Energy Security Insights

Volume 6 • Issue 1 • January–March 2011

CONTENTS

Editor
Deepti Mahajan

The Energy and Resources Institute

www.teriin.org

Energy choices: Looking to the future

Energy is a prime mover for the country's quest for inclusive socio-economic development as well as meeting the Millennium Development Goals. The goals of poverty eradication, improved living standards, and increased economic output imply increasing energy requirements. To meet its energy demands, however, India is heavily dependent on imported fuels. Currently, the country imports close to 75% of its petroleum requirements and although it is a coal–rich country, even coal is being imported. As per TERI's estimates, total commercial energy consumption may increase from 284 mtoe in 2001 to 1727 mtoe in 2031 (Compound Annual Growth Rate: 6.2%) in a business-as-usual (BAU) scenario. Coal remains the dominant fuel in the commercial energy mix and its share increases by 6.4 times from 148 mtoe to 940 mtoe during 2001 to 2031. (CAGR: 6.4%). Petroleum consumption also increases rapidly, mainly on account of the transport sector, and increases by over 6 times over the period 2001-2031. This exercise further indicates that the maximum allowable indigenous production levels for all fuels is achieved by the year 2016. As far as import dependence is concerned, in a BAU scenario, for coal it increases to 72% in 2031, and in the case of oil it reaches 88%. Moreover, CO_2 emissions from the energy sector are estimated to increase from 0.9 billion tonnes in 2001 to 5.8 billion tonnes in 2031. Therefore, the dependence on imports for coal, oil, and gas would increase significantly in the future; even with scenarios that reflect higher efficiencies and large reductions in CO_2 emissions.

Energy security concerns of India, and technological solutions, need to be seen against this backdrop. India's "Integrated Energy Policy (IEP)" emphasized the roles of hydro, nuclear, and renewable energy in broad–basing its energy portfolio. However, the large–scale exploitation of our hydro energy resources is constrained by issues pertaining to rehabilitation and resettlement of the displaced populace.

While nuclear energy, as per IEP, *theoretically offers India the most potent means to long-term energy security*, in light of recent happenings at Fukushima nuclear plant in Japan; greater focus is required to be placed on the safety aspects of nuclear energy, including taking the civil society in confidence at each stage of its development.

This apart, our endeavour has to be to explore renewable and non–conventional routes like next generation fuels derived from agri-residues and algae, state-of-the-art solar thermal technologies, and shale gas, to name a few that are based on indigenous resources. These technological solutions might not prove to be cost–effective in the near future but it is essential that research and development is carried out with a long–term perspective. Some of these, then, may help in diversifying our energy portfolio and in making the country more energy secure.

Amit Kumar

Amit Kumar
Director, Energy Environment Technology Development, TERI

Shale gas in India: developmental, technological, and policy issues

Amit Kumar Verma
The Energy and Resources Institute, New Delhi

The increasing gap between demand and supply of conventional energy resources has led to an increasing interest in the exploration of unconventional energy sources. Recently, there have been discussions on the possibility of tapping unconventional resources like methane hydrates, oil shale, coal bed methane (CBM), and shale gas to meet India's burgeoning domestic energy demand. The Directorate General of Hydrocarbons (DGH) has estimated prognosticated gas resources from gas hydrates to be 1894 TCM, and has identified areas in the north-east which have potential for shale oil. Also, India has prognosticated CBM resources, which are estimated to be approximately 4.6 TCM. Yet a number of issues need to be examined in the context of shale gas development. One of the key associated environmental concerns is that the process involved in extraction of shale gas is highly water-intensive. This paper examines the shale gas scenario in India, including resource potential, technology gaps, policy, regulation, finance, and environmental concerns.

Introduction

In 2003, global demand for energy stood at 420.7 quadrillion BTU. By 2030, it is expected to reach 721.7 quadrillion BTU (EIA 2006). Known conventional resources of energy are being continuously used up while gap between supply and demand is increasing. This has brought into focus the development of new unconvential resources of energy. Gases that are difficult to discover, characterize, and to be produced commercially by conventional technology, are known as unconventional natural gas resources. Rogner (1997) categorized natural gas from coalbeds, tight sands, shales, hydrates, deep formations, and geopressurized zones as unconventional gas resources. Presently, natural gas from coalbeds, tight sands, and shales are commercially produced. These resources are typically located in heterogeneous, extremely complex, and often poorly understood geologic systems. For example, oil is located at a confined place inside reservoirs, while shale has a more lateral spread. Horizontal drilling is, therefore, more important for exploration of shale gas as compared to oil well exploration. Even with current technological advances, large quantities of water are required for hydrofracturing for shale gas production, while water is only required for secondary recovery in oil production.

The distribution network required for transmission of shale gas depends on the quality of shale gas. Existing pipelines can be used for transmission of shale gas if it meets its BTU standard, which is generally specified by pipeline companies in the "General Terms and Conditions (GTC)" section of their tariffs. Since India does not have any shale gas producing wells, it is difficult to predict the quality of gas that will be produced.

Technological advances, currently attractive natural gas prices, and the need to replace declining conventional reserves make unconventional gas resources a favourable option. Figure 1 illustrates the position of unconventional gas resources in the resource triangle (Holditch 2003).

The concept of the resource triangle was used by Masters and Grey to find a large gas field and build a company in the 1970s (Masters 1979). The concept is that all natural resources are distributed log-normally in nature. Usually, best or highest-grade deposits occur in small proportions, but once found, they are easy to extract. As one moves to the bottom of the resource triangle, the reservoirs are lower

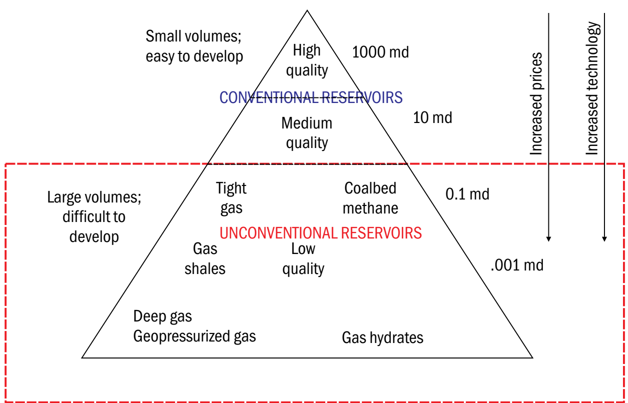

Figure 1 Resource triangle for natural gas (md = milli darcy)
Source Holditch 2003

grade, which usually means reservoir permeability is lesser. These low permeability reservoirs, however, are usually much larger than the higher quality reservoirs and require improved technology and suitable gas pricing before they can be developed and produced economically.

In recent years, there has been increased interest in developing and producing shale gas. Shale gas reservoirs are becoming a focus of attention around the world, especially in the US and Canada. Presence of fractures and very low permeability (10–100 nano Darcys) rocks make shale reservoirs very complex. Basins of Appalachian and Michigan in the US have been producing gas from shallow and fractured shale formations for decades. The scenario has completely changed with the development of technology for creating permeable reservoirs and achieving high rates of gas production by using intensively stimulated horizontal drilling and hydrofracturing. These technologies have enabled deep- and low-permeability gas shale formations to become highly productive.

Global potential of shale gas

Rogner (1997) estimated shale gas resources for the world through a 'top-down' study of world hydrocarbon resources at about 16,110 TCF (456 TCM). The International Energy Agency (IEA) reported in the World Energy Outlook 2009 that about 40% of Rogner's estimated resource endowment would become recoverable, which will be equivalent to 6,350 TCF (180 TCM). Many European basins are in the exploration phase, with maximum potential found to be in three areas: the Alum Shale of Sweden, the Silurian Shales of Poland, and the Mikulov Shale of Austria. The preliminary gas shale resource assessment for these three basins stands at 1,000+ TCF (~30 TCM), with a potential recoverable resource of 140 TCF (4 TCM) (ARI 2009).

The development of shale gas has not been studied much in China and India, but it is estimated that the two countries have numerous shale gas basins that are only now beginning to be evaluated. In April 2010, Reliance Industries Limited (RIL) entered into a joint venture with the US-based Atlas Energy, Inc., under which RIL acquired 40% interest in Atlas' core Marcellus Shale acreage position (RIL 2010). Atlas Energy, Inc. was recently acquired by Chevron Corp. on 17 February 2011. The Company believes that it will be able to drill over 450 horizontal wells on the acquired acreage (42,000 acres) assuming 1,000 feet spacing between lateral wells. As a result of these acreages, the Atlas/Reliance joint venture will now control approximately 343,000 Marcellus Shale acres, of which approximately 206,000 acres belong to Atlas (Business Wire 2010).

Recently, Shell and PetroChina announced plans to jointly evaluate and develop gas shales in the Sichuan Province.

