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EDITORIAL

RECENT TRENDS IN BIOLOGICAL SCIENCES

Imagine a world where there is abundant and healthy food for everyone, where the environment is resilient and flourishing, where there is sustainable, clean energy, where good health is the norm. All these daunting challenges are interdependent – growing of more food without harming natural environments, exploring new energy sources without global warming or have adverse health effects. Fortunately, advances in the life sciences have the potential to contribute innovative and mutually reinforcing solutions to reach all of these goals. Some plausible contributions of the life sciences to meet these challenges are :

(i) a wide variety of plants with faster maturation, drought tolerance, and disease resistance could contribute to a sustainable increase in local food production.

(ii) Food crops could be engineered for higher nutritional value, including higher concentrations of vitamins and healthier oils.

(iii) Critical habitats could be monitored by arrays of remote sensors.

Note that in the 19th century, persons investigating the living world used to be termed as "naturalists" with interdisciplinary research activities, combining biology, geology, and physics. Now, after decades of high productive specialization, the study of life is again becoming more interdisciplinary, by necessity combining previously disparate fields to create a new horizon of Biology." The essence of this new horizon is the re-integration of sub-disciplines of biology, along with greater influence from the physical and computational sciences, mathematics, and engineering. This has the potential to devise new approaches that address traditional and systems level questions in new, interdisciplinary, and especially, quantitative ways.

Modern researches in Biology rely on integrating knowledge from many disciplines to derive deeper understanding of biological systems. That deeper understanding both allows the development of biology-based solutions for society's problems and also feeds back to enrich the individual scientific disciplines that contributed to these new insights. It is critically important to recognize that in near future, Biology will not replace the ongoing research; that research is the foundation on which the future Biology rests and on which it will continue to rely. If we compare our understanding of the living world to the assembly of a massive jigsaw puzzle, each of the sub-disciplines of biology has been assembling sections of the puzzle. The individual sections are far from complete and continued work to fill those gaps is critical. Indeed, biological systems are so complex that it is likely that major new discoveries are still to be expected, and new discoveries very frequently come from individual scientists who make the intellectual leap from the particular system they study to an insight that illuminates many biological processes.

Now it is time to invest in the development of the new aspects of biology because the life sciences are in the midst of a historical period analogous to the early 20th century in the physical sciences. The discovery of the electron in 1897 marked the beginning of a major turning point in the history of science. Over the next few decades, physics, chemistry, and astronomy were all transformed. Physicists uncovered the fundamental constituents

of matter and energy and discovered that these constituents interact in unanticipated ways. Chemists related the structure and properties of substances to the interactions of electrons surrounding atomic nuclei. Astronomers related the light received from stars and the sun to the chemical properties of the atoms generating that light. In this way, new connections within the physical sciences became apparent and drove further advances. These theoretical advances also led to practical applications that transformed society. Having a "parts list" of the physical world enabled scientists and engineers to develop technologies that would not have been possible without this understanding. These technologies led in turn to the electronic industry, the computer industry, and the information technology industry, which together have created a world that could scarcely have been imagined a century ago. Before the transition associated with the discovery of the electron, scientists gathered increasing amounts of data, but those data could not be put to full use because of the lack of a conceptual framework. After that discovery, previously gathered data took on new usefulness, entirely new areas of inquiry emerged, and discovery and application accelerated rapidly. Such discoveries are critical junctures that send science and society in new directions.

Responses to great challenges often must be enunciated, formulated, and launched before the capabilities to meet those challenges are in place. In this way, the response often motivates the creation of the necessary capabilities. The decisions to send humans to the moon and to sequence the human genome were both made when the relevant technologies were far from being up to the job. In each case, establishing a bold and specific target created unforeseen routes to solutions. Recent technological and scientific advances have brought the life sciences to a point where rapid progress toward understanding complex biological systems is possible. Many of the essential ingredients are already in place. Biotechnology is already emerging as an interdisciplinary, system-level, computationally intensive subject. A piecemeal strategy, with many different agencies, interdisciplinary projects and investing in various technologies would continue to advance the efforts of some pioneer researchers whose work has enormous promise. But the cross-cutting technologies and tools that would genuinely empower the Biotechnology will definitely require significant investment and advance planning. We all expect that such sustained development in biological sciences will result the eventual realization of our imagination mentioned in the beginning of this editorial.

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Science is a way of thinking much more than it is a body of knowledge.

—Carl Sagan

ENERGY STRATEGIES FOR INDIA

Prof. Ajit Kumar Saha, D.Sc., F.N.A

When I express my gratitude to members of India Science Congress for having chosen me for the highest office. I do not use words of mere conventional courtesy. I deeply appreciate this honour, thought I may right away say that I not admire your choice.

In keeping up with recent tradition, I was required to lay down a focal theme for this Session and I chose one which has become a matter of global concern. In our younger days, energy was taken for granted. Very seldom we were concerned with the finiteness of its availability. The thinking of our scientist pioneers had mainly to do with how to develop the energy potentialities, and get on with the business of generating the industrial and agricultural growths necessary to improve the quality of lives of our people. The General President of the 21st Session of the Science Congress said in 1938[1].

"If we desire to fight successfully the scourge of poverty and want from which 90% of our countrymen and suffering, if we wish to remodel our society and renew the springs of our civilization and culture, and lay the foundations of a strong and progressive national life, we must make the fullest use of the power which a knowledge of Nature has given us. We must rebuild our economic system by utilizing the resources of our land, harvesting the energy of our rivers, prospecting for the riches hidden under the bowels of the earth, reclaiming deserts and swamps, conquering the barriers of distance"

In choosing my theme I pay my respects to him, for I am beholden to him in more ways then one.

Today this easy optimism has to a large measure disappeared. We know now that much of the energy pools from which we have been drawing our sustenance are of finite dimensions and would vanish very soon. No doubt there are other energy pools which are replenishable or inexhaustible for all practical purposes; but the technologies to use them have yet to be developed. Our populations are exploding and a tremendous pressure is building up in the form of demands for improvement of the quality of lives of our people. The problem of energy now dominates all our thoughts and actions. I propose to discuss some aspects of the energy problem of India and present most humbly some possible strategies. I realise of course that the problem is of unsurpassing complexity and it would be presumptuous for any person to say that this or that is the solution. What I would hope is that my address would generate discussions among the community of scientists and technologists, for any solution must necessarily depend heavily upon them. I must emphasise from the beginning that I am no expert in this field, I only know some parts of it as a physicist. The problem needs multidisciplinary treatment. I started collecting data and informations and what I intially prepared was of a size quite unsuitable for this occasion and must await the

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*   General President, 67th Indian Science Congress held during January, 1980 at Jadavpur.

[1.]   Meghnad Saha (1983) : The problems of Indian rivers. Presidential address to National Institute of Science of India.

pleasure of the DST to see the light of the day. In this address I have summarised what I had written.

HISTORIC PERSPECTIVE OF ENERGY USE[2]

It is fascinating to study the evolution of technology from paleolithic times to the modern age and see the many ways energy has been harnessed by man. Fire, wind, flowing water and oil from vegetable and animal origins were the main energy sources right upto the medieval times. Animal and man power dominated the economy and much of the wars of the ancient world was as much for the replenishment of slaves and animal stocks as for land and precious materials like gold. The great forests provided the wood necessary for fuel till the beginning of the Industrial Age. This induced forest clearings on a very massive scale; the forests in China were virtually destroyed by 1000 B. C. Oil, asphalt, naphtha, natural gas and coal were known in the ancient world. In China natural gas was transported through bamboo pipes in 1000 B. C. There was a resistance against the use of coal because of the smoke. Edward I of England legislated capital punishment for burning of coal. With the coming of the Industrial Revolution, machines came to their own and abundant sources of energy and technologies of energy conversions for running the machines became imparative. Whatever remained of the forests would have vanished because of this strident demand for energy, were it not for the fact that the demands of the steel industry for a cheap reducing agent brought coal into extensive use in the economy, leading to its use as a source of heat also.

THE CONCEPT OF ENERGY[3]

Before I survey the technologies for conversion of energy, I should like to draw your attention to the evolution of the concept of energy. Understanding of the concept did not come easily. In the ancient world, the mechanical advantages of the inclined plane and the five fundamental machines — the wheel and axel, the levers, the pulleys, the wedge and the endless screw were well known and their disadvantages in terms of speeds were realised. But there was no clear concept of energy; indeed same words were used to represent energy, force and momentum. However one could see two distinct lines of evolution of the concept: one was a search for something which was conserved, and the other a search for a perfect machine (perpetuum mobile) of the first kind which was to run without any input. Leonardo da Vincl was one of the first to realise the impossibility of such a machine. Lagrange, who laid the analytic foundations of Dynamics, wrote down the energy equation as an equation of conservation. But neither he nor others, who preceeded him like the great Newton, used the word energy. The word existed however, being probably coined by Aristotle. We own to J. Bernoulli, Young and Corriolls the meanings of the words energy and work, as used in modern science.

It was very soon realised that mechanical energy in its two forms: kinetic and potential, were not the only forms in which energy could exist. There are many other forms in which energy may be found. The classical work of Mayer and Joule led to the understanding of the real natural of heat. We now realise that if a suitable physical process can be found, then energy can be transformed from one to another — a concept on which our technological civilisation stands. The concept led to the magnificient branch of physics known as Thermodynamics which was the result of the great works of Carnot, Clausius and Lord Kelvin. This discipline embraces all our energy conversion technology that exists now or that may come. At the begining of this century another conceptual step was taken by the Einstein, relating mass to energy, the consequences of which were far reaching. This work is one of the greatest intellectual achievements of this century. The utilisation of

2. E. Ayres & C. A. Scarlott: Energy sources-The wealth of the world, McGraw Hill (1952). E. Cook: Man, Energy, Society, Freeman, 1976; C. A. Berg: Process innovation and changes in industrial energy use, Science, 199, p 608, 1978

3. Energy-historical development and concepts Vol.1. Benchmark series, Papers on Energy edited by R. B. Lindsay and M. E. Hawley. Academic Press.

energy of nuclear fission or fusion are based on Einstein's celebrated equation $E = mc^2$.

THERMODYNAMICS OF ENERGY CONVERSION TECHNOLOGY[4]

The foundation of Thermodynamics were laid in 1824 by Camot in his classical paper: "Reflections on the motive power of fire and the machines fitted to develop that power". He wrote

"If the honour of discovery belongs to a nation in which it (steam engine) has acquired its growth and all its development, this honour cannot be refused to England. Savery, Newcomen, Smeaton and the famous Watt, Woolf, Trevithick, and some other English engineers, are the veritable creators of the steam engine. ... Notwithstanding the satisfactory condition to which they have been brought to day, their theory is very little understood, and the attempts to improve them are still directed almost by chance.

This paper sparked of a flood of research leading to the understanding of engines, i.e. of all mechanisms converting energy of any form into work. The understanding is embodied in the statements of the second law of thermodynamics of which various forms exist. Lord Kelvin's statement is : Processes which convert work into heat without any other change is irreversible; it is impossible to convert completely heat extracted from a body at uniform temperature into work without causing any other changes. Other changes stand for the changes that are left with, after the completion of the process. There are other alternative statements of the law, of which the most famous is that of Clausius. All the statements are of course equivalent i.e. derivable from each other. Rankine introduced the concept of effciency of conversion, defined by

$$\eta = W/Q_2,$$

4. Applications of energy 19th century. Vol. 2, Second law of Thermodynamics vol. 5, Benchmark Series-Papers on Energy edited by R. B. Lindsay and M. E. Hawley. Academic Press; M. N. Saha & B. N. Srivastava : A treatise on heat, Ind. Press; G. F. C. Rogers and Y. R. Mayhew : Engineering Thermodynamics, Longmans Green. & Co. Ltd., 1967.

where $W = Q_2 - Q_1$ is the work delivered by the engine and Q_2 is the heat taken from a source at temperature T_2 and Q_1 is the heat transferred to a sink at lower temperature T_1. Engines were made to work in cycles so that the working fluid returned periodically to its initial state. In the calculations, the sequence of thermodynamic processes through which the working fluid was made to go, were all assumed to be reversible. This means that if the thermodynamic processes, envisaged, take the fluid from state 1 to state 2 through a sequence of nearly equilibrium states, then a little coaxing would take the system in the reverse direction from state 2 to state 1. In practise this is not possnile, and the main reason for irreversibility is the existence of friction which converts a part of the work into heat. For reversibility all of this frictional heat should be reconvertible into work without other changes of the environment. The second law prohibits this, because according to it only a part of the frictional heat can be converted to work, the balance being delivered to a sink at lower temperature, It was realised early that all reversible engines have same efficiencies. The engine contemplated by Carnot was also a reversible engine and had efficiency

$$\eta = 1 - T_1/T_2,$$

where T_2 and T_1 are the temperatures of the heat source and sink respectively. Efficiencies of irreversible engines are lower than those of reversible engines. If an engine, working in a particular sense of the cycle, takes heat from a source, converts a part of it into work and delivers the balance to a sink at lower temperature, then when worked in the reverse cycle, the engine will act a heat pump or a refrigerator i.e. it will take heat from a body at lower temperature, combine this heat with the work that is done on it by an outside agency and deliver the sum total to a body at higher temperature than the sink. It is a heat pump because it pumps heat from a body at lower temperature to one at higher; it is also a refrigerator because it takes heat from the body at lower temperature.

The science of thermodynamics developed very rapidly leading to deeper understanding of engines and other energy converters. For thermal engines Rankine introduced the practice of indicating the processes on pressure-volume diagrams or entropy-temperature diagrams. The various thermodynamic potentials were defined in course of time and extensively used. Clausius himself introduced the concept of Entropy-a concept of fundamental importance in theoretical physics as shown by the work of Boltzmann. For engines with flowing fluids like turbines, the thermodynamic potential enthalpy introduced by Kammerling Onnes proved very useful. For combustion of fuels and analysis of chemical reactions Gibb's potential became very important. The potentials are defined by

Enthapy : $H = U + pV$,

Gibb's potential : $G = H - TS$,

where U = internal energy, S = entropy, p = pressure, V = Volume, T = temperature. Gibb's potential is connected to reaction rate K of a chemical reaction by the equation

$K = \exp.[-\Delta/RT]$;

K is also connected with the partial pressure and the mole numbers of the molecules participating in the reaction.

Quality of Energy : While energy can be converted from one form to another, some forms of energy are better than others because they convert with smaller loss during conversion. The second law says that only a part of heat can be converted into work, the rest being lost to the sink. Thus heat is energy of low quality. On the other hand there is very small loss when electric energy is converted to work, and we can say that electric energy is of high quality. Sunlight has energy of low quality. Energy can be transformed from a form of low quality to a form of high quality only at the expense of a large part of it. However, once it is so converted there will be very small loss in its further utilisation.

Efficiency vs. Power Output of Engines : Though energy conversion efficiency of an engine is an important parameter for an engine, the efficiency will reach the ideal calculated for the engine only if the fundamental thermodynamic processes of the conversion cycle are reversible. This necessity makes the operation of the engine very slow, because slowness allows reversibility. Thus the power output for a high efficiency engine necessarily becomes small. A fast engine gives large output of power but has low efficiency because of the irreversibilities induced in the thermo-dynamic processes. However, at low and moderate speeds the power output may be proportional to effciency. What we have stated about efficiency falling with increasing power output will be noticeable at high speeds as irreversibility and friction losslow-ering the efficiency dominate in the region whereas power output increases linearly with speed till the slipoff point is reached.

ENERGY CONVERSION OF YESTERDAY AND TODAY

I do not propose to go into any detail about the present day energy conversion machines. Broadly speaking the thermal engines work on one or the other of the following cycles :

1.	Joule-Brayton cycle, Atkinson cycle	: The gas turbines, jet aircraft engine etc. usually utilise this cycle. Power 3-50 MW
2.	Otto, Diesel and dual cycles	: Internal combustion engines automobiles, aircraft piston engines, Diesel electricity generators etc. utilise these cycles. Power ~ 1500 – 2000 kW.
3.	Rankine cycle	: Steam and vapour turbines are based on this cycle. Power ~ 1 – 500 MW
4.	Constraint free jet flow	: Jet and rocket engines.

Though in principle there are all reversible engines, the efficiencies are different from that of the Carnot,

because heat is not drawn from a definite temperature and delivered to another definite temperature. Cycles which have the Carnot efficiency are the Stirling and the Ericsson cycles.

Heat engines are classified by the way they use their fuels :

1. internal combusion engines in which the heat is added inside the engine, e.g. automobiles, aircraft engines, gas turbines, jet engines and rockets.
2. external combustion engines in which the working substance is heated outside the engine, e.g. steam engines, steam turbines and Stirling engines.

Heat engines have another kind of description :

1. reciprocating engines, e.g. automobiles, Stirling engines, aircraft piston engine,
2. rotary engines-turbines, Wankel or Scissor engines and
3. linear jet engines and rockets.

Heat engines are characterised by :

1. maximum temperature and pressure,
2. specific fuel consumption,
3. power to volume, and power to weight ratios for airborne engines,
4. cost to power ratio for electricity generators and
5. maximum thrust available for jets and rockets.

With the end use in view, the following thumb rule may be kept in mind for selection of the type of engine which is most suitable for the purpose :

1. multistage steam turbines in tandem with fission reactors in the region 200-500 MW,
2. solid fossil fueled steam turbines for electric generators in the region 50-300 MW,
3. gas turbines for electric generators and aircraft populsion in the region 0.5-50 MW,
4. oil fired steam turbines for marine propulsion,
5. Diesel/Otto engines for land locomation, small boats agriculture pumps and motive power for industrial machines,
6. Stirling engines using inferior quality fuels

for machines and pumps in the agriculture sector,
7. low power, low efficiency solar engines using nontoxic organic liquids for rurilf areas

Commercially available heat engines have achieved efficiencies 0.08 (solid fuel rockets) to 0.58 (multistage steam turbines in tandem with fission reactors) and power levels achieved range from 10^3 MW to few kW. It must be remembered that heat engines are a nuisance in the sense they are sources of thermal polution, as about half of the heat is thrown to the environment without doing anything useful.

The other types of engines: dynamo (electrical energy) $\leftrightarrow$ motor (work) are well known. Pachionotti demonstrated the relation between the two. These engines are a very important component in energy economy-generation of electricity being heavily dependent on work electricity converters. The efficiencies and power outputs arc of high orders.

Water turbines are the most essential component in hydroelectricity generation, These are very ancient devices. In modern forms they can be classed like other turbines in two classes-impulse turbine e.g. Pelton water wheel and reaction turbines like Francis or Kaplan turbines.

MAGNETOHYDRODYNAMIC GENERATION OF ELECTRICITY

Another important technology engaging attention of scientists and technologists all over the world is the possibility of direct conversion of the energy of a flowing plasma to electricity. Magnetohydro-dynamics describes the interaction of an electrically charged fluid flowing through a magnetic field. The principle of energy conversion is given below[5]. A Charged particle moving through a magnetic field B, experiences a force $E = ev \times B$, where v is the velocity of the particle. An electric field is also generated, $E = F/e = -\Delta\varphi$, where φ = electric potential due to the field E. If v, B are perpendicular to each other and the charge moves a length *l* along

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5. Analysis by Dr. B. K. Banerjea

E, whose direction is perpendicular to both v and B, the induced electromotive potential across l is Bvl. The charge is in a plasma, which has an internal resistivity $1/\sigma$, where σ is the coductivity of the plasma medium, a is given by $\sigma = ne^2 \tau/m$ where τ = effective electron collision time, m = mass of electrons and n = electron density. Thus there will be a voltage drop across the plasma. Let V_T be the terminal voltage available for the outside load, i.e. $V - V_T$ is the voltage drop across the plasma conductor. If α = cross section of the plasma and l = its length, then plasma volume = Ω = αl, and its conductance is $l/\alpha\sigma$. The current i through the plasma is

$$i = \frac{\alpha\sigma}{l}(V - V_T) = \frac{\alpha\sigma}{l}(1-k)V,$$

where k = V_T/V = electric load factor. The power avilable is

P = iV_T = Ωk (1 – k) $\sigma B^2 V^2$,

i. e. Power density = Pd = k (1 – k) $\sigma B^2 V^2$.

Typical values of the above parameters for actual MHD generators are

k = 0.7 – 0.8 σ = 10 – 20 mhs/in, B ~ 5 – 6 Tesla

v = 600 – 1000 m/s reaching sonic velocity at the throat of the nozzle for a given temperature there.

The power density outputs are of the order

P_d = 25 – 150 MW/m^3,

It will be noticed that a MHD generator combines the flowing medium principle of a conventional turbine with that of the usual electric dynamo. The MHD generator is much simpler, atleast in principle. There are no heated moving parts subject to mechanical stresses, and external cooling if required, is more easily achieved. Vapour/gas heated to very high temperatures should be usable. The basic MHD process being a volume process the power

generation should increase with rise of generator size. The ratio of surface losses to net power output is, in principle, very favourable compared to conventional thermal turbines. MHD should be ideal for large scale power generation.

The most important part of a MHD plant resembles a rocket engine ventauri through which the hot vapour/gas expands. This expander is surrounded by strong magnetic field produced by standard methods; in some MHD plants very high magnetic fields have been produced by superconductor devices. Temperatures from 1500°K to 2500°K have been used. Seed materials like potassium or caesium carbonates are evaporateded and injecting into the vapour/gas stream flowing through the ventauri to improve the conductivity of the plasma. The electron temperature is much higher than the vapour/gas temperature. The hot outgoing vapour/gas of the MHD generator can be used to heat a stream of vapour/gas, which can be fed into a second conventional vapour/gas turbine. The MHD generator vapour/gas turbine combination should have efficiency higher than 50%, because much higher temperatures can, in principle, be used. In liquid metal MHD generators, electric conductivity is obtained by injecting a liquid metal into a vapour or liquid to obtain a continuous liquid phase. These are not yet promising.

Starting with the idea that India must find alternative efficient use of coal for energy generation purpose, an Indian MHD[6] facility is being set up at Tiruchirapally through colaborative efforts of BARC and BHEL and funding by DST. The plan is to have a coal based MHD generator with 5-15 MW thermal input. Technical consultation has been established for this project with Institute of High Temperature at Moscow.

On the global scene, the Soviet U-25 MHD pilot plant directed by Prof. A. E. Sheindlin, operated continuously in 1977 for 250 hrs at a power output of upto 12 MW into a Moscow grid. USA has completed a 5 Tesla superconducting magnet for MHD application at the Argonne National

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6. I am indebted to Shri C. Ambasankaran of BARC for information on the Indian MHD programme. Further informations to be found in Progress Report No. 3-MHD generation project, BARC, 1978.

Laboratory. USSR has operated a high power MHD generator, upto 30 MW, in a pulse mode for geophysical application. There are many other MHD projects in various countries in different stages of completion. Mention may be made of Mark VI project in USA.

SOLAR ENERGY

The sun pours in energy all round us, and nature has evolved methods of converting the electromagnetic energy of its radiation to a form, which we can use as food and fuel. We shall later review briefly this wonderful technology which nature has evoloved. We are just beginning to understand this technology, but we are nowhere near imitating it. There is an intense effort going on all over the world to convert solar energy, for this source of energy can be taken to be eternal. I shall review here some of these efforts and the results achieved.

In the latitude range where India is situated, the average integrated solar radiative energy on a horizontal surface at a place like Hyderabad should be 4.9 kWh/m^2 and this may rise on sunny days to 7 kWh/m^2. The total energy received by our land mass annually is about 60×10^{16} kwh which is a very large amount. But the radiation spatial density is very low and conversion factor is very small, and special measures are necessary to improve the conversion factor

1. optical concentration,
2. reduction of emissivity by special coatings and
3. reduction of convective and conductive losses.

In any book on utilisation of solar energy house plans are shown which are nearly autonomous in their power requirement for space heating and cooling. In other words these power requirements are, for most of the time, met by the conversion of solar energy and the dependence on other sources of energy are reduced. Indeed except for the expense, this seems to be an well established technology.

There are many laboratories in India-NPL is one important centre-where R&D work is going on for the utilisation of solar energy for space cooling/heating. There are intense global R&D efforts for improving the solar absorption coatings. According to an analysis[7] the efficiency of the solar absorption coatings is given by

η = energy extracted/incident energy

$$= \alpha P - \frac{1}{xF}\left[\epsilon\sigma\left(T_s^4 - T_0^4\right) + E_0 + E_d\right],$$

where α = absorptance of solar energy, x = optical gain, F = insolation or solar power recived, P = fraction of energy extracted for external work, T_s = surface temperature, and T_0 = environment temperature, E_0, E_d are respectively conductive and convective losses, both being proportional to $T_s - T_0$. To maximise this expression a/ϵ must be maximised, which makes selective coatings necessary capable of absorbing as much solar flux in the wavelength region $0.35 - 1.5$ μm and radiate in the infrared region $1.5 - 30$ μm. For most metals $a/\epsilon \sim 50$. Semiconductor layers are transparent in the infrared region and provide good selective absorbers. Various multilayered absorbers for in infrared have been successfully tried. Waveguide principle for selective absorption appear promising. The other part of the technology is concerned turn carries it to the working fluid. The main difficulty here is the loss of efficiency of heat transfer, because of the drop of temperature of the primary fluid in the heat exchanger for heat transfer to the working fluid tube between entry and exit points. There are encouraging results obtained by using a heat exchange system using wicks. Many fluids — water, Dowtherm A, mercury, potassium etc. have been tried as the primary heat transfer fluid. Each has its special merits and faults. If all these developments can lead to low cost systems, then these coupled to a low power engine like the Stirling engine can provide a reliable energy device for the rural sector, in particular for the agriculture sector for the pumping irrigation water.

I should say something of optical gain i.e. concentration of solar energy by mirrors. The great

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7. Analysis by Dr. B. K. Banerjea

mathematician of the ancient world, Archemedes of Syracuse, considered by Whitehead to be the founder of mathematical physics, is often credited with constructing a burning mirror which set the besieging Roman ships on fire. However, I have not found any reference to this incident in Plutarch's life of Marcellus. Today this principle has been very successfully tried in many countries. In one system 1000 mirrors each $10' \times 10'$ spread over an area of 1 mile^2 follow the sun, and reflect its radiation on to a boiler on the top of a 1500' tower, where a temperature of about 1000°C is obtained. A 50kW plant has been built in Italy and a megawatt solar furnace has been built in France for material research. In similar systems constructed in the other countries temperatures upto 3500°C have been obtained.

But the breakthrough in solar conversion technology has not yet happened. The world is waiting for a cheap photovoltaic conversion system. Intense R&D efforts on a global scale are going on to develop such a system. According to an estimate of possible theoretical efficiencies of photovoltaic conversion[8]

η_m = efficiency under proper matched condition

$$= \frac{V_m^2}{V_g V_c} t_s u(x_g),$$

where V_m = junction potential for which power output is a maximum, V_g = the band gap $V_c = kT_c/e$, T_c = temperature of the cell, t_s = probability that photon of energy $> h v_g$ will produce an electron-hole pair, $x_g = E_g/kT_s$, $E_g = ev_g$, T_s = black body temperature of solar radiation and $u(x_g)$ = ultimate

$$\text{efficiency} = \frac{h v_g Q_s}{P} \frac{\left[x_g \int_{x_g}^{\infty} x^2 dx / (e^x - 1) \right]}{\left[\int_{x_g}^{\infty} x^3 dx / (e^x - 1) \right]}$$

8.   Analysis by Dr. B. K. Banerjea
9.   M. B. Prince : Silicon solar energy converter, *Jour App. Phys.* 26, p. 534 (1955).
10. J. Loferski : Theoretical considerations governing the choice of the optimum semiconductor for photovoltaic solar energy conversion. *Jour. App. Phys.* 27, p. 777 (1956).

where Q_s = number of photons per unit are of frequency $\geq v_g = E_g / h$, P = total radiation incident per unit area. The best experimental value for Si obtained by Prince[9] and Loferski[10] is about 14%. On the basis of above estimates the efficiency can be improved upto 26%. However for the same power range Si cells are about 1000-2000 times costlier than solar heat engines with high optical concentration. Power obtained from Si cells can be increased by a factor 100-200 using high optical gain system. For Si, the short circuit current is 28 ma/cm^2 and open circuit voltage rises from low values to 0.6 volts at insolation 1 kW/cm^2, the maximum power output being 11 mW/cm^2 at output voltage of 0.45 V. Si leads the field from art overall point of view; indeed the solar cells used in space satellites are almost exclusively made of Si. For effective photovoltaic action the crystal should be defect free and of high purity (99.999999%) to avoid recombination of electron-hole pairs and loss of charge carriers. The other possible semiconductors for photovoltaic conversion are InP, GaAs and CdTe. The following methods are usually used to produce the crystal materials,

1. Czochralski method for ingots of 3 cm diameter,
2. float zone technique,
3. ribbon or sheet growing by rolling,
4. dentritic web techniques,
5. edge defined film growth techniques,
6. epitaxial thin film growth techniques, and
7. evaporated thin film growth techniques.

The limits of photovoltaic cell performance reached today are shown below :

Physical dimension	area	: $\leq$ 35 cm^2/cell
	shape	: $2 \times 2, 2 \times 4, 2 \times 8, 3 \times 3, 4 \times 8$ cm $\times$ cm
	thickness	: 2 – 20 mils
	mass/area	: upto 0.0117gm/cm^2
Electrical output	power/area	: up to 19mW/cm^2
	conversion	:
	efficiency	: 13.5 –14%
	area/Watt	: down to 52 cm^2/ Watt
	price/Watt	: 25/wall (1973)

Environmental limits	temperature	:	190°C – 900°C
	insolation	:	5 mW/cm^2 – 3 mW/cm^2
	moisture	:	upto 95% at 85°C

The incorporation of an electric field in the bulk silicon resulting from an impurity gradient, increases the radiation resistance. Retarding drift fields near the back surface gives increased cell voltage. Enhanced bulk response cells have high minority carrier diffusion lengths and higher short circuit currents and open circuit voltage. With present day technology about 7500 kWh of electricity is required for producing solar cells to cover 1 m^2 of a solar panel. With working efficiency of 10% and average isolation of 0.5 kW/m^2 this panel will produce 7500 kWh in less than 42 sunlit hours (6-8 days). This promises a bright future for breeding of solar panels.

I wish to close this survey with an idea — the Powersat concept — that is recently being talked about, which would look perfectly alright in science fiction but may never be realised in practice. This idea conceives of relay to earth of solar energy collected by a large collection panel of solar cells fixed on a stationary geosatellite. Because of absence of atmosphere and the sunlight being available for almost 22 hrs, the insolation should be about ten times larger. The solar energy collected is to be converted to microwave power and directed to earth by a microwave transmitter of high directivity, which is to be locked to a ground based microwave rectenna, to receive the microwave energy and convert it to an electricity. Microwave is being

thought of, because of its relative low loss while travelling through the atmosphere. The arguments against the idea are :

1. life of the solar panel may be shortened because of bombardment by cosmic rays,
2. microwave may heat up the ozone layers with disastrous consequences,
3. the degree of locking of the transmitter to rectenna, that is required, may be very difficult to achieve, whereas a failure in this respect will be catastropic for the inhabitants area round the ground station, and
4. the experience of Skylab has shown that satellite life times are unpredictable.

