My attention was drawn to a report in The Hindu of August 1, 2015 (Coimbatore Edition) on fuel utilisation issue recently by the National Sample Survey Office (NSSO). Highlights of this report are

a) Two thirds of the rural households rely on firewood for cooking.

b) Two thirds of the urban households use LPG for cooking.

c) 14% of urban households (including half of the poorest 20%) still rely on firewood.

d) Use of LPG in rural households has gone up from 2%, two decades ago to 15% in 2011-12.

e) In North Indian States, Cow dung cake is a major fuel for cooking in a third of the households in UP and Punjab, a quarter in Haryana and a fifth in Bihar.

f) A fourth of the rural households still rely on kerosene for lighting - Rural households in A.P., Punjab, Tamil Nadu and Kerala used electricity for Lighting but in UP only 40% rural households had electricity.

My memory went back to the Presidential address of Dr. Homi Bhabha to the first U. N. Conference on Peaceful Uses of Atomic Energy held in Geneva in August 1955 (nearly sixty years ago). Assisted by Shri Sohrab Patuck of the Tata Administrative Service, Bhabha drew attention to the fact that India’s major fuels then were firewood and cow dung. The combined contribution of coal and oil was overshadowed by the traditional fuels. Bhabha drew attention to the dangers of deforestation, which indeed has happened and the loss of organic nutrients to the soil through burning of cow dung.

It has come to me as a surprise that we are using in absolute terms more firewood and more cow dung cake as cooking fuel now than we did in 1950’s! A second point that emerges is that the substantial additional fuel to the Indian economy by way of locally produced coal or imported petroleum has largely been used by the urbanised sections of society and those that are employed by organised industry. There is no doubt that some part of the energy has gone to increase food production for irrigation pumping, fertilizer and pesticide production and of course to transporting food articles from the farm to the urban consumer. The consequence of this situation is the continuing poverty and deprivation of large sections of the rural population (excluding the large land holders). I will now go back to discussing the more limited commercial energy issues. But we must not overlook the large rural energy problem.
In broad terms, India's consumption of commercial energy is roughly half from coal and half from petroleum. Coal production in India is about 600 million tonnes and we import about a hundred million tonnes of coal composed both of coking and power grade coal. So for as petroleum is concerned, we reached 70% self reliance in the 1980's or so, but now we depend close to 75% on imports as domestic production has not seen any dramatic increase. So far as natural gas production is concerned, India remains a minor player. Last year a substantial power generation capacity based on gas remained non operational due to non-availability of gas. We do import some LNG but until last year when oil prices were high, landed LNG cost was US $10/mmbtu and hence was an expensive fuel. It is unfortunate India has so far not succeeded in obtaining piped natural gas from Iran, Central Asia or Myanmar, Indonesian and Malaysian natural gas got cornered by Japan and Thailand in the 1990's to be supplied as LNG at the then prevailing low prices. Unless something changes dramatically, India is not able to take advantage of a gas based energy revolution. Even with regard to shale gas, India's potential is not high, currently confined to Cambay basin, Krishna, Godavari, Damodar and Cauvery. There are risks of polluting water bodies and water itself becoming a scarce commodity, shale gas development may not be welcome. On one ground shale gas scores compared to coal mining, in being more benign on the land than the latter. Our present Coal Minister has said that India's coal production would be ramped up to a billion tonnes per annum over the next some years. However given the fact that much of our coal seams are in the remaining forested areas of the country, whether such large scale mining is possible remains an open question.

On a long term basis, India's coal consumption has increased at about 5% per annum and petroleum consumption at about 7% per annum. Unless some other primary fuel is available as a substitute, these growth rates may continue if Indian economy were to grow at 7% or more in the coming years. Looking at the electric power sector, we may note that starting with a base of a mere 2GW in 1950, installed capacity now is about 250 GW. Looked at in isolation, the 125 fold growth in 65 years may appear good. China in the same time span has gone up from 2GW to about 850 GW! If we are serious about Make in India and about building essential infrastructure of high speed trains, steel plants, cement plants and so forth, a rapid increase in power generating capacity is a must.

