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सत्यमेव जयते

Report of the Working Group on R&D for the Energy Sector for the formulation of The Eleventh Five Year Plan (2007-2012)

Submitted to the Planning Commission

December, 2006

Office of the Principal Scientific Adviser to the Government of India
Vigyan Bhawan Annexe, Maulana Azad Road, New Delhi-110 011

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C O N T E N T S

Background

In May, 2006, the Planning Commission had constituted a ***Working Group on R&D for the Energy Sector for the formulation of the Eleventh Five Year Plan (2007-2012),*** with Dr. R. Chidambaram, Principal Scientific Adviser to the Government of India, as its Chairman. The Office of the Principal Scientific Adviser to the Government of India served as the secretariat to the Working Group. A copy of the order number M-11011/2/2006-EPU dated the 9th of May, 2006, notifying the constitution of the said Group, is available as ***Annexure-I***. The order gives the composition of the Group, as also its terms of reference. The list of members, who were co-opted with the approval of the Chairman, is available as ***Annexure-I A***.

2. The Working Group held a total of three meetings for finalizing its report. The minutes of those meetings, held on the 14th of June, 2006, the 20th of July, 2006 and the 20th of September, 2006, are available as ***Annexures- II, III and IV***. All members of the Working Group, including a few special invitees who had been invited to attend the meetings, have contributed to the writing of the various sections of the report. Their contribution has been duly acknowledged at the beginning of each section.

R. Chidambaram

CHAIRMAN, WORKING GROUP

DATE: 29th DECEMBER, 2006

PLACE: NEW DELHI

Preface

Research and development in the energy sector has to be aimed at achieving energy security while ensuring harmony with the environment. To meet the ever increasing energy demand in the country in an environment friendly and sustainable manner, one has to look for clean coal technologies, safe nuclear and innovative solar. However, one has to also recognize that there is no 'silver bullet' and several parallel paths have to be pursued to fulfill the increasing demand for energy for continued economic development.

2. In the Indian context, some of the steps one could consider for taking-up in the Eleventh Five Year Plan are the following:-

- Intensification of exploration for all energy sources including uranium, coal and petroleum,
- Improving resource recovery during extraction of all energy sources, particularly coal, oil and gas,
- Developing methods for exploiting energy sources, currently considered unviable such as development of in-situ gasification for recovery of coal buried deep in the earth,
- Conducting research to ensure that environmental regulations are based on Indian conditions characterized by tropical climate and high density of population,
- Increasing share of hydro, nuclear and renewable sources in the energy mix,
- Intensifying work on all aspects of fast breeder reactors including advanced fuels and associated fuel cycle technologies,
- Accelerating studies for early deployment of thorium technologies and fusion systems,
- Looking for breakthrough technologies for exploiting renewable sources, particularly solar which has a very high potential in the country,
- Developing clean-coal technologies (Ultra-super critical technology, Integrated Gasification Combined Cycle, Atmospheric fluidized bed combustion, pressurized fluidized bed combustion) suitable for Indian coal, which is characterized by high ash content,
- Bringing-in efficiency in the use of non-commercial energy sources (such as animal residue, bio-mass, urban and rural waste including agricultural waste),
- Strengthening power delivery infrastructure so as to ensure quality (in terms of voltage and frequency), reliability (no black outs and brown outs), efficiency (low transmission and distribution losses) and provide for large inter-regional transfer (to exploit generating potential wherever it exists),
- Continuing measures to improve energy efficiency of industry and transport,

- Developing mass transit systems in urban areas so as to reduce dependence on personal transport,
- Hydrogen (production, storage and end use) technologies as alternate energy carrier.

3. Mechanisms for funding research in energy technologies other than nuclear are sub-optimal. Recognizing that research in energy technologies is very important for efficient exploitation of indigenous energy resources, ***it is of utmost importance to set-up a Standing Oversight Committee for R&D in the Energy Sector***. This view was fully endorsed by all members of the Working Group during its meetings. It had also emerged during the meetings that such a Committee could, most appropriately, be chaired by the Principal Scientific Adviser to the Government of India, with Secretaries (or their representatives) of the following Ministries/ Departments, as members: -

    i) Ministry of Power

    ii) Ministry of New and Renewable Energy

    iii) Department of Science and Technology

    iv) Ministry of Petroleum and Natural Gas

    v) Department of Atomic Energy

    vi) Ministry of Coal

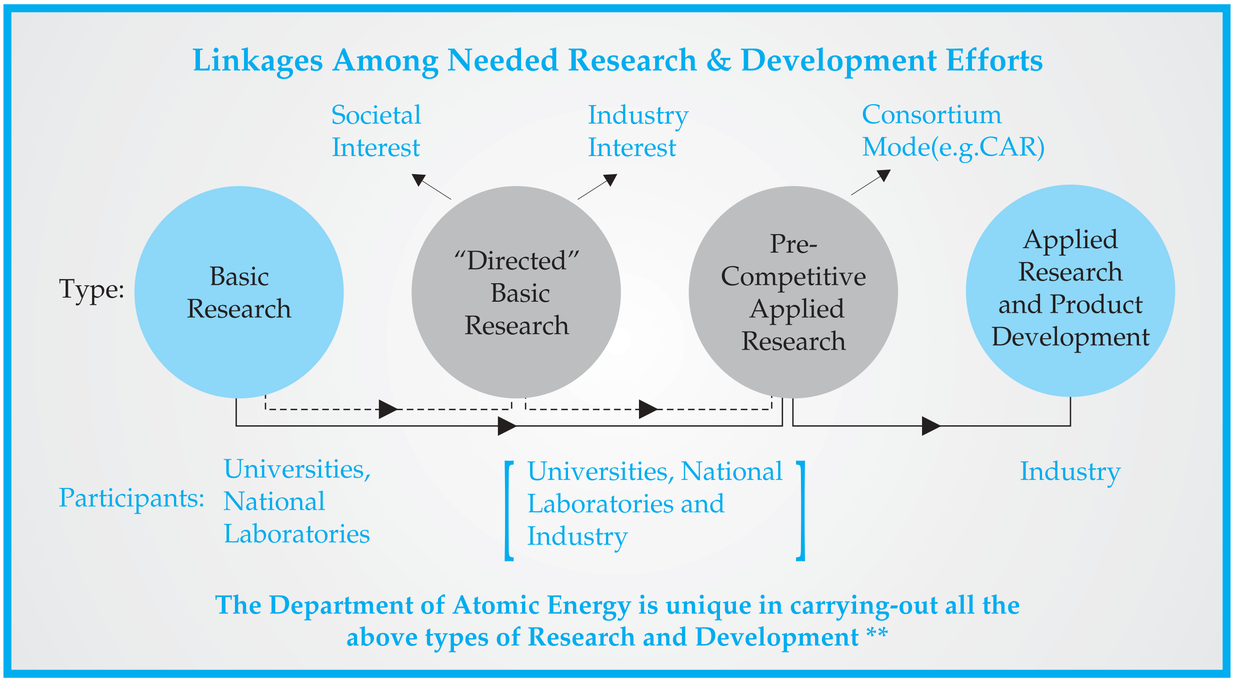
    vii) Department of Heavy Industries

    The Office of the Principal Scientific Adviser to the Government of India could function as the Secretariat to the Committee. The Oversight Committee will constitute separate Steering Committees for looking after specific areas of energy R&D. These Steering Committees will be comprised of scientists having the required domain knowledge and experience in the given area of energy R&D.

4. The Working Group supported the creation of a National Energy Fund (NEF), the idea of which has already been mooted in the recently prepared report of the Planning Commission's Expert Committee on Integrated Energy Policy. There is a strong case for funding by the government both directly and through fiscal incentives. The latter accounts for the bulk of government support in the developed countries. Fiscal incentives, however, have not resulted in significant expenditure on R&D by the Indian industry. An annual allocation should be made by the government for energy R&D. Individuals, academic & research institutions, consulting firms, and private & public sector enterprises could all compete for grants from this fund for identified and directed research.

5. The Working Group also felt the need for ***'Directed' Basic Research*** to be promoted in the Energy Sector. In its execution, and in the requirement of no other deliverables than knowledge generation, 'directed' basic research is no different from conventional basic research. So the University academics should be comfortable with this kind of research. The selected areas are

determined in a national perspective, just like in technology foresight. 'Directed' basic research may be in an area where the knowledge generation would benefit Indian Society ***in the long term***, or it may be in a area where the results of the research would benefit Indian Industry ***in the long term***. The concept of 'directed' basic research is best explained in the following diagram:



***** A note on spin-offs of nuclear energy R&D into other energy areas, as received from the Department of Atomic Energy, is available as Annexure-V.***

6. The report has covered all areas of energy R&D (except atomic energy R&D) that are perceived to be of relevance to the country's energy mix during the next 5-6 years. ***An amount of Rs. 5310.00 crores is projected as the requirement for addressing the energy R&D needs brought-out in this report, over and above the plan budgets (for the eleventh five year plan period) of the Ministries and Departments dealing with R&D in the energy sector, i.e. the Ministry of New & Renewable Energy, the Ministry of Power, the Ministry of Petroleum & Natural Gas, the Ministry of Coal and the Department of Atomic Energy***. For example, the amount of Rs. 1085.00 crores, projected by the Ministry of New & Renewable Energy ***(please see Annexure-X)*** as its requirement for supporting Research, Design & Development on different aspects of renewable energy technologies during the eleventh five year plan period, ***is not included*** in the said amount of Rs. 5310.00 crores.

7. The Oversight Committee mentioned in **para 3** above will guide and monitor the utilization of the said amount of Rs. 5310.00 crores during the eleventh five year plan period. That amount, the break-up of which is given in the ***Annexure-VI***, will be disbursed through the Department of Atomic Energy by creating a Board of Research in Energy Science and Technology (BREST), operated on the same lines as the Board of Research in Nuclear Sciences (BRNS). That amount will be used for supporting inter-Institutional and inter-Ministerial / inter-Departmental research

in areas like energy-related materials, combustion initiative, etc. mentioned in this report and for the setting-up of Centres of Excellence in Universities / National Laboratories / Mission-oriented Agencies in the energy sector.

8. A notional figure of about 2% of the projected Rs. 5310.00 crores could be channelized through the Office of the Principal Scientific Adviser to the Government of India for the implementation of projects such as those on Integrated Gasification Combined Cycle technology in the eleventh five year plan.

R. Chidambaram

CHAIRMAN, WORKING GROUP

DATE: 29th DECEMBER, 2006

PLACE: NEW DELHI

Section – I

Development and Production of New Materials

Authors:

i) **Dr. Baldev Raj, Distinguished Scientist and Director, Indira Gandhi Centre for Atomic Research, Kalpakkam – *Special Invitee*.**

ii) **Shri S.K. Goyal, Head, R&D Centre and Group General Manager, Corporate R&D, Bharat Heavy Electricals Limited, Hyderabad – *Member*.**

1.1 Introduction

1.1.1 The total installed electricity generation in India has grown more than hundred times since independence in 1947 (from 1363 MWe in 1947 to about 1,40,000 MWe in 2005). To sustain the projected GDP growth rate, the energy production levels must be stepped up to 1350 GWe by 2050. It is thus clear that, every source of energy needs to be exploited with adequate attention to the commercial viability and environmental aspects. The energy sources are complimentary in contribution of power and must compete with respect to cost and sustainability of earth. A recent study by DAE estimates approximate percentage contributions of various resources towards electricity generation in the year 2050 to be 49% by coal, 3.8% oil, 11.8% gas, 8.3% hydro, 2.4% non-conventional renewable and 24.8% nuclear. Based on the above projections, the anticipated tonnage of special steels required for fossil-fired and nuclear power plants till 2050 would be about 5-6 million tones.

1.1.2 It is estimated that electricity investment from 2001-2030 would be approximately US$ 10 Trillion (based on $ cost of 2000). This excludes fuel cost. India's investment in electricity in this period is estimated to be approximately US$ 665 billion. It can be inferred that materials and manufacturing would be a major portion of this investment. On a conservative side, one can assume materials cost to be US$ 150 billion and manufacturing cost to be US$ 300 billion. The manufacturing capabilities in the country for power equipment are high. However, it has to be made internationally competitive and cost effective by inputs of modeling, virtual manufacturing, surface engineering, testing and evaluation, etc. A proposal has been prepared, after brainstorming session chaired by Dr. R. Chidambaram, Principal Scientific Advisor to Government of India on advanced manufacturing of engineering materials. The proposal has also been discussed with Dr. V. Krishnamurthy, Chairman, National Manufacturing Competitiveness Council. This proposal has been endorsed by Dr. V. Krishnamoorthy and is figuring in the XIth Plan proposals.

1.1.3 As on today, a large fraction of the annual requirement of special steels required by power plant industry is being met by imports. It is likely that in future the power plant materials may not be available at affordable cost from external sources. Therefore, there is a very strong incentive to develop advanced materials and deploy them in new and existing power plants to improve the operating performance and reliability, availability, maintainability and operability. Materials development has rich traditions and capabilities in the country. However, it is missing links with respect to pilot scale melting, shaping and extensive characterization. This critical gap has to be abridged for India to have indigenous capability in development of current and advanced materials for energy sector. After success on the pilot plant scale, public and private organizations should be in position to take this development to the supply of actual tonnage. Synergy and consortia approaches have to be proposed and ensured. Current proposal addresses R&D resources required to take India's capability to a level where materials can be developed confidently and can be handed over to the large tonnage producers for supplying materials with confidence.

1.1.4 It is necessary that an integrated materials development programme for power generation is initiated covering fossil-fired power, advanced steam turbine, gas turbine and advanced nuclear energy systems comprising of nuclear fission (fast breeder reactors) and fusion. Materials for renewable energy sector are needed for fuel cells, solar cells bio-energy, wind and ocean energy applications. Each sector of renewable energy requires a separate materials development strategy and implementation. I believe this is being addressed in a separate proposal. However, this aspect should not be missed in the XIth Plan period for taking-up the comprehensive materials development and supply strategy for energy security in the country with an aim to be a global leader, in this area.

1.1.5 We should collaborate comprehensively with other initiatives in Europe, Japan and USA and establish coherence to get success in this important area of national importance.

1.2 National Consortium for Materials in Energy Systems

1.2.1 The aim is to establish world class Consortium to achieve self-reliance, by the country, in the production of materials required by the energy sector and make India as a Global Leader for the supply of manufactured components with advanced materials at lower cost. Meaningful work in the development of materials needs facilities and manpower, which are totally dedicated. BHEL R&D and IGCAR have facilities that are barely enough to meet their own requirements. However, these two organizations can serve as ideal nodal agencies for setting-up of the Consortium. Some of the public sector undertakings like MIDHANI need to be strengthened for developing materials at laboratory and pilot plant scale. At present MIDHANI have melting facilities to produce ingots of more than 1000 Kg. The development of new alloys with optimum chemical composition calls for production of large number of laboratory heats of usually 50-100 Kg and subsequent production of pilot plant scale melts of 500 Kg. Furthermore, MIDHANI needs necessary equipment for cold and hot working the pilot plant scale melts. A broad outline of the facilities and man power required are given in ***Annexure VII***.

1.3 Vision of the Initiative

1.3.1 To set up a World Class Consortium for Energy Materials with select facilities for development of advanced materials for power generation and make India a Global leader for the manufacture and export of power plant equipment. The vision also envisages strengthening the infrastructure of competent industries and raising the level of expertise in the consortium engaged in Energy Materials Development. A coherent synergism would be built by networking the facilities and expertise available in industry, research and academic institutions for achieving the scientific breakthroughs in the development of energy materials.

1.4 Mission

i) To develop advanced materials at lower cost and make India a Global Leader in the export of manufactured components required by power sector

ii) To provide sound scientific and technological base for the development of advanced materials that will permit boiler operation of steam temperatures up to 760 ^{o}C

iii) Work with alloy developers, fabricators, equipment vendors and power generation plants to develop cost targets for the commercial deployment of alloys and processes developed

iv) To enable domestic boiler, steam generator and turbine manufacturers to globally compete for the construction and installation of high efficiency coal fired power plants and combined cycle plants

v) To lay the ground work for the development of Indian Code for the approval of newly developed materials

1.5 Approach

1.5.1 In order to meet the above mission, a two-layer approach would be followed. Corporate R&D, BHEL, Hyderabad and IGCAR, Kalpakkam would act as nodal agencies based on their own inherent strengths in basic and applied research in materials development and characterization of steels and superalloys. Coherent synergism will be brought in through networking with various other units of BHEL, DAE, DMRL, MIDHANI, CSIR, educational institutions and various other Public and Private Sector industries in the second layer. The synergism between these two layers is expected to make this initiative very vibrant and productive. The facilities available in reputed private industries would also be utilized.

1.6 Conceptual Execution

i) Innovative Alloy Design

ii) Melting and Processing of Clean Steels and Superalloys

iii) Establishment of Innovative Heat Treatment Schedules

iv) Characterization of Microstructure using Advanced Techniques

v) Evaluation of Tensile, Creep, LCF, Creep-Fatigue Interaction and Fracture Toughness of New Steels

vi) Mathematical Modeling of Creep and Fatigue Properties and Extrapolation

vii) Evaluation of Suitable Welding Technologies for Advanced Ferritic Steels

viii) Development of Compositions to Resist Type IV Cracking in HAZ of Weldments

ix) Development of Non-Destructive Testing as a Tool for on-line Correction of Melts

1.7 Materials Development in Energy Sector

1.7.1 The traditional coal-fired power plants are marked with emissions of environmentally damaging gases such as CO_2, NO_x and SO_x at alarmingly high levels. Adoption of ultra supercritical (USC) power plants with increased steam temperatures and pressures significantly improves efficiency, reducing fuel consumption and environmental emissions by a commensurate degree. Increase of steam parameters from around 180 bar and 540^o C-560^{o}C to ultra supercritical condition of 300 bar and 600^{o}C have led to efficiency increases from around 40% in 1980 to 43-47% in 2006. A further enhancement of thermal efficiency may be obtained by combining an advanced steam cycle plant with a gas turbine; in this way efficiencies of over 60% are possible.

1.7.2 The major limiting factor on the ability to raise temperatures and pressures is the availability of materials with adequate creep properties. In order to minimize investment costs, which also influence the effective cost of electricity generation, the greatest possible use must be made of Ferritic-Martensitic steels for all major components in both boiler and steam turbine. Specifically steels of the 9-12%Cr class are required with long-term creep strength and oxidation resistance in steam, along with ease of fabrication for large forgings, castings and pipe sections. At present, national and international projects aiming at the development of high-Cr martensitic steels capable of steam conditions upto 650^{o}C are under progress in Japan, Europe and USA.

1.7.3 The modified 9Cr1Mo steel, which is being widely used in fossil fired power plants, appears to have reached its full potential. The upper steam temperature limit is not more than 600^{o}C and the weldments of this steel exhibit lower ductility and creep-fatigue cracking in the Heat Affected Zone (HAZ) thus indicating the importance of further research work on ferritic steel weldments and development of materials that resist Type-IV cracking in the HAZ.

1.7.4 In India, electric power generation by coal-fired ultra supercritical power plants becomes important to meet the needs of growing population and economy. Energy generation combined with low carbon dioxide emissions is important to protect global environment in the 21st century. Although increased thermal efficiency brings considerable benefits with regard to the conservation of fossil fuels and reduction of emissions, the plant components are subjected to more arduous operating conditions. Materials properties define the limits on achievable temperatures and pressures and efficiency improvements can be achieved by development of better heat resistant materials and understanding their performance under relevant creep and thermo-mechanical fatigue loads, high temperature corrosion due to flue gases and steam-side oxidation. Efforts are on in Europe, Japan and USA to develop a competitive, innovative and high-efficient coal-fired technology with steam temperature beyond 700°C. Nickel-based superalloys are foreseen for the high-temperature sections of boiler piping and turbine as they seem well adapted for the temperature range 700-800°C. Superalloys are being developed for thin-walled super and reheater tubes, thick-walled outlet headers and steam piping, and castings and forgings for turbines. Various alloys used for advanced steam turbine components are given in Table 1 ***(please see Annexure-VII)***.

1.7.5 In combined cycle plants, gas turbines feature as key components of the most efficient forms of advanced power generation technology available. The high versatility and flexibility enables gas turbines to be used as a means of generating power using operational cycles such as conventional simple cycle, combined cycle and combined heat and power generation systems. A range of fuels can be used including natural gas, synthetic gas, bio-mass liquid fuels. Air blown gasification (ABGC) offers the potential for cleaner coal technology that benefits from increases in gas turbine efficiency and super critical steam cycle development to produce lower emissions. The principal innovation, which underlies the development of combined cycle plant is the replacement of iron-based alloys by nickel-based alloys for the highest temperature components. These alloys are already used in the aerospace and gas turbine industries. However much larger components are required for boilers and steam turbines than are currently produced and there are significant technical challenges to be met to achieve the required properties under significantly different conditions of environment, stress and temperature. Therefore demonstration of manufacturing capability and materials characteristics are required. Various advanced materials proposed for land based gas turbine components are included in Table.2 ***(please see Annexure-VII).***

1.7.6 A range of competing advanced coal fired gasification combined cycle system have been developed in the USA, Japan and Europe. The use of such combined cycle system to generate electricity from coal offers many advantages over conventional coal fired power generation system, including increased efficiency of power generation and lower environmental emissions (specifically CO_2, SO_X, NO_x and particulates). As with the more conventional power generation technologies, the influence of material issues on the development of these processes can be considerable, as it is necessary that components in these processes have adequate lifetime in their operational environments. Some of the materials used for gasification systems are given in Table.3 ***(please see Annexure-VII).***

1.7.7 Advanced nuclear power systems (Fast Breeder Reactors and Fusion Reactors) are being designed with the potential to make significant contributions towards future energy demands in an environmentally acceptable manner. The economic efficiency and reliability of nuclear energy in India has been demonstrated by the reactors operating today. Fast Breeder Reactors (FBRs) are the inevitable source of energy in the next fifty years. The materials inside the reactor core have to withstand intense neutron irradiation and temperatures upto 650^{o} C. These hostile environments introduce materials problems unique to fast reactors, like void swelling, creep and embrittlement which determine the permissible life of core components. Since fuel cycle cost is strongly linked with burn-up of nuclear fuel, development of core materials resistant to void swelling and irradiation embrittlement is very important and a challenging task. While most of the core and structural materials used in the Fast Breeder Test Reactor (FBTR) were imported, all the materials required for Prototype Fast Breeder Reactor (Alloy D9 for core components, 316L(N) and 304L(N) for structural materials, Mod.9Cr1Mo for steam generator materials) have been developed within the country as a long-term strategy. IGCAR has played a leading role in the collaborative efforts carried out with MIDHANI, SAIL and NFC.

1.7.8 Development of improved versions of alloy D9 (D9I) for fuel pins is an essential pre-requisite for improved fuel burn-up. We need to develop simultaneously special grades of void swelling resistant ferritic-martensitic steels with high creep strength and low ductile-brittle transition temperature before and after irradiation to realize 200,000 MWd / t target burn-up of FBR fuel. This would result in significant economy in fuel cycle cost of FBRs and make them competitive and more environment-friendly. In advanced FBR concepts, oxide dispersion strengthened ferritic steels (ODS alloys) are contemplated for use upto 650^{o}C as possible material for fuel cladding. The development of these alloys in India requires establishment of facilities for production of pre-alloyed powders, high energy attrition mills for mechanical alloying, hot iso-static pressing and powder extrusion facilities. This is an area, which should be seeing enthusiastic co-operation between IGCAR, BHEL, DMRL, ARCI, IITs, NFC, VSSC, and several other private sector industries.

1.7.9 Fusion energy represents a promising alternative to fossil fuels and nuclear fission for energy production. It offers the potential of numerous attractive features as a sustainable, broadly available, large-scale energy source, including no emissions of green house gasses, and no-long lived radioactive waste. Conceptual Tokomak fusion reactor designs are under consideration and currently an international collaboration is in progress with the aim of building the International Thermonuclear Experimental Reactor (ITER) as the next step forward in developing this power source. India has recently joined the ITER as one of the seven full partners, the others being China, European Union, Japan, Korea, Russia and USA. India will be testing its own blanket module in ITER and requires the development of radiation resistant and low activation materials. The challenging conditions of operating temperatures up to 1200°C for the diverter and ~500°C for the first wall, with the need to minimize sputtering and radiation damage are countered by multi-material solutions involving a plasma-facing armour layer on low activation ferritic steels. Dimensional stability associated with high void swelling under irradiation is a key issue, and modified 8-9% Cr ferritic-martensitic steels with W, V and Ta additions are emerging as the first choice. Ferritic steels show an upper operational temperature limit due to loss of creep strength above 500-550°C. Consideration is therefore being given to the development of ODS Ferritic-Martensitic steels utilizing the low activation matrix compositions. The additional creep strengthening is derived by nanoparticles of Y_2O_3 and TiO_2; this approach essentially mirrors that taken for Ferritic steel FBR core components.

1.7.10 It may be noted that the composition of Mod.9Cr1Mo and its derivatives and nitrogen added stainless steels are being regularly modified for high temperature applications. Production of high quality steels necessitates use of special steel making processes like Vacuum Arc Melting, Vacuum Induction Melting, and Electro Slag Refining etc. The new initiatives in materials development for fossil-fired, steam and gas turbines, and fission and fusion reactors calls for a three tier approach comprising of laboratory (<100Kg), pilot scale (500-1000Kg), and large scale production (>1000 Kg) of the materials in the required dimensions and product forms. The laboratory and pilot scale development of materials in India are currently hindered by lack of melting and characterization facilities. No concerted efforts have been initiated to develop advanced ferritic steels and superalloys required by energy sector. Like many other countries, India has to take initiative in starting a programme on the development of advanced ferritic steels and superalloys. The advanced Ferritic steels are also finding wide range of applications both in fission and fusion nuclear programmes.

1.7.11 The current status of India in attempting to manufacture these advanced materials has been very limited. In spite of several challenges in the development of high quality steels and welding electrodes, IGCAR, Kalpakkam has achieved a remarkable progress in the indigenous production of Modified 9Cr1Mo steel tubes of 24 meters length with very close tolerances for Prototype Fast Breeder Reactor Steam Generator applications. Plates have been produced in large dimensions required specially for the manufacture of large components in collaboration with SAIL, steam generator tubes in collaboration with MIDHANI and NFC and forgings in collaboration with MIDHANI. Forgings of Mod. 9Cr1Mo have also been produced by BHEL, Hyderabad, in co-operation with a private industry. These are the only instances where Modified 9Cr1Mo has been produced in India. A few castings and forgings of E911 and G911 grade, on experimental basis have been produced by Central Foundry and Forged Plant (CFFP) of BHEL. A large number of welding electrodes with specifications better than the international benchmarks and at cost competent rate have been developed by IGCAR, in close collaboration with MIDHANI and private industries.

1.7.12 Some of the international research programmes undertaken in the last 2 to 3 decades along with the time and expenditure involved are given in Table - 4 ***(please see Annexure-VII).*** It can be seen that the time and expenditure involved in the development of new materials up to the utilization stage is quite large and may be of the order of one or two decades in time and millions to billions of dollars in terms of costs. Initiatives must be taken in India to indigenize and modify the existing grades and develop innovative materials to meet the large national needs and emerge as a Global Leader in the supply of manufactured components by the end of decade based on Indian materials. Large facilities for evaluating long term properties, such as Creep, Fatigue, Corrosion, etc should be set up.

1.8. Strategy Towards Code Approval of Indigenously Developed Materials

1.8.1 India's requirement of steels for power sector is being met mainly by importing either at finished product stage or intermediate / starting material stage. Integrated materials programme should be directed to achieve the following objectives:

i) Minimize the steel imports

ii) Development of Indigenous capabilities for pilot scale melting

iii) Development of advanced steel grades and their qualification

iv) Establishing India as World-class steel producer for exports

1.8.2 Road map to achieve the above objectives are summarized below:

(a) Indigenous Production and Exports

i) Steel production units in the country should produce India's major demands without any import at either primary (ingot) or secondary stage (intermediate hollow bar for tubes production) or finished product. Next stage should be directed to capture partially world market by exporting produces at competitive price. This is specifically for steels being in use over the last few decades and included in the design codes. One of the most demanding tasks for the validation of high temperature steels for use in power plants is the development of a comprehensive database of long-term creep test results. To enter world market, it will be obligatory to generate materials creep rupture data through testing of number of heats over the temperature range of interest with rupture times of at least 10,000 hours to establish allowable stresses. The creep rupture data of at least 30,000 hours is needed to make a valid extrapolation for design life of 105 h or more and demonstrate that the generated allowable stresses meet the minimum requirements of internationally accepted design codes. In fact, the products should demonstrate superior properties compared to the minimum or average requirements of the design codes. Technical bulletins / booklets should be brought out like any foreign reputed steel producer to bring out the production range, fabrication and welding procedures.

ii) To enter the world's market with relative ease, it is prudent that Indian steel producers create joint ventures / collaboration with reputed international steel producers. Major steel users in the country should also introduce contractual agreements to enhance use of Indian produced steels.

(b) Indigenous Development of Advanced Steels

i) Inspite of India's knowledge base not inferior to advanced nations, India's steel industry and materials community have not been able to introduce any steel grade. Enormous potential exists to introduce new grades of steels to result in economic power production and less polluting environment by raising plant parameters to result in higher cycle efficiency. The integrated materials development programme should be directed towards development of materials with mechanical properties set in comparison to existing or under development steel grades. For example, Cr-Mo steel development programme for advanced super-critical boilers can be based on the resulting design allowable stress at least equal to creep resistant austenitic stainless steel grade like 316.

ii) Development of a new creep resistant material for fossil power sector will demand generation of tensile, creep strain and stress to rupture data. Additionally, corrosion data, thermal ageing effects, weldability and creep data on weldments needs to be generated. One should direct R&D for inclusion of a material initially in ASME code case and then as a codified material in ASME code and IBR. Creep data generation would be preferred upto one-third of design life (33,000 h) with most of data in the range of 1000-10000 h. National consortium of steel producers and R&D institutions should be formed to generate the necessary data for inclusion in the design codes. It will take at least 5 years high temperature data for a material to be considered for inclusion in the code. The history of development of modified 9Cr-1Mo (Grade 91) is well known. With an objective of selection of materials for liquid metal fast reactors, Gr.91 was developed mainly through testing in USA and got included in the ASME code after nearly 8 years. Introducing a new grade for use in power boiler usually takes a long time.

iii) By generating extensive creep data upto 10, 000 hours at various laboratories in the country a provisional data sheet for Indian materials could be established with extended time extrapolations. On acquiring data of 30,000 hours, the extrapolations can be verified and validated to obtain creep data upto 1,00,000 hours.

1.9 Conclusion

1.9.1 India has credible expertise in materials science and engineering. The expertise in steel making for manufacturing components is also of high standard. Academic and research aspects of materials such as steels and superalloys for energy systems are distributed. The expertise in non-metallic materials such as elastomers, which are vital for energy systems (fossil and nuclear) is lacking but seeds of excellence exist. Materials for renewable energy system and fuel cells are not considered in this proposal. We were informed that it is being addressed separately. This proposal addresses the issue of strengthening of facilities for making steels and superalloys. Setting-up of facilities for non-metallic is be identified. The proposal recommends mechanisms to achieve success in development of existing materials for energy systems and their utilization by the utilities. Consortium and networking approach has been successful particularly in Europe which has emerged as leaders. We have recommended consortium and networking approach, focused international collaborations, being a part of the international databases, etc. to enhance the pace of our progress to meet the objectives. There is a good confidence that we can supply a large demand of materials for fossil and nuclear energy systems indigenously on a cost competitive and quality basis. The demand for India is so large that if we are successful in meeting the demands for our energy needs, we have the possibility of emerging as world leaders with support of business strategies and policy decisions.

1.9.2 The energy systems, are rapidly evolving to meet high thermal efficiency and less environmental burdens. Thus, there is an urgent need for designing and developing advanced materials and manufacturing technologies. Plan of work and strategy is outlined in this proposal. A proposal on Advanced Manufacturing to enable making of components for current and future energy systems at internationally competitive levels is complementary to this proposal and is being proposed in the Working Group on Cross Disciplinary Technologies (eleventh plan period) under the Steering Committee on Science and Technology.

1.9.3 There are limited and incomplete facilities for special alloy steel production [like the Mishra Dhatu Nigam Limited (MIDHANI), Hyderabad] and for steel forgings [like the Heavy Engineering Corporation Limited (HEC), Ranchi]. To fill important future (and present) gaps in these areas for the energy sector as well as for strategic systems, it is necessary to make substantial investments in such facilities. In the case of the HEC, Ranchi, the transfer of its forging division to a public sector undertaking like the Bharat Heavy Electricals Limited (BHEL) may also be considered. It is recommended that an indicative budget of Rs. 200.00 crores may be provided for these. The exact roadmap for this may be decided after a brainstorming session, to which, inter alia, the Department of Atomic Energy, the BHEL, the MIDHANI and the Larsen and Toubro Limited may be invited.

1.9.4 There is also an emergent need to create facilities for the high temperature testing of mechanical properties of materials (particularly creep and fatigue) which are, currently, none-existent in the country.

1.10 Requirement of Funds

An amount of Rs. 400.00 crores is projected as the requirement of funds for the creation of facilities mentioned in the ***Annexure-VII*** and those mentioned in para ***1.9.3*** above.

Section – II

R&D in Biofuels

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2.1 Introduction

2.1.1 Among the various options of Biofuels, the following have huge potential for India as energy sources and can fulfill different energy needs for the transportation as well as stationary applications like power generation for the urban and rural sectors:

- **SVO / Biodiesel**
- **Ethanol**
- **Biogas / Syn-gas**
- **Next generation biofuels like bio-oil, bio-ethanol, Fischer-Tropsch liquid, bio-dimethyl ether (DME), bio-hydrogen etc.**

2.1.2 A massive time bound strategy is needed for research and development at every stage i.e. production, processing / conversion and application / use of biofuels to make them a commercially attractive and wholesome energy option for the country.

2.1.3 **Present challenges for R&D in biofuel sector** lie mainly in judicious plantations of energy crops and establishing the facilities for conversion into biofuels of appropriate specification. Adequate data also needs to be generated that establish conclusively the tangible gains realizable in the transportation and power generation sector. While supporting the implementation of projects for currently available biofuels, it will be necessary to promote the transition towards next generation biofuels (from ligno-cellulosic biomass), which go beyond utility as thermal energy source and can be produced from a wider range of biomass feedstock in an energy efficient way and at a reduced cost. Co-production of fuel and by-products in integrated bio-refineries will improve the overall economy and competitiveness of biofuels and therefore coordination with potential user industries of the by-products is desirable. The units that would produce biofuels (such as biodiesel) would need to be modular in the sense that they would need to be co-located with the plantations (i.e. the plantations would need to be spread within a radius of 7-8 km of the units). This modular approach would bring obvious advantages of reduced cost of transportation and handling of the feedstock (for e.g. Jatropha). It would also be important to set-up testing labs in different locations of the country for testing and certifying the quality of biofuels produced.

2.1.4 For consistent supply of quality biomass feedstock, research on improving crop yields using advanced technologies should be taken-up carefully. While developing innovative technologies and processes, apart from economic factors, other issues such as environmental impact – both positive such as green house gas mitigation and negative such as potential threat to biodiversity from monoculture-energy balance keeping total perspective in view including aspects such as energy required for producing fertilizers and pesticides used in the cultivation of energy crops, and the potential competition of food production will have to be taken into account.

2.2 Feedstock/ Raw Material (Cultivation, Harvesting and Primary Processing)

2.2.1 Biodiesel can be produced by planting Tree Borne Oilseed crops (TBOs) and shrubs such as Jatropha, Pongamia, Mahua etc on the degraded lands classified as wastelands. India has large number of species yielding non-edible oils like *Jatropha curcas* (Ratanjot) *Pongamia pinnata/glabra* (Karanj), *Hevea braziliensis* (Rubber) *Madhuca indica/longifolia* (Mahua), *Calophyllum inophyllum* (Undi), *Salvadora persica/oleoides* (Pilu), etc. The Jatropha oil offers certain advantages in processing into biodiesel from the perspective of fatty acid composition and the low phospholipid content.

2.2.2 Oil seeds available from other trees, which can yield suitable grade oil on economical scale, can also be tried in the initial stages to run pilot R & D projects. Considering various factors, physico-chemical characteristics like oil yield, sustenance in different type of wastelands including moderately saline soils, fruiting, FFA content etc. **Jatropha** (Ratanjot) and **Pongamia** (Karanj) places good options for plantations although little is known at this stage regarding the performance of Pongamia-based biodiesel.

2.2.3 Enhancement of the oil yield from better plant varieties, improved oil seed species and fast-growing tree crops which are capable of delivering fruits at short gestation periods for the enhanced production of biodiesel than the contemporary is needed.

2.2.4 Fast growing seaweeds and microalgae as a source of biogas besides the conventional organic matter deployed for such purposes.

2.2.5. R&D Areas / Topics:

A) Medium / Long Term

i) Improved cultivation and agricultural practices for the enhancement of seed yield and oil content in Tree Borne Oilseed varieties through screening of germplasm / genetic engineering and tissue culture etc for cultivation under different agro-climatic conditions.

Work on cultivation aspects of *Jatropha curcas* was initiated in the mid-nineties by Vinayak Rao Patil (in Nasik, Maharashtra), CSMCRI, Bhavnagar (in Behrampur, Orissa) and others. Since then a great deal of information has been obtained on the practices that will need to be followed to ensure productivity of such plantations. Plantations have now been established by CSMCRI on wasteland in two different agro climatic zones. These were raised from seeds as well as cuttings of selected plants. Significant differences in growth, flowering, male / female ratio, seed yield , seed to kernel ratio, oil content and $^{12}C/^{13}C$ ratio were observed indicating the possibility of improving the species for seed yield, oil content and tolerance to environmental stresses. Useful learning was also obtained on disease outbreak and means of dealing with the same. Under the CSIR NMITLI programme, a large number of provenances have been collected and the best selections are being made keeping both seed yield and oil content in mind. An important recent achievement is the success in tissue culture of Jatropha from shoot tip and successful transplantation of such plants in the field. However, much remains to be done to raise the productivity of the tissue culture protocol. Yet another area of research is plant breeding to improve further the traits of plants.

ii) Development of crop varieties with more sugar or starch content and adaptable to diverse agro-climatic conditions for bioethanol production.

In view of the ongoing debate regarding energy input vs. energy output from bioethanol, there is a need to utilize agricultural practices that improve the output to input ratio. This would include more effective use of bio-fertilizers such as the patented *Kappaphycus* seaweed sap that has raised sugar productivity by as much as 40% in field trials conducted by Renuka Sugar Mills.

iii) With the introduction of fast growing seaweeds in Indian waters, especially the *Kappaphycus alvarezii* seaweed, there is an opportunity to look beyond land-based plants for energy. The production of biogas from drifted seaweeds was worked on many years back and it is feasible to look at biogas as a co-product along with seaweed liquid fertilizer. It would be desirable to set-up a pilot project to produce five cylinders of biogas per day from seaweed akin to the LPG cylinders. This, in turn, will call for deployment of associated technologies such as scrubbing of carbon dioxide, compression of the gas, etc. There is also great potential to utilize smoke stack emission to raise the biomass production rate. There is great advantage in moving to the sea for biofuel since it does not compete with scarce land resources, requires no fertilizer nor any water for irrigation.

B) Technology development/demonstration/commercialization projects for Short Term:

i) Improvement in irrigation management techniques / schedules, spacing, fertilizer doses, pruning, intercropping with suitable crops etc. under different agro-climatic conditions.

The studies conducted in the field have revealed the critical importance of appropriate agronomic **practices (pit depth; spacing; fertilizer needs, irrigation needs, etc.) in addition to practices such as pruning to increase the number of branches and promote "bushiness" of the *Jatropha* plant. Promising results have been obtained by application of deoiled Jatropha cake in the Jatropha plantation itself. To ensure some income from the land in the initial phase itself, inter-cropping has been successfully carried out in Orissa with pulses such as green gram, black gram and Bengal gram. Another aspect in the context of large-scale cultivation is the development of appropriate harvesting techniques such as the vibrator.**

ii) Identification and control of pest and diseases.

During field experiments, rare occurrence of diseases (root rot fungal disease; white patch due to leaf minor insects) has been observed which needs to be promptly managed, for which a database of effective controls is essential.

iii) Implementation of technology development projects for primary processing like efficient oil extraction, filtration, degumming, drying etc. Already the know how for processing vegetable oil into EN14214 grade biodiesel, integrated with by-product recovery, has been developed and even transferred to industry.

iv) Plantation of energy crops and development of cluster based model for collection of seeds, farm management, storage, decortication, extraction of oil from oilseeds using existing oil expellers. Logistics of seed storage need to be worked out to minimize oil degradation on storage. Use of stabilizers to prevent degradation of oil has also to be looked into. Another aspect to look at is the utilization of capsule shell as a source of energy. It has been established to have similar calorific value to that of coal and given that it comprises 40% of total capsule weight, there is considerable scope to utilize it if it can be compacted in the form of briquettes.

v) The deployment / plantation for appropriate type of biomass / petro-crop depending upon varied climatic conditions.

vi) Acid oil (used vegetable oil) can also used as one of the raw materials for the production of biodiesel. Currently many biodiesel manufacturers are using it as raw material for biodiesel production.

2.2.6 Processing / Refining / Conversion Technologies

A) The presently available conversion technologies are as follows:

i) Oilseeds $\xrightarrow{\text{Extraction}}$ SVO $\xrightarrow{\text{Transesterificationn} \;\leftarrow\; \text{Methanol}}$ Bio-diesel

ii) Sugarcane $\xrightarrow{\text{Fermentation}}$ Ethanol

iii) Organic Residues $\xrightarrow{\text{Digestion / bio-methanation}}$ Bio-gas

iv) Energy Crops/Biomass Wastes $\xrightarrow{\text{Gasifier}}$ Syn-gas

2.3 SVO / Biodiesel:

2.3.1 Biodiesel is produced by transesterifying oils and fats and is chemically known as fatty acid methyl ester. There are three basic routes to biodiesel production from oils and fats:

- Base catalyzed transesterification of the oil with methanol.
- Enzyme-catalyzed transesterification
- Direct acid catalyzed esterification of the oil with methanol.
- Conversion of the oil to fatty acids, and then to alkyl esters with acid catalysis.

2.3.2 While enzymatic transesterification is expensive and more in the research phase, the other three methods can be used in batch or in continuous mode for processing of SVO into biodiesel. World over the base-catalysed method is preferred when the FFA content of the oil is low. The process can have certain disadvantages if not practiced properly, e.g., formation of emulsion during purification. These problems have now been overcome in the process developed by CSMCRI, Bhavnagar and base-catalysed transesterification of SVO is being routinely carried out for oils having as high as 8% FFA. The most common form of biodiesel uses methanol to produce methyl esters as it is among the cheapest alcohols available and processing tends to be simpler. Ethanol can also be used to produce an ethyl ester biodiesel and higher alcohols such as iso-propanol and butanol have also been used. It is to be noted, however, that there is an optimum chain length for biodiesel and the use of longer chain alcohols may be beneficial when the fatty acid chain length in vegetable oils is shorter than desirable. A byproduct of the transesterification process is the production of glycerol. There are other by-products as well.

2.3.3 R&D Areas / Topics:

A) Short Term

i) Transesterification process for handling high FFA interference and compatibility of the process for multiple feedstocks. There are two ways of handling the problem of high FFA. One would involve acid catalysed transesterification and the other would involve elimination of the FFA with concomitant production of usable soap.

ii) R&D for removing the commonly encountered problems like deactivation of basic catalyst by FFA, deactivation of acidic and basic catalyst by water etc. Such difficulties are best handled by ensuring that the oil is first refined to remove FFA and then made moisture-free prior to transesterification. In the case of acid oils, the acid catalysis should be resorted to since FFA removal is not practical in this case.

iii) Development of storage additives for SVO and biodiesel indigenously. The key aspect in case of SVO would be prevention of FFA build-up and also elimination of oxidation instability. In the case of biodiesel, the additives would be essential for oxidation stability and reduction of pour point where utilization of biodiesel under very cold conditions is desired. Besides these, there could be additives to enhance engine performance of biodiesel which calls for extensive research. Such issues become especially important when use of biodiesel in neat form is desired to take maximum advantage of its high flash point, high cetane value and low emissions. It is noteworthy that neat biodiesel does not come under the Explosives and Petroleum Act & Rules on account of its high flash point.

iv) Use of solid catalyst in place of base / acid catalyst in transesterification process. This would be important if biodiesel is produced in un-integrated manner by poor technologies. In the fully integrated process developed at CSMCRI, such problems are fully overcome making it a zero effluent discharge process with recovery of catalyst as potash fertilizer. Nonetheless, research should continue on solid catalysts but it must be borne in mind that the conversions will have to be quantitative, the reaction should ideally be done under ambient conditions, and the catalyst must not suffer deactivation. An equally important issue is the use of excess methanol and the problems that are encountered in recovering such methanol. An imaginative solution is necessary.

v) Development of some simple transesterification process for converting SVO to bio-diesel using locally available means which can be used by villagers by employing a simple reactor / vessel for local power generation to help in distributed power generation for remote villages where grid connectivity cannot be provided. This can be taken up immediately since under rural conditions the batch process would be more appropriate and such a process has already been developed by CSMCRI, Bhavnagar. The process is under ambient conditions, except thermal energy required for oil expelling, soap manufacture and distillation of glycerol. It is also a zero discharge process, with co-production of oil cake, soap, potash fertilizer and refined glycerol. The cake, soap and fertilizer can be used locally itself. Moreover, the biodiesel is of EN14214 quality which can be used in neat form in tractors, generator sets, etc. as already demonstrated.

vi) It is proposed to set up a 5 cu. m. / day biogas unit utilizing residue obtained after expelling sap from *Kappaphycus alvarezii* seaweed. It is further proposed to purify and compress the gas and fill it into gas cylinders for easy transportation and use.

B) Medium Term

i) Enzymatic degradation of lignocellulosic biomass by standardizing specific microbes and optimization of fermentation parameters for high conversion rate of lignocellulose into biodiesel.

ii) Application oriented R&D to find out new application areas for using glycerol as by-product of transesterification in industries. The focus should be on high volume applications such as their use in production of polyurethane and biodegradable polymers.

iii) Development of continuous process of transesterification for biodiesel production relevant to large scale plants. It is important to point out that transesterification is not the rate limiting step and that processes are constrained by time taken for oil expelling, oil refining, purification and solvent / glycerol recovery.

iv) R&D to use bio-ethanol in place of fossil methanol in transesterification process and studying the overall performance of the process and quality of product vis-à-vis the methyl ester.

C) Technology development/demonstration/commercialization projects:

i) Technology development to use alcohols of higher molecular weights like propanol, butanol etc. to improve the cold flow properties of the resulting ester and to make this process more efficient.

ii) Technology development for downsizing the transesterification facility for development of modular portable plants for biodiesel production at a much smaller scale and its demonstration for rural applications. The CSMCRI process is already quite appropriate for 200 liter scale onwards and a demonstration plant is already in operation in Rajasthan which hopes to process 300 tonnes of Jatropha seed per annum operating in one shift.

iii) Assessment of economy of scale of transesterification plant, cost of production, life-cycle costing and ROI etc. The cost of producing biodiesel would however largely be dictated by seed cost.

iv) Setting-up of an integrated economic size bio-diesel plant based on multiple feedstock containing varying proportions of FFA. It is best to do this by keeping an integrated product portfolio in mind rather than having sole focus on biodiesel.

2.4 Bioethanol:

2.4.1 Bio-fuels like bio-ethanol are mainly extracted from molasses produced in the sugar-making process in India. The three main types of feedstocks used for ethanol production worldwide are:

- Sugars (like molasses, cane sugar, beet, sweet sorghum and fruits)
- Starches (like corn, wheat, rice, potatoes, cassava, sweet potatoes, etc.) and
- Lignocelluloses (like rice straw, bagasse, other agricultural residues, wood, and energy crops).

2.4.2 Among the various competing processes, bioethanol from lignocellulosic biomass appears to have economic potential. The crops residues such as rice straw, bagasse etc. are not currently used to derive desired economic and environmental benefits and thus they could be important resource for bioethanol production. The major source of feedstock required for ethanol production in India comes from sugarcane-sugar molasses.

2.4.3 Sugarcane crops require long time as well as high irrigation and fertilization. These factors explain the high costs involved in the production of sugarcane and ethanol, and question the competitiveness of producing sugarcane relative to other crops. In this case higher level of alcohol by fermentation would automatically reduce the cost of purification. So there is ample scope for modification in the present fermentation process used in the sugar industry for the production of ethanol

2.4.4 The production of ethanol from biomass / lignocelluloses involves:

- Pretreatment to hydrolyze the hemicellulose,
- Hydrolysis of cellulose to produce glucose,
- Fermentation of sugars to ethanol, and
- Ethanol recovery.

