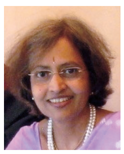
Challenges in the Quest for Clean Energies

I. Background

Sheela K Ramasesha



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Global warming has become a matter of concern for all living beings on earth. Electricity generation to meet our growing power demand is the main cause for it. About 80% of the electricity generated around the world is by combusting fossil fuels. This process emits greenhouse gases that are responsible for global warming. The present levels of greenhouse gases like CO_2, NO_X, methane, CFC and HCFC are much higher than the pre-industrial period. In the Indian scenario, 69% of the greenhouse gas emission is from electricity generation. This article highlights the need to consider the renewable sources of energy to generate electricity to contain the global warming trends.

Introduction

With urbanization and technological developments, worldwide energy consumption has increased in the last century. Energy is required to run all the devices that we use daily and in industries that manufacture these devices. Thus, the energy required per person per year in the world has increased almost 4-fold during the last century (*Figure* 1). The world population is expected to be above 9 billion by 2050. The energy requirement of the world is expected to increase by ~49% from 522 exajoules (10^{18} Joules) in 2007 to 779 exajoules in 2035 (*Figure* 2).

Electricity is a widely-used source of energy, which is easy to generate, distribute and use. Industries, where most of the goods we use are manufactured, run on electricity. Electricity can be generated by converting many different forms of energy such as thermal, kinetic and mechanical. Generation of electricity from thermal energy has been achieved by the burning of coal and

Keywords
Climate change, greenhouse gases, electricity, generation, renewable energies.

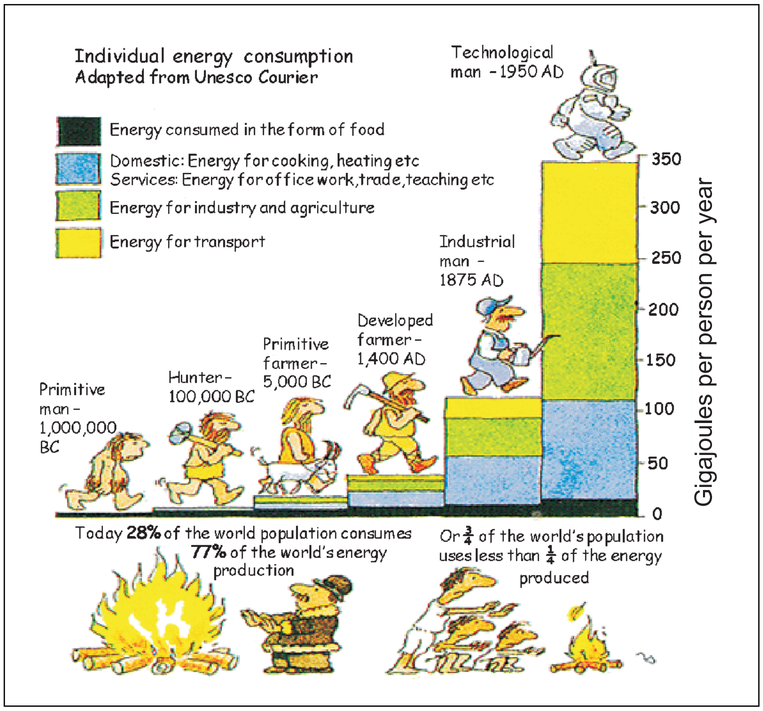

Figure 1. Individual energy consumption during different time periods.

Source: World Nuclear Association.

petroleum. In fact, the dependence on fossil fuels for electricity generation is very high. As seen in *Figure* 3, about 80% of electricity is generated using oil, natural gas and coal.

There are many problems with the dependence on fossil fuels for the generation of electricity. The fossil fuel resources will deplete in the future and hence can cripple economic growth. In addition and more importantly, there are adverse effects on the atmosphere from burning fossil fuels. The gases, called 'greenhouse gases', which are released during the burning of fossil fuels result in 'enhanced greenhouse effect'.