Shale gas: potential in India

Shale falls under the group of elastic sedimentary rocks with particles of less than 0.002 mm. It is a common rock formation found across the world. India has 26 sedimentary basins with an area of 3.14 million sq. km. It has vast shale deposits across the Gangetic plain, Assam, Gujarat, Rajasthan, and in coastal areas. Shale is widely known as a source of gas, but its extraction has been viewed as uneconomic because of its low permeability—gas does not flow easily through this rock. Exploration for oil and gas has traditionally focused on limestone and sandstone—two rocks, which have high permeability.

Shale sequences are explored by state-owned Oil and Natural Gas Corporation of India (ONGC). ONGC has found potential for shale gas production in the basins of Damodar, Cambay, Krishna-Godavari, and Cauvery. The company has estimated the shale gas reserves in some sedimentary basins, such as those of Damodar and Cambay, and has declared a resource potential of about 35 and 90 TCF of gas, respectively. This potential, when compared to the existing gas resources in India, such as from the country's largest gas field of Reliance Industries in the KG basin (estimated to contain approximately 10 TCF of gas) is indeed large (Airy 2010). ONGC has recently produced shale gas in the country for the first time at Icchapur in the Durgapur district of West Bengal. According to ONGC, a 2000-metre deep well at the shale formation encountered gas on 25 January 2011. ONGC started drilling the first shale gas well at Icchapur village on 26 September 2010. The company has awarded a contract to Schlumberger for the pilot project (*The Economic Times* 2011).

Oil India Limited (OIL) is also exploring shale gas potential in regions, such as the Assam-Arakan region and the Cambay basin. Recently, EIA has estimated the technical recoverable shale gas potential in India to be 60 TCF (EIA 2011). Also, according to Platts, geologists and engineers in India are estimating the country's resources at somewhere between 600 and 2,000 TCF of potential gas. That is equal to about two centuries' worth of gas at the country's current consumption rate (Holland and Maria 2011).

Technological status

Horizontal drilling

In the last few years, several technical advances have been made in the well drilling field, which include logging while drilling (LWD), measurement while drilling (MWD), geo-steering, under-balance drilling of horizontal wells, coiled tubing drilling technique, and steerable rotary assembly for horizontal drilling, amongst others.

Recent advances in directional drilling technology have enabled wells to deviate from being nearly vertical to extend horizontally into the reservoir formation. This increases the capacity of wells to collect oil and gas. Six to eight horizontal wells drilled from only one well pad can access the same reservoir volume as 16 vertical wells. Using multi-well pads can also significantly reduce the overall number of well pads, access roads, pipeline routes, and production facilities required; thereby minimizing habitat disturbance, impacts on the local population, and the overall environmental footprint.

In the case of thin or inclined shale formations, a long horizontal well increases the length of the well bore in the gas-bearing formation and, therefore, increases the surface area for gas to flow into the well. In some sandstone and carbonate formations, injecting dilute acid dissolves the natural cement that binds sand grains, thus, increasing permeability. In tight formations like shale, inducing fractures can increase flow by orders of magnitude. However, before stimulation—or for that matter, production—can take place, the well must be completed and cased (CRS 2009).

Shale gas wells are not hard to drill, but difficult to complete. In almost every case, the rock around the well-bore must be hydraulically fractured before the well can produce a significant amount of gas. The pumped fluid, under pressures of up to 8,000 PSI, is enough to crack shale as much as 1,000 metres in each direction from the well bore. In deeper high-pressure shales, operators pump slick water and proppant. Nitrogen-foamed fracturing fluids are commonly pumped on shallower shales and shales with low-pressure reservoirs.

The drilling of horizontal wells is costlier as compared to vertical wells. For example, in the US, a new horizontal well drilled from the surface costs 1.5–2.5 times more than a vertical well (Joshi 2003). A re-entry horizontal well costs about 0.4–1.3 times more than its vertical counterpart. For many horizontal well projects, the finding (developing) cost —defined as well cost divided by well reserves—is about $0.75–1.0/ft^3. This is about 25%–50% lower than the cost of buying proven producing reserves (Joshi 2003). A horizontal well and its performance are depicted in Figures 2 and 3.

Hydraulic fracturing

Introduced in the US in 1947, hydraulic fracturing has till date been utilized in over a million wells. It uses water pressure to create fissures in deep underground shale formations that allow oil and natural gas to flow. When combined with directional

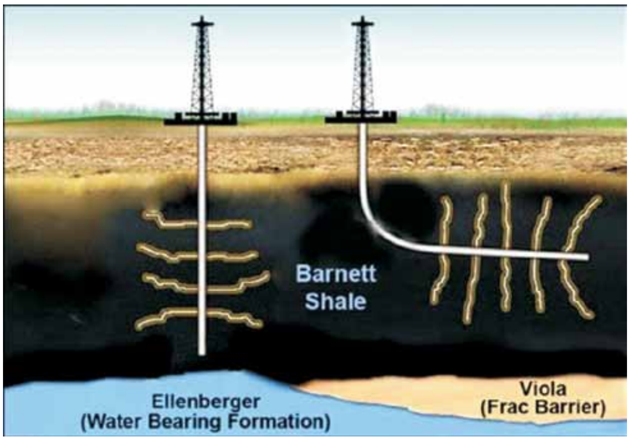

Figure 2 Directional drilling technology
Source http://www.horizontaldrilling.org/ [Accessed on 2 December 2010]

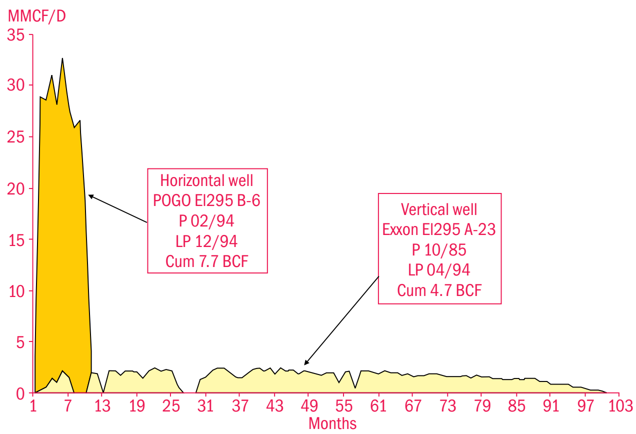

Figure 3 Comparison of cumulative production of natural gas over time for horizontal and vertical wells
Source AGA's Chris McGill
http://www.theoildrum.com/node/5961 [Accessed on 28 December 2010]

ESI_March 2011.indd 4 10/3/2011 11:28:10 AM

drilling, hydraulic fracturing is capable of unlocking enormous amounts of shale gas. Figure 2 shows the process involved in hydraulic fracturing.

In a hydraulic fracturing job, fracturing fluids or pumping fluids consisting primarily of water and sand, are injected under high pressure into the producing formation, creating fissures that allow resources to move freely from rock pores where they are trapped. Hydraulic fracturing fluid contains 90% water, 9.5% sand, and chemicals like acid, NaCl, polyacrylamide, ethylene glycol, borate salts, and so on. Spent, or used fracturing fluids, are normally recovered at the initial stage of well production, and recycled in a closed system for future use or are disposed of under regulation.

For a single horizontal well, it typically takes 4–8 weeks to prepare the site for drilling; 4 or 5 weeks of rig work, including casing and cementing and moving all associated auxiliary equipment off the well site before fracturing operations commence; and 2–5 days for the entire multi-stage fracturing operation.

Policy and regulation

The Directorate General of Hydrocarbons (DGH), the upstream regulator, is drafting an approach paper for shale gas exploitation in India. The present production sharing contract (PSC) for oil, gas assets, and coal bed methane blocks does not allow a company to exploit the clean fuel found in rock formations under the ground in India. DGH is planning to give shale gas exploration acreages by the end of 2011. The government plans to move to the Open Acreage Licensing Policy (OALP) regime by 2012, which will make India a favourable destination for exploration and production of crude and natural gas (PTI 2010). This will enable upstream companies to bid for any oil and gas block without waiting for the announcement of bidding as is the case under the New Exploration Licensing Policy (NELP) regime.

The current Indian exploration policy regime allows companies to produce only conventional oil and gas from their exploration blocks. If they find non-conventional resources, such as coal bed methane or shale gas, they are forbidden to produce them. When drilling for oil, every company hits shale deposits, but ignores their gas potential since the companies are not allowed to harness it. The exploration policy regards any non-conventional deposit finds as an unwarranted windfall for the exploring company, and requires separate bidding for non-conventional energy.

Shale gas policy also needs to take cognizance of the fact that the development of shale gas requires significant amounts of water, and in a water-stressed country like India, this issue is of significant concern. Hence, it is important to reconcile policy and regulations on the concurrent and related demands for local and regional water resources—be it for drinking water, wildlife habitat, recreation, agriculture, industry or other purposes. Communication with local water planning agencies, state agencies, and regional water basin commissions will be important in this regard.

