Nuclear Power Need & Key Issues: Bangladesh Perspective

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This study is dedicated to our Parents

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PREFACE

On the eve of the special moments of golden jubilee of Bangladesh, the most buzzing word is 'Digitalization'. Digital Bangladesh implies the broader use of computers and embodies the modern philosophy of effective and vibrant use of technology in terms of implementing the promises in education, health, job facility and poverty reduction. Broader implementation of technology cannot be imagined without the supply of adequate electricity. The energy resources to produce electricity is not sufficient enough to fulfill the current demand and will not be able to fulfil the future demand as well to build 'Digital Bangladesh'.

Bangladesh is an energy hungry country. The per capita energy consumption in Bangladesh is one of the lowest (321 KWH) in the world. At the same time, huge population density is creating enormous pressure on our power sector. Electricity is the constitutional right of every people. But only 40% of our total population has the access to electricity and the population is growing at geometrical rate and thus the possibility of meeting with the future ever growing demand of electricity is gradually going beyond our capability.

The gross domestic product (GDP) or gross national product (GNP) of a country is entangled with the rate of per capita consumption of electricity. The inadequate production of electricity is affecting the standard of human life or human development index (HDI) of the people of our country.

We have been envisioned that the contribution of industry to GDP will be increased to 40% by 2021 to make our country a developed one from the developing one. But the speed of enrichment is very slow due to lack of sufficient energy.

All the power plants in our country use fossil fuels e.g. coal, oil, gas etc. for producing electricity. But there are many drawbacks such as environmental hazards, fluctuating prices, low efficiency, effect on human health, non-renewable, need of huge amount of reserves etc.

Renewable energy e.g. solar energy, hydro energy, wind energy, geothermal energy, bio-energy etc. is another promising source of energy resource. But the problem is that the production of electricity from this sources are not technically competitive to meet the growing electricity need. Although hydro power, solar power and biogas are used in our country, their efficiency is not mentionable.

Traditional energy sources emit greenhouse gases which affect the climate. Bangladesh being a coastal land is a victim to this climatic deterioration. Bangladesh signed 2015 Paris Agreement on the reduction of climate change. To reduce the climate change, alternative to traditional sources of electricity production must be brought into consideration.

Considering the facts such as ever growing demand, limited resources, efficiency, production cost, environmental issues, Nuclear Energy is the best suitable option for electricity production in Bangladesh.

The primary objective of our study is to impose proper knowledge in a convenient way on Nuclear Energy to the mass people highlighting its good effects from several perspectives. Apart from this, to make people aware of the challenges behind the establishment of a Nuclear power plant and the measures to be undertaken to withstand those challenges.

Table of Contents

Dedication....................2
Declaration....................3
Acknowledgement....................4
Preface....................5

Chapter 1 10
Introduction 10
Chapter 2 13
Electricity 13
2.1 Energy and Electricity 13
2.2 Electricity and Economic Development 15
2.3 Primary Energy Sources 17
  2.3.1 Fossil Fuels 18
  2.3.2 Renewable Sources 24
Chapter 3 27
Bangladesh 27
3.1 General 27
3.2 Population 27
3.3 ECONOMY 30
3.4 DEVELOPMENT GOALS 31
Chapter 4 34
Nuclear Power 34
4.1 Nuclear Reaction: 34
  4.1.1 Nuclear Fission Reaction: 34
4.2 Nuclear Power Reactors 36
  4.2.1 Development 36
  4.2.2 Types 37
  4.2.3 Evolution 43
  4.2.4 Growth Trend 45
4.3 Nuclear Fuel Cycle 48
  4.3.1 Front End 49

4.3.2 Back End 52
4.3.2.1 Open Cycle 52
4.4 Waste Management 55
4.4.1 Nuclear Wastes 55
4.4.2 Spent Fuel 56
4.4.3 High Level Waste 57
4.4.4 Intermediate Level Waste 59
4.4.5 Low Level Waste 59
4.5 Decommissioning: 60
Chapter 5 63
Nuclear Power Need 63
5.1 Power System Reliability 63
5.2 System Economy 63
5.3 Energy Sustainability 64
5.4 Climate Change 65
Chapter 6 67
Bangladesh Power System 67
6.1 Development 67
6.2 Present Status 68
6.3 Primary Energy Sources 69
6.4 Power Load Forecasts 69
Chapter 7 71
Rooppur Nuclear Power Plant 71
7.1 History 71
7.2 Site Location 71
7.3 Recent Development 72
7.4 Contract with Russian Supplier 73
7.6 Responsible Parties 75
7.7 Construction Schedule 75
7.8 Manpower 76
7.9 Operation & Management 77
7.10 Regulatory Control 78
Chapter 8 79
Key Issues 79

8.1 Knowledge Transfer and Independent Plant management 79
8.2 Supply of Fuel 80
8.3 Waste management 80
8.4 Disaster Management and Liabilities 81
8.5 Nuclear Plant Decommissioning 82
Chapter 9 83
Conclusion 83
References: 85

Chapter 1

Introduction

For four decades the world has been learning to live with nuclear energy. The learning process has been exciting, frustrating, and sometimes frightening; it is far from over. Indeed it may be just beginning. We have learned a great deal about how to release nuclear energy; how to control it, and how to make use of it. We have even learned to take it for granted. But we have not yet learned to live with it. Nuclear energy, in all its aspects is already shaping the world. The future of our globe will depend to a startling extent on what we know about nuclear energy, and what we do about it. The crucial decisions will not wait another four decades. Concentrated high-quality energy has become a staple commodity in our industrial society. The most concentrated energy available is nuclear energy, made accessible by nuclear reactors. The energy contained in 1 kilogram of uranium, if it were all to be released in a nuclear reactor, would be equivalent to that produced by burning some 3000 tonnes-of coal. It is not, of course, quite that simple; the possibly apocryphal British workman who filched some uranium reactor fuel and tried to burn it in his grate was disappointed. But there is no doubt that the world's reserves of uranium represent a staggering store of energy. If suitable reactors and other facilities are provided, it becomes possible to exploit uranium, which would otherwise be virtually useless. The same is true of the even more plentiful metal thorium. These constructive possibilities were identified very early in the development of nuclear energy, even as plans were taking shape to release nuclear energy explosively. The awesome destructive power of nuclear weapons dominated the scene for the first post-war decade. But by the mid-1950s scientists and engineers were well on their way to harnessing this power for peaceful purposes. The prospects looked brighter and brighter. There had, to be sure, been a surge of euphoric predictions in the aftermath of the two nuclear explosions over Japan which ended the Second World War. So-called 'atomic power' would run a car on an engine the size of a fist; we would soon live in houses heated by uranium; 'atom-powered' aircraft would be able to remain aloft indefinitely; 'atom-powered' rockets would enable us to cross the ocean in three minutes - and so on. But the people who really understood the implications of nuclear energy were much more realistic. They chose applications whose development seemed fairly straightforward; and their efforts bore fruit. A nuclear reactor releases nuclear energy in the form of heat; the heat is used to generate steam, and the steam to generate electricity - with conventional electrical equipment. Since the mid-1950s nuclear generation of electricity has become a full-fledged technology. From the outset it seemed that the nuclear approach to electricity generation would have certain advantages and disadvantages, in comparison with conventional generating stations which raise steam by burning coal, oil or gas. Fossil-fuelled power stations are less expensive to build than comparable nuclear power stations. On the other hand, it was expected that the running cost of a nuclear power station would be considerably less than that of running a fossil-fuelled station. Some early publicity went 10 so far as to declare that nuclear electricity would be too cheap to meter. But as usual those on the inside made no such claim. Instead they calculated the total cost of a unit of electricity generated by a fossil-fuelled or by a nuclear station, taking into account both capital and running costs. Estimates differed slightly, but there was every likelihood that a unit of nuclear electricity would cost only about one-fifth as much as a unit of fossil fuel electricity. On this basis nuclear power stations looked an excellent investment. In the ensuing years, the bases for these economic calculations varied. For a time the cost of oil remained low, while that of coal increased; some nuclear costs also increased, and the balance remained uncertain. By the late 1960s mounting public concern for the environment was drawing attention to the problems arising from large - scale use of fossil fuel: health hazards from underground coal-mining, ecological damage from surface mining, marine pollution from transport of oil, and air pollution from the burning of coal and oil. By contrast nuclear power stations seemed environmentally inoffensive. In the early 1970s the upward surge of oil prices, and increasingly uneasy labor relations in the coal-fields, added to the comparative economic attractions of nuclear power. The gradual and tentative industrial commitment to nuclear power for a time accelerated dramatically; so did the nuclear component of total electricity output. Governments wanted to lessen their dependence on the petroleum exporting countries; electricity supply systems wanted to lessen their dependence on coal, especially because of their vulnerability to recalcitrant unions. Nuclear electricity generation seemed the obvious alternative. In the longer term, it was argued, coal and oil would become irreplaceable raw materials for the chemical industry, and should be reserved for these uses, while nuclear energy was used for electricity. Electricity, it was further argued, is a premium form of energy, versatile, high-grade and clean at the point of use. It ought accordingly to make up an ever-larger proportion of the total energy used. Since nuclear sources could most readily be used to provide electricity, it all seemed to fit together very neatly. World energy use would continue to rise rapidly; so would energy use per person, as more and more people shared in the benefits of modern technology. One authoritative view foresaw a world in which world-wide energy consumption per person would be twice that of present-day Americans - this energy would be provided by some 4000 clusters of nuclear power stations, each cluster containing enough reactors to produce five times the output of today's largest power station. For such a high energy future the role of nuclear energy would be crucial. Only by the most vigorous possible growth of nuclear capability could humanity's energy requirements be met. Such an argument was in many ways persuasive. It was not, however, unanswerable, and while some voices were calling for more and larger reactors as fast as possible, other voices were asking other questions, some of which still remain difficult to answer. The earliest questioning derived from lingering public fear and distrust of nuclear energy, because of its first appearance as the most devastating weapon ever used. Gradually, certain specific issues crystallized out of the general unease. The world has somehow got used - albeit with deep unease and recurrent protest - to the overwhelming destructive 11 power stored in the nuclear arsenals of the USA, the Soviet Union, the U K, France and China; few would hesitate to identify these arsenals as the most terrible threat to the future of life on earth. But apart from these explicit military aspects of nuclear energy, several other aspects also give rise to concern. We sha ll examine these in some detail in the coming chapters. It must here suffice to mention them briefly, as issues which will recur repeatedly in later discussion. Nuclear reactors and other nuclear facilities produce and contain enormous quantities of material which is 'radioactive'. Some radioactive materials are very dangerous to living things, and may remain so for unimaginably long times. These materials must on no account be allowed to escape in quantity from nuclear facilities. Such facilities release small amounts of radioactivity to their surroundings during normal operations. One area of bitter controversy concerns the standards and controls applied to these releases. Some critics with impressive credentials consider present standards far too lax, especially if there is to be a continuing increase in the number and size of nuclear installations. Another major concern is operating safety, not only of the various designs of reactor themselves but also of their support facilities, including transport systems. It has become unpleasantly clear that such safety must take into account the possibility not only of accidents but also of sabotage, and even military attack. A protracted, expert disagreement about safety has plagued the most popular design of reactor, and continues unresolved. Other designs have not thus far been subjected to such intense independent scrutiny. One category of radioactive material arising from nuclear activities requires particular attention. This is the 'high-level' waste from used reactor fuel. High-level waste contains large amounts of substances which are dangerously radioactive, and will remain so for hundreds of years. What to do with these wastes is a question as yet unanswered. Provisional answers have been proposed, and interim management is said to be adequate, but in the long term the question becomes one not of technology but of ethics. Should we create these dangerous substances in ever-increasing quantities, to leave them to our remote descendants? Ethics aside, it has become abundantly apparent that considerations of safety affect the overall cost of nuclear power. Just as coal-mining must take account of the cost of health measures, land reclamation and pollution control, the use of nuclear power must allow for costs of extra safety measures and related provisions. The optimistic cost comparisons originating in the early 1950s, which favored nuclear over fossil fuels, no longer look unarguable, as we shall describe. Expenditure alone, however massive, seems unlikely to provide the requisite guarantees for one aspect which might narrowly be related to safety. As the world economy comes to rely more and more on nuclear reactors as a source of power, so traffic in 'fissile' materials increases - materials which can be made into nuclear weapons. Author inactive studies have shown that provision for the security of these materials is all too often perfunctory. The prospect of nuclear weapons in the hands of unstable governments, 12 terrorist organizations or deranged fanatics is not one calculated to encourage a rosy view of the global future. Dealing with this danger may entail special government nuclear police forces, relentless official probing of personal histories of nuclear employees, monolithic central administration of public policy, and other activities which come uncomfortably close to outlining a virtually totalitarian social structure. It becomes apparent, when considering these intractable problems, that the decisions we make about nuclear energy will determine in large measure the kind of world our grandchildren will inherit. The issues this technology has created constitute a remarkable microcosm of the present predicament of our planet. The nuclear predicament raises a host of social, political and even ethical problems, many of them with long-term implications beyond any foreseeable horizon. Clearly such issues demand the fullest public consideration, the widest possible participation in the crucial decisions to come. Public participation in nuclear decision-making has for too long been either tentative or desperate, largely because the issues have seemed to be cloaked in the most esoteric scientific obscurity. But the veil of mystery surrounding nuclear matters has always been primarily one of military secrecy, not of intellectual inaccessibility.

Chapter 2

Electricity

2.1 Energy and Electricity

Energy:

Energy is fundamental to the quality of human lives. Nowadays, we are totally dependent on an abundant and uninterrupted supply of energy for living and working. The simplest definition of energy can be given as "The ability of a system to perform work". In classical mechanics energy is conceptually and mathematically very useful property. Work, a form of energy, can be formulated as,

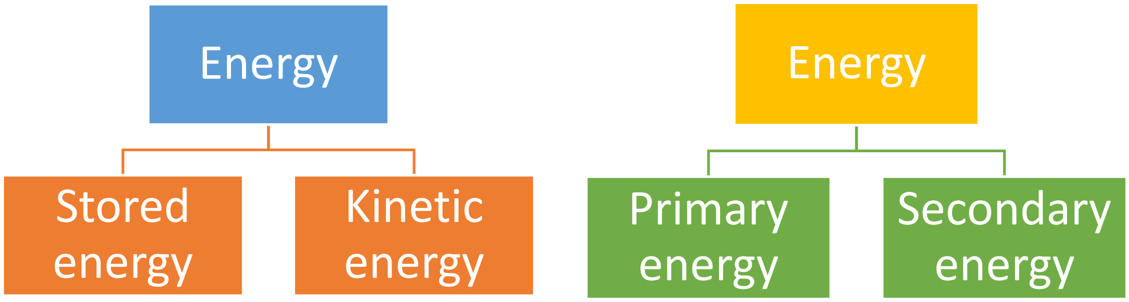
$W=\int_c F.ds$

This says that the work (W) is equal to the line integral of the force (F) along the path 'C'. To do work means transforming energy from one state to other. This implies the total work done by an object is energy. Work and thus energy is frame dependent.

Work is certainly an important 'manifestation' of energy but it is not the only 'palpable' form of energy. Energy can exist in many forms. It can be transferred from one form to other. Hence, a more complete definition of energy can be given as,

"*Energy is a property of objects which can be transferred to other objects or converted into different forms*"

Energy can be found in different forms. It can be categorized in two ways.



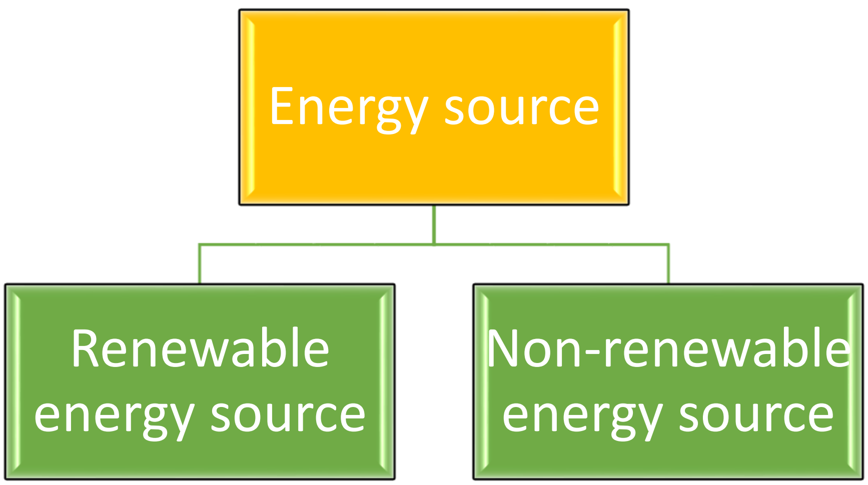
Stored energy is the energy of an object due to its position.

Kinetic energy is the energy of mass in motion. Ex: Blowing wind

Primary energy is an energy form found in nature that has not been subjected to any conversion or transformation process.
Secondary energy is one that is made using primary energy. Ex: electrical energy.
A brief discussion about other different types of energy is given below:

Types of energy	Explanation	Example
Mechanical energy	Sum of kinetic energy and potential energy	Moving objects such as vehicles
Electrical energy	Energy that is caused by moving of electric charges	Batteries in a cell phone
Thermal energy	The internal energy present in a system due to its temperature	Electric heater
Nuclear energy	Source of power which is created from energy released by a nuclear reaction	Nuclear fission

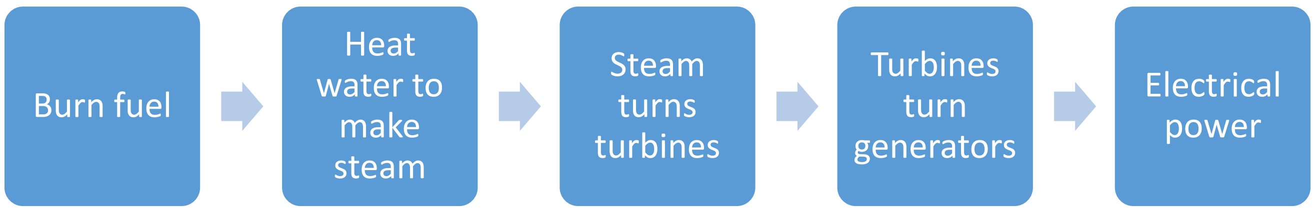
In physics there is a universal law of conservation of energy which says that the total energy of an isolated system remains constant, in other words it is said to be conserved over time. Energy can neither be created nor destroyed, rather it can be transformed to different forms. For example, electrical energy can be converted to light energy in electric bulbs.
A source from which useful energy can be extracted or recovered either directly or by means of conversion or transformation process is called energy source. Energy sources can be classified in different manners.



1. **Renewable energy source:** Renewable energy is defined as the energy that is collected from resources which are naturally replenished on a human timescale. This source of energy is always available in nature. For example, sunlight, water, wind etc. are known as renewable energy source.
2. **Non-renewable energy source:** Non-renewable energy comes from sources that will run out or will not replenished in our lifetimes or even in many, many lifetimes. Most non-renewable energy sources are fossil fuels such as coal, petroleum, natural gas etc.

Electricity:
Electricity is the most widely used form of energy. To understand electricity the concept of ‘charge’ must be clear. ‘Charge’ is a physical property of a matter that causes it to experience

force when it is placed in an electric field. There are two types of charges which are ‘positive charge’ and ‘negative charge’. Like charges repel and unlike charges attract.
Electricity is associated with the presence and flow of electric charge. Electricity is actually the secondary form of energy. It can be produced by the conversion of other energy sources. Electricity is produced from the primary source of energy. It can be produced from either renewable energy source or non-renewable energy source. By using the primary energy source as fuel, electricity can be generated from the conversion of thermal energy and mechanical energy.



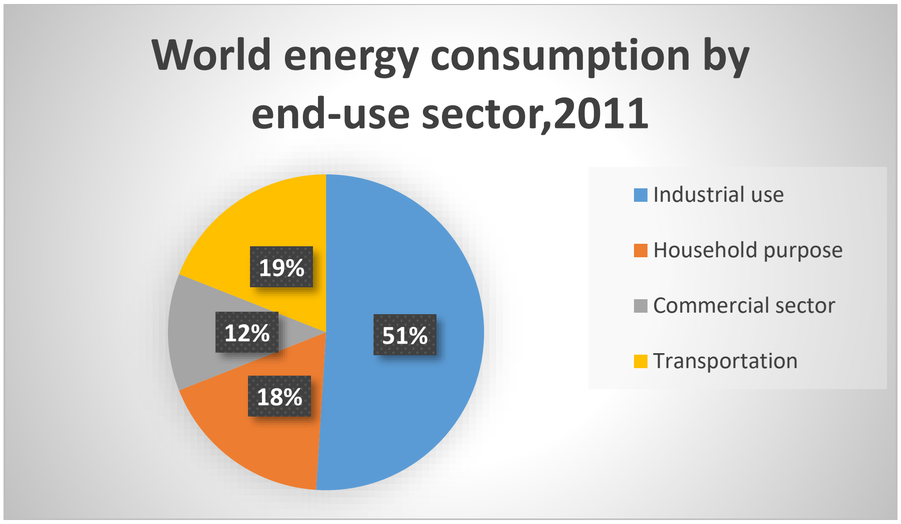
Electricity is something that people cannot live without. In almost every step of human lives, electricity is necessary. Electricity is a constitutional right of a human. An industry can never be thought without the electricity. A nation can never progress without sufficient electricity. The economic status of a country depends on the per capita consumption of electricity. Thus electricity is very important in human life.

2.2 Electricity and Economic Development

Access to electricity is a constitutional right of a human being. Without electricity life can never be thought. Electricity is used virtually in every minute of every single day. The major application areas of electricity can be divided as the following:

1. Industrial use
2. Households purpose
3. Commercial sector
4. Transportation

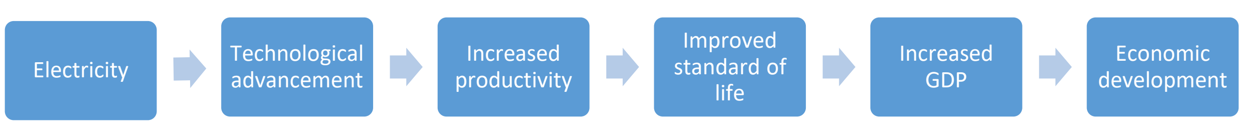
Industries have many kinds of machines and these machines are fully dependent on electricity. Industrial area of using electricity includes mostly manufacturing case.
Another very important use of electricity is for household purpose. Most of the household works are dependent upon electricity such as heating, lighting, cooking, refrigerating, washing etc.



Commercial sector includes retail, office, educational institution, government buildings, public street lighting etc. The major use of electricity in this areas are ventilation, cooling, powering computers, security purpose, powering elevators etc.
From the discussion above, it is clear that electricity being applicable in almost every sector, is so vital for a country. Thus adequate production of electricity is related to the economic growth of a country. Economic growth can be defined as a positive change in the level of goods and services produced by a country over a certain period of time. Economic growth is directly related to percentage increase in GNP of a country. In real sense, economic growth is related to increase in per capita national output or net national product of a country that remain constant or sustained for many years. There are some important factors that affect the economic growth of a country.

1. **Standard of living:** To increase GDP, country must ensure a better quality of life.
2. **Natural resources:** Countries that have a lot of natural resources are able to use them to produce goods & services cheaper than a country that has to import natural resources.
3. **Technological development:** Technological development helps in increasing productivity with the limited amount of resources. The selection of right technology also plays a role for the growth of an economy.
4. **Investment in capital goods:** To increase GDP, country must invest in capital goods. For this case, factories and industries must always be in operation.

To cope up with the above mentioned factors, access of electricity is must. At present world, overall development is dependent largely upon technological advancement. Technological advancement is impossible without electricity.
As a whole, this can be demonstrated by the following flow diagram



Human development reports by UNDP suggests that the countries with better HDI have better access and production of electricity than the countries with low HDI.

