ELECTRICITY SUSTAINABILITY AND NUCLEAR POWER:
PERSPECTIVE BANGLADESH

A THESIS REPORT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL & ELECTRONIC ENGINEERING, ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT) IN PRACTICAL FULFILLMENT FOR THE DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL & ELECTRONIC ENGINEERING

SUPERVISED BY

KAZI OBAIDUL AWAL

ASSISTANT PROFESSOR

ISLAMIC UNIVERSITY OF TECHNOLOGY

BOARD BAZAR, GAZIPUR

SUBMITTED BY

REYADUL ISLAM MAHMUD

KHAN JABID HASAN

MD SHIHAB SHAHRIAR

DEPERTMENT OF ELECTRICAL & ELECTRONIC ENGINEERING,

ISLAMIC UNIVERSITY OF TECHNOLOGY

BOARD BAZAR, GAZIPUR

Declaration

We do hereby declare that this report has not been submitted elsewhere for obtaining any degree or diploma or certificate or for publication.

Signature

Reyadul Islam Mahmud	**: 082479**
Khan Jabid Hasan	**: 082478**
Md. Shihab Shahriar	**: 082480**

Countersigned:

Kazi Obaidul Awal

Assistant Professor

EEE Department, IUT

Approved by:

Prof. Dr. Md. Shahid Ullah

Head, EEE Department, IUT.

ACKNOWLEDGEMENT

At first we would like to start by praising the Almighty ALLAH that the thesis was able to reach the end.

We would like to thank our supervisor Kazi Obaidul Awal, Assistant Professor, EEE department for his earnest help, guidance and motivation towards the completion of this thesis work.

We would like to thank our parents for their consistent inspiration and encouragement for us to consummate our goal.

We are grateful to all the teachers and staff members of the department of EEE for their consistent support and enthusiasm.

None but the less we thank our batch mates, our beloved friends, for their supports, assists and for being there no matter what.

ABSTRACT

Adequate and quality electricity at an affordable price is a key element for socio-economic development of a country. Electricity is secondary or delivered form of energy produced from the primary sources e.g. fossil fuels, fissile materials, and renewable sources like hydro, wind, solar, tide, geothermal, bio-mass, ocean current etc. About 65% of global electricity currently is produced from fossil fuels: coal, gas and oil. The reserves of the fossil fuels are finite, geographically not uniformly distributed and in some counties the reserves are maturing. The prices of fossil fuels often fluctuate partly due to demand and supply imbalance and partly on geopolitics. The use of fossil fuels release enormous amount of greenhouse gases resulting global warming and climate change. Environmental pollution and transportation of large quantities of fossil fuels for bulk electricity generation are also issues of concerns. The thesis primarily presents electricity and nuclear power from the perspective of sustainability. Bangladesh scenario has also been touched.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

1.1 OBJECTIVE

Energy, particularly electricity is an essential element for economic and social development of a country. About 1.6 billion global population mostly living in South Asia, Sub Saharan Africa and East Asia do not have access to electricity. Even those who have an access, the quality of electricity can hardly be maintained due to supply constraints. Electricity is a secondary form of energy converted from the primary energy sources: fossil fuels, nuclear fuels, hydro and renewable energy sources. Demand of electricity is growing and will continue to grow to meet the economic and social needs of expanding global population. Fossil fuels (presently producing about 66% of global electricity) are finite and the reserves are maturing. Besides, these fuels emit greenhouse gases causing climate change and other pollutants effecting air and water quality, and irreversible changes in the eco-system. Most renewable sources are yet to be cost effective and technically dependable for bulk energy supply. The poor countries are more vulnerable to the climate change and environment pollution. Sustainable electricity or energy security, environment pollution, and the climate change are now key challenges before the world community. In this case Nuclear power may address the issues of electricity sustainability. The main objective of our thesis is to give a brief idea on energy sustainability, nuclear power and discuss about a sustainable diversified energy mix suitable for Bangladesh where nuclear power plays the major role.

1.2 BRIEF OVERVIEW

As fresh blood is most needed for a human to live comfortably, like that electricity is must for the development of a country. We will find a lot of examples if we look at the developed countries of the world. The production of electricity along with GDP is considered to measure which country is more developed now-a-days. But BANGLADESH is lagging far behind in this aspect.

We’ll try to give some ideas to mitigate the electricity problem of BANGLADESH in this Thesis along with that we have tried to give a diversified energy mix which can mitigate the power or electricity problem of our country.

We have talked about the Electricity and human development link which actually pictures the relation between Electricity and the growth of human demand.

We have discussed about Electricity Sustainability in this thesis which is the sustainable provision of energy that meets the needs of the present without compromising the ability of future generations to meet their needs.

Again in this thesis we have discussed about Nuclear Power , Basic nuclear physics and evolution of nuclear power, advantages and disadvantages of Nuclear power, waste management system of nuclear power plants, cost of establishment of a nuclear power plant and etc.

At the last we discussed about the ROOPUR Nuclear power plant which is a big hope for Bangladesh. There we have given a brief history of this project including history, financing, justification, waste management system and the barriers of this project.

1.3 KEY TERMINOLOGIES

The key terminologies used in the paper are defined below:-

i) Energy: Energy is capacity to do work. Work cannot be done without the expense of energy.

ii) Electricity: Electricity is the flow electric power or charge. It's the secondary form of energy, produced from primary sources of energy.

iii) Electrical System: It may be defined as all activities starting from generation of electricity to end use. The activities include generation, transmission and distribution of electricity, facility wirings and the connected loads.

iv) Electricity Security: may be defined as the national policy actions assuring the availability of electricity at affordable prices and in sufficient quantities for a reasonable future period (30 to 50 years, depending on many factors).

v) Electricity Intensity: is the ratio of the quantity of electricity consumed for producing unit gross domestic product (GDP).

vi) Sustainable Energy: "means environmentally sound, safe, reliable, affordable energy, in other words, energy that supports sustainable development in all its economic, environmental, and social and security dimensions".

vii) Economies in Transition: "national economies that are moving from a period of heavy government control toward lessened intervention, increased privatization, and greater use of competition".

viii) Greenhouse Gases (GHGs): "heat trapping gases in the atmosphere that warm the Earth's surface by absorbing outgoing infrared radiation and re-radiating part of it downward. Water vapor is the most important naturally occurring greenhouse gas, but the principal greenhouse gases, whose atmospheric concentrations are being augmented by emission from the human activities, are carbon dioxide, methane, nitrous oxide and halocarbons".

ix) Primary Energy: is the energy extracted directly from nature e.g. crude oil, hard coal, natural gas, wood, solar-wind-hydro power, uranium (as we receive from nature) etc.

x) Renewable Energy: The energy sources which are naturally renewed with time e.g. hydro, wind, solar, tide etc.

xi) Traditional Energy: are those energy sources which the homo-sapiens have been using from the pre-historic days e.g. muscle power, biomass, wind, solar radiation etc.

xii) Biomass: is the organic non-fossil material oil or gas of biological origin, which constitutes an exploitable energy resource.

xiii) Energy System: may be defined as all the activities starting from the exploration of the primary energy sources to the end use including processing, transportation, conversion, distribution etc.

xiv) Energy Services: are used to describe consumer benefits, which include: lighting, air-conditioning, refrigeration, cooking, transportation, providing motive power etc.

xv) Energy Chain: includes activities that link the primary energy to deliver energy services.

xvi) Energy Intensity: is the ratio of the quantity of energy consumed for producing unit gross domestic product (GDP).

xvii) Energy Forms: There are different forms of energy, gas, coal, oil, hydro, nuclear, electricity, light, heat, potential, kinetic etc. The selection or suitability of the form will depend on the end use. *Electricity is the most preferred form.*

xviii) Nuclear Materials: Nuclear materials are those materials which are fissionable with neutrons e.g. uranium (Ur), thorium (Th), Plutonium (Pu) etc and constitutes both fissile and fertile materials.

xix) Fissile Materials: Fissile materials are those materials which are fissionable by thermal neutrons: ^{233}Ur, ^{235}Ur ^{239}Pu.

xx) Fertile Materials: Fertile materials are those materials which are fissionable by fast neutrons: ^{232}Th, ^{234}Ur, ^{238Ur} etc.

xxi) Fission: Fission is the breaking of nucleus of an atom (Ur, Pu)

xxii) Fusion: Fusion is the fusing or combining of two nucleus (^{2}H, ^{3}H, ^{4}He)

xxiii) Reserves: are those occurrences of energy sources or minerals that are identified and measured as economically and technically recoverable with current technology and prices.

xxiv) Resources: are those occurrences of energy sources or minerals with less certain geological and/or economic/technical recoverability characteristics, but that are considered to become potentially recoverable with foreseeable economic and technological development.

CHAPTER 2: PRIMARY ENERGY SOURCES

2.1 General

Electricity, as already said before, is secondary or delivered form of energy produced from primary sources: fossil fuels (coal, oil and gas), nuclear and new renewable sources like: hydro, solar. Wind, bio-mass, tide, ocean current, geothermal etc.

"World primary energy consumption – including oil, natural gas, coal, nuclear and hydro power – grew by 1.4% in 2010, the slowest growth since 2001. Non-OECD primary energy consumption exceeded OECD consumption for the first time. The Asia-Pacific region accounted for 87% of the world's energy consumption growth. For the third consecutive year, coal accounted for the majority of primary energy consumption growth. Chinese consumption growth slowed for the fifth consecutive year, yet China accounted for nearly three-quarters of global growth. Energy consumption among exporting regions remained robust, with above-average growth in the Middle East and Africa. Consumption in the US fell by 2.8%, the largest decline since 1982."

2.2 Fossil Fuel Reserves

Nature took more than 3 million years to produce the fossil fuels. The fossil fuels are now being depleted at a rate that is 100,000 times faster than they are being formed. The tern is not sustainable. The reserves depend on various factors: available technology, demand and the economic cost. The **Fig. 1** reproduced below will help in understanding the dynamics of energy reserve and resource situations.

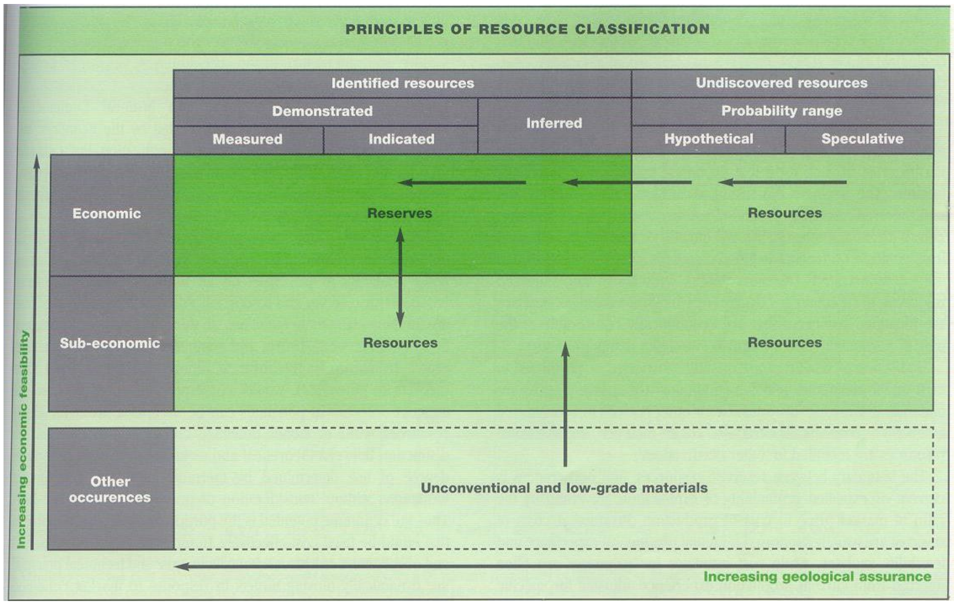


Fig 1: Principles of Reserve & Resource Classification

The summary of the world's proven fossil fuels reserves are shown at **Table- 1** below:

Table -1 World's Proven Fossil Fuel Reserves

Country/Region	Coal Billion Tons	Oil Billion Tons	Gas Trillion cft
Total North America	246	9.7	313
Total Europe & Eurasia	272	19.2	2221
Saudi Arabia	-	36.3	267
Total Middle East	33 (includes Africa)	102 (41%)	2681 (60%)
Africa		16.6	518
Total Asia Pacific	254	5.6	544
Total World	826	170.8	6534

Source: BP Statistical Review of World Energy, June 2009

2.2.1 Coal Reserve

Coal is the largest potential energy source among the fossil fuels. The total world coal reserve is about 826 billion tons. The detail break up is given at **Annex -I**. But coal is the dirtiest or most pollutant among the fossil fuels. Coal is geographically better distributed compared to gas and oil. The energy content/ton varies widely depending on the type of coal: anthracite, bituminous, lignite, peat etc. - so is the pollutants like: ash, sulfur lead etc.

2.2.2 Gas Reserve

Gas is the second largest fossil fuel energy source. The global proven gas reserve is about 6534 Tcf or 185.02 Tcm. Gas reserves are confined largely in certain key areas of the world: Russia, Middle East etc. The detail information on world gas reserve is shown in **Annex-II.** It is the cleanest compared to coal and oil. It has alternate uses too, particularly for production of fertilizer.

2.2.3 Oil Reserve

Oil is used primarily in transportation and communication sectors as fuel for vehicles and aviation. Oil, to some extent, is used for emergency or stand by generation of electricity. The energy content per ton of oil is more than coal but less than gas. It is less environmentally than coal. The world's present proven oil reserve is about 1258 billion barrels or 170.8 billion tons. About 60% of the world's oil reserve is located in Middle East. Saudi Arabia alone has world's 41% reserve. The detailed information on world oil reserve is shown in **Annex-III.**

2.3 Nuclear Fuels

The movement of nuclear fuels is restricted under different convention and treaties adopted by the IAEA. The world's proven reserves of Uranium and Thorium are about **5.5** and **2.6** million tons respectively. The detailed breakups are shown in **Annex-IV and Annex- V** respectively.

2.4 Renewable Sources

The renewable energy sources are: hydro, solar, wind, ocean current, tide, bio-fuels, geothermal etc. The world has very large renewable energy potential (**Table – 2)**. The renewable energy sources produce less GHG and are more environment friendly. But the present technologies are yet not developed enough to make these sources economically viable for bulk electricity generation.

Table-2 Summary of the Renewable Energy Base

(Exa-Joules A Year)

Resource	Current Use[a]	Technical potential	Theoretical potential
Hydropower	9	50	147
Biomass energy	50	>276	2,900
Solar energy	0.1	>1,575	3,900,000
Wind energy	0.12	640	6,000
Geothermal energy	0.6	5,000	140,000,000
Ocean energy	n.e.	n.e.	7,400
Total	56	>7,600	>144,000,000

2.4.1 Hydro

"Hydroelectricity generation grew by 2.8%, with global growth above the 10-year average for the fourth time in the past five years. Chinese hydroelectric output grew by 20.3%, double the 10-year average and sufficient to account for all the global increase. Elsewhere hydroelectric output was weaker than average, falling by 0.4%"

2.4.2 Other Renewable Sources

"Renewable energy continued to grow strongly. Global wind and solar generation capacity increased by 29.9% and 69%, respectively – both figures above the 10-year average. Driven by a favorable policy environment, US wind capacity rose by 49.5%, surpassing Germany as the world's capacity leader. Ethanol production rose by one-third driven by continued strong growth in the US and Brazil."

2.5 Comparative Advantages and Detriments: Each type of primary energy source has its own inherent advantages and disadvantages. Of the three types of fossil fuels gas is the least environment polluting. Gas can be used for generation of electricity and also as heat source for cooking and heating, prime fuel in vehicles, production of fertilizers etc. Oil is more pollutant than gas but cleaner compared to coal. Each primary energy source has its own pollution and other associated problems that have to be considered by the users. Some of these problems are highlighted in **Table- 3** below:-

Table-3 Pollution and Other Problems of Primary Energy Sources

Fuel Source	Problems
Oil	Global warming; air pollution by vehicles; acid rain; oil spills; oil rig accidents
Natural gas	Global warming; pipe leakage; methane explosions
Coal	Global warming; environmental spoliation by open-cast mining; land subsidence due to deep mining; spoil heaps; groundwater pollution; acid rain
Nuclear power	Global warming (despite what they say); radioactivity (routine release, risk of accident, waste disposal); misuse of fissile material by terrorists; spread of nuclear weapons
Biomass	Effect of landscape of and biodiversity; groundwater pollution due to fertilizers; use of scarce water; competition with food production
Hydroelectric	Displacement of populations; effect on rivers and groundwater; dams (visual intrusion and risk of accident); seismic effects; downstream effects on agriculture
Wind power	Noise; visual intrusion in sensitive landscapes; bird strikes; TV interference
Tidal power	Destruction of wildlife habitat; reduced dispersal of effluents
Geothermal	Release of polluting gases (SO2, H2S, etc); groundwater pollution by chemicals including heavy metals; seismic effects
Solar energy	Sequestration of large land areas; use of toxic materials in manufacture of PV cells; visual intrusion in both rural and urban environments

Source: World Coal Institute - Coal Facts.htm-2007

CHAPTER 3: ELECTRICITY AND HUMAN DEVELOPMENT LINK

3.1 ELECTRICITY ND HUMAN DEVELOPMENT

Works have to be done for production, services and living. Electricity is extremely fast, clean and easy to use. Electricity is used to provide final energy for industrial production, diverse utilities and services e.g. for lighting, air conditioning, cooking, pumping, running machines and industries, entertainments, mobiles, televisions, ICT, imaging, diagnosis of diseases, treatment, sensing and controlling devices etc. Economic development of a country as such is directly linked with electricity.

The economic status as well as the quality of life of the citizens of a country is directly linked with the per capita consumption of electricity. This is also dependent on the status of electrification of a country (**Table 1).** Out of more than 200 global states GDP (per capita), Human Development Indicators (HDI), per capita annual electricity consumption and electrification rate of some of the representative developed, developing and least developed countries (with special stress on the OIC member states) have been highlighted in the table. The data clearly endorse the need and importance of accessibility and affordability of quality electricity for economic elevation as well as for quality life.

Table- 1

Economy –Electricity Linkage

Country/States	GDP per capita (PPP-US$)	HDI Ranking	Electricity Consumption per capita (kilowatt hours)		Electrification rate (%)
Year--	2005	2005	(kWh) 2004	(% Change) 1990-2004	2005
Norway	41420	2	26657	6.5	100
Japan	31267	8	8459	21.8	100
USA	41890	12	14240	11.9	100
Germany	29461	22	7442	10.4	100
South Korea	22029	26	7710	178.3	100
Kuwait	26321	33	15423	75	100
Saudi Arabia	15711	61	6902	57.9	97
Malaysia	10882	63	3196	129.6	98
China	6757	81	1684	112.4	99
Turkey	8407	84	2122	109.5	
Iran	7968	94	2460	126.7	97
Indonesia	3843	107	476	75	54
Egypt	4337	112	1465	93.0	98
Morocco	4555	126	652	84.7	85
India	3452	128	618	77.6	56
Pakistan	2370	136	564	61.6	54
Bangladesh	2053	140	154	111.0	32
Sudan	2083	147	116	123.1	30
Nigeria	1128	158	157	-119	46
Benin	1141	163	81	72.3	22
Mali	1033	173	41	36.7	
Niger	781	174	40	-13.0	
OECD	29197	N/A	10360		100
Low Human Dev.	1112	N/A	134		25
World	9543	N/A	2701		76

Source: UNDP Human Development Report 2007/2008, pages 302-305

If the economy of a country suffers from economic recession, it affects the rate of consumption of electricity. The economies of the developed countries including USA have recently been suffering from economic recessions with negative GDP) growth**.** The primary energy source price fluctuations are also linked with economic recession (**Fig. 2).**

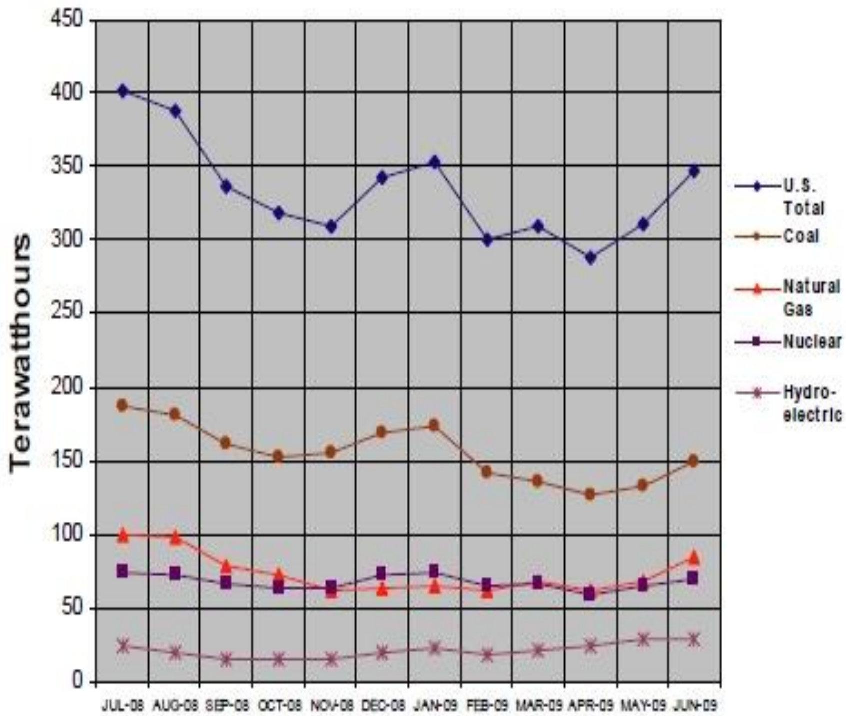


Fig. 1 Net Generation by Major Energy Source: Total (All Sectors), July 2008 through June 2009**,** *Source: EIA Monthly Power Report, September 2009*

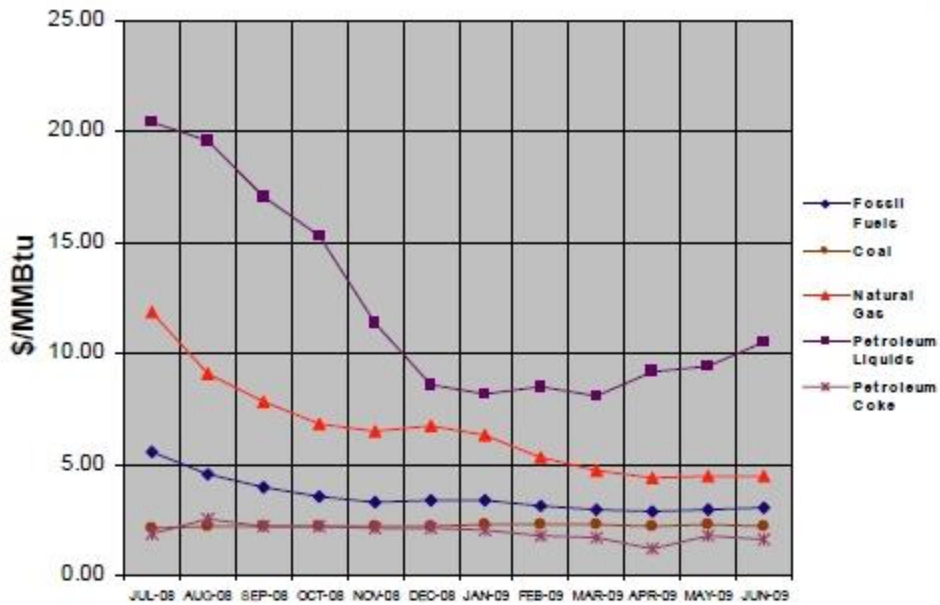
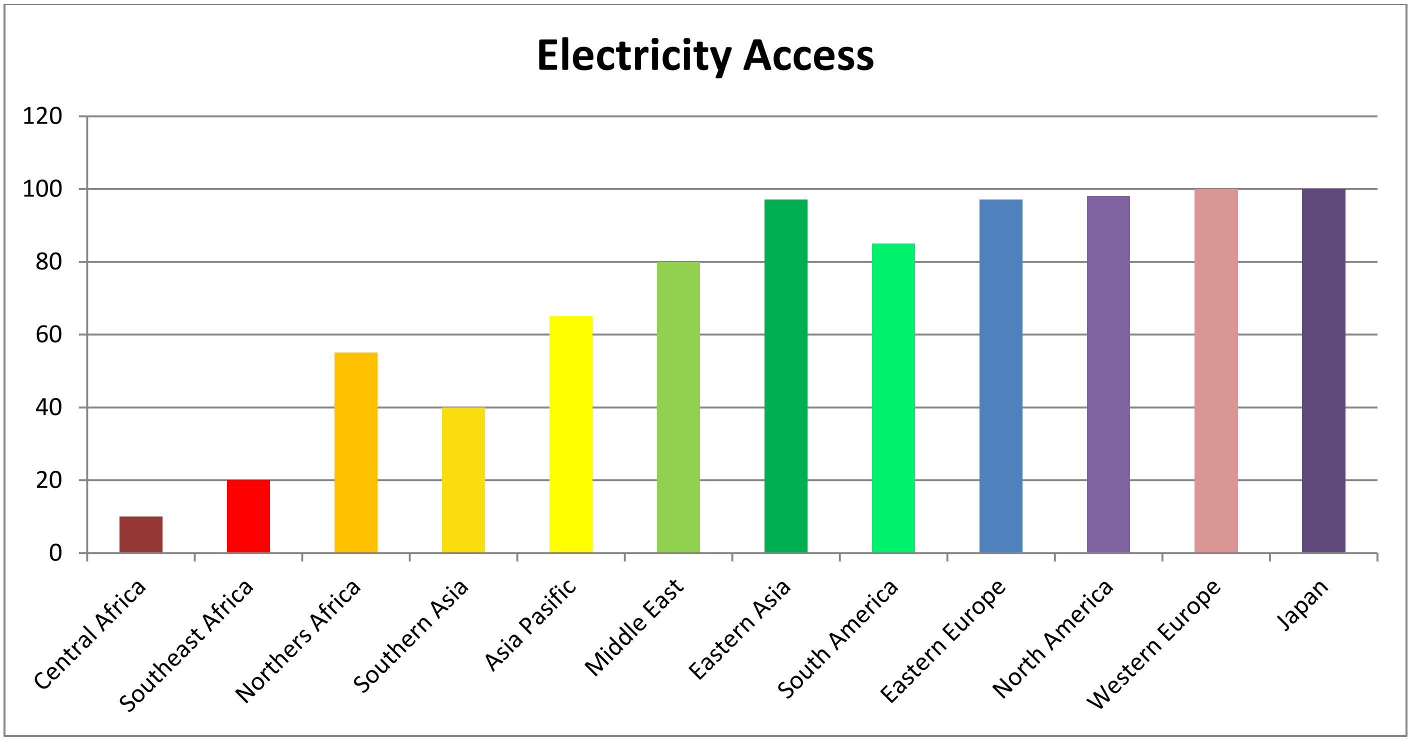


Fig. 2 Fluctuation of Prices of Primary Energy Sources

Source: EIA Monthly Power Report, September 2009

This graph shows where people who have electricity supplied to their homes live. Electricity access includes that sourced from a publicly used grid and self-generated electricity (possibly from solar, wind or hydroelectric sources). Here, shows access, not the quantities of electricity used. The percentage of people with access to electricity in their own homes is over 97% in Eastern Asia, Eastern Europe, North America, Western Europe and Japan. 7 of the 10 territories with the lowest access to electricity are in Southeastern Africa. We can see that countries that have more access of electricity are more developed than the others.



**The below entry consists of total electricity generated annually plus imports and minus exports, expressed in kilowatt-hours. The discrepancy between the amount of electricity generated and/or imported and the amount consumed and/or exported is accounted for as loss in transmission and distribution.

Table 2 Countries with High Electricity Consumption and their GDP

Countries with high electricity consumption	Electricity Consumption(KWH) (*100000000)	GDP (millions of US$)
China	46930	6989000
United States	37410	15060000
European Union	30370	17720000
Japan	8597	5855000
Russia	8576	1885000
India	6006	1843000
Canada	5495	1759000
Germany	5445	3629000
France	4609	2808000

Table 3 Countries with low electricity consumption and Their GDP

Countries with low electricity consumption	Electricity Consumption(KWH) (*100000)	GDP (millions of US$)
Tonga	37,200,000	400
Cook Islands	29,760,000	
Nauru	29,760,000	
Montserrat	20,460,000	300
Kiribati	20,460,000	200
Saint Helena, Ascension, and Tristan da Cunha	7,440,000	283
Niue	2,790,000	10.01
Gaza Strip	202,000	12
Northern Mariana Islands	48,300	633.4

Table 4 Electricity Consumption in South Asia and GDP

	Electricity Consumption(KWH)	GDP (millions of US$)
Bangladesh	23,940,000,000	115000
Pakistan	74,350,000,000	204100
Nepal	4,833,000,000	18300
Bhutan	184,000,000	1830
Maldives	542,000,000	2100

Sources: 1. The World Fact book, Central Intelligence Agency

2. GDP (Nominal), The World Fact book, Central Intelligence Agency. Accessed on 16, 2012.

The human beings started use of electricity during 80s of the 19th century. Electricity has changed the life style and global growth pattern during the last century. Now people can lead much better quality life without using directly other form of energy: coal, firewood, cow dung, kerosene etc. The economy, as stated before, is directly linked with energy and electricity in particular. *Electricity is the most preferred form of energy*. The growth rate of electricity is naturally the highest compared to other forms of energy **[Fig.3].**

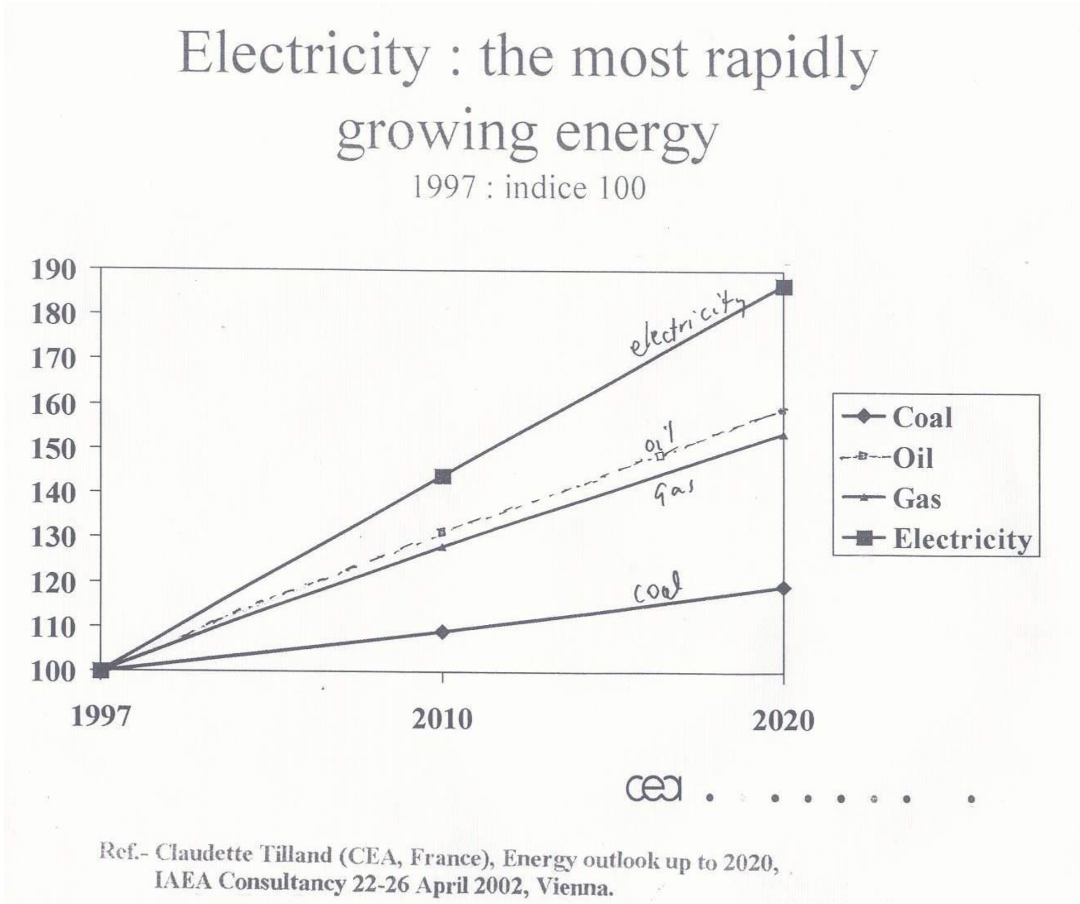


Fig. 3 Electricity is the Most Preferred Form of Energy

The growth of electricity depends on many factors: socio-economic condition, population, availability of primary sources, types of economy etc. The electricity growths for the period of 1971 to 1997 in some selected parts of the world are shown at **Fig.4.**

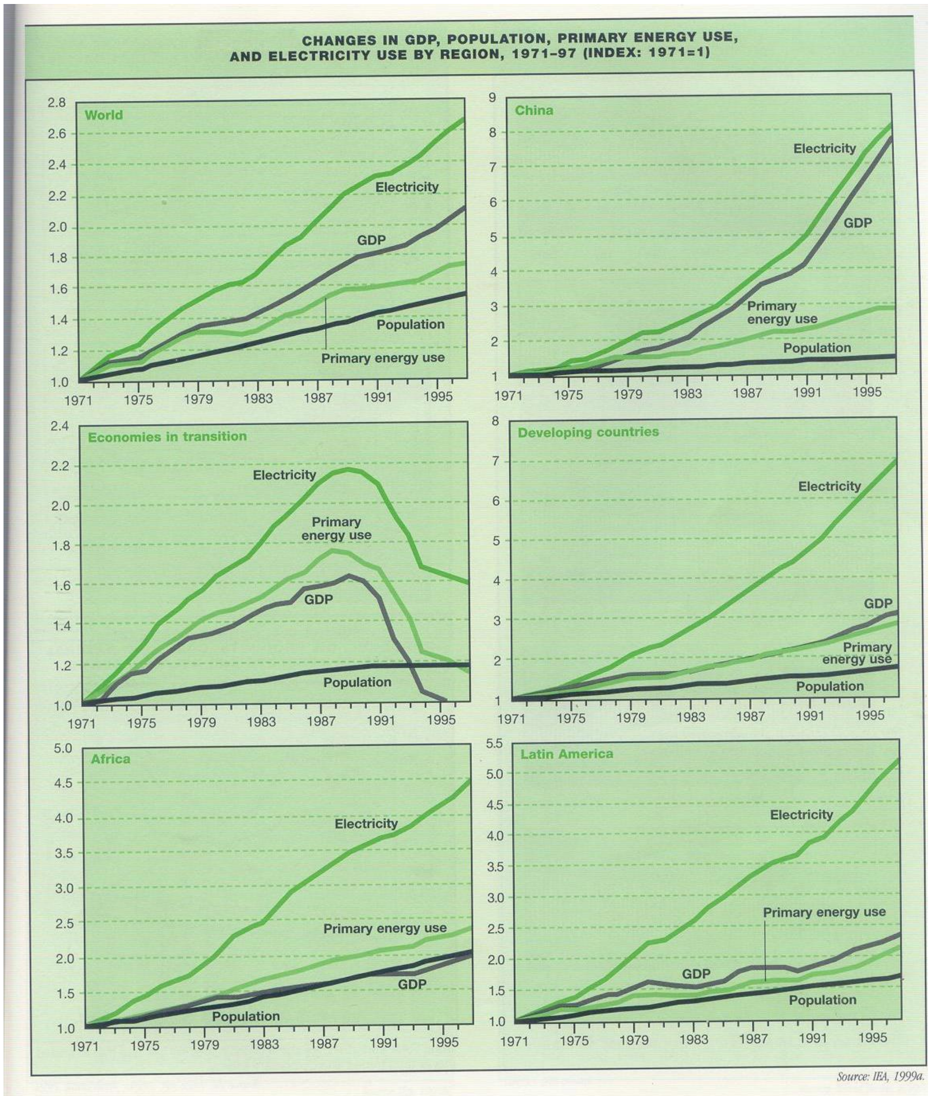


Fig. 4: Changes in Gross Domestic Product, Population, Primary Energy Use and Electricity Use by Region for the Period 1971 to 1997

The world economy is dynamic and now passing through a critical period. Energy sustainability, global warming and climate change, environmental pollution, global unrest, terrorism all are affecting economy and demand. Projections have been and are being made by different energy related national and international bodies at different times. The forecasts are valid to a certain degree of uncertainty due dynamic and changing technology as well as geopolitics. More comprehensive energy related information published recently by the DOE, BPC, IEA and EIA have been compiled in Reference Document – Vol. – I.

