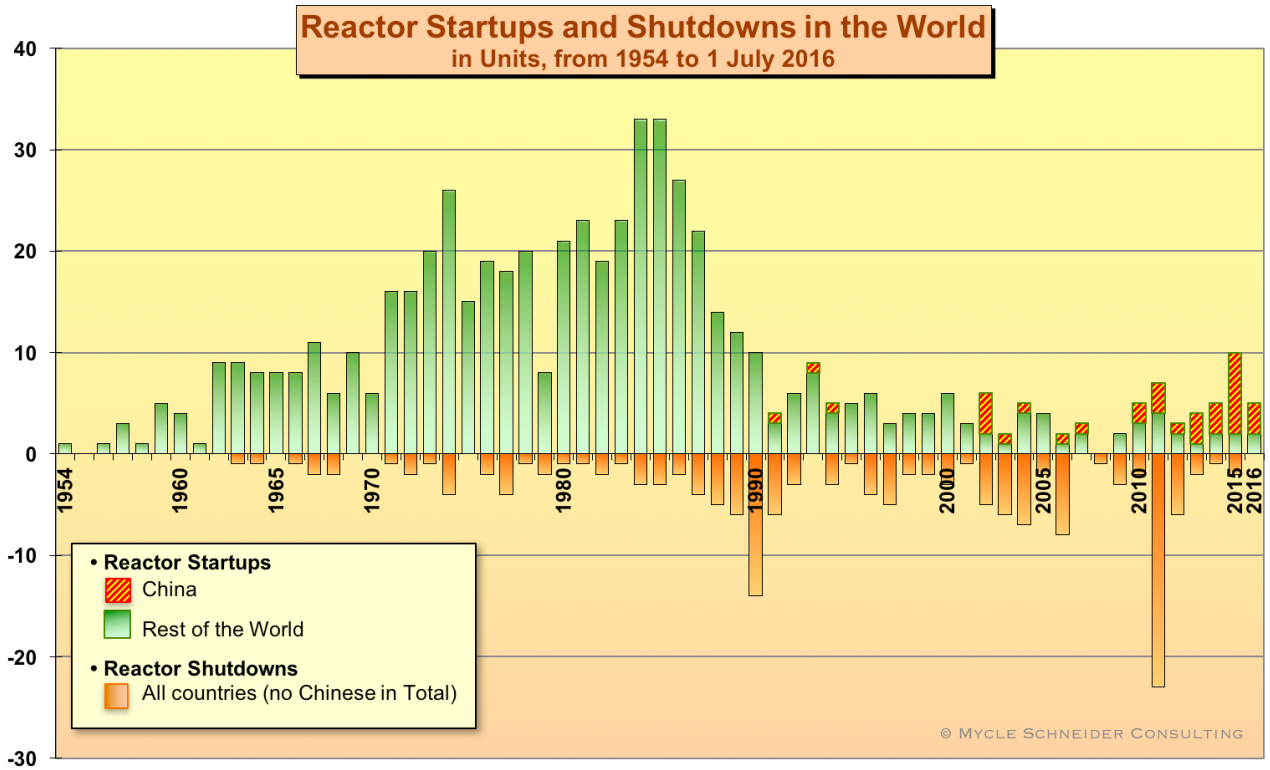
The World Nuclear Industry Status Report 2016 (WNISR) provides a comprehensive overview of nuclear power plant data, including information on operation, production and construction. The WNISR assesses the status of new-build programs in current nuclear countries as well as in potential newcomer countries. The WNISR2016 edition includes again an assessment of the financial status of many of the biggest industrial players in the sector. This edition also provides a Chernobyl Status Report, 30 years after the accident that led to the contamination of a large part of Europe. The Fukushima Status Report gives an overview of the standing of onsite and offsite issues five years after the beginning of the catastrophe.

The Nuclear Power vs. Renewable Energy chapter provides global comparative data on investment, capacity, and generation from nuclear, wind and solar energy.

Finally, Annex 1 presents a country-by-country overview of all 31 countries operating nuclear power plants, with extended Focus sections on Belgium, China, France, Japan, and the United States.