The Ministry of Environment and Forests (MoEF)/Central Pollution Control Board (CPCB) or State Pollution Control Board (SPCB)/Pollution Control Committee (PCC) are responsible for framing regulatory and policy issues for injection of waste water (from hydro fracturing) or management of hazardous wastes in the gas basin. Laws and regulations need to be modified to meet the demand of large quantity of fracturing water without affecting the continuous supply of drinking water or significantly lowering the groundwater level. Transportation, processing, and treatment and disposal of wastes, will need to be carried out strictly as per the Guidelines on Hazardous Wastes (M&H) Rules, 1989/2000 and 2003 as amended. Waste water (or fracturing water) and exhaust gases are covered under the provisions of the Water (Prevention and Control of Pollution) Act, 1974 and the Air (Prevention and Control of Pollution) Act, 1981.

Availability of land too will pose a problem as land ownership and distribution in India is a complex political and social issue. A regulatory framework has to be developed to get the right of exploration even if land is state- or privately-owned. Also, a fund is required in line with CERLA in the US for fixing the liability of persons responsible for release of hazardous waste at E&P sites of shale gas, and a trust fund needs to be established to provide for clean-up when no responsible party can be identified.

Financial mechanisms

In the US, a 1977 status report by the Technology Assessment Board on the gas potential from Devonian shales of the Appalachian Basin calculated that these shales contain as much as 15–25 TCF of readily recoverable reserves that could be produced economically over a 20-year period at prices of $2–3 per thousand cubic feet (Congress of States 1977). Such a production rate is likely to require extensive drilling (to the order of 69,000 wells), a considerable expansion of the gas pipeline connecting network, and may take up to 20 years to achieve.

MIT had initiated a shale gas study in 2010 and estimated that a substantial portion of the shale resource base is economic at prices between $4/MCF and $8/MCF using a 2007 cost base (MIT EI 2010). Drilling cost is one of the major components in assessing economic feasibility of shale gas development. For example, wells at Woodford were 6,000–11,000 ft deep and cost about $3.3 million to drill and complete with multiple fractures required (ARI 2009).

The amount of water and pressure required for hydrofracturing depends on the depth of the shale and its characteristics. This in turn determines the cost of the process. For example, a typical hydrofracturing process, which required 1,000 BBL of water upto a depth of 3900 ft costs close to $9,750 (Congress of States 1977).

Environmental concerns

Excessive water consumption, contamination of drinking water wells, and surface water contamination as a result of both drilling activities and fracturing fluid disposal, adversely affect the environment. The Marcellus Shale in Pennsylvania, US has the potential to produce nearly 500 TCF of clean-burning shale gas. Pennsylvania's Department of Environmental Protection estimated that 16 million gallons of fresh water per day will be used by the shale gas industry in 2010, which will eventually rise to 19 million gallons per day by 2011 (Fryer 2009).

India can store only relatively small quantities of its fickle rainfall. While arid rich countries (such as the US and Australia) have built over 5,000 cubic metres of water storage per capita, and middle-income countries like South Africa, Mexico, Morocco, and China can store about 1000 cubic metres per capita, India's dams can store only 200 cubic metres per person. Also, India can store only about 30 days of rainfall, compared to 900 days in major river basins in arid areas of developed countries. Considering the above facts about India's water security, availability of water for large scale hydrofracturing will be a major problem for development of shale gas in India (World Bank 2005).

Leakage of fracturing fluids is another environmental concern. There are potentially three ways in which leakage of fracturing fluids can take place and contaminate aquifers: leakage from naturally occurring or induced fractures, leaks on surface, and migration of fluids due to poor cementation. These leakages can be prevented by following best practices and state-of-the-art cementation and fracture monitoring techniques, which prevent drilling fluids, hydraulic fracturing fluids, or natural gas from leaking into the permeable aquifer and contaminating groundwater.

The majority—60% to 80%—of the injected fracturing additives return in flow-back. Typically, it "contains proppant (sand), chemical residue, and trace amounts of radioactive elements that naturally occur in many geologic formations" (Daniel *et al* 2009). The flow-back water storage issue is probably a major cause of contamination of drinking water. The US Department of Environmental Protection (DEP) reported close to 130 cases since 2008 where wastewater spilled into creeks and tributaries due to human error. Also, the flow-back's high content of total dissolved solids (TDS) and other contaminants will need to be adequately treated before being discharged into surface waters. There are reports of spillover from a well pad near a home, which damaged the owner's land and pond. Some cows have been reported to have died due to pond water contamination (Walsh 2011). Technologists suggest that an appropriately designed and cased well could help prevent drilling fluids, hydraulic fracturing fluids or natural gas from leaking into the permeable aquifer and contaminating groundwater. It should also prevent groundwater from leaking into the well.

Hydrofracturing companies generally use a particular combination of additives in the form of different chemicals for a particular well. Composition of additives varies from well to well, and it is kept proprietary by the companies, which show reluctance to disclose such information. Regulations need to be put in place for companies to disclose the composition of chemicals used for hydrofracturing.

Also, some soils and geologic formations contain low levels of naturally occurring radioactive material (NORM). When NORM is brought to the surface during shale gas drilling and production operations, it remains in the rock pieces of the drill cuttings and in solutions of produced water, or, under certain conditions, precipitates out in scales or sludges. According to the US Department of Energy, the radiation from NORM, however, is weak and cannot penetrate dense materials, such as steel used in pipes and tanks (US Department of Energy 2009).

Nevertheless, this remains a concern that calls for further investigation.

Conclusion

Credible and factual information on shale gas resources, relevant technologies for developing these resources, the regulatory framework under which development takes place, and the practices necessary to mitigate potential impacts on the environment and communities, is required before any significant advance is made in the area. While geo-technical and geo-physical surveys need to be conducted to further delineate potential shale deposits, extensive R&D efforts need to be made in order to better understand technological, policy, and environmental imperatives.

References

Airy A. 2010. **India emerges as shale gas hub**. *The Hindustan Times*. 1 September.

Advanced Resources International (ARI). 2009. **Worldwide gas shales and unconventional gas: a status report**. Advanced Resources International.

Briscoe J and Malik R P S**. India's Water Economy: Bracing for a Turbulent Future,** World Bank Report No. 44376, pp 4.

Business Wire. 2010. **Atlas Energy, Inc. and Reliance Industries jointly acquire over 42,000 additional acres within their core Marcellus Shale position**. The Street. Details available on http://www.thestreet.com/story/10732553/atlas-energy-inc-and-reliance-industries-jointly-acquire-over-42000-additional-acres-within-their-core-marcellus-shale-position.html [Accessed on 21 April 2010].

Congress of States. 1977. **Status report on the gas potential from Devonian Shales of the Appalachian Basin**. Congress of States, NTIS order #PB-274856, USA.

Congressional Research Service (CRS). 2009. **Unconventional gas shales: development, technology, and policy issues.** Congressional Research Service.

Energy Information Administration (EIA). 2006. International Energy Outlook, Department of Energy, EIA. Details available at http://www.eia.doe.gov/oiaf/archive/aeo06/index.html. [Accessed on 30 December 2010]

Energy Information Analysis. 2011.**World Shale Gas Resources: an initial assessment of 14 regions outside the United States.** US Department of Energy.

Fryer M. 2009. **New technology helps treat waste water in Marcellus Shale operations**. *Leader Times*, Kittanning, Pennsylvania. Details available online at: http://www.allbusiness.com/energy-utilities/utilities-industry-water/13585264-1.html.

Holditch S A. 2003, **The increasing role of unconventional reservoirs in the future of the oil and gas business.** *Journal of Petroleum Technology* **55**(11): 34–79.

Holland B and Santa-Maria S. 2011. **Will India emerge energy powerhouse via shale gas?** *The Economics Times*. Details available on http://economictimes.indiatimes.com/opinion/policy/will-india-emerge-energy-powerhouse-via-shale-gas/articleshow/7512828.cms?curpg=2 [Accessed on 26 May 2011].

Joshi S D. 2003. **Cost/benefit of horizontal wells**. [SPE 83621]. Paper presented at the *2003 SPE Western/AAPG Pacific Section Meeting*, Long Beach, California, USA, 19–24 May 2003.

Masters J A. 1979. **Deep Basin Gas Trap, Western Canada.** *AAPG Bulletin* **63**(2):152 pp.

MIT Energy Initiative (MIT EI). 2010. **The future of natural gas: an interdisciplinary MIT study**. MIT.

Press Trust of India (PTI). 2010. **Shale gas exploration acreages to be available from next year.** In *DNA* (Mumbai), 28 August 2010. Details available online at: http://www.dnaindia.com/money/report_shale-gas-exploration-acreages-to-be-available-from-next-year_1429889.

Rogner H H. 1997). **An assessment of world hydrocarbon resources**. *Annu. Rev. Energy Environ.* **22**: 217–262.

Reliance Industries Limited (RIL). 2010. **Exploration and Production**. Details available online at: http://www.ril.com/html/business/exploration_production.html.

Schlumberger. 2005. **A Supplement to Oil and Gas Investor.**

Soeder D J and Kappel W M. 2009. ***Water Resources and Natural Gas Production from the Marcellus Shale***. USGS West Trenton Publishing Service Center; *Pennsylvania Geology* (2008), Commonwealth of Pennsylvania Department of Conservation and Natural Resources. *Pennsylvania Geology* 38.

