HYMN TO AGNI - THE GOD OF FIRE

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Man has been perennially searching for new sources of energy. This is because he is a puny creature but his dreams are big. His physical prowess is limited but he wants to move mountains, change the course of rivers, fly to stars and what not. He needs a slave to help him fulfill his dreams... a genie who comes out of the proverbial bottle at the flick of a finger and does his bidding ! Energy is such a slave and man never seems to have enough of it. This paper is devoted to a short history of Man's search for new sources of energy. We show that this search has typically led to several encounters of Man with Fire..... AGNI in one of its manifestations either fashioning fuels for storage and future use or assisting us in consuming fuels for energy release.. helping us release the genie from the bottle. As we trace this history we stand in awe of AGNI and its various manifestations and cannot help but follow our ancestors in singing a HYMN in praise of the Lord of Fire ! Hence, the title of the paper !

Speaking quantitatively, modern man needs a minimum amount of energy to live a life of comfort and dignity. In fact the per capita electricity consumption in a given country is a good indicator of the human development index of a given country (Figure 1). As you can see India has been crawling up this curve (where life expectancy at birth is used as an indicator of development index) steadily after independence and still has a long way to go before it reaches levels comparable to developed countries like those in Europe and Japan. Table I gives a comparison of the per capita electricity consumption in various parts of the world. Developing countries like India are still at 1/5th of the average world consumption, 1/17th of that of the average developed world and 1/50th of that of North America. As more and more of the developing countries climb up the curve of the human development index the overall requirements of energy in the world will be enormous. Thus the search for new sources of energy continues, nay, gets intensified year after year.

As mentioned above, the average electricity consumption per person for living a comfortable life (i.e. for heating, cooling, cooking, lighting, transporting, manufacture etc) in the developed world is 6000 KWH / year. This is about 17 Kilo Watt Hours or 17 units of electricity per day. We, in India have available only 1 KWH per person per day. One KWH is the energy used up by a 100 watt bulb in ten hours of continuous operation or the energy used by a typical air conditioner in half an hour's operation. It is the equivalent of energy used up in lifting about two thousand 100 kilogram bags of rice through a height of 2 meters. It is also the energy that could be supplied by six slaves working full time (10-12 hour day). Thus we see that modern creature comforts do not come easy. To keep an average man in the developed world comfortable and happy would need the energy equivalent of the full time services of about 100 slaves !!

This brings us to a discussion of muscle power. This was the first source of energy used by man.. first his own and then that of his slaves and animals. The great pyramids in Egypt were built with muscle power and the galley ships of Rome which were used to conquer a good part of Europe were powered by the muscle powers of slaves. Closer to home, even today we see horses, bullocks and camels pulling carts, ploughing fields and grinding oil seeds and men and women engaged in various form of manual labor. However, it is easy to show that the use of muscle power is of limited utility in a world as hungry for energy as it is today. We now outline this argument.

Take human labor. The energy source is food. The average intake of food per day per person is about 2500 Calories which is equivalent to about 3 KWH of energy. Most of this energy is used up for the business of staying alive, for example keeping warm (did you know that each of us is radiating about 100 watts of infrared radiation during all our waking hours), doing repair and maintenance of degrading muscle and tissue, for growth etc. At the most we may be able to divert about 10 per cent of input energy during waking hours to do useful work ~ 0.3/2 ~.15 KWH per person per day. This explains why we need about 100 slaves working full time to keep 1 modern man in comfort, obviously something which is not acceptable even in principle in a free democratic world !! This also shows that the use of muscle power to fulfill our energy needs has very limited utility.

Let us now discuss how animals(including man) manage to do work and generate heat, so essential for life. Basically, animals are controlled furnaces "slowly burning" the fuel of food to generate energy. For example, sugars and fats from the food chemically combine with the oxygen that we take in during respiration and form carbon dioxide and water and release energy. This energy is partly dissipated as heat in our bodies and is partly stored in our muscles for future use. This storage also takes the form of a chemical reaction. Energy is soaked up by an ADP (adenosine diphosphate) molecule which combines with some inorganic phosphate in the body in an endothermic reaction to form the ATP (adenosine triphosphate) molecule. The basic reaction rates are made decent even at the relatively low room and body temperatures by the strategy of employing special catalysts (enzymes) to accelerate the chemical reactions. ATP is the basic storehouse of energy in our bodies. Whenever we need to do some work, our brain sends signals to our muscles which contract and reconvert ATP to ADP releasing the stored energy which is then used for doing useful work and producing heat. Thus we face our first encounter with AGNI. Living matter is a slow fire undergoing combustion and converting energy trapped in food into a usable form. We stand in awe of AGNI for the sophistication of the tools that it employs for the management of energy by living matter.

We now turn to the next most basic source of energy, namely, the combustibles...things which burn. This is our direct encounter with Fire or AGNI. Fire was discovered about 25000 years ago and has dominated human civilization since then. First Man discovered natural fire and only learnt how to keep it alive by adding combustibles like wood, dry leaves, fat from dead animals etc to it ; later he learnt how to ignite a fire at will. Fire revolutionized man's life by contributing to heat, light (freedom from cold and fear) cooking(hence health), weaponry(discovery of metals) and so on. It was first really put to work in the steam engines of the 19^{th} century and led to the Industrial Revolution and the explosive growth of the western civilization. Thus began the age of fossil fuels ! Internal combustion engine and the generators of electricity were invented and revolutionized the way in which we use energy. Modern man had arrived and coal, oil and natural gas became key commodities. 20^{th} century has been the century of fossil fuels. Availability and the price of fuels has determined the pace of world economic development. It has also colored the political map of the world. The question we must wrestle with is.. Can we depend on fossil fuels as the main source of energy in the 21^{st} century and beyond ? Let us look at this question in a fundamental quantitative manner.

Fossil fuels like coal, oil and gas are hydrocarbons produced from remains of plants and animals which are trapped for millions of years under the earth due to geological upheavals. They have energy stored in them just like food and they also release it by a process of combustion.

$$\text{Hydrocarbons} + \text{oxygen} \underset{\text{(FIRE)}}{=} \text{water} + \text{carbon dioxide} + \text{energy}$$

In either case(food or fossil fuels) energy is liberated because electronic linkages binding atoms in a fuel are weaker than those in product molecules i.e. binding energy / carbon atom in fuel is less than the binding energy / carbon atom in products with the result that the difference of binding energies / atom is released by the chemical combustion process. Typical binding energies stored in electronic linkages are of the order of fractions of an electron volt / atom and a molecule has several such linkages which get rearranged in the chemical combustion process.

$$\text{Typical energy released / mol} \sim 1 \text{ eV} \sim 10^{-19} \text{ watt secs}$$

Now it is known that a gram molecule of any substance has 6×10^{23} Molecules. Thus we can calculate the amount of energy liberated by burning one gram mol of the fuel. This leads to the conclusion that 1 ton of hydrocarbon fuel typically liberates few thousand KWH of energy. Now the total known reserves of fossil fuel on the earth $\sim 10^{12}$ tons which is equivalent to about 10^{16} KWH of energy. On the other hand the energy required by the 5 billion inhabitants of this earth for a reasonable lifestyle is of order $6000 \times 5 \times 10^{9}$ KWH per year i.e. 3×10^{13} KWH per year. Thus our fossil reserves will last us only for ~ 300 years. Detailed estimates show that gas will finish in 50 years, oil in 100 years and coal in about 300 years !!