Reactor Status and Nuclear Programs

Startups and Shutdowns. In 2015, 10 reactors started up (eight in China, one in Russia, and one in South Korea) and two were shut down (Grafenrheinfeld in Germany and Wylfa-1 in the U.K.). Doel-1 was shut down in January when its operational license ran out, but was restarted in December after a lifetime extension was approved. Final closure decisions were taken on five reactors in Japan that had not generated power since 2010-11, and on one Swedish reactor that had been offline since 2013.



The China Effect

In the first half of 2016, five reactors started up, three in China, one in South Korea and one in the U.S. (Watts Bar 2, 43 years after construction start), while none were shut down. However, the permanent closure of one additional reactor has been announced in Japan. Ikata-1, that had not generated any power since 2011.

Operation and Construction Data[1]

Reactor Operation. There are 31 countries operating nuclear power plants, one more than a year ago, with Japan restarting two units.[2] These countries operate a total of 402 reactors—excluding Long Term Outages (LTOs)—a significant increase, 11 units, compared to the situation mid-2015, but four less than in

1 See Annex 1 for a country-by-country overview of reactors in operation and under construction as well as the nuclear share in electricity generation.

2 Unless otherwise noted, the figures indicated are as of 1 July 2016.

1987 and 36 fewer than the 2002 peak of 438. The total installed capacity increased over the past year by 3.3 percent to reach 348 GW[3], which is comparable to levels in 2000. Installed capacity peaked in 2006 at 368 GW. Annual nuclear electricity generation reached 2,441 TWh in 2015—a 1.3 percent increase over the previous year, but 8.2 percent below the historic peak in 2006. The 2015 global increase of 31 TWh is entirely due to production in China where nuclear generation increased by 30 percent or 37 TWh.

WNISR classifies 36 Japanese reactors[4] as being in LTO.[5] Besides the Japanese reactors, one Swedish reactor (Ringhals-2) and one Taiwanese reactor (Chinshan-1) meet the LTO[5] criteria. All ten reactors at Fukushima Daiichi and Daini are considered permanently closed and are therefore excluded in the count of operating nuclear power plants.

Share in Energy Mix. The nuclear share of the world's power generation remained stable over the past four years, with 10.7 percent in 2015 after declining steadily from a historic peak of 17.6 percent in 1996. Nuclear power's share of global commercial primary energy consumption also remained stable at 4.4 percent—prior to 2014, the lowest level since 1984.[6]

The "big five" nuclear generating countries—by rank, the U.S., France, Russia, China, and South Korea—generated about two-thirds (69 percent in 2014) of the world's nuclear electricity in 2015. China moved up one rank. The U.S. and France accounted for half of global nuclear generation, and France produced half of the European Union's nuclear output.

Reactor Age. In the absence of major new-build programs apart from China, the unit-weighted average age of the world operating nuclear reactor fleet continues to rise, and by mid-2016 stood at 29 years. Over half of the total, or 215 units, have operated for more than 30 years, including 59 that have run for over 40 years, of which 37 in the U.S.

Lifetime Extension. The extension of operating periods beyond the original design is licensed differently from country to country. While in the U.S. 81 of the 100 operating reactors have already received license extensions for up to a total lifetime of 60 years, in France, only 10-year extensions are granted and the safety authorities have made it clear that there is no guarantee that all units will pass the 40-year in-depth safety assessment. Furthermore, the proposals for lifetime extensions are in conflict with the French legal target to reduce the nuclear share from the current three-quarters to half by 2025. In Belgium, 10-year extensions for three reactors were approved but do not jeopardize the legal nuclear phase-out goal for 2025.

Lifetime Projections. If all currently operating reactors were shut down at the end of a 40-year lifetime—with the exception of the 59 that are already operating for more than 40 years—by 2020 the number of operating units would be 22 below the total at the end of 2015, even if all reactors currently under active construction were completed, with the installed capacity declining by 1.7 GW. In the following decade to 2030, 187 units (175 GW) would have to be replaced—four times the number of startups achieved over the past decade. If all licensed lifetime extensions were actually implemented and achieved, the number of operating reactors would still only increase by two, and adding 17 GW in 2020 and until 2030, an additional 144.5 GW would have to start up to replace 163 reactor shutdowns.

Construction. As in previous years, fourteen countries are currently building nuclear power plants. As of July 2016, 58 reactors were under construction—9 fewer than in 2013—of which 21 are in China. Total capacity under construction is 56.6 GW.