2.4.5 Both enzyme based and non-enzyme based process configurations are used to obtain ethanol from biomass. In the non-enzyme based approach, acid is used for both hemicellulose and cellulose hydrolysis. While Separate Hydrolysis and Fermentation (SHF) is used in the non-enzyme based fermentation. Both these processes have their own advantages and disadvantages based on the type of feedstock being used.

2.4.6 R&D Areas / Topics:

A) Short Term

i) Increasing the yield of sugarcane, sugar content in the cane juice and utilization / distillation of secondary cane juice to produce ethanol.

ii) Undertaking rigorous input-output analysis.

iii) Looking at best options for production of absolute alcohol relevant both to petro-diesel and biodiesel preparation.

B) Medium / Long Term

i) R&D for development of an efficient process for the production of Bio-ethanol from alternative sources like sweet sorghum, rice stalks wasted grains and ligno- celluloses.

ii) New decomposition routes to decompose biomass into cellulose, hemi cellulose and lignin at one step to produce ethanol – to avoid an additional pretreatment step to remove lignin, which consumes additional energy.

iii) Development of fast acting, standardized and specific microbial species for biomass degradation to produce bio-ethanol.

iv) Development of cost effective processes for processing of lignocellulosic biomass to produce bioethanol.

- Development of efficient and cost effective chemical and physical pretreatment technology of lignocellulosics to make the biomass matrix more accessible to enzymes.
- Development and selection of optimized organisms and process for fermentation of mixed sugars like hexoses and pentoses etc. into bio-ethanol.
- Integration of process steps for process design and scale-up for industrial application.

v) R&D for development of an efficient fermentation process for production of bio-ethanol from starch.

vi) Purification of bio-ethanol by either azeotropic distillation or by use of molecular sieves is an important area along with bio-ethanol production.

vii) An important research area is genetic engineering of petrocrop i.e. to genetically improve tree species to produce better quality and quantity of oil.

C) Technology development/ demonstration/commercialization projects:

i) Technology development to modify the present fermentation process used in the sugar industry for the production of ethanol.

ii) Development and standardization of enzyme based process configuration for producing ethanol and making this process cost effective and efficient.

iii) Utilisation of indigenously developed pervaporation membranes and molecular sieves in the alcohol drying process.

2.5 Next Generation Biofuels:

2.5.1 Syn gas and bio hydrogen are other newer options, which could be explored after proper R&D in these areas. Synthesis gas produced from the gasification of biomass in the gasifiers can be used directly as fuel gas for process heat in industries or for electricity generation through gas turbines or can be thermo-chemically converted into different fuels (gaseous and liquid) after purification of gas by pressure swing adsorption (PSA) and gas shift processes and polymerization (like Fischer-Tropsh etc.) and into liquid fuels like methanol, petrol, diesel, Methyl Tetra Butyl Ether etc. or into gaseous fuels like hydrogen from methanol produced after polymerization of syn gas.

2.5.2 Production of syn gas from different feedstocks and its purification and conversion into fuels involves major technological issues which need to be researched and developed first at an economically viable scale for proper utilization of this option for India.

2.5.3 Similarly, pyrolysis of biomass for the production of bio-oil or pyrolysis oil presents another option for harnessing biomass resource for fuel generation. Pyrolysis of biomass involves heating biomass at partial vacuum or modified gaseous environment at high temperatures to obtain bio-oil, char and other specialized chemicals suitable for industries. However, pyrolysis process is known for long and its utility needs to be reviewed vis-à-vis other options.

2.5.4 R&D Areas / Topics:

A) Long Term

i) ***Next Generation Bio-fuels:***

a) **Syn gas:** Conversion of biomass into synthesis gas and different value added bio-products through thermo-chemical conversion (bio-refinery concept) by cost-effective, highly resistant and high activity catalysts.

b) **Bio-hydrogen:** Production of bio-hydrogen from ligno-cellulosic material through gasification and synthesis or biological process like microbial degradation.

c) **Bio-oil:** Production of bio-oil or pyrolysis oil from biomass and other waste materials through flash pyrolysis.

R&D to design the pyrolysis reactor using high temperature sustaining materials in reactors walls, by-product separation and flow etc and efficiency for making this process more efficient and economically suitable.

d) **Fischer-Tropsch (FT) liquid, Bio-dimethyl ester (bio-DME)** through gasification, synthesis of ligno-cellulosic material.

e) **Development of petrol-alcohol-water micro emulsion fuel as a substitute for petrol and ethanol blended petrol.** PCRA has sponsored a project in this area to Department of Chemical Engineering, IIT-Delhi.

ii) Production of bio-diesel from alternative sources of biomass like algae and other aquatic organisms. However, production of biogas from algae can be initiated in the short term itself.

2.6 Application / Use Sector

2.6.1 Biofuels mainly biodiesel and bioethanol could be used as a substitute to conventional petroleum or in blending, to power both stationary as well as mobile engines. Straight Vegetable Oils (SVOs) also provides an option for stationary engines after undergoing some preliminary treatment. However, performance of the engines in long run and the design modifications required for the engines using these biofuels needs to be examined and researched in near term before promoting their large scale commercial use. It also needs to be borne in mind that after oil expelling and refining, there is not that much more one needs to do to make biodiesel and therefore the advantages may be limited compared to the disadvantages.

2.6.2 **Uses of by-products after transesterification** of SVO are other issues which need to be tackled. Glycerol, oil seed cake and fruit hull are the major byproducts in the production of biodiesel. In transesterification process with every 100 liters of biodiesel produced, around 10 liters of glycerol is generated as a by-product. The glycerol is contaminated with solvent, catalyst and other impurities which necessitates purification. The production of huge amount of glycerol as by-product of transesterification in future will exceed the requirement / demand and therefore R&D for newer applications areas for glycerol usage like fiber production etc may be searched in for optimum utilization of glycerol. Many companies have already initiated R&D programmes aimed at utilizing glycerol as a polyol assuming that it will be an inexpensive feedstock in future.

2.6.3 **Similarly, oil seed cake** may be used as substitutes for chemical fertilizers in fields but various technical issues exists in this, which needs to be encountered before hand. Also, in view of the high deficit in the diet of livestock and the future availability of Jatropha cake, farmers may use this oil seed cake as animal feeds only after detoxification and feeding trials. But, it is found that the cake contains crude proteins and so the *in-vitro* digestion in animals is very low, indicating higher content of bypass proteins. Moreover, it would be difficult to tell physically which cake has been detoxified and which has not and, therefore, it may be better to consider cultivation of non-toxic varieties of Jatropha in specific locations for use of the cake locally as cattle feed.

2.6.4 R&D Areas in the Application / Use Sector:

A) Short / Medium Term

i) New application development for glycerol like bio-fibre production, biodegradable plastics, etc, which may be useful to the industries, as well revisitng old applications such as their utility in surface coatings, polyurethane, anti-freeze, etc.

ii) R&D projects to optimize the use of oilseed cake as manure by removing the residual (toxic) effects of cake in soil, rate of degradation of cake in various soil types and under different climatic conditions, rate of release of nutrients in soil and their optimum uptake by plants. The cake should be used as it is to take advantage of its nematicidal properties already established by Anand Agriculture University and CSMCRI for tomato cultivation.

The cake also application as manure in a number of other crops and initial sale of Jatropha cake has already been effected at Rs 3000 per tonne. There is room to study a large variety of crops and also to undertake detailed study to dispel any apprehensions there may be about residual toxicity that creeps into the soil or into the produce.

iii) The chemical composition of Jatropha cake clearly indicates presence of certain anti-nutrients but, otherwise, the cake is rich in essential nutrients, especially the amino acid composition. It may be useful to utilize the cake as a source of amino acid and to destroy all anti-nutrients and other unwanted substances in the course of producing such useful amino acid formulations. It is best not to consider the application of cake directly as animal feed to avoid risk of consumption of cake that is not suitably detoxified.

iv) R&D in the field of design / modification of present automobile engines, stationary equipments etc. and development of energy efficient equipment like lanterns and stoves to run on SVO or biodiesel similar to kero lamps.

v) Investigation on the effect of bio-oil after alternate ways of treatment on heavy engines e.g. tractors etc.

vi) Alternate use of jatropha cake other than fertilizer e.g. biogas, pesticides and large DG sets etc.

vii) Instead of looking at the SVO as a source of fuel, it may be useful to look at its application as an additive in diesel at low levels (1-2 %) if there are any gains that accrue from such use, e.g. improved lubricity of the fuel.

B) Identified areas for technology development/demonstration/ commercialization:

i) Demonstration using biodiesel and SVO in diesel engines and stationary equipments and studying their effects on performance and storage stability after required minimum period of operation.

2.7 Biomass Gasification

2.7.1 Fuelwood, agricultural residues (rice husk, sugarcane trash and coconut shells), wheat straw, pulse sticks, press mud etc. are the main gasification fuels today. Biomass is available throughout the country but the present biomass usage is mainly for cooking in chulhas (cook stoves) with poor efficiency. In addition to residues that are available, it is possible to have dedicated plantations on wasteland or degraded lands that are not normally used for agriculture, for gasification purpose.

2.7.2 Theoretically, almost all kinds of biomass with moisture content of 5-30% can be gasified. However, not every biomass fuel can lead to the successful gasification. Development work carried-out with common fuels such as coal, charcoal and wood indicate that fuel properties such as surface, size and shape as well as moisture content, volatile matter and carbon content influence gasification.

2.7.3 Biomass-based power generation can have higher capacity factors. The conversion options are thermo chemical or biochemical. The thermo chemical processes involve combustion, gasification or pyrolysis. Biomass gasification involves conversion of solid biomass (carbon fuels) into carbon monoxide and hydrogen rich producer gas by thermo chemical process and is accomplished in air sealed, closed chamber, under slight suction or pressure relative to ambient pressure. Gasification produces a corrosive gas which can be used to drive either turbine for electricity or for process heat in industrial applications. Though gasifiers in India has reached commercial production stage, technical issues related to gasifier performance, gas cleaning system, standardization of gasifier for multiplicity and feedstock compatibility etc. are some areas in gasification which needs further research and development for full exploitation of this technology.

2.7.4 Design of gasifier is one typical technologically challenging area which is still under development. Designing of gasifiers depends upon type of fuel used and whether gasifier is portable or stationary. Induction of a gasifier system into a specific industry is also not a simple add-on job. The process and equipment used in the Small Scale Industries may have to be modified to some extent to accommodate the gasifier. This integration requires system engineering inputs from expert groups and some trial runs. Many small, trivial matters related to operation and maintenance procedures will have to be sorted out during this period. Also, a certain amount of fine-tuning might be required in the first few months of installation. These will require the presence of both the manufacturer and technology-provider on the site.

2.7.5 Identified R&D Projects for Biomass Gasifier:

A) Medium Term

i) R&D for new cost effective, anticorrosion materials for turbines to withstand the corrosive and poisonous nature of biomass gasifier gas.

ii) Process based R&D to increase efficiency and sustainability of PSA and gas shift reactions as part of a long-term strategy to produce other liquid fuels and hydrogen from syn gas.

iii) Biomass direct gasification or pyrolysis routes.

iv) Feedstock availability, reliability, environmental impacts and evaluation at semi-commercial / commercial scales are important issues.

v) Collaboration with some experts / expert organizations working in these areas may be necessary.

vi) Initiate studies on briquettes of Jatropha capsule hulls as fuel equivalent to the coal.

B) Identified areas for technology development/demonstration/commercialization:

i) Development of technology for process and equipment standardization to develop biomass gasifiers for varied biomass feedstock compatibility and its demonstration.

ii) Technology development in the area of efficient cleaning of the gas and adaptability of the product of gasification to the specific requirement of the gas combustion system for use in gas fired engines, turbines and fuel cells.

2.8 Issues regarding Cultivation of Superior Jatropha.

2.8.1 The current knowledge on cultivation of elite variety of jatropha is limited. The success of jatropha based biofuel programme is almost fully dependent on the yield per hectare. Therefore, there is an urgent need to develop elite varieties of jatropha and to distribute these on mass scale. One has to also appreciate that in order to replace just 5% of the current consumption of 55 million metric tonnes per annum of diesel in the country, 12 to 15 million tonnes of seed would be required to be planted in an area of approximately 1 million hectares of waste land to produce the desired quantity of 3 million metric tonnes per annum of bio-diesel.

2.8.2 Some systematic efforts have been made by Department of Bio-Technology (DBT) under its jatropha mission research programme during last 4 years. DBT has sponsored research programmes for identification of elite accessions of jatropha from the existing historical good plantations and multiplication of these under supervision of agricultural scientists at various locations. Currently, 18 such programmes are in progress and it is estimated that more than 2 million high yielding jatropha plants have been produced. The criteria of plant selection has been fixed as seeds which have more than 30% oil containing more than 70% unsaturated fatty acids.

2.8.3 There is a need for accelerated research in the following areas, so as to understand the gene diversity of jatropha.

- Superior genotypes need to be identified and seeds collected need to be deposited at one common place, inventorised, documented and stored under different agroclimatic zones.
- Disease and pest management studies to be taken up.
- Genotypes may be screened under in vivo conditions for biotic stress.
- Develop morphometric data.
- Tissue culture infrastructure developed by department may be optimally used for developing tissue culture protocol for jatropha.
- Quality planting material may be made available for large scale demonstration.
- For addressing the problem of biotic stress:
  - Grafting approach could be taken.
  - Look for natural rootstocks for large scale grafting.
- Microsatellite markers may be developed for oil yield.
- Setting-up of vegetative multiple gardens.
- Finger printing of elite genotypes.

- Studies on seed harvesting, storage & oil expelling.
- Development of complete agro-technology package.

2.9 Requirement of Funds: -

An amount of Rs. 200.00 crores is projected as the requirement of funds for doing R&D in bio-fuels in the eleventh five year plan.

Section – III

Rural Energy R&D to Promote the Available Energy Technologies

Authors:

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3.1 Rural Energy Technologies

3.1.1 Penetration of rural energy technologies varies across socio-economic groups, and across regions. Despite a well-intentioned attempt to cater for the energy needs of rural India, and particularly the poor, the rural energy programme has not appeared to meet these needs on any meaningful scale, through insurmountable constraints associated with their very marginality, paradoxically. Limited success has occurred in this side of rural economy.

3.1.2 Although all the rural energy systems have evolved through a process of research and development, a critical test of their appropriateness, and ultimate usefulness, their application in the field, e.g. it is estimated that more than 3 million biogas plants are installed around the country though the potential of large-scale implementation of biogas technology remains unrealized. The use of electricity for cooking, which includes biogas, only accounted for about 2% and 3% for rural and urban areas respectively, and sharply demonstrates the continued minority status of such alternative fuels.

3.1.3 Popularization, use and adoption of rural energy technologies to comprehend the energy needs of the rural at a recognizable scale among others depend on factors like:

i) Resource availability

ii) Technical constraints related to adoption and use / application in the field

iii) Basic objective related to dissemination of technology and Method adopted for distribution / delivery of the technology

iv) Proper linkage of the technologies

v) Social behavior of the technology user

vi) Financial constraints with technology

vii) Policy and institutional constraints etc., to name a few

3.2 Basic Resource Availability with regard to Technology Deployment & Use / Application

3.2.1 Raw material, basic infrastructure and basic resource for deploying / operating the technology at an economic scale may not be available or is scarce or scarcity arises due to season, alternate uses etc. In such cases even the deployed technologies fails and become obsolete with due time as resource is sub-adequate and no actual efforts made for sustenance of the resource for running the technology.

3.2.2 For e.g. considerable technical, economic and social problems exist in the form that the biogas plants were mostly underfed with dung, by 30-50%. Although, in theory, there was enough cattle to provide the required amounts of dung, competing demands with non-beneficiaries were evident, who collected dung for fuel, in the absence of crop residues. Gas production was also found to fall to 30% of its rated production in winter months, due to greater direct use of dung, for fuel. Similarly, water scarcity or difficulty in obtaining water, e.g., from a distant source, may also impose further constraints on the viability of biogas technology in a rural environment. To function properly, a biogas plant requires feeding a mixture of cow-dung and water, in the ratio of 1:1 or 4:5, thus imposing a significantly higher daily water demand over domestic needs.

3.2.3 Considerable constraints may also exist in the provision of space and water that are likewise necessary for a biogas plant. The smallest 3 m^3 family size plant requires about 27 m^2 of land. When area for the plant and a compost pit for the slurry is taken into account, which in many circumstances may not be available. The characteristic clustering of houses in a village between networks of narrow lanes may render land enough around the homestead to accommodate a biogas plant as the exception, rather than the rule. Even if surplus land is available, issues of land tenure and ownership may prohibit the construction of a plant. Manpower in the form of skilled masonary workers for the establishment of the plant especially the foundation (knowledge of design is involved) is unavailable at the village level. This is accounted for by the lack of training of workers regarding the design of the systems and the basic knowledge involved in preliminary designs.

3.3 Technical Constraints in Adoption and Use

3.3.1 Technology barriers and constraints play a major role in the success of the energy technologies in rural areas. Failure of a technology at field occurs usually because of the improper designing, selection of design, technical problems associated with operation, maintenance, use etc.

3.3.2 For e.g. certain factors become evident with the failure of biogas plants and its implementation at the grass root level in villages:

- Problems associated to design: Looking at the key features of the Janata model, one of the two most famous models in our country with fixed-dome, in contrast to the floating dome of the KVIC model. The Janata system is about 30% cheaper to construct than a KVIC model of the same capacity with added advantages that there are no moving parts, making local construction possible and maintenance easy. But, savings may diminish with scale with this design, so Janata may be more appropriate for small-scale users. One disadvantage with the fixed-dome design is that gradual accumulation of sludge is likely within the system, making periodic cleaning necessary.

3.3.3 Similarly, the biogas programme was not able to cater to the needs of the poorest and marginalized, as these groups fail the technical requirements to maintain a viable plant. Technical parameters like alkalinity, temperature of operation at different feed levels, quantity of feed for optimum gas production, problems with choking of the inlet and outlet pipes, nature of methanogenic bacteria etc. paved the path for its unsuccessful operation in Indian villages. There are also other technical problems like the type of soil etc. which remain unaddressed and so only 70% plants succeeded of the total 27,000 established (as per a study done by MNES in 1993). Lack of technical expertise available: It is still very difficult to find a proper technical expertise in villages for rectification of a technical problem say related to transmission of current from a pv cell to the lighting system or a pump.

3.4 Problems with Dissemination

3.4.1 Rural energy technology is mostly disseminated in the rural areas because it is an efficient, simple to use and environment friendly technology option and therefore considered as suitable to the rural environment. Emphasis is for disseminating the technology (target oriented) and popularizing it, rather than a package of products and services actually in want by the rural community.

3.4.2 For e.g. promotion of improved chulhas or improved cook stoves is promoted in villages with the objective of providing healthy cooking option to the women and various targets are fixed for distribution in villages, however, no assessment need felt for the technologies and services at the local level. In this case objective is clearly popularization and distribution, the basic elements like awareness of the benefits of using improved chulhas to the village women, demonstration at house itself and the choice of demonstration sites for wider impact and greater reach were missing.

3.5 Method of Technology Distribution

3.5.1 Method usually adopted for distributing a particular energy technology at the village level is either through agencies like NGO's or state nodal agencies or through local authorities. Such agencies engage workers as basic manpower to distribute such technologies in villages. Motivation of workers employed in the task of dissemination and the level of their motivation to mobilize the community, repair, maintenance and user training were missing in the overall approach of the workers involved in the task. One obvious reason for the failure of solar cookers in India among all like high cost, technical difficulties etc. is because of the disinterest of the workers in spreading the technology on account of the low salary of the workers involved in this task.

3.6 Monetizing the Linkage of Technology

3.6.1 Linking energy to productive use and income generation is necessary. Usually while fixing the targets only the provision of minimum energy for lighting and cooking are addressed as they are limited by the availability of financial resources. Income generation should be linked to the basic approach for the wholesomeness of such programmes.

3.6.2 For e.g. deployment of biogas plants in villages suffered problems like availability of labour for establishing plants. Labour shortages were attributed to economic factors, such as low pay compared to agricultural labour.

3.7 Social Problems Associated with the use of Technology

3.7.1 In India social beliefs are so strong that it affects adversely the successful deployment / development of the technologies in the villages. For e.g. in the case of biogas plant deployment in villages social factors were also evident in the non-availability of labour, particularly the stigma associated with working with dung; considered as a low-caste task, and usually performed by women.

3.8 Association of Women & Gender Dimensioning

3.8.1 User of biomass needs to be targeted. For e.g. to deploy rural biogas and improved chulha the target should be the ultimate user that is women. However, most such activities in the past have taken for granted that farmer essentially means men and meetings in panchayats, blocks only restrict to involvement of male, which keeps the prospective user (women) away from the programme leading to failure.

3.9 Financial Constraints Related to Technology

3.9.1 Rural energy technology is too costly for the villagers to afford even after being largely subsidized by the government. There occurs problems in getting loans and micro-credit financing or the initial cost of deployment / establishment other than technology / product (for e.g. structure for establishing), is very high or there may be lack of awareness about the incentives / subsidies on energy products among the villagers.

3.9.2 For e.g. the cost of infrastructure for establishing a biogas plant is still quite high. It is quite difficult for a poor villager to establish even a small capacity plant. Even if he wants to establish the plant he has to look at other aspects like availability of enough cattle, enough water etc.

3.9.3 Cost of solar cooker is still high even after subsidies. A solar cooker with cost of Rs. 6,000/- (distributed by NEDA) after subsidy will be difficult to buy. Other thing is that if the reflecting glass brokes, there is no mechanism by which a villager can get component funding.

3.10 Policy and Institutional Constraints

3.10.1 There is lack of funds and R&D infrastructure support for the refinement of already developed technology. Once the technology is developed and product made concerns are diverted towards its distribution in rural areas. Whether or not the technology is properly working in the field and what are the possibilities of refining the technology and making it more cost-effective and efficient, is very rare. For e.g. solar cooker is a very known technology from the very early, yet efforts for increasing its efficiency or decreasing cost are limited as it is taken for granted that solar cooker is an article of subsidy. Same age old cookers are still been sold at the village level. Similarly, institutional infrastructure and dedicated institutes working for R &D in rural energy sector are still missing. Same is with biogas plants which still suffer from problems like low efficiency of gas production (30%) or incomplete digestion.

Section – IV

Combustion Research Initiative

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4.1 Introduction

4.1.1 92 percent of India's energy use involves some form of combustion or other. Yet even today, our understanding of combustion processes is limited and with it our ability to effectively control and manage combustion processes (used everywhere from power generating plant, railways, automobiles and aircraft) in a manner that maximises efficiency (energy conservation) and at the same time reduces environmental impact.

4.1.2 Efficient combustion is key to both fuel economy and emissions. In this proposal, we will focus on critical research and development needed in combustion, covering applications in the automotive and aerospace sectors, where liquid / gaseous fuel combustion is involved.

4.1.3 Today, Indian vehicle manufacturers depend on laboratories abroad for combustion studies that are essential for developing new engines. This is both expensive and not suited enough for iterative technology development process. If the Indian companies are to design and develop power trains, a truly world-class combustion center is needed in India.

4.1.4 New automobile engine technologies such as high pressure Common Rail Direct Injection (CRDI), Gasoline Direct Injection (GDI), Homogeneous Charge Compression Ignition (HCCI), low NO_x combustion etc., are quite complex and would need sophisticated combustion diagnostic techniques to validate engine fluid dynamic and combustion models.

4.1.5 Gas turbine combustors are likewise key in several sectors including power generation and aerospace. Here too, the demand for better fuel efficiency coupled with cleaner emissions will be critically needed for future industry competitiveness. While gas turbine engine development is going on in small pockets in India, to prepare for the next decade, considerable focus and investment will be necessary.

4.1.6 Instrumentation is required for highly accurate measurement of flow velocity, droplet / particle sizing and spectroscopic measurements for temperature and species concentrations, etc. Such equipments are now commercially available.

4.1.7 In view of this, it is recommended that a ***Combustion Research Institute*** be set-up in India during the 11th Plan period. The Institute must have state-of-the-art research facilities for studying the complex modern engine combustion systems, including -

- Competency in computational fluid dynamics and combustion modeling. There is some capability in the country in this respect.
- Lasers and diagnostic techniques for non-intrusive, in-situ and spatially and temporally precise measurements at fast pace; these measurements are essential for validation of in-cylinder computational results produced through CFD analysis of the engine combustion system. Both the facilities and expertise in diagnostics are lacking in India due to their cost intensive nature.

4.1.8 The Institute must have upstream and downstream interfaces with R&D institutions engaged in fuel research and automobile manufacturers. Ideally, the Institute must engage in serious research and it could grow rapidly to a critical mass of say 100 research scientists in 3-5 years time. The balance between basic and application research at the center will depend on whether the center is located as part of an existing laboratory or is developed as an independent institution.

4.2 Objectives

4.2.1 To provide state-of-the-art experimental and modeling facilities in combustion research for frontier research in the area of engine combustion and gas turbine combustors.

4.2.2 To undertake project based investigations for research and development work for automotive industry and aerospace industry (for gas turbine combustor applications), and other users.

4.2.3 To train manpower in the area of combustion science and technology.

4.3 Scope

4.3.1 The Institute may develop capabilities and train research manpower in combustion diagnostics and modeling to optimize:

- Intake / Exhaust Manifold System
- In-cylinder flow
- Gas turbine combustors
- Combustion Chamber
- Fuel Injection System
- Port Injection
- Spray Characteristics
- NO Formation
- Particulate Matter
- Fuel Economy

4.4 State-of-the-Art

4.4.1 A brief review of some of the state-of-the-art technique used in researching Internal Combustion Engines (ICE) are as below:

A **In-cylinder/Combustor Flow Diagnostics:** Typical equipment required would be a Particle-Image Velocimetry (PIV) system, which would include a double-pulsed Nd: YAG laser, a cross-correlation camera, optics and hardware such as seeder. In addition, a high-speed PIV system would include:

- Double Pulsed Nd: YLF Laser with a 1-2 kHz pulse repetition rate

- High Speed Double Shutter Camera
- Related Software

B **Fuel Spray Diagnostics:** Typical equipment would include a Phase Doppler Analyzer (PDA) system which can simultaneously obtain droplet size and velocity information.

C **In-cylinder/Combustor Imaging and Photography:** In-cylinder processes such as fuel injection, or flame propagation need to be studied to locate zones of fuel impingement on walls, fuel transport, flame initiation and propagation for knock detection. To carryout these studies, the optical access and high-speed image acquisition facilities are needed. For optical access, fiber-optic based sensors embedded in spark plugs, or endoscope-based systems for transmitting the laser light into the actual firing engine are used. User-specific optical engines with pre-designed optical access can also be procured. For high-speed image acquisition, a high-speed camera with frame rates approaching one million frames per second is required. Some commercial systems are available; however, specific research issues will require tailor-made experiments.

- Reaction Zone Mapping.
- Planar Laser Induced Florescence (PLIF) for instantaneous & simultaneous OH and CH_2O measurement.

D **Combustion Species Visualization:** Typical species of interest include fuel, OH and NO. In-cylinder visualization of fuel is of interest since this directly provides information on fuel-air mixing prior to combustion. Imaging of OH-species which are highly reactive species produced during combustion is considered important. Planar Laser Induced Fluorescence (PLIF) imaging of OH is useful in combustion studies. However, very good qualitative information can be obtained by carefully designed experiments. Typical equipments will include Nd: YAG lasers, dye lasers, intensified CCD cameras, shaft encoders, and associated electronics and optics.

E **Temperature Measurement:** Since it is very difficult to make intrusive temperature measurements inside engines, optical diagnostics offers a good alternative wherein a complete two-dimensional temperature field can be obtained. Typical techniques involve planar, instantaneous two-line PLIF Thermometry using Nd: YAG and dye lasers and ICCD Cameras. Other techniques include time resolved point wise temperature measurement by Rayleigh scattering and major species measurement by Raman scattering using Argon ion laser.

4.5 Soot Measurement: Additional Research Areas

i) Optimization of injection process

ii) Determination of ignition angle and ignition delay

iii) Fuel consumption optimization

iv) Emission reduction (NO_x, HC, Soot etc.)

v) Engine Mapping

vi) Assessment of combustion noise

vii) Rotary oscillation / forsinal Vibration analysis

viii) Knock analysis (Evaluation, monitoring etc.)

4.6 Management Structure

4.6.1 This proposal envisages to evolve a fully autonomous well structured central organization where the host and visiting scientists would work together in the project mode. The Governing Council may have representation from user industries, research institutions, Defence and Space organizations. In the beginning, it may be worthwhile to strengthen existing research groups (*IIT Chennai, IISc Bangalore and IIT Kanpur*) and bring them into a consortium mode project.

4.6.2 At IISc Bangalore, a basic flow visualization setup is being developed. The current facility includes a pulsed, high-powered Nd: YAG laser with the second and fourth harmonic frequencies to give visible and ultra-violet laser light. An intensified CCD camera and a high-speed camera are also available. A portion of the inlet manifold of a four-stroke engine has been made from a transparent material in order to allow for optical access. The objective of the study is to investigate the fuel-air two-phase flow in the inlet manifold of carbureted engines and also engines with PFI. Techniques such as planar Mie-scattering, PLIF and PIV will be used in this study. The overall goal is to explore strategies for cold start emission control in engines.

4.6.3 The combustion and flow diagnostics facilities at IIT Madras include:

- Phase-Doppler Particle Analyzer (PDPAV) Laser Doppler Velocimetry (LDV)
- Planar Spray Measurements
- Particle Image Velocimetry (PIV)
- Stereo-PIV
- Planar Laser-Induced Fluorescence (PLIF)
- High-Speed Flame Chemiluminiscence Imaging and Image / Signal Processing

4.6.4 A core team of scientists could be selected including from among the following:

- Prof. Pramod S Mehta, IIT Madras
- Dr. R.V. Ravikrishna, IISc, Bangalore
- Dr. B.N. Raghunandan, IISc, Bangalore
- Dr. R.I. Sujith, IIT Madras
- Dr. S.R. Chakravarthy, IIT Madras
- Dr. Abhijit Kushari, IIT Kanpur
- Dr. Anjan Ray, IIT Delhi

- Dr Amitava Datta, Jadavpur University
- Dr. V. Ramanujachari, DRDL, Hyderabad

4.6.5 The scientists from Automotive Industry, Defence Research Institutions, ARAI, CIRT and others could also be invited.

4.7 Project Implementation Plan

4.7.1 **Phase 1/ year 2007:** The Office of the Principal Scientific Adviser to the Government of India may like to initiate a consortium project at an estimated cost of Rs.50 crores to:

- build a critical mass of scientific equipment and manpower resources at the existing centers of research (*IIT Chennai, IISc Bangalore and IIT Kanpur*), and
- Prepare a detailed project implementation plan for setting-up the Institute, including interaction / study of the Sandia Labs, in USA and the University of Aachen, Germany.

4.7.2 **Phase 2/ 2007 to 2010**: The Planning Commission may like to consider appropriate scale of investment to set-up a national laboratory of regional and global levels of competency. The institute will require significant private sector participation. The relevant model could be that of Combustion Research Facility of Sandia Laboratory, USA. Estimated cost: Rs.200.00 crores ***(break-up given in the table on the following page)***.

S.No.		Items	Rs.(Crores)
I.	**Instrumentation**		
1.	Velocity Measurement	High Speed PIV-Stationary	5.00
		High Speed PIV-Portable	5.00
2.	Spray Diagnostics (Droplet size and velocity)	3 component LDV / PDPA	6.00
3.	Temperature measurement	Two-line PLIF Anemometry	4.00
4.	Time resolved temperature	Rayleigh Scattering	2.00
5.	Fuel-Air Mixing	Acetone PLIF-Stationary	3.00
		Acetone PLIF-Portable	5.00
6.	Reacting Zone Imaging	PLIF	2.00
7.	Major Species Measurement	Raman Scattering	3.00
8.	Soot Measurements	LII	2.00
9.	Particulate Measurement		3.00
10.	Engine Pressure and Emissions Measurement Systems		2.00
11.	Flow and other auxiliary measurement devices		3.00
12.	Engine dynamometer		5.00
13.	Data Acquisition System		5.00
14.	Image and Data Processing Software		5.00
II.	**Test Centre**		
1.	Optical Research Engine and accessories		10.00
2.	Research gas turbine combustor with feed system		10.00
3.	Auxiliary systems for operation of test unit		10.00
4.	Building (2 Acres of Land) & Conditioning Equipment		20.00
III.	**Computational Facilities including CFD codes**		20.00
IV.	**Training & Administration**		20.00
V.	**Maintenance and Recurring expenditure for 5 years @ Rs.10 crore per year**		50.00
	Grand Total		**200.00**

Section – V

Energy R&D
in the Indian Railways

Authors:

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5.1 About Indian Railways & RDSO

5.1.1 Railways were introduced in India, in the year 1853 and several state as well as privately owned railway systems grew as it expanded its presence and scope through the twentieth century. In order to enforce standardization and co-ordination amongst various railway systems, the Indian Railway Conference Association (IRCA) was set up in 1903 which was followed by the Central Standards Office (CSO) in 1930, for preparation of designs, standards and specifications. However, till independence, most of the designs and manufacture of railway equipments was entrusted to foreign consultants. After independence with the resultant growth in country's industrial and economic activities which lead to phenomenal increase in the demand for rail transportation, there was a significant shift in emphasis in the area of design & manufacture. A new organization called Railway Testing and Research Centre (RTRC) was set-up in 1952 for testing and conducting indigenous applied research in railway technology. Later, CSO and the RTRC were merged into a single unit called Research Designs and Standards Organization (RDSO) came into being on 7th March 1957, as an attached office of Railway Board. The status of RDSO has been changed from an 'Attached Office' to 'Zonal Railway' with effect from 1st January 2003.

5.1.2 RDSO is the sole R&D organization of Indian Railways and functions as the technical advisor to Railway Board, Zonal Railways and Production Units. Basically, its major functions involve:

- Development of new and improved designs.
- Development, adoption, absorption of new technology for use on Indian Railways.
- Development of standards for materials and products specially needed by Indian Railways.
- Technical investigation, statutory clearances, testing and providing consultancy services.
- Inspections of critical and safety items of rolling stock, locomotives, signaling & telecommunication equipment and track components.

5.1.3 RDSO also offers international consultancy services in matters pertaining to design, testing and inspection of railway equipments as well as survey for construction of new lines. RDSO is now an ISO: 9001-2000 certified organization.

5.1.4 The total expenditure for the year 2004-2005 was Rs. 79.30 crores. (Rs. 65.74 crores under revenue and Rs. 13.56 crores under plan head).

5.2 Energy R&D at RDSO

5.2.1 Implementation of CNG on Diesel Electric Multiple Units (DEMUs) and Diesel Locos

Operation of DEMUs on CNG was taken up with a view to reduce running cost and also improve emissions. After studying the technical details, RDSO communicated clearance for carrying out modifications on 1400 HP DEMUs to convert to dual fuel mode. Preliminary trials have been done.

5.2.2 Development of 6000 hp Locomotive

Based on RDSO report, Railway Board communicated its consent for development of a 6000 HP AC-AC locomotive. A draft specification has been prepared keeping in view the proposed dedicated Freight Corridor between Delhi-Howrah and Delhi-Mumbai and sent to Railway Board.

5.2.3 Development of 1600 hp AC/AC DEMUs

Development of BG 1600 hp AC-AC DEMU was undertaken to provide faster passenger service for urban traffic with increased carrying capacity. Specification finalized and issued to Railway Board.

5.2.4 Locotrol

Considering limitations of coupler capacity, the requirement for a remote control system for locomotive through a wireless link was projected for controlling locomotives. Locotrol provides enormous benefits in the operations on long stretches of steep gradients. It is essential for mountainous terrains, and also for hauling heavy loads. Separate specifications for ALCO locomotives and EMD locomotives have been finalized.

5.2.5 Use of HSD-CNG Blends

i) World wide CNG is being used increasingly in transport sector in place of conventional diesel fuel as it is a low cost, environment friendly fuel and available in abundance as compared to conventional fuel. Keeping in view the above factors in India, CNG has been used for the first time by Government of Delhi in Delhi Transport Corporation buses, TSRs, Tempos, and other transport means. The results of its use was quite encouraging as the pollution contaminants viz. NO_x, SO_2, gaseous matters and other particulate matters level was brought down considerably in and around Delhi atmosphere.

ii) In Indian Railways Diesel Shed / SSB of Northern Railway (NR) pioneered the prestigious project of operating DEMU and MAK Engine WDS4 on dual-fuel mode (CNG+HSD). After feasibility study of the project, the technical report was made along with M/s. Cummins in July 2004, which was cleared by RDSO for trial purpose Clearances was also obtained from Chief controller of explosives Nagpur. In DPC No. 19002 work of conversion of its engine into dual fuel mode started in November 2004. Minor structural changes were made and CNG Cylinders cascade and other required parts of CNG-Kit were provided. This DPC was successfully operated on dual fuel and load simulations were conducted at in-house made load-box. The line trial was conducted on 23.4.2005 successfully for the first time and after several line trials RDSO gave its clearance on 10.08.2005. Shortly it is to be introduced in regular passenger services.

iii) In a dual-fuel engine, CNG shall replace 50% of diesel thereby reducing operating costs by 30%. Savings of the order Rs. 24 Lakhs is expected per DEMU per annum if engine runs 400 Hours per month. Moreover, CNG burns cleaner than diesel and leaves no particulate matter. This will result in reduced smog effect and will provide a cleaner atmosphere.

5.2.6 Implementation of Bio Diesel on Indian Railways (IR)

i) Evaluation of the performance of bio–diesel blends on DLW engine. Following is observed:

- Reduced emissions,
- Energy security,
- Conservation of foreign exchange; and
- Potential to offer rural employment.

ii) Infrastructure for storing the fuel has been created at Alambagh Shed, Lucknow. NR is processing for procurement of blend bio-diesel. Detailed activities on bio-diesel are as follows:

a) Preliminary Test Bed Evaluation: Preliminary testing of bio-diesel on 3100 hp diesel engines as an alternate fuel was carried out in RDSO in November 2002. This testing was constrained owing to a limited availability of bio-diesel. Bio diesel blends of 5, 10 and 20% were tested. It was observed that the engine was able to maintain full power output with the bio-diesel blends. The specific fuel consumption had deteriorated slightly.

b) Trial on Shatabdi Express: The first successful field trial run was conducted on December 31st, 2002, on TKD based loco no. 14008 WDM2C to haul the prestigious New Delhi to Amritsar Shatabdhi Express using 5% blend of Bio-Diesel. It was inaugurated by Honorable Railway Minister, Shri Nitish Kumar and Railway Board Member (Mechanical), Shri S. Chasarathy. The observations are summarized below:-

- No unusual deposits noticed on the filter surfaces.
- The fuel injection pumps and injector nozzles were found satisfactory and free of gum deposits.
- During the trip, SFC was observed to be 4.56 liters per 100 GTKM.
- No adverse effect was noticed on any loco components on the trial.

c) Signing of MOU Between IR & Indian Oil Corporation Ltd. (IOC): IOC and IR signed an MOU on 12-2-03 for plantation of Jatropha Curcas for which IR offered plantation sites in Rajkot and Bhavnagar Divisions. Two locations - one near Surendra Nagar and another at Than Chotila were selected. The total available land at these two locations is 80.9 Hectares out of which initially 70 Hectares was estimated as cultivable due to presence of buildings and other civil structures at these sites. IOC issued work order for site preparation and plantation on 31-01-04 but the work front available was only 30 Hectares as against the initial estimate of 70 Hectares. In Surendra Nagar, about 4 Hectares of land remains marooned making it unfit for any cultivation activity. IOC has taken-up the matter with the municipal committee. The matter is still pending with the local administration. At Thane Chotila out of 57 Hectares of land initially identified for Jatropha plantation practically on site only 21 Hectares of land is available. Approximately, a stretch of 2 km of land is in the physical possession of a local farmer whereas the remaining land is mostly covered by the garbage / waste disposal of the local industries. IOC has already identified 30-35 Hectares of land in the district of Rajkot and 40 Hectares of land in Joravarnagar-Sayala section for the Jatropha plantation and has asked the Sr.D.E.N / Rajkot (HQ) to handover one of these plots to start cultivation.

IOC has already completed plantation of 1,10,000 saplings out of a target total of 1,75,000 saplings. Further Plantation of Jatropha Curcas saplings is in progress.

d) **Testing of Bio-Diesel on 16-Cyl Power Pack in ED-Directorate:** Detailed testing and evaluation of Bio-Diesel was conducted during April-May 2004 at RDSO on the 3100 hp Diesel engine test bed. Five kiloliters of Bio-Diesel was made available to RDSO by IOC with an objective to carry-out the detailed performance evaluation as well as optimization of 10%, 20%, 50% and 100% blends of Bio-Diesel. The results of the testing were encouraging and showed the tremendous potential of Bio-Diesel as a future fuel for Indian Railways.

e) **Field Trial of Bio-Diesel Blended Fuel (B-10) On Jan Shatabdhi (Lucknow-Allahabad):** After encouraging results of test bed evaluation, Bio-Diesel (B-10 blend) was used to haul Jan-Shatabdi express between Lucknow and Allahabad. Three successful round trips were carried-out (a distance of 202 Kms one way). The locomotive developed the required power and did not loose on time, which was a significant forward step in the direction of trial of bio-fuels on locomotives.

f) **Work Done by Southern Railways:**

- Southern Railway on its own part planted about 2 lakh Jatropha and Pungam (Karanj) plants on their vacant land and also erected and commissioned a small plant for the extraction and transesterification of Jatropha oil (capacity only 5 litres a day) at Loco Works Perambur, which of course though miniscule in its capacity is a good beginning and will educate the masses about the development and contribute to the level of awareness. Their plant can also handle discarded used cooking oil.

- Based on the success of this lab-scale plant, the Railway Board advised GM / S. Rly, to initiate action to set-up an esterification plant to convert raw Jatropha oil into FAME (fatty acid methyl ester) as no transesterification plant is hitherto available commercially in the market.

- Southern Railway, with the in-house efforts, erected an esterification plant at LW / PER to produce Bio-Diesel from raw Jatropha with a capacity of 150 litres per day. This small plant has already yielded approximately 15898 litres of Bio-Diesel up to Feb 2005. The design and fabrication of the process equipments, chemical processing technology and recovery of various by-products etc were entirely carried out in-house at LW / PER. Initially, Southern Railway tried this Bio-Diesel at different levels of blends varying from 20% to 100% on road vehicles. The details of the vehicles on which Bio-Diesel was tried is as follows:

Tata Sumo	100% Bio-Diesel
Voyager	20% Bio-Diesel
Jeep	100% de-gummed pungam oil
Jeep	20% de-gummed pungam oil

The performance of all of four vehicles was found to be satisfactory.

- Encouraged by this successful effort this fuel was tried on YDM 4 loco at 5% level of blending. The performance of YDM 4 with Bio-Diesel is being monitored by Sr.D.M.E/ Diesel/GOC and satisfactory results have been observed till now.
- Some prestigious firms like TAFE (Tractors and Farm Equipment – Chennai) and M/S. Cummins have come forward to place work order on Southern Railways for the supply of Bio-Diesel for evaluation of this fuel on their prime movers i.e. tractor engines and 700HP Diesel Electric Multiple Units.
- A plant for producing 300 litres of Bio-Diesel per day from the raw oil has been approved in M&P item at a cost of Rs. 7.5 Lakhs under G.M's power and the installation is in progress.
- Southern Railways has placed a purchase order for procurement of 92000 Kg of Jatropha / Pungam seeds at a total cost of Rs. 30.17 lakhs under fuel budget to ensure ready basic raw material.

g) Work Done by South Eastern Railways:

- South Eastern Railway has done a commendable job in the direction of promoting Bio-diesel. Jatropha Curcas has been planted systematically on a large scale. Out of a total of 4.21 lakhs of saplings planted about 3.80 lakh survived.
- For the current year 7 lakh samplings have been planned. About 4 lakh saplings are ready in the divisions's nursery. South Eastern Railway has adopted a scientific approach by raising saplings in controlled and treated environment to ensure maximum survival rate and healthier plants.
- A tender has been opened for setting-up a production plant for 2000 litres of Bio-Diesel per day on a turnkey basis. The production plant is integrated to oil extraction unit. The tender has received a good response and as many as five bidders have participated.
- Kharagpur division has the distinction of running the first ever train on Bio-Diesel in South Eastern Railway. Train no. 461 (Khragpur-Jaipur) was flagged by Shri Basudev Acharya, Chairman Railway. Standing Committee on 29-06-05. The other two trains run on this fuel are 203/204 (Charagpur-Bhubhaneshwar) and 8027/8028 (Shalimar-Dhigha).

5.3 Future Energy Action Plan for Indian Railways

5.3.1 The concept of use of CNG & its blends with HSD can be further extended to the WDM-2 class of locos, power cars, DG sets etc. bringing enormous economic benefit to the railways and environmental benefit to the country. By switching over to CNG as an alternate fuel, Railways will be contributing significantly to the national energy pool.

5.3.2 Railways in the transportation sector are a major user of energy in India. Railways are reported to be using as much as 5% of the total diesel oil consumption within the country. Railways are also using near about 1.5% of the electrical energy consumed in India. So there exists a need to concentrate efforts on use of hydrogen and fuel cells as alternate energy sources. Few potential application areas are as follows:

a) Stationary Applications

- Supplement power source in Production Units
- Supplement power source in Workshops

b) Non-Stationary Applications

- Passenger coaches – Lighting and fans
- Air–conditioned coaches
- Power for Diesel-Electric Multiple Units
- Power source for shunting engines operating in metros

5.3.3 It is suggested that to begin with stationary applications may be considered. An ideal choice would be Diesel Locomotive Works. At DLW power for specific applications, can be generated using fuel cells. It is proposed to install a solid oxide fuel cell or a phosphoric acid fuel of 250–500 KW capacity for generating power at DLW.

5.3.4 Subsequently a project can be undertaken for developing fuel cell powered vehicles like DEMU or even shunting locomotives.

5.3.5 **5000 hp diesel electric locomotive:** Keeping in view the need for high horsepower locomotives for hauling heavier trailing loads and based on Railway Board's proposal, it is proposed to develop a 5000 hp loco under TOT with EMD.

5.4 Pilot Project Proposals:

5.4.1 Life Cycle assessment of biodiesel for utilization as a transport fuel for the diesel locomotives of Indian Railways ***(proposal endorsed by the Working Group, for funding by the Indian Railways)*****.**

i) Biodiesel is a domestically produced renewable fuel that can be manufactured from vegetable oils, or recycled restaurant oils. Biodiesel is safe, biodegradable, and reduces serious air pollutants such as particulates, carbon monoxide, hydrocarbons, sulphates etc. Blends of 20% biodiesel can be used in unmodified diesel engines. Biodiesel can also be used in its pure form (B100), but it too may require certain engine modifications to avoid maintenance and performance problems. Use of biofuels including biodiesel is a key area for the Indian Government and the Planning Commission.

ii) Utilization of biodiesel is a mission area for Indian Railways. Indian Railways is in a unique position for advancing the use of biodiesel because it can be the producer and consumer of biodiesel. Indian Railways has about 5000 diesel locomotives which consume about 2 billion litres of diesel fuel per anum. Although this consumption is only 4% of the total consumption of diesel fuel in India, even partial replacement of this 4% by a renewable fuel like biodiesel leads to saving of foreign exchange for India as also generate opportunities for the Indian agricultural sector as well as the Indian industry.

iii) As part of the project to enhance use of biodiesel on Indian Railways, Research Designs and Standards Organization the R&D wing of the Ministry of Railways proposes to initiate a project on biodiesel which shall include the vertical integration of all activities form well to wheel. These activities shall include: -

- Earmarking of surplus Railway land for growing of oil crops like Jatropha (~700 Ha).
- Undertaking the plantation of oil crops on this land.
- Producing oil seeds through the above crops.
- Collection of surplus oil seeds from the Forest department through assistance by the State Government.
- Setting-up a 400 mt/ year transesterification plant in RDSO with the following components:
  a. Shelling machines for the seeds
  b. Oil expellers with solvent extraction technique
  c. Oil refining plant
  d. Heterogeneous catalyst based transesterification plant
  e. Facility for post treatment of the biodiesel including additive addition so that the biodiesel is able to meet the IS: 15607(2005) standards.
  f. Testing facilities for biodiesel
  g. Blending facilities for biodiesel
  h. Transportation facilities for biodiesel
  i. Storage facilities at Alambagh diesel shed, the diesel locomotives of this shed shall be nominated to run on the biodiesel and its blends
- Engine test facilities including the following: -
  a. Engine simulation software
  b. Single cylinder engine test rig along with dynamometer
  c. Test commander for the single cylinder test rig
  d. Tribological studies facilities

e. High speed data acquisition system

f. Instrumentation to capture various low and high speed data

g. Emissions test car to monitor the emission characteristics of locomotives operating on biodiesel and its blends.

h. Experimental facilities for developing new compatible materials for biodiesel and its blends.