We thus reach the following fundamental conclusions regarding fossil fuels. It has taken almost a billion years for the earth to build up the 10^{12} tons of fossil fuel reserves and humanity can squander them away in less than 500 years. The enclosed sketch(Figure 2) by Shepherd(1998) which shows the fossil fuel era as a short lived blip in the checkered history of mankind dramatically captures the import of this conclusion. It is worth noting that fossil fuels have many other applications(e.g. manufacture of petrochemicals) and form a component of wealth which truly belongs to all our future generations... our children, grandchildren and their progeny. The hard question is, should we unilaterally decide to burn away all this wealth and leave nothing for them ? The second major issue with continued and enlarged use of fossil fuels for all of our energy needs is the environmental degradation that it causes and the possibility that it may be leading to the greenhouse effect and the warming of the earth's atmospheric temperature which could have far reaching and detrimental effects to the life on this planet. This may mean that we have to clean up the environment and that the cost of the clean up has to be added to the cost of fossil fuels.. If this is done, the fossil fuels will no longer remain cheap. Another major issue with fossil fuels is their uneven distribution on the globe. Countries with 6 per cent of the world's population are endowed with 66 per cent of the oil wealth of the world. This has led to serious political conflicts, wars and a great deal of energy insecurity among nations who have no direct access to the oil wealth. From these and many other similar considerations, it seems clear that fossil fuels are not a long term solution to the energy problem of the world.

We saw that food and fossil fuels had 'energy' stored in them in the form of weak electronic linkages of atoms. How did the energy get stored in these molecules and where did it really come from ? We know that it came from the SUN that fierce manifestation of AGNI up in our skies. Let us see how this works.

Solar radiation is directly utilized by the green coloring matter in plants(chlorophyll) to carry out photosynthesis :

Carbon dioxide + water + light = sugars, carbohydrates etc + oxygen

Our Sun aims about 10^{17} Watts of power in the form of solar radiation to the earth. About a hundredth of a per cent of this power is trapped by the green coloring matter of plants and is engaged in photosynthesis and the resulting growth of plant matter. About one millionth of the total plant matter on the earth is trapped by the geological upheavals and converted to fossil fuels. Thus 10^{7} watts of the incoming solar energy is trapped into fossil fuels. This gives us an upper limit to the possible fossil fuel reserves as energy equivalent of 10^{7} watts for a billion years. This translates into 10^{17} KWH of fuels which is close to 10^{13} tons of fossil fuels. This number is at the same time awe inspiring and frightening. It is gratifying and awe inspiring because we see LORD AGNI at work in the form of our SUN and see that it has provided for us all this fossil fuel wealth so that we may remain warm and comfortable for all these thousands of years. It is frightening and sobering because we note that the upper limit is close to our known reserves, that is, things are really running out and there is not a lot more there which we haven't tapped yet !! Thus we may say our prayer..Homage to Thee O AGNI ! We know now that Thou had Provided but we have squandered. Let Wisdom prevail now !!

We now turn to renewables. AGNI in the form of our SUN delivers a lot of energy to the earth, albeit in a dilute form. Out of a total of 10^{17} watts, about two thirds falls on the earth and is directly converted to heat. This energy, if trapped, can be used and various modes of its utilization come under the banner of solar energy. About one third is used up in evaporation, precipitation and storage in the water cycle. This is the energy which we see in mighty rivers rolling down mountainsides and which can be utilized in various forms of water mills, hydroelectric projects, etc. About half a per cent is stored in kinetic energy of winds which can be used by windmills, windfarms producing electricity etc. A really small amount, namely a hundredth of a per cent is trapped by photosynthesis for storage in vegetation and plants ; of this, as already stated, a miniscule fraction (one millionth) gets stored by the geological upheavals in the bowels of the earth in the various forms of fossil fuels. Let us see what are the prospects of using solar energy in its various manifestations.

We start with hydropower. Energy of the moving water in the rivers has been used since antiquity. It was used in water mills to grind corn, run irrigation systems, saw wood, run textile looms... and so on. Modern version of the usage is in the form of running dynamos in hydro electric power stations. This form of electricity generation has many good features :

It is non polluting, renewable and relatively less expensive. Its demerits are that its capacity is limited by geography and that it typically takes up a large land area, thus displacing a large number of families. In India, the total potential capacity is about 85 gigawatts (nearly ten per cent of our total requirement eventually). However, the actual installed capacity is less than a third of the total potential and there is substantial room for growth.

If we look at solar power we see that it is too dilute and diffuse to be directly of much use for centralised urban industrial complexes. It may be used mostly for residential applications such as solar cookers, water heaters, solar refrigeration etc Problems which have not been yet solved satisfactorily include the problem of storage of heat during night or cloudy periods etc.. Solar photovoltaics i.e. direct conversion of sunlight into electricity by the use of semiconductor materials is still high maintenance, relatively inefficient and expensive and has therefore found application only in niche areas like space vehicle power systems,power systems at remote places etc. Another method by which solar energy may be used is through the generation of biomass. Schemes for exploitation include fast growing cash crops used for direct burning or for conversion into alcohols for use as liquid fuels or even for conversion into biogass which can be conveniently transported for use in homes and small industries. There were great hopes that these sources could be quickly assimilated and integrated with the rural economies in India. But the process of adoption has been slow and the integration has not really taken off.

Wind power has limited applicability in coastal areas where the wind velocities tend to be high. The installed capacity in India is about 1.7Gigawatts but its capacity utilization is quite low (about ten per cent).

There are some innovative ways of using solar energy which we shall briefly present in the discussion about future prospects towards the end.

We finally turn towards AGNI in the SUN. What is the fundamental source of energy in the SUN ? This takes our trail towards Nuclear energy. We know that our Sun has been burning brightly for about 5 billion years. It has thus spewed out

$$4 \times 10^{26} \quad \times \quad 5 \times 10^{9} \quad \times \quad 3 \times 10^{7} \quad \sim \ 6 \times 10^{43} \text{ Joules}$$

[watts of radiation x no of Yrs x seconds /Yr ~ Energy in Joules]

of energy ! Sun has a mass of about 10^{33} gms. Even if we assume that every atom of Sun 'burnt' in a chemical fire, rearranging electronic linkages, we would at best produce about

$$10^{33} \quad x \quad 6 \times 10^{23} \quad x \quad 1.6 \times 10^{-20} \quad \sim \quad 10^{37} \text{ Joules}$$

[mass x no of atoms / gm x energy rel/ atom ~ chemical energy]

So the chemical energy that would be liberated by burning all the mass of the sun in a chemical fire is more than a million times smaller than the energy it has already released. And the SUN is still young and going strong in spite of this fantastic rate of energy release. We thus note that the AGNI in our Sun cannot be a chemical FIRE. It is indeed special. It is a thermoNUCLEAR fire !!!