The Economic Times. 2010. **ONGC hits shale gas at Icchapur.** Details available at http://articles.economictimes.indiatimes.com/2011-01-28/news/28426823_1_shale-gas-damodar-basin-cambay-basin [Accessed on 29 December 2010].

Walsh B. 2011. **The Gas Dilemma**, *Time,* 11th April, 2011, pp.31-37

US Department of Energy. 2009. **Modern shale gas development in the United States: a primer**. US Department of Energy, Office of Fossil Energy. 62 pp.

Harnessing energy from algae

Subhash Chandra Mathur and Sumit Mathur
Samarpit International Group

Petrochemical resources are limited and their availability is bound to decrease in the times to come. Also, due to their adverse impact on the environment which has lead to global warming, the use of these fossil fuels has to be reduced by both the developed as well as the developing world. Development of CO_2-neutral sustainable fuels, thus, becomes a high priority in the research regimes across the world. Energy generation from plants like rape or oil palm may not be the best option as these may also serve as food sources. Hydrogen, which is used by fuel cells to generate electricity, could be a likely alternative due to absence of greenhouse gas generation in fuel-cell technologies. Some energy experts have even gone to the extent of predicting that within a few decades, the world will switch to a purely hydrogen-driven existence, where energy will be abundant, inexpensive, and non-polluting.

Hydrogen can be extracted from fossil fuels, but currently this entails higher expenses than directly using oil or natural gas. Water can also be split into hydrogen and oxygen through electrolysis, but that requires electricity, which again might be generated using fossil fuels or from renewable sources such as wind or solar energy that are costly options.

Rising oil prices, competing demands for food and biofuel sources, and the world food crisis have ignited interest in algaculture (farming algae) for producing vegetable oil, bio-diesel, bio-ethanol, bio-gasoline, bio-methanol, bio-butanol, and other biofuels, utilizing land that is unsuitable for agriculture.

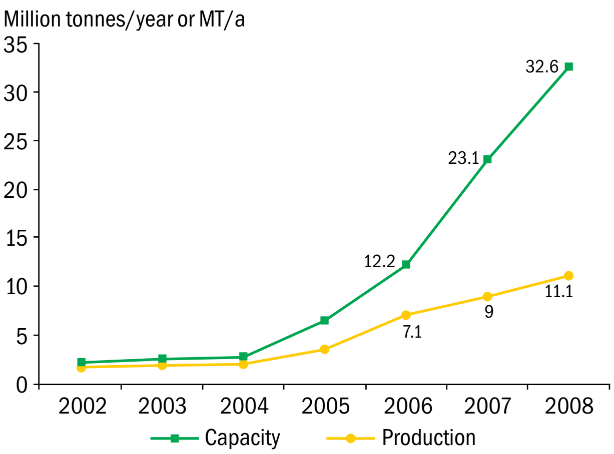

Figure 1 World biodiesel production and capacity
Source Emerging Markets Online 2008

Microalgae are mono-cellular, plant-like organisms engaged in photosynthesis and converting carbon dioxide (CO_2) into biomass. Algal biomass contains three main components: carbohydrate, protein, and natural oils. Therefore, it is capable of producing a number of potential fuels, such as methane gas via biological or thermal gasification, ethanol via fermentation, bio-diesel, and the direct combustion of algal biomass to produce steam or electricity.

Recent research initiatives have proven that microalgae biomass appears to be one of the most promising sources of renewable bio-diesel. Microalgae commonly double their biomass within 24 hours, and because of their high oil productivity are good for the production of bio-diesel. Using microalgae to produce bio-diesel will also not compromise production of food, fodder, and other products derived from crops. Moreover, generation from micro-algae is largely CO_2 neutral, as they absorb CO_2 during their growth and later release it again when they are used for energy production. Industrial CO_2 emissions may also be used as a 'resource', as algae grow faster at high CO_2 concentrations and, hence, produce more biomass for energy production. The algae could well be used in waste water treatment and can be grown in different environments in both fresh and salt water. Cultivation of microalgae has thus emerged as one of the most promising sources for bio-oils that may significantly contribute to tomorrow's energy supplies.

John Gartner, in his article *Algae: Power Plant of the future?* (Gartner 2002) states that Hans Gaffron, a German researcher, had observed in 1939 that algae would (for a reason that was unknown then) sometimes switch from producing oxygen to producing hydrogen instead, but only for a short time period. Under normal circumstances, algae contain mainly hydrocarbons and proteins while the fat content does not exceed 20% of the total dry weight. But, in 1980, it was discovered that under nutritional stress or in saline environments, certain microalgae will accumulate up to 72% of their weight as lipids (fatty substances). A typical algal mass has a heating value (heat produced by combustion) of 8,000–10,000 BTU/lb, which is better than lignite. The heating value of algal oil and lipids is 16,000 BTU/

ESI_March 2011.indd 9 10/3/2011 11:28:11 AM

lb, which is better than anthracite. A breakthrough finally came 60 years later in 1999, when University of California at Berkeley professor Tasios Melis, along with researchers from the National Renewable Energy Lab, discovered that depriving the algae of sulphur and oxygen would enable it to produce hydrogen for sustained periods of time.

Figure 2 shows the process of extraction of cellulosic ethanol where bio-diesel is extracted from the fats in algae – a process that is being researched on extensively. There are two practical and very common methods of large-scale production of micro-algae (Khan and Rashmi 2008). These are:

Raceway ponds: It is a closed loop re-circulation channel that is typically about 0.3 m deep. There is a paddlewheel, which mixes and circulates the algal biomass. The flow is guided around bends by baffles placed in the flow channel. Raceway channels are built in concrete or compacted earth, and generally lined with white plastic. During daylight, the culture is fed continuously in front of the paddlewheel where the flow begins. On completion of the circulation loop, broth is harvested behind the paddlewheel. The paddlewheel operates all the time to prevent sedimentation.

Photo-bioreactors (PBs): PBs have been successfully used for producing large quantities of microalgal biomass. PBs essentially permit single-species culture of microalgae for prolonged durations. Tubular PB consists of an array of straight transparent tubes that are usually made of plastic or glass. The solar collector tubes are generally 0.1 m or less in diameter. The tube diameter is limited because light does not penetrate too deep in the dense culture broth that is necessary for ensuring high biomass productivity of the PB. Microalgal broth is circulated from a reservoir to the solar collector and back to the reservoir.

The potential of microalgae for making liquid fuels has led to the emergence of a number of companies in the field. Extensive research is being conducted to identify the most efficient and cost-effective process for commercial production of bio-oils from algae. However, only a handful of these efforts are close to pilot-scale production of fuels. These include Sapphire Energy and Cellena Oil, which is backed partially by Shell Oil.

One of the patented technologies that use a mix of raceway ponds and PBs for production of biofuels from algae is the HR BioPetroleum Technology. In the pilot plant, a selective strain of algae is grown in a PB at constant conditions that favour continuous cell division and prevent contamination of the culture by other organisms. The main body of the production PB is a long series of four large temperature- and pH- controlled tubes that are connected together in parallel. The algae are exposed to sunlight while kept in suspension to maximize growth. Subsequently, the

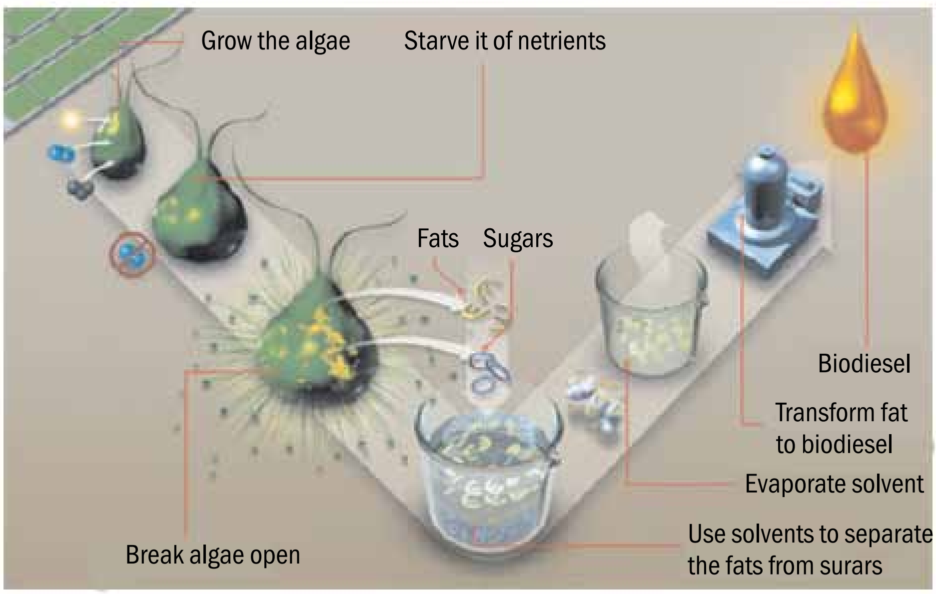

Figure 2 Extraction of bio-diesel
Source http://cepweb.wordpress.com/2010/05/30/promising- new-research-on-cellulosic-ethanol/

algae are transferred from the PBs to an open pond system, which is paddlewheel driven, re-circulating raceway, fitted with a durable plastic liner. The goal here is to expose the cells to nutrient deprivation and other environmental stresses that lead, as rapidly as possible, to synthesis of bio-diesel. Environmental stresses that stimulate oil production can be applied rapidly by transferring culture from the PB to an open pond. Ponds, like PBs, are exposed to sunlight. Depending on the desired product, the pond is harvested on the second or third day, and the algae cells are concentrated by gravitation into slurry. Excess water is then removed, and further concentrated by centrifugation. The wet biomass is then dried. The oil and other by-products are extracted by a proprietary process.