Box 1.
How is Coal Formed?

Ancient trees and plants that fell into the swamp water millions of years ago were converted into porous brown matted mass that is a mixture of moisture and carbon by the bacteria. This mass is called peat. Over time, the pressure from sand and mud above it squeezed the liquid out resulting into a pasty dark mass that hardened into coal. Peat can also be dried and used as fuel.

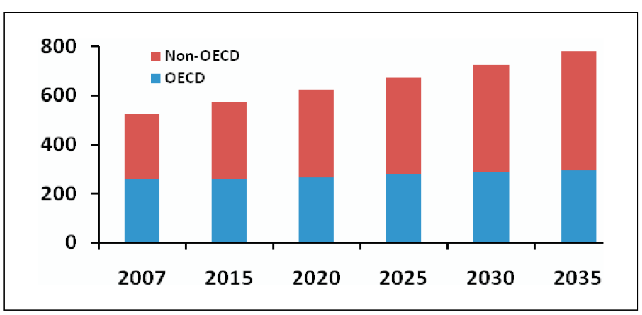

Figure 2. Projected world energy consumption. The unit on the *y*-axis is exajoules (10^{18}Joules). OECD is Organization for Economic Cooperation and Development having the membership of most of the developed countries.

Source: US Energy Information Administration (EIA).

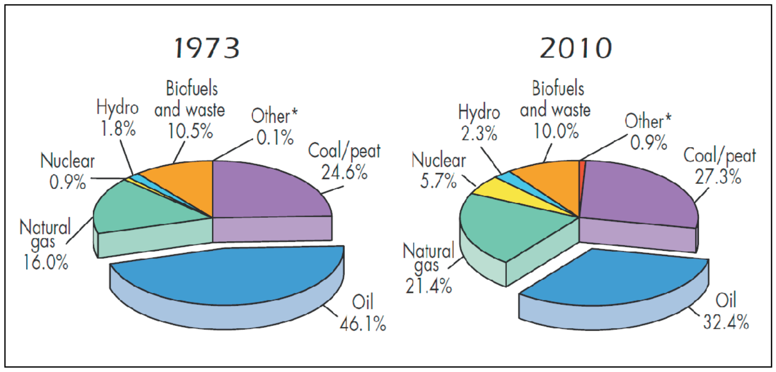

Figure 3. Resource consumption (in percentage) to generate energy during 2010 is compared to that in 1973. Most of the power is generated from coal, oil and natural gas. Other* includes geothermal, solar, wind, heat, etc.
Source: International Energy Agency, "Key World Energy Statistics 2012".
Courtesy: Key World Energy Statistics 2012 © OECD/IEA, p.6.

Greenhouse effect has been described in detail in an earlier article in *Resonance* [1]. The term 'greenhouse effect' is used to highlight the fact that some gases (e.g., water vapor, carbon dioxide and methane) in the earth's atmosphere absorb radiation emitted by the earth much more than the radiation from the sun. They thus act like the glass in a greenhouse that allows the solar radiation to pass but is opaque to radiation emitted by the plants in the greenhouse.

Without the greenhouse gases, heat would escape back into space and earth's average temperature would be much colder than the present comfortable temperatures; not warm enough for humans to live.

Some amounts of greenhouse gases are needed in the earth's atmosphere to act as a 'blanket' and maintain atmospheric temperatures. Without these gases, heat would escape back into space and Earth's average temperature would be much colder than the present comfortable temperatures; not warm enough for humans to live. On the moon, for instance, the temperature during sunshine is as high as 230 °F (110 ºC), while in darkness the moon's surface temperature is a low –290 °F (–179 ºC) [2]. The average temperature on moon's surface is 0 °F (–18 ºC) compared to earth's 15 ºC at sea level even though both earth and moon are roughly equidistant from the sun. The greenhouse gases form an insulation to retain the heat that is emitted from the earth's surface. However, due to industrialization, emission of greenhouse gases has increased and the earth's temperature has gone up by more than 1.5 ºC in the last century (*Figure* 4) [3]. There are many studies that focus on predicting the effect of climate change on plant and animal species over