The paper highlights the recent US Energy Information Administration (EIA) published data below:-

“World net electricity generation increases by an average of 2.4 percent per year from 2006 to 2030 in the *IEO2009* reference case. Electricity is projected to supply an increasing share of the world’s total energy demand and is the fastest-growing form of end-use energy worldwide in the mid-term. Since 1990, growth in net electricity generation has outpaced the growth in total energy consumption (2.9 percent per year and 1.9 percent per year, respectively), and the growth in demand for electricity continues to outpace growth in total energy use throughout the projection”

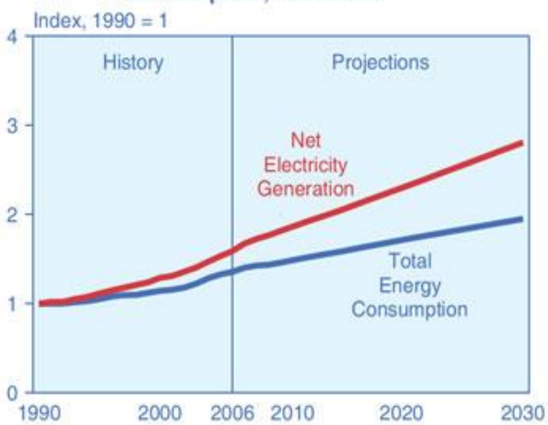
“World net electricity generation increases by 77 percent in the reference case, from 18.0 TWh in 2006 to 23.2 TWh in 2015 and 31.8 TWh in 2030. Although the current recession is expected to dampen electricity demand in the near term, the reference case projection does not anticipate that the recession will be prolonged and expects growth in electricity demand to return to trend after 2010. The impact of the recession on electricity consumption is likely to be felt most strongly in the industrial sector, as manufacturing slows as a result of lower demand for manufactured products. Demand in the building sector is less sensitive to changing economic conditions than the industrial sector, because people generally continue to consume electricity for space heating and cooling, cooking, refrigeration, and hot water heating even in a recession.

In general, growth in the OECD countries, where electricity markets are well established and consuming patterns are mature, is slower than in the non-OECD countries, where a large amount of demand goes unmet at present. The International Energy Agency estimates that nearly 32 percent of the population in the developing non-OECD countries (excluding non-OECD Europe and Eurasia) did not have access to electricity in 2005—a total of about 1.6 billion people . Regionally, sub-Saharan Africa fares the worst: more than 75 percent of the population remains without access to power. High projected economic growth rates support strong increases in demand for electricity among the developing regions of the world through the end of the projection period.”

“The non-OECD nations consumed 45 percent of the world’s total electricity supply in 2006, and their share of world consumption is poised to increase over the projection period. In 2030, non-OECD nations account for 58 percent of world electricity use, and the OECD share declines to 42 percent (Figure 49). In the developing countries, strong economic growth translates to growing demand for electricity. Increases in income per capita lead to improved standards of living, rising consumer demand for lighting and appliances, and growing requirements for electricity in the industrial sector. As a result, total net electricity generation in the non-OECD countries increases by an average of 3.5 percent per year in the reference case, led by non-OECD Asia (including China and India), with annual increases averaging 4.4 percent from 2006 to 2030 (Figure 50). In contrast, net generation among the OECD nations grows by an average of 1.2 percent per year from 2006 to 2030.”

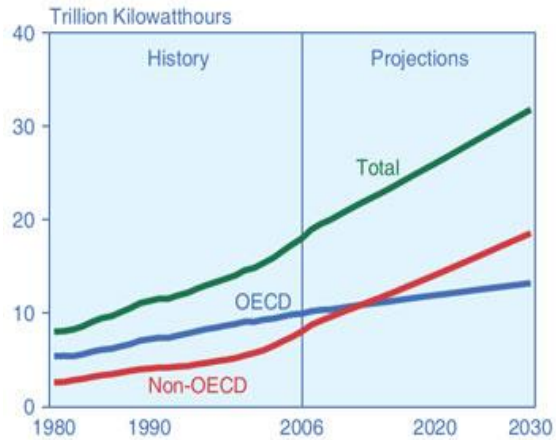
The growth rate of the developing states like China, India, Brazil, Indonesia, Pakistan, Vietnam, and Bangladesh are projected to be higher compared to the growth rates of the OECD countries.

Figure 48. Growth in World Electric Power Generation and Total Energy Consumption, 1990-2030



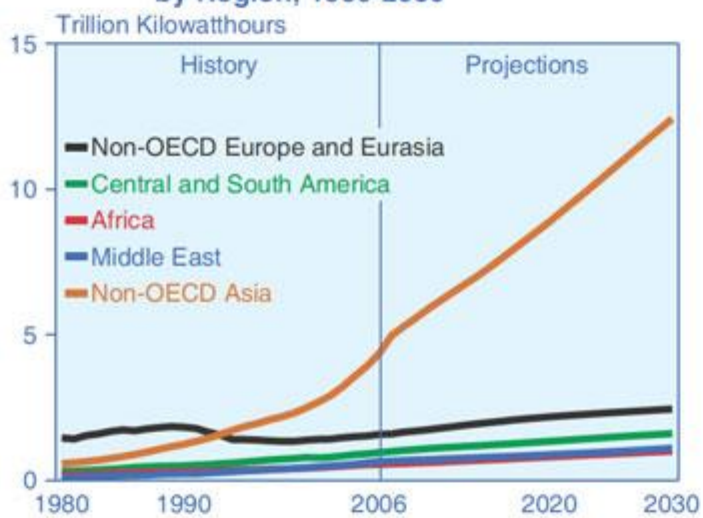
Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

Figure 49. World Net Electric Power Generation, 1980-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

Figure 50. Non-OECD Net Electricity Generation by Region, 1980-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

From all this data we can surely understand the importance of electricity in the economic growth and human development of a country. The current study has demonstrated the richness of the Information contained in the comparison of HDI to per capita energy consumption also.

EIA World Energy Projections, Plus 2009

3.2 GLOBAL TREND

World electricity demand is projected to double between 2000 and 2030, growing at an annual rate of 2.4% (see Table 1). This is faster than any other final energy source. Electricity's share of total final energy consumption rises from 18% in 2000 to 22% in 2030. Electricity demand growth is strongest in developing countries, where demand will climb by over 4% per year over the projection period, more than tripling by 2030. Consequently, the developing countries' share of global electricity demand jumps from 27% in 2000 to 43% in 2030.

The next three decades will see a pronounced shift in the generation-fuel mix in favor of gas and away from coal - the most widely used fuel today worldwide. The role of nuclear power is also expected to decline markedly, because few reactors will be built and some existing ones will be retired. Nuclear production is projected to peak at the end of this decade and then decline gradually. Its share of global power generation will, therefore, drop sharply from around

Table 1: **Electricity Balance,*** Worldwide, 2000-2030

	2000	2010	2020	2030	Average annual growth 2000-2030 (%)
Gross generation (TWh)	15,391	20,037	25,578	31,524	2.4
Coal	5,989	7,143	9,075	11,590	2.2
Oil	1,241	1,348	1,371	1,326	0.2
Gas	2,676	4,947	7,696	9,923	4.5
Hydrogen-fuel cells	0	0	15	349	n.a.
Nuclear	2,586	2,889	2,758	2,697	0.1
Hydro	2,650	3,188	3,800	4,259	1.6
Other renewables	249	521	863	1,381	5.9
Own use and losses (Mtoe)	235	304	388	476	2.4

Includes transport, agriculture and non-specified uses of electricity.

As of June 2006, there were 441 nuclear power reactors in operation around the world. They total 369GW (e) of generating capacity and supply about 16% of the world's electricity. This percentage has been roughly stable since 1986, indicating that nuclear power has grown at the same rate as total global electricity for 20 years. There are also 27 new reactors under construction. *Table 2* shows the distribution across countries of both operating reactors and those under construction.

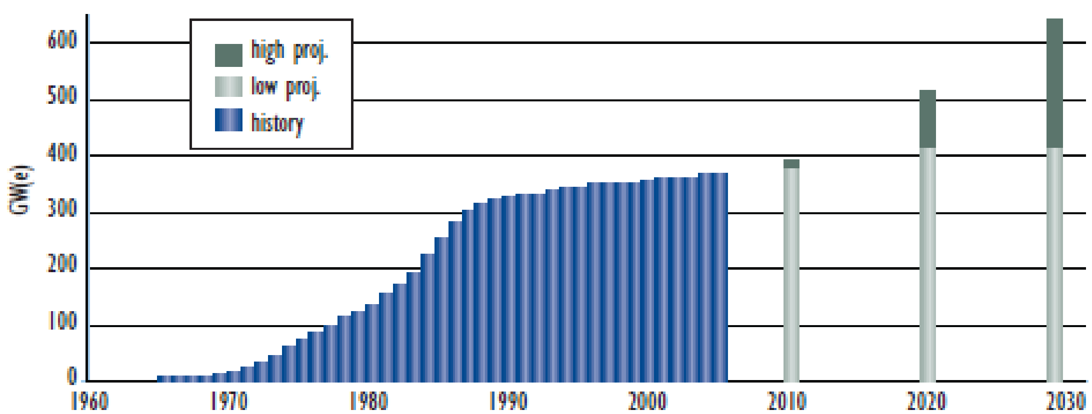
Table 2: Nuclear Power Reactors in Operation and Under Construction in the World (as of June 2006)

Country	*Reactors in operation*		*Reactors under construction*		*Nuclear electricity supplied in 2005*		*Total operating experience through 2005*	
	No of units	*Total MW(e)*	*No of units*	*Total MW(e)*	*TW·h*	*% of Total*	*Years*	*Months*
Argentina	2	935	1	692	6.4	6.9	54	7
Armenia	1	376			2.5	42.7	38	3
Belgium	7	5,824			45.3	55.6	205	7
Brazil	2	1,901			9.9	2.4	29	3
Bulgaria	4	2,722	2	1,906	17.3	44.1	137	3
Canada	18	12,599			86.8	14.6	442	8
China	10	7,572	3	2,610	50.3	2.0	56	11
Czech Republic	6	3,368			23.3	30.5	86	10
Finland	4	2,676	1	1,600	22.3	32.9	107	4
France	59	63,363			430.9	78.5	1,464	2
Germany	17	20,339			154.6	31.0	683	5
Hungary	4	1,755			13.0	37.2	82	2
India	15	3,040	8	3,602	15.7	2.8	252	0
Iran, Islamic Republic of			1	915				
Japan	55	47,593	1	866	280.7	29.3	1,221	3
Korea, Republic of	20	16,810			139.3	44.7	259	8
Lithuania	1	1,185			10.3	69.6	39	6
Mexico	2	1,310			10.8	5.0	27	11
Netherlands	1	449			3.8	3.9	61	0
Pakistan	2	425	1	300	2.4	2.8	39	10
Romania	1	655	1	655	5.1	8.6	9	6
Russian Federation	31	21,743	4	3,775	137.3	15.8	870	4
Slovakia	6	2,442			16.3	56.1	112	6
Slovenia	1	656			5.6	42.4	24	3
South Africa	2	1,800			12.2	5.5	42	3
Spain	8	7,446			54.7	19.6	237	2
Sweden	10	8,910			69.5	44.9	332	6
Switzerland	5	3,220			22.1	32.1	153	10
Ukraine	15	13,107	2	1,900	83.3	48.5	308	6
United Kingdom	23	11,852			75.2	19.9	1,377	8
United States	103	98,145			780.5	19.3	3,087	6
Total[b]	441	369,122	27	21,421	2,625.9	16%	11,991	8

a. Data are from the IAEA's Power Reactor Information System (http://www.iaea.org/programmes/a2/index.html), b. Note: The total includes the following data in Taiwan, China: — 6 units, 4,904MW(e) in operation; 2 units, 2,600MW(e) under construction; — 38.4TW·h of nuclear electricity generation, representing 20.3% of the total electricity generated in 2005; — 146 years, 1 month of total operating experience.

As shown in the table, nuclear power is mainly used in industrialized countries. In terms of new construction, however, the pattern is partly reversed. Sixteen of the 27 new reactors under construction (59%), and half of the 22GW (e) under construction are in developing countries. Current expansion, as well as near-term and long-term growth prospects, is centered in Asia. Of the 27 reactors under construction worldwide, 16 are in Asia. In addition, twenty-five of the last 35 reactors to have been connected to the grid are in Asia. *Figure 1* shows historical growth in worldwide nuclear generating capacity since 1960 plus high and low projections through 2030 by the International Atomic Energy Agency (IAEA).The low projection assumes that no new nuclear power reactors will be built beyond those already under construction or currently planned. Nuclear power capacity grows only slightly in this projection, to 416GW (e) in 2020, before Leveling off. The high projection incorporates nuclear projects proposed beyond those already firmly committed. Global nuclear power capacity in this projection grows steadily to 640GW (e) in 2030, an average growth rate of slightly over 2% per year. While both projections show significant differences in different parts of the world, both project greatest growth in the Far East. There is also significant expansion in Eastern Europe in both projections, and

Figure 1: Installed Nuclear Power Generating Capacity Worldwide

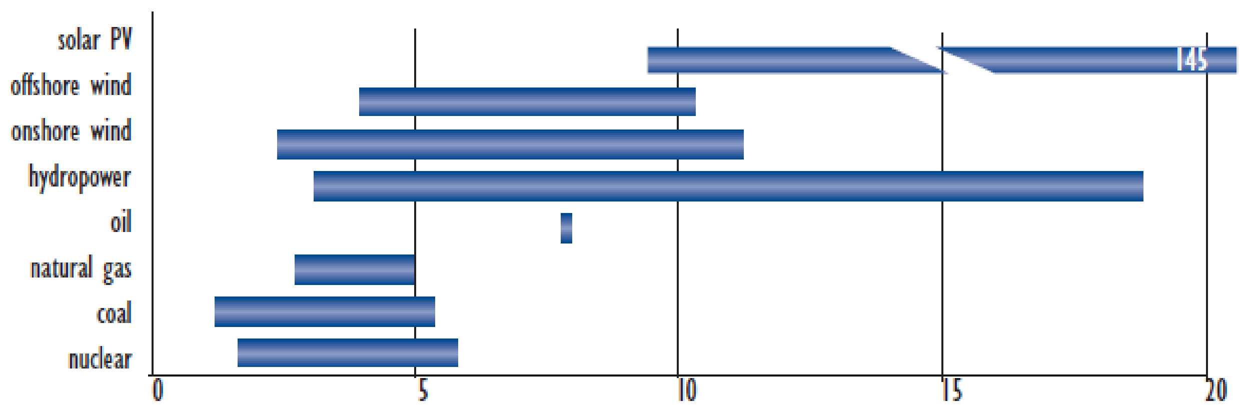


The blue bars to the left show historical growth from 1960 through 2005. The bars on the right show the IAEA's latest low and high projections.

for North America in the high projection. In Western Europe, there is a contraction in the low projection as retirements outpace new construction, but substantial growth in the high projection. Growth rates are high in the Middle East and South Asia in both projections, although these regions start from a small 2005 base. In recent years expectations for nuclear power have been rising: i.e. more people are expecting future growth closer to the high projection in *Figure 1* than to the low projection. There are five reasons. First is strong performance. Nuclear power's good and lengthening track record is reflected in the 11,991 reactor-years of experience shown in *Table 2*, improved capacity factors (from 73% in 1990 to 83% in 2004), lower generating costs and an excellent safety record. There has been one accident with major off-site consequences at Chernobyl in 1986. That accident cost lives and caused widespread misery. But it also brought about major changes, including the founding of a 'safety culture' of constant improvement, thorough analysis of experience and sharing of best practices. This safety culture has been demonstrating its effectiveness for two decades, and this safety record provides the basis for countries considering constructing nuclear power plants. Second, energy forecasts keep showing persistent long-term growth, which increases interest in all energy sources. Third is energy supply security. In the 1970s concerns about supply security, triggered by the oil shocks, were a major cause of nuclear expansion in both Japan and France. Similar concerns may also prove important today. Fourth are new environmental constraints, particularly the entry-into-force of both the Kyoto Protocol and the EU Emissions Trading Scheme in 2005. The complete nuclear power chain, from resource Extraction to waste disposal, including reactor and facility construction, emits only 1–6 grams of carbon equivalent per kilowatt-hour. This is about the same as wind and hydropower and well below coal, oil and natural gas. In the past, nuclear power's advantage of very low greenhouse gas (GHG) emissions has been invisible to investors, as the lack of restrictions or taxes on such emissions meant there was no economic value to their avoidance. Now, in countries with emission restrictions, there is a tangible financial benefit to avoiding GHG emissions. Fifth are policy developments favorable to nuclear power in key countries around the world. These include specific nuclear power expansion plans in countries such as India, China, Japan, the Republic of Korea, the Russian Federation and France. They include new energy legislation in the US and statements by the British prime minister in anticipation of a new review of UK energy policy that was due out in June 2006. They also include the broad support expressed by high-level representatives of 74 governments, including 25 representatives at the ministerial level, at a conference organized by the IAEA and French government in Paris in 2005. The vast majority of participants affirmed that nuclear power can make a valuable contribution to meeting energy needs and sustaining the world's development in the 21st century, for a large number of both developed and developing countries. Among them were a number of countries currently without nuclear power programmes, such as Egypt, Indonesia, Morocco, Poland, Turkey and Vietnam. India currently leads the world in nuclear power construction, with eight of the world's 27 reactors under construction. It plans a 10-fold nuclear power increase between 2002 and 2022 to 10% of the electricity supply, and a 100-fold increase to 2052 to 26% of the electricity supply. A 100-fold increase is equivalent to average growth of 9.2%/yr, identical to average global growth in nuclear power from 1970 through 2004. China is experiencing tremendous energy growth and is developing all energy sources, including nuclear power. It has three reactors under construction and plans a five- to six-fold expansion in just the next 15 years. Japan has 55 reactors in operation, one under construction, and plans to add 10 reactors by 2014, increasing nuclear power's share of electricity to more than 40%. South Korea connected its 20th reactor in 2005 and started site preparations for two more. Russia has 31 nuclear power plants in operation and four under construction, second only to India. In 2005 construction started at Olkiluoto-3 in Finland, the first new construction in Western Europe since 1991. France will start construction of a new 1,600MW (e) reactor in 2007. Some believe that nuclear power's future in the US will be a critical determinant of its future worldwide. For several decades, US nuclear expansion has taken the form of power up rates and license renewals at existing nuclear power plants. Forty-two reactors have received 20-year license renewals, for a total licensed lifetime of 60 years each. New energy legislation in 2005, which provides government coverage of costs associated with certain potential licensing delays and a production tax credit for up to 6,000MW(e) of advanced nuclear power capacity, has, however, prompted broad industry interest in new construction. The US Nuclear Regulatory Commission is reviewing three applications for early site permits, and it expects to receive four applications for combined construction and operating licenses by the end of 2007, with several more possible in

2008. The new interest shown in developing countries faces challenges associated with high capital costs, infrastructure requirements, waste management and the fuel cycle. Possible responses to these challenges include regional co-operation, interconnected grids, shared facilities, shared education and training programmes, shared expertise in safety and operation, and shared skilled labor pools.2 They also include small and medium-size reactor (SMR) designs that allow a more incremental investment than is required for a big reactor, and provide a better match to grid capacity in countries with smaller grids. In addition, new international fuel cycle arrangements, such as the US Global Nuclear Energy Partnership and the Russian proposal for a system of international centers providing fuel cycle services, could reduce burdens associated with fuel cycle and waste management issues, thus lowering the threshold for introducing nuclear power.

Figure 2: The Ranges of Levelized Costs Associated with New Construction as Estimated in Seven Recent Studies for Electricity Generating Technologies in Different Countries (PV = photovoltaic)



The most important determinant of nuclear power's future is cost-competitiveness compared with alternatives. Nuclear power plants have a 'front-loaded' cost structure, i.e. they are relatively expensive to build but relatively inexpensive to operate. Thus, existing well-run operating reactors continue to be a generally competitive profitable source of electricity, but for new construction, the economic competitiveness of nuclear power depends on several factors. First, it depends on the alternatives available. Some countries are rich in alternative energy resources, others less so. Second, it depends on the overall electricity demand in a country and how fast it is growing. Third, it depends on the market structure and investment environment. Other things being equal, nuclear power's front-loaded cost structure is less attractive to a private investor in a liberalized market that values rapid returns, than to a government that can look longer-term, particularly in a regulated market that assures attractive returns. Private investments in liberalized markets will also depend on the extent to which energy-related external costs and benefits (e.g. pollution, GHG emissions and waste and energy supply security) have been internalized. In contrast, government investors can incorporate such externalities directly into their decisions. Also important are regulatory risks. Different countries have different approval processes, and political support varies. Some processes are less predictable than others and create greater investment risks. *Figure 2* summarizes new construction cost estimates from seven recent studies.3 It shows fairly broad cost ranges, with much overlap among different technologies.

Except for oil-fired electricity generation (estimated in only one study) the high end of each cost range is at least 100% higher than the low end. This is due partly to different technological assumptions across the studies, but also to the factors listed above. Moreover, the ranges in *Figure 2* incorporate only internalized costs. If high enough priority is given to improving national energy self-sufficiency, for example, the preferred choice in a specific situation might not be the least expensive.

Spot prices on the uranium market have risen more than five-fold since 2000, to US$117/kgU. However, the latest compilation of global uranium resources by the IAEA and the OECD/NEA expects total conventional resources of uranium available at less than US$130/kgU to last several hundred years using current technology and current consumption rates (second column from the right in ***Table 3***, top row of numbers). If unconventional uranium resources associated with phosphate deposits are included, the figure more than doubles (right column), and if recycling technologies are used, resource longevity in measured in thousands of years (bottom row). Since all the numbers in ***Table 3*** are based on current uranium consumption rates, they will all decrease in proportion to any expansion of nuclear power. For high-level waste, the most progress on disposal facilities has been made in Finland, Sweden and the USA although none is expected to be in operation much before 2020. In Finland construction work began in 2004 on the underground laboratory at Olkiluoto that will be used to characterize the local geology and may later be incorporated into the final repository. Sweden has begun detailed geological investigations at two candidate sites. The Swedish Nuclear Fuel and Waste Management Company (SKB) hopes to make a final site proposal by about 2008. In the US the Waste Isolation Pilot Plant in New Mexico began accepting military waste in 1999 for permanent disposal, and in 2002 the US government decided to proceed with the Yucca Mountain disposal site. A license application for the repository at Yucca Mountain, US, was scheduled for submittal to NRC in 2004, but has been delayed.

Table 3: Years of Resource Availability for Various Nuclear Technologies4

Reactor/Fuel cycle	*Years of 2004 world nuclear electricity generation with identified conventional resources*	*Years of 2004 world nuclear electricity generation with total conventional resources*	*Years of 2004 world nuclear electricity generation with total conventional resources and phosphates*
Current fuel cycle (LWR, once-through)	*85*	*270*	*675*
Pure fast reactor fuel cycle with recycling	*5,000–6,000*	*16,000–19,000*	*40,000–47,000*

Nuclear power is not a one-size-does-fit solution. Each country's situation is different, and each must make its own energy choices. But nuclear power will certainly be part of the mix of solutions. The current outlook is that it will be a growing part of the mix, driven by expanding energy needs, energy security concerns, limits on greenhouse gas emissions and the sustained strong performance of nuclear plants.

CHAPTER 4: ELECTRICITY SUSTAINABILITY

The concept of sustainability

The word sustainability is derived from the Latin *sustinere* (*tenere,* to hold; *sus,* up). Dictionaries provide more than ten meanings for *sustain*, the main ones being to “maintain", "support", or "endure”. However, since the 1980s *sustainability* has been used more in the sense of human sustainability on planet Earth and this has resulted in the most widely quoted definition of sustainability as a part of the concept *sustainable development*, that of the Brundtland Commission of the United Nations on March 20, 1987: *“sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”*

Sustainable development, or sustainability for short, is easily understood at its most basic level. It means simply in a global context any economic or social development should improve, not harm, the environment. This concept has developed from a global political process over the last three decades of twentieth century into one that now touches every part of society.

Nevertheless sustainability is one of the most diversely applied concepts among academics and professionals discussing the future. It has cut across all disciplines and professions and has developed many complexities.

In whatever way sustainability is defined and analyzed it is important to see that its roots did not come from academic discussion as from a global political process.

Sustainability is a broad and rich subject, but let me focus my comments on two areas.

1. Electricity efficiency and the great opportunities it provides
2. The role of several key electricity technologies which can help to achieve sustainability.

Again human consumption has direct impact on sustainability. One of the initial attempts to express human impact mathematically was developed in the 1970s and is called the I PAT formula. This formulation attempts to explain human consumption in terms of three components: population numbers, levels of consumption (which it terms "affluence", although the usage is different), and impact per unit of resource use (which is termed "technology", because this impact depends on the technology used). The equation is expressed:

$$I = P \times A \times T$$

Where: I = Environmental impact, P = Population, A = Affluence, T = Technology

Electricity Sustainability

Sustainable electricity is the sustainable provision of electricity that meets the needs of the present without compromising the ability of future generations to meet their needs. Technologies that promote sustainable electricity include nuclear technology, renewable technology such as hydroelectricity, solar energy, wind power, geothermal energy etc.

Nuclear energy and sustainability

Only recently nuclear energy has been subjected to detailed studies in terms of its potential contribution to establishing sustainable development (see, for example, NEA, 2000 and Rogner, 2001). Most analysts confirm that nuclear energy does at present not meet some essential requirements for constituting a sustainable energy resource (e.g. Bruggink and van der Zwaan, 2002), and that, in particular, the current use of LWR technology cannot be qualified sustainable (Rothwell and van der Zwaan, 2003). Arguments concerning radioactive waste, reactor accidents, nuclear proliferation and terrorism, and economic competitiveness all play a role in the discussion regarding the sustainability of nuclear energy. Likewise, however, it has been pointed out that it is hard to claim that any of the present so-called “renewable” meet all criteria of a sustainable energy resource. One of the major reasons is that renewable have so far not been applied on a large (global) scale, so that the risks involved with their usage cannot yet be apparent. Fundamental issues determining the (un)sustainability of renewable relate to land usage, materials use, waste production and environmental impact.

While today not being a sustainable energy resource, nuclear energy – along with other presently available energy options – could play a transitional role towards establishing sustainable energy systems. Whereas changes in energy infrastructures, including nuclear ones in particular, occur generally relatively slowly, nuclear energy should still be viewed in a dynamic way. During a transitional phase with some role for nuclear power, some of the more problematic aspects of nuclear energy might be rendered significantly more sustainable. Recent technological developments in the nuclear field have been considerable, and are likely to continue, e.g. with respect to increasing reactor safety or building more proliferation-resistant reactors. This could give nuclear energy a potential role beyond the aforementioned transition period. To some extent, depending on perspectives of both time and location, nuclear energy *could* therefore contribute to establishing paths towards sustainable energy systems and thereby to achieving sustainable development.

An important reason for developing a domestic nuclear energy capacity in the past was its potential to greatly enhance national energy independence, mainly since nuclear fuel (uranium) is widely available, cheaply acquirable and easily storable. Arguments of energy supply security will continue to motivate countries, including those in the developing world with presently modest or absent shares of nuclear energy to electricity production, to develop domestic nuclear power facilities. Since the subject of climate change mitigation has been recognized as one of the largest present global challenges, nuclear energy has received renewed consideration. Whereas even a massive expansion of nuclear energy world-wide would not be a panacea for the problem of global warming, its potential share in controlling atmospheric temperature increases could be significant. Given the size of the global change problem, nuclear energy might indeed deserve increased attention. Nuclear power might need to be expanded on a global scale, or at least should not be left out of the current energy mix, and developing countries could in principle play a role in a continued, perhaps intensified, employment of nuclear fission.

CHAPTER 5: NUCLEAR POWER

5.1 BASIC NUCLEAR PHYSICS

Nuclear Structure

An atom consists of an extremely small, positively charged nucleus surrounded by a cloud of negatively charged electrons. Although typically the nucleus is less than one ten-thousandth the size of the atom, the nucleus contains more than 99.9% of the mass of the atom! Nuclei consist of positively charged protons and electrically neutral held together by the so-called strong or nuclear force. This force is much stronger than the familiar electrostatic force that binds the electrons to the nucleus, but its range is limited to distances on the order of a few x10-15 meters.

The number of protons in the nucleus, Z, is called the atomic number. This determines what chemical element the atom is. The number of neutrons in the nucleus is denoted by N. The atomic mass of the nucleus, A, is equal to Z + N. A given element can have many different isotopes, which differ from one another by the number of neutrons contained in the nuclei. In a neutral atom, the number of electrons orbiting the nucleus equals the number of protons in the nucleus. Since the electric charges of the proton and the electron are +1 and -1 respectively (in units of the proton charge), the net charge of the atom is zero. At present, there are 112 known elements which range from the lightest, hydrogen, to the recently discovered and yet to-be-named element 112. All of the elements heavier than uranium are manmade. Among the elements are approximately 270 stable isotopes, and more than 2000 unstable isotopes.

Radioactivity

In 1896, Henri Becquerel was working with compounds containing the element uranium. To his surprise, he found that photographic plates covered to keep out light became fogged, or partially exposed, when these uranium compounds were anywhere near the plates. This fogging suggested that some kind of ray had passed through the plate coverings. Several materials other than uranium were also found to emit these penetrating rays. Materials that emit this kind of radiation are said to be radioactive and to undergo radioactive decay.

In 1899, Ernest Rutherford discovered that uranium compounds produce three different kinds of radiation. He separated the radiations according to their penetrating abilities and named them a alpha, b beta, and g gamma radiation, after the first three letters of the Greek alphabet. The radiation can be stopped by a sheet of paper. Rutherford later showed that an alpha particle is the nucleus of a He atom, ^{4}He. Beta particles were later identified as high speed electrons. Six millimeters of aluminum are needed to stop most b particles. Several millimeters of lead are needed to stop g rays , which proved to be high energy photons. Alpha particles and g rays are emitted with a specific energy that depends on the radioactive isotope. Beta particles, however, are emitted with a continuous range of energies from zero up to the maximum allowed for by the particular isotope.

α decay

The emission of an a particle, or ^{4}He nucleus, is a process called a decay. Since a particles contain protons and neutrons, they must come from the nucleus of an atom. The nucleus that results from a decay will have a mass and charge different from those of the original nucleus. A change in nuclear charge means that the element has been changed into a different element. Only through such radioactive decays or nuclear reactions can transmutation, the age-old dream of the alchemists, actually occur. The mass number, *A*, of an a particle is four, so the mass number, *A*, of the decaying nucleus is reduced by four. The atomic number, *Z*, of ^{4}He is two, and therefore the atomic number of the nucleus, the number of protons, is reduced by two. This can be written as an equation analogous to a chemical reaction. For example, for the decay of an isotope of the element 263Sg: The atomic number of the nucleus changes from 106 to 104, giving rutherfordium an atomic mass of 263-4=259. a Decay typically occurs in heavy nuclei where the electrostatic repulsion between the protons in the nucleus is large. Energy is released in the process of a decay. Careful measurements show that the sum of the masses of the daughter nucleus and the a particle is a bit less than the mass of the parent isotope. Einstein's famous equation, $E=mc^2$, which says that mass is proportional to energy, explains this fact by saying that the mass that is lost in such decay is converted into the kinetic energy carried away by the decay products.

β Decay

Beta particles are negatively charged electrons emitted by the nucleus. Since the mass of an electron is a tiny fraction of an atomic mass unit, the mass of a nucleus that undergoes decay is changed by only a tiny amount. The mass number is unchanged. The nucleus contains no electrons. Rather, b decay occurs when a neutron is changed into a proton within the nucleus. An unseen neutrino, , accompanies each b decay. The number of protons, and thus the atomic number, is increased by one. For example, the isotope ^{14}C is unstable and emits a β particle, becoming the stable isotope ^{14}N: In a stable nucleus, the neutron does not decay. A free neutron, or one bound in a nucleus that has an excess of neutrons, can decay by emitting a b particle. Sharing the energy with the b particle is a neutrino. The neutrino has little or no mass and is uncharged, but, like the photon, it carries momentum and energy. The source of the energy released in b decay is explained by the fact that the mass of the parent isotope is larger than the sum of the masses of the decay products. Mass is converted into energy just as Einstein predicted.

γ Decay

Gamma rays are a type of electromagnetic radiation that results from a redistribution of electric charge within a nucleus. A g ray is a high energy photon. The only thing which distinguishes a g ray from the visible photons emitted by a light bulb is its wavelength; the g ray's wavelength is much shorter. For complex nuclei there are many different possible ways in which the neutrons and protons can be arranged within the nucleus. Gamma rays can be emitted when a nucleus undergoes a transition from one such configuration to another. For example, this can occur when the shape of the nucleus undergoes a change. Neither the mass number nor the atomic number is changed when a nucleus emits a g ray in the reaction

$$^{152}\mathbf{Dy^{*}} \text{ ----> } \mathbf{^{152}Dy + \gamma}$$

Half-life

The time required for half of the atoms in any given quantity of a radioactive isotope to decay is the half-life of that isotope. Each particular isotope has its own half-life. For example, the half-life of ^{238}U is 4.5 billion years. That is, in 4.5 billion years, half of the ^{238}U on Earth will have decayed into other elements. In another 4.5 billion years, half of the remaining ^{238}U will have decayed. One fourth of the original material will remain on Earth after 9 billion years. The half-life of ^{14}C is 5730 years, thus it is useful for dating archaeological material. Nuclear half-lives range from tiny fractions of a second to many, many times the age of the universe.

Fusion

Fusion is a nuclear process in which two light nuclei combine to form a single heavier nucleus. An example of a fusion reaction important in thermonuclear weapons and in future nuclear reactors is the reaction between two different hydrogen isotopes to form an isotope of helium:

$$^{2}\mathbf{H} + \mathbf{^{3}H} \text{ ----> } \mathbf{^{4}He + n}$$

This reaction liberates an amount of energy more than a million times greater than one gets from a typical chemical reaction. Such a large amount of energy is released in fusion reactions because when two light nuclei fuse, the sum of the masses of the product nuclei is less than the sum of the masses of the initial fusing nuclei. Once again, Einstein's equation, $E=mc^2$, explains that the mass that is lost it converted into energy carried away by the fusion products.

Even though fusion n is an energetically favorable reaction for light nuclei, it does not occur under standard conditions here on Earth because of the large energy investment that is required. Because the reacting nuclei are both positively charged, there is a large electrostatic repulsion between them as they come together. Only when they are squeezed very close to one another do they feel the strong nuclear force, which can overcome the electrostatic repulsion and cause them fuse.

Fusion reactions have been going on for billions of years in our universe. In fact, nuclear fusion reactions are responsible for the energy output of most stars; including our own Sun. Scientists on Earth have been able to produce fusion reactions for only about the last sixty years. At first, there was small scale studies in which only a few fusion reactions actually occurred. However, these first experiments later lead to the development of thermonuclear fusion weapons.