- Setting up of auxiliary systems like: -

a. Heat exchangers of adequate capacity

b. Cooling towers

c. Power back-ups

- Suitable state-of-the-art data acquisition system for field monitoring of the biodiesel run locomotives. The objective of the above pilot project shall be to:-

a) To establish the technical feasibility of running diesel locomotives on biodiesel.

b) To establish the well to wheel costs for production and use of biodiesel.

c) To study the environmental aspects of use of biodiesel.

d) To modify / develop appropriate engine test rigs.

e) To develop a successful IIP(Industry Institute partnership) model by entering into MOUs with academic institutions like IITs / IISc for the development and use of biodiesel as a fuel for diesel locomotives of Indian Railways.

iv) Duration of the project shall be for five years.

v) The cost elements of the above project shall be as follows: -

Sr.No	Element	Cost (in Rs. Crore)
1.	Cost of leveling and land development	5
2.	Cost of approach roads	5
3.	Cost of Fencing	10
4.	Cost of plantation	5
5.	Cost of farm maintenance and cultivation facilities	1
6.	Cost of seeds collection and transportation facilities	1
7.	Cost of seeds cortication facilities	1
8.	Cost of oil expelling facilities	1
9.	Cost of oil purchases facilities	0.5
10.	Cost of transesterification and refining facilities	25

Sr.No	Element	Cost (in Rs. Crore)
11.	Cost of storage and handling facilites	2
12.	Cost of blending and post treatment facilites	5
13.	Cost of transportation facilities	3
14.	Cost of manpower employed for the above facilities including consultants if any	10
15.	Cost of Auxilliary facilities	20
16.	Cost of Data acquisition, monitoring systems and test rigs	10
	TOTAL	**114.5**

vi) After successful completion of the project, the developed economic and technological model shall be available for wide scale implementation. Similar model can then be developed for other renewable fuels. The data and reports generated during the project shall be available for use by other agencies and the Planning Commission.

5.4.2 Technological Upgradation of Engine Design and Testing Capabilities *(the Working Group recognized the fact that the RDSO needs to be upgraded)*.

i) There is need for continuous upgradation of our capabilities for design and testing of diesel engines. RDSO can take-up this task in collaboration with identified academic and research institutions. The objective will be fast ferry and frigate propulsion with regard to (a) mass/power ratio, (b) operating torque envelope, (c) overall dimensions, (d) fuel consumption and (e) smoke particularly in partial load operation. Improved designs should also incorporate (i) simple design and easy access for maintenance, (ii) high reliability in service (iii) low operating costs (iv) extended maintenance intervals, (v) low exhaust and noise emission.

ii) Engine development would address problems like

- design of better suspensions
- improved bearings
- Development and Evaluation of Gas Inlet Casing
- Testing of Indigenously Developed Components
- Refining the Design of Indigenous Manufacture of Steel Cap Pistons
- Design Improvement in Steel Cap Pistons
- Development of High Efficiency
- Indigenously Developed Test Stand
- Testing of Injector Nozzles for Mechanical Fuel Injection Pump
- Switchover to Double Helix Fuel Injection
- Pumps for Diesel Locomotives

- Evaluation of Lubricating Oil
- Additives & Fuel Saving Devices
- Review of Drawings of Various Components of existing engines

iii) Engine test facilities including the following: -

a. Engine simulation software

b. Single cylinder engine test rig along with dynamometer

c. Test commander for the single cylinder test rig

d. Tribological studies facilities

e. High speed data acquisition system

f. Instrumentation to capture various low and high speed data

iv) Additionally it is also proposed to carry-out research on diagnostics for diesel and electric locomotives through a microprocessor based control system. This will include development of appropriate instrumentation and signal processing strategy for various equipments which form part of the transmission and also for other auxiliary machines on board the locomotives. This will enable real time monitoring of vital locomotive equipments like prime mover, rotating machines, traction motor suspension bearings, axle bearings, radiator drive, compressor, transformer, tap changer, pantograph, etc. on electric/diesel locomotives. It is proposed to build a microprocessor based control system as a fault diagnostics aid. The processor will also have data storage facility for future references. The processor will involve development of appropriate instrumentation system and signal processing strategies for fault identification in the locomotive. It will also have self-diagnostic features. Typical problems in diesel locomotive and electric locomotive rotating machinery include Unbalance, Misalignment, Bending resonance, Oil Film Whirl, Cocked rotor, Shaft distortion, Mechanical looseness, Rotor rub, Gearbox defects, Asymmetric shaft etc. Diagnostic Systems will include On-line data-acquisition and display over multiple-channels simultaneously, Frequency analysis and Real-Time FFT display, RMS value computation, On-line trending analysis, On-screen trend display, data storage with date-time information, safe, tolerable and alarm limits for all channels, Automatic visual and audio alarm in case of limit crossing, Algorithmic diagnosis scheme and Communication from rolling stock to the central control.

v) The cost elements of the above project shall be as follows:

Sr.No.	Element	Cost (in Rs. Crore)
1.	Test rigs	50.00
2.	Design Softwares	5.00
3.	Data acquisition & monitoring systems	20.00
4.	Embedded System Development	30.00
	TOTAL	105.00

5.4.3 Setting-up of Single Cylinder Research facilities in the Engine Development Directorate at RDSO for Collaborative research programme between Indian Oil Corporation Limited and Indian Railways *(provision for funding this project made by the Working Group in this report).*

i) Engine Development Directorate under Research Designs & Standards Organization (RDSO) of Indian Railways has been engaged in conducting research on large bore engines used for rail traction and high capacity DG sets. The directorate has been carrying-out research on ALCO DLW / Bombardier design 4 stroke, 16-V, 12-V, 6-I and ElectroMotive Diesels design 2 stroke 16-V engine on its four engine test beds.

ii) With a view conduct research on development of alternative fuels like biodiesel, CNG etc., evaluation of new designs of lube oils, low Sulphur ppm HSD and development of emission compliant engines and locomotives, it is required to set-up single cylinder research facilities in the directorate. Two such single cylinder research engines would be set-up with required instrumentation.

iii) The details about the single cylinder research engines and the instrumentation etc. are given below: -

A) ALCO 251 Engine single cylinder research engine

1. Test Room
2. Motored Dynamometer with all Accessories
3. Test Bed Mechanical Systems
4. Coolant Conditioning System
5. Exhaust Back Pressure Adjustment System
6. Oil Conditioning System
7. Combustion Air Conditioning System
8. Air Consumption Mass Measurement
9. Single Cylinder Engine – Mass Balanced to Second Order
10. Test Bed Automation Sytem
11. Conrol and Simulation System
12. Data Post Processing System
13. System Cabinet and Cable Boom
14. Temperature Measurement Instrumentation
15. Pressure Measurement Instrumentation
16. Cylinder Pressure Measurement
17. Cylinder Optical Measurement System
18. Humidity Measurement

19. Fuel Consumption Measuring System
20. Blow by Meter
21. Opacimeter
22. Data Indicating and Recorder Equipment
23. Uncooled Pressure Transducers
24. MICROFEMs
25. Angle Encoder
26. Canbuscard and Software
27. TDC-Measurement Equipment
28. Commissioning and Training
29. Suitable Documentation
30. Non Regulated Pollutants Measuring Equipment
31. Engine Simulation Software and Hardware
32. Emission Measurement Equipment

B) EMD 710 G3B engine single cylinder research engine

1. Test Room
2. Motored Dynamometer with all Accessories
3. Test Bed Mechanical Systems
4. Coolant Conditioning System
5. Exhaust Back Pressure Adjustment System
6. Oil Conditioning System
7. Combustion Air Conditioning System
8. Air Consumption Mass Measurement
9. Single Cylinder Engine – Mass Balanced to Second Order
10. Test Bed Automation System
11. Conrol and Simulation System
12. Data Post Processing System
13. System Cabinet and Cable Boom
14. Temperature Measurement Instrumentation
15. Pressure Measurement Instrumentation
16. Cylinder Pressure Measurement

17. Cylinder Optical Measurement System
18. Humidity Measurement
19. Fuel Consumption Measuring System
20. Blow by Meter
21. Opacimeter
22. Data Indicating and Recorder Equipment
23. Uncooled Pressure Transducers
24. Microfems
25. Angle Encoder
26. Canbuscard and Software
27. TDC-Measurement Equipment
28. Commissioning and Training
29. Suitable Documentation
30. Non Regulated Pollutants Measuring Equipment

Some of the facilities shall be shared by both the research engines

iv) Approximate cost of the two single cylinder research engines with the scope as given above is approximately Rs 45.00 crores. The project will be take-up jointly by the RDSO and the IOC R&D.

v) The list of research activities planned to be taken up jointly by RDSO and IOC R&D are: -

a. Combustion Simulation
b. Thermodynamic Simulation
c. Fuel Injection Simulation
d. Engine Dynamics Simulation
e. Combustion Analyses
f. Pollutant Formation Analyses
g. Evaluation of Alternative Fuels like Biodiesel
h. Emission Measurements
i. Emission Reduction Strategies
j. Engine Optimization for Alternative Fuels
k. Engine Upgradation for Higher Horsepower and Lower Fuel Consumption
l. Tribological Studies

Section – VI

Hydrogen as A Source of Clean Energy

Author:

Office of the Principal Scientific Adviser to the Government of India, based on the inputs received during and after a brainstorming session that it had organized in New Delhi on the 11th of October, 2006 on "Hydrogen for Energy in India". The contribution made by Dr. S.K. Chopra, Principal Adviser and Special Secretary, Ministry of New and Renewable Energy (MNRE), New Delhi and his colleagues in the MNRE is also acknowledged.

6.1 Introduction

6.1.1 Hydrogen has the potential to replace gaseous and liquid fossil fuels in the future. In recent years, significant progress has been reported by several countries, including India, in the development of hydrogen as an alternative fuel. Serious concerns relating to energy security are driving this global transformation effort towards a hydrogen economy.

6.1.2 India is heavily dependent on imported fossil fuels for meeting its ever-increasing energy demands. This is particularly true for the transport sector, as India currently imports about two-thirds of its requirement of petroleum products. There is always an uncertainty about the assured supply of petroleum products, whose prices have been spiralling upwards. Significant efforts have been made in the last four to five years for the development and commercialization of hydrogen energy in the world, especially in advanced countries like the United States, Japan, Germany and Canada. India is one of the few developing countries, along with Brazil and China, which have strong research, development and demonstration programmes on hydrogen energy. There is a need to accelerate the development of hydrogen energy technologies in India as a substitute for petroleum products in partnership with the research organizations and the industry. The adoption of hydrogen involves finding solutions to many challenges relating to its production, storage, transportation, delivery, utilization and safety aspects.

6.2 Hydrogen Production

6.2.1 At present, hydrogen is mainly produced by reformation of hydrocarbons and gasification of coal. Hydrogen is also available as a by-product from the chlor-alkali industry. These methods result in carbon dioxide emission and are not environmentally sustainable. Hydrogen can also be produced through biological conversion of various organic effluents from distilleries and starch / sugar processing industries. Hydrogen is also produced through electrolysis of water. Several other methods, including high temperature electrolysis of water, thermo-chemical, photo-electrochemical, photo-catalytic and microbial decomposition of water, and also from various renewable sources like biomass and solar energy, are in various stages of research and development. The emerging methods for hydrogen production include the following:

- Production from biomass (gasification, pyrolysis of solid biomass, fermentation of liquid manure, industrial effluents) and through biological routes.
- High-temperature thermo-chemical splitting of water (from high-temperature nuclear reactors or solar concentrators).
- Low-temperature water splitting through photo-catalytic processes (involving semi-conducting powders spread on water-containing solutions which produce hydrogen on exposure to sunlight).
- Photo-electrochemical processes (involving wet photovoltaic systems).
- Harnessing of gas hydrates.

- Ethanol reforming.
- Membranes to purify hydrogen from reformats.

6.2.2 Electrolysis using electricity from renewable sources is considered as the long-term solution and is a technology favoured by environmentalists. However, capital costs of renewable energy systems need to be reduced significantly for electrolysis to become a large-scale production method. Such technologies would lead to production of hydrogen in a decentralized manner for large-scale use. No single production technology is likely to meet the requirement of hydrogen for the new and emerging applications in power generation and the transport sector in the near and medium term. Therefore, all possible options should be pursued in a prioritized manner. Research efforts also need to be undertaken for the production of hydrogen based on coal and nuclear energy.

6.3 Hydrogen Storage

6.3.1 Hydrogen is most commonly stored in high-pressure gaseous cylinders. It can also be stored in liquid form, which requires low temperatures with cryogenic storage systems. Various other methods of hydrogen storage include:

- Solid state storage in inter-metallic hydrides, complex hydrides, carbon nanostructures, metal organic complexes, clatherate hydrates, glass microspheres and liquid hydrides (*for* example cyclohexane, zeolites and aerogels).
- Storage in chemicals (like ammonia).
- Bulk storage in underground storage and gas pipelines.

6.3.2 At present, in India, hydrogen is stored in commercially available tanks / cylinders at pressures up to 175 bars. In recent years, new types of composite tanks / cylinders, which can store hydrogen at about 350-700 bars, have been developed in the US, Japan and other countries. Such tanks can store up to 10-12 weight per cent of hydrogen. Worldwide, research efforts are in progress to develop tanks and materials that can store hydrogen at pressures higher than 700 bars. In many countries, limited network of hydrogen pipelines have been set up. Hydrogen pipes that are in use today are made of regular pipe steel. Embrittlement of such pipelines limits their life and, therefore, alternative / composite materials are required to be developed. The existing hydrogen storage methods with some improvements may be adequate for stationary power generation; but use of hydrogen as a transport fuel would need higher weight percent storage capacity.

6.4 Hydrogen Transportation & Delivery

For a hydrogen-based economy to take shape, the key economic determinants would be the cost and safety of the fuel distribution system from the site of hydrogen production to the end user. This is true of any fuel, but hydrogen presents unique challenges because of its high diffusivity, extremely low density as a gas and liquid, and its broad flammability range. These unique properties present special cost and safety considerations at every step of distribution – from manufacture to, ultimately, on-board vehicle storage. Also, critical is the form of hydrogen in which it is shipped and stored. Hydrogen can be transported as a pressurized gas or a cryogenic liquid; it can be combined in an absorbing metallic alloy matrix or absorbed on or in a substrate, or transported in a chemical precursor form such as lithium, sodium metals or chemical hydrides.

6.5 Hydrogen Utilization

Apart from its existing uses in industry, hydrogen can be used for a wide range of applications, including power generation and transportation. It is possible to use hydrogen directly in Internal Combustion (IC) engines, mix it with diesel and Compressed Natural Gas (CNG) and also use it as a fuel in fuel cells to directly produce electricity. It has been used as a fuel in spacecrafts.

6.6 The Indian Scenario

6.6.1 The Government of India, mainly through the Ministry of New and Renewable Energy (the erstwhile Ministry of Non-conventional Energy Sources), has been supporting a broad-based research, development and demonstration programme on different aspects of hydrogen including its production, storage and utilization as a fuel for transport and power generation. Several research, scientific and educational institutions, laboratories, universities and industries are involved in implementing various projects on hydrogen energy technology. The emphasis has been on development of improved methods for hydrogen production based on renewable energy, improved materials / devices for hydrogen storage and efficient utilization of hydrogen energy as a fuel.

6.6.2 As a result of those efforts, hydrogen-operated motorcycles, three-wheelers and small generators have been developed in the country. In addition, PEMFC (Polymer Electrolyte Membrane Fuel Cell), PAFC (Phosphoric Acid Fuel Cell), and fuel cell-battery hybrid van have been developed. Hydrogen production from distillery waste, bagasse and other renewable sources has also been undertaken. Hydrogen storage in metal hydrides has also been developed and demonstrated for motorcycles, three-wheelers and small generators. At present, research efforts are on to further improve the performance of these vehicles and generators.

6.7 National Hydrogen Energy Board and National Hydrogen Energy Road Map

6.7.1 Realizing the importance of hydrogen as a fuel for the future and to accelerate the development in this area, the Ministry of New and Renewable Energy (the then Ministry of Non-Conventional Energy Sources) had set-up the National Hydrogen Energy Board (NHEB) in October, 2003 under the Chairmanship of the Minister of State for Non-Conventional Energy Sources. In February, 2004, the NHEB had set-up a Steering Group under Shri Ratan N Tata, Chairman, Tata Sons, to prepare the National Hydrogen Energy Road Map. The Steering Group set-up five expert groups on hydrogen production, storage, applications in transport and power generation sectors and hydrogen system integration. The National Hydrogen Energy Road Map was accepted by the NHEB in January, 2006.

6.7.2 In order to achieve the goal of energy security for the country through large-scale use of hydrogen in future as a fuel for transportation and power generation, the Road Map lays emphasis on development of the total hydrogen energy system. This includes hydrogen production, its storage, transport and delivery, applications, hydrogen safety, codes and standards, public awareness' and capacity building. The Road Map has highlighted hydrogen production as a key area of action. In addition to the existing methods of hydrogen production based on steam methane reformation, production of hydrogen from nuclear energy, coal gasification, biomass, biological and renewable energy methods need to be developed urgently. In order to meet the immediate requirement of hydrogen, the Road Map has proposed that the excess / by-product hydrogen available from the chlor-alkali industry, fertilizer plants and refineries should be tapped. It has recommended that demonstration of hydrogen technologies for automobile applications and power generation would facilitate creation of infrastructure required for large-scale introduction of hydrogen in selected locations. There is a need to systematically upgrade the hydrogen energy technologies and make them technically and commercially viable. With this in view, the Road Map has identified two major initiatives: Green Initiative for Future Transport (GIFT) and Green Initiative for Power Generation (GIP).

6.7.3 GIFT aims to develop and demonstrate hydrogen-powered IC engines and fuel cell-based vehicles ranging from small two / three wheelers to cars / taxies, buses and vans through different phases of development. It is envisaged in the Road Map that one million hydrogen-fuelled vehicles would be on Indian roads by 2020. The focus would be on two and three wheelers, which constitutes the major proportion of vehicles on Indian roads.

6.7.4 GIP envisages developing and demonstrating hydrogen fuelled IC engines / turbines and fuel cell-based decentralized power generating systems ranging from few kilowatts to megawatt-size systems through different phases of technology development and demonstration. This initiative would help the country in providing clean energy in a decentralized manner to rural and remote areas, besides power generation for urban centres. It is envisaged in the Road Map that decentralized hydrogen-based power generation of about 1000 MW aggregate capacity would be set-up in the country by 2020.

6.7.5 The Road Map has also suggested suitable pathways that would help the industry, government, research organizations, academia, non-governmental organizations and other stakeholders to achieve the national goals for transition to a hydrogen energy based economy from the present fossil fuel based economy through strong Public Private Partnership. The National Hydrogen Energy Road Map would form the basis for the preparation of an action plan and programmes on different components of the hydrogen energy system for realizing the vision of hydrogen energy for India in the coming decades. An investment requirement of Rs.25,000 crores has been projected in the Road Map for undertaking R & D and for setting-up the infrastructure for supply of hydrogen for the targets envisaged for 2020.

Technology Development Mission Mode Projects Suggested in the National Hydrogen Energy Road Map

- Clean Coal Gasification Technologies for Hydrogen Production
- Hydrogen Production through Biological Routes
- Hydrogen Production through Renewable Energy Routes
- Hydrogen Production through Nuclear thermo-chemical water splitting route
- Hydrogen Storage in Hydrides
- Hydrogen Storage in Carbon Nano-structures
- Development of IC Engine for Hydrogen fuel
- Development of PEM and SOFC Fuel Cell Technologies

6.7.6 The Ministry of New and Renewable Energy is setting-up a hydrogen dispensing station jointly with the Indian Oil Corporation Limited (IOC) at the IOC retail outlet near C.G.O. Complex, New Delhi. That Ministry will also undertake a development-cum-demonstration project for blending of hydrogen with Compressed Natural Gas (CNG) as a fuel for vehicles through the Society of Indian Automobile Manufacturers (SIAM), the IOC and the vehicle manufacturers.

6.8 Fuel Cells

6.8.1 It is predicted that in the near future, fuel cells will become economically viable, thus bringing closer the era of the fuel cell based hydrogen economy. There is a worldwide consensus on the strategic and economic importance of fuel cells, reflected in the dramatic increase in investment by governments and companies. Fuel cells are a family of technologies. Each one has unique technical issues and approaches to commercialization. A comprehensive strategy for fuel cells should address the unique requirements of the portable, stationary and transportation markets and also take advantage of the common elements that can be identified among the various applications.

6.8.2 Successful development of low-cost, high-performance and reliable components is critical to achievement of overall system cost and performance goals for all fuel cell types and applications. Furthermore, high performance is required to improve power plant packaging (volume and weight) for a given power output. This issue is particularly important for transportation applications where weight and efficiency effect the achievable driving range and volume constraints are strict.

6.8.3 Cost and durability are the biggest challenges. Reducing costs is not easy when only a small number of fuel-cell systems are being made. Cost is a barrier for all types of fuel cells across all applications. Cost reductions must be realized in raw materials, manufacturing of fuel cell stacks & components and bought-out items. The amount of cost reduction required depends on the type of fuel cell and application. Raw materials costs must be reduced by a combination of alternative (lower cost) materials, quantity pricing, and reduction in required amounts of expensive materials. Manufacturing cost reductions can be partly realized from classical learning curve gains. However, it will, most likely, require introduction of new and innovative manufacturing technologies or designs requiring simpler manufacturing processes. Because of the specialized requirements of components for fuel cell systems, costs are unusually high at low volumes.

6.8.4 Maintaining durability is tough when features such as freeze-start and operation under reduced relative humidity are required.

6.8.5 For the rating of improvements in fuel cell technology, commonly agreed measures for system efficiency, such as power density, dynamic behavior and durability, are indispensable. This requires the definition of harmonized testing procedures both for entire fuel cell systems and for system components for which a variety of boundary conditions need to be taken into account (e.g. different applications and stack concepts, types of fuels and quality, etc). To date, no standardized test procedures for fuel cells, stacks and systems exist. The same applies for their assessment against user requirements in the stationary, transport and portable applications. In practice, many laboratories and manufacturers have developed their own test protocols to meet their needs and those of their customers showing clearly the need for harmonization of testing procedures and measurement methods. The success of a fuel cell based hydrogen economy depends on availability of low cost hydrogen, preferably from renewable sources.

6.8.6 In the fuel cell area, the focus of research should be on the following :

- Low temperature fuel cells (Alkaline and PEMFC)
- High temperature fuel cells (Molten Carbonate Fuel Cell, MCFC and Solid Oxide Fuel Cell, SOFC)
- High temperature reversible fuel cells
- Direct alcohol fuel cells

The stress should be on ***system development*** and not just ***materials development***.

6.8.7 In addition to the above aspects, there is a need to strengthen R & D efforts in the following areas:

- Development of indigenous low cost membrane
- Development of low cost graphite based bipolar plates
- Development of higher CO tolerant anode catalyst
- Development of cheaper cathode catalyst
- Development of electrode support substrate (graphite paper)

- Low cost hydrogen sensors using MEMS technology
- Ceramic based hydrogen sensors
- Low cost manufacturing methods
- Low cost heat exchangers for high temperature and low temperature fuel cells

6.9 Some Directed Basic Research Areas

i) R&D has shown that the high surface area carbon seems to be the best, but the high surface area carbon undergoes corrosion very fast depending on application. Therefore, basic understanding of the types of carbons for use in fuel cells is essential.

ii) Nano catalysts have high surface area and perform better. The challenge is how to translate the good performance showed by the nano catalysts in electrochemical studies (half cell) into single cell and eventually in the stack. The issue here is how to retain the activity of the (nano) catalyst without its sintering during fuel cell operation.

iii) The fuel cell electrode is a complex subject with a number of simultaneous reactions taking place in its structure. The electrode contains, besides the catalyst, a substrate layer, hydrophobic material, hydrophilic material and conducting carbon powder. The electrode structure, amongst other things, determines the percentage utilization of the catalyst which is low at the moment. The challenge is to improve catalyst utilization to the maximum.

iv) The fuel cell cathode performance determines the performance of the cell and the stack as it is in the cathode (in the PEMFC) that the full process of reactant diffusion, electron & proton migration and charge transfer kinetics unfolds. Further, the presence of liquid water complicates this interplay. Thickness, composition and pore-space morphology steer the balance of transport and reaction. The size distribution and wetting properties of the pores control water and heat exchange: hydrophilic micro-pores are good for evaporation and hydrophobic mesoporous are good for gas transport. Understanding the rules of this process is crucial for optimal catalyst utilization, water management and the overall successful performance of the cell.

v) There are several engineering issues. Stack assembly and system integration are complex issues. Many scientists tend to model / simulate only one or two aspects in the design and tend to extrapolate the same to larger systems. The modeling studies should be necessarily followed by hardware development and evaluation.

6.10 Areas for Research, Development & Demonstration:

i) PEMFC technology development for decentralized power generation & automotive applications and their demonstration.

ii) Development of new generation high temperature fuel cells (SOFC).

iii) Development of alkaline fuel cells.

iv) Development and deployment of direct alcohol fuel cells.

v) Development of regenerative fuel cells.

vi) Integrated power generating system comprising solar/bio-sources and fuel cell stacks.

vii) Hydrogen/ fuel cell vehicle programme - this project will be a collaboration of various industry groups, academia, governments and transport companies to demonstrate fuel cell vehicle technology in a real world environment.

6.11 Recommendations on Some More R&D Topics

A. Directed Basic Research:

- Thermodynamics of hydrogen absorption-desorption.

B. Applied Research

- Flow visualization

C. Engineering

- High temperature engineering
- Heat Integration
- Vibration studies
- Shock mounts
- Temperature environments
- Humidification
- Power conditioning
- Embedded system controllers
- On-line fault diagnostics
- Hydrogen handling
- Oxygen handling
- Packaging
- Start-stop dynamics
- Duty Cycle Management

6.12 Requirement of Funds:-

Keeping in view the importance of hydrogen as an alternate fuel of the future for both the transport and the power generation sectors, and also its potential for ultimately providing energy security to the country, it would be desirable to launch a ***National Mission on Development of Hydrogen Energy***, with the Ministry of New and Renewable Energy as a key player. An amount of Rs. 350.00 crores may be allocated for R&D in this sector during the eleventh five year plan period.

Section – VII

Advanced Coal Technologies

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7.1 Integrated Gasification Combined Cycle (IGCC) Demonstration Plant in the Country – A Brief Report on the S&T Work Done to Establish the First (~100 MWe) IGCC Demonstration Plant in the Country.

7.1.1 In November, 2002, the Prime Minister's Office (PMO) suggested to the Principal Scientific Adviser (PSA) that synergy between BHEL and NTPC should be established for the indigenous development of the IGCC technology and for the subsequent setting-up of the first IGCC (~100 MWe) demonstration plant in India.

7.1.2 To oversee this, the PSA's Office set-up an R&D Committee on IGCC under the chairmanship of the Scientific Secretary.

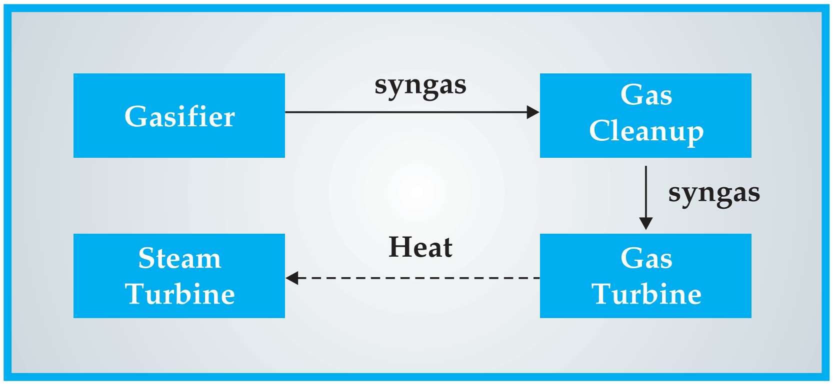
7.1.3 The R&D Committee noted that the IGCC plant, based on the Pressurized Fluidized Bed (PFB) concept, was ideally suited for the high ash (35% to 45%) Indian coal. However, there was not much international experience available with PFB. BHEL had already set-up three R&D plants based on PFB [200 mm diameter Advanced Pressurized Fluidized Bed Gasifier (APFBG) (coal feed: 1.2 T/ day); 450 mm diameter Performance Evaluation and Demonstration Unit (PEDU) (18 T/ day) and 1.1m diameter Combined Cycle Demonstration Plant (CCDP) (150 T/ day, 6.2 MWe)]. Therefore, by using these BHEL plants, operating at different regimes of coal and air / steam flow (see Table-1), there was a unique opportunity to carry-out experiments and their simulations. These simulations could then be reliably used for arriving at the design of the ~100 MWe plant.

Table 1. Some Operating Conditions for BHEL Plants

	APFBG	PEDU	CCDP
Coal (kg/hr)	33	131	4287
Air (kg/hr)	69	303	8064
Steam (kg/hr)	6.1	20	775
Operating pressure (bar)	1.28	5	8

7.1.4 As is well known, an IGCC plant has three islands: a gasifier and allied coal / ash handling equipment, a gas clean-up system and the two turbines (one gas turbine and one steam turbine) ***(see fig.1)***.

Fig.1: Coal Gasification within the IGCC Concept



Since a gas clean-up system was already available in the CCDP, and also as its cost was a small fraction of the total (~ 5%), the Committee decided to concentrate on the gasifier part first. BHEL had already made a design for a 100 MWe plant. This was the upgraded version of their 6.2 MWe plant based on a similarity principal. However, NTPC had some technical reservations on this.

7.1.5 Therefore, for carrying-out design validation of the BHEL's 100 MWe plant, a Working Group was constituted by the R&D Committee. This was headed by Dr. R.R. Sonde (then at the Heavy Water Board, Department of Atomic Energy), with representation from both BHEL and NTPC.

7.1.6 The following performance parameters were selected for this 100 MWe plant:

i) Carbon conversion efficiency ~85%

ii) Cold gas efficiency ~71%

iii) Gross efficiency ~ 39%

iv) Gas Calorific Value (LCV) ~ 1000-1100 Kcal / Nm^3

v) Broad operating range with a good availability factor, long term operation, etc.

7.1.7 The Working Group has carried-out the following work, inter alia, during the last three years:

i) A large number of experiments on APFBG and PEDU (the CCDP became available for experiments in March, 2004) to optimize the external parameters like air to steam ratio, air to coal ratio, coal size, etc. and internal parameters like temperature, residence time distribution, superficial velocity, etc.

ii) Residence time distribution for determination of coal particles through radio tracer techniques, using La^{140} produced in the Dhruva reactor at Bhabha Atomic Research Centre (BARC).

iii) X-ray radiography studies for bubble hydrodynamics. For this a special gadget was designed and fabricated. The measurements were done at BARC.

iv) Intermediate gas composition measurements.

v) Gas contaminant analysis by neutron activation techniques.

vi) Porosity and moisture content measurements.

vii) Reviewed the past data on BHEL's R&D plants.

viii) Developed Artificial Neural Network (ANN) and phenomenological models to interpret the data (The PSA's Office had sanctioned a project to the National Chemical Laboratory, Pune, for the development of this for fluidized bed coal gasifiers. This project has recently been completed). Typical simulation results for some runs on the CCDP are displayed in ***Table-2***.

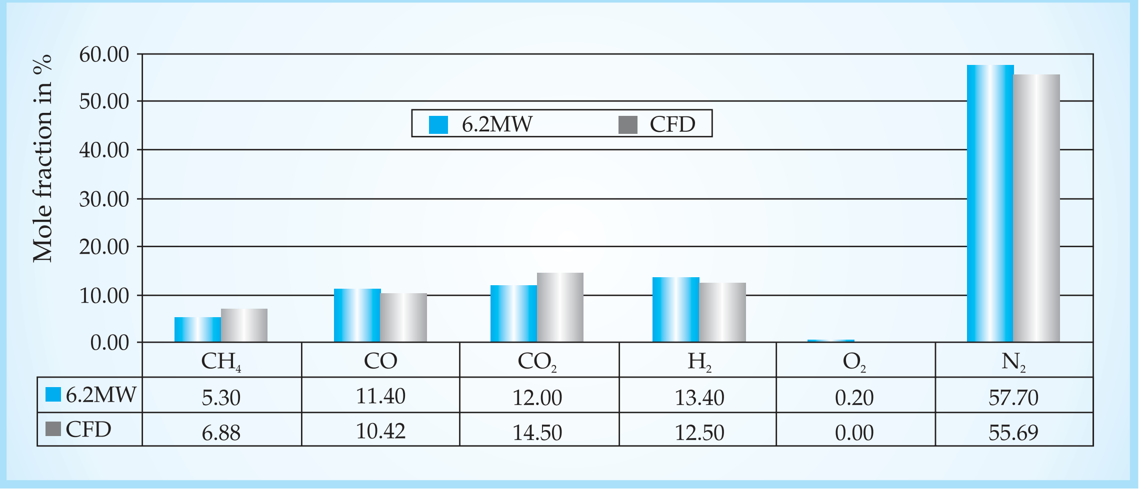
Table 2. Analysis of Experimental Data using the Models Developed (CCDP)

	20.7.05, 5 bar, 950°C			21.7.05, 8 bar, 1025°C		
Parameter	**Expt**	**NFM**	**PFM**	**Expt**	**NFM**	**PFM**
Carbon Conversion (%)	80.44	78.59	80.4	89.2	91.93	93.35
Dry Gas Composition (Vol %)						
CO	14.40	11.8	13.12	16.90	17.92	18.88
CO_2	13.9	15.9	15.05	11.7	12.08	11.48
CH_4	1.20	1.3	1.37	1.30	1.02	1.16
H_2	15	16.21	15.91	15.1	14.95	14.43
N_2	55	54.8	54.56	54.5	54.03	54.05
Cold Gas Efficiency (HCV)	54.13	53.8	56.12	66.5	66.09	67.62

Expt: ***Experimental Result*** **NFM:** ***Net Flow Model*** **PFM:** ***Plug Flow Model***

7.1.8 The agreement is very encouraging. In addition to this project, BHEL had commissioned an independent study in the Indian Institute of Technology, Madras, for the Computational Fluid Dynamics (CFD) analysis of the fluidized bed gasifier in IGCC plants. The CFD model was validated using the data obtained from the CCDP ***(see fig.2)***. The model also predicts the performance of the 125 MWe gasifier.

Fig.2:Comparison between Experimental and CFD Data for CCDP Plant



7.1.9 Conduct of some of the above work required modifications in the R&D plants of BHEL. These were carried-out by BHEL. A vast amount of data were generated from the experiments done on the APFBG and the PEDU. The Working Group concluded from these experiments that carbon conversion efficiency and cold gas efficiency are not a strong function of coal quality (i.e. its source or its exact ash content). The efficiency figures obtained for the APFBG and the PEDU were lower than expected, possibly due to the high heat loss in small rigs or operation of rigs at lower pressures or bubble formation in the gasifier.

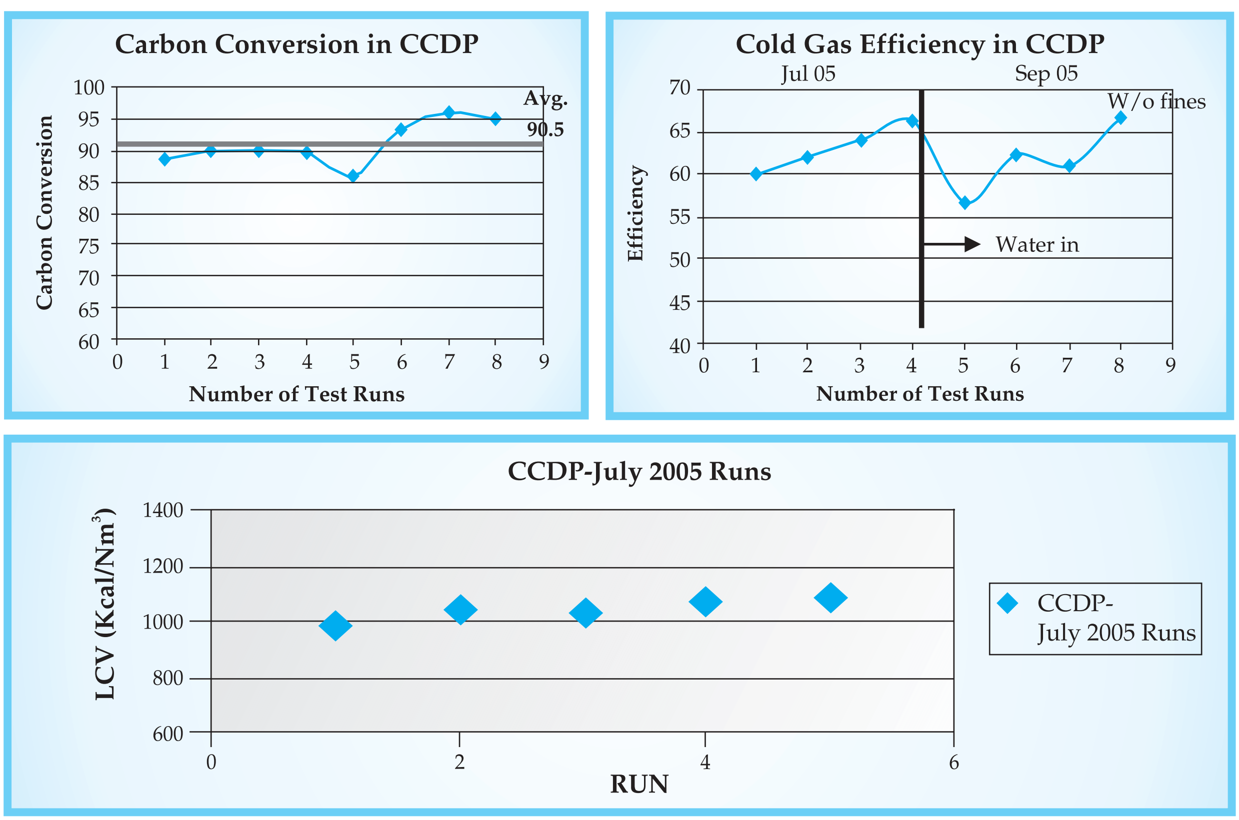
7.1.10 The scale-up strategy, emerging from the studies done on the APFBG and the PEDU, pointed to:-

- the need for operating the 100 MWe plant at a pressure of about 30 bar (maximum operating pressures of APFBG, PEDU and CCDP are 1, 5 and 8 bars, respectively). Therefore, to evaluate the pressure effects, further experiments were proposed on the CCDP, operating at higher pressures.

7.1.11 During July 20-21, 2005, 5 sets of experiments were done by the Working Group on the CCDP at pressures varying from 5 bar to 8 bar and temperatures varying from 950°C to 1050°C. The results of these tests were to the satisfaction of the Working Group. The good performance of the CCDP was, primarily, due to substantial modifications done in that rig by BHEL during September, 2003 to March, 2004. A major modification was the addition of a flat plate distributor. This improved the uniformity of the fluidization and the bed temperature, leading, in turn, to the operation of the CCDP at temperatures as high as 1050°C and consequent improvement in the overall gasifier performance.

7.1.12 Results of the experiments done on the CCDP have shown that at a temperature of 1050°C, the carbon conversion efficiency in the CCDP was 88-89%, while the cold gas efficiency was 68.8%. The LCV was ~ 1100 Kcal / Nm^3 (see fig.3). These are quite close to the set values. The results of September, 2005 experiments were on the lower side as the coal (of finer size and having higher water content) conditions were changed and thus not acceptable.

Fig.3: Carbon Conversion & Efficiencies for the CCDP



7.1.13 The model predictions, using the NCL developed models, for the 125 MWe plant operating at 30 bar are given in the Table-3 for two different types of coal and temperature conditions.

Table 3. Model Predictions for the 125 MWe Plant at 30 Bar

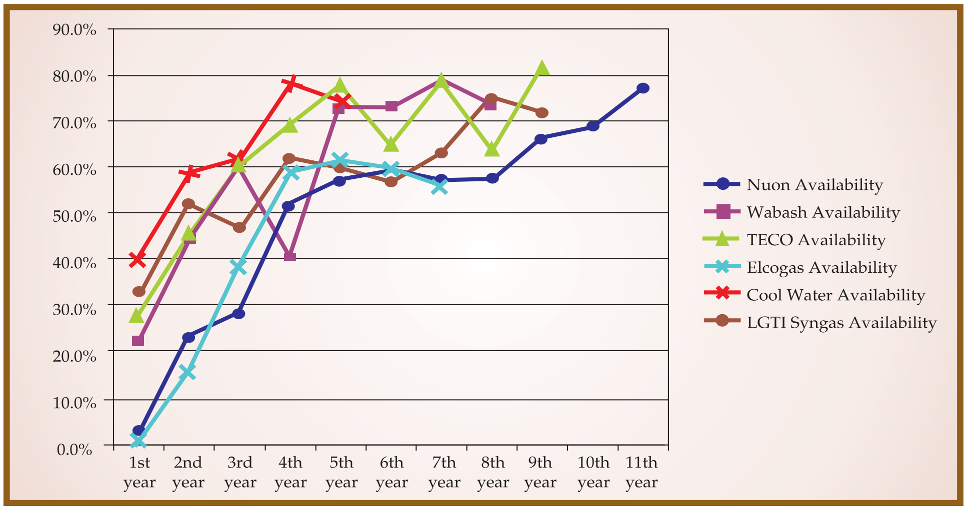
Carbon Conversion (%)	**93.21**	**92.3**	**93.74**
Dry Gas Composition (Vol %)			
CO	**20.75**	**20.83**	**24.7**
CO_2	**10.6**	**10.47**	**8.58**
CH_4	**2.17**	**2.1**	**2.01**
H_2	**15.1**	**14.93**	**15.42**
N_2	**51.38**	**51.67**	**49.28**
Cold Gas Efficiency (HCV)	**72.62**	**71.64**	**71.41**

These show that one may go ahead in setting-up the 100 MWe IGCC Plant.

7.1.14 Now that the technical feasibility of upgrading the 6.2 MWe CCDP of the BHEL to 100 MWe has been satisfactorily established, a detailed project report may be prepared jointly by the BHEL and the NTPC for setting-up the first 100 MWe IGCC demonstration plant in the country with financial support from the Government of India. It is also suggested that BHEL and NTPC should continue to do more experiments and simulations on the 6.3 MWe plant.

7.1.15 According to O. Maurstad (LFEE 2005-002 WP), low availability is still an issue with IGCC plants world over ***(see Fig. 4)***. It can be seen that most of the plants were able to reach the 70-80% availability after a number of years. It is hoped that newer plants will do so in a shorter span of time as solutions like adding a spare gasifier etc. exist. It is suggested that we can gather this experience on the proposed 100 MWe demonstration plant.

Fig. 4: IGCC Availability History (from LFEE 2005-002 WP)



7.1.16 In a meeting of the Inter-ministerial Steering Group on IGCC chaired by the Secretary (Power) on the 15th of December, 2005, it was decided that the BHEL and the NTPC should come-out with a detailed project report, positively by the 15th of January, 2006. It was pointed-out that the cost of the 100 MWe demonstration plant would be around Rs. 800.00 crores. The Secretary (Power) gave the following decision on the funding of the proposed plant:

- Rs. 4.00 crores per MW to be contributed by NTPC.
- The remaining cost to be met partly by BHEL and partly by the Planning Commission as grants-in-aid.

7.1.17 The detailed project report recently prepared by the BHEL for a 125 MWe IGCC demonstration plant has pegged the total project cost as about Rs. 900.00 crores. Of this, Rs. 500.00 crores (@ Rs. 4.00 crores per MW) shall be contributed by the NTPC. The BHEL will contribute Rs. 50.00 crores. ***It is proposed by the Working Group that the balance amount of Rs. 350.00 crores may be contributed, by the Government of India, as grants-in-aid to the project***.

7.2 IN-SITU Gasification of Coal and Lignite

7.2.1 Underground gasification is a process by which coal or lignite is converted in-situ to a combustible gas that can be used as a fuel or chemical feed stock. Considered as a clean coal technology for utilization of coal / lignite resources, the method may be employed for exploitation of only such resources which are not techno-economically suitable for conventional mining. The process involves:

- Drilling of two adjacent boreholes into the coal seam and establishment of a linkage between the two by directional drilling and / or controlled ignition.
- Injection of pressurized oxidant such as air or oxygen through one of the boreholes (injection well).
- Recovery of product gases through the second borehole (production well).

7.2.2 The typical gas recovered using air injection may consist of mainly hydrogen, carbon monoxide, carbon dioxide, methane and higher hydrocarbons. The gas may have calorific value of around 850 Kcal / Nm^3 and after processing can be utilized for power generation in an integrated gasification combined cycle power plant of suitable capacity or for other purposes.

7.2.3 Trials of the method have reportedly been carried-out in several countries successfully but sustained commercial application over a long period does not appear to have been undertaken or not yet established. In the recent past a successful trial of the method has reportedly taken place in Australia, but large-scale application is yet to be made. In India the advantages that may accrue from successful implementation of the technique are

- Utilization of unmineable coal and lignite resources.
- Additional coal based power generation capacity to meet the demand-supply gap.
- Reduced strain on rail transportation for coal.
- Availability of industrial fuel gas for industries located in coal bearing areas.

7.2.4 Although Underground Coal Gasification (UCG) is considered by and large as an environmentally clean technology, the effect of gases produced on the ground water regime needs to be thoroughly examined, especially for such areas where ground water resources are limited.

7.2.5 A project funded by S&T grant of the Ministry of Coal on UCG was undertaken towards the end of 1980s with guidance from Russian experts. Considerable exploratory work was carried-out in twelve coal and one lignite bearing areas. The site chosen for pilot-scale study was a lignite deposit in Rajasthan. Field trial of the method was not eventually carried out due to apprehension of groundwater contamination at the site.

7.2.6 Another project with an approved outlay of Rs 11.25 crore and duration of four years, being funded jointly by S&T grant of Ministry of Coal and Department of Science and Technology has been taken-up by Neyveli Lignite Corporation in 2005. The objectives of the project include evaluation of exploration data and selection of a suitable lignite block for UCG trial, carry-out pilot-scale studies and assess heat value of the gas produced. Collection of exploration data is currently underway.

7.2.7 Considering the likely benefits which may accrue from successful application of underground coal gasification technology the Working Group recommends simultaneous trials by coal companies in association with research institutions in a number of suitable areas during the XIth Plan so that the country's fossil fuel resources can be fully utilized and the rising gap between coal supply and demand can be reduced. R&D projects in this area should also include investigations related to long-term effects on groundwater and surface localities. Two additional projects with a total outlay of Rs. 30.00 crores may be undertaken during XIth Plan for establishing viability of the method and guidelines for future commercial application.

7.3 Coal to Oil Conversion

7.3.1 The prevailing level of prices of crude oil and petroleum products warrants a fresh look at coal liquefaction processes. The options available for meeting the rising demand of petroleum products through conversion of coal to oil need serious consideration as the country depends heavily on imported petroleum. The rising costs and questions related to adequate and assured supply of oil from overseas sources have a significant bearing on both the national economy and energy security.

7.3.2 Although some isolated studies have been carried-out in India in the past, the technology for conversion of coal to oil suitable for Indian coals for maximum yield at least possible cost is yet to be established. Notable among the studies was an R&D project funded by S&T grant of the Ministry of Coal carried-out by Central Fuel Research Institute (Dhanbad) in the early 1990s in which several catalysts were tried-out for conversion of synthesis gas (H_2:CO = 2:1) from coal into liquid hydrocarbons.

7.3.3 In some countries extensive work, including pilot-plant scale investigations, has been done broadly on two different routes:

(a) Indirect liquefaction by coal gasification and subsequent conversion of synthesis gas to liquid products through Fischer-Tropsch (FT) process;

(b) Direct liquefaction of coal by catalytic hydrogenation based on Bergius-Pier process.

7.3.4 In South Africa the indirect route is being followed on a commercial scale by a company (Sasol) for many years. Currently, plants of the company are reported to have a combined production capacity of 1,15,000 barrels of oil a day including other petroleum products. In China a coal liquefaction research centre has reportedly been set up in Shanghai and a commercial plant is under construction based on the latest direct liquefaction technology in collaboration with a US company (Hydrocarbon Technologies Inc).

7.3.5 It is understood that Oil India Limited has recently undertaken some preliminary studies on direct coal liquefaction with the help of the earlier mentioned US company and the possibility of setting-up a plant with low-ash-high-sulfur Assam coal is under consideration. One of the constraints being faced in setting-up the plant is limited production of coal from the north-eastern coalfields. Keeping in view the large reserves of high-ash coals in India, which occur in most of the coalfields of the country, the indirect route for coal liquefaction through gasification and subsequent FT synthesis cannot be ruled out and may turn out to be one of the cost-effective options.