ENERGY FROM NUCLEAR FISSION[11]

Nuclear fission was discovered by Hahn and Strassmann[12] in 1939, and the phenomenon analysed by Meitner and Frisch[13] in 1939. There is a famous paper by Bohr and Wheeler[14], in which the phenomenon was analysed from the point of view of vibrations of a charged liquid drop. I mention this because Bohr's first paper was also on charged liquid drop.

The controlled release of nuclear energy in a chain reaction was announced by Fermi in 1942 in a telegram "The Italian navigator has just landed in the new world". Thus Fermi informed the world that his experimental pile has reached criticality. This was followed in 1945 by the explosion of the bomb on the deserts of New Mexico at Almogordo, which made Openheimer quote from the Bhagbad Gita[15]

"DIBI SŪRYASAHASRASYA BHABED
YUGAPADUTTHIĀ
YADI BHĀH SADRSĀ SĀSYAD̄
BHAS̄ASTASYA MAHĀTMANA"

Translation

If 1000 suns rise at once one time in the sky
Only that will resemble the brilliance of the
Great Soul

At 8.15 AM on Aug 6, 1945 a U bomb fell on Hiroshima; three days later on Aug 9, 1945 a Pu

11. I acknowledge the help given to me in preparing this section by my colleague Prof. S.K. Mukherjee.
12. Von O. Hahn and F. Strassmann: Uber die Nachweis und des Verhalten der bei der Bestrahlung des Urans mittels Neutronen entehenden Erdalkalimetalle, *Naturwis* 27,11(1939).
13. L. Meitner and O.R. Frisch: Disintegration of U by neutrons, a new type of nuclear reaction, *Nature* 143, p. 239(1939).
14. N. Bohr and J. Wheeler: The mechanism of nuclear fission, *Phys. Rev.* 56, p. 426 (1939). N. Bohr: Determination of the surface tension of water by the method of jet vibration, *Phil Trans Roy Soc* A 209, p. 281, (1909).
15. Bhagbad Gita : 12th Sloka, llth adhaya, Biswarupadarshanayoga.

bomb fell on Nagasaki. With such awe inspiring fanfare the nuclear age was ushered in for mankind.

Scientists and technologists all over the world saw in the brilliant experiment of Fermi, a prototype of a technology which could perhaps solve the global energy problem for all times to come. Meghnad Saha[16] was one of the pioneers of India, who by his writings and speeches, endeavoured to inform the public of the nuclear possibilities. Dr. H.J. Bhabha laid the foundation, in 1948, of a nuclear policy for India, and the country was launched on the path to nuclear developments. Unfortunately, after thirty years, doubts about our nuclear capabilities are being cast, which cannot be lightly brushed away, as our dependence on imported technology, plants, and materials, is being more and more revealed. Moreover, there are fierce debates, raging all over the world, whether exploitation of nuclear energy is really desirable, and whether man can live with nuclear energy.

I should like to describe the fission process very briefly. Certain very heavy nuclei like certain isotopes of uranium (U) and thorium (Th) are unstable against fission into two or more fragments, when irradiated with neutrons. The energy release can be very large (~ 200 Mev/ reaction) compared to normal energy releases in chemical reactions, which take place in the combustion of chemical fuels. More than one neutron is emitted in the fission reactions which make chain reactions and breeding of nuclear fuels possible. Nuclear species, which are important for fission, are grouped under

$${}^{232}_{90}\text{Th} + \text{n} - {}^{233}\text{Th}\xrightarrow[23.3\text{m}]{\beta^-} {}^{233}_{91}\text{Pa}\xrightarrow[27.4\text{d}]{\beta^-} {}^{233}_{92}\text{U}\xrightarrow[1.6\times10^5\text{y}]{\alpha} {}^{239}\text{Th}$$
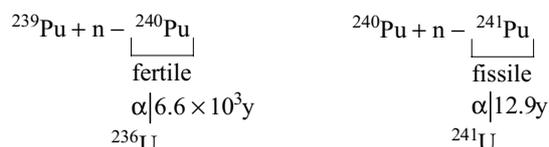
fertile ⌊___⌋   fissile ⌊___⌋

$${}^{238}\text{U} + \text{n} - {}^{239}\text{U}\xrightarrow[23.5\text{m}]{\beta^-} {}^{239}_{93}\text{Np}\xrightarrow[2.33\text{d}]{\beta^-} {}^{239}_{94}\text{Pu}\xrightarrow[2.4\times10^4\text{y}]{\alpha} {}^{235}\text{U}$$

fertile ⌊___⌋   fissile ⌊___⌋

$$\alpha \Big| 4.6 + 10^9\text{y}$$
$${}^{234}\text{Th}$$
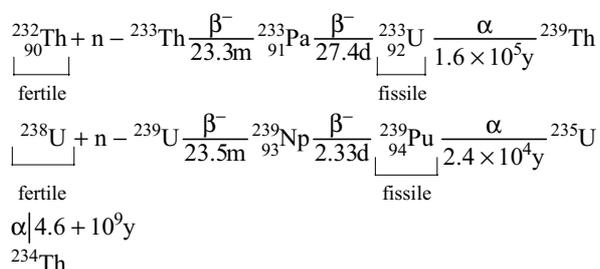
16. For a list of the writtings and speeches of Meghnad Saha on nuclear energy see Appendix.
17. Breeder Reactors — by W. Mitchell III and G.E. Turner, U.S. Atomic Energy Commission Office of Information Services 1972 (Revised).

$${}^{239}\text{Pu} + \text{n} - {}^{240}\text{Pu} \qquad\qquad {}^{240}\text{Pu} + \text{n} - {}^{241}\text{Pu}$$

⌊___⌋ fertile   ⌊___⌋ fissile

$$\alpha \big| 6.6\times10^3\text{y} \qquad\qquad \alpha \big| 12.9\text{y}$$
$${}^{236}\text{U} \qquad\qquad\qquad\qquad {}^{241}\text{U}$$

two heads : (1) fissile isotopes, which suffer fission after absorbing neutrons e.g. ${}^{233,\,235}\text{U}$, ${}^{239,\,241}\text{Pu}$. Some examples of conversion of fertile isotopes are given below. The isotope ${}^{233}\text{U}$ does not occur in nature and the abundance of the other isotopes of U are ${}^{238}\text{U}$ 99.28%, ${}^{235}\text{U}$ 0.72% and ${}^{234}\text{U}$ 0.0058%. Pu isotopes are entirely man made.

The average numbers of neutrons emitted per neutron absorbed in a fissionable material is represented by η. It has to be > 1 for sustenance of chain resction in a reactor. This parameter depends on the neutron energy and the fuel material. Generally η varies from 1 to 3 and has intermediate values for thermal neutrons, low values for neutrons of intermediate energies, and high value for fast neutrons. However it rises dramatically with even slight enrichment of ${}^{235}\text{U}$ in the U-fuel. This is the philosophy behind enrichment of U. η is high for ${}^{239,\,241}\text{Pu}$ or ${}^{233}\text{U}$, which is why in breeder reactors, these second generation fuels are produced from the neutron irradiation of the fertile isotopes ${}^{238}\text{U}$ or ${}^{232}\text{Th}$ contained in blankets in the reactors. The advantage of breeding is brought out neatly in the statement. "Johnny had 3 truck loads of Pu. He used 3 of them to light New York for 1 year. How much Pu did Johnny have left? Answer 4 truck loads"[17]. Approximate values of η for various materials and neutron energies are given in the following table

Approximate Table of η

Material	When thermal neutron is absorbed	When fast neutron is absorbed
U^{232}	2.3	2.45
U^{225}	2.1	2.3
Pu^{239}	2.12	2.7
Pu^{241}	2.1	2.7

Thus for ${}^{232,\,235}\text{U}$, the energy of the neutron makes little difference, whereas the Pu isotopes are best used as fuel for fast reactors, i.e. those which

employ fast neutrons. Breeding of fissile material from fertile material is not possible with η ~ *2*. Thus breeder reactors with U isotopes are unlikely unless one uses ^{233}U. Breeders with ^{239}Pu isotopes would be very efficient with fast neutrons.

The other important thing in a reactor is the moderator whose purpose is to slow down the fission produced neutrons without absorbing them. The performance of a moderator is measured by a figure of merit called moderating ratio. Some typical values are well known moderators are given in the following table[18].

Moderating Factor

Moderator	Moderating factor
Zr-hydride	49
Organic luquids	60-90
Light water	72
Be	159
Graphite	160
BeO	190
D_2OPure	1.2×10^4
D_2O 99.8 atom	2.3×10^2

In reactor systems moderators are used to thermalise the neutrons. Often in addition to this function, liquid moderators are also used as coolants. Control rods are made of materials like B or Cd with large cross sections for capture of neutrons, and are used to control the reactor activity or to shut it down.

Before we look at the reactor types now in use, brief review must be given of enrichment technology[18] for U. U enrichment is increasing the amount of fissile isotopes $^{233, 235}$U in particular of ^{235}U, from the natural abundance to the % desired in a particular reactor configuration of a nuclear weapon. The historic metheds are :

1. the electromagnetic separation method — Calutron,
2. the gas diffusion method and
3. gas centrifuge method.

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18. J. J. Glacken-The dangerous drift in U enrichment. *Bulletin American Scientists* Vol. 32, p. 22, 1976.

The methods (2) and (3) are in wide use. U is transformed to UF_6, which is a gas. Gas diffusion method depends on the fact that the lighter isotopes of U have a highter average velocity, and so when the gas is passed through a specially prepared Ni barrier, the emerging gas is very slightly enriched in U^{235}. Many thousand stages are required for useful enrichment. There are many technical difficulties that have to be faced. Theoretically the centrifuge method should be the cheapest method. However, the success achieved is not remarkable. It employs the principle of centrifuge separation. Among the modern methods we must mention the Becker nozzle process, in which UF_6 is forced at high velocity through the space between a pair of blades and a circular groove. Centrifugal and pressure effects concentrate the heavier isotopes at the wall of the groove behind the second blade. Another method is the Fenn Shock which is based on aerodynamics, and does not depend on too sophisticated a technology. A high powered blower and nozzle drives a supersonic stream of UF_6 against hollow metal shaped tubes. The heavier isotope collects behind the shock wave formed. The latest separation concept utilises laser technology, in which laser irradiation raises specific U isotopes to excited levels, creating appreciable differences of energy between the various isotope species. The Tarapur reactor in India depends on enriched U fuel. Unfortunately India's U enrichment programme leaves much to be desired.

The reactor types may now be classified. There are many ways of doing this :

1. by purpose,
2. by fuel,
3. by the state of layout of the fuel in the reactor,
4. by the type of moderator,
5. by the type of coolant which takes away the heat and transfers it to the media for the electricity generator turbine,
6. by the neutron energy, and
7. by the electricity output and
8. by the temperature.

Often the name indicates the type of the reactor and some important technical detail regarding it. Thus when a fast reactor is mentioned, we immediately understand that the neutrons employed have high velocity and the fuelis most likely to be ^{235}U or ^{239}Pu. A breeder reactor will most certainly have these fuel and very little moderator control, permitting fast neutrons, and there must be a blanket of fertile material from which the fissile materials have to be bred. LWR is a light water reactor in which moderator and coolant is light water, and the neutron moderation is by light water only, which is not very effective, so that the fuel has to be enriched U. The Tarapur reactor is of this type. CANDU stands for Canadian deuterium reactor in which the moderator is D_2O which is a very high quality moderator *i.e.* a moderator which does not capture neutron. Hence ^{235}U in its natural abundance can be used. The three other Indian nuclear power stations are equipped with reactors of this type. Unfortunately, after the Pokhran explosion, the colaboration whih Canada on these projects has

ceased. Other moderators, which have been used, are graphite and Be. Other coolants used are CO_2, He, organic liquids and liquid metals like Na. LMFBR stands for liquid metal fast breeding reactor. One also gets an idea of the temperature and pressure conditions within the reactor from its name. BWR stands for boiling water reactor, where the coolant light water is allowed to transform into steam and drive a turbine. PSR stands for pressurised warer reactor where the coolant water is kept at a high pressure of-2200 psi and a temperature of~600F and made to deliver the heat to another water circuit through a heat exchanger. HTGR is a high temperature gas cooled reactor. A heterogeneus reactor is the usual type in which the fuel rods are separate from each other and mounted in a geometry dictated by the neutron economy desired. A homogeneous reactor is one in which the fuel is mixed with a suitable moderator. MSBR is a reactor of this type, the letters standing for molten salt breeder reactor. The state of the art in reactor technology can be seen in Table 1.

Table 1. Power Reactors : Types and characteristics

Reactor type	fuel form	Enrichment	Neutron Energy	Moderator	Coolant	Control	Cladding
LWR/PWR (Converter)	UC	Enriched U (3.2% U-235) & possibly recycled Pu	Thermal	Water	Water	B_4C. Ag-In-Cd Rods	Zircaloy
LWR/BWR (Converter)	,,	Enriched U (2.8% U-235)	,,	,,	,,	B_4C	,,
HWR (CANDU) (Converter)	,,	Natural (.7% U-235)	,,	Heavy water	Heavy water	Moderator level	,,
SGHWR (Converter)	UO_2	Enriched U (3% U-235)	,,	Heavy water	Water	B_4C	
HTGR (Converter)	UC_2, ThC_2	Enriched (93% U-235) recycled U-233, Th-232	,,	Graphite	Helium gas	,,	
LWFBR (Breeder)	PUO_2 UO_2	Recycled Pu and U-238	Fast	None	Liquid sodium	B_4C	Stainless steel
LWBR (Breeder)		Recycled U-233 and Th-232	Thermal	Water	Water		
GCFBR (Breeder)		Recycled Pu & U-238	Fast	None	Helium gas	B_4C	Graphite
MSBR (Breeder)	U fluorides	Molten fluorides of U-233 and Th-232	Thermal	Graphite	Molten salt		

LWR - Light water reactor	CANDU - Canadian deuterium uranium	LWGR - Light water breeder reactor
PWR - Pressurized water reactor	SGHWR - Steam generating heavy water reactor	GCFBR - Gas cooled fast breeder reactor
BWR - Boiling water reactor	HTGR - High temperature gas cooled reactor	MSBR - Molten Salt breeder reactor
HWR - Heavy water reactor	LMFBR - Liquid metal fast breeder reactor	

Rationale of nuclear energy production : I summarise below various aspects of nuclear energy production, about which such fierce debate is raging all over the world. What emerges clearly is that every country has seriously to consider the various points of the arguments and decide for itself, whether it is prepared to go through the great hazards for the sake of energy that it could get. For India, if we must have nuclear energy, then the whole unclear energy programme of the country has to be reoriented. For this country, unclear energy can be possible only along the path of breeder technology. The lead time for this technology is so large that it is doubtful that nuclear energy could ever contribute in any effective measure to our energy economy or serve even as a stop gap system to fill up the time till a more dependable and safer alternative energy systems emerge.

The various arguments for and against nuclear energy are summarised below.

ASPECTS OF NUCLEAR ENERGY PRODUCTION

1. Positive aspects

   A. National/Social benefits

- Electricity for the economy.
- Weapon grade Pu bred in FBR's to increase defence capability and as nuclear deterrent.

   B. Other considerations

- Energy density very large resulting in small fuel weights.
- Global nuclear resources possibly large.
- With FBR, the nuclear resources can be made to last over longer span of time,
- Nuclear energy exploitation may be unavoidable and imperative when other alternative energy resources are scarce.

   C. Indian scenario

- Indian U reserves are small but Th reserves in monazite sand are very large so that breeder technology is needed.

2. Uncertain aspects

- The cost of nuclear electricity is quite uncertain, and when compared with hydel or thermal electricity it may be quite high of one considers the high cost of plant maintenance and final plant shut down, fuel processing and recycling and security measures.

3. Negative aspects

   A. Cost

   Installation

- Long lead time for installation.
- Fuel enrichment technology very expensive.
- Reactor boiler and heat exchanger technology are not of conventional thermal plant types, because of radioactivity and radiation damage and fatigue of the materials involved.
- Commercial thermal electricity generation plant has in any case to be dovetailed at the tail end of a nuclear plant.
- General high level of investment necessary for a nuclear plant.
- Additional high investment necessary for reactor safety.

   Maintenance and operation of plant

- Very high level of technical expertise and skill necessary to operate and maintain a nuclear power plant.
- Fuel processing and recycling process cost very high.
- In FBR's the generation of high weapon grade Pu Present grest security problem. There is great risks of hijacking of Pu and proliferation of nuclear weapons.
- High cost of replacement of reactor parts, damaged and fatigued by the intense radiation in the reactor.
- Useful life of a reactor may compare unfavourably with those conventional hydel or thermel plants.
- High cost of radioactive waste disposal.

Final close down of plant

● High cost of protection measures for reactor parts after final shut down of plant, which measures may have to be extended for centuries.

B. National/Social hazards

Health hazards

● Hazards of mining nuclear fuel.

● Hazards of fuel processing and recycling of nuclear fuels.

● Hazards to personnel operating the reactor.

Environmental hazards

● Atmospheric polution caused by leakage of radioactive gases from reactors. Thermal polution due to large output of heat to the atmosphere in the cooling towers and to the cooling water.

● Environmental polution due to dispersal of radioactive waste caused by geological processes.

Disaster aspects

● There is no fail safe system against nuclear plant disaster

● Typical nuclear power plant disaster is not an explosion but is a core melt down, which has actually happened.

C. Indian capability

● Enrichment plant for U to be used in LWR has yet to be established.

● Heavy water production for use in existing CANDU reactors has to be improved.

● Very large dependence on foreign technology and vital materials and components necessary to install and operate a nuclear power plant. Import of this technology and materials must have political conditions attached, which is a fact of life.

● Indian U reserves are not sufficient, but Th reserves are very large, which points to the dangerous road of FBR technology.

● The long lead time necessary to install nuclear power plants makes it very unlikely that nuclear energy can help in the deepening energy shortage by the turn of the century.

● Effective measures (legislative and executive) probably have yet to be evolved for mitigating the hazards of health, polution, waste disposal; codes for nuclear security or disaster have yet to be worked out.

I shall briefly comment on some of these aspects, which have been listed above.

Radioactive hazards and waste disposal : A 3000 MWe nuclear plant generates, allowing for monoperating periods, about 1200 kg of fission products annually, occupying a volume of 4 ft^3, which present serious health and pollution hazards. Some of the radioactive products, that are generated, are

Ver long life	: $^{129}I(1.6 \times 10^7 y)$, $^{99}Tc(2 \times 10^6 y)$, $^{239}Pu(2.4 \times 10^4 y)$, $^{243}Am(7.3 \times 10^3 y)$, $^{240}Pu(6.5 \times 10^3 y)$, $^{241}Am(440y)$.
Long life (1y–100y)	: $^{238}PU(85y)$, $^{137}Cs(30y)$, $^{90}Sr(28y)$, $^{244}Cm(17y)$, $^3T(11.8y)$, $^{85}Kr(10.6y)$, $^{147}Pm(2.52y)$, $^{155}Eu(1.7y)$, $^{106}Ru(1y)$.
Short life (~ days)	: $^{144}Ce(290d)$, $^{95}Zr(63.3d)$, $^{91}Y(52d)$, $^{89}Sr(50.4d)$, $^{131}I(8.05d)$, $^{99}Mo(67$ hr$)$, $^{90}Y(64.2$ hr$)$, $^{140}(La(40.2$ hr$)$, $^{127}Te(9.35$ hr$)$, $^{129}Te(74$ min$)$, $^{144}Pr(17.5$ m$)$, $^{106}Rh(30$ sec$)$.

All these fission products reside in the fuel except the gaseous products, which may leak out of the fuel cladding materials through microcraks or fissures caused by radiation damage and heat. So great care has to be taken of

1. fuel transfer,
2. fuel storage for decay,
3. fuel transportation and
4. reprocessing of fuel in fuel cycling processes, by which the fissile materials are extracted for future use.

To check for leak of gaseous fission products constant monitoring must be imposed. Gaseous radioactive products halogen and noble gas isotopes are constantly removed from primary coolants and kept in storage tanks for the radioactives to die out before release to the atmosphere. The liquid wastes are stored in storage tanks, continuously sampled and monitored and released to rivers or seas, when the safety limits of activities are reached. Thus gaseous and liquid radioactive waste are ultimately disposed off into the earth's biosphere, which is very undesirable. The disposal of soild radioactive waste presents much more difficult problem. We shall consider this a little later.

Fuel cycling : The spent fuel rods in a reactor have to be processed so that U and Pu portions are extracted. This makes a large amount of Pu available, which by various clandestine methods - thefts, hijacking, smuggling etc. - may contribute to nuclear proliferation, resulting in many countries feeling very pleased with themselves with a bomb or two in their possession. It is very doubtful that hijacking can be prevented against a determined bid by kamakaze type of terrorists, to whom life is of no consequence. Making of a bomb, once the weapon grade Pu is obtained, is a much simpler problem. It is not necessary to have a delivery system for the bomb. Its parts can be smuggled into the enemy territory system for the bomb. Its parts can be smuggled into the enemy territory, assembled and detonated by remote control. Apart from this hazard, Pu^{239} has a half life of 24100y and is perhaps one of the deadliest toxic substances made by man. If it leaks to the environment it would create a dangerous environmental situation. Fortunately Pu does not move easily from place to place or from one biosystem to another like ^{90}Sr. some solutions have been proposed for security of weapon grade Pu :

1. One method is to have Pu always unseparated from the fission products; infact a fuel fissium (containing all the fission products) was considered for the LMFBRs-this would make extraction of Pu very expensive.

2. The second method considers a throw away fuel cycle, *i.e.* Pu would never be allowed to be recovered from the spent fuels — this defeats the whole purpose of the FBR systems.

3. The third method envisages generation of nuclear energy in heavily guarded nuclear parks where all the operations from mining, enrichment, energy production, fuel cycling and disposal are to be collectively done.

Solid radioactive waste disposal : Solid waste are usually calcinated as phosphate glass or solidified under spray solidification techniques. The method of disposal are usually.

1. Retrievable surface storage system-the solid wastes are stored in sealed canisters, about 1'-diameter and 10'-long, designed to stand up to tornadoes, earthquakes, floods and aircraft disasters. The storage is either above ground allowing normal air cooling or in water pool; such storage requires heavy security arrangements;

2. Storage in geological formations, such as salt mines, in canisters sealed off from the biosphere; this would not need heavy security arrangements, the only human surveillance that is needed is that no drill holes are made in the vicinity. Other geological formations which may be suitable are basaltic formations or ice structures.

3. The third method of disposal considers shooting the radioactive wastes stored in space vehicles to the sun; this is prohivitively expensive.

4. The fourth method is to subject the wastes to nuclear reactions to convert them to short lived products; this will be also very expensive and energy intensive.

Reactor accident : The hazards to populations depend on the type and severity of the accident, the degree to which the safety containment of the reactor system performs successfully, the population distribution in the vicinity and the meteorological conditions. It must be noted that reactors can not

explode like a bomb. What may occur, and what nearly occured at the Three Miles Island, is a core melt down. If the cooling system of a reactor fails, or if there is a power transient, then the core melts down and makes its way through the concrete floor of the containment vessel to the ground below. It is only that a then large release of radioactive fission products to the environment is made possible. A 1000 MW LWR contains about 12 G curie radioactivity in the form of fission products after sustained operation. Of this the greatest hazards are presented by ^{90}Sr and ^{131}I. If l/4th of the ^{131}I comes to the atmosphere, then the permissible concentration over all America will be exceeded by a factor of 2 upto a height of 10,000m. Half of the ^{90}Sr may contaminate the annual fresh water of all America to six times the permissible limits. The Rasmussen[19] report examined the possibility of reactor accident and concluded that the probability of 100 or more fatalities from 100 reactors was 1 in 10^4 years, the same as being hit by a meteorite, and the probability of 1000 or more fatalities from 100 reactors was 1 in 10^6 years, whereas the same for meteorite was 1 in 10^5 years. But recent experience and other analyses by various bodies of scientists do not agree with these conclusions. However the fact remains that because of the extreme care taken for reactor safety, the overall safety records of nuclear plants have been outstanding.

ENERGY CONVERSION TECHNOLOGY OF THE 21ST CENTURY[20]

Fusion Technology-Thermounclear Reactions[20] : Eddington[21] posed the question in his book: What is the mechanism that supplies energy to the stars ? This question was solved by Bethe[22], Who proposed the famous C cycle as the

reaction system which release the energy necessary to support the stellar structure. Man is now attempting so simulate the stellar conditions in the laboratory, and thereby evolve a technology for energy condition, which if successful, may solve our energy problem for all times to come. Unfortunately, as in nuclear fission the bomb came first. On November 1, 1952 a small coral island Elugelab in the Eniwetok atou, 13 mile^2 in area, disappeared from the face of the earth, and the world come to know of the hydrogen bomb "Super", Dr. H. J. Bhabha in his presidential address at the first Geneva Conference (1955) on peaceful uses of atomic energy predicted that fusion energy will be in production for our use within two decades from 1955.

The principle involved in this technology is the release of energy when very light nuclei come together and fuse. The particle accelerators can be used to accelerate the nuclei to the energy necessary for fusion. However this method would be terribly expensive and energy intensive. The other method is to use very high temperatures, so that a large fraction of the nuclei would have sufficient velocities to overcome the Coulomb repulsion and fuse. The temperatures at which fusion reactions take place are of the order of M° K. Matter at such temperatures is completely ionised and the name plasma is given to this state. The power released as a result of thermonuclear reactions is given by

$$P_f = \frac{1}{2} \ n_1 n_2 < \sigma \ V> Q \ \text{ergs/cm}^3 \ \text{sec,}$$

where P_f = power released by the fusion reactions, n_1, n_2 are the densities of the colliding nuclear species, Q = energy released by the reaction, $< \sigma \ V >$ is the value of the product of the cross section of the reaction with the velocity averaged over the maxwelliam velocity distribution in the plasma i.e.

$$< \sigma \ V > = \left(\frac{8}{\pi T}\right)^{1/2} \frac{M}{m^2}^{3/2} \int_0^\infty \sigma \exp\left[-\frac{ME}{mT}\right]\frac{E}{T} dE$$

where M = mass of the target particle, m = mass of bombarding particle and T = temperature in kiloelectron volts. Thus for the DT reaction

19. Reactor safety study (WASH - 1400), National Research Council (usually referred to as the Rasmussen Report) 1975.
20. I am indebted to Prof.S.K. Mukherjee for preparing this section.
21. A.S. Eddington: Internal constitution of the star, Cambridge Univ. Press, 1926,
22. H. Bethe : Energy production in stars, *Phys. Rev.* 55, p. 434 (1939).

$P_{DT} = n_D n_T < \sigma V > Q \times 10^{-7}$ Watt/cm^3, Q = 5.6 $\times 10^{-6}$ ergs.

so that

P_{DT} (T = 10 keV) = 6.2 × 10^{-29} $n_D n_T$ Watt/cm^3,

P_{DT} (T = 100 keV) = 4.5 × 10^{-28} $n_D n_T$ Watt/cm^3,

Here temperature is measured in kiloelectron volts :

1 eV = 1.60 × 10^{-12} erg.

We have also to consider a process which tends to cool the plasma. This is the process of bremstrahlung radiation by the electrons colliding with the ions of the plasma. The rate of cooling by production of bremstrahlung is give by
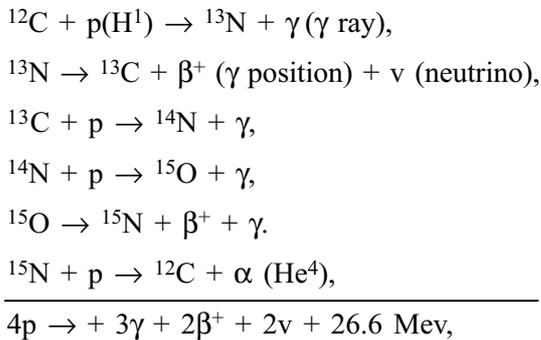
$$P_B = g \frac{32\pi}{3^{3/2}}, \frac{\left(2\pi k T_e\right)^{1/2} e^6}{m^{3/2} c^3 h} n_e \sum \left(n_i Z^2\right)$$

$$= 5.35 \times 10^{-31} n_e \sum \left(n_i Z^2\right) T_e^{1/2} \text{ Watts/cm}^3.$$

where n_e and n_i are the dentisties of electron and ions in the plasma and T_e is the electron temperature. This rises as $T_e^{1/2}$ whereas P_f rises much faster. At a particular temperature the curves cut; above this temperature the fusion release from the plasma becomes selfustaining. This temperature is called the ignition temperature T_{ig}.
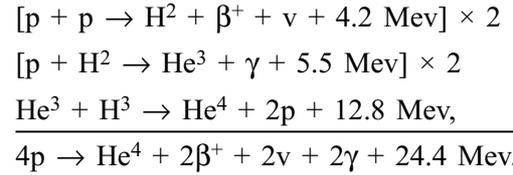
Some fusion reactions : The reactions which are important from the point of view of astrophysics are

1. **C cycle :**

^{12}C + p(H^1) → ^{13}N + γ (γ ray),

^{13}N → ^{13}C + β$^+$ (γ position) + v (neutrino),

^{13}C + p → ^{14}N + γ,

^{14}N + p → ^{15}O + γ,

^{15}O → ^{15}N + β$^+$ + γ.

^{15}N + p → ^{12}C + α (He^4),
___
4p → + 3γ + 2β$^+$ + 2v + 26.6 Mev,

So effectively, four hydrogen nuclei are consumed to form a nucleus of helium with liberation of energy. This is the process that sustains the sun.

2. Proton-proton cycle :

[p + p → H^2 + β$^+$ + v + 4.2 Mev] × 2

[p + H^2 → He^3 + γ + 5.5 Mev] × 2

He^3 + H^3 → He^4 + 2p + 12.8 Mev,
___
4p → He^4 + 2β$^+$ + 2v + 2γ + 24.4 Mev.

This reaction system sustained the sun at early stages of its evolution.

It would be useless to try to simulate the above reactions on earth to generate energy, because even at the temperatures prevailing inside the sun, their rates of reaction will be too slow under earth condition. Only the huge mass of the steller body keeps them going. Hence almost all the attempts to simulate fusion reaction on earth are based on the element deuteron, which (D ≡ H^2) is relatively abundant on our planet. It is estimated that the amount of deuterium heavy water present in our oceans is about 5 × 10^{19} gms. The different fusion reactrions involving D are given below. In what follows, σ denotes the cross scetion of the reaction and T_{ig} the ignition temperature.

1. ^{2}D + ^{3}T → n + α + 17.6 Mev,
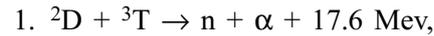
α_{max} = 5 barn at 100 kev, T_{ig} = 47 M°K. Note that a carries away 20% of the energy.

2. D + D → n + ^{3}He + 3.27 Mev,
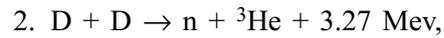
α_{max} = 0.1 barn at 600°K, T_{ig} = 400 M°K

D + D → p + T + 4.03 Mev,
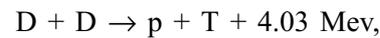
3. Catalysed D reaction : It is basically the above D-D reaction in which the reaction products are also burned at the same rate at which they are produced.