Fusion is the process that takes place in stars like our Sun. Whenever we feel the warmth of the Sun and see by its light, we are observing the products of fusion. We know that all life on Earth exists because the light generated by the Sun produces food and warms our planet. Therefore, we can say that fusion is the basis for our life. When a star is formed, it initially consists of hydrogen and helium created in the Big Bang, the process that created our universe. Hydrogen isotopes collide in a star and fuse forming a helium nucleus. Later, the helium nuclei collide and form heavier elements. Fusion is a nuclear reaction in which nuclei combine to form a heavier nucleus. It is the basic reaction which drives the Sun. Lighter elements fuse and form heavier elements. These reactions continue until the nuclei reach iron (around mass sixty), the nucleus with the most binding energy. When a nucleus reaches mass sixty, no more fusion occurs in a star because it is energetically unfavorable to produce higher masses. Once a star has converted a large fraction of its core's mass to iron, it has almost reached the end of its life. The fusion chain cannot continue so its fuel is reduced. Some stars keep shrinking until they become a cooling ember made up of iron. However, if a star is sufficiently massive, a tremendous, violent, brilliant explosion can happen. A star will suddenly expand and produce, in a very short time, more energy than our Sun will produce in a lifetime. When this happens, we say that a star has become a supernova.

While a star is in the supernova phase, many important reactions occur. The nuclei are accelerated to much higher velocities than can occur in a fusing star. With the added energy caused by their speed, nuclei can fuse and produce elements higher in mass than iron. The extra energy in the explosion is necessary to overcome the energy barrier of a higher mass element. Elements such as lead, gold, and silver found on Earth were once the debris of a supernova explosion. The element iron that we find all through the Earth and in its center is directly derived from super novae and dead stars.

Fission

Fission is a nuclear process in which a heavy nucleus splits into two smaller nuclei. An example of a fission reaction that was used in the first atomic bomb and is still used in nuclear reactors is

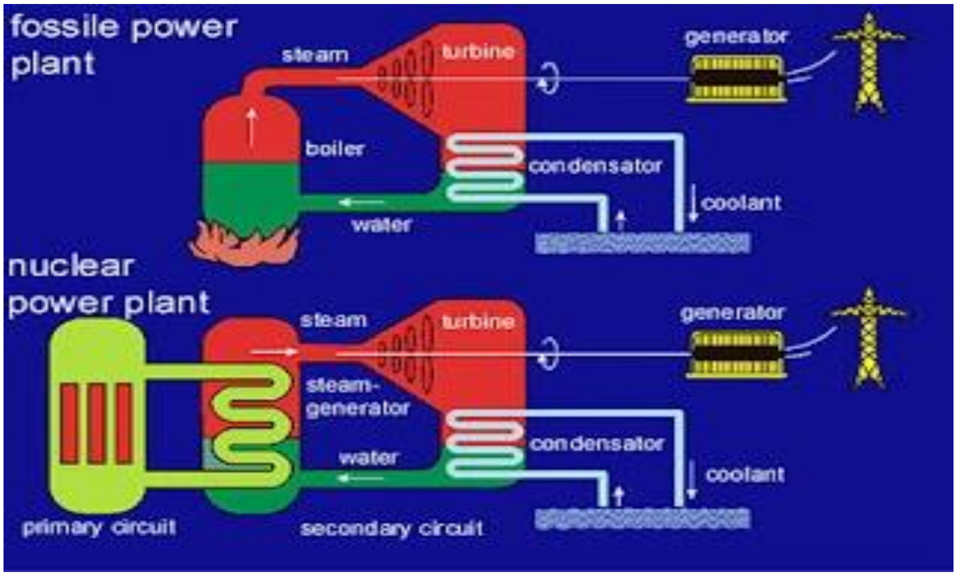
$$^{235}\mathbf{U + n \dashrightarrow {}^{134}Xe + {}^{100}Sr + 2n + 200\ MeV}$$

The products shown in the above equation are only one set of many possible nuclei. Fission reactions can produce any combination of lighter nuclei so long as the number of protons and neutrons in the products sum up to those in the initial fissioning nucleus. As with fusion a great amount of energy can be released in fission because of heavy nuclei, the summed masses of the product nuclei are less than the mass of the fissioning nucleus. Fission occurs because of the electrostatic repulsion created by the large number of positively charged protons contained in a heavy nucleus. Two smaller nuclei have less internal electrostatic repulsion than one larger nucleus. So, once the larger nucleus can overcome the strong nuclear force which holds it together, it can fission. Fission can be seen as a "tug-of-war" between the strong attractive nuclear force and the repulsive electrostatic force. In fission reactions, electrostatic repulsion wins.

Fission is a process that has been occurring in the universe for billions of years. As mentioned above, we have not only used fission to produce energy for nuclear bombs, but we also use fission peacefully everyday to produce energy in nuclear power plants.

5.2 NUCLEAR PLANT TYPES: ADVANTAGES AND DISADVANTAGES

Nuclear power is generated using Uranium, which is a metal mined in various parts of the world. The structure of a nuclear power plant in many aspects resembles to that of a conventional thermal power station, since in both cases the heat produced in the boiler (or reactor) is transported by some coolant and used to generate steam. The steam then goes to the blades of a turbine and by rotating it; the connected generator will produce electric energy. The steam goes to the condenser, where it condenses, i.e. becomes liquid again. The cooled down water afterwards gets back to the boiler or reactor or in the case of PWRs to the steam generator.



The great difference between a conventional and a nuclear power plant is how heat is produced. In a fossil plant, oil, gas or coal is fired in the boiler, which means that the chemical energy of the fuel is converted into heat. In a nuclear power plant, however, energy that comes from fission reactions is utilized.

How it works

Nuclear fission makes heat → heat water to make steam → steam turns turbines → turbines turn generators → electrical power sent around country

- Nuclear power stations work in pretty much the same way as fossil fuel-burning stations, except that a "chain reaction" inside a nuclear reactor makes the heat instead.
- The reactor uses Uranium rods as fuel, and the heat is generated by nuclear fission. Neutrons smash into the nucleus of the uranium atoms, which split roughly in half and release energy in the form of heat.
- Carbon dioxide gas is pumped through the reactor to take the heat away, and the hot gas then heats water to make steam.
- The steam drives turbines which drive generators. Modern nuclear power stations use the same type of turbines and generators as conventional power stations.

In Britain, nuclear power stations are built on the coast, and use sea water for cooling the steam ready to be pumped round again. This means that they don't have the huge "cooling towers" seen at other power stations. The reactor is controlled with "control rods", made of boron, which absorb neutrons. When the rods are lowered into the reactor, they absorb more neutrons and the fission process slows down. To generate more power, the rods are raised and more neutrons can crash into uranium atoms.

Nuclear Power Plant Types

Several nuclear power plant (NPP) types are used for energy generation in the world. The different types are usually classified based on the main features of the reactor applied in them.

The most widespread NPP's are:

- **Light water reactors**: both the moderator and coolant are light water (H_2O). To this category belong the pressurized water reactors (PWR) and boiling water reactors (BWR).

- **Heavy water reactors (CANDU):** both the coolant and moderator are heavy water (D_2O).

- **Graphite moderated reactors:** in this category there are gas cooled reactors (GCR) and light water cooled reactors (RBMK).

- **Exotic reactors (fast breeder reactors and other experimental installations).**

- **New generation reactors**: reactors of the future.

Advantages

- Nuclear power costs about the same as coal, so it's not expensive to make.
- The amount of fuel required is quite small; therefore there is no problem of transportation, storage etc.
- Does not produce smoke or carbon dioxide, so it does not contribute to the greenhouse effect.
- Produces huge amounts of energy from small amounts of fuel.
- Produces small amounts of waste.
- The output control is most flexible.
- Nuclear power is reliable.

Disadvantages

1. The fuel used is expensive and is difficult to recover.
2. The fission by-products are generally radioactive and may cause a dangerous amount of radioactive pollution.
3. Although not much waste is produced, it is very, very dangerous. It must be sealed up and buried for many years to allow the radioactivity to die away.
4. The initial capital cost is very high as compared to other power plants.
5. Nuclear power is reliable, but a lot of money has to be spent on safety - if it does go wrong, a nuclear accident can be a major disaster. People are increasingly concerned about this - in the 1990's nuclear power was the fastest-growing source of power in much of the world. In 2005 it was the second slowest-growing.
6. The cooling water requirements of a nuclear power plant are very heavy.

5.3NEW GENERATION OF NUCLEAR POWER PLANTS AND FUTURE TREND

The nuclear power plants in service today were conceptually designed and developed during the 1960s. At that time, it was deemed necessary to achieve maximum efficiency and minimum cost in order to compete successfully with coal- or oil-burning plants. The latter were priced at 15% of their present cost and used fuel that was very cheap by current standards. In order to maximize efficiencies in the nuclear plants, temperatures, pressures, and power densities were pushed up to their highest practical limits. Safety features were exemplary for that era, and even for current safety practices in other industries. But they were not up to present-day demands for **super-super safety** in the nuclear industry.

As the public became more concerned with nuclear safety, the Nuclear Regulatory Commission required that new safety equipment and procedures be added on. The amount of labor and materials for these add-ons exceeded that for the plant as originally conceived. With this added complexity, the plants became difficult and expensive to construct, operate, and maintain. Moreover, the level of safety was still limited by the original conceptual design.

The New Design Philosophy

By the early 1980s it became apparent that a new conceptual design of nuclear reactors was called for. The cost of electricity from coal- and oil-burning plants had escalated to the point where their competition did not require maximum efficiency from nuclear plants. Furthermore, the added efficiency achieved by pushing temperatures, pressures, and power densities to their limits was overshadowed by the efficiency lost due to shutdowns when these limits were exceeded. But above all it would be much easier to satisfy the public's demand for super-super safety by starting over with a new conceptual design than by using myriads of add-ons to a design originally targeted on rather different goals.

In the mid-1980s, several reactor vendors undertook these new designs. Let us consider some of the thinking that served as their basis.

In attempting to obtain maximum performance per unit of cost, designers nearly always find it advantageous to build plants with higher power output. This is the widely applicable principle of "**economies of scale**." For example, it is the reason why, before fuel costs became an issue, American automobiles were large — in stamping out an auto body, machining an engine cylinder, or in any other such operation, it doesn't cost much more to make it large than to make it small. It thus costs substantially less to build and operate a 1,200,000-kW plant than two 600,000-kW plants of the same basic design. In line with the old goals, plants were therefore built in the former size range, and constantly grew larger. This trend still dominates in foreign countries.

However, if safety is the primary goal, as it is in the United States today, it is much easier to assure that adequate cooling will be available if there is only half as much heat to dissipate. In fact, in a 1,200,000-kW reactor, cooling requires elaborate pumps, while in a 600,000-kW reactor it can be handled by simple gravity flow with natural convection. Cool water enters the bottom of the reactor, which heats it, causing it to rise because warm water is lighter. This process sets up a natural circulation driven only by gravity. Unlike pumps which can fail and are driven by electric power which may not always be available, gravity never stops working. That makes the 600,000-kW reactor inherently safer. This is called "**passive stability**," since no active measures by operators or by mechanical or electrical control systems are required. The operator could shut off the electric power and go home without any harm coming to the reactor.

Natural circulation can also be used to protect the containment from breaking open due to excess pressure. In present-day power plants, active cooling using water pumps are necessary to control the pressure. But with the smaller reactor, there is less energy to dissipate, making natural circulation a viable alternative.

Of course the safety of the larger reactor system can always be improved by adding extra pumps and extra diesel-driven generators to provide power for them in the event of failures, but this drives up the cost. Moreover, this extra equipment must be periodically tested, maintained, and repaired. The control systems that start the equipment when it is needed, and open and close the necessary valves, must be maintained and frequently tested. As a result of problems like these, a super-super safe 1,200,000-kW reactor might cost almost as much as two super-super safe 600,000-kW reactors. Moreover, the 1,200,000-kW reactor is still not as safe because human failures can enter the picture for instance, a person can push the wrong button in starting a pump or opening a valve or the person who installed an automatic system for performing these functions can make a mistake in wiring. In addition, with more pipes entering the reactor there are more opportunities for a pipe to break, causing a **loss-of-coolant accident (LOCA)**.

We have seen that the time required for construction can be a very important ingredient in determining costs, and it obviously takes longer to construct a larger plant. This was not an important factor in the early 1970s, when large plants could be built in 4 or 5 years, as they still are today in France and Japan. But with the very elaborate and time-consuming practices now required in the United States, construction times have become an important factor in determining the relative costs of large and small reactor plants. For example, with elaborate tests and documentation for these tests required for every weld, reducing the number of required welds results in substantial time saving. Since they have fewer pumps and valves and less piping, smaller reactor plants require fewer welds, which reduce the time needed for constructing them.

Still another consideration is that many more parts of a smaller reactor than of a larger one can be produced and assembled in a factory. Operations are much more efficient in a factory than at a construction site because permanently installed equipment and long-term employees can be used to produce many copies of the same item for many different power plants. Use of transient construction workers and portable equipment to do a wide variety of jobs just once introduces all sorts of inefficiencies.

When all of these matters are taken into account, it turns out that if **super-super safety** is a primary concern, two 600,000-kW reactors may even be cheaper and are certainly considerably safer than a single 1,200,000-kW reactor.

In France and England, one government-owned utility provides electricity for the whole country. But in the United States there are hundreds of utilities, and they are generally rather small. Consider a typical American situation: a particular utility's service load is growing by 100,000-kW per year, and signs indicate that it will continue to grow at that rate for the next few years. A 600,000-kW plant might be an attractive investment to take care of this growth, but a 1,200,000-kW plant would be much more expensive and would provide a lot more power than needed for a long time. Moreover, it is hard to predict how long the growth will continue; if it should fall off, the utility may never need the full 1,200,000-kW. Thus a 600,000-kW size is better suited to the needs of an American utility. This is not the case for the huge French and British national utilities, which generally have a load growth of several million kilowatts per year.

Since the 600,000-kW size range is optimum for U.S. utilities, reactor vendors are competing to provide them. In fact, not only are U.S. reactor vendors developing them, but foreign vendors who build larger reactors for their own countries are developing 600,000-kW reactors to sell to American utilities. Coal- and oil-burning power plants of this size have always been available and are the most widely used plants in the United States.

Another aspect of the new design philosophy is to favor a larger tolerance to variation in operating conditions over optimizing efficiency. This represents an abandonment of the controlling principle of reactor design in the 1960s. For example, optimum plant efficiency requires heating the water to the highest possible temperature, but increased temperature accelerates corrosion of steam generator tubes. In the new design, water temperatures are reduced from 615°F to 600°F, and, in addition, a new stainless steel alloy that is more durable under exposure to high-temperature water is used for steam generator tubes. As another example, the reactor must be shut down for safety reasons if the power density the energy per second produced by each foot of fuel assembly exceeds a predetermined limit. Present reactors operate at 5.5 kW per foot, but in the new reactors this is reduced to 4.0 KW per foot. The change reduces efficiency, but it means fewer shutdowns due to excessive power density.

Another change in the new design is to favor simplicity over complexity. Adding complex equipment and operations may improve the efficiency of a reactor, but it also introduces more possibilities for equipment failures and operator mistakes. In earlier reactors, living with these problems was deemed to be a worthwhile sacrifice, but the new design philosophy is that it is not.

In addition to changes in design philosophy, there have been many lessons learned from experience that can be incorporated into the new reactors. These include systems for adding small quantities of various chemicals to the water to reduce corrosion problems, employing different materials for certain applications, and using new methods for construction. The principal lesson learned from the Three Mile Island accident is the significance of making important information easily available to the operator. The revolution in computer and telecommunications technology over the last two decades offers bountiful opportunities for improvements here in revamping the control room and instrumentation systems, and providing graphic displays, diagnostic aids, and expert systems to handle a variety of situations. Because of the passive stability features, there are few situations which require the operator to take emergency action. This also makes the reactor easier to operate.

The Next Generation

In the mid-1980s, Electric Power Research Institute (EPRI), the private research arm of the electric utility industry, undertook to set design goals for new reactors that make use of currently available technology and incorporate the philosophy expounded above. That project developed the following specifications:

1. Reducing the probability of a core damage accident by at least a factor of 10 compared to reactors presently in commercial operation a much larger factor is now anticipated by those designing and evaluating the new reactors.
2. Developing a much simpler design with larger margins for safety.
3. Achieving an operating lifetime of 60 years, and availability for producing power at least 85% of the time (versus the present average of 70% for both nuclear and coal-burning plants).
4. Providing electricity for lower cost than coal-burning plants. (Present indications are that it will be at least 15% lower.)
5. Completing construction in 3 to 5 years (versus more than 12 years in recently completed nuclear plants).
6. Producing a design standardized at a high-quality level with licensing assured.

A mammoth effort both in the United States and abroad is now underway to develop reactors to these specifications. The principal designs that have emerged include a pressurized water reactor called AP-600 (for advanced passive 600,000 kW), developed by Westinghouse and partner companies; a boiling water reactor called SBWR (where S stands for simpler, smaller, safer), developed by General Electric, Bechtel, and the Massachusetts Institute of Technology; a liquid-metal-cooled reactor called PRISM (for power reactor inherently safe module), developed by General Electric in collaboration with Argonne National Laboratory; and a gas-cooled reactor called MHTGR (modular high-temperature gas-cooled reactor), developed by GA Technologies plus a consortium of other companies. Utilities from France, Italy, the Netherlands, Japan, Korea, and Taiwan have also participated with these companies in developing the designs.

In addition, large programs for developing advanced reactor designs have emerged in France, Britain, Germany, and Japan, although these have been on larger reactors without the passive stability features. A Swedish effort is developing the PIUS (process inherent ultimate safety) reactor, a 640,000-kW PWR with essentially no dependence on active equipment.

In the United States, the AP-600 and the SBWR are expected to pass the licensing requirements and be ready for commercial orders by 1995, but the PRISM and MHTGR will not reach that stage until after the turn of the century.

For the interim of the next few years, American reactor vendors have developed improved versions of the reactors now in service, with several changes targeted on reducing complexity and improving safety. They also expect to have a long-term market for these reactors, called the APWR and ABWR (A for advanced), in foreign countries. One of them has already been ordered for construction in Japan. The modifications reduce the probability of a severe accident tenfold, have increased margins for error in key areas, and give operators more time to respond to emergency situations. These reactors should be certified for licensing in the United States by 1992.

Let us examine the salient features of some of the next-generation reactors.

The AP-600

The AP-600 obtains its emergency cooling from huge water tanks mounted above the reactor. Some of these are pressurized with nitrogen gas, allowing them to inject water even if the reactor remains at high pressure, as it may in some accident scenarios. In most cases, neither electric power nor operator action is needed to start injection. For example, if the pressure in the reactor falls due to a break in the system, the valves connecting some of the tanks to the reactor are automatically pushed open by the fact that the pressure on the tank side is being higher than on the reactor side. Actually, present reactors have similar systems. The "**accumulators**" operate on the same principle, but with enough water for only about 15 minutes, as compared with several hours in the AP-600.

One of the large tanks above the reactor serves as a place to deposit heat. It is connected to the reactor by two pipes, one leading to the bottom of the reactor vessel and one to the top. As water in the vessel is heated, it automatically rises in the upper pipe and is replaced by cool water from the lower pipe, establishing a natural circulation which transfers heat from the reactor into the water tank. This is analogous to air heated by a radiator in a house rising (because it is lighter) and spreading through the room to transfer the heat from the radiator to all the air in the room.

Water tanks pressurized with nitrogen gas also provide sprays to cool the atmosphere inside the containment and remove some of the volatile radioactive materials from the air in the event of an accident. Again, no pumps are needed.

The steel containment shell is cooled by air circulating between it and the concrete walls, again by gravity-induced convection. In addition there is water draining by gravity onto the containment shell, though the air circulation alone is sufficient to provide the necessary cooling. Air circulation keeps the pressure inside below 40 pounds per square inch in the worst accident scenarios.

Probabilistic risk analyses yield estimates that a core damage accident can be expected only once in 800,000 years of reactor operation, and that there is less than a 1% chance that this will be followed by failure of the containment. This makes the AP-600 a thousand times safer than the current generation of reactors. It is also much simpler, reducing the number of valves by 60%, large pumps by 50%, piping by 60%, heat exchangers by 50%, and ducting by 35%, and control cables by 80%. The volume of buildings required to have a very high degree of earthquake resistance is thereby reduced by 60%. It is estimated that the plant can be constructed in 3 to 4 years. All of these factors contribute to reducing the cost.

AP1000

The Westinghouse AP1000 is a 2-loop PWR which has evolved from the smaller AP600, one of the first new reactor designs certified by the US NRC, in 2005. Simplification was a major design objective of the AP1000, in overall safety systems, normal operating systems, the control room, construction techniques, and instrumentation and control systems provide cost savings with improved safety margins. It has a core cooling system including passive residual heat removal by convection, improved containment isolation, passive containment cooling system to the atmosphere and in-vessel retention of core damage (corium) with water cooling around it. No safety-related pumps or ventilation systems are needed. It is being built in China, and the Vogtle site is being prepared for initial units in USA. The first four units are on schedule, being assembled from modules. It is quoted as 1200 MWe gross and 1117 MWe net (3400 MWt), though 1250 MWe gross in China. Westinghouse earlier claimed a 36 month construction time to fuel loading. The first ones being built in China are on a 51-month timeline to fuel loading, or 57-month schedule to grid connection, but ate likely to do better than this.

Westinghouse is working with SNPTC and SNERDI in China to develop jointly a passively safe 1400 MWe design from the AP1000, the CAP1400, and this may extend to a larger, 3-loop CAP2100 design if the passive cooling system can be scaled to that level. Westinghouse has agreed that SNPTC will own the intellectual property rights for any AP1000 derivatives over 1350 MWe.

ABWR

The advanced boiling water reactor (ABWR) is derived from a General Electric design. Two examples built by Hitachi and two by Toshiba are in commercial operation in Japan (1315 MWe net), with another two under construction there and two in Taiwan. Four more are planned in Japan and another two in the USA. It is basically a 1380 MWe (gross) unit (3926 MWt in Toshiba version), though GE Hitachi quote 1350-1600 MWe net and Hitachi is also developing

600, 900 and 1700 MWe versions of it. Toshiba outlines development from its 1400 MWe class to a 1500-1600 MWe class unit (4300 MWt), and an 800-1000 MWe class derivative was envisaged. Tepco is funding the design of a next generation BWR, and the ABWR-II is quoted as 1717 MWe.

The first four ABWRs were each built in 39 months on a single-shift basis. Though GE and Hitachi have subsequently joined up, Toshiba retains some rights over the design, as does Tepco. Both GE-Hitachi and Toshiba (with NRG Energy in USA) are marketing the design. Design life is 60 years. It has a high level of active safety.

Both Toshiba and GE-Hitachi have applied separately to NRC for design certification renewal.

ESBWR

GE Hitachi Nuclear Energy's **ESBWR** is an improved design that utilizes passive safety features and natural circulation principles and is essentially an evolution from a predecessor design, the SBWR at 670 MWe. GE-H says it is safer and more efficient than earlier models, with 25% fewer pumps, valves and motors, and can maintain cooling for six days after shutdown with no AC or battery power. The emergency core cooling system has eliminated the need for pumps, using passive and stored energy.

The ESBWR (4500 MWt) will produce approximately 1600 MWe gross, and 1535 MWe net, depending on site conditions, and has a design life of 60 years. It was more fully known as the Economic & Simplified BWR (ESBWR) and leverages proven technologies from the ABWR. The ESBWR is in advanced stages of licensing review with the US NRC for GE Hitachi and is on schedule for full design certification in 2012. Design approval was in March 2011.

GEH is selling this alongside the ABWR, which it characterizes as more expensive to build and operate, but proven. ESBWR is more innovative, with lower building and operating costs and a 60-year life.

APWR

Mitsubishi's large APWR - advanced PWR of 1538 MWe gross (4451 MWt) - was developed in collaboration with four utilities (Westinghouse was earlier involved). The first two are planned for Tsuruga, coming on line from 2016. It is a 4-loop design with 257 fuel assemblies and neutron reflector, is simpler, combines active and passive cooling systems in double containment, and has over 55 GWd/t (and up to 62 GWd/t) fuel burn-up. It is the basis for the next generation of Japanese PWRs. The planned APWR+ is 1750 MWe and has full-core MOX capability.

The **US-APWR** will be 1700 MWe gross, about 1620 MWe net, due to longer (4.3m) fuel assemblies, higher thermal efficiency (37%) and has 24 month refueling cycle. Its emergency core cooling system (ECCS) has four independent trains, and its outer walls and roof are 1.8 m thick. US design certification application was in January 2008 with approval expected in mid 2013 and certification in 2014. In March 2008 MHI submitted the same design for EUR certification, as **EU-APWR,** and it will join with Iberdrola Engineering & Construction in bidding for sales of this in Europe. Iberdrola would be responsible for building the plants.

The Japanese government is expected to provide financial support for US licensing of both US-APWR and the ESBWR. The Washington Group International will be involved in US developments with Mitsubishi Heavy Industries (MHI). The US-APWR has been selected by Luminant for Comanche Peak, Texas, and when the COL application for the new reactors was lodged Luminant and MHI announced a joint venture to build and own the twin-unit plant. This Comanche Peak Nuclear Power Co is 88% Luminant, 12% MHI.

APR1400

South Korea's APR-1400 Advanced PWR design has evolved from the US System 80+ with enhanced safety and seismic robustness and was earlier known as the Korean Next-Generation Reactor. Design certification by the Korean Institute of Nuclear Safety was awarded in May 2003. It is 1455 MWe gross in Korean conditions, 1350-1400 MWe net (4000 MWt) with 2-loop primary circuit. The first of these is under construction - Shin-Kori-3 & 4, expected to be operating in 2013. Fuel has burnable poison and will have up to 55 GWd/t burn-up, refueling cycle c 18 months, outlet temperature 324ºC. Projected cost at the end of 2009 was US$ 2300 per kilowatt, with 48-month construction time. Plant life is 60 years, seismic design basis is 300 Gal. A low-speed (1800 rpm) turbine is envisaged. It has been chosen as the basis of the United Arab Emirates nuclear program on the basis of cost and reliable building schedule, and is being offered in Finland. Following pre-application meetings with NRC since 2010, an application for US Design Certification is planned in March 2013.

Based on this KOPEC is developing an EU version (APR1400-EUR) with double containment and core-catcher, and a more advanced1550MWe (gross) version, the **APR+**.

In addition some of the APR features are being incorporated into a development of the OPR-1000 to give an exportable **APR-1000** intended for overseas markets, notably Middle East and Southeast Asia, and will be able to operate with an ultimate heat sink of 40°C, instead of 35°C for the OPR-1000. Improved safety and performance will raise the capital cost above that of the OPR, but it this will be offset by reduced construction time (40 months instead of 46) due to modular construction.

Atmea1

The **Atmea 1** has been developed by the Atmea joint venture established in 2007 by Areva NP and Mitsubishi Heavy Industries to produce an evolutionary 1150 MWe net 93150 MWt) three-loop PWR using the same steam generators as EPR. This has 37% net thermal efficiency, 157 fuel assemblies 4.2 m long, 60-year life, and the capacity to use mixed-oxide fuel only. Fuel cycle is flexible 12 to 24 months with short refuelling outage and the reactor has load-following and frequency control capability.

Following an 18-month review, the French regulator ASN approved the general design in February 2012. The reactor is regarded as mid-sized relative to other modern designs and will be marketed primarily to countries embarking upon nuclear power programs. It has three active and passive redundant safety systems and an additional backup cooling chain, similar to EPR.

Areva-EdF-CGNPC project

Early in 2012 Areva NP and EdF agreed in principle with China Guangdong Nuclear Power group to develop a mid-size PWR on the basis of CGNPC's CPR1000, with third-generation safety features. It is not clear whether Mitsubishi Heavy Industries might be involved, though Areva has said that it wants the design to be based on Atmea1. If a new reactor design results, it would be a competitor for Atmea1.

Kerena

Together with German utilities and safety authorities, Areva NP has also developed another evolutionary design, the Kerena, a 1290 MWe gross, 1250 MWe net (3370 MWt) BWR with 60-year design life formerly known as **SWR 1000**,. The design, based on the Gundremmingen plant built by Siemens, was completed in 1999 and US certification was sought, but then deferred.

It has two redundant active safety systems and two passive safety systems, including a core-catcher, similar to EPR. The reactor is simpler overall and uses high-burnup fuels enriched to 3.54%, giving it refuelling intervals of up to 24 months. It has 37% net efficiency and is ready for commercial deployment.

AES-92, V392

Gidropress late-model VVER-1000 units with enhanced safety (AES 92 & 91 power plants) are being built in India and China. Two more are planned for Belene in Bulgaria. The **AES-92** is certified as meeting EUR, and its V-392 reactor is considered state of the art. They have four coolant loops and are rated 3000 MWt.

AES-2006, MIR-1200, VVER-TOI

A third-generation standardised **VVER-1200** (V-491) reactor of 1170 MWe net, 1200 MWe gross and 3200 MWt is in the AES-2006 plant. It is an evolutionary development of the well-proven VVER-1000 in the AES-92 plant, with longer life (60 years for non-replaceable equipment), greater power, and greater efficiency (34.8% net instead of 31.6%) and up to 70 GWd/t burn-up. It retains four coolant loops.

The lead units are being built at Novovoronezh II and Leningrad II, to start operation in 2014. An AES-2006 plant will consist of two of these OKB Gidropress reactor units expected to run for 50-60 years with capacity factor of 90%. Ovrnight capital cost was said to be US$ 1200/kW and serial construction time 54 months. They have enhanced safety including that related to earthquakes and aircraft impact with some passive safety features, double containment, and core-catcher.

Atomenergoproekt say that the AES-2006 conforms to both Russian standards and European Utilities Requirements (EUR). In Europe the basic technology is being called the Europe-tailored reactor design, **MIR-1200** (Modernised International Reactor) with some Czech involvement.

In 2010 Atomenergoproekt announced the **VVER-TOI** (typical optimised, with enhanced information) design with upgraded pressure vessel, increased power to 3300 MWt and 1255-1300 MWe gross (nominally 1300), improved core design to increase cooling reliability, further development of passive safety with 72-hour grace period requiring no operator intervention after shutdown, lower construction and operating costs, and 40-month construction time. It will use a low-speed turbine-generator. The project was initiated in 2009 and is due to be complete and submitted for EUR accreditation in December 2012. In October 2011 the design was reported as half complete. In June 2012 Rosatom said it would apply for VVER-1200 design certification in UK and USA, through Rusatom Overseas, probably with the VVER-TOI version.

The **VVER-1500** model was being developed by Gidropress. It will have enhanced safety, giving 1500 MWe gross from 4250 MWt. Design was expected to be complete in 2007 but the project was shelved in 2006 in favour of the evolutionary VVER-1200. It remains a 4-loop design, with increased pressure vessel diameter to 5 metres, 241 fuel assemblies in core enriched to 4.4%, burn-up 45-55 and up to 60 GWd/t and life of 60 years. If revived, it will meet EUR criteria.

In China, there are two indigenous designs based on a French predecessor but developed with modern features. In October 2011 CNNC announced that its **ACP1000** was entering the engineering design stage, based on Fuqing units 5 & 6, with 1100 MWe nominal power and load-following capability. It has 177 fuel assemblies, 18-month refuelling interval, and a 60-year design life. Its three coolant loops deliver 3060 MWt, inside double containment and having active safety systems with some passive elements. Seismic rating is 300 gal.

In parallel, China Guangdong Nuclear Power Corporation (CGNPC) led the development of the **ACPR1000**, a 3-loop unit of about 1100 MWe with 157 fuel assemblies (same as French predecessor), double containment and core-catcher. Its safety attributes comply with international requirements and it has a design life of 60 years.

IRIS

Another US-origin but international project which is a few years behind the AP1000 is the IRIS (International Reactor Innovative & Secure). Westinghouse is leading a wide consortium developing it as an advanced 3rd Generation project. IRIS is a modular 335 MWe pressurised water reactor with integral steam generators and primary coolant system all within the pressure vessel. It is nominally 335 MWe but can be less, eg 100 MWe. Fuel is initially similar to present LWRs with 5% enrichment and burnable poison, in fact fuel assemblies are "identical to those ... in the AP1000". These would have burn-up of 60 GWd/t with fuelling interval of 3 to 3.5 years, but IRIS is designed ultimately for fuel with 10% enrichment and 80 GWd/t burn-up with an 8-year cycle, or equivalent MOX core. The core has low power density. IRIS could be deployed in the next decade, and US design certification is at pre-application stage. Estonia once expressed interest in building a pair of them. Some consortium partners are interested in desalination, one in district heating.

VBER-300

OKBM's **VBER-300** PWR is a 295-325 MWe unit (917 MWt) developed from naval power plants and was originally envisaged in pairs as a floating nuclear power plant. It is designed for 60 year life and 90% capacity factor. It now planned to develop it as a land-based unit with Kazatomprom, with a view to exports, and the first unit will be built in Kazakhstan.

The VBER-300 and the similar-sized VK300 are more fully described in the Small Nuclear Power Reactors paper.

RMWR

The Reduced-Moderation Water Reactor (RMWR) is a light water reactor, essentially as used today, with the fuel packed in more tightly to reduce the moderating effect of the water. Considering the BWR variant (resource-renewable BWR - RBWR), only the fuel assemblies and control rods are different. In particular, the fuel assemblies are much shorter, so that they can still be cooled adequately. Ideally they are hexagonal, with Y-shaped control rods. The reduced moderation means that more fissile plutonium is produced and the breeding ratio is around 1 (instead of about 0.6), and much more of the U-238 is converted to Pu-239 and then burned than in a conventional reactor. Burn-up is about 45 GWd/t, with a long cycle. Initial seed (and possibly all) MOX fuel needs to have about 10% Pu. The void reactivity is negative, as in conventional LWR. A Hitachi RBWR design based on the ABWR-II has the central part of each fuel assembly (about 80% of it) with MOX fuel rods and the periphery uranium oxide. In the MOX part, minor actinides are burned as well as recycled plutonium.

The main rationale for RMWRs is extending the world's uranium resource and providing a bridge to widespread use of fast neutron reactors. Recycled plutonium should be used preferentially in RMWRs rather than as MOX in conventional LWRs, and multiple recycling of plutonium is possible. Japan Atomic Energy Research Institute (JAERI) started the research on RMWRs in 1997 and then collaborated in the conceptual design study with the Japan Atomic Power Company (JAPCO) in 1998. Hitachi have also been closely involved.

A new reprocessing technology is part of the RMWR concept. This is the fluoride volatility process, developed in 1980s, and is coupled with solvent extraction for plutonium to give the Fluorex process. In this, 90-92% of the uranium in the used fuel is volatalised as UF6, then purified for enrichment or storage. The residual is put through a Purex circuit which separates fission products and minor actinides as high-level waste, leaving the unseparated U-Pu mix (about 4:1) to be made into MOX fuel.

Heavy Water Reactors (moderated and mostly cooled by heavy water)

In Canada, the government-owned Atomic Energy of Canada Ltd (AECL) has had two designs under development which are based on its reliable CANDU-6 reactors, the most recent of which are operating in China. In 2011 the reactor division of AECL became Candu Energy, a subsidiary of SNC-Lavalin.

The CANDU-9 (925-1300 MWe) was developed from the CANDU-6 also as a single-unit plant. It has flexible fuel requirements ranging from natural uranium through slightly-enriched uranium, recovered uranium from reprocessing spent PWR fuel, mixed oxide (U & Pu) fuel, direct use of spent PWR fuel, to thorium. It may be able to burn military plutonium or actinides separated from reprocessed PWR/BWR waste. A two year licensing review of the CANDU-9 design was successfully completed early in 1997, but the design has been shelved.

EC6

Some of the innovation of this, along with experience in building recent Korean and Chinese units, was then put back into the Enhanced CANDU-6 (EC6) - built as twin units - with power increase to 750 MWe gross (690 MWe net, 2084 MWt) and flexible fuel options, plus 4.5 year construction and 60-year plant life (with mid-life pressure tube replacement). This is under consideration for new build in Ontario and overseas.