Nuclear energy is perhaps the biggest discovery of twentieth century. It all started with Einstein who while working out the consequences of his special theory of relativity came to the startling conclusion that mass and energy are interconvertible and that mass is actually a very concentrated store house of energy. His famous equation

$$E = m c^2$$

said it all. Here c is the velocity of light in vacuum which is a very large number. Thus each gram of matter, if destroyed, can generate about 10^{14} Joules of energy and the entire energy liberated by the SUN till now could have been generated by destruction of only 10^{29} gms(i.e..01 per cent) of solar mass which would not have had any other measurable or significant consequences. Thus we have a possible source of energy to explain the prodigious release of energy by our SUN.

Let us understand this source of energy a little better. The Bohr-Rutherford model of the atom had already shown that the mass of the atom is concentrated in a tiny nucleus (with a size of order 1/ ten million millionth of a centimeter) which is positively charged and made up of protons and neutrons, whereas all the electrons which are negatively charged and make the atom neutral form a swarm about 100000 times larger in size. Hence nuclear reactions, as opposed to chemical reactions (which only rearrange the electronic linkages), could change mass and release energy if some mass is lost in the rearrangement of nuclear matter. There are two significant types of nuclear reactions which may be used for energy release. In the nuclear fission reactions, heavy elements like Uranium are made to fragment into lighter nuclei which have more binding energy/nucleon i.e. have nucleons sitting in deeper energy wells (Figure 3). The result is that energy is released in the process. This is the basis of the atomic bomb and also the power producing nuclear reactors which are widely used around the world. In another type of nuclear reaction, the so called nuclear fusion process energy is released when light nuclei like hydrogen combine to form heavier nuclei like helium. Again the nucleons go into deeper energy wells when they form helium and the energy difference is released as the kinetic energy of the products of the nuclear reaction. Typically, binding energy inside the nucleus arises because of the strong nuclear forces and per nucleon is million times stronger than the binding energy per atom which is due to electromagnetic forces (through the various electronic linkages). Hence, weight for weight, nuclear reactions release a million times more energy than chemical reactions or in other words energy packing in nuclei is a million times denser than in atoms.

Nuclear fusion reactions power the Sun. Sun releases its energy by the thermonuclear fusion of protons. The reaction

$$H + H + H + H = \text{Helium} + \text{electrons} + \text{energy}$$

in which four protons fuse to produce a Helium nucleus is catalyzed by the presence of Carbon, Nitrogen and Oxygen nuclei. Thermonuclear fusion works because of the high temperatures inside the Sun. High temperatures are necessary because the positively charged protons would normally repel each other because of Coulomb forces. At high temperatures, the kinetic energy of motion can give the nuclei ability to approach each other and sufficient proximity assists in quantum mechanical tunneling through the Coulomb barrier and their ultimate fusion. Thermonuclear fusion has been successfully demonstrated on the earth in the so called hydrogen bombs. However, the peaceful utilization of the nuclear fusion energy is more difficult. This is because one needs to find a good containment device for the high temperature matter . In the Sun and the stars the matter is contained by intense gravitational fields. However, on the earth that is not practical. Hence magnetic bottles are used. We shall discuss them in more detail a little later.

Fission reactors have been commercially exploited for more than 50 years. Thus today France produces more than 75% of its power in Fission reactors, USA 25 %, Japan 33 %, Korea 40 % and so on. India is producing only 3 % of its power requirements by the nuclear fission process. Currently, there is an ambitious program of expansion with a desire to produce about 20 gigawatts of nuclear power by the year 2020. The exploitation of fission technology faces certain important challenges. Firstly, there is the problem of radioactive waste disposal. Fission processes lead to some long lived radioactive products which have to be properly disposed off. One technology which has been developed is that of reducing the volume of the waste and then immobilizing it in a solid matrix. This solid waste residue is then stored deep inside some unused mines at sufficient depth. This technology has been mastered and appears to be quite safe but is still facing opposition by environmental groups. Other methods which are under development include actinide burning in fission and fusion reactors wherein the long lived radioactive waste products are themselves subjected to neutron irradiation to transmute them into short lived isotopes and also to extract some further energy from the nuclei. These methods are still in an early stage of development. A second problem faced by the fission reactors is the radiation hazard and the safety problems. This fear has accentuated because of the well known accidents like the Three Mile Island or the Chernobyll reactor accident. Whereas one cannot ignore the concern in the minds of the public, it is to be remarked that with sufficient care and precautions such incidents have been few and far between and the record of the fission power industry so far has been quite good. There is an irrational fear of invisible radiation in the minds of the public which can only be removed by education and actual statistical data on accidents / casualties in fission power industries versus the hazards of competitive energy industries, It is also necessary that this data is collected and disseminated by some independent disinterested watchdog agency rather than by the promoters of this or that technology. A third problem faced by the fission reactor technology is the uneven distribution of the fuels like Uranium and thorium which makes energy security problem for some nations severe. Lastly, with fission there is the possibility of proliferation of the fissile material falling in the hands of rogue nations and/or of terrorist groups which might lead to serious problems. All these challenges, each one of which can be confronted and solved, have given fission a bad name with the result that the growth in fission power stations has been impeded and there has been relatively a stagnant period in its development for the past decade or so. However, with the fast realization that absence of fission power means either energy starvation and/or facing severe environmental degradation problems, there is an increased realization that fission power has to play its legitimate role in the energy scene of a rapidly developing world.

We now turn to a discussion of the nuclear fusion process. This process has not yet been converted into a commercially viable process. Why should we invest in its development ? There are several outstanding merits of this process because of which stakes in its rapid development and deployment are high. What are these merits ?

Firstly, the fuel for this process is limitless. Deuterium is a heavier isotope of hydrogen, and is a component of heavy water, which is naturally distributed in the ratio 1 part in 6000 in sea water. Thus if we can use pure deuterium fusion reactions we have literally oceans of fuel, which can last mankind for millions of years. If we want to use tritium, it can be bred from Lithium which is widely distributed in the earth's crust and the oceans. Both deuterium and tritium will be readily accessible to most nations giving widespread energy security. Secondly, the energy is very clean. There is no atmospheric pollution, no green house gas emissions etc. Thirdly, the radioactivity from waste products in fusion is negligible and in principle, can be totally eliminated. This is because, unlike fission, the reaction products themselves are non radioactive. Radioactivity is induced in the surrounding materials by the fast neutrons coming from the fusion reaction. One can reduce its hazards by utilizing low activation materials, which are currently a major area of development. One can also totally eliminate it by the use of advanced fusion reactions like proton - Boron reactions, Deuterium- Helium 3 reactions etc; however, this will be only possible when the containment problems of high temperature plasmas by magnetic fields are properly solved. Fourthly, fusion reactions are inherently safe ; the reaction is difficult to ignite and there is no possibility of a chain reaction or a melt down. Lastly, there are no dangers of proliferation, no worries that some rogue nation or terrorist group will steal strategic material for a nuclear weapon. Thus fusion looks like the ultimate solution to the energy problems of mankind. Major programs for its development are going on around the world.