D + D → n + ^{3}He + 2.27 Mev,

D + D → p + T + 4.03 Mev,

D + ^{3}He → α + p + 1.83 Mev,
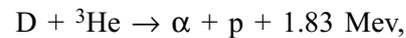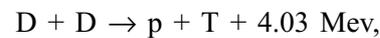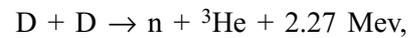
α_{max} = 0.7 barn at 600 Kev, T_{ig} = 320 M°K

D + T → n + α + 17.6 Mev,
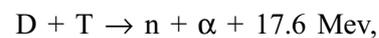
α_{max} = 5 barn at 100 kev, T_{ig} = 47 million °K
___
6D → 2α + 2p + 2n + 21.6 Mev,
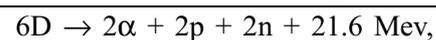
T_{ig} = 290 million °K. Note that α and p carry away more than 60% of the energy.

The temperature needed to ignite the DT reaction is relatively low and the cross-section is very high. This is why very intense effort is going on to harness this reaction, and it is highly probable that the first generation of fusion reactors will involve this reaction. The drawback is the use of T (tritium) as fuel, which is radioactive and one of the most toxic materials made by man. Moreover, this has to be bred in he ^{6}Li blanket of the reactor by neutron capture. In addition, the high flux of energetic neutrons produced would induce radioactivity in the surrounding of the reactor, causing very serious environmemtal polution. The neutrons would carry 80% of the energy, which has to be extracted through the indirect and inefficient steam cycel.

The DD reaction and the catalysed D reaction appear to be attractive because the resources of D in deuterium is almost without limit. There is no need to breed T, all of what is produced being consumed in the reaction. But the magnetic confinement system has to be vastly improved before it can be applied to this reaction. Also the ignition temperature is much higher. The number of neutrouns per unit of energy for this reactor of the same order as for DT, though in this case they carry away only about 33% of the reaction energy. They present tremendous health hazards and a very high potential for environment pollution.

Because of these polution and health hazards, intensive searches are being made for clean fusion reactions which may yield safe and abundant nuclear power and very low neutron yield. The reactions under investigations are :

1. $p + {}^{11}B \rightarrow 3\alpha + 8.7$ Mev,

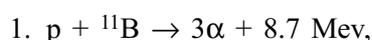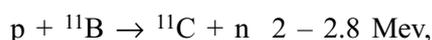$$\alpha_{max} = \begin{cases} 0.71\,\text{barn at E}_p \sim 700\,\text{Kev and 0.2} \\ \text{barn at E}_p \sim 1.4\,\text{Mev} \end{cases}$$

The side reactions

$p + {}^{11}B \rightarrow {}^{11}C + n \quad 2 - 2.8$ Mev,

$\alpha + {}^{11}B \rightarrow {}^{14}N + n + 0.2$ Mev,

have very low cross-sections can be avoided.

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23. Meghnad Saha : Ionisation in the solar chromosphers, *Phil, Mag. Sr.* VI, 60, P. 472, (1920).

2. $p + {}^6Li \rightarrow {}^3He + \alpha + 4$ Mev,

$^3He + {}^3He \rightarrow a + 2p + 12.9$ Mev,

$^3He + {}^6Li \rightarrow 2\alpha + p + 16.8$ Mev,
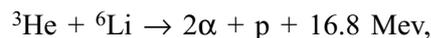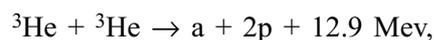
$\alpha_{max} = 0.3b$ at $E_p \sim 1.8$ Mev.

Only a few neutrons are produced in parasitic reaction associated with this chain. These materials are called advanced thermonuclear fuel. Their strikingly important advantages are : The fuels (^{11}B and ^{6}Li) are cheap, abundant, radioactive, and the fusion reactions involving them present no health or environmental hazards. The reactions energies are almost all carried away by changed particles; hence direct conversion to electrical energy is possible without going through the indirect and inefficient steam cycle. The obstacles in the way of practical realisation of these reactions are their relatively low cross-sections and difficulty of application of magnetic and inertial containment systems to such heavy nucliei. A tritiumless and neutronless fusion reactor will go a long way towards public acceptance of thermonuclear energy.

We have been mentioning temperatures in the range of M° K. Matter exists in the plasma state at such high temperatures. The study of the production and behaviour of high temperature plasma has become a important branch of Physics; one of the most important tool in the hand of physicists studying plasma, is the famous Ionisation Equation[23] of Meghnad Saha.

$$\log\left[\frac{x^2}{1-x^2}.P\right] = -1.79 \times 10^4 \frac{1}{T} + 1.5\log T + 0.2,$$

where x = the fraction ionised, T = temperature, p = pressure. With this equation he interpreted the spectra of the stars for us, and this made him one of the immorfals of Modern Physics.

Fusion Reactors : I shall now briefly, review the technical aspects of possible practical fusion reactors that may emerge. The current which employs the reactions DD, DT etc. which require

temperatures in the range 10^7 to 10^9 °K. Such a hot plasma would naturally tend to expand and cool. Thus the important technical problem is how to confine the plasma for the time necessary. Confinements by various methods, which we shall briefly mention later, have been employed to prevent the hot plasma from coming into contact with the walls of the containing vessel and thereby losing energy. Confinement by a magnetic field has become very important today. Such a problem is not faced by the stars, for gravitation does the confinement for them. There are problems of plasma instabilties in a magnetically confined high temperature plasma. We have mentioned that a hot plasma may lose energy and cool by the bremstrahlung process. The other sources of energy loss of plasma is by the electron drag mechanism, by which the ion temperature falls because of the cool electrons of the plasma. Because of these loss mechanisms, effort is made to confine the plasma for a short time only, which is sufficient however for the thermonuclear reactions to be effective. Thus the fusion reactors working in the pulsed mode would produce short busts of power. Lawson[24] investigated this problem and found that the condition of fusion is given by a parameter N which is the product of the ion density and confinement time of the plasma.

$$N = n\tau = g.\frac{12kT}{<\sigma v> Q},$$

where n = number of ion/cm^3, g = energy gain, s = reaction cross section, v = ion velocity, T = temperature, Q = the energy liberated in a single reaction and k is the Boltzmann constant. For DT reaction, kT = 10 keV and Q = 17.6 MeV, so that the Lawson number N = 7×10^{13} sec/cm^3 for the break-evenpoint. For energy generation $g \simeq 10$, then N = $n\tau = 7 \times 10^{14} \simeq 10^{15}$ sec/cm^3.

Confinement Techniques : The usual methods employed to confine plasma are :

1. by magnetic field as mentioned above and

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24. J. D. Lawson : Proc. *Phys. Soc.* B70, 6, (1957).

2. by inertial means where a fuel pellet is heated more quickly thant the time taken for the pellet to disintegrate.

Typical values of nt for magnetic confinement range from 10^{14} to 10^{15} sec/cm^3 for plasma densities n $\simeq$ 10^{14} to 10^{15} cm^3 and $\tau \simeq$ 1 sec. For inertial confinement $\tau \simeq 10^{-9}$ sec so that n $\simeq$ 10^{25} to 10^{26}/cm^3, which is the concentration for solids.

Magnetic Confinement : There are two principal ways of confining a plasma by magnetic fields. In open ended systems, magnetic mirrors are used in which an injected plasma moves between the mirror throats and is heated by magnetic compression methods. Among the closed systems, the best known are the toroidal pinch systems in which the magnetic field is bent into a toroidal shape. The plasma moves along the field lines in the torus and are pinched to high compression by passing a large electric current along the axis of the torus. This current generates poloidal magnetic field which confines the plasma and heats it. But this brings along many types of instabilities in the plasma that work against in their effective confinement. Many modifications of the torodial and poloidal magnetic fields have been adopted to control the current flow in the plasma and contain the instabilities. One that shows the best promise and is now the most widely investigated, is called the Tokamak (toroidal magnetic chamber), a machine pioneered in the USSR during the sixties.

In a Tokamak, the poloidal magnetic field produced by the current flowing through the plasmas, is very weak compared to the toroidal field. The plasma current is induced by an external magnetic field by transformer action and produces ohmic heating of the plasma. Though this ohmic heating is the largest single factor for heating of the plasma, supplementary means to heat further the plasma upto the fusion temperatures are almost always adopted. These are required because there is a limit to the use of very high current densities no account of the loweing of resistivity of plasma with

temperature anc the onset of instabilities with very high currents. There types of supplementary heating has been tested no Tokamaks :

1. heating by neutral beam injection.

2. heating by adiabatic magnetic compression of the plasma, and

3. radiofrequency heating at ion-cyclotron frequencies, at lower hybrid frequencies or at the electron-cyclotran frequencies. Of these, the neutral beam injection method has proved by far the most successful one.

The early success of the Tokamak system led to its widespread investigation, so much that in 1968 there were nine Tokamaks (all in USSR) and there are now more than 100 operational Tokamaks in USSR, USA, Europe, Japan and other countries, and their performance parameters are being constantly improved and are fast approaching the values required the fusion reactors ($N \simeq 10^{14}$ sec/cm^3 and $T_{ion} \simeq 10^8$ °K). Some notable achievements are : Alcator Tokamak at MIT achieved $N = 3 \times 10^{13}$ sec/cm^3. Princeton large Tokamak (PLT) achieved energy confinement time $\tau = 100$ ms and $T_{ion} = 7 \times 10^7$ °K. PLT also demonstrated the success of the nuetral beam heating method. The general experience is that the energy confinement time increases with the dimension of the minor radius of the torus. Hence there is an all out effort to construct larger Tokamaks. Examples are—the JET of the European community, the TFTR of USA, JT-60 of Japan & T-10M of USSR; all are in construction or design stages and are expected to be operational by 1982-83. The key issues at present are :

1. the impurity control in the plasma.

2. plasma fueling,

3. control of the instabilities,

4. the developments of high voltage beams,

5. the development of superconducting coils, and

6. thermal burning of the fuel and its control. It is to be understood that the development is still very much in research stages and a commercial fusion reactor of the magnetically confineded plasma type is not expected to come before the next twenty five years.

The other magnetic confinement systems (non-Tokamaks) being tried as

1. mirror machines—the tandem mirror systems and long linear systems with various end plugging schemes,

2. mirror-torus hybrid systems : the Elmp Bumpy Torus (EBT) and the Tormac,

3. reversed field systems : the field-reversed mirror, the reversed-field Z-pinch, and the Spheromak.

The state of art in the Tokamak give below in table 2.

Table 2. Magnetic Confinement : Tokamarks

a = minor radius, discharge tube, (cm); R = major radius (cm);

a* = minor radius, limiter, (cm); B = on-axis torodial magnetic field (max), (kG)

COUNTRY Laboratory	Experiment	a	R	B	Comments
AUSTRALIA Canberra	LT-3	10	40	14	Low-q studies
BELGIUM Lab.Plasma Brussels	Erasmus	50×50 squeare	50	8.7	Low aspect ratio. R.F heating
CANADA Saskatchewan	Stor	4	22	20	Turbulent heating device
FRANCE	Petula	15*	72	16-25	RF heating studies
Grenoble	Wega	16*	–	15-25	heating methods
GERMANY Fed. Rep. Garching	Asdex	40	164	30	Axially symmetric Divertor experiment
ITALY Frascati	FT	21	83	100	High current Dnsity, High B

COUNTRY Laboratory	Experiment	a	R	B	Comments
JAPAN Jaeri	JFT-2	25*	90	18	Small aspect ratio. Iron core
	JT-60	100	300	50	Large Tokamak device–extends tokamak para-meters closer to reactor para-meters.
Tohoku	Asperator T-3	<24	25	5	Small aspect ratio, magnetic plasma limiter.
The NETHER-LANDS FOM–Jutphaas	Torture	9	45	20	Turbulent heating
UK UKAEA—Culham	Dite	27*	117	27	Divertor and injection
USA MIT	Alcator	9.5	54	100	High current and particle densities
ORNL	Ormak	23	80	<30	Low aspect ratio, with neutral beam heating
Princeton Plasma Physics Laboratory	ATC	18 –11	90 –38	–	Ohmic heating followed by adiabatic compression
	PLT	45	132	50	Large toroidal apparatus of Tokamak type
USSR Kurchatov	T-12	8×16	36	8	Cross-section elongated along main axis of symmetry with two poloidal divertors
	TM-3	8*	40	35	Studies of thermal insulation and HF heating

Inertial confinement methods : The ideas, here, is to heat the fuel pellets of fusion ignition temperature by bringing into play on them a high power beam, the energy of which is absorbed in the outer less dense region of the fuel pellet, and then transported to the highly compressed pellet core. The pellets should be capable of achieving high density to conform to the necessary confinement times. The typical problems associated with this method are :

1. development of the driver technology, and
2. planning an effective implosion sequence and target design.

The driver requirements for a break-even case for DT reaction are estimated to require energy-100 kJ and a power of 100 TW. To construct a large-scale commercial reactor of 10 GW operating at 10 pps., a driver of a few MJ yield would be needed. The different drivers at present under consideration are :

1. high power laser beam,
2. relativistic electron beams (REB),
3. light-ion beams (LIB), and
4. heavy-Ion beam (HIB),

Laser driven fusion is one of the most difficult but promising fusion schemes under development. Laser produces very high instantaneous power density over a very small area an thus can drive a fuel pellet to ignition temperature and density. To acheive success, the laser beam has to deliver most of its energy to the fuel mass to compress the fuel by implosion before heating it and before the shock wave can disperse the fuel mass.

The state of the art is given in table 3.

Table 3. Interial Confinement

Place	Name of Machine	Type & status	Laser Power TW	Pulse energy kT	Compression gm/cm^3	Neutron yield
1. Lawrence Livermore Laboratory (LLL)	Argus	Nd-glass, operating	4.5	2.2 Jh	0.5	2×10^9
	Shiva	–do–	26	10	100	10^{11}
	Nova	Nd-glass, in construction	300	500	300	14^{18}

F–4

Place	Name of Machine	Type & status	Laser Power TW	Pulse energy kT	Compression gm/cm^3	Neutron yield
2. Los Alamos Scientific Laboratory	TBS	CO_2, in operation	0.8	0.8	0.04	10^5
Helios		CO_2, in	21 operation Since 1978	10.7	–	–
	Antares	in construction	200	100	100	10^{17}
3. Limeil	Coquelicot	Nd-glass, in operation	0.25	0.02		10^5
	Camelia	Nd-glass in operation	1	–	–	10^7
4. Osakha	Gekko II	Nd-glass in operation	0.6	0.2	0.2	10^5
	Gekko IV	–do–	4	2	–	10^7
	Gekko XII	Nd-glass, in construction	20	20	10-100	10^{14}
	Lekko I	CO_2, in operation	2	0.2	–	–
	Lekko II	–do–	1	1	–	–
	Lekko X	CO_2, in construction	10	10	10-100	10^{14}

Migma or Fusion with colliding Beams : The concept of the Migma scheme is completely different from the thermonuclear schemes. While in the schemes described above, the idea is to heat the plasma to produce thermonuclear reaction, the Migma scheme is an attempt to achieve fusion reaction by the collision of beam in intersecting orbits. Based on the concept of intersecting storage rings (ISR), developed in accelerator technology, in "Migma" (a greek word for mixture) one single accelerated beam is made to collide with itself. In the Migma chamber placed in a magnetic field an ion beam from a 3 Mev accelerator is injected. If the strength of the magnetic field decreases outwards, the ion orbit would exhibit precession in addition to revolutions. If after one half precession period, another beam is injected, the orbits will continue processing in the head-on collision configuratrion at the centre, with multiple traversal factor of about 10^8/sec. In a preliminary design called Migma III at the Migma Institute of USA, a magnetic field of 60 kG and an acceleration power of 60 kW are being planned. A prototype

demonstration plant generating continuous power of 1 kW is expected to be in operation soon. The greatest advantage of the Migma concept is that advanced fuel can be used with the consequent elimination of almost all radioactivities.

At the moment, the objective of simulating the stellar conditions in terrestrial conditions seems very remote. But if it is ever achieved and if it does not give rise to environmental and ecological hazards of such magnetudes that they cannot be controlled, then we should have solved the problem of energy for all times to come. Who would have thought that there was so much in a glass of water. But like nuclear fission, nuclear fusion may give rise to unexpected surprises and problems, and it would not be wise to be too optimistic. In any case the perfection of this technology will not take place before the 21st Century is well under way. Fusion energy may not contribute to mitigate our immediate energy crisis.

BIOCONVERSION OF ENERGY[25]

We have discussed the evolution of engines in the hands of man. We should also consider the far more wonderful energy converters that appear in

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[25.] This section has been prepared in consultation with my colleagues Prof. N. N. Saha and Dr. S. K. Ghosh.

the biologial world, which includes us. The bioenergy converters are truly awe inspiring-self-reproducing, self-regulatory and of very high efficiencies. I shall only briefly describe two systems :

1. the photosynthetic conversion system for solar energy used by the plant kingdom, which comes under the class autotrophs on which we feed, and

2. the energy conversion system within us and other members of the heterotroph class, which convert the food to energy necessary for the work that we have to do.

In living systems whether the energy is derived from the sun or from the metabolism of organic compounds, most of it is stored in adenosine triphosphate (ATP) and used when needed. ATP is transformed into adenosine disphosphate (ADP) in a reaction, which is exergonic, liberating about 9 kcal/mole. By donation of the terminal phosphate group to other molecules, ATP creates phosphorylated speecies of high free energy, which can participate in cellular reactions, that otherwise could not take place. The transformation $ADP \rightarrow ATP$ takes place at special sites in the mitochondrial, the chloroplast and the bacterial cell membranes. The specific mechanism of $ADP \rightarrow ATP$ is just beginning to be understood. It is known that large proton concentration and electropotential differentials are built up on two sides of the membrane, and the energy released in the various metabolic degradation is stored in these gradients. In the chemiosmotic theory the debris of metabolic degradations, mostly H^+ and CO_2, are removed by specific transport mechanisms, which are also responsible for the establishment of the gradients. The protons accumulated outside the membrane move in, and the ADP molecules are phosphorylated, and the resulting ATP molecules are transported out by the gradient. This is what happens in the mitochondrial and bacterial cell membranes. The process is reversed in the membranes of chloroplast where $ADP \rightarrow ATP$ transformations takes place outside the cell.

Every year the plants of the earth trap solar energy by photosynthesis and combine about 150 GT of carbon with 25 GT of hydrogen liberating about 400 GT of oxygen. Only 10% of the total photosynthesis is carried on by the green plants, the rest being done by algae, diatoms and dinoflagellates in marine environments. Broadly speaking what happens in photosynthesis in that atmospheric CO_2 is reduced recording to the equation

$$6CO_2 + 6H_2O + h\nu \text{ (sum)} \rightarrow C_6H_{12}O_6 + 6O_2,$$

which is balanced by the reverse respiratory process.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy},$$

There are two major phases of photosynthesis. In the first phase called the light reaction phase, light is captured by the pigments i.e. chlorophyll (chla), in the chlorosplast by a complicated photoinduced electron transport mechanism working through the cooperative interaction of two distinct photochemically active systems. In the second phase, the catalyser chla of the light reaction phase is restored and the ADP molecule is transformed to ATP. The carbon assimilation process in plants, using the ATP so produced, goes through by way of th Calvin cycle, which is broadly as follows :

$$2H^+ + CO_2 + 2NADPH + 3ATP + 3H_2O \rightarrow \frac{1}{6} \text{ Hexose} + 2\ NADP^+ + 3P_i + 3ADP,$$
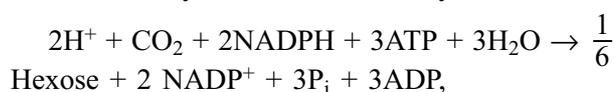
In green plants and algae, chlorophyll a and b are mainly used with the maximum of absorption of solar energy at 6500 Å and 6750 Å. Green photosynthetic bacteria use chlorobium-chlorophyll with absorption maxium at 7200 Å and 7470 Å. Other types of bacteria use other types of cholorophylls. The important difference in bacterial photosynthesis is that no oxygen is produced and the reactions take place only in the presence of suitable oxidisable matter.

For heterotophs, like members of the animal kingdom, carbohydrate is the metabolite, and the energy conversion takes place in two steps. The first part of the carbohydrate metabolism is an anaerobic process, called glycolysis, which is a process left over from the early deveopments of Evolution. The process in animal muscles starts from starch or starch like polysaccharides which produce glucose, and through a sequence of complex reactions the glucose is converted to lactic acid. Two molecules of ATP are needed to drive the glycolytic sequence or reactions and four molecules of ATP are finally produced i.e. Q ≈ 2 × 9 = 18 kcals/mole of energy is available to the cell. The effective reaction is :

Glucose + 2ATP → 2 Lactic acid + 4 ATP,
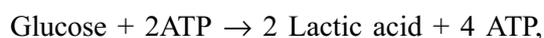
ΔG = – 54 kcal, Q = 18 kcal,

so that the efficiency of glycolysis is ;

$$\eta \approx \frac{18}{54} \times 100 = 33\%$$

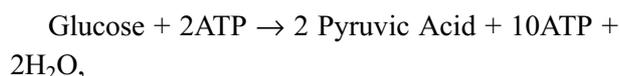In presence of oxygen the final product of glycolysis is not lactic acid but two molecules of pyruvic acid and ten molecules of ATP :

Glucose + 2ATP → 2 Pyruvic Acid + 10ATP + $2H_2O$,

ΔG = – 140 kcal, Q = 8 × 9 = 72 kcal

In other organisms, the process of glycolysis is slighly altered. In yest, for example, two molecules of ethanol are formed instead of lactic acid.

In course of evolution the mitochondrion appeared after about 23 G years, and the stage was set of find metabolic pathways to use oxygen from the environment. The second part of the carbohydrate metabolism is the final development, and is indeed an aerobic mechanism, enabling the cell to call upon larger amounts of energies stored in the organic molecules. What happens is that pyruvic acid, which is now the final product of glycolysis, is taken to further stages of degradation through a cycle, variously called the Kreb cycle,

the TCA cycle or the citric acid cycle, to finally produce carbon dioxide and water. The net effect is :

Glucose + 2ATP → 2 Pyruvic Acid + 10ATP + $2H_2O$,

2 Pyruvic Acid + $6O_2$ → $6H_2O$ + $6CO_2$ + 30ATP
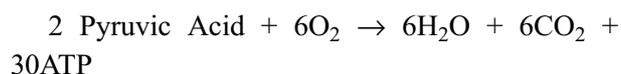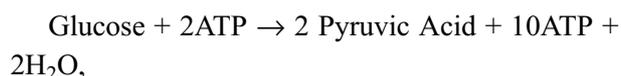
Total number of ATP molecules produced in the carbohydrate metabolism = 8 + 30 = 38, i.e. Q = 9 × 93 = 342 kcal. Also ΔG = – 688 kcal. Thus the efficiency of the reaction is :

$$\eta = \frac{342 \times 100}{688} \approx 50\%.$$

Had we constructed a heat engine working between the normal body temperature 37°C and a condenser temperature 20°C, we would have an efficiency of only 5.5% which would mean only about 38 kcal of the total of 688 kcal would be usefully available. This demostrates our high efficiency as bioengines.

I regret that I have no time to describe the other wonderful aspect of the bioengines evolved by nature, viz, their sensing and monitering systems for rapidly changing external and internal environments, together with the extremely efficient autocontrol and regulatory mechanisms, which evolution has incorporated within the system.

The complex sequence of equations described above should not divert our attention from the basic fact that, what is being achieved through all these complexities is a very simple chemical reaction, viz the combustion of hydrogen by combination with oxygen, forming water. The carbon skeletons of the metabolite molecules only provide a suitable reservoir to store the energy of this combustion to make it available when needed.

ENERGY POOLS OF EARTH

The principal energy pools of the earth from which we draw energy, originate from the sun and the earth acting separately and in conjunction. The

nuclear fuels-uranium and thorium are found in earth's crust. In some regions of the earth there are other sources of energy which are classed as geothermal energy (volcanoes, hot rocks and hot springs). The earth, in conjunction with the moon, produces tides and tidal currents. The atmosphere of the earth heated by solar radiation generates winds, which also have served the energy needs of man. In the materials drap within the earth, man has loked for fuels. We are searching for a technology to liberate energy out of earth's water by the fusion process and also for a technology for cheap production of hydrogen the emerging fuel. But in the immediate past, for more important were the pools created by the sun. We have seen how nature has worked out wonderful conversion mechanisms to store energy in the living bodies. The living bodies, after death and passage of millions of years, are converted under suitable conditions into the fossil fuels, which have been our main energy source so far. We are considering also how we can ourselves transform solar energy to a form directly and immediately useful to us. Some of the pools-the pools of fossil fuels and the nuclear fuels, are of limited dimension and therefore of limited duration. The biological pools like those derived form the forests and the vegetables and the animal wastes are replenishable. Other pools, which depend on earth's internal heat and sun's radiated energy, are eternal for all practical purpose.

GROWTH RATES AND MODELS FOR WITHDRAWAL FROM LIMITED STOCK

Before we consider the next part of the theme, a word about growth rates is necessary. There are many ways of estimating growth rates. One methods is by the index number K_n

$$K_n = 100\, P_n/P_o, \tag{1}$$

where P_o is the value of what is to be estimated at some selected fiduciary year and P_n is the value after n years. If the growth is according to an annual compound rate x% (x = APGR = annual

percentage growth rate) then the growth is exponential

$$P_n = P_o\left(\frac{1+x}{100}\right)^n = P_o e^{n\lambda},$$

where $\lambda = 1n\,(1 + x/100)$ year^{-1}

The APGR x is given by

$$x/100 = \text{anti log}\, [(\log P_n - \log P_o)/n] - 1 \tag{2}$$

The doubling time is given by

$$\tau = \log 2/\log\,(1 + x/100) \text{ year.}$$

The cumulative sum S_n is given by

$$S_n = \sum_i^{o,n} P_i = \frac{100 P_o}{x}\left[\left(1 + \frac{x}{100}\right)^{n+1} - 1\right]. \tag{3}$$

If we have a reserve R of some commodity and the production at t = 0 is P_o and the APGR is x%, then the time when the reserve is exhausted is N years where

$$N + 1 = \log\left(1 + \frac{x}{100}\cdot\frac{R}{P_o}\right)\Big/\log\left(1 + \frac{x}{100}\right). \tag{4}$$

This equation will be used in this study for making estimates of the life time of the reserves. For source limited growth the production curves is not exponential but has the shape of a bell i.e. the production rises, reaches a maximum and then declines. A model of this type has been given by Elliot and Turner[26]. According to this model if S is the cumulative production, then the annual production P = dS/dt is given by

$$\frac{dS}{dt} = \frac{\lambda S}{R}\left(1 - \frac{S}{R}\right), \tag{5}$$

where R = the lutimate resource produced and λ = a constant. The first factor on the right takes care of the demand, and the second factor depends on the remaining supply. This equation integrates to

$$S = \frac{R}{1 + e^{\alpha - \lambda t/R}}, \tag{6}$$

where α is the constant of integrations. The maximum production occurs at $t = t_m$ when dP/dt = 0 i.e. $S(t_m) = R/2$. This gives

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26. M.A. Elliot and N. C. Turner : American Chemical Society meeting, Boston, Massachusetts April (1972).

$$\alpha = lt_m/R \qquad (7)$$

i.e. $\quad S = \dfrac{R}{1 + e^{-\lambda(t-t_m)/R}}, \qquad (8)$

The annual production is given by

$$P = \frac{\alpha e^{-\lambda(t-t_m)/R}}{[1 + e^{-\lambda(t-t_m)/R}]^2}$$

$$= P_0 e^{\lambda t/R} \text{ as } t \to 0, \lambda/4 \text{ as } t \to t_m, 0 \text{ as } t \to \pm\infty,$$

where $P_0 = P\ (t = 0) = \dfrac{\lambda e^{\lambda t_m/R}}{\left(1 + e^{\lambda t_m/R}\right)}$, The curve

S(t) rises with t, passes through the value R/2 at t_m and reaches a saturation value R as $t \to \infty$. The curve P(t) first grows with t, reaches a maximum at t_m and then decays to zero as $t \to \infty$. The estimate of the time of exhaustion of a fuel supply depends on the time when P effectively vanishes. The parameter λ may change with time with development of technology of fuel recovery and production. The parameter R depends on total resource available with a given recovery technology. There are other similar models (Hubert[27]). I shall not however use these models, for in the first place the parameters for mining of various fuels in India are yet to be estimated, Moreover, what predictions I have to make do not need such a refined time analysis; infact the production of various fuels in India seem to follow, at least for the present, the exponential growth. It will, therefore be sufficient to adopt a simple exponential growth for which equation (4) will do.

FUELS

The nonrenewable fuels that are most widely known are : fossil fuels — coal, oil, natural gas, oil from shales and tar sands and the nuclear fuels — uranium and thorium. These fuels are handled by normal market procedures and are therefore known as commercial fuels as distinguished form noncommercial fuels-firewood, animal dung and vegetable waste, which are seldon bought or sold

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27. M. K. Hubert : Energy resources for power production in environment aspects of nuclear power stations, Vienna International Atomic Energy Agency p 13-43, (1971).

and are gathered by consumers. In estimating the fuel resources certain distinctions are made. When assessing the total fuel recoverable from the deposit, there are many economic and technological considerations whether the mine can be worked. Even if the mine is worked, it can be worked only for some limited time after which the existing recovery technology becomes too expensive. The resources which can be immediately recovered by normal techniques are the reserves. The parts which can be recovered at some future date, when it is economic to use more expensive technology, which may exist or may have to be developed, are called the submarginals or the indicated resources. Thus when we say that a particular resource is exhausted, the statement is to be understood against the economics of available recovery technology. There may be quite an amount of resources still left in the deposits, but it may be too expensive to recover it for consumption. In addition there may be other deposits not yet discovered, but for which sufficient geological evidence exist. These are called inferred resources.

I shall now speak about each individual fuels, and describe the global and Indian reserves, submarginals and inferred resources and the various processings to which they are required to be submitted.

FOSSIL FUELS

Coal : Coal is a type of rock consisting of plant organic material, occuring as individual beds with sandstones, shales and clays in a sedimentary sequence. In different geological ages, mainly in the Carboiniferous period, plant materials were deposited in inland bogs, coastal swamps and the river deltas. In course of millions of years, through burial and consequent rise of temperature and pressure, the organic matter was compacted, and in presences of moisture and absence of air, underwent fermentation processes, and passed through various stages of codification. The various stages are, on water and air free basis

1. Wood :C~51%, H~6%,O~43%,
2. Peat : C~60%, H~6%, O~34%,
3. Lignites : C~66%, H~6%, O~28%,
4. Subbituminous coals : C~75%, H~5%, O~20%,
5. Bituminous coals : C~91%, H~4%, O~5%, .
6. Anthracite : C~96%, H~3%, O~l%,

The calorific values change as follows

1. Wood : 7747 Btu/lb,
2. Peat : 7030 Btu/lb,
3. Lignite : 7000 Btu/lb,
4. Subbituminous coal : 9500 Btu/lb,
5. Bituminous : low volatile 14000 Btu/lb, high volatile 13500 Btu/lb,
6. Anthracite : 12700 Btu/lb.

Coking coals are used for metallurgical purposes, and is produced by dry distillation and incomplete combustion of coal to boil off the volatile matter with enrichment of the carbon component. Not all coals can be cokified. Charcoal was earlier used in metallurgy and was produced by charring wood. In India coal occurs in two stratigraphic horizons[28] :

1. the lower Gondwanas of the permian age, and
2. the coal and lignites of the Tertiary age.