Box 2. Energy Conversion Table

1 kWh = 3.412 Btu
1 Barrel of crude oil = 1714 kWh
1 ton of oil equivalent (toe) = 11630 kWh

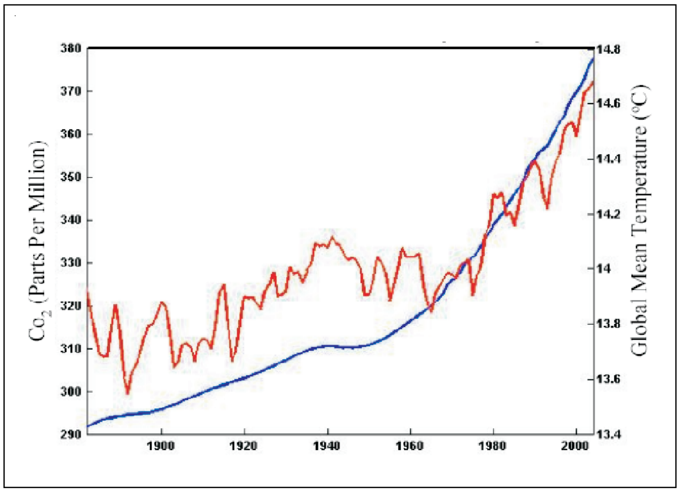

Figure 4. The graph shows the increase in the average global temperature (red line) over the past 100 years. CO_2 variation is shown with the blue line.

the next few decades [4–6]. Extinction of species could be due to many reasons related to climate change. Some of the reasons are the new epidemic patterns, the changes in the vegetation or change in local temperature. Predictions are also made based on modeling studies on the melting of ice in the polar regions leading to the rise in sea level and other effects of global warming [7, 8].

The main greenhouse gases responsible for the global warming are carbon dioxide (CO_2), nitrogen oxides (cumulatively referred to as NOX for NO_x, but mainly N_2O), methane (CH_4), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and other halocarbons. As can be seen in *Table* 1**,** the atmospheric content of these gases has gone up quite significantly in the last few centuries. The global warming potential (see *Box* 3 for definition) of these gases is alarmingly high. The long term consequences of CO_2 emission are depicted in *Figure* 5. Even after the CO_2 emission is stopped, it is predicted that the sea level rise due to thermal expansion and melting of ice will be observed for a few more millennia.

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Methane (CH_4) is emitted into the atmosphere from natural and anthropogenic sources. The main sources of methane emission are landfills, natural gas and oil systems, coal mining, and livestock manure management. Decomposition of solid waste without proper disposal processes generates a large amount of

Greenhouse gas	Pre-industrial concentration	Concentration in 2005	Global Warming Potential (GWP)	Atmospheric life in years	Anthropogenic sources
Carbon dioxide, CO_2	280 ppm	380 ppm	1	Variable	Fossil fuel combustion Cement manufacturing
Methane, CH_4	700 ppb	1774 ppb	21	12	Coal mining Rice paddles Livestock Landfill waste
Nitrous oxide, N_2O	270 ppb	319 ppb	310	114	Petroleum combustion Fertilizers manufacturing and usage

Table 1. The table lists the greenhouse gases with their concentrations before industrialization and in 2005. ppm is parts per million and ppb parts per billion.
Data source: IPCC Climate Change 2007; Synthesis Report.

methane. With increase in urban population all over the world, methane generation is also on the rise (*Figure* 6). This is not a favorable scenario since methane absorbs 21 times more heat per molecule than carbon dioxide.