Serial No	Name of the countries	Population (in millions)	HDI ranking	Per capita GDP (US$)	Per capita electricity consumption (KWh per person)	Primary energy consumption (million BTU per person)
1.	Norway	5	1	74,822	23,485	386.7821
2.	Australia	24	2	50,962	9,485	282.5536
3.	Switzerland	8	3	80,675	7,315	157.5292
4.	Denmark	5	4	52,114	6,026	142.8904
5.	Netherlands	17	5	43,603	6,920	244.7931
6.	Germany	81	6	40,997	7,191	165.4359
7.	USA	321	8	55,805	12,185	312.7856
8.	Singapore	6	11	52,888	7,764	578.6075
9.	Sweden	10	14	49,866	13,986	235.8462
10.	United Kingdom	65	14	43,771	5,071	134.4848
11.	Korea(S)	51	17	27,195	9,165	231.9725
12.	Japan	127	20	32,486	6,763	164.0746
13.	France	64	22	37,675	6,986	165.941
14.	Qatar	2	32	76,576	9,660	790.3388
15.	Saudi Arabia	31	39	20,813	6,680	339.0145
16.	United Arab Emirates	10	41	36,060	15,131	728.423
17.	Kuwait	4	48	29,363	17,030	577.2546
18.	Russia	144	50	9,055	7,285	213.3957
19.	Malaysia	31	62	9,557	3,724	108.7642
20.	Brazil	204.5	75	8,670	2,249	60.18965
21.	China	1372	90	7,990	3,925	77.54149
22.	Egypt	89	108	3,740	1,408	41.64045
23.	Indonesia	256	110	3,362	623	25.67914
24.	India	1314	130	1,697	565	19.747
25.	Bangladesh	160	142	1,287	233	6.41709
26.	Pakistan	199	147	1,450	357	13.54428
27.	Nigeria	182	152	2,743	115	4.98645
28.	Cameroon	24	153	1,232	223	6.08944
29.	Sudan	41	167	2,175	159	6.69117
30.	Afganistan	32	171	600	78	4.12351
31.	Chad	14	185	943	7	0.34302

2.3 Primary Energy Sources

Energy is the capacity to do work and is required for life processes. An energy resource is something that can produce heat, power life, move objects, or produce electricity. Matter that stores energy is called a fuel. Human energy consumption has grown steadily throughout human history. Early humans had modest energy requirements, mostly food and fuel for fires to cook and keep warm. In today's society, humans consume as much as 110 times as much energy per person as early humans. Most of the energy we use today come from fossil fuels (stored solar energy). But fossils fuels have a disadvantage in that they are non-renewable on a human time scale, and causes other potentially harmful effects on the environment. In any event, the exploitation of all energy sources (with the possible exception of direct solar energy used for heating), ultimately rely on materials on planet Earth.

Primary energy is an energy form found in nature that has not been subjected to any conversion or transformation process. It is the energy contained in raw fuels and other forms of energy received as input to a system. Primary energy can be renewable or non-renewable.

Primary energy sources take many forms including nuclear energy, fossil energy like oil, coal and natural gas and renewable energy sources like wind, solar, geothermal and hydropower. These primary energy sources are converted into electricity, a secondary energy source which flows through power lines and other transmission infrastructure to our home and business.

Now here we are discussing about the Primary Energy Sources.

2.3.1 Fossil Fuels

Fossil fuels are fuels formed by natural processes such as anaerobic decomposition of buried dead organisms. The age of the organisms and their resulting fossil fuels is typically millions of years and sometimes exceeds 650 million years. Fossil fuels contain high percentages of carbon and include petroleum, coal and natural gas. Other commonly used derivatives include kerosene and propane. Fossil fuels range from volatile materials with low carbon-hydrogen ratios like methane, to liquid like petroleum, to nonvolatile materials composed of almost pure carbon like anthracite coal. Methane can be found in hydrocarbon fields either alone, associated with oil or in the form of methane clathrates.

The theory that fossil fuels formed from the fossilized remains of dead plants by exposure to heat and pressure in Earth's crust over millions of years was first introduced by Geogius Agricola in 1556 and later by Mikhali Lomonosov in the 18^{th} century.

The origin of fossil fuels, and biomass energy in general, starts with *photosynthesis*. Photosynthesis is the most important chemical reaction to us as human beings, because without it, we could not exist. Photosynthesis is the reaction that combines water and carbon dioxide from the Earth and its atmosphere with solar energy to form organic molecules that make up plants and oxygen essential for respiration. Because all life forms depend on plants for nourishment, either directly or indirectly, photosynthesis is the basis for life on Earth.

$$nCO_2 + nH_2O + \text{Energy} \longrightarrow C_nH_{2n}O_n + nO_2$$

Carbon Dioxide, Water (from atmosphere); Solar Energy; Simple Sugar (Plant matter); Oxygen to atmosphere

Fossil Fuels to electricity:

Fossil fuel power stations have machinery to convert the heat energy by burning the fuels into mechanical energy which then operates an electrical generator. The prime mover may be a steam turbine, gas turbine or both of them combined.

Coal:

Coal is a fossil fuel and is the altered remains of prehistoric vegetation that originally accumulated in swamps and peat bogs. The energy we get from coal today comes from the energy that plants absorbed from the sun millions of years ago.

Types of coal:

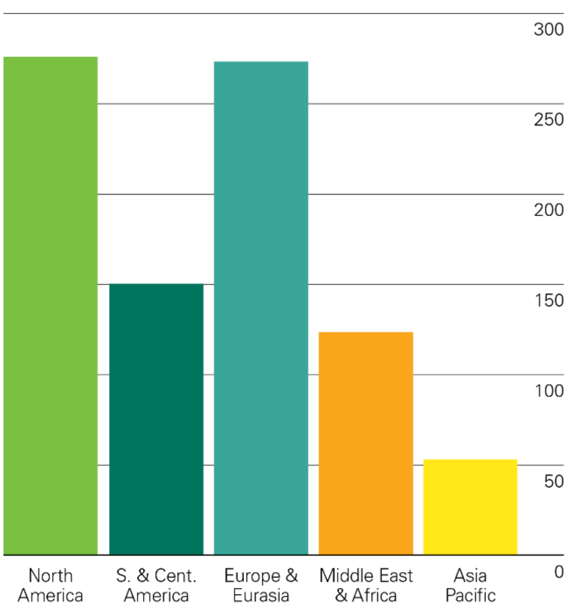
Low rank coals	High rank coals
• **Softer**	• Harder and stronger
• **Earthy appearance**	• Lower moisture levels
• **High moisture levels**	• High carbon content
• **Low carbon content**	• High energy content
• **Low energy content**	• Heat content <35,300 KJ/Kg
• **Heat content <28,700 KJ/Kg**	

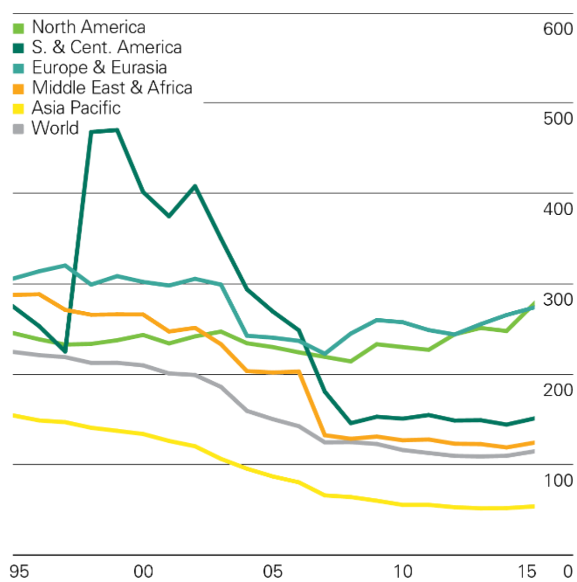
Coal reserve to production ratios:

Reserve to production ratio the ratio that indicates the remaining lifespan of a natural resource. This ratio is expressed in terms of years, and is used in forecasting the future availability of a resource to determine project life, income, employment etc.

$$\text{RPR} = \frac{\textbf{amount of known resource}}{\textbf{amount used per year}}$$

World proved coal reserves in 2015 were sufficient to meet 114 years of global production, by far the largest R/P ratio for any fossil fuel. By region, Europe & Eurasia holds the largest proved reserves while North America has the highest R/P ratio – 276 years. The Asia Pacific region holds the second-largest reserves, but higher rates of production – accounting for 70.6% of global output – leave it with the lowest regional R/P ratio (53 years). The following charts show the coal reserve by region (left) and the coal reserve growth by year (right).



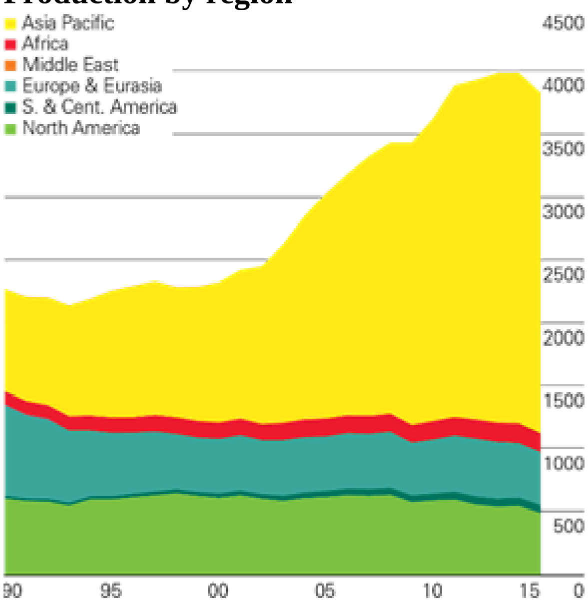


Source: BP statistical review of world energy, 2016

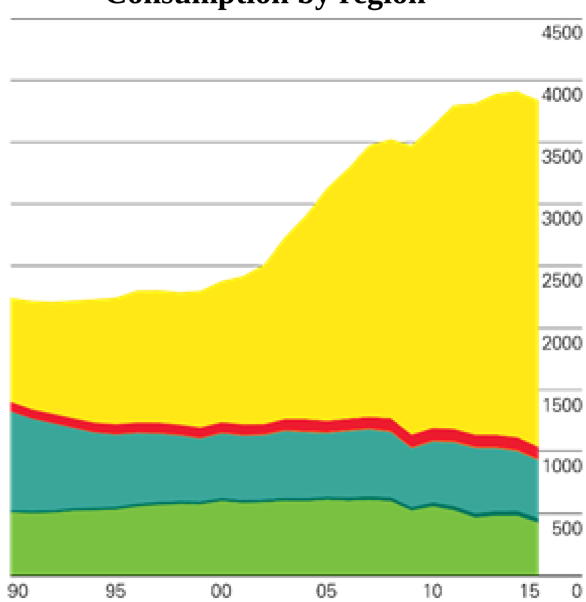
Coal production vs. consumption by region (Million tonnes oil equivalent):

World production and consumption of coal declined in 2015, by 4% and 1.8%, respectively. Production fell for the first time since 1998, with large declines in Asia Pacific (-2.9%) and North America (-10.3%). China remained by far the world's largest producer even though output fell by 2%. Coal consumption declined in all regions except South & Central America and Asia Pacific. The US and China accounted for all of the net decline in global consumption.

Production by region



Consumption by region



Source: BP statistical review of world energy, 2016

Merits and demerits of Coal:

Merits	Demerits
• **Inexpensive energy source**	• High emission of greenhouse gases (13,787 Million Metric Tons per year)
• **A versatile energy source**	• Mining destruction
• **Independent of weather**	• Generation of huge waste
• **Known technology**	

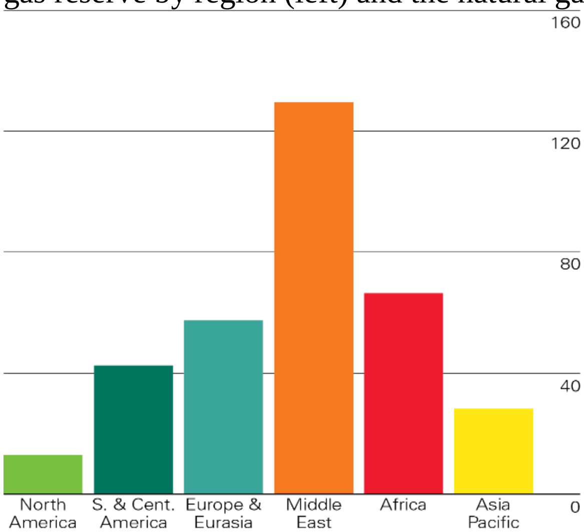
Natural Gas:

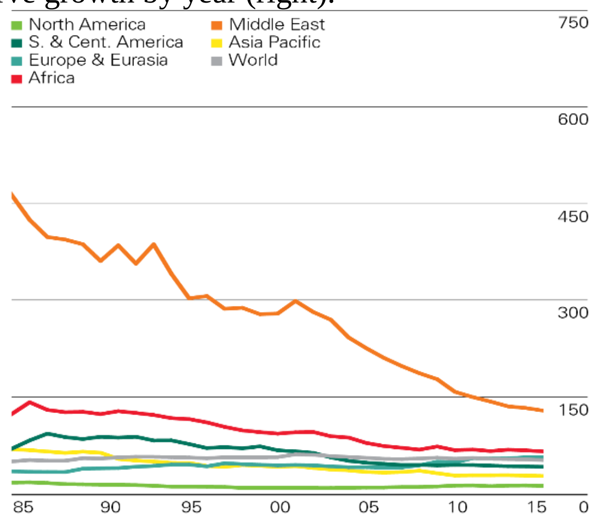
Natural gas is a naturally occurring hydrocarbon gas mixture consisting primarily of methane but commonly including varying amounts of other higher alkanes and sometimes a small percentage

of carbon dioxide, nitrogen, hydrogen sulfide or helium. It is formed when layers of decomposing plant and animal matter are exposed to intense heat and pressure supplied by existing under the surface of the Earth over millions of years. The energy that the plants originally obtained from the sun is stored in the form of chemical bonds in the gas.
Natural gas is a fossil fuel used as a source of energy for heating, cooking and electricity generation. It is a major source of electricity generation through the use of gas turbines and steam turbines. It is also well suited for a combined use in association with renewable energy sources such as wind or solar. Natural gas burns more cleanly than other hydrocarbon fuels such as oil and coal. It produces less carbon dioxide per unit of energy released. Burning natural gas produces about 30% less carbon dioxide than burning petroleum and 45% less carbon dioxide than coal.

Reserve to Production ratio of Natural Gas:

Global proved natural gas reserves in 2015 fell slightly (by 0.1 trillion cubic meters) to 186.9 tcm, sufficient to meet 52.8 years of current production. Small declines in Russian and Norwegian reserves drove the decline. Reserves have increased by 29.6 tcm over the past decade. The Middle East region holds the largest proved reserves (80 tcm, 42.8% of the global total), and has the highest regional R/P ratio (129.5 years). The following charts show the natural gas reserve by region (left) and the natural gas reserve growth by year (right).



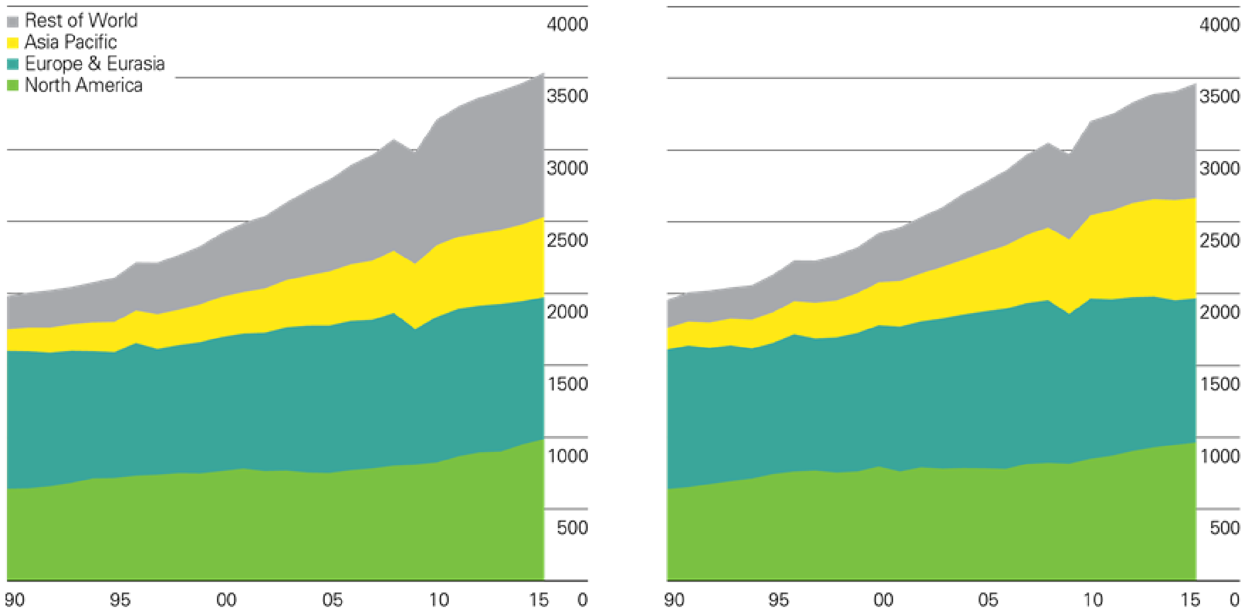


Source: BP statistical review of world energy, 2016

Natural Gas production vs. consumption by region:

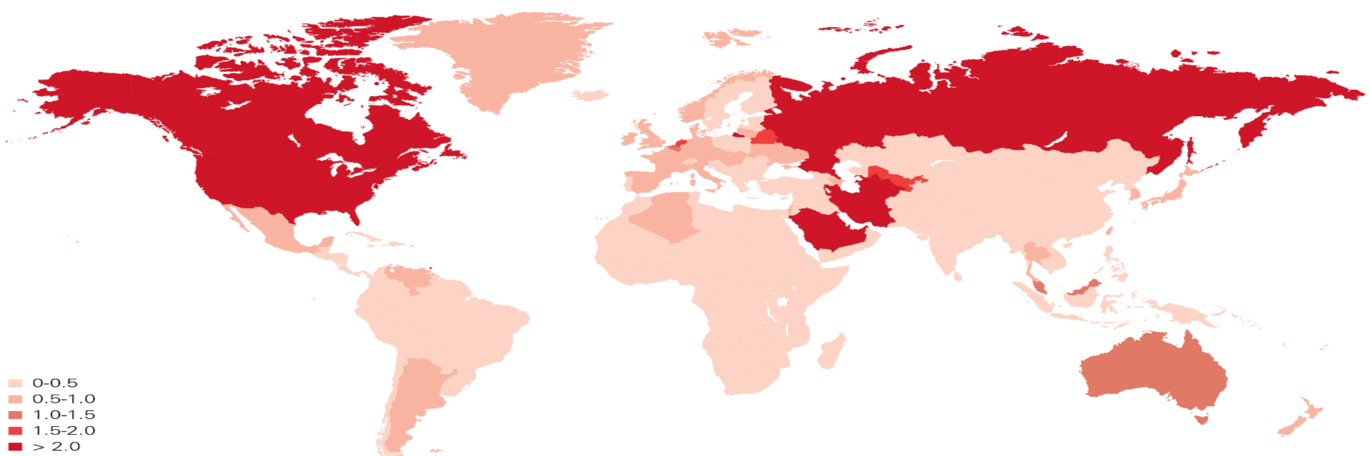
World natural gas production growth accelerated to 2.2% in 2015, slightly below the 10-year average growth of 2.4%. North America (+3.9%) recorded the largest growth increment while production in Europe & Eurasia declined by 0.7%, with large declines in the Netherlands and Russia. Consumption growth (+1.7%) also accelerated from a very weak 2014, but remained below the 10-year average of 2.3%. The Middle East recorded the strongest regional growth rate (+6.2%), while consumption in Europe & Eurasia declined by 0.3%.

Production by region **Consumption by region**



Source: BP statistical review of world energy, 2016

Per capita Gas consumption:



Source: BP statistical review of world energy, 2016

Merits and Demerits of Natural Gas:

Merits	Demerits
• **Less harmful than coal or oil** • **Easy storage and transport** • **Burns cleaner** • **Versatility**	• Toxic and flammable • High emission of greenhouse gases (6,799 Million Metric Tons per year) • Expensive installation

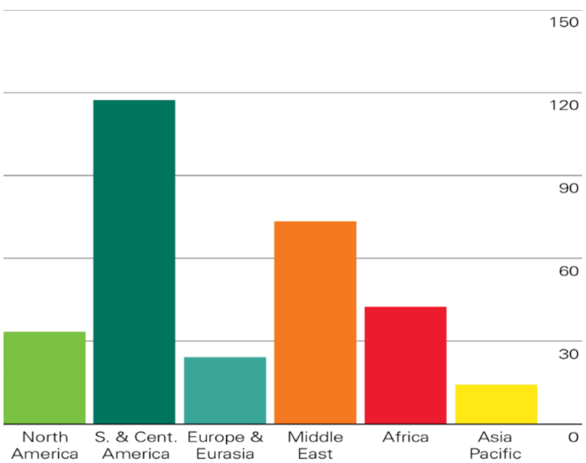
Oil:

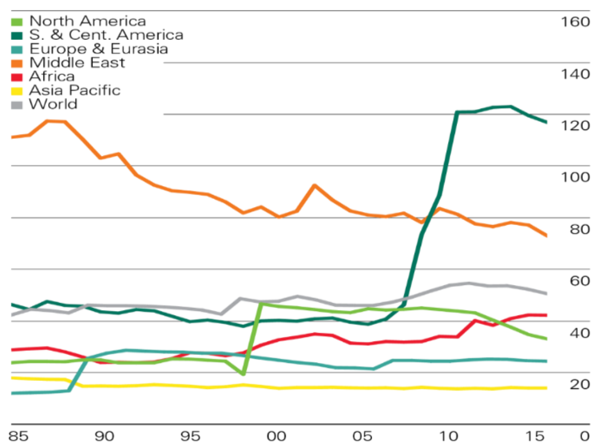
Petroleum is a naturally occurring yellow to black liquid found in geological formations beneath the Earth's surface which is commonly refined into various types of fuels. It consists of hydrocarbons of various molecular weights and other organic compounds. The name petroleum covers both naturally occurring unprocessed crude oil and petroleum products that are made of refined crude oil. Petroleum is formed when large quantities of dead organisms usually zooplankton and algae, are buried underneath sedimentary rock and subjected to both intense heat and pressure.

The hydrocarbons in crude oil are mostly alkanes, cycloalkanes and various aromatic hydrocarbons while the other organic compounds contain nitrogen, oxygen and sulfur, and trace amount of metals such as iron, nickel, copper and vanadium.

Oil reserve to production ratios:

Global proved oil reserves in 2015 fell by 2.4 billion barrels (-0.1%) to 1697.6 billion barrels. Reserves have nonetheless increased by 24%, or 320 billion barrels, over the past decade and are sufficient to meet 50.7 years of global production. Brazil recorded the largest decline, with proved reserves falling by 3.2 billion barrels, while Norwegian proved reserves grew by 1.5 billion barrels. OPEC countries continue to hold the largest share (71.4%) of global proved reserves. On a regional basis, South & Central American reserves have the highest R/P ratio, 117 years. The following charts show the oil reserve by region (left) and the natural gas reserve growth by year (right).