How does one achieve fusion in the laboratory ? As discussed above matter has to be kept at a high temperature so that sufficient fusion reactions might occur. Thus for a deuterium- tritium mixture one needs to create a temperature of about 100 million degrees and have the product of density and confinement time exceed a critical value. Only then can a fusion fire be ignited or only then can the great Thermonuclear AGNI be invoked. In magnetic fusion one starts with matter at sub atmospheric densities (say about 100000 times rarer than air), heats it to about 100 million degrees and holds the hot matter away from material walls for several seconds in cages made of nonmaterial magnetic field lines. If this is done, enough fusion reaction take place in the fire to throw out energetic neutrons which may be trapped in outer blankets, to create heat, generate steam and run steam turbines to generate electricity like in a fission reactor. [Figure 4a] The energy of the product helium atoms is reabsorbed in the hot matter to keep it hot even as we keep adding more and more fuel to it. In this manner,a fusion fire once ignited, will stay ignited. The key to success in this endeavor is the concept of magnetic bottles (Tokamaks) which can keep hot matter or plasma away from material walls. [Figure 4b] Matter at hundred million degrees is in the plasma state, a state in which each atom is broken by collisions into nucleus and electrons ; thus a plasma is a collection of hot nuclei and electrons. This swarm of charged particles has many special properties which distinguishes it from a normal gas. From the fusion engineers point of view it has good properties such as it can be heated by electric currents and microwaves which allows us to take it to ignition temperatures ; indeed such temperatures have been achieved in the magnetic containers in various laboratories around the world. But it also has bad properties such as loss of heat by electric and magnetic storms created by collective effects (mob effects by the swarms of charged particles) which causes the fire to cool down when it should stay hot and ignited. It has taken the science of plasmas several decades to develop enough sophistication so that it would be understood why these mob effects arise, how they may be avoided or sometimes how they may be cleverly used to assist in lighting and maintaining a fusion fire. Figure shows the progress towards an ignited fusion reactor. From the early days of fusion research, the key parameter has been improved by a factor of about 100000 and now one is within a factor of 5 of what is needed for a successful commercial fusion reactor.[Figure 5] In some large tokamaks in USA and Europe one has actually demonstrated the production of about 20 Megawatts of fusion power steadily for several seconds. The next step is the demonstration that such plasmas can be maintained steadily for hours together so that fusion fire once ignited may continue to give energy by addition of more and more fuel. This is the aim of the next generation of these experiments.

The largest of these experiments, which will have plasmas of sizes very similar to a commercial fusion reactor, is being done internationally in the so called ITER (International Thermonuclear Experimental Reactor) experiment. ITER will be built at a cost of about 5 billion dollars (Rs 25000 Crores) which will be shared by the partners USA, Europe, Russia, Japan, Canada, China and South Korea. Each partner has to contribute a minimum of ten per cent towards the cost of the project. Furthermore they are also typically supporting a national program of comparable magnitude to stay abreast of the latest developments. The engineering design of ITER is over and construction is likely to start in 2006. [Figure 6] The experiment will start yielding key results by the year 2015. Most people believe that the earliest that fusion reactors may be commercially deployed is by the year 2035 and the latest is by the year 2050.

Our national program in fusion started in the early eighties at the Institute for Plasma Research in Gandhinagar. We have indigenously built a tokamak ADITYA which was commissioned in 1989 and on which experiments have been conducted since then. [Figure 7] ADITYA is like a miniature artificial Sun which is contained by magnetic cages for fractions of a second and in which temperatures of several million degrees have been achieved. We are now in the process of assembling our second generation experiment, a steady state superconducting tokamak SST1, in which the key feature will be keeping the fusion fire alive for 1000 seconds. [Figure 8]. This experiment should be operational within a year and is likely to be the first experiment keeping the hot fusion plasma alive for such a long time ; the experiment will therefore yield key information of interest to ITER. The cost of participation in ITER is about ten times larger than our present resources and so it appears that we shall have to keep abreast of the international developments only by conducting a clever national program.

We now begin the mopping up operations, namely, begin the process of summing up what we learnt by following the trail of AGNI in search of sources of energy. In the process we shall also touch upon some new ideas which may form the basis of future options and also take a deeper look at AGNI and at ourselves. We learnt that muscle power is out because of its inefficiency and our large needs. Fossil fuels are also around for about a hundred years or so at most. In the long run the workhorse will be nuclear energy, especially its release using the thermonuclear fusion fire. Renewables like hydro, wind, solar etc are definitely in but may play a subsidiary role.

New ideas on improved utilization of solar energy abound and are active areas of research. Thus it is believed that accelerated photosynthesis and/ or dissociation may be achieved by using modern tools of genetic engineering. Work is currently being done on the development of algae / bacteria which would use sunlight and water as inputs and generate hydrogen as a product. Hydrogen is an excellent fuel since it is a gas and can be readily transported by pipes, and is totally non polluting since it produces only water as a combustion product. Trapping of energy in the sunlight into hydrogen would thus be an excellent development. Another attractive idea for utilization of solar energy is the solar satellite concept.[Figure 9] In this concept solar power stations are put in earth stationary orbits where they would see sun all the time(no problem of night and day), would not occupy valuable real estate on the ground, would not be affected by dust, atmosphere and clouds etc and would beam concentrated energy to ground power stations through microwave beams. This concept mitigates many of the shortcomings of solar energy utilization and detailed design work and development work at the component level is in progress. There are also dreamers like Freeman Dyson, who have asked the question : Why should we be satisfied with a hundred millionth of Sun's energy which it chooses to beam at us ? Dyson would like to trap all of Sun's energy by using human engineering skills on a grand scale. Thus he would take a planet like Saturn, break it up and use its material to surround the Sun completely with a spherical shell near the orbit of Jupiter, as shown in the figure [Figure 10]. One would then line the inside of this spherical shell with equipment which converts solar energy into a usable form and transport it to earth for utilization by us, the energy hungry hordes of humans ! Dyson believes that technological civilizations more advanced than us might already be carrying out engineering projects on a planetary scale like this.