In the five decades after India's independence, the growth in electricity, coal and petroleum sectors was due to the dominant role of the public sector enterprises in the respective fields. However the ills of the large public sector behemoths - like overstaffing, high labour welfare costs, lack of accountability, corruption, political interference and unsatisfactory service to the public at large resulted in opening up the energy sector to greater involvement of the private sector. It is too early to say whether expected benefits have accrued to the country as a result of the entry of the private sector in the energy field. The addition to power capacity by private players is still quite slow. Entry of private sector into coal mining has got mired into the controversy regarding mining leases. In the natural gas sector, the great expectation about large amounts of gas coming out of the Krishna Godavari basin, at affordable costs, has not been realised. The hope held among certain energy economists that the 2003 Electricity Act and other initiatives taken around then that competition would promote lower prices for energy services, has not been realised.

We will now discuss the electricity sector in greater detail, as this is a field I am more familiar with. For a long time now, electric power is sold across the country at a rate that is about one rupee less (per kWh) than it costs to produce. Sometimes the differential is more so as we produce more kWhs, we have a higher loss, which shows up in the books of the electricity boards (or their successors, the distribution companies). In the tariff fixation, there is a complex scheme of subsidies - free power to agriculture, various levels of subsidies to domestic users, industry users paying more than full cost plus fair profit and so forth. All these ills were there prior to the Electricity Act of 2003, and they continue to be there. If a unit of electricity results in GDP growth that is substantial, then we could accept the aggregate loss of the electric supply system as just another element of tax. However, the snag is that the non-electricity user (and there are many in India) also has to carry the burden of loss on sale of electricity. But the political system has come in the way of rational pricing of electricity supply in the past and appears to continue to do so in future also. This tariff policy is a big deterrent for creating internal resources to sustain a healthy growth of the electric supply system. In a recent case a private power producer was forced to seek a revision in the cost of power due a levy imposed by the government of the country from which coal was sourced. Unless we have a power sector in good economic health, we can hardly expect to have a healthy growing economy.

In the first couple of decades after independence, the emphasis was on building hydro-electric power stations as part of multipurpose river valley projects. From the 1970's onwards building coal based power stations was taken up actively. Now coal and gas based generation dominates the field with hydro making only small gains as it is facing opposition from environmentalists. Wind energy has made good progress. I have personally seen large wind energy farms near Kudankulam (Kanyakumari) and Coimbatore in Tamilnadu and in Chitrardurga in Karnataka. India made an early entry into nuclear power with our first atomic power station going operational in 1969. This station at Tarapur was imported from the USA and uses low enriched uranium as
fuel. This power station has completed forty five years of safe operation and supplies power at less than one rupee per kWh! Lewis Strauses, an early Chairman of the US Atomic Energy Commission had made a claim that in his grandson’s time, nuclear electricity would be too cheap to meter! This was before any nuclear power station had been built. I shall discuss later the experience on cost of nuclear power from our more recent stations.

Our experience with the US on Tarapur has been a mixed one. The station was built in five and a half years - something of a record for nuclear power stations. It was financed by a low interest long term loan. But getting fuel from the US on a timely basis was a huge problem. After India had its first nuclear test in 1974, US supplies of fuel became erratic from 1980 onwards, France agreed to supply fuel for Tarapur. However US companies were prevented from supplying spares or technical information after 1974. India had to stand on its own in solving various technical problems and sourcing from within India all spare parts and replacement components.

Our second nuclear power station in Rajasthan was built with cooperation from Canada. The two reactors of this station use natural uranium as fuel and heavy water as moderator. The Canadian Technology was emerging and so it took longer to build these reactors. In addition, localisation of supply of components and equipment was taken up seriously in order to lay the foundations of a self-reliant nuclear industry. The first unit of the Rajasthan station went into operation in 1972 but hardly operated for a little more than a decade, when there was a problem with a major nuclear component (called end shield). In the meantime, work had commenced on the second unit. But with the Pokhran test of 1974, Canada discontinued cooperation with India. India completed the second unit at Rajasthan in 1980 on its own and began to operate it in a reliable and safe manner, incorporating all the lessons learnt on the first unit. The remotely operated on load refuelling machines were a particular challenge and our engineers and technicians began to operate them successfully. It is this feature that enables natural uranium to be used as fuel.

