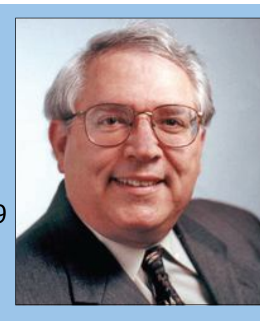
The Future of Nuclear Energy

Professor Mujid S. Kazimi

Director, Center for Advanced Nuclear Energy Systems,
Massachusetts of Institute Technology, Cambridge, Massachusetts, USA 02139
kazimi@mit.edu



1. Introduction

Nuclear power provides 17% of world electricity, through plants located in 33 countries. After a very rapid program for building nuclear plants in the 70's and the 80's, there has been a slow down in the number of new plants. In the past 10 years, however, the fraction of electricity provided by nuclear energy has been kept constant by deriving more energy from the existing plants, and by a few additional plants mostly in Asian countries, like South Korea, Japan and China. The demand for electricity in the fast growing economies of China and India has led to an ambitious plan for a large rise in the share of nuclear in their electricity supply. In addition, after decades of stagnation in nuclear power in the US, new orders appear imminent to partly meet the strong demand for electricity. All together, the announced intentions around the World will add by 2025 about 165 new plants to the existing 442 plants.

2. Key Features

The new demand for nuclear energy stems from rising concerns about the emissions of carbon dioxide to the atmosphere, and also from the need for economic stability in energy supply in the face of episodic escalation in the prices of oil and natural gas. The traditional market for nuclear plants is mostly in the industrial world, thus leading to relatively large plants, approaching 1500 MWe size as a new standard reactor size. New designs of light water cooled reactors are now available. Some, like the Advanced Boiling Water Reactor (ABWR) and the European Power Reactor (EPR) are evolutionary designs from the older generations of these types of reactors. Other designs, such as the AP1000 and the ESBWR, are significantly simplified designs that have new safety features that do not require active intervention by the operators to become operational. While initial designs of these reactors were for small capacity, their output is now comparable to that of the evolutionary plants.

However, to achieve a larger difference in mitigating carbon emissions, there is a need for smaller plants that can serve in the smaller electricity grids in many parts of the world. While the economics of large nuclear power plants are known and found to be competitive with fossil alternatives, questions about the ability of smaller plants to compete remain open. Various vendors are offering smaller units, some of them rely on water cooled technology derived from the familiar large plants, but others employ different jcoolants. For example, the South African project to build gas cooled reactors coupled with gas turbines aim at a unit size of about 200 MWe. At such a size, it is possible to build the main components at a factory then assemble them at the site, significantly speeding up the building time of the plant. Several reactors can be co-located in one site to provide larger power supplies if needed. The advantage of the small capacity in graphite moderated gas cooled plant, such as the South African project, is to enable the removal of decay heat after reactor shutdown without the need for active pumping of any coolant. This natural (or passive) decay heat removal eliminates the loss of coolant as a serious accident in such a plant. Another example of an advanced pant that accomplishes this with water cooling is the 300 MWe Westinghouse integrated plant called IRIS, which places the steam generators in the same vessel as the reactor core, thus reducing the total plant cost, and also eliminating the loss of coolant accident as a serious accident.

In the U.S., which alone has about 30% of the world nuclear electric capacity, no new nuclear power plant has started operation in the last decade but the nuclear energy output from existing plants has been rising. However, there are elements of transition on four fronts taking place that are likely to speed up the growth of nuclear energy utilization:

a) A new regulatory approach for licensing of new plants has been introduced. The approach decouples the certification of a plant design form the application for construction, and also makes the construction and operation license a single license. Therefore, it is possible that for each reactor design, there will be a single permit, and that standardized plant designs will speed up the process of construction, including permitting, on different sites. This standardization of plant permits will lure the U.S. utilities into buying the standard design to avoid lengthy delays. In addition, the government has offered to insure the first 6 plants against regulatory delays so as to facilitate the utility decision for nuclear plants without the risk of interveners, using the NRC process to force lengthy delay.

b) The government has recently extended the loan guarantees for non-emitting power sources to include nuclear plants. This will facilitate lowering the cost of money used for their construction.

c) There is also financial support for research and development of future technology options that can provide an efficient source of hydrogen production from water, either by electrolysis or by thermochemical means. Hydrogen is in demand at refineries to sweeten the increasingly heavy oils. Such hydrogen is also needed to facilitate the use of unconventional oils such as sand tars and shale oils in the transportation sector. Furthermore, in the long run, the hydrogen may be needed for cars powered by fuel cells.

d) A revised policy with regards to the nuclear fuel cycle was announced this year. The policy aims to facilitate a Global fuel supply system (more precisely a group of countries that collectively provide the service to countries that want nuclear energy), and collection of the spent fuel. In anticipation of an increase in the need for spent fuel disposal in the fuel supply countries, the U.S. is willing to reverse its prohibition against the recycling of spent fuel. Thus, it will join France, Russia and Japan as countries that can recycle the fuel and reduce the amount of long term radioactivity that needs to be isolated in geologic repositories.