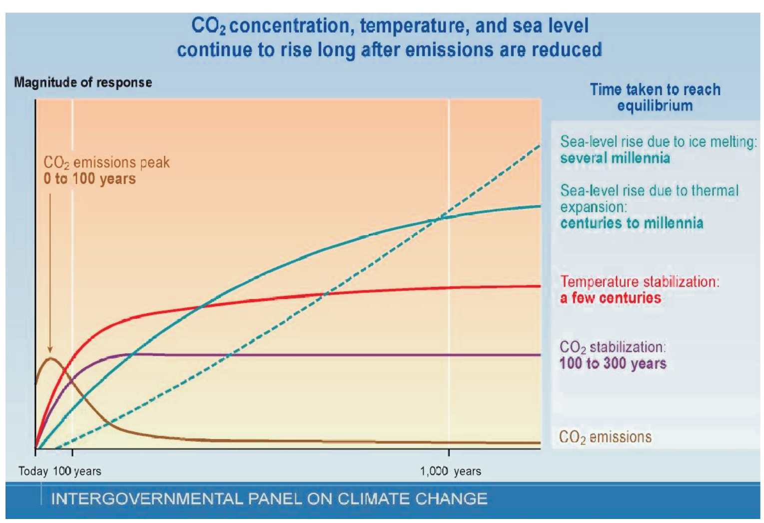

Figure 5. The effects of CO_2 emissions on the global temperature, ice melting and sea level. The effects of CO_2 released into the atmosphere today would last for over 1000 years.
Source: http://www. grida. no/ climate/ipcc_tar/slides/large/ 01.17.jpg

Box 3. Global Warming Potential (GWP)

In simple terms, GWP is the relative amount of heat trapped by 1 kg of a certain gas compared to that by the same amount of reference gas which is carbon dioxide. Mathematically, according to International Panel for Climate Change (IPCC), GWP of a certain gas x is expressed as (ref- IPCC 2007 Report, Working Group 1: *The Physical Science Basis*, Section 2.10),

$$\mathrm{GWP}(x) = \frac{\int_0^{\mathrm{TH}} RF(x)\,\mathrm{d}t}{\int_0^{\mathrm{TH}} RF(r)\,\mathrm{d}t} = \frac{\int_0^{\mathrm{TH}} a(x)\cdot x(t)\,\mathrm{d}t}{\int_0^{\mathrm{TH}} a(r)\cdot r(t))\,\mathrm{d}t},$$

where RF(x) and RF(r) are the radiative forcing of gas x and reference gas, respectively; a_x is the radiative forcing due to a unit increase in atmospheric abundance of the gas x in $\mathrm{Wm}^{-2}\,\mathrm{kg}^{-1}$ and a_r is the corresponding quantity for reference gas. [$x(t)$] and [$r(t)$] are the time-dependent decay in abundance of the instantaneous release of the gas I and reference gas, respectively. TH is the time horizon over which the calculation is considered.

As defined by IPCC, "The radiative forcing of the surface-troposphere system (due to a change, for example, in greenhouse gas concentration) is the change in net irradiance (in Wm^{-2}) at the tropopause after allowing stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures held fixed." In simple terms it is the change in the net vertical irradiance (in Watts per square metre, Wm^{-2}) at the tropopause (top of the troposphere) due to an internal change such as a change in the concentration of a gas. Usually radiative forcing is computed after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with all tropospheric properties held fixed at their unperturbed values.