The Gondwana coals are set in the basin like depressions of older formations and are aligned along four main river valleys :

1. Damodar-koel,
2. Sone-Mahanadi,
3. Pranhita-Godavari and
4. Satpura basin. Outside these river basins are the coal fields of Rajmahal Hills and the Deoghar group.

All these are found in the golden triangle defined by the 24° N latitude line, 78° E longitude line to 16° N latitude and then to 88° E. The tertiary coals

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28. T. N. Basu and T. P. Basu : Coal resources and extraction technology in india.

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are best developed in the north eastern region. The lignites are found in Kashmir, Rajasthan, Gujrat and Tamilnadu. Unfortunately, no new coal fields have been found recently.

Coal exploration techniques are the normal geological prospecting techniques. Recently geologging techniques, measuring resistivity, density and γ-radioactivity, are also being employed. Coal mining methods depend largely on the orientation of the coal seams with respect to the surface. The usual methods for underground mining are :

1. room and pillar method,
2. long wall technique, and
3. short wall technique.

The tecniques of surface mining are :

1. cover area stripping,
2. contour stripping and
3. Auger mining.

A concept tried experimentally in USSR and USA viz. underground gasification of coal, is worthy of consideration because :

1. the products are cheaper on account of low investments,
2. environmental perturbations are smaller,
3. mining hazards are avoided and
4. a possibility opens of going to very great depths.

In India 25-27% of the coal comes from surface mining. The low scale of wages, the necessity of generating employment, and the scarcity of capital and various technical reasons, have dictated the very primitive methods followed. The stripping of open cast mining is only 3 : 1, and the average output is 0.3-2.5 MT per annum from a mine. Underground mining employs bord and pillar method, though recently the long wall technique has been tried. The mining equipments are also very primitive. By 1973 all Indian mines, excepting a few captive mines, have been nationalised. It is a matter of great regret that nationalisation has not effectively improved mining of coal in India or its distribution and avilability.

Coal is classified in a variety of ways :

1. by type depending upon the plant type which generated it and the geological modification that followed.
2. by rank to indicate the degree of metamorphism and finally
3. grade to describe the composition of impurities in it.

Very powerful methods have been developed to determine the above characterisations of coal[29]. In India though all types of coal are available, very little care is taken to characterise them, which lessens their utility for a particular end use. There is a great shortage of coking coal in India, all of which comes from only one particular mine in Bihar. Infact we have started importing coking coal.

GSI estimated in 1976 the coal and lignite deposits in India for seams 1.2 m and above, and upto depths of 600 m as given in the following table.

Indian Coal Resources (in GT)

	Proven Reserve	Submarginals	Inferred	Total
Prme coking	3.25	1.59	0.46	5.30
Medium coking	3.79	4.27	1.31	9.38
Semi to weakly coking	1.21	2.60	0.91	4.72
Total coking coal	8.25	8.46	2.68	19.40
Noncoking coal	12.49	23.61	28.25	64.35
Total coal	20.74	32.07	30.93	83.74

According to the recovery technology used in Indian mines, only 55% of the noncoking coal in extractable, of which 25% has to be rejected because of high ash content, reducing the usable percentage to $0.75 \times 0.55/100$ i.e. 41% only. For coking coal this figure is still lower viz. 29%, because of the

29. B. R. Cooper : Research challenge-clean energy from coal, *Physics Today* Aug. 1978.
30. Energy : Global prospects 1985-2000. Workshop of alternative energy strategies Me. Graw Hill Book Co.

loss at washeries. This gives the recoverable coking coal as $29 \times 19,40/100 = 5.62$ GT, and the recoverable noncoking coal as $41 \times 64.35/100 = 26.38$ GT. Thus the total recoverable coal is only 32 GT.

According to the estimates of the workshop of alternative energy strategies (WAES)[30], the global coal reserves and resources in 1974 are as follows

Global Coal (in GT)

Proven reserves	Total (Reserve + Submarginals + Infrared)
737	1327

Thus India has only 2.8% of world's proven reserves of coal and only 6.3% of world's total resources of coal.

Coal conversion technology : Coal is not convenient for many end energy uses; transport, domestic and agriculture sectors are examples. It is some times imperative, particularly in the background of oil scarcity, to convert the coal into liquid or the gaseous forms for convenience of transport and domestic consumption. The basic reactions of coal gasification are

1. Hydrogasification :

$$C + 2H_2 \rightarrow CH_4 \quad \text{Coal methenation}$$

$$\left. \begin{array}{l} C + H_2O \rightarrow CO + H_2 \\ CO + H_2O \rightarrow CO_2 + H_2 \end{array} \right\} \text{Cracking of water}$$
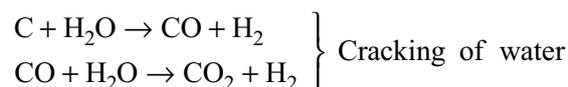
2. Catalytic shift conversion

$$CO + H_2O \rightarrow CO_2 + H_2$$

3. Catalytic methenation

$$CO + 3H_2 \rightarrow CH_4 + H_2O$$
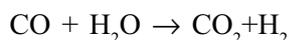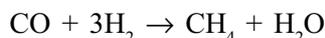
These are the basic processes, and many production methods are on trial or in course of development. The idea is to enrich the methane content of the gas produced, or alternatively to extract the hydrogen itself as the output fuel. The main systems are

1. hydrogasifier systems,
2. steam-iron systems and
3. electrothermal systems.

There are three basic ways to liquify coal :

1. addition of hydrogen,
2. depletion of carbon (pyrolysis), and
3. breaking coal down to individual carbon atoms and resynthesising to desired liquid fuel.

In this area intense global R & D work is going on, and in India also we must immediately intensify the research already started. Sir J. C. Ghosh had initiated a number of studies on this subject by a number of committees of the Government. We may mention some projects which are going on abroad; coal gasification — Atgas, Bigas, Cogas, Hygas, hydrane, Synthane; coal liqufaction; COED, CONSOL, H-coal-process, hydrosulphurisation, Meyer's process, solvent refined coal process, Synthoil.

Oil and Natural Gas : Petroleum is the general name of the liquid form of fossil fuels. Decay of plants and animal matter in ancient marine environments in course of million of years gave rise to oil and natural gas.

Oil prospecting technology is very sophisticated, employing seismic and magnetic measurements for detection of rock structure formations, which are capable of bearing oil deposits. The technology is so well developed, that it is possible to prospect and extract oil from the deposits on the continental shelves and deep oceans. Recently satellites like Landsat are being used for oil prospecting by remote sensing methods.

In India the petroleum geologists have marked 27 basins on land and offshore - a sedimentary area of about 1.41 M km^2 on land, and 0.26 M km^2 laying within 100 m isobath of offshore shelf zone. Most successful has been the exploration and oil extraction in Assam-Arakan area and the Cambay basin. In the later basin, the recently discovered oil deposits in Gujrat and the Bombay high structure

are well known. The rate of discovery of new oil deposits seems encouraging.

Oil recovery technology is very well developed. In the primary method, oil is driven out of the well by the pressure of the deposits inside the well. Other methods are:

1. stimulation by fluid injection,
2. reduction of viscosity of oil by mixing with gases and surfactants,
3. thermal stimulation by steam injection,
4. underground ignition and
5. acidisation.

Nuclear stimulation has been tried in USA to fracture oil bearing rocks, but public opinion, there, is against this technology.

Products from oil refineries are vital in the economy: Liquid Petroleum Gas (LPG), gasoline, kerosene and air turbine fuels, gas oils, High Speed Diesels (HSD), Light Diesel Oil (LDO), fuel/furnace oils, lubricating oils and greases, and petroleum coke are some of the petroleum products. Because of the convenience of use and easy and cheap availability prior to the OPEC embargo in 1974, there was a dramatic global switch over from coal to oil in the sixties, and India also followed suit. In absence of oil all these products must be substituted by coal derived products.

According to an estimate by ONGC made in 1978 the total resources of oil and natural gas, including the reserves, the submarginals and the inferred resource are shown below

Indian Oil and Natural Gas

Oil (GBbl)	Natural gas (Tft, 3)
2.06 GBbl $\equiv$ 282 MT	3.4

WAES[31] gives the global reserve of oil as follows

Global Oil and Natural Gas

Oil Proven reserve (GBbl)	Natural gas proven reserve (Tft)
658	2352

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31. Energy : Global prospects 1985-2000. Workship of alternative energy strategies Me. Graw Hill Book Co.

Thus India has only 0.3% of world's oil reserve and 0.15% of world's natural gas reserves.

HYDROGEN-THE FUEL OF THE IMMEDIATE FUTURE[32]

It is clear that prospects for conventional fossil fuels for this country are not bright, though the oil gap may be attempted to be met by ethanol from biowaste, the possibilities of which we shall discuss while considering the technology of using biomass for energy. We have therefore to look for some radically new fuel, and this brings us to hydrogen, the emerging fuel.

The element hydrogen, which is so abundant in the universe, is ninth in abundance by weight in the earth's crust. It is found in many organic and inorganic substances on earth, but most of it exists in the form of water, which is therefore the ultimate source of this fuel. The calorific value of hydrogen is 68.32 kcal/mole at 25°C, which compares well with those for the fossil fuels. It is an ideal fuel in the sense that it is non-polutant, the production of combustion being water which is good for the environment.

The present methods of production of hydrogen are :

1. coal gasification, which we have mentioined already and which is Of limited use because of limited availability of coal, and
2. various water cracking methods :
   a. electrolysis,
   b. thermal decomposition,
   d. hybrid methods, and
   e. photolysis.

The most promising of all these methods is the thermochemical cracking of water. The major difficulty is the high Gibb's energy for the reaction.

[32.] I have received help in preparing this section from my colleague Dr. B. G. Ghosh
[33.] C. Marchetti : Chemical Economy & Engineering Review 5, (1973); G. de Beni and C. Marchelti : A chemical process to decompose water using heat, Am, Chem, Soc, Meeting, Boston, 9 April (1972).

$H_2O + H_2 + \frac{1}{2}O_2,$
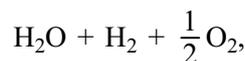
Thus to get any appreciable reaction rate from this reaction very high temperatures would be needed. The problem has been solved by achieving the target through a number of intermediate steps with simaller Gibb's energies, which permit the intermediate reactions to run efficiently at lower temperature. A very encouraging reaction system examined by Marchetti[33] and called by him Mark I, is

a. Mark I reaction system

$CaBr_2 + 2H_2O \rightarrow Ca(OH)_2 + 2HBr$ (730°C),

$Hg + 2HBr \rightarrow HgBr_2 + H_2$ (250°C),

$HgBr_2 + Ca(OH)_2 \rightarrow CaBr_2 + H_2O + HgO$ (200°C),

$HgO \rightarrow Hg + \frac{1}{2}O_2$ (600°C)
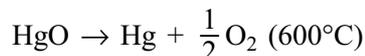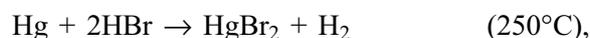
Many other cycles have been proposed :

b. $Cl_2 + H_2O \rightarrow 2HCl + \frac{1}{2}O_2$ (800°C),

$2HCl_3 + 2VOCl \rightarrow 2VOCl_2 + H_2$ (170°C),

$4VOCl_2 \rightarrow 2VOCl + 2VOCl_3$ (600°C),

$2VOCl_2 \rightarrow 2VOCl + Cl_2$ (200°C),

c. $Cl_2 + H_2O \rightarrow 2HCl + \frac{1}{2}O_2$ (800°C)

$2HCl + \frac{1}{2}S_2 + 2FeCl_2 \rightarrow H_2S + 2FeCl_3$ (100°C),

$H_2S \rightarrow H_2 + \frac{1}{2}S_2$ (800°C),

$2FeCl_3 \rightarrow 2FeCl_2 + Cl_2$ (420°C),

d. $2H_2O + SO_2 + xI2 \rightarrow H_2SO_4 + 2HI_x$ (27°C),

$2HI_x \rightarrow xI_2 + H_2$ (77°C–177°C)

$H_2SO_4 \rightarrow H_2O + SO_2 + \frac{1}{2}O_2$ (827°C–927°C)
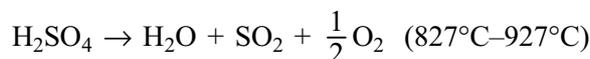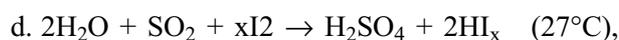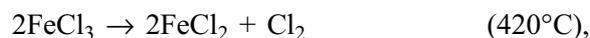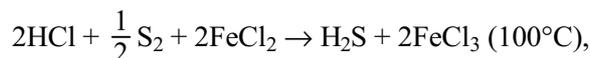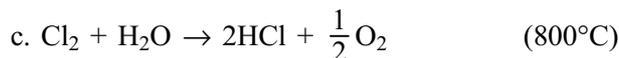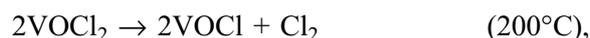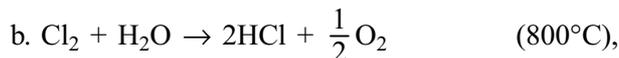
I_x represents a mixture of several polylodides.

A typical plant employing cycle d) may produce hydrogen at the rate of 40 g mole/h. The empirical overall efficiency of hydrogen production is defined by

$$\in = \frac{\text{heat obtained by combustion of 1 mole of } H_2}{\text{Total heat input for production of } H_2}$$

The efficiency of the various hydrogen production cycles are still under study. Marchetti expects efficiencies in the region of 45-50%. So far cost of production is concerned, it is expected to be in the region of $ 1.50 per MBtu, which may be an assessment on the high side. Solar energy can be utilised in the sulphu-iodine cycle d) to produce hydrogen.

The classical method of splitting water is of course electrolysis but this is too heavily electricity intensive. The main motivation of the RεD in this area is to reduce the electricity input by considering the thermodynamic aspects of the reaction. Indeed it is possible to devise a system working at about 1000 °C, in which 46%, of the energy for the cracking of water would come from thermal sources. Improvements for reaction kinetics at the electrodes are also going on at a quick pace.

In the hybrid cycle some of the reactions in a cluster of reactions in the thermo-chemical decomposition of water are not driven thermally, but are carried on in an electrolytic cell. One potentially successful hybrid cycle was proposed by Schultz and Fiebelmann[34].

$$SO_2 + Br_2 + H_2O \rightarrow 2HBr + H_2SO_4,$$

$$2HBr \rightarrow H_2 + Br_2,$$

$$H_2SO_4 \rightarrow H_2O + SO_2 + \frac{1}{2}O_2$$

The prospects for hybrid cycle production of hydrogen seems quite bright.

Photolysis of water by absorption of solar radiation in region of wavelength 1800-1900 Å does not seem very promising; however if fusion reactions develop they may provide a suitable source of necessary photons for photolysis.

The public mind has not yet accepted hydrogen as a possible energy fuel because of its possible

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[34]. Schulz, G. and Fiebelmann, P. 'Electrolysis of hydrobromic acid, 2nd World Hydrogen Conference, Zurich, August (1978).

hazzards. But careful work has shown that as a fuel hydrogen can be safer than coal gas provided ceartain precautions are taken. Hydrogen has already been adapted in internal combustion engines for providing motive power for road and air transport. Its use for rocket propulsion is well known. Hydrogen can be efficiently stored as hydrides and in the latti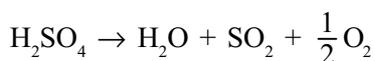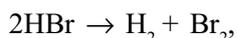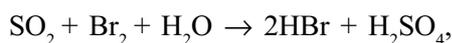ce structures of certain rare earth metals. The following table gives the ratio of weights/ volume of hydrogen container to gasoline container for the two fuels of same energy.

Storage type	By weight (inclusive of weight of container)	By volume
Gas at 200 psi	15.0	24.5
Metal hydride (Magnesium hydride with 40% prosity)	4.6	4.0
Liquid hydrogen	2.4	3.8

Hydrogen can be also piped to the user in conventional pipelines as has been demonstrated in some countries in Europe. A very important nonenergy use of hydrogen is the possibility of using it in place of coke for metallurgy as a reducing agent. The water pool from which hydrogen can be drawn is of almost limitless dimension, and is constantly replenished by its combustion in course of use. Hydrogen can indeed be called the fuel of the immediate future. We shall see that unless intense RεD is started on hydrogen production and utilisation technology immediately, we shall be in serious trouble after 1990.

FUEL CELLS

Fuel cell is a very old concept given by Grove in 1839 which received renewed attention because of its success in space programmes. It is a galvanic energy conversion device, circumventing the limitations of the Carnot cycle. The energy is supplied in the path : Chemical energy—electrical energy, and an efficiency 100% can be theoretically expected. The overall chemical reaction is :

fuel + oxidant → reaction product + heat,

Anode : fuel → fuel oxidation product + ne,

Cathode : oxidant + ne → oxidant reduction product.

Also, $\Delta G = -nFE = \Delta H - T\Delta S$, where F = Faraday constant, E = electric voltage across the cell. The change of chemical energy $Q = -\Delta H$. Thus efficiency of the fuel cell is

$$\eta = \frac{nFE}{Q} = \frac{\Delta G}{Q} = 1 - \frac{T\Delta S}{H},$$

Theoretically the efficiency achieved is much higher than what is possibe for thermal engines. Some typical reaction systems used in fuel cells are given in the following table.

Some reaction systems under tiral for fuel cells

Basic reaction	n	T = 300°K		T = 900°K	
		E (volts)	η	E (volts)	η
$C + O_2 \rightarrow CO_2$	4	1.02	1.00	1.02	1.02
$2C + O_2 \rightarrow 2CO_2$	4	0.70	1.25	0.98	1.75
$2CO + O_2 \rightarrow 2CO_2$	4	1.33	0.91	1.06	0.72
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	8	1.04	1.00	1.04	1.00
$2H_2 + O_2 \rightarrow 2H_2O_4$	4	1.18	1.94	1.03	0.80

It is seen from the table that η may be > 1. We shall illustrate by analysing the reaction representing the combustion of hydrogen at 150°C. The thermodynamic potentials in the steam cracking reaction at 150°C.

H_2O (gas) → $H_2 + O_2$,
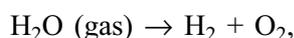
are[35] $\Delta H = 58.14$ kcal/mole, $\Delta G = 52.99$ kcal/mole and ΔS at this temperature is 12×10^{-3} kcal/mole. Therefore,

$$\frac{T\Delta S}{\Delta S} \text{ at } 150°C = \frac{423 \times 12 \times 10^{-3}}{58.14} = 0.087.$$

Thus the efficiency of the fuel cell for hydrogen system at 150°C i.e. 423°K

$\eta = 1 - 0.087 = 0.913$ or $\sim 91.3\%$

35. J. O. M. Bockris Energy : The solar hydrogen alternative p. 159. The Architectural Press, London (1979).

The thermodynamic efficiency of a fuel cell, therefore, depends on the magnitude and the sign of the entropy change during the reaction. Accordingly, when gaseous substances are consumed in course of the reaction, entropy of the system may be expected to decrease, and the theoretical efficiency would be smaller than unity; when gaseous substances are formed the opposite effect is observed. Of course, the practical efficiences of the existing fuel cells are much lower than theoretical values, but these values greatly exceed the efficiencies of heat engines.

Important consideration in determining the usefulness of fuel cells as an electric power source are the fuels, their cost, availability, energy density, toxicity, handling problems like transporation and storage, It is not possible here to discuss the various chemical systems and fuel cell designs which are under trial. some of these are given in tables 4 and 5. The prospects are indeed very bright. The important features of a fuel cell on its credit side are :

1. there is no moving part in the cell,
2. It is highly efficient,
3. it is a silent device,
4. it can be made on modular principle, and
5. it can be switched into use or switched off immediately and need no idling time. However, the power density output is low, rarely exceeding 1 kW/kg.

Coal fired fuel cells may be useful for central electricity production. Though the first entry or hydrogen in energy economy is expressed to be through internal conversion engines, the final form of the transducers fed by hydrogen energy may well be the fuel cells because of their higher efficiency. Fuel cells will be used wherever portable power plants are necessary and in sectors where silence and avoidance from polution are desired. In the urban sector fuel cell powered vehicles may ultimately replace the internal conversion engines that are in use today and against which there is so much objection from environment protectionsist.

Table 4. Advanced Fuel Cell Systems

	Electrolyte	Reactant	Electrode catalyst	Heat & water removal	Cell construction and observation
Alstholm (France)	KOH	Hydrazine (N_2H_4 - H_2O_2)	Ag/Co	Circulating electrolyte	Nonporous electrodes density packed, surface coating cat.
Engelhand Mineral Chemicals Corp.	Cone. H_2PO_4	Impure H_2-air	Pt Metal	Air or circulating coolant	Hydrophobic electrode matrix type construction bipolar stacking operates at atm. press.
Siemens Ag. (Germany)	KOH	$H_2 - O_2$(air)	Raney Ni/Ag	Circulating electrolyte	Cat. layer supported on asbestor sheet, operates at 1 atm. press
Varta (Germany)	KOH	$H_2 - O_2$ (air)	Raney Ni/Ag	Circulating electrolyte	Electrodes of carbonized Ni substrate with embedded Raney catalyst, operating 1 atm.
Pratt & Whitney Division, United Tech. Corpn.	KOH	$H_2 - O_2$ (air)	Pt. metal Ag	Evaporative cooling	Matrix-type construction
Pratt & Whitney Division, United Tech. Corpn	Cone. H_2PO_4	impure H_2 — air	Pt. metal	Air or air with circulating cooling	Detail not published

Table 5. Synthetic fuels for fuel cells

Fuel	Storage	Basic reaction	Hazards
Hydrogen 200 atms guage pressure	Compressed gas	None	Hazardous famable gas
Reversible hydride (Fe, Ti-hydride ect)	Solid	Hydrogen release $FeTiH_{0.1}+H_2 \rightarrow FeTiH_{1.95}$	
Non reversible solid hydride (CaH_2)	Solid	Reaction with water $CaH_2 +2H_2O \rightarrow Ca(OH)_2 +2H_2O$	Flamable solid
Methanol	Liquid	Steam reforming at 200°C $CH_3OH + H_2O C_2 + 3H_2$	Hazardous flamable liquid
Anhydrous NH_3	Compressed liquid	Thermal cracking at 750°C $2NH_2 \rightarrow N_2 + 3H_2$	Hazardous material poisonous liquid
Hydrazine hydrate	Liquid	None	–

I cannot stress too much that intense RεD is necessary in the area of fuel cells and in the allied field of electrode developments.

FUEL FROM BIOMASS

Search for alternative sources of energy basin in recent years focussed attention on the energy possibilities of biomass derived from both land and aquatic sources.

Biowaste : An important component of biomass is biowaste which can be classified in the following boad groups :

1. agrowaste-sugar cane trash, weed, crop stubble, straw and spolied fodder,
2. agroindustry waste-oil cakes, baggase, rice brans, tobacco wastes, fruit wastes and vegatable processing wastes, tea wastes, jute wastes, textile industry wastes,
3. forest litters-twigs, branches, barks and leaves,
4. acquatic biowastes-marine algae, sea weeds, water hyacinths,
5. human waste-facces, urine and other wastes and
6. animal wastes-cattleshed wastes (durg, urine, general litter), poultry litter, sheep and goat droppins, slaughter house wastes (blood and meat), fish waste, leather and wool waste.

Many of the waste materials have very important nonenergy use as source of organic manures and in paper and hard board industry. But in recent years, because of the possibility of obtaining methane from these wastes by anaerobic fermentation, these materials have achieved the status of important sources of energy.

Anaerobic degradation of plant waste depends on its cellulose content. The presence of lignin is a nuisance, for it is nonbiodegradable and protects the cellulose from bacterial attacks. The biodegradation takes place in three stages :

1. anaerobic bacteria bearing cellulolytic, lipolytic and proteolytic potency convert the cellulose, the lipids and the proteins into soluble monomers;

2. these then serve as the substrates for the microorganisms for conversions into soluble organic acids-mainly acetic acid; and finally

3. these acids are reduced by hydrogen or formic acid, generated by other bacteria, and converted to methane. If efficiently run 8–9 ft^3 of gas containing 60% of methane per Ib of biomass can be obtained. The sludge after biogradation contains noncellulosic materials, mainly ligin, which can be used as manure.

All over the world the production of methane from animal waste has aroused considerable interest. In India by the middle of 1973 about 6250 so called gobar gas plants have been set up under the supervision of KVIC in various Indian states. We give a rationale of a typical plant and analyse the economic benefits from it. The basic data on drug outturn of Indian cattle is taken from Meghnad Saha's[36] very last paper published posthurously. Gobar gas plant is a multiproduct output unit in which a fuel of low quality is transformed into a fuel of high quality together with a sludge which has merits as a manure, so that here is a case of having the cake and eating it too. We give an analysis of the advantages of conversion of dung into biogas and sludge.

36. Meghand Saha. Fuel in India. *Nature* p. 923 May 19, 1956
37. Survey of rural energy consumption in northern India, National Council of Applied Economic Research.
38. C. N. Acharya, Organic manures series No. 2 p. 13, National Council of Applied Economic Research.
39. K. S. Parekh : Energy-Second series. (1976).

BASIC DATA ABOUT DUNG AND ITS DERIVATIVES :

Dung :

5 kg of green dung = 1 kg of dry dung.
Thermal value of dry dung = 2444 kcal/kg (SRECNI[37]).
Cumbustion efficiency of dry dung = 11%
Thus heat available from dry dung = 269 kcal/kg = 54 kcal/kg of green dung.

Fertiliser value of dung :

1 kg of green dung = 3.5 gm of nitrogen, 1.2 gms of P_2O_5 and 1.7 gm of K_2O (C. N. Acharya[38]).

Compost from dung (Parekh[39]) :

1 kg of green dung = 0.1 kg of compost containing 1.5 gm of nitrogen.

Average outturn of green dung per cattle head = 13.5 kg/day of which only 40% is usually collected (Meghnad Saha quoted above. See also the discussion of noncommercial fuel of India in this address).

Biogas :

Calorific value of methane = 5.93 kcal/L.
% of methane in gobar gas = 60% (Parekh).
Thus calorific value of gobar gas = 3.6 kcal/L.

Gobar gas yield = 36.25 L/kg of green dung (Parekh). Of this the thermal value is 130.5 kcal. The yield is dependent on the season, being less in winter than in summer.

Dry sludge (Parekh) :

1 kg of green dung yields 144 gm of sludge.
1 kg of sludge contain 20 gm of nitrogen.

Dimension of biogas plant :

Digestion time ~ 50 days.

1 kg of green dung mixed with water produce. 357×10^{-3} m^3 of slurry. Thus if x kg is the daily input of green dung, then volume of the digester should be

$$V = 17.8 \times 10^{-3} \times m^3.$$

We give the calculation for a plant of digester volume ~ 1 m³, so that the input of dung is required to be 56.2 kg of green dung per day. If the dung collection is at 40% efficiency, then the number of cattle head necessary to yield this outtum of green dung is about 10, whereas if the plant has a dairy attached to it, only 4 cattle heads are necessary. An input of 56.2 kg/day of green dung ≡ 20.5 T/year of green dung.

Evidently dung treated through a gobar gas plant is more useful both as a fuel and as a manure. But it must be realised that dung is a poor man's fuel. Any attempt to commercialise or monopolise it in the hands of the richer classes of the society, who are able to affort gobar gas plants, may lead to the poorer classes being deprived of this fuel, which would create a social problem. There are other problems—the spread of sophisticated technology necessary to build gobar gas plants among villages in remote parts of the country, efficient method of collection of dung and night soil, the mechanism of transporting the gas to rural consumers, and similar problems, have yet to receive easy workable solutions.

Table 6 : Benefit analysis of a gobar gas plant of volume 1m³.

Factors uder consideration	Yield	Combustion	Fertiliser
1. Green dung	56.2 kg/d ≡ 20.5 T/y		
Dry dung	11.2 kg/d ≡ 4.1 T/y		
Thermal value		3.03 Mcal ≡ 1.11 Gcal/y	
Fertiliser value			196.7 g/d ≡ 71.8 kg/y of nitrogen, 67.4 g/d ≡ 24.6 kg/y of P₂O₅ and 95.6 g/d ≡ 34.9 kg/y of K₂O
2. Gobar gas	2.04 kL/d ≡ 0.744 ML/y		
Thermal value		7.34 Mcal/d ≡ 2.68 Gcal/y	
Sludge	8 kg/d = 2.95 T/y		
Sludge-fertiliser value			160 g/d ≡ 58.4 kg/y of nitrogen
3. Compost	5.62 kg/d ≡ 2 T/y		
Fertiliser value			84.3 g/d ≡ 30.8 kg/y of nitrogen

Biomass : Biomass or biota is a more general term compared to biowaste and encompasses all biological materials originating in land and aquatic environments. There are very strong arguments for and against large scale conversion of biomass for energy and other uses. Arguments against are :

1. though biomass is perennial i.e. a replenishable source of energy, the quantum of land available to grow it is limited because of very pressing demands for other uses, and

2. planned production of biomass will need many basic inputs-water and inorganic nutrients for replenishment of the soil.

Arguments in favour are :

1. sufficient powerful technologies exist to convert biomass into fuels like ethanol, and no lead time is required to use these technologies in our economy,

2. much of the biomass can be grown on barren and fallow lands, and valuable agricultural lands need not be trespassed and on.

3. muhc of the biota can be grown in acquatic environments.

At present there exist three different pathways for extracting energy from biomass :

1. direct combustion of biomass,
2. chemical treatment of biomass for production of,
   a. compounds rich in carbon and hydrogen
   b. compounds poor in oxygen and nitrogen-elements which do not add to the energy content.
   c. compounds rich in double bonds, and
   d. compounds rich in ring structures, and
3. as feed materials for work animals.

It is will know that the efficiency of conversion of food energy to work by animals is about 4.5% only. This is too small, and apart from the fact that work animals must have food, there is not much interest in converting biomass into animal food.

The pathways to convert biomass into energy fuels are :

1. thermal
2. purely chemical and
3. biological

The thermal methods embrace patrial oxidation, hydrogenation, pyrolysis and steam reforming. The chemical process include hydrolysis-chemical and enzymatic, and other chemical conversion methods. The biological processes include anaerobic fermentation biophotolysis and similar methods. The conversion efficients can be very high.

A very high interesting aspect of biomass conversion is that is product can be integrated in an agriculture farm economy. A scheme is under trial is USA in which corn stovers can be fermented into a product called stillage, which is an ideal food for nonruminants and also simultaneously produce the valuable fuel ethanol. Bagasse in another valuable source for ethanol and a new process is under development in Canada. In Indian alcohol used to be produced from the molasces, left over as waste in the sugar industry, which have no further use. The production of this power alcohol has steadily declined as shown in the table 7 :

Table 7 : Production of Power Alcohol (in GL)

Year	Production	Year	Production
1951	26.49	1972	0.88
1956	46.69	1973	0.58
1961	53.77	1974	0.65
1966	2.47	1975	1.74
1971	0.68	1976	0.96

Source : Statistical Abstract 1977.

Some basic data for ethanol production are : 1T of starch can yield 0.568 T of ethanol; 5.6 T of molasces (50% sugar) can yield 1 T of ethanol. It is clear that very intense R∈D efforts have to be made to include conversion of biomass, into energy fuels in our economy.