7.3.6 The Working Group proposes that suitable technologies should be established for different types of Indian coals through laboratory and pilot-plant scale studies, for assessment of techno-economic feasibility, so that commercial operation can be facilitated in future if necessary. The studies can be undertaken by CSIR laboratories like Central Fuel Research Institute (Dhanbad), National Chemical Laboratory (Pune) or Indian Institute of Chemical Technology (Hyderabad) in collaboration with coal and oil companies.

7.3.7 A broad fund provision of Rs 200.00 crores may be considered for the above laboratory and pilot-plant scale studies during the Eleventh Five Year Plan. Funding of projects may be jointly undertaken by the Department of Science and Technology, Ministry of Coal and Ministry of Petroleum and Natural Gas.

7.4 Coal Bed Methane

7.4.1. In India preliminary activities related to exploitation of Coal Bed Methane (CBM) began in the early 1990s and till 1997 the Ministry of Coal (MoC) had allotted some coal bearing areas for CBM exploration and exploitation. In July 1997 a CBM policy was framed and the Ministry of Petroleum and Natural Gas (MoP&NG) was made the administrative ministry. As per guidelines of the approved CBM policy prospective blocks are to be delineated by deliberation between MoC and MoP&NG and are to be allotted by the latter through global bidding for exploitation in line with the practice followed for oil and natural gas resources. Till 2006 a total of 26 CBM blocks have been delineated and corresponding data packages have been prepared, mainly by the Central Mine Planning and Design Institute (CMPDI). These blocks have been offered for development through three rounds of global bidding by MoP&NG. The blocks covering a total area of 13591 sq km hold prognosticated CBM resources of 1449 BCM.

7.4.2 In the course of carrying-out delineation of blocks and assessment of resources it was felt that there was a need to undertake R&D work in this emerging field of resource utilization along with the need for dedicated coalfield-wise data generation. Two R&D projects were thus taken-up and are currently underway, details of which are summarized ahead:

(a) Coal bed methane recovery and commercial utilization: The project, jointly funded by S&T grant of MoC, UNDP and Global Environment Facility (GEF), is being executed by CMPDI and Bharat Coking Coal Limited (BCCL). With a total outlay of Rs 94.427 crore the project is intended to establish and demonstrate CBM recovery techniques and commercial utilization of methane recovered from an active mining area. The project is expected to be completed by the end of 2007.

(b) CBM exploration through slim-hole drilling: With the help of R&D funding of Coal India Limited (CIL) CMPDI is carrying-out parametric data generation and assessment of in-place CBM resources through slim-hole drilling in two CBM blocks in Jharia and Ranigunj coal fields, which have been allotted to a consortium of CIL and ONGC. The objectives of the project are as follows:

- Establishment of optimum pattern for exploration of CBM under Indian conditions.
- Exploring the possibility of data generation on in-situ reservoir characteristics from NQ size slim-hole, which is hitherto not practiced.
- Testing the efficacy of various available CBM simulator models used for production forecasting under Indian conditions, and, if needed, recalibration to suit local condition.
- Acquisition of technical know-how by CIL personnel in the field of large diameter CBM well drilling, completion and production testing.

7.4.3 Fund allocated for R&D under this project is Rs. 19.92 crore and the project is expected to be completed by 2011.

7.4.4 Other than continuation of the second project for most of the XI Plan period R&D work can be taken-up in the following fields:

- Utilization potential of ventilation air methane (VAM) from working mines.
- Application of enhanced CBM recovery techniques in Indian conditions.
- Standardization of indirect method of gas yield prediction from coal exploration programme.

7.4.5 R&D projects to cover the above fields may be undertaken by CMPDI in association with other organizations/institutes. The total fund requirement is broadly estimated at Rs. 35.00 crores and may be met jointly by the Ministry of Coal and Ministry of Petroleum and Natural Gas.

7.5 Carbon Capture and Storage (Including Climate Change Issues)

7.5.1. R&D Activities in CO_2 Capture and Sequestration Technologies

7.5.1.1. India is currently on a high economic growth path and its energy consumption will increase significantly in the coming decades. As the world's fifth largest emitter of CO_2, India needs to develop a balanced portfolio of responses that will allow us to be an effective participant in evolving international agreements to address climate change concerns. This “climate portfolio” needs to include activities on the various aspects of the climate change problem, including better understanding the science and the potential impacts, developing technological responses for adaptation and mitigation, and formulating policies that take into account the economic costs.

7.5.1.2. India has responded to climate change by (i) promoting energy efficiency across all sectors, (ii) switching over to low carbon intensity fuels and (iii) moving aggressively in the adoption of renewable energy technologies. They may be sufficient to meet short-term goals, but there is a general belief that they will not be able to solve the problem in the mid- and long-term. The purpose of this concept paper is to briefly discuss an important opportunity, which we should consider as part of our technological response, namely the capture and sequestration of CO_2 from large stationary sources. Carbon dioxide capture and storage (CCS) will play an important role in addressing climate change because of the high fossil fuel based economy.

7.5.1.3. Based on the current research and demonstration projects most of them in the US and Canada suggests that the main challenge regarding CO_2 capture technology is to reduce the overall cost by lowering both the energy and the capital cost requirements. While costs and energy requirements for today’s capture processes are high, the opportunities for significant reductions exist, since researchers have only recently started to address these needs. One strategy that looks extremely promising is to combine CO_2 removal with advanced coal energy conversion (pre-combustion) processes that have features, which will enable low energy intensive capture.

7.5.1.4. The major options for CO_2 storage are underground or in the ocean. Statoil, an oil company in Norway, is presently storing one million tonnes per year of CO_2 from Norwegian gas fields in an aquifer beneath the North Sea. Exxon and Pertamina at their Natuna gas field in the South China Sea may soon undertake a larger aquifer storage project. Besides aquifers, geologic storage options include active oil wells (in connection with enhanced oil recovery), coal beds, and depleted oil and gas wells. The issues, which need clarification, include storage integrity and reservoir characterization. Ocean CO_2 disposal would reduce peak atmospheric CO_2 concentrations and their rate of increase by accelerating the ongoing, but slow, natural processes by which most current CO_2 emissions enter the ocean indirectly. The capacity of the ocean to accept CO_2 is almost unlimited, but there are questions that still need to be addressed about its effectiveness (how long will the CO_2 remain sequestered) and about the environmental impacts associated with increased seawater acidity near the injection point.

7.5.2. Some of the Reasons why Research into CO_2 Capture, Use, and Disposal Technologies is important are:

7.5.2.1 It is a prudent measure since there are only a limited number of strategies to reduce greenhouse gas emissions. The field of CO_2 capture and sequestration is still being researched with many questions needing to be addressed to make these technologies viable. At this time, it is judicious to explore all potential mitigation options in a balanced way, so that a broad range of strategies are available to help meet future policy goals.

7.5.2.2 These technologies provide a long-term greenhouse gas mitigation option that allows for continued large-scale use of our abundant fossil energy resources.

7.5.2.3 With continued research, these technologies have the potential to provide a cost-effective mitigation option in response to policies aimed at limiting greenhouse gas emissions and ultimately stabilizing greenhouse gas concentrations in the atmosphere.

7.5.2.4 These technologies can be used as an alternate option in case new non-fossil energy sources like solar or present non-fossil energy sources like nuclear cannot gain sufficient market share and / or acceptance.

7.5.2.5 These technologies could be a low cost mitigation option if hydrogen were to become a major energy carrier.

7.5.3. CO_2 Capture Technology

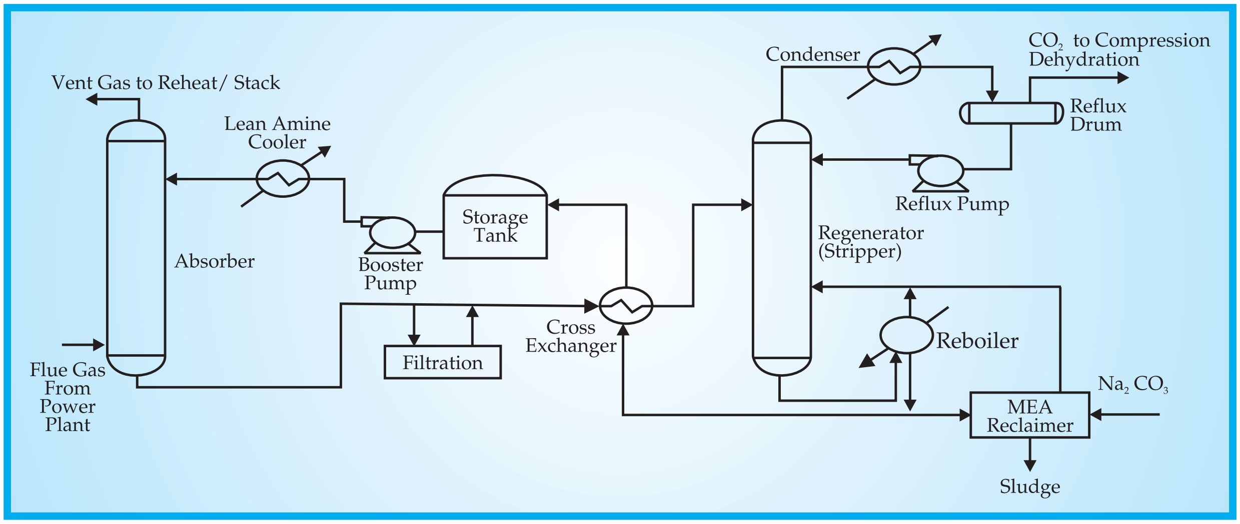
7.5.3.1 CO_2 capture processes have require significant amounts of energy, which reduces the power plant's net power output. Table 1 shows typical energy penalties associated with CO_2 capture — both as the technology exists today and how it is expected to evolve in the next 10-15 years. Advanced coal technologies are primarily IGCC power plants. Both conventional coal and gas use similar capture technologies, but because gas is less carbon intensive than coal, it has a lower energy penalty. The relatively low energy penalty for advanced coal can be attributed to features in its process that allow for less energy intensive captures methods.

TABLE 1. Typical Energy Penalties due to CO_2 Capture

Power Plant Type	Today	Future
Conventional Coal	27 - 37% (Herzog and Drake, 1993)	15% (Mimura *et al.*, 1997)
Gas	15-24% (Herzog and Drake, 1993)	10-11% (Mimura *et al.* 1997)
Advanced Coal	13 - 17% (Herzog and Drake, 1993)	9% (Herzog and Drake, 1993)

7.5.3.2 To date, all commercial CO_2 capture plants use processes based on chemical absorption with a monoethanolamine (MEA) solvent. MEA was developed over 60 years ago as a general, nonselective solvent to remove acid gases, such as CO_2 and H_2S, from natural gas streams. The process was modified to incorporate inhibitors to resist solvent degradation and equipment corrosion when applied to CO_2 capture from flue gas. Also, the solvent strength was kept relatively low, resulting in large equipment sizes and high regeneration energy requirements (Leci, 1997). As shown in Figure 1, the process allows flue gas to contact an MEA solution in the absorber. The MEA selectively absorbs the CO_2 and is then sent to a stripper. In the stripper, the CO_2 -rich MEA solution is heated to release almost pure CO_2. The lean MEA solution is then recycled to the absorber.

Figure 1. Process Flow Diagram for the Amine Separation Process



7.5.3.3 Other processes have been considered to capture the CO_2 from the flue gas of a power plant - e.g., membrane separation, cryogenic fractionation, and adsorption using molecular sieves – but they are less energy efficient and more expensive than chemical absorption. The reason can be attributed to the very low CO_2 partial pressure in the flue gas. Further research is in progress to make these processes cost-effective.

7.5.3.4 Advanced coal power plants offer many new opportunities for CO_2 capture. One example is to integrate CO_2 capture with an Integrated Gasification Combined Cycle (IGCC) power plant (Doctor *et al.*, 1996). IGCC plants first gasify the fuel (coal/refinery rejects) to produce a pressurized synthesis gas (mainly CO_2 and H_2). Next, for CO_2 capture, after removal of impurities that might foul the catalyst, the synthesis gas is reacted with steam in a shift reactor to produce CO_2 and H_2. The CO_2 and H_2 are then separated, with the hydrogen being combusted to produce CO_2 -free energy. The CO_2 stream is available for use or disposal. The partial pressure of CO_2 is sufficiently large in an IGCC plant (as opposed to pulverized coal plants) to allow use of a physical absorbent like Selexol (dimethyl ether of polyethylene glycol), which greatly reduces the energy requirements.

7.5.3.5 Power technologies such as fuel cells or other advanced cycles are evolving and may become available to use the hydrogen rich fuel gas produced from the coal gasifier/shift-reactor/CO_2 separator. These technologies are likely to yield higher energy efficiencies and, therefore, further reduce the penalties associated with CO_2 capture.

7.5.3.6 In addition to power plants, there are a number of large CO_2 -emitting industrial sources that could also be considered for application of capture and sequestration technologies. In natural gas operations, CO_2 is generated as a by-product. In general, gas fields contain up to 20% (by volume) CO_2, most of which must be removed to produce pipeline quality gas. Therefore, sequestration of CO_2 from natural gas operations is a logical first step in applying CO_2 capture technology, as witnessed by the Sleipner West project in Norway and the proposed Natuna project in Indonesia. Finally, in the future, similar opportunities for CO_2 sequestration may exist in the production of hydrogen-rich fuels (e.g., hydrogen or methanol) from carbon-rich feedstocks (e.g., natural gas, coal, or biomass). Specifically, such fuels could be used in low-temperature fuel cells for transport or for combined heat and power. Relatively pure CO_2 would result as a by-product (Williams, 1996; Kaarstad and Audus, 1997).

7.5.4. Geological Storage Options

7.5.4.1 Depleted oil and gas reservoirs appear to be the most promising land storage option, at least in the near-term (Herzog *et al.*, 1993). Because these reservoirs have already demonstrated their ability to contain pressurized fluids for long periods of time, their storage integrity is likely to be good. However, most of the wells would have to be re-drilled, and actual effective capacity is uncertain given that changes to the reservoir may have occurred due to water / brine intrusion or geo-structural alteration. The oil and gas industry has significant experience in the management of such reservoirs, but is particularly concerned about long-term liability issues. Most oil and gas reservoirs are not located near primary sources of CO_2 production, so a new CO_2 pipeline network would be needed to connect power plants with suitable storage sites. The costs, environmental impacts and safety issues associated with such a network need to be considered in any analysis of this storage option. Piping and storage costs will be very site-specific.

7.5.4.2 Active oil and gas reservoirs could also be used. For example, CO_2 is used routinely for enhanced oil recovery (OTA, 1978; Lake, 1989). The amount of CO_2 that can be utilized for EOR and related applications is small compared to total CO_2 emissions and CO_2 can currently be supplied from natural sources at about one-third the cost projected for CO_2 captured from power plants (Herzog *et al.*, 1993). Hence there is no immediate incentive to utilize power plant CO_2 for this purpose. However, if credits for the avoided CO_2 emissions are considered, the price of power plant CO_2 is reduced and this option becomes very attractive. While the basic technology exists for EOR, additional research is required to modify EOR operations to optimize the storage of $CO_{2.}$

7.5.4.3 CO_2 can also be used to enhance the recovery of coal bed methane (Gunter *et al.,* 1997). Using this technology, abandoned and uneconomic coal seams become potential storage sites. Unlike EOR, where CO_2 break-through eventually occurs, the injected CO_2 becomes adsorbed to the coal surface and hence remains sequestered. Although still in the development stage, the process has been tested in pilot scale field studies conducted by Amoco and Meridian in the San Juan Basin and three other fields.

7.5.4.4 Based on the above discussion, several steps need to be implemented to further the development of land-based CO_2 storage. It should be emphasized that some of the needed information is actually available, but not accessible due to proprietary considerations, these obstacles must be overcome in order to avoid costly duplication of work in India.

7.5.5. R&D for Technology Development in India

7.5.5.1 India needs to carry-out basic R&D and technology development as it will help in facilitate in technology learning and adaptation to Indian conditions. It needs to establish a test center for carrying out research in CO_2 capture technologies from various types of combustion sources on the lines done by the IEA. The IEA has established an international test center in Canada. The International Test Centre develops technologies to reduce carbon dioxide emissions, especially those produced by the energy sector. Its capture techniques help decrease the amount of carbon dioxide released into the atmosphere, and pave the way for new storage and disposal methods and new industrial uses for the gas. The International Test Centre has two components:

i) A $5.2-million (~ Rs 25 crores) pre-commercial scale technology demonstration plant at SaskPower's Boundary Dam Power Station near Estevan

ii) A $3.3-million (~ Rs 15 crores) pilot plant at the University for greenhouse gas technology development and screening.

7.5.5.2 The group at the test centre has been working on advanced CO_2 separation technologies, targeting the main application areas of industrial gas processing and CO_2 removal from flue gases and other industrial gas streams. The ultimate goal of the research programme is to develop more effective CO_2 separation processes to remove CO_2 from the above-mentioned applications. Since CO_2 capture and storage is very energy intensive their work has focussed on cost reduction as well as reducing energy penalties. The work deals with research projects related to high efficiency CO_2 separation processes.

7.5.5.3 It is suggested that India carry-out similar and other related research programmes so that it will facilitate technology absorption and innovation. The topics suggested are:

- Determination of CO_2 absorption capacity
- Evaluations of Thermodynamic Data (related to gas separation processes)
- Studies of CO_2 absorption kinetics in various solvents
- Formulation of high performance CO_2 absorption solvents
- Searching for high performance absorbers and regenerators
- Studies of Reactive Membranes for Gas Separation Processes
- Developing design strategies for high efficiency CO_2 absorption processes
- Studies of corrosion and corrosion control in CO_2 & Solvent environments
- Studies of solvent degradation in CO_2 absorption processes
- Modelling and simulation of gas separation processes
- Optimisation and cost studies of cogeneration-based CO_2 capture
- Knowledge-based systems for solvent selection in CO_2 separation processes
- Intelligent monitoring and control of CO_2 generating systems

7.5.6 Requirement of Funds

An amount of Rs. 125.00 crores is projected as the requirement of funds for doing R&D in Carbon Capture and Storage (including climate change issues) in the eleventh five year plan.

Section – VIII

Ultra Super Critical Technologies

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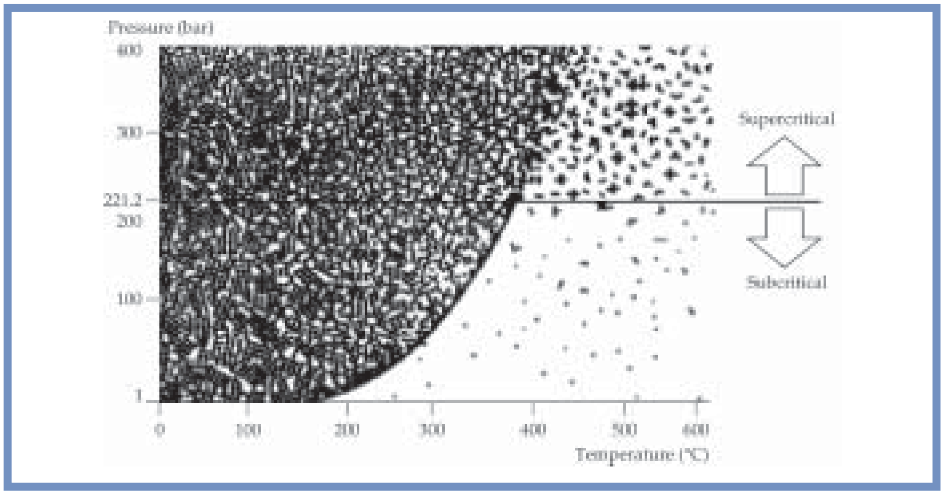
8.1 What is Critical About Supercritical?

8.1.1 There's nothing "critical" about supercritical. "Supercritical" is a thermodynamic expression describing the state of a substance where there is no clear distinction between the liquid and the gaseous phase (i.e. they are a homogenous fluid). Water reaches this state at a pressure above 22,1 megapascals (MPa).

Molecular Structure of Water as Function of Pressure and Temperature



8.1.2 The "efficiency" of the thermodynamic process of a coal fired power plant describes how much of the energy that is fed into the cycle is converted into electrical energy. The greater the output of electrical energy for a given amount of energy input, the higher the efficiency. If the energy input to the cycle is kept constant, the output can be increased by selecting elevated pressures and temperatures for the water-steam cycle. Power plants operating at supercritical steam pressures are termed as "Supercritical" power plants.

8.1.3 Supercritical power plants, due to their higher efficiencies, have significantly lower emissions of pollutants such as fly ash, and Oxides of Sulphur and Nitrogen than sub-critical plants for a given power output.

8.1.4 Up to an operating pressure of around 19 MPa in the evaporator part of the boiler, the cycle is sub-critical. This means, that there is a non-homogeneous mixture of water and steam in the evaporator part of the boiler. In this case a drum-type boiler is used because the steam needs to be separated from water in the drum of the boiler before it is superheated and led into the turbine. Above an operating pressure of 22,1 MPa in the evaporator part of the boiler, the cycle is supercritical. The cycle medium is a single phase fluid with homogeneous properties and there is no need to separate steam from water in a drum. Once-through boilers are therefore used in supercritical cycles.

8.2 Advanced Steels

8.2.1 Currently, for once-through boilers, operating pressures up to 30 MPa represent the state of the art. However, advanced steel types must be used for components such as the boiler and the live steam and hot reheat steam piping that are in direct contact with steam under elevated conditions. Therefore, a techno-economic evaluation is the basis for the selection of the appropriate cycle parameters.

8.2.2 Steam conditions up to 30 MPa / 600°C / 620°C are achieved using steels with 12 % chromium content. Up to 31,5 MPa / 620°C / 620°C is achieved using Austenite, which is a proven, but expensive, material. Nickel-based alloys, e. g. Inconel, would permit 35 MPa / 700°C / 720°C, yielding efficiencies up to 48%. Manufacturers and operators in Europe and other countries are cooperating in publically sponsored R&D projects with the aim of constructing a demonstration power plant of this type.

8.3 The Turbine Generator Set

8.3.1 There are several turbine designs available for use in supercritical power plants. These designs need not fundamentally differ from designs used in subcritical power plants. However, due to the fact that the steam pressure and temperature are more elevated in supercritical plants, the wall-thickness and the materials selected for the high-pressure turbine section need reconsideration. Furthermore, the design of the turbine generator set must allow flexibility in operation. While subcritical power plants using drum-type boilers are limited in their load change rate due to the boiler drum (a component requiring a very high wall thickness), supercritical power plants using once-through boilers can achieve quick load changes when the turbine is of suitable design.

8.4 The Boiler

8.4.1 Apart from the turbine generator set, the boiler is a key component in modern, coal fired power plants. Its concept, design and integration into the overall plant considerably influence costs, operating behavior and availability of the power plant.

8.4.2 Once-through boilers have been favored in many countries, for more than 30 years. They can be used up to a pressure of more than 30 MPa without any change in the process engineering. Wall thicknesses of the tubes and headers however need to be designed to match the planned pressure level. At the same time, the drum of the drum-type boiler which is very heavy and located on the top of the boiler can be eliminated.

8.5 Other Power Plant Cycle Components

8.5.1 A comparison of the water-steam cycle equipment in subcritical and supercritical coal fired power plants shows that the differences are limited to a relatively small number of components i.e. to the feedwater pumps and the equipment in the high pressure feedwater train i.e. downstream of the feedwater pumps.

8.6 Operational Issues

8.6.1 More than 400 supercritical power plants are operating in the US, in Europe, Russia and in Japan. Due to different approaches in their design and operation performance results are not uniform. While the rapid introduction of very large plants in the US in the early 70s created problems in the availability, due to forced outage, of these plants, feedback from other operators is very positive. Availability of supercritical plants, operating in other countries are reported to be equal or even higher than those of comparable sub-critical plants.

8.6.2 There are no operational limitations due to once-through boilers compared to drum type boilers. In fact once-through boilers are considered better suited to frequent load variations than drum type boilers, since the drum is a component with a high wall thickness, requiring controlled heating.

8.6.3 Once-through boilers do not have a boiler blowdown. This has a positive effect on the water balance of the plant with less condensate needing to be fed into the water-steam cycle and less waste water to be disposed of.

8.7 Possible Areas of R&D for the Development of Ultra Super Critical Technologies

8.7.1 The following are some of the possible areas of R&D: -

i) Material development to withstand high pressure, high temperature, oxidation, erosion and corrosion for steam generator tubes, main steam piping and high pressure turbine.

ii) Know-why development involving heat transfer, pressure drop, flow stability at ultra-supercritical conditions.

8.8 Requirement of Funds

An amount of Rs. 30.00 crores is projected as the requirement of funds for doing R&D in Ultra Super Critical Technologies in the eleventh five year plan.

Section – IX

Provenness of New Technologies Developed Indigenously

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9.1. Introduction

9.1.1 The key impediment for wider acceptance / commercialization of indigenous technologies has been the proven-ness. Even if some of the technologies which have been successfully proven on semi-commercial / demonstration scale, the insistence by clients for multiple references and references for similar objectives has been a major deterrence. Some affirmative actions are urgently needed to back the efforts of commercialization of indigenous technologies.

9.1.2 In many of the cases the scale and complexities of the process units make the process technologies very capital intensive. Clients do not favor selecting any new technology and always prefer technologies having previous references. Proven-ness is a key factor for selection of technology in most of the industries. This factor acts against the commercialization of indigenously developed technologies as clients insist on reference and unless, the indigenous technology is commercialized, there cannot be any reference.

9.1.3 The following actions are being proposed:

A) Promote upscaling & commercialization of indigenous process technologies

i) The scale and complexities of process units in petroleum refining make the process technologies very capital intensive. The technology obsolescence factor is not high and process units, once installed, are expected to operate for 2-5 years or even more in some cases. As a result, refiners do not favor selecting any new technology and always prefer technologies having previous references. Proven-ness is a key factor for selection of technology in petroleum refining industry. This factor acts against the commercialization of indigenously developed technologies as refineries insist on reference and unless, the indigenous technology is commercialized, there cannot be any reference. One way to break this deadlock would be to offer refineries suitable tax incentives in line with those given in backward areas or SEZs or by states for promoting investment, so that there would be a positive factor for them to decide in favor of commercializing technologies based on indigenous R&D. In this regard, it is proposed that tax incentives e.g. excise duty waiver or reduction etc. should be given to the refinery for **the first-time implementation of an indigenous technology on commercial scale / semi-commercial scale**. This inducement would encourage refineries to relax their strict norms for prior reference to opt for first time user of an indigenous technology. This unit, later on, would act as a demonstration-cum-reference unit for subsequent commercialization.

ii) In general, the product price of a reasonable size pilot plant cannot compete with the product price of an economic size commercial plant. Providing some incentives to this gap in product price may encourage the clients to invest in the pilot scale or semi-commercial scale facility before going to commercialization. To cover up the viability gap on product price of pilot scale plant and economic size plant, excise duty concession should be given to the clients for the **first-time implementation** of an indigenous technology on semi-commercial scale or reasonable size pilot scale.

B) Screening of new indigenous technology by experts

i) It is suggested for setting-up of sectoral expert committees consisting of renowned experts drawn from industries, ministries and academia for screening of newly developed indigenous technology / products through critical review of all the laboratory / pilot plant data to ascertain the suitability of the claims of the inventors and technology developers and to assess the risk potential. It is assumed that whenever a new indigenous technology would pass the techno-commercial evaluation criteria of the expert committee, it would not be rejected by the clients for want of commercial reference. Clients would then be in comfort level for considering a technology for commercialization.

ii) Before creating a new mechanism, it may be useful to explore whether the existing Sectoral Scientific Advisory Committees (SAC) under different Ministries, could be made effective and strengthened to be empowered for certifying the indigenously developed technologies for commercialization.

iii) It may be made quasi-mandatory for the clients to accept the recommendations of the SAC experts on a new indigenous technology while tendering. Otherwise, clients would have to justify for the rejection of an indigenous technology once expert committees recommend it.

C) Technical collaboration with experienced licensers

i) When an Indian technology developer has been tied-up with a reputed and established international partner for development of an indigenous technology, the expertise and history of the international partner should be given equal weightage with that of the Indian partner while qualifying for the criteria of proven-ness and prior reference and handholding of such technologies.

D) Customs duty waiver for in-house R&D centers

i) Research and development for new technologies requires import of many sophisticated equipment and pilot plant. It is proposed that to encourage the R&D centers of commercial organizations particularly PSUs (DSIR recognized), the waiver in customs duty to be given like CSIR laboratories and academic institutions.

E) It may be noted that many of the above recommendations have also been made in the report of the Sub-Committee of SAC-C submitted to PSA under the Chairmanship of Dr. V. Krishnamurthy, Former Member, Planning Commission on "**Stimulating Demand for Indigenous Technology Products**". Examples are:

i) Stipulation on the Indian bidder in the commercialization of indigenous technology / products that it has been supplied in the international market or have foreign collaborator or in commercial operation for 3/5 years needs to be reversed once the proven-ness is cleared by the expert committee subject to the performance guarantees / warrantees provided by the technology developer.

ii) One should encourage establishments with products and services with reasonable content of indigenous technology, so long it is offered by reputed organization or the products backed by adequate technology support and tested to international standards. Thus a change in purchase procedure is essential for encouraging indigenous technology developers to facilitate in the competition with foreign counterparts.

iii) For such cases where technology development is mature at pre-commercial launch levels, it is important that the matter is taken-up at higher level in the Government for evolving simplified procedures to encourage indigenously researched products, especially when the Government is the buyer or is funding the projects.

iv) The requirements of prior field experience for all types of indigenously generated products that satisfy the specifications and other test requirements normally stipulated by the takers may be eliminated.

v) For helping the smaller industries, proper testing facilities may be created with certifying authorities so that users feel confident of the quality of the products.

vi) New / emerging technologies can be undertaken tuning them at the conceptual stage itself to the requirements of the users. A few such technologies that can be advantageous to the economy, can be concentrated upon by users and technology providers.

vii) Indigenous technology / products development itself be sponsored by the users of the products. This practice is quite common in the Japanese and Korean industry as well as in China.

viii) Policy makers and programme manages should be kept informed by the technology generators about the status of indigenous lab level technologies developed by them in a manner, which is comprehensive and relating to the needs of the users.

9.2. Case Studies

Examples of indigenous technologies developed by Indian Petroleum R&D institutes and BHEL (R&D) are as under: -

9.2.1 Major Technologies / Products / Services Developed by Indian Petroleum R&D Institutes

a) Process technologies

- **INDMAX:** Residue upgradation to LPG, light olefins and high octane Gasoline
- **INDE Treat and INDE Sweet:** Effective removal or conversion of undesirable sulpur components, naphthenic acids, acid gases from LPG, light and middle distillates, natural gas and fuel gas
- **Oililvorous-S:** Bio-remediation of oily sludge
- **Needle Coke:** Production of needle coke

- **INDALIN+ :** Conversion of various naphtha streams to LPG and gasoline
- **Naphtha Hydrocracking:** Conversion of naphtha streams to Auto LPG and gasoline through hydrocracking
- **Hydroprocessing Technologies:** Diesel hydrotreating, Food Grade hexane
- **Separation Processes:** Aromatic extraction, dewaxing ,deasphalting
- **Conversion processes:** Catalytic reforming (SR&CCR), visbreaking & delayed coking

b) Products

- **i-Max** Super catalyst additive for LPG boosting
- **VGO hydrocracking catalyst** for maximization of HSD and LPG
- ***SERVO*®-DS** Stabilizer for distillate fuels
- ***SERVO*®- AO** Antioxidant for various types of gasoline blends including thermally and catalytically cracked components
- ***SERVO*®-LI** Diesel lubricity improver
- **Models/Simulators for** refinery processes
- **Specialty additives & chemicals**

c) Services

- Hydroprocessing and FCC Catalyst Management, evaluation, revamp and technical solutions, pilot plant studies
- Thermal Cracking technical solutions
- Maximization of LPG in FCC and hydrocracking processes
- Crude evaluation / assay
- Analytical sciences
- Performance evaluation of fuels, lubricants & greases
- Material Failure Analysis (MFA), Remaining life Assessment (RLA) of Refinery / Pipeline / Marketing equipment & installations
- Setting up of petroleum R&D laboratory
- Tribological / Engine aspects of fuels & lubricants
- Field trials and emission testing of lubricants and fuels
- Bio-diesel: Process for production

Some of these technologies have been successfully demonstrated in commercial or semi-commercial scale. However, the key impediment for wider acceptance / commercialization of indigenous technologies has been the proven-ness.

9.2.2 BHEL R&D Practices for Introducing New Products (Not Supported by Collaborators)

a) The new products pass through many of the following steps as a requirement for customer acceptance.

i) Design as per specification / market requirement

ii) Validation of design by standard softwares

iii) Quality checks for models/hardwares developed

iv) Validation of design by design vetting team with members drawn from other units/ academic institutions /outside agencies.

v) Model making and performance prediction by model testing as per Standards

vi) Prototype testing at Standard testing places /Labs

vii) Customer witnessing of model tests

viii) Site validation / field testing

ix) Offer to customer as free demonstration unit

x) Offer to customer at designed cost

xi) Providing performance guarantee for a specified period

b) The above procedure has been followed in the cases enclosed (boiler feed pump, 8 MW High Speed Impulse Turbine, Hydro turbine, GIS, C&I products etc).

c) The above customer specific persuasive steps work well with customers with good rapport and on projects non-funded by agencies like World Bank. However, we have real problems in fulfilling criteria such as similar products working for 2-3 yrs at 2-3 places for funded projects.

9.2.3. Provenness in T&D Products: Example 145 KV GIS:

a) Subsequent to globalization, BHEL has taken keen initiative in developing state-of-the-art equipment for use in Energy sectors. The equipment developed address a wide range of applications in prime areas like Generation, Transmission & Distribution (T&D) and Industry.

b) One of the prime equipment indigenously developed in the field of T&D is a “Gas Insulated Substations (GIS)” for 145kV systems.

c) It is experienced that the demonstration sites are not offered by the utilities for reliability related issues and lack of experience with the new equipment. Sites for demonstration are seldom offered by the utilities even if the installation is offered at no cost.

d) The qualification requirements like field experience are added in tenders for such installations. This requirement is not met by the manufacturers in the country for reason sighted above. The qualification criteria varies from 15 to 5 years depending on voltage class of such equipment. This tender requirement has been a factor-prohibiting introduction of indigenous equipment in the country through tendering route. Other modes of purchasing the equipment are not entertained by the utilities for reasons of providing equal opportunity to suppliers. The qualification requirements also varies in time and quantity from utility to utility.

e) While it may be essential to introduce a qualification requirement to block products manufactured in other countries on this ground, a provision for introducing **Indian technology** on negotiated basis shall be available to the utilities for encouraging new developments in the country.

f) Provision of such a means will not only help introduction of new GIS technology, but will also help generating required qualification with time. The exercise in long term will add to country's wealth and render independence in critical technology area of T&D.

9.3. Policy Recommendations

9.3.1 During the second meeting of **the Working Group**, a need was felt to develop high value materials for energy sector particularly the power sector which are very cost intensive. Dr. Baldev Raj, a special invitee to the meeting, has explained to continue the research in this area so that indigenous materials can be developed saving billions of dollars in foreign exchange. It was also discussed and deliberated that it will be essential to create a certification authority to certify and predict the satisfactory performance in the actual application of the materials being developed indigenously.

9.3.2 To quote one of the examples, in the area of aviation of lubricant technology it has been observed that the indigenous products developed, need to be qualified after testing vigorously as per stipulated standards and taking into confidence of Aviation OEMs. In this category, it is relevant to mention that currently Indian Civil Aviation industry uses lubricants which are being imported from Exxonmobil and Shell which are overseas companies based on the already proven/ certified status of their products. After World war II, the French Govt. made it mandatory to use the lubricants from French company specially for Aviation applications so that at the time of need the national security can not be put in danger. To meet the requirements of Indian Air Force, activities were conducted in 1980s by Defence forces including IAF, Indian Oil and other agencies in India to develop defence requirements and some of the products were indigenised, and are being used in some of the applications. Some of the special aviation products are still being imported in the absence of certification. The efforts are being made to indigenize these special products locally either through creating a manufacturing facility based on Nyco France technology at AVI Oil (having only approvals for Defence Aircrafts) or developing equivalent aviation engine lubricant through a collaborative programme taken-up by DRDO/CSIR Labs along with IOC R&D Centre. These activities of indigenization will be complete only if there is a set up of a full-fledged indigenous certifying agency.

9.3.3 Based on the above, it can be concluded that there is a need to form a certification agency either under the umbrella of Bureau of Indian Standard or any such organization which can formulate the terms and reference for this agency to work in this direction for energy sector. A suitable committee can address the following parameters to finally chalk-out a definite plan: -

i) To form specification for development of materials in order to maintain its consistency and quality.

ii) Formulate scheme / protocol for evaluation of such materials.

iii) Need to install / commission test facilities as per standard protocols used nationally or internationally.

iv) Actual application trials for the satisfactory performance in working equipments under close monitoring.

v) Formulation of certification authority based on parameters explained above.

vi) Documentation of all such methodologies and creation of approving authority.

Section – X

R&D in the Power Sector

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10.1. The Indian Power Sector is facing major challenges today with the introduction of Reforms, Globalization and Liberalization policy of the Government. Despite our country's planners attaching utmost importance to energy sector since beginning and there being manifold increase in installed generation capacity and transmission networks, energy and peak power shortages are not only continuing, but further increasing. Besides power shortages, even the quality of the power supply in respect to reliability, stability and security is not ensured. It is of vital importance to focus our attention now on ways and means to build expertise within the country, to find solutions for the problems existing in the system and also for the problems that may arise in the future. Research is urgently needed to bridge the knowledge and technology gaps, more so due to changes in technology today at a more profound and faster pace in the new millennium.

10.2. Realizing the importance of Research & Development, the Ministry of Power constituted a Standing Committee on R&D to frame 15 years Perspective Plan for R&D in the Indian Power Sector. While formulating the National Perspective Plan, the Committee critically reviewed the growth of the power sector, assessed the existing R&D infrastructure in the country and identified the crucial R&D needs for the power sector. All the key players like CEA, CPRI, NTPC, POWER GRID, NHPC, NEEPCO, BBMB, DVC, NPTI, THDC, NJPC, IITs and BHEL had participated in that task and brought out a report in June, 2002.

10.3. The Working Group feels that it would be worthwhile to reproduce here, in tabular form, the sector-wise summary of funds requirement for conducting R&D activities in the power sector, as given by the Committee in its Report: -

All figures in Rs. crores.

Budget Requirements	First Five Years			Second Five Years		
	S	M	L	S	M	L
Thermal Power generation	640	20	5	-	320	5
Hydro Power generation	100	10	5	25	100	25
Nuclear Power generation	-	10	5	-	70	5
Renewable sources	50	5	5	-	55	5
Transmission	35	100	5	-	250	10
Distribution	100	50	-	50	130	-
Human resources development	10	-	-	5	-	-
R&D Infrastructure developments	20	-	-	20	-	-
Total	**955**	**195**	**25**	**100**	**925**	**50**
Grand Total	**1175**			**1075**		

S-Short term projects ***M-Medium term projects*** ***L-long term projects.***

10.4. The suggestions of the Working Group on the measures to be taken for the upgradation of the testing facilities in a key research institute of the power sector – i.e. the Central Power Research Institute (CPRI), Bangalore – are summarized in the ***Annexure-VIII***. Those suggestions have also been endorsed by the Director General, CPRI.

Section – XI

Renewable Energy R&D

Author:

i. **Dr. Bibek Bandyopadhyay, Scientist 'G' and Head, Solar Energy Centre, Ministry of Non-conventional Energy Sources (now the Ministry of New and Renewable Energy), New Delhi -** ***Member.***

11.1 Introduction

11.1.1 India needs to sustain an annual economic growth rate of 8-10% for quite some time to be able to meet its economic and human development goals. Such a growth rate would generate progressively increasing demands for energy. To sustain a growth rate of 8% upto 2032, India would, in the very least, need to increase its energy supply by 3 to 4 times, and electricity supply by 5 to 7 times of today's levels. Currently, the Indian economy is dependent on a complex energy mix. This includes around 30% of non-commercial energy sources that are being used in an extremely inefficient way to imported petroleum products. India's fossil fuels are likely to last about 50 years if the consumption pattern continues to grow at existing rates, and with the uncertain and volatile nature of international crude prices (and possibly supplies) it is important that we look for alternatives to reduce this dependence.

11.1.2 Located in the tropical region, India is endowed with abundant natural sources of energy, which are perennial and environmentally desirable. The estimated potential of power generation from these various sources at current level of technology itself is over 100,000 MW. This is apart from the huge potential of harnessing thermal energy from various renewable energy sources. For over more than two decades, several renewable energy technologies have been developed and deployed. However, there is an urgent need to improve the performance of existing technologies and develop new and emerging technologies. Technological progress has taken place in the sector both in the country and elsewhere. Many of the technologies have emerged and some more are expected to emerge as powerful contributors to the global energy mix. Global investment in the renewable energy sector rose from $30 billion in 2004 to $39 billion in 2005. The largest investments have been in bio-diesel, grid-connected solar photovoltaic and wind power. Bio-diesel production in 2005 doubled from that in 2004, while solar PV capacity increased by 60% and wind power capacity by 24%. From long term perspective, it is now an ideal time to advance this clean power and energy for decades to come and set our goals for short term and long term achievements. Therefore, we must expand and accelerate the Research, Design & Development (RD&D) efforts in renewable energy technologies so that we can secure supply of low cost, clean and sustainable energy sources.

11.1.3 RD&D carried-out during the past 10 years has been somewhat inadequate to make a dent on indigenous commercial production as a bulk of this research was carried-out in research institutions and universities without adequate inter-linkages with industry. Outputs of RD&D projects need to be clearly established beforehand and funding needs determined in relation with those outputs and the effort required to attain these outputs. However, investment in the past in RD&D could be treated as an exercise in capacity building, which should come in very handy during the 11th Plan to launch major initiatives. Recently, the Ministry has prepared a detailed document about RD&D goals, aims; focus areas and related aspects, which is available on the website of the Ministry. During the 11th Plan, as far as possible, RD&D efforts must be carried-out in association with industry.

11.2 Potential of Renewable Energy Technologies

11.2.1 India is endowed with enormous potential of renewable energy resources to meet its energy needs. However, in spite of large potential the high cost and need for storage are some of the major barriers in large scale diffusion of renewable energy technologies. It is recognized that there is a down ward trend in the cost of renewables and the reliability is gradually improving. In the Indian context power generation from wind and biomass has become near commercial. However, the decentralized energy applications require significant cost reduction to be adopted on large scale without subsidy support from the Government. The long term benefit of renewable energy technologies and associated social and environmental gains justify subsidy for renewables. In this context the potential of different renewable energy technologies that can be effectively harnessed would largely depend on the future technology developments and breakthrough for cost reduction.

11.3 Estimated Potential of Major Renewable Energy Sources in the Country

- Biomass Power : 69,000 MW
  - Agro residues : 16,000 MW
  - Bagasse : 5,000 MW
  - Plantations : 45,000 MW*****
  - Waste to Energy : 3,000 MW
- Wind Power : 45,000 MW******
- Solar Power : 50,000 MW*******
- Small Hydro Power : 15,000 MW
- Biogas Plants : 12 million
- Biofuels : 20 MMT / annum

***** A potential of 45,000MW is feasible from biomass plantation on around 20 m ha of waste lands yielding 10MT / ha / annum of woody biomass given 4000 kcal / kg with system efficiency of 30% and 75% PLF. Bringing waste lands under biomass cultivation would require a major inter ministerial effort.

****** Considering sites having wind power density of 250 W / sq.m. or higher and assuming 3% land availability and area requirement for wind farm at 12 ha / MW.

******* Depending upon future developments that might make solar technology cost competitive for grid power generation.

11.4 RD&D Objective

11.4.1 The main objective of RD&D during the 11th plan and beyond is to reduce the cost, improve the performance efficiency, reliability and life of the systems for energy independence of the country through clean and sustainable renewable energy technologies.

11.5 Priority Areas of RD&D in Renewable Energy Technologies

11.5.1 The Integrated Energy Policy Report, prepared by the Planning Commission, has recognized that “From a long term perspective and keeping in mind the need to maximally develop domestic supply options as well as the need to diversify energy sources, renewables remain important to

India's energy sector. It would not be out of place to mention that solar power could be an important player in India attaining energy independence in the long run. With a concerted push and a 40 fold increase in their contribution to the primary energy, renewables may account for only 5 -6% of India's energy mix by 2031-32. While this figure appears small, the distributed nature of renewables can provide many socio-economic benefits.

11.5.2 The global projections for deployment of renewable energy technologies are more promising. Germany plans to generate 20% of its electricity from renewables by 2020 and Sweden intends to give up fossil fuels entirely. In USA also a number of states have adopted standards setting a minimum goal for the electricity generation from renewables. Therefore, our efforts should be to exceed this projection and aim for higher percentage of electricity generation from renewables. However, this will call for extensive RD&D efforts to make renewable energy technologies more reliable, long life and cost effective.

11.5.3 While the Ministry would continue to support development and deployment of various renewable energy technologies, keeping in view the short term and long term energy interest of the country, it would be necessary to focus on some specific technologies during the 11th plan that needs to be pursued more vigorously.

11.5.4 With a view to accelerate RD&D efforts in renewable energy, the Ministry has identified Solar energy, Wind energy, Bio-fuels and Hydrogen / Fuel Cell technologies, where time bound focused RD&D efforts are required to meet the short term, as well as long term research goals. The short term goals for various renewable energy technologies during the 11th plan period are given in ***Annexure- IX***.

11.5.5 The RD&D activities need to be oriented towards meeting systems/ equipment requirement for the following deployment aims for wider use of renewable energy technologies in the country:

i) Grid interactive renewable power: Around 10% of the additional grid power installed capacity to be met through renewable power by 2012 and around 15% by 2032.

ii) Alternate Fuels – bio-fuels, synthetic fuels and hydrogen: Substitution of up to 10% oil by bio-fuels, synthetic fuels and hydrogen in transport, portable and stationary applications by 2032.

iii) Energy recovery (about 25%) from municipal waste – in 423 classes-I cities including 107 municipal corporations where suitable waste is available – by 2032.

iv) Solar Water heating systems -100% coverage of major community users like hotels and hospitals etc. by 2032.

v) 100% coverage of street lighting control systems by solar sensors in 423 class-I cities including 107 municipal corporations by 2022.

vi) Energy recovery from industrial wastes (25%) where suitable waste is available across the country – by 2032.

vii) Solar Water heating systems – 100% coverage of select industries which have significant pre-heating requirement, by 2032.

viii) Cogeneration – 100% coverage of potential sugar and other biomass based Industry by 2032

ix) Provision of lighting / electricity in around 10,000 remote un-electrified census villages apart from remote hamlets of electrified census villages – by 2012

x) Augmentation of cooking, lighting and motive power through renewable energy means in electrified villages – by 2032.

11.6 Budgetary Estimates for 11th Plan

11.6.1 An amount of Rs. 1085.00 crores is required to support RD&D on different aspects of renewable energy technologies, as per details given in ***Annexure-X***.

11.7 The RD&D Structure

11.7.1 Elements of research

i) Establish a research portfolio broad enough to encompass basic science, to technology development, to prototype development.

ii) Establish research priorities based on market opportunities.

iii) Attract and involve the best and the brightest brains wherever available to get the work done.

iv) Ensure synergy throughout the process between Government, academia, research labs, and industry so that all issues of policy, funding, technology and marketing are comprehensively addressed.

11.7.2 Increased investments and a dynamic Government-Industry partnership will revitalize R&D programmes, accelerate revolutionary advances and lead to new discoveries to help attain our energy security goals.

11.7.3 The benefits of renewable energy research have never been more critical, for these are the technologies that benefit our environment, our economy and our security.

11.7.4 It is recognized that the long term interest of the country in developing and harnessing the renewable energy technologies would be better served when indigenous RDD efforts are encouraged and supported by the Government. The Government needs to take a liberal approach in developing emerging technologies and processes. The risk in developing new and emerging technology ideas, where the benefits of the technology development are not to be necessarily visible in next 3–5 years, the risk must be covered largely by the Government. However, wherever the technologies have matured to certain extent and are already being pursued by the industry in commercial / semi commercial manner, the research support should be based on the principle of sharing the benefits and the costs. The overall approach of the R&D support in the renewable energy sector should aim at achieving significant reduction in the cost and improving the product life and reliability.

11.7.5 The thrust areas for RDD efforts in various renewable energy technologies have been identified to achieve the short term goals of the 11th plan as well as the long term goals to develop new technology concepts.