Dr. Bhabha died in the Mont Blanc air crash in January, 1966 and before his untimely death, he convinced the Government of India that the third nuclear power station, to be built at Kalpakkam, Tamil Nadu would be designed and executed as a fully Indian venture. It was my good fortune that Dr. Sarabhai (who succeeded) Dr. Bhabha as Chairman, AEC posted me as the Chief Project Engineer, Madras Atomic Power Project (MAPS). Developing all round industrial capability to make all the components and materials was a tough proposition. In the meantime, India refused to join the Nuclear Non-Proliferation Treaty that the US, USSR and UK had launched in 1970. In 1974, India went ahead with the Pokhran I test. The US and its allies in North America, Europe and elsewhere embargoed supply to India of equipment or materials destined for nuclear use. When Madras unit I was made operational in July 1983, India joined a select band of countries that could design and build nuclear power plants on their own namely USA, USSR, UK, France, Canada and Japan.

Following successful completion of MAPS, India took up building nuclear power units at Narora, Kakrapura, Rajasthan expansion and Kaiga. India had now entered an industrial phase of nuclear power plant building, with very little inputs from outside the country. From the 1990’s onwards, our nuclear power units turned in very good performance, remaining on line continuously for very long periods. In May 1998, India conducted the Pokhran II series of nuclear tests, in view of adverse geopolitical developments in the region. Pakistan also conducted its tests before the end of May 1998. Thus both India and Pakistan became overt nuclear weapon states and along with Israel, all outside the NPT.

Predictably, the US expressed its unhappiness about India’s actions and Indo - US relations went through a brief period of chill. However by the early years of the new century, US began to explore how to accommodate a de facto nuclear state India, in the global scheme of things. There were marathon meetings between Strobe Talbott of US and Jaswant Singh of India at many places around the world. However it was left to President George Bush and Prime Minister Manmohan Singh to reach an agreement to work towards a nuclear rapprochement on July 18, 2005. Given the complexity of the issues involved, the Indo - US cooperation agreement was signed in September 2008, after the IAEA had concluded a special protocol with India and the nuclear supplier’s group issued its consent on civil nuclear cooperation with India. Agreements were signed with France and Russia also in 2008. In more recent times, similar agreements have been signed by India with UK, Kazakhstan, Canada and others. Following these agreements, India is now accessing uranium from some of these countries.

Although India made an early start in harnessing nuclear energy, the growth of nuclear power capacity has been modest. A principal reason was the embargoes that were placed on India for nuclear imports. India built reactors on its own but they were of about 230mw capacity. The two 540 mw reactors were built in the period 2000-2010. During this period, we had also embarked on the Kudankulam project with Russian collaboration to build 2X1000 MW light water reactors, using low enriched uranium. So when the July 18, 2005 agreement between US and India was reached, there was expectation that a number of large sized nuclear power units would be built in the next decade or so. In fact the US received a broad letter of intent that India would procure nuclear power plants of about 10,000 MW capacity, subject to the cost of power from these units being competitive with power from alternate sources in the concerned region.
India and France had an ongoing dialogue to build six reactors with an output of 1600 MW each, at a site in Maharashtra, at Jaitapur near Ratnagiri. Similarly Russia was very keen to supply more 1000 MW VVER reactors, similar to the ones under construction at Kudankulam. On the Indian side, our parliament passed civil nuclear liability law in 2010. In the law adopted by India, there is a specific provision that there would be a right of recourse against a supplier in the event of a wilful neglect or a latent or patent defect. Industry practice world over has been that the operator is solely liable and the supplier is indemnified. Given the background of the Bhopal tragedy, lawmakers in India did not want to allow the suppliers to go scot free under all circumstances. The US nuclear suppliers especially were not prepared to accept the Indian law and pressed India for amending it to their satisfaction. India has recently provided an insurance mechanism to the supplier to cover this risk.