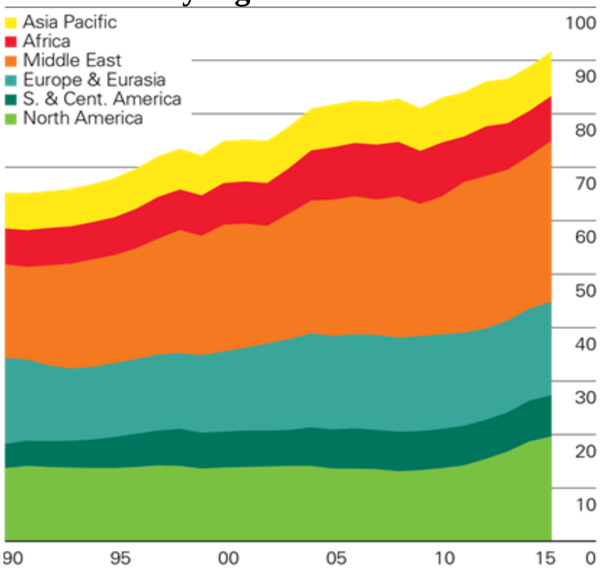


Source: BP statistical review of world energy, 2016

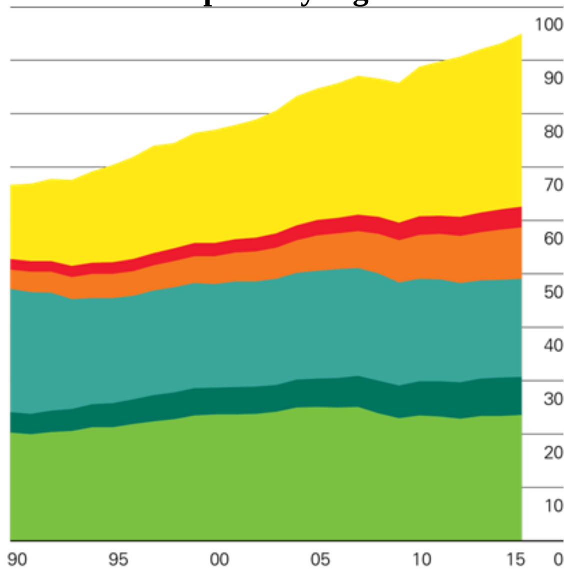
Oil production vs. consumption by region (Millions barrels daily):

World oil production growth in 2015 significantly exceeded the growth in oil consumption for a second consecutive year. Production grew by 2.8 million b/d, led by increases in the Middle East (+1.5 million b/d) and North America (+0.9 million b/d). Global oil consumption increased by 1.9 million b/d, nearly double the 10-year average, with above-average growth driven by OECD countries. The Asia Pacific region accounted for 74% of global growth, with China once again contributing the largest national increment to global oil consumption growth (+770,000 b/d).

Production by region



Consumption by region



Source: BP statistical review of world energy, 2016

Merits and Demerits of oil:

Merits	Demerits
• **High energy density** • **Easy availability and transportation** • **Constant power source**	• High emission of greenhouse gases (11,695 Million Metric Tons per year) • Growth in terrorism and violence

2.3.2 Renewable Sources

Renewable energy can be defined as the energy that is collected from resources which are naturally replenished on a human timescale. Renewable energy resources exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. At the national level at least 30 countries around the world already have renewable energy contributing more than 20% of energy supply. National renewable energy markets are projected to continue to grow strongly in the coming decade and beyond.

Types of Renewable Energy sources:

- Solar Energy: **It is the energy that is found from the radiant light and heat from the sun, is harnessed using an ever evolving technologies such as solar heating, photovoltaic, artificial photosynthesis etc. to produce electricity.**
- Wind Energy: Airflows can be used to run wind turbines which is coupled with a generator which produces electricity.
- Hydro Energy: It is the energy of falling water of fast running water, which is harnessed for running turbine and thus electricity is generated.
- Geothermal Energy: High temperature geothermal energy is from thermal energy generated and stored in the Earth.

- Bio Energy: It refers to plants or plant derived materials which are specifically called lignocellulose biomass. It can be used directly via combustion to produced heat.

Renewable Energy situation worldwide:
The following table shows the data of the total capable energy source over the whole world for generating electricity.

Renewable energy source	Total capacity (GW)
Hydropower	1064
Bio energy	106
Geo thermal energy	13.2
Solar energy	227
Wind energy	433

Source: REN21, Global status report, 2016

Top countries for producing electricity using renewable energy sources:
A portfolio of renewable energy technologies is becoming cost-competitive in an increasingly broad range of circumstances, in some cases providing investment opportunities without the need for specific economic support and cost reduction in critical technologies such as wind and solar are set to continue.

Renewable energy source	Ranking				
	1	**2**	**3**	**4**	**5**
Solar energy	Germany	Italy	Belgium	Japan	Greece
Hydro power	China	Brazil	Canada	USA	Russia
Bio energy	USA	China	Germany	Brazil	Japan
Geo thermal energy	USA	Philippines	Indonesia	Mexico	New Zealand
Wind energy	Denmark	Sweden	Germany	Ireland	Spain

Source: REN21, Global status report, 2016

2.3.3 Nuclear Fuels

Nuclear fuel is a substance that is used in nuclear power stations to produce heat to power turbines. Heat is created when nuclear fuel undergoes nuclear fission. Most nuclear fuels contain heavy fissile elements that are capable of nuclear fission, such as uranium-235 or plutonium-239. Nuclear fuel has the highest energy density of all practical fuel sources.

Types of nuclear fuel:

Oxide fuel	**UOX**	➢ **It is heated to form U_3O_8 that can then be converted by heating in an argon / hydrogen mixture to form UO_2** ➢ **The thermal conductivity of uranium dioxide is very low**
	MOX	➢ MOX fuel, is a blend of plutonium and natural or depleted uranium

		➢ An alternative to low enriched uranium (LEU) fuel used in the light water reactors which predominate nuclear power generation
Metal fuel	TRIGA fuel	➢ TRIGA fuel is used in TRIGA (Training, Research, Isotopes, General Atomics) reactors ➢ Uses UZrH fuel, which has a prompt negative fuel temperature coefficient of reactivity
	Actinide fuel	➢ Metal actinide fuel is typically an alloy of zirconium, uranium, plutonium, and minor actinides
	Molten Plutonium	➢ Molten plutonium, alloyed with other metals to lower its melting point
Ceramic fuel	➢ Uranium Nitride ➢ Uranium Carbide	
PWR fuel	➢ Pressurized Water Reactor (PWR) fuel consists of cylindrical rods put into bundles ➢ A uranium oxide ceramic is formed into pellets and inserted into Zircaloy tubes that are bundled together ➢ The fuel bundles usually are enriched several percent in ^{235}U	
BWR fuel	➢ Boiling Water Reactor (BWR), the fuel is similar to PWR fuel except that the bundles are "canned" ➢ In modern BWR fuel bundles, there are either 91, 92, or 96 fuel rods per assembly depending on the manufacturer	

Present Scenario of Nuclear Fuel over the World:

Nuclear power currently contributes about 11% of world electricity supply and is projected by the International Energy Agency to grow steadily in the next 20 years. Electricity demand growth is low in most of the countries where nuclear power is well established, but remains strong in many developing countries and it is in these countries that the great majority of nuclear capacity growth is to be expected. Until the Fukushima accident in Japan in March 2011, the outlook for nuclear power around the world was improving. Despite the setback that Fukushima represents, many countries are putting more emphasis on satisfying environmental and security of supply objectives in their energy strategies, which should favor increased nuclear power. Three scenarios for world nuclear generating capacity up to 2035 have been prepared, referred to as the Reference, Upper and Lower Scenarios. At mid-2015, world nuclear capacity was 379 GWe. In the Reference Scenario this is expected to rise to 404 GWe by 2020 and to 552 GWe by 2035. In the Upper Scenario, the equivalent figures are 429 GWe in 2020 and 720 GWe in 2035. In the Lower Scenario, nuclear generating capacity effectively stagnates in the period to 2030 and then drops away with many reactor closures in the period to 2035.

World known resources of uranium are more than adequate to satisfy reactor requirements to well beyond 2035. World uranium production has stopped rising, falling to 56,250 tU in 2014. The currently depressed uranium prices have curtailed exploration activities and the opening of new mines; in some cases, existing mines have stopped production.

Chapter 3

Bangladesh

3.1 General

Bangladesh is a sovereign country in South Asia. Located at the apex of the Bay of Bengal. The area of Bangladesh is 143,998 sq km & bordered by India and Myanmar and is separated from Nepal and Bhutan. Bangladesh is the world's eighth-most populous country and the third-most populous among Muslim-majority countries. The official Bengali language is the sixth most-spoken native language in the world. Poverty is deep and widespread, but Bangladesh has in recent years reduced population growth and improved health and education. Islam is the largest religion in Bangladesh, making up 90.0% of the population. The majority of Bangladeshi Muslims are Sunni, followed by the Shia and Ahmadiya. Formerly East Pakistan, Bangladesh came into being only in 1971, when the two parts of Pakistan split after a bitter war which drew in neighboring India. The low-lying country is vulnerable to flooding and cyclones, and stands to be badly affected by any rises in sea levels.

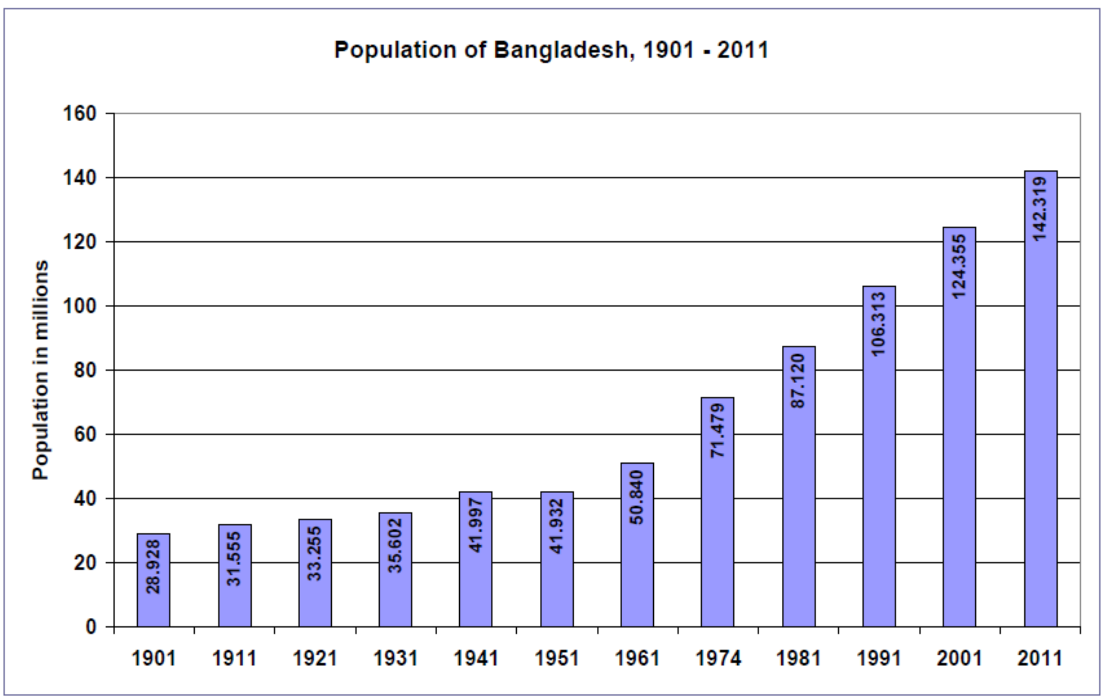
3.2 Population

The population of Bangladesh as of 15 March 2011 is 142.3 million (census 2011 result), much less than recent (2007–2010) estimates of Bangladesh's population ranging from 150 to

170 million and it is the 8th most populous nation in the world. In 1951, the population was 44 million. It is also the most densely populated large country in the world, and it ranks 11th in population density, when very small countries and city-states are included.
Bangladesh's population growth rate was among the highest in the world in the 1960s and 1970s, when its population grew from 65 to 110 million. With the promotion of birth control in the 1980s, the growth rate began to slow. The fertility rate now stands at 2.55, lower than India (2.58) and Pakistan (3.07) The population is relatively young, with 34% aged 15 or younger and 5% 65 or older. Life expectancy at birth is estimated to be 70 years for both males and females in 2012. Despite the rapid economic growth, about 26% of the country still lives below the international poverty line which means living on less than $1.25 per day. Bengalis constitute 98% of the population.

Population**:**
168,957,745 (July 2015 EST.)
Country comparison to the world**:** 9

Graph 1: Population figure of the territory now forming Bangladesh, since 1901.

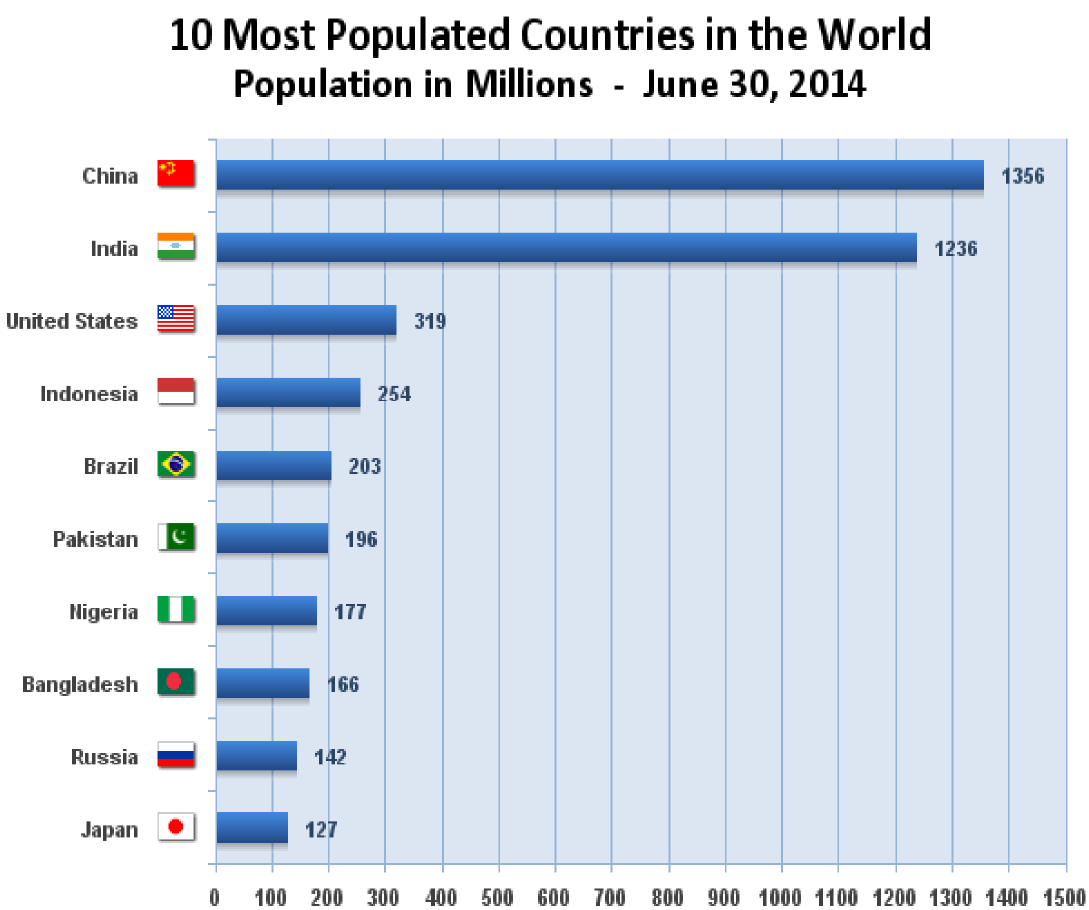


Note: Enumerated population for 1974-2011, adjusted population for previous censuses.

Table D: Population and growth rate in selected Asian countries, 2010

Country	Population 2010 (millions)	Average population growth rate % (2005-2010)
Thailand	61.8	0.7
Myanmar	50.5	0.9
Sri Lanka	20.4	0.9
Bangladesh	**142.3**	**1.3**
India	1,214.5	1.4
Malaysia	27.9	1.7
Nepal	29.9	1.8
Pakistan	184.8	2.2
Singapore	4.8	2.5

Source: *State of the world population 2010*, UNFPA,
except for Bangladesh: *2011 Population & Housing Census, Preliminary Results*



3.3 ECONOMY

Bangladesh's economy has grown roughly 6% per year since 1996 despite political instability, poor infrastructure, corruption, insufficient power supplies, slow implementation of economic reforms, and the 2008-09 global financial crisis and recession. Although more than half of GDP is generated through the service sector, almost half of Bangladeshis are employed in the agriculture sector with rice as the single-most-important product.

Garment exports, the backbone of Bangladesh's industrial sector, accounted for more than 80% of total exports and surpassed $25 billion in 2015. The sector continues to grow, despite a series of factory accidents that have killed more than 1,000 workers, and crippling strikes, including a nationwide transportation blockade implemented by the political opposition during the first several months of 2015. Steady garment export growth combined with remittances from overseas Bangladeshis - which totaled about $15 billion and 8% of GDP in 2015 are the largest contributors to Bangladesh's sustained economic growth and rising foreign exchange reserves.

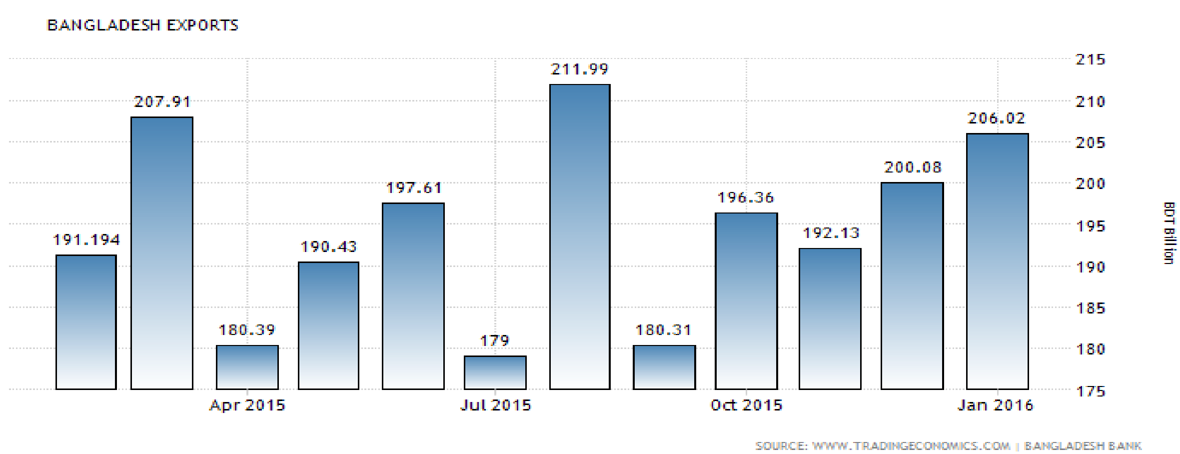


TABLE:
SOUTH ASIA: RATES OF GROWTH OF REAL GDP, 2009-2014

	2009	2010	2011	2012[a]	2013[b]	2014[b]
SOUTH ASIA	7.0	8.3	5.8	4.4	5.0	5.7
BANGLADESH	5.7	6.1	6.7	6.2	6.3	6.4
INDIA	8.2	9.6	6.9	5.5	6.1	6.5
IRAN, ISLAMIC REPUBLIC OF	4.0	5.9	2.0	-1.9	-0.9	1.5
NEPAL	4.5	4.8	3.9	4.0	3.7	4.0
PAKISTAN	3.6	3.5	3.0	3.8	4.2	4.4
SRI LANKA	3.5	8.0	8.3	6.5	6.7	6.4

SOURCE: UN/DESA, BASED ON DATA OF THE UNITED NATIONS STATISTICS DIVISION AND INDIVIDUAL NATIONAL SOURCES.

GDP growth in the Key Trading Partners (%)					
	2013	2014	2015	2016*	2017*
World	3.17	3.35	2.90	3.31	3.56
United States	1.49	2.43	2.43	2.52	2.39
United Kingdom	2.16	2.94	2.41	2.39	2.26
Germany	0.41	1.58	1.52	1.81	2.03
Euro area (15 countries)	-0.28	0.88	1.50	1.75	1.94
OECD - Total	1.21	1.85	2.01	2.23	2.28
France	0.75	0.17	1.07	1.34	1.63
Spain	-1.67	1.36	3.16	2.73	2.49
Turkey	4.19	2.91	3.15	3.43	4.08
Netherlands	-0.41	1.01	2.21	2.45	2.70
Japan	1.59	-0.10	0.59	0.96	0.53
Italy	-1.75	-0.38	0.76	1.44	1.40
India	6.90	7.29	7.21	7.33	7.37
China	7.70	7.30	6.75	6.54	6.22
Canada	2.00	2.44	1.18	1.99	2.33
Belgium	0.02	1.35	1.30	1.46	1.63
Source: OECD					
*Projected					

3.4 DEVELOPMENT GOALS

Goal 1: Eradicate extreme poverty and hunger

- Reduce micronutrient deficiencies among vulnerable children in selected underachieving districts.
- Increase access to improved health and basic education services in underserved areas, focusing on children from poor urban communities and the Chittagong Hill Tracts (CHT).

Goal 2: Achieve universal primary education

- Contribute to government primary education targets for boys and girls:
    - 95 per cent net enrolment rate
    - 85 per cent completion
    - 65 per cent achievement of nationally defined competencies.
- Provide quality non-formal primary education to 200,000 working children between the ages of 10 and 14.

Goal 3: Promote gender equality and empower women

- Educate and encourage 1 million adolescent girls and boys, their families and their communities to reduce child marriage, dowry and other forms of abuse, exploitation and violence against girls.

Goal 4: Reduce child mortality

- Achieve 85 per cent immunization coverage of children under-one against the six childhood diseases in all low coverage districts.
- Motivate caregivers of children under-five to practice a set of essential child care behaviors.
- Reduce drowning and other injury-related deaths from 48 to 40 per 100,000 children aged one to seventeen in selected sub-districts.

Goal 5: Improve maternal health

- Increase the accessibility, number and quality of obstetric care facilities nationwide and encourage women to seek help from maternal and neonatal health services.

Goal 6: Combat HIV/AIDS, malaria and other diseases

- Educate 30 per cent of adolescents aged ten to eighteen in selected districts on HIV/AIDS, empowering them to reduce their vulnerability to the virus.
- Provide comprehensive prevention of parent to child transmission (PPTCT) packages including antiretroviral prophylaxis, treatment and support to 80 per cent of HIV-positive pregnant women, their spouses and children.
- Protect children made vulnerable by HIV and AIDS by providing care and support services.

Goal 7: Ensure environmental sustainability

- Improve standards of sanitation, safe water and hygiene behavior on a sustainable basis, among 30 million people.
- Contribute to government water and sanitation targets:
    - 100 per cent access to safe water by 2011
    - 100 per cent access to sanitation facilities by 2013.

Goal 8: Develop a Global Partnership for Development

- Partner with national and international media to advocate for the rights and participation of Bangladeshi children and women.
- Contribute to the development of more effective legislative and enforcement systems to protect children. Advance the appointment of an independent Child Rights Commissioner to address children's issues.

Chapter 4

Nuclear Power

4.1 Nuclear Reaction:

A nuclear reaction is considered to be the process in which two nuclear particles (two nuclei or a nucleus and a nucleon) interact to produce two or more nuclear particles or γ-rays (gamma rays). Thus, a nuclear reaction must cause a transformation of at least one nuclide to another.
Sometimes if a nucleus interacts with another nucleus or particle without changing the nature of any nuclide, the process is referred to a nuclear scattering, rather than a nuclear reaction.
In principle a reaction can involve more than two particles colliding, but such an event is exceptionally rare.
If the particles collide and separate without changing, the process is called an elastic collision rather than a reaction.
A nuclear reaction can be represented by an equation similar to a chemical equation, and balanced in an analogous manner.
In principle, a reaction can involve more than two particles colliding, but because the probability of three or more nuclei to meet at the same time at the same place is much less than for two nuclei, such an event is exceptionally rare. "Nuclear reaction" is a term implying an induced change in a nuclide, and thus it does not apply to any type of radioactive decay (which by definition is a spontaneous process).
Natural nuclear reactions occur in the interaction between cosmic rays and matter, and nuclear reactions can be employed artificially to obtain nuclear energy, at an adjustable rate, on demand.
There are two types of nuclear reaction. They are -1) Nuclear Fission Reaction & 2) Nuclear Fusion Reaction.