- The current average time since work started at the 58 units under construction is 6.2 years, a considerable improvement from the average of 7.6 years one year ago. This is mainly because four units with 30+ construction years were taken off the list (two started up, two were suspended) and work started on six new reactors.
- All of the reactors under construction in 9 out of 14 countries have experienced delays, mostly year-long. At least two thirds (38) of all construction projects are delayed. Most of the 21 remaining units under construction, of which eleven are in China, were begun within the past three years or have not yet reached projected start-up dates, making it difficult to assess whether or not they are on schedule.
- Three reactors have been listed as "under construction" for more than 30 years: Rostov-4 in Russia and Mochovce-3 and -4 in Slovakia. As no active construction has been ongoing and with the construction

3 All figures are given for nominal net electricity generating capacity. GW stands for gigawatt or thousand megawatt.

4 Including the Monju reactor, shut down since 1995, listed under "Long Term Shutdown" in the International Atomic Energy Agency (IAEA), Power Reactor Information System (PRIS), database.

5 WNISR considers that a unit is in Long-Term Outage (LTO) if it produced zero power in the previous calendar year and in the first half of the current calendar year. This classification is applied retroactively starting on the day the unit is disconnected from the grid. WNISR counts the startup of a reactor from its day of grid connection, and its shutdown from the day of grid disconnection.

6 According to BP, "Statistical Review of World Energy", June 2016.

contract cancelled, Khmelnitski-3 and -4 in Ukraine have been taken off the list.

- Two units in India, Kudankulam-2 and the Prototype Fast Breeder Reactor (PFBR), have been listed as "under construction" for 14 and 12 years respectively. The Olkiluoto-3 building site in Finland reached its tenth anniversary in August 2015.
- The average construction time of the latest 46 units in ten countries that started up since 2006 was 10.4 years with a very large range from 4 to 43.6 years. The average construction time increased by one year compared to the WNISR2015 decennial assessment.

Construction Starts & New Build Issues

Construction Starts. In 2015, construction began on 8 reactors, of which 6 were in China and one each were in Pakistan and the United Arab Emirates (UAE). This compares to 15 construction starts—of which 10 were in China alone—in 2010 and 10 in 2013. Historic analysis shows that construction starts in the world peaked in 1976 at 44. Between 1 January 2012 and 1 July 2016, first concrete was poured for 28 new plants worldwide—fewer than in a single year in the 1970s.

Construction Cancellations. Between 1977 and 2016, a total of 92 (one in eight) of all construction sites were abandoned or suspended in 17 countries in various stages of advancement.

Newcomer Program Delays/Cancellation. Only two newcomer countries are actually building reactors—Belarus and UAE. Public information on the status of these construction projects is scarce. Further delays have occurred over the year in the development of nuclear programs for most of the more or less advanced potential newcomer countries, including Bangladesh, Egypt, Jordan, Poland, Saudi Arabia, Turkey, and Vietnam. Chile and Lithuania shelved their new-build projects, whereas Indonesia abandoned plans for a nuclear program altogether for the foreseeable future.

Nuclear Economics: Corporate Meltdown?

Nuclear Utilities in Trouble. Many of the traditional nuclear and fossil fuel based utilities are struggling with a dramatic plunge in wholesale power prices, a shrinking client base, declining power consumption, high debt loads, increasing production costs at aging facilities, and stiff competition, especially from renewables.

- In **Europe**, energy giants EDF, Engie (France), E.ON, RWE (Germany) and Vattenfall (Sweden), as well as utilities TVO (Finland) and CEZ (Czech Republic) have all been downgraded by credit-rating agencies over the past year. All of the utilities registered severe losses on the stock market. EDF shares lost over half of their value in less than a year and 87 percent compared to their peak value in 2007. RWE shares went down by 54 percent in 2015.
- In **Asia**, the share value of the largest Japanese utilities TEPCO and Kansai was wiped out in the aftermath of the Fukushima disaster and never recovered. Chinese utility CGN, listed on the Hong Kong stock exchange since December 2014, has lost 60 percent of its share value since June 2015. The only exception to this trend is the Korean utility KEPCO that still operates as a virtual monopoly in a regulated market, controlling production, transport and distribution. Its share value has gone up by 80 percent since 2013.
- In the **U.S.**, the largest nuclear operator Exelon lost about 60 percent of its share value compared to its peak value in 2008.