Energy plantation[40] : A few remarks about energy plantation is called for — a concept which is very important in the context of biomasses. For the production of biomass besides the cash crops one can resort to intense agri - and silvi - cultures as well as grow photosynthetic algae and bacteria One should also examine the plants grown in their totality. Thus if grapes are grown, one should think also of the kinds which are rich in fermentable sugars. Plantations of fast growing trees like *Eucalyptus zincyphus* Prosopis etc. can be established easily in the foot hills and plains. In the temperature and subtemperature zones trees like the willow and the poplars can be easily grown. This man made agroforests would not only provide the biomass, but would also help to mitigate industrial polution, and establish a valuable symbiosis with the environment. *Casurina* is another type of tree very successful tried in south India, which besides providing the biomass, fixes nitrogen for the soil very efficiently. Another similar plant is *Leucacena*, leucocephala which has been very successfully tried in Philipines. There is an important experiment in USA to use the latex of certain plants for producing compounds which may substitute for petroleum. A species of Enphorbia, specially *E. tirucallis* is ideally suited for its fast growth, wide adaptibility and suitable sap consistency. Varieties of large and bacteria of high photosynthetic efficiency may also be artificially cultivated. A large scale R∈D in genetic engineering is necessary to improve these varieties. DST has already set up a committee to consider programmes for handling biomass.

OTHER ENERGY SOURCES IN INDIA

Let us now take a quick look at the prospects of utilising hydro, wind, tidal and geothermal energies in India. The information of hydroenergy is drawn from the report of the Fuel Policy Committee, 1974 (RFPC)[41] of the Government of India. The date on

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[40.] Survey of rural energy consumption in northern India, National Council of Applied Economic Research.

[41.] Report of the Fuel Policy Committee, Government of India (1974).

wind and tidal energy is from the NCST report : Report of the power and Fuel sector, 1974[42].

HYDROENERGY

India is paritcularly blessed with hydroenergy potential. The great pioner engineer Visheshwarya established the first major hydel station in India Shivasamudram in Karnataka to provide electricity to the Kolar gold fields. Meghnad Saha[43] was another pioneer, who wrote extensively on river controls and hydroelectricity to generate public and government interest in multipurpose river projects. The river systems of India can be divided in 6 general groups :

1. north west India-rivers of Indus basin,
2. central India including-both east and west flowing rivers,
3. the Ganga system with all its tributaries,
4. eastern India-Brahmaputra system and rivers of the adjacent areas,
5. east flowing rivers of south India, and
6. west flowing rivers of south India.

According to estimates of Central Water and Power Commission (CWPC)[44] made from investigations in the period 1959-60, the total hydel potential of India is 41.17 GW, which means that the total hydel output at 60% load factor could be 216 TWh annually. This has been recently upgraded in 1971 by the Power Economy Commirtee (PEC)[45] to 80-100 GW, which means an annual output at 60% load factor of 420-525 TWh of electricity. India is divided into five power zones :

1. northern India-Himachalpradesh, Haryana, Jammu and Kashmir, Panjab, Rajasthan and Uttarpradesh,

2. western India-Gujrat, Madhyapradesh and Maharashtra,
3. south India-Andhrapradesh, Karnataka, Kerala and Tamilnadu,
4. eastern India-Bihar, Orissa and west Bengal and
5. north eastern India-Assam and adjacent states and Manipur.

The hydel potential distribution is as follows: north India-10.73 GW (26.0%), west India 7.17 GW (7.4%), south India 8.10 GW (19.4%), east India 2.69 GW (6.6%) and north east India 12.46 GW (30.3%), the figures in the brackets indicating the % shares of the original estimate of CWPC.

Let us now survey how much of this hydel potential has been actually developed in India. Upto 1970/1 the installed hydel capacities were as follows: north India 2.08 GW (19.4%), west India 0.99 GW (13.8%) south India 2.81 GW (34.6%), east India 0.44 GW (16.5%) northeast India 0.07 GW (0.57%), total = 6.39 GW (15.5%), the figures in the bracket indicating % share of the estimate of CWPC for the region. Thus the progress of hydel development leaves much to be desired. By 1977/8 the total hydel installed capacity reached the figure of 9.97 GW i.e. about 24% CWPC's estimate. The Assam region, in particular, seems to be very badly neglected.

Thirring[46] proposed in 1956 at the world power Conference a hydel project on R. Tsangpo, or R. Bramhaputra, as it is known in India , for which he estimated a potential of generating annually 147-333 TWh of electricity. The project is of immense dimensions and can only be undertaken jointly by China, Tibet and India.

There are many aspects of hydel projects which must be taken into consideration, which is very seldom done. Most major hydel projects are multipurpose projects : flood controls, agricultural use of the water are some important aspects besides generation of electricity. Seismic rationale and water holding capacity of the site, change of soil conditions due to concentration of certain metal

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42. Report of the Fuel and Power Sector, NCST (1974).
43. For a list of articles of Meghnad Saha on river controls see appendix.
44. Survey, made by the Central water and Power commission, Government of India.
45. Progress of Power Economy Committee, Government of India (1973).
46. Calder. R : After the seventh day, p. 319 Mentor Book (1961).

ions and consequent ecological changes, reduction of the useful life of dams caused by raising of their beds by soils washed from the banks resulting from massive deforestation of the banks, are some of the many consideration. Codes for mitigation of disasters from the dam bursts caused by excessive rainfall have yet to be worked out. I do not think that the probable courses of water released by dam bursts have been clearly worked out for any dam, and the people shifted from these areas, or where that cannot be done, diversion channels for the surging water from dam bursts have been established. Another unfortunate feature of hydel production is that it is completely dependent on rainfall and general meteorological conditions. So the production will drastically fall in the years of drought, as has happened last year. Hydel stations and dams are often installed at inaccessible places, and transmission of hydel power to the consumer often poses problems. Also dams are likely to produce profound changes in the environment and the ecology of the surrounding country.

Wind Energy : A minimum wind speed of 10 km/hr is considered to be useful for working-windmills for the agricultural sector. For 80% of the days in Karnataka, Maharashtra and Gujrat with 10 or more hours, and 40% of the days with 20 or more hours with maximum duration in the monsoon months, the wind has this minimum speed. For 20% of the days in Madhyapradesh, 10 hrs of such wind is available. Along the sea coasts and on high hilly areas, such wind is available; such areas are therefore suitable locations for windmills. Windmills can be used for the following purposes:

1. water pumping, and
2. providing electricity in rural areas.

R&D work on aeolian engines is being carried out at NAL. Unfortunately, not much progress has yet been made in perfection of designs suitable for India, or in the construction and installation of such devices on any large scale.

Tidal Energy : The water level of the sea rises and falls periodically because of the joint action of

the moon and the sun. Thus if basins and dams are created at the mouths of the rivers, the water flowing in during high tide can be stored and allowed to flow out during ebb tide, driving turbines to generate electricity. Suitable sites may be found in the Gulf of Cambay, Gulf of Kutch and the Hugly basin. Preliminary assessment based on the French experience at Le Ranee indicates that the cost of generation of tidal power will be high. No progress has been made in this field in India.

Geothermal Energy : There are three types of geothermal energy fields in India :
1. steam fields with temperature gradient > 50° C/km depth,
2. hot water fields with gradients 30°- 50° C/km depth and
3. normal fields with gradient < 30° C/km depth.

Extensive investigations have been made by the Geological Survey of India of the geothermal regions of various parts of India. Two possible sites :
1. the Puga valley of Ladakh and
2. the Manikaran kasol area in Himachal pradesh received recommendations for geothermal developments.

POPULATION OF INDIA

In any prediction about the energy demand of a country, its population is an important parameter. In India it is one of the imponderables, and we can only make intelligent guesses about it. For our purpose, it is neccessary also to estimate the rural and urban populations. According to a world Bank estimate the population growths in India are as given in the table 8.

Table 8. Urban and rural populations in India

	1965/6	1968/9	1970/1	1973/4
Urban	92(18.9)	101(19.4)	108(19.8)	120(20.5)
Rural	395(81.1)	420(80.6)	438(80.2)	465(79.5)
Total	487(100)	521(100)	546(100)	585(100)

(in M persons). Figures in brackets indicate % shares
Source : India The Energy Sector by P.D. Henderson[47]

The APGR's for the period 1970/1 - 1973/4 are :

urban 3.6%, rural 2.0%.

47. P. D. Henderson : India-The Energy sector, World Bank, Oxf. Univ. Press, 1975.

For study on non-commercial fuel in India, we shall need the rural population in 1976. According to the APGR for rural population, this figure should be 484 M.

If the above APGR's are allowed to remain unchecked, then the population figures will be as given in the table 9.

Table 9. Population projections in India on present trends. Population given in M person

	1979/80	1982/3	1983/4	1990/1	1991/2	2000/1	2035/6
Urban	148	165	171	219	227	312	1075
Rural	523	555	567	651	664	794	1587
Total	671	720	738	870	891	1106	2662

With such a population load, the energy problem for India can never be solved. I hope therefore, that wisdom will dawn upon us, and the family planning projects will become effective by 1991/2 and 1% APGR will be achieved for both rural and urban populations, in the scenario I shall consider here after, I shall assume that the APGR'S would remain constant upto 2000/1 AD after which an APGR of 0.5% would be achieved for both populations. The population projections on these assumptions are given in table 10.

Table 10. Population of India and projections 1960/1 to 2035/6 (in M persons) assumed in this study

Year	Rural	Urban	Total	Year	Rural	Urban	Total
1960/1	356	79	435	1985/6	589	184	773
1965/6	395	92	487	1990/1	651	219	870
1970/1	438	108	546	1991/2	664	227	891
1975/6	484	129	613	1995/6	691	236	927
1979/80	523	148	671	2000/1	726	248	974
1980/1	534	154	688	2035/6	864	295	1159

APGR's : For period 1960/1 to 1991/2 rural population 2%, urban population 3.6%, for period 1991/2 to 2000/1 rural and urban population both 1% and after 2000/1 both 0.5%.

PRODUCTION AND CONSUMPTION OF ENERGY

To understand the production and consumption of energy in India, we meet with the difficulty that substantial portion of the energy fuels is not handled by market processes, i.e., these are not sold and purchased, but are gathered for use by the consumers. It is therefore customary to divide the energy fuels in two classes :

1. commercial fuels which pass through the market : coal, oil, natural gas, and nuclear minerals and
2. noncommercial fuels which do not : firewood, vegetable waste and animal dung.

We shall first consider the commercial energy, which again can be divided in two classes :

1. primary energy derived from the fossil fuels, used in the original form without any transformation and
2. secondary which, like electrical energy, are transformed forms of energy.

In spite of my best efforts I have not been able to collect data about the energy productions and consumptions for recent years. So I have been forced to make intelligent guesses about them from the APGR trends. Table 12 contains the data for energy productions of all types. This would be the master table upon which all subsequent analysis would be based. The data collected from published data are printed in heavy types, and those calculated from the APGRS or by other means are printed in light types in this table.

COAL REPLACEMENT VALUES

The energy data in the tables are given in an uniform unit, which does not represent the thermal values expressed by coal equivalent (CE) values of the fuels or various forms of energy. We have rather, as is the practice, used their coal replacement (CR) values. The CR values are different from the

CE values, because whereas CE only emphasises the thermal value, CR reflects many other things - convenience for consumers, technology of use, managerial skills for production and distribution. The Energy Survey of India Committee[48] recommended in 1965 the CR values of various fuels and energy forms which are given in table 11.

Table 11. CE and CR values of various fuels and energies

	Original units	CE value	CR value
Coal all types	1MT	1MT	1MT
Oil	1MT	2MT	6.5 MT
Natural gas	1m³	1.8MT	3.6 MT
Electricity	1TWh	1MT	1MT
Firewood	1MT	0.95 MT	0.95-0.7 MT (depending on chullah)
Veg.waste	1MT	—	0.61 MT
Dung	1MT	—	0.3-0.4 MT

Source : RFPC[49] and SRECNPI[50]

PRODUCTION OF COMMERCIAL ENERGY IN INDIA

The production of various commercial fuels and commercial energies in India from 1960/1 to 1978/9 are shown in table 12 (fig. 1). The main source that consulted was the Report of the Fuel Policy Committee of the Covernment of India. 1974 (RFPC); also some information were given by individuals[51]. The % slares of the various forms of energy in the total is given table 13.

48. Energy Survey of India Committee, Government of India, 1965.
49. Report of the Fuel Policy Committee, Government of India, 1974.
50. Survey of Rural Energy Consumption of Northern India, National Council of Applied Economic Research.
51. I am specially indebted to Dr. J. Gururaja of the Department of Science and Technology and Dr. P. K. Mukhopadhyay of Oil and National Gas Commission.

Fig 1. India Energy Production

Certain trends will be evident in this table 12:

(1) Coal : The APGR for coal production for the period 1971/2 to 1974/5 is 7%. Projecting on this growth rate, we get a possible figure for coal production in 1979/80 as 124.0 MT. But I have very serious doubts if this figure has been actually achieved. In fact the informations collected later show a decline of coal production from the figures given in table 12, the productions being 99.68 MT in 1975/6, 101.04. MT in 1976/7,101.00 MT is 1977/8 and 101.90 MT in 1978/9. The % share of coal in the total commercial energy has varied from 47% in 1960/1 to possibly 31% in 1979/80.

(2) Oil : The APGR for oil import for the period 1975/6 to 1977/8 is 6.8%. It is quite clear that the global crisis of oil has not affected the oil import in India, which means that the switch over to oil in the sixties in this country was too drastic to revert back to coal. Projecting on an APGR of 6.8%, the oil import in 1979/80 should be 123.6 MTCR. The APGR for domestic oil production for the period 1973/4 to 1977/8 in 9.3% On this basis, the domestic oil production in 1979/80 should be 73.9 MTCR. Thus the total oil available in 1979/80 should be 197.5 MTCR. The % share of oil in the total commercial energy produced varied from 46% in

Table 12. Production of energy in India from 1960/1 to 2035/6 (in MTCR)

Year	Coal	Import	Oil Domestic	Total	Hydel	Total Commercial	Fire-wood	Veg waste	Dung	Total non-commercial	Total Energy
1960/1	55.7	51.3	3.2	54.5	7.8	118.0	30.8	22.6	17.2	70.6	188.6
1961/2	55.2	55.9	4.5	60.4	9.8	125.4	31.4	23.0	17.5	71.9	197.3
1962/3	63.5	59.1	7.8	66.9	11.8	142.2	32.0	23.5	17.9	73.4	217.6
1963/4	65.1	61.7	11.7	73.4	14.0	152.5	32.7	24.0	18.2	74.9	227.4
1964/5	62.8	63.0	15.6	78.6	14.8	156.2	33.3	24.5	18.6	76.4	232.6
1965/6	67.7	63.0	22.1	85.1	15.2	168.0	34.0	24.9	19.0	77.9	245.9
1966/7	68.6	63.0	31.8	94.8	16.7	180.1	34.7	25.4	19.4	79.5	259.6
1967/8	68.5	65.6	37.0	102.6	18.7	189.8	35.4	26.0	19.8	81.2	271.0
1968/9	71.4	74.7	39.6	114.3	20.7	206.4	36.1	26.5	20.1	82.7	289.1
1969/70	75.7	78.0	43.5	121.5	23.0	220.2	36.8	27.0	20.5	84.3	304.5
1970/1	72.9	84.5	44.8	129.3	25.2	227.4	37.5	27.5	21.0	86.0	313.4
1971/2	72.1	96.8	46.8	143.6	28.0	243.7	38.3	28.1	21.4	87.8	331.5
1972/3	76.9	104.0	47.4	151.4	27.2	255.5	39.1	28.7	21.8	89.6	345.1
1973/4	78.1	111.1	47.4	158.5	34.3	270.9	39.8	29.3	22.2	91.3	362.2
1974/5	88.4	107.2	50.0	157.2	37.9	283.5	40.6	29.9	22.7	93.2	376.7
1975/6	94.6	101.4	54.6	156.0	42.0	292.6	41.4	30.4	23.1	94.9	387.5
1976/7	101.2	108.5	58.5	167.0	46.5	314.7	42.2	31.0	23.6	96.8	412.3
1977/8	108.2	115.7	67.6	183.3	51.5	343.0	43.1	31.6	24.0	98.7	442.5
1978/9	115.9	123.6	73.9	197.5	57.0	370.4	43.9	32.3	24.5	100.7	471.8
1979/80	124.0	132.0	80.8	212.7	63.1	399.8	43.9	32.3	25.0	101.2	501.0
1980/1	132.7	141.0	88.3	229.3	69.8	431.8	43.9	32.3	25.5	101.7	533.5
1982/3	142.0	150.6	96.5	247.1	77.3	466.4	43.9	32.3	26.0	102.2	568.6
1985/6	180.1	–	137.7	137.7	116.2	434.0	43.9	32.3	28.1	104.3	538.3
1987/8	213.0	–	164.5	164.5	142.4	519.9	43.9	32.3	29.3	105.5	625.4
1990/1	261.0	–	214.8	214.8	193.2	669.0	43.9	32.3	29.7	105.9	774.9
1991/2	279.2	–	–	–	213.8	493.0	43.9	32.3	29.8	106.0	599.0
2000/1	280.0	–	–	–	525.0	805.0	43.9	32.3	30.6	106.8	911.8
2035/6	280.0	–	–	–	525.0	805.0	43.9	32.3	34.0	110.2	915.2

APGR's : Coal (1971/2-74/5) 7%, Imported Oil (1975/6-77/8) 6.8%, Domestic Oil (1973/4-77/8) 9.3%. Hydel (1965/6-71/2) 10.7%, all noncommercial fuels upto 1978/9 2% after which firewood and vegwaste constant. During continues to be 2% upto 1987/8 after which 0.3%

Doomsdays : Imported Oil : 1982/3, Domestic Oil : 1990/1. Hydel reaches saturation level in 2000/1. Source : RFPC, SRECNI and private informations

Table 13. % Share of various components of energy from 1960/1 to 2000/1

Year	Coal	Oil	Hydel	Commercial Total	Firewood	Veg waste	Dung	Non Commercial Total
1960/1	29	29	5	63	16	12	9	37
1965/6	27	35	6	68	14	10	8	32
1970/1	23	41	8	72	12	9	7	28
1975/6	24	40	11	75	11	8	6	25
1979/80	25	42	13	80	9	6	5	20
1982/3	25	44	14	83	7	5	5	17
1983/4	34	24	20	78	9	7	6	22
1985/6	33	28	22	81	8	6	5	19
1990/1	33	–	25	86	6	4	4	14
1991/2	47	–	36	83	7	5	5	17
1995/6	31	–	58	89	5	3	3	11
2000/1	31	–	58	89	5	3	3	11

1960/1 to possibly 53% in 1979/80. This shows the dramatic switch over to oil in the sixties in this country, which has been in line with what other countries have done.

(3) Electricity : The APGR for hydel (hydroelectricity) production for the period 1965/6 to 1971/2 has been 10.7%. On this basis, the hydel production in 1979/80 should be 63.1 MTCR or 63.1 Twh. The share of hydel in the total commercial energy varied from 7% in 1960/1 to 16% 1978/9. The analysis for thermel (thermal electricity) production will be done little later when we consider the coal and oil consumptions for power production. I have not shown in table 13 the % share of total electricity in the total energy, as thermel part of it is already accounted for in the coal and oil production. This is given later in table 19.

(4) Nuclear energy : Nuclear electricity started coming in from 1969/70. Since then the production has declined. In 1972/3 nuclear portion was only 1.6% of the total electricity produced. We may therefore leave out this energy entirely from our consideratios, as it cannot possibly have any influence on the energy budget for the next decade.

## CONSUMPTION OF COMMERCIAL ENERGY IN INDIA

Unfortunately, the only reliable data for commercial energy consumption, that is available, is for period from 1953/4 to 1970/1, as given by the REPC. The figures for 1960/1 to 1970/1 are given in tables 14, 15 and 16. Inspite of my best efforts I could not get reliable data for the energy consumption after this period. I have closely studied the energy consumption pattern from 1960/1 to 1970/1 in the hope that this will give an idea of which particular economic sector will be hit to what degree in the event of shortage of some particular fuel or some particular form of energy.

I shall first define the customary divisions of the economic sectors, that is made for study of commerical energy consumption :

1. mining and industry (M&I),

2. transport (T),
3. domestic (D),
4. agriculture (A) and
5. establishment (E) which is associated with both government and commerce. To these I have added another sector :
6. power (P), which covers the production of electricity from coal and oil i.e. thermal production. I have added another head
7. unaccounted (U), which is the difference between the energy produced and energy consumed and covers losses, wastages before the energy reaches the consumer, nonenergy uses and similar items. The amount under U for oil is particularly large.

We shall first look at the amount of energy consumed in the different sectors fig 2. M&I Sector takes the dominant role, and its consumption rose from 39.7 MTCR in 1960/1 to 76.3 MTCR in
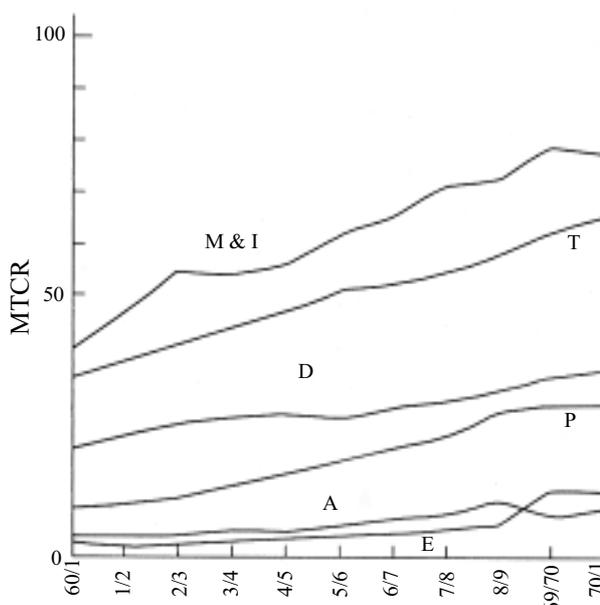
Fig 2. Energy Consumption in different sectors

1970/1. The next important sector is T which consumed 34.1 MTCR in 1960/1 and 64.5 MTCR in 1970/1-a steady linear increase. Next is the D sector whose consumption varied from 20.8 MTCR in 1960/1 to 35.5 MTCR in 1970/1. P took 9.1 MTCR in 1960/1 and 28.1 MTCR in 1970/1. The

Table 14. Consumption of coal in India (in MTCR) from 1960/1 to 1970/1

Year	PR	M&I	T	D	E	P	C	U
1960/1	55.7	20.9	16.0	2.8	0.7	6.7	47.1	3.6
1961/2	55.2	24.2	16.7	2.8	0.4	7.2	51.3	3.9
1962/3	63.5	28.0	17.4	3.2	0.5	8.0	57.1	6.4
1963/4	65.1	27.0	17.4	3.5	0.7	9.8	58.4	6.7
1964/5	62.8	27.2	17.4	3.4	0.3	10.5	58.8	4.0
1965/6	67.7	30.1	17.3	4.1	0.3	12.4	64.2	3.5
1966/7	68.6	30.4	16.9	4.5	0.5	13.0	65.3	3.3
1967/8	68.5	33.0	16.7	4.3	0.5	14.7	69.2	−0.7
1968/9	71.4	31.9	16.3	4.3	0.5	15.4	68.4	3.0
1969/70	75.7	35.3	16.1	4.8	0.4	17.1	73.7	2.0
1970/1	72.9	31.1	15.9	4.1	0.3	17.1	68.5	4.4

PR = Production, M&I = Mining and Industry, T = Transport, D = Domestic, E = Establishment, P = Power, C = Total consumption (Energy use), U = Unaccounted.
Source : RFPC

Table 15. Consumpton of oil in India (in MTCR) from 1960/1 to 1970/1

Year	PR	M&I	T	D	A	E	P	C	U
1960/1	54.5	7.2	17.3	16.5	2.7	–	2.4	46.1	8.1
196112	60.4	7.7	19.5	18.5	2.9	–	2.7	51.3	9.1
1962/3	66.9	9.4	21.8	20.3	3.2	–	2.5	57.2	9.7
1963/4	73.4	6.6	25.3	20.3	3.6	0.6	3.0	59.2	14.0
1964/5	78.6	7.1	27.5	21.6	3.6	0.1	4.3	64.2	14.4
1965/6	85.1	8.1	31.3	20.0	4.4	0.8	5.3	69.9	15.2
1966/7	94.8	9.0	33.1	20.6	5.1	1.0	6.6	75.4	19.4
1967/8	102.6	9.9	35.3	21.4	5.3	1.6	7.9	81.4	21.2
1968/9	114.3	10.4	39.7	23.8	6.8	1.6	11.3	93.6	20.0
1969/70	121.5	9.4	43.3	25.5	4.5	7.3	10.5	100.5	21.0
1970/1	129.3	10.9	47.2	27.6	4.5	6.9	11.0	108.1	21.2

PR = Production, M&I = Mining and Industry, Transport, D = Domestic, A = Agriculture, P = Power, C = Total consumption (Energy use), U = Unaccounted.
Source : RFPC

Table 16. Consumption of electricity in India (in TWh & MTCR) from 1960/1 to 1970/1

Year	PR	M&I	T	D	A	E	C	U
1960/1	16.9	11.6	0.8	1.5	0.8	2.2	16.9	0.0
1961/2	19.8	14.5	0.6	1.7	1.0	1.6	19.4	0.4
1962/3	22.5	16.5	0.9	1.9	1.1	2.1	22.5	0.0
1963/4	26.9	19.1	0.8	2.1	1.1	2.1	25.2	1.7
1964/5	29.6	20.9	1.0	2.2	1.4	2.2	27.7	1.9
1965/6	32.9	22.6	1.2	2.4	1.9	2.5	30.6	2.3
1966/7	36.3	24.4	1.3	2.6	2.1	2.8	33.2	3.1
1967/8	41.3	26.8	1.4	2.9	2.6	3.1	36.8	4.5
1968/9	47.4	29.9	1.3	3.2	3.5	3.6	41.5	5.9
1969/70	50.6	32.3	1.4	3.5	3.8	4.0	45.0	5.6
1970/1	53.3	34.3	1.4	3.8	4.5	4.5	48.5	4.8

PR = Production, M&I = Mining and Industry, T = Transport, D = Domestic, A = Agriculture, E = Establishment, C = Total consumption (Energy use), U = Unaccounted.
Source : RFPC

A and E sectors are very small consumers: for A the rise is from 3.5 MTCR to 9 MTCR and for E the rise is from 2.9 MTCR to 11.7 MTCR.

Next let us examine the consumtpion pattern of coal, oil and electricity in terms of % shares (fig. 3).
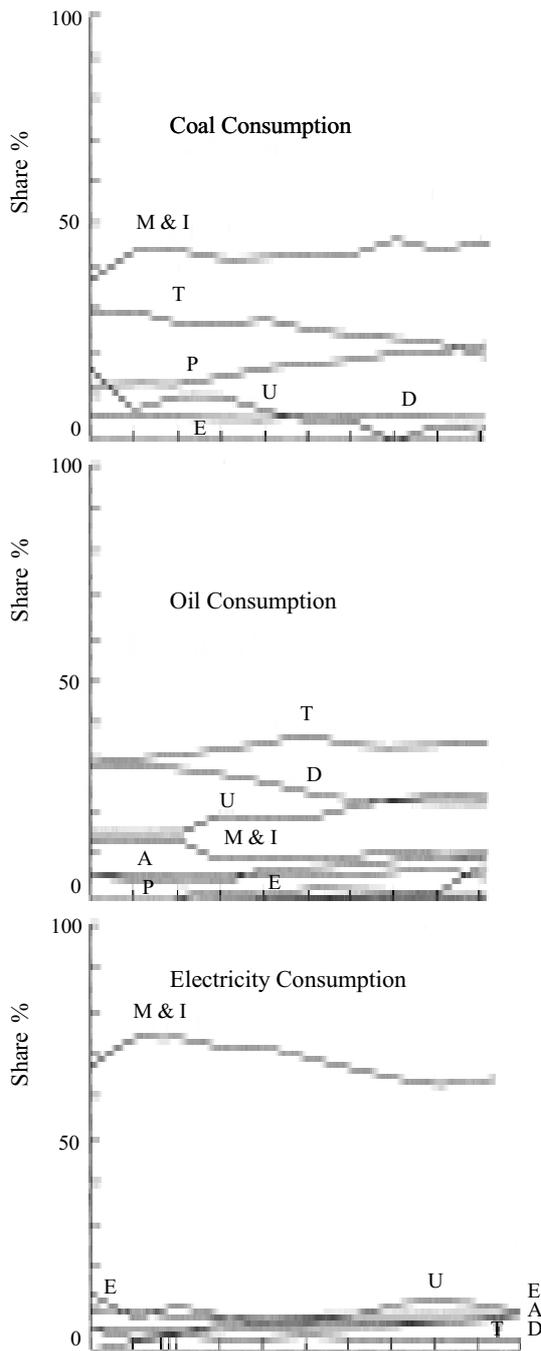

Fig 3. Consumption of energy in different economic sectors

Coal : The consumption in the M&I sector dominates and has been in the neighbourhood 44% for all the ten years. The next important sector for coal is T, for which the % share, however, is decreasing over the years reaching the level of 22% in 1970/1. The consumption of coal in the P sector increased, reaching 17% in 1970/1. The other sectors consume coal in insignificant amounts.

Oil : Here the T sector dominates, being steady in the range 32-37%. The next big consumer is the D sector, where the % share has decreased with time, being about 28% in 1970/1. The U head holds quite a substantial share, being about 21% in 1970/1 i.e., quite a large amount of oil does not come for energy use. The consumption in P sector is not large, being about 9% in 1970/1. The consumptions in other sectors are small. The E and A sectors both consumed about 5% of the oil in 1970/1. If this pattern continues, then oil shortage will spell disaster for the T and D sectors. In these sectors liquid or gas fuels are preferred. If replacement has to be derived from coal, then R&D work for liquifaction or gasification of coal and installation of the necessary plants must be expedited. In terms of quantities, T and D sectors together consumed oil of amount 74.8 MTCR, in 1970/1, which is a very large amount.

Electricity : The sector which dominates in the use of electricity is the M&T sectors, the level of consumption in 1970/1 being 65%. All other sectors are rather insignificant consumers, seldom rising above 8%. Oil shortage will indirectly hit the M&I sectors through a shortage of thermel production.

Now let us examine fuel and energy flows in the different sectors (fig 4) :

M&I Sector : In the early sixties coal and electricity used to dominate this sector. However, by 1970/1 electricity has surpassed coal, electricity being 45% and coal 41%. Oil in 1970/1 contributed only 14%. Thus oil shortage will only indirectly affect this sector through the electricity it produces.

T Sector : Here oil surpasses coal to a very large measure in 1970/1. In 1970/1 oil had 79% share where coal had only 25%. Electricity had very little contribution. The T sector will therefore be crushed by oil shortage, as we have already mentioned.

sector in 1970/1 was only 9 MTCR. Here effective replacement has to be found in developing Stirling engines for pumping water for irrigation purposes.