The Fukushima accident of March 2011 had a big impact on the revival of nuclear power worldwide. It is now clear that the tragedy could have been avoided if Tokyo Electric Power Company had installed emergency diesel generators at a height above the maximum flood level of the site. It is no doubt true that the earthquake was a very strong one and the accompanying tsunami was unprecedented. A big weakness that was revealed was that the Japanese regulators were lax in performing their functions and the utility itself negligent in ensuring plant safety under conditions that were predicted by some of the Japanese seismologists and engineers. Fukushima resulted in delaying startup of Kudankulam unit by nearly two years due to local opposition. Germany which had a very good track record in operating nuclear power units has announced retiring progressively its operating nuclear power units. However, the US, France, Russia, China, Korea and India believe that nuclear power is safe and an important part of their energy mix.

Our discussions with France on the European Pressurised Reactor (EPR) got drawn out due to internal review in France of safety of nuclear power units under beyond design basis accidents. When India and France embarked on discussion of cost of power from EPRs built in India, projected costs were substantially higher than costs anticipated by India. Early in 2015, following discussions between Prime Minister Narendra Modi and President Francois Hollande, the French nuclear power plant builder Areva is engaged on discussions with Larsen and Toubro and other Indian industries to reduce construction costs by a higher level of localization. Results of this exercise are awaited.

The Nuclear Power Corporation of India (NPCIL) is in discussions with Westinghouse of USA, who is building four reactors of their AP-1000 series in the US. At present safety documentation is being made available for review by the Indian Atomic Energy Regulatory Board. Initial indicative costs appear much higher than Indian expectations. With regard to General Electric of US, the discussions are even more in a preliminary stage. Unless a meeting ground is reached with US nuclear power plant builders in the next year or so, the 2005 agreement would have conferred Nuclear Respectability on India but not given any Nuclear Kilowatt hours!

Kudankulam unit I is presently under its first refueling cycle. Unit II is in the startup mode. Russia has agreed to supply units III and IV. Units I and II have a power cost of Rs.4/kWh. Units III and IV have a capital cost of Rs.20 crores per MW and this will result in a power cost of Rs.6.5/kWh in 2021-22. Russia has agreed to supply more reactors; there is space for the fifth and sixth units at Kudankulam. Another site would have to be identified for additional VVER units.

NPCIL has designed its own 700 MW PHWR unit and four of them are under construction, two each at Kakrapara (units III and IV) and at Rajasthan (units VII and VIII). Recently, Government of India has sanctioned construction of two 700MW PHWR at a site in Haryana. The cost per MW is Rs 15 crores and the cost of power is likely to be Rs 6.5/kWh in 2021-22 period.

I was recently at Kaiga, near Karwar where four reactors of 225MW (PHWR) were in operation. The first two units were operating at 100% power and units III and IV at well above 100%. Reactors at Kaiga have operated for over 300 days continuously; they have exceeded 400 days on a number of occasions. One of the Kaiga reactors crossed 500 days, highest for any reactor in India then. The record among Indian reactors is RAPS V which was on line for 765 days continuously (the second highest in the world). Kaiga is supplying power at Rs 3/kWh. It is one of the most beautiful nuclear power stations anywhere in the world.

If we have to accelerate our nuclear power capacity, we must build more 700MW PHWRs (Immediately two more will be built at Kaiga) - this can be achieved by committing to some 8 or 10 units at one time so that industry can batch produce the components and reduce the manufacturing period. Construction could be taken up at two or three sites. A similar strategy should be adopted by taking up eight or ten 1000 MW VVER at more than one site, and with a high degree of localization of equipment supply. Discussions with France and US should continue but action on more PHWRs and VVERs should not be delayed any further.