We now ask a final question in our journey tracing the sources of energy. We found that most of the sources were ultimately traced to nuclear fuels either burning in the nuclear fire of our Sun or some day burning in our reactors. We may ask where does the energy trapped in nuclear fuels come from ? For this we have to trace the genesis of elements, that is understand the nucleosynthesis of light and heavy elements. This problem has been studied in detail by cosmologists and astrophysicists. It is believed that in the beginning there was the BIG BANG and the PRIMORDIAL FIRE or the earliest AGNI was born. This FIRE started as a ball of radiation. As it expanded and cooled it created material particles like quarks and gluons forming the so called quark gluon plasma. As the ball cooled further, the quarks condensed into protons, neutrons and some of the lightest elements like Helium, Lithium, Boron,…etc. Soon gravitation rolled dense matter in local regions into fusion furnaces known as stars. Heavier elements like Carbon, Nitrogen and Oxygen are formed in the fusion furnaces of young stars. Iron is the most stable nucleus and would be the end product of all nuclear reactions. Elements beyond iron are formed by neutron capture processes. We see the rich variety of elements because cooking in the primitive universe and stars is imperfect. If the cooking had been perfect there would be iron everywhere and there would be no nuclear fuels.

To put this all into a perspective we may take a deeper look at ourselves. What are we ? We are highly organized collections of molecules made out of the same constituent atoms, same partially cooked elements....hydrogen, carbon, nitrogen, oxygen ….Each atom of our body is billions of years old. Thus each hydrogen nucleus of my body was fashioned from quarks in that primeval AGNI 14 to 15 billion years ago ! Each Carbon, Nitrogen and Oxygen nucleus here has been fashioned by imperfect cooking in the fusion furnace of some star, spewed out into space during its death throes and picked up by the gas cloud from which our Sun and its planets have emerged. With this perspective we understand that this whole Game is being played by AGNI with its partially cooked range of nuclei. We may thus verily say to AGNI :

Thou art the Source
and fashioned every limb of mine….
Thou art the Sustainer
and provide Energy to keep me together
And when I am ready to Sleep
into thy bosom only will I disappear !

We thus see that in spite of our modern scientific background, in expressing our deepest yearnings, our sentiments are no different from those of our Rigvedic ancestors who sang Hymns to AGNI !

Figure 1 : Human Development Index (or life expectancy at birth) versus annual per capita electricity consumption.

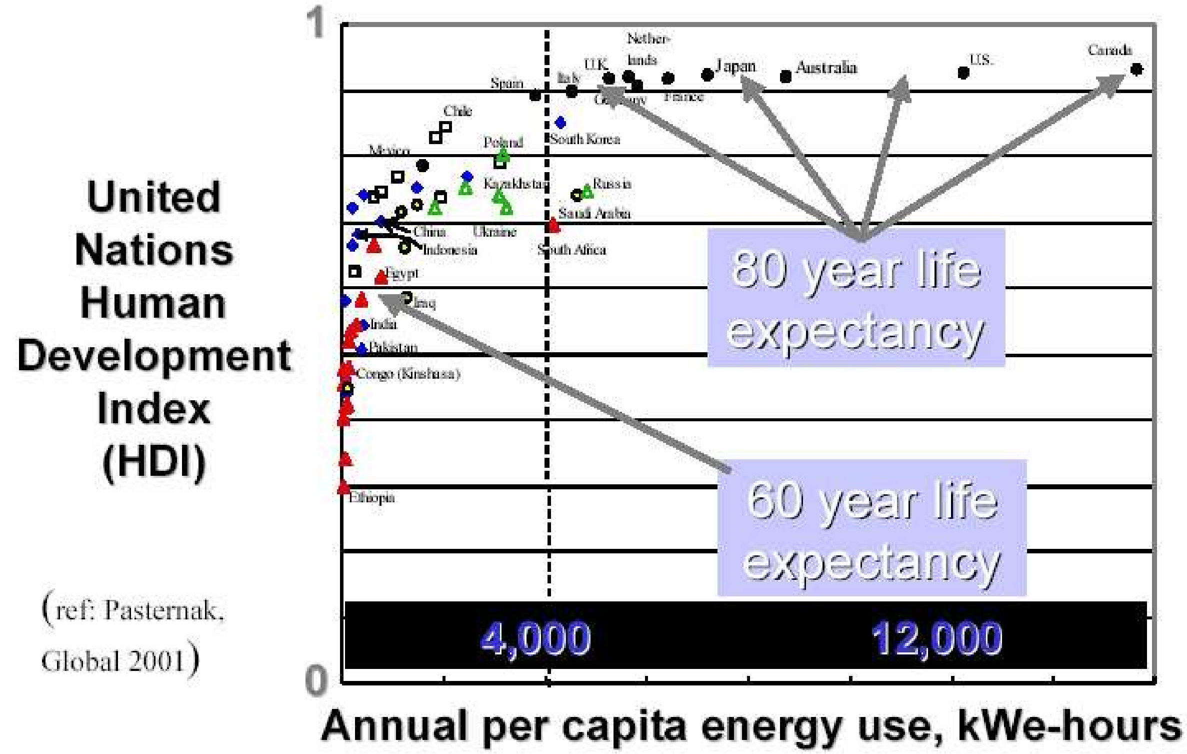

Figure 2 Fossil fuel era in the few thousand year history of mankind.