11.7.6 There are several funding mechanisms for technology initiatives that exist today. For example, the Technology Development Board funds commercialization of research but it focuses generally on short-term goals. Some years back, the "New Millennium Indian Technology Leadership Initiative" (NMITLI) was announced which is a consortia based approach involving the partnership of the Government and private industry, technical labs, academic institutions, venture capital funds etc. with the partners being chosen through competitive bids for different elements of the programmes. The Ministry should also adopt such successful models developed by other Scientific Ministries, especially the DST and CSIR, to support RDD, technology absorption and technology transfer to facilitate RDD in renewable energy technologies. The integrated energy policy has also recommended creation of National Energy Fund (NEF) for supporting research in energy technologies.

11.7.7 The following further steps would be useful in giving a boost to the public-private partnership for:-

i) Creation of a global acquisition fund to support Indian firms in acquiring technology intensive foreign companies;

ii) Amending tax laws to facilitate treating knowledge as sweat equity;

iii) Encouraging Scientists and Academics to become innovation based entrepreneurs;

iv) Facilitating sharing of R&D facilities between a number of companies;

v) Promoting the movement of Scientists and technologists from industry to public R&D institutions and vice versa.

11.7.8 It will be necessary to get regular feed back from the industry to identify the specific areas of research / technology up gradation where industry needs immediate help in improving the product design, quality, reliability and bring about the desired cost reductions. Involvement of recognized R&D units in private sector needs to be encouraged. The Ministry will encourage and provide support to private and public sector to invest in and undertake R&D in renewable energy technologies.

11.7.9 The industry is expected to play an important role in absorption of research. Apart from supporting RDD involving industry, the Government will also facilitate patent search, patenting and technology transfer.

11.8 Indian Renewable Energy Industry

11.8.1 There has been a significant growth in the share of renewable energy sector in the total installed power generation capacity in the country during the last decade. A large number of decentralized / of grid devices / systems have been installed. The export of renewable energy devices / systems is also growing rapidly. This has been possible largely due to the growing share of indigenous manufacture of renewable energy systems for a variety of applications. Manufacturing units for such systems by several entrepreneurs are either independently set up or established as joint ventures with foreign collaboration. A number of small-scale and medium sector units are also engaged in the manufacture of parts, components and systems for the sector.

11.8.2 In addition to the setting up of manufacturing units in the country, it is important to ensure that the industry is able to make products as per the latest national and international standards and specifications. This will require setting-up of the world class R&D and testing and quality assurance facilities by the industries and also seek product qualification testing from independent national / international agencies. This will require partial financial support from the Government. The Government will provide a package of fiscal and financial incentives to industry to encourage (i) investments in the renewable energy sector, (ii) set-up world class testing and quality assurance facilities, (iii) obtain national / international product qualification certification and (iv) invest in R&D in the renewable energy sector to make the products more reliable and cost competitive.

11.8.3 It is proposed to provide the following additional incentives to Indian renewable energy industry

i) 150% accelerated depreciation to set up R&D Centres in the country in renewable energy, which must be recognized as R&D Centre by the Government

ii) Soft loan at 2 – 3 % annual interest rate, to be repaid in 8 – 10 years, for specified technologies, raw materials and components

iii) Grant support (50%) to seek international certificate for the purpose of exports.

iv) Grant / loan to encourage industry in setting up research facilities, pilot manufacturing facilities, to be identified by the Ministry from time-to-time.

11.8.4 The above-mentioned approach would help the Indian renewable energy industry in not only providing reliable and sustainable solutions for the growing energy needs of the country, but also help in attaining a leadership role in the world renewable energy market.

11.9 Awareness Creation

11.9.1 There is lack of sufficient awareness among various stakeholders about renewable energy applications and other benefits of renewable energy technologies. Governmental agencies including the local, Government, industry and academics need to be regularly informed about the benefits of renewable energy. Extensive educational and awareness programmes will be required to cover different target groups. This will include students, researchers, industry, service providers and various other agencies including local authorities dealing with building codes, fire, electricity distribution, transport safety and regulations etc. Separate curricula, suitable for different target groups, need to be developed and up-dated from time-to-time for imparting education about renewable energy to school children, college students, research students etc. Lack of specialized centres to impart education and training is another limitation, which needs to be over come during the 11^{th} plan.

11.10 Human Resource Development

11.10.1 It is recognized that no research and technology development can be sustained without specialized and skilled man power to undertake the work. The industry also requires trained manpower. Rapid growth in the renewable energy sector would be possible if trained manpower is available for variety of activities. The IITs and other Engineering colleges need to be pursued to design and develop specialized course in renewable energy. In addition, such institutes should be technically and financially supported to take-up projects to develop and demonstrate renewable energy products and participate in national and international competitions. Further to support manpower development at academic institutions and also in the research organizations, the Ministry would offer fellowships to undertake doctoral / post doctoral research in renewable energy, for a period ranging upto 5 years. This will help in establishing a work force of qualified scientists and engineers in the country in this fast growing sector.

11.11 Specialized Centres

11.11.1 The Ministry has already set-up some technology specific Centres – Solar Energy Centre (SEC), Centre for Wind Energy Technology (C-WET), National Institute for Renewable Energy (NIRE). In addition, Ministry provides support to Advanced Hydro Energy Centre (AHEC) at Roorkee. Keeping in view the ambitious research and development goals for various renewable energy technologies during the 11^{th} plan, it will be necessary to strengthen these Centres and redefine their role. With a view to consolidate research efforts and take-up advanced research and demonstration during the 11^{th} plan, these centres should also help in developing educational and training materials, organizing workshops and seminars and also coordinating research and technology development efforts in the specific technologies of their interest. These centers should also coordinate with international groups working in their areas of specialization, validate the technology demonstrations and assist the research groups, industry and the policy makers in bench marking the technologies from time-to-time.

11.11.2 In addition to the specialized centres for R&D, it is also necessary to identify various test laboratories / organizations with proven capabilities which can set-up specialized testing and certification facilities for different renewable energy products made in the country. These centres will be accredited by the Ministry in consultation with the specialized centres and BIS. This will ensure availability of reliable and quality products in the country and also facilitate export of products.

11.12 Conclusion

11.12.1 India has large human resource and entrepreneurship to design and develop innovative renewable energy systems that can be used by common man as well as feed power to the grid. The renewable energy technologies have potential to meet our emerging energy needs. A lot needs to be done for large scale diffusion of renewable energy technologies leading to energy independence of the country. This will require time bound and planned RD&D efforts to make them reliable, long life and easily accessible by reducing their cost and improving efficiency. By 2032 the renewable energy technologies should find a centre place in the over all energy mix of the country. The steps proposed for RD&D in renewable energy technologies in 11th plan and beyond would help India achieve this ambitious goal.

Section – XII

Energy Storage Systems

Author:

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12.1 Introduction

12.1.1 Man has devised myriad ways to generate, distribute and use energy. However, it is well recognized that our weakest link to future is energy storage. Methods for storage of electrical energy by use of flywheels and compressed air are still to mature. Electrochemical materials in rechargeable batteries and ultracapacitors provide a convenient and efficient medium for storage of energy on a small-to-medium scale. Because of their small size, modular design, silent operation, high efficiency, and instantaneous response, batteries and ultracapacitors are convenient power packs. Apart from providing energy on demand as for portable gadgets, remote area lighting and uninterruptible power supplies, these electrochemical devices can help buffer load fluctuations as well as meet power demands of emerging technologies such as in electric and hybrid electric vehicles, and satellites. The catastrophic anthropogenic environmental fallouts of our dependence on fossil fuels hang above us like the Democles' sword. In as much as we are concerned only by the end-use for energy such as in a flashlight or an MP3 player, our focus today is not on the oil, but on any convenient energy source. Now, if that energy can be made available at the touch of a button, it would add to our comfort and convenience. It is here that electrical energy becomes the most user-friendly. Batteries have an additional advantage: they are portable.

12.2 Applications Areas

12.2.1 Batteries in Industry and Commerce

i) The earliest stationary power application was in telephony, which then expanded into other areas such as railway signal system, lighting in operation theatres, communication gadgets, and miner's lamps. Today batteries are part of the uninterruptible power supply units of establishments, large and small, as well as in ships and submarines, computing facilities and nuclear control stations. They are also ideal for stand-alone applications, away from the main grid. In such cases as for remote lighting as is being exploited in the national literary mission, batteries can be coupled with a primary renewable source (wind energy, solar energy, biomass, etc.) as may suit the end-use locality.

ii) The industry relies heavily on batteries (forklift trucks, power tools) and so do other sectors such as medical care (hearing aids, heart pacemakers) and military (sonobuoys, missiles, ships, submarines) and space (satellites, space stations). Space power is a specialty application. Here, the batteries must be hermetically sealed, must be light and small, and must be capable of getting recharged with solar panels. Additionally, they must operate for the entire service life of the satellite, which may require more than 20,000 cycles, at low temperatures. In the case of electric vehicles, which is proving more popular given the alarming levels of pollution in our metropolises, batteries must be amenable to fast charge, must be loaded with enough energy to last a reasonably long trip, and must have the power to support acceleration and hill climbing.

12.2.2 Consumer Applications

The number of applications to which batteries are put to use is indeed mind-boggling. Batteries are so ubiquitous that their list of applications seems endless: home (flashlights, radios, clocks, door chimes, lawnmowers), consumer and entertainment (wrist watches, toothbrushes, children's toys, DVD players, digital cameras), communication (landline and cell phones, PDAs, computers), and transportation (SLI, central locking system and power windows).

12.2.3 Electric Traction

A theme that readily strikes when one thinks of electrochemical power systems is electric traction. Ever since it became the first car to break the 100 kmph barrier in 1899, the electric car has been an attractive proposition. They are quiet, nearly non-polluting, and have acceptable speeds and ranges. However, the internal combustion engine vehicles with more convenient features overtook the electric car and the bottom fell off the electric vehicle market. It must be noted that even after factoring in the engine weight and a low Carnot efficiency of about 30%, the energy that can be derived from gasoline, which has a theoretical storage efficiency of 12.3 kWh.kg^{-1}, is two orders higher than that of common batteries.

12.3 Battery Systems

The number of commercial storage batteries runs into more than a dozen. However, only those systems that hold promise for development and exploitation will be discussed here. It must be noted that the selection of a battery for an application is not straightforward. It depends upon the application, and the cost and technical specifications of the battery.

12.3.1 Lead-acid Batteries

i) The workhorse among the rechargeable batteries, the lead-acid battery caters to a multitude of portable, industrial and automotive applications as well as in the storage of solar and wind power. No wonder, this system commands 60% of the secondary battery market. In addition to traditional flooded electrolyte designs such as Plantè, Fauré (pasted) and tubular electrode types, valve-regulated cells with immobilized electrolyte are also manufactured. Much effort is expended in improving specific energy, specific power, deep-discharge cycle life and pulse power discharge characteristics of these batteries. Special mention must be made of research on cells with bipolar designs, and thin, light-weight and non-corroding substrates for electrodes. Sealing, gas recombination catalysts and battery heat dissipation are other aspects being addressed to improve safety, performance and life of the batteries. When it comes to peak power (150–400 W.kg^{-1}), lead-acid batteries have no competition, but efforts are on to increase the energy density of commercial batteries to 50 Wh.kg^{-1}.

ii) Lead-acid batteries are widely used as power sources for a number of slow-speed electric vehicles: forklift trucks, golf carts, etc. For such stationary applications as load-leveling and load-shaving, where battery mass is immaterial, the choice is invariably the lead-acid battery. The choice is natural given its availability in large ampere-hour capacities and low cost. Conventional flooded-electrolyte lead-acid batteries require topping-up and acid vapors from the batteries can pose corrosion hazards. Valve-regulated lead-acid batteries, on the other hand, release no acid spray and require no maintenance, and are, therefore, preferred.

12.3.2 Nickel-iron Batteries

Despite its attractive features such as low cost, ability to sustain about 3000 cycles, a calendar life of at least 20 years, tolerance to electrical and mechanical abuse, a specific energy of 50–60 $Wh.kg^{-1}$ and specific power of 80–150 $W.kg^{-1}$, the nickel-iron alkaline battery has somehow been sidelined. Of special interest to a tropical country like India is that nickel-iron batteries show better charge acceptance at elevated temperatures. Moreover, the ambient temperature in India permits the use of the cheaper sodium hydroxide as an electrolyte instead of potassium hydroxide. Key problems in commercializing this technology are poisoning of the iron electrode, gas evolution (requiring constant water maintenance), and high rate of self-discharge. It must be mentioned that scientists at the Indian Institute of Science have demonstrated a recombinant catalyst for use in nickel-iron batteries, opening the prospect of making them completely sealable. The erstwhile Soviet Union used nickel-iron batteries extensively in their railways and industrial trucks, where electrical efficiency was not an over-riding factor. Major application areas for nickel-iron batteries are in electric traction and forklift trucks.

12.3.3 Nickel-metal Hydride Batteries

For decades, the nickel-cadmium battery ruled the portable battery market. However, the toxicity of cadmium and memory effect slowly led to its eclipse by the nickel-metal hydride (Ni-MH) battery. Although the cell voltages of both the systems are almost the same (1.2–1.3 V), the specific energy and power of the Ni-MH system are higher (60–80 $Wh.kg^{-1}$; 200–300 $W.kg^{-1}$). Moreover, the pulse power capability of Ni-MH batteries is also higher. However, Ni-MH batteries fare poorly in relation to their predecessor in terms of cost, self-discharge rate and charge acceptance at elevated temperatures. Typical application areas for Ni-MH batteries are portable electronic devices such as cell phones, toys and calculators. Because of their high power capabilities, Ni-MH batteries are an attractive option for electric vehicles.

12.3.4 Lithium-ion Batteries

Although lithium-ion batteries hold a lion’s share in the consumer electronics market, price and safety are key barriers to totally replacing lead-acid or nickel-metal hydride batteries for load-leveling or electric vehicle applications. Lithium polymer electrolyte batteries with electrolyte-laden polymer membranes as separators are set to revolutionize the battery industry. Such batteries can be mass produced and are leak-proof, thin, flexible, and safe. However, today these power packs are limited to specialized electronic and aerospace applications where flexibility of shape and thinness of cells are desirable and cost is of secondary importance. Lithium-ion batteries have already established a niche market, especially in the cell phone industry. However, lithium-ion batteries are expensive and require considerable care in controlling the voltage during charging. The cost is escalated by incorporation of safety circuits and other protection mechanisms. Given their high energy and power densities

(80–180 $Wh.kg^{-1}$ and 200–1000 $W.kg^{-1}$, respectively), lithium-ion batteries are highly suitable for electric traction. However, this would call for a drastic reduction in cost as well as a substantial improvement in safety.

12.3.5 Zinc-air Batteries

Constructed with cheap, non-toxic materials and by simple manufacturing methods, this system represents one of the most economic devices for energy storage. Several countries including China and Germany have exploited the zinc-air system in electric scooters, and small fleets of minivans and buses. It has specific energy and power of 100–200 $Wh.kg^{-1}$ and 80–100 $W.kg^{-1}$, respectively. The cycle life of this system is typically 450 cycles. Zinc electrode shape change and deposit morphology are among problems that are being tackled on the anode side. In parallel, much effort is expended in developing an electrically rechargeable bifunctional air electrode. Additionally, problems relating to carbon corrosion, water transpiration and carbonation of the electrolyte need to be tackled.

12.3.6 Rechargeable Alkaline Manganese Dioxide Batteries

Zinc-Rechargeable Manganese Dioxide Cells (called RAM cells) are projected to conquer a large chunk of the consumer power source market. These cells combine a secondary zinc gel electrode with a rechargeable modified form of manganese dioxide in an alkaline electrolyte solution. A variant of this technology, where the zinc gel electrode is replaced with a metal hydride electrode, is also being developed. The technologies of the systems are similar to those of the Leclanché cell and nickel-cadmium / nickel-metal hydride, their manufacture will need minor alterations to existing production lines. One conspicuous advantage of RAM cells over other rechargeables is their excellent charge acceptance and charge retention at elevated temperatures, which make them attractive for tropical countries like ours. In the near-term, practical RAM batteries with an energy density of 80 $Wh.kg^{-1}$ and power density of 150 $W.kg^{-1}$ are expected to grip the small appliances powers source market as well as to create an impact in the electric vehicle scene.

12.4 Ultracapacitors

12.4.1 Electrochemical capacitors are similar to electrolytic capacitors except that they store electrostatic charge in the form of ions on the surface of materials with high surface areas. The electrical characteristics of electrochemical capacitors (also called double layer capacitors) are intermediate between batteries and conventional dielectric capacitors. Ultracapacitors are electrochemical capacitors in which an electrode of large surface area is combined with a material that can be reversibly oxidized and reduced over a wide potential range. For the same volume, ultracapacitors have 100 times the capacity of conventional capacitors and a peak specific power that is 100 times that of batteries. Moreover, they can be discharged at rates up to 10–20 times faster than batteries, and can sustain as many as 100,000 charge-discharge cycles. However, their energy density is 20–50 times lower than that of batteries. Since their commercial production by NEC and Matsushita in the late 1970s, electrochemical capacitors have drawn tremendous attention for applications in not only consumer gadgets but also in specialty sectors such as military, space and electric traction.

12.4.2 Ultracapacitors are ideal for sudden transient power demands, while batteries are ideal for continuous supply of energy. For hybrid electric traction applications, ultracapacitors are complementary to batteries: while the energy necessary for normal drive comes from batteries, ultracapacitors provide bursts of energy for acceleration and hill-climbing. The latter are also adept at accepting instantaneous regenerative energy during braking and downhill drives.

12.4.3 Electrochemical capacitors come in a variety of forms: double layer capacitors with activated carbons with sulfuric acid electrolyte (power density: 500 $Wh.kg^{-1}$; $W.kg^{-1}$) or organic liquid electrolyte (power density: 500–1000 $W.kg^{-1}$; and 5000 $W.kg^{-1}$ with advanced prototypes); metal oxide capacitors (power density: 2000 $W.kg^{-1}$; and 10,000 $W.kg^{-1}$ expected with hydrous ruthenium oxides); and conducting polymer capacitors (power density: <500 $W.kg^{-1}$). While the cyclability of the conducting polymer type is limited to over 10,000 cycles, the others can sustain about 100,000 cycles. The double layer capacitor is a more mature system compared to the others. Advancement in this category of energy storage systems depends on the synthesis and availability of new electrode materials.

12.5 Recycling Spent Batteries

12.5.1 Although batteries present little or no pollution at the sites of their use, there are environmental problems associated with their primary and secondary production (at places far away from the place of use) as well as their disposal. Moreover, battery cycling can pose environmental hazards. For example, recycling spent lead-acid batteries can release lead into the atmosphere. Lead is known to be a neurotoxin capable of reducing cognitive functions. Thus, the environmental effects of recycling should not be overlooked.

12.5.2 Batteries and ultracapacitors contain toxic metals that are potentially scarce. In fact, one of the restraining factors in the large scale exploitation of batteries is the limited availability of metals. The service life of the battery, recyclability of the metallic constituents, abundance and availability of metals, metal-winning processes, etc. have a definite effect on the extent of exploitation of metals in batteries and ultracapacitors. Apart from the metallic content in the anodes (cadmium, lead, lithium, sodium, zinc) and cathodes (cobalt, manganese, nickel, silver), passive components such as current collectors, lugs, bus bars, etc. are also made of metals. This calls for a regulated collection of spent batteries and ultracapacitors, and reclamation of metals therefrom. Collection of spent batteries from organized sectors is straightforward, but their consumption volume is small. However, the bulk consumer is the common man, who needs to be educated on the importance of conserving metals.

12.6 Battery Safety

12.6.1 Batteries contain highly energetic materials in a small volume. It is thus inevitable that battery abuse, often inadvertent, can lead to hazards. This is all the more a concern with lithium-based systems. However, safety concerns are not restricted to lithium battery systems alone. For example, in 2002 Nikon recalled 9,100 Coolpix 2000 digital cameras exported to the US because the AA-size alkaline cells in them presented a possible risk of short-circuit and overheating of the battery compartment. Notwithstanding the tacit acknowledgement by lithium battery scientists and manufacturers of the inherent risk posed by the highly energetic active materials that make-up these batteries, it is the market forces that drive the proliferation of lithium battery systems. The chemistry of lithium batteries dictates the use of highly active materials, leaving risk-related areas to be tackled separately.

12.6.2 A number of safety mechanisms have been suggested for safe use of lithium-ion batteries, and several have even been adopted: safety vents, thermal fuses, electronic charge controllers, positive temperature coefficient elements, shutdown separators, electrolyte constituents that are more oxidation-tolerant or less flammable, shutdown additives, and redox shuttles. One of the key areas that must be addressed in order to render lithium-ion battery technology safe is the electrolyte. There is increasing emphasis on the replacement of the conventional aprotic organic solvents with solid polymer electrolytes. Lithium-ion polymer batteries also offer higher energy densities and design flexibility. In parallel, electrolytes based on ionic liquids as well as non-flammable ones based on fluorinated and organophosphorus compounds are also being investigated. Attempts to tackle safety issues in lithium-ion batteries must be multi-pronged. Such a drive should pool in expertise from a variety of settings such as battery science and technology, materials science, polymer technology, solution chemistry, synthetic organic chemistry, thermal analysis, electronics, and packaging.

12.7 Battery Management

With the advent of mixed-signal electronic circuits (combined digital and analog circuits on a single chip) and with the emergence of applications with stringent power requirements, a battery management system becomes mandatory. Such a system should ensure proper regulation of charge-discharge protocols for different battery chemistries, monitor cell / battery temperature, gauge individual cell capacities in a pack, assess state-of-health of cells, and ensure safety. The system architecture would depend on the battery chemistry and end-use. It is necessary that such a monitoring system is based on sensors and measurement gadgets that work on low power, but with precision. Multi-functional chips are ideal for addressing the varied requirements of such a regulating mechanism.

12.8 Conclusions

The importance of investing in battery research needs no emphasis. The world market for batteries is a whopping US$ 55 billion. With new applications being unveiled by the day, this market is set on an exponential growth profile. Furthermore, advancements in electronics and miniaturization call for further improvements in existing battery technologies and search for new ones based on hitherto unexplored materials and concepts. It is predicted that India, along with Brazil, China, Czech Republic and South Korea, is set to register the strongest gains in battery market in the near future. It is, therefore, recommended that a Centre of Excellence for conducting R&D in energy storage systems be set-up at an appropriate location in the country. The approximate cost of setting-up such a Centre would be Rs. 150.00 crores.

12.9 Requirement of Funds: -

A total amount of Rs. 400.00 crores is projected as the requirement of funds for setting-up the said Centre of Excellence (Rs. 150.00 crores) and doing R&D in energy storage systems (Rs. 250.00 crores) in the eleventh five year plan.

Section – XIII

Futuristic Energy Sources

Author:

i. **Shir V.K. Sibal, Director General, Directorate General of Hydrocarbons, Ministry of Petroleum and Natural Gas, New Delhi –*Special Invitee*.**

13.1 Gas Hydrates:

13.1.1 Gas Hydrates are naturally occurring solids that are composed of water molecules forming a rigid lattice of cages around the methane gas molecules of low molecular weight. The gas hydrates occur below the seabed in deep oceans as well as in the permafrost regions of the world. Based on available scientific data, preliminary estimates for gas hydrates in India is about 1900 Trillion Cubic Metres (TCM). Detailed gas hydrate reserve estimates have not been made by Directorate General of Hydrocarbons for different areas till date. The National Gas Hydrate Programme (NGHP) was initiated in 1997 by the Ministry of Petroleum and Natural Gas with participating agencies i.e. Oil and Natural Gas Corporation Limited, GAIL (India) Limited, Directorate General of Hydrocarbons, Oil India Limited, National Geophysical Research Institute, National Institute of Oceanography and Department of Ocean Development. This programme was conceived by Government for exploring gas hydrates in the Indian deep waters. The programme was reconstituted in year 2000 by the Ministry of Petroleum and Natural Gas to give a greater thrust in this direction, by making Director General, Directorate General of Hydrocarbons, as Technical Coordinator of the programme, Secretary, Petroleum and Natural Gas as Chairman of Steering Committee and six technical working sub-groups, constituted by involving scientists / engineers from above mentioned organizations. Till date, since its inception, a large volume of seismic data covering entire offshore areas of the country has been studied that includes special processing of data for identification of gas hydrate signatures.

13.1.2 Based on these studies, three areas in Krishna-Godavari Basin, Andaman sea and west coast were identified for further scientific investigations. A road map was also prepared for NGHP. As per the road map, detailed geoscientific investigations were carried-out in the KG Basin and Kerala Konkan basin by the NGHP through National Institute of Oceanography. Based on the results of seismic data studies and geoscientific investigations, ten sites in Mahanadi, KG & KK basins and Andaman Sea were identified for drilling / coring of gas hydrates in the deepwaters. The drilling / coring for gas hydrates is a very specialized activity and India is the third country in the world to do so, after United States of America (USA) and Japan. The services for such specialized activity are not available commercially in the world. With sustained efforts by Directorate General of Hydrocarbons, with Integrated Ocean Drilling Program & USA, the drillship JOIDES Resolution along with all the scientific equipment and scientists onboard has carried-out drilling /coring in Indian offshore during the period April 2006 to August, 2006 under an agreement between Directorate General of Hydrocarbons and a “US Consortium” of companies.

13.1.3 The drilling / coring activities carried-out by the drillship indicated presence of large quantities of Gas Hydrates in one of the wells in K.G. Basin. A specialized core repository has been constructed in Panvel, Mumbai for storing all the valuable gas hydrate cores for future studies.

13.1.4 After completion of the studies, it would be possible to establish the presence of gas hydrates in the various selected sites. Detailed scientific studies of the core samples will be carried-out in Indian laboratories, as well as in the reputed foreign laboratories in the USA and Canada for which separate Memoranda of Understanding have been signed with United States Geological Survey (USGS), Department of Energy (DOE), USA and Natural Resource Council (NRC) of

Canada. Through these studies it will be possible to establish the gas hydrate characterization and the geological modeling in Indian offshore areas. In the next step, resource estimation for these selected areas will be carried-out during 2006-07 after acquiring state of the seismic data in the discovery areas.

13.1.5 Subsequently, the R&D work to develop simulation models and mathematical models through international cooperation is planned to be completed by 2008-09, followed by pilot production in the discovery area in K.G. basin and if commercially viable production technology is available anywhere in the world or in India, it is planned to begin commercial production of gas from gas hydrates beyond 2010-11.

13.1.6 During the Eleventh Five Year Plan, the above R&D programme including pilot production project and acquisition of further geo scientific data are estimated to cost around Rs.350.00 crores on a tentative basis.

13.2 Oil Shale

13.2.1 Preamble

i) Oil shales are usually fine-grained sedimentary rocks containing relatively large amounts of organic matter from which significant quantities of shale oil and combustible gas can be extracted by destructive distillation. The product thus generated is known as synthetic crude or more simply, syncrude. Included in most definitions of oil shale, either stated or implied, is the potential for the profitable extraction of shale oil and combustible gas or for burning as a fuel. An oil shale which has a very high proportion of organic matter in relation to mineral matter is categorized as a coal.

ii) Oil shales range in age from Cambrian to Tertiary and occur in many parts of the world. Deposits range in size from small occurrences of little or no economic value to those of enormous size that occupy thousands of square miles and contain many billion barrels of potentially extractable shale oil. Total world resources of oil shale are conservatively estimated at 2.6 trillion barrels. However, petroleum-based crude oil is cheaper to produce than shale oil because of the additional costs of mining and extracting the energy from oil shale. Because of these higher costs, only a few deposits of oil shale are currently being exploited in China, Brazil, and Estonia. However, with the continuing decline of petroleum supplies, accompanied by increasing costs of petroleum, oil shale presents opportunities for supplying some of the fossil energy needs of the world in the years ahead.

13.2.2 History of the Oil Shale Industry

i) The use of oil shale for extraction of shale oil is more than 200 years old. An oil shale deposit at Autun, France, was exploited commercially as early as 1839. The Scottish oil shale industry began about 1859, the year that Colonel Drake drilled his pioneer well at Titusville. As many as 20 beds of oil shale were mined at different times. Mining continued during the 1800s and by 1881 oil shale production had reached one million metric tonnes per year. With the exception of the Ward War II years, between 1 and 4 million metric tonnes of oil shale were mined yearly in Scotland from 1881 to 1955 when production began to decline, then ceased in 1962. Canada produced some shale oil from deposits in New Brunswick and Ontario in the mid-1800s. In Sweden, the alum shale was retorted for hydrocarbons on a small scale in the late 1800s. Production continued through World War II but ceased in 1966 because of the availability of cheaper supplies of petroleum crude oil.

ii) With the introduction of the mass production of automobiles and trucks in the early 1900s, the supposed shortage of gasoline encouraged the exploitation of oil shale deposits for transportation fuels in the United States of America (USA). Many companies were formed to develop oil shale deposits of the Green River Formation in western USA, especially in Colourado. The USA has an estimated 1.8 trillion barrels of oil trapped in shale, most of it concentrated in the Green River Formation, which covers northwest Colourado and parts of Utah and Wyoming. This estimate is more than all the proven reserves of crude oil in the world today.

iii) In the USA, many licenses were issued in the 1970s for exploitation of shale oil. However, after several large-scale mine facilities were developed in the 1970s, the work gradually ceased and the last large-scale mining and retorting facility in western USA which was operated by Unocal from 1980, closed down in the year 1991. Unocal produced 4.5 million barrels of oil from oil shale averaging 34 gallons of shale oil per tonne of rock over the life of the project.

iv) Estonia, Brazil and China are some of the countries that are actively involved in extraction of syncrude from oil shale. In the USA, major Research, Development and Demonstration projects are underway for the systematic exploitation of these resources. The best known of these is the Shell's Mahagony project in Uinta basin in USA.

13.2.3 The Indian Scenario

i) North-East India is endowed with rich deposits of coal. The coal is found in the Barail Formation of Tertiary age. Carbonaceous shale occurs interbedded with the coal. The presence of coal and shale has been recorded in wells drilled for hydrocarbons by the Oil and Natural Gas Corporation Limited and the Oil India Limited. These formations outcrop on the surface towards the south of the oil fields in a region called the Belt of Schuppen. Studies have indicated that these coals and carbonaceous shale constitute the principal source rocks that have generated the hydrocarbons produced from the region.

ii) The favorable characteristics of Assam coal for conversion to liquid fuels has been known for a long time. Central Fuel Research Institute (CFRI), Dhanbad had carried-out a feasibility study on this subject and submitted a report as far back as in 1968. Commonly, the assessment of the yield of hydrocarbons from coal or oil shale is based on pyrolysis or heating under controlled conditions. The standard method has been the Fischer Assay, a scaled down retorting process in which the residue and generated by-products viz. hydrocarbons are collected, measured and chemically analyzed. Evaluation of the yield potential can also be determined quantitatively by another pyrolysis technique called

Rock-Eval pyrolysis. In this equipment, small quantities of the sample are pyrolyzed under controlled conditions. The amount of hydrocarbons generated and expelled can be volumetrically determined by this method.

iii) In the late 1980s, Oil India Limited and Robertson Research Inc. (UK) had analyzed a large number of rock samples obtained from oil wells, outcrops and coal mines in connection with hydrocarbon exploration in the region. The Rock-Eval yields for the coal and carbonaceous shale indicate prolific hydrocarbon potential for Barail Coals, of the order of 280 kgs of hydrocarbons per tonne of rock. The Barail Series oil shale gave a maximum yield of about 80 kg hydrocarbons per tonne of rock. This compares favorably with some of the yield values obtained from other oil shale deposits in the world.

iv) Following a published report on the Oil Shale and Coal resources of the north east India, the government of India constituted a Task Force on Oil Shale and related Coal from the north eastern region under the Chairmanship of Sri. B.K. Rao, former Secretary in the Ministry of Coal, in the year 1991. In the report, the Task Force, spelt-out certain recommendations and conclusions, some of the most pertinent of which are reproduced below:

- The presence of carbonaceous shale having the characteristics of oil shale has been recorded in Upper Assam area occurring within the Baragolai and Tikak Parbat Formations of the Barail Group. But stratigraphic position, thickness and extent of these oil shale horizons are not known. Systematic study, sampling and analysis in potential areas is required.

- The potential area of study for the oil shale of the Barail Group is located in the northern part of the Belt of Schuppen. This area is well mapped geologically and maps in 1: 25,000 and larger scales are available. Several sections of the Barail and younger rocks have been studied in details and measured from this area. Thus, once the target horizons of oil shale are identified from critical sections, their extension and extrapolation may not be difficult.

v) In order to assess the viability of syncrude generation from the Assam coal, Oil India Limited established a pilot plant for the extraction of oil from the coals of Assam with technology from the USA. It is learnt that Oil India Limited is considering adoption of a more suitable technology available from China for further studies on coal liquefaction.

vi) With respect to oil shale, the current position is that the resources are not known with any measure of confidence. Much more ground work needs to be undertaken before the reserves can be established. Once this is done, selection of the appropriate technology can be taken up.

13.2.4 Processes for Syncrude Production & Environmental Issues

i) Various technologies for production of syncrude from coal / oil shale are currently known throughout the world. Most of the commercial processes are based on pyrolysis and / or distillation coal / oil shale in a retort to which heat can be supplied either directly through combustion within the retort or indirectly by performing the combustion outside of the retort and contacting hot gases or solids with coal / oil shale feed. Most modern oil shale technology involves variations of directly heated retorting. Some of the well known indirect processes are Lurgi-Ruhrgas, TOSCOII, Union Oil 'A' and 'B', Petrosix, Paraho shale oil etc. All processes use the oil shale itself or its by products as the source of heat.

ii) Retort structures may also be formed underground by a combination of explosive fracturing and mining. This is termed In-Situ Processing. The necessary heat is provided by injecting air or hot gases and steam to sustain movement of the fire front in oil shale formation in either a horizontal or vertically downward mode, causing the shale oil to collect at the bottom of the In-Situ retort, from where it can be pumped to the surface. Geo Kinetics In-Situ and Occidental Modified In-Situ processes are two well known examples.

iii) The processes of syncrude production results in significant quantities of spent shale. These are absolutely barren and cannot support any vegetation and may also retain toxic ingredients. The disposal of spent shale thus poses a serious environmental challenge. However, the In-Situ process has certain advantages in this aspect. For instance, the disposal of solid wastes is taken care of, the environmental degradation such as deforestation is minimized, the hazardous gases emissions into the atmosphere is contained and problems related to waste water disposal containing toxic elements is substantially reduced.

iv) The Directorate General of Hydrocarbons, under the Ministry of Petroleum and Natural Gas, has embarked on a project for the evaluation of oil shale resources and their syncrude potential in parts of Upper Assam and neighboring area in Arunachal Pradesh. The proposed study by the Directorate General of Hydrocarbons is expected to provide valuable information on this fossil fuel source. Considering the energy security of our country, the project is of national importance.

v) The exploration for oil shale deposits would involve field work, mapping, and collection of rock samples from surface exposures, drilling of few core holes, preparation of maps and feasibility studies.

vi) Directorate General of Hydrocarbons has identified an agency to carry-out the studies. The total cost of the project is of the order of 13 to 14 crores. The project is likely to commence early next year and is expected to be completed in two years. This is the first time that a project of this nature is being attempted in India. Therefore, the work will involve a significant R & D component for which financial resources of the order of 2 to 3 crores would be needed.

vii) If the results of the study indicate significant oil shale potential in the area, a pilot plant for extraction of oil shale for syncrude production may be set-up for which an estimated amount of Rs.15.00 crores is envisaged.

Section – XIV

Energy Efficiency

Author:

i. **Dr. Ajay Mathur, Director General, Bureau of Energy Efficiency, New Delhi –** ***Special Invitee.***

14.1 Research & Development in Energy Efficiency

14.1.1 Energy demand in the Indian economy has been growing at about 5 to 7% per year over the past two decades, and is expected to accelerate in the year's ahead, in keeping with the expected higher rates of economic growth. The Integrated Energy Policy expects energy demand to double every 10 years over the next 25-year period.

14.1.2 The challenges in meeting this demand are immense. Following 'business as usual' practices, if all of this additional demand is met through increase in energy supply, it would severely strain balance of payments due to the increasing volume of fuel imports (of oil & gas, and increasingly of coal); enhance the vulnerability of the Indian economy to macro-economic shocks due to the volatility in the prices of imported fuels; and create unacceptably high environmental impacts on indoor air quality, urban and regional air quality, and water quality.

14.1.3 Consequently, the continuous enhancement of energy efficiency, and the increasing penetration of renewable energy in the energy mix are essential components, as the Integrated Energy Policy suggests, of India's future energy strategy. Energy Efficiency in the Indian economy has been increasing at about 0.4 to 1% per annum in terms of the energy intensity, measured as kilograms of oil equivalent required to produce a rupee of GDP, but studies suggest that this rate could increase, and possibly double.

14.1.4 Assessment of the energy use in industry, buildings, transport, appliances, and other sectors has indicated that the range of specific energy consumption with in any one particular sector varies widely; some units in the sector exhibit energy efficiency which is at the global technological frontier, while many units in the same sector have energy efficiencies which are much lower than those of the front-runners. In some sectors, notably, in the small and medium enterprises, and in buildings, global leaders are difficult to find, and average energy use is poor. In other sectors, especially appliances, advanced technologies are available, but their penetration is relatively low and there seems to be no large scale transformation in progress towards better energy use.

14.1.5 Continuous improved energy use implies both a change in personal habits and life styles (such as walking short distances instead of driving, or switching off lights when not needed), and the increasing penetration of higher efficiency technology products for energy end-use. The former have short term benefits, while the latter are essential to ensure sustainability and continued increases in energy efficiency.

14.1.6 The Government of India, in recognition of the need to institutionalize the promotion of energy efficiency, enacted the Energy Conservation Act, 2001, which created the Bureau of Energy Efficiency (BEE). In implementing its statutory mandate, the BEE is, inter-alia, focused on:

a) Enhancement of energy efficiency in new commercial buildings through the development of the Energy Conservation Building Code for new large commercial buildings

b) Promote the enhanced adoption of higher efficiency appliances by users through the introduction of energy-consumption labels; and

c) Facilitate the more rapid enhancement of energy efficiency in industry through the creation of sectoral energy consumption norms.

14.1.7 In order to meet these goals, the BEE is implementing a broad programme in XIth Five Year Plan. The XIth Plan of BEE enables the institutionalization of the activities mentioned above, and capacity building to help in its implementation.

14.1.8 The Energy Efficiency R&D Plan complements the BEE's XIth Plan Programme by supporting the Research and Development activities that would be required to ensure that the necessary energy efficient products are available, and that continuous evolution of energy efficient products continues to occur.

14.1.9 The objective of the energy efficiency R&D programme is to enable and develop and support the test and marketing of energy efficient products and their adoption in enterprises and household. The strategic approach is one of creating consortia of product developers and product users, together with organizations that can provide the research and engineering skills necessary to develop / upgrade products. The programme would support the incremental costs of product development, and would expect product developers and users to bear the majority of costs, and to reap the benefits of innovative product development.

14.1.10 The programme focuses on development of energy efficient products for three sets of applications:

(i) Energy Efficient Buildings, and building components;

(ii) Energy Efficient appliances; and

(iii) Energy Efficient technologies for the SME sector.

14.2 Energy Efficient Buildings and Building Components

14.2.1 The Energy Conservation Building Code developed by the BEE defines the design principles through which new, large commercial buildings would need to be designed in the future so as to reduce their energy demand. In doing so, the building design would address issues such as the area of windows in proportion to the total wall area, the quality of windows, the passage of natural lighting and ventilation through the building, and the choice of lighting & HVAC systems.

14.2.2 The focus of the R&D programme would be on product development in the following areas:

- Development of Energy Efficiency Windows
- Development of low cost insulation material
- Development of simulation software to predict the energy used in buildings

14.2.3 In the first two focus areas, the programmes would promote the development, testing and adoption of more energy efficient products. The programme would support product testing, and the adoption of prototypes in pilot buildings, together with the monitoring and evaluation of their effectiveness in operation. The performance of the efficient products would be widely disseminated amongst potential users (architects and developers) so as to promote their greater adoption.

14.2.4 The development, testing and validation of simulation software for energy efficient buildings would be supported by the comparative evaluation of various software through testing them on the performance of existing buildings, and the modification of the most appropriate software that best represent various kinds of buildings and climatic conditions. Further, weather data sets for use with these simulation models would also to put together for various Indian cities.

- **Funding Support**

The basic costs of products development and its application in the pilot buildings would be met by product developers and users. The R&D programme would support costs for testing, the incremental costs of its adoption in pilot buildings and the costs of monitoring, evaluation and training. The Plan budget for this activity would be a total of Rs.50.00 crores; with Rs.22.00 crores being planned for the development of energy efficient windows; Rs.17.00 crores planned for the development of low cost insulation; and Rs.11.00 crores for the development of the simulation software.

14.3 Energy Efficiency Appliances

14.3.1 During the XIth Plan, R&D efforts on energy efficiency appliances will focus on:

- Development of Energy Efficient Ceiling Fans;
- Development of very-low energy consuming circuits for stand-by power; and
- Development of low cost LED-based lamps for space lighting.

14.3.2 India is the largest producer and user of ceiling fans but this sector has not seen much technological improvement over the pat 70 years. The current technological platform based on an induction motor – capacitor system is reaching the limits of efficiency as measured in terms of the volumetric air flow delivered by the fan for each watt of electrical power. During the XIth Plan, the R&D programme will focus on the development and testing of alternate technological platforms (based on DC motors or linear motors for energy efficient ceiling fans. The programme will bring together a consortia of Ceiling Fans Manufacturers and R&D Institutions to develop prototypes, and test a range of prototype based on advanced electric power technologies combined with electronic power management systems. Reliable and robust prototypes would be further supported for long term monitoring and evaluation tests.

14.3.3 The increasing use of stand-by power in offices and households (through the use of devices such as computers, televisions, set-top boxes, Xerox machines, etc.) would be addressed through a programme to develop low cost electronic circuits which reduce the stand-by power demand of these devices to less than 0.5 watt. During the XIth Plan, consortia of manufacturers and R&D organizations would design and test the energy performance of advanced circuits, as well as their long term reliability so as to provide service with low energy requirements.

14.3.4 In the near future, LED-based lights promise to provide the highest lighting-to-electricity use ratio amongst all lighting devices. However, LED is unidirectional and, at present, are best suited for task lighting applications. Their large scale use for lighting rooms, offices and other spaces is constrained by the availability of appropriate luminaries through which their light could be dispersed throughout the room. During the XIth Plan, this programme would seek to bring together manufacturers of lamps & luminaries, lighting engineers and building developers, to develop a wide variety of luminare-lamp configurations, and to test the lighting performance of these prototypes in pilot buildings. The lighting performance of the high quality, low cost lamps would be disseminated through training programmes to architects and lighting engineers.

- **Funding Support**

The Plan funding required for the development of energy efficiency appliances would be Rs.80.00 crores, of which Rs.20.00 crores would be budgeted for the development & testing of energy efficient ceiling fans, Rs.50.00 crores for the development of low energy consuming stand-by circuits, and Rs.10.00 crores for the development, installation and testing of energy efficient LED lighting systems.

14.4 Energy Efficient Technology for the SME Sector

14.4.1 During the XIth Plan, the BEE will focus on the upgradation of energy efficiency of 25 clusters of SMEs across the country. These clusters belongs to industrial sub-sectors such as textile, brass, ice-plants, plywood, rice-mills, foundry, carpet-weaving, khandsari, glass, light engineering, and forest & agro-based products. This R&D programme will support the energy efficient technology development in 5 of these sub-sectors: rice-mills, textiles, agro & food processing, brass, and lighting engineering.

14.4.2 In each of these sub-sectors, research institutions with the appropriate technical skills would be matched with SME clusters, and with the current technology providers in these clusters. These consortia will develop / adapt, install and test the more efficient technologies. The strategy would be to carry-out the development/adoption within the premises of one or more SME units, so that the inputs of these user units about their needs and their operating experiences is fully incorporated in the development process. Further, the engineering skills of the research organizations and manufacturing skills of the technology provider would be integrated in the development of the energy efficient technology. If required, assistance in terms of product design would also be provided so as to ensure the energy-efficient technology is user friendly. Following testing, the technology performance would be demonstrated to other units in the cluster with a view to enhance its adoption.

- **Funding Support**

During the XIth Plan, a total sum of Rs.75.00 crores is budgeted for the development and adoption of energy efficient technologies in the SME sectors. The average expenditure expected in the development of each of the 5 technologies is expected to be Rs.15.00 crores during the Plan period.

14.5 Budgetary Outlay for the XIth Plan

The total budget requirement for the period of 5 years for the R&D activities associated with energy efficiency would be Rs.205.00 cores.

Section-XV

Technologically Important Crystals – A Facility to Manufacture Polysilicon for Production of Single Crystals of Silicon

Author:

i. Office of the Principal Scientific Adviser to the Government of India, New Delhi, based on the inputs received during the National Conference on Advances in Technologically Important Crystals (NC-ATIC), held in the Department of Physics and Astrophysics, University of Delhi, Delhi, during October 12-14, 2006. The input received subsequently from Dr. S.C. Sabharwal, Head, Spectroscopy Division, Bhabha Atomic Research Centre, Mumbai, is also acknowledged.

15.1 Single crystals of silicon are of national importance, having strategic and commercial implications. Indeed, the silicon technology has become a measure of the intellectual and industrialization level of any country. It is time for India to initiate an aggressive plan for the manufacture of poly and single crystals of silicon (required by foundries) to produce:

(i) Solar cells

(ii) Microelectronics devices

(iii) Power devices

(iv) Photo detectors for industrial computer tomography, medical imaging, baggage scanning, etc.

(v) Communications

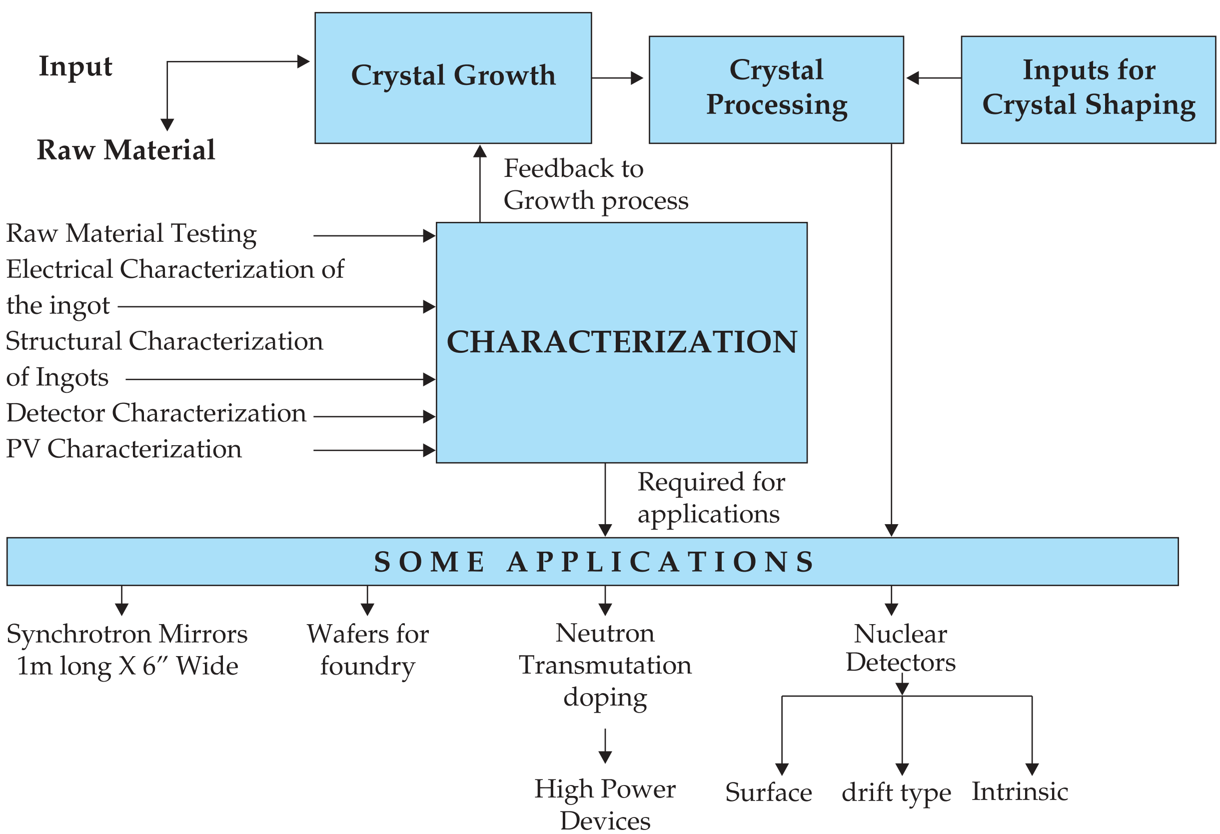
(vi) Integrated circuits for automation, process control, etc.