India consumes crude oil at a level far above its production rate, leading to reliance on external oil supplies. Even if crude oil use was not growing at 5-6% annually, India's reserves would run out in less than 20 years at current extraction rates. With an estimated 70% of petroleum being consumed by automobiles, developing liquid alternative fuels for vehicles is vital, thereby making the case for biofuels. However, producing crop-based fuels in a country so densely populated, with poor food security indicators and limited arable land, would be difficult and dangerous. Table 1 compares the capacity of biofuel generation from different sources. According to the study *Biodiesel 2020 – A Global Market Survey, Feedstock Trends and Forecasts* (Emerging Markets Online 2008), India has up to 60 million hectares of non-arable land available to grow jatropha, and intends to replace 20% of diesel fuels with jatropha-based bio-diesel. India is already one of the world's biggest producers of algae. Bio-diesel from algae can be interchanged or mixed with regular diesel, which is a significant vehicle fuel in India.

Extensive research is also on to identify specific strains of algae, and to develop processes and technologies, wherein biofuel from algae can be directly used in transportation, rather than blending them with fossil fuels. But the battle has just started. The *Biodiesel 2020* study reveals that the bio-diesel industry is entering a new era of transition to alternative feed stocks, emerging technologies, and revised government policies favouring sustainable feed stocks and fuels. Each of these transitions presents both challenges and growth opportunities for bio-diesel developers, producers, feedstock producers, and entrepreneurs. On the other hand, according to the US Energy and Policy Advisor Daniel Kammen, the most interesting feature about algae is that it is a wildcard[1]. There are some real breakthroughs required for a reasonable sized scale of production of algae-oils, sufficient to run even a car. According to Cristen Conger, although algae is currently the most energy-dense biofuel source, the cost of producing algae oil is prohibitively expensive[2]. The US Department of Energy estimates that biofuel would cost around $8 per gallon at the pump. Other experts have projected prices of more than $50 per gallon because of inefficient production and harvesting methods.

Table 1 Gallons of oil per acre for various sources

Gallons of oil per acre per year	
Algae	500–20000
Oil Palm	635
Coconut	287
Jatropha	207
Rapeseed/Canola	127
Peanut	113
Sunflower	102
Safflower	83
Soybeans	46
Hemp	39
Corn	16

Source Khan and Rashmi 2008

Kansas State University engineers, Wenqiao Yuan and Zhijian, believe that growing algae on very large floating platforms in the ocean could dramatically reduce expenses associated with algae-oil production by providing free sources of sunlight, nutrients, controlled temperature, and water[3]. However, the ocean environment could present some unavoidable problems such as weather extremities. Some reports

[1] See 'Daniel Kammen: Energy from Algae is a wildcard.' Available at http://earthsky.org/energy/daniel-kammen-energy-from-algae-is-a-wildcard. Date accessed 20 December 2010.

[2] Cristen Cogner, 'Could cheap algae oil power our energy future?' Available at http://news.discovery.com/earth/algae-biofuel-renewable-energy.html. Date accessed 21 December 2010.

[3] Kay Garrett, 'K-state engineers study surface texture and algae growth.' Available at http://www.k-state.edu/media/newsreleases/nov09/algae110309.html. Date accessed 20 December 2010.

even suggest that it will be at least 10 – 15 years before we can hope to have found a satisfactory solution to this challenge.

Thus the future of commercial-scale production of biofuel and energy from algae is still unclear. While the research and pilot tests will continue and even more funds and resources will be committed and deployed, the world at large should continue laying emphasis on energy conservation and efficient utilization of electrical as well as thermal energy. We must acknowledge that at present it is far cheaper and easier to conserve energy than to generate more from renewable sources, and the environmental impact of ever increasing generation from fossil fuels is already there for the world to see.

References

Emerging Markets Online. 2008. ***Biodiesel 2020 – A Global Market Survey, Second Edition***. Multi-Client Study, Emerging Markets Online, Texas, USA.

Gartner J. 2002. **Algae: Power Plant of the Future?**. Details available at http://www.wired.com/science/discoveries/news/2002/08/54456, last accessed on 1 November 2010.

Khan S A and Rashmi. 2008. **Algae: a novel source of renewable energy and carbon sequestration**. *Akshay Urja* **2**(2): 14-18.

Accelerating research and deployment of nuclear fusion technology for India's long-term nuclear power goals

William A Gracias
The Energy and Resources Institute, New Delhi

Introduction

The development of civil nuclear energy in India has been steadily progressing since the establishment of the first nuclear reactor in the 1950s. India's nuclear dream has largely been based on the three-stage programme outlined several decades ago (see figure 1), which envisages a shift from uranium (U) fuel (which is in short supply and expensive) to Thorium (Th) fuel, thus, becoming self-reliant for fuel supply. This has been envisaged simply on the basis of resource availability—India is blessed with modest amount of Th resources. However, since Th cannot be used directly in fission reactors as it is not available in fissile form, it has to first undergo transmutation to form U-233, which is fissile and can be used in a conventional nuclear power plant.

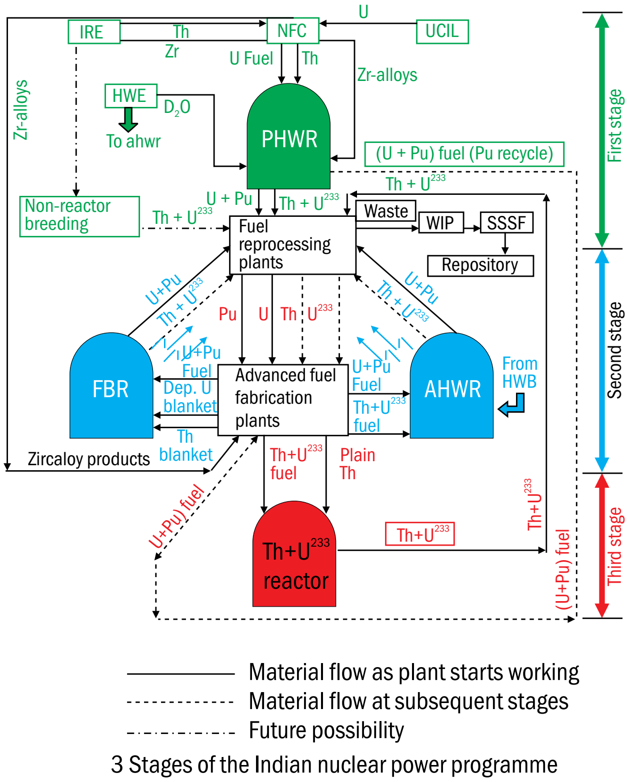

Figure 1 India's three-stage nuclear programme
Source Nuclear Power for National Development – a national perspective. Available at http://nuctrans.org/Nuc_Trans/locations/india/india.htm; accessed on 10.03.2011

The process of transmutating India's Th resources by incorporating Th in the blanket of the fast breeder reactors (FBRs) is part of the second stage, where India hopes to generate fuel (U-233) for its third-stage reactors. However, this process of transmutating Th to U-233 in FBRs (as shown in figure 1 by the left-hand blue reactor) is a rather slow process, with a doubling time[1] of approximately 15 years (if plutonium-uranium carbide fuel is used). To accelerate this phase, fusion reactors can play a major role, as they have higher neutron production and also provide additional power supply from fusion reactions. Thus neutrons from a fusion reaction can also be used to support a subcritical fission reactor. If a fusion tokamak with its current state of technology is combined with a fission reactor, then a Th-fuelled reactor could work in symbiosis with it as it could supply the tokamak with power to drive it[2].