ACR

The Advanced Candu Reactor (ACR), a 3rd generation reactor, is a more innovative concept. While retaining the low-pressure heavy water moderator, it incorporates some features of the pressurised water reactor. Adopting light water cooling and a more compact core reduces capital cost, and because the reactor is run at higher temperature and coolant pressure, it has higher thermal efficiency.

The ACR-700 design was 700 MWe but is physically much smaller, simpler and more efficient as well as 40% cheaper than the CANDU-6. But the ACR-1000 of 1080-1200 MWe (3200 MWt) became the focus of attention by AECL. It has more fuel channels (each of which can be regarded as a module of about 2.5 MWe). The ACR will run on low-enriched uranium (about 1.5-2.0% U-235) with high burn-up, extending the fuel life by about three times and reducing high-level waste volumes accordingly. It will also efficiently burn MOX fuel, thorium and actinides.

Regulatory confidence in safety is enhanced by a small negative void reactivity for the first time in CANDU, and utilizing other passive safety features as well as two independent and fast shutdown systems. Units will be assembled from prefabricated modules, cutting construction time to 3.5 years. ACR units can be built singly but are optimal in pairs. They will have 60 year design life overall but require mid-life pressure tube replacement.

ACR is moving towards design certification in Canada, with a view to following in China, USA and UK. In 2007 AECL applied for UK generic design assessment (pre-licensing approval) but then withdrew after the first stage. In the USA, the ACR-700 was listed by NRC as being at pre application review stage. The first ACR-1000 unit could be operating in 2016 in Ontario.

The **CANDU X** or SCWR is a variant of the ACR, but with supercritical light water coolant (eg 25 MPa and 625ºC) to provide 40% thermal efficiency. The size range envisaged is 350 to 1150 MWe, depending on the number of fuel channels used. Commercialization envisaged after 2020.

AHWR

India is developing the Advanced Heavy Water reactor (AHWR) as the third stage in its plan to utilize thorium to fuel its overall nuclear power program. The AHWR is a 300 MWe gross (284 MWe net, 920 MWt) reactor moderated by heavy water at low pressure. The calandria has about 450 vertical pressure tubes and the coolant is boiling light water circulated by convection. A large heat sink - "Gravity-driven water pool" - with 7000 cubic meters of water is near the top of the reactor building. Each fuel assembly has 30 Th-U-233 oxide pins and 24 Pu-Th oxide pins around a central rod with burnable absorber. Burn-up of 24 GWd/t is envisaged. It is designed to be self-sustaining in relation to U-233 bred from Th-232 and have a low Pu inventory and consumption, with slightly negative void coefficient of reactivity. It is designed for 100-year plant life and is expected to utilize 65% of the energy of the fuel, with two thirds of that energy coming from thorium via U-233.

Once it is fully operational, each AHWR fuel assembly will have the fuel pins arranged in three concentric rings arranged:

Inner: 12 pins Th-U-233 with 3.0% U-233,
Intermediate: 18 pins Th-U-233 with 3.75% U-233,
Outer: 24 pins Th-Pu-239 with 3.25% Pu.

The fissile plutonium content will decrease from an initial 75% to 25% at equilibrium discharge burn-up level.

As well as U-233, some U-232 is formed, and the highly gamma-active daughter products of this confer a substantial proliferation resistance.

In 2009 an export version of this design was announced: the **AHWR-LEU**. This will use low-enriched uranium plus thorium as a fuel, dispensing with the plutonium input. About 39% of the power will come from thorium (via in situ conversion to U-233), and burn-up will be 64 GWd/t. Uranium enrichment level will be 19.75%, giving 4.21% average fissile content of the U-Th fuel. While designed for closed fuel cycle, this is not required. Plutonium production will be less than in light water reactors, and the fissile proportion will be less and the Pu-238 portion three times as high, giving inherent proliferation resistance. The AEC says that "the reactor is manageable with modest industrial infrastructure within the reach of developing countries."

In the AHWR-LEU, the fuel assemblies will be configured:
Inner ring: 12 pins Th-U with 3.555% U-235,
Intermediate ring: 18 pins Th-U with 4.345% U-235,
Outer ring: 24 pins Th-U with 4.444% U-235.

High-Temperature Gas-Cooled Reactors (graphite-moderated)

These reactors use helium as a coolant at up to 950ºC, which either makes steam conventionally or directly drives a gas turbine for electricity and a compressor to return the gas to the reactor core. Fuel is in the form of TRISO particles less than a millimeter in diameter. Each has a kernel of uranium oxycarbide, with the uranium enriched up to 17% U-235. This is surrounded by layers of carbon and silicon carbide, giving a containment for fission products which is stable to 1600°C or more. These particles may be arranged: in blocks as hexagonal 'prisms' of graphite, or in billiard ball-sized pebbles of graphite encased in silicon carbide.

HTR-PM

The first commercial version will be China's HTR-PM, being built at Shidaowan in Shandong province. It has been developed by Tsinghua University's INET, which is the R&D leader and Chinergy Co., with China Huaneng Group leading the demonstration plant project. This will have two reactor modules, each of 250 MWt/ 105 MWe, using 9% enriched fuel (520,000 elements) giving 80 GWd/t discharge burnup. With an outlet temperature of 750ºC the pair will drive a single steam cycle turbine at about 40% thermal efficiency. This 210 MWe Shidaowan demonstration plant is to pave the way for an 18-unit (3x6x210MWe) full-scale power plant on the same site, also using the steam cycle. Plant life is envisaged as 60 years with 85% load factor.

PBMR

South Africa's **Pebble Bed Modular Reactor** (PBMR) was being developed by a consortium led by the utility Eskom, with Mitsubishi Heavy Industries from 2010. It drew on German expertise and aimed for a step change in safety, economics and proliferation resistance. Production units would be 165 MWe. The PBMR would ultimately have a direct-cycle (Brayton cycle) gas turbine generator and thermal efficiency about 41%, the helium coolant leaving the bottom of the core at about 900°C and driving a turbine. Power is adjusted by changing the pressure in the system. The helium is passed through a water-cooled pre-cooler and intercooler before being returned to the reactor vessel. (In the Demonstration Plant it would transfer heat in a steam generator rather than driving a turbine directly.) However, development has ceased due to lack of funds and customers.

GT-MHR

A larger US design, the **Gas Turbine - Modular Helium Reactor** (GT-MHR), is planned as modules of 285 MWe each directly driving a gas turbine at 48% thermal efficiency. The cylindrical core consists of 102 hexagonal fuel element columns of graphite blocks with channels for helium and control rods. Graphite reflector blocks are both inside and around the core. Half the core is replaced every 18 months. Burn-up is about 100,000 MWd/t. It is being developed by General Atomics in partnership with Russia's OKBM Afrikantov, supported by Fuji (Japan). Initially it was to be used to burn pure ex-weapons plutonium at Seversk (Tomsk) in Russia. The preliminary design stage was completed in 2001, but the program has stalled since. In February 2010 General Atomics announced its Energy Multiplier Module (EM2) design, based on the GT-MHR.

Areva's Antares is based on the GT-MHR.

Fast Neutron Reactors (not moderated, cooled by liquid metal)

Several countries have research and development programs for improved Fast Breeder Reactors (FBR), which are Fast Neutron Reactors (FNR) configured with a conversion or breeding ratio of more than 1 (ie more fissile nuclei are produced than are fissioned). These use the uranium-238 in reactor fuel as well as the fissile U-235 isotope used in most reactors.

About 20 liquid metal-cooled FBRs have already been operating, some since the 1950s, and some have supplied electricity commercially. About 300 reactor-years of operating experience have been accumulated. See also Fast Neutron Reactors paper.

Natural uranium contains about 0.7 % U-235 and 99.3 % U-238. In any reactor the U-238 component is turned into several isotopes of plutonium during its operation. Two of these, Pu 239 and Pu 241, then undergo fission in the same way as U 235 to produce heat. In a fast neutron reactor this process is optimized so that it can 'breed' fuel, often using a depleted uranium blanket around the core. FBRs can utilize uranium at least 60 times more efficiently than a normal reactor. They are however expensive to build and could only be justified economically if uranium prices were to rise to pre-1980 values, well above the current market price.

For this reason research work almost ceased for some years, and that on the 1450 MWe European FBR has apparently lapsed. Closure of the 1250 MWe French **Superphenix** FBR after very little operation over 13 years also set back developments.

Research continues in India. At the Indira Gandhi Centre for Atomic Research a 40 MWt fast breeder test reactor has been operating since 1985. In addition, the tiny Kamini there is employed to explore the use of thorium as nuclear fuel, by breeding fissile U-233. In 2004 construction of a 500 MWe prototype fast breeder reactor started at **Kalpakkam**. The unit is expected to be operating in 2012, fuelled with uranium-plutonium oxide (the reactor-grade Pu being from its existing PHWRs) and with a thorium blanket to breed fissile U-233. This will take India's ambitious thorium program to stage 2, and set the scene for eventual full utilization of the country's abundant thorium to fuel reactors.

Japan plans to develop FBRs, and its Joyo experimental reactor which has been operating since 1977 is now being boosted to 140 MWt. The 280 MWe **Monju** prototypes commercial FBR was connected to the grid in 1995, but was then shut down for 15 years due to a sodium leak. It restarted in 2010.

Mitsubishi Heavy Industries (MHI) is involved with a consortium to build the **Japan Standard Fast Reactor** (JSFR) concept, though with breeding ratio less than 1:1. This is a large unit which will burn actinides with uranium and plutonium in oxide fuel. It could be of any size from

500 to 1500 MWe. In this connection MHI has also set up Mitsubishi FBR Systems (MFBR). The demonstration FR model is due to be committed in 2015 and on line in 2025, and a 1500 MWe commercial FR is proposed by MHI for 2050.

The Russian **BN-600** fast breeder reactor at Beloyarsk has been supplying electricity to the grid since 1981 and has the best operating and production record of all Russia's nuclear power units. It uses uranium oxide fuel and the sodium coolant delivers 550°C at little more than atmospheric pressure. The BN 350 FBR operated in Kazakhstan for 27 years and about half of its output was used for water desalination. Russia plans to reconfigure the BN-600 to burn the plutonium from its military stockpiles.

Advanced FNRs include the following:

BN-800

The first BN-800, a new more powerful (880 MWe gross, 2100 MWt) FBR from OKBM with improved features is being built at Beloyarsk. It has considerable fuel flexibility - U+Pu nitride, MOX, or metal, and with breeding ratio up to 1.3. With three loops, outlet primary coolant temperature is 547ºC and steam temperature 470ºC. Service life is 40 years. It has much enhanced safety and improved economy - while capital cost is 20% more than VVER-1200, operating cost is expected to be only 15% more than VVER. It is capable of burning 1.7 to 2 tons of plutonium per year from dismantled weapons and will test the recycling of minor actinides in the fuel. The BN-800 has been sold to China, and two units are due to start construction there in 2012.

However, the BN-800 is likely to be the last such reactor design built (outside India's thorium program), with a fertile blanket of depleted uranium around the core. Further fast reactors will have an integrated core to minimize the potential for weapons proliferation from bred Pu-239.

BN-1200

Rosatom has been developing the BN-1200, based on BN-600 & 800, to be built at Beloyarsk about 2020. It will be 2900 MW thermal at 550°C, giving 1220 MWe. Thermal efficiency is 42% gross, 39% net. Breeding ratio 1.2 initially with MOX fuel. This is part of its "strategic scientific project aimed at building a new technology platform for nuclear power." The design is expected to be complete in 2017, as approaching Gen IV type with 60-year service life. Estimated capital cost is similar to VVER-1200.

BREST

Russia has experimented with several lead-cooled reactor designs, and has used lead-bismuth cooling for 40 years in reactors for its 7 Alfa class submarines. Pb-208 (54% of naturally-occurring lead) is transparent to neutrons. A significant new Russian design from NIKIET is the BREST fast neutron reactor, of 300 MWe (700 MWt) or more with lead as the primary coolant, at 540ºC, and supercritical steam generators. It is inherently safe and uses a high-density U+Pu nitride fuel with no requirement for high enrichment levels. No weapons-grade plutonium can be produced (since there is no uranium blanket - all the breeding occurs in the core). Also it is an equilibrium core, so there are no spare neutrons to irradiate targets. The initial cores can comprise Pu and spent fuel - hence loaded with fission products, and radio logically 'hot'. Subsequently, any surplus plutonium, which is not in pure form, can be used as the cores of new reactors. Used fuel can be recycled indefinitely, with on-site reprocessing and associated facilities. A pilot unit is planned for Beloyarsk by 2020, and 1200 MWe (2800 MWt) units are proposed. Both designs have two cooling loops.

ELSY

The European Lead-cooled SYstem (ELSY) of 600 MWe in Europe, led by Ansaldo Nucleare from Italy and financed by Euratom. ELSY is a flexible fast neutron reactor which can use depleted uranium or thorium fuel matrices, and burn actinides from LWR fuel. Liquid metal (Pb or Pb-Bi eutectic) cooling is at low pressure .The design was nearly complete in 2008 and a small-scale demonstration facility is planned. It runs on MOX fuel at 480°C and the molten lead is pumped to eight steam generators, though decay heat removal is passive, by convection.

PRISM

In the USA, GE was involved in designing a modular liquid metal-cooled inherently-safe reactor - PRISM**.** GE with the DOE national laboratories were developing PRISM during the advanced liquid-metal fast breeder reactor (ALMR) program. No US fast neutron reactor has so far been larger than 66 MWe and none has supplied electricity commercially.

Today's **PRISM** is a GE-Hitachi design for compact modular pool-type reactors with passive cooling for decay heat removal. After 30 years of development it represents GEH's Generation IV solution to closing the fuel cycle in the USA. Each PRISM Power Block consists of two modules of 311 MWe each, operating at high temperature - over 500°C. The pool-type modules below ground level contain the complete primary system with sodium coolant. The Pu & DU fuel is metal, and obtained from used light water reactor fuel. However, all transuranic elements are removed together in the electrometallurgical reprocessing so that fresh fuel has minor actinides with the plutonium. Fuel stays in the reactor about six years, with one third removed every two years. Used PRISM fuel is recycled after removal of fission products. The commercial-scale plant concept, part of a Advanced Recycling Centre, uses three power blocks (six reactor modules) to provide 1866 MWe. See also electrometallurgical section in Processing Used Nuclear Fuel paper.

A variant of this is proposed to utilize the UK's reactor-grade plutonium stockpile. A pair of PRISM units built at Sell afield would be operated initially so as to bring the material up to the highly-radioactive 'spent fuel standard' of self-protection and proliferation resistance. The whole stockpile could be irradiated thus in five years, with some by-product electricity and the plant would then proceed to re-use that stored fuel over perhaps 55 years solely for 600 MWe of electricity generation.

KALIMER

Korea's KALIMER (Korea Advanced Liquid Metal Reactor) is a 600 MWe pool type sodium-cooled fast reactor designed to operate at over 500ºC. It has evolved from a 150 MWe version. It has a transmitter core, and no breeding blanket is involved. Future development of KALIMER as a Generation IV type is envisaged.

5.4 The Nuclear cycle

The nuclear cycle is categorized into two parts: the front-end and back-end fuel cycle. At the front-end of the nuclear cycle, the portion involving fuel before it is delivered to a power plant, includes the mining of uranium ore at mines, the milling process where uranium is extracted, conversion where uranium is transformed into a gaseous form, the enrichment of uranium to the desired form, and finally, the solidification of the enriched uranium and its fabrication into fuel .The back-end of the fuel cycle entails the storage of spent fuel, the re-processing of spent fuel and generated waste, the management of low-, intermediate-, and high-level waste, the decommissioning and decommissioning phase of a nuclear power plant and the restoration of closed mines . Energy won from nuclear energy is through the nuclear fission of certain uranium isotopes and fissionable isotopes produced from uranium. Uranium is an element that generally occurs naturally in low concentration and can be found in soil, rock and water. There are various isotopes of uranium but only certain ones, mainly uranium-235, are fissile and suitable for nuclear use.

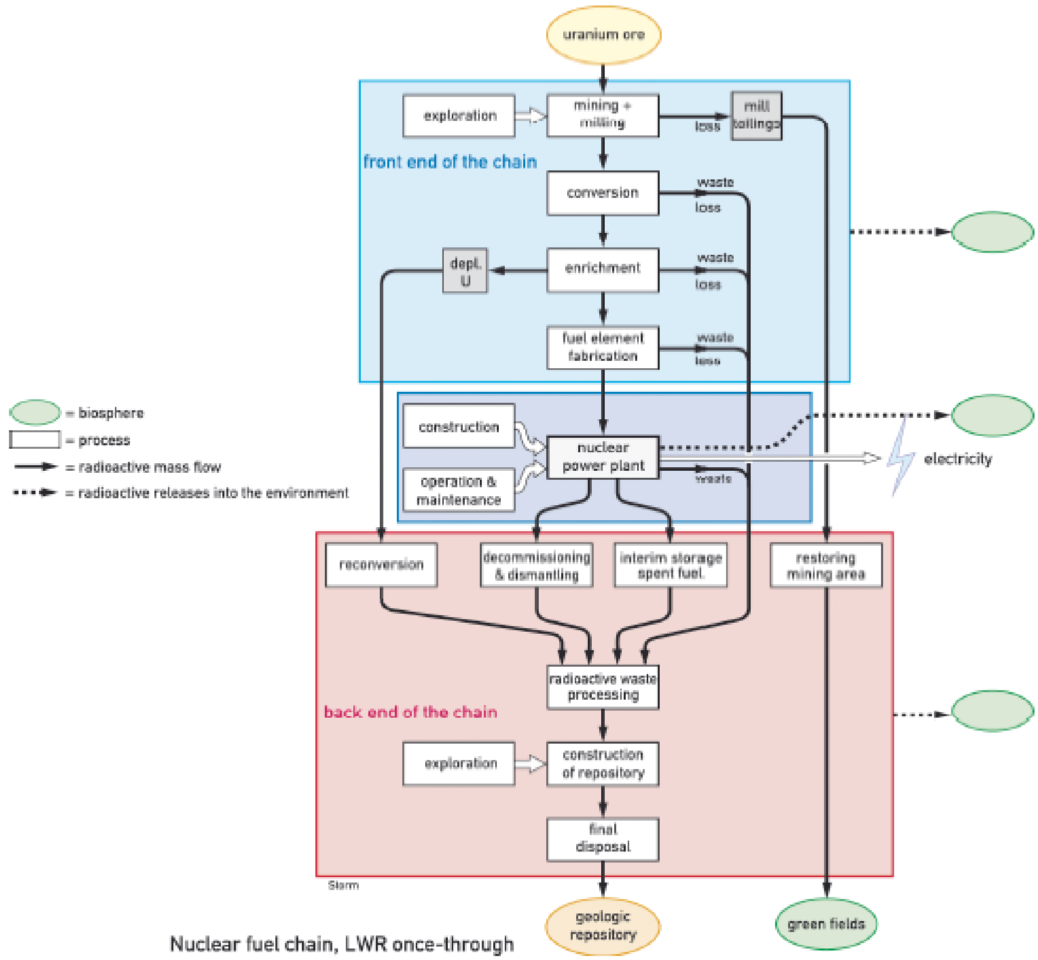


Figure : Full Nuclear Process Chain Adopted from Storm van Leeuwen (2006)

5.4.1 Construction

The construction phase of a nuclear power plant involves the fabrication, transportation, and use of materials to build generators, turbines, cooling towers, control rooms, and other infrastructure developments. The construction of a nuclear power plant requires certain amounts of steel and concrete, amongst other materials, which are energy and carbon intensive. Commonly, discussions regarding the construction of nuclear power plants are consumed with the economic viability of such construction projects and the potential in energy production. Nevertheless, the materials used for construction have a strong link with CO2 emissions and must be critically explored in the context of environmental impacts.

5.4.2 Mining and Milling

Uranium mining is the process of extracting uranium ore from the ground. Uranium is a metal that has to be chemically extracted from uranium ore and subsequently, treated and converted to be used for nuclear energy. There are various mining methods, which can be utilized to extract uranium and because it is generally present in minute quantities the extraction process is very volume intensive. Although, there are exceptions to where there are higher concentrations of uranium, such as in Australia and Canada. Uranium can be extracted in general by using two methods: open-pit mining or underground mining. Open-pit mining entails the removing of the top layer of burden allowing for extraction to occur in a large open air pit and underground mining entails the digging of tunnels allowing for the ore to be extracted underground. An additional method sometimes applied to uranium extraction is in-situ leaching (ISL). This method involves retaining the ore in the ground and recovering uranium from it by dissolving it. This is done by pumping particular chemicals into the underground ore body and consequently, after a time period ranging from 3-25 years, extracting the uranium-bearing liquid. According to World Nuclear Association,

"Uranium ISL uses the native groundwater in the ore body which is fortified with a complexing agent and in most cases an oxidant."

Subsequent to the uranium solution being extracted from the ground the uranium is recovered by milling. Once the uranium has been mined it must be milled to extract the uranium oxide from the ore. To avoid having to transport large amounts of material, the milling process is commonly carried out near the mining site. Milling entails grinding large amounts of rock into fine slurry, which is then leached in sulfuric acid to extract what is called "yellowcake." Yellowcake is a uranium ore concentrate containing above 80 percent uranium. A byproduct of the mining and milling process are tailings. Tailings are solid waste products comprised of most of the original ore processed to extract uranium, including radioactivity.

5.4.3 Preparing Fuel (Conversion & Enrichment)

The preparation process of nuclear fuel depends on the source technology. For light water-reactors, which are most common, for the uranium to be usable it requires conversion into a gaseous form known as hexafluoride to subsequently, be enriched to prepare nuclear fuel. Thus, the yellowcake substance is transported to a conversion plant and later to an enrichment facility. The uranium, to be useful in light water-reactors, must have a uranium-235 concentration of at least 3.5 percent, in comparison with the 0.7 percent in which it is present in natural uranium.

The enrichment process entails removing approximately 85 percent of uranium-238 from uranium hexafluoride known as "**enrichment tails**". Once U-238 has been removed, the uranium, which is left, mainly uranium-235, is enriched and passes on to the next stage of the cycle. The 15 percent of enriched uranium are then converted into ceramic pellets of uranium dioxide, packed in zirconium alloy tubes and finally, are bundled together to form fuel elements for reactors. The enrichment tails retain diminutive amounts of uranium-235 and are therefore, not used for energy. However, such depleted uranium can sometimes be used by being converted into metals for a variety of purposes, such as munitions or ballast in airplanes, because it is denser than lead. However, most enrichment tails remain in their gaseous form and are stored.

5.4.4 The Reactor

The type of reactor defines the lifetime of a nuclear reactor. However, at present the average lifetime of a nuclear reactor can be approximated between 30-40 years, whereas it runs at full capacity for approximately 24 years. Throughout the lifetime of a nuclear reactor, maintenance and refurbishing is necessary until, eventually corrosion and radioactivity make maintenance not viable.

5.4.5 Generation and Waste

Once the fuel has been prepared it can be used to generate heat for steam and consequently, to produce energy. Along the phases of the nuclear cycle, significant amounts of waste are generated. Due to the various levels of radioactive contamination of materials, a long-term and safe containment of waste is necessary to prevent exposure to the environment, as well as the public. The radioactive elements in the waste are present in different concentrations and have different half-lives therefore, requiring different ways in dealing with different waste, especially for material with radioactive contamination that last for long periods of time. The International Atomic Energy Agency has established a classification system for radioactive waste. Radioactive waste is placed within three categories: Low-level waste (LLW), Intermediate-level Waste (ILW), and High-level waste (HLW). Low-level waste, because of its low radionuclide content allows for normal handling and transportation and does not require any shielding. Intermediate-level waste does require shielding because of its radionuclide content but no provision for heat dissipation. High-level waste consists of highly radioactive liquid, containing mainly fission products, as well as some actinides, which is separated during chemical reprocessing of irradiated fuel (aqueous waste from the first solvent extraction cycle and those waste streams combined with it); any other waste with radioactivity levels intense enough to generate significant quantities of heat by the radioactive decay process; spent fuel, if it is declared a waste (IAEA, 1994, p. 8). In addition, the IAEA (1994) classification makes a differentiation within ILW and LLW between short and long-lived waste and alpha bearing waste. Short- and long-lived waste refers to the decay of radioactive waste based on an acceptable or not acceptable activity level from a radiological viewpoint.

"Alpha bearing waste is radioactive waste containing one or more alpha emitting radionuclide, usually actinides, in quantities above acceptable limits established by the national regulatory body."

ILW and LLW are generally stored in near-surface waste disposal sites to isolate the waste from the human environment and allow for the natural decay of radioactivity. In regards to the management of HLW only hypothetical concepts exist past basic storage, until now; high-level waste is disposed of by storage. Current consideration propose deep ecological disposal. The sources of waste range from spent fuel elements, emissions and catastrophic releases through accident, plutonium and dismantling of the reactor itself. Notably, no effective disposal method for nuclear waste has yet been adopted.

5.4.6 Fuel Re-Processing

The nuclear fuel cycle can be classified into two types: a once-through and closed fuel cycle. Some reactors operate on a once-through cycle that disposes of spent fuel directly where other reactors operate on a closed fuel cycle, separating waste products from unused fissionable material so that it can be reused as fuel. Once the concentration of the used uranium decreases to below 1 percent it can be re-processed to recover uranium for reuse. The re-processing process is highly complex and requires a higher degree of enrichment and is not always incorporated in the cycle for security concerns. Re-processing is also used for recovering plutonium from spent fuel, raising concerns about potential proliferation. Consequently, to avoid its diversion and theft certain safeguard methods would have to be put in place. In addition,

"Reprocessing is widely recognized to be uneconomical and is likely to remain so in the foreseeable future".

5.5 WASTE MANAGEMENT

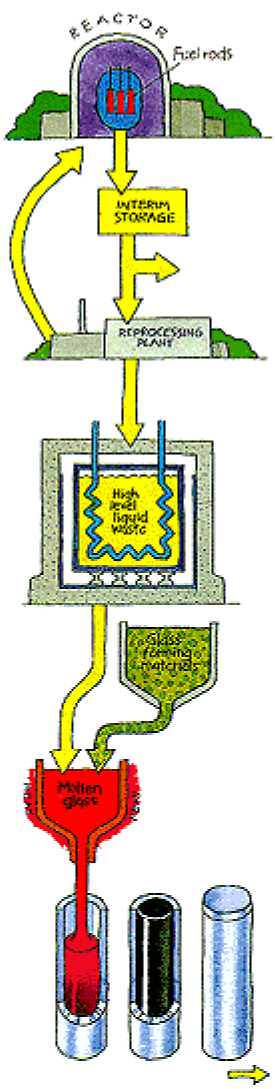
Nuclear power is characterized by the very large amount of energy available from a very small amount of fuel. The amount of waste is also relatively small. However, much of the waste is radioactive and therefore must be carefully managed as hazardous waste.

Since the radioactive wastes are essentially created in a nuclear power reactor, it is accepted that they are the responsibility of the country which uses uranium to generate power. There is no moral or legal basis for the responsibility to be elsewhere.

Types of radioactive waste (radwaste)

Low-level Waste is generated from hospitals, laboratories and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters etc. which contain small amounts of mostly short-lived radioactivity. It is not dangerous to handle, but must be disposed of more carefully than normal garbage. Usually it is buried in shallow landfill sites. To reduce its volume, it is often compacted or incinerated (in a closed container) before disposal. Worldwide it comprises 90% of the volume but only 1% of the radioactivity of all radwaste.

Intermediate-level Waste contains higher amounts of radioactivity and may require special shielding. It typically comprises resins, chemical sludges and reactor components, as well as contaminated materials from reactor decommissioning. Worldwide it makes up 7% of the volume and has 4% of the radioactivity of all radwaste. It may be solidified in concrete or bitumen for disposal. Generally short-lived waste (mainly from reactors) is buried, but long-lived waste (from reprocessing nuclear fuel) is disposed of deep underground.



High-level Waste may be the used fuel itself, or the principal waste separated from reprocessing this. While only 3% of the volume of all radwaste, it holds 95% of the radioactivity. It contains the highly-radioactive fission products and some heavy elements with long-lived radioactivity. It generates a considerable amount of heat and requires cooling, as well as special shielding during handling and transport. If the used fuel is reprocessed, the separated waste is vitrified by incorporating it into borosilicate (Pyrex) glass which is sealed inside stainless steel canisters for eventual disposal deep underground.

Reprocessing

If the used fuel is later reprocessed, it is dissolved and separated chemically into uranium, plutonium and high-level waste solutions. About 97% of the used fuel can be recycled leaving only 3% as high-level waste. The recyclable portion is mostly uranium depleted to less than 1% U-235, with some plutonium, which is most valuable.

Arising from a year's operation of a typical l000 MWe nuclear reactor, about 230 kilograms of plutonium (1% of the spent fuel) is separated in reprocessing. This can be used in fresh mixed oxide (MOX) fuel (but not weapons, due its composition). MOX fuel fabrication occurs in Europe, with some 25 years of operating experience. The main plant is in France, and started up in 1995. Japan's slightly smaller plant is due to start up in 2012.

Across Europe, over 35 reactors are licensed to load 20-50% of their cores with MOX fuel.

The separated high-level wastes - about 3% of the typical reactor's used fuel - amounts to 700 kg per year and it needs to be isolated from the environment for a very long time.

Major commercial reprocessing plants are operating in France and UK, with capacity of almost 5000 tones of used fuel per year, - equivalent to at least one third of the world's annual output. A total of some 90,000 tons of spent fuel has been reprocessed at these over 40 years.

Immobilizing high-level waste

Solidification processes have been developed in several countries over the past fifty years. Liquid high-level wastes are evaporated to solids, mixed with glass-forming materials, melted and poured into robust stainless steel canisters which are then sealed by welding. The vitrified waste from the operation of a 1000 MWe reactor for one year would fill about twelve canisters, each 1.3m high and 0.4m diameter and holding 400 kg of glass. Commercial vitrification plants in Europe produce about 1000 tons per year of such vitrified waste (2500 canisters) and some have been operating for more than 20 years. A more sophisticated method of immobilizing high-level radioactive wastes has been developed. Called 'SYNROC' (synthetic rock), the radioactive wastes are incorporated in the crystal lattices of the naturally-stable minerals in a synthetic rock. In other words, copying what happens in nature. This process is still being developed for specialist application.

Waste disposal

Final disposal of high-level waste is delayed for 40-50 years to allow its radioactivity to decay, after which less than one thousandth of its initial radioactivity remains, and it is much easier to handle. Hence canisters of vitrified waste, or used fuel assemblies, are stored under water in special ponds, or in dry concrete structures or casks, for at least this length of time.

The ultimate disposal of vitrified wastes, or of used fuel assemblies without reprocessing, requires their isolation from the environment for a long time. The most favored method is burial in stable geological formations some 500 meters deep. Several countries are investigating sites that would be technically and publicly acceptable, and in Sweden and Finland construction is proceeding in 1.9 billion year-old granites.

One purpose-built deep geological repository for long-lived nuclear waste (though only from defense applications) is already operating in New Mexico, in a salt formation.

After being buried for about 1000 years most of the radioactivity will have decayed. The amount of radioactivity then remaining would be similar to that of the corresponding amount of naturally-occurring uranium ore from which it originated, though it would be more concentrated.

Layers of protection

To ensure that no significant environmental releases occur over a long period after disposal, a 'multiple barriers' disposal concept is used. The radioactive elements in high-level (and some intermediate-level) wastes are immobilized and securely isolated from the biosphere. The principal barriers are:

- Immobilize waste in an insoluble matrix, eg : borosilicate glass, Synroc (or leave them as uranium oxide fuel pellets - a ceramic).
- Seal inside a corrosion-resistant container, eg stainless steel.
- Surround containers with betonies clay to inhibit any groundwater movement if the repository is likely to be wet.
- Locate deep underground in a stable rock structure.

For any of the radioactivity to reach human populations or the environment, all of these barriers would need to be breached, and this would need to happen before the radioactivity decayed to innocuous levels.

5.6 NUCLEAR POWER ECONOMICS

Nuclear power is cost competitive with other forms of electricity generation, except where there is direct access to low-cost fossil fuels. Fuel costs for nuclear plants are a minor proportion of total generating costs, though capital costs are greater than those for coal-fired plants and much greater than those for gas-fired plants.

Assessing the relative costs of new generating plants utilizing different technologies is a complex matter and the results depend crucially on location. Coal is, and will probably remain, economically attractive in countries such as China, the USA and Australia with abundant and accessible domestic coal resources as long as carbon emissions are cost-free. Gas is also competitive for base-load power in many places, particularly using combined-cycle plants, though rising gas prices have removed much of the advantage.

Nuclear energy is, in many places, competitive with fossil fuels for electricity generation, despite relatively high capital costs and the need to internalize all waste disposal and decommissioning costs. If the social, health and environmental costs of fossil fuels are also taken into account, the economics of nuclear power are outstanding.

The cost of fuel

From the outset the basic attraction of nuclear energy has been its low fuel costs compared with coal, oil and gas-fired plants. Uranium, however, has to be processed, enriched and fabricated into fuel elements, and about half of the cost is due to enrichment and fabrication. In the assessment of the economics of nuclear power allowances must also be made for the management of radioactive used fuel and the ultimate disposal of this used fuel or the wastes separated from it. But even with these included, the total fuel costs of a nuclear power plant in the OECD are typically about a third of those for a coal-fired plant and between a quarter and a fifth of those for a gas combined-cycle plant. The US Nuclear Energy Institute suggests that for a coal-fired plant 78% of the cost is the fuel, for a gas-fired plant the figure is 89%, and for nuclear the uranium is about 14%, or double that to include all front end costs.

In March 2011, the approx. US $ cost to get 1 kg of uranium as UO2 reactor fuel (at current spot uranium price):

Uranium:	8.9 kg U_3O_8 x $146	US$ 1300
Conversion:	7.5 kg U x $13	US$ 98
Enrichment:	7.3 SWU x $155	US$ 1132
Fuel fabrication:	per kg	US$ 240
Total, approx:		US$ 2770

At 45,000 MWd/t burn-up this gives 360,000 kWh electrical per kg, hence fuel cost: 0.77 c/kWh.

Fuel costs are one area of steadily increasing efficiency and cost reduction. For instance, in Spain the nuclear electricity cost was reduced by 29% over 1995-2001. This involved boosting enrichment levels and burn-up to achieve 40% fuel cost reduction. Prospectively, a further 8% increase in burn-up will give another 5% reduction in fuel cost.

Uranium has the advantage of being a highly concentrated source of energy which is easily and cheaply transportable. The quantities needed are very much less than for coal or oil. One kilogram of natural uranium will yield about 20,000 times as much energy as the same amount of coal. It is therefore intrinsically a very portable and tradable commodity.

The fuel's contribution to the overall cost of the electricity produced is relatively small, so even a large fuel price escalation will have relatively little effect (see below). Uranium is abundant.

There are other possible savings. For example, if used fuel is reprocessed and the recovered plutonium and uranium is used in mixed oxide (MOX) fuel, more energy can be extracted. The costs of achieving this are large, but are offset by MOX fuel not needing enrichment and particularly by the smaller amount of high-level wastes produced at the end. Seven UO2 fuel assemblies give rise to one MOX assembly plus some vitrified high-level waste, resulting in only about 35% of the volume, mass and cost of disposal.