(vii) Light emitting devices

(viii) Nuclear radiation detectors

15.2 An integrated programme envisaged on silicon technology, as shown in ***Fig. 1***, includes the preparation and characterization of polysilicon, single crystals and their processing to produce finished products of the required specifications for a number of applications.

Fig. 1. Integrated Programme on Si Technology Development



15.3 India does not produce single crystals of silicon, or even the raw material needed to grow these – i.e. polysilicon. The industry is totally dependent on imports. However, because of the increasing demand worldwide, import is becoming difficult. It is, therefore, essential to take steps to remedy this situation.

15.4 To take stock of the situation, a brainstorming session was held in the Office of the Principal Scientific Adviser to the Government of India on the 4th of August, 2006, with attendance from both the academia and the industry. Dr. S.C. Sabharwal, Head, Spectroscopy Division, Bhabha Atomic Research Centre, Mumbai; Shri M. Thirumavalavan, Member (Research Staff), Central Research Laboratory, Bharat Electronics Limited, Bangalore; Dr. T.C. Tripathi, Scientist 'G', Ministry of New and Renewable Energy, New Delhi and Shri S. Ravi, Scientist, Solid State Physics Laboratory, Delhi, were requested to prepare a position paper on semiconductor crystals (in particular, Si). This was discussed in a special session on the 13th of October, 2006 in the National Conference on Advances in Technologically Important Crystals, held in the University of Delhi, Delhi.

15.5 The important recommendation of the deliberation in that session was to setup a facility for the production of:

- 2500 tonnes per annum (TPA) polysilicon*,
- Czochralski growth of silicon single crystals of diameters up to 8",
- Cutting, lapping and polishing of crystals to produce wafers catering to foundry requirements,
- Characterization of poly, single crystals and finished wafers.

The estimated cost of setting-up of such a facility would be about Rs. 1200.00 crores.

**** It is envisaged that by 2012, the demand for silicon wafers in India will go upto about 1000 million wafers. The corresponding requirement of polysilicon material for manufacturing silicon ingots and wafers (to make solar cells) is likely to go up to around 2000-3000 TPA.***

Section-XVI

Light Emitting Diodes (LEDs)– A Viable Alternative to Fluorescent Lighting

Author:

i. **Office of the Principal Scientific Adviser to the Government of India, New Delhi.**

16.1 Background

16.1.1 A light-emitting diode (LED) is a semiconductor device that emits incoherent narrow-spectrum light when electrically biased in the forward direction. This effect is a form of electroluminescence. The colour of the emitted light depends on the composition and condition of the semiconducting material used, and can be infrared, visible or near-ultraviolet. Rubin Braunstein of the Radio Corporation of America first reported on infrared emission from gallium arsenide (GaAs) and other semiconductor alloys in 1955. Experimenters at Texas Instruments, Bob Biard and Gary Pittman, found in 1961 that gallium arsenide gave off infrared (invisible) light when electric current was applied. Biard and Pittman were able to establish the priority of their work and received the patent for the infrared light-emitting diode. Nick Holonyak Jr. of the General Electric Company developed the first practical visible-spectrum LED in 1962.

Blue, green and red LEDs.

16.2 LED Technology

16.2.1 Physical Function

i) An LED is a unique type of semiconductor diode. Like a normal diode, it consists of a chip of semiconducting material impregnated, or doped, with impurities to create a p-n junction. As in other diodes, current flows easily from the p-side, or anode, to the n-side, or cathode, but not in the reverse direction. Charge-carriers — electrons and electron holes — flow into the junction from electrodes with different voltages. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon.

ii) The wavelength of the light emitted, and therefore its colour, depends on the band gap energy of the materials forming the p-n junction. In silicon or germanium diodes, the electrons and holes recombine by a non-radiative transition which produces no optical emission, because these are indirect bandgap materials. The materials used for an LED have a direct band gap with energies corresponding to near-infrared, visible or near-ultraviolet light.

iii) LEDs are usually constantly illuminated when a current passes through them, but flashing LEDs are also available. Flashing LEDs resemble standard LEDs but they contain a small chip inside which causes the LED to flash with a typical period of one second. This type of LED comes most commonly as red, yellow, or green. Most flashing LEDs emit light of a single wavelength, but multicoloured flashing LEDs are available too.

iv) LED development began with infrared and red devices made with gallium arsenide. Advances in materials science have made possible the production of devices with ever-shorter wavelengths, producing light in a variety of colours.

v) LEDs are usually built on an n-type substrate, with electrode attached to the p-type layer deposited on its surface. P-type substrates, while less common, occur as well. Many commercial LEDs, especially GaN/InGaN, also use sapphire substrate. Substrates that are transparent to the emitted wavelength, and backed by a reflective layer, increase the LED efficiency. The refractive index of the package material should match the index of the semiconductor, otherwise the produced light gets partially reflected back into the semiconductor, where it gets absorbed and turns into additional heat.

vi) The semiconducting chip is encased in a solid plastic lens, which is much tougher than the glass envelope of a traditional light bulb or tube. The plastic may be coloured, but this is only for cosmetic reasons or to improve the contrast ratio; the colour of the packaging does not substantially affect the colour of the light emitted.

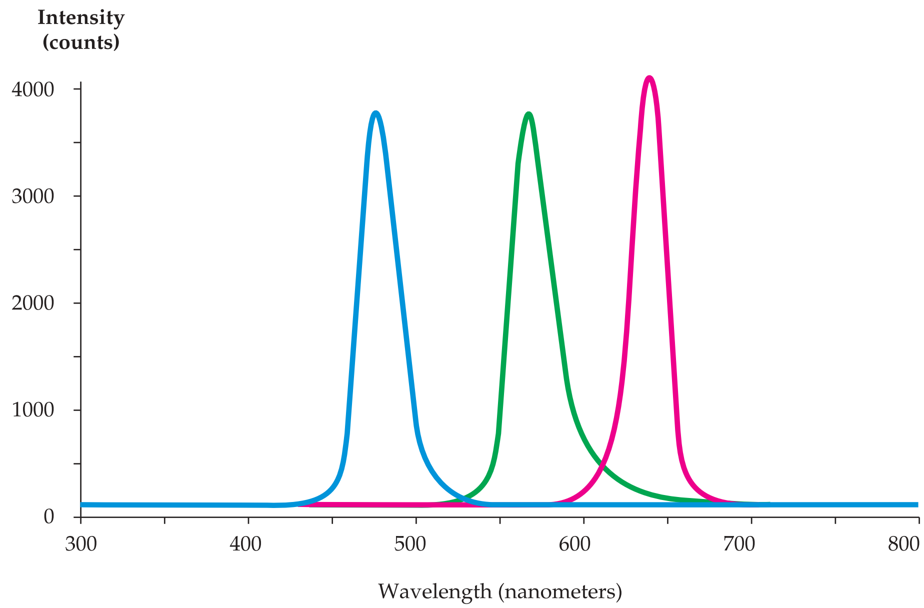
vii) Conventional LEDs are made from a variety of inorganic semiconductor materials, producing the following colours:

- Aluminum gallium arsenide (AlGaAs) - red and infrared
- Aluminum gallium phosphide (AlGaP) - green
- Aluminum gallium indium phosphide (AlGaInP) - high-brightness orange-red, orange, yellow, and green
- Gallium arsenide phosphide (GaAsP) - red, orange-red, orange, and yellow
- Gallium phosphide (GaP) - red, yellow and green
- Gallium nitride (GaN) - green, pure green (or emerald green), and blue also white (if it has an AlGaN Quantum Barrier)
- Indium gallium nitride (InGaN) - near ultraviolet, bluish-green and blue
- Silicon carbide (SiC) as substrate — blue
- Silicon (Si) as substrate — blue (under development)
- Sapphire (Al_2O_3) as substrate — blue
- Zinc selenide (ZnSe) - blue
- Diamond (C) - ultraviolet
- Aluminum nitride (AlN), aluminum gallium nitride (AlGaN) - near to far ultraviolet

16.2.2 Organic Light-Emitting Diodes (OLEDs)

i) If the emitting layer material of an LED is an organic compound, it is known as an Organic Light Emitting Diode (OLED). To function as a semiconductor, the organic emitting material must have conjugated pi bonds. The emitting material can be a small organic molecule in a crystalline phase, or a polymer. Polymer materials can be flexible; such LEDs are known as PLEDs or FLEDs.

Combined spectral curves for blue, yellow-green, and high brightness red solid-state semiconductor LEDs. FWHM spectral bandwidth is approximately 24-27 nanometres for all three colours.



ii) Compared with regular LEDs, OLEDs are lighter, and polymer LEDs can have the added benefit of being flexible. Some possible future applications of OLEDs could be:

- Inexpensive, flexible displays
- Light sources
- Wall decorations
- Luminous cloth

iii) At present (2006) OLEDs are used in small portable colour video displays such as cellphone and digital camera screens, and user interfaces on MP3 players. Large-screen colour displays have been demonstrated, but their life expectancy is still far too short (<1,000 Hrs) to be practical.

16.2.3 Operational Parameters and Efficiency

i) Most typical LEDs are designed to operate with no more than 30-60 milliwatts of electrical power. Around 1999, Philips Lumileds introduced power LEDs capable of continuous use at one watt. These LEDs used much larger semiconductor die sizes to handle the large power input. Also, the semiconductor dies were mounted to metal slugs to allow for heat removal from the LED die. In 2002, Lumileds made 5-watt LEDs available with efficiencies of 18-22 lumens per watt.

ii) In September, 2003, a new type of blue LED was demonstrated by the company Cree, Inc. to have 35% efficiency at 20 mA. This produced a commercially packaged white light having 65 lumens per watt at 20 mA, becoming the brightest white LED commercially available at the time. In 2006 they have demonstrated a prototype with a record white LED efficiency of 131 lumens per watt at 20 mA.

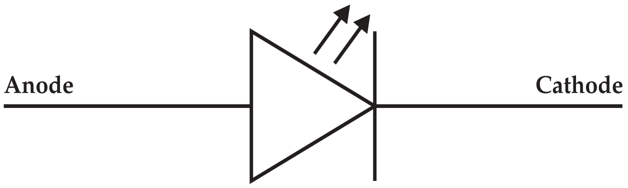
iii) Today, OLEDs operate at substantially lower efficiency than inorganic (crystalline) LEDs. The best efficiency of an OLED so far is about 10%. These promise to be much cheaper to fabricate than inorganic LEDs, and large arrays of them can be deposited on a screen using simple printing methods to create a colour graphic display.

16.3 Considerations in Use

16.3.1 Advantages of Using LEDs

- LEDs produce somewhat more light per Watt than do incandescent bulbs; this is useful in battery powered devices.
- LEDs can emit light of an intended colour without the use of colour filters that traditional lighting methods require. This is more efficient and can lower initial costs.

LED Schematic Symbol



- The solid package of an LED can be designed to focus its light. Incandescent and fluorescent sources often require an external reflector to collect light and direct it in a usable manner.
- When used in applications where dimming is required, LEDs do not change their colour tint as the current passing through them is lowered, unlike incandescent lamps, which yellow.
- LEDs are built inside solid cases that protect them, unlike incandescent and discharge sources, making them extremely durable.
- LEDs have an extremely long life span: upwards of 100,000 hours, twice as long as the best fluorescent bulbs and twenty times longer than the best incandescent bulbs. (Incandescent bulbs can also be made to last an extremely long time by running at lower than normal voltage, but only at a huge cost in efficiency; LEDs have a long life when operated at their rated power.)

- Further, LEDs mostly fail by dimming over time, rather than the abrupt burn-out of incandescent bulbs.
- LEDs light-up very quickly. A typical red indicator LED will achieve full brightness in microseconds; LEDs used in communications devices can have even faster response times.
- LEDs can be very small and are easily populated onto printed circuit boards.

16.3.2 Disadvantages of Using LEDs

- LEDs are currently more expensive, in lumens per rupee, than more conventional lighting technologies. The additional expense partially stems from the relatively low lumen output and the drive circuitry and power supplies needed.
- LED performance largely depends on the ambient temperature of the operating environment. “Driving” an LED “hard” in high ambient temperatures may result in overheating of the LED package, eventually leading to device failure. Adequate heat-sinking is required to maintain long life. This is especially important when considering automotive, medical, and military applications where the device must operate over a large range of temperatures, and are required to have a low failure rate.
- LEDs require complex power supply setups to be efficiently driven. In indicator applications, a simple series resistor can be used; however, this sacrifices a large amount of energy efficiency.
- LEDs typically cast light in one direction at a narrow angle compared to a incandescent or fluorescent lamp of the same lumen level.

16.4 LED Applications

16.4.1 List of LED Applications

Some of these applications are further elaborated upon in the following text.

- Architectural lighting
- Status indicators on all sorts of equipment
- Traffic lights and signals
- Exit signs
- Motorcycle and Bicycle lights
- Toys and recreational sporting goods, such as the Flashflight
- Railroad crossing signals
- Continuity indicators
- Flashlights. Some models that do not even use batteries are of this type.
- Light bars on emergency vehicles.

- Thin, lightweight message displays at airports and railway stations and as destination displays for trains, buses, trams and ferries.
- Red or yellow LEDs are used in indicator and alphanumeric displays in environments where night vision must be retained: aircraft cockpits, submarine and ship bridges, astronomy observatories, and in the field, e.g. night time animal watching and military field use.
- Red, yellow, green, and blue LEDs can be used for model railroading applications.
- Remote controls, such as for TVs and VCRs, often use infrared LEDs.
- In optical fiber and Free Space Optics communications.
- In dot matrix arrangements for displaying messages.
- Glowlights, as a more expensive but longer lasting and reusable alternative to Glowsticks.
- Movement sensors, for example in optical computer mice.
- Because of their long life and fast switching times, LEDs have been used for automotive high-mounted brake lights and truck and bus brake lights and turn signals for some time, but many high-end vehicles are now starting to use LEDs for their entire rear light clusters. Besides the gain in reliability, this has styling advantages because LEDs are capable of forming much thinner lights than incandescent lamps with parabolic reflectors. The significant improvement in the time taken to light up (perhaps 0.5s faster than an incandescent bulb) improves safety by giving drivers more time to react.
- Backlighting for LCD televisions and displays. The availability of LEDs in specific colours (RGB) enables a full-spectrum light source which expands the colour gamut by as much as 45%.
- New stage lighting equipment is being developed with LED sources in primary red-green-blue arrangements.
- LED phototherapy for acne using blue or red LEDs has been proven to significantly reduce acne over a 3 month period.
- As Voltage Reference in electronic circuits. The constant voltage drop (e.g. 1.7 V for a normal red LED) can be used instead of a Zener diode in low-voltage regulators. Zener diodes are not available below voltages of about 3 V.

16.4.2 Illumination Applications

i) LEDs used as a replacement for incandescent light bulbs and fluorescent lamps are known as solid-state lighting (SSL) - packaged as a cluster of white LEDs grouped together to form a light source (pictured). LEDs are moderately efficient; the average commercial SSL currently outputs 32 lumens per watt (lm / W), and new technologies promise to deliver up to 80 lm / W. The long lifetime of LEDs make SSL very attractive. They are also more mechanically robust than incandescent light bulbs and fluorescent tubes. Currently, solid state lighting is becoming more available for household use but is relatively expensive, although costs are decreasing. LED flashlights, however, already have become widely available. Recently a number of manufacturers have started marketing ultra-compact LCD video projectors that use high-powered white LEDs for the light source. Another alternative design is to use red, green, and blue LEDs in a sequential DLP design.

Spotlights made of many individual LEDs.

ii) Incandescent bulbs are much less expensive but also less efficient, generating from about 16 lm / W for a domestic tungsten bulb to 22 lm / W for a halogen bulb. Fluorescent tubes are more efficient, providing 50 to 100 lm / W for domestic tubes (average 60 lm / W), but are bulky and fragile and require starter or ballast circuits that sometimes buzz audibly. Compact fluorescent lamps, which include a quiet integrated ballast, are relatively robust and efficient, fit in standard light bulb sockets, and are currently the best choice for efficient household lighting.

iii) Proponents of LEDs expect that technological advances will reduce costs such that SSL can be introduced into most homes by 2020. However, they are still not commercially viable for general lighting applications, and so LEDs are found today in illumination applications where their special characteristics provide a distinct advantage. This can be seen in the widespread use of LEDs in traffic signals and indicator lamps for trucks and automobiles.

iv) Due to their monochromatic nature, LED lights have great power advantages over white lights when a specific colour is required. Unlike traditional white lights, the LED does not need a coating or diffuser that can absorb much of the emitted light. LED lights are inherently coloured, and are available in a wide range of colours. One of the most recently introduced colours is the emerald green (bluish green, about 500 nm) that meets the legal requirements for traffic signals and navigation lights.

v) There are applications that specifically require light without any blue component. Examples are photographic darkroom safe lights, illumination in laboratories where certain photo-sensitive chemicals are used, and situations where dark adaptation (night vision) must be preserved, such as cockpit and bridge illumination, observatories, etc. Yellow LED lights are a good choice to meet these special requirements because the human eye is more sensitive to yellow light (about 500 lm / watt emitted) than that emitted by the other LEDs.

vi) The first residence lit solely by LEDs was the “Vos Pad” in London. The entire flat is lit by a combination of white and RGB (colour changing) LEDs.

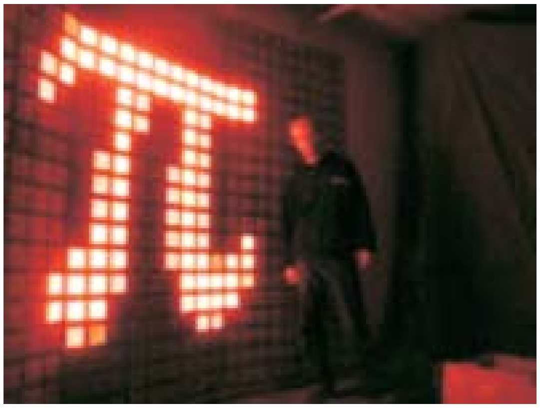
16.4.3 LED Display Panels

i) There are two types of LED panels: conventional, using discrete LEDs, and Surface Mounted Device (SMD) panels. Most outdoor screens and some indoor screens are built around discrete LEDs, also known as individually mounted LEDs. A cluster of red, green, and blue diodes is driven together to form a full-colour pixel, usually square in shape. These pixels are spaced evenly apart and are measured from center to center for absolute pixel resolution. The largest LED display in the world is over 1,500 feet long and is located in Las Vegas, Nevada, U.S.A.

ii) Most indoor screens on the market are built using SMD technology — a trend that is now extending to the outdoor market. An SMD pixel consists of red, green, and blue diodes mounted on a chipset, which is then mounted on the driver PC board. The individual diodes are smaller than a pinhead and are set very close together. The difference is that minimum viewing distance is reduced by 25% from the discrete diode screen with the same resolution.

iii) Indoor use generally requires a screen that is based on SMD technology and has a minimum brightness of 600 candelas per square meter (unofficially called nits). This will usually be more than sufficient for corporate and retail applications, but under high ambient-brightness conditions, higher brightness may be required for visibility. Fashion and auto shows are two examples of high-brightness stage lighting that may require higher LED brightness. Conversely, when a screen may appear in a shot on a television show, the requirement will often be for lower brightness levels with lower colour temperatures (common displays have a white point of 6500-9000K, which is much bluer than the common lighting on a television production set).

LED panels allow for smaller sets of interchangeable LED to be one large display.



iv) For outdoor use, at least 2,000 nits are required for most situations, whereas higher brightness types of up to 5,000 nits cope even better with direct sunlight on the screen. Until recently, only discrete diode screens could achieve that brightness level. (The brightness of LED panels can be reduced from the designed maximum, if required.)

v) Suitable locations for large display panels are identified by factors such as line of sight, local authority planning requirements (if the installation is to become semi-permanent), vehicular access (trucks carrying the screen, truck-mounted screens, or cranes), cable runs for power and video (accounting for both distance and health and safety requirements), power, suitability of the ground for the location of the screen (check to make sure there are no pipes, shallow drains, caves, or tunnels that may not be able to support heavy loads), and overhead obstructions.

16.4.4 Early LED Flat Panel TV History

i) Perhaps the first recorded flat LED television screen prototype to be developed was by James P Mitchell in 1977.

ii) The early display prototype was red monochromatic. The blue LED did not emerge until the early-1990s, completing the RGB colour triad. High-brightness colours gradually emerged in the 1990s enabling new designs for outdoor signage and huge video displays for stadia.

16.4.5 Multi-touch Sensing

i) Since LEDs share some basic physical properties with photodiodes, which also use p-n junctions with band gap energies in the visible light wavelengths, they can also be used for photo detection. These properties have been known for some time, but more recently so-called bidirectional LED matrices have been proposed as a method of touch-sensing. In 2003, Dietz, Yerazunis and Leigh published a paper describing the use of LEDs as cheap sensor devices.

ii) In this usage, various LEDs in the matrix are quickly switched on and off. LEDs that are on shine light onto a user's fingers or a stylus. LEDs that are off function as photodiodes to detect reflected light from the fingers or stylus. The voltage thus induced in the reverse-biased LEDs can then be read by a microprocessor, which interprets the voltage peaks and then uses them elsewhere.

16.5 The Indian Scenario

16.5.1 India, at present, is more successful in system level development (Solid State Lighting -SSL) with imported LEDs (chips/final LEDs), whereas wafer manufacturing is only at the research level addressing very limited issues of wafer fabrication. SSL development refers to packaging of basic chips into LEDs and assembling several LEDs into SSL lamps. The basic chips required for this are currently being imported. M/s. Kwality Photonics Pvt. Ltd., Hyderabad, are one of the private companies involved in this activity. They import the processed wafers from the

USA and Taiwan. The Bharat Electronics Limited (BEL) is also producing SSL based traffic signal indicators. It is also interested in setting-up a facility to manufacture white LEDs in the country for which it is likely to sign an MoU shortly with M/s CREE, USA.

16.5.2 Recently, other than the BEL's, there have been some more efforts to setup a LED manufacturing facility in India. The National Thermal Power Corporation Limited (NTPC) is planning to electrify thousands of villages in the next five years under the Rajiv Gandhi Grameen Vidyuktikaran Yojana (RGGVY). In view of their low power consumption, the NTPC is interested to adapt SSL based lamps for lighting purposes in these villages. The volume of SSLs required for this purpose will be several tens of millions. The NTPC and the Society for Integrated Circuit Technology and Applied Research (SITAR), a society of the Government of India, are contemplating to establish a vertically integrated LED manufacturing facility in India to avoid import of the processed wafers. This will provide a cost effective solution for lighting the villages. Both the NTPC and the SITAR are contemplating to form a Joint Venture (JV) company to venture into the production of LEDs and SSL lamps. Towards this, an MoU has been signed recently between them.

16.5.3 The Office of the Scientific Adviser to the Government of India will, shortly, convene a meeting with all the stakeholders, including the NTPC, the SITAR and the BEL, in the context of this technology and its application, particularly in the Rural Sector.

16.6 Requirement of Funds

An amount of Rs. 1000.00 crores is projected as the requirement of funds for setting-up a LED manufacturing facility in the country during the eleventh five year plan period.

Section-XVII

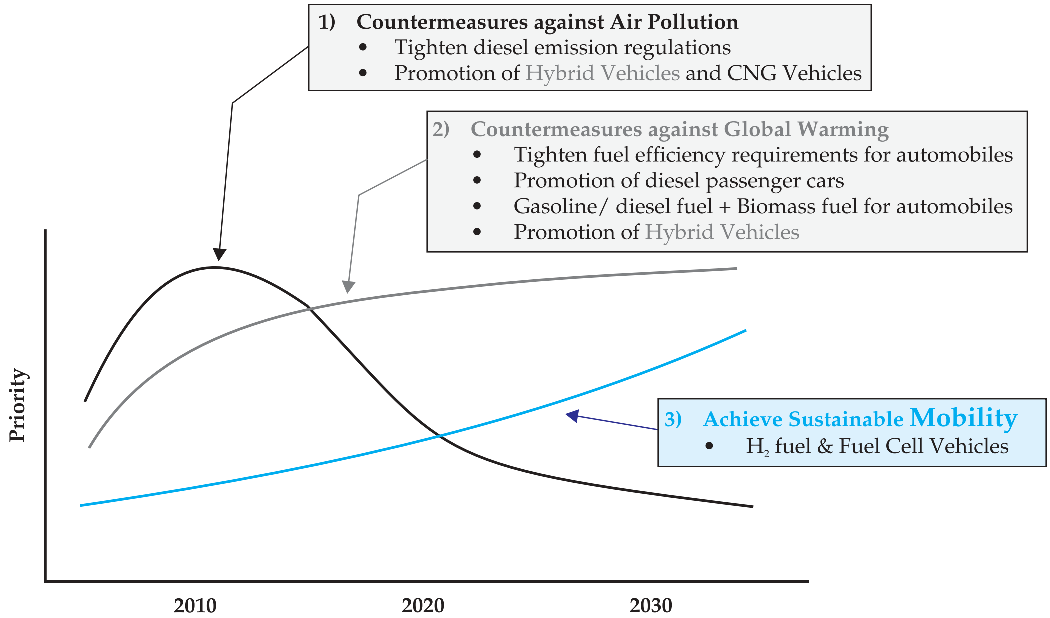
Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) – Viable Alternate Propulsion Systems

Authors:

i. **Shri S.N. Marathe, Director, Automotive Research Association of India (ARAI), Pune – *Special Invitee.***
ii. **Dr. G.K. Sharma, Director, Central Institute of Road Transportation (CIRT), Pune – *Special Invitee.***
iii. **Dr. Arun Jaura, Senior Vice President, Mahindra & Mahindra Limited, Mumbai – *Special Invitee.***

17.1 Background

17.1.1 The world is now focusing on the impending energy crisis and each country's need to concentrate on energy security as well as growing pollution and environmental concerns. With its new developing market, all eyes are currently on Asia. Emerging Asian markets, especially countries such as China, Korea, and India, are witnessing rapidly growing economies. But, rapid growth has also brought soaring urban populations, growing pollution concerns and a concomitant massive requirement for energy resources. **It is estimated that by 2030, Asia's car population will reach an incredible 400 million**.



17.1.2 Inspite of improvement in emission norms (Bharat 1 & 2), today's motor vehicles remain a major source of regional air pollution and global greenhouse gases. Hybrid-electric vehicles (HEV) have emerged as a synergistic vehicle / energy system that could meet society's need for practical and sustainable personal transportation while avoiding these technical obstacles and environmental constraints. HEVs have the potential to revolutionize transportation in two ways:

- **Improved fuel economy**: First, they can use conventional fuels (e.g., gasoline) much more efficiently and more cleanly. A hybrid-electric propulsion system produces as much as a doubling of fuel economy compared to the same vehicle with a conventional engine and automatic multi-speed transmission.

- **Reduced emissions**: Motor vehicles are a major source of NO_x, the key precursor emission to the formation of low-level ozone. On a global basis, carbon dioxide (CO_2) levels increase each year, due in large measure to the increasing use of fossil fuels, and other "greenhouse gases." An HEV version of the same vehicle using gasoline can produce 1 / 10 of the current levels of emission.

17.1.3 In the US, it was estimated that if 10,000 hybrid electric vehicles were substituted for the than current standard vehicles, then:

- Smog-causing emissions of nitrogen oxides would be reduced by 1,700 tonnes annually.
- Carbon dioxide emissions would be reduced by 83,000 tonnes annually the equivalent to planting 2 million trees.
- Diesel fuel usage would be reduced by 7.2 million gallons, which requires 1 million barrels of crude oil to produce.

These benefits are expected to be significant in Indian conditions, given the fact that the frequent start-and-stops on Indian roads have adverse effect on the overall efficiency and environmental performance of internal combustion engines.

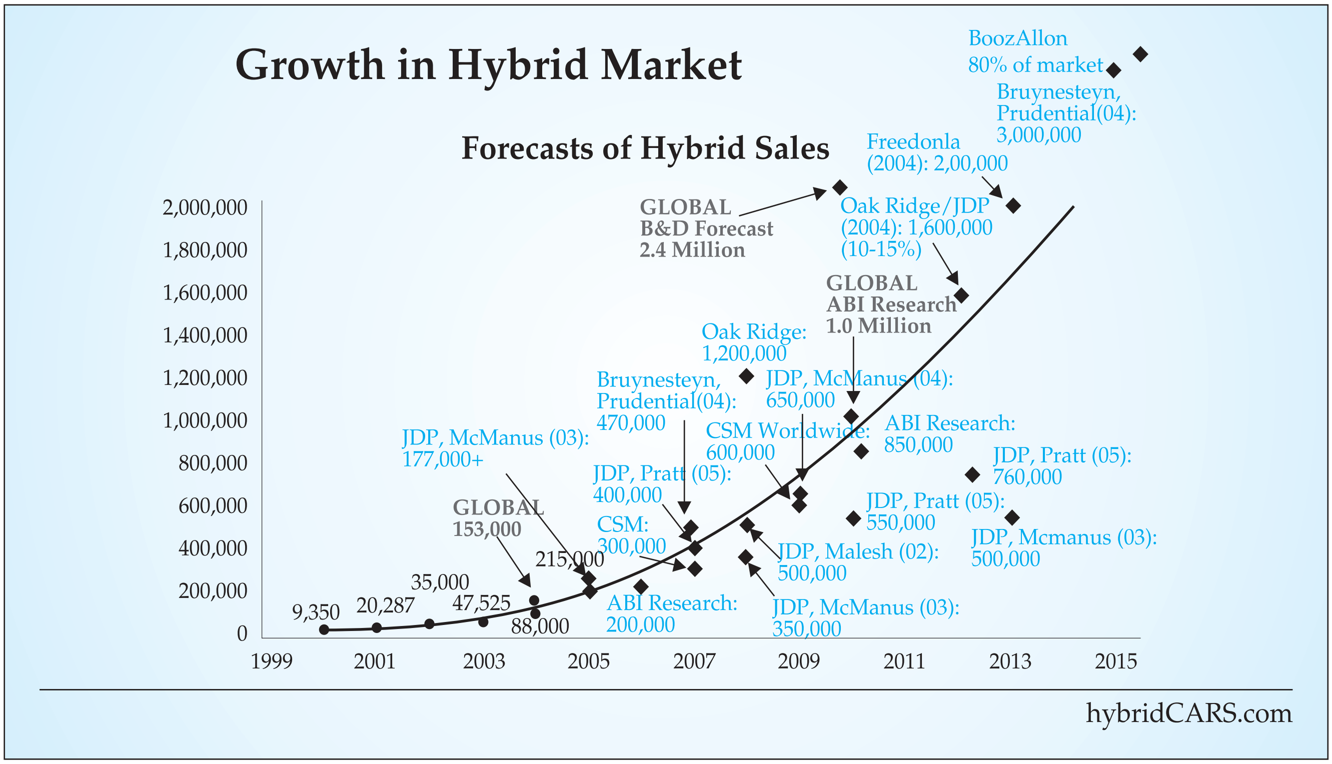
17.1.4 There are major research efforts underway in the US, Europe and Japan. China has also made significant progress towards the development of electric and hybrid electric vehicles. The FreedomCar and Fuel Partnership programme in the United States focus on the high-risk research such as fuel cells and advanced hybrid propulsion systems, to provide a full range of affordable cars and light trucks that are free of foreign oil and harmful emissions. The Future Truck and Future Car competitions were launched to bring together academia and industry, to help train the future work force and increase public awareness about alternative fuel technologies.

Chinese hybrid bus

Indian EV/ HEV efforts

17.1.5 Here in India, we continuously impress the rest of the world with our grasp of new technologies and our rapidly growing economic development. But, we are already over-stretching our energy consumption, facing a rapidly growing demand for energy, and are plagued with high and growing pollution levels with serious health consequences. Furthermore, we currently import 2.09 million bbl / day (2 / 3 of our oil consumption); this dependence on foreign oil is hazardous for our energy security. Transportation consumes 50% petroleum products and vehicular emissions are one of the two primary sources of air pollution in India, which leads to serious health consequences.

17.1.6 Given these environmental and political concerns, as well as the rapid depletion of our resources, it's imperative that we lead the world and create new and innovative solutions. But, even in a nation like ours, with millions of brilliant minds, we have to foster a nurturing environment in which change and new, groundbreaking ideas can take hold.



17.2 Need for a Focused Hybrid Electric Vehicle Programme

17.2.1 The development of alternate propulsion technologies, especially hybrid electric vehicle technologies, is imperative for the advancement of energy conservation and environmentally-friendly applications. Although several major vehicle manufacturers have started developing hybrid electric vehicle concepts, much more R&D efforts are required to build a sustainable hybrid electric vehicle marketplace. In order to achieve this, the development of the following key enablers will be requisite:

- Different architectures and optimal configurations through modeling & simulation;
- Electronic controls, energy storage and drives;
- Complementary engine and transmission management systems; and
- Evolving protocols for safety and recyclability concerns.

17.2.2 As in most cases of advanced automotive technology applications in India, the vehicle manufacturers and component manufacturers have to liaise with or license out technologies from the global tier-1 firms. This dependence on foreign technology vendors is a major stumbling block in acquiring competitiveness in a global sense, since the Indian firms need to compete with much larger global firms in the acquisition of such technologies, and have much less bargaining power. On the other hand, the really strong players in the HEV market (like Toyota and Honda) have focused on having a hold on the key technologies and they have filed a large number of patents as well, as part of this strategic objective.

17.2.3 Hybrid electric vehicles are most effective in stop-and-go driving. The electric drive system is used to manage the load and engine operation is maintained in high efficiency region, and this leads to both better fuel economy and lower CO_2 emissions. Through the use of hybrid electric-IC engine configuration, the engine can be down sized. The performance of the vehicle is also improved through finer step transmissions ratios, better torque management, eliminates engine idle and recovers the kinetic energy through regenerative braking. According to the transportation needs and the function of assisted-electric-propulsion, a full range of options have to be developed in India including Mild Hybrid and Full Hybrids.

17.2.4 The proposed multi-pronged approach uniting the resources of government, academia, automotive manufacturers, and energy providers has the potential to generate adequate technology know-how for mass introduction of hybrid electric vehicles.

17.3 Proposal

17.3.1 India can lead by developing a “National Hybrid Propulsion Platform”, focusing on hybrid electric vehicles (HEVs) and undertaking the development of environment -friendly and energy-efficient transportation technologies through a multi pronged approach:

A. Key Component Focus: Developing a Sustainable Marketplace

B. Vehicle Focus: Advancing Propulsion Technologies

C. Student Focus: Investing in the Future Workforce

17.3.2 New and innovative solutions would be developed in each of these key focus areas by bringing together the best minds in India in a strategic collaboration of academia, government, and the top OEMs. This partnership could be a 50:50 cost share proposition between the Indian Government and the OEMs (i.e. the industry). A proposal for Rs.350.00 crores is being suggested in this note.

17.3.3 Indian citizens would benefit greatly from this proposition because this would be used to create energy efficient and sustainable transportation technologies which would improve energy security, decrease pollution, develop cost-competitive technologies that consumers can afford.

A. Key Component Focus: Developing a Sustainable Marketplace

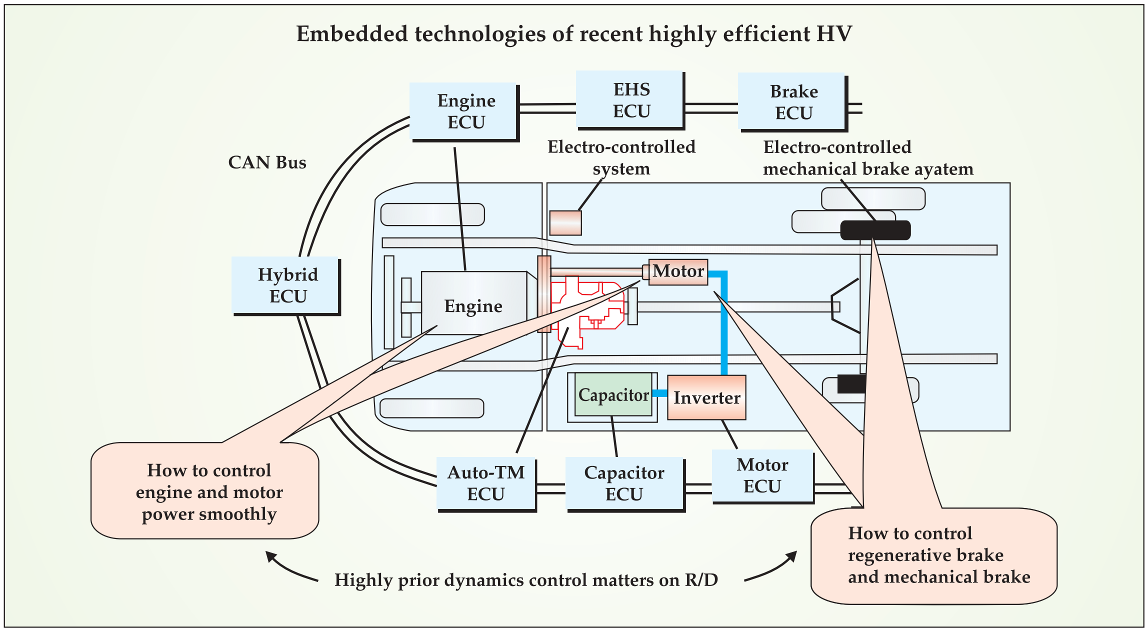
i. Energy Storage Systems*

ii. Traction Drives and Power Electronics **(Rs. 225.00 crores)**

- In order to ensure a sustainable future market for these emerging technologies, we need to ensure that the key components of these future technologies are cutting-edge and readily available to the consumer. To do this, we need to focus on the design and development of the core technologies such as energy storage systems and traction drives and power electronics, which will form the core of future sustainable mobility technologies such as

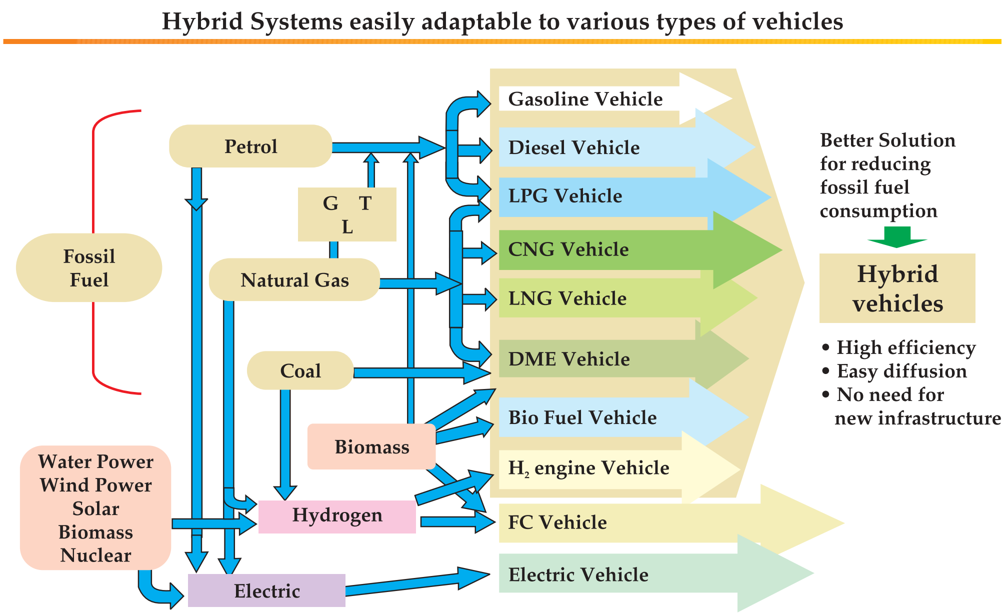
** The budgetary requirement for doing R&D in Energy Storage Systems is already projected separately in the **Section XII**.*

hybrid and fuel cell vehicles. To secure the availability of these technologies, we can leverage other emerging low-cost, high volume production centers by sourcing and strategic partnerships.



B. **Vehicle Focus: Advancing Propulsion Technologies (Rs. 100.00 crores)**

- Furthermore, the partnership needs to have well-specified goals to ensure progress. In the beginning, this partnership could focus on hybrid technology and build a fleet of 5-20 vehicles and could be released in four major metropolitan cities and some of India's most polluted cities by 2010. These goals can only be met with cooperation from all-levels.



C. Student Focus: Investing in the Future Workforce (Rs. 25.00 crores)

- This programme could also support university level competitions similar to the Future Car and Future Truck Competitions held in the United States. In these programmes, teams of students receive a vehicle from an OEM and then re-engineer the conventional vehicle with at least 25% higher fuel economy, without sacrificing the performance, utility, safety, and affordability customers want. An OEM could sponsor the competition in a year (including supply of vehicles), and another OEM could sponsor in the following year. We have many talented young engineers, and this would spawn new ideas and innovations in the technology, train our future workforce, and generate public interest and support for these groundbreaking technologies.

17.4 Outcome

17.4.1 It is recommended that we initiate a strategic partnership of stakeholders including the relevant departments of the government (DST, DHI & DIT), about half-dozen automotive companies with an annual turnover crossing Rs.500.00 crores, and national academic institutions.

17.5 Meeting Record

17.5.1 The proposal was finalized by a sub-group comprising of:

- Shri S.N. Marathe, Director, Automotive Research Association of India (ARAI), Pune.
- Dr. G.K. Sharma, Director, Central Institute of Road Transportation (CIRT), Pune.
- Dr. Arun Jaura, Senior Vice President, Mahindra & Mahindra Limited, Mumbai.

On 20th December, 2006 in Pune as part of the IEEE workshop on Electric & Hybrid Electric Vehicles. The meeting was attended by several participants from academia, tier-1 suppliers and other automotive manufacturers.

17.6 Hybrid Electric Vehicle Component Technologies

17.6.1 The major technologies that need to be developed were identified through two workshops (New Delhi, July 2006 and Pune, December 2006).

A. Electric Motor: (Axial Flux, Radial Flux and Variable Gap Axial Flux configurations need to be tried)

- PM BLDC / PM Synchronous motor
- Switched Reluctance Motors
- Liquid cooled induction motor

B. Transmission for HEV

- Advantageous configuration and shifting strategy

- Electromagnetic brakes and clutches
- Actuators for automatic clutch actuation and gear shift

C. Energy storage *(BEV and HEV)*

- Batteries (Li-ion battery / Ni-MH battery & Fast battery charger)
- Ultracapacitors
- Flywheel storage

D. Electronic components *(Focus on low cost, compact designs)*

- Low cost compact design, high voltage safety
- Power electronics for high voltage systems
- DC-DC converter
- Inverter
- Packaging of power electronics
- Cooling for power electronics and Motor (heat pipe option also)

E. Controls

- DSP / FPGA controllers or their combination.
- Hybrid control systems (Different modes and prime mover)
- Operation / True hybrid modes / Power flow management / Recirculation of power)
- Sensors & Network

17.7 Requirement of Funds

Of the amount of Rs. 350.00 crores projected in this Section for doing research for the development of the above-listed technologies, an amount of Rs. 175.00 crores is proposed to be sought from the Planning Commission as budgetary support in the eleventh five year plan, with the remaining Rs. 175.00 crores coming from the Industry.

ANNEXURES

ANNEXURE-I (MENTIONED IN THE BACKGROUND)

No.M-11011/2/2006-EPU
Government of India
Planning Commission
(Power & Energy Division)

Yojana Bhawan, Sansad Marg,
New Delhi, the 9th May. 2006

ORDER

Sub.: Constitution of a Working Group on R&D for Energy Sector for formulation of the Eleventh Five Year Plan (2007- 2012)

It has been decided to constitute a Working Group on R&D for Energy Sector in the context of the preparation of the Eleventh Five Year Plan *(2007-2012)*. The Composition and Terms of Reference of the Group will be as follows:

A. Composition:

Dr. R. Chidambaram, Principal Scientific Adviser to Government of India - Chairman

Members

Representatives of the Ministries

1. Secretary, Department of Science & Technology
2. Adviser (Energy), Planning Commission
3. Adviser (S& T), Planning Commission
4. Executive Director, Technology Information Forecasting and Assessment Council (TIFAC)
5. Representative of Council for Scientific and Industrial Research (CSIR)
6. Representative of Department of Atomic Energy
7. Head, Center for Energy Studies, Indian Institute of Technology (lIT), Delhi
8. Head, R&D Centre, Bharat Heavy Electricals Limited (BHEL)
9. Head, R&D Centre, National Thermal Power Corporation (NTPC)
10. Chairman & Managing Director, Central Mine Planning & Design Institute Limited
11. Representative from Oil & Natural Gas Corporation (ONGC)
12. Director (R&D), Indian Oil Corporation (IOC)
13. Shri Neeraj Sinha, Scientist (E), Office of the Principal Scientific Adviser – Member-Secretary

B. Terms of Reference.

The terms of reference of the Working Group will be as under: -

i) To evolve a vision and develop an approach for R&D in the Energy Sector for the Eleventh Five Year Plan and beyond.

ii) To identify thrust area for the Eleventh Plan and suggest their inter-se priorities.

iii) To suggest ways by which inter-institutional collaboration are leveraged for higher efficiencies better outcomes.

iv) To suggest strategies for expanding and strengthening societal application for energy technologies for improving the quality of life of the Indian population.

v) To explore the mechanisms for funding R&D in the energy sector and assess the requirement of funds for the Eleventh Five Year Plan.

vi) To suggest means of catalyzing industry academia collaboration for development and application of energy technologies.

vii) To identify energy technologies which can be taken up under mission mode and co-coordinated R&D.

2. In order to assist the Working Group in its task, separate Sub-Groups on specific aspects may be formed by the Working Group. These sub-Groups will furnish their reports to the Working Group.

3. The Chairman of the Working Group may-co-opt other Experts as may be considered necessary.

4. The Working Group will submit its report to the Planning Commission latest by the 30th September, 2006.

5. Non-official members of the Working Group shall be entitled to payment of TA /DA from Planning Commission as per SR 190 (a). Official members will be paid TA /DA by their respective Departments/ Organizations as per the rules of entitlement applicable to them.

6. The name(s) of representative(s) of various organizations as per the above composition may be communicated to the Member-Secretary of the Working Group under intimation to Shri Surya P. Sethi, Adviser (Energy), Planning Commission.

7. Shri M. Satyamurty, Joint Adviser (Coal), Planning Commission, Room No. 345, Yojana Bhavan, Tel No. 23096743, will be the Nodal Officer for this Working Group in the Planning Commission and further query/correspondence in this regard may be made with him.

Sd/-
(K.K. Chhabra)
Under Secretary to the Government of India

To:

The Chairman & Members (including Member-Secretary) of the Working Group.

Copy for information to:

1. P.S. to Deputy Chairman /MOS (Plg.)/Members/Member-Secretary, Planning Commission.
2. All Principal Advisers/ Advisers/ JS (SP & Adm.)
3. Prime Minister's Office, South Block, New Delhi
4. Information Officer, Planning Commission
5. For general information in Yojana Bhawan through e-mail

Sd/-
(K.K. Chhabra)
Under Secretary to the Government of India

ANNEXURE-I A (MENTIONED IN THE BACKGROUND)

LIST OF CO-OPTED MEMBERS OF THE WORKING GROUP

The following were co-opted as members of the Working Group with the approval of the Chairman:

i) Dr. Bibek Bandyopadhyay, Scientist 'G' and Head, Solar Energy Centre, Ministry of New and Renewable Energy, New Delhi.

ii) Dr. Leena Srivastava, Executive Director, The Energy and Resources Institute, New Delhi.

iii) Dr. Nalinaksh S. Vyas, Professor, Department of Mechanical Engineering, Indian Institute of Technology Kanpur, Kanpur.

ANNEXURE-II (MENTIONED IN THE BACKGROUND)

MINUTES OF THE 1st MEETING OF THE WORKING GROUP ON R&D FOR THE ENERGY SECTOR FOR THE FORMULATION OF THE ELEVENTH FIVE YEAR PLAN (2007-2012).

The 1st meeting of the Working Group on R&D for the Energy Sector for the formulation of the Eleventh Five Year Plan (2007-2012) was held in the Committee Room 'C', Vigyan Bhawan Annexe, Maulana Azad Road, New Delhi – 110 011 on Wednesday, the 14th of June, 2006 at 1030 hr.

2. The meeting was chaired by Dr. R. Chidambaram, Principal Scientific Adviser to the Government of India.

3. The list of participants is annexed. Leave of absence was granted to Dr. R.B. Grover, Director, Strategic Planning Group, Department of Atomic Energy (DAE), Mumbai, who was not able to attend the meeting owing to some sudden and unforeseen circumstances. Probably, owing to a similar reason, Dr. Naresh Kumar, Head, R&D Planning Division, Council of Scientific and Industrial Research (CSIR), New Delhi, also did not attend the meeting, despite having confirmed his participation earlier.