Accelerator driven system (ADS) is another option for generating neutrons. When a beam of high energy protons from an accelerator impinge on a target of lead or lead-bismuth, high energy neutrons are produced by spallation reaction between high energy protons and the target nuclei. These neutrons can be directed to a sub-critical reactor where they are absorbed by the surrounding Th blanket, thus, breeding U-233. While the accelerator-driven systems aim for a novel and safe Th burner, fusion systems like the 'experimental fusion breeder reactor' (EFBR) aim for a large-scale Th-to-uranium converter. By breeding the Th between the first wall and the neutron shield (see figure 2), the EFBR can serve as an alternative pathway to realizing the third

[1] The time taken for the fuel in the reactor to double in quantity.
[2] Fusion reactors currently do not work for long periods with high gain factors. As a result, they are net energy consumers and would need a constant supply of power to maintain the plasma current. A Th fission reactor could very well supply this power while receiving neutrons from a fusion reactor.

stage of the nuclear programme. Currently, both the programmes are being pursued in India.

But, why use nuclear energy at all? The nuclear energy sector in India, which had gained momentum with private sector engagement, has become cautious after the unfortunate earthquake and tsunami in Japan, and the nuclear crisis that followed. The risks associated with current state of the art of nuclear energy technology can be brought down through fusion energy systems as the fusion reaction gets quenched immediately if there is a slight disturbance/ breach in the plasma (let alone an earthquake of the scale of Japan's). The ongoing research on the ITER is already looking at various failure scenarios and risks of radioactive leakage from the reactor (Gulden, Ciattaglia, and Massaut 2005), the most relevant being the simultaneous failure of all cooling systems together, similar to what occurred in Japan's Fukushima Dai-ichi reactor.

Besides accelerating the pace of India's nuclear power programme, fusion also has the possibility of reducing the country's projected radioactive waste production from the fission programme, should it continue in its current form (although it follows the closed fuel cycle with relatively lower waste generation as compared to the open cycle followed in many other countries). Figure 3 depicts the waste generation from India's plants on a conservative basis, assuming that India adds 63 GW of nuclear power capacity by 2100 (as against the year 2032 targeted by the DAE). On the other hand, nuclear fusion produces relatively very less waste with shorter half-lives[3], mostly arising out of irradiated plant components that are removed for replacement.

Fusion: the science and programme in India

In fission, a heavy isotope like U-235 (which constitutes 0.7% of naturally occurring uranium) is commonly used to produce electricity in nuclear fission reactors by allowing it to interact with thermal neutrons[4] and thereby splitting it into secondary products. The other main isotope of uranium, U-238, does not undergo nuclear fission with thermal neutrons, but it eventually decays to Pu-239 (which is fissile and with a higher probability than U-235). In contrast to fission, nuclear fusion involves the fusing of light nuclei, thereby releasing energy per nucleon of much higher order as compared to nuclear fission. Figure 4 illustrates the binding energy per nucleon versus the atomic masses. One can see that the binding energy released per nucleon is higher in the case of fusion reactions. Consequently, a certain mass of fissile fuel would yield much less energy as compared to the same mass of 'fusile' fuel[5].

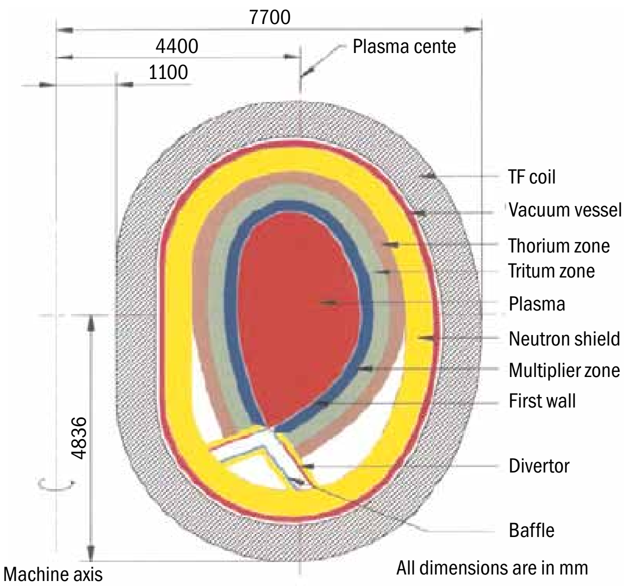

Figure 2 Vertical cross-section of the FBR
Source Grover, Ravi; Nuclear Energy Programme in India; Sept 2007. Available at http://nuclear.inl.gov/global07/d/ravi_grover.pdf, accessed on 10.03.2011

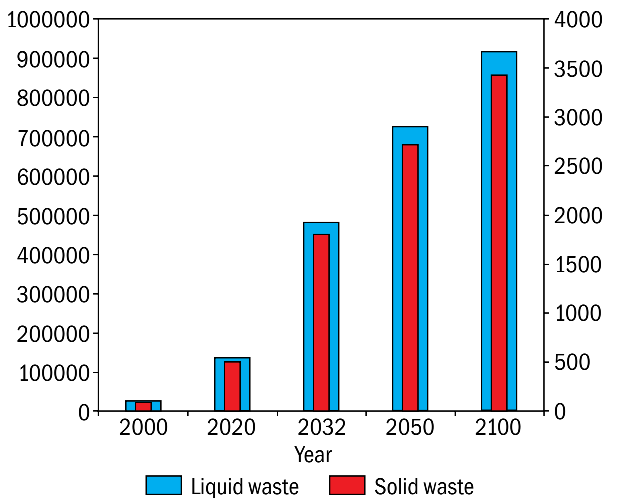

Figure 3 Conservative projection of waste generation volumes (m^3)
Source Based on figures given in K K Rao (2001), Radioactive waste: The problem and its Management, Current Science, Vol. 81, No. 12, pp.1534-1546; and based on existing capacity data from http://www.npcil.nic.in/main/AllProjectOperationDisplay.aspx

3 Half life – the time taken by a radioactive species of an element to decay to half it's original quantity. It is used to understand how fast a radioactive species will stop being radioactive.

4 Thermal neutrons have an average speed of only a few km/s (also known as slow neutrons), as against fast neutrons which have an average speed of tens of km/s

5 Fusion fuels like deuterium (D), tritium (T), etc.

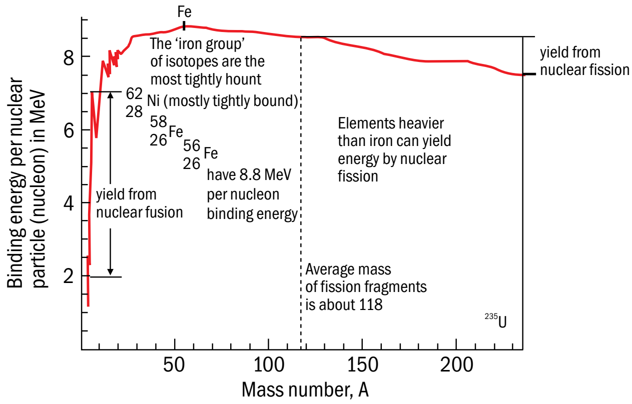

Figure 4 Binding energy per nucleon as against mass number
Source Indira Gandhi Centre for Atomic Research, India. Available at http://www.igcar.ernet.in/nuclear/binding_energy.htm; accessed on 15.02.2011

So, a 1,000-MW plant of fusion would have much less fuel at any given point than a 1,000-MW plant of fission. A typical fission plant consumes around 30 metric tonnes of fuel per year and produces about a tonne of radioactive waste from the reaction (Ragheb 2011), while a fusion plant is expected to consume about 0.25 metric tonnes of fuel per year and produce no waste from the reaction[6]. Another way to appreciate this is by looking at the fractional energy yield[7] from the two most common fission and fusion reactions (see Table 1). We see that the energy released per fusion reaction exceeds that from fission reactions by an order of about four.

In case of fission, there is also the added challenge of disposing high-level nuclear waste. In fusion, apart from dealing with activated structural components during plant repair/maintenance/decommissioning, there are no radioactive by-products that need to be stored away for dissipation (such as spent fuel rods, and so on) (Notredame 2005).

Table 1 Comparison of reactions and their yield energy

Sl. No.	Reactants (energy, MeV)	Products (energy, MeV)	Fractional energy yield	Energy (J) from 1 kg fuel
Fission				
	U-235 (218,896.8), n (939.57)	Cs-140, Rb-93, 3n (~215)	0.00098	3.38×10^{14}
Fusion				
	D (1875.62), T (2808.92)	He-4 (3727.38), n (939.57)	0.00375	0.88×10^{14}

Source Sourced from Georgia State University. Available online at: http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/nucbin.html; last accessed on 16 February 2011.

The process of fusion is naturally difficult to control and achieve without expending sufficient energy at the startup of the reactor. The reactor has to reach a condition of gain (Q)[8] value greater than 1 to be called a power plant. Currently, some devices across the world have achieved Q values of 1 for brief periods, thereby demonstrating that a fusion power plant is technically feasible[9]. The other advantage of nuclear fusion over fission—apart from having higher energy yield—is that the fuel resource for fusion is nearly plentiful. Refer to table 2 for a comparison of fission and fusion fuel resources worldwide.

U, Pu and Th are the primary fission power plant fuels that are being used today, while D and T are the primary fusion fuels. Li is a source of Tritium which is not a naturally occurring substance and has to be generated from Li.