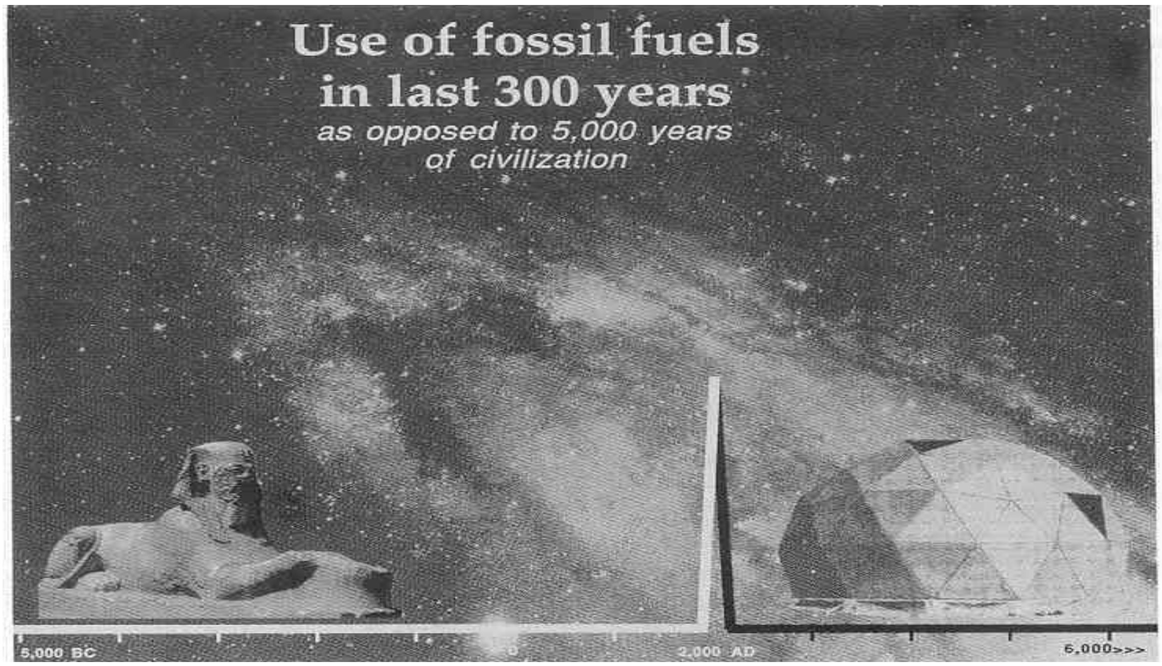

Figure 3 Energetics in nuclear fission and fusion reactions

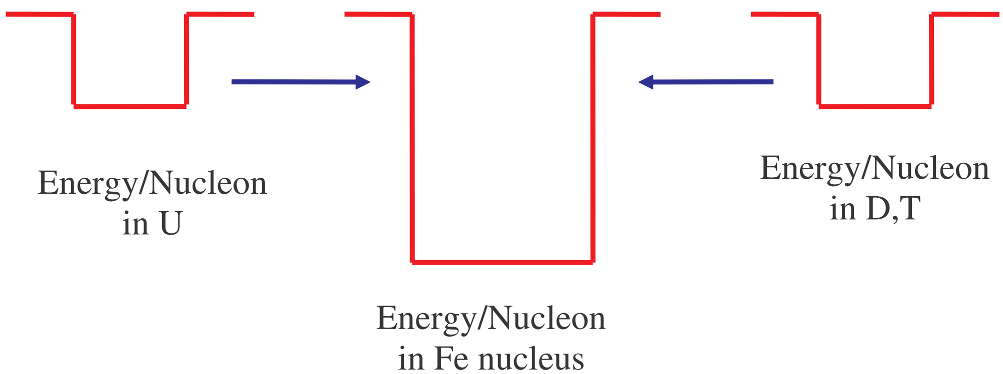

Figure 4a Components of a fusion reactor

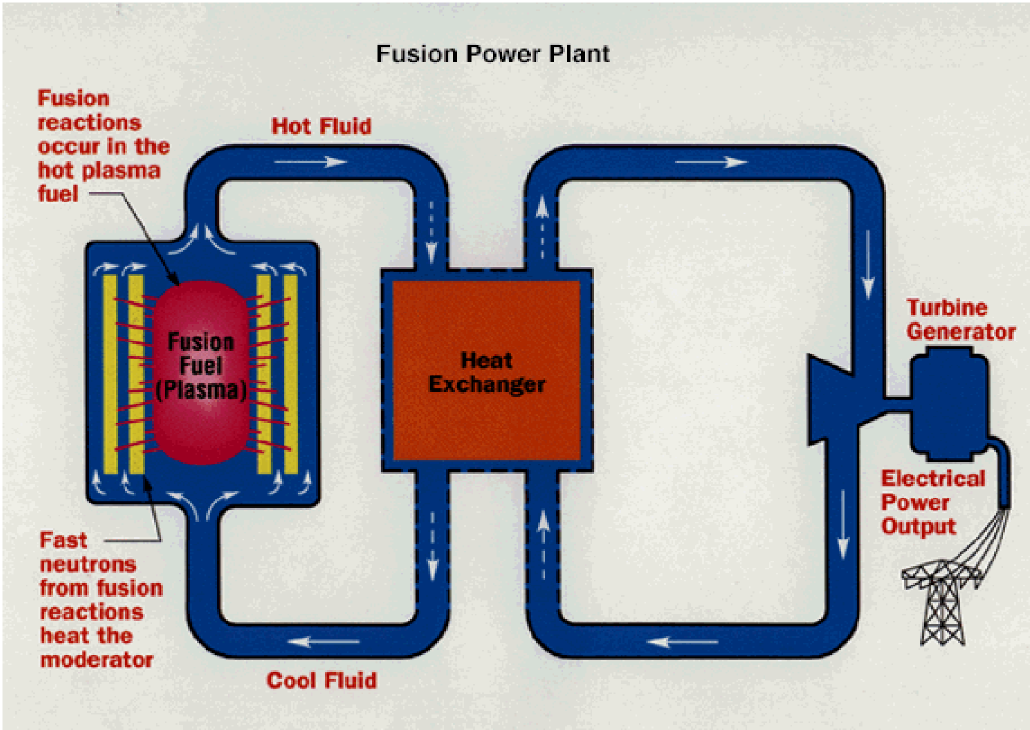

Figure 4 b Magnetic Bottles ...the Tokamak Concept where the magnetic cage is produced by a combination of plasma currents and external coil currents