4.1.1 Nuclear Fission Reaction:

The most notable man-controlled nuclear reaction is the fission reaction which occurs in nuclear reactors. In nuclear physics and nuclear chemistry, nuclear fission is either a nuclear reaction or a radioactive decay process in which the nucleus of an atom splits into smaller parts (lighter nuclei). The fission process often produces free neutrons and gamma photons, and releases a very large amount of energy even by the energetic standards of radioactive decay.
Fission is another word for splitting. The process of splitting a nucleus is called nuclear fission.
Uranium or plutonium isotopes are normally used as the fuel in nuclear reactors, because their atoms have relatively large nuclei that are easy to split, especially when hit by neutrons.
When a uranium-235 or plutonium-239 nucleus is hit by a neutron, the following happens:

1. The nucleus splits into two smaller nuclei, which are radioactive
2. Two or three more neutrons are released
3. Some energy is released

The additional neutrons released may also hit other uranium or plutonium nuclei and cause them to split. Even more neutrons are then released, which in turn can split more nuclei. This is called a chain reaction. The chain reaction in nuclear reactors is controlled to stop it going too fast.

A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus. This nucleus in turn produces neutrons, and the process repeats. The process may be controlled (nuclear power) or uncontrolled (nuclear weapons).

U235 + n → fission + 2 or 3 n + 200 MeV

If each neutron releases two more neutrons, then the number of fissions doubles each generation. In that case, in 10 generations there are 1,024 fissions and in 80 generations about 6 x 10 23 (a mole) fissions.

To maintain a sustained controlled nuclear reaction, for every 2 or 3 neutrons released, only one must be allowed to strike another uranium nucleus. If this ratio is less than one then the reaction will die out; if it is greater than one it will grow uncontrolled (an atomic explosion). A neutron absorbing element must be present to control the amount of free neutrons in the reaction space. Most reactors are controlled by means of control rods that are made of a strongly neutron-absorbent material such as boron or cadmium.

In addition to the need to capture neutron, the neutrons often have too much kinetic energy. These fast neutrons are slowed through the use of a moderator such as heavy water and ordinary water. Some reactors use graphite as a moderator, but this design has several problems. Once the fast neutrons have been slowed, they are more likely to produce further nuclear fissions or be absorbed by the control rod.

Spontaneous Fission

The spontaneous nuclear fission rate is the probability per second that a given atom will fission spontaneously--that is, without any external intervention. If a spontaneous fission occurs before the bomb is fully ready, it could fizzle. Plutonium 239 has a very high spontaneous fission rate compared to the spontaneous fission rate of uranium 235. Scientists had to consider the spontaneous fission rate of each material when designing nuclear weapons.

Nuclear fusion

Nuclear fusion involves two atomic nuclei joining to make a large nucleus. Energy is released when this happens.

The Sun and other stars use nuclear fusion to release energy. The sequence of nuclear fusion reactions in a star is complex, but overall hydrogen nuclei join to form helium nuclei. Here is one nuclear fusion reaction that takes place:

Hydrogen -1 nuclei fuse with hydrogen-2 nuclei to make helium-3 nuclei

For a fusion reaction to occur it is necessary to bring the nuclei so close together that nuclear forces become important and "glue" the nuclei together. The nuclear force only acts over incredibly small distances and has to counteract the electrostatic force where the positively charged nuclei repel each other. For these reasons fusion most easily occurs in a high density, high temperature environment.

On Earth, nuclear fusion was first reached in the explosion of the Hydrogen bomb. In a non-destructive manner, fusion has also been reached in different experimental devices aimed at studying the possibility of producing energy in a controlled fashion.

5.2 Nuclear Power Source:

In fissile material power sources can be classified into two different types. These are – 1) Fissile & 2) Fertile Materials.
Fissile Materials:
A nuclide that is capable of undergoing fission after capturing low-energy thermal (slow) neutrons. Although sometimes used as a synonym for fissionable material, this term has acquired its more-restrictive interpretation with the limitation that the nuclide must be fissionable by thermal neutrons. The most important fissile materials for nuclear energy are an isotope of plutonium, plutonium-239, and an isotope of uranium, uranium-235. Uranium-235 occurs in nature. For all practical purposes, plutonium-239 does not.
What is plutonium-239?
Plutonium-239 (hereafter referred to as "plutonium") is a heavy element consisting of 94 protons and 145 neutrons. It can have a number of chemical forms. Nuclear weapons use plutonium metal. Plutonium dioxide is used as a component of some nuclear fuels. Plutonium has a half-life of over 24,000 years (a half-life is the time it takes for half of a given amount of radioactive material to decay into other elements).
Americium-241 to curium-242 to curium-243 (or, more likely, curium-242 decays to plutonium-238, which also requires one additional neutron to reach a fissile nuclide)
Since these require a total of 3 or 4 thermal neutrons to eventually fission, and a thermal neutron fission generates only about 2 to 3 neutrons, these nuclides represent a net loss of neutrons. In a fast reactor, they may require fewer neutrons to achieve fission, as well as producing more neutrons when they do fission.

4.2 Nuclear Power Reactors

The source of nuclear power is the nucleus of an atom. If the nucleus of an atom is broken by a hitting neutron 200 Mev of energy is produced. A nuclear reactor is a device where a nuclear fission chain reaction is initiated, sustained and controlled. The heat produced by nuclear fissions is used to generate electricity in a nuclear power plant like in a conventional steam power plant.

4.2.1 Development

Nuclear reactor designs are usually categorized by "generation"; that is, Generation I, II, III, III+, and IV. The key attributes characterizing the development and deployment of nuclear power reactors illuminate the essential differences between the various generations of reactors.
The neutron was discovered in 1932. The concept of a nuclear chain reaction brought about by nuclear reactions mediated by neutrons was first realized shortly thereafter, by Hungarian scientist Leó Szilárd, in 1933. He filed a patent for his idea of a simple reactor the following year while working at the Admiralty in London. However, Szilárd's idea did not incorporate the idea of nuclear fission as a neutron source, since that process was not yet discovered. Szilárd's ideas for nuclear reactors using neutron-mediated nuclear chain reactions in light elements proved unworkable.
Inspiration for a new type of reactor using uranium came from the discovery by Lise Meitner, Fritz Strassmann and Otto Hahn in 1938 that bombardment of uranium with neutrons produced a barium residue, which they reasoned was created by the fissioning of the uranium nuclei. Subsequent studies in early 1939 revealed that several neutrons were also released during

the fissioning, making available the opportunity for the nuclear chain reaction that Szilárd had envisioned six years previously.

On 2 August 1939 Albert Einstein suggested that the discovery of uranium's fission could lead to the development of "extremely powerful bombs of a new type", giving impetus to the study of reactors and fission.

Eventually, the first artificial nuclear reactor, Chicago pile-1 was constructed at the University of Chicago, by a team led by Enrico Fermi, in late 1942. By this time, the program had been pressured for a year by U.S. entry into the war. The Chicago Pile achieved criticality on 2 December 1942 at 3:25 PM. The reactor support structure was made of wood, which supported a pile of graphite blocks, embedded in which was natural uranium-oxide 'pseudo spheres' or 'briquettes'.

Soon after the Chicago Pile, the U.S. military developed a number of nuclear reactors for the Manhattan Project starting in 1943. The primary purpose for the largest reactors was the mass production of plutonium for nuclear weapons.

The first nuclear power plant built for civil purposes was the AM-1 Obninsk Nuclear Power Plant, launched on 27 June 1954 in the Soviet Union. It produced around 5 MW (electrical).

The first commercial nuclear power station, Calder Hall in Sellafield, England was opened in 1956 with an initial capacity of 50 MW (later 200 MW).

A generation II reactor is a design classification for a nuclear reactor, and refers to the class of commercial reactors built up to the end of the 1990s. Prototypical generation II reactors include the PWR, CANDU, BWR, AGR, and VVER.

These are contrasted to generation I reactors, which refer to the early prototype of power reactors, such as Shippingport, Magnox/UNGG, Fermi 1, and Dresden.

A generation III reactor is a development of generation II nuclear reactor designs incorporating evolutionary improvements in design developed during the lifetime of the generation II reactor designs. These include improved fuel technology, superior thermal efficiency, passive nuclear safety systems and standardized design for reduced maintenance and capital costs. The first Generation III reactor to begin operation was Kashiwazaki (an ABWR) in 1996.

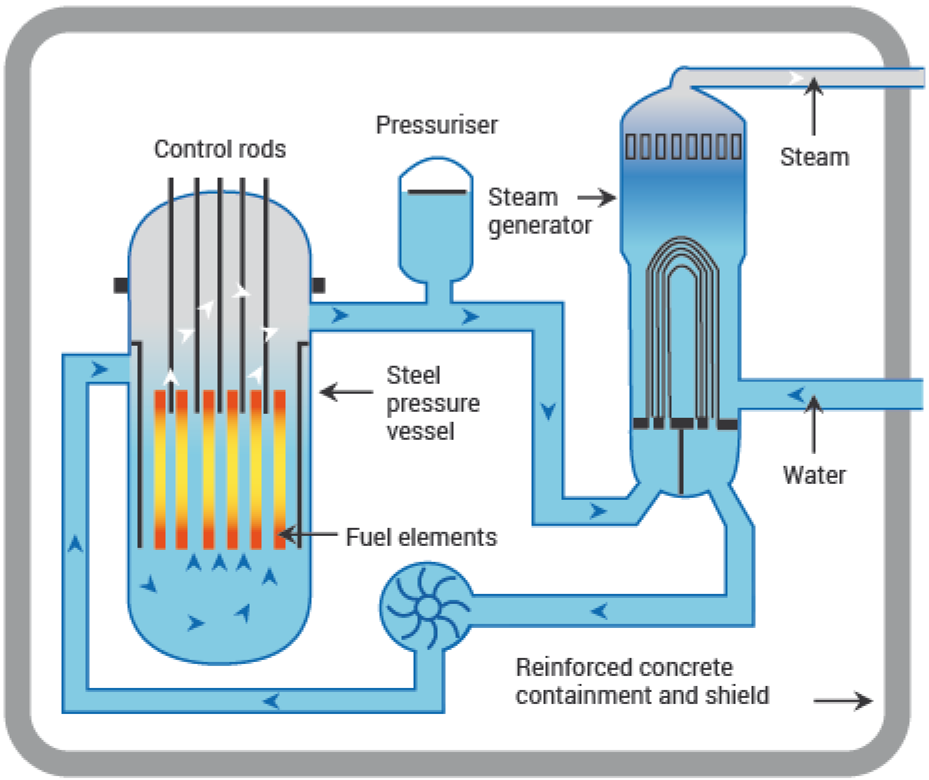
Due to the lack of reactor construction in the Western world, very few third generation reactors have been built in developed nations. In general, Generation IV designs are still in development, and might come online in the 2030s.

4.2.2 Types

Pressurized water reactor (PWR)

This is the most common type, with over 230 in use for power generation and several hundred more employed for naval propulsion. The design of PWRs originated as a submarine power plant. PWRs use ordinary water as both coolant and moderator. The design is distinguished by having a primary cooling circuit which flows through the core of the reactor under very high pressure, and a secondary circuit in which steam is generated to drive the turbine. In Russia these are known as VVER types – water-moderated and -cooled.

A Pressurized Water Reactor (PWR)

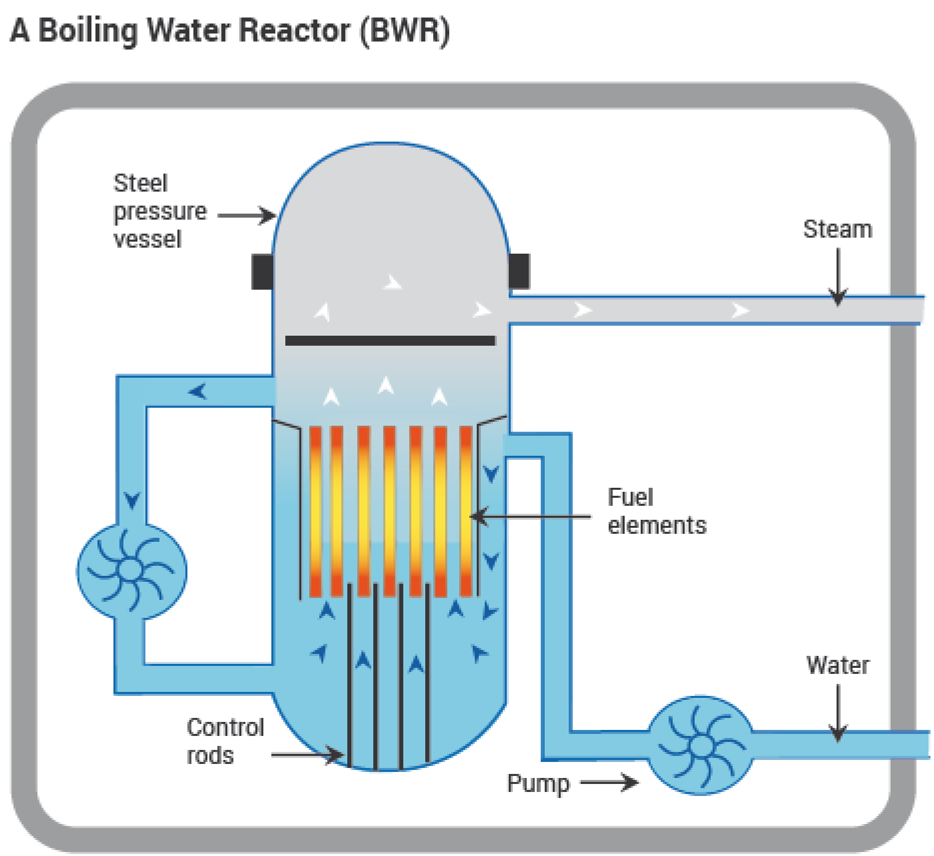


A PWR has fuel assemblies of 200-300 rods each, arranged vertically in the core, and a large reactor would have about 150-250 fuel assemblies with 80-100 tonnes of uranium.
Water in the reactor core reaches about 325°C, hence it must be kept under about 150 times atmospheric pressure to prevent it boiling. Pressure is maintained by steam in a pressuriser (see diagram). In the primary cooling circuit the water is also the moderator, and if any of it turned to steam the fission reaction would slow down. This negative feedback effect is one of the safety features of the type. The secondary shutdown system involves adding boron to the primary circuit.
The secondary circuit is under less pressure and the water here boils in the heat exchangers which are thus steam generators. The steam drives the turbine to produce electricity, and is then condensed and returned to the heat exchangers in contact with the primary circuit.

Boiling water reactor (BWR)

This design has many similarities to the PWR, except that there is only a single circuit in which the water is at lower pressure (about 75 times atmospheric pressure) so that it boils in the core at about 285°C. The reactor is designed to operate with 12-15% of the water in the top part of the core as steam, and hence with less moderating effect and thus efficiency there. BWR units can operate in load-following mode more readily then PWRs.
The steam passes through drier plates (steam separators) above the core and then directly to the turbines, which are thus part of the reactor circuit. Since the water around the core of a reactor is always contaminated with traces of radionuclides, it means that the turbine must be shielded and radiological protection provided during maintenance. The cost of this tends to balance the savings due to the simpler design. Most of the radioactivity in the water is very short-lived*, so the turbine hall can be entered soon after the reactor is shut down.

A BWR fuel assembly comprises 90-100 fuel rods, and there are up to 750 assemblies in a reactor core, holding up to 140 tons of uranium. The secondary control system involves restricting water flow through the core so that more steam in the top part reduces moderation.

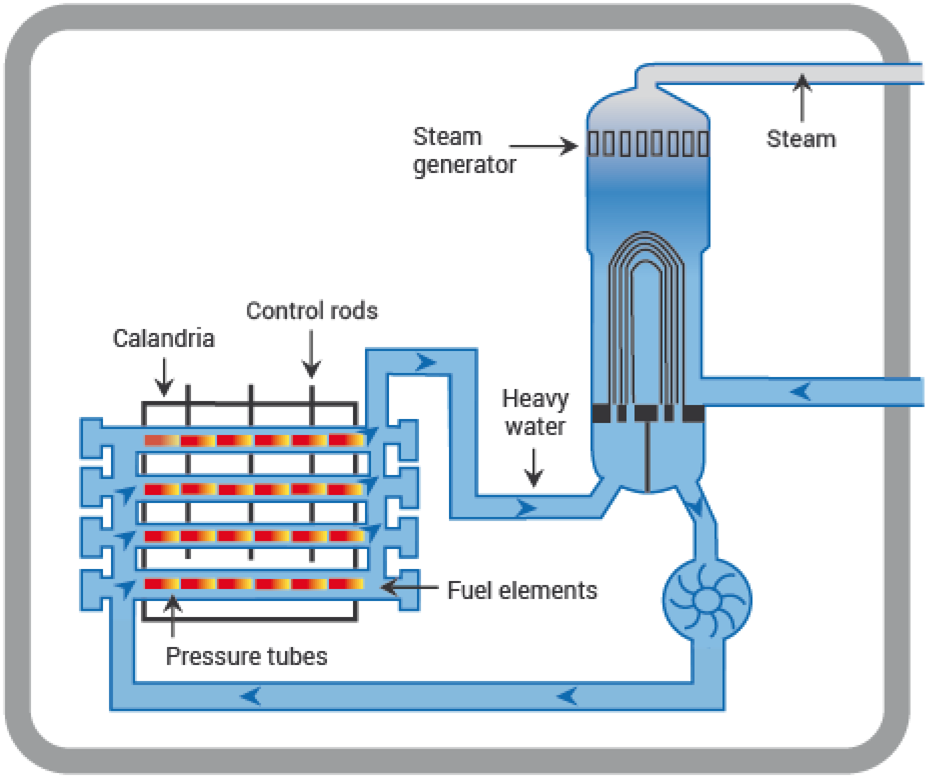


Pressurized heavy water reactor (PHWR)

The PHWR reactor design has been developed since the 1950s in Canada as the CANDU, and from 1980s also in India. PHWRs generally use natural uranium (0.7% U-235) oxide as fuel, hence needs a more efficient moderator, in this case heavy water (D_2O).** The PHWR produces more energy per kilogram of mined uranium than other designs, but also produces a much larger amount of used fuel per unit output.

The moderator is in a large tank called a calandria, penetrated by several hundred horizontal pressure tubes which form channels for the fuel, cooled by a flow of heavy water under high pressure in the primary cooling circuit, reaching 290°C. As in the PWR, the primary coolant generates steam in a secondary circuit to drive the turbines. The pressure tube design means that the reactor can be refueled progressively without shutting down, by isolating individual pressure tubes from the cooling circuit. It is also less costly to build than designs with a large pressure vessel, but the tubes have not proved as durable.

A Pressurized Heavy Water Reactor (PHWR/Candu)



A CANDU fuel assembly consists of a bundle of 37 half meter long fuel rods (ceramic fuel pellets in zircaloy tubes) plus a support structure, with 12 bundles lying end to end in a fuel channel. Control rods penetrate the calandria vertically, and a secondary shutdown system involves adding gadolinium to the moderator. The heavy water moderator circulating through the body of the calandria vessel also yields some heat (though this circuit is not shown on the diagram above).

Newer PHWR designs such as the Advanced Candu Reactor (ACR) have light water cooling and slightly-enriched fuel.

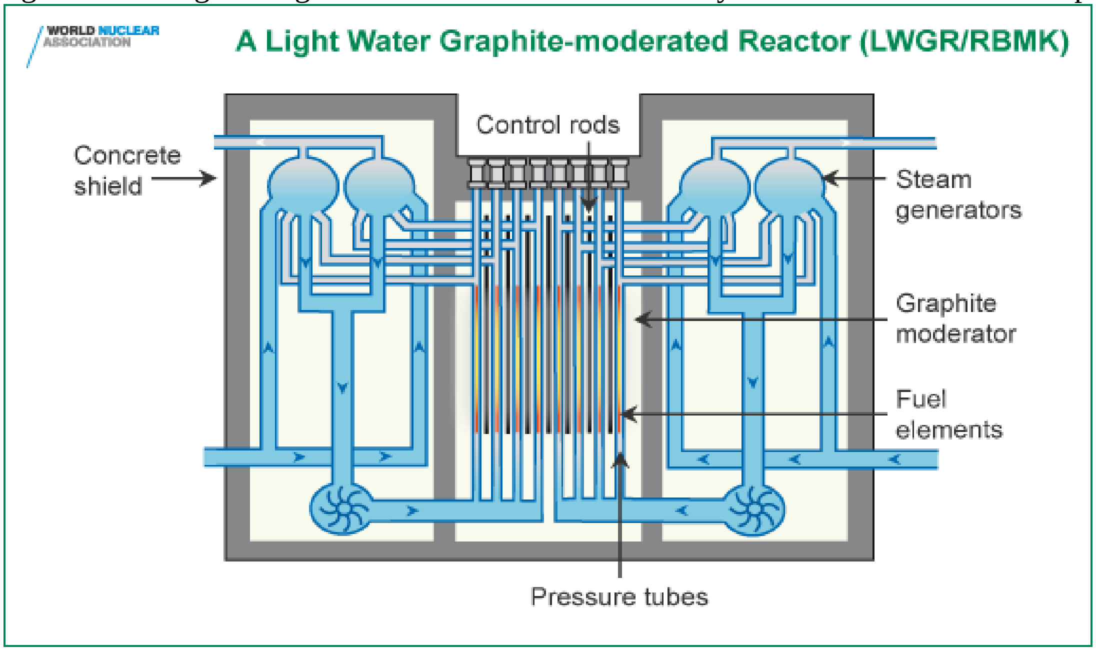
CANDU reactors can accept a variety of fuels. They may be run on recycled uranium from reprocessing LWR used fuel, or a blend of this and depleted uranium left over from enrichment plants. About 4000 MWe of PWR might then fuel 1000 MWe of CANDU capacity, with addition of depleted uranium. Thorium may also be used in fuel.

Light water graphite-moderated reactor (RBMK)

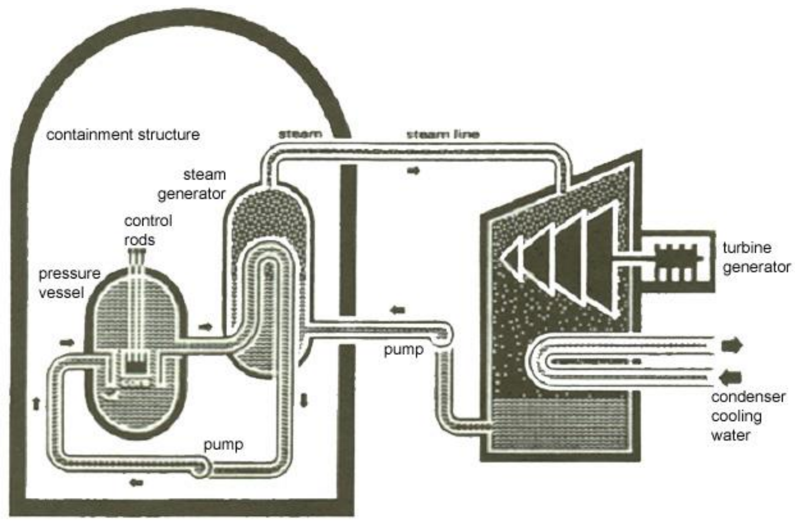
This is a Soviet design, developed from plutonium production reactors. It employs long (7 meter) vertical pressure tubes running through graphite moderator, and is cooled by water, which is allowed to boil in the core at 290°C, much as in a BWR. Fuel is low-enriched uranium oxide made up into fuel assemblies 3.5 meters long. With moderation largely due to the fixed graphite, excess boiling simply reduces the cooling and neutron absorption without inhibiting the fission reaction and a positive feedback problem can arise, which is why they have never been built outside the Soviet Union.

The Soviet-designed RBMK (*reaktor Bolshoi moshchnosty kanalny*, high-power channel reactor) is a pressurized water-cooled reactor with individual fuel channels and using graphite as its

moderator. It is also known as the light water graphite reactor (LWGR). It is very different from most other power reactor designs as it derived from a design principally for plutonium production and was intended and used in Russia for both plutonium and power production.
The combination of graphite moderator and water coolant is found in no other power reactors in the world. As the Chernobyl accident showed, several of the RBMK's design characteristics – in particular, the control rod design and a positive void coefficient – were unsafe. A number of significant design changes were made after the Chernobyl accident to address these problems.