4. The Chairman welcomed all the members and special invitees to the 1st meeting of the Working Group. He then informed the Working Group that the following two had been co-opted as members of the Working Group:

i) Dr. Bibek Bandyopadhyay, Scientist 'G' and Head, Solar Energy Centre, Ministry of Non-conventional Energy Sources (MNES), Gwalpahari, Gurgaon – to represent the MNES; and

ii) Dr. Leena Srivastava, Executive Director, The Energy and Resources Institute (TERI), New Delhi – as a member on "gender issues", who is also working in the energy sector.

5. The Chairman started by saying that more than a decade ago, he had postulated that 'per capita electricity consumption' was one of the important measures of human development, the other being 'female literacy' and that these could easily replace the three measures postulated by the United Nations Organization for the same. The growth of R&D in the energy sector, leading to better and more efficient energy resources was, therefore, a key to a developing economy such as India's.

6. The Chairman then highlighted, for the members benefit, the important portions of the terms of reference of the Working Group.

7. He then made following observations: -

i) The Working Group would have to take into account the fact that its area of work would partially overlap with some Committees/ Working Groups formed by the Planning Commission for the formulation of the Eleventh Five Year Plan. One such Committee – the Steering Committee on Science & Technology – was chaired by the Principal Scientific Adviser to the Government of India himself.

ii) During the course of the meeting, the member organizations could also spell-out whatever support they needed from the Government of India to continue their in-house R&D efforts in the Eleventh Plan.

iii) The Working Group would need to identify those areas of energy that needed what he calls '***directed basic research***'. 'Directed' basic research means basic research – open-ended – and without defined deliverable but in a focused area.

iv) Rural energy technology delivery, such as Gharats in the State of Uttaranchal, would also need to be focused on by the Working Group. The Office of the Principal Scientific Adviser to the Government of India (O/o the PSA to the GoI) had already started working in this direction by roping-in the Bharat Heavy Electricals Limited (BHEL), the Indian Institute of Technology (IIT), Delhi and the Maulana Azad National Institute of Technology (MANIT), Bhopal, to help improve the quality of the turbines used in those Gharats. Interconnectivity of mini/ micro hydel plants, as well as Gharats, in rural areas was desirable to ensure the availability of decentralized power in those areas.

v) The O/o the PSA to the GoI would be willing to convene brainstorming sessions on specific energy R&D areas identified by the members for getting more clarity on those areas.

vi) ***The prime agenda of the Working Group would be to develop a Road Map for India on R&D in the Energy Sector in as much detail as possible***. The Road Map would indicate the corresponding funds required from the Planning Commission.

vii) The representative of the DAE – Dr. R.B. Grover – would be requested to give a note on spins-off of nuclear energy R&D into other energy areas.

viii) The Working Group would also need to take into account "climate change issues", i.e. the effect of greenhouse gases on the environment, while preparing the Road Map.

ix) Developments happening internationally in all the areas of energy R&D would also need to be taken into account while preparing the Road Map.

x) Intensive R&D on developing alternate fuels for surface transportation, as suggested by the Core Group on Automotive R&D (CAR) constituted by the O/o the PSA to the GoI – would need to be taken-up.

xi) Likewise, energy efficient technologies like Integrated Gasification Combined Cycle (IGCC) for coal based power generation would need to be focused upon. The R&D Committee on IGCC – constituted by the O/o the PSA to the GoI in January, 2003 – could prepare a detailed Road Map on this subject for integration into the Road Map to be prepared by the Working Group.

8. The Chairman then invited comments from the members.

8.1 Indian Oil Corporation Limited (IOC):

8.1.1 Dr. R.P. Verma, Executive Director (R&D), IOC, Faridabad, made the following observations: -

i) Techno-commercially competing technologies should get concessions –such as excise duty exemptions for five years available to units operating in Special Economic Zones (SEZs) or backward areas – to grapple with the problem of "provenness" of technologies.

ii) In-house R&D centres of corporates – such as the one of the IOC in Faridabad – should be recognized as national level laboratories (like those of the CSIR).

8.1.2 The Chairman appreciated the problem of "provenness" and suggested that organizations like the Technology Information, Forecasting and Assessment Council (TIFAC) could bring together domain experts to certify the "provenness" of any given new technology – subject to the performance guarantees / warrantees being provided by the technology developer – to get around the problem of "provenness". The Secretary, Department of Science and Technology (DST) and the Executive Director, TIFAC – who are also members of the Working Group – agreed to this suggestion of the Chairman.

8.1.3 The Chairman then decided that the IOC and the TIFAC would jointly prepare a document on how to certify the "provenness" of new technologies developed indigenously and submit the same to the Member-Secretary within two weeks.

8.1.4 On a request of the IOC representative, the Chairman agreed to help the IOC in getting the tomography study of trickle bed reactors, using radio tracer techniques, done in association with the Bhabha Atomic Research Centre (BARC), Mumbai.

8.2 BHEL:

8.2.1 Shri S.K. Goyal, Head, R&D Centre and Group General Manager, BHEL, Hyderabad, highlighted the in-house R&D work being done by the Corporate R&D Centre of the BHEL in Hyderabad. He also informed the Working Group that in addition to doing in-house R&D, the BHEL also provides funds to research institutes, such as the IIT, Roorkee and the Osmania University, Hyderabad, for conducting R&D on selected topics. The BHEL also has chair-professors in the IIT, Delhi and the IIT, Roorkee.

8.2.2 On the Chairman's suggestion, Shri Goyal agreed to help the IOC and the TIFAC in preparing the document mentioned in para 8.1.3 above.

8.2.3 The Chairman also suggested that the said document being made jointly by the IOC, the BHEL and the TIFAC should contain financial implications as well.

8.2.4 On a request of the BHEL representative, the Chairman agreed that a note may be prepared by the BHEL, in consultation with the Central Power Research Institute (CPRI), Bangalore, for upgrading the latter's testing facilities. This note would form an annexure to the Road Map to be prepared by the Working Group.

8.2.5 Recognizing the importance of developing new materials, the Chairman suggested that a Road Map be prepared on the subject jointly by the Corporate R&D Centre of the BHEL and Dr. Baldev Raj, Distinguished Scientist and Director, Indira Gandhi Centre for Atomic Research, Kalpakkam – who is a materials expert. This Road Map could be an annexure to the Road Map to be prepared by the Working Group. To facilitate the preparation of the Road Map on materials, the O/o the PSA to the GoI could sponsor a brainstorming session.

8.3 TIFAC:

8.3.1 Dr. Anand Patwardhan, Executive Director, TIFAC, New Delhi, highlighted the hydrogen programme of the TIFAC and also informed the Working Group that the TIFAC had started working on developing bio-products. ***He emphasized the importance of the country having a clear mandate on a low carbon future through energy R&D***. He also felt that while there was a lot of documentation on "supply side" in the energy sector, not enough was available on the "demand side". The Road Map to be prepared by the Working Group should address this anomaly.

8.4 MNES:

8.4.1 After giving a brief introduction to the functions of the MNES, Dr. Bibek Bandyopadhyay made the following observations: -

i) Intelligent building design should be a prime area of focus since it can lead to a reduction of almost 40% in power consumption. Increased R&D in this area was, therefore, important.

ii) R&D on the development of ***third generation*** solar photovoltaic cells should be taken-up in a mission mode.

iii) R&D on the development of wind turbines for low wind regime areas (which are aplenty in India) was a must.

iv) Mapping of offshore wind areas should also be taken-up.

8.4.2 The Chairman suggested that the scientist-to-scientist interaction between the MNES and the BARC – that was recently facilitated by the O/o the PSA to the GoI – should help in the preparation of a Road Map for R&D in the renewable energy sector which could then be a part of the Road Map to be prepared by the Working Group.

8.4.3 On the suggestion of the Secretary, DST, the Chairman also decided that the CSIR representative – Dr. Naresh Kumar – may be requested to give a status note on the development of wind turbines that was being done by the National Aerospace Laboratory of the CSIR under its New Millennium Indian Technology Leadership (NIMITLI) programme. The Member-Secretary assured to arrange the needful.

8.5 TERI:

8.5.1 Dr. Leena Srivastava, Executive Director, TERI, made the following observations:

i) The Working Group would need to focus on the short-term as well as the long-term R&D needs in the energy sector.

ii) R&D for the development of bio-fuels needs to be intensified.

iii) Better models of Improved Chulhas (cook stoves) needed to be developed through intensified R&D for reducing the drudgery of the rural women.

iv) Likewise, a lot more R&D needs to be done for providing clean fuels in rural areas.

v) R&D should be done keeping in mind the inter-linkages between energy, environment, and health.

8.5.2 The Secretary, DST, suggested here that it would be worthwhile to setup a special cell on energy R&D using the public-private partnership model.

8.5.3 The Chairman then opined that it would also be perhaps worthwhile to have a ***"Standing Oversight Committee for R&D in the energy Sector"***.

8.5.4 The Chairman also decided that the TIFAC and the TERI could jointly prepare a note on what direction should rural energy R&D take to promote the available energy technologies. The TERI representative informed the Working Group that India was now a member country of the International Energy Agency's (IEA's) Greenhouse Gases R&D Technology programme. She also informed that the nodal organization in the Government of India for this purpose is the Ministry of Power. With a view to have a better understanding of what this programme was all about and also with a view to ensure that India's participation in such programmes continued to remain beneficial to its energy sector, the Chairman requested Shri M. Satyamurthy, Joint Adviser, Planning Commission, to help in identifying the concerned officer of the Ministry of Power so that he/ she could be invited to the next meeting of the Working Group.

8.6 Oil and Natural Gas Corporation Limited (ONGC):

8.6.1 Dr. D.M. Kale, Executive Director (R&D), Keshava Deva Malaviya Institute of Petroleum Exploration, ONGC, Dehradun, made the following observations: -

i) The ONGC is actively pursuing the development of Underground Coal Gasification (UCG) technology by tying-up with the Academia (IIT, Bombay). The ONGC has also tied-up with the BARC to develop a thermo-chemical reactor for generating hydrogen.

ii) The development of high energy density batteries (such as Li-Ion) for use in electric vehicles was also an area that interested the ONGC. A technical collaboration with the IIT, Kharagpur, for this development work, was also being considered by the ONGC.

iii) CO_2 sequestration was being tried-out by the ONGC in one of its old oil wells in Ankleshwar, Gujarat.

8.6.2 The Chairman desired that the R&D Committee on UCG, recently constituted by the O/o the PSA to the GoI, should develop a potential Road Map on UCG development for integration in the Road Map to be prepared by the Working Group.

8.7 National Thermal Power Corporation Limited (NTPC):

8.7.1 Shri M.C. Nebhnani, Head, R&D Centre and General Manager, NTPC, Noida, made the following observations: -

i) Non-Destructive Experiments (NDE) were regularly being conducted by the NTPC R&D Centre to prolong the life of the critical components of power plants, thereby saving the company a substantial amount of money.

ii) As recently decided by the NTPC's Board of Directors, 0.5% of the company's profit in any given year would be spent on R&D in the next year.

iii) R&D on gas turbine coatings, to improve the life of the turbine blades, was an important area that required focused R&D.

8.7.2 The Chairman suggested here that a note be prepared on R&D in the corporate sector by the IOC, the BHEL, the ONGC and the NTPC, giving details of in-house R&D expenditure and also mentioning the names of their major grantee institutions.

8.7.3 Shri Nebhnani emphasized the need of greater R&D on bio-diesel and other bio-fuels. He also suggested that the plethora of organizations working in this, and other areas such as hydrogen energy, fuel cells and clean coal technologies, ***need to work in a synergistic way***.

8.7.4 On the Chairman's suggestion, Shri Nebhnani agreed to provide to the Working Group, within the next two weeks, all relevant information contained in several reports that have recently been prepared on R&D in the power sector by the Ministry of Power and other related agencies.

8.8 IIT, Delhi:

8.8.1 Professor M.K.G. Babu, Head, Centre for Energy Studies, IIT, Delhi, informed the Working Group about the work being done by his Centre on R&D in the Energy Sector.

8.8.2 His colleague, i.e. Dr. S.C. Mullick, Professor, Centre for Energy Studies, highlighted the importance of intensifying R&D for the development of intelligent buildings, based on the principles of solar passive architecture.

8.8.3 The Chairman then emphasized the need of determining from the Bureau of Energy Efficiency, Ministry of Power and the Petroleum Conservation Research Association, Ministry of Petroleum and Natural Gas, whether they needed any R&D inputs for augmenting their performance. He also suggested that representatives from both those bodies could be invited for the next meeting of the Working Group, given the fact that energy efficiency in industries, especially energy intensive industries like the Aluminum industry, was a matter that needed to be addressed by the Working Group.

8.9 Central Mine Planning & Design Institute Limited (CMPDIL):

8.9.1 Shri S. Chakrabarti, Director Technical (RD&T), CMPDIL, Ranchi, informed the participants about the work being done by his Institute in various areas of energy R&D, especially Coal Bed Methane (CBM) and UCG. He further informed that his Institute was currently implementing two funded projects on CBM.

8.9.2 The Chairman then decided that the CMPDIL and the ONGC may prepare status notes on CBM and gas hydrates, respectively, for integration in the Road Map to be prepared by Working Group.

9. After the presentation by Shri Sajid Mubashir, Scientist 'F', TIFAC, on the work being done by the CAR, the Chairman desired that the TIFAC may prepare a note on the setting-up of an Institute on Automotive Combustion for integration in the Road Map to be prepared by the Working Group.

10. With a view to integrate – in the Road Map to be prepared by the Working Group – the status of energy R&D in the Indian Railways, the Chairman decided that the IOC representative would coordinate with the Research Designs and Standards Organization (RDSO), Lucknow and the IIT, Kanpur (contact person: Professor Vyas) for preparing a note on the subject. He further decided that Professor Vyas could be invited for the next meeting of the Working Group as a co-opted member.

11. In conclusion, the Chairman requested that all status notes / documents / Road Maps – as decided in the meeting – may be prepared by the members before the next meeting of the Working Group – to be held within three weeks in New Delhi.

12. The meeting then ended with a Vote of Thanks to the Chair.

ANNEXURE TO THE MINUTES OF THE 1ST MEETING OF THE WORKING GROUP ON R&D FOR THE ENERGY SECTOR FOR THE FORMULATION OF THE ELEVENTH FIVE YEAR PLAN (2007-2012)

Date : ***14th June, 2006***

Time : ***1030 hr***

Venue : ***Committee Room 'C', Vigyan Bhawan Annexe***
Maulana Azad Road, New Delhi-110 011

LIST OF PARTICIPANTS

Sl. No.	Name, Designation and full address of the Organisation	Status
1.	**Dr. R. Chidambaram** Principal Scientific Adviser to the Government of India 318, Vigyan Bhawan Annexe Maulana Azad Road **New Delhi – 110 011.**	**Chairman**
2.	**Dr. T. Ramasami** SecretaryDepartment of Science and Technology Technology Bhawan, New Mehrauli Road New Delhi-110 016	**Member**
3.	**Shri M. Satyamurty** Joint Adviser (Coal) Planning Commission Yojana Bhawan, Sansad Marg New Delhi-110 001.	**Representative of Shri Surya P. Sethi, Adviser (Energy), Planning Commission, New Delhi, who is a Member of the Working Group.**
4.	**Dr. Anand Patwardhan** Executive Director Technology Information, Forecasting and Assessment Council Department of Science and Technology Vishwakarma Bhawan Shaheed Jeet Singh Marg New Delhi – 110 016.	**Member**
5.	**Dr. M.K.G. Babu** Head Centre for Energy Studies Indian Institute of Technology Delhi Hauz KhasNew Delhi - 110 016	**Member**
6.	**Shri S.K. Goyal** Head, R&D Centre and Group General Manager Corporate R&D Bharat Heavy Electricals Limited Vikas Nagar Hyderabad-500 093	**Member**

Sl. No.	Name, Designation and full address of the Organisation	Status
7.	**Shri M.C. Nebhnani** Head, R&D Centre and General Manager National Thermal Power Corporation Limited, Research and Development Centre, A-8A, Sector-24, Noida, 201 301	**Member**
8.	**Shri S. Chakrabarti** Director Tech. (RD&T) Central Mine Planning & Design Institute Ltd. (CMPDIL) Gondwana Place, Kanke Road Ranchi - 834 008	**Representative of Shri S.Chaudhuri, Chairman & Managing Director, CMPDIL, who is a Member of the Working Group.**
9.	**Dr. D.M. Kale** Executive Director (R&D) Keshava Deva Malaviya Institute of Petroleum Exploration Oil and Natural Gas Corporation Limited 9, Kaulagarh Road Dehradun-248 195	**Member**
10.	**Dr. R.P. Verma** Executive Director (R&D) Indian Oil Corporation Limited R&D Centre, Sector-13 Faridabad- 121 007	**Member**
11.	**Dr. Bibek Bandyopadhyay** Scientist 'G' and Head Solar Energy Centre Ministry of Non-conventional Energy Sources Gwalpahari, Gurgaon. ***Postal Address:*** Block No. 14, C.G.O. Complex, Lodi Raod, New Delhi-110 003.	**Member**
12.	**Dr. Leena Srivastava** Executive Director The Energy and Resources Institute Darbari Seth Block, India Habitat Centre Complex, Lodi Road New Delhi-110 003	**Member**
13.	**Shri Neeraj Sinha** Scientist 'E' Office of the Principal Scientific Adviser to the Government of India 326, Vigyan Bhawan Annexe Maulana Azad Road New Delhi – 110 011.	**Member-Secretary**

Sl. No.	Name, Designation and full address of the Organisation	Status
14.	**Shri S. Chatterjee** Scientist 'G' Office of the Principal Scientific Adviser to the Government of India 313A, Vigyan Bhawan Annexe Maulana Azad Road New Delhi – 110 011.	**Special Invitee**
15.	**Dr. S.C. Mullick** Professor Centre for Energy Studies Indian Institute of Technology Delhi Hauz Khas New Delhi – 110 016.	**Special Invitee**
16.	**Shri A.K. Ghosh** General Manager (PSE) Bharat Heavy Electricals Limited BHEL House, Siri Fort New Delhi - 110049	**Special Invitee**
17.	**Shri Sajid Mubashir** Scientist 'F' Technology Information, Forecasting and Assessment Council Department of Science and Technology Vishwakarma Bhawan Shaheed Jeet Singh Marg New Delhi – 110 016	**Special Invitee**
18.	**Shri P.R. Basak** Scientist 'F' Technology Information, Forecasting and Assessment Council Department of Science and Technology Vishwakarma Bhawan Shaheed Jeet Singh Marg New Delhi – 110 016.	**Special Invitee**
19.	**Shri Arghya Sardar** Scientist 'D' Technology Information, Forecasting and Assessment Council Department of Science and Technology Vishwakarma Bhawan Shaheed Jeet Singh Marg New Delhi – 110 016.	**Special Invitee**
20.	**Dr. M. Govinda Raj** Senior Research Officer (Petroleum) Planning Commission Power & Energy Division Yojana Bhawan, Sansad Marg New Delhi-110 001	**Special Invitee**

ANNEXURE-III (MENTIONED IN THE BACKGROUND)

MINUTES OF THE 2nd MEETING OF THE WORKING GROUP ON R&D FOR THE ENERGY SECTOR FOR THE FORMULATION OF THE ELEVENTH FIVE YEAR PLAN (2007-2012).

The 2nd meeting of the Working Group on R&D for the Energy Sector for the formulation of the Eleventh Five Year Plan (2007-2012) was held in the Hall number 3, Vigyan Bhawan, Maulana Azad Road, New Delhi – 110 011 on Thursday, the 20th of July, 2006 at 1030 hr.

2. The meeting was chaired by Dr. R. Chidambaram, Principal Scientific Adviser to the Government of India.

3. The list of participants is annexed. Leave of absence was granted to the following: -

i) Dr. T. Ramasami, Secretary, Department of Science and Technology (DST), New Delhi – he was represented in the meeting by Dr. Malti Goel, Scientist 'G', DST, New Delhi.

ii) Adviser (S&T), Planning Commission, Yojana Bhawan, New Delhi.

iii) Dr. Naresh Kumar, Head, R&D Planning Division, Council of Scientific and Industrial Research (CSIR), New Delhi.

iv) Dr. R.B. Grover, Director, Strategic Planning Group, Department of Atomic Energy (DAE), Mumbai.

v) Shri S.K. Goyal, Head, R&D Centre and Group General Manager, Corporate R&D, Bharat Heavy Electricals Limited (BHEL), Hyderabad – he was represented in the meeting by Dr. Dr. B.P. Singh, General Manager, Corporate R&D, BHEL, Hyderabad.

vi) Dr. R.P. Verma, Executive Director (R&D), Indian Oil Corporation Limited (IOC), R&D Centre, Faridabad – he was represented in the meeting by Dr. K.P. Naithani, General Manager, R&D Centre, IOC, Faridabad and Dr. Ujjwal Manna, Senior Research Manager, R&D Centre, IOC, Faridabad.

There was no message from either Shri S. Chaudhuri, Chairman & Managing Director, Central Mine Planning & Design Institute Ltd. (CMPDIL) or Dr. D.M. Kale, Executive Director (R&D), Oil and Natural Gas Corporation Limited (ONGC), New Delhi, regarding their not being able to attend the meeting. Both members were also not represented by any of their colleagues from the CMPDIL and the ONGC, respectively.

4. The Chairman welcomed all the members and the special invitees to the 2nd meeting of the Working Group. A welcome was also extended to Dr. Nalinaksh S. Vyas, Professor, Department of Mechanical Engineering, Indian Institute of Technology Kanpur (IITK), Kanpur, who had been co-opted as a member of the Working Group just before its 2nd meeting.

5. The Chairman then made the following observations: -

i) The Office of the Principal Scientific Adviser to the Government of India (PSA's Office) could, if the members so desired, convene brainstorming sessions on those areas of energy

R&D that were not discussed in the first meeting so as to crystallize the recommendations on those areas for inclusion in the Working Group's report.

ii) R&D on the development of bio-fuels should form an important chapter in the Working Group's report.

iii) For establishing active inter-linkages, the Planning Commission may keep the Working Group informed of the activities of the main Committee on Energy for the Eleventh Five Year Plan (2007-2012) chaired by the Member (Energy), Planning Commission.

iv) The Working Group should address Climate Change R&D in its report. The member from The Energy and Resources Institute (TERI) - Dr. Leena Srivastava, Executive Director – could do the needful in this regard.

v) As action taken on the minutes of the first meeting, a very good report on the Development of New Materials (for thermal plants) had been received jointly from Dr. Baldev Raj, Distinguished Scientist and Director, Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam and the Corporate R&D, BHEL, Hyderabad.

vi) The Working Group's report could highlight a possible new mechanism of funding R&D projects by way of inviting offers (through the print and electronic media) from interested organizations for developing any given technology in a time bound manner.

vii) Directed Basic Research was a new concept and could be addressed in the Working Group's report.

6. The minutes of the first meeting of the Working Group, held in New Delhi on the 14th of June, 2006, were, thereafter, confirmed.

7 (i) On the Chairman's request, a review of the action taken on the minutes of the said 1st meeting was done by the Member-Secretary. From the review, it emerged that action was yet to be taken by the following members on the paras indicated against their names:

Sr. No.	Name of the Member, with the name of the Organization	Action to be taken on
1.	Dr. R.B. Grover, Director, Strategic Planning Group, Department of Atomic Energy, Mumbai	**Para-7(vii)**
2.	Dr. B. Bandyopadhyay, Scientist 'G' and Head, Solar Energy Centre, Ministry of Non-conventional Energy Sources (MNES) and Dr. S. Banerjee, Director, Bhabha Atomic Research Centre (BARC), Mumbai	**Para-8.4.2**
3.	Shri M. Satyamurty, Joint Adviser (Coal), Planning Commission, New Delhi	**Para-8.5.4**
4.	Dr. R.P. Verma, IOC; Shri S.K. Goyal, BHEL; Dr. D.M. Kale, ONGC	**Para-8.7.2**
5.	Dr. D.M. Kale, ONGC	**Para-8.9.2**
6.	Dr. Anand Patwardhan, Technology Information, Forecasting and Assessment Council (TIFAC), New Delhi	**Para-9**

7 (ii) The Member-Secretary also informed those present that a detailed Action Taken Report (ATR) on the minutes of the 1st meeting had been emailed to all members and special invitees a day before the meeting. A hardcopy of the ATR had also been placed in the meeting folders of the participants.

7 (iii) After the review of the action taken, the Chairman felt that the TIFAC and the TERI would need to work further for refining the report submitted by them, as action taken on the para 8.5.4 of the minutes of the 1st meeting, on the direction rural energy R&D should take to promote the available energy technologies. The Chairman also felt that Dr. R.P. Verma of the IOC would need to similarly refine the note submitted by him, as action taken on the para 10 of the minutes, on the status of energy R&D in the Indian Railways. Dr. N.S. Vyas of the IITK could help Shri Verma in doing so.

7(iv) It was also noted that action on paras 8.4.2, 8.5.4 and 9 of the minutes of the 1st meeting of the Working Group was underway by Dr. B. Bandyopadhyay, MNES; Shri M. Satyamurty, Planning Commission and Dr. Anand Patwardhan, TIFAC, respectively and that they would submit the ATR on the said paras before the next meeting of the Working Group. Dr. Anand Patwardhan suggested that if the Working Group agreed, he would create a small sub-group of experts (such as Dr. V. Sumantran, Former Vice President, Tata Motors Limited and Dr. V.K. Saraswat, Chief Controller (R&D), Defence Research and Development Organization) for helping the TIFAC in preparing the note on the setting-up of an Institute on Automotive Combustion in India (i.e. action on the para 9 of the minutes of the 1st meeting of the Working Group). The Working Group agreed to this suggestion of Dr. Patwardhan’s.

8. On the Chairman’s request, Dr. Baldev Raj – a special invitee to the meeting – presented the paper prepared on the Development of New Materials. In summary, the paper highlighted the direction that R&D efforts should take for making India self sufficient in materials (for thermal plants) in the next 10 years. Dr. Baldev Raj opined that when this happens, India would end-up saving billions of dollars in foreign exchange. Dr. Baldev Raj suggested that a comprehensive “Energy Portal” should be created. The Chairman suggested that the TIFAC could perhaps take-up this task.

9. The Chairman decided that the said note on Development of New Materials would form a very important chapter in the Working Group’s report.

10. Dr. Malti Goel of the DST highlighted the importance that Department was giving to the area of materials by informing that a project had been sanctioned to the Indian Institute of Science, Bangalore, on the development of technologies for the forming of aluminum and aluminum alloy components for use in the automobile and other industries. She opined that the development of such lighter weight materials / alloys would lead to energy conservation since the production of light weight material is less energy intensive. Dr. Anand Patwardhan opined that the development of new materials was an area which the Indian industry could also take-up for funding.

11. After further discussion, it was decided that the members from the IOC and the BHEL would jointly submit a report to the Member-Secretary, before the next meeting of the Working Group, on the certification of materials used in the oil industry and the power sector. The member from the National Thermal Power Corporation Limited (NTPC) could provide help on the preparation of that note to the IOC and the BHEL.

12. Dr. B. Bandyopadhyay of the MNES stressed the need for the country to have a silicon manufacturing facility at the earliest in order to make available, in enough quantities, polysilicon for the manufacture of solar photovoltaic (SPV) cells. According to him, the indigenous SPV industry was not able to cater either to the domestic, or to the international demand of SPV cells, just because of non-availability of polysilicon, in sufficient quantities. The Chairman agreed with the view of Dr. Bandyopadhyay and opined that the silicon crystal growth facility coming-up in the BARC, Mumbai, could be a starting point for the solution to this problem, though the BARC project is aimed at detector development.

13. The Working Group then had a detailed discussion on research for the development of bio-fuels. It was noted that bio-diesel could be very useful for distributed power generation in the country. It was also noted that the processes for producing bio-fuels in the country were currently very primitive and needed R&D to improve them. The Chairman then suggested that members from the TERI, the IOC, the NTPC and the TIFAC may jointly prepare a note on “R&D for bio-fuels” that would form an important chapter in the Working Group’s report. The TIFAC would play the lead role in this effort. The special invitee from the Petroleum Conservation Research Association (PCRA), New Delhi – Shri A.K. Goel, Director (R&D) – would help in the preparation of that note. Dr. Leena Srivastava of the TERI added here that biomass gasification was close to commercialization and could also be included in the preparation of the note on bio-fuels.

14. Shri Surya P. Sethi, Adviser (Energy), Planning Commission, then made the following observations: -

i) Specific technologies that are related to supercritical systems need to be identified and included in the Working Group’s report.

ii) The Working Group’s report must attempt to identify as to what agencies would lead applied research in the country. The best option would be to make the Indian industry do it.

iii) The Planning Commission was also thinking of setting-up an ***Energy Fund*** which could be used for funding R&D in the energy sector. Shri A.K. Ghosh, General Manager (PSE), BHEL, New Delhi – a special invitee to the meeting – informed the Working Group that the BHEL was already working on the development of supercritical pressure technologies and that it was setting-up a test rig for the purpose in its Tiruchirappalli unit in technical association with the Indian Institute of Technology Bombay (IITB), Mumbai.

15. The Chairman then opined that the PSA’s Office could organize a brainstorming session on supercritical technologies before the next meeting of the Working Group. The invitees to the session could include the IITs, the Nuclear Power Corporation of India Limited, the BARC and the Larsen & Toubro Limited (to represent the industry).

16. The note prepared by the Corporate R&D of the BHEL on the upgradation of the testing facilities of the Central Power Research Institute (CPRI), Bangalore – as action taken on the para 8.2.4 of the minutes of the 1st meeting of the Working Group – was then reviewed by the Chairman. To a query of the Chairman, Dr. B.P. Singh of the Corporate R&D, BHEL, clarified that the Director General (DG) of

the CPRI had been consulted in the preparation of the said note. The Chairman felt that a formal approval of the DG, CPRI, would be required on the approach suggested in the said note before it could be included in the Working Group's report. The Director General of the Bureau of Energy Efficiency (BEE), Ministry of Power, New Delhi – who was a special invitee to the meeting – could help the BHEL in this regard. Dr. B.P. Singh agreed to arrange the needful. Since some views were expressed by some of the members on the approach adopted in the said note not being clear, the Chairman also opined that the BHEL could make suitable amends in the note in association with the DG, CPRI.

17. On some views expressed by Dr. S.C. Mullick of the IIT Delhi, the Chairman assured that all aspects of R&D in solar energy, including solar thermal energy, would be addressed in the Working Group's report by the representative of the MNES, i.e. Dr. B. Bandyopadhyay.

18. The Chairman decided that he would hold the next meeting of the Working Group in the 2nd / 3rd week of August, 2006.

19. The meeting then ended with a Vote of Thanks to the Chair, and to all the members and special invitees present, by the Member-Secretary.

ANNEXURE TO THE MINUTES OF THE 2nd MEETING OF THE WORKING GROUP ON R&D FOR THE ENERGY SECTOR FOR THE FORMULATION OF THE ELEVENTH FIVE YEAR PLAN (2007-2012).

Date : *20th July, 2006*

Time : *1030 hr*

Venue : *Committee Room 'A', Vigyan Bhawan Annexe*
Maulana Azad Road, New Delhi-110 011

LIST OF PARTICIPANTS

Sl. No.	Name, Designation and full address of the Organisation	Status
1.	**Dr. R. Chidambaram** Principal Scientific Adviser to the Government of India 318, Vigyan Bhawan Annexe Maulana Azad Road New Delhi – 110 011.	**Chairman**
2.	**Dr. (Mrs.) Malti Goel** Scientist 'G' Department of Science and Technology Technology Bhawan, New Mehrauli Road New Delhi-110 016.	**Representative of Dr. T. Ramasami, Secretary Department of Science and Technology, New Delhi, who is a Member of the Working Group.**
3.	**Shri Surya P. Sethi,** Adviser (Energy) Planning Commission Room No. 261, Yojana Bhawan Sansad MargNew Delhi-110 001.	**Member**
4.	**Dr. Anand Patwardhan** Executive Director Technology Information, Forecasting and Assessment Council Department of Science and Technology Vishwakarma Bhawan Shaheed Jeet Singh Marg New Delhi – 110 016.	**Member**
5.	**Dr. M.K.G. Babu** Head Centre for Energy Studies Indian Institute of Technology Delhi Hauz Khas New Delhi - 110 016.	**Member**
6.	**Dr. B.P. Singh** General Manager Corporate R&D Bharat Heavy Electricals Limited (BHEL) Vikas Nagar Hyderabad-500 093	**Representative of Shri S.K. Goyal, Head, R&D Centre and Group General Manager, Corporate R&D, BHEL, Hyderabad, who is a Member of the Working Group.**

Sl. No.	Name, Designation and full address of the Organisation	Status
7.	**Shri M.C. Nebhnani** Head, R&D Centre and General Manager National Thermal Power Corporation Limited, Research and Development Centre, A-8A, Sector-24, Noida, 201 301.	**Member**
8.	**Dr. K.P. Naithani** General ManagerIndian Oil Corporation Limited R&D Centre, Sector-13 Faridabad- 121 007.	**Representative of Dr. R.P. Verma, Executive Director (R&D), Indian Oil Corporation Limited, R&D Centre, Faridabad, who is a Member of the Working Group.**
9.	**Dr. Bibek Bandyopadhyay** Scientist 'G' and Head Solar Energy Centre Ministry of Non-conventional Energy Sources Gwalpahari, Gurgaon. ***Postal Address:*** Block No. 14, C.G.O. Complex, Lodi Raod, New Delhi-110 003.	**Member**
10.	**Dr. Leena Srivastava** Executive Director The Energy and Resources Institute Darbari Seth Block, India Habitat Centre Complex, Lodi Road New Delhi-110 003.	**Member**
11.	**Dr. Nalinaksh S. Vyas** Professor Department of Mechanical Engineering Indian Institute of Technology Kanpur Kanpur-208 016.	**Member**
12.	**Shri Neeraj Sinha** Scientist 'E' Office of the Principal Scientific Adviser to the Government of India Room No. 326, Vigyan Bhawan Annexe Maulana Azad Road New Delhi-110 011.	**Member-Secretary**
13.	**Dr. Baldev Raj** Distinguished Scientist and Director Indira Gandhi Centre for Atomic Research Kalpakkam – 603 102 Tamilnadu	**Special Invitee**
14.	**Shri V.S. Verma** Director General Bureau of Energy Efficiency NBCC Tower, Hall No. IV, 2nd Floor, 15, Bhikaiji Cama Place New Delhi-110 066.	**Special Invitee**

Sl. No.	Name, Designation and full address of the Organisation	Status
15.	**Shri S. Chatterjee** Scientist 'G' Office of the Principal Scientific Adviser to the Government of India 313A, Vigyan Bhawan Annexe Maulana Azad Road New Delhi – 110 011.	**Special Invitee**
16.	**Dr. R.P. Guupta** Scientist 'E' Office of the Principal Scientific Adviser to the Government of India Room No. 311, Vigyan Bhawan Annexe Maulana Azad Road New Delhi-110 011.	**Special Invitee**
17.	**Shri A.K. Goel** Director (R&D) Petroleum Conservation Research Association Sanrakshan Bhavan 10- Bhikaiji Cama Place New Delhi-110 066.	**Special Invitee**
18.	**Shri A.K. Ghosh** General Manager (PSE) Bharat Heavy Electricals Limited BHEL House, Siri Fort New Delhi – 110049.	**Special Invitee**
19.	**Shri K.P. Singh** Chief Engineer Central Electricity Authority Sewa Bhawan, R.K. Puram New Delhi-110 066.	**Special Invitee**
20.	**Dr. S.C. Mullick** Professor Centre for Energy Studies Indian Institute of Technology Delhi Hauz Khas New Delhi - 110 016.	**Special Invitee**
21.	**Shri M. Satyamurty** Joint Adviser (Coal) Planning Commission Yojana Bhawan, Sansad Marg New Delhi-110 001.	**Special Invitee**
22.	**Shri P.R. Basak** Scientist 'E' Technology Information, Forecasting and Assessment Council Department of Science and Technology Vishwakarma Bhawan Shaheed Jeet Singh Marg New Delhi – 110 016.	**Special Invitee**

Sl. No.	Name, Designation and full address of the Organisation	Status
23.	**Dr. Ujjwal Manna** Senior Research Manager Indian Oil Corporation Limited R&D Centre, Sector-13 Faridabad- 121 007.	**Special Invitee**
24.	**Shri Rahul Kumar** Senior Scientific Officer-II Technology Information, Forecasting and Assessment Council Department of Science and Technology Vishwakarma Bhawan Shaheed Jeet Singh Marg New Delhi – 110 016.	**Special Invitee**

ANNEXURE-IV (MENTIONED IN THE BACKGROUND)

MINUTES OF THE 3RD MEETING OF THE WORKING GROUP ON R&D FOR THE ENERGY SECTOR FOR THE FORMULATION OF THE ELEVENTH FIVE YEAR PLAN (2007-2012).

The 3rd meeting of the Working Group on R&D for the Energy Sector for the formulation of the Eleventh Five Year Plan (2007-2012) was held in the Committee Room A, Vigyan Bhawan Annexe, Maulana Azad Road, New Delhi – 110 011 on Wednesday, the 20th of September, 2006 at 1030 hr.

2. The meeting was chaired by Dr. R. Chidambaram, Principal Scientific Adviser to the Government of India.

3. The list of participants is annexed. Leave of absence was granted to the following: -

i) Dr. T. Ramasami, Secretary, Department of Science and Technology (DST), New Delhi.

ii) Dr. C.M. Kumar, Joint Adviser (S&T), Planning Commission, Yojana Bhawan, New Delhi.

iii) Dr. Naresh Kumar, Head, R&D Planning Division, Council of Scientific and Industrial Research (CSIR), New Delhi.

iv) Dr. D.M. Kale, Executive Director (R&D), Oil and Natural Gas Corporation Limited (ONGC), New Delhi.

v) Professor M.K.G. Babu, Head, Centre for Energy Studies, Indian Institute of Technology Delhi (IITD), New Delhi – *he was represented in the meeting by Dr. S.C. Mullick, Pofessor, Centre for Energy Studies, IITD, New Delhi*.

vi) Dr. Leena Srivastava, Executive Director, The Energy and Resources Institute (TERI), New Delhi.

vii) Shri S. Chaudhuri, Chairman & Managing Director, Central Mine Planning & Design Institute Ltd. (CMPDIL), Ranchi – *he was represented in the meeting by Shri S. Chakrabarti, Director Tech. (RD&T), CMPDIL, Ranchi*.

4. The Chairman welcomed all the members and the special invitees to the 3rd meeting of the Working Group.

5. The Chairman then made the following observations: -

i) Since number of experts has contributed inputs in writing each chapter of the report, names of the experts should be mentioned at the footnote of each chapter.

ii) The 'Integrated Energy Policy' prepared by the Planning Commission was appreciated. He mentioned about the useful recommendations made by the TERI in their National Energy Vision document and opined that it may be a valuable basis for giving recommendations in Working Group report.

iii) The participants may send in writing their comments and suggestions for any changes / addition / subtraction on any chapter, as they feel appropriate. This draft report will be edited and changes would be incorporated accordingly.

iv) It was suggested that though funding may come from various departments/ ministries/ organizations/ industries, proposals may be approved by a Technical Committee c on Energy R&D formed for the purpose.

v) Authors of each chapter should send the budget estimate for the required resource in each area for incorporation in the final report.

vi) The need of R&D in the area of high temperature steel of 700^0C was emphasized. The Bharat Heavy Electricals Limited (BHEL) and the National Thermal Power Corporation (NTPC) were asked to send inputs on this.

vii) The need of the Directed Basic Research in R&D in defined areas was strongly recommended, which comes in between basic research and product development. This was informed that the same is mentioned in the preface of the report. There is a need to identify areas for Directed Basic Research e.g. High Temperature New Materials for energy.

6. Dr. K Bhanu Shankar Rao from Indira Gandhi Centre for Atomic Research (IGCAR) said that high temperature new material development would form a part of their project proposal as Directed Basic Research.

7. The minutes of the second meeting of the Working Group, held in New Delhi on 20^{th} July 2006, were, thereafter, confirmed.

8. Dr. R.P. Verma, Executive Director - R&D, Indian Oil Corporation Limited (IOC) made some general comments on the draft report for consideration of the Working Group like sector wise reorientation of the chapters, highlighting the technological gaps in each area, inclusion of fuel cell in the chapter on hydrogen etc. The Working Group later considered his remarks.

9. The Working Group decided that the **Chapter VII** may be renamed as **"Advanced Coal Technologies"** with the following five sub-sections:

7.1 Integrated Gasification Combined Cycle (IGCC) Demonstration Plant in the Country

7.2 A new sub-section on In-situ Coal Gasification to be added (CMPDIL will prepare this sub-section)

7.3 A new sub-section on Coal liquefaction to be added (CMPDIL to prepare this sub-section)

7.4 An edited version of Chapter X on Coal Bed Methane to be placed in this sub- section (CMPDIL to edit this)

7.5 The Chapter XIII may be renamed as "Carbon capture and storage" and an edited version of it to be placed in this sub-section [Technology Information, Forecasting & Assessment Council (TIFAC) to edit this sub-section]

10. The Working Group strongly felt that R&D on IGCC needs to be continued in the country. Chairman told that this would be recognized in the Preface of the report.

11. Shri Ajai Vikram Singh, Former Secretary of the Ministry of Non-conventional Energy Sources (MNES) mentioned that resource allocation in each of the energy R&D areas should form an integral

part of the recommendations of the working group report and a roadmap for futuristic energy technology R&D should be suggested for better use of this report by the Planning Commission.

12. Prof. Anand Patwardhan, Executive Director, TIFAC, suggested that the title of Chapter IV needs to be changed and be written as “Combustion Research Initiative”. This was agreed by the Working Group. TIFAC to submit the edited version of this Chapter with inputs from Dr. V Sumantran and Dr. VK Saraswat.

It was noted that the budgetary estimate of Rs.96 crores as given in chapter IV of the draft report should be written as Rs.200 crores as revised by Dr. Saraswat.

13. Prof. N.S. Vyas of IIT-Kanpur discussed about the two proposals of Indian Railways given in Chapter V of the draft report. Chairman opined that the proposal on bio-diesel does not contain any R&D component, however it would be endorsed in the report with funding support from Indian Railways. Regarding the other proposal on design, development and testing facilities of engines, it would be recognized in the report that RDSO needs to be upgraded.

14. Shri N. Bakthavatchalam, Vice President (Projects), Bannari Amman Sugars Limited raised the pricing issues on ethanol. As pricing is a policy issue therefore it was suggested that it is out of the scope of this Working Group. Bannari Amman was asked to send information to Shri Surya P. Sethi, Adviser (Energy), Planning Commission for considering the issue by the Policy Working Group.

15. IOC was asked to write a para on the issues regarding cultivation of jatropha like germplasm, tissue culture etc. for forwarding to the Ministry of Agriculture.

16. Society of Indian Automobile Manufacturers (SIAM) was asked to write a para on vehicle and engine development with regard to use of bio-fuels under the Chapter II (R&D on biofuels).

17. With reference to Chapter VI on ‘Hydrogen as a clean source of Energy’ it was felt that the chapter needs to be rewritten by MNES as part of the chapter on “Renewable Energy”. The content could include ‘Hydrogen Technology Roadmap’ of CAR report and this may be obtained from SIAM. MNES should also add Fuel Cell in this chapter. Dr. Chidambaram said that he was planning to call a brainstorming session on ‘Directed Basic Research’ in the Hydrogen Energy Sector.

18. It was decided that Chapter VIII on “Certification of Materials” to be put after Chapter XII as policy recommendations.

19. It was decided that Chapter XI on “Upgradation of testing facilities of the Central Power Research Institute (CPRI), Bangalore” to be put as an annexure to Chapter XIV on “R&D in the Power Sector”.

20. Regarding Chapter XII on “Provenness of New Technologies Developed Indigenously” it was felt that the chapter is too long. The sub section 12.1 to be kept intact whereas one of the examples of the IOC and the BHEL to be given as case studies. This task of modifying the chapter accordingly was given to the TIFAC.

21. With regard to chapter XV on ‘Spin Offs of Nuclear Energy R&D’, it was decided that this may be put as an annexure to the report and the reference of the same would be mentioned in the preface of the report.

22. Dr. Sikka pointed out that the Chapter XVI on 'Gas Hydrates - A Future Energy Source' is more of a review paper. It was decided that it should go as an annexure to the report under Futuristic Energy Sources, which may also include other futuristic sources like Tar Sand, Oil shale etc.

23. MNES suggested that the report should include a chapter on 'Energy Storage'. It was decided that a New Chapter on 'Energy Storage Systems' to be included in the report and the chapter would cover different storage systems like batteries, ultra-capacitors, super conducting flywheels etc. MNES was asked to write this chapter in consultation with Prof. A.K. Shukla, Director, Central Electrochemical Research Institute (CECRI), Karaikudi, Tamil Nadu, for necessary inputs.

24. It was strongly felt that a chapter on R&D for "Energy Efficiency" needs to be included in the report. Bureau of Energy Efficiency would be asked to write this chapter.

25. Chairman decided that another meeting i.e. the 4th Meeting of the Working Group would be held to finalize the report and recommendations in Energy R&D to the Planning Commission.

26. The meeting then ended with a Vote of Thanks to the Chair, and to all the members and special invitees.

ANNEXURE TO THE MINUTES OF THE 3RD MEETING OF THE WORKING GROUP ON R&D FOR THE ENERGY SECTOR FOR THE FORMULATION OF THE ELEVENTH FIVE YEAR PLAN (2007-2012)

Date : ***20th September, 2006***

Time : ***1030 hr***

Venue : ***Committee Room 'A', Vigyan Bhawan Annexe***
Maulana Azad Road, New Delhi-110 011

LIST OF PARTICIPANTS

Sl. No.	Name, Designation and full address of the Organisation	Status
1.	**Dr. R. Chidambaram** Principal Scientific Adviser to the Government of India 318, Vigyan Bhawan Annexe Maulana Azad Road New Delhi – 110 011.	**Chairman**
2.	**Shri Surya P. Sethi,** Adviser (Energy) Planning Commission Room No. 261, Yojana Bhawan Sansad Marg New Delhi-110 001.	**Member**
3.	**Dr. Anand Patwardhan** Executive Director Technology Information, Forecasting and Assessment Council Department of Science and Technology Vishwakarma Bhawan Shaheed Jeet Singh Marg New Delhi – 110 016.	**Member**
4.	**Dr. R.B. Grover** Director Strategic Planning Group Department of Atomic Energy Anushakti Bhawan Chhatrapati Shivaji Maharaj Marg Mumbai 400 001.	**Member**
5.	**Dr. S.C. Mullick** Professor Centre for Energy Studies Indian Institute of Technology Delhi Hauz Khas New Delhi - 110 016.	**Representative of Dr. M.K.G. Babu, Head, Centre for Energy Studies, Indian Institute of Technology Delhi, who is a Member of the Working Group.**

Sl. No.	Name, Designation and full address of the Organisation	Status
6.	**Shri S.K. Goyal** Head, R&D Centre and Group General Manager Corporate R&D Bharat Heavy Electricals Limited (BHEL) Vikas Nagar Hyderabad-500 093	**Member**
7.	**Shri M.C. Nebhnani** Head, R&D Centre and General Manager National Thermal Power Corporation Limited Research and Development Centre A-8A, Sector-24, Noida, 201 301.	**Member**
8.	**Shri S. Chakrabarti** Director Tech. (RD&T) Central Mine Planning & Design Institute Ltd. (CMPDIL), Gondwana Place, Kanke Road Ranchi - 834 008	**Representative of Shri S. Chaudhuri, Chairman & Managing Director, CMPDIL, who is a Member of the Working Group.**
9.	**Dr. R.P. Verma** Executive Director (R&D) Indian Oil Corporation Limited R&D Centre, Sector-13 Faridabad- 121 007.	**Member**
10.	**Dr. Bibek Bandyopadhyay** Scientist 'G' and Head Solar Energy Centre Ministry of Non-conventional Energy Sources Gwalpahari, Gurgaon. ***Postal Address:*** Block No. 14, C.G.O. Complex, Lodi Raod, New Delhi-110 003.	**Member**
11.	**Dr. Nalinaksh S. Vyas** Professor Department of Mechanical Engineering Indian Institute of Technology Kanpur Kanpur-208 016.	**Member**
12.	**Dr. S.K. Sikka** Scientific Secretary to the Principal Scientific Adviser to the Government of India 324-A, Vigyan Bhawan Annexe Maulana Azad Road New Delhi – 110 011.	**Special Invitee**
13.	**Shri Ajai Vikram Singh** Former Secretary Ministry of Non-conventional Energy Sources Block -14, CGO Complex Lodi Road, New Delhi 110 003.	**Special Invitee**

Sl. No.	Name, Designation and full address of the Organisation	Status
14.	**Dr. B. Bhargava** Director Solar Energy Centre Ministry of Non-conventional Energy Sources Block -14, CGO Complex Lodi Road, New Delhi 110 003	**Special Invitee**
15.	**Dr. K. Bhanu Shankar Rao** Head Mechanical Metallurgy Division Indira Gandhi Centre for Atomic Research Kalpakkam – 603 102 Tamilnadu	**Special Invitee**
16.	**Shri S. Chatterjee** Scientist 'G' Office of the Principal Scientific Adviser to the Government of India 313A, Vigyan Bhawan Annexe Maulana Azad Road New Delhi – 110 011.	**Special Invitee**
17.	**Shri Dilip Chenoy** Director General Society of Indian Automobile Manufacturers, Core 4-B, 5th Floor India Habitat Centre, Lodi Road New Delhi-110 003	**Special Invitee**
18.	**Shri A.K. Goel** Director (R&D) Petroleum Conservation Research Association Sanrakshan Bhavan 10- Bhikaiji Cama Place ew Delhi-110 066.	**Special Invitee**
19.	**Shri K.P. Singh** Chief Engineer Central Electricity Authority Sewa Bhawan, R.K. Puram New Delhi-110 066.	**Special Invitee**
20.	**Shri G. Behari** Director (R&D) Centre for Energy Studies Indian Institute of Technology Delhi Sewa Bhawan, R.K. Puram New Delhi-110 066.	**Special Invitee**
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Sl. No.	Name, Designation and full address of the Organisation	Status
22.	**Shri M. Satyamurty** Joint Adviser (Coal) Planning Commission Yojana Bhawan, Sansad Marg New Delhi-110 001.	**Special Invitee**
23.	**Shri P.R. Basak** Scientist 'E' Technology Information, Forecasting and Assessment Council Department of Science and Technology Vishwakarma Bhawan Shaheed Jeet Singh Marg New Delhi – 110 016.	**Special Invitee**
24.	**Shri N. Bakthavatchalam** Vice President (Projects) Bannari Amman Sugars Limited 1212, Trichy Road Coimbatore – 641 018.	**Special Invitee**
25.	**Shri G. Vyas** Ganeral Manager Bannari Amman Sugars Limited 1212, Trichy Road Coimbatore – 641 018.	**Special Invitee**
26.	**Shri Rahul Kumar** Senior Scientific Officer-II Technology Information, Forecasting and Assessment Council Department of Science and Technology Vishwakarma Bhawan Shaheed Jeet Singh Marg New Delhi – 110 016.	**Special Invitee**

ANNEXURE-V (MENTIONED IN THE PREFACE)

SPIN-OFFS OF NUCLEAR ENERGY R&D INTO OTHER ENERGY AREAS

(Author: Dr. R.B. Grover, Director, Strategic Planning Group, Department of Atomic Energy, Mumbai – *Member*)

A) SPIN-OFFS FROM R&D AT INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH

Contact Person: Director, IGCAR

1) Structural Engineering

i. Theoretical and Experimental structural integrity assessment of engineering components.

ii. Fracture assessment including analysis leak before break for various components.

iii. Fatigue and fracture testing methodology for laboratory standard samples and real time components of engineering structures.

iv. Structural dynamics and seismic analysis of engineering components.

v. Mechanical testing of ferritic steels and stainless steels for property assessment related to design and structural integrity assessment.

vi. Finite element modeling of hot working and cold working processes.

vii. Artificial neural network approach for life prediction of engineering components.