Comparing the economics of different forms of electricity generation

A 2010 OECD study Projected Costs of generating Electricity set out some actual costs of electricity generation, from which the following figures are taken:

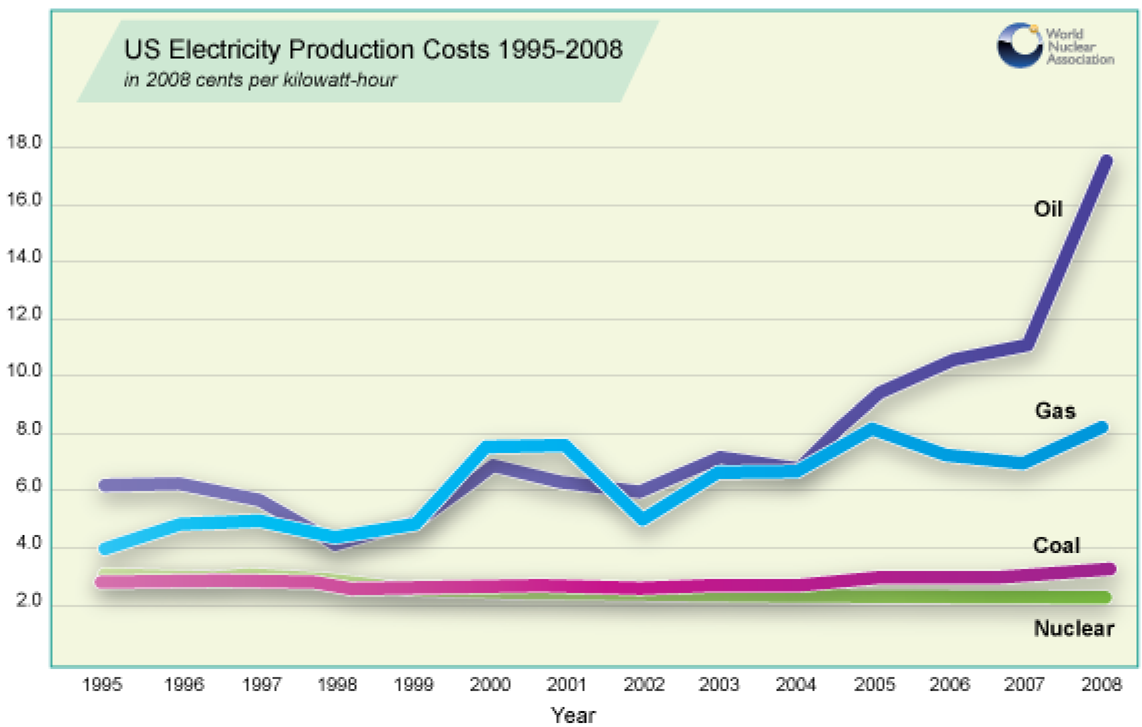
Actual Costs of Electricity (US cents/kWh)

technology	region or country	At 10% discount rate	At 5% discount rate
Nuclear	OECD Europe	8.3-13.7	5.0-8.2
	China	4.4-5.5	3.0-3.6
Black coal with CCS	OECD Europe	11.0	8.5
Brown coal with CCS	OECD Europe	9.5-14.3	6.8-9.3
CCGT with CCS	OECD Europe	11.8	9.8
Large hydro-electric	OECD Europe	14.0-45.9	7.4-23.1
	China: 3 Gorges	5.2	2.9
	China: other	2.3-3.3	1.2-1.7
Onshore wind	OECD Europe	12.2-23.0	9.0-14.6
	China	7.2-12.6	5.1-8.9
Offshore wind	OECD Europe	18.7-26.1	13.8-18.8
Solar photovoltaic	OECD Europe	38.8-61.6	28.7-41.0
	China	18.7-28.3	12.3-18.6

Source: OECD/IEA-NEA, 2010, Projected Costs of Generating Electricity, Tables 3.7 This shows the levelised cost, which is the average cost of producing electricity including capital, finance, owner's costs on site, fuel and operation over a plant's lifetime.

It is important to distinguish between the economics of nuclear plants already in operation and those at the planning stage. Once capital investment costs re effectively "sunk", existing plants operate at very low costs and are effectively "cash machines". Their operations and maintenance (O&M) and fuel costs (including used fuel management) are, along with hydropower plants, at the low end of the spectrum and make them very suitable as base-load power suppliers. This is irrespective of whether the investment costs are amortized or depreciated in corporate financial accounts – assuming the forward or marginal costs of operation are below the power price, the plant will operate.

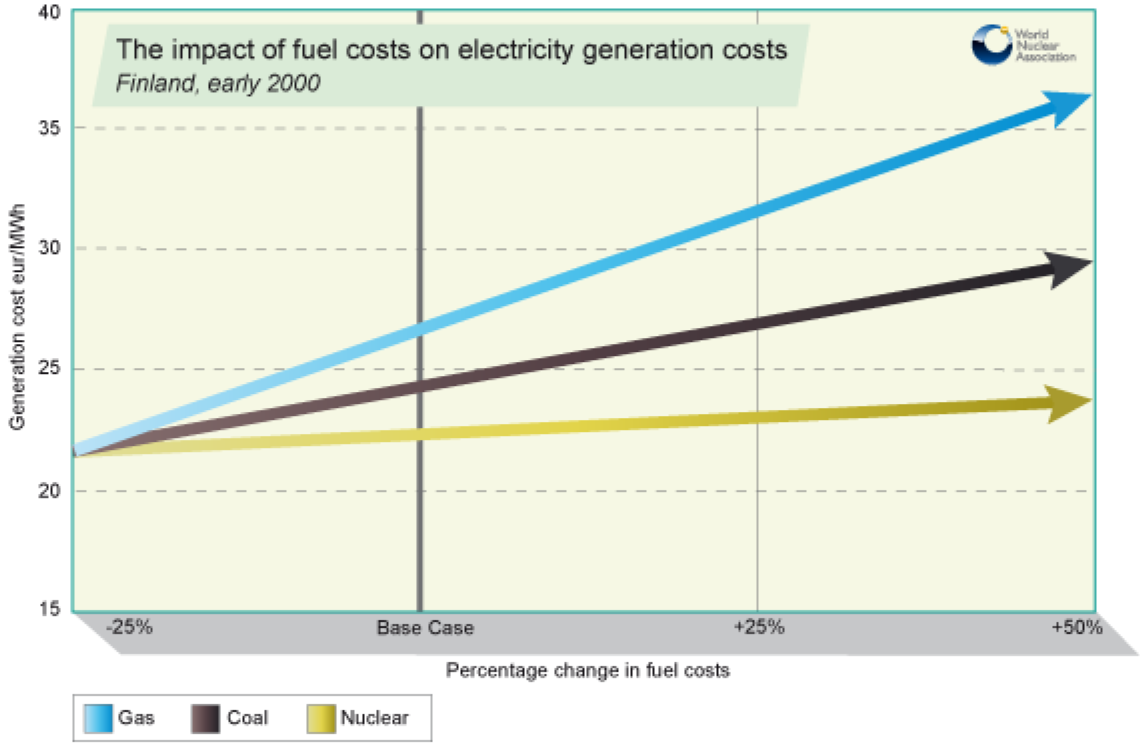
US figures for 2008 published by NEI show the general picture, with nuclear generating power at 1.87c/kW.



Production Costs = Operations & Maintenance + Fuel. Production costs do not include indirect costs or capital.

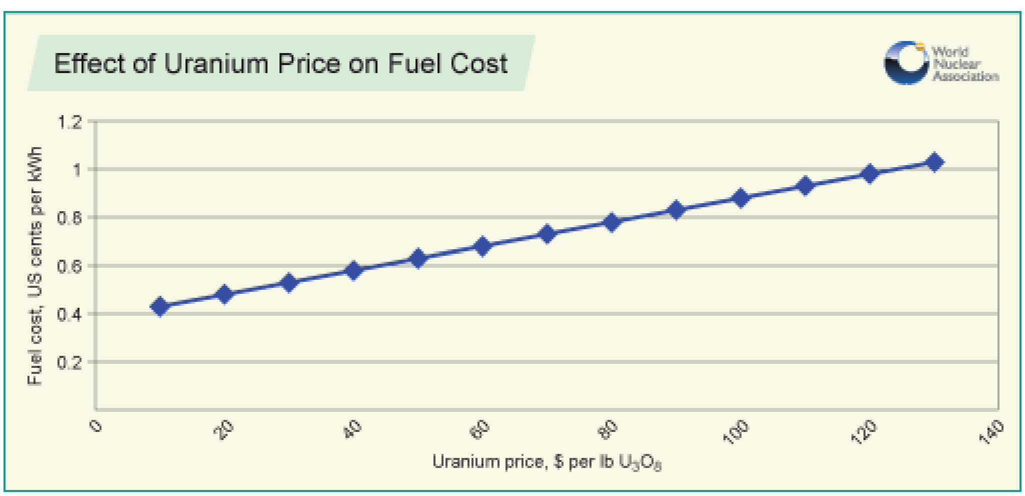
Source: *Ventyx Velocity Suite, via NEI*

A Finnish study in 2000 also quantified fuel price sensitivity to electricity costs:



These show that a doubling of fuel prices would result in the electricity cost for nuclear rising about 9%, for coal rising 31% and for gas 66%. Gas prices have since risen significantly.

The impact of varying the uranium price in isolation is shown below in a worked example of a typical US plant, assuming no alteration in the tails assay at the enrichment plant.



Doubling the uranium price (say from $25 to $50 per lb U3O8) takes the fuel cost up from 0.50 to 0.62 US cents per kWh, an increase of one quarter, and the expected cost of generation of the best US plants from 1.3 US cents per kWh to 1.42 cents per kWh (an increase of almost 10%). So while there is some impact, it is comparatively minor, especially by comparison with the impact of gas prices on the economics of gas generating plants. In these, 90% of the marginal costs can be fuel. Only if uranium prices rise to above $100 per lb U3O8 ($260 /kgU) and stay there for a prolonged period (which seems very unlikely) will the impact on nuclear generating costs be considerable.

Nevertheless, for nuclear power plants operating in competitive power markets where it is impossible to pass on any fuel price increases (ie the utility is a price-taker), higher uranium prices will cut corporate profitability. Yet fuel costs have been relatively stable over time – the rise in the world uranium price between 2003 and 2007 added to generation costs, but conversion, enrichment and fuel fabrication costs did not followed the same trend.

For prospective new nuclear plants, the fuel element is even less significant. The typical front end nuclear fuel cost is typically only 15-20% of the total, as opposed to 30-40% for operating nuclear plants.

Future cost competitiveness

Understanding the cost of new generating capacity and its output requires careful analysis of what is in any set of figures. There are three broad components: capital, finance and operating costs. Capital and financing costs make up the project cost.

Capital costs comprise several things: the bare plant cost (usually identified as engineering-procurement-construction - EPC - cost), the owner's costs (land, cooling infrastructure, administration and associated buildings, site works, switchyards, project management, licenses, etc), cost escalation and inflation. Owner's costs may include transmission infrastructure. The term "overnight capital cost" is often used, meaning EPC plus owners' costs and excluding financing, escalation due to increased material and labor costs, and inflation. Construction cost – sometimes called "all-in cost", adds to overnight cost any escalation and interest during construction and up to the start of construction. It is expressed in the same units as overnight cost and is useful for identifying the total cost of construction and for determining the effects of construction delays. In general the construction costs of nuclear power plants are significantly higher than for coal- or gas-fired plants because of the need to use special materials, and to incorporate sophisticated safety features and back-up control equipment. These contribute much of the nuclear generation cost, but once the plant is built the cost variables are minor.

Long construction periods will push up financing costs, and in the past they have done so spectacularly. In Asia construction times have tended to be shorter, for instance the new-generation 1300 MWe Japanese reactors which began operating in 1996 and 1997 were built in a little over four years, and 48 to 54 months is typical projection for plants today.

Decommissioning costs are about 9-15% of the initial capital cost of a nuclear power plant. But when discounted, they contribute only a few percent to the investment cost and even less to the generation cost. In the USA they account for 0.1-0.2 cent/kWh, which is no more than 5% of the cost of the electricity produced.

Financing costs will depend on the rate of interest on debt, the debt-equity ratio, and if it is regulated, how the capital costs are recovered. There must also be an allowance for a rate of return on equity, which is risk capital.

Operating costs include operating and maintenance (O&M) plus fuel. Fuel cost figures include used fuel management and final waste disposal. These costs, while usually external for other technologies, are internal for nuclear power (ie they have to be paid or set aside securely by the utility generating the power, and the cost passed on to the customer in the actual tariff).

This “back-end” of the fuel cycle, including used fuel storage or disposal in a waste repository, contributes up to 10% of the overall costs per kWh, - rather less if there is direct disposal of used fuel rather than reprocessing. The $26 billion US used fuel program is funded by a 0.1 cent/kWh levy.

Calculations of relative generating costs are made using levelised costs, meaning average costs of producing electricity including capital, finance, and owner’s costs on site, fuel and operation over a plant's lifetime, with provision for decommissioning and waste disposal.

It is important to note that capital cost figures quoted by reactor vendors, or which are general and not site-specific, will usually just be for EPC costs. This is because owner's costs will vary hugely, most of all according to whether a plant is Greenfield or at an established site, perhaps replacing an old plant.

Mid 2008 vendor figures for overnight costs have been quoted as:

GE –Hitachi ESBWR just under $3000/KW

GE –Hitachi ABWR just over $3000/KW

Westinghouse AP1000 about $3000/KW

There are several possible sources of variation which preclude confident comparison of overnight or EPC (Engineering, Procurement & Construction) capital costs - eg whether initial core load of fuel is included. Much more obvious is whether the price is for the nuclear island alone (Nuclear Steam Supply System) or the whole plant including turbines and generators - all the above figures include these. Further differences relate to site works such as cooling towers as well as land and permitting - usually they are all owners' costs as outlined earlier in this section. Financing costs are additional, adding typically around 30%, and finally there is the question of whether cost figures are in current (or specified year) dollar values or in those of the year in which spending occurs.

5.7 PROBLEMS OF INTRODUCING NUCLEAR POWER IN DEVELOPING COUNTRIES

In his Annual Report to the United Nations General Assembly in October last year, IAEA Director General El Baradei pointed out that "nuclear power is undergoing something of a renaissance", which means a growing number of countries are looking seriously at introducing or expanding the use of nuclear power as part of their energy mix and that the use of nuclear power for electricity production seems certain to rise significantly in the next few decades. To date, the use of nuclear power has been concentrated in developed countries. Ten years ago nuclear power had stopped growing in developed countries. As most of them were allies or friends of the United States under its nuclear umbrella, they had no need or intention to develop nuclear weapons by way of getting access to civilian fissile material and gradually upgrading them to the weapons grade. Moreover, developing countries did not regard nuclear power as a key energy source in the past. Therefore, proliferation of fissile material was not an outstanding issue and a grave concern of the international community prior to the 1980s.But in the face of their growing dependence on energy imports and constraints of global environmental problems developing countries are required to take various energy policy measures including options for nuclear energy development.

Now in providing assistance to developing member states the IAEA has found that adequate infrastructure were often taken so that would ensure a smooth and successful introduction of nuclear power in developing countries. The key factors here are:

- Planning and decision making capabilities
- Organizational structures
- Electricity grid size and structure
- Qualified manpower
- Industrial support
- Financing

During the planning stage, the major task of a developing country is to identify, assess, and analyze available resources and potential weaknesses, and to devise measures to strengthen weak infrastructures. This task has to be performed with objectivity and requires both an in-depth knowledge of the country and expertise in the requirements derived from nuclear power technology. The first can only be contributed by national staff, but regarding technology requirements, manpower development needs and in setting up manpower development programmes.

Another obstacle for developing countries like Bangladesh in introducing nuclear energy is that they face lack of trust from the world community. Developed countries with advanced nuclear technologies and developing countries planning to introduce nuclear energy will have to cooperate in constructing and operating nuclear plants setting safety/security regulations and preventing the proliferation of nuclear weapons.

5.8 BASIC INFRASTRUCTURE REQUIRED TO SET UP A NUCLEAR POWER PLANT: PERSPECTIVE BANGLADESH

The decision to implement nuclear power requires expert and public input in the early stages of the development of the policy. Establishment of a basic nuclear power infrastructure follows the formalization of a positive decision on nuclear power. Nuclear power projects have a long duration of development and implementation and it is necessary for the government to provide assurances through policy and legislation that the long term interests of the investors are not adversely affected by political changes.

Nuclear power implementation agency

The formulation of the policy and the initial development of the basic elements of nuclear infrastructure organizations, prior to the involvement of the electric utilities and investors, may be facilitated through the establishment of a dedicated agency by the government and referred to in this publication as nuclear power implementation agency (NPIA). The NPIA is set up by the government to study the nuclear power option for the purpose of drafting the nuclear policy, identifying the basic infrastructure elements and planning their implementation.

In formulating the recommendations to the government, the NPIA should undertake the following basic assessment activities:

- Position of nuclear power in the electricity market and generation mix.
- Economics of nuclear power.
- Legal, regulatory and legislative aspects of nuclear power.
- Environmental and siting aspects of nuclear power.
- Nuclear power technology.
- Nuclear fuel cycle including waste management and decommissioning.

- Expected role of the government and the private sector in the development of the nuclear programme.
- Extent of availability of the industrial base and of the human resources needed for the nuclear programme in the country.
- Extent of the uranium resources in the country and its impact on the fuel supply policy.
- Public acceptance.

Physical facilities

Physical facilities needed for effective implementation of the nuclear power plant are to be established in compliance with the codes, standards and regulations or by using the best engineering and organizational practices.

Site

The most important element of infrastructure is the existence of a site with acceptable characteristics such as appropriate geological and seismic conditions, access to adequate cooling water, proper location on the grid, etc. The selected site will have to have its own infrastructure features and facilities as described below:

a. Water supply
b. Power supply
c. Transport/Access
d. Micro earthquake monitoring station
e. Meteorological and hydrological station
f. Town site and administration facilities

Grid

The interaction between the grid and the nuclear power plant is impacted by several factors including:

- Size of the plant output compared to the grid size,
- Location of the plant on the grid,
- Reliability of the grid interconnects.

Other things which should be considered are:

- Establishing physical protection facility
- Component management and manufacture
- Standard calibration laboratory facilities
- Storage/Disposal of low and medium radioactive waste
- Spent fuel storage and disposal facilities
- Safeguards plan and equipment

- Emergency response facilities/ Emergency response organization
- Emergency notification of nuclear incidents
- Communication facility etc

Establishment of government policy regarding implementation of nuclear power makes it possible for the country/utility to embark on the implementation of the first nuclear power plant. A number of activities would have to be undertaken following the formal approval of nuclear power by the government or the utility. These activities can, to a great extent, be undertaken in parallel and will lead to the preparation and issuing of bid specifications to potential reactor suppliers.

Site selection and environmental assessment

Nuclear power site selection is a lengthy and extensive activity requiring the engagement of a number of disciplines. In general a number of sites are considered first for a high level screening resulting in ranking of the sites and finally selection of the preferred site for full site investigation and environmental assessment. The major areas considered in the final investigation of the preferred site include:

– Integration into the electric grid system Geology, tectonics and volcanic
– Geology, tectonics and volcanic studies
– Seismology and seismic engineering
– Hydrology (including ground water, floods and tsunamis)
– Cooling water availability, intake and discharge
– Demography and land use
– Meteorology and atmospheric dispersion (including wind patterns, tornados and hurricanes)
– Study of flora and fauna
– Nuclear safety and radiation protection aspects
– General environmental effects
– Risks from man-made events
– Local infrastructure
– Cultural and historic sites
– Access and emergency response roads
– Air, land and sea transportation patterns
– Legal aspects
– Public consultation

Moreover adequate measures should be taken to maintain a very good waste management system to ensure safety from nuclear radiation.

Bangladesh has achieved notable progress in its nuclear power infrastructure development, according to a team of international experts from the IAEA. An Integrated Nuclear Infra-structure Review (INIR) mission concluded that Bangladesh has mostly met the conditions for knowledgeable decision making and is actively preparing for the Rooppur nuclear power plant project. Bangladesh recently concluded an Inter-Governmental Agreement (IGA) with Russia for the first nuclear power plant. Mr JK Park, Director of the IAEA Division of Nuclear Power and INIR mission team leader said that,

‘The mission team made 50 recommendations and 20 specific suggestions to assist the national authorities in preparing the infrastructure necessary to implement the project’

It is also recognized that Bangladesh has strong expertise especially in safeguards, security and radiation protection. Bangladesh began consideration of nuclear power in the 1960s, and with the Government approval of a national action plan in 2000, reinvigorated its efforts in recent years. The nuclear power plant would contribute to solving dire energy shortages and future increased demand for energy. The IGA with Russia is for two 1000 MW(e) units as well as fuel supply, take-back of spent fuel, training and other services. The Government of Bangladesh is considering either a Government owned turnkey project or a Build-Own-Operate-Transfer (BOOT) contract.

CHAPTER 6: SAFETY AND SAFEGUARD OF A NUCLEAR POWER PLANT

In relation to nuclear power, Safety is closely linked with Security and in the nuclear field also with Safeguards.

Safety focuses on unintended conditions or events leading to radiological releases from authorized activities. It relates mainly to intrinsic problems or hazards.

Security focuses on the intentional misuse of nuclear or other radioactive materials by non-state elements to cause harm. It relates mainly to external threats to materials or facilities.

Safeguards focus on restraining activities by states that could lead to acquisition of nuclear weapons. It concerns mainly materials and equipment in relation to rogue governments.

6.1 POSSIBLE SAFETY FAILURES

Nuclear power plants are some of the most sophisticated and complex energy systems ever designed. Any complex system, no matter how well it is designed and engineered, cannot be deemed failure-proof. The reactors themselves were enormously complex machines with an incalculable number of things that could go wrong.

A particular nuclear scenario was loss of cooling which resulted in melting of the nuclear reactor core, and this motivated studies on both the physical and chemical possibilities as well as the biological effects of any dispersed radioactivity. Those responsible for nuclear power technology in the West devoted extraordinary effort to ensuring that a meltdown of the reactor core would not take place, since it was assumed that a meltdown of the core would create a major public hazard, and if uncontained, a tragic accident with likely multiple fatalities.

The main safety concern has always been the possibility of an uncontrolled release of radioactive material, leading to contamination and consequent radiation exposure off-site. Earlier assumptions were that this would be likely in the event of a major loss of cooling accident (LOCA) which resulted in a core melt. The TMI experience suggested otherwise, but at Fukushima this is exactly what happened. In the light of better understanding of the physics and chemistry of material in a reactor core under extreme conditions it became evident that even severe cores melt coupled with breach of containment would be unlikely to create a major radiological disaster from many Western reactor designs, but the Fukushima accident showed that this did not apply to all. Studies of the post-accident situation at Three Mile Island (where there was no breach of containment) supported the suggestion, and analysis of Fukushima is pending.

Extreme natural phenomenon such as earthquake or tsunami can damage any nuclear power plant. The Fukushima accident is the recent example on that.

In any light-water nuclear power reactor, hydrogen is formed by radiolysis decomposition of water. This needs to be dealt with to avoid the potential for explosion with oxygen present.

There can also be terrorist attacks in the nuclear power plant. Since the World Trade Centre attacks in New York in 2001 there has been concern about the consequences of a large aircraft being used to attack a nuclear facility with the purpose of releasing radioactive materials.

6.2 Safety Mechanisms of a Nuclear Power Reactor

By regulation, the design of the nuclear reactor must include provisions for human (operator) error and equipment failure. Nuclear Plants in the western world use a "Defense in Depth" concept which is a system with multiple safety components, each with back-up and design to accommodate human error. The components include:

1. *Control of Radioactivity*

This requires being able to control the neutron flux. Recall that in a nuclear reactor when a neutron is captured by a fuel nucleus (generally uranium) the nucleus splits releasing radioactive particles (or undergoes fission). Hence if we decrease the neutron flux we decrease the radioactivity. The most common way to reduce the neutron flux is include neutron-absorbing control rods. These control rods can be partially inserted into the reactor core to reduce the reactions. The control rods are very important because the reaction could run out of control if fission events are extremely frequent. In modern nuclear power plants, the insertion of all the control rods into the reactor core occurs in a few seconds, thus halting the nuclear reaction as rapidly as possible. In addition, most reactors are designed so that beyond optimal level, as the temperature increases the efficiency of reactions decreases, hence fewer neutrons are able to cause fission and the reactor slows down automatically.

2. *Maintenance of Core Cooling*

In any nuclear reactor some sort of cooling is necessary. Generally nuclear reactors use water as a coolant. However some reactors which cannot use water use sodium or sodium salts.

3. *Maintenance of barriers that prevent the release of radiation*

There is a series of physical barriers between the radioactive core and the environment. For instance at the Darling Nuclear Generation Station in Canada the reactors are enclosed in heavily reinforced concrete which is 1.8m thick. Workers are shielded from radiation via interior concrete walls. A vacuum building is connected to the reactor buildings by a pressure relief duct. The vacuum building is a 71m high concrete structure and is kept at negative atmospheric pressure. This means that if any radiation were to leak from the reactor it would be sucked into the vacuum building and therefore prevented from being released into the environment.

The design of the reactor also includes multiple back-up components, independent systems (two or more systems performing the same function in parallel), monitoring of instrumentation and the prevention of a failure of one type of equipment affecting any other.

Further, regulation requires that a core-meltdown incident must be confined only to the plant itself without the need to evacuate nearby residence.

Safety is also important for the workers of nuclear power plants. Radiation doses are controlled via the following procedures,

- The handling of equipment via remote in the core of the reactor
- Physical shielding
- Limit on the time a worker spends in areas with significant radiation levels
- Monitoring of individual doses and of the work environment

6.3 Safeguards

Traditional safeguards are arrangements to account for and control the use of nuclear materials. This verification is a key element in the international system which ensures that uranium in particular is used only for peaceful purposes.

It is important to understand that nuclear safeguards are a means of reassurance whereby non-nuclear weapons states demonstrate to others that they are abiding by their peaceful commitments. They prevent nuclear proliferation in the same way that auditing procedures build confidence in proper financial conduct and prevent embezzlement. Their specific objective is to verify whether declared (usually traded) nuclear material remains within the civil nuclear fuel cycle and is being used solely for peaceful purposes or not.

Non-nuclear-weapons state parties to the NPT agree to accept technical safeguards measures applied by the IAEA. These require that operators of nuclear facilities maintain and declare detailed accounting records of all movements and transactions involving nuclear material. Almost 900 nuclear facilities and several hundred other locations in 57 non-nuclear-weapons countries are subject to regular inspection. Their records and the actual nuclear material are audited. Inspections by the IAEA are complemented by other measures such as surveillance cameras and instrumentation.

The aim of traditional IAEA safeguards is to deter the diversion of nuclear material from peaceful use by maximizing the risk of early detection. At a broader level they provide assurance to the international community that countries are honoring their treaty commitments to use nuclear materials and facilities exclusively for peaceful purposes. In this way safeguards are a service both to the international community and to individual states, who recognize that it is in their own interest to demonstrate compliance with these commitments.

The inspections act as an alert system providing a warning of the possible diversion of nuclear material from peaceful activities. The system relies on-

6.3.1 Nuclear Material Accountability

Nuclear material accountability is very important for the safeguard of any nuclear power plant. To avoid any unwanted situation several stapes should be taken. This includes tracing all inward and outward transfers and flow of material in any nuclear facility. To do so some important steps such as sampling and analysis of nuclear material, onsite inspections, review and verification of operating records must be implemented.

6.3.2 Physical and Cyber Security

Physical security of a nuclear power plant is another very important topic. Restricting access to nuclear materials at the site of use is very much needed in any nuclear power plant.

Computer systems that help operate nuclear reactors and their safety equipment are generally isolated from the Internet to protect against outside intrusion. However, the nuclear industry should take measures to ensure that its nuclear plants are protected from cyber attacks.

6.3.3 Material Containment and Surveillance

Material Containment and Surveillance deals with the Use of seals, automatic cameras and other instruments to detect unreported movement or tampering with nuclear materials, as well as spot checks on-site. The material surveillance is primarily concerned with detection of insider adversary activities, and is, therefore, a collection of information through devices and/or personnel observation to detect unauthorized movements of nuclear material, tampering with containment of nuclear material, falsification of information related to location and quantities of nuclear material, and tampering with safeguards devices. In order for visual surveillance to be considered effective, the person(s) observing must be capable of recognizing unauthorized activities, correctly assessing the situation, and reporting the activities to appropriate response personnel in time to deter theft, diversion, or radiological sabotage. If the recognition, assessment, or reporting is not effectively implemented, then the visual surveillance methodology is deficient and additional means must be used to ensure detection and response.

All NPT non-weapons states must accept these 'full-scope' safeguards, which apply to all nuclear facilities in the country. IAEA inspectors regularly visit these facilities to verify completeness and accuracy of records.

Uranium supplied to nuclear weapons states is not, under the NPT, covered by safeguards. However normally there is at least a "peaceful use" clause in the supply contract, and in the case of Australia, a bilateral safeguards agreement is required which does cover all uranium supplied and all materials arising from it (as "Australian obligated nuclear materials" - AONM). Neither the peaceful use clause nor the bilateral treaty means that materials are restricted to facilities on the state's list of facilities eligible for IAEA inspection.

6.4 Perspective Picture Of Global Nuclear Energy in The Post-Fukushima & Pre-Fukushima Accident

The first full-scale commercial nuclear reactor was connected into the Pittsburgh grid of USA on 18 December 1957. Hundreds of nuclear power reactors have been in operation globally since the 1950s. In the year 2011, the total 440 nuclear power reactors are in operation. Over the years, the interest in nuclear power generation has come about because of the realization that it has the advantages over fossil fuels include in terms of lower operating cost, absence of green house gases, less fuel requirement and energy security.

The devastating earthquake and tsunami that struck Japan on 11 March 2011 caused a catastrophic impact. The round-the-clock news of Fukushima nuclear plant accident along the news of loss of over 25,000 lives and damages of the residential, commercial and industrial parts of Fukushima and the adjacent areas has developed a sense of panic about nuclear power plants (NPPs) in many parts of the world. As a result, significant sentiment has been created in the European and North American countries that generated a debate for scaling down the expansion of their nuclear power sectors. Basically, in the post-Fukushima period, most of the Europe North American did not have major interest in nuclear energy “traditionally” for various reasons, including availability of alternatives and popular opposition. The major exception to this has been France, a global leader in nuclear power produces about 75% of its electricity from nuclear reactors. France avoided most of the global anti-nuclear concerns in the post-Fukushima era. This nation is now promising to upgrade its safety procedures, including a reassessment of the potential effects of natural disasters on nuclear plant operations. In the post-Fukushima era, both of the Finland and France has an ongoing project. The US has just two under construction on its own territory, despite being the principal exporter of reactors.

On the other hand, the Eastern European countries and Latin American countries were strongly committed nations to nuclear programme in the pre-Fukushima period. The Fukushima nuclear accident will not likely have a significant impact on the expansion of their nuclear power sectors. Russian federation has announced that it will go ahead with its programme. Nuclear energy is still considered safe despite the Fukushima incident to them. In the pre-Fukushima era, the Russian Federation (11), Bulgaria, the Slovakian Republic and Ukraine (each 2),) and Argentina and Brazil (each 1) are still continuing their ongoing projects.

The ongoing global energy crisis is already having a telling effect on the development endeavors of developing nations of Asian nations, especially those with huge number of population, scarcity of indigenous energy resources and a fast-growing demand for energy. After decades of decline, certain factors have contributed to renewed interest in nuclear energy as a substitute for fossil energy. These factors include gradual decreasing reliance on imported fossil fuel having financial, political and security implications, rapid depletion of oil/gas/coal reserves in fossil-energy-rich countries, improving energy security through energy-mix diversification and mitigation of global warming. The absence of nuclear-related disasters since Chernobyl has mainly calmed legitimate concerns about the potential safety of nuclear energy.

It is the reality that in the post-Fukushima accident, the Asia-Pacific region was the main arena for nuclear energy expansion. More than 100 nuclear projects of various scales are active consideration for implementation in this region. China has an ambitious nuclear vision; it has 24 ongoing projects worldwide. China is followed by South Korea (6) and India (4). There are many others, including Taiwan (2), Pakistan (1) and Japan (1). Other nuclear enthusiasts include Iran, which, despite UN sanctions, finally completed its Bushehr Nuclear Reactor (1000 MW) on 21 August 2010 with Russian assistance. In addition, in the pre-Fukushima era, a number of countries in this region had started active programme aiming at adding nuclear energy to their energy mix. These include Vietnam, Indonesia, Bangladesh, Malaysia and Thailand.

Despite Fukushima accident, the Asian countries have remained committed to the continuity of their nuclear programs. For example, China has an ambitious planning for building nuclear power plants. The country has 77 nuclear reactors at various stages of construction, planning, and discussion. The country will remain number one in nuclear operating countries having about 100 projects on its list of which many will be realized in the next two decades. After Fukushima, China did not stop their construction nor made any official statement to the effect of its plan to impose a construction moratorium on its nuclear projects. The Chinese government only suspended approval for new nuclear power projects so as to revisit and if necessary revise safety standards as a precautionary measure, on March 16, 2011. To remove any ambiguity about its long-term objectives, on March 26, 2011 the Chinese government clearly stated its commitment to continue its nuclear program, reaffirming its goal of developing nuclear power as a clean energy source while stressing the safety of the country's nuclear power facilities. China plans to have 66 nuclear power plants by 2020 and the country will launch new nuclear energy projects with a combined generating capacity of 40,000 MW. The Taiwan government also expressed strong desire to the continuity of its nuclear program on March 15, 2011. The Taiwan's President stated said that there was no need to shut down operations at the country’s three nuclear power plants despite public concerns over their safety caused by the Japanese accident. Nor was there any need to suspend the construction of Taiwan’s new nuclear reactors. The nation acknowledged the necessity of reviewing safety and response measures in place while assuring the public about the safe operation of its existing three nuclear reactors.

In India, the dilemma is this: it has 20 nuclear plants in operation, with an additional 23 on order. In the post-Fukushima period, India has a vision to have 20,000 MWe nuclear capacities on line by 2020 and 63,000 MWe by 2032. India has a vision of becoming a world leader in nuclear technology due to its expertise in fast reactors and thorium fuel cycle. In line with past practice such as at the eight-unit Rajasthan nuclear plant, India intends to set up five further "Nuclear Energy Parks", each with six to eight reactors with total capacity about 10,000 MW at each of the single location. By 2032, about 40,000 – 45,000 MW electricity would be provided from these five parks. After Fukushima accident the Indian government did not revised nuclear vision rather the Prime Minister of India has cautiously announced a "special safety review" of all plants.

The South Korea meets about 35% of its electricity demand from nuclear energy. At present the country has 21 NPPs in operation and six reactors are in under construction. The country has a plan to have 35 nuclear power plants by 2024. After Fukushima accident, on March 22, 2011 the Korean nuclear authority declared the vision of expansion of its nuclear power programme. The government announced checking the adequacy of nuclear safety measures in reaction to the Fukushima case both for domestic purposes and also for guaranteeing the export-worthiness of Korean nuclear technology. On March 28, 2011, South Korean Minister of Knowledge Economy reiterated and reconfirmed South Korea’s commitment to expanding its nuclear sector. The country is now in the process of supplying the UAE with four 1000 MW reactors as per its December 2009 contract.

In the post-Fukushima era, the Vietnam considers implementation of eight projects over the next 20 years with Russian and Japanese assistance. The country is actively considering building two nuclear reactors by 2020 in collaboration with Russian Federation. This nation did not change its nuclear vision. Vietnam has only reacted to the Fukushima incident by stressing the necessity of ensuring that the highest possible nuclear safety measures are in place. The Indonesian government has also dismissed the Fukushima accident as a strong reason for shelving its nuclear program. Along these lines, on March 18, 2011 the head of nuclear energy development at Indonesia's National Nuclear Energy Agency said that concerns about a disaster like that of Japan's were misplaced because Indonesia’s future plants would use technology far more advanced than that of the Fukushima plant built in the 1970s. On March 30, 2011 Indonesia’s Energy Ministry mentioned that the country’s nuclear policy would not change due to recent incident. Only Thailand and the Philippines have negative or cautionary reactions to the Fukushima incident.