Liquid metal fast breeder reactor (LMFBR)
Fast reactors are called fast breeders when they produce more nuclear fuel, by converting uranium-238 into plutonium-239 or thorium-232 into uranium-233, than they consume. No light material like water can normally be used as coolant in fast reactors as light materials slow down fast neutrons .liquid sodium is the perfected coolant in fast reactors .Obviously, no moderator is needed in fast reactors .Since sodium becomes radioactive inside the core and it reacts violently with water ,an intermediate sodium loop is used in between the primary sodium loop and the secondary steam generating system in order to isolate the radioactive primary loop from the steam generating system. Most fast reactors built during the last century are being closed down mainly for political reasons. India is experimenting to build fast reactors using thorium-232 as fertile material. It is converted to fissile uranium-233 by absorption of neutrons.



Liquid metal fast breeder reactor (LMFBR)

Nuclear reactors serve three general purposes. **Civilian reactors** are used to generate energy for electricity and sometimes also steam for district heating; **military reactors** create materials that can be used in nuclear weapons; and **research reactors** are used to develop weapons or energy production technology, for training purposes, for nuclear physics experimentation, and for producing radio-isotopes for medicine and research. The chemical composition of the fuel, the type of coolant, and other details important to reactor operation depend on reactor design. Most designs have some flexibility as to the type of fuel that can be used. Some reactors are dual-purpose in that they are used for civilian power and military materials production. The two tables below give information about civilian and military reactors.

Table: Nuclear Power Plants in Operation by Type

Reactor type	Country	Number	GWe	Fuel	Coolant	Moderator
Pressurized Water Reactor(PWR)	US, France, Japan*, Russia, China	271	270	Enriched UO_2	Water	Water
Boiling Water Reactor(BWR)	US, Japan, Sweden	84	81.2	Enriched UO_2	Water	Water
Pressurized Heavy Water Reactors(PHWR)	Canada, India, S. Korea	48	27.1	Natural UO_2	Heavy water	Heavy water
Gas-cooled Reactor(AGR & Magnox)	UK	17	10	Natural U , Enriched UO_2	CO_2	Graphite

Light Water Graphite Reactor(RBMK)	Russia	15	10.4	Enriched UO_2	Water	Graphite
Fast Neutron Reactor(FBR)	Russia	1	0.6	PuO_2 and UO_2	Liquid sodium	None
TOTAL		436	399			

GWe=Thousands of megawatts (gross), ***Operable,**
Source: World Nuclear Association

4.2.3 Evolution

Nuclear power technology has evolved in three distinct generation .The first generation of prototype reactors was followed by second-generation power reactors that currently supply Europe with electricity.
Today, third generation (GEN III) nuclear plants with enhanced safety and competitiveness are being built in France and Finland. Evolutionary GEN III + designs will become available in the near future. A fourth generation (GEN IV) of reactors is the subject of an intense R&D effort .These system should be available for commercial use from 2025.
GEN IV reactors are truly innovative. They will combine extreme safety with competitive economics. The design use passive safety features to ensure zero off-site impacts even in the worst accident scenarios.
GEN IV reactors will make much more efficient use of uranium resources. Some designs use clothed fuel cycles to 'burn' waste within the reactors, thereby reducing final waste quantities and enhancing resistance to nuclear proliferation.

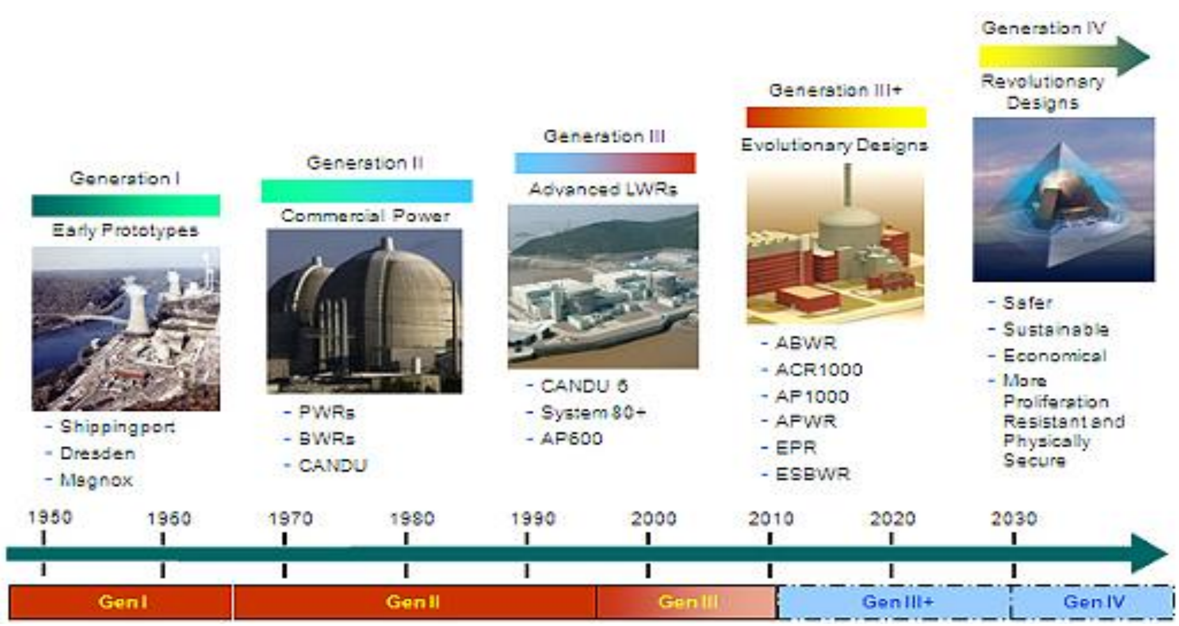


FIG: EVOLUTION OF NUCLEAR POWER PLANT REACTORS

Generation I

Gen I refers to the prototype and power reactors that launched civil nuclear power. This generation consists of early prototype reactors from the 1950s and 1960s, such as Shippingport (1957–1982) in Pennsylvania, Dresden-1 (1960–1978) in Illinois, and Calder Hall-1 (1956–2003) in the United Kingdom.

Generation II

Gen II refers to a class of commercial reactors designed to be economical and reliable. Designed for a typical operational lifetime of 40 years, 2 prototypical Gen II reactors include pressurized water reactors (PWR), CANada Deuterium Uranium reactors (CANDU), boiling water reactors (BWR), advanced gas-cooled reactors (AGR), and Vodo-Vodyanoi Energetichesky Reactors (VVER). Gen II reactors in the United States are regulated by the NRC pursuant to 10 CFR Part 50. Gen II systems began operation in the late 1960s and comprise the bulk of the world's 400+ commercial PWRs and BWRs. These reactors typically referred to as light water reactors (LWRs).

Generation III

Gen III nuclear reactors are essentially Gen II reactors with evolutionary, state-of-the-art design improvements.7 These improvements are in the areas of fuel technology, thermal efficiency, modularized construction, safety systems (especially the use of passive rather than active systems), and standardized design.8 Improvements in Gen III reactor technology have aimed at a longer operational life, typically 60 years of operation, potentially to greatly exceed 60 years, prior to complete overhaul and reactor pressure vessel replacement. Confirmatory research to investigate nuclear plant aging beyond 60 years is needed to allow these reactors to operate over such extended lifetimes. Unlike Gen I and Gen II reactors, Gen III reactors are regulated by NRC regulations based on 10 CFR Part 52.

Generation III+

Gen III+ reactor designs are an evolutionary development of Gen III reactors, offering significant improvements in safety over Gen III reactor designs certified by the NRC in the 1990s. In the United States, Gen III+ designs must be certified by the NRC pursuant to 10 CFR Part 52. Examples of Gen III+ designs include:

- VVER-1200/392M Reactor of the AES-2006 type
- Advanced CANDU Reactor (ACR-1000)
- AP1000: based on the AP600, with increased power output
- European Pressurized Reactor (EPR): evolutionary descendant of the Framatome N4 and Siemens Power Generation Division KONVOI reactors
- Economic Simplified Boiling Water Reactor (ESBWR): based on the ABWR
- APR-1400: an advanced PWR design evolved from the U.S. System 80+, originally known as the Korean Next Generation Reactor (KNGR)
- EU-ABWR: based on the ABWR, with increased power output and compliance with EU safety standards.

Generation IV

Nuclear scientists have left implementation of the Gen III+ and SMR designs to the engineers, believing them to be within the current state-of-the-art, and have instead focused on nuclear alternatives—commonly called Gen IV—that still require considerable fundamental research. Conceptually, Gen IV reactors have all of the features of Gen III+ units, as well as the ability, when operating at high temperature, to support economical hydrogen production, thermal energy off-taking, and perhaps even water desalination. In addition, these designs include advanced actinide management.24 Gen IV reactors include:

• High temperature water-, gas-, and liquid salt–based pebble bed thermal and epithermal reactors.

• Liquid metal–cooled reactors and other reactors with more-advanced cooling. One such design is the Power Reactor Innovative Small Module (PRISM), a compact modular pool-type reactor developed by GE-Hitachi with passive cooling for decay heat removal.

• Traveling wave reactors that convert fertile material into fissile fuel as they operate, using the process of nuclear transmutation being developed by TerraPower. This type of reactor is also based on a liquid metal primary cooling system. It is also being designed with passive safety features for decay heat removal, and has as a major design goal minimization of life cycle fuel costs by both substantially increasing the burn up percentage and internally breeding depleted uranium.

• Hyperion Power Module (25 MW module). According to Hyperion, uranium nitride fuel would be beneficial to the physical characteristics and neutrons of the standard ceramic uranium oxide fuel in LWRs.

4.2.4 Growth Trend

Today there are some 440 nuclear power reactors operating in 31 countries plus Taiwan, with a combined capacity of over 385 GWe. In 2014 these provided 2411 billion kWh, over 11% of the world's electricity.

Over 60 power reactors are currently being constructed in 13 countries plus Taiwan (see Table below), notably China, South Korea, UAE and Russia.

Each year, the OECD's International Energy Agency (IEA) sets out the present situation and also reference and other, particularly carbon reduction scenarios. World Energy Outlook 2014 had a special focus on nuclear power, and extends the scope of scenarios to 2040. In its New Policies scenario, installed nuclear capacity growth is 60% through 543 GWe in 2030 and to 624 GWe in 2040 out of a total of 10,700 GWe, with the increase concentrated heavily in China (46% of it), plus India, Korea and Russia (30% of it together) and the USA (16%), countered by a 10% drop in the EU. Despite this, the percentage share of nuclear power in the global power mix increases to only 12%, well below its historic peak. Low-Nuclear and so-called High-Nuclear cases give 366 and 767 GWe nuclear respectively in 2040. The low-carbon ‘450 Scenario’ gives a cost-effective transition to limiting global warming assuming an effective international agreement in 2015, and this brings about more than doubling nuclear capacity to 862 GWe in 2040, while energy-related CO_2 emissions peak before 2020 and then decline. In this scenario, almost all new generating capacity built after 2030 needs to be low-carbon.

It is noteworthy that in the 1980s, 218 power reactors started up, an average of one every 17 days. These included 47 in USA, 42 in France and 18 in Japan. These were fairly large - average power was 923.5 MWe. So it is not hard to imagine a similar number being commissioned in the years ahead. But with China and India getting up to speed in nuclear energy and a world energy demand increasing, a realistic estimate of what is possible (but not planned at this stage) might be the equivalent of one 1000 MWe unit worldwide every 5 days.

Increased capacity

Increased nuclear capacity in some countries is resulting from the up rating of existing plants. This is a highly cost-effective way of bringing on new capacity.

There is a question of scale, and large units will not fit into small grids. A conservative guide is that peak power demand must be met with effective installed capacity and about 20% reserve margin. Also, the largest single plant should not be more than 10% of base-load, or 5% of peak demand.

Numerous power reactors in USA, Belgium, Sweden and Germany, for example, have had their generating capacity increased.

Nuclear plant construction

Most reactors currently planned are in the Asian region, with fast-growing economies and rapidly-rising electricity demand.

Many countries with existing nuclear power programs (Argentina, Armenia, Brazil, Bulgaria, China, Czech Rep., India, Pakistan, Romania, Russia, Slovakia, South Korea, South Africa, UAE, Ukraine, UK, USA) have plans to build new power reactors (beyond those now under construction).

In all, over 160 power reactors with a total net capacity of some 182,000 MWe are planned and over 300 more are proposed. Energy security concerns and greenhouse constraints on coal burning have combined with basic economics to put nuclear power back on the agenda for projected new capacity in many countries.

Plant life extension and retirements

Most nuclear power plants originally had a nominal design lifetime of 25 to 40 years, but engineering assessments of many plants have established that many can operate longer. In the USA over 75 reactors have been granted license renewals which extend their operating lives from the original 40 out to 60 years, and operators of most others are expected to apply for similar extensions. Such license extensions at about the 30-year mark justify significant capital expenditure for replacement of worn equipment and outdated control systems.

In France, there are rolling ten-year reviews of reactors. In 2009 the Nuclear Safety Authority (ASN) approved EdF's safety case for 40-year operation of the 900 MWe units, based on generic assessment of the 34 reactors. There are plans to take reactor lifetimes out to 60 years, involving substantial expenditure.

The Russian government is extending the operating lives of most of the country's reactors from their original 30 years, for 15 years, or for 25 years in the case of the newer VVER-1000 units, with significant upgrades.

Power reactors under construction

Start †		Reactor	Type	Gross MWe
2016	India, NPCIL	Kudankulam 2	PWR	950
2016	India, NPCIL	Kakrapar 3	PHWR	640
2016	India, Bhavini	Kalpakkam	FBR	470
2016	Russia, Rosenergoatom	Novovoronezh II-1	PWR	1070
2016	USA, TVA	Watts Bar 2	PWR	1180
2016	China, CNNC	Sanmen 1	PWR	1250
2016	China, SPI	Haiyang 1	PWR	1250
2016	China, CNNC	Changjiang 2	PWR	650
2016	China, CNNC	Fuqing 3	PWR	1080
2016	China, CGN	Fangchenggang 2	PWR	1080

2016	India, NPCIL	Rajasthan 7	PHWR	640
2016	Pakistan, PAEC	Chashma 3	PWR	300
2017	Slovakia, SE	Mochovce 3	PWR	440
2017	Russia, Rosenergoatom	Pevek FNPP	PWR x 2	70
2017	Russia, Rosenergoatom	Leningrad II-1	PWR	1070
2017	UAE, ENEC	Barakah 1	PWR	1400
2017	China, CGN	Taishan 1	PWR	1700
2017	China, CGN	Taishan 2	PWR	1700
2017	China, CNNC	Sanmen 2	PWR	1250
2017	China, SPI	Haiyang 2	PWR	1250
2017	China, CGN	Yangjiang 4	PWR	1080
2017	China, CNNC	Fuqing 4	PWR	1080
2017	China, China Huaneng	Shidaowan	HTR	200
2017	China, CNNC	Tianwan 3	PWR	1060
2017	Russia, Rosenergoatom	Rostov 4	PWR	1200
2017	Korea, KHNP	Shin-Kori 4	PWR	1350
2017	Korea, KHNP	Shin-Hanul 1	PWR	1350
2017	India, NPCIL	Kakrapar 4	PHWR	640
2017	India, NPCIL	Rajasthan 8	PHWR	640
2017	Pakistan, PAEC	Chashma 4	PWR	300
2018	Russia, Rosenergoatom	Novovoronezh II-2	PWR	1070
2018	Slovakia, SE	Mochovce 4	PWR	440
2018	France, EdF	Flamanville 3	PWR	1600
2018	Finland, TVO	Olkilouto 3	PWR	1720
2018	Korea, KHNP	Shin-Hanul 2	PWR	1350
2018	UAE, ENEC	Barakah 2	PWR	1400
2018	Brazil	Angra 3	PWR	1405
2018	Argentina	Carem25	PWR	27
2018	China, CGN	Yangjiang 5	PWR	1080
2018	China, CNNC	Tianwan 4	PWR	1060
2019	USA, Southern	Vogtle 3	PWR	1200
2019	USA, SCEG	Summer 2	PWR	1200
2019	UAE, ENEC	Barakah 3	PWR	1400
2019	China, CGN	Fangchenggang 3	PWR	1150
2019	China, CGN	Hongyanhe 5	PWR	1120

2019	China, CGN	Yangjiang 6	PWR	1080
2019	China, CNNC	Fuqing 5	PWR	1150
2019	Romania, SNN	Cernavoda 3	PHWR	720
2020	Russia, Rosenergoatom	Leningrad II-2	PWR	1070
2020	China, CGN	Hongyanhe 6	PWR	1120
2020	China, CGN	Ningde 5	PWR	1150
2020	China, CGN	Fangchenggang 4	PWR	1150
2020	China, CNNC	Fuqing 6	PWR	1150
2020	UAE, ENEC	Barakah 4	PWR	1400
2020	Romania, SNN	Cernavoda 4	PHWR	720

† *Latest announced year of proposed commercial operation*

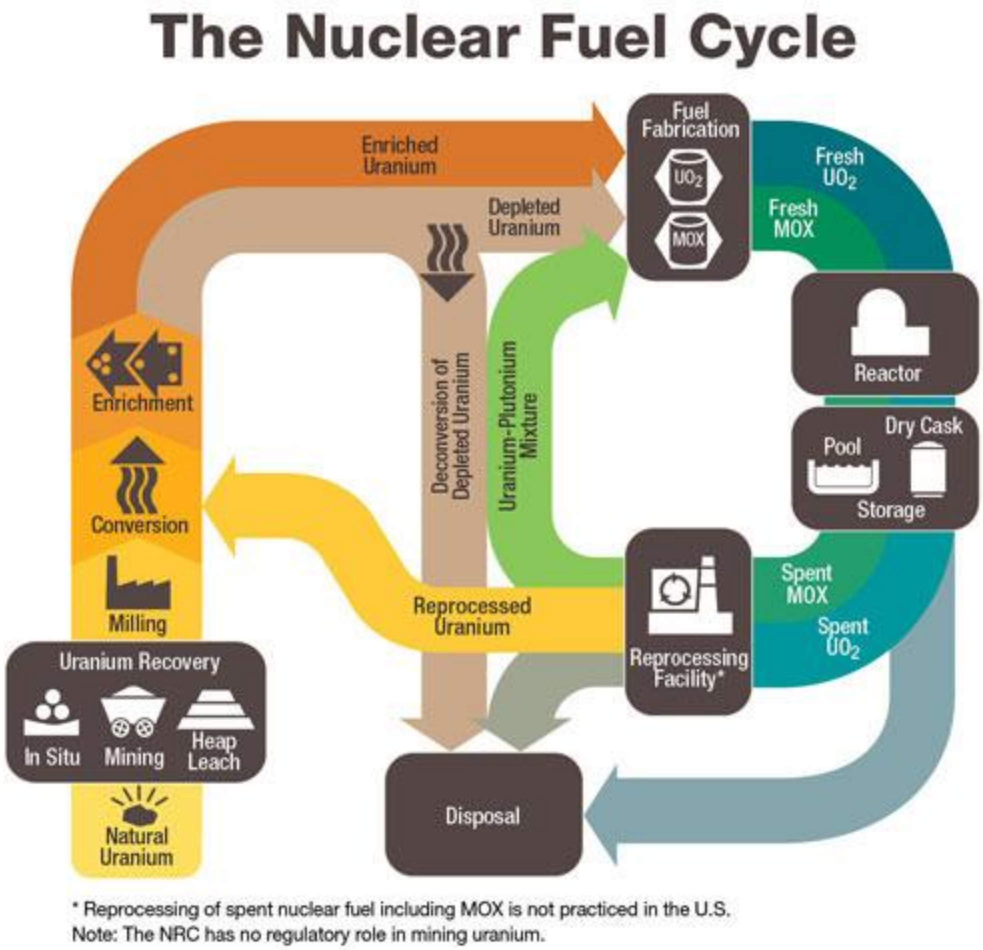
Source: World Nuclear Associations Information Papers

4.3 Nuclear Fuel Cycle

Nuclear Fuel Cycle can be defined as the set of processes to make use of nuclear materials and to return it to normal state. It starts with the mining of unused nuclear materials from the nature and ends with the safe disposal of used nuclear material in the nature.

To produce energy from Uranium in a nuclear reactor, it must be passed through in a series of different processes. The complete set of processes to make nuclear fuel from uranium ore is known as front end of the nuclear fuel cycle. The processes in the front end of the nuclear cycle are mining and milling, conversion, enrichment and fuel fabrication.

After producing energy in the reactor, nuclear fuel becomes spent fuel. Spent fuel has also to be processed in a storage facility or in a reprocessing facility if it is being recycled. Temporary storage, reprocessing, long-term storage, or final storage of spent fuel are together called back end of the nuclear fuel cycle.



4.3.1 Front End

Mining

Uranium is an element that is widely distributed within the earth's crust as ores. Its principal use is as the primary fuel for nuclear power plants. The uranium ore needs to be mined and then processed (milled) before being usable. Uranium ore is mined by open-pit or underground mining methods and the uranium is extracted from the crushed ore in processing plants or mills using chemical methods. Sometimes it is possible to pass chemical solutions to the ore beds and dissolve the uranium from the ore directly. This process is known as in-situ leaching. This is the first step in a nuclear fuel cycle. The feed for mining & milling process is uranium ore and the product is U3O8 compound, which is mostly called yellowcake due to its color.

Uranium ore - the principal raw material of nuclear fuel

Milling

Uranium is an element that is widely distributed within the earth's crust as ores. Its principal use is as the primary fuel for nuclear power plants. The uranium ore needs to be mined and then processed (milled) before being usable. Uranium ore is mined by open-pit or underground mining methods and the uranium is extracted from the crushed ore in processing plants or mills using chemical methods. Sometimes it is possible to pass chemical solutions to the ore beds and dissolve the uranium from the ore directly. This process is known as in-situ leaching. This is the first step in a nuclear fuel cycle. The feed for mining & milling process is uranium ore and the product is U_3O_8 compound, which is mostly called yellowcake due to its color.

Conversion

The term conversion refers to the process of purifying the uranium concentrate and converting it to the chemical form required for the next stage of the nuclear fuel cycle. There are three such forms in common usage: metal, oxide (UO_2) and uranium hexafluoride (UF_6).

UF_6 is the predominant product at this stage of the nuclear fuel cycle since it is easily converted to a gas for the enrichment stage, as employed in world's most common reactor types (LWRs). For the PHWR fuel cycle, which generally uses natural uranium oxide as the fuel, conversion to the UF_6 is unnecessary. Uranium is purified and converted to UO_2 or UO_3. The Magnox fuel cycle uses natural uranium in metal form. So the feed for this stage is U_3O_8 concentrate, and the products are UF_6, oxide (UO_2 or UO_3) or metal, in applicability order.

Yellowcake - the form in which uranium is transported to a conversion plant

Enrichment

Uranium naturally consists of about 0.7% of 235U isotope which is the main energy source in thermal reactors. For LWR technology which is the most common reactor type, it is impossible to build a nuclear reactor with the natural occurrence of 235U, so the 235U content should be increased with a special process. This process is called enrichment.

There are two commercially available technologies: gaseous diffusion and centrifuge. Both techniques are based on the slightly different masses of the uranium isotopes nuclei. So the enrichment is defined as the process of increasing the amount of 235U contained in a unit quantity of uranium. The feed for this stage is Natural UF6 and the product is enriched UF6. The other output of the process is the uranium which has lower fissile content than the natural uranium. It is known as enrichment tail or depleted uranium.

UF_6 - used in enrichment

Fuel Fabrication

Enriched uranium in UF6 form is converted to UO2 powder to make fuel for LWR technology. This powder then is formed into pellets, sintered to achieve the desired density and ground to the required dimensions. Fuel pellets are loaded into tubes of zircaloy or stainless steel, which are sealed at both ends. These fuel rods are spaced in fixed parallel arrays to form the reactor fuel assemblies. The whole process is referred as fuel fabrication. The similar procedure is adopted for natural uranium oxide fuel for some reactor types. The feed of this process is enriched or natural uranium oxide powder and the product is fuel assembly.