In the early years of this century, the strategic planning group of the Department of Atomic Energy made a projection of the likely demand for electricity in the time horizon up to 2052. This study revealed that the installed capacity may have to go up to 1250 to 1350 GW by 2052, allowing for some 5000 kwh/capita. Of this the nuclear component was estimated to be between 275-300 GW. Since then we have seen dramatic increase in lighting efficiency through the use of LEDs and...
motor efficiencies in the industry through a variety of innovations. Similarly energy efficiency in steel, cement and other industries has improved substantially. We may therefore project a lower per capita consumption of 3000 kwh. So the capacity required by 2052 would be a more realistic 750-810 GW. Even taking the lower figure of 750G, we may need a nuclear capacity of 275 GW. Fossil fuels (coal and gas) may contribute 275GW and 200 GW could come from renewable and hydro.

During 2005-2008 when we were discussing the Indo-US nuclear agreement, I had suggested that India needed some 30 to 50 GW of nuclear capacity in the first stage using natural and low enriched uranium. This of course was an interim target. The 2050 target of 275 GW of nuclear power may consist of some 125 GW of natural uranium and low enriched uranium reactors, 100 GW of fast breeder reactors and 75 GW of thorium based and other advanced systems. Therefore we need to develop our own PWR which along with our own PHWR could contribute significantly to the first stage 125 GW of nuclear power. Our BARC-NPCIL has completed the design of 900 MW Indian Pressurised Water Reactor, which should be taken up for execution at the earliest.

The Prototype Fast Breeder Reactor of 500 MW at Kalpakkam is about to be started up in the next few months. Two Fast Breeder Reactors of 600 MW are planned at Kalpakkam to follow the PFBR. The FBRs will use the plutonium in the spent fuel of the first stage reactors. The rate of induction of FBRs will depend on the rate at which plutonium is available. We also have a design of a 300 MW Advanced Heavy Water Reactor (AHWR) which would demonstrate the feasibility of using thorium as a fuel. Again this project needs to be taken up for execution soon. India has a limited amount of natural uranium. We can in the new regime, post 2008 agreements, import both natural and enriched uranium from overseas. The plutonium from spent fuel using both local and imported uranium can fuel a large number of fast reactors. As we reach the stage of using thorium, we shall depend more and more on locally produced thorium.

There is a resolve in the country to push renewable energy as fast as possible. We are using 1.25 MW and 2.5 MW wind turbines at many places. We should also explore offshore wind turbine complexes use say 16 x 5 MW units. We are making a start on large scale solar energy harnessing. A recent project for Tamilnadu mentions a cost of Rs. 7/kWh. If we take into account the subsidy element, the real cost will be about Rs. 9/kWh. While this may be acceptable for a promotional project, large scale induction of solar and wind energy would depend on sharp reduction in costs over the next few years. Recently the Minister of State for Power, Coal and New and Renewable Energy stated that the target for renewable energy for 2022 would be 175 GW (up from 30 GW at present).

Unless costs come down, the subsidy burden would become excessive.

Although Indian industry has grown quite well in supplying the needs of the energy sector, there are significant gaps. One such is the field of high quality heavy forgings. To fill this gap, NPCIL and L&T have jointly set up an integrated forge plant at Hazira. Apart from the big stuff, we need local manufacturers to make high quality valve actuators, limit switches, micro switches, sensors and so forth.

With regard to R&D support to energy industries, we have institutions such as the Central Fuel Research Institute, Central Power Research Institute, Indian Institute of Petroleum, Central Electronic Laboratory, Semiconductor Complex, R&D Labs of DAE and so forth. Yet we have difficulty in resolving problems such as turbine-generator vibrations, in a prompt manner. While BHEL has set up manufacturing capabilities of international standards, they have to do more in mastering the basic technologies embedded in their products. Strong networking with academic institutions on a continuing basis is necessary to create centers for stress analysis, vibrations, creep, fatigue, high temperature behavior, corrosion and so forth.