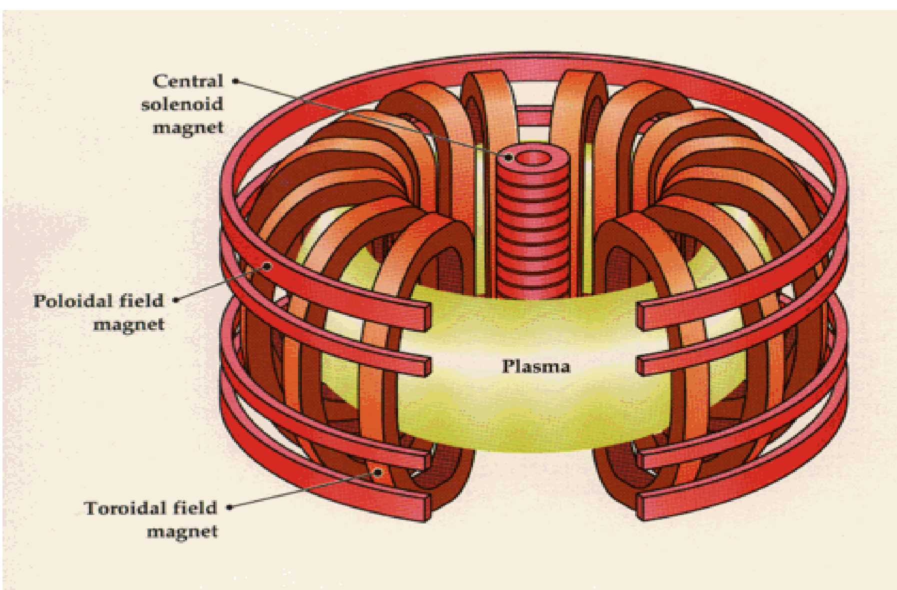

Figure 5 Progress in the critical parameters for fusion reactor experiments

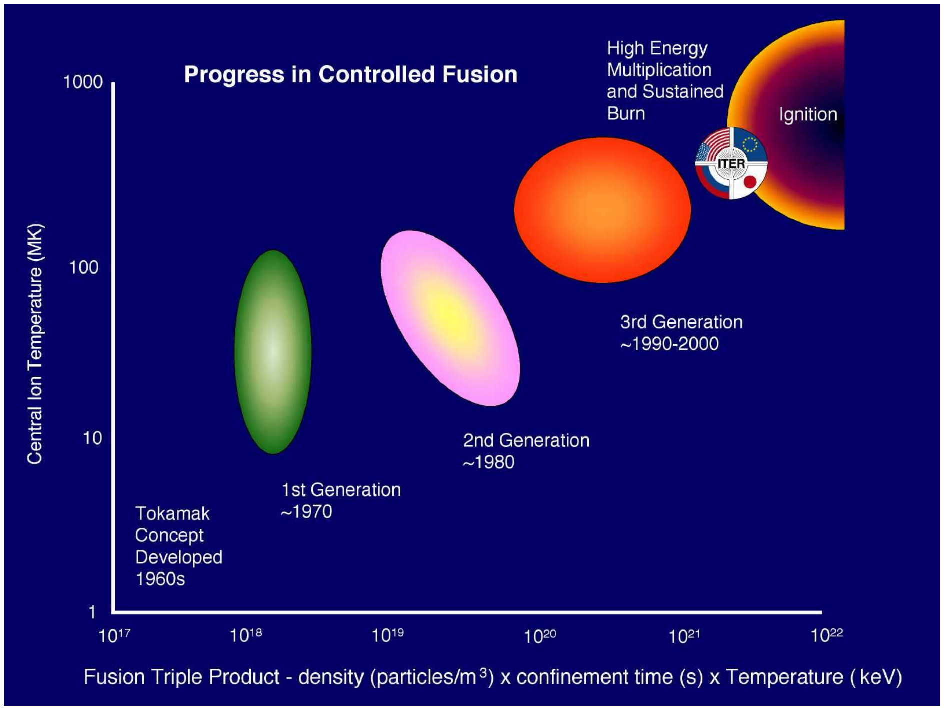

Figure 6 ITER, the International Thermonuclear Experimental Reactor.

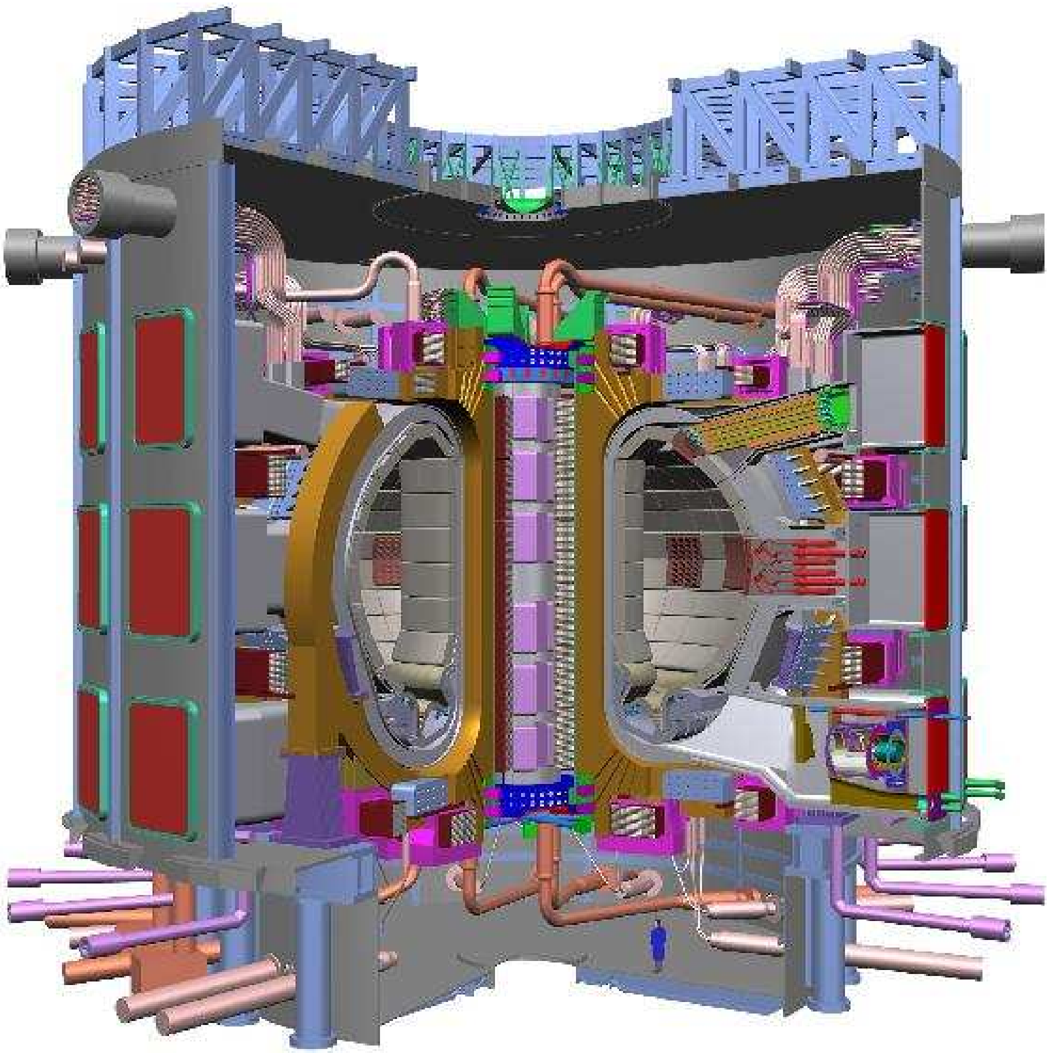

Figure 7 : ADITYA, the indigenously built tokamak at Institute for Plasma Research, Gandhinagar

Figure 8 SST 1, the superconducting steady state tokamak, which will hold a fusion plasma for a 1000 seconds, being fabricated and assembled at Institute for Plasma Research, Gandhinagar