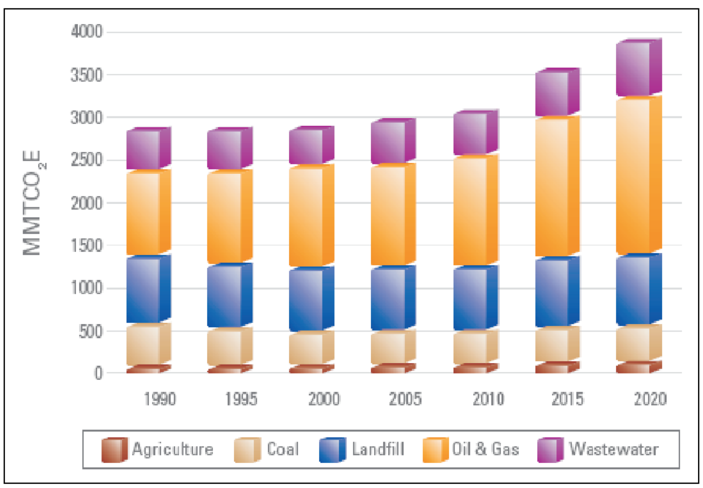

Figure 6. The chart gives global methane emission by sectors over the years. The unit on the *y*-axis is $\mathrm{MMTCO_2E}$, which is Million Metric Tons of Carbon Dioxide Equivalent. Projections for future are based on certain theoretical models. [$\mathrm{MMTCO_2E}$ = (million metric tons of a gas) × (GWP of the gas)]
Source: Global Methane Initiative

N_2O absorbs 270 times more heat per molecule than carbon dioxide. With increased usage of fertilizers, automobiles, etc. there is an increase of N_2O in the atmosphere.

Nitrous oxide (N_2O) is emitted during agricultural and industrial activities such as fertilizer and nylon manufacturing [9]. Agricultural activities contribute about 85% of N_2O emission mainly from synthetic fertilizers and animal waste dropped on soils (either as manure or by animals themselves during grazing) and agricultural waste burning. N_2O is also released naturally from oceans and by bacteria in soils. Emission of N_2O also occurs when solid waste or fossil fuels are burnt. The fact to be noted is that N_2O absorbs 270 times more heat per molecule than carbon dioxide. With increased usage of fertilizers, automobiles, human and animal waste disposals, there is an increase of N_2O in the atmosphere by almost 15% as of year 2000 from the value of ~283 parts per billion in 1750.

Halocarbons is a general term used for synthetic organic compounds containing halogens like fluorine, chlorine, bromine or iodine, and carbon. The halocarbons containing chlorine and fluorine, generally called CFC (chlorofluorocarbon) and HCFC (hydrochlorofluorocarbon), cause ozone depletion in the outer atmosphere of the earth. One CFC molecule can degrade 10,000 ozone molecules before its removal. These molecules have a long lifetime in the atmosphere (*Table* 2). To reduce the lifetime, hydrogen was added to make HCFCs. These molecules are less

Table 2. The halocarbon species with the greenhouse warming potential (GWP), their lifetime in the atmosphere, the emission levels in the year 1990 and the predicted emission levels in 2020.
Source http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/123.htm

Species	Chemical Formula	100 Years GWP	Atm. Lifetime (Years)	Atm. Release (kilo Metric Ton)
CFC-114	$CClF_2CClF_2$	9300	300	34.8 (1990)
CFC-115	CF_3CClF_2	9300	1700	1672 (2020)
HFC-23	CHF_3	11700	264	6.4 (1990)
HFC-236fa	$C_2H_4F_3$	6300	209	1722 (2020)
Perfluoromethane	CF_4	6500 - 23900	2600 - 50000	40.6 (1990) 173.4 (2020)
Perfluoroethane	C_2F_6			
Perfluorobutane	C_4F_{10}			
Sulfur hexafluoride	SF_6			

stable (up to18 yrs) in the atmosphere. Later HFCs (hydrofluorocarbons) with no chlorine were synthesized which are not known to cause ozone depletion.

These halocarbons undergo liquid to gas phase transition just by releasing pressure. The pressures required to bring about the transition are very small (30–50 bar). Hence, they can be easily used in sprays. Halocarbons are used as refrigerants, in semiconductor industries, in making foams, fire extinguishing agents, solvents, aerosol spray propellants, and chemical reagents. Their usage increased several fold in the 1970s. The effect of these molecules on ozone depletion was studied by Molina and Rowland [10], for which the duo and Paul Crutzen won the Nobel Prize in 1995. The international environment groups agreed not to use halocarbons extensively by signing the Montreal Protocol in late 1980s. The terms and conditions of the treaty have been amended several times in the last 20 years.