E. Sector : The total consumption of energy in this sector was very low, being only 11.7 MTCR.
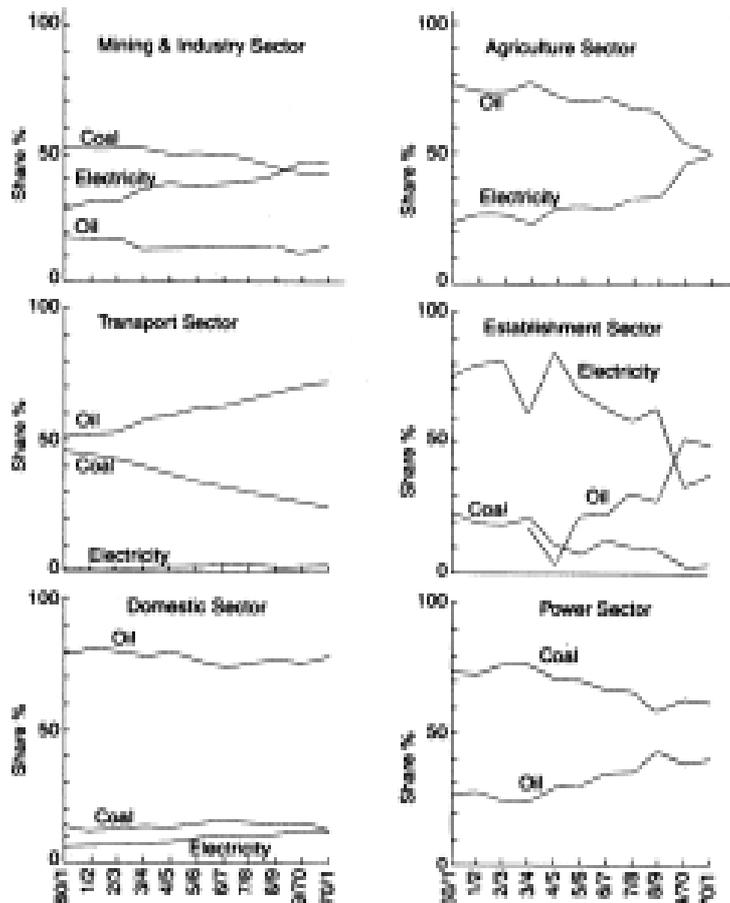

Fig 4. Energy Consumption pattern of coal, oil and electricity in terms of % shares

D Sector : The pattern is similar to T Sector. Oil dominates, reaching the level of 78% in 1970/1. Coal and electricity mattered very little, both being in the region of 11% in 1970/1. This sector, as we have already stated will be very hard hit by oil shortage.

A Sector : Coal is not seen in this sector at all. Oil used to dominate in the early sixties. But by 1970/1, oil and electricity achieved equal shares in this sector. This sector will also be sensitive to oil shortage. But the total consumption of energy in this

There was wide fluctuation in the oil and electricity consumptions. In 1970/1 oil was 59% and electricity 38%. The share of coal declined steadily.

P. Sector : The coal share is total thermel declined steadily from 74% in 1960/1 to 61% in 1970/1, whereas the oil share increased from 26% to 39%.

Use of oil products : We should look at the fine structure of oil product production to understand the impact of oil shortage more completely. The production of oil products in 1975 in 1975 is given in table 17.

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Table 17. Production of petroleum products and sectorial consumptions of oil in India for 1970/1

Source : India-The Energy Sector by P. Henderson[52].

| Production of petroleum products[53]			Sectorial consumption of oil as % of total oil consumption		
Item	**MT**	**%**	**Sector**	**MT**	**%**
Light distillates					
Naptha	0.90	5	M&T	1.68	10
Motor spirits	1.44	8	T	7.27	44
Others	0.30	3	D	47.24	25
			A	0.69	5
	2.64	16	E	1.07	6
Middle distillates			P	1.70	10
Kerosene	3.31	18	Total	16.65	100
HSDO (High Speed Diesel Oil)	3.85	21			
LDO (light Diesel Oil)	1.09	6			
Aviation, turbine fuel	0.71	4			
	8.96	49			
Heavy end distillates					
Fuel oil and fuel oil products	4.78	27			
Bitumen	0.80	4			
Others (lubes and greases)	0.80	4			
	6.38	35			
Total	17.98	100			

The total production figure of 17.98 MT(≡ 116.9 MTCR) in table 17 in somewhat different from the figure 16.65 MT *(≡ 108.2 MTCR)*, of which the CR value was given earlier in table 15. This is because the sources from which the two figures were taken are different. The sectorial consumptions are easy to understand in terms of the oil products. Kerosene is mainly used in the D-sector. HSD is used in the road transport 78%, and for diesel locomotives 12%, and the rest of HSD being employed for other uses. LDO is used in A-sector for energising irrigation pump sets 40%, in the P-sector 7%, in the T sector 5%, and industrial sector 48%. Fuel oil is used as follows : P sector 26%, industry-textile industry 10%, steel 8%, steam raising 36%, T-sector : shipping 10%. Motor spirits are almost wholly used in the T-sector. Naptha is used in the industry sector and bitumen in the E-sector. This picture would help to understand how the economy would be effected by the coming oil crisis.

Production of thermel and the efficiency of electricity use : In the game of forecasting, it will be necessary to examine the production of thermel

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52. P. Henderson: India-the energy sector. World Bank, Oxf. Univ. Press.
53. The production figures given in Hendersons book is for calendar years. We have assumed that production for 1960/1 is 0.75x production in 1970 + 0.25x production in 1971, the production figures being as given by Henderson.
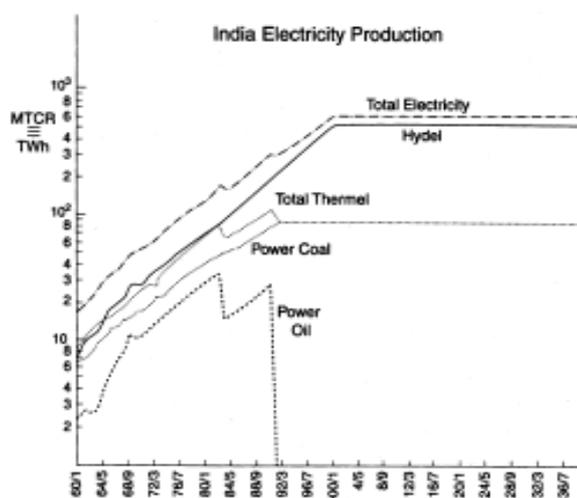
Fig 5. Electricity Production

from coal and oil and not to base the predictions on APGR of thermel production only, because of the anticipated oil shortage. The APGR of the thermel production in the period 1965/6 to 1971/2 was 10.2%. But the thermel production was not explicitly shown in the energy production for it was already accounted for under coal and oil productions. Table 18 (fig 5) gives the production data of electricity production for the period 1960/1 to 1970/1, all the components, hydel and thermel (produced by the utilities and nonutil-ities) shown separately and the % shares are shown in table 19. The % shares of hydel and thermel production in the total electricity produced in the period 1960/1 to 1970/1 (fig 6), fluctuates in the range 47% to 53%. The % share of power coal in total * electricity produced has declined from 39.6% in 1960/1 to 32.1% in 1970/1, and thf % shares of power coal in total coal has varied from 12% in 1960/1 to 23.5% in 1970/1. The % share of power oil in total electricity has changed from 14.2% In 1960/1 to 20.6% in 1970/1, and the % share of power oil in total oil has changed from 4.4% in 1960/1 to 8.5% in 1970/1. We shall use these data when we try to forecast the scenario at the turn of the century.

Let us see how efficiently is electricity being used in India. The Indian experience is that there is heavy loss in transmission and other causes, such
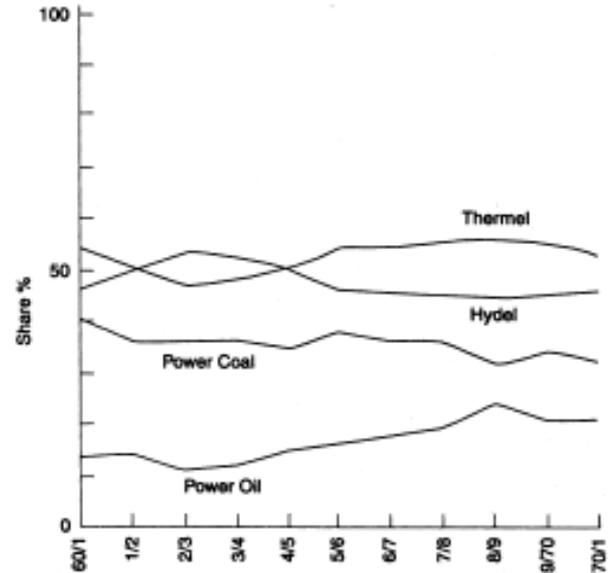

Fig 6. The % shares of the thermel production in the total electricity produced in the period 1960/1 to 1970/1. India electricity Production.

as commercial losses like piracy and misreading of meters. An estimate of such losses can be derived from the data for 1970/1: total production electricity = 61.2 GWh, total amount of electricity consumed

Table 18. Production of thermel in India from 1960/1 to 2000/1 (in TWh s MTCR)

Source : RFPC and projections

Year	Thermel	Power coal	Power oil	PC % in total Thm	PO % in total Thm	PC % in total C	PO % in total O
1960/1	9.1	6.7	2.4	73.6	26.4	12.0	4.4
1965/6	17.7	12.4	5.3	70.1	29.9	18.3	6.2
1970/1	28.1	17.1	11.0	60.8	39.2	23.5	8.5
1975/6	46.7	28.0	18.7	60.0	40.0	29.6	12.0
1979/80	67.3	39.7	27.6	59.0	41.0	32.0	13.0
1982/3	83.2	48.6	34.6	58.4	41.6	32.0	13.0
1983/4	67.0	52.0	15.0	77.6	22.4	32.0	13.0
1990/1	111.4	83.5	27.9	74.9	25.0	32.0	13.0
1991/2	89.3	89.3	–	100.0	–	32.0	–
1995/6	89.6	89.6	–	100.0	–	32.0	–
2000/1	89.6	89.6	–	100.0	–	32.0	–

Thm = Thermel, PC = power coal, PO = power oil, C = coal, O = oil

Table 19. Production of electricity in India from 1960/1 to 2000/1 (In TWh)

Source : RFPC and projections

Year	Hydel	Thermel	Total electricity	Hyd % in total El	PC % in total El	PO % in total El	Thm % in total El	El % in total El
1960/1	7.8	9.1	16.9	46.2	39.6	14.2	53.8	9.0
1965/6	15.2	17.7	32.9	46.2	37.7	16.1	53.8	13.4
1970/1	25.2	28.1	53.3	47.3	32.1	20.6	52.7	17.0
1975/6	42.0	46.7	88.7	47.4	31.6	21.0	52.6	22.9
1979/80	63.1	67.3	130.4	48.4	30.4	21.2	51.6	26.0
1982/3	85.7	83.2	168.9	50.7	28.8	20.5	49.3	27.8
1983/4	94.8	67.0	161.8	58.6	32.1	9.3	41.4	34.0
1990/1	193.2	111.4	304.6	63.4	27.4	9.2	36.6	39.3
1991/2	213.8	89.3	303.1	70.5	29.5	–	29.5	50.6
1995/6	321.1	89.6	410.7	78.2	21.8	–	21.8	45.1
2000/1	525.0	89.6	614.6	85.4	14.6	–	14.6	67.2

PC = power coal, PO = power oil, Hyd = hydel, Thm = thermel, El = electricity, E = energy

= 48.5 GWh showing a loss of 12.7 GWh which amounts to 20% of what was produced. Of this the line loss was 9.3 GWh. Much of this loss could be reduce if instead of high voltage AC transmission, high voltage DC transmission was introduced in India so far. This would mean, however, a total change of the transmission systems and the consumer's utilisation systems. In India not much progress has been achieved in introducing the DC transmission technology.

Another aspect of utilisation of electricity is to see how well the power generated is used in face of fluctuating demands by adjustment of the proper mix of electricity from different sources. Customarily this is measured by the following parameters

$$\text{Load factor} = \frac{\text{Energy demand (kWh)}}{\text{Peak load (kW)} \times 8760}$$

$$\text{Demand factor} = \frac{\text{Peak Load (kW)}}{\text{Peak capacity (kW)}}$$

Plant factor = Load factor × demand factor.

In India in 1970/1, the values achieved for these efficiency parameters are :

Load factor: 0.657, demand factor: 0.828, plant

factor: 0.527. The load factor value is disturbing, because the figure shows that our electricity system is not able to cope with fluctuating loads. An electricity price reorganisation on a differential basis for offpeak load, might smoothen the fluctuating load. Demand factor is much higher than the usual safety margin of 25% required, i.e. the plants are working near the peak capability, leaving little margin for outrages and maintenance. The plant factor of 53% is considered satisfactory.

RURAL ENERGY—NONCOMMERCIAL ENERGY

India's consumption of non commercial energy is largely terra incognita. There has been a number of past studies, which are unacceptable for the purpose of obtaining the general picture, because of the limitations of the scope of those studies or of the basic assumptions. I should like to base my study on a recent survey made of the rural energy consumption of northern India (SRECNI)[54], composed of the states Delhi, Haryana, Himachalpradesh, Punjab and Rajasthan with about 150 M population, made by the National Council of Applied Economic Research for 1975/6. This survey, which analyses sectorwise consumptions of

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[54.] Survey of rural energy consumption in northern India (SRECNI), National Council of Applied Economic Research.

commercial and non commercial energies in this region of India, seems more trustworthy than the earlier ones, because of the very detailed nature of the study. In absence of such data from other rural regions of India, I have converted the consumption data of SRECNI for various fuels into per capita amounts and then made the quite unjustifiable assumption that this is also the per capita consumtion for these fuels for the rest of rural India. In this way I have arrived at a picture of rural consumption of energy in India, and of the commercial and noncommercial components in it, which I hope would be closer to reality than the previous estimates of the RFPC.J1209

In table 20 is given the per capita rural consumption of both the commercial fuels and noncommercial fuels: firewood, vegetable waste, charcoal and above all dung, all estimated in MTCR unit using the conversion factors given in table 11.1 also give estimates of kcal of food input for a man day of labour. 2000 kcal for Construction sector and 1200 kcal for a man day labour: in other sectors, and an animal day (8 hr) labour of 18400 kcal. The economic sectors of energy consumption are the usual ones: Transport, Domestic, Agriculture, Establishment together with a new one Construction. I have, however, joined the Establishment and Construction sectors, as this would be more

Table 20. Per capita energy consumption in rural northern India in 1975/6.

Source : SRECNI[55]

Commercial (kgCR/cap)	T	D	A	E	Total
Coal/Coke	0.827	0.780	–	6.367	7.973
Kerosene	–	6.793	–	2.153	8.947
HSD & LDO	10.760	–	43.087	1.987	55.833
Petrol	0.720	–	–	–	0.720
Fuel Oil	–	–	–	0.033	0.033
Electricity (Wh/cap ≡ kg CR/cap)	0.033	1.713	10.753	0.980	13.480
	12.340	9.286	53.840	11.520	86.986
Noncommercial (kgCR/cap)					
Firewood	–	83.720	–	4.060	87.780
Vegwaste	–	57.927	–	6.647	64.573
Dung	–	47.427	–	1.547	48.973
Charcoal	–	1.193	–	3.367	4.560
		190.267		15.621	205.887
Animate energy (M cal/cap)					
Man energy	1.07	–	92.47	12.33	105.87
Animal energy	18.47	–	356.67	–	375.14
	19.54		449.14	12.33	481.01

Sectors: T = Transport, D = Domestic, A = Agriculture, E = Establishment including Construction.

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[55]. Survey of Rural Energy Consumption in Northern India, National Council of Applied Economic Research.

consistent with what has been done for commercial fuels. Table 20 brings out the dismal picture of energy consumption in rural India, and the sheer poverty and miserable quality of life resulting therefrom.

I now assume the APGR for rural population given earlier (2%), which gives a rural population in 1975/6 as a 484M. With this rural population multiplied to the per capital rural consumption of energy derived above, we can arrive at an estimate of the total consumption of rural energy in India during 1975/6. The noncommercial component is taken out and shown in table 12. I do not favour division of energy consumption in rural and ubran sectors for the commerical eneryg, for such a distinction is difficult to make. But the above analysis serves to estimate the noncommercial energy, which is almost entirely used in the rural sector. We also postulate that the per capita energy consumption in rural India is invariant with time, so that the APGR of the total rural energy consumption is expected to follow the APGR of rural population viz 2.0% at least upto 1978/9. The projection for noncommercial fuels estimated in this was are given in table 12.

FORECASTING THE ENERGY SCENARIO IN 2000 A.D.

We are now prepared to look ahead at what is likely to happen during the remaining twenty years, which would bring us to the close of this century. The game of planning was started in India by Meghnad Saha, at whose insistence the Indian National Congress set up the Natiohal Planning

56. Report of Power and Fuel Sub-committee, Sub-committee, National Planning Committee series, ed by K. T. Shah, Vora & Co. Pub Ltd. (1947).
57. Report of River Training and Irrigation Sub-committee, National Planning Committee Series, ed by K.T. Shah, Vora & Co. Pvt. Ltd. (1947).
58. Report of the Energy Survey of India, Government of India (1965).
59. Report of the Fuel Policy Committee, Government of India (1947).
60. Report of the Fuel and Power Sector, National Committee of Science and Technology (1974).

Committee in 1938 with Jawharlal Nehru as Chairman. Prof. Saha was Chairman of the Power and Fuel sub committee[56] and a member of the River Training and Irrigation Sub-committee[57]. The reports of the National Planning Committee should be read by all those who wish to study the evolution of the concept of planning of economy in this country. Since then there have been many studies of the energy problem in India. Mention must be made of the reports of various committees set up by the Government of India from time to time: Report of the Energy Survey of India Committee of India, 1965[58], Report of the Fuel Policy Committee, 1947[59], Report of the Fuel and power sector of the National committee on Science and Technology 1974[60]. There are many studies of specific fuels and their forecasts by individuals and various organisation of the Government, and numerous studies made by the National Council of Applied Economic Research. Recently a study has been made of the energy problem by a working group of the Planning Commission. Unfortunately, though the report of the working group is ready, I was not able to have a look at it.

How does one make a forecast on a complex problem like that of energy? The standard methods are:

1. extrapolation from past trends in energy consumption,
2. use of regression models which correlate past state of energy consumption with the past state of economic activity,
3. use of the end use approach which is a detailed construction norms of energy consumption for various categories in differnt economic sectors for determination of the energy demand likely be faced by the growth of consumer categories in future under some postulated economic growth.

The use of detailed models 2) or 3) has justification in a stable economy, where there is no problem of energy resources threatening to dry up, and where the various elasticity coefficients

measuring the responses to various demands of the economy are stable and known. These models are not well adopted to meet the demands of a crisis. On the other hand, one would think that forecasts depending on past trends should also not be of may help for a scenario involving a crisis. It is like driving a car forward by looking at the rear view mirror, with a prayer to God that there is no sudden change of direction of the road ahead. However, in 1980, we have a fair idea of the status of the energy resources available to us in this country, which I hope I have been able to bring out clearly to you. So I was encouraged to go ahead and do some predictions using the first method for what they are worth. In any case, this is the best one can do, who does not have a big secretariate to help him and has only a pocket calculator and some loyal friends who are ever ready to come to assistance.

There is very close correlation between certain economic variables like the Gross National Product and the energy production, and the correlation is used often to determine the energy demand for a particular GNP desired for the economy by the planners. However, when energy is in short supply, the approach should be the other way round i.e. the energy supply should be first estimated and then GNP worked out and the economy planned in detail.

I did not consider a scenario in which the population is allowed to grow unchecked and in which there is no limit to the capacity to produce the fuels necessary, if their resources are available. The scenario which I think is most likely is described below.

1. Population : The population scenario has been described already : the APGR would be 2% for rural and 3.6% for urban population upto 1991/2, for both populations the APGR's would be 1% from 1991/2 to 2000/1 and 0.5% after 2000/1. An APGR for the population higher than this will spell disaster for the country.

2. Oil : The APGR for import of oil for the period 1975/6 to 1977/8 is 6.8%. But the import of oil cannot be continued much longer after this year, because of the price escalation. In 1973/4 oil prices were in the region of $ 3 per Bbl; in 1979/80 no body is surprised when oil prices are quoted in the region of $ 25-35 per Bbl. The price trends are rising more and more steeply. I expect that the oil suports will cease for all practical purposes by 1982/3, at which time the oil import prediction from an APGR of 6.8% should be about 160.8 MTCR. The APGR for domestic oil production was for period 1973/4 to 1977/8 9.3%. The total reserve of our domestic oil is 2.06 G Bbl $\equiv$ 0.282 GT $\equiv$ 1.833 GTCR and the domestic production of crude in 1978/9 was 11.4 MT $\equiv$ 73.9 MTCR. Using equation (4) with the above data we expect the Doomsday for domestic oil production to be around 1990/1, unless very large new deposits of oil are discovered. Thus within eleven years from now, all our oil reserves are expected to dry up, which will have devastating effect on our economy. We are perhaps feeling already the approach of this disaster. In 1990/1, the domestic production of oil is expected to be 214.8 MTCR.

If in this scenario one looks at the per capita oil production, then because of high APGR's assumed for both imported and domestic oil, the per capita oil production increases as shown in table 20.

Table 20. Per capita oil production in India (in 10 × TCR/cap)

1960/1	1.25	1982/3	3.70
1965/6	1.75	1983/4	1.56
1970/1	2.37	1985/6	1.78
1975/6	2.54	1990/1	2.47
1979/80	3.17	1991/2	–

This means that we shall be geting increasingly more oil per capita except for a drastic fall in 1983/4, after which there is steady rise again till a total colapse in 1991/2. It will be an important decision for the Government to determine at what level the per capita oil production has to be maintained. Laissez faire exploitation of our oil resources may not be permitted much longer and to conserve what we have, oil consumption most

certainly will have to be rationed and oil substituted by other fuels like ethanol or hydrogen. The luxury of a personal petrol driven car may very soon be a thing of the past. Even if per capita domestic oil production is drastically reduced from 1979/80 and maintained at a constant level of 1.25×10^{-1} TCR/cap, which is the 1960/1 level, the Doomsday for oil in India can pushed only to 1996/7 and not much further, if there is total ban on oil import after 1978/9.

3. Coal : The APGR for coal production is 7% in the period 1971/2 to 1974/5. If this growth rate can be maintained, about which there can be room for doubt, the output of coal should be 280 MT by 1991/2. I feel that it it beyond our capacity to produce much more than this. We are already witnessing a crisis in coal production because of managerial failures, transportation breakdowns, the failure of the symbiosis that should exist between coal and electricity, and the primitive condition of our mining methods and equipments. There are reasonable doubts whether 7% APGR can be maintained upto 1991/2.1 have assumed that this APGR will be maintained because the Government is under compulsion to do so, for otherwise the situation would be too aweful to think about. In the scenario that I am contemplating, I propose to maintain the level of coal production at 280 MT from 1991/2 onwards. If the 7% APGR could be maintained, then using the coal production figure for 1975/6, which is 94.6 MT and the coal reserve of 83.74 GT we get Doomsday for coal in India around 2035/6 AD. If, as we have seen, the useful part of the coal is taken to be only 32 GT, the Doomsday comes in on 2021/2 AD. If the coal production is kept constant at 280 MT, then the Doomsday for 94.6 MT reserve goes well into the twenty third century (2260/1 AD). Of course, the per capita coal production will reduce drastically from 3.00×10^{-1} MT in 1990/1 to 2.42×10^{-1} MT in 2035/6. It is quite clear that we can not be complacent about our known coal reserves, because

India's mining capacity will have to improve with time from dire necessity, and coal production may rise above 280 MT. Thus there is an imperative need for intense prospecting for coal.

If we consider the per capita coal production, then becuase of the high APGR of coal production, it should steadily increase with time. But in practice, this might not happen. Assuming, however, that everything goes alright, we get the per capita coal productions as given in table 21.

Table 21. Per capita coal production in India (in $10 \times TC/cap)^2$

1960/1	1.28	1985/6	2.33
1965/6	1.39	1990/1	3.00
1970/1	1.33	1995/6	3.02
1975/6	1.54	2000/1	2.87
1979/80	1.85	2035/6	2.42
1980/1	1.93		

It appears that there will never be enough coal available to divert it for liquifaction or gasification for providing substitution for oil, and alternative substitutes for oil must be found.

4. Electricity : If the 10.7% APGR for hydel can be maintained, them ignoring the fact that dams have finite useful lives, the hydel potential for this country, as estimated by the Power Economy Committee viz. 420-525 TWh of annual electricity production, will be reached by 2000/1. But this means tremendous civil engineering work and a very large programme for manufacture of machineries for electricity generation by the end of this century. Thus the hydel productions in 1999/2000 should be 482 TWh and in 2000/1 525 TWh, which is an increase of 43 /TWh. This means that hydel installation of 8 GW capacity with the civil construction work for the necessary dams have to be completed within that year. It is difficult to foresee whether a task of such magnitude can be achieved in this country.

Before we try to estimate the total production on electricity in the coming years, let us consider

the thermel production. There are many imponderables about it, and we can only make intelligent guesses about them. We have to guess how much coal could be raised, transported and distributed and how much oil would be available in the face of crushing rise of oil prices. We may project the thermel production on the basis of the coal and oil production scenario that I have described. The APGR for thermel production for period 1965/6 to 1971/2 (table 19) was 10.2%. Subsequently it is likely that the APGR may have fallen. But I have projected on this APGR till 1978/9, after which the oil availability may be too erratic. The % shares of power coal in total thermel fell from 73.6% to 60.8% and power oil in total thermel rose from 26.4% to 39.2% in the period 1960/1-1970/1 (table 18). To estimate the shares of power coal and power oil in the total thermel from 1970/1 to 1977/8,1 have assumed 60% for power coal and 40% for power oil. This resulted in % shares of power coal and power oil in total coal and total oil to rise from 23.5% to 31.5% and 8.5% to 12.4% respectively in this period. To project beyond 1977/8 we have assumed the % shares of power coal in total coal and power oil in total oil as 32% and 13%, assuming that if the fuels are available then because of demands from other setors, the fuels will flow into the power sector in this ratio. The projection for thermel upto 2000/1 has been made in this way and is presented in table 18. The hydel production has been assumed to keep to a steady 10.7% APGR till the saturation level in 2000/1. The % shares of hydel and thermel in total electricity produced are shown in table 19. After 1990/1 the only sources of electricity that we can think of now are coal and hydroflow. The % share are nearly equal till 1982/3 after which hydel would begin to dominate. The % shares of electricity in total energy are also shown in table 19. From a minor share in 1960/1, electricity should dominate by the end of the century, because we have not contemplated any restrictions on hydel development.

The per capita electricity production is as shown in the table 22

Table 22. Per capita electricity production (in kWh/cap) in India from 1960/1 to 2000/1

Year	Hydel	Thermel	Total Electricity
1960/1	18	21	39
1965/6	31	36	67
1970/1	46	52	98
1975/6	69	76	145
1979/80	94	100	194
1982/3	119	116	235
1983/4	128	91	219
1985/6	150	98	248
1990/1	222	128	350
1991/2	240	100	340
1995/6	346	97	443
2000/1	539	92	631

Thus hydel production should have increased in 1979/80 by 5.2 times the 1960/1 figure and should increase by 29.9 times by 2000/1. The thermel production should have increased in 1979/80 by 4.8 times the 1960/1 figure and should fluctuate due to oil scarcity reaching a level of 4.4 times by 2000/1. Per capita commercial energy increaes by a factor of 3.1 in the period 1960/1 to 2000/1 and most of the incease is due to the hydel component. Per capita noncommercial energy will actually decline by a factor of 1.5 in this period. This would mean that the poorer communities in the rural areas will be very hard hit by scarcity of fuel in he coming years. Per capita total energy available increases in this period by a factor of 2.2 only, even if the hydel can be developed. This does not mean much increase of prosperity for the country. By 1979/80 we should have about 5.0 times increase of total electricity production over the 1960/1 figure, and by 2000/1 we expect 16.2 times increase in our scenario, inspite of the fact that oil may perhaps not be available after 1990/1. This is because we expect that the large hydel potential of the country can be developed. The above analysis shows how important it is to develope this potential. The world average per capita electricity consumption in 1970

was 1361 kWh/capita; whereas Norway consumed 14635 kWh/capita and USA 8009 kWh/capita in that year, thus this country has a long way to go before its electricity production and consumption can compare with those of other countries.

Another scenario for hydel is more probable perhaps; this is based on the assumption that the capital annual hydel production in 1979/80, which in 94 kWh/capita, cannot be easily exceeded. Then the hydel production to 2000/1 would be as given below.

Table 23. Total hydel production (in TWh) in India if per capita hydel production is constant and = 94 kWh/capita year

1979/80	57	91/2	82
82/3	68	95/6	84
83/4	69	2000/1	92
90/1	73		

This means it would take very long time to reach the target assessed by Power and Economy Committee. The annual increase of hydel production is about 2 TWh which would mean annual hydel installation of 380 MW, which is not too much.

5. **Noncommercial Fules :** I give some reasons below which leads me to believe that not much more than 100.7 MTCR amount of noncommercial fuel will be available hereafter.

AVAILABILITY OF NONCOMMERCIAL FUEL

Firewood

Let us first look into the availability of firewoods which requires an examination of land utilisation in India. Table 23 gives the relevant data since most of the firewood

61. Statistical Abstracts 1977. Central Stasticial Organisation Government of India.
62. Domestic Fuels in India, National council of Applied Economics Research (1959)

Table 23. Land utilisation in India in 1972/3. All areas given in 10^7 hectare

Source : Statistical Abstract 1977[61]. Figures in brackects indicate % shares of the total land utilised.

Total geographic area	=	32.87
Total land utilised	=	30.41 (92.5% of total land)
Forest area	=	6.53 (21.5)
Land area under non-agricultural use	=	1.62 (5.3)
Barren and uncultivable fallow land area	=	2.63 (8.6)
Permanent pastures and other grazing land	=	1.28 (4.2)
Land area under miscellaneous cultivated tree crops and groves not included in the area shown	=	0.46 (1.5)
Cultivable waste land area	=	1.58 (5.2)
Balance area under cultivation	=	16.15 (53.1)

comes from our forests let us look at our forest wealth. The data given in table 23 is very disturbing. Forests cover only 21.5% of the utilised land and this can only men disaster from ecological and climatic points of view. It is therefore extremely urgent for the Government to seriously review its forest policy before it is too late. Time targeted R&D work is necessary to established energy plantations on cultivable waste land which forms 5.2% of the utlilised land. However, there will be other important claims on this area. According to a study of National Council of Applied Economic Research made in 1959, not all firewood is collected from forests but from other areas. The survey gives the firewood consumed for this year as 31 MTCR and charcoal[62] 1/MTCR i.e. a total of 32 MTCR. However, the out turn of firewood from forests was only 375 Mcft. Allowing for an extra third on this as illegal cutting, we get a total of 500 Mcft of firewood which is equivalent of 5 MTCR. Deducting this from the total 31 MTCR, we find that 27 MTCR of firewood was collected from outside the forest area. This is extremely serious. Our estimate

from SRECNI survey is that firewood used in 1978/9 is 43.9 MTCR, and I hope that it is realised from what has been said, that this cannot be increased much more.

VEGWASTE

This is mostly agrowaste and depends on the agricultural output, and the rest depends on droppings from trees and various other plants. It is very difficult to estimate the proportions of the various components, and the problem should be studied in depth. The agricultural output depends on the cultivated land, which is already about 53.1% of the utilised land, and perhaps cannot be increased and further. The trees are diminishing in number, and their droppings must necessarily decrease henceforth. Moreover, there are other important demands on vegwastes for nonenergy industrial use. An important example is the utilisation of just sticks for production of hard boards. The figure for vegwaste obtained from the SRECNI study for 1978/9 is 32.3 MTCR and it is very likely this figure will remain constant with time.