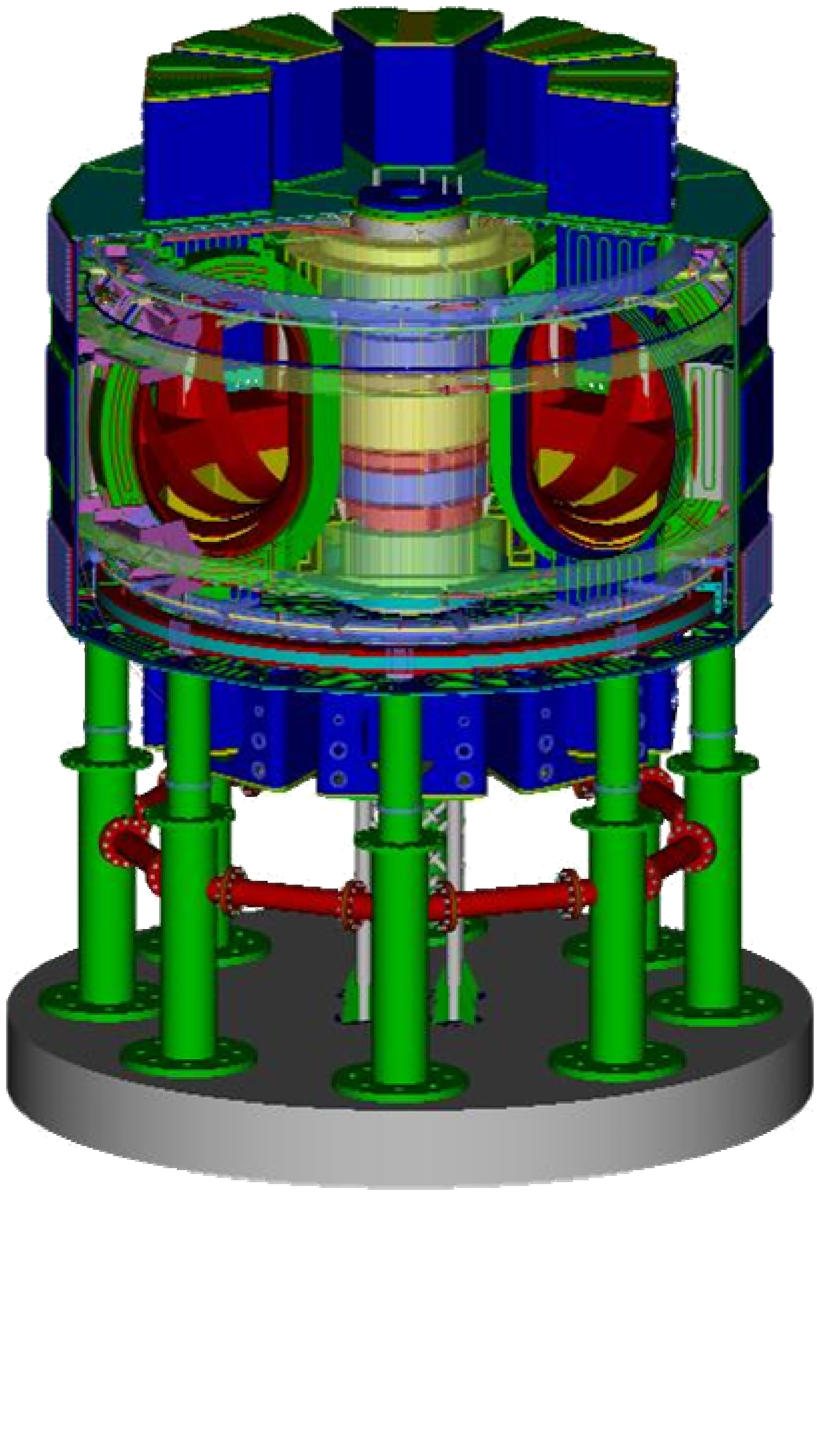

Figure 9 The Solar satellite concept

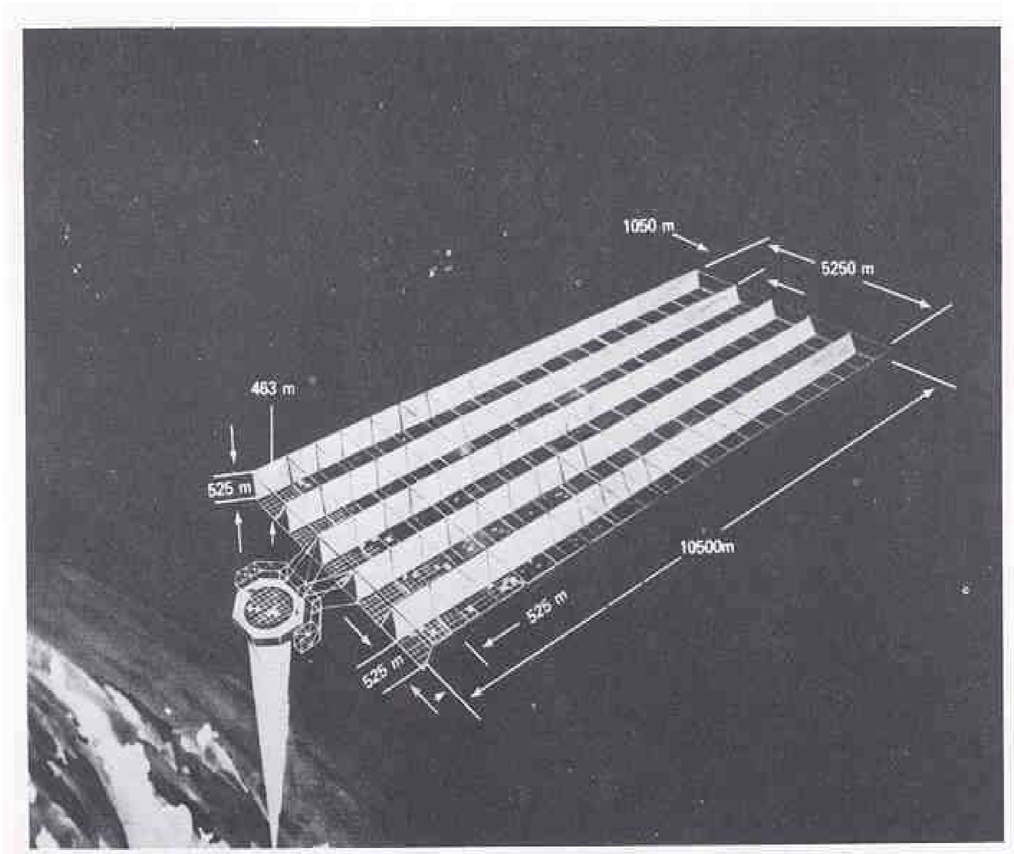

Figure 10 : Our Sun surrounded by the Dyson sphere collecting all of sun's radiation and beaming the energy to earth.

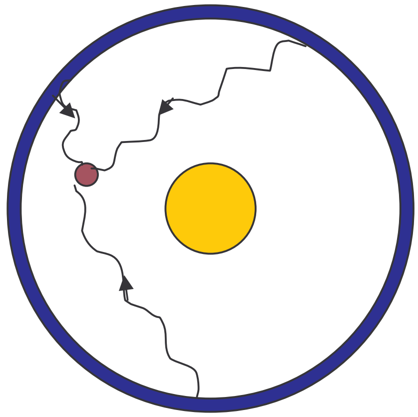

Table 1

HDI Rank	Country	Electricity consumption per capita(kilowatt-hours)	
▼ ▲	▼ ▲	1980	2000
1	Norway	18,289	24,422
2	Iceland	12,553	24,779
3	Sweden	10,216	14,471
4	Australia	5,393	9,006
5	Netherlands	4,057	6,152
6	Belgium	4,402	7,564
7	United States	8,914	12,331
8	Canada	12,329	15,620
9	Japan	4,395	7,628
10	Switzerland	5,579	7,294
30	Korea, Rep. of	859	5,607
104	China	253	827
127	India	130	355
139	Bangladesh	16	96
144	Pakistan	125	352