Nuclear fuel - a compact, inert, insoluble solid

4.3.2 Back End

4.3.2.1 Open Cycle

The open fuel cycle is the mode of operation in which the nuclear material passes through the reactor just once. After irradiation, the fuel is kept in at-reactor pools until it is sent to away from-reactor storage. It is planned that the fuel will be conditioned and put into a final repository in this mode of operation. This fuel cycle strategy is the one currently adopted by many nuclear power countries. However, no final repositories for spent fuel have yet been established. As it can be seen in Fig. 2, this strategy is definitely applied today for pressurized heavy water reactors (PHWR) and graphite moderated light water cooled reactors (RBMK).

4.3.2.2 Closed Cycle

The closed fuel cycle is the mode of operation in which, after a sufficient cooling period, the spent fuel is reprocessed to extract the remaining uranium and plutonium from the fission products and other actinides. The reprocessed uranium and plutonium is then reused in the reactors. This recycle strategy has been adopted by some countries mainly in light water reactors (LWR) in the form of mixed oxide (MOX) fuel. Apart from the current LWR recycling experience, another closed fuel cycle practice is the recycle of nuclear materials in fast reactors in which, reprocessed uranium and plutonium are used for production of fast reactor (FR) fuel. By suitable operation, such a reactor can produce more fissile plutonium than it consumes.

Nuclear Power Plant
The reactor itself is irradiator for nuclear fuel. It burns the fuel, produces energy and spent fuel. There are currently 7 types of reactors in the world (classification is based on NFCSS assumptions): PWR, BWR, PHWR, RBMK, GCR, AGR, WWER.
The feed for reactor is fresh fuel containing uranium and plutonium, in case of Mixed Oxide (MOX) fuel, for existing nuclear fuel cycle options. The product is the spent fuel consisting of new nuclides such as fission products (Cs, I,), minor actinides (Np, Am, Cm) and Plutonium as well as the uranium. The biggest part of the spent fuel is still uranium.
Reprocessing

The spent nuclear fuel still consists of significant amount of fissile material that can be used to produce energy. The considerable amount of 235U is still contained in the spent fuel and there are new fissile nuclides that were produced during normal operation of nuclear reactor such as 239Pu. Some nuclear fuel cycle options consider taking out the fissile material from the spent fuel, re-fabricating it as fuel and burning in reactor. MOX fuel is the most common fuel that uses reprocessed material. Reprocessing process is based on chemical and physical processes to separate the required material from spent nuclear fuel. The feed of this process is spent fuel and the products are reusable material and High Level Wastes (HLW).

MOX Fuel Fabrication

Separated plutonium is converted into an oxide powder, packed in leak tight cans and transported to plutonium fuel fabrication facilities for the production of MOX fuels for Light Water Reactors and Fast Reactors. Because of the fissile isotopes ^{239}Pu and ^{241}Pu, plutonium is used as substitute for ^{235}U. But ^{241}Pu decays into the non-fissile and highly radioactive^{241}Am. For this reason the utilization of plutonium for MOX fuel should ideally take place shortly after its separation from the spent fuel.

In general MOX fuel pellets are produced from UO_2 and PuO_2 powders in a similar way to the uranium fuel. In enriched uranium, the fissile material is inherently present in the fuel. In MOX fuel, the fissile material, plutonium, has to be added to the carrier material, uranium. This blending of two fissile / fertile materials is the most specific difference between uranium and MOX fuel manufacturing. The rod and assembly design of MOX fuel is universally based on, and also follows the evolutions of, uranium fuel design, with only minor modifications at most.

Electricity

Electricity production with conventional production forms, such as coal, oil and nuclear power, include four main stages. All of them generate electricity by: (1) heating water to (2) generates steam that (3) makes the turbine rotate to (4) enable the generator to produce electricity.

In a nuclear power plant, to produce the steam, the water in the reactor (known as cooling water) is heated up by fission chain reaction. Rarely, a gas like helium is used for cooling and transferring heat. When the nucleus of an atom of, for example, U-235 absorbs a neutron, it may split (or fission) into two pieces, giving off energy as heat and a few more neutrons to continue this nuclear chain reaction. This chain reaction is controlled to produce exactly the desired amount of energy.

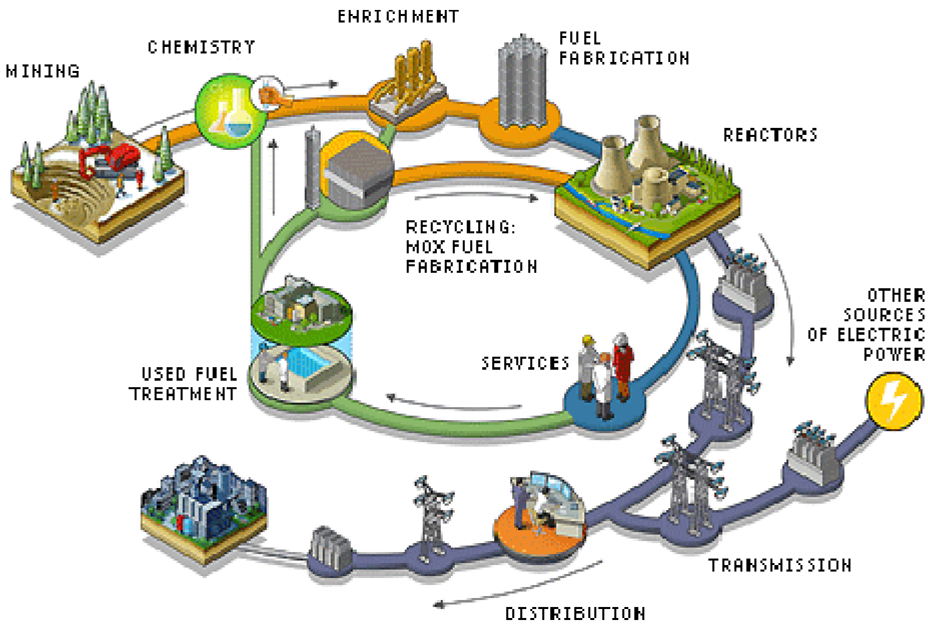
The produced steam is extremely hot, several hundred Celsius degrees. Also the pressure is high. The steam is directed to turbines, making the turbine blades move and, thus, rotating the turbines at high speed. The kinetic energy of the rotating turbines is converted into electrical energy in generators. The electricity we use every day is distributed via grid.

Spent Fuel Storage

Spent fuel, which is not reprocessed, could be stored for temporarily for future use or could be stored for indefinitely. Spent fuel could be stored in pools (wet type) or in silos (dry type). After a storage period in interim storage facilities (AR or AFR type), spent fuel will be prepared for reprocessing or conditioned for further storage or disposal. This process is performed by spent fuel conditioning facilities.

HLW and Spent Fuel Disposal

After being properly conditioned, spent fuel can be disposed in deep geological formations for an indefinite period of time until a non-hazardous level of radioactivity from the actinides and fission products is reached by decay.



Material balance in the nuclear fuel cycle

The following figures may be regarded as typical for the annual operation of a 1000 MWe nuclear power reactor typical of many operating today, using 4.5% enriched fuel and with 45 GWd/t burn-up:

Mining	Anything from 20,000 to 400,000 tons of uranium ore
Milling	249 tons of uranium oxide concentrate (which contains 211 tons of uranium)
Conversion	312 tons of uranium hexafluoride, UF_6 (with 211 tU)
Enrichment	35.9 tons of enriched UF_6 (containing 24.3 t enriched U @ 4.5%) – balance is 'tails' @ 0.22%
Fuel fabrication	27.6 tons UO_2 (with 24.3 t enriched U)
Reactor operation	8760 million kWh (8.76 TWh) of electricity at 100% output, hence 24 tons of natural U per TWh
Used fuel	27.6 tons containing 280 kg transuranic (mainly plutonium), 26 t uranium oxide (<1.0% U-235), 1 ton fission products.

The following figures assume the annual operation of 1000 MWe of nuclear power reactor capacity such as in the new AP1000 or EPR, with 5% enriched fuel and higher (65 GWd/t) burn-up:

Mining	Anything from 20,000 to 400,000 tons of uranium ore
Milling	192 tons of uranium oxide concentrate (which contains 163 tons of uranium)
Conversion	241 tons of uranium hexafluoride, UF_6 (with 163 tU)
Enrichment	25 tons of enriched UF_6 (containing 16.85 t enriched U) – balance is 'tails' @ 0.22%
Fuel fabrication	19.1 tons UO_2 (with 16.85 t enriched U)
Reactor operation	8760 million kWh (8.76 TWh) of electricity at 100% output, hence 18.6 tons of natural U per TWh

Used fuel	19.1 tons containing 200 kg transuranic (mainly plutonium), 18.3 t uranium oxide (<1.0% U-235), <0.6 t fission products

Between the above figures, *Uranium 2014: Resources, Production and Demand* ('Red Book'), from the OECD NEA & IAEA, said that efficiencies on power plant operation and lower enrichment tails assays meant that uranium demand per unit capacity was falling, and the report's generic reactor fuel consumption was reduced from 175 tU per GWe per year at 0.30% tails assay (2011 report) to 163 tU per GWe per year at 0.25% tails assay. The corresponding U_3O_8figures are 206 tonnes and 192 tonnes per GWe per year.

4.4 Waste Management

Nuclear fuel cycle produces wastes at different stages of processing. Some of the wastes are radioactive and require special treatment for protecting human health and minimizing its impact on the environment. The amount of nuclear wastes is very small relative to wastes produced by fossil fuel electricity generation. Used nuclear fuel can be treated as a resource or simply as a waste. Nuclear wastes are neither particularly hazardous nor hard to manage relative to other toxic industrial wastes. In countries with nuclear power, radioactive wastes comprise less than 1% of total industrial toxic wastes.

4.4.1 Nuclear Wastes

Radioactive waste is waste that contains radioactive material. Radioactive waste is usually a by-product of nuclear power generation and other applications of nuclear fission or nuclear technology, such as research and medicine. Radioactive waste is hazardous to most forms of life and the environment, and is regulated by government agencies in order to protect human health and the environment.

Radioactivity naturally decays over time, so radioactive waste has to be isolated and confined in appropriate disposal facilities for a sufficient period until it no longer poses a threat. The time radioactive waste must be stored for depends on the type of waste and radioactive isotopes. It can range from a few days for highly radioactive isotopes to millions of years for slightly radioactive ones.

Radioactive waste comes from a number of sources. In countries with nuclear power plants, nuclear armament, or nuclear fuel treatment plants, the majority of waste originates from the nuclear fuel cycle otherwise there is no waste of nuclear origin. Other sources include medical and industrial wastes, as well as naturally occurring radioactive materials (NORM).

Types of wastes:

There are 3 types of nuclear wastes:

1. High level waste
2. Intermediate level waste
3. Low level waste

	Volume	**Radioactive content**
High level waste	3%	95%
Intermediate level waste	7%	4%
Low level waste	90%	1%

4.4.2 Spent Fuel

Spent nuclear fuel is occasionally called used nuclear fuel. When fuel rods in a nuclear reactor are “spent” or no longer “efficient in producing electricity”, they are removed from the reactor core and replaced with fresh fuel rods. This fuel rod is known as spent nuclear fuel.

The spent fuel is 95–96% uranium with an enrichment level at or slightly above that of natural uranium, 1% plutonium, 0.1% other actinides and 3–4% fission products.

The spent fuel rods are still highly radioactive and continue to generate significant heat for decades. The fuel assemblies, which consist of dozens to hundreds of fuel rods each, are moved to pools of water to cool. They are kept on racks in the pool, submerged in more than twenty feet of water, and water is continuously circulated to draw heat away from the rods and keep them at a safe temperature.

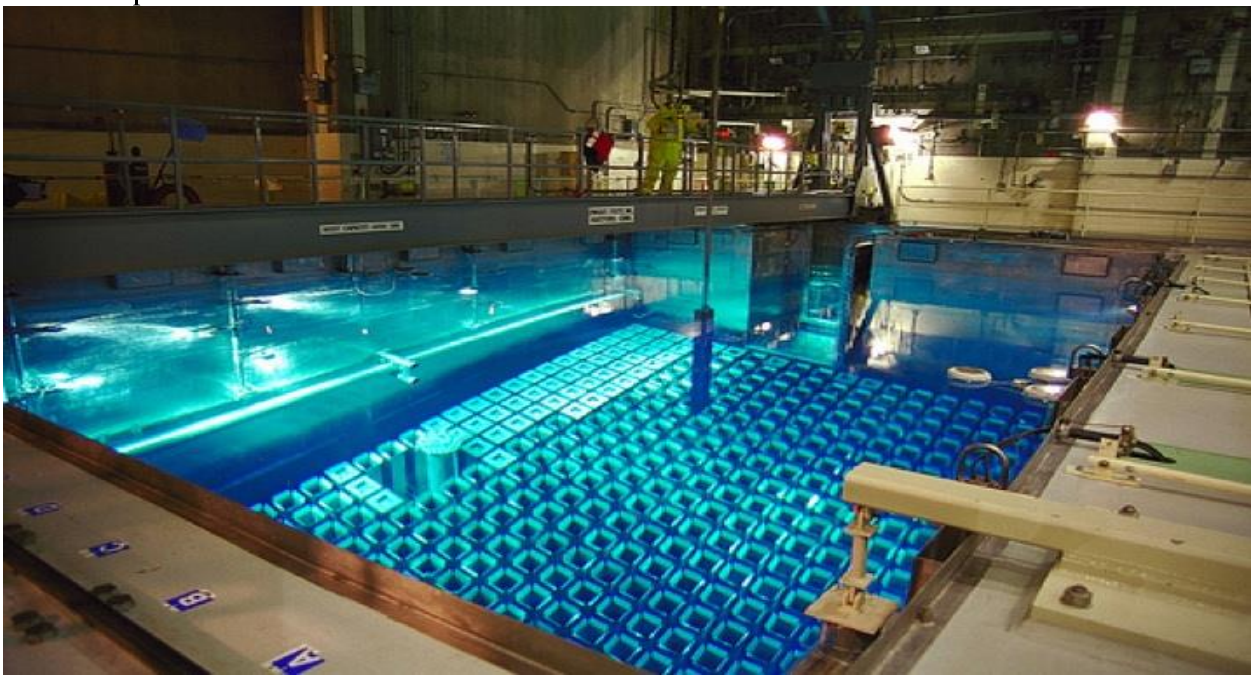


Figure: Spent Fuel Pool

Risks of spent nuclear fuel:

- If a malfunction or a natural disaster causes the water to leak from the pool or the cooling system to stop working, the rods will begin to heat the remaining water in the pool, eventually causing it to boil and evaporate. If the water that leaks or boils away cannot be replenished quickly enough, the water level will drop, exposing the fuel rods.
- Once the fuel is uncovered, it could become hot enough to cause the metal cladding encasing the uranium fuel to rupture and catch fire, which in turn could further heat up the fuel until it suffers damage. Such an event could release large amounts of radioactive substances, such as cesium-137, into the environment.
- The spent fuel pools in boiling-water reactors are located only within the secondary containment of the reactor and not within the more robust primary containment that is designed to keep radiation released from the reactor vessel during an emergency event from escaping into the environment. Thus, any radiation released from a spent fuel pool

is more likely to reach the outside environment than is radiation released from the reactor core.

Dry cask storage:

As it is discussed earlier that the spent nuclear fuel has to be disposed, spent nuclear fuel pool was used for the disposal. Instead of spent fuel pool, dry cask storage can be used. Dry cask storage is a method of storing spent nuclear fuel that has already been cooled in the spent fuel pool for at least one year and often as much as ten years. Casks are typically steel cylinders that are either welded or bolted closed. The fuel rods inside are surrounded by inert gas. Ideally, the steel cylinder provides leak-tight containment of the spent fuel. Each cylinder is surrounded by additional steel, concrete or other material.

Figure: Dry Cask Storage

By transferring fuel from spent fuel pools to dry casks, plants can lower the risk from spent fuel in several ways:

- With less spent fuel remaining in the pools, workers will have more time to cope with a loss of cooling or loss of water from the pool, because the amount of heat released by the spent fuel is lower. With less heat, it takes longer for the water to heat up and boil away.
- If there is less fuel in the pool, it can be spread out more, making it easier for the fuel to be cooled by water, or even air if the pool is rapidly drained after an accident.
- Because there is less fuel in the pool, if workers are unable to prevent an accident, the amount of radioactive material emitted from the pool will be much lower than it would be otherwise.

4.4.3 High Level Waste

High-level radioactive wastes (HLW) are the highly radioactive materials produced as a byproduct of the reactions that occur inside nuclear reactors.

- It contains fission products and transuranic elements generated in the reactor core.
- Though it is only 3% of total volume but it is responsible for 95% of total radioactivity.
- It is highly radioactive and often hot.
- HLW is the most dangerous and the main candidate for geological disposal.
- Certain radioactive elements (such as plutonium 239) in "spent" fuel will remain thousands of years.

Disposal of High level wastes can be done by following ways:

1. Above ground disposal
2. Geological disposal
3. Deep borehole disposal
4. Disposal at subduction zones
5. Ocean disposal
6. Disposal in outer space

1. Above ground disposal	➢ Waste from a spent fuel is sealed in a steel cylinder which is place in a concrete cylinder which acts as a radiation shield. ➢ Cheap, relatively easy to construct and monitor. ➢ Dry cask storage area.
2. Geological disposal	➢ The basic concept is to locate a large, stable geological formation and use mining technology to excavate a tunnel where rooms or vaults can be excavated for disposal of HLW. ➢ The goal is to permanently isolate nuclear waste from the human environment. ➢ In nature, sixteen repositories were discovered at the Oklo mine in Gabon. ➢ In order to store the high level radioactive waste in long-term geological depositories, specific waste forms need to be used which will allow the radioactivity to decay away while the materials retain their integrity for thousands of years. The materials being used can be broken down into a few classes: glass waste forms, ceramic waste forms, and nanostructured materials.
3. Deep borehole disposal	➢ Placing the waste as much as 5 km beneath the surface of the Earth. ➢ Waste is sealed in strong steel containers and lowered down the borehole, filling the bottom one or two km of the hole. ➢ Borehole is then sealed with materials, including perhaps clay, cement, crushed rock etc. ➢ Environmental impact is small. ➢ Can be carried out near nuclear power plant eliminating transportation risks.

The last three methods of disposal are impractical. Disposal in outer space is very costly and there is high risk of space vehicle failure. Ocean disposal has been declared illegal by international treaty. Disposal at subduction zones has a high risk of earthquakes since located on plate boundaries.

4.4.4 Intermediate Level Waste

Intermediate-level waste (ILW) contains higher amounts of radioactivity and in general require shielding, but not cooling. Intermediate-level wastes includes resins, chemical sludge and metal nuclear fuel cladding, as well as contaminated materials from reactor decommissioning. It may be solidified in concrete or bitumen for disposal.

4.4.5 Low Level Waste

Low-level wastes include paper, rags, tools, clothing, filters, and other materials which contain small amounts of mostly short-lived radioactivity. Materials that originate from any region of an Active Area are commonly designated as LLW as a precautionary measure even if there is only a remote possibility of being contaminated with radioactive materials. Such LLW typically exhibits no higher radioactivity than one would expect from the same material disposed of in a non-active area, such as a normal office block.

Some high-activity LLW requires shielding during handling and transport but most LLW is suitable for shallow land burial. To reduce its volume, it is often compacted or incinerated before disposal. Low-level waste is divided into four classes: **class a**, **class B**, **class C**, and **Greater Than Class C** (**GTCC**).

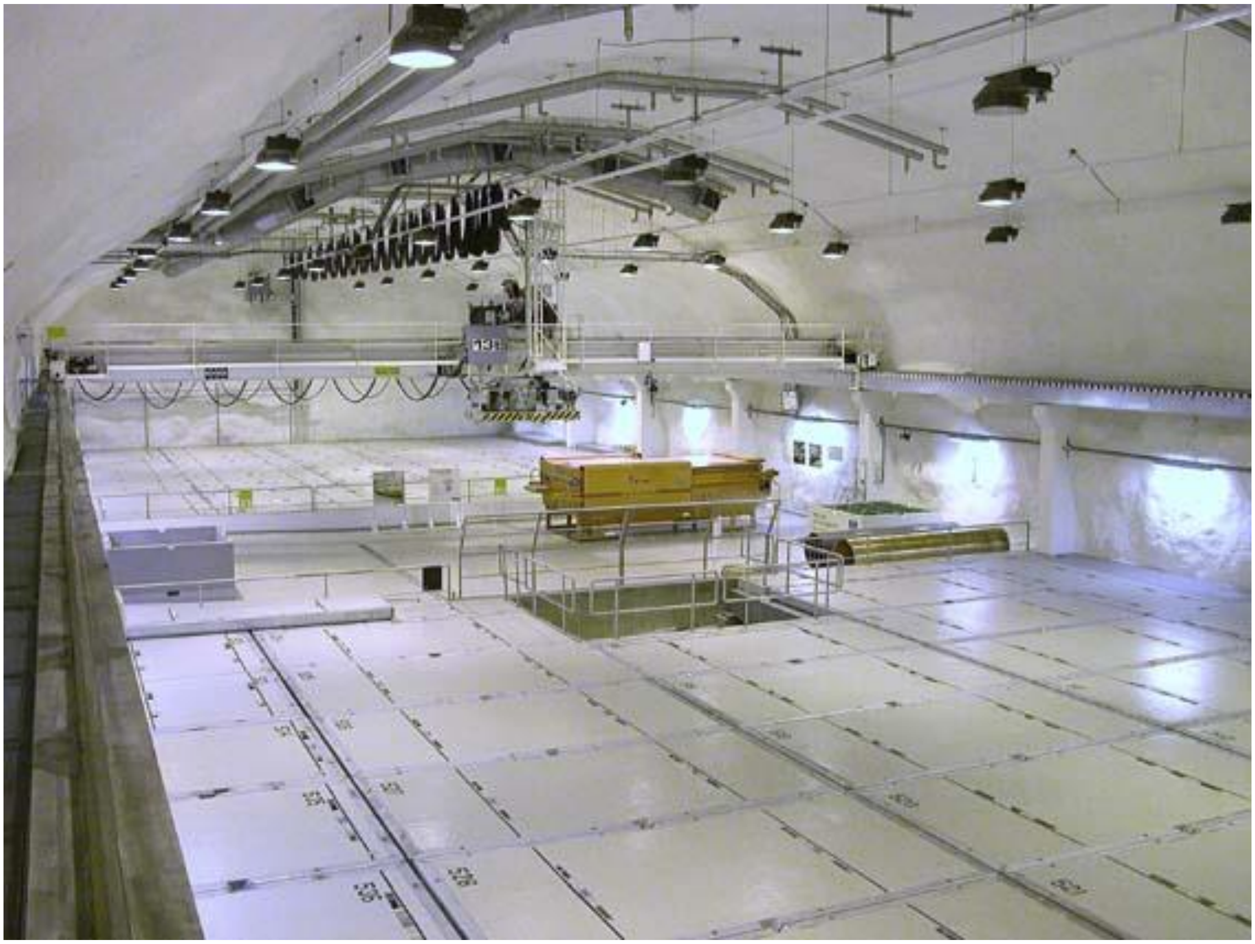


Figure: Low and Intermediate Level Waste Repository at Olkiluoto in Finland (Posiva)

4.5 Decommissioning:

Nuclear decommissioning is the process whereby a nuclear power plant site is dismantled to the point that it no longer requires measures for radiation protection. The presence of radioactive material necessitates processes that are occupationally dangerous, hazardous to the natural environment, expensive, and time-intensive.

Decommissioning is an administrative and technical process. It includes clean-up of radioactive materials and progressive demolition of the plant. Once a facility is fully decommissioned, no radiologic danger should persist. The costs of decommissioning are spread over the lifetime of a facility and saved in a decommissioning fund. After a facility has been completely decommissioned, it is released from regulatory control and the plant licensee is no longer responsible for its nuclear safety. Decommissioning may proceed all the way to "greenfield" status.