AREVA Debacle (new episode). The French state-controlled integrated nuclear company AREVA is technically bankrupt after a cumulative five-year loss of €10 billion (US$10.9 billion). Debt reached €6.3 billion (US$6.9 billion) for an annual turnover of €4.2 billion (US$4.6 billion) and a capitalization of just €1.3 billion (US$1.5 billion) as of early July 2016, after AREVA's share value plunged to a new historic low, 96 percent below its 2007 peak. The company is to be broken up, with French-state-controlled utility EDF taking a majority stake in the reactor building and maintenance subsidiary AREVA NP that will then be opened up to foreign investment. The rescue scheme has not been approved by the European Commission and could turn out to be highly problematic for EDF as its risk profile expands.

Operating Cost Increase - Wholesale Price Plunge. In an increasing number of countries, including Belgium, France, Germany, the Netherlands, Sweden, Switzerland and parts of the U.S., historically low operating costs of rapidly aging reactors have escalated so rapidly that the average unit's operating cost is barely below, and increasingly exceeds, the normal band of wholesale power prices. Indeed, the past five years saw a dramatic drop of wholesale prices in European markets, for example, about 40% in Germany and close to 30% in the Scandinavian Nord Pool in 2015 alone.

Utility Response. This has led to a number of responses from nuclear operators. The largest nuclear operator in the world, the French-state-controlled utility EDF, has requested significant tariff increases to cover its operating costs. In the U.S., Exelon, the largest nuclear operator in the country, has been accused of "blackmailing" the Illinois state over the "risk" of early retirements of several of its reactors that are no longer competitive under current market conditions. In spite of "custom-designed" tools, like the introduction of modified rules in capacity markets that favor nuclear power, an increasing number of nuclear power plants cannot compete and fail to clear auctions. In Germany, operator E.ON closed one of its reactors six months earlier than required by law. In Sweden, early shutdown of at least four units has been confirmed because of lower than expected income from electricity sales and higher investment needs. Even in developing markets like India, at least two units are candidates for early closure as they are losing money.

Chernobyl+30 Status Report

Thirty years after the explosion and subsequent fire at unit 4 of the Chernobyl nuclear power plant on 26 April 1986, then in the USSR, now in independent Ukraine, the consequences are still felt throughout the region.

Accident Sequence. A power excursion—output increased about 100-fold in 4 seconds—a hydrogen explosion and a subsequent graphite fire that lasted 10-days released about one third of the radioactive inventory of the core into the air.

Environmental Consequences. The chimney effect triggered by the fire led to the ejection of radioactive fission products several kilometers up into the atmosphere. An estimated 40 percent of Europe's land area was contaminated (>4,000 Bq/m^2). Over six million people still live in contaminated areas in Belarus, Russia and Ukraine. A 2,800 km^2 exclusion zone with the highest contamination levels in a 30-km radius has been established in the immediate aftermath of the disaster and upheld ever since.

Human Consequences. About 130,000 people were evacuated immediately after the initial event, and in total about 400,000 people were eventually dislocated. Around 550,000 poorly trained workers called "liquidators", engaged by the Soviet army in disaster management, received amongst the highest doses.

Health Consequences. A recent independent assessment expects a total of 40,000 fatal cancers over the coming 50 years caused by Chernobyl fallout. Over 6,000 thyroid cancer cases have been identified so far, another 16,000 are expected in the future. Similarly, 500 percent increases were observed in leukemia risk in both Belarus and Ukraine. Some new evidence indicates increased incidences of cardiovascular effects, stroke, mental health effects, birth defects and various other radiogenic effects in the most affected countries. Strong evidence has been published on Chernobyl related effect on children, including impaired lung function and increased breathing difficulties, lowered blood counts, high levels of anemias and colds and raised levels of immunoglobulins.

Remediation Measures. In 1986, under extremely difficult conditions, the liquidators had built a cover over the destroyed reactor called the "sarcophagus" that quickly deteriorated. Under the Shelter Implementation, Plan financed by 44 countries and the EU, a US$ 2 billion New Safe Confinement (NSC) has been built. The NSC is a gigantic mobile cover that will be pushed over the old sarcophagus and serve as protection during the dismantling of the ruined nuclear plant.

Waste Management. The largest single risk potential at the Chernobyl site remains the spent fuel from all four units that is to be transferred to a recently completed dry storage site between end of 2017 and April 2019. Construction of a liquid and solid waste treatment facilities were completed in 2015.