Concerns about the safety of nuclear reactors are legitimate and are being addressed through a variety of policy options. While safety concerns are legitimately raised, this is no argument for dismissing nuclear energy. Only three significant accidents (Three Miles Island, Chernobyl and Fukushima) had occurred since the 1950s in which only Chernobyl caused death, radioactive-related diseases and damage to the surrounding environment. This is a good record for the 441 plants in operation as of 2010. The Fukushima accident only reiterates the need for a strengthened system of national, regional and international emergency preparedness and response as well as for strengthened cooperation among national regulatory authorities and among relevant international organizations.

6.5 Considerations for Implementation of Rooppur Nuclear Power Project in The Post-Fukushima Era

It has realized that the fundamental major reasons for the continued interest in nuclear energy in the post-Fukushima Era is still valid across the Asian countries. The incident of Fukushima nuclear power plant is an unfortunate event. This accident does not conclude that nuclear energy is totally unsafe. Reflecting global realities, most of the nations of this region have long considered nuclear energy as a necessary component of the region's sustainable energy mix.

Bangladesh is an energy-starved nation with limited resources. Thus, the country requires an energy-mix diversification to improve its energy security to ensure access to quality electricity to a quarter of urban and over three-quarters of rural areas. To reach the outlined targets and milestones for enhancing generation capacity to 20,000 MW by 2021; the option of nuclear energy is inevitable for the country. Following the paths of our regional countries, Bangladesh should implement its decision for introduction of 2000 MW nuclear power generation to evolve a justifiable, secured and reliable electricity generation mix supportive to transform the country into a technology based middle income level nation by 2021.

The first nuclear power plant to come into operation usually takes 5-6 years for construction and commissioning. The early decision on construction to build the nuclear power plant at Rooppur is unlikely to solve the existing crisis but the introduction of nuclear power generation will ensure energy security in the mid to long-term future and also open a new dimension in the advancement of science and technology. Starting construction of Rooppur Nuclear Power Plant (RNPP) has become mandatory for energy security reasons.

For a safe and secured implementation of RNPP, Bangladesh needs to establish an effective independent nuclear regulatory authority for integration of nuclear regulatory constraints for realization of a safe nuclear power project site, selection of a inherently safe reactor and developing procedures for attaining of the safety goals of the defense-in-depth levels.

It has become essential for Bangladesh to undertake a comprehensive program completion of relevant engineering study for design and documentation for construction of RNPP in a safe and secured manner. A systematic study in the areas of geodesic and topographic; geotechnical and seismic; geology and hydrogeology; aero meteorology and ecology are essential for designing the engineering parameters have become essential for designing nuclear reactor appropriate for Rooppur site. The identified vendor can play a significant role in determining the site specific engineering parameters. Bangladesh should consider seriously for starting training program for the personnel and experts for construction and operation of the Rooppur nuclear power plant from the vendor sources.

Various types of generation III or generation III+ pressurized water reactors (PWR) are now available and the most common are the European Pressurized Reactor of Frampton and Siemens, France; AP-1000, USA; Korean PWR-1400 and Russian VVER-1000 and VVER-1200 etc. Among the GEN-III reactors, the advanced versions of this VVER-1000 have been built at Taiwan in China and are being built at Kudankulam in India. A generation III or generation III+ PWR with advanced inherent safety features, four safety barriers, multi-redundant safety trains, and passive engineering safety systems, complimented with the latest safety codes for severe accident prevention and even capable of tolerating any severe man-made or natural events namely seismic events, tsunami, flooding and other natural events. Bangladesh is seeking cooperation from the identified vendor country to build an inherently safe nuclear reactor at Rooppur. Bangladesh is seeking cooperation from the identified vendor country to build an inherently safe nuclear reactor at Rooppur. The completion of construction and commissioning of two units of 1000 MW(e) capacity each by 2020 could contribute about 10% of the total energy mix for power generation.

CHAPTER 7: BANGLADESH

Background and Present Organizational Structure of the Electricity Industry of Bangladesh

The universal feature of the organization structure can be considered as visible structure, as described in terms of dimensions such as centralization of decision-making, ownership pattern, standardizations of procedures, extensive use of written rules and regulations, specialization of roles and functions. Current structure of Bangladesh's Electricity supply industry also has the universal feature of a typical organization.

7.1 Initial ownerships

Electric power generation was started in 1901 in the then Dhaka city of Bangladesh (the then Bengal under British rule) by a personal initiative (BPDB, 2010). The public sector entered into the industry when the government established improvement of power sector Electricity Directorate in 1948, Water and Power Development Authority (WAPDA) in 1959 for further development of the electricity supply industry. After the emergence of Bangladesh in 1971 the Government created Bangladesh Power Development Board (BPDB) in 1972 (BPDB, 2010). The Government started major reformation in this industry by establishment of Rural Electrification Board (REB) in 1977, Dhaka Electricity Supply Authority (DESA) in 1991, and Dhaka Electric Supply Company (DESCO) in 1998 (Malek, 2004).

7.2 Present structure of the industry

At present electricity supply industry of Bangladesh is controlled by the Ministry of Power, Energy, and Mineral Resources (MPEMR) (Sarkar*et al.*, 2003). The ministry controls this industry through Power Division and Power Cell, which were established in 1998 to regulate, to manage, and to lead the electricity supply industry reform programs (World Bank, 2001; Sarkar*et al*, 2003). State-owned 'Power Grid Company of Bangladesh (PGCB)' is responsible for transmission only and electricity generation and distribution activities are opened to private, public and foreign involvement, although Government owned bodies are still dominating (Sarkar*et al.*, 2003). An autonomous body named 'Energy Regulatory Commission', that has the authority to issue licenses, ensure compliance with license conditions, and set tariffs, was established in 2003 (World Bank, 2003).

7.3 Electricity Crisis

Bangladesh electricity supply industry is controlled by the centralized bureaucratic system of the Ministry of Power, Energy, and Mineral Resources (MPEMR) and its subordinate organizations

Power Division and BPDB. It is believed that the organizational inefficiency along with other factors is responsible for the current electricity crisis.

7.4 Organizational structure and Reform Policy

Kerr and Savelsberg (2001) argue that reformation is done by the state for welfare of the people. The locus of responsibility for welfare is refocused in what we see as part of a broader new social agenda which encompasses changed roles, expectations, rights and responsibilities for individuals, organizations, and governments (Kerr and Savelsberg, 2001). Bangladesh government has kept the electricity business in its jurisdiction with a view to serve the mass people either in the name of corporate body or of company as this industry has an immense social, political and economic importance. As a result Bangladesh electricity supply industry is highly centralized within the bureaucratic system, although private participation is there (Alam*et al*.,2004). Tayeb (1994) discusses that, high degree of centralization means all the decisions are taken at the top of the organizational hierarchy. In this situation the employees cannot express their opinions and it does not reflect the consultations and information exchange (Tayeb, 1994). In Bangladesh all the decisions are taken by the cabinet and the ministry without consulting with the stakeholders.

7.5 Privatization and Public-Private-partnership

Williamson (2002) discusses that, the main rationale for privatization is the belief that private industry is managed more efficiently than state enterprises, because of the more direct incentives faced by an organizational manager who either has a direct personal stake in the profits of an enterprise or else is accountable to those who do. But, in Bangladesh public-private-partnership or privatization take place in the case of urgency and emergency rather than increase efficiency of the electricity supply industry (Gratwick and Eberhard, 2008). Independent Power Producers (IPPs) take part in electricity generation under privatization and private-public partnership policy of Bangladesh government at the moment when government funds are not available and crisis in electricity supply becomes acute. Although Bangladesh adopted electricity supply industry reformation policy and the private sector power generation policy in 1996 to encourage private investment in this industry (BOI, 2010; World Bank, 2003), it takes a long process for approval of these IPPs projects due to political influence, corruption and inefficiency.

7.6 Electricity crisis due to organizational weaknesses

Electric supply industry of Bangladesh subsidizes its residential customers as well as its commercial and industrial customers, although the industry is not able to meet their operational costs (Khan, 2003). Khan (2003) suggests that, the Government of Bangladesh (GoB) funds to Rural Electrification Board (REB) to meet the revenue deficit and the operational losses. REB and DESA in Bangladesh also receive power from BPDB at subsidized rates. Temple (2002) estimates that, in the year 2002, the average cost of electricity supply was taka 3.08 per kWh whereas, the average selling price of BPDB was below its cost of supply, providing a total subsidy of 12170 million taka to its customers in the year 2002. The losses of BPDB have been attributed to mainly three factors: Low Average tariff, high system losses of (including pilferage, non-billing, non-payment of bills, etc) and low rate of bill recovery (ADB, 1997; Rahmatullah, 2001).

7.6.1 Inefficient organizational management

In view of the fact that BPDB has been in losses, unable to recover its operation cost through sales revenue, the subsidy to REB come from public funds rather than cross-subsidization from BPDB's other customers (Alam*et al*., 2004).Alam*et al*. (2004) argues that, these losses implied that allocation to BPDB by the government could not be fully utilized for capital investment in expanding electricity infrastructure. Also it is likely that this affected the available resources with the government for allocation to the rural electrification program (TIB, 2007).

7.6.2 Corruption

Klitgaard (1988) defines corruption as "the abuse of office for personal gain". In Bangladesh electricity supply industry corruption takes many forms, ranging from grand corruption – the capture of high office of government by elites and the uses of these offices for private gain – to "petty" corruption – the use of bribes or other "facilitating payments" to provide services, bend or break laws (TIB, 2007; Azfar, 2002; Johnston, 1996) . TIB (2007), World Bank(2003), Newbery(2006) & Smith(2004) think Bangladesh electricity supply industry suffers from all sort of malpractices and inefficiencies, particularly 'corruption'. Ahmad (2007) argues that, corruption takes place because of inadequacies in existing public management systems as well as in social and cultural role
www.ccsenet.org/eer Energy and Environment Research Vol. 1, No. 1; December 2011
Published by Canadian Center of Science and Education 17
of communal bonds and kinship ties within social framework'. On the other hand Mauro (1993), opines that, 'speed money'or 'bribe' helps to conquer the 'bureaucratic red tape' works as motivation for the industrious government employees. Due to the alleged corruption in the electricity supply industry the present Prime Minster and ex-Prime Minister along with their political and bureaucratic colleagues were arrested and they are still facing the court (Bangladesh Awami League, 2010).

7.6.3 Weak governance: Theft and lack of accountability

Accountability covers the issues such as, making the elected representatives to answer for their policies to the voters, making the public servants answerable for their mistakes and seeking redress from government agencies and officials by the member of public (Mulgan, 2000). Mulgan (2000) suggests that there should be a relation between accountability and efficiency and accountability leads to responsibility for political and managerial aspects. Laking (2001) and Khan (2003) argue that, the main form of corruption in Bangladesh Power Development Board (BPDB) and Dhaka Electric Supply Authority (DESA) is system loss and the employees of these organizations are responsible for that loss. System loss occurs mostly due to the theft of electricity by unauthorized connections and unpaid bills and the employees of these organizations assist these activities (Smith, 2004; Khan, 2003; Laking, 2001). Engineers of the electricity supply industry oppose the reformation process as their professional body named, 'Institution of Engineers in Bangladesh (IEB)' that is controlled by the political leaders, is partly against the reformation process in this sector (Bhattacharyya, 2003; IEB, 2000). Hill and Lynn (2004) demonstrate that, political actors who pursue their interests through the hierarchical structures of national political institutions control over the officers and organizations having the administrative authority and thus the staffs are not formally accountable to anyone.

7.7 Other weaknesses

Apart from the organizational inefficiencies there are some other factors those are considered as equal responsible for the current electricity crisis.

7.7.1 Wrong policy

Governance framework has the power to make policy and its implementation quite different from reformers' intentions (Boyne *et al*. 2003). Forbes *et al*. (2004) suggests that different levels of governance influence one another, that is, that the organization of governance impacts what, how, and for whom public services are provided. Public managers control formal structures and authority below the level of national policy making, other discretionary choices by public managers, and the characteristics of service provision (Forbes *et al*., 2004). TIB (2007) finds that due to the indecision of the Power Division of Bangladesh in policy formulation process some proposed power plants both in the public and private sectors could not start its operations on time and thus the crisis has been deepen in these days. On the other hand wrong site selection and wrong policies to build new power plants are also responsible for the delay (TIB, 2007).

7.7.2 Insufficient Government funding

USAID-SARI/Energy (2007) finds that Bangladesh Government had insufficient fund for electricity supply industry since its emergence as electricity generation, transmission and distribution require large financial investment. Bangladesh's electricity generation plants have been constantly incapable to meet system demand since 1990s (Newbery, 2005). Newbery (2005) argues that, shortages of government funds for electricity generation plant maintenance and for installation of new plants have created this acute problem in Bangladesh.

7.7.3 Inadequate public-private investment

Bangladesh started 'privatization' and 'public-private-partnership 'in 1994, consulting with the World Bank and Asia Development Bank (ADB, 2001). MacEwan (2002) argues that, as the private company earns enormous profits for its owners, 'privatization' is not always suitable and it is particularly tricky when it swaps an inefficient government monopoly. (Newbery, 2006) thinks that, Bangladesh have been more successful than India in continuing to attract foreign private investment, although it was the most corrupt country in the world till 2005.On the other hand Bhuyan (2009) argues that, although Bangladesh adopted 'private sector generation policy' in 1996 and declared its vision in 2000, it has not received significant amount of investments in this sector ever after a decade. Experts, businesspersons, donors think there are still scope to invest in Bangladesh electricity supply industry ("Enough scope to invest in power sector……", 2010).

7.7.4 Long term absence of government oversight

Womukonya (2003) , TIB (2007) and (Bhattacharyya, 2007) identify many causes of the crisis those are not properly over-sighted by the government over the years, although those are creating current electricity crisis: 1)
www.ccsenet.org/eer Energy and Environment Research Vol. 1, No. 1; December 2011
18 *ISSN 1927-0569 E-ISSN 1927-0577*
Strong labor unions but lower public-sector wages; 2) Outdated and robust machineries and plant design; 3) Inferior quality of incoming electric power; 4) Poor maintenance and weak system of metering customers; 5)Illegal connections, tampered meters and uncollected bills ; 6)Weak legal measure for unpaid bills;7) insufficient fund for maintenance and investment;8)Demand exceeds capacity and distorted tariffs; 9) High subsidies. Although Bangladesh has a strong and effective act, "Electricity Act, 1910" to prevent electricity theft and to collect unpaid bills, it is not enforced properly due to malpractice and negligence of court (TIB, 2007; Smith, 2004). TIB (2007) opines lower-wage, but strong labour union (CBA) causes corruption within an organization.

7.8 Other Responsible Factors: Not Only the Organizational Inefficiency

Roles of the politicians, civil bureaucrats as well as the private investors are also responsible for the electricity crisis. Boyne (2003) finds seven types of service performance indicators: quantity of output, quality of outputs, efficiency, equity, outcomes, value for money, and consumer satisfaction. However, Forbes *et al*. (2004) argues that, political-system interactions in principle might influence government performance that offers several potential advantages and disadvantages in the design and analysis of the determinants of public organization performance.

Politicians' role

Public organizations are more directly open to political influence than private organizations. But public organizations are not equally open; rather, it is important to be aware of the degree of organizational self-containment (Simon & Thompson, 1991, p. 42). Political corruption becomes a systemic feature of information age politics. Since character assassination needs some substance from time to time, systemic political corruption provides ample opportunity, as a market of intermediaries is created to leak and counter-leak damaging information (McNeil, 1978). In political, corruption is devoted primarily to the public sphere in which political actors operate (Heywood, 1997). Bangladesh always faces extremely confrontational, non-cooperation, partisan politics and almost all the parties have been blamed for corruption in power sector (Bhuyan, 2009; Bhattacharyya, 2007). Moreover, present bipolar political setting and the hatred politics between ruling alliance and opposition alliance lead to paralyzing the roles of the government (Bhattacharyya, 2007; Economist, 1999). In this crisis the same situation is prevailing and ruling alliance, including the Prime Minister is blaming previous government alliance (present opposition alliance) for the current electricity crisis(Bangladesh Awami League, 2010).

Civil servants' activities

Forbes *et al*. (2004) argues that staff satisfaction, performance-related pay, personnel stability, job security, and staff morale act as variables for better performance of the civil servants. Transparency International, Bangladesh survey carried out in 2000-2007 found that government losses revenue greatly due to the corruption of the civil servants in electricity supply industry and in the ministry (TIB, 2000; TIB, 2007; Khan, 2003). Recently the Prime Minister of Bangladesh blamed the bureaucrats for the backdrop of a dull rate of implementation of the development projects including the electric supply sector (Hossain, 2010). In a conference, experts of electricity sector, intellectuals, businesspersons, other elites also criticized the bureaucrats saying, in Bangladesh a power project, public or private, needs to hurdle over at least five major committees for getting approval, which sometimes takes years under the existing process'("Lengthy process……", 2010).

Role of private investors

Privatization can be very constructive where it results in increased competition, and useful where it eases fiscal pressures, but public service is always inferior to private acquisitiveness as a motivating forces (Williamson, 2002). Williamson (2002) investigates that, under certain circumstances, such as where marginal costs are less than average costs ,it is too complex to be easily compensated by regulation (for example, in the case of electricity supply) and thus he believes public ownership is preferable than private enterprise. But in the case of Bangladesh private investors are also selected among the politicians of the ruling party (TIB, 2007). As a result inexperienced investors creates problem in building new power plants.

Activities of parliament

Bevir*et al*. (2003) argues that, the reform (NPM) processes ensure the parliamentary debates and questions, committee hearings in most of the developing nations as well as Bangladesh. The World Bank (2003) praises the role of Bangladesh Parliament named, 'JatiyaSangsad' that it helps to pass the electricity reforms related acts. Khan (2003) asserts that, The JatiyaSangsad (parliament) should be the focal point of all activities in a parliamentary democracy. He further says that the parliament has become the medium for passing bills for ruling government (Khan, 2003). Although Khan (2003) says, the Parliamentary Standing Committees do not work effectively, the electricity crisis issues were discussed several times and the PM along with her other colleagues placed the current status and strategies of the crisis mitigation in the parliament ('1,200 MW more power…..', 2010). Again, sometimes the ruling party does not want to discuss the electricity crisis issues, even though the opposition party demands ('JS SESSION ROUND-UP……..', 2010) . So, Parliament is also politically driven and not playing any vital role for this crisis.

World Bank (2003) identifies that, due to high system loss, large account receivables, the poor management and inability to rationalize tariff rate and introduce other reforms, concessional loan for the power sector from the multilateral development partners was not available. Consequently, needed investments for generation, transmission and distribution of electricity could not be made. The losses to BPDB in Bangladesh also adversely affected availability of financial resources from multilateral institutions as they withdrew from financing the power sector in Bangladesh (Alam*et al.*, 2004).

7.9 Government's Strategies to Meet the Crisis: Impact on the Organization

The cabinet of Bangladesh government and the ministry have taken some immediate strategies as well as long term strategies to overcome the electricity crisis.

Immediate strategies

The Bangladesh government and the Prime Minister have taken some instant measures to reduce social unrest and dissatisfaction: Prime Minster and her cabinet rapidly approved some huge projects that are also have allegation of corruption, without following the rules and laws ("PM approves emergency power plant……", 2010).Quick Rental Power Plant project have been introduced and Power Division, BPDB carried out decisions of shutting down some fertilizer factories and diverting gas for power generation, rationing the use of air conditioners in private homes/offices, 1 hr electricity outage every alternate hour ("PM Orders 1 hr Outage ………", 2010). All these were contingency approach of the Ministry, Power division and BPDB though no measures have been taken to enhance organizational efficiency and to stop political interference.

Long-term strategies

The Cabinet of Bangladesh government and the power division of the ministry have taken some immediate but long term strategies to mitigate current electricity crisis. Some of the mentionable strategies are: project to build ten "peaking power plants" and project to modify and renovate the old generation units which will produce electricity in 2011 ("Cabinet body approves 3 rentals ………", 2010). Bangladesh is going to install a nuclear power station with the help of Russia and going to import electricity from India, Nepal, Bhutan and Myanmar ("Dhaka and Moscow sign nuclear….", 2010).

7.10 NECESSITY OF DIVERSIFIED ENERGY MIX FOR BANGLADESH

Bangladesh is a low energy-consuming nation. Major source of our primary energy is natural gas. It is considered as one of the driving forces of the economy. The concept of applying an energy-mix was absent in the energy and power sector. At present, more than 70% of the country's energy needs depend on indigenous gas and about 88% of the power plants are run by gas. Without making any realistic estimation, it was thought by the concerned that "Bangladesh is floating on gas" just about one decade back. But the reality is that the prevailing energy crisis is partly due to unjustifiable overwhelming dependence on gas. Now, the total gas-based installed power generation capacity could not be utilized due to lack of adequate gas supply. Even more worrisome is the fact that the reserve of this indigenous primary fuel supply is getting so scarce that it is forcing severe measures like shutting down fertilizer factories, rationing gas supplies for household and transport uses and keeping idle installed power units. Realizing the limitations in the reserve potential as well as constraints in extraction and supply, the government suspended new gas connections to the industrial sector since 2009 and to the households since July 2010. The embargo on new connection may continue until gas scarcity mounts. Moreover, the new homeowners are being encouraged to use liquefied petroleum gas (LPG) cylinders for cooking in order to reduce the dependency on natural gas.

Bangladesh should acknowledge its limited reserve of natural gas. The maximum extractable reserve (proven + probable) is about 20.50 TCF (Trillion Cubic Feet) in which more than 9.00 TCF has already been consumed. Considering in line with the Vision 2021 of the present government, to implement the target of producing 11500 MW of new electricity by 2015 and recalling the average rate of consumption of gas of the last 17 years as well as sector-wise annual demand, it can easily be estimated that an additional 6.5 TCF gas will be required by that period and the proven reserve will be exhausted. Moreover, the existing gas deficit against the national demand on a daily basis is expected to increase further in the future. A full-scale gas exploration has become essential to increase the reserve potential of this resource; however it is yet to mature. Thus, the prevailing crisis will be deepening unless a greater share of other fuels is included in the energy mix urgently.

At present, there is no immediate available option for alternative of indigenous gas to meet the country's base-load power requirements. The most potential alternative option is our indigenous coal. Large reserves of high-quality coal containing low sulfur have been discovered in the northern areas of the country. Total in-place proven geological reserves is about 1,000 (one thousand) million tons. Among five discovered coal mines, the Boropukuria coal mine has only started commercial production by using underground mining method from September, 2005 with the annual target of 1 million ton of coal extraction. A 250MW power plant has been running by using the coal. This coal, if developed in a sustainable manner with proper attention to social and environmental safeguards, can support a significant part of the growing energy and electricity demand in the mid-to long-term future as an alternative fuel supply option in our country. Thus, quick finalization of coal policy and formation of coal extraction plan consistent with the national demand is essential for building base-load power plant and also using it in the industries as a source of energy.

Although there are enough reserves of coal in the country, there remains anxiety for the extraction methods and the technological security. The geological condition as well as the economic, social and environmental constraints on extensive open mining extraction from all discovered mines of an over-populated fertile agricultural land area remains an obstacle to large-scale coal mining. These issues need to be addressed rationally. The indigenous coal can supply a part of the total energy demand of the near to long-term future. Additional fuel options must be considered. There is no more economic and environment friendly potential hydro sites in Bangladesh. The potential hydro resources are almost fully exploited. The resource potential of other form of renewable energy, namely wind energy can make some inroads but its potential is mainly limited to coastal areas and offshore islands with strong wind regimes. These coastal settings afford limited opportunities for wind-powered pumping and electricity generation. The country has limited reserves of natural gas liquids with some potential for finding oil deposits. However, exploratory activities done so far have not resulted in any significant oil discoveries. Thus, virtually all-liquid fuels are imported.

Renewable energy only in the form of traditional biomass are contributing about 35% of the national energy consumption especially in the rural areas. Over dependence on this noncommercial traditional energy is causing reduction of the area of forest that results the environment changes along with enhances desertification and deforestation process. To reduce deforestation and desertification process and arrest environment degradation, alternate sources of biomass will have to be popularized among rural people. It is also felt that the supply of biomass fuels might have attained its saturation level or even is being supplied beyond their sustainable level (for example over-use of certain agricultural wastes are depriving the soil of vitally important micro nutrients). It is generally believed that the renewable energy can be converted into modern energy with available and evolving technologies that can make significant contributions to the total energy supply. For example, the potential of solar energy is quite high; although current utilization is minimal. Therefore, it must be realized that a part of the demand for electricity should be addressed through the use of solar photovoltaic (PV) systems especially in the off-grid region, remote and rural areas. Unfortunately, the solar photovoltaic or fuel cells, etc are yet to be developed for commercial applications.

Considering the present recoverable reserves of fossil fuels (gas and coal), limited potentials of renewable (hydro and wind) and future energy demand scenario of the country, it is easily understandable that Bangladesh needs to consider for imported energy either in the final energy form (electricity) or primary energy fuels to extend a reliable energy envelope to all citizens and to use energy to promote economic and social welfare with the least impact on the environment. Over the years, the country is actively considering energy cooperation with neighbors for energy trade and energy infrastructure development. But with due consideration of the existing demand-supply scenario of neighboring countries and their future demand growth scenario as well as geographical location, it apparently seems that the option of electricity import is very limited. Therefore, imported energy fuels have to consider for our energy mix.

Internationally, the options of imported energy fuels for power generation are limited to petroleum products, coal and nuclear. Coal is identified as the one of the main sources for emission of green house gases and the associated environmental degradation. Huge additional cost related to infrastructure development is necessary for importing and transporting of fossil fuels namely coal to the plant site. Moreover, the price, trading strategy and supply scenario of the global coal market may be affected after the post-Kyoto period. If the country considers only coal as imported energy option, there will be a gradual phase transition in fuel-based power generation from its existing gas-based capacity to the coal-based one in the future. From the lessons learned from the existing mono-fuel based energy sector development policy, we must recall that a single fuel-based energy sector can neither support the sustainable development nor guarantee of energy security in the context of economic and environmental dimensions. In case of oil, availability and price of petroleum products in the international market are now subjected to severe uncertainties. Moreover, the recent political developments in the oil/gas-exporting countries will certainly influence the dynamics of supply strategy and trading scenario in international oil market in the mid to long-term future. Thus, it is not prudent to depend on oil for power generation.

On the other hand, electricity by nuclear energy has been producing since 1950s and hundreds of nuclear power reactors are now in operation. The nuclear power has achieved the status of a mature technology. It has become the most viable component for electricity production for a nation with a limited energy resource. The advantages of this option include: lower operating cost, absence of green house gases, and requirement of less fuel and hence less sensitivity to fluctuations in the price of fuel. Moreover, the spent nuclear fuel is being reprocessed today and nuclear power is made available for process heat. Unfortunately, still there is a growing fear about the standards of safety of nuclear reactors and the safety concerns still remain one of the highest barriers in introduction and expansion of nuclear power generation. However, it is the reality that there has never been any public harm from any reactor licensable in the West or anywhere today. Since the 1950s only three significant accidents had happened that released radioactive materials. The accident of Three Mile Island, USA in February 1979 did not cause any harm to humans and the environment due to the containment structures of the reactor. Due to absent of containment structure the accident of Chernobyl (USSR) in April 1986 has caused significant harm to human and environment. The accident of Fukushima nuclear power plant, Japan in March 2011 has developed as a result of violent shaking from the historic magnitude-9.1 earthquake and the subsequent tsunami. The crisis has began when the plant experienced cooling problems due to damage of the stand-by-diesel generators due to tsunami. Exaggerated reports on the Fukushima accident have portrayed it as another Chernobyl. This unrealistic picture has been the result of various factors and create fear among many people regarding the accident's negative effect on human health and safety, however, to date, neither the Japanese nuclear authorities nor the International Atomic Energy Agency (IAEA) have reported any deaths, injuries or medical complications caused by radiation exposure among the Japanese population.

It is important to note that the Three Mile Island and Chernobyl accidents had focused attention on a global issue of nuclear safety and the nuclear industry has been fostering a global nuclear safety culture that draws on almost 13,000 reactor-years of practical experience. We must realize that the accident of Fukushima was not technologically faulty reason, the plant survived against an unprecedented 9.1 magnitude earthquake. The plant's containment structure prevented the release of radioactive material, but a leak through the cooling system. The amount of release of radioactive material in a much smaller area in the plant's vicinity would be about 10% of that of Chernobyl. The Fukushima accident's main cause could be easily fixed by installing reactor cooling systems at an elevated platform with due consideration to tsunamis. The Fukushima accident is not a proof of nuclear energy being unsafe but it actually showed how containment structures could prevent disasters like Chernobyl. A realistic assessment of the Fukushima nuclear plant will be made by the IAEA soon. The Fukushima accident reiterates the need for a strengthened system of national, regional and international emergency preparedness and response as well as for strengthened cooperation among national regulatory authorities and among relevant international organizations.

Considering the existing recoverable reserves of indigenous gas and coal, limited resource potential of hydro and wind, insignificant electricity trading opportunity with neighbors, perspective dynamics of the international fossil fuels market in the post-Kyoto period and near to long-term impact of the recent instability as well as changing of governments and armed conflicts in many oil/gas-exporting countries and premature stage of other form of renewable Bangladesh should consider nuclear power as a vital component of the country's energy mix. This proven technology could be a safe, secure, reliable, economic and sustainable source for producing electricity. Thus, due attention will be given for implementation of Rooppur Nuclear Power Plant to cater to the future energy needs of the country.

CHAPTER 8: ROOPUR NUCLEAR POWER PLANT PROJECT

BACKGROUND:

The proposal for building a Nuclear Power Plant in the western zone of the country was first conceived in 1961. Since then a number of feasibility studies were conducted, each of which established that the project was technically and economically feasible. The then Pakistan Government gave formal approval for 70 MW, 140 MW and 200 MW plant in 1963, 1966 and 1969, respectively.

In 1978-79, the government considering the role of nuclear power in meeting energy demands of the country, the government conducted a feasibility study on the project. The study clearly identified nuclear option as appropriate and viable for Bangladesh. Following liberation the ECNEC had approved the PP for a 125 MW nuclear power plant in 1980. The follow-up study, conducted in 1986-87 also reconfirmed the findings on technical, economical and financial viability of the project, and two units of 300 MW were recommended for implementation. Pre-implementation phase activities for construction of two units of 600 MWe reactors on the Rooppur site with a time lag of two years were carried out systematically by BAEC with the support from IAEA and other national organizations during the period 1999 - 2003.

SITE SAFETY REPORT OF ROOPPUR NUCLEAR POWER PLANT

The Site Safety Report of RNPP finalized in 2002 incorporating all safety related parameters was reviewed by IAEA. During 1999-2002, some additional investigations for the Site mainly in the areas of Hydrology & Morphological Analysis, Subsoil Investigation, Seismic Studies and Radiological Dispersion Studies have been carried out as per IAEA recommendations. The Site Safety Report is being updated in collaboration with the IAEA.

PREPERATION OF DRAFT BID DOCUMENT

The draft of bid invitation documents was prepared in 2002. The draft is being updated in collaboration with IAEA.

GOVERNMENT COMMITMENT

The Implementation Committee (now known as the Cabinet Committee on Rooppur Nuclear Power Project), was formed headed by Honourable Head of the Government in 1992 to accelerate the implementation process of the project. A Technical Sub-Committee was formed in 1995 headed by the Principal Secretary. During 1992–2000, several meetings of the Implementation Committee were held chaired by the Head of the Government and decisions were taken to expedite implementation of the Rooppur Nuclear Power Project (RNPP). It was decided that in the first stage, a 600 MW nuclear power plant is to be constructed on the designated site, which is to be followed by a repeat unit on the same site. Accordingly pre-implementation phase activities of 600 MW RNPP were completed. The government has approved an ADP project for the 2008 – 2011 cycle entitled, "Accomplishment of Essential Activities to Implement 600 MW(e) Rooppur Nuclear Power Plant" to accomplish preparatory work for the construction of a medium size (600-1000) NPP.

COMMITMENT OF IAEA AND RECENT DEVELOPMENT

The Bangladesh Delegations to the General Conference of the IAEA had made requests to the Director General of the IAEA to support and provide assistance for implementation of the decision taken by the Government in 2007. The DG, IAEA assured Bangladesh of the support of the Agency. At an initiative a Mission from Bangladesh visited the IAEA Headquarters in Vienna in May, 2008 to identify the areas of the Agency's technical support for implementation of RNPP.

The IAEA agreed to provide assistance to Bangladesh for finalizing Site Safety Report, preparation of Bid Document, updating National Action Plan for RNPP and developing capacity building for early implementation of RNPP as well as comprehensive national legal frameworks through HRD programme and expert services under the IAEA's TC programme. The IAEA has already approved a Technical Assistant (TC) Project on Rooppur Nuclear Power Project for the cycle 2009 – 2011.

FINANCING

Financing is the main challenge confronting implementation of RNPP. Nuclear power plants entail comparatively higher capital investment, yet one redeeming feature is its very low fuel cost, which makes the life cycle power generation cost cheaper than its conventional alternatives. In fact the incremental capital cost can be easily recovered from the saving on fuel cost alone in a matter of 3-5 years. This obvious advantage may make the task of debt servicing comparatively easier. Other advantage of nuclear power is its spin off benefits. That entail, acquisition of a whole range of technologies with quality compatible to the demands in the global market.

The current overnight cost for a Medium to large size NPP is about US $ 1500 per KWe. The cost includes owner's cost like training of O&M personnel up to decommissioning of the reactor.

The main feature of nuclear power is that the whole plant can be divided into a number of individual packages that can be supplied from diversified sources. This would help splitting the financing burden into a number of partners or a number of companies. For example a 600 MW nuclear plant would cost about USD 1 billion. About 30% of total project involvement (mostly civil construction works) can be undertaken locally funded by GOB. The whole supply can be divided into four packages such as (a) Nuclear Island (30% of the total), (b) Conventional Island

(25%); (c) Balance of the System (20%) and (d) Civil construction (25%). It may be expected that the main supplier will be able to mobilize fund for Nuclear Island as suppliers' credit or commercial credit or a combination of the two. There are diversified sources of supply of items, systems, sub-systems and components of Conventional Island and Balance of the System package. Individual suppliers may help procuring finance as suppliers' credit or commercial credit or a combination of the two. In case of nuclear, the capital expenditure usually follow the so-called 'S' Curve, i.e. annual phasing is likely to be 10%, 30%, 25%, 20% and 15% as shown in Figure 1. Thus, the financing burden for individual supply source per annum will be within tolerable limits. Financing package will, therefore, have to entail substantial in innovativeness, intensive dialogues persuasions and possibly involvement of individuals at the high levels of the governments concern. The preferable type of contract may be the turn-key or split package with total responsibility lying with the main plant contractor.

The issues of global climate change and the question of availability and uncertainty of oil price, the nuclear industry worldwide is now growing up. It may be reasonably expected that the manufacturers would join hand with the Government of Bangladesh in mobilizing funds from the international capital market under present global changed attitude towards nuclear power.

Traditionally, the first nuclear power plant is financed through bilateral arrangements. The financial conditions for borrowing loans for RNPP construction are very important. Bangladesh needs to identify the financing modalities for implementation of RNPP. To reduce the overall risk in implementation, Bangladesh may request the government of the nuclear technology vendor countries to share some risks for the NPP exported technologies and NPP Project finalization.

The RNPP is identified economically viable through several feasibility studies. Credible government support in the form of loan guarantee, long-term power purchasing agreement, and production tax credit based on energy supply security objectives are vital for implementation of Rooppur Nuclear Power Project.

JUSTIFICATION

Nuclear power generation is considered as most sustainable viable energy option. The advantages of this option include absence of green house gases, lower operating cost, less fuel and hence less sensitive to fluctuations in the price of fuel. The capacity of continuous and equal level power generation make the cost of a nuclear power plant cheaper in spite of its comparatively higher capital cost. The spin-off benefits of the nuclear options are enormous and the process of its implementation will help acquiring various state-of-the-art technologies that will eventually benefit many other sectors of the national economy.