To achieve nuclear fusion, a unique device is required. The tokamak is a device that confines hot plasma, using magnetic fields, to create conditions for nuclear fusion. It consists of a vacuum vessel in the shape of a donut, where the hot plasma resides and where fusion occurs. The donut is surrounded by a series of toroidal magnetic coils (see figure 5) that help in creating toroidal field lines that trap the plasma and keep it away from the walls of the reactor. Another set of coils surrounds the central vertical axis (polloidal field coils), and help in stabilizing the plasma during operation. The radius of the donut structure is called the major radius of the tokamak, while the radius of the vertical cross-section of the donut (shown in figure 5 [a]) is called the minor axis of the tokamak.

Apart from these basic structural components, the tokamak is also equipped with heat supply systems like laser plasma heating, radio-frequency heating, and neutral beam heating. All of these are, in turn, supported by a sophisticated network of diagnostics, cooling systems, control actuators, signal processing, and fuel injection devices. Figure 5 [b] illustrates the basic tokamak configuration alongside a cut-away of the tokamak, complete with diagnostics,

6 See http://www.iter.org/sci/fusionfuels.
7 This is the ratio of energy released in the reaction to the energy contained in the reactants before the reaction occurs.
8 Gain is the ratio of energy produced by the reactor to the energy consumed to achieve fusion conditions.
9 ITER and the sequel DEMO reactor would together demonstrate commerical viability of the system.

Table 2 Worldwide nuclear fuel comparison

Sl. No.	Fuel	Estimated quantity worldwide (metric tonnes)	Estimated quantity in India (metric tonnes)	World electricity generation potential (GW-yr)*
Fission				
1	U ore[a]	5,404,000	1,03,552	328 (in PHWRs)
2	Pu[b]	1,270	4.24	42,231 (in FBRs)
3	Th[c]	1,160,000	3,60,000	1,55,502 (in 3rd stage Th-reactors)
Fusion				Years to supply world electricity needs at 1995 levels
1	D	4.68 x 10	unknown	150 bil years
2	Li	11,000,000[d]	unknown	3000 years[e]
3	Tritium	0.025[f]	unknown	unknown

[a] The ore is called triuranium octoxide (U_3O_8), commonly known as yellow cake.
[b] This quantity is for 1995 levels and includes military as well as commercial plutonium.
[c] Some sources peg India's thorium reserves at 5,18,000 tonnes of metal.
[d] This only accounts for reserves in ore deposits; another 200 billion tonnes are dissolved in sea water
[e] This only accounts for reserves in ore deposits; another 60 million years would be available if Li from sea water is used
[f] Accounts only for naturally occurring Tritium and not the Tritium produced in light water reactors and other facilities across the world.
* See http://www.iter.org/doc/www/edit/Lists/doc_galleries/Attachments/18/08_Anil Kakodkar.pdf

Sources World Nuclear Association (2009); Gupta (2010); Makhijani (1997); Mian (2011); Jayaram (undated); BARC (2011); Ongena and van Oost (2006)

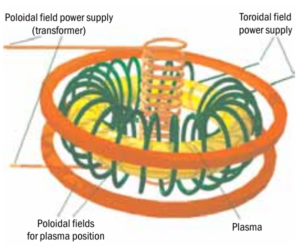

Figure 5 (a) The typical coil arrangement in a tokamak
Source http://www.fusione.enea.it/FTU/powers.html.en; accessed on 07.03.2011

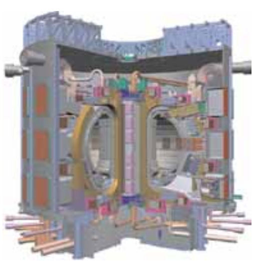

Figure 5 (b) A tokamak configuration (ITER)
Source http://www.plasma.inpe.br/LAP_Portal/LAP_Site/Text/Tokamak_Development.htm; accessed on 07.03.2011

controls and heating. The brilliance of this device can be appreciated by the fact that the temperature at the core of the plasma is to the tune of 100 million Kelvin, and this is carefully varied near the vacuum vessel walls to be tolerable by the plasma-facing wall surface. This is seen in figure 6 where the cross-sectional view of the plasma of the Japanese tokamak JT-60U (6 [a]) is juxtaposed with the plasma current density from core to wall (6 [b]) and the electron-ion temperature from core to wall (6 [c]).

With development of EFBR, the nuclear fusion concept can be advanced along with the 3-stage programme, thereby leading to twin benefits of completing the 3-stage programme and having a new improved concept of fusion ready for future energy needs of the country. The nuclear fusion programme in India has been separately spearheaded by the Institute for Plasma Research (IPR), Gandhinagar. Fusion research started in India on a fundamental level with the Saha Institute for Nuclear Physics (SINP) commissioning a Toshiba tokamak in 1987. The IPR commissioned ADITYA in 1989 - India's first indigenously designed and constructed tokamak that worked on the pulsed transformer principle. Now, IPR is in the process of commissioning its latest indigenous Steady State Tokamak (SST-1)(Gracias 2008). Unlike the ADITYA, SST-1 will be a steady state device, wherein the external current will be supplied to the

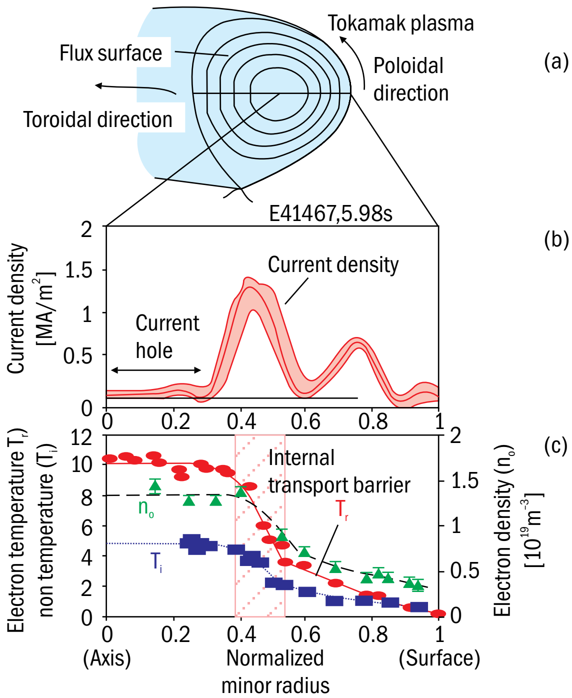

Figure 6 Temperature variation inside the plasma from core to wall interface[10].
Source IAEA R&D Review. 2006. *Nuclear fusion research and development.*

[10] where 1 eV = 11,605 K; hence 10 keV in the graph corresponds to 11,60,50,000 K = 116 million K

plasma in a continuous manner, rather than in pulses (as in the ADITYA's transformer-like action). As a result of continuous operation of the plasma, the instabilities that disrupt the fusion process are avoided, thus allowing the tokamak to move towards a gain value of IPR is also the domestic agency for India empowered to design, build, and deliver advanced systems and sub-systems for the ITER confinement project, which have been assigned to India under the international ITER agreement.

Although IPR and other agencies in the country might be viewed by critics as expensive science projects, they still remain critical building blocks of India's nuclear power programme and its quest for energy security. The possibility of using fusion reactors as breeders for the third stage provides an additional opportunity for India to pursue magnetic fusion. This not only allows India to look at alternative energy sources (in this case sea-water), but also ensures that the third stage of the nuclear programme's closed cycle approach is not constrained by international fuel supply agreements and stringent dual-use restrictions.

This would make the nuclear power programme complete and sustainable, while bringing down costs of generation over time. This is because a lot of the physics-related challenges that need to be solved are closely linked to the cost of the plant (Cook, Hender, Knight *et al.* 1999). Sooner these challenges are solved, quicker the fusion plants could be commercialized, leading to lower direct cost of electricity from these plants and better environmental benefits from lowered CO_2 emissions (Tokimatsu, Asaoka, Konishi *et al.* 2002).

Trajectory of nuclear fusion research

Fusion research in India is now headed along a very ambitious and calculated path that can help meet the three-stage programme needs of breeding Th, as well as explore the feasibility of nuclear fusion as a sustainable power source for the future. After the successful operation of ADITYA, and now the experience that will be gained from operation of SST-1, India's capability at research, development and deployment of magnetically confined fusion plasmas will be immensely enriched. Further, the learnings and contributions from ITER collaboration will add a lot to India's approach to managing nuclear fusion development.