Fukushima+5 Status Report

Over five years have passed since the Fukushima Daiichi nuclear power plant accident (Fukushima accident) began, triggered by the East Japan Great Earthquake on 11 March 2011 (also referred to as 3/11 throughout the report) and subsequent events. This assessment includes analyses of onsite and offsite challenges that have arisen since and remain significant today.

Onsite Challenges. In June 2015, the Japanese government revised the medium- and long-term roadmap for the decommissioning of the Fukushima Daiichi site. Key components include spent fuel removal, fuel debris evacuation and limitation of contaminated water generation.

- **Spent Fuel Removal.** Spent fuel is to be removed from unit 3 between Financial Years (FY) 2017 and 2019, from unit 2 between 2020 and 2021 and from unit 1 between 2020 and 2022.

- **Molten Fuel Removal.** Radiation levels remain very high inside the reactor buildings (about 4-10 Sievert per hour) and make human intervention impossible. No conclusive video footage is available and it remains unknown where the molten fuel is actually located. Commencement of work on fuel debris removal is planned for 2021. However, no methodology has been selected yet.
- **Contaminated Water Management.** Large quantities of water (about 300 cubic meters per day) are still continuously injected to cool the fuel debris. The highly contaminated water runs out of the cracked containments into the basement where it mixes with water that has penetrated the basements from an underground river. The commissioning of a dedicated bypass system and the pumping of groundwater has reduced the influx of water from around 400 m^3/day to about 150 to 200 m^3/day. An equivalent amount of water is decontaminated to some degree—it contains still very high levels of tritium (over 500,000 Bq/l) and stored in large tanks. The storage capacity onsite is 800,000 m^3. A frozen soil wall that was designed to further reduce the influx of water was commissioned at end of March 2016. Its effectiveness is under review.

Workers. Between 3,000 and 7,500 workers per day are involved in decommissioning work. Several fatal accidents have occurred at the site. In September 2015, the Ministry of Health recognized, for the first time, the leukemia developed by a worker who had carried out decommissioning tasks as an occupational disease.

Offsite Challenges. Amongst the main offsite issues are the future of tens of thousands of evacuees, the assessment of health consequences of the disaster, the management of decontamination wastes and the costs involved.

Evacuees. According to government figures, the number of evacuees from Fukushima Prefecture as of May 2016 was about 92,600 (vs. 164,000 at the peak in June 2013). About 3,400 people have died for reasons related to the evacuation, such as decreased physical condition or suicide (all classified as "earthquake-related deaths"). The government plans to lift restricti on orders for up to 47,000 people by March 2017. However, according to a survey by Fukushima Prefecture, 70 percent of the evacuated people do not wish to return to their homes (or what is left of them) even if the restrictions are lifted, while 10 percent wish to return and 20 percent remain undecided.

Health Issues. Conflicting information has been published concerning the evolution of thyroid cancer incidence. While a Fukushima Prefectural committee concluded that "it is unlikely that the thyroid cancers discovered until now were caused by the effects of radiation", but it did not rule out a causal relationship. In contrast, an independent study from Okayama University concluded that the incidence of childhood thyroid cancer in Fukushima was up to 50 times higher than the Japanese average.

Decontamination. Decontamination activities inside and outside the evacuation area in locations, "where daily activities occur" throughout Fukushima Prefecture, have been carried out on 80 percent of the houses, 5 percent of the roads and 70 percent of the forests, according to government estimates. However, the efficiency of these measures remain highly questionable.

Cost of the Accidents. The Japanese Government has not provided a comprehensive total accident cost estimate. However, based on information provided by TEPCO, the current cost estimate stands at US$133 billion, over half of which is for compensation, without taking into account such indirect effects as impacts on food exports and tourism.

Fukushima vs. Chernobyl

Every industrial accident has its own very specific characteristics and it is often difficult to compare their nature and effects. The large explosions and subsequent 10-day fire at inland Chernobyl led to a very different release pattern than the meltdowns of three reactor cores at coastal Fukushima. The dispersion of radioactivity from Chernobyl led to wide-spread contamination throughout Europe, whereas about four fifths of the radioactivity released from Fukushima Daiichi came down over the Pacific Ocean. Radioactivity in the soil mainly disappears with the physical half-lives of the radioactive isotopes (30 years for the dominant cesium-137). Radioactive particles are greatly diluted in the sea and many isotopes, including cesium-137, are water soluble. This does not mean that radioactivity released to the ocean does not have effects, particularly in fish species near the coast, but further away any effects are difficult to identify.