Over the decades, coal and oil have been playing the key role and considered as the largest sources of energy in both developed and developing countries. At the same time, about 16% of global electricity has been generated from nuclear reactors. The options of imported fuel for power generation are limited to petroleum products, coal and nuclear. Among the imported energy options, the availability and price of petroleum products in the international market are subjected to severe uncertainties. Thus, it is not prudent to depend on oil for power generation. However, coal is the vital imported fuel option, but solution to problems of logistics of internal transportation and handling of imported coal would necessitate building additional infrastructures. For example, a 1000 MW nuclear plant would require about 27 tons of low enriched uranium compared to 2.7 million tons of coal and 2 million tons of oil annually, respectively. In case of coal, this is equivalent to roughly 7000 tons of coal per day. Water transportation inland may become uncertain in the lean period. Movement of such a cargo daily by railway (about 150 bogies moving from port inland and the same number of empty bogies shuttling back to transport the next consignment from the port of entry) would put tremendous pressure on the railway network. In addition, in case of coal, the emission of green house gases is a matter of great concern. It is likely that in future a global consensus on limiting green house gases from coal would impose some form of restrictions, such as carbon tax. The future global energy scenario would be compounded with the advent of the global concern on environment that might influence the dynamics of the international coal market.

At the beginning of 2008, 31 nations use 439 nuclear reactors with an installed electric net capacity of about 372 GW to produce 16% of global electricity. Nuclear power's share of worldwide electricity production rose from less than 1% in 1960 to 16% in 1986 and that percentage has held essentially constant in the 21 years since 1986. The US has the maximum number with 103 operating units. France was next with 59, Japan followed with 55 and Russia had 31 operating NPP. Of the 31 countries with nuclear power, the percentage of electricity supplied by nuclear ranged widely: from a high of 78% in France; to 54% in Belgium; 40% in Republic of Korea; 37% in Switzerland; 30% in Japan; 19%t in the USA; 16% in Russia; 4% in South Africa; and 2% in India and China.

Present nuclear power plant expansion is centered in Asia and Eastern Europe. 19 of the 31 units under construction at the end of 2007 were in Asia and 26 of the last 36 reactors connected to the grid were in Asia. India has 17 nuclear power reactors and currently gets about 3% of its electricity. But today India has six reactors under construction and the country's plans for nuclear are even more impressive. Additional, 12 NPPs are in planning stage, for a 8-fold increase by 2022 to 10% of the electricity supply and a 75-fold increase by 2052 to reach 26% of the electricity supply. A 75-fold increase works out to an average of 9.4%/yr, about the same as average global nuclear growth from 1970 through 2004. China, as one of the world's fastest growing economies and the second largest consumer of energy, looking more on nuclear power to distribute evenly its energy sources. There are currently has 11 nuclear reactors in operation, with a total capacity of around 8,000 MW and accounts for less than 2% in the country's total power generation. China has declared its ambitious vision for NPP and currently, it has seven reactors under construction and plans for more twenty-six large sizes reactors to increase the country's nuclear power capacity to 40,000 MW by 2020. There are four reactors are under construction in Korea and three in Japan. Japan and Korea plans for more 12 and 29 reactors, respectively. Among Eastern European countries seven more NPPs are under construction in Russia, two more in Ukraine and 2 in Bulgaria. All of the NPPs are being built in the above-mentioned countries because they make economic sense.

Internationally, the nuclear renaissance is gathering steam from the beginning of this millennium. A turn around in strategy is already evident in USA and UK, where the new policy issues envisage renewing the pledge to build new nuclear power plants in the coming decades. The world's leading industrial nations, the Group of Seven (G7) has unanimously accepted nuclear as one of the potential power sources, which the Group in the past had been unable to agree primarily due to opposition from Germany. The EU leaders at a summit in March 2007 adopted a resolution that included nuclear power as a legitimate means of meeting the EU's greenhouse gas emissions reduction target. Finland has four reactors providing a quarter of its electricity and is now building a fifth and talking about the sixth. Many developing countries like Indonesia, Poland, Thailand, Turkey and Vietnam have strong plans to introduce nuclear power by 2020.

MAJOR HURDLE CROSSED

Bangladesh has made a significant headway in the strive for setting up its first-ever nuclear power plant at Rooppur in Pabna with Russia assuring it of both financial and technological assistance.

"A major portion of the Tk 1,200-1,500 crore estimated expenditure and all kinds of technological support for building the 1,000-megawatt power plant will be given by Russia ," State Minister for Science and Technology Yeafesh Osman told The Daily Star.

The main hurdle of finding a financier for the proposed plant is now over. Terms and conditions of Russia's providing the fund will be discussed at a meeting with government high ups scheduled for January 25, he said.

Last year, Dhaka and Moscow signed a draft agreement on technological support from Russia for building the power plant. This followed a memorandum of understanding (MoU) signed in 2009.

Responding to a question, the state minister said the power plant might also be set up on the basis of build-own-operate-transfer (BOOT). A final deal with Russia concerning the plant is expected to be signed within this year with the aim of commissioning it by 2017.

"The prime minister has asked us to complete all preparatory work so that the deal can be struck during her visit to Russia between June and September," he said.

Yeafesh hoped construction of the plant would begin during the tenure of the present government.

All heavy equipment for the plant will be brought through waterways, he said.

Meanwhile, in the last three years the government has made considerable progress in meeting the requirements specified by the International Atomic Energy Agency (IAEA) for building the long-cherished nuclear power plant to resolve the country's energy crisis.

A number of deals, framework agreements and MoUs have already been signed with Russia for peaceful use of nuclear power, technology transfer, creating human resources to run a nuclear power plant, supply of required fuel and taking spent fuel back.

IAEA has a set of general guidelines regarding a nuclear power plant. Recently, it gave Dhaka 20 specific suggestions concerning the financier and ownership of the proposed plant, its safety measures and legal framework.

“Safety is our first priority. Officials of Russian state atomic energy corporation and IAEA, who have visited Bangladesh and the Rooppur site, are highly impressed to see our infrastructures,” said Yeafesh.

On safety measure, he said one more crucial deal -- nuclear radiation safety control-- will be signed in the next few months. Under the deal, Russia will fully cooperate with Bangladesh in radiation leakage control. The cabinet recently approved a draft of the deal.

“The planned nuclear plant will be built with modern technology, and there will be no chance of radiation leakage as in Japan's Fukoshima,” he said. The nuclear reactor will automatically be shut down in case of any leakage.

Bangladesh is going to make a law and form an independent regulatory body to carry out IAEA's suggestion of forming a legal structure for implementing a nuke project. The cabinet last month approved in principle a draft Bangladesh Atomic Energy Regulatory Act, which is now being vetted by the law ministry.

The state minister said the draft will be placed at the coming parliament session. And a five-member independent regulatory body comprising experts will be formed after it is enacted.

This body will be the supreme authority regarding the nuclear plant, its operation and use.

Russia will train Bangladeshi engineers and other technical persons for creating necessary workforce to operate the plant. The trainees will work in Russian plants for two years before their assignment in Bangladesh.

Yeafesh said the Russian and IAEA delegations were impressed to see that the research reactor of Bangladesh Atomic Energy Commission (BAEC) at Savar was operating successfully for 30 years. “You have already some people who can be useful for handling nuclear plant,” he quoted an official of the Integrated Nuclear Infrastructure Review mission of IAEA.

While visiting Bangladesh in November last year, the mission concluded that Dhaka met most of the pre-conditions.

BAEC Director DrShawkat Akbar, who is also the project director of the proposed Rooppur plant, said implementation of the nuclear project greatly depends on finalising the financier, ownership of the plant and risk factor management.

The IAEA wants clarity about all this, he said, adding all the issues must be resolved within this year for setting up the plant by 2017.

As suggested by IAEA, the government has to involve various stakeholders and conduct a nationwide campaign so that people are well aware of the project and its risk factor.

A total of 292 acres of land was acquired -- 260 acres for the nuclear plant and 32 acres for offices and residences-- in Ishwardiupazila of Pabna after the then government decided in 1961 to set up the plant. Necessary equipment was also being brought but the ship carrying those did not come to Chittagong port. Instead, it went to Karachi and the project was shelved.

WHY THE DELAY?

It is reported that Russia agreed "to provide as credit 85% of the estimated Tk.12,000-15,000 crore needed for setting up the first-ever nuclear power plant in Bangladesh." Initially $ 500 million will be provided for conducting necessary studies and preparation of the design for the 1,000 MW nuclear power plant. This was disclosed by the officials of the Ministry of Science and Technology (MST) following a visit to Moscow by a high level Bangladesh delegation.

According to the state minister for science and technology, Russia would submit a financing proposal within a month. He further informed that 60 studies would be required for setting up the nuclear plant. So far 12 studies have been completed. The Russian delegation urged Bangladesh to complete the remaining studies in two years though the state minister hopes to complete them earlier.

It may be recalled that Bangladesh and Russia first signed a protocol in May 2009 on peaceful usages of atomic energy. One year later, a framework agreement was signed in Moscow for cooperation in "design, construction and operation of nuclear power and research reactors, nuclear fuel supply, taking back the spent nuclear fuel and nuclear waste management, personnel training …," etc.

Although the framework agreement appears to be sufficient for signing a contract for the supply and construction of a nuclear power plant, several additional protocols were signed subsequently. A primary deal for installing a 2,000 MW nuclear plant was signed in February, 2011, and another deal was signed one year later for providing "advisory support to the Bangladesh Regulatory Commission on regulation, licensing and supervision."

The Nuclear Regulatory Commission is supposed to be an independent body to oversee reactor safety, reactor licensing, radioactive material safety, spent-fuel management, etc. in order to protect public health and the environment. If the Russians become both supplier of reactors and adviser to the regulatory body, the whole purpose of "regulation, licensing and supervision" will be compromised.

As time is passing, we are getting increasingly confused about the actual status of the nuclear project. To start with, we do not understand why we spent three years to sign so many protocols and yet we do not know when we shall sign the final deal for the supply and construction of the nuclear plant. To save time and money, could we not sign just one protocol, instead of so many, incorporating all the required provisions?

We also do not know the basis for estimating the cost of the project as it does not tally with the actual costs of nuclear power plants being sold by Russia to other countries. The estimated cost of Tk. 12,000-15,000/ crore ($1.47-1.84 billion, roughly) for a 1,000 MW plant corresponds to $1,470-1,840 per kW. Russia signed a contract with Belarus last July for the supply of two 1,200 MW nuclear reactors with a price tag of $4,166 per kW and is due to sign another contract with Turkey for four similar reactors at the same per kW cost. Taking this price as a bench mark, a 1,000 MW reactor at Rooppur should cost more than Tk. 34,000 crore. Is there any reason to believe that Russia would favour us by supplying two 1,000 MW reactors at less than one-half of the current market price?

What are the 60 studies needed for the construction of the plant and why should it take two more years to complete them? Could we not have brought all the required studies under one package and started doing them in 2009 in order to complete them by now? If it takes two years to complete the remaining studies and we allow another year for preparation of the project proposal and contract negotiations, it is likely that we would not be able to sign the final contract before 2015, i.e. 6 years after the initiation of negotiations in 2009, though normally it should not have taken more than 2-3 years.

Why is it taking so long to sign the final contract? Do we have a problem of management at the top level? None of the senior level engineers/scientists of the Commission seem to have any previous experience of dealing with nuclear reactor vendors. Moreover, several of them have no nuclear background. What is worse is that the major decisions on the project are being taken by the ministry even though the Commission is supposed to be an autonomous organisation. Under such circumstances, is the government being correctly advised on the Rooppur issue?

The dealings of the past three years suggest that we are not fully prepared in terms of technical manpower and other infrastructure development. We should not forget that both the Chernobyl and the Fukushima nuclear accidents were man-made and the consequences of the Fukushima accident worsened because of faulty or delayed decisions by the top management. The development of a competent team of nuclear experts is, therefore, an essential pre-requisite for initiation of a nuclear power programme.

In addition, there are some safety issues about the Russian reactors which came to light after the Fukushima accident. These issues need to be resolved satisfactorily. As a matter of fact, the delay in the implementation of the Rooppur project may be a boon and not a bane. Our priority task should be to build necessary technical manpower not only for safe operation of the nuclear plant but also for proper management of the project, starting from its initiation to final completion. If necessary, we should recruit experienced nuclear engineers of Bangladeshi origin from abroad and place them at the top management of the project.

Signing a half-baked final deal without full preparations may ultimately prove to be a costly and risky venture. Going slow for a safer reactor appears to be a much better option for us, keeping in mind that both the costs and the consequences of risks can have unimaginable dimensions.

NUCLEAR WASTE MANAGEMENT AT ROOPPUR

NUCLEAR fuel that undergoes fission in nuclear reactors consists of heavy elements like uranium-235, available in nature, and uranium 233 and plutonium-239, both produced artificially from thorium-232 and uranium-238, respectively, in nuclear reactors by interaction with neutrons.

The concentration of uranium-235 in natural uranium is very low, only 0.71%. The rest is uranium-238, a heavier isotope of uranium which does not fission in normal reactors. For use in light water reactors, it is necessary to enrich, i.e. increase the concentration of, uranium-235 to 3% to 4%.

Nuclear fuel requires several stages of processing before it can be put inside nuclear reactors in the form of fuel assemblies or bundles. The uranium ore undergoes milling, conversion to uranium hexafluoride, enrichment and again conversion to its final form -- uranium dioxide.

This oxide looks like a black powder, which is compacted to form small pellets about one centimeter in diameter and of the same height. These pellets are put inside metallic tubes called claddings, which are later sealed to prevent leakage of any substance from inside. The tubes form what are known as fuel bundles or assemblies.

Nuclear fuel does not burn like normal fossil fuels, which produce ash and flue gases. Instead, it undergoes fission inside a nuclear reactor and produces energy and fission products, which may be either solids or gases. The fission products are highly radioactive. The energy is carried away by the coolant to produce electricity. The fission products stay inside the fuel or the sealed cladding.

The fuel assemblies can stay inside a reactor for several years before they are replaced with new ones. The used fuel assemblies, after being taken out of the reactors, are called spent fuel. They produce heat even after they are taken out of the reactor, because of the intense gamma radiation, and need cooling. They are, therefore, stored in a pool of circulating water.

The spent fuel contains some unused uranium-235 and plutonium-239 plus uranium-238, which can be recovered by reprocessing the spent fuel, and can be reused in nuclear reactors. After reprocessing, the recovered uranium is sent for further enrichment.

Mixed with uranium dioxide, the plutonium-239 can be used as fuel after conversion into oxides. The highly radioactive fission products are separated from the spent fuel and stored in sealed and shielded canisters in safe depositories.

Nuclear fuel produces waste at different stages of processing. Some of the waste are radioactive and require special treatment for protecting human health and minimising their impact on the environment.

Radioactive waste is normally classified into three categories, namely low-level, medium-level and high-level waste depending on the amount, types and half-lives of radioactivity.

Half-life is the time taken by a radioactive substance or isotope to lose half of its activity. Half-lives vary from a fraction of a second to millions of years. Radioactivity decreases with time as the isotopes decay into stable and non-radioactive ones. Short-lived isotopes decay quickly whereas long-lived ones decay slowly.

Low-level waste contains small amounts of short-lived radioactivity. It is not dangerous to handle but needs to be disposed of carefully. Usually, it is buried underground, only a few feet deep. If necessary, it can be compacted or incinerated in a closed container to reduce the volume before final disposal. By volume, it consists of 90% of all radioactive waste worldwide, but contains only 1% of the total radioactivity.

The residue after mining and milling of uranium contains very low-level radioactivity and is generally buried in the mines. Depleted uranium (the left-over after enrichment), containing mostly uranium-238, is less radioactive than natural uranium.

Medium-level waste contains higher amounts of radioactivity and may require special shielding before disposal. Worldwide, it consists of 7% of the volume and contains 4% of the radioactivity of all radioactive waste. If necessary, it can be solidified through mixing with concrete or bitumen before disposal.

The short-lived waste from nuclear reactors can be buried like low-level waste, but the long-lived waste is disposed of deep underground. Because of shorter half-lives, both low-level and medium-level waste lose their radioactivity in time and become harmless after disposal.

High-level waste includes spent fuel and the main waste from reprocessed fuel. It consists of 3% of the volume of all radioactive waste and contains 95% of the radioactivity. It is comprised of highly radioactive fission products and some heavy elements with long-lived radioactivity. It generates a significant amount of heat and requires cooling and special shielding during handling and transportation.

If the spent fuel is reprocessed, the separated waste is vitrified, i.e. turned into glass by mixing it with borosilicate glass which is sealed inside stainless steel canisters for storage or disposal deep underground. Liquid high-level waste is evaporated to solids, mixed with glass-forming materials, melted, and poured into stainless steel canisters which are sealed by welding, again for storage or disposal.

If the spent fuel is not reprocessed, all the highly radioactive isotopes stay inside the fuel assemblies, which become high-level waste. Used fuel assemblies occupy about nine times the volume of equivalent vitrified high-level waste which results from reprocessing.

Whether reprocessed or not, the volume of high-level waste is modest. A typical large reactor produces about 3 cubic meters of vitrified waste or 25-30 tonnes of spent fuel per year. Because of its small volume, it is not difficult to store in isolated locations.

The transuranium elements (heavier than uranium) formed inside the nuclear reactors by absorption of neutrons have longer half-lives (thousands of years) compared with those of fission products (about 30 years or less).

It is possible to solve the problem of management of long-lived heavy elements by converting them into fission products with shorter half-lives by transmutation, i. e. irradiating them with fast neutrons in reactors causing fissions. The resulting fission products have shorter half-lives. Disposal of such short-lived fission products will be much easier than the tranuranium elements with long half-lives.

Final disposal of high-level waste is delayed for 40-50 years to allow its radioactivity to decay, after which less than one-thousandth of its initial radioactivity remains, and it is much easier to handle. Hence, canisters of vitrified waste, or used fuel assemblies, are stored under water in special ponds, or in dry concrete structures or casks for at least this length of time.

The final disposal of vitrified wastes, or of used fuel assemblies without reprocessing, requires their isolation from the environment for long periods. The most acceptable method is to bury them in dry, stable, geological formations deep underground, preferably inside abandoned salt mines.

According to available information, Russia is likely to supply nuclear fuel in the form of fuel assemblies for the proposed nuclear power plant at Rooppur, and take the spent fuel back. If this arrangement can be successfully implemented, Bangladesh will not have to worry about disposal of any high-level nuclear waste as all high-level waste, together with the spent fuel, will be transported back to Russia in properly shielded containers.

Bangladesh has to ensure that it gets back full credit for the unused uranium and plutonium that will be transported to Russia with the spent fuel. Russia may, however, charge Bangladesh the cost of handling, transportation and reprocessing of the spent fuel and that of safe storage of the high-level nuclear waste.

In case the spent fuel is not taken back by Russia, Bangladesh will store the spent fuel in a safe location close to the nuclear power plant for the time being. It is now widely believed that the present share of electricity generation through nuclear power will increase manifold in the near future, mainly because of environmental considerations, since nuclear power is the only alternative to fossil fuels now available in large commercial quantities that does not produce harmful greenhouse gases.

As a result, the demand for nuclear fuel will also increase and, consequently, there will be a market for spent nuclear fuel since it contains valuable unused uranium and fissile plutonium which can be recycled in nuclear reactors. Moreover, several new designs of nuclear reactors, which can be fueled by spent fuel without reprocessing, are now under development. This may further increase the demand for spent fuel in the international market.

Handling, storage and disposal of low and medium-level nuclear waste pose no serious problem. Bangladesh Atomic Energy Commission has the necessary expertise and experience to manage such waste and, in fact, has been doing so since the construction of its research reactor in 1986 at the Atomic Energy Research Establishment (AERE) at Savar. There is, therefore, no reason to worry about the management of nuclear wastes from the Rooppur nuclear power plant.

9. CONCLUSION

Energy and electricity in particular, is essential for continued human development and economic growth. It ‘is central to achieving the interrelated economic, social, and environmental aims of sustainable human development’.

Electricity and final energies are not accessible or affordable to more than 1.6 billion people who live mostly in least developed and developing countries in acute poverty and deprivation. The electricity need of these large numbers of deprived and downtrodden people has to be addressed in order to achieve the MDGs.

Electricity is the most preferred form of energy. The growth of electricity is the fastest compared to other energy forms of energy and this will continue in the coming years to meet the economic, health and social need of the expanding global population, particularly in the developing and the least developed countries.

Electricity is produced from primary sources. The reserves of the presently dominant primary sources: coal, oil and gas are maturing. Nature took about three million years to produce these sources. The large use of the fossil fuels is emitting GHG and are resulting climate change as well as irreversible changes in the ecosystem. In spite of the GEF and many international incentives the world will remain dependent primarily on fossil fuels in the coming two to three decades.

"Much of the world's electricity…. is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to remain substantially the same". Climate change resulting from excessive use of fossil fuels and bio-mass put the world biggest challenge in the 21st century.

The world community has to 'develop a multilateral framework for avoiding dangerous climate change under the post -2012 Kyoto Protocol; has to put in place policies for sustainable carbon budgeting – the agenda for mitigation; strengthen the framework for international cooperation and has to put climate change adaptation at the centre of the post 2012 Kyoto framework and international partnership for poverty reduction'.

Nuclear power can address the issues of energy sustainability and climate change. But the problems of safety, security, radiation protection and particularly nuclear proliferation are the issues which the world leaders have to solve with mutual trust and global governance.

Comprehensive assessments and analyses with knowledge and reliable data and actions with wisdom will be necessary to address energy and electricity related sustainability and climate change issues. This is essential for a more stable and livable world, particularly in this age of globalization and information and communication technology and expanding global unrest and terrorism.

Proper understanding and consensus among the parties at stakes on national energy issues from the country's energy reserve/resource base and socio-geo-economic condition are essential for energy security and sustainable development. The planned energy mix has to be optimized in the context of the national needs and aspirations and global perspectives.

The goal is of course achievable if the ethics based strong commitment, mutual trust and active support and cooperation of the world leaders and the multinational economic-giants could be ensured.

10. <u>Annexes:</u>

1. **Annex – I** : World's Proven Coal Reserve
2. **Annex –II** : World's Proven Gas Reserve
3. **Annex –III** : World's Proven Oil Reserve
4. **Annex –IV** : World's Uranium Reserve
5. **Annex – V** : World's Thorium Reserve

Annex- I: World's Proven Coal Reserve

Proved reserves at end 2008

Million tonnes	Anthracite and bituminous	Sub-bituminous and lignite	Total	Share of total	R/P ratio
US	108950	129358	**238308**	28.9%	224
Canada	3471	3107	**6578**	0.8%	97
Mexico	860	351	**1211**	0.1%	106
Total North America	113281	132816	**246097**	29.8%	216
Brazil	–	7059	**7059**	0.9%	*
Colombia	6434	380	**6814**	0.8%	93
Venezuela	479	–	**479**	0.1%	74
Other S. & Cent. America	51	603	**654**	0.1%	*
Total S. & Cent. America	6964	8042	**15006**	1.8%	172
Bulgaria	5	1991	**1996**	0.2%	70
Czech Republic	1673	2828	**4501**	0.5%	75
Germany	152	6556	**6708**	0.8%	35
Greece	–	3900	**3900**	0.5%	58
Hungary	199	3103	**3302**	0.4%	351
Kazakhstan	28170	3130	**31300**	3.8%	273
Poland	6012	1490	**7502**	0.9%	52
Romania	12	410	**422**	0.1%	12
Russian Federation	49088	107922	**157010**	19.0%	481
Spain	200	330	**530**	0.1%	32
Turkey	–	1814	**1814**	0.2%	21
Ukraine	15351	18522	**33873**	4.1%	438
United Kingdom	155	–	**155**	*	9
Other Europe & Eurasia	1025	18208	**19233**	2.3%	268
Total Europe & Eurasia	102042	170204	**272246**	33.0%	218
South Africa	30408	–	**30408**	3.7%	121
Zimbabwe	502	–	**502**	0.1%	287
Other Africa	929	174	**1103**	0.1%	*
Middle East	1386	–	**1386**	0.2%	*
Total Middle East & Africa	33225	174	**33399**	4.0%	131
Australia	36800	39400	**76200**	9.2%	190
China	62200	52300	**114500**	13.9%	41
India	54000	4600	**58600**	7.1%	114
Indonesia	1721	2607	**4328**	0.5%	19
Japan	355	–	**355**	*	289
New Zealand	33	538	**571**	0.1%	111
North Korea	300	300	**600**	0.1%	17
Pakistan	1	2069	**2070**	0.3%	496
South Korea	133	–	**133**	*	48
Thailand	–	1354	**1354**	0.2%	75
Vietnam	150	–	**150**	*	4
Other Asia Pacific	115	276	**391**	*	26
Total Asia Pacific	155809	103444	**259253**	31.4%	64
Total World	**411321**	**414680**	**826001**	**100.0%**	**122**
of which: European Union	8427	21143	**29570**	3.6%	51
OECD	159012	193083	**352095**	42.6%	164
Former Soviet Union	93609	132386	**225995**	27.4%	433
Other EMEs	158700	89211	**247911**	30.0%	60

*More than 500 years.

*Less than 0.05%.

Source of reserves data: World Energy Council, 2009.

Notes: Proved reserves of coal – Generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known deposits under existing economic and operating conditions.

Reserves-to-production (R/P) ratio – If the reserves remaining at the end of the year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate.

Annex- II: World’s Proven Gas Reserve

Proved reserves

	At end 1988 Trillion cubic metres	At end 1998 Trillion cubic metres	At end 2007 Trillion cubic metres	At end 2008 Trillion cubic feet	At end 2008 Trillion cubic metres	At end 2008 Share of total	At end 2008 R/P ratio
US	4.76	4.65	6.73	**237.7**	**6.73**	3.6%	11.6
Canada	2.67	1.75	1.63	**57.7**	**1.63**	0.9%	9.3
Mexico	2.08	0.85	0.51	**17.6**	**0.50**	0.3%	9.1
Total North America	9.51	7.24	8.88	**313.1**	**8.87**	4.8%	10.9
Argentina	0.77	0.69	0.44	**15.6**	**0.44**	0.2%	10.0
Bolivia	0.15	0.15	0.71	**25.1**	**0.71**	0.4%	51.0
Brazil	0.11	0.22	0.27	**11.5**	**0.33**	0.2%	23.6
Colombia	0.13	0.20	0.12	**4.0**	**0.11**	0.1%	12.4
Peru	0.34	0.25	0.33	**11.8**	**0.33**	0.2%	98.5
Trinidad & Tobago	0.29	0.56	0.48	**17.0**	**0.48**	0.3%	12.2
Venezuela	2.86	4.15	4.84	**170.9**	**4.84**	2.6%	*
Other S. & Cent. America	0.15	0.14	0.07	**2.4**	**0.07**	*	17.5
Total S. & Cent. America	4.79	6.35	7.27	**258.2**	**7.31**	4.0%	46.0
Azerbaijan	n/a	0.81	1.16	**42.3**	**1.20**	0.6%	81.3
Denmark	0.08	0.10	0.07	**1.9**	**0.06**	*	5.5
Germany	0.36	0.26	0.14	**4.2**	**0.12**	0.1%	9.2
Italy	0.33	0.27	0.13	**4.2**	**0.12**	0.1%	14.2
Kazakhstan	n/a	1.81	1.85	**64.4**	**1.82**	1.0%	60.3
Netherlands	1.73	1.77	1.39	**49.1**	**1.39**	0.8%	20.6
Norway	2.30	3.79	2.88	**102.7**	**2.91**	1.6%	29.3
Poland	0.17	0.14	0.11	**3.9**	**0.11**	0.1%	27.1
Romania	0.17	0.36	0.63	**22.2**	**0.63**	0.3%	54.6
Russian Federation	n/a	43.51	43.32	**1529.2**	**43.30**	23.4%	72.0
Turkmenistan	n/a	2.51	2.43	**280.6**	**7.94**	4.3%	*
Ukraine	n/a	1.02	0.93	**32.6**	**0.92**	0.5%	49.2
United Kingdom	0.59	0.76	0.34	**12.1**	**0.34**	0.2%	4.9
Uzbekistan	n/a	1.58	1.59	**55.8**	**1.58**	0.9%	25.4
Other Europe & Eurasia	38.81	0.40	0.43	**15.6**	**0.44**	0.2%	43.2
Total Europe & Eurasia	44.53	59.09	57.39	**2220.8**	**62.89**	34.0%	57.8
Bahrain	0.19	0.14	0.09	**3.0**	**0.09**	*	6.3
Iran	14.20	24.10	28.13	**1045.7**	**29.61**	16.0%	*
Iraq	2.69	3.19	3.17	**111.9**	**3.17**	1.7%	*
Kuwait	1.38	1.48	1.78	**62.9**	**1.78**	1.0%	*
Oman	0.28	0.57	0.98	**34.6**	**0.98**	0.5%	40.7
Qatar	4.62	10.90	25.46	**899.3**	**25.46**	13.8%	*
Saudi Arabia	5.02	6.07	7.30	**267.3**	**7.57**	4.1%	96.9
Syria	0.11	0.24	0.28	**10.0**	**0.28**	0.2%	51.8
United Arab Emirates	5.66	6.00	6.44	**227.1**	**6.43**	3.5%	*
Yemen	0.16	0.48	0.49	**17.3**	**0.49**	0.3%	*
Other Middle East	†	†	0.05	**1.7**	**0.05**	*	18.4
Total Middle East	34.34	53.17	74.17	**2680.9**	**75.91**	41.0%	*
Algeria	3.23	4.08	4.50	**159.1**	**4.50**	2.4%	52.1
Egypt	0.33	1.02	2.07	**76.6**	**2.17**	1.2%	36.9
Libya	0.83	1.32	1.54	**54.4**	**1.54**	0.8%	96.9
Nigeria	2.48	3.51	5.22	**184.2**	**5.22**	2.8%	*
Other Africa	0.82	0.84	1.21	**43.3**	**1.23**	0.7%	66.2
Total Africa	7.68	10.77	14.54	**517.5**	**14.65**	7.9%	68.2
Australia	1.11	1.65	2.41	**88.6**	**2.51**	1.4%	65.6
Bangladesh	0.35	0.30	0.37	**13.1**	**0.37**	0.2%	21.4
Brunei	0.32	0.38	0.34	**12.4**	**0.35**	0.2%	28.8
China	0.92	1.37	2.26	**86.7**	**2.46**	1.3%	32.3
India	0.60	0.67	1.06	**38.5**	**1.09**	0.6%	35.6
Indonesia	2.56	2.18	3.00	**112.5**	**3.18**	1.7%	45.7
Malaysia	1.49	2.41	2.39	**84.3**	**2.39**	1.3%	38.2
Myanmar	0.27	0.29	0.49	**17.5**	**0.49**	0.3%	39.9
Pakistan	0.65	0.61	0.85	**30.1**	**0.85**	0.5%	22.7
Papua New Guinea	0.13	0.43	0.44	**15.6**	**0.44**	0.2%	*
Thailand	0.20	0.42	0.32	**10.7**	**0.30**	0.2%	10.5
Vietnam	n/a	0.17	0.48	**19.7**	**0.56**	0.3%	70.1
Other Asia Pacific	0.27	0.51	0.40	**13.9**	**0.39**	0.2%	22.1
Total Asia Pacific	8.86	11.39	14.80	**543.5**	**15.39**	8.3%	37.4
Total World	**109.72**	**148.01**	**177.05**	**6534.0**	**185.02**	**100.0%**	**60.4**
of which: European Union	3.65	3.77	2.91	**101.4**	**2.87**	1.6%	15.1
OECD	16.57	16.17	16.56	**587.3**	**16.63**	9.0%	14.6
Former Soviet Union	38.46	51.48	51.50	**2013.1**	**57.00**	30.8%	71.8

More than 100 years.
Less than 0.05.
Less than 0.05%.
n/a not available.
Notes: Proved reserves of natural gas – Generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions.
Reserves-to-production (R/P) ratio – If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate.
Source of data – The estimates in this table have been compiled using a combination of primary official sources and third-party data from Cedigaz and the OPEC Secretariat.

Annex- III: World's Proven Oil Reserve

Proved reserves

	At end 1988 Thousand million barrels	At end 1998 Thousand million barrels	At end 2007 Thousand million barrels	At end 2008 Thousand million tonnes	Thousand million barrels	Share of total	R/P ratio
US	35.1	28.6	30.5	**3.7**	**30.5**	2.4%	12.4
Canada	11.9	15.1	28.6	**4.4**	**28.6**	2.3%	24.1
Mexico	53.0	21.6	12.2	**1.6**	**11.9**	0.9%	10.3
Total North America	100.0	65.3	71.3	**9.7**	**70.9**	5.6%	14.8
Argentina	2.3	2.8	2.6	**0.4**	**2.6**	0.2%	10.5
Brazil	2.8	7.4	12.6	**1.7**	**12.6**	1.0%	18.2
Colombia	2.1	2.5	1.5	**0.2**	**1.4**	0.1%	6.0
Ecuador	1.5	4.1	4.0	**0.5**	**3.8**	0.3%	20.3
Peru	0.9	0.9	1.1	**0.2**	**1.1**	0.1%	25.5
Trinidad & Tobago	0.6	0.7	0.9	**0.1**	**0.8**	0.1%	15.2
Venezuela	58.5	76.1	99.4	**14.3**	**99.4**	7.9%	*
Other S. & Cent. America	0.6	1.1	1.4	**0.2**	**1.4**	0.1%	27.7
Total S. & Cent. America	69.2	95.6	123.5	**17.6**	**123.2**	9.8%	50.3
Azerbaijan	n/a	n/a	7.0	**1.0**	**7.0**	0.6%	20.9
Denmark	0.5	0.9	1.1	**0.1**	**0.8**	0.1%	7.7
Italy	0.8	0.8	0.9	**0.1**	**0.8**	0.1%	21.1
Kazakhstan	n/a	n/a	39.8	**5.3**	**39.8**	3.2%	70.0
Norway	7.3	11.7	8.2	**0.9**	**7.5**	0.6%	8.3
Romania	1.2	1.2	0.5	**0.1**	**0.5**	*	13.3
Russian Federation	n/a	n/a	80.4	**10.8**	**79.0**	6.3%	21.8
Turkmenistan	n/a	n/a	0.6	**0.1**	**0.6**	*	8.0
United Kingdom	4.3	5.1	3.4	**0.5**	**3.4**	0.3%	6.0
Uzbekistan	n/a	n/a	0.6	**0.1**	**0.6**	*	14.6
Other Europe & Eurasia	63.2	2.1	2.1	**0.3**	**2.1**	0.2%	13.4
Total Europe & Eurasia	77.3	104.9	144.6	**19.2**	**142.2**	11.3%	22.1
Iran	92.9	93.7	138.2	**18.9**	**137.6**	10.9%	86.9
Iraq	100.0	112.5	115.0	**15.5**	**115.0**	9.1%	*
Kuwait	94.5	96.5	101.5	**14.0**	**101.5**	8.1%	99.6
Oman	4.1	5.4	5.6	**0.8**	**5.6**	0.4%	20.9
Qatar	4.5	12.5	27.4	**2.9**	**27.3**	2.2%	54.1
Saudi Arabia	255.0	261.5	264.2	**36.3**	**264.1**	21.0%	66.5
Syria	1.8	2.3	2.5	**0.3**	**2.5**	0.2%	17.2
United Arab Emirates	98.1	97.8	97.8	**13.0**	**97.8**	7.8%	89.7
Yemen	2.0	1.9	2.7	**0.3**	**2.7**	0.2%	23.9
Other Middle East	0.1	0.2	0.1	**†**	**0.1**	*	10.6
Total Middle East	653.0	684.3	755.0	**102.0**	**754.1**	59.9%	78.6
Algeria	9.2	11.3	12.2	**1.5**	**12.2**	1.0%	16.7
Angola	2.0	4.0	13.5	**1.8**	**13.5**	1.1%	19.7
Chad	–	–	0.9	**0.1**	**0.9**	0.1%	19.4
Republic of Congo (Brazzaville)	0.8	1.7	1.9	**0.3**	**1.9**	0.2%	21.3
Egypt	4.3	3.8	4.1	**0.6**	**4.3**	0.3%	16.4
Equatorial Guinea	–	0.6	1.7	**0.2**	**1.7**	0.1%	12.9
Gabon	0.9	2.6	3.2	**0.4**	**3.2**	0.3%	37.0
Libya	22.8	29.5	43.7	**5.7**	**43.7**	3.5%	64.6
Nigeria	16.0	22.5	36.2	**4.9**	**36.2**	2.9%	45.6
Sudan	0.3	0.3	6.7	**0.9**	**6.7**	0.5%	38.1
Tunisia	1.8	0.3	0.6	**0.1**	**0.6**	*	18.5
Other Africa	1.0	0.7	0.6	**0.1**	**0.6**	*	12.0
Total Africa	59.0	77.2	125.3	**16.6**	**125.6**	10.0%	33.4
Australia	3.4	4.1	4.2	**0.5**	**4.2**	0.3%	20.4
Brunei	1.2	1.0	1.1	**0.1**	**1.1**	0.1%	16.9
China	17.3	17.4	16.1	**2.1**	**15.5**	1.2%	11.1
India	4.5	5.4	5.5	**0.8**	**5.8**	0.5%	20.7
Indonesia	9.0	5.1	4.0	**0.5**	**3.7**	0.3%	10.2
Malaysia	3.4	4.7	5.5	**0.7**	**5.5**	0.4%	19.8
Thailand	0.1	0.4	0.5	**0.1**	**0.5**	*	3.9
Vietnam	0.1	1.9	3.4	**0.6**	**4.7**	0.4%	40.8
Other Asia Pacific	1.0	1.3	1.1	**0.1**	**1.1**	0.1%	12.8
Total Asia Pacific	39.9	41.3	41.3	**5.6**	**42.0**	3.3%	14.5
Total World	**998.4**	**1068.5**	**1261.0**	**170.8**	**1258.0**	**100.0%**	**42.0**
of which: European Union	8.3	8.9	6.7	**0.8**	**6.3**	0.5%	7.7
OECD	118.3	89.2	90.3	**12.0**	**88.9**	7.1%	13.2
OPEC	764.0	827.2	957.1	**129.8**	**955.8**	76.0%	71.1
Non-OPEC‡	173.5	157.6	174.7	**23.6**	**174.4**	13.9%	14.8
Former Soviet Union	60.9	83.8	129.2	**17.4**	**127.8**	10.2%	27.2
Canadian oil sands*	n/a	n/a	150.7	**24.5**	**150.7**		
Proved reserves and oil sands	n/a	n/a	1411.7	**195.3**	**1408.7**		

More than 100 years.
Less than 0.05.
Less than 0.05%.
Excludes Former Soviet Union.
'Remaining established reserves', less reserves 'under active development'.
Notes: Proved reserves of oil – Generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions.
Reserves-to-production (R/P) ratio – If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate.
Source of data – The estimates in this table have been compiled using a combination of primary official sources, third-party data from the OPEC Secretariat, *World Oil*, *Oil & Gas Journal* and an independent estimate of Russian reserves based on information in the public domain. Canadian proved reserves include an official estimate of 22.0 billion barrels for oil sands 'under active development'. Reserves include gas condensate and natural gas liquids (NGLs) as well as crude oil.
Annual changes and shares of total are calculated using thousand million barrels figures.