There are several ways for using the nuclear reactors to reduce carbon emissions from the transportation sector. Nuclear reactors could become the source of heat needed for extraction of heavy oils from tar sands or shale as well as for the hydrogen to sweeten it. Several oil companies are exploring the implications of using small reactors to aid in unconventional oil recovery. The reactors need to be sufficiently mobile to facilitate moving from one area to another in the sand fields. The temperature needed is not more than 220°C, therefore almost any of today's reactors can be used, if the price against alternatives would allow it. In addition, plans for developing high temperature reactors have been drawn by the international group called Generation IV International Forum, in order to prepare a technology for more efficient electricity and hydrogen production using nuclear power. The U.S. will in fact build a demonstration plant of direct conversion helium cooled plants before 2020 for that purpose. The Helium cooled reactors will operate with a maximum coolant temperature around 800 C and be able to directly or indirectly couple to helium turbines, and produce electricity at an efficiency of about 45%. The high temperature reactors can be used in combination with regular gas driven power plants to reduce the use of gas in heating the fluid, and that can reduce the net emissions of carbon as well.

There are important questions about the ramifications of significant expansion in the nuclear fuel cycle:

1) Does the world have enough uranium to support such an expansion without resorting to fuel breeding in the more expensive fast reactors? The answer to this question is that it is a matter of economics. As long as U extraction from lower grade ores is less costly than the extraction of new fissile materials from breeder reactors, the fuel will continue to be dominated by uranium mining. This is likely to be the case at least for the first half of the century.

2) What fuel cycle is best to reduce the need for disposal of spent fuel? There is a strong incentive to take the fuel to higher burnups so that the volume of spent fuel per unit energy production is reduced. Such high burnup fuel is on the drawing boards of many companies, and is likely to materialize in the next decade or two.

3) What industrial capacity is needed to allow nuclear to expand at a rate three to four times the rate experienced near the end of the last century? There is a definite need to beef up the ability to enhance U extraction, the ability to forge large sections of steel and to build reinforced concrete sections in a more modern and speedy way. Thus, the growth of nuclear energy would only come if it is accompanied with growth in some other industrial sectors.

How can the world cope with an expanded use of nuclear civilian applications without increasing the threat of nuclear weapons? The International Atomic Energy Agency Director General, Mohamed ElBaradie, is on record that the fuel cycle facilities should function as international facilities, under the IAEA. In addition, the U.S. government has announced at the beginning of 2006 a new global policy to allow wider use of nuclear energy through an agreement by a few fuel cycle states to provide fuel to, and to agree to receive back the spent fuel from, the rest of the world. Either approach will limit the access to strategic material and its transfer from the civilian world to the military world. If a wide agreement on such an international order develops, it would help overcome several of the issues facing the expansion of nuclear power.

3. Conclusions

It seems that the world is in the dawn of a new era for nuclear energy. The rate at which nuclear energy growth will materialize is subject to several challenges. However, if we are to have stable supplies of affordable energy without emissions of carbon gases, or other greenhouse gases, to the atmosphere, nuclear energy must grow in the 21st century to serve large and small countries, under an international order for the production of fresh fuel, spent fuel storage and reprocessing, and eventual disposal of nuclear waste.

4. Bibliography

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Speaker's Biography

Mujid S. Kazimi is Tokyo Electric Power Company Professor of Nuclear Engineering and Professor of Mechanical Engineering at Massachusetts Institute of Technology. He held positions at Brookhaven National Laboratory and Westinghouse Electric Corporation prior to joining the MIT faculty in 1976. He has extensive expertise in nuclear reactor design and safety analysis, nuclear fuel cycle analysis and heat transfer in power systems. He is the founding Director of the MIT Center for Advanced Nuclear Energy Systems (2000-present). He has served as Head of the Department of Nuclear Engineering (1989-1997). Dr. Kazimi has served on numerous national and international advisory panels for the US Department of Energy, US Nuclear Regulatory Commission, the US National Research Council, the Spanish CIEMAT research center, and the Swiss Paul Sherer Research Institute. Currently he is a member of the Board of Managers of Battelle Energy Alliance, which manages the Idaho National Laboratory for DOE. He is a co-author of *Nuclear Systems*, a two volume book on thermal analysis and design of nuclear fission reactors and over 200 journal and conference papers. He is a Fellow of the American Nuclear Society.

Dr. Kazimi was born in Jerusalem, Palestine in November 1947. He received a B.Eng. degree in 1969 from Alexandria University in Egypt, an M.S. degree in 1971 and a Ph.D. degree in 1973 from MIT (all in nuclear engineering).