Some parameters can be compared, and some are model estimates based on calculations and assumptions: care needs to be taken in interpreting their conclusions. Under practically all criteria, the Chernobyl accident appears to be more severe than the Fukushima disaster: 7 times more cesium-137 and 12 times more iodine-131 released, 50 times larger land surface significantly contaminated, 7–10 times

higher collective doses and 12 times more clean-up workers. More people were evacuated in the first year at Fukushima than at Chernobyl. However, the number has tripled over time to about 400,000 at Chernobyl because more and more people were displaced as more hotspots were identified.

Nuclear Power vs. Renewable Energy Deployment

The transformation of the power sector has accelerated over the past year. New technology and policy developments favor decentralized systems and renewable energies. The Paris Agreement on climate change gave a powerful additional boost to renewable energies. For the Paris Agreement 162 national pledges called Intended National Determined Contributions (INDCs) were submitted of which only 11 mention nuclear power in their plans and only six actually state that they were proposing to expand its use (Belarus, China, India, Japan, Turkey and UAE). This compares with 144 countries that mention the use of renewable energies and 111 that explicitly mention targets or plans for expanding their use.

Investment. Global investment in renewable energy reached an all-time record of US$286 billion in 2015, exceeding the 2011 previous peak by 2.7 percent. China alone invested over US$100 billion, almost twice as much as in 2013. Chile and Mexico enter the Top-Ten investors for the first time, both countries having doubled their expenditure over the previous year. A significant boost to renewables investment was also given in India (+44 percent), in the U.K. (+60 percent) and in the U.S. (+21.5 percent). Global investment decisions on new nuclear power plants remained an order of magnitude below investments in renewables.

Installed Capacity. In 2015, the 147 GW of renewables accounted for more than 60 percent of net additions to global power generating capacity. Wind and solar photovoltaics both saw record additions for the second consecutive year, making up about 77 percent of all renewable power capacity added, with 63 GW in wind power and 50 GW of solar, compared to an 11 GW increase for nuclear power. China continued the acceleration of its wind power deployment with 31 GW added—almost twice the amount added in 2013—and with a total of 146 GW wind capacity installed significantly exceeding its 2015 goal of 100 GW. China added 14 GW of solar and overtook Germany as the largest solar operator. China started up 7.6 GW of new nuclear capacity, over 68 percent of the global increase.

Since 2000, countries have added 417 GW or wind energy and 229 GW of solar energy to power grids around the world. Taking into account the fact that 37 GW are currently in LTO, operational nuclear capacity meanwhile fell by 8 GW.

Electricity Generation. Brazil, China, Germany, India, Japan, Mexico, the Netherlands, Spain and the U.K.—a list that includes three of the world's four largest economies—now all generate more electricity from non-hydro renewables than from nuclear power.

In 2015, annual growth for global generation from solar was over 33 percent, for wind power over 17 percent, and for nuclear power 1.3 percent, exclusively due to China.

Compared to 1997, when the Kyoto Protocol on climate change was signed, in 2015 an additional 829 TWh of wind power was produced globally and 252 TWh of solar photovoltaics electricity, compared to nuclear's additional 178 TWh.

In China, as in the previous three years, in 2015, electricity production from wind alone (185 TWh), exceeded that from nuclear (161 TWh). The same phenomenon is seen in India, where wind power (41 TWh) outpaced nuclear (35 TWh) for the fourth year in a row. Of all U.S. electricity, 8 percent was generated by non-hydro renewables in 2015, up from 2.7 percent in 2007.

The figures for the European Union illustrate the rapid decline of the role of nuclear: during 1997–2014, wind produced an additional 303 TWh and solar 109 TWh, while nuclear power generation declined by 65 TWh.

In short, the 2015 data shows that renewable energy based power generation is enjoying continuous rapid growth, while nuclear power production, excluding China, is shrinking globally. Small unit size and lower capacity factors of renewable power plants continue to be more than compensated for by their short lead times, easy manufacturability and installation, and rapidly scalable mass production. Their high acceptance level and rapidly falling system costs will further accelerate their development.