DUNG

Meghnad Saha[63] in his last paper made a very interesting study of availability of dung fuel, and his approach to the problem was accepted as realistic by NCAER in their report on Domestic Fuel[64]. He made an estimate of the dung collected from the report of marketing of cattle[65] in India which stated that an average adult Indian cow produced 25 1b/day of green dung, young cow 18 1b/day, an adult

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[63.] Meghnad Saha. Fuel in India, *Nature*, May 19, p. 923, (1956)

[64.] Domestic Fuels in India, National council of Applied Economics Research (1959)

[65.] See Meghnad Saha. *loc. cit.*

[66.] See Meghnad Saha. *loc. cit.*

[67.] Statistical Abstract 1977, Central Statistical Organisation, Government of India.

buffalo 60 1b/day and an young buffalo 40 1/b day. Prof. Saha assumed 180 M heads of cattle with composition 140M heads of cow and 40M heads of buffaloes. With the age structure for both groups : 70% adult and 30% young, the dung outturn should be as given below :

	Number (in M heads)	Annual green dung outturn (MT)
1. Cow population		
Adult	98	405
Young	42	125
	140	530
2. Buffalo population		
Adult	28	278
Young	12	79
	40	357
Total :	180	887

Thus, average yield of green dung by a cattle head per year = 4.93T/year = 13.50 kg/day. According to the Memorandum on the Development of Agricultural and Husbandry (1944)[66] and 40% of dung is collected. Thus of 887 MT green dung only 354 MT green dung or 71 MT dry dung is available This gives the ratio.

$$\frac{\text{Dry dung (fuel)}}{\text{Green dung outturn}} \times 100 = \frac{71 \times 100}{887} = 8\%$$

Thus average dry dung collected per cattle head = 0.39 T/y

Our calculation from the SRECNI study requires 23.1 MTCR of dry dung in 1975/6 which is equivalent to 76.96 MT of dry dung or 962 MT of green dung. This would require 195 M heads of cattle. According to statistical abstract 1977[67] the cattle population growths are as given below

	1961	1972	APGR
Number of cows (in M heads)	176	178	0.1%
Number of buffaloes (in M heads)	51	59	1.3%
Total (in M heads)	227	237	0.3%

With these APGR's the cow number is 178.5 heads and buffalo number is 61.3 M heads, i.e. a total of 240 cattle heads in 1975/6 which is sufficient for the dung required. If the rural population grows unchecked at APGR of 2%, then the dung demand, which should also grow at this rate, will very soon outstrip the supply, which grows at the rate of 0.3% only. If this happens in x years after 1975/6 then x is a solutions of

$$195 \times (1.02)^x = 240 (1.003)^x$$

which gives x = 12 years, i.e. the year when dung supply will be inadequate is 1987/8. We have allowed 2% growth of rural human population upto 1991/2. So the dung supply can be allowed to grow at 2% APGR upto 1987/8, when it reaches the fugure 29.3 MTCR (dry dung). After this year the dung supply may rise very slowly at an APGR of 0.3% the APGR for cattle population of India.

It must be recognised that we have taken a very low CR value for dung viz. 0.3%. With improvement of utilisation technology e.g. conversion into gobar gas, the net energy available from the dung collected may be much larger than what is put in table 12.

SUMMARY

We may now summarise the main points of this study.

Oil gap : The Doomsday for oil import has been set in 1928/3 and domestic oil in 1990/1. We have seen that the shortage of oil will profoundly affect two economic sectors : the Transport and the Domestic. We have calculated the per capita oil consumptions for these sectors for 1970/1, which is 0.137 TCR/cap, and projected with this per capita consumption as constant with time to find the amount of oil consumed in these sectors for subsequent years. This assumes no real growth of consumption of oil in these sectors. Table 24 shows the state of affairs for these sectors upto 2000/1.

Table 24. Oil gap (in MTCR)

Oil demand for T&D sectors calculated at the 1970/1 per capita level of 0.137 TCR/cap

Year	Oil available	Oil demand (T&D sectors)	%	Gap
1970/1	129.3	74.8	58	
1975/6	156.0	84.0	54	
1979/80	212.7	91.9	43	
1982/3	247.1	94.6	40	
1983/4	137.7	101.1	73	
1985/6	115.3	105.9	92	
1990/1	214.8	119.2	55	
1991/2	–	122.0	–	122.0
1995/6	–	827.0	–	127.0
2000/1	–	133.4	–	133.4

Thus by 1990/1 the oil gap may dominate the Transport and Domestic sectors. This gap must be filled up by alternative liquid fuels. The production of ethanol from bio waste may not be sufficient, for the amount of biowaste available will have reached saturation by 1978/9. The only other alternative seems to be hydrogen, which must enter the economy by the next ten years.

Coal : The coal production has been assumed to rise steadily at 7 % rate. But to maintain this steady APGR tremendous changes are necessary in the managerial structures and mining methods; the symbiosis of coal and electricity must be restored. The assumption made here that coal production will level off at 280 MT by 1991/2, if such changes cannot be made, seems to be realistic. The Doomsday for coal for 280 MT annual production will be in 2260/1. It is also very clear from the expected per capital coal production that not much coal can be spared for liquifaction or gasification as substitute fuel for the Transport and Domestic sectors.

Electricity : The optimistic picture that emerges of electricity production is based on the assumption that the 10.7% APGR can be maintained for hydel production. This may be too much to expect. The question of transmission of hydel from the place of generation to the consumers will become very important in future. To solve this problem, hydrogen may have to be produced at the site of electricity

production, which could then be piped to the consumer. The loss of electric energy in transmission must be reduced by replacing gradually the high voltage AC transmission systems by the high voltage DC transmission ones.

This then the picture of what I feel would be shape of things to come. It will be clear that I am putting too much trust in our capacity to develope hydroenergy. If we fail in doing this, then ofcourse the country will face a disaster of unprecedented magnitude. Even if everything goes alright, does the per capita energy, which becomes available, mean prosperity for the country.

Tolstoy asked the question : how much land does a man need. A similar question may be asked about energy. How much energy do we really need? An American consumed in 1970/1 about 328.8 M Btu of energy i.e. about 11.7 TCR, which is very large compared to India per capita energy 0.57 TCR for the same period. Indeed if one examines the energy comsumption of various global areas in 1970 given in table 25 one can see that the developed countries with 26.1% of the world population consume 77.9% of the energy. Indian

per capita energy 0.57 TCR is comparable with the per capita energy for noncommunist Asia for 1970/1 which is 16.9 M Btu i.e. 0.60 TCR. Meghnad Saha had all his life struggled to fight this injustice, and his wish was that this country achieves the same energy consumption level as the developed countries. But today in face of energy shortage, the per capita energy consumption in developed country seems a preposterous way of spending the limited resources available.

On the other hand the advance of technology based on increasing consumption of energy has certainly improved the quality of life of many classes of the society. The increasing pace of energy consumption is very neatly summarised in the dedication page of the survey " Energy and man[70]" : "For the grandparents .. who found 110 kWh/capita/day was more than enough, for the parents .. who thought 150 kWh/capita/day was about right, for the brothers and sisters .. who have been doing well on 250 k Wh/capita/day and for the children .. who will probably feel like they're having to skimp at 350 kWh/capita/day" The figures are presumably for total energy. The Indian figure[71] for total energy

Table 25. Energy consumption of various countries in 1970

Country	Energy consumption (in q = 10^{15} Btu)		Population (in G = 10^9 a persons)		Per capita energy (in M Btu)
Africa	3.64	(1.7)	0.35	(9.7)	10.40
Asia (communist)	11.34	(5.3)	0.79	(21.9)	14.35
Asia (Non-Communist)	20.76	(9.7)	1.23	(34.0)	16.90
Latine America	9.20	(4.3)	0.28	(7.8)	32.90
North America	74.25	(34.7)	0.23	(6.4)	326.80
Oceania	2.35	(1.1)	0.02	(0.5)	117.50
USSR & East Europe	44.72	(20.9)	0.35	(9.7)	127.80
West Europe	47.72	(22.3)	0.36	(10.0)	132.50
	213.98	(100)	3.61	(100)	59.28

Source : J. P. Harnett[68]. Figures in brackets indicate % shares

68. J. P. Harnett : The case for alternative energy sources, article in Alternative Energy Sources.
70. Energy and Man–Technological and Social Aspect : ed Morgan M.G. The Institute of Electrical and Electronics Engineers Press.
71. Note : Using calorific value of anthracite-12700 Btu/lb, ITCE = 28 MBtu = 8202kwh.

is 12.8 kWh/capita/day in 1970/1, which may rise to 21.1 kWh/capita/day in 1970/1, which may rise to 21.1 kWh/capita/day in 2000/1. Technology has increased the expectation of people of all walks of life, and it is unthinkable that its forward march

can be halted or reversed. We have a long way to go to meet the energy demand, which is bound to rise steeply.

In table 26 we see the per capita production of various forms of energy. The non-power coal

We cannot attack the energy problem unless our attitudes change. In the coming years, the energy question will surpass all other national problems in importance and urgency. The Government must realise the key role that energy plays in the economy

Table 26. Per capita energy production (in 10 × TCR/person = 10^4 kwh/person)

Year	Nonpower Coal	Nonpower Oil	Electricity	Total Commercial	Total Non-Commercial	Total Energy
1960/1	1.13	1.20	0.39	2.72	1.62	4.34
1965/6	1.13	1.64	0.67	3.45	1.60	5.05
1970/1	1.02	2.17	0.98	4.17	1.57	5.74
1971/2	1.09	2.24	1.45	4.78	1.55	6.33
1977/8	1.26	2.76	1.94	5.96	1.51	7.47
1978/9	1.43	3.22	2.35	7.00	1.43	8.43
1982/3	1.50	1.36	2.19	5.05	1.40	6.45
1983/4	1.58	1.55	2.48	5.61	1.35	6.96
1990/1	2.04	2.15	3.50	7.69	1.22	8.91
1991/2	2.13	–	3.40	5.53	1.19	6.72
1995/6	2.05	–	4.43	6.48	1.15	7.63
2000/1	1.95	–	6.31	8.26	1.10	9.36

production increases by a factor of 1.9 to a maximum in 1991/2 and then declines. Oil may vanish by 1990/1, creating an oil gap of 122 MTCR, i.e., 18.8 MT in the Transport and Domestic sectors, which has to be met. Per capita electricity increases by a factor of 16.2 in the period 1960/1 to 2000/1. But whether this will be possible is doubtful. In table 22 we have seen that per capita hydel increases by a factor of 29.9 in this period whereas thermel increases only by a factor of 4.4. Thus if the APGR of the hydel is not maintained, then electricity will be a scarce commodity as it is already threatening to be.

ENERGY STRATEGIES FOR THE FUTURE

I shall be very happy if my forecasts are proved to be wrong. But my fear is that what will actually happen may be far worse than what I have described. So the country must be put on a state of preparedness to face the dangerous situations that will come. I do not know the answers to what must be done -I do not believe any body does. I shall, however, suggest a few points, which I think are relevant. In the hope that specialists would discuss them and indicate the path, which the country should follow.

and lives of the people, who would put up with energy shortage only to the point that the Domestic sector is not touched and the food supply systems, which is a matter for the Transport sector, does not collapse. If the energy question is allowed to drift, then the politicians indulging in the luxury of the power game, would be swept away as unworthy of trust of the people. We, scientists value our freedom to work on problems of our choice : this freedom will be lost, if we do not participate in energy reserach. We have a wonderful status in society. Other people pay and we do what we want. If we neglect to work on energy, our privileged status cannot be defended, in a energy less society. Energy research must, therefore, be undertaken as a matter of compulsion in all R&D institutes of the country. The technologists may find very soon that the society would not have much use for them, if they do not lavish the care and attention to the design, manufacture, installation, operation and maintenance of the energy conversion machines, which is required. The workers must cooperate to see that the energy supply to the various economic sectors are assured, for otherwise they would suffer as much as others in the disasters that would follow.

Energy is a multidiscipled subject and educationists must carefully arrange that the Universities and the I.I.T's have energy as an important item in their syllabi and also design practical training courses for those who would take up energy as a career. The media has a major role to play in making the awareness of the problem pervade through all strata of society. All of us must realise the urgency of the problem and be ever vigilant that things are properly done. Energy crisis has to be treated on a war time footing.

To formulate a strategy for energy, reliable data and informations should be easily available on various forms of energy, both in regard to quantity and efficiency of production and distribution, their consumptions in the various economic sectors with assessments of various end uses. Unfortunately, in India, the data that are available, are too old and incomplete to be useful. Thus it is imperative that a monitoring agency be set up to undertake this task.

The country evidently must have an energy policy. I do not know which organisation should undertake the formulaition of the policy. I can at least suggest, for what it is worth, what should be discussed while formulating the policy statement. Evidently the policy must contain considerations the following points :

1. Energy resources and exploitation

● Prospecting for new resources, Development of prospecting methods for remote areas and under oceano using remote using methods for prospecting.

● Preparation of a master inventory of energy resources of the country.

● Modernisation of mining methods and equipments: Consideration of secondary and tertiary recovery methods for oil wells which are exhausted with respect to primary methods, deep coal mining.

● Assesment of the biomass that can be gathered without endangering the ecology of the country.

● Establishing energy plantation for biofuels.

● A trade policy for regulating export of energy resources and import of energy fuels.

2. Alternative uses of existing fuels

● Intense R&D programme for liquifaction and gasification of coal within a considered time frame so that by 1990/1 the plants can be ready to provide coal based liquid fossil fuel to domestic and transport sectors.

● Intense R&D programme for production of ethanol from biomass and introduction into the economy of other bioconversion systems.

● Rethinking of the gobar gas programme to make the gas available to the poorer classes of society.

3. Hydel & electrification programme

● Rethinking of the various aspects of the existing hydel projects for taking corrective measures.

● Laying down a hydel production programme for the country, for we may have to depend on hydel in increasing proportions.

● Replacement of A.C. transmision by D.C. systems.

● Rural electrification should be reconsidered if hydel production cannot be increased.

4. Energy conversion machines

● A review of what types of energy machines and plants should be manufactured in the country and what should be imported.

5. Energy pricing

● A policy for pricing various forms of energy that is should to the consumers and recommendations of differential rates, whenever necessary.

6. Regulatory aspects

● To consider the pollution and damage to environment and ecology from energy production from fossil or nuclear fuesl, hydel etc. and what legislations to pass and how to enforce them.

7. New energy sources

● Intense R&D programme for hydrogen production with the target that production begins by 1990/1.

● Intense R&D programme for fuel cell development.

● A solar energy policy for its utilisation with Stirling engines in the Rural Agriculture for irrigation pumps and generally for sector for space heating and cooling, and a R&D work programme for photovoltaic converters, should be laid down.

● Installation of aeolian engines where strong winds are available, tidal energy stations at gulf of Cambay and Kutch and the mouth of Hugly in West Bengal.

● Consideration of prospects of utilisation of geothermal station.

8. Collaboration with other countries on energy R&D

● To the consider research programmes on energy, which are too expensive for this country or lack native expertise, for which collaborations should be established with other countries magnetohydrodynamics, fusion energy programmes, solar energy programmes, etc.

9. Nuclear fission energy

● Rethinking about what to do with this technology : whether to go on with it, in which case a reorganisation of the whole programme will be needed, or whether to taper it off in view of the known hazards, which seem almost unsurmountable.

10. Perspective for the future

● A plan for fuel replacements when the shortages really set in – ethanol to take the place of oil now and hydrogen coming in by 1990/1.

● Consideration of per capita producton of various forms of energy and consumption in various enconomic sectors upto the end of this century, for this provide the basis to plan the other aspects of the economy.

11. Energy Ministry.

● Restructuring of the Energy Ministry to vitalise it for planing for energy and endowing it with the necessary overall powers for executive actions.

12. Various Agencies and Research Institutes

● Reorienting the charters of various agencies and R&D organisations and allotment of tasks to them to meet the energy challange.

13. Education and training.

● Introduction of energy prominently in the sylabi of the Universities, the IITs and the Technical Colleges, and designing of practical training courses on various aspects of energy.

There are many aspects that I have not touched at all in this study.

● The historic perspective has been only very briefly described. This is a fascinating field for study for scholars, particularly with respect to what happened in India in the past, which is not so well known.

● I have considered a few likely scenarios. Many other scenarios are possible which should be examined in detail to work out the best strategies to meet the crisis looming ahead. The strategies should have a flexibility so that they can be adapted to altered situations.

● The discussion of structures and logistics of large energy plants and their management has been completely left out. This is of immediate importance in view of the present crisis of management.

● I have not considered the rise of cost of energy and the effect on various sectors of the economy and on the social ethos.

● I have just touched on the effect of energy scarcity on a few chosen sectors of the economy arid that also rather casually. I have not discussed the profound social changes that are likely to follow as a result of the scarcity.

● The conservation aspect has not been touched at all. This should be an important area in which study in depth has to be conducted, for many administrative and legislative measures are dependent on such studies.

● I have not discussed the pollution apects of energy production and consumption. The Industrial Revolution had started the release to the atmosphere of CO_2 and many hazardous gases, aerosols and various particulates. The release of CO_2 is dramatically demonstrated by the Suess effect. What will be the long term effect on the global climate is a matter of intense controversy. Completely opposing conclusions are put forward, all basing their speculations on what would happen to the ozone layer.

● The question of acceptance by society of new modes of energy has not been discussed. There are many other questions related to interacton of energy and society which need detailed analysis.

● I have not considered the global scenarios in any detail and the interactions between other countries and ours on energy, which must assume importance in years to come. We can not live in isolation and energy is an area in which international discussions, collaborations and agreements will be very much needed.

● I have also not considered the tremendous stock of energy resources which are likely to be found below the oceans and on the continental shelves and the methods of prospecting for them, assessing the dimensions of the deposits and possible recovery technologies. There are other important questions regarding such deposits- who owns them, does the principle of Res Cummunis apply to the resources in the sea or do such resources, in practice, belong only to the technologically advanced nations, who have the expertise as prospect for and exploit such wealth?

I have tried to cover many things in course of this address, from very sublime concepts like Migma to some rather profane things like dung. I hope that I have been able to show to you the tip of the iceberg. This is as much as I could do in the time available to me. The opinions I have expressed are my own. There will be other opinions and other views. I do not wish you to agree with me; rather if this address gives rise to vigorous discussions among you, then I shall have achieved my purpose. The crisis is right on us, and there is so much to be done. It would be wrong to think that we shall some how muddle through. A lot of thinking, preparation and organisation will be needed, if we have to face the challenge. To be or not to be is now very much the question.

My appeal to those who ordain our lives is to spare a thought on the shape of things to come. In a world, where energy will be scarce, much of the issues on which we fight so fiercely will lose their relevance. The arguments we use would be just so many empty words, devoid of any meaning. In such a world, it would be sufficient for the day, to live from one moment to the other, and survive.

The warning bells of Spaceship Earth are ringing. Do not ask me for whom the bells toll-it tolls for you, for me, for all the people of earth of today and tomorrow. Shall we heed the warnings and take up the challenge?

Finally I turn once more to the 21st President, who did so much to draw our attention to these problems, and who thought so much about them. We have come across his thoughts and studies althrough this address. With the deepest humility, I dedicate this work to him. His life and philosophy stand as a shining beacon in the gloom that is setting on our world.

Thank you ladies and gentlemen.

ACKNOWLEDGEMENTS

APPENDIX

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UNITS

1. Decimal Scales :

Milli (m)	$= 10^{-3}$,
Centi (c)	$= 10^{-2}$,
Kilo (k)	$= 10^{3}$,
Mega (M)	$= 10^{6}$,
Giga (G)	$= 10^{9}$,
Tera (T)	$= 10^{12}$,
USA n-trillion	$= 10^{3(n+1)}$,
European n-trillion	$= 10^{6n}$

2. Weights

1b		kg
1		0.4536
2.205		1
1 short ton	=	2000 1b,
1 long ton	=	2240 1b,
1 quintal	=	10^2 kg,
1 tonne (T)	=	10^3 kg

3. Lengths

ft		m		
1		0.3048		
3.281		1		
1 inch	=	12^{-1} ft,		
1 mile	=	5280 ft	=	1.609 km
1 cm	=	10^{-2}m,		
1 km	=	10^3m	=	0.6213 mile

4. Areas

ft^2		m^2		
1		9.29		
10.76		1		
1 Acre	=	43560 ft^2,		
1 mile^2	=	640 Acre		
1 Areas	=	10^2 m^2		
1 hectare (ha)	=	10^4m^2,		
1 km^2	=	10^6m^2	=	100 ha
1 mile^2	=	2.59 km^2,		
1 km^2	=	0.3861 mile^2		

5. Volumes

ft^3	litre (L)
1	28.31
3.532 × 10^{-2}	1

1 L $= 10^3$ cm^3,
1 m^3 $= 10^6$ cm$^3 = 10^3$ L
1 ft^3 $= 2.831 × 10^{-3}$ m^3,
1 m^3 $= 35.32$ ft^3
1 Imp gallon $= 4.546$ L,
1 USA fluid gallon $= 3.785$ L
1 Petrol barrel (BBI) $= 42$ USA fluid gal $= 158.9$ L

6. Energies

Ftlb	k joule (kj)	Btu
k cal	Hph	kWh
1	1.356 × 10^{-3}	1.285 × 10^{-3}
3.241 × 10^{-4}	5.051 × 10^{-7}	3.766 × 10^{-7}
7.377 × 10^2	1	9.486 × 10^{-1}
2.390 × 10^{-1}	3.725 × 10^{-4}	2.778 × 10^{-4}
7.776 × 10^2	1.054	1
2.520 × 10^{-1}	3.927 × 10^{-4}	2.929 × 10^{-4}
3.086 × 10^3	4.184	3.968
1	1.559 × 10^{-3}	1.162 × 10^{-3}
1.98 × 10^6	2.684 × 10^3	2.542 × 10^3
6.416 × 10^2	1	7.457 × 10^{-1}
2.665 × 10^6	3.6 × 10^3	3.414 × 10^3
8.601 × 10^2	1.340	1

Very large energy units :

1 Therm	=	10^5 Btu,
1 Quad (q)	=	10^5 Btu,
1 Quint (Q)	=	10^{18} Btu	=	292.9 TWh.

Very small energy units :
1 eV = 1.6 × 10^{-19} J,
1 Mev = 1.6 × 10^{-13} J,
1 erg = 10^{-7} J

7. Powers

Hp (mechanical horsepower)	kW
1	7.457 × 10^{-1}
1.341	1

Watt (W) = Joule/sec

CLIMATE CHANGE AND CORAL VULNERABILITY

Sharmila Chandra

This is entirely a review article intended to raise awareness about one of the most dangerous consequences of global warming. The oceans are repositories of some of the most valuable resources of the world and human-induced global warming puts them at risk. All scientists and environmentalists must be conscious of this fact and make efforts to save them from overexploitation.

Global warming is today an issue of concern for every nation. The genesis of global warming can be related to a combination of factors including an excessive increase in human population, a more than optimum consumption of energy and matter, increasing degradation of the environment, rapid deforestation leading to loss of valuable topsoil, indiscriminate use of non-biodegradable biocides, relentless release of toxic synthetic chemicals and radioactive waste into the seawater, profuse oil-spill in the oceans, acidification of oceans and on top of all, rise in temperature.

Global warming, coupled with ozone-depletion, is causing thermal expansion of oceans, increased precipitation, melting of the polar ice-caps and retreat of mountain glaciers—all of which are leading to a pronounced rise in sea level.

One of the most significant marine organisms are coral polyps which secrete lime and in the process, form coral reefs. Reef-building corals are called hermatypic. Coral reefs form one of the most important marine ecosystems of the world. They occupy less than 1% of the total area of the oceans, but host at least 25% of all marine life[2]. They provide a natural habitat for thousands of marine organisms including coralline fish, sponges,

mollusks, echinoderms, crustaceans, etc. However, corals are extremely fragile and vulnerable to thermal stress and other environmental parameters. They also have a very low adaptive capacity[1]. Coral bleaching may be defined as a process in which corals expel the algae that exist within them or their constituent algae die. The relationship between corals and their constituent algae is very intricate. Inside the sac of every coral polyp there exists a single-celled algae called zooxanthellae. Zooxanthellae provide 30% of the nitrogen and 91% of the carbon needs of a coral host. In the process of photosynthesis, the algae gives off oxygen that the coral polyp requires to survive. In return the polyp gives the algae carbon dioxide and other substances the algae needs. Thus, there is a symbiotic relationship between the coral and the zooxanthellae. When the temperature of seawater rises, the symbiosis between the coral and the algae breaks down. It is then that the coral expels the algae and turns white. Bleaching induces biochemical changes in the composition of the coral tissues, including reduction in protein and amino acids. Also, there occurs a fall in the lipid content of the coral tissues. Since the coral derives its energy from this microscopic organism, the coral is then deprived of its source of energy. Without symbiotic algae, the coral either dies from starvation or becomes so weak[3], that it succumbs to

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harmful bacteria and seaweeds which can poision and kill coral on contact.

As seawater begins to warm, immediately a complex cascade of molecular signals are sent out, which trigger the process of coral bleaching. The corals suffer from apoptosis, that is, a programmed and self-inflicted cell death, in which they kill off some of their cells as they undergo thermal stress. Apart from bleaching, increased ocean temperatures also affect coral larvae survival negatively. This means that as temperatures continue to rise, there are fewer baby corals replacing the ones that have already died.

Mass coral bleaching events were rare about 30 years ago, but have increased in frequency in the past few years. Studies have revealed that this type of mass coral bleaching, in which entire reefs may be wiped out, are positively related to the increase in sea surface temperature in recent times[10]. Australia's Great Barrier Reef, the longest in the world, has suffered eight bleaching events since 1980, the worst being in 2002 when 55% of the total reef area was affected. The frequency of these events appears to be increasing. The Caribbean and western Pacific were identified by the researchers as the areas where most corals are threatened. The Elkhorn Coral, a critical reef-building species was included in the U.S. Endangered Species List in 2006 due to a rapid decline in its population. The Staghorn Coral, another Caribbean reef-building species, is also under threat.

Coral atolls still exist in the Lakshwadeep group of islands in India, which are made up of 12 atolls and 3 reefs. Islands such as Kadmat, Minicoy, Kalpeni, Kilpan and Chetlat are typical atolls. However, these are also endangered with the possibility of extinction. Increasing ocean temperatures related to global warming and climate change caused a 70% loss in corals of the reef ecosystems off Lakshwadweep and the Andamans in 1998. There are reports of 80%-90% loss in Lakshwadeep corals during 1998 probably due to the El Nino event of 1997-1998. The type of coral most affected was *Acropora.* The Expert Team constituted by the Planning Commission, Government of India, to review the status of the coral reefs in Lakshwadeep reported that in Kavaratti only 30% of the corals remained live and the rest were dead corals. Patches of sea grass and seaweeds were seen by them in some shallow water zones. The team noted that extensive bleaching had taken place due to rise of sea surface temperature in the wake of the El Nino event of 1997-1998, which had impacted over 40%-90% of live coral cover. There were no more than 10% live corals in the Kadmat Island after the bleaching event. In 2000 A.D., WWF identified Lakshwadweep as a global marine ecoregion. It is part of the marine ecoregion: Maldives, Chagos, Lakshwadweep Atolls - Chagos Archipelago (United Kingdom), India, Maldives, Sri Lanka. In the year 1998, ocean temperatures increased to an excess of 2°C above the normal summer maxima that exists in this part of the Indian Ocean. It has been found that a rise of just 1°C in ocean temperatures lasting as little as two to three days is sufficient to start bleaching events[6]. The year 1998 was the warmest of the century (NOAA, 1999). In that particular year, coral bleaching took place in 60 countries and island nations at sites in the Pacific Ocean, Indian Ocean, Red Sea, Persian Gulf, Mediterranean Sea and Caribbean Sea. The corals of the Andaman and Nicobar Islands as well as the Lakshwadeep Islands were severely affected, with greater man 70% mortality reported in the Maldives, Andamans, Lakshwadeep Islands and 75% in the Seychelles Marine Park System and the Mafia Marine Plant off Tanzania. The Global Coral Reef Monitoring Network recognised four overlapping levels of coral

bleaching related to this event. These were - 1. Catastrophic coral bleaching, in which 95% of shallow water corals in the Maldives, Bahrein, Singapore, Sri Lanka and Tanzania were bleached, 2. Severe coral bleaching which adversely affected 50% to 70% corals in Kenya, Sychelles, Japan, Thailand and Vietnam, leading to their death, 3. Moderate coral bleaching resulting in 20% to 50% coral mortality with chances of quick recovery and 4. Insignificant bleaching[9]. In Lakshwadweep's Bangaram Island, only white rubble exists; it is a graveyard of dead coral. In fact, it has been predicted that with rising ocean temperatures, this kind of ecological disaster will become more common in near future.

This Coral Triangle forms the apex of marine biodiversity. It supplies the Indian and Pacific Oceans with genetic biodiversity, delivered by the ocean's genetic highway currents[8]. A very large variety of marine organisms depend on coral reefs for their existence. In fact, this hotspot is very close to the biodiversity hotspot of the Western Ghats. (Table No. 1).

The reefs in the Coral Triangle have also been indirectly affected by global climate change. The El Nino Southern Oscillation event in 1998 resulted in a rise of SST by almost 7°C from the previous year in parts of the eastern Pacific[5], while in the Indian Ocean, the SST was higher by 2°-3° C. during May-June 1998, which triggered off the process of coral bleaching. Bleached corals were observed in 82% of the coral cover in the lagoon reefs of the Lakshwadeep Islands and bleaching related mortality was as high as 26%. Particularly, tabular, branching and massive corals were affected. In addition to the 1998 event, the year 2010 is said to have witnessed the largest single bleaching event ever recorded. In this year, massive death of corals took place in the South Asian and Indian Ocean reefs over a period of a few months following the bleaching event in the region.

Table No. 1. Coral Damage During 1998 Bleaching[4]

Country	Percentage destroyed during 1998 bleaching	Recovery potential
Lakshwadeep (India)	70–90	Good
Maldives	70–90	Good to medium
Chagos	70–90	Good
Sri Lanka	70–90	Medium to low

Other factors affecting the health of coral reefs are changes in sea level, greater intensity and frequency of storms, changes in ocean circulation, variation in precipitation and land runoff and increasing ocean acidification, all of which are directly or indirectly related to climate change. Bleaching events are often accelerated by large-scale oceanographic processes and oceanographic cycles. Aerosols and local water quality also play a role in coral bleaching. These factors effectively reduce the adaptability of corals.

Past studies have shown a positive correlation between increased acidification, aragonite saturation and declining coral growth. Man-made carbon dioxide emissions are rapidly changing the current pH level of seawater, rendering the oceans acidic. The IPCC 4th Assessment Report estimates that by the end of the century, ocean pH will decline from the current level of 8.1 to 7.8, due to rising concentrations of atmospheric CO_2.

It has been found that the key threshold of coral reefs is an atmospheric carbon dioxide concentration of 500 parts-per-million (ppm). About one-third of all the carbon dioxide emitted into the atmosphere is absorbed by the oceans. This is an ideal condition for the formation of carbonic acid. The seawater readily combines with the carbon dioxide forming carbonic acid. In the process, hydrogen ions are released and the concentration of carbonate ions falls. These chemical processes cause an intensification and increase in the ocean's acidity.