The International Atomic Energy Agency (IAEA) has defined three options for decommissioning, the definitions of which have been internationally adopted:

- Immediate Dismantling (or Early Site Release/'Decon' in the US): This option allows for the facility to be removed from regulatory control relatively soon after shutdown or termination of regulated activities. Final dismantling or decontamination activities can begin within a few months or years, depending on the facility. Following removal from regulatory control, the site is then available for re-use.
- Safe Enclosure ('Safstor') or deferred dismantling: This option postpones the final removal of controls for a longer period, usually in the order of 40 to 60 years. The facility is placed into a safe storage configuration until the eventual dismantling and decontamination activities occur after residual radioactivity has decayed. There is a risk in this case of regulatory change which could increase costs unpredictably.
- Entombment (or 'Entomb'): This option entails placing the facility into a condition that will allow the remaining on-site radioactive material to remain on-site without ever removing it totally. This option usually involves reducing the size of the area where the radioactive material is located and then encasing the facility in a long-lived structure such as concrete, that will last for a period of time to ensure the remaining radioactivity is no longer of concern.

Example of decommissioning work underway

Mothball

When a plants nuclear lifetime is over, it radiates radioactive nuclear wastes or radiation in the environment which is highly hazardous for all the surrounding life forms. At this case, that particular plant is sealed in ‘MOTHBALLING’ process. In some decommissioning process sometimes the clean-up of radioactive materials take a long period of time. At this case we can use ‘MOTHBALL’ process for that particular plant. Mothballing is the preservation of a production facility without using it to produce. Machinery in a mothballed facility is kept in working order so that production may be restored quickly if needed.


Bataan Nuclear Power Plant (BNPP) in Philippines after mothballing

Chapter 5

Nuclear Power Need

5.1 Power System Reliability

Reliability is theoretically defined as the probability of success. In brief Reliability is the probability of a device or system performing its function adequately for the period of time intended, under the operating conditions intended. The function of an electric power system is to provide electricity to its customers efficiently and with a reasonable assurance of continuity and quality. Thus the reliability of power system is the probability of providing customers with continuous service and with a voltage and frequency within prescribed ranges around the nominal values.
To maintain the reliability of a power system, some factors must be ensured:

- There should not be any interruption of power supply to the consumers
- A fixed frequency should be maintained at the grid. Frequency must not fluctuate over the tolerable range
- Voltage should not fluctuate more than the tolerable range at the consumer end
- Power plant must have some reserve power to face the sudden crisis

The best advantage of a nuclear power plant over other power plants is, nuclear power can work as a base load. Base load power sources are those plants which can generate dependable power to consistently meet the demand. Nuclear power plant does not require a lot of maintenance as the other plants so it can work for a longer period of time.
Requirement of reserve power for a nuclear power system is very low compared with other plants. Unless environmental disaster occurs, nuclear power plant can operate continuously. Thus power system reliability can be maintained by nuclear power plant.

5.2 System Economy

A power station is required to deliver power to a large number of consumers to meet their requirements. While designing and building a power station, efforts should be made to achieve overall economy so that per unit cost of production is as low as possible. This will allow the electric supply company to sell electricity at a profit and ensure reliable service.
There are several factors which influence the production cost. Nuclear power plant is capable of overcoming many of the influential factors such as

- Nuclear plants require fissile fuel, generally Uranium. In a nuclear power plant very less amount of fuel is required compared with the plants where fossil fuels are used. The total fuel cost of a nuclear power plant is 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. For a coal fired plant 78% of cost is the fuel, for a gas fired plant it is about 89% while for nuclear plants the figure is 14% only *(source: US Nuclear Energy Institute).* This low fuel cost has given nuclear energy an advantage compared with fossil energies.

- In order to build a power plant, a handsome amount of capital cost is needed. This capital costs include the cost of site preparation, construction, and manufacture, commissioning and financing a nuclear power plant. Among these costs the construction cost is comparatively high in nuclear power plant as it needs to use some special equipment such as reactor core, control rods, reactor vessel, neutron moderator etc. and to incorporate sophisticated safety features. Despite the consideration of high investment cost of a nuclear power plant, the low plant operating cost and almost zero external cost to society for plant operation gives nuclear power a significant advantage over fossil fuel fired power plants.
- The lifetime of a nuclear power plant is comparatively much high than the fossil fuel fired plants. Usually the lifespan of a steam turbine power plant is around 25 years, for the gas turbine plants it is almost 15 years while the lifetime of a nuclear power plant is almost 60 to 70 years which makes nuclear power superior to fossil energies.

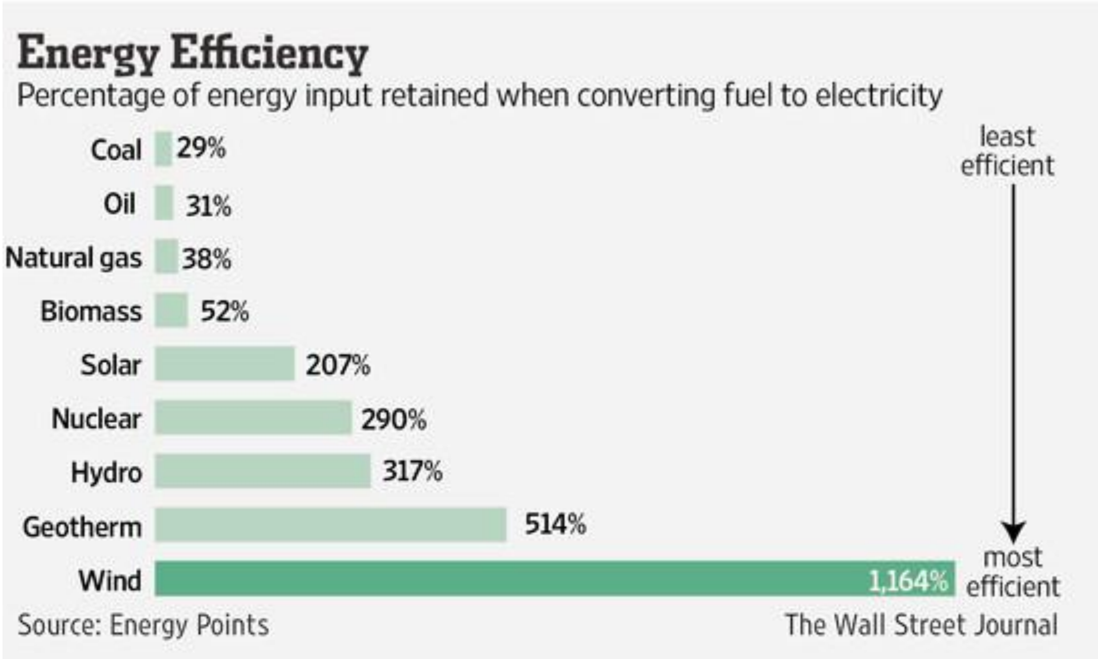
Thus it can be concluded that, building a nuclear power plant rather than other types of plants can be economically sounder scrutinizing all the facts regarding economic issues.

5.3 Energy Sustainability

Sustainable energy can be delineated as any type of energy that can potentially be used well into the future without harming future generations. The modern world relies on a vast energy supply to fuel everything. Production of electricity depends more on the fossil fuels in the current world. This vast use of fossil energies is leading the world towards a greater threats to energy security. Besides pollution of energy sources especially fossil fuels in increasing day by day. Most fossil fuels are burned to turn into energy and in this process they emits nitrogen oxides which stands for the cause of pollution of the environment. Another fact with the fossil fuels is that these energy sources are not well efficient to produce usable energy. Thus more fuel is required to get desired result. As a result usage of fossil fuels is getting incredibly high in the past decades since the need of energy has become sky high. So the future generation has become uncertain regarding the energy situation. Amount of fossil fuels may not be sufficient enough for the future generation to fuel. That's why energy must be sustainable. Energy should be used in such a manner that energy is stored for the future world. To make the energy sustainable, some facts must be followed. These are the following:

1. ***Efficiency:*** The efficiency of the energy sources must be improved. Much of the energy content of the available energy sources is wasted by the inefficiencies the energy conversion and distribution processes. Electric power plant efficiency is defined as the ration between the useful electricity output from the generating unit, in a specific time and the energy value of the energy source supplied to the unit in the same time period. Efficiency of the energy sources should be higher because fuel requirement will become less for the higher efficient sources. The following picture shows the comparison of the

efficiency of different energy sources while converting into electricity.



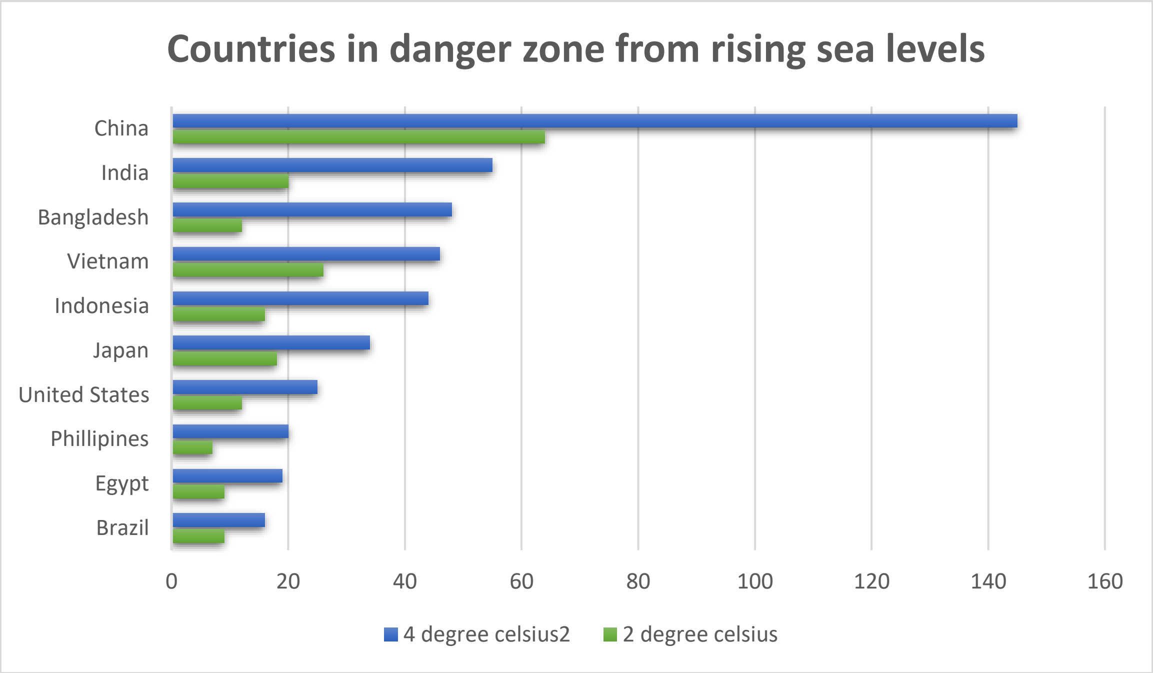
2. ***Diversification:*** Energy diversification refers to a nation using multiple sources of energy to run its economy and public services, eliminating dependence on any one source of energy. Such diversification can mean both renewable and non-renewable sources as well as multiple carriers. In the current world, production of electricity mostly depends on fossil fuels. Nuclear sources can be the helping hand in case of the diversification. Same output can be got from the nuclear sources as from the fossil fuels. This diversification can release the pressure from the fossil energy sources.
3. ***Low wastage:*** Sustainability of energy sources can be improved by reducing the waste of energy. Low waste will lead the world having more energy reserved for the future. Thus any energy source can become sustainable.

Nuclear energy source can be used to diversify from the other energy sources as it is a pretty efficient source to produce electricity.

5.4 Climate Change

Environmental consequences of energy production throughout the world, the production, supply and consumption of energy sources is associated with the emissions of pollutants to air, soil and water causing environmental damage that impacts on the health and well-being of all living things. Global concerns about climate change have focused attention particularly on emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG) into the atmosphere. Combustion of fossil fuels has historically been a major cause of the increased concentration of GHG in the atmosphere.
The capacity of certain gases in the atmosphere to trap heat emitted from the earth's surface, thereby insulating and warming the Earth. Without the thermal blanketing of the natural

greenhouse effect, the Earth's climate would be about 33° Celsius cooler too cold for most living organisms to survive. The greenhouse effects has warmed the Earth for over 4 billion years. Increment of the global temperature is causing the rise of sea level. Rising sea level will erode beaches and coastal wetlands destroying essential habitat and leaving coastal areas more prone to flooding. Sea levels could rise rapidly with accelerated ice sheet disintegration. Global temperature increases of 3-4° could result in 330 million people being permanently displaced through flooding.



Source: world economic forum

Expanding energy access requires systematic planning to find the synergy of different sources that deliver energy that is affordable, while conserving resources and environment friendly. The nuclear energy is reliable and cost effective when comparing with the fossil fuel based power stations. For the generation of electricity, using nuclear fuel as primary energy source will minimize the environmental bad impacts rather than using fossil fuels. Fossil fuels create wastes mostly GHG whereas nuclear fuel never generate any kind of GHGs. Despite a nuclear power plant produces radioactive wastes but these wastes are managed carefully so that it does not affect the environment. In fact, nuclear power is the only energy producing industry which takes full responsibility for all its wastes.

Thus it is preferable to maximize the use of nuclear fuel as electricity generation cause fossil fuels have already failed to promise to build a GHG free environment while nuclear fuel have already proved itself a clean fuel for reducing global warming.

Chapter 6

Bangladesh Power System

6.1 Development

At the time of partition of Indo-pak sub-continent, in the year 1947 when the British colonial rulers left, power generation and distribution of this part of the country were in the hands of some private companies. The power supply to then 17 provincial districts was within the township in a limited way. The generation voltage was 400 volts. Power used to be supplied to most of the districts during nighttime only. Only exception was Dhaka City where power used to be supplied by two 1500 kW generators and the generation voltage was 6600 volts and this was the highest supply voltage. There was no long distance transmission lines. Besides power used to be generated by some industries (tea, sugar and textiles) and railway workshops. In aggregate the generation capacity of the country was 21 MW. The generation capacity of the power utility companies together was only 7 (seven) MW and there was no transmission system.
In 1948, Electricity Directorate was created in order to plan and improve power supply situation. In 1959, Water and Power Development Authority (WAPDA) was created and the power sector really started working satisfactorily. In 1960, Electricity Directorate was merged with WAPDA. The basic philosophy was to give more autonomy to an organization for development of this basic infrastructure. At that time relatively higher capacity plants were built at Siddhirganj, Chittagong and Khulna (highest plant size was only 10 MW Steam Turbine at Siddirganj). At the same time Kaptai dam was under construction under Irrigation department. Unit size of Kaptai was 40 MW, which for that time was considered to be a large power plant. Side by side construction of Dhaka-Chittagong 132 KV transmission line was in progress. Construction of Kaptai dam and commissioning of Dhaka-Chittagong 132 KV transmission line in the year 1962 may be taken as milestone of power development of this country. During mid-1970s government emphasized on the rural electrification for achieving a desirable social uplift in the country. A different approach and a new model was considered for undertaking a comprehensive scheme. Thus the Government created Rural Electrification Board (REB) in October 1977. Later in 1991 Dhaka Electric Supply Authority (DESA) now DPDC was created basically to operate and develop distribution system in and around Dhaka (including the metropolitan city) and bring about improvement of customer service, collection of revenue and lessen the administrative burden of BPDB. Public investments and state ownership have been the traditional means to exercise control over the electricity sector. Government regulated the natural monopoly of power supply primarily to protect the consumer’s interest. The situation is fast changing. Structural changes are taking place and new corporate characters are emerging. The gradual expansion of the infrastructure has also been justified by the need for realizing social goods relating to rural electrification and low cost electricity supply to the public.

6.2 Present Status

Bangladesh is an energy hungry country. Power infrastructure of Bangladesh is small and insufficient but the demand is rapidly increasing. The per capita power consumption in Bangladesh is about 136kwh which is one of the lowest in the world but for huge population density our power sector is in enormous pressure. In Bangladesh, electricity is the major source of power and most of the economic activities depends on electricity.

Total electric power generation (installed) capacity of Bangladesh is 5823MW [according to BPDP, June 2010] and only three-fourth of which is considered to be available. The present effective power generation capacity per day is about 4000 MW and the demand is 5000MW. Only 40% of our total population has the access to electricity and in rural areas it is less than that.

Bangladesh has small reserves of oil and coal, but potentially very large natural gas resources that's why, most of the generation plant used natural gas as fuel. Some coal, diesel, furnace oil is also used in production of electric power. About 87% of our total electric power is produced by natural gas, 5.75 % by furnace oil, 4.29 % by coal, 3.19 % by diesel and 3.95 % is produced from hydro-electric plant.

Generation Capacity	12,339 MW (March 2016)
Present Demand	10,953 MW (December 2015)
Present Generation	5581~7775 MW
Highest Generation	8348 MW(April 2016)
Per Capita Generation	371 KWh (December 2015)
Transmission Line	9789 KM (December 2015)
Distribution Line	3,72,000 KM (March 2016)
Distribution Loss	10.49% (January 2016)
Total Consumers	20.4 Million (March 2016)
Access to Electricity	76% (March 2016)

6.3 Primary Energy Sources

Natural Gas is the most important source of energy in our country as it accounts for about 75% of the total commercial energy of the country. At present, about 37% of natural gas production is used as fuel for electricity generation. Overdependence on the natural gas must be reduced as the present reserve is not sufficient enough to support the country for long term economic growth. Bangladesh, with a very low reserve of petroleum, has become a net petroleum import country. Because of the recent liquid oil based power plants, petroleum requirements have increased by 28% in 2011. Because of the unrest in Middle-East region, petroleum price is going up which will increase import bill of Bangladesh Petroleum Corporation (BPC).
Aside from natural gas and petroleum, coal resource of the country is still underutilized because of lack of proper guideline. Coal policy, which will ensure proper guideline regarding the usage of this resource for the economic development of the country, is yet to be finalized. Lack of investment in power generation in the last decade has created electricity shortage. With a view to combat this, the Government of Bangladesh has taken initiative to set up power plants so that the country has sufficient electricity within 2016.
Successful implementation of this is highly dependable on the supply of fuel. Over dependency on gas for electricity generation must be reduced, while coal and renewable energy based power plants must be introduced for sustainable electricity generation. Overall, in long term, an intelligent mix of the different available energy sources can enable Bangladesh to ensure a sustainable economic growth of the country. Right conditions and framework at policy and regulatory level is a must.
As per November, 2016

Fuel type	Capacity, MW	Total, %
Coal	250	1.92
Natural gas	8208	63.14
HFO	2684	20.65
HSD	1528	11.75
Hydro	230	1.77
Imported	100	0.77

6.4 Power Load Forecasts

Load forecasting of electricity and power demand plays a vital role in the economic and secured operation of power systems. Bangladesh government has taken consideration of several plans for the future. Those can be stated as

- To actively develop domestic primary energy resources

- To establish the power system portfolio by fuel diversification
- To realize a low carbon society by introducing high efficient power supply sand low CO_2 emission technology
- To build an infrastructure necessary for stable power supply under joint coordination by the multi-sector
- To build an efficient and effective mechanism, organization and regulations for stable power supply
- To reduce the poverty through the growth of socio-economy

The targets that should be taken in consideration to fulfill these plans are-

- To maintain domestic primary energy supply over 50%
- Fuel composition ratio as of 2030: coal 50%, natural gas 25%, others 25%
- To improve 10 points thermal efficiency on average
- To jointly build a deep sea port facility by power, industry and commercial sector
- To establish an organization for long-term stable fuel supply security
- To formulate regulations for compulsory regular inspection of power stations by leadership of government

Chapter 7

Rooppur Nuclear Power Plant

7.1 History

The proposal was made in 1961. Government took 253.90 acres of land in that year to build the plant. In 1963 the plant was approved. Discussions took place with the Canadian government in 1964 and 1966. Discussions with the governments of Sweden and Norway were also going on in those years. However, no real progress was achieved. After the independence of Bangladesh, the Government of Bangladesh started discussion with the Soviet Union in 1974, however no agreement was reached. In 2001 the government adopted a national Nuclear Power Action Plan. In 2009 the Bangladesh government again started discussion with the Russian government and on 13 February the two governments signed a memorandum of understanding. Rosatom said they would start construction by 2013.

In 2013 a group of Bangladeshi scientists and the global diaspora voiced profound concern over the safety and economic viability of the plant. Several separate issues were raised, from the unsuitability of the site to the obsolescence of the VVER-1000 model proposed, questionable financing arrangements and a lack of agreement with Russia over nuclear waste disposal.

In 2015 the proposal was delayed by a year. Rosatom offered a two VVER-1200 reactor power plant, increasing output to 2.4 GWe

By December 2015 the The Daily *Star* reported that the estimated cost of the plant had climbed to US$13 billion, from statements of around US$4 billion made earlier in the same year. Transparency International Bangladesh expressed concern on 28 December 2015 about the safety of the proposed plant, stating "Even reputed Russian environmentalists consider Russian nuclear reactors unsafe".

In 2016 ground preparation work commenced. The $12.65 billion contract is 90% funded by a loan from the Russian government. The two units generating 2.4 GWe are planned to be operational in 2023 and 2024. Rosatom will operate the units for the first year before handing over to Bangladeshi operators. Russia will supply the nuclear fuel and take back spent nuclear fuel.

7.2 Site Location

The nuclear power plant will be built at Rooppur, 200 km north-west of Dhaka, at Paksey union on the bank of the river Padma in the Ishwardi sub-district of Pabna District, in the northwest of the country.

Location of Ruppur Nuclear Power Plant in Bangladesh

7.3 Recent Development

Bangladesh has made noticeable progress with its nuclear power program. The mission, a follow-up to an IAEA Integrated Nuclear Infrastructure Review (INIR) in 2011, found that Bangladesh had initiated responses to all its earlier recommendations and suggestions.
The team identified Bangladesh's main achievements as the establishment of a nuclear safety regulatory body; the selection of the Rooppur site; undertaking site characterization and environmental impact assessment; and the adoption of a law to establish the Nuclear Power Plant Company Bangladesh Ltd, which will be the operating organization for the plant. Coordination among relevant government entities had been strengthened, but formalized procedures between the future operator and the regulatory body have yet to be established, it noted.
The IAEA team found implementation of some responses still required further attention, including strengthening Bangladesh's national project plan to reflect the actual status of the program and its future challenges. It also suggested a national and institutional human resource plan be finalized, a national communication strategy put in place for stakeholder involvement and public information, and that policies for the management of low and medium level radioactive waste should be formally approved.

80 percent work to start the main construction on a 1,062-acre land in the first phase has been completed.
The construction of the 2,400-megawatt power plant’s main infrastructure started in 2014.
The Press Information Department recently organized a tour of journalists to the project site.
Project officials said the issue of averting risk has been given top priority.
The power plant would be able to withstand an earthquake measuring up to magnitude 9 on Richter scale, they said.
The initiative to set up the nuclear plant was taken in 1961. Later in 1963, Rooppur was selected out of 12 proposed sites for the plant.

After the Awami League-led government came to power in 2009, it took fresh initiative to implement the 50-year old proposal.

Rooppur Power Plant Project

Location: Rooppur in Pabna
Area: 1,062 acres
Capacity: 2,400MW with two units of 1,200MW each
Technology: VVER-1200, Russia
Foundation stone laid: October, 2013
Cost: $12.65 billion (Tk 1.12 trillion)
Opening: Targeted launch of first unit is 2022. The second one will be launched the following year.
Longevity: 30 to 80 years

7.4 Contract with Russian Supplier

Bangladesh has signed $11.38 billion credit deal with Russia in Moscow on July 26 to implement the Bangladesh’s first ever 2,400 MW nuclear power plant at Rooppur in Pabna.
On July 18, the Russian government approved a deal to loan up to $11.38 billion to build the Rooppur nuclear power plant in Bangladesh.
The Bangladesh cabinet, earlier on June 27, approved the draft of the inter-governmental state credit agreement to be signed between Bangladesh and Russia for the construction of the power plant project with an estimated cost $12.65 billion, Bangladeshi officials said.
Of the amount, $11.38 billion will come from Russia and rest of the funding will be provided by Bangladesh.

7.5 Project Implementation Plan

Atomstroyexport (ASE) of Russia and Bangladesh Atomic Energy Commission (BAEC) to had a regular coordination meeting at Rooppur Nuclear Power Project site at Ishwardi .The meeting to review the results and plans for the beginning of an active phase of construction works and development of design documentation. A high power ASE delegation from Moscow to reach Rooppur this morning to take part at the meeting.