Annex- IV: World's Proven Uranium Reserve

Known Recoverable Resources* of Uranium 2007

Country	tonnes U	percentage of world
Australia	1,243,000	23%
Kazakhstan	817,000	15%
Russia	546,000	10%
South Africa	435,000	8%
Canada	423,000	8%
USA	342,000	6%
Brazil	278,000	5%
Namibia	275,000	5%
Niger	274,000	5%
Ukraine	200,000	4%
Jordan	112,000	2%
Uzbekistan	111,000	2%
India	73,000	1%
China	68,000	1%
Mongolia	62,000	1%
other	210,000	4%
World total	**5,469,000**	

Reasonably Assured Resources plus Inferred Resources, to US$ 130/kg U, 1/1/07, from OECD NEA & IAEA, *Uranium 2007: Resources, Production and Demand* ("Red Book").

Sources:
World Nuclear Association

Annex- V: World's Proven Thorium Reserve

Estimated world thorium resources

(Reasonably assured and inferred resources recoverable at up to US$80/kg Th)

Country	Tonnes	% of total
Australia	452,000	18
USA	400,000	16
Turkey	344,000	13
India	319,000	12
Venezuela	300,000	12
Brazil	302,000	12
Norway	132,000	5
Egypt	100,000	4
Russia	75,000	3
Greenland	54,000	2
Canada	44,000	2
South Africa	18,000	1
Other countries	33,000	1
World total	**2,573,000**	

REFERANCES:

1. *IAEA,2012*
2. *IEA,2012*
3. *The Massachusetts Institute of Technology, The Future of Nuclear Power, Cambridge, Massachusetts, USA (2003);*
4. *The University of Chicago, The Economic Future of Nuclear Power, Chicago, Illinois, USA (2004);*
5. *The Royal Academy of Engineering, The Cost of Generating Electricity, London, UK (2004);*
6. *General Directorate for Energy and Raw Materials (DGEMP),*
7. *French Ministry of the Economy, Finance and Industry, Paris, France (2003);*
8. *Ministry of Economy, Trade and Industry, Tokyo, Japan (2004);*
9. *Matt Ayres, Morgan MacRae and Melanie Stogran, Lovelies Unit Electricity Cost Comparison of Alternate Technologies for Base load Generation in Ontario, Canadian Energy Research Institute (CERI), Calgary, Alberta, Canada, 2004;*
10. *Nuclear Energy Agency and International Energy Agency, Projected Costs of Generating Electricity: 2005 Update, Organization for Economic Co-operation and Development, Paris, 2005. 2. NEA/IAEA (2006), Uranium 2005: Resources, Production and Demand, OECD Nuclear Energy Agency, NEA No. 6098, Paris. Sokolov Y A, McDonald A, "The Nuclear Power Options for Africa", ATDF Journal, Vol 2, Issue 2, pp 12–18, 2005*

    (http://www.atdforum.org/IMG/pdf/nuclearpower_options_Africa.pdf).

11. *Bruggink, J. J. C. and B. C. C. van der Zwaan, 2002, "The role of nuclear energy in establishing sustainable energy paths", International Journal of Global Energy Issues* ***18,*** *2/3/4.*
12. *Saha, P.C., 2003, "Sustainable energy development: a challenge for Asia and the Pacific region in the 21st century", Energy Policy,* ***31****, 1051-1059*
13. *Rogner, H. H., 2001, "Nuclear power and sustainable energy development" Journal of Energy and Development* ***26****, 2, 235-258.*
14. *NEA, 2000, Nuclear Energy in a Sustainable Development Perspective, Nuclear Energy Agency, OECD, Paris.*
15. *Nuclear Engineering International, various, and 2002 Reactor Design supplement. March 2012: Atmea1 reactor.*
16. *ABB Atom Dec 1999; Nukem market report July 2000*
17. *The New Nuclear Power, 21st Century, Spring 2001*
18. *Lauret, P. et al, 2001, The Nuclear Engineer 42, 5*
19. *Smirnov V.S. et al, 2001, Design features of BREST reactors, KAIF/KNS conf.Proc*
20. *OECD NEA 2001, Trends in the Nuclear Fuel Cycle*
21. *Carroll D & Boardman C, 2002, The Super-PRISM Reactor System, The Nuclear Engineer 43,6*
22. *Twilley R C 2002, Framatome ANP's SWR1000 reactor design, Nuclear News, Sept 2002*
23. *Torgerson D F 2002, The ACR-700, Nuclear News Oct 2002*
24. *IEA-NEA-IAEA 2002, Innovative Nuclear Reactor Development*
25. *Perera, J, 2003, Developing a passive heavy water reactor, Nuclear Engineering International, March*
26. *Sinha R.K.& Kakodkar A. 2003, Advanced Heavy Water Reactor, INS News vol 16, 1*
27. *US Dept of Energy, EIA 2003, New Reactor Designs*
28. *Matzie R.A. 2003, PBMR - the first Generation IV reactor to be constructed, WNA Symposium*
29. *LaBar M. 2003, Status of the GT-MHR for electricity production, WNA Symposium*

30. *Carelli M 2003, IRIS: a global approach to nuclear power renaissance, Nuclear News Sept 2003*
31. *Perera J. 2004, Fuelling Innovation, IAEA Bulletin 46/1*
32. *AECL Candu-6 & ACR publicity, late 2005*
33. *Barnaby, F., Barnham, K., Kemp, L., Rogers, P. & Storm van Leeuwen, J.W. (2007). Secure Energy? Civil Nuclear Power, Security and Global Warming. Oxford Research Group, UK*
34. *BP (2007). Statistical Review of World Energy. Information retrieved on August 10, 2008 from the World Wide Web: www.bp.com/centres/energy/*
35. *BP (2005). BP Statistical Review of World Energy. Information retrieved November 23, 2008 from the World Wide Web: http://www.bp.com/worldenergy/*
36. *Chambers, D.B., Cassaday, V.J. & Lowe, L.M. (1989). Exposures from Mining and Mine Tailings. Radiat. Phys. Chem., Vol. 34, No. 2, p.p. 295-307.*
37. *Crowly, K.D. (1997). Nuclear Waste Disposal: the Technical Challenges. Phys. Today, Vol. 50 (6), p. 32-39*
38. *Deffeyes, K.S. & MacGregor, I.D. (1980). World Uranium Resources. Scientific American, Vol. 242 (1), p. 50-60*
39. *Diehl, P. (2004). Uranium Mining and Milling Wastes: An Introduction. Information retrieved on September 9, 2008 from the World Wide Web: http://www.wise-uranium.org/uwai.html#TAILCON*
40. *Energy Watch Group (EWG) (2006). Uranium resources and Nuclear Energy. Information retrieved August 10, 2008 from the World Wide Web: http://www.energywatchgroup.org/*
41. *Fleming, D. (2007). The Lean Guide to Nuclear Energy: A Life-Cycle in Trouble. The Lean Economy Connection, London.*
42. *Frois, B. (2008). Nuclear Energy in a Global Context. Nuclear Physics A 805 p.320c- 327c.*
43. *Lenzen, M. (2008). Life cycle energy and greenhouse gas emissions of nuclear energy: A review. Energy Conversion and Management, 49, 2178-2199.*
44. *MIT (2003). The Future of Nuclear Power: An Interdisciplinary MIT Study. Massachusetts: The MIT Press.*
45. *Mudd, G.M. (2008). Radon Releases from Australian Uranium Mining and Milling Projects: Assessing the UNSCEAR approach. Journal of Environmental Radioactivity, Vol. 99, p. 288-315*
46. *Nuclear Energy Institute (2008). World Statistics: Nuclear Energy Around the World. Information retrieved on August 6, 2008 from the World Wide Web: http: http://www.nei.org/resourcesandstats/nuclear_statistics/worldstatistics/*
47. *Sovacool, B. (2008). Valuing the Greenhouse Gas Emissions from Nuclear Power: A Review. Energy Policy 36, p.2950-2963*
48. *Storm van Leeuwen, J.W. (2006). Secure Energy: Options for a Safer World. Factsheet 4: Energy security and Uranium Reserves. Oxford Research Group. Information retrieved August 13, 2008 from the World Wide Web: http://www.stormsmith.nl/*
49. *Storm van Leeuwen, J.W. (2006). Nuclear power and Global Warming. Information retrieved on August 13, 2008 from the World Wide Web: http://www.stormsmith.nl/ http://www.stormsmith.nl/publications/storm_Van_Leeuwen_presentation.pdf*
50. *Storm van Leeuwen, J.W. (2006). Energy from Uranium. Oxford Research Group. Information retrieved August 13, 2008 from the World Wide Web: http://www.stormsmith.nl/*
51. *Storm van Leeuwen, J.W., & Smith, P. (2005). Nuclear Power-The Energy Balance. Information retrieved on September 14, 2008 from the World Wide Web: http://www.stormsmith.nl/*
52. *Storm van Leeuwen, J.W., & Smith, P. (2007). Nuclear Power-The Energy Balance. Information retrieved on September 14, 2008 from the World Wide Web: http://www.stormsmith.nl/*
53. *Vandenhove, H., Sweeck, L., Mallants, D., Vanmarcke, H., Aitkulov, A., Sadyrov, O., Savosin, M., Tolongutov, B., Mirzachev, M., Clerc, J.J., Quarch, H. & Aitaliev, A. (2006). Assessment of Radiation Exposure in the Uranium Mining and Milling area of Mailuu Suu, Kyrgyzstan. Journal of Radioactivity, Vol. 88, p. 118-139 Verbruggen, A. (2008). Renewable and Nuclear Power: A Common*

Future? Energy Policy, Vol. 36, p. 4036-4047 World Energy Outlook WEO (2006). World Energy Outlook 2006. Information retrieve September 13, 2008 from the World Wide Web: *http://www.worldenergyoutlook.org*

54. *World Nuclear Association (2005). Outline History of Nuclear Energy. Information retrieved August 11, 2008 from the World Wide Web:* *http://www.world-nuclear.org/info/inf54.html*
55. *World Nuclear Association (2008). Environmental Aspects of Uranium Mining. Information retrieved on August 13, 2008 from the World Wide Web:* *http://www.world-nuclear.org/info/inf25.html?terms=tailings*
56. *World Nuclear Association (2006).The Nuclear Fuel Cycle. Information retrieved on August 3, 2008 from the World Wide Web:* *http://world-nuclear.org/education/nfc.htm*
57. *World Nuclear Association (2008).In Situ Leach (ISL) Mining of Uranium. Information retrieved on September 11, 2008 from the World Wide Web:* *http://www.world-nuclear.org/info/inf27.html?terms=In-situ+Leaching*
58. *World Nuclear Association (2008). Environmental Aspects of Uranium Mining. Information retrieved on September 9, 2008 from the World Wide Web: http://worldnuclear.org*
59. *World Nuclear Association (2008). Conversion and Enrichment. Information retrieved on September 9, 2008 from the World Wide Web: http://worldnuclear.org*
60. *World Nuclear Association (2007). Decommissioning Nuclear Facilities. Information retrieved on November 19, 2008 from the World Wide Web: http://worldnuclear.org*
61. *OECD/ IEA NEA 2010, Projected Costs of Generating Electricity.*
62. *OECD, 1994, The Economics of the Nuclear Fuel Cycle*
63. *NEI: US generating cost data.*
64. *Tarjanne, R & Rissanen, S, 2000, Nuclear Power: Lest-cost option for baseload electricity in Finland; in Proceedings 25th International Symposium, Uranium Institute*
65. *Gutierrez, J 2003, Nuclear Fuel - key for the competitiveness of nuclear energy in Spain, WNA Symposium.*
66. *University of Chicago, August 2004, The Economic Future of Nuclear Power.*
67. *Nuclear Energy Institute, August 2008, The cost of new generating capacity in perspective.*
68. *$40 Billion boost for nuclear power in Russia Russia Today Retrieved on July 31, 2008*
69. *"New nuclear plants get go-ahead". BBC. 2008-01-10. Retrieved 2008-01-10.*
70. *BBC's UK Electricity Calculator illustrates new nuclear role to meet future demand.http://news.bbc.co.uk/2/shared/spl/hi/uk/06/electricity_calc/html/1.stm*
71. *International Atomic Energy Agency (2011). "Power Reactor Information System". IAEA.*
72. *World Nuclear Power Reactors & Uranium Requirements. World Nuclear Association(WNA). 6 February 2011.*
73. *Suga, Masumi; Shunichi Ozasa (September 7, 2009). "China to Build More Nuclear Plants, Japan Steel Says". Bloomberg.com.*
74. *"China Should Control Pace of Reactor Construction, Outlook Says". Bloomberg News. January 11, 2011.*
75. *http://www.eref-europe.org/dls/pdf/2007/eref_pr_260907.pdf EREF EREF deplores COFACE state aid decision of the European Commission in the case of nuclear power support, September 2007*
76. *http://www.energyprobe.org/energyprobe/images/NuclearCost/NuclearCost_files/frame.htmEnergy Probe, "Critique of the Official View of Ontario's Energy Future", Presentation to the Canadian Academy of Engineering, June 2007.*
77. *Mycle Schneider, Steve Thomas, Antony Froggatt, Doug Koplow (August 2009). The World Nuclear Industry Status Report 2009 Commissioned by German Federal Ministry of Environment, Nature Conservation and Reactor Safety, p. 7.*
78. *http://www.elfi.fi/fi/lehdistotiedotteet/olkiluoto-3-n-myohastyminen-tulee-kalliiksi-pohjoismaisille-sahkonkaytta-2.html ELFI press release, September 2007*

79. GE Hitachi (2008). *"Advanced Boiling Water Reactor (ABWR) Fact Sheet". Retrieved 07-03-2011.*
80. *"S. Korea to Build 12 More Nuclear Reactors by 2022". The Korea Times.*
81. *Tony Halpin (2007-04-17). "Floating nuclear power stations raise spectre of Chernobyl at sea". The Times Online.*
82. *Andrew England, Peggy Hollinger, Song Jung-a. "S. Koreans win $20B UAE nuclear power contract". Financial Times (CNN).*
83. *BP statistical review of world energy (June 2009): http:www.bp.com/statistical/review*
84. *World energy outlook 2009*
85. *Diaz Maurin, François (26 March 2011). "Fukushima: Consequences of Systemic Problems in Nuclear Plant Design". Economic & Political Weekly (Mumbai)* ***46*** *(13): 10–12.*
86. *Jan Willem Storm van Leeuwen (2008). Nuclear power – the energy balance*
87. *www.australia.gov.au*
88. *Perrow, C. (1982), 'The President's Commission and the Normal Accident', in Sils, D., Wolf, C. and Shelanski, V. (Eds), Accident at Three Mile Island: The Human Dimensions, Westview, Boulder, pp.173–184.*
89. *A costly feud in Bangladesh (1999, November 18).The Economist.p. 45. Retrieved September 24, 2011 from http://www.economist.com/node/260161*
90. *ADB.(2001). Power sector reform.Quarterly economic update, March 2001, Bangladesh: Asian Development Bank, Bangladesh Resident Mission.*
91. *Alam, M. S., Kabir, E., &Chowdhury, M. A. K. (2004). Power sector reform in Bangladesh: Electricity distribution system. Energy, 29, 1773-1783. http://dx.doi.org/10.1016/j.energy.2004.03.005 www.ccsenet.org/eer Energy and Environment Research Vol. 1, No. 1; December 2011 20 ISSN 1927-0569 E-ISSN 1927-0577*
92. *Andersen, A. (2001). Global Best Practices in Power Sector Reform: Confederation of Indian Industry. India: Arthur Andersen Pty Ltd.*
93. *Anheier, H. K. (2000). Managing nonprofit organizations: Toward a new approach. Civil Society Working Paper, January 1.*
94. *Aubert, V. (1952).White-collar crime and social structure.American Journal of Sociology, 58, 263-271. http://dx.doi.org/10.1086/221148*
95. *Azfar, O. (2002). Corruption. In Encyclopedia of Public Choice (Eds.), IRIS: University of Maryland, College Park. http://dx.doi.org/10.1023/A:1019943100310*
96. *Bacon, R. W. (1995). Privatization and Reform in the Global Electricity Supply Industry.Annual Review: Energy and the Environment, 20, 119-143. http://dx.doi.org/10.1146/annurev.energy.20.1.119*
97. *Bacon, R. W., & Besant-Jones, J. (2002). Global Electric Power Reform, Privatization and Liberalization of the Electric Power Industry in Developing Countries, The Energy and Mining Sector Board, The World Bank Group, Energy & Mining Sector Board Discussion Paper Series 2.*
98. *Bangladesh PM Orders 1 hr Outage Every Alternate Hour.(Apri 8, 2010).Energy Bangla.Retrieved November 5, 2010 from http://www.energybangla.com/index.php?mod=article&cat=PowerSector&article=2432*
99. *Bangladesh Power Development Board (BPDB), (2010). Retrieved June 3, 2010 from http://www.bpdb.gov.bd/*
100. *Bennett, C. (1991).What* **is** *policy convergence and what causes it? British Journal of Political Science, 21, 215-33. http://dx.doi.org/10.1017/S0007123400006116*

101. Bevir, M., Rhodes, R. A. W. and Weller, P. (2003). Traditions of governance: interpreting the changing role of the public sector. Public Administration, 81(1), 1-17. http://dx.doi.org/10.1111/1467-9299.00334

102. Bhattacharyya, S. C. (2007). Power sector reform in South Asia: Why slow and limited so far? Energy Policy, 35, 317-332. http://dx.doi.org/10.1016/j.enpol.2005.11.028

103. Bhuyan, A. R. (2009). Challenges for the Bangladesh Economy: Priority Economic Agenda for the New Government.Thoughts on Economics, 19(1), 1-19.

104. Bogason, P. &. Musso, J. A. (2006). The Democratic Prospects of Network Governance.The American Review of Public Administration, 36(3). http://dx.doi.org/10.1177/0275074005282581

105. Boyne, G. A., Farrell, C., Law, J., Powell, M., & Walker, R. M. (2003).Evaluating public management reforms: Principles and practice. Buckingham, UK: Open University Press.

106. Boyne, G. A. (2003). Sources of public service improvement: A critical review and research agenda. Journal of Public Administration Research and Theory, 13 (3), 367-394. http://dx.doi.org/10.1093/jpart/mug027

107. Cabinet body approves 3 rental power projects without tender. (May 27, 2010). The Bangladesh Today. Retrieved November 5, 2010 from http://www.thebangladeshtoday.com/archive/May%2010/27-5-2010.htm

108. Common, K. R. (1998). Convergence and transfer: a review of the globalization of new public management. International Journal of Public Sector Management, 11(6), 450-550. http://dx.doi.org/10.1108/09513559810244356

109. Crozier, M. (1964).The Bureaucratic Phenomenon.Chicago: Univ. Chicago Press. Dhaka and Moscow sign nuclear cooperation deal: Russia extends full support for setting up nuclear power plants in Bangladesh. (May 22, 2010). The Bangladesh Today.Retrieved November 5, 2010 from http://www.thebangladeshtoday.com/archive/May%2010/22-5-2010.htm

110. Dhaka Electric Supply Authority (DESA). (2010). Retrieved November 3, 2010 from http://www.desa.com.bd/

111. Dhaka Electric Supply Company (DESCO). (2010). Retrieved November 3, 2010 from http://www.desco.org.bd/

112. Eikenberry, A. M., &Kluver, J. D. (2004). The marketization of the nonprofit sector: civil society at risk? Public Administration Review, 64(2), 132-141. http://dx.doi.org/10.1111/j.1540-6210.2004.00355.x

113. Encourage private investments in power sector. (May 6, 2010). The Daily Star.Retrieved November 6, 2010 from http://www.thedailystar.net/story.php?nid=137286

114. Enough scope to invest in power sector: Bangladesh business confidence improving. (February 14, 2010). The New Nation.Retrieved November 6, 2010 from http://www.ittefaq.com/issues/2010/02/14/news0853.htm

115. Fitchner& Power Cell.(2006). Power sector Financial Restructuring and Recovery Plan.Power Sector Development Technical Assistant Project.Bangladesh Ministry of Power, Energy and Mineral Resources. www.ccsenet.org/eer *Energy and Environment Research Vol. 1, No. 1; December 2011 Published by Canadian Center of Science and Education 21*

116. Forbes, M., & Lynn, Jr. L. E. (2005). How Does Public Management Affect Government Performance? Findings from International Research. Journal of Public Administration Research and Theory, 15, 559-584. http://dx.doi.org/10.1093/jopart/mui035

117. *Godshell, C. T. (2004). The case for bureaucracy: A public administration polemic. (4th ed.). Washington, DC: Congressional Quarterly Press.*
118. *Gortner, H. F., Nichols, K. L., & Ball, C. (2007).Organization Theory: A Public and Nonprofit Perspective. Thomson Learning, USA :Wadsworth.*
119. *Gratwick, K. N., &Eberhard, A. (2008). Demise of the standard model for power sector reform and the emergence of hybrid power markets, Energy Policy, 36, 3948–3960. http://dx.doi.org/10.1016/j.enpol.2008.07.021*
120. *Gutierrez, L. E. (1996). How do sub-Saharan African countries compare? In Symposium on Power Sector Reform and Efficiency Improvement in sub-Saharan Africa, Johannesburg, RSA: ESMAP Report No. 182/96 RSA, Dec 8–9, 1995.*
121. *Haque M. A., &Rahman, J. (2010). Power Crisis and Solution in Bangladesh .Bangladesh J. Sci. Ind. Res., 45(2), 155-162. http://dx.doi.org/10.3329/bjsir.v45i2.5714*
122. *Heywood, P. (1997). Political Corruption: Problems and Perspectives. Political Studies, 45, 417-435. http://dx.doi.org/10.1111/1467-9248.00089*
123. *Hill, C. J., & Lynn Jr., L. E. (2004). Is hierarchical governance in decline? : Evidence from empirical research. Journal of Public Administration Research and Theory, 15, 173-195. http://dx.doi.org/10.1093/jopart/mui011*
124. *Hossain, S. (2010, April 01). PM resents lengthy project execution process. The New Age.p.1. Retrieved November 4, 2010 from http://www.newagebd.com/2010/jun/01/front.html#3*
125. *IEB, (2000). Comments on policy statement on power sector reforms. Retrieved from http://shakti.hypermart.net/electricity/*
126. *Johnston, M. (1996). Public Officials, Private Interests and Sustainable Democracy: When Politics and Corruption Meet. In Conference of Corruption in the World Economy (Chapter 3, p. 71). Washington, D.C: Institute of International Economics.*
127. *Jorgensen, T. B., Hansen, H. F., Antonsen, M., &Melander, P. (1998). Public organizations, multiple constituencies and governance. Public Administration, 76(3), 499-518. http://dx.doi.org/10.1111/1467-9299.00114*
128. *Jreisat, J. E. (1997). Public Organization Management: The development of theory and process. Westport, CT, USA: Quorum Books. JS SESSION ROUND-UP: Most burning issues omitted in discussion. (April 07, 2010). The New Age. Retrieved November 4, 2010 from http://www.newagebd.com/2010/apr/07/front.html*
129. *Khan, M. A. (2010, April 10). Crippling Energy crisis .The Daily Star.p.8.*
130. *Khan, M. M. (2003). State of Governance in Bangladesh, The Round Table, 92(370), 391-405.*
131. *Klitgaard, R. (1988). Controlling Corruption. Berkeley: University of California Press.*
132. *Laking, R. (2001). Bangladesh: the state of governance: Report prepared for the Asian Development Bank (ADB). Dhaka: ADB.*
133. *Larbi, G. A. (1999). The New Public Management Approach and Crisis States: UNRISD Discussion Paper No. 112. Geneva, Switzerland: United Nations Research Institute for Social Development.*
134. *Lawmakers fear public anger outburst over water, power: Army deployment from today to help WASA in water supply. (April 01, 2010). The New Age.Retrieved November 4, 2010 from http://www.newagebd.com/2010/apr/01/front.html#1*
135. *Lengthy process sets back power projects. (April 14, 2010). The Daily Star.Retrieved June 6, 2010 from http://www.thedailystar.net/newDesign/news-details.php?nid=134312*

136. *Linder, S. H., &Rosenau, P. V. (2000).Mapping the Terrain of the Public-Private Policy Partnership.In P.V. Rosenau, Public-Private Policy Partnerships (edition, pp.1-18). Cambridge MA: MIT Press.*
137. *Lowndes, V. &Skelcher, C. (1998). The dynamics of multi-organizational partnerships: an analysis of changing modes of governance. Public Administration, 76(2), 313-333.* *http://dx.doi.org/10.1111/1467-9299.00103*
138. *www.ccsenet.org/eer Energy and Environment Research Vol. 1, No. 1; December 2011 22 ISSN 1927-0569 E-ISSN 1927-0577*
139. *Madden, G., Savage, S., & Kemp, S. (1997). Measuring Public Sector Efficiency: A Study of Economics Departments at Australian Universities.Education Economics, 5(2), 153-68.* *http://dx.doi.org/10.1080/09645299700000013*
140. *Malek, B. G. M. A. (2004). Lecture on electricity as the driving force of the civilization: Bangladesh. 45th Convention, Institution of Engineers of Bangladesh, Khulna. Energy, 29, 1773-1783.*
141. *McNeil, K. (1978). Understanding Organizational Power: Building on the Weberian Legacy. Administrative Science Quarterly, 23(1), 65-90. http://dx.doi.org/10.2307/2392434*
142. *Ministry of Power, Energy and Mineral Resources. (2010). Private Sector Power Generation Policy of Bangladesh, 1996. Retrieved June 3, 2010 from http://www.powerdivision.gov.bd*
143. *Moore, M. H. (1984). A Conception of Public Management.In Teaching Public Management (edition, pp.1-12). MA: Harvard University Press.*
144. *Muhith sees far-reaching impacts of energy crisis. (April 14, 2010). The Daily Star.Retrieved November 6, 2010 from http://www.thedailystar.net/newDesign/news-details.php?nid=132890*
145. *Mulgan, R. (2000). 'Accountability': An ever-expanding concept. Public Administration, 78(3), 555-573. http://dx.doi.org/10.1111/1467-9299.00218*
146. *Murray, M. A. (1975). Comparing public and private management: An exploratory essay.Public Administration Review, July-August, 364-371. http://dx.doi.org/10.2307/974538*
147. *Newbery, D. (2006). Power Sector Reform, Private Investment and Regional Cooperation. In South Asia: Growth and Regional Integration (edition, pp.43-170). World Bank. Orchard, L. (1998). Managerial, economic rationalism and public sector reform in Australia: connections, divergences, alternatives. Australian Journal of Public Administration, 57(1), 19-32. http://dx.doi.org/10.1111/1467-8500.00003*
148. *Parker, R. & Bradley, L. (2000). Public sector: evidence from six organizations. International Journal of Public Sector Management, 13(2), 125-141.*
149. *People won't tolerate power crisis after 5-6 months: Subid Ali. (May 23, 2010). The Bangladesh Today. Retrieved November 5, 2010 from http://www.thebangladeshtoday.com/archive/May%2010/23-5-2010.htm*
150. *PM approves emergency power plant without tender. (April 09, 2010). The New Age.Retrieved Nonember 4, 2010 from http://www.newagebd.com/2010/apr/09/front.html#3*
151. *Pollitt, C. (2000). Is the emperor in his underwear: An analysis of the impacts of public management reform. Public Management Review, 2(2), 181–199. http://dx.doi.org/10.1080/14719030000000009*
152. *Power Cell. (2010). accessed on 03/11/2010 http://www.powercell.gov.bd/*
153. *Power Division. (2010). accessed on 03/11/2010 http://www.powerdivision.gov.bd/*

154. Pugh, D. S., Hickson, D. J., Hinings, C. R. & Turner, C. (1968).Dimensions of Organiztion structure. Administrative Science Quarterly, 13, 65-105. http://dx.doi.org/10.2307/2391262
155. Rahman, S. (2010, April 04).Energy crisis puts economy at risk: Businessmen warn of cut export earnings. The Daily Star.p.8. Retrieved November 4, 2010 from http://www.thedailystar.net/newDesign/latest_news.php?nid= 23235
156. Rahmatullah, B. D. (2001) Power sector reforms—a strategic proposition. Engineering News, Institution of Engineers, (January–February), 49.Dhaka.
157. Rahmatullah, B. D. (2001). System Loss in Power Sector: A major challenge for economic sustainability. Dhaka: Engineering News, Institution of Engineers; (May–June)
158. REB. (2010). acessed on 03/011/2010 http://www.reb.gov.bd/
159. Simmel, G. (1950). The Sociology of Georg Simmel.Transl. ed. K Wolff. New York: Free Press
160. Simon, D. (1994). Crimes of the Criminal Justice System.Cincinnati, OH: Anderson. Simon, H. A., & Thompson, V. A. (1991). Public administration revisited. Society, 28(5), 41-45. http://dx.doi.org/10.1007/BF02695687
161. Smith, T. B. (2004). Electricity theft: a comparative analysis, Energy Policy, 32, 2067–2076. http://dx.doi.org/10.1016/S0301-4215(03)00182-4
162. www.ccsenet.org/eer Energy and Environment Research Vol. 1, No. 1; December 2011 Published by Canadian Center of Science and Education 23 Staw, B. M., Sandelands, L. E., & Dutton, J. E. (1981). Threat-rigidity effects in organizational behavior. Administrative Science Quarterly, 26, 501-524. http://dx.doi.org/10.2307/2392337
163. Tayeb, M. (1994). Organizations and National Culture: Methodology Considered. Organization Studies, 15(3), 429-446. http://dx.doi.org/10.1177/017084069401500306
164. TIB.(2000) .Corruption in public service departments. Retrieved from http://www.ti-bangladesh.org/docs/misc/overview1.htm.
165. Transparency International Bangladesh (TIB). (2007). The State of the Governance in the Power Sector of Bangladesh: Problems and the Way Out. Dhaka: TIB.
166. Turner, M. (2002).Choosing Items from the Menu: New Public Management in Southeast Asia.International Journal of Public Administration, 25(12), 1493-1512. http://dx.doi.org/10.1081/PAD-120014258
167. Ullah , A. (June 05, 2010). Fixing problems of Bangladesh power sector. The Financial Express.Retrieved November 7, 2010 from http://www.thefinancialexpress-bd.com/more.php?news_id=97794
168. USAID: Bangladesh. (2010). Large Unsatisfied Demand for Energy', Energy, USAID: Bangladesh, Dhaka, viewed 8 November, 2010, http://www.usaid.gov/bd/programs/energy.html
169. USAID-SARI/Energy. (2007). 'Bangladesh: Energy sector overview', South Asian regional Initiative for Energy (SARI/Energy), USAID, Washington, viewed 8 November 2010, http://www.sari-energy.org/PageFiles/Countries/Bangladesh_Energy_detail.asp
170. Vaughan, D. (1992). Theory elaboration. In C Ragin , H. B., What is a Case?(ed., pp.173-202). New York: Cambridge Univ. Press.
171. Vaughan, D. (1999). The dark side of organizations: mistake, misconduct, and disaster. Annual Review of Sociology, 25, 271-305. http://dx.doi.org/10.1146/annurev.soc.25.1.271
172. Williams, T. A. (1992). Reforming Public sector work.Australian Journal of Public Administration, 51(3),275-285. http://dx.doi.org/10.1111/j.1467-8500.1992.tb02613.x

173. *Williamson, J. (2002). What Washington Means by Policy Reform. In J. Williamson, Latin American Adjustment: How much Has Happened? (Ed).Washington: Institute for International Economics.*
174. *World Bank. (1996). Bangladesh: Government That Works – Reforming the Public Sector. Washington, D.C.*
175. *World Bank.(2001). Global Development Finance 2001, World Bank, Washington D.C.*
176. *World Bank. (2003). Private Solutions for Infrastructure in Bangladesh, the International Bank for Reconstruction and Development, the World Bank, Washington, D.C.*
177. *World Energy Council. (1998). The Benefits and Deficiencies of Energy Sector Liberalisation: Volume 1(pp.121.) London: World Energy Council.*
178. *Zekeyo, J. P. (2001). Rural electrification reform and programme in Cameroon. In: Wamukonya, N. (Ed.), Proceedings of the African High Level Regional Meeting on Energy and Sustainable Development for CSD9.*
179. The daily star
180. Ministry of Science and technology Bangladesh
181. Atomic energy commission Bangladesh