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Indian Power Scenario

Coming to the Indian context of power generation and the greenhouse gas emissions, India's economy is growing at an average rate of ~8%. In order to fuel the economic growth rate the power requirement and generation will also grow. The power generation in India has been mostly from fossil fuels like coal and petroleum [11]. From *Figure* 7, it is clear that in India the GHG created during power generation amounts to about 69% of the total GHG produced from all the activities [12]. According to the Ministry of Power, currently, about 65% of the ~1.8 x 10^5 MW power that is

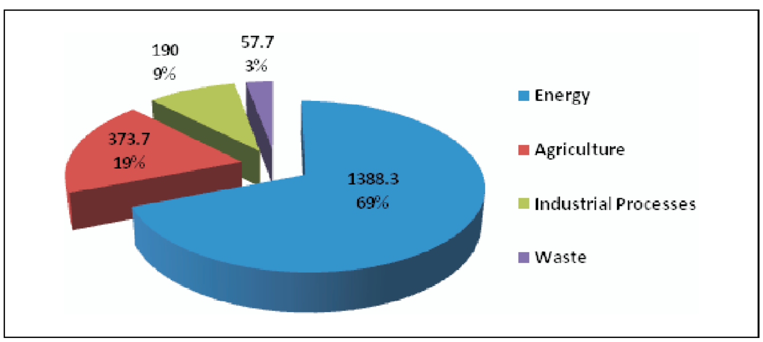

Figure 7. Greenhouse gas emissions by sector in India during 2007. The numbers are in $MMTCO_2E$.

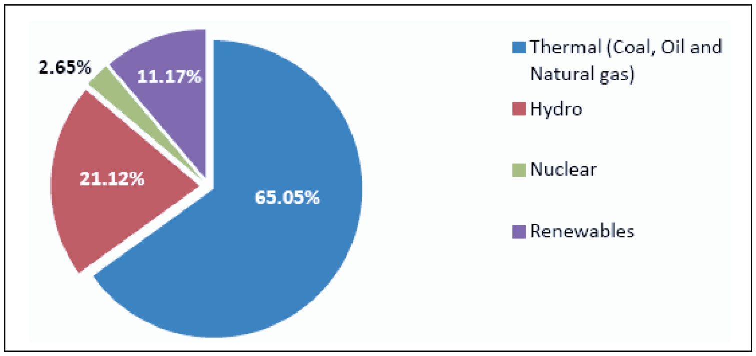

Figure 8. Energy generation resources (in percentage) in India. Nuclear and renewables form a small share in the resources used for power generation.

generated in the country is from thermal power plants. The second largest source of power is hydroelectricity. Hydroelectricity is heavily dependent on rains and hence, power generation level drops drastically during periods of drought leading to power shut downs in areas where power supply is from hydroelectric plants. Nuclear and renewable sources amount to very small percentage of power generation capacity in the country as shown in *Figure* 8.

India is heavily dependent on coal for its power generation. According to the Ministry of Coal, the proven coal reserve is 105 billion tons and the production during the period Apr. 2009 – Jan. 2010 was 413 million tons showing an increase of 8% over the same period of the previous year. It is estimated that, if the national power requirement increases at the same rate, by 2031 the coal requirement will be 1481 million tons. The proven reserves of coal will not last long if the production of coal has to fuel the national power requirement.

In India, the GHG created during power generation amounts to about 69% of the total GHG produced from all the activities.

In addition and more importantly, power plants running on fossil fuels emit a huge amount of CO_2. *Figure* 9 shows the increase in CO_2 emission from coal burning (up to 2008) and is expected to increase further in coming decades. The emission is expected to increase 3-fold compared to the 1990 levels. From the analysis of historical temperatures from 1941 to 1999 over 150 stations around the country, the annual mean temperature is found to have increased by 0.42 °C per 100 years with South Indian stations showing a maximum rise of 1.06 °C per 100 years and the North Indian stations showing a fall of 0.38 °C per 100 years [13].