In December 25, 2015 the General Contract for construction of Rooppur NPP on a turn-key basis was signed between Atomstroyexport and Bangladesh Atomic Energy Commission. This event opened the way for beginning of full-scale works on construction of Rooppur NPP site facilities.
By the beginning of 2016, Atomstroyexport has already implemented civil works to build the so-called pioneer base and the first phase of construction and erection base at Rooppur NPP site. Therefore the plans for 2015 have been 100% implemented. In 2016, the works on construction and erection base will be continued, and the work on foundation pits for power Units 1 and 2 as well as soil stabilization activities for these pits are to be completed. Infrastructure works are also underway and equipment is delivered as required and scheduled.
Rooppur NPP project is implemented in accordance with the Agreement signed between the Governments of Russia and Bangladesh of 2 November 2011. The General Contractor is Atomstroyexport as part of ASE Group of Companies representing engineering division of Rosatom State Corporation.

The design for Rooppur NPP was selected to be AES-2006, a Russian design with VVER-type reactors of 1200 MW each having a prototype at Novovoronezh NPP-2 (Russia). This is an evolutionary design of Generation III+ which meets all international safety requirements and recommendations. This design was offered for Rooppur NPP as the most efficient in terms of safety and reliability as well as the most beneficial for Bangladesh from economic point of view.
ASE Group of Companies was established within the frame of the engineering division of Rosatom State Corporation by merging four leading companies of the industry: (Nizhny Novgorod Atomenergoproekt, Atomstroyexport, Atomenergoproekt and ATOMPROEKT).

ASE is one of the world leaders in nuclear power engineering and holds 30% of the global NPP construction market.
ASE has representative offices, branch offices and operational offices in 15 countries around the world, with almost 80% of its portfolio coming from the projects abroad.
Besides, the company also provides services in the field of NPP decommissioning, construction of facilities for RAW and SNF management, research reactors, thermal power plants as well as a full range of EPC, EPC(M) and PMC services for any complex engineering assets.

7.6 Responsible Parties

Russian company JSC Atomstroyexport will begin preparatory works for construction of Bangladesh's first nuclear power plant this month as the Bangladesh Atomic Energy commission issued performance.
The preparatory works include setting up of residential village for the contractor's personnel and an initial base for the power plant to be built at Rooppur in northern Pabna district worth TK US$1.5-2.0 billion.
In October 2013, Russian firm JSC NIAEP, the management company of Atomstroyexport, signed a $265 million deal with Bangladesh Atomic Energy Commission.

BAEC/Rosatom - Rooppur Nuclear Power Plant - Bangladesh - Construction Project Profile is a crucial resource for industry executives and anyone looking to access key information about the Rooppur Nuclear Power Plant construction project.

BAEC/Rosatom - Rooppur Nuclear Power Plant - Bangladesh - Construction Project Profile report utilizes a wide range of primary and secondary sources, which are analyzed and presented in a consistent and easily accessible format. WMI strictly follows a standardized research methodology to ensure high levels of data quality and these characteristics guarantee a unique report.

7.7 Construction Schedule

Work on the Rooppur nuclear power plant is going on with an aim to issue site license, determine techno-economic solutions and assess environmental impacts by this year.
The license will guarantee that the site is suitable for construction, operation and maintenance of a specific technology and capacity reactor.
The Bangladesh Atomic Energy Regulatory Authority will issue the license on the basis of normative acts and regulations of the governments of Bangladesh and Russia and with the recommendation of the International Atomic Energy Agency (IAEA).
Two crucial issues -- technology and the cost -- of the reactor would be determined in the techno-economic solutions, he added.
These have been done under the first deal Dhaka and Moscow inked in June last year in their quest for a nuclear power plant in Bangladesh.
Activities of the nuke plant construction slowed down due to political turmoil in Bangladesh and yearend vacation in the last couple of months. However, the project director said they were very

much on target of completing all activities in time.
Design and drawing of the reactor, working and construction condition, and structures of the nuke plant would also be done in this phase.
The two countries have meanwhile started discussion to sign the third deal for preparation of nuclear plant construction through developing required infrastructure, service facilities and setting up of equipment on the site.
Both the minister and the PD expressed the hope that installation of the reactor would be completed by 2020 with a view to adding power to the national grid the following year.
Russia is giving technical and financial support to build the plant and has promised to install the latest and safest type of reactor complying with all post-Fukushima international safety regulations. Russian state nuclear power company Rosatom would provide the nuclear power plant.
Last year, Moscow provided Dhaka a $500 million loan to complete the preparatory works.
Russia, which is now building several dozen nuke plants in different countries, will also provide 90 percent of the construction cost that ranges between Tk 12,000 crore and Tk 15,000 crore.

7.8 Manpower

The government has undertaken a human resource development plan to build skilled manpower for running and maintaining a hi-tech establishment like nuclear power plant.
Russia with it's over 70 years of experience in the nuclear field is extending support in this regard.
Bangladesh is steadily moving forward with its nuclear power program to become one of the members of global nuclear elite club.
The first ever nuclear power plant project of the country is being implemented with Russian assistance at Rooppur of Pabna district. The Rooppur Nuclear Power Plant (NPP) will be built using latest generation 3+ VVER 1200reactors. It is expected that Bangladesh will receive its first nuclear power by 2024. The government is actively considering another nuke plant in the southern part of the country as well.
As agreed, Russia will hand over the Rooppur NPP to Bangladesh management after commissioning and running it for a short period during provisional takeover. Bangladesh should obtain the capability to run and maintain this hi-tech establishment.
The program was organized by the Russian State Atomic Energy Corporation - Rosatom in cooperation with the International Atomic Energy Agency (IAEA) with the purpose of building leadership competencies in managing nuclear energy programs, particularly in newcomer countries that seek to develop nuclear power or other nuclear applications.
Saint-Petersburg Branch of the Rosatom Central Institute for Continuing Education and Training (ROSATOM-CICE&T) hosted the program.
Representatives from eighteen countries including Bangladesh, Algeria, Belarus, Bolivia, Brazil, Ghana, Egypt, Zambia, Indonesia, Jordan, Cambodia, Kenya, Malaysia, Nigeria, Slovakia, Tunisia, Turkey, and Ethiopia participated in the educational program in St. Petersburg.

IAEA, international and Rosatom experts specializing in various fields shared their experience and best practices on all nineteen infrastructure issues as mentioned in the IAEA Milestone document covering technical, legal, financial and societal aspects of national nuclear programs.

The course introduced the participants to a range of topics on the use of nuclear energy, such as issues of nuclear infrastructure development, safety management and safety culture, updates in reactor technologies, and nuclear knowledge management.
Besides theoretical sessions of the program, practical trainings such as the unique NKM Business Simulation Game were included where participants experienced of their own the need of knowledge preservation and sharing among nuclear industry stakeholders.
In the group project on “Infrastructure Development,” the participants brainstormed on solutions to overcome the main problems in development of nuclear infrastructure such as national position, management, legal framework, regulatory framework and human resource development – which were more commonly recommended during the IAEA Integrated Nuclear Infrastructure Review (INIR) missions based on the six years long experience in INIR.
IAEA already conducted its follow-up INIR mission in Bangladesh two months ago, and made a comment that Bangladesh has made noticeable progress in implementing the recommendations of an IAEA.
In the NEM School, the general IAEA idea, generally the guideline, which can show the path, was presented. Rosatom could be a good friend to provide cooperation in developing the infrastructure in due time. It is much more useful to collaborate both with IAEA and experienced solution providers like Rosatom for a newcomer like Bangladesh, the program was told.
Besides lectures and practical sessions, several informative technical tours were organized during the School. The participants had the opportunity to visit the construction site of Leningrad NPP 2 (VVER-1200 reactors) including the reactor hall, turbine hall and the full-scope simulators used for operator training.
They also visited the Emergency Response Center of ROSATOM in St. Petersburg, the full-scope simulator of the Floating NPP “Akademik Lomonosov” and the Nuclear Industry Information Center (NIIC).

7.9 Operation & Management

Bangladesh inherited a corps of very highly qualified nuclear scientists and nuclear engineers, some of whom built, commissioned and operated the Karachi Nuclear Power Plant. They either left or retired from the Commission without being replaced. A few of those who had left built nuclear power reactors in Argentina, South Korea and Romania. Most of the engineers now working with the BAEC were trained either for operation of the research reactor at the Atomic Energy Research Establishment (AERE) at Savar or for maintenance of the BAEC's establishments. They hardly have any experience of construction or operation of any large unit like a nuclear or a conventional power plant. Even the DG of the IAEA, Yukiya Amano, admitted that “Bangladesh lacks in manpower.” Although negotiations with the Russians started four years ago, there were no serious attempts by BAEC to recruit and train engineers either for the management of the project or for application of nuclear regulations.
Contrary to standard practices, Russia granted a loan of US$ 500 million (Tk4, 000 crores) to Bangladesh and the Executive Committee of the National Economic Council (ECNEC) approved the first phase of the nuclear power project at a cost of Tk 5,242 crores without knowing the total cost of the project and before completion of the feasibility study.
The cost of a 1,000 MWe nuclear power reactor is estimated by the government to be US$ 1.5-2.0 billion (Tk 12,000- 16,000 cores) even though, according to the market price, it should cost

about US$ 4.0 billion (Tk 32,000 crores) each.
The site conditions at Rooppur have changed during the last fifty years. The flow of water in the Ganges have decreased significantly due to the Farakka Barrage. The population around the site has also doubled. A re-evaluation of the Rooppur site is, therefore, essential to ensure the availability of cooling water, transportation of heavy equipment to the site, safety of the plant and evacuation of an estimated three million people to a safe zone in case of a nuclear accident.
Concerns have also been expressed about the safety of the VVER-1000 reactors. Contracts for 11 VVER-1000 reactors in Eastern Europe were cancelled for failure to meet the European safety standards. Some of the countries are now planning to build VVER-1200 reactors which produce 1200 MWe power and have enhanced safety features like a core damage frequency (CDF) of 1×10-7. VVER-1200 reactors are designed to meet the safety standards of both USNRC and European Utilities' Requirements (EUR). With the projected peak power demand of over 20,000 MW, it may be possible to integrate 1200 MWe reactors into the grid of Bangladesh by 2022/23. It is, therefore, strongly recommended that we consider VVER-1200 reactors, instead of VVER-1000 reactors, for Rooppur for improved safety.
From the above discussions, it is evident that neither the Rooppur project is being managed professionally nor the government being advised properly. It is, therefore, essential that the management of the project is handed over to a professional body like a nuclear power corporation that will own, build and operate all nuclear power plants in Bangladesh, like in India and many other countries. We also need a strong and independent nuclear regulatory authority and a competent operation and maintenance (O&M) team. All such bodies should be manned by engineers with experience of construction and/or operation of nuclear/conventional power plants but trained in nuclear reactor technology.
Additionally, we should not rush to build a nuclear power plant until we are fully prepared with the required manpower and infrastructure. If our engineers could build and operate nuclear power reactors abroad, they can certainly do so at home provided we train our manpower properly, buy the safest available nuclear reactors and religiously apply the nuclear safety regulations.
BAEC was appointed by the 1973 Presidential Order, the BANPAP, 2000 and National Committee on RNPP, 2011 for implementation of Rooppur NPP until otherwise decided by the Government. Nuclear Power Company of Bangladesh was established under the Nuclear Power Plant Act 2015 [Act No. 19 of 2015]. NPCB will become nuclear power operating organization (Licensee). 12.65 Billion US$ General Contract for the construction of 2 x VVER-1200 MWe (AES-2006) was signed between BAEC and ASE on 25th December, 2015.

7.10 Regulatory Control

The BAERA Act-2012 has been formulated based on IAEA Handbook of Nuclear Law and existing NSRC Act-1993.Inputs from several IAEA experts have also been taken while formulating the draft of the Act.
Provisions of the BAERA Act-2012 cover nuclear safety, security and safeguard of nuclear as well as radioactive materials and also ensure civil liability for nuclear damage in the event of an accident. An independent regulatory body has been established on 12th February, 2013. The NSRC Rules were notified and put to force on September 18, 1997. The Rules incorporate the principal requirements of the Basic Safety Standards -115, 1996 (IAEA).

At present BAERA has total 71 staffs. BAERA has recently proposed a new Organizational Structure as per IAEA INIR mission recommendation. ν The basic philosophy of this proposed Organizational Structure is consistent with IAEA-TECDOC-1513. ν BAERA has identified total 360 personnel for the Regulatory Control of RNPP (2xunit) to perform different regulatory work functions.

Chapter 8

Key Issues

8.1 Knowledge Transfer and Independent Plant management

In the field of nuclear power there should be acknowledgement for general people of the surrounding. People should be provided required knowledge related to nuclear power or power plants and their social effects. The government has undertaken a human resource development plan to build skilled manpower for running and maintaining a hi-tech establishment like nuclear power plant.

Russia with it's over 70 years of experience in the nuclear field is extending support in this regard.

Bangladesh is steadily moving forward with its nuclear power program to become one of the members of global nuclear elite club.

IAEA, international and Rosatom experts specializing in various fields shared their experience and best practices on all nineteen infrastructure issues as mentioned in the IAEA Milestone document covering technical, legal, financial and societal aspects of national nuclear programs. The course introduced the participants to a range of topics on the use of nuclear energy, such as issues of nuclear infrastructure development, safety management and safety culture, updates in reactor technologies, and nuclear knowledge management.

Besides theoretical sessions of the program, practical trainings such as the unique NKM Business Simulation Game were included where participants experienced of their own the need of knowledge preservation and sharing among nuclear industry stakeholders.

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(AES-2006) was signed between BAEC and ASE on 25th December, 2015. BAEC is the owner of the plants. Government has formed high-level committees to carry out the functional responsibilities of the NEPIO; BAEC is working as a secretariat of the NEPIO.

8.2 Supply of Fuel

Uranium is one of the world's most abundant metals and can provide fuel for the world's commercial nuclear plants for generations to come. Nuclear power plants do not burn any fuel. Instead, they use uranium fuel, consisting of solid ceramic pellets, to produce electricity through a process called fission. Uranium is a fairly common element in the Earth's crust. Uranium is approximately as common as tin or germanium in the Earth's crust, and is about 40 times more common than silver. Uranium is present in trace concentrations in most rocks, dirt, and ocean water, but can be economically extracted currently only where it is present in high concentrations. Still, the world's present measured resources of uranium, economically recoverable at the arbitrary price ceiling of 130 USD/kg, are enough to last for between 70 and 100 years.
In order to keep the nuclear power plant under continuous operation we need continuous supply of fuel & that is Uranium.

8.3 Waste management

Nuclear power is the only large-scale energy-producing technology which takes full responsibility for all its wastes and fully costs this into the product.
The amount of radioactive wastes is very small relative to wastes produced by fossil fuel electricity generation.
Used nuclear fuel may be treated as a resource or simply as a waste.
Nuclear wastes are neither particularly hazardous nor hard to manage relative to other toxic industrial wastes.
Safe methods for the final disposal of high-level radioactive waste are technically proven; the international consensus is that this should be geological disposal.
All parts of the nuclear fuel cycle produce some radioactive waste (radwaste) and the relatively modest cost of managing and disposing of this is part of the electricity cost, *i.e.* it is internalized and paid for by the electricity consumers.
At each stage of the fuel cycle there are proven technologies to dispose of the radioactive wastes safely. For low- and intermediate-level wastes these are mostly being implemented. For high-level wastes some countries await the accumulation of enough of it to warrant building geological repositories; others, such as the USA, have encountered political delays.
Unlike other industrial wastes, the level of hazard of all nuclear waste – its radioactivity – diminishes with time. Each radionuclide contained in the waste has a half-life – the time taken for half of its atoms to decay and thus for it to lose half of its radioactivity. Radionuclides with long half-lives tend to be alpha and beta emitters – making their handling easier – while those

with short half-lives tend to emit the more penetrating gamma rays. Eventually all radioactive wastes decay into non-radioactive elements. The more radioactive an isotope is, the faster it decays.
The main objective in managing and disposing of radioactive (or other) waste is to protect people and the environment. This means isolating or diluting the waste so that the rate or concentration of any radionuclides returned to the biosphere is harmless. To achieve this, practically all wastes are contained and managed – some clearly need deep and permanent burial. From nuclear power generation, none is allowed to cause harmful pollution.
All toxic wastes need to be dealt with safely, not just radioactive wastes. In countries with nuclear power, radioactive wastes comprise less than 1% of total industrial toxic wastes

8.4 Disaster Management and Liabilities

The growth in the application of nuclear science and technology in the fields of power generation, medicine, industry, agriculture, research and defense has led to an increase in the risk of occurrence of Nuclear and Radiological emergencies.
India has traditionally been vulnerable to natural disasters on account of its unique geo climatic conditions and it has, of late, like all other countries in the world, become equally vulnerable to various man-made disasters.

Nuclear and Radiological Emergency can arise in a nuclear facility at plant level leading to plant/ site or offsite emergency depending upon the extent of its impact on the surroundings. It can also take place while using radiation sources, either at Hospitals, Industries, Agriculture or Research Institutions due to loss or misplacement or due to faulty handling. The other events that can lead to Nuclear or Radiological Emergency in the public domain, include, accident of a vehicle carrying radioactive/nuclear material, due of an orphan source i.e. the source which is not under regulatory control or due to usage of radiation source/radioactive material in malevolent activities.
Any radiation incident resulting in or having a potential to result in exposure and/or contamination of the workers or the public in excess of the respective permissible limits can lead to a nuclear/radiological emergency.
Operators of nuclear power plants are liable for any damage caused by them, regardless of fault. They therefore normally take out insurance for third-party liability, and in most countries they are required to do so.
The potential cross boundary consequences of a nuclear accident require an international nuclear liability regime, so national laws are supplemented by a number of international conventions. Liability is limited by both international conventions and by national legislation, so that beyond the limit (normally covered by insurance) the state can accept responsibility as insurer of last resort, as in all other aspects of industrial society.
The international Convention on Supplementary Compensation for Nuclear Damage (CSC) has entered into force, and will largely replace other conventions.
Most conventions and laws regarding nuclear third party liability have at their heart the following principles:

- Strict liability of the nuclear operator
- Exclusive liability of the operator of a nuclear installation

- Compensation without discrimination based on nationality, domicile or residence
- Mandatory financial coverage of the operator's liability
- Exclusive jurisdiction (only courts of the State in which the nuclear accident occurs have jurisdiction)
- Limitation of liability in amount and in time

However, nuclear emergencies can still arise due to factors beyond the control of the operating agencies; e.g., human error, system failure, sabotage, earthquake, cyclone, flood, etc. Such failures, even though of very low probability, may lead to an on-site or off-site emergency. To combat this, a number of system upgrades have been planned to mitigate/prevent such emergencies. However, proper emergency preparedness plans must be in place so that there is minimum avoidable loss of life, livelihood, property and impact on the environment.

8.5 Nuclear Plant Decommissioning

Nuclear decommissioning is the process whereby a nuclear power plant site is dismantled to the point that it no longer requires measures for radiation protection. The presence of radioactive material necessitates processes that are occupationally dangerous, hazardous to the natural environment, expensive, and time-intensive.

Decommissioning is an administrative and technical process. It includes clean-up of radioactive materials and progressive demolition of the plant. Once a facility is fully decommissioned, no radiologic danger should persist. The costs of decommissioning are spread over the lifetime of a facility and saved in a decommissioning fund. After a facility has been completely decommissioned, it is released from regulatory control and the plant licensee is no longer responsible for its nuclear safety. Decommissioning may proceed all the way to "greenfield" status.

All power plants, coal, gas and nuclear, have a finite life beyond which it is not economically feasible to operate them. Generally speaking, early nuclear plants were designed for a life of about 30 years, though with refurbishment, some have proved capable of continuing well beyond this. Newer plants are designed for a 40 to 60 year operating life. At the end of the life of any power plant, it needs to be decommissioned, cleaned up and demolished so that the site is made available for other uses.

For nuclear plants, the term decommissioning includes all clean-up of radioactivity and progressive dismantling of the plant. This may start with the owner's decision to write it off or declare that it is permanently removed from operation. For practical purposes it includes defueling and removal of coolant, though NRC at least defines it as strictly beginning only after fuel and coolant are removed. It concludes with license termination after decontamination is verified and wastes removed.

Chapter 9

Conclusion

At present, demand for electricity is increasing throughout the world. The primary sources of energy are limited and to cope up with the current demand, their scarcity has become a concern. From Bangladesh perspective, tremendous pressure is exerted upon natural gas for electricity production. Natural gas is being imported for the same purpose which further imposes fiscal pressure. Gas, while should be used for household purpose is being used in power plants which is an adverse situation in terms of energy. Another fossil fuel is coal which is also used to generate electricity. But it has dangerous effect on environment. Transportation of coal is very complex and not favorable for the environment. Crude oil is not available in Bangladesh so it cannot be used as fuel for electricity generation.

Bangladesh is said to be one of the biggest energy-starved countries, with the present demand for electricity at 7500 plus MW (Mega Watt) as opposed to the production of 5000 to 5800 MW. Access to electricity in Bangladesh is one of the lowest, about 40 percent of the total population are without access to adequate, cheap and quality energy. At present, we have to depend on indigenous energy resources, which are finite as well - gas, oil, furnace oil and coal to produce electricity. And about 55 per cent of our natural gas is used to produce this power. The reserve of gas is not infinite and will soon run out and before that happens, we must adopt alternative energy sources, be it renewable with a bio-ecological/green revolution or build nuclear power plants (NPP). Hence, the government recently decided to join the world's 30-strong nuclear power club.

Now, very interestingly, the NPP stands on the border between citizens of Bangladesh's greatest hopes of almost uninterrupted power supply and its deepest fears for the future – a nuclear catastrophe with contamination which can destroy scores of livelihood.

On one hand, atomic energy offers a clean alternative energy that can free us from the shackles of fossil fuel dependence. But contrary, it can summon omen of the greatest devils of disaster with examples of quake-ruptured Japanese power plants belching radioactive steam, and the dead zone surrounding Chernobyl's nuclear contamination site where even today, babies are born with birth defects.

By every humane measure, the world needs more energy. Energy multiplies human labor, increasing productivity. It builds and lights schools, purifies water, powers farm machinery, drives sewing machines and robot assemblers, stores and moves information. Bangladesh population is increasing, passing one hundred and fifty-six million as per 2014 census. Yet one third two billion people lack even electricity. Development depends on energy supply, and the alternative to development is suffering poverty, disease and premature death potentiating violence to force redistribution of material wealth. Beyond altruism, considerations of national security require developed nations to foster increasing energy production in their more populous developing counterparts. For safety as well as security, to meet unanticipated natural, ecological and technological challenges, that energy supply should come from diverse sources.

As greenhouse gases accumulate in the atmosphere, finding ways to generate power cleanly, affordably, and reliably is becoming an even more pressing imperative. Nuclear power is not a silver bullet, but it is a partial solution that has proved workable on a large scale. Countries will need to pursue a combination of strategies to cut emissions, including reining in energy demand, replacing coal power plants with cleaner natural gas plants, and investing in new technologies such as renewable energy and carbon capture and sequestration. The government's role should be to help provide the private sector with a well-understood set of options, including nuclear power—not to prescribe a desired market share for any specific technology.

Bangladesh must take a number of decisions to maintain and advance the option of nuclear energy. The initial reaction to the safety lessons of Fukushima must be translated into action; the public needs to be convinced that nuclear power is safe. Washington should stick to its plan of offering limited assistance for building several new nuclear reactors in this decade, sharing the lessons learned across the industry. It should step up its support for new technology and advanced computer-modeling tools. And when it comes to waste management, the government needs to overhaul the current system and get serious about long-term storage. Local concerns about nuclear waste facilities are not going to magically disappear; they need to be addressed with a more adaptive, collaborative, and transparent waste program.

These are not easy steps, and none of them will happen overnight. But each is needed to reduce uncertainty for the public, the energy companies, and investors. A more productive approach to developing nuclear power—and confronting the mounting risks of climate change—is long overdue. Further delay will only raise the stakes.

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