In the area of renewable energy, namely wind and solar, there is an opportunity for Indian Science and Technology to make original contributions and we must encourage our researchers in every way possible. Across the whole spectrum of energy technologies our goal should be not only to make in India but to make in India using Indian designs and Indian Technology.

Concluding Remarks:

India is located some distance above the equator and well below the latitudes that experience severe winters, except along the Himalayas. So it is not a land that needs large amounts of energy for space heating. We are increasingly resorting to air conditioning in our cities and towns, as we are forced to live in apartments rather than individual bungalows. Much of India is well endowed with solar energy. Even if it were possible to expand harvesting of solar energy in a massive way, we need other forms of reliable and continuous sources of energy to support an industrialised society that will assure a reasonable quality of life to the large population of the country. Lee Kwan Yu, the builder of modern Singapore stated in his 2005 Nehru Memorial Lecture.

"Since the industrial revolution, no country has become a major economy without becoming an industrial power"

We must shed our lurking suspicion of modern technology and accept it whole heartedly and master it. For this to happen we must develop nuclear and solar energy actively, using fossil fuels as a bridge to get there. In the longer term, we may also be able to harness thermo nuclear (or fusion) energy or indeed the energy in the hot rocks, below the surface of the earth.
**Action points on the Energy Issue**

1. Do not burn cow dung as fuel. Build large number of bio
gas (or bio-methanation) plants to return nutrients to soil
and produce gas for cooking (milk coops and dairyco
help?).

2. Shift rural domestic fuel from fire wood and dung cake to
Gobar Gas, Coke briquettes, kerosene and LPG.

3. All new coal fired power plants to use supercritical and
ultra supercritical boilers to get higher efficiency. Follow
developments in the coal gasification combined cycle
designs to achieve still higher efficiency.

4. Replacement of all lighting systems to LED. Motor
efficiency improvements across all users.

5. Implement mass transport systems in all cities.
Encourage electric cars and buses, especially in urban
areas.

6. While present day motor cars are more efficient than
earlier designs, revolutionary designs using materials and
structures as used in space vehicles could give much
higher fuel efficiency.

7. Develop lower cost higher efficiency solar photo voltaics
and wind generators.

8. Pursue energy saving across the entire chain of electricity
production, transmission and distribution, using new
technologies from the IT industry.

9. Pursue actively the nuclear options of first, second and
third stages with highest emphasis on Indian design,
Indian manufacture and Indian technology.

10. Intensify search for hydrocarbons on land and offshore,
acquire assets abroad; lay down pipelines overland or
offshore to source from friendly countries. Also acquire
overseas coal and uranium assets wherever feasible.

11. Develop designs for a practical solar cooker (present
designs are OK for rice, dal & veg). Roti is the problem.
Can a PV with inductive heating do the job?

12. Pursue basic research on production of H\textsubscript{2}
using solar
energy (Prof. CNR Rao himself is doing this kind of
work).

13. Scientists and Technologists must spread message about
the relevance of their work for societal benefit.
Opponents of any tech venture are experts at
communication. Our S&T personnel are poor
interlocutors.

14. Ajit Doval (NSA) said this in Mumbai recently (4/8/15)
“National strength is based on national will and national
will depends on what the nation thinks. The Indian media
has its own compulsions much like I have my own. But we
denigrate all the time. We should spread positivity and
optimism and build a healthy nation together”.

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**Dr. M.R. Srinivasan** played a key role in the advancement of Pressurised Heavy Water Reactor (PHWR) technology. Early in his
career, Dr. Srinivasan worked with Dr. Homi Bhabha in the development of Apsara reactor. He served as the Chairman of Atomic
Energy Commission and Secretary, Department of Atomic Energy. Dr. Srinivasan has been a senior advisor at the International
Atomic Energy Agency during 1990-92 and the founder member of World Association of Nuclear Operators. In recognition of his
immense contributions, Dr. Srinivasan was conferred Padma Vibhushan (2015), Padma Bhushan (1990) and Padma Shri (1984) by
the Indian government.