Conclusion

If India intends to continue with the three-stage programme, then the fuel challenge has to be overcome - Th is not a fissile material, and it needs to be 'bred' to be made fissile and usable in our plants. The FBR is one option, but the breeding rate in such reactors is not high enough to help us move on to the next stage of the programme without an overhead of imported fuel purchase and repatriation as per the dual use terms signed with the country of origin of the fuel. Alternative technologies, which offer shorter doubling time, need to be explored and developed. The potential technologies under investigation and possible development are based on the use of an external non-fission source of neutrons. The neutrons could be generated either by a spallation reaction using a high-energy proton accelerator or by fusion reactions involving deuterium/tritium nuclei. ADS would be a good option for a Th burner that is proliferation free. The fusion systems like tokamaks are aiming for a large-scale Th-to-uranium converter[11]. Inertial confinement fusion (ICF) systems are not likely to be viewed at par with magnetically confined

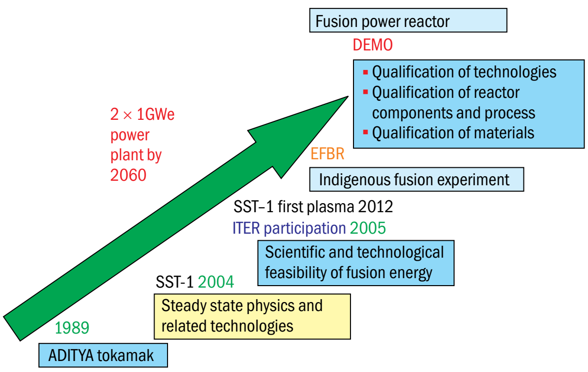

Figure 7 Likely nuclear energy development trajectory in India
Source IAEA, ITER et al.

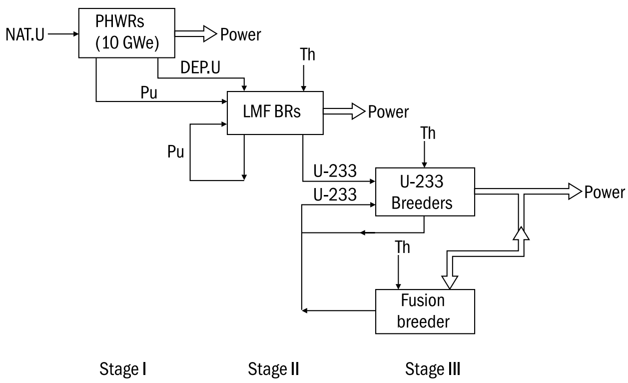

Figure 8 Modified three-stage programme with nuclear fusion
Source Ramanna, Raja; Indian nuclear programme: achievements and prospects; Journal of Korean nuclear society, Vol. 19, No. 3, September 1987

[11] **Source** Department of Atomic Energy. Available online at www.dae.gov.in/publ/doc11/index.htm; las accessed on 4 March 2011

fusion systems (MCF) due to their value in studies of hydrogen bomb yields[12]. Also experience with developing and operating ICF systems is much less as compared to MCF devices like the tokamak.

Therefore more research on MCF is required to move towards a responsible and secure path of nuclear power. But several aspects of such a path would have to be assessed in advance before one sets out to achieve it, lest the pace of such development slackens and results in delaying desirable results.

Fusion energy research and development in India goes much beyond the goal of supporting ITER. The National Fusion Science and Technology Programme document stresses on the need for a programme that takes India further into establishing its own indigenous fusion power plants (Programme Committee, PSSI Workshop 2006).To achieve this objective, the government would not only have to allocate fusion energy the appropriate priority along with other national developmental goals, but also demonstrate that priority by providing requisite funds for research and development. To effectively channel funds and human resources, the country would need to embark on a large-scale collaborative framework involving not only institutes and laboratories from within the country, but also foster strategic and academic links with some pioneering laboratories and universities from across the world.

To take the country's agenda forward, there is also an urgent need for awareness generation about nuclear energy, in general, its risks, benefits, and more specifically the advantages of fusion energy over fission. In most science courses at the undergraduate level, nuclear energy is introduced only at a basic level. Although the DAE has created a special post-graduate training school of international repute (i.e. BARC Training School) for its engineers and physicists, there is a need for introduction of such post-graduate courses in other institutions and universities across the country, where comprehensive courses on nuclear energy with various specializations (fission, fusion, materials, and so on) are offered. With the creation of such opportunities, India will be able to evolve a critical mass of qualified professionals in the coming years, who can lead its developmental work in nuclear fusion.

References

Bhabha Atomic Research Centre. 2011. **Anushakti: atomic energy in India– strategy for nuclear energy**. Details available at http://www.barc.ernet.in/about/anu1.htm; last accessed on 10 March 2011.

Cook I, Hender T C, Knight P J, Ward D J. 1999. **Direct cost of electricity from fusion power plants**. 26th EPS Conference on Controlled Fusion and Plasma Physics, ECA Vil. 23J, 225–228 pp. Details available at http://epsppd.epfl.ch/Maas/web/pdf/p1030.pdf; last accessed on 29 January 2009.

Gracias W A. 2008. **Nuclear fusion power in Asia: an energy option of the future**. *AEI newsletter* (6).

Gulden W, Ciattaglia S, Massaut V. 2005. ***Nuclear Engineering and Safety, Awareness workshop for EU on ITER***. Garching: European Fusion Development Agreement (EFDA)

Gupta R. 2010. **India's atomic mineral resources: prospects, challenges and future directions for sustainable development,** Third Asian Mining Congress. Details available at http://www.ucil.gov.in/web/India's_Atomic_Mineral_Resources.pdf; last accessed on 8 March 2011.

Jayaram K M V. **An overview of world thorium resources incentives for further exploration and forecast for thorium requirements in the near future**. Details available at http://www.iaea.org/inisnkm/nkm/aws/fnss/fulltext/0412_1.pdf; last accessed on 10 March 2011.

Makhijani A. 1997. **Plutonium as an energy resource**; *Energy & Security* (1). Details available at http://www.ieer.org/ensec/no-1/puuse.html; last accessed on 16 February 2011.

Mian Z. 2011. **Fissile material challenge and the conference on disarmament**. Details available at weblink - http://www.fissilematerials.org/blog/UNSG-Disarm-25-Feb.pdf.

Notredame J-M. 2005. ***Controlled fusion, from basic plasma physics to nuclear engineering***. ICENES.

[11] US Department of Energy. 1997. **Draft public guidelines to Department of Energy, classification of information**. Details available at https://www.osti.gov/opennet/forms.jsp?formurl=document/guidline/pubgd.html, accessed on 04.04.2011; and National Nuclear Security Administration. **Inertial Confinement Fusion and High Yield**. Details available at http://www.nnsa.energy.gov/aboutus/ourprograms/defenseprograms/futurescienceandtechnologyprograms/inertialconfinementfusionandh; last accessed on 4 April 2011.

Ongena J and van Oost G. 2006. **Energy for Future Centuries: Will fusion be an Inexhaustible Safe and Clean Energy Source?** *Trans. Fusion Sci. Technol.* **49** (2).

Programme Committee, PSSI Workshop on Nuclear Fusion Programme: ITER and Beyond; Institute of Plasma Research. 2006. **Nuclear Fusion Programme**. Details available at http://nfp.pssi.in/documents/NFP-01_%20Opportunities-Rev%202.pdf; last accessed on 14 February 2011.

Ragheb M. 2011. **Management of Radioactive Waste**. In *Nuclear Plasma and Radiation Science (Part III)*.University of Illinois, Urbana-Champaigne. Details available at https://netfiles.uiuc.edu/mragheb/www/NPRE402ME405Nuclear Power Engineering/Management of Radiooactive Waste.pdf; last accessed on 8 May 2011.

Tokimatsu K, Asaoka Y, Konishi S, Ogawa Y, Okano K, Yamaji K. 2002. **Evaluation of economical introduction of nuclear fusion based on a long-term world energy and environment model**. Details available at http://www.iaea.org/programmes/ripc/physics/fec2002/pdf/sep_03.pdf; last accessed on 29 January 2009.

World Nuclear Association. 2010. **Supply of Uranium**. Details available at http://www.world-nuclear.org/info/inf75.html; last accessed on 15 February 2011.

Centre for Research on Energy Security

Centre for Research on Energy Security (CeRES) was set up on 31 May 2005. The objective of the Centre is to conduct research and provide analysis, information, and direction on issues related to energy security in India. It aims to track global energy demands, supply, prices, and technological research/breakthroughs – both in the present and for the future – and analyse their implications for global as well as India's energy security, and in relation to the energy needs of the poor. Its mission is also to engage in international, regional, and national dialogues on energy security issues, form strategic partnerships with various countries, and take initiatives that would be in India's and the region's long-term energy interest. *Energy Security Insights* is a quarterly bulletin of CeRES that seeks to establish a multistakeholder dialogue on these issues.

Previous issues of this newsletter are available at <http://www.teriin.org/div_inside.php?id=41&m=3>.

For inclusion in mailing list, contact

M K Bineesan
Centre for Research on Energy Security
T E R I, Darbari Seth Block
I H C Complex, Lodhi Road
New Delhi – 110 003

Tel. 2468 2100 or 4150 4900
Fax 2468 2144 or 2468 2145
India +91 • Delhi (0)11
E-mail bineesan@teri.res.in

Printed and published by Dr R K Pachauri on behalf of The Energy and Resources Institute, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi – 110 003 and printed by him at Innovative Designers and Printers and published at New Delhi.