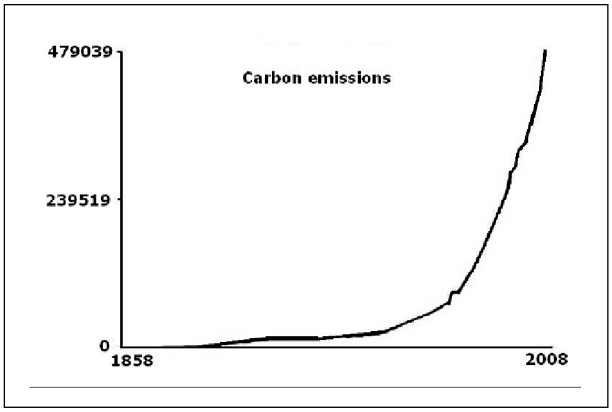

Figure 9. Carbon dioxide emissions from fossil fuel/gas burning and cement manufacturing in India. The unit on the *y*-axis is metric tons of carbon.
Data Source: http://rainforests.mongabay.com/carbon-emissions/India.html

Himalayan glaciers have shrunk by an overall average of 21% [14]. Extreme rainfall events have increased but there is a decrease in the number of rainy days during monsoon in many parts of the country during the past 50 years.

India, being a rapidly growing economy, places increasing demand on the energy sector. It is estimated that, assuming the current rate of economic and industrial growth, energy requirement in 2030 will be 5 times more than the present demand. The country also needs to reduce dependence on oil imports for political and economic reasons because by 2030, it is estimated that India will require about 5.6 million barrels of oil per day out of which >90 % has to be imported (*Figure* 10) [15].

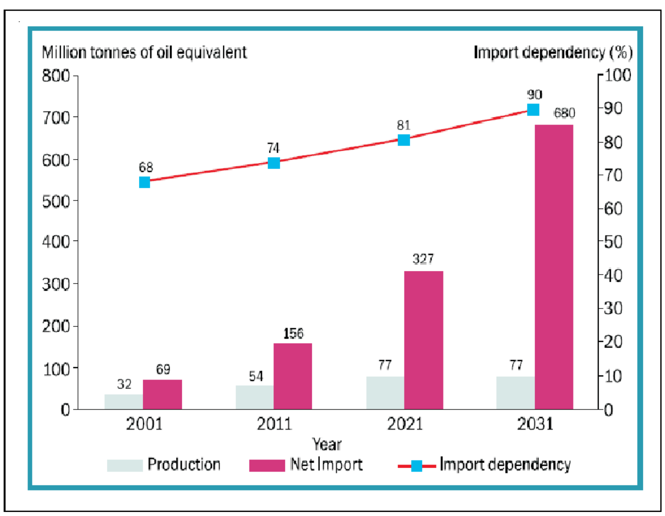

Figure 10. Projected production, imports and import dependency of petroleum assuming a compounded annual growth rate of 7%.

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It is clear that there is a global need to start power generation without emitting the greenhouse gases. Renewable energy sources and other green technologies are being considered very seriously by most countries around the world. In India, the government has set up a separate ministry to look into the renewable energy sources and support research in these areas. As per the Government of India directive the targets set in the 11th 5-year plan for the period 2007–2012 are:

- Wind Power – 10500 MW
- Small Hydro Power – 1400 MW
- Biomass Power/Co-generation/Gassification – 1700 MW
- Solar Power – 50 MW
- Energy from Urban/Industrial waste – 400 MW
- Distributed off-grid renewable power – 950 MW

Total proposed renewable power – 15,000 MW at a cost of ~Rs. 4000 Crores.

India's potential for power generation from renewable sources is almost 100,000 MW though as of January, 2013 only about 24,000 MW power is generated from these sources.

Conclusion

Thus, in this part, we saw the effects of industrialization on the environment. Industrialization by itself is not a bad thing to have happened. We need to be more responsible in using the natural resources and shift towards generating power with green technologies. In subsequent articles in this series, we will study some of the green technologies like solar, wind, biomass and others.

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