Ocean acidification threatens to decimate creatures that form a calcium carbonate shell, including coral, shellfish, foraminifera, cocoliths, i.e., carbonate oozes and phytoplankton, that form the very base of the marine food chain. This is because the carbonate ion is critical in formation of carbonate minerals and these carbonate minerals are used by marine biota to form shells and skeletons.

The equation may be represented thus-
←——— Mineral Formation
$[CaCO_3] \longleftrightarrow [Ca^{2+}] + [CO_3^2]$
Dissolution ———→

Calcium carbonate exists in two main minerals –aragonite and calcite. Corals are mostly made from aragonite. As seawater becomes more acidic, the solubility of aragonite increases, resulting in undersaturation.

Corals are extremely vulnerable to changes in ocean conditions. Rising atmospheric CO_2 and its equilibration with surface ocean water is lowering both the pH and carbonate saturation state (Ω) of the oceans. It is a fact that both coral species richness and coral colony size decline with increasing proximity to low-saturation, low-pH waters as has been proved from *in-situ* chemical and biological data. Reef-building corals are adversely impacted by declining aragonite and calcite saturation. Jokiel, at the Hawai Institute of Marine Technology, in his "proton flux hypothesis" of 2011, has proved that calcification of coral skeletons is dependent on the passage of hydrogen ions between the water column and the coral tissue. This process ultimately disrupts the ability of corals to create an aragonite skeleton[7]. Lowered calcification rates are problematic for coral reefs because it creates weakened coral skeletons leaving them susceptible to breakage and decreasing protection.

The ultimate result is a reduced rate in the building of coral reefs, which decreases the resiliency of the corals from bleaching, disease and coral death due to high ocean temperatures. Further, reef building rates could decrease to a point at which it is insufficient to maintain the reefs themselves. The IPCC 4th Assessment Report estimates that by the end of the century, ocean pH will decline from the current level of 8.1 to 7.8, due to rising atmospheric CO_2 concentrations.

Acidification of sea water has been found to be very rapid in the areas off the coast of North America. These waters have become so acidic that they are actually dissolving the skeletons and even shells of coral, clams and starfish.

Corals often develop a minimum resistance to bleaching effects. Large coral colonies such as *Porites* are able to withstand extreme temperature shocks, while fragile branching corals such as table coral are far more susceptible to heat stress. Corals consistently exposed to low stress levels often develop more resistance to bleaching.

Also, there are many factors that determine the outcome of a bleaching event. These may be listed as stress-resistance which reduces bleaching, tolerance to the absence of zooxanthellae and how quickly new coral grows to replace the dead. Coral and zooxanthellae health and genetics also influence bleaching.

Recent studies have revealed that with constantly rising ocean temperatures and increased ocean acidification, corals may cease to survive very soon.

Coral reefs support more species per square metre than any other marine ecosystem. Because of this kind of biodiversity, coral reefs have been called the rainforests of the sea. They provide a natural habitat for thousands of marine organisms including coralline fish, sponges, mollusks, echinoderms, crustaceans and so on. Through the photosynthesis carried out by their constituent algae, corals serve as a vital input of food into the tropical and sub-tropical marine food-chain and assist in recycling the nutrients too. Marine plankton coexists with corals and forms a vital constituent of the

marine food web. Thus, a coral reef is a nursery for the juvenile forms of many marine creatures.

Coral reefs act as a bulwark against storm surges, tsunamis and cyclones. They play a major role in shoreline protection. For example Moorea in French Polynesia only experiences a 10 cm tidal range due to its protective barrier reef. On the other hand, since coral cover is low in the Lakshwadeep Islands, the island faces a serious problem of coastal erosion. With the near extinction of coral reefs, tropical storms, tidal waves and cyclones have become more frequent. Hence, reefs are likely to experience greater coastal erosion, sedimentation and turbidity, which would add to their demise.

In the light of the above situation, it is recommended that certain steps be taken immediately to save coral reefs that are particularly endangered.

1. Virgin and pristine reefs should be declared as protected areas.

2. Exploitation of the reefs and coral harvesting must be stopped.

3. Alternative means of livelihood can be provided to communities that excessively depend on coral reefs and fisheries.

4. Creation of marine reserves off limits to fishing will also help in this respect.

5. Awareness must be created among the public and the local government agencies regarding the needs for conservation of coral reefs.

6. Regulation of wastewater discharge from the land and maintaining high water quality could also help in the conservation of coral reefs.

7. The ultimate way to save coral reefs is to cut down carbon emissions. It is said that if current emission trends continue, then coral bleaching will become an annual event by 2030-2070. In this way, coral reefs could be

eliminated altogether by 2100A.D. Current estimates suggest that reefs could take hundreds of years to recover. It is estimated that most reefs will disappear in the next 40 years. In fact, reefs around the West Indies in the Caribbean will cease to exist by 2020 and the Great Barrier Reef will altogether disappear in just 30 years. Thus, tropical marine environments are likely to be the first casualties of climate change.

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VIRUS AS A BIOSENSOR

Rajib Deb, Satish Gaikwad, Sanjeev K. Shukla, C. Madhan Mohan and Sohini Dey *

Virus-based sensors (mainly phages) may lead to development of new strategies for the rapid, specific and sensitive monitoring or detection of chemicals, explosives, proteins, microbes and toxins for various applications in conjunction with various traditional analytical methods like Quartz Crystal Microbalance (QCM) and Enzyme-Linked Immuno-Sorbent Assay (ELISA) as well as various optical and electrochemical devices.

INTRODUCTION

Biosensors are analytical devices that can provide quantitative or semi-quantitative information by exploiting a chemical or biological recognition element which is either integrated within or is closely associated with a transducer interface that can convert chemical, physical, or biological interactions into a measurable output[1]. There are many applications of biosensors such as for detecting different analytes *viz.* explosives, proteins, DNA, tumor markers, bacteria, viruses, microbes and toxins in foods, environmental samples or clinical materials[2]. In terms of the transducer properties, biosensors can be classified as optical, magnetic thermometric, piezoelectric, micromechanical, and electrochemical. Since the transducers normally do not have specificity against a target analyte, introduction of target-specificity to the sensors is a difficult task. In addition, the analysis of samples is always complicated by the broad range of concentration over which the analytes might be present, the limited volumes of the samples, and the heterogeneous nature of the samples. Hence, there is a pressing need for the development of target-selective sensors[3]. Viruses, though their natural function is to store and transport genetic material, have recently been demonstrated to act as templates for the synthesis and assembly of nano materials, as vehicles for targeted drug and gene delivery, and as probes for sensing and imaging. These novel functions of the viruses are possible due to the reason that they specifically infect their host and thus can be used as a specific biosensing agents[4, 5].
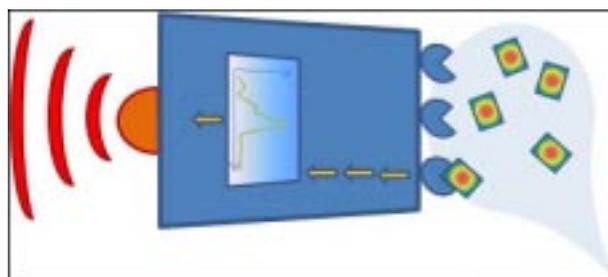
Figure 1 : General setup of a biosensor

(Analytes are detected by immobilized recognition elements such as antibodies, microorganisms, enzymes that are converted to optical, piezoelectric, calorimetric or electrochemical signals which can be easily quantified).

TYPES OF VIRUSES USED AS A BIOSENSOR

Three types of viruses may be used for these applications *viz.* bacteriophages, plant and animal

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viruses. The use of viruses in sensing is being actively developed, and many opportunities are available for scientists to explore in this area.

Of the different viruses being studied bacteriophages (shortened to phages)—viruses that specifically infect bacteria-have proved to be the most powerful candidates for the reasons that a well-established technique, called phage display, can be used to identify target-recognizing peptides or proteins from a combinatorial phage-displayed random peptide or protein library, which in turn results in the selection of target-specific virus particles[6].

PHAGE DISPLAY : VIRUS BASED BIOSENSOR

Phages are bacteria-specific viruses. There are two major types of phage in nature: lytic and nonlytic. Lytic phages like T4 and MS2 phage infect bacteria and when the bacterial cells are destroyed, the new phages will infect new host cells[7]. It is the lytic phage that has been proposed for use as an anti-bacteria treatment strategy (phage therapy). However, the nonlytic phages such as fd and M13 phages do not break the host bacterial cells when they infect their host cells. Instead, the phages undergo lysogeny i.e., the phage genome is integrated with the host DNA and replicated. The host cells thus continue to survive and reproduce, and the phages are reproduced and amplified. Therefore, nonlytic phages such as M13 and fd phages are often used in recombinant DNA engineering.

The well-established phage display technique is mainly based on filamentous phages. M13 and fd phages both have an almost identical structure and morphology. They have a cylindrical structure composed of about 3000 highly ordered copies of the major coat protein (pVIII) which surrounds a circular single-stranded DNA genome. The single-stranded DNA encodes pVIII on the major coat and four other structural proteins at two tips : pIII, pVI,

pVII, and pIX. At one tip of the cylinder there are five copies each of pIII and pVI, while at the other tip there are five copies each of pVII and pIX. By inserting DNA that encodes foreign peptides into the genes of the coat proteins, the peptides are themselves displayed on the outer surface of the phage at the tips (for example, pIII or pIX display) and/or along the length of the filamentous scaffold (pVIII display). This leads to the single, double, or triple display of different peptides or proteins on a single virus particle.
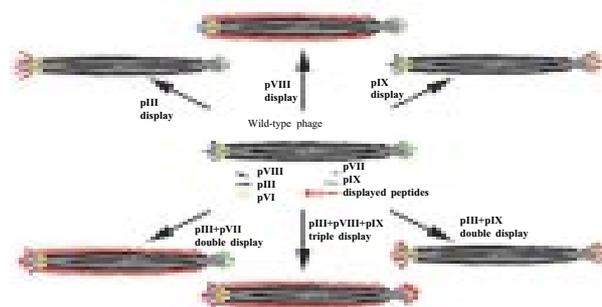

Figure 2 : Phage Display peptides

PHAGES IN SENSOR DEVELOPMENT

Although phage display has been applied since the 1980s for the identification of target-specific peptide or protein probes, the use of phages in the sensor area is new. Phages have several desirable chemical and biological properties for the development of a real-time sensor to rapidly and selectively detect and monitor antigen molecules. Firstly, phage display can be applied to select peptides or proteins that can specifically recognize a target and display the target-specific peptide or protein on the surface of the phage, thereby enabling the phage to become a target-specific probe. Secondly, nonlytic phages such as M13 and fd can be cost-efficiently mass-produced by infecting bacteria. Thirdly, phages are stable in a variety of harsh conditions, such as under acidic or basic pH ranges, and in the presence of nucleases or proteolytic enzymes. Fourthly, phages are also thermally stable (up to 180°C), and chemically

stable. So far, phages have been used in four ways in the development of sensors: 1) nonlytic phages (M13 or fd) selected by phage display and displaying the target-specific peptides or proteins as a target-recognizing sensing probe serve as an antibody substitute; 2) target-recognizing peptides, proteins, or antibodies identified by phage display are chemically synthesized or genetically produced, and directly used as probes; 3) lytic phages (T4 or T7) can act as bacteria-sensing probes by breaking its bacteria host strain specifically and releasing the cell-specific contents from the bacteria, thereby leading to the detection of the specific bacteria strain; and 4) the phage nanofibers can be conjugated with other biomolecules or nanomaterials to form a composite device that can be responsive to some external stimuli.

COUPLING OF BIOANALYTICAL METHODS WITH PHAGES

Phages can be engineered to bear target-specific peptides or proteins for bio-recognition. However, they do not themselves have physical properties that can be exploited to generate a readable output upon binding to a specific target analyte. Thus, the current application of phage in developing sensors relies on the integration of the probe (target-specific phage or phage-derived peptides or proteins) into an analytical device that can convert the recognition process between the probe and a target analyte into a readable output. Phages can be coupled with traditional analytical methods such as the Quartz Crystal Microbalance (QCM) and Enzyme-Linked Immuno-Sorbent Assay (ELISA) as well as optical and electrochemical methods[8, 9].

QCM BIOSENSORS BASED

A QCM can respond sensitively to nanogram-changes in mass. A QCM sensor is made of a disk-shaped, AT-cut piezoelectric quartz crystal, which is coated on both sides with metallic electrodes (such as gold)[10]. A reduction in the resonance

frequency of the piezoelectric crystal will be observed in response to the adsorption of a small amount of mass onto the electrode surface, with the frequency reduction being proportional to the adsorbed mass. The change in the resonance frequency (Δf) of the crystal is directly related to the mass change (Δm) according to the equation.

$$\Delta f = \frac{-2n f_0^2 \Delta m}{A(\mu \rho)^{1/2}}$$

where n is the overtone number, μ is the shear modulus of the quartz (2.947×10^{11} gcm^{-1} s^{-2}), f_0 is the frequency of the resonator, A is the piezoelectrically active crystal area, and ρ is the density of the quartz (2.648 gcm^{-3}). Thus, the QCM is actually a very sensitive balance that can measure mass on the nanogram scale and can be used for the real-time analysis of biomolecular interactions. Such QCM sensors have been developed for immunoassays, as well as for bacterial, virus, and toxin detection like the immobilization of bacteria-recognizing phages on the QCM transducer surface. The rapid detection of *Salmonella typhimurium* bacteria in solution was achieved by using fd phage, which was affinity-selected by the phage display technique and physically adsorbed onto the piezoelectric transducers, as a detection probe. The specific binding of bacteria by the phage immobilized on the transducers then caused a change in the resonance frequency of the QCM sensors. It was found that the phage-bearing QCM sensors had a very short response time (less than 180 s) and a detection limit as low as 10^2 bacteria cells per mL. The main drawback of this method is that it lacks selectivity[10]. Thus, target-specific phages or proteins identified by the phage display technique can be immobilized on the QCM transducer surface to eliminate this disadvantage.

ELISA BASED BIOSENSOR

ELISA is generally used for detecting biological agents and agent-specific antibodies. There are two

types of ELISA : Indirect ELISA in which the target antigen is captured by one antibody and detected by a second antibody and direct ELISA in which the antigen in the sample solution will compete with labeled antigen to bind to the antibodies. Phage probes can serve as antibody substitutes in direct ELISA. For example, fd phage probes that can capture their targets, such as β-gal, streptavidin, and neutravidin, can be used in direct ELISA. Consequently, direct ELISA using phage probes as antibody substitutes can specifically detect bacteria, spores, and viruses. The most specific spore-binding phage, which was selected from a landscape phage library by using the phage display technique and which displayed a peptide (EPRLSPHS) on its major coat, showed a binding affinity to spores of _B. anthracis_ Sterne 3.5 to 70 folds higher than that to spores of other _Bacillus_ species[11].

OPTICAL BIOSENSOR BASED PHAGES

There are two types of optical sensing. In the first type, sensing is achieved by measuring the change in intensity at a particular wavelength, and includes techniques such as UV/Vis spectrometry, fluorescence/phosphorescence spectrometry, bio/chemiluminescence, and IR spectrometry. In the other type, sensing is achieved by detecting the changes in the chemical properties upon changing the wavelength, and include techniques such as Surface Plasmon Resonance (SPR), Fluorescence Resonance Energy Transfer (FRET), and colorimetry[8].

SURFACE PLASMON RESONANCE (SPR)

SPR results from the light-induced excitation of surface plasmons and is related to changes in the refractive index induced by the molecules near the metallic surface[12]. SPR has been exploited in the development of sensors because it enables the sensitive, rapid, real-time, and label-free detection of biomolecules in a small sample volume. Phages

can enable the development of SPR sensors for target-specific detection in two ways : by immobilizing the target-specific phage on the sensor chip or a phage displaying a scFv antibody to the virulence factor actin polymerization by immobilizing the target-specific protein selected by phage display on the sensor chip. For example a study was conducted where in actin polymerisation protein (ActA) was immobilized on the SPR sensor chip by physical adsorption. This SPR sensor chip was then used to specifically detect the common food-borne bacteria _L. monocytogenes_.

IMMUNOFLUORESCENCE ASSAYS

The immunofluorescence assay exploits fluorescence spectrometry and specific biorecognition to obtain quantitative results. The lytic phage will destroy bacterial cells and cause the cell components to be released when it infects the cells. If the cell-specific components released from the cells can be detected, the lytic phage can be used as a probe to detect bacteria. One method takes advantage of the fluorescence properties of the released cell components. Blasco _et. al._, (1998) developed a sensitive and rapid assay to detect bacteria by using _E. coli_ and _Salmonella newport_ as the model bacteria using ATP bioluminescence probes[2].

PHAGES IN ELECTROCHEMICAL BIOSENSOR

Biosensors based on electrochemical methods have been widely studied because they are simple, rapid, highly sensitive, amenable to miniaturization, and can be operated in turbid media[9]. Such electrochemical sensors are proposed for the detection of microbes and toxins. The surface of the electrodes in an electrochemical sensor can be coated with a variety of materials such as polymers, sol-gel, ionophores, enzymes, antibodies, DNA, bacteria, viruses, and toxins, which has led to the development of various electrochemical sensors[13].

The immobilization of a target-specific phage probe onto the surface of the working electrodes of electrochemical sensors can enable the target-specific detection of target analytes.

OTHER VIRAL AGENTS AS BIOSENSOR

Similar to phages, other viruses, including the tobacco mosaic virus[14], cowpea chlorotic mottle virus[15] etc. have been used for templating the synthesis of nanomaterials. Inorganic materials can be formed either outside the coat or inside the core of rod like viruses such as TMV. For example, copper nanowires were prepared by electronless deposition within the central channel of TMV particles. Nanomaterials can be synthesized either outside the coat or inside the core of icosohedral viruses such as CCMV[6].

VIRUS LIKE NANO MATERIALS (VLNS) AS BIOSENSOR

Viruses such as M13 or T7 phage can be viewed simply as a protein coat assembled around a nucleic acid (DNA or RNA). There is electrostatic interaction between the nucleic acid inside the virus and the protein coat, which is made of many copies of protein subunits. Thus, the formation of such a virus particle can be simplified as the assembly of protein subunits around a nuclei acid template driven by the electrostatic interaction. Therefore, if the nucleic acid in the virus is replaced by an inorganic nanomaterial and the inorganic nanomaterial surface is functionalized to mimic the electrostatic behavior of the nucleic acid, a Virus Like Nanomaterial (VLN) will result from the electrostatic self-assembly of proteins around the nanomaterial. Viral protein purified from the virus particle is needed to form such a VLN. The self-assembly of viral protein around nanoparticle templates to form virus like particles (VLPs) has been successfully demonstrated. For example, the coat protein from a Brome Mosaic Virus (BMV) can self-assemble around a functionalized AuNP core to form a VLP[16]. The assembly of virus proteins around nanomaterials will allow the resultant VLNs to bear target-specific peptides or proteins on the surface.

CONCLUSION

Virus based sensors have been actively studied and have become increasingly attractive as an area of nanotechnology. Phage-based sensors are still the most popular in this field because selectivity is a very important property of a chemical and biological sensor, and phage can be engineered to bear a target-specific motif by using the well-established phage-display technique. For the development of advanced chemical and biological sensors with improved sensitivity and specificity, viruses need to be combined with new analytical methods and the fabrication of micro and nano functional devices by applying virus-like nanomaterials and exploiting supramolecular materials self-assembled from viruses and nanomaterials.

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KNOW THY INSTITUTIONS

CSIR-NATIONAL AEROSPACE LABORATORIES, BANGALORE

National Aerospace Laboratories (NAL), a constituent of the Council of Scientific and Industrial Research (CSIR), India is the only civilian aerospace R & D laboratory in the country. Started on June 1, 1959 in Delhi, it moved to Bangalore in 1960 and later on to its own two campuses (Kodihalli and Belur) in Bangalore. CSIR-NAL is a high-technology oriented institution focusing on advanced disciplines in aerospace and has a mandate to develop aerospace technologies with strong science content, design and build small and medium size civil aircraft and support all national aerospace programmes. It has many advanced test facilities recognized as National Facilities. These are not only best in the country but are also comparable to other similar facilities in the world. NAL's committed efforts over the last five decades have resulted in achieving expertise and core competencies in most of the disciplines of aeronautics. It has always readily accepted challenges and delivered programme-critical products and technologies and has become the preferred destination for almost all the mission-mode aerospace programmes in the country. It would not be improper to say that LCA Tejas development would have been difficult without NAL's contributions and that every major aerospace programmes of DRDO and ISRO has some significant contributions from CSIR-NAL.

As is in its mandate, in 1983-84, CSIR-NAL started a project to fabricate an all-composite aircraft using a kit bought from the Rutan Aircraft Company in USA. The project led by the indefatigable Prof R B Damania, gave CSIR-NAL teams very valuable insights into building-airworthy composite structures. The aircraft, called the Light Canard

Research Aircraft (LCRA), was ready by the end of 1986 made its maiden flight on 26 February 1987. After the LCRA success, CSIR-NAL seriously started the preparatory work to design and build small and medium sized aircraft. Today, NAL's two seat aircraft (15 built so far) named 'HANSA' a pioneering *ab-initio* all composite design, certified by DGCA in the year 2000 under JAR-VLA certification is catering to the needs of flying clubs in the country. SARAS, the 14 seat (7 ton class) multirole transport aircraft to be certified under FAR 23 category is being designed and built by CSIR-NAL had its maiden flight on May 29, 2004. It has been designed for multiple roles like executive transport, light package carrier, remote sensing, air ambulance etc. Indian Air Force is expected to be the launch customer for SARAS with HAL as the production partner. The five seat General Civil Aviation aircraft named CNM-5 has the distinction of being the country's first public-private partnership (PPP) for development of civil transport aircraft. It is being developed by CSIR-NAL in collaboration with M/s Mahindra Aerospace Pvt. Ltd. (MAPL), Bangalore and had its maiden flight on the 1st September 2011 in Australia. It is proposed to be certified first under CASA, the Australian Certification Authority. CNM-5 is an ideal aircraft for air taxi, air ambulance, training, tourism and cargo applications.

NAL's contributions to major national programmes have carved niche for itself. Key technology successes of NAL include; carbon fibre airframe components using innovative and cost-effective fabrication technologies and Fly-by-wire Flight Control Laws design for the Tejas programme. An achievement with far reaching implications is the development of aerospace grade carbon fibres, a technology which is high on the list of sanctions. CSIR-NAL is playing a lead role jointly with many academic institutions in the National Programme on Micro Air Vehicles (NP-MICAV) of DRDO/DST. MAVs of Black Kite, Golden Hawk and Pushpak with a 300mm span, 300 gms weight and endurance of 30 minutes have been developed. These MAVs are currently undergoing user trials. The other key technology successes are; nano-coatings, sunshield mirrors for satellites, and design and development of 55HP Wankel engine with VRDE for DRDO-ADE's Nishant UAV. NAL's association with India's space programmes has been very fruitful. NAL has carried out acoustic tests on all of ISRO's launch vehicle stages as well as satellites. It is very proud to say that every Indian aerospace vehicle has graduated out of NAL's 1.2m Trisonic Wind Tunnel which is performing reliably for over 50 years.

NAL has made significant contributions in the area of new technologies and systems. The high speed combustor design and related test facilities has been developed for hypersonic vehicles. Radomes are an area of strength in NAL and its multi disciplinary team has established a niche technology covering mechanical, electromagnetic, aerodynamic and structural design, testing and certification aspects. Radomes have been developed for ground based as well as air borne applications, this include the 12.9 meter dia Doppler Weather Radar Radome for ISRO, and nose radomes for Jaguar and Saras aircrafts. The institution contributed to developing technologies relating to advanced aircraft structures like co-cured co-bonded composite parts, variable resin infusion technology, and indigenous autoclaves for composite airframe manufacture. Active Noise Control (ANC) system for fighter aircraft has been developed and as also a host of surface modification technologies.

Over the years, NAL has successfully addressed the avionics challenge. DRISHTI, an airport runway visibility assessor system developed is a fast and accurate transmissometer. Engine Instruments and Crew Alert System (EICAS) and a 3-axes digital autopilot system developed for Saras aircraft is first of its kind in India and has the potential for use in other aircraft programmes both in India and Abroad.

CSIR-NAL's Flight Operation Quality Assurance (FOQA) software has been the key tool for aviation and is being used by many Indian aircrafts for over a decade.

CSIR-NAL is known for its expertise and capabilities in many disciplines of aeronautics. It has a very strong base in advanced computational and experimental fluid dynamics which has substantially contributed to speeding up the design of complex flight vehicles. Our laboratory is recognized as India's premier organization for carrying out failure analysis and accident investigations of aircrafts. CSIR-NAL's structural technological capabilities cover dynamic analysis of structures including aeroelastic testing and analysis. The full-scale fatigue test facility provides inputs that can lead to a substantial increase in the operational life of airframes. NAL has achieved considerable success in using smart materials for structural health monitoring and also sensors and actuators. It has a proven ability in the area of design, testing and analysis of advanced engine components.

Many technologies have been developed for societal applications. NAL's pioneering efforts in parallel processing hardware and software development have given the country advanced metrological computational capabilities. NALSUN solar selective coating for industrial and domestic solar water heaters, wind turbines of 300 kW and 500 kW capacity for wind energy harvesting, coatings for cutting tools to enhance wear resistance and improved tool life are some of the significant achievements with societal impact.

CSIR-NAL is continuously striving towards new strategic initiatives to meet the challenges of future. To name a few initiatives in this regard are; a major programme initiative on national civil aircraft development for regional connectivity, and design & development of sub 200 mm class Micro Air Vehicles to meet the needs of strategic and civilian use. Further, NAL is expected to play a significant role in the proposed development of Advanced Medium Combat Aircraft by ADA and the Fifth Generation Fighter Aircraft and Medium Transport Aircraft programmes of HAL. In conclusion it may be well said that CSIR-NAL aims to reach greater achievements in futuristic aerospace technologies and participation in national development efforts.

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Conferences / Meetings / Symposia / Seminars

XXXVI All India Conference of The Indian Botanical Society on Plant Wealth and Human Welfare, October 18-20, 2013 Gorakhpur, U.P.

Topics : Bioenergy, Plant Biofunction, Nutraceuticals, Herbal medicine, Forestry and Horticulture IPR issues, Biological Control.

Contact : Prof N. N. Tripathi, Orginizing Secretary, Department of Botany, D.D.U. Gorakhpur University, Gorakhpur (U.P.), Phone : Cell : +91 9450883779, +91 9415083883, +91 9450129022, 9450885374, E-mail : plantibs2013@gmail.com/plantibs2013@yahoo.in.

National Conference on Emerging Trends in Engineering & Sciences (ETES-2013), 9-10 Nov. 2013, Haridwar, Uttarakhand

Themes :

● Electrical Engineering   ● Electronics & Communication Enginneering

● Computer Science Engineering   ● Physical Sciences

● Chemical Sciences   ● Mathematical Sciences

● Pharmaceutical Sciences

Contact : Professor R. D. Kaushik Chairman, ETES-2013, Professor & Head, Department of Chemistry, Dean Faculty of Engineering & Technology, Dean, Faculty of Science, Gurukul Kangri University, Haridwar-249404 (Uttarakhand), India. E-mail : fet.etes2013@gmail.com or sanjeev.lambha@gmail.com website : www.gkv.ac.in

Internatinal Conference on Challenges : Chemistry and Biology of Carbohydrates (Carbo-XXVIII) January 20-22, 2014 Dehra Dun

Themes :

● Fundamental aspects of carbohydrates in chemistry, biology and chemical biology, and technologies/processes related to chemistry, biotechnology, and industrial applications.

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S & T ACROSS THE WORLD

POP! BURSTING THE BUBBLE ON CARBONATION

The refreshing bite of carbonation is an integral part of beverages consumed around the globe. Carbonated beverages are produced when carbon dioxide is dissolved in a liquid, typically under high pressure. This can happen naturally in certain spring waters or in fermented beverages like beer. Carbon dioxide also can be added to beverages through production processes. In either case, when pressure is reduced by opening a bottle or can of a carbonated beverage, some of the carbon dioxide is released from the solution in the form of bubbles. After a sip, enzymes in the mouth convert the remaining free carbon dioxide into carbonic acid. The acid then activates sensory nerve endings, which signal the mild irritation that we refer to as 'bite.'

In the study, published in the public access journal *PLOS ONE,* the Monell researchers examined the role that bubbles play in carbonation bite. In the first experiment, they took advantage of the fact that bubbles cannot form when atmospheric pressure is raised above a certain level. Twelve healthy adults were comfortably seated in a hyperbaric chamber and asked to rate the bite intensity of several concentrations of carbonated water. The ratings were collected once while under normal atmospheric pressure (with bubbles) and a second time at higher pressure (no bubbles), equivalent to diving to a depth of 33 feet in sea water. There was no difference in the bite reported in the two conditions, even though bubbles are physically unable to form at the higher pressure.

Although bubbles aren't necessary for bite, they still could be contributing to the overall sensation of carbonation. Thus, a second experiment was designed to address this possibility In this experiment, 11 adults rated the intensity of bite in a laboratory setting. The ratings were made for carbonated water under normal conditions and again when additional air bubbles were added to the liquid. The researchers were surprised to find that air bubbles enhanced the bite of the carbonated bubbles, presumably by stimulating the sense of touch. Together, the studies reveal that carbon dioxide bubbles are not directly responsible for the bite of carbonation. However, by stimulating the sense of touch inside the mouth, bubbles do enhance the bite sensation beyond the chemical irritation caused by carbonic acid. Future experiments will continue to explore the interactions between chemical and mechanical stimuli.

ELUSIVE Z-DNA FOUND ON NUCLEOSOMES

New research published in BioMed Central's open access journal *Cell & Bioscience* is the first to show that left-handed Z-DNA, normally only found at sites where DNA is being copied, can also form on nucleosomes. The structure of DNA which provides the blueprint for life has famously been described as a double helix. To save space inside the nucleus, DNA is tightly wound around proteins to form nucleosomes which are then further wound and compacted into chromatin, which is further compacted into chromosomes. But this familiar image of a right handed coil (also called B-DNA) is not the only form of DNA. At sites where DNA is being copied into RNA (the messenger which is used as the instruction to make proteins) the DNA needs to unwind, and, in a process of negative supercoiling, can form a left-handed variety of the DNA double helix (Z-DNA).

It was originally thought that Z-DNA could only be formed in the presence of active RNA polymerase (the enzyme which assembles RNA). However more recently it has been discovered that SWI/SNF, a protein involved in remodeling nucleosomes and allowing RNA polymerase access to DNA, can convert certain sequences of B to Z-DNA. The team of researches led by Dr Keji Zhao discovered that they could convert B-DNA to Z-DNA on nucleosomes by the addition of SWI/SNF and ATP (the cell's energy source) and that the Z-nucleosome formed was a novel structure. Dr Zhao, from the NIH, explained, "The fact that we have found Z-DNA on nucleosomes is a new step in understanding the roles of chromosome remodeling and Z-DNA in regulating gene expression. While the Z-nucleosome is likely to be a transient structure it nevertheless provides a window of opportunity for the placement of DNA binding proteins which may recruit, regulate, or block the transcription machinery and hence protein expression."