2) Manufacturing, welding and coating technologies

i. Manufacturing and welding technology for austenitic stainless steel, ferritic steel, and other dissimilar joining.

ii. Processing MAPS and instability MAPS of 304SS, 316SS, 304 LSS, 316 L1 SS, modified 9Cr-1Mo steel etc.

iii. Manufacturing technology for components like Pressure Vessels, Steam Generator, Condenser, Pumps etc.

iv. Surface cleaning and treatment procedures for steels and stainless steels.

v. Titanium manufacturing technology and its dissimilar joining process with stainless steels.

vi. In situ repair welding technology of steam turbines in power plants.

vii. Time-temperature sensitization diagrams for various austenitic stainless steels.

viii. Hard facing coating technology for satellite, colmonoy, boride and aluminide coatings.

ix. plasma nitriding technology on stainless steels for hard facing.

3) Non-destructive and robotics technologies

i. Host of conventional and advanced NDT techniques for laboratory and engineering components evaluation in real time.

ii. Small size sample testing for mechanical property evaluation.

iii. Precise CNC based profilometric technology.

iv. In service inspection technology of plant components during service.

v. Remote handling devices for in service inspection of plant components.

vi. Manipulators for non-destructive evaluation applications.

vii. Robotics technology for sampling, transportation, analysis, inspection etc.

4) Hydrodynamic and chemical measurement technologies

i. Velocity, flow, level and vibration measurement and sensing technology.

ii. Chemical analysis of bulk and trace quantity of elements in liquid, solid and gas media.

iii. Simulation and modeling of unit operations in chemical process.

iv. Chemical sensor technology for on line monitoring of chemical species in liquid, gas and solid materials.

B) SPIN-OFFS FROM R&D AT BHABHA ATOMIC RESEARCH CENTRE

Contact Person: Director, Reactor Design and Development Group, B.A.R.C.

1) Non-Intrusive on-line Health monitoring of Steam Turbine

i) BARC has developed an on-line diagnostic system for providing early warning of incipient blade cracking and failure in steam turbines used in power plants. The turbines are commonly used to drive generators to produce electricity in many coal, oil and gas fired thermal power plants, as well as nuclear power plants. Several disks, fitted with blades at their circumference, are mounted on the rotor of a turbine. During operation of these turbines, steam is guided on the blades thus causing the rotor to rotate at very high speed

ii) Periodic non-destructive inspection of these blades helps in identifying any defects and cracks existing at the time of inspection during long shutdown of the turbo generator unit. Obviously, this cannot be done very often. Blade failure during turbine operation could cause wide spread devastation. Many such serious accidents have occurred and reported from all over the world. An early warning about a problematic stage can prevent occurrence of such accidents.

iii) Work was initiated in BARC to develop a blade vibration based reliable diagnostic system, which can detect change in vibration characteristics and provide an early warning of incipient blade cracking and failure. The development of such a system is extremely challenging. Discriminating blade related signals in extremely noisy steam environment is like picking up sound of pin drop in a noisy room. On top of it, detecting altered vibration characteristics of one defective stage among several healthy ones is a daunting task. The detection technique developed by BARC successfully meets these challenging requirements.

iv) The system can be installed in an operating plant and it costs even less than the existing system for shaft and bearing vibration monitoring. The technique has been tested and validated in both thermal and nuclear power plants. In principle, the technique is also applicable to large rotary compressors and gas turbines.

2) Heat transfer, pressure drop and stability studies on Super Critical fluids

i) Super critical fluids have the advantage that there is no phase change because of operation above the thermodynamic critical point (CP) eliminating the occurrence of the critical heat flux phenomenon. Avoidance of the two–phase region results in the elimination of equipments such as the steam–water separators and dryers resulting in compact design. In addition, supercritical power plants have improved efficiency compared to conventional power plants. Because of the excellent heat transfer characteristics of supercritical water, it is used in thermal power plants. Besides, its use in advanced nuclear power plants is also contemplated. In this context, R&D programme on supercritical water reactors (SCWRS) has been taken up in BARC. Use of supercritical fluid in power plants requires reliable data on the heat transfer, pressure drop and stability behaviour of supercritical fluids. However, these data are not readily available. Hence an experimental investigation is underway to meet the following objectives.

- Generation of database for stable and unstable operation
- To generate pressure drop data.
- To generate data on the heat transfer coefficient under supercritical conditions
- Scaling laws for supercritical fluids.
- Corrosion studies and limited blow down studies to estimate of critical flow rate.

ii) For the thermal hydraulic analysis, a computer code has been developed in house to analyze the steady state and stability behaviour. The computer code uses supercritical water property routines developed in-house. The data being generated will be highly useful for nuclear plants as well as thermal power plants using supercritical water.

C) SPIN-OFFS FROM R&D AT INSTITUTE FOR PLASMA RESEARCH

Contact Person: Prof. P.I. John, I.P.R.

1) Plasma Nitriding of Hydropower Components

i) Generating units in many hydro power plants in India face problems of forced outages due to silt damages to turbine components such as runner, guide vanes, surface liners of turbine top cover and bottom ring and labyrinth sealing ring.

ii) The Himalayan rivers carry huge quantity of silt load (several thousand of ppm) during monsoon period of April-September. The silt comprises of 90-95% quartz particles, which, causes abrasive loss of material from the affected components. To evolve a cost effective solution to combat silt erosion of underwater components of hydro turbines, we along with NHPC have evaluated plasma nitriding of hydro turbine components to reduce wear.

iii) Surface hardness of 1255 HV and case depths of 250 microns was observed after plasma nitriding of 13CrNi4 steel. Similarly, the surface hardness of 1220 HV and case depths of 150 microns was observed after plasma nitriding of 18CrNi10 steel.

iv) For, the first time, we proved that we could plasma nitride the welded surface made of SS 444L and SS 309Mo. The welded surface was initially stress relieved before plasma nitriding. The results indicated a case of ~250 microns for both these welded surfaces, but the surface hardness of SS 444L was 973HV compared to surface hardness of ~1200HV on SS 309Mo steel. Since SS 444L is a martensitic steel and contains lower alloying elements than SS 309Mo, its lower surface hardness after plasma nitriding rules out its usage for rehabilitation. SS 309Mo is an appropriate material for welding compared to SS 444L for increased surface hardness after plasma nitriding. Erosion results indicated that plasma nitrided 13CrNi4 samples performed better than the 18CrNi4 and the reworked samples. The tests were carried out according to ASTM G72 standard for 10 hours.

v) FCIPT has plasma nitrided several guide vanes for NHPC. A surface hardness of 1250 HV and a case depth of 250 microns were obtained after plasma nitriding. The field results indicated an enhanced improvement in the life of the components compared to the untreated component.

2) Teflon Like Coating for Fast Breeder Reactor Components

i) Inflatable Seals are used in the annular spaces of Prototype Fast Breeder Reactor (PFBR) Rotatable Plugs (RP) & PFBR Inclined Fuel Translift Machine (IFTM) to restrict the radioactive release. The seal rubbing face and the shell surface are required to be coated with Teflon to minimize friction and possibilities of failure. Teflon has been chosen as the coating material because of its lowest coefficient of friction, minimum stick-slip and stable tribological characteristics. Elastomer seal material cannot be treated at elevated substrate temperatures as they loose their properties. FCIPT has developed Plasma Enhanced Chemical Vapor Deposition (PECVD) process to deposit Teflon like coating on Elastomer and Steel surfaces that produces nearly frictionless surface.

ii) PECVD is a process by which it is possible to deposit high quality film at low substrate temperature. Fluoro Carbon precursors (CF_2=CF_2, CF_2=CF-CF_3) were generated by pyrolysing solid Teflon material at 450^{o}C. These precursors were introduced in plasma where the precursor molecules get fragmented and transport to the surface of the elastomer. The coating achieved from this process was found uniform, smooth, defect free and having good adhesion on steel surfaces. Teflon coating was confirmed by XPS (X-ray Photoelectron Spectroscopy) studies. The surface of the plasma-coated elastomer test samples were also analyzed using optical microscope and Scanning Electron Microscope (SEM) at FCIPT.

Optical Micrographs show clear difference between the roughness of untreated and plasma Teflon coated elastomer surface.

iii) Four times reduction in surface roughness was achieved in test samples. After confirming required qualities of the coating on test samples, first milestone of the project was achieved which was demonstration of successful deposition of Teflon like coating on 0.5 meter diameter seal surface. Next milestones of this project are optimization and demonstration of the process for 2 meter, 4 meter and 6 meter diameter seal surfaces.

3) Anti-reflection Films on Solar Cells

i) We have developed SiO_xN_y anti-reflection coating with a thickness of 870 $\pm$ 15 A° for textured Si-solar cells using PECVD on single crystal p-type Si (100) and textured Si-solar cells. We grow SiO_xN_y films using a safe organo-silicon precursor, HMDSN: (CH_3)6Si2NH. Using the criterion of bond co-ordination constraints, we grow SiO_xN_y films corresponding to an average bond co-ordination $N_{av} < 3$. It is known that SiO_2 exhibits a N_{av} ~2.67 which systematically increases to a N_{av} ~3.5 for Si_3N_4. N_{av} ~ 3 separates device quality films from defective interfaces. The elemental composition of the films was determined using XPS and AES depth profiles and could be varied between $SiO_{1.9}N_{0.1}$ to $SiO_{1.6}N_{0.3}$. An improvement of 1 % in the efficiency (AM 1) of solar cells is obtained due to the coating.

ii) Following an initial *ex-situ* cleaning, the wafers were subjected to an *in-situ* cleaning using an Ar gas discharge before carrying out PECVD with wafers placed on the live electrode. Relative concentrations of oxygen and nitrogen in the films were controlled by varying N_2 flow rate between 25-50 sccm at a fixed flow rate of 50 sccm of HMDSN. The vaporized HMDSN, containing 1.5% water vapor as source of oxygen was mixed with N_2 gas prior to introduction into the plasma via a shower head which formed one plate of the capacitive glow discharge. The depositions were carried out at a substrate temperature of 120°C as depositions at higher temperature result in carbon contamination in the films. The resulting films deposited on Si (100) were amorphous as confirmed by absence of diffraction peaks using grazing incidence X-ray diffraction. XPS and small-spot (~1μm) electron-induced AES measurements were carried out in a Multi-technique Physical Electronics System 5702 (U.S.A.). XPS and AES studies were done at a vacuum of $8x10^{-10}$ torr with the pressure rising to $6x10^{-9}$ torr during etching. XPS was carried out using MgKα (ΔE = 0.9 eV) and monochromatic AlKα source (ΔE = 0.5 eV). A depth profile of a thermally grown 1000 A° Ta_2O_5 film was used to calibrate the thickness of the SiO_xN_y films.

iii) Atomic concentrations as a function of depth obtained from an electron-induced AES depth profile, with etching time converted into depth shows that composition is fairly uniform over the thickness of the deposited film. Similar profiles have been obtained over the area of films deposited on 125-mm pseudo square solar cells. The mid-point of the crossover in Si and oxygen concentrations is the film thickness and gives a deposition rate of ~60 A°/ min. While this deposition rate is small, we could grow $SiO_{1.6}N_{0.3}$ films up to a thickness of 2700 A° at the same deposition rate. Having established the conditions for growing high-quality films using HMDSN and knowing the deposition rate and composition, films of thickness 870±15 A° were grown as an AR coating for textured 125 mm pseudo-square Si-solar cells. A batch of 60 cells were tested for efficiency (AM 1) before and after deposition. The AM 1 efficiency increased from 12.0% to 13.1±0.1% for the entire batch of solar cells.

4) Metallic jet production using pulsed electrical discharges in water

i) Capacitor-bank driven pulsed electrical discharges in water can create high pressures, of the order of several tens of kilobars. Such pressures have industrial applications, such as in rock fragmentation. We report, for the first time, the use of such discharges to accelerate thin metallic liners to high velocities. The liners turn into high-velocity jets which can perforate metal sheets.

ii) These experiments make use of a 15 kV, 60 kJ capacitor bank. The bank delivers energy to the load through a coaxial cable. The load is a fluid-filled cavity consisting of a right-circular cylinder, one end of which is heavily tamped. The other end is bounded by a conical copper liner. The cavity is filled with a viscous fluid. Discharge of the capacitor bank dumps energy in a small region of the fluid, producing a high pressure "hot zone''. The resulting shock / pressure waves produce liner collapse and acceleration, leading to a high-velocity jet. Approximate measurements indicate that the velocity lies in the range 1.4-1.6 km / sec.

iii) We have studied the performance of these jets for metal plate perforation. Jets produced by a copper liner can perforate up to 5 mm of aluminium sheet.

5) Energy Recovery from Waste Pyrolysis

i) We have developed plasma torch-based pyrolysis systems for the treatment of medical and plastic wastes. Possible reactions, which take place during the pyrolysis of polymer waste, are described below:

$C_6H_{10}O_5 + \text{Heat} \Rightarrow CH_4 + 2CO + 3H_2O + 3C$ —— (1)

Cellulose

$[-CH_2-CH_2-]_n + H_2O + \text{Heat} \Rightarrow xCH_4 + yH_2 + zCO$ —— (2)

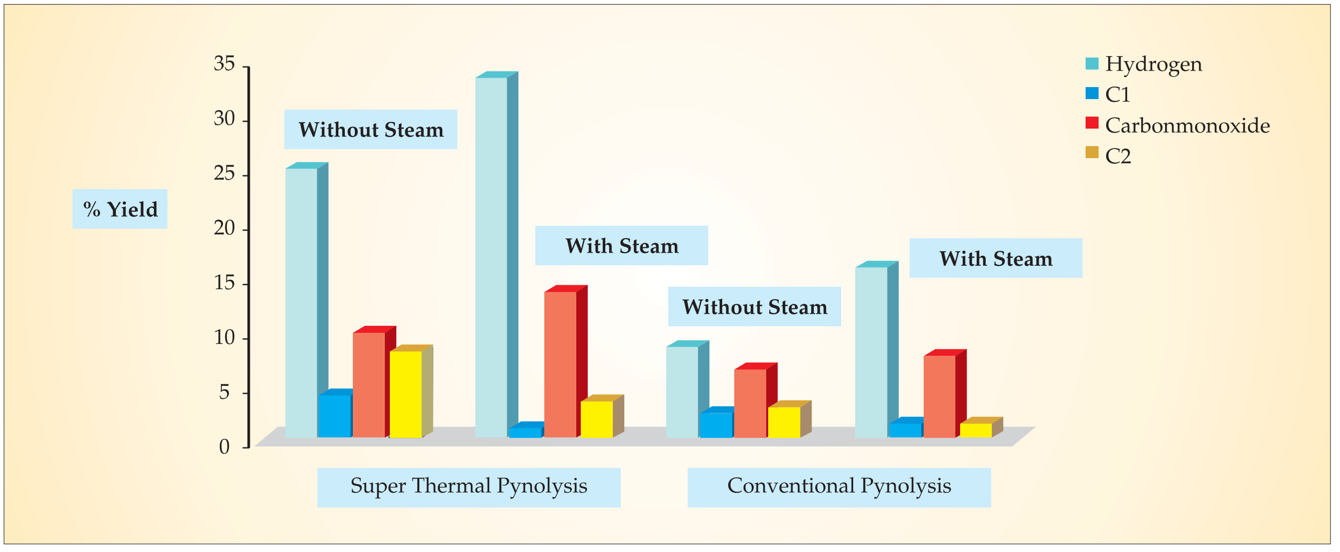
Polyethylene

$3C + 2H_2O + \text{Heat} \Rightarrow CH_4 + 2CO$ —— (3)

ii) Gas chromatograph results of the plasma pyrolysed polymer compounds reveals that typical gaseous products formed are rich in hydrogen and carbon monoxide with some lower hydrocarbons. As the total quantity of H_2 and CO in the gaseous mixture is more than 49% by volume (shown in figure) thus provide very high temperature on burning. The proportion of these gases increase with super thermal pyrolysis where the plasma flame is in direct contact with the waste material.

iii) It has been found that this gas composition is better than that obtained in biomass gasification from the perspective of energy generation. Biomass provides 3500-4000 kcal energy from 1 kg of waste.

Gases	Biomass	Plasma Pyrolysis
$CO + H_2$	38-44%; H_2: 18%	45-60%; H_2: 33%
CO_2	4-5%	4-8%
N_2	50%	30-50%
CH_4	1-3%	3-6%
Other HC	<0.5%	2 -7%
HCl; NO_x	Negligible	< 20 ppm; < 85 ppm
Total Combustible Gases	39-47%	50-65%



ANNEXURE-VI (MENTIONED IN THE PREFACE)

BREAK-UP OF THE PROJECTED AMOUNT OF RS.5310.00 CRORES FOR PURSUING R&D IN DIFFERENT AREAS OF THE ENERGY SECTOR IN THE ELEVENTH FIVE YEAR PLAN.

Sl. No.	Name of the Area	Amount projected (Rs. in crores)
1.	**Development and production of new materials**	400.00
2.	**R&D in biofuels**	200.00
3.	**Combustion research initiative**	200.00
4.	**Energy R&D in the Indian Railways**	45.00
5.	**Hydrogen as a source of clean energy**	350.00
6.	**Advanced coal technologies**	
	i) Setting-up of the first (~100 MWe) IGCC demonstration plant in the country.	350.00
	ii) In-situ gasification of coal and lignite	30.00
	iii) Coal to oil conversion	200.00
	iv) Coal bed methane	35.00
	v) Carbon capture and storage (including climate change issues)	125.00
7.	**Ultra super critical technologies**	30.00
8.	**Energy storage systems**	400.00
9.	**Futuristic energy sources**	
	i) Gas hydrates	350.00
	ii) Oil shale	15.00
10.	**Energy efficiency**	205.00
11.	**Technologically important crystals – a facility to manufacture polysilicon for production of single crystals of silicon**	1200.00
12.	**Light Emitting Diodes (LEDs) – a viable alternative to fluorescent lighting**	1000.00
13.	**Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) – viable alternate propulsion systems**	175.00
	Grand Total	5310.00

ANNEXURE-VII (MENTIONED IN THE SECTION-I ON DEVELOPMENT AND PRODUCTION OF NEW MATERIALS)

FACILITIES TO BE ESTABLISHED:

1.	Alloy Development facilities for laboratory melts (50Kg-100Kg)	Rs. 25 Crores
2.	Cold Working and Hot Working Facilities	Rs. 25 Crores
3.	Heat Treatment Furnaces	Rs. 5 Crores
4.	Sophisticated chemical analysis equipment	Rs. 9 Crores
5.	Facilities for microstructural characterization (TEM, SEM, MICROPROBE, Optical Microscopes)	Rs. 18 Crores
6.	Laboratory for creep testing (Consisting of test points of the order of 150 along with associated data logger, Uninterrupted power supply etc.)	Rs. 18 Crores
7.	Laboratory for Low Cycle and High Cycle Fatigue Testing at Elevated Temperatures and under Corrosion Environments	Rs. 10 Crores
8.	Tensile, Impact and Hardness Testing Laboratory	Rs. 6 Crores
9.	Laboratory for Metallography	Rs. 2 Crores
10.	Simulation Equipment for Generating Microstructures	Rs. 5 Crores
11.	Welding and long-term operation of components	Rs. 3 Crores
12.	Buildings for housing various facilities	Rs. 5 Crores
13.	Ferritic Steels Development and processing	Rs. 20 Crores
14.	Superalloys Development and processing	Rs. 35 Crores
14.	Modeling of Processes and Properties	Rs. 2 Crores
15.	Precision Machining of Samples	Rs. 2 Crores
16.	Salaries and Infrastructure	Rs. 10 Crores
	Total Cost:	**Rs. 200 Crores**

TOTAL MAN POWER PROPOSED: (35 Employees+10 Research Students)

1.	Metallurgists :	8
2.	Mechanical Engineers:	5
3.	Chemists:	2
4.	Electrical / Electronics	3
5.	Diploma Holders:	5
6.	Laboratory Assistants:	5
7.	Tradesman:	5
8.	Secretary	2
9.	**Research Students**	**10**

Funding for the above Consortium during 2007-2012 should be entirely supported by Government of India. However, a consortium of members consisting of power plant equipment manufacturers, utilities and steel and superalloy manufacturers should be formed. Consortium should also include R&D personnel of proven track record to develop advanced materials for high technology applications. The operation of consortium can be worked-out by consultations to ensure whole hearted participation of the Indian industries by extending facilities, sharing the expertise and costs involved in the materials development. The project may have to be extended beyond 2012 and further funding will be sought from Government of India and industry partners in the consortium, based on the review of the progress achieved during 2007-2012.

The materials development initiative would bring in several "Spin-offs". It would reduce duplicated research in energy sector and provides opportunities for professionals from a variety of research, academic and industries to collaborate, increasing the overall effectiveness of India's scientific and technology base. The materials developed in this programme are also of substantial interest to Chemical and Petrochemical industries.

Table 1: Materials for the High Pressure Steam Turbine

Component	566^{0}C	620^{0}C	700^{0}C	760^{0}C
Casings/ shells (Valves; steam chests; nozzle box; cylinders)	Cr MoV (cast) 10Cr MoVNb	9-10%Cr (W) 12CrW (Co)	CF8C+ CCA617 Inconel 625 IN 718 Nimonic 263	CCA617 Inconel 740
Bolting	422 9-12% CrMo V Nimonic80A	9-12%CrMo V A286 IN 718	Nimonic105 Nimonic115 Waspaloy IN 718	U700 U710 U720 Nimonic 105 Nimonic 115
Rotors/ Discs	1 Cr MoV 12 CrMoVNbN 26NiCrMoV11 5	9-12% CrWCo 12CrMoWVNbN	CCA617 Inconel 625 Haynes 230 Inconel 740	CCA617 Inconel 740
Vanes/ Blades	422 10 CrMoVNbN	9-12% CrWCo	Wrought Ni Base	Wrought Ni Base
Piping	P22, P91	P91, P92	CCA617	Inconel 740

Table 2: Advanced Materials for Various Gas Turbines

Components	GE	SIEMENS	ABB	Westinghouse
BUCKETS	Rene N5 SC GTD111, DS, SC IN738, U500	IN738LC, IN713 DS, SC, IN792 Nim 90, 80A PWA 1483 SC	CMSX2,4, CM247LC IN713LC, IN738LC IN939, U720, 520 Nim 90, 80A	IN738, X750 DS, CM247LC, MGA1400 DS WES DS, WES SC,
NOZZLES	FSX414 DS, SC X 45 / 40, N155 GTD222, Rene N5 SC	IN939 DS, SC PWA 1483 SC	IN939, DS CM247LC FSX414 DS, SC X 45 / 40, MM509	ECY768 (MM509) IN 939 MGA2400 DS & SC WES 100, X 45
COMBUSTORS	HS188, Nim263 HASTELLOY-X	15Mo3 with Tiles IN617 Liner		IN617, HS230 & Ni Base with TBC
TURBINE ROTOR	IN718, IN706 M152, A286 CrMoV	X12CrNiMo 1 2		CrMoV
COMPRESSOR ROTOR	CrMoNiV CrMoV	25NiCrMoV 11 5 26NiCrMoV 14 5		
COMPRESSOR BLADES	X10Cr13 CUSTOM 450	X4CrNiMo 16 51 X20Cr13 X20CrMo13		

Table 3: Materials for Gasification Systems

Alloy	Composition (wt %)			
	Cr	Ni	Fe	Others
AC66	27	32	Bal	0.1 Ce, 0.9 Nb
AISI 310	25	20	Bal	1.8 Si
Aisi 310L	25	20	Bal	0.7 Mn
AISI 316L	17	11	Bal	2.3 Mo
AISI 347	18	11	Bal	1.7 Mn, 0.6 Nb, 0.5 Si
Alloy 800L	21	32	Bal	1.2 Mn
Alloy 800H	21	32	Bal	0.71 Mn
AMAX 25-36-3	26	38	Bal	3.3 V, 1 Mn, 0.3 Nb
AMAX 25Cr35 Ni1.5 A12 Si	25	35	Bal	2 Si, 1.5 Al
Fecralloy 631072	19.6	0.2	Bal	5.4 A1, 2 Si
Fecralloy 31085	20.4	0.1	Bal	4.9 A1, 2 Si
Haynes 120	25	37	Bal	0.55 Si
Haynes 160	28	Bal.	2	29 Co, 2.7 Si
Haynes 556	21.6	19.9	Bal.	18 Co
HR3C	24.9	20.3	Bal	1.2 Mn, 0.4 Si
IN 625	21.5	Bal.	2.5	9.1 Mo
MA 956	20	0.1	Bal.	5 A1, 0.5 Y as $Y_2 O_3$
Nicrofer 6025	25	Bal.	9.5	
Nicrofer 5923	23	Bal.	1.5	
Nicrofer 45 TM	27.5	Bal.	23	2.7 Si
PM 2000	20	-	Bal.	5.5 A1, 0.5 Ti 0.5 Y_2O_3, 0.09 Si
Sanicro 28	27	31	Bal.	3.33 Mo
Sicromal 9	13.5	-	Bal.	1 A1, 1 Si

Table 4: International Scenario

Some of the Important International Programmes aimed at Developing Materials for High Thermal Efficiency Power Plants are:

Programme	Agency	Purpose	Time Frame	Cost, Rs
COST 501	European Co-operation Commission on Science and Technology (from website)	Materials for Power Generation	1986 - 1997	5000 crore
ECCC	European Creep Collaborative Committee (16 countries, 40 organizations)	Development of creep data for high temperature plant	1992-1996 1997-2001 2002-2006	
COST 522 – Energy Generation in 21st Century: Ultra Efficient, Low emission Plants	European	To develop ferritic steels for advanced steam power plants up to 650°C	1998 - 2003	
COST 536				
Thermie AD 700	European	Advanced Power Plants operating at 700°C	1998-2004 P-I 2001-2006 P-II 2006- P-III	120 crore 60 crore 90 crore
DOE Vision 21 Project	USA	Power Plants operating at 732°C		
Advanced Materials Developemnt	NIMS, Japan	Power Plants Upto 650°C	1996-	
US project on Boiler Matls, DOE OCDO			2002-2007	100 crore

Resource Persons:

Dr. Baldev Raj (Distinguished Scientist and Director, IGCAR, Kalpakkam 603102,

Dr. K. Bhanu Sankara Rao (Head, Mechanical Metallurgy Division, IGCAR, Kalpakkam 603 102)

Shri S.K. Goyal (Head, Corporate R&D Centre, BHEL, Vikas Nagar, Hyderabad 500 093)

Dr. C.R. Prasad (General Manager, Metallurgy Laboratory, Corporate R&D Centre, BHEL, Vikas Nagar, Hyderabad 500 093)

ANNEXURE-VIII (MENTIONED IN THE SECTION-X ON R&D IN THE POWER SECTOR)

UPGRADATION OF THE TESTING FACILITIES OF THE CENTRAL POWER RESEARCH INSTITUTE (CPRI), BANGALORE

(Author: Shri S.K. Goyal, Head, R&D Centre and Group General Manager, Corporate R&D, Bharat Heavy Electricals Limited, Hyderabad - Member.)

1) T&D Equipment manufacturer in India have been using CPRI facilities for qualification tests of their equipment developed in India or designs acquired vide different modes of technology acquisition.

2) The IEC and other related standard have been revised and are upgraded frequently and compliance to latest standard is common from utilities / customers.

3) The validity of test document has been reduced to five years and is likely to differ since customer specific.

4) The development of new indigenous equipment is constrained for quite some time for non-availability of test laboratories, specially the high power lab, and the limitation of test voltages and test currents.

5) The HPL at CPRI, Bangalore also does not have advance controls for precise control of test events and precision triggering devices to control the discharge of high energy at the desired instance. No major additions have been made in the capacity of the laboratory for past 15 years. The facility is not available for conducting High power tests freely.

6) BHEL on an average spends Rs. 4-5 Cr every year, for testing its products at various short circuit testing laboratories world over. The periodicity of test (5-Years) makes the testing process perpetual. The products include Circuit breakers, Transformers (both power and instrument), On load tap changers etc. Gas insulated substations have been added to this list recently.

7) In order to restrict drain of FE and to encourage faster development and certification of T&D products in INDIA it is necessary that CPRI strengthen their facilities and operation urgently.

8) In order to improve the range and efficiency of the test laboratory and to bring it at par with International laboratories, following additional facilities are suggested for addition to HPL (High power Laboratory, CPRI Bangalore):

Circuit Breaker under Dielectric Evaluation

9) Addition to short circuit testing capabilities:

i) The short circuit generator in a High power laboratory is used to generate power required for short circuit test. The generator is a low impedance alternator which is driven by a high capacity synchronous motor. A flywheel is attached to the machine to maintain speed during short circuit (max 3 sec.) period. The prime mover is disconnected and the generator runs on energy stored in the fly wheel while the test is on. The generator is protected for over current by a master breaker.

ii) The existing short circuit generator at CPRI, Bangalore has a capacity of 2500 MVA. The capacity is ¼ of KEMA laboratories. The generator is required to be supplemented with another SC Generator of minimum 2500 MVA to accomplish test on 400 kV / 63kA circuit breaker per unit. The addition will enhance short circuiting capabilities of HPL and will also make laboratory available for tests at half capacity during maintenance of one of the generators.

Short Circuit Generators at High Power Test Laboratory

Short Circuit Generators (Closer View)

10) A gas based 2.5 MVA captive power plant:

i) The power availability and power quality in Bangalore at times paralyses the operations of the test laboratory. The high input requirement of the test station also bar operation of the facility during power shortage. The low voltages available during power shortage too prohibit use of the facility. CPRI has made arrangements to improve voltage profile by installing boosters, however it does not completely resolve this difficulty.

ii) In view of these constraints and importance of the tests, it is suggested that a captive power plant shall be installed and run by CPRI to make the facility available to Indian manufacturers at all times. The installation will make CPRI independent of power problems and voltage regulation.

11) Addition of Capacitor bank at synthetic test facility:

In order to limit the total short circuit power requirements (Giga watts) during circuit breaker evaluation, test laboratories in synthetic test mode use independent voltage and current sources. The short circuit current is supplied from a short circuit generator while the recovery voltage is applied from a capacitor bank charged to desired voltage. Synthetic test facility available at CPRI is limited to a capacitor bank voltage of 400kV. In order to extend this facility for future requirements the voltage circuit of the STF has to be up graded to meet recovery requirements of circuit breakers, rated 500kV per break.

Capacitor Bank (Voltage Source)

12) Voltage divider for Power Frequency and Transient Recovery Voltage.

The up gradation of STF capabilities also calls for matching high voltage measurement probes for measurement of transient voltages applied and withstood by the test object. The current probe needs to be amended for higher short circuit currents of the order of 100kA.

Synthetic Test Facility (STF)

13) Power Transformers to address requirement of higher kA designs:

In order to utilize the enhanced short circuit capabilities the short circuit transformers shall also be upgraded for both direct and synthetic test facilities. Direct test shall call of increased output voltage and short circuit capability. For STF only 33kV transformers need to be strengthened for higher short circuit currents.

Power Transformers

14) State of art high resolution, precise recording system for capturing switching transients:

Controls have a very important role in short circuit testing of power equipment. They are employed to accurately synchronize various elements participating in testing set-up. The devices include short circuit generator / voltage and current sources, make switch, test object, re-ignition circuits, spark gaps, measurement and recording instruments etc. The synchronization has to be highly reliable and in a very harsh environment influenced by high heavy E and H-Fields (electrostatic and electromagnetic fields).

15) Improved Re-ignition circuit (same for all the voltages)

Re-ignition circuits are specifically used for testing circuit breakers and help extending arcing to next half cycle in a circuit breaker, by injecting arc sustaining energy near current zero. The device shall be triggered accurately to achieve desired results. Improved re-ignition circuit with proper shielding from electro-static and electro-magnetic field is essential for reliable tests.

16) Laser fired and optically controlled trigger gaps:

This **device** is a part of the voltage circuit in STF. Laser fired gaps are accurate and are remotely controlled using non-contact mediums like LASER, simplifying high voltage insulation related challenges. The device precisely ionizes the spark gap and helps transferring charge from voltage source to the test set-up.

17) High resolution recording system

i) Dedicated soft-wares have been used by International test laboratories for acquisition of test details/ data during a short circuit test. Non availability of this facility results in difficulty in analyzing failures and the reasons causing failure. Normally a visual display unit (VDU) is provided at client's desk by laboratories to see on-line the performance of the test object. Apart from visual feed back the software based recording system has the data available in the memory for future analysis.

ii) The final report preparation is also simplified with the help of these soft-wares**.**

18) Auxiliary breaker for up to 500kV :

During synthetic testing of circuit breakers an auxiliary breaker is used to disconnect the power frequency current and to isolate the generator against applied recovery voltage. As the laboratory is up-graded requirement of an auxiliary breaker is imminent. The spares for these breakers shall be stocked as the auxiliary breaker contact require frequent replacement due to severity of test duties.

19) SF6 Gas and Gas handling, storage and disposal equipment.

With increased awareness of about global warming and mild global warming potential (GWP) offered by SF6 gas it is important to conserve SF6 used at test stations. It is thus suggested that the test agency shall have sufficient means for storage, recycle and disposal SF6 gas quantities applicable to their installation.

20) Spares modules for testing equipments

21) Independent Client assembly bay and material handling equipment.

In order to avoid storage of test objects in test area and to protect client's equipment from passive damage it is important that the test bay be occupied with the test object only. Independent client bay are constructed and made available to clients at nominal charges by International laboratories. As client disturbance is minimized in the test area, the availability of the test station is also enhanced

22) Addition of capacitors for capacitive switching test

Capacitive switching tests are important test covered in standards. The breakers are tested for capacitive duties using capacitive loads arranged by the test laboratory. These capacitive loads shall be made available and shall be adequate for circuit breakers up to 400 kV. The voltage sources for this test shall have capability to cover voltage factors up to 1.4.

23) Interference/Noise related issues.

Noise immunity is of utmost important for reliable operation of a short circuit test laboratory. Modern optical connection provides this immunity and is most suited for this application. It is suggested that the laboratory renovated conventional connections using sate-of-the –art connection for control and measurement applications.

24) Membership of STL (Short-circuit Testing Liaison) and BVQI certification.

ANNEXURE – IX (MENTIONED IN THE SECTION-XI ON RENEWABLE ENERGY R&D)

RD&D THRUST AREAS & MAJOR ACTIVITIES FOR 11TH PLAN

1 Bio-energy

1.1 It is proposed to take up focused RD&D projects in the area of bio-energy resource identification and biomass conversion to energy through combustion, pyrolysation, atmospheric and high pressure gasification, plasma and bio-methanation.

1.1.1 **Bio-energy Resource**

Resource Atlas for Bio-energy covering crop residues, forest residues, MSW, industrial wastes etc.

1.1.2 **Biomass Conversion**

a. Development of MW-scale fluidized bed biomass gasifiers, hot gas clean up system and optimum integration of the system following the principles of Integrated Gasification Combined Cycle (IGCC).

b. Development of poly-generation facilities for the production of liquid fuels, variety of chemicals and hydrogen in addition to power production through IGCC route and establishing the concept of a Bio-refinery.

c. Raising efficiency of atmospheric gasification to 25-30% along with cooling systems, complete tar decomposition and safe disposal of wastes in commercial production.

d. Raising system efficiency of small (upto 1 MW) combustion and turbine technologies to 20% plus.

e. Design and Development of high rate anaerobic co-digestion systems for biogas / synthetic gas production.

f. Development of gasifier systems based on charcoal / pyrolysed biomass.

g. Design and development of systems for their coupling with Stirling engine and turbines.

h. Development of efficient kilns / systems for charcoal production / pyrolysation of biomass

i. Laying down standards for various bio-energy components, products and systems.

1.1.3 **Bio-energy Utilization**

a. Design and development of engines, Stirling engine and micro-turbine for biogas / producer gas / bio-syngas.

b. Design and development of direct gas fired absorptive chillers, driers, stoves, etc., and improvement in biomass furnaces, boilers etc.

c. Improved design and development of processes / de-watering device for drying of digested slurry.

d. Improving/ upgrading biogas and syngas quality.

e. Improved design and development of Pelletisation/ Briquetting technology for RDF.

f. Development of driers for MSW and industrial wastes.

g. Design and development of equipment for waste segregation.

2 Bio-Fuels

a. Develop technology for production of ethanol from sweet sorghum and sugar beet.

b. Developed technology for production of ethanol from ligno-cellulosic materials such as rice straw and other agricultural and forestry residues.

c. Study petrol engine performance using more than 10% blend of ethanol with petrol and undertaking engine modifications including emission studies with different levels of ethanol blend with petrol.

d. Study physico-chemical properties of all potential non-edible oils for production of bio-diesel for application in transport, stationary and other applications.

e. Developing efficient chemical/catalyst conversion processes.

f. Development of bio-catalyst and heterogeneous catalyst for production of bio-diesel.

g. Alternate use of bio products.

h. Data generation and production of bio-diesel from all possible feedstocks.

i. Response of different available additives and their dosages on the bio-diesel.

j. Effect of bio-diesel on corrosion.

k. Stability of bio-diesel.

l. Engine performance and emissions based on different feedstock based bio-diesels.

m. Toxicological studies and test to check adulteration.

n. Engine modifications for using more than 20% bio-diesel as blend with diesel.

o. Design and development bio-liquid fuel engines for stationery, portable and transport applications.

p. Development of second-generation bio-liquid fuels and related applications.

q. Response of different available additives and their dosages on the bio-diesel.

3 Solar Photovoltaic Energy

3.1 The research, design and development efforts during the 11th plan should be focused on development of silicon and other materials, efficient solar cells, low cost production techniques, thin film materials and devices, concentrating PV technology, PV systems designs and improvements, etc. Following is a list of some of the thrust areas for re-search support in solar photovoltaic technology:

3.1.1 Silicon and other Materials

a) R&D and pilot scale development of process to make poly silicon material using alternative methods to make solar grade silicon to achieve direct electricity consumption of about 125 kWh / kg of material produces, with trace impurities of heavy metals to sub ppb level and carbon and boron limited to ppb level.

b) Improvements in the process to make poly silicon material using conventional deposition technique for reducing the direct electricity consumption of about 125 kWh / kg of material produces, with trace impurities of heavy metals, carbon and boron limited to ppb.

3.1.2 Crystalline Silicon Solar Cells

a) Crystalline silicon solar cell efficiency in commercial production to be increased to average 17 -18% and more

b) Facilitate industry to develop and adopt indigenous technology to produce multi crystalline silicon ingots and solar cells with conversion efficiency of 17% and more in commercial production

c) R&D on alternative device structures to make crystalline silicon solar cells to demonstrate high efficiency (22 – 24% on small size laboratory devices)

3.1.3 This Film Solar Cell Modules

a) Development of large area integrated poly crystalline thin film modules using different materials (12% efficiency and long life)

3.1.4 New Materials based Solar Cells

a) Design and development of new thin film device structures using dye sensitized, organic and nano materials (solar cell efficiency 5 -10%)

3.1.5 Concentrating Solar Cells & Modules

a) Design and development of concentrator solar cells and modules (25 -30%) and testing of MWp scale systems.

b) Development of two axis tracking system.

3.1.6 PV Systems; storage, BOS, Modules, Designs

a) Improving the effective PV module life to 25 years and more, with total degradation within 10% of the initial rating.

b) Development of long life storage batteries (5 – 10 years) suitable for PV applications

c) Development and testing of new storage systems up to MWp scale

d) Design, development and testing of grid connected PV systems and components

e) Upgrading the testing and characterization facilities for PV materials, devices, components, modules and systems

f) Study and evaluate new materials, device structures and module designs etc.

4. Solar Thermal Energy

4.1 For the 11th Plan, activities on research, design and development leading to deployment and commercialization of various solar thermal technologies for power generation, industrial process heat systems, solar cooling are proposed, in addition to the continuing efforts to develop technologies for improvements for various low temperature applications viz. solar water heating, solar cooking. The major thrust areas include the following:

(i) Solar thermal power generation

The proposed activities would cover design and development of concentrating solar thermal power systems including parabolic troughs, central receiver systems and dish / engine systems.

A) Parabolic Trough technology

Design and development of systems having performance characteristics of internationally available technology. This will include

a. RD&D of components viz. receiver tubes for operating temperature range of about 400 C., parabolic reflector, tracking system and structures.

b. RD&D on heat transfer medium, such as, oil, water and room temperature ionic fluids for receivers.

c. RD&D on 1 MW capacity system; higher capacity system based on proven technology may also be considered

B) Central Receiver Technology

- RD&D of components such as heliostats, tracking mechanism, tower structure, receiver etc.
- RD&D on 2 MW capacity system with provision of storage

C) Dish/ Engine/ Turbine Technology

The following activities / programmes are envisaged to explore dish / engine technology for solar thermal power generation:

a) Design and development of large area solar dish with Stirling and other engines to produce power in kW-range.

b) Design and development of dish / Stirling engine power plants for distributed generation in the capacity range of 100 kW and above.

c) Design and development of Stirling engines, having capacity in the range of 500 W to 1500 W (suitable for family, community and distributed power generation) along with appropriate balance of systems including solar dish and controls.

d) Design and development of other solar compatible power generation technology like Brayton cycle turbines.

(ii) Solar Heat (upto 250°C) for Industrial Processes

The efforts will be made at to develop advanced solar collectors with optical efficiency greater than 75% and overall heat loss coefficient reduced to 4.0 W/m^2K (or lower) for flat plate collectors. For industrial process heat applications, the development of high performance solar concentrating collectors and systems will also be undertaken. It is proposed to undertake up to 20 R&D installations, each of about 50 kWth capacity based on the developed technology in different industries with a view to fine-tune the technology as well as technology validation.

(iii) Low Temperature Applications

(a) Solar cooking Systems

Newer, more efficient and cost effective designs of solar cookers will be developed to suit different cooking habits of the people. Studies related to storage of heat in solar cookers are also envisaged. The concept of multipurpose use of Solar Cookers towork as a cooker/ dryer/ water pasteuriser is to be tested to make it more useful there by reducing energy consumption. Training programmes and pilot demonstration projects for newer technologies/ concepts are also proposed to be taken up.

(b) Solar Distillation/ Water Purification Systems

There is a need to develop high yield designs of solar distillation system with a view to produce practical installations of the capacity ranging 1000 litres per day and above for water purification for variety of applications.

(c) Solar Air Heating, Drying and Food Processing Systems

The research activities to produce standardized and cost effective designs of solar air heating and drying systems for different products viz. agricultural produce, fruits, vegetables, tea, spices, fish, bagasse, urban & industrial wastes and fuels etc. are proposed to be taken-up.

(d) Solar cooling

Development of cooling systems in appropriate capacity ranges for space cooling as well as applications in cold storages with active involvement of industry is proposed. For establishing the technology, installation of about 500 tonne capacity systems is proposed for monitoring, evaluation, and design optimization studies.

(e) Solar Architecture

The work in the area of solar assisted energy efficient architecture is proposed to be continued, especially, with regard to the following:

a) To evaluate performance of such buildings with a view to disseminate the information on a wider scale.

b) To develop advance components viz. smart windows, building integrated solar devices etc.

c) To develop rating procedures for buildings based on energy efficiency and commensurate with the Indian climate and uses.

(f) Solar Detoxification of Wastes

It is proposed to continue studies in the area of solar detoxification of different type of wastes with the objective to develop suitable catalysts and the processes for solar detoxification of wastes. A few pilot demonstration plants are envisaged in industry.

(g) Development of Low Cost Materials

For manufacturing of various types of solar collectors, there is a shortage of low cost and suitable materials along with development of new fabrication processes such that bulk use of materials is reduced and production process is automated to achieve cost reduction goals. It is proposed to take up R&D projects in this area during the 11th Plan.

(iv) Development of performance standards and support to RTCs

Development of performance standards for new range of products will be undertaken. The Regional Test Centres for testing of solar thermal devices and systems, which have been supported by the Ministry and have been accredited by BIS, will continue to be supported and strengthened to undertake testing of new products as per requirement of the industry.

5 Wind Energy

a) Indigenous design, development and manufacturing capability for MW-scale Wind Electric generators (WEGs)

b) Design, development and manufacture of small WEGs upto 10 kW capacity, that can start generating power at very low cut in speeds (~ 2 to 2.5 m / sec).

c) Design, development and manufacture of submersible direct drive wind pumps in different capacity ranges (up to 10 HP) for low wind regimes.

d) RD&D on carbon fiber and other new generation composites etc.

e) RD&D on high efficiency electronics for protecting, controlling, optimizing performance, power management & conversion and establishing connectivity with the grid to export or import power.

6 Small Hydropower Development

6.1 It is proposed to launch a coordinated research and development programme led by industry and in conjunction with universities and research institutions addressing the following areas:

6.1.1 E&M Works

Adaptation of high pole permanent magnet excitation generators to small hydro.

a) Development of low speed generators (direct-drive low-speed generators for low heads).

b) Development of submersible turbo-generators.

c) Development of high efficiency turbines in kW range.

d) Flexible small hydro turbines for low head (<5 m).

e) Development of screening systems for downstream and upstream migrating aquatic life.

f) Development of standardized control and monitoring systems.

g) RD&D for development of technology packages for Mini/ Micro hydro systems fitted with suitable electronics and optional maintenance-free-rechargeable batteries for their use for lighting and other small power applications in capacity range of 200W to 5 kW for highly decentralized and dispersed applications.

6.1.2 Civil Works

Development of software that allow a fast and efficient civil work design.

a) Development of standardized/ systemized hydraulic structures.

b) Development of efficient desilters with high head intakes, of self-cleaning water intakes, and of trash racks.

c) Guide on the design of power houses.

6.1.3 Others

a) Development of good-practice design guidelines for developers and engineers.

b) Development of standards and control procedures dedicated to small hydro.

c) Guidelines for improved methods for in-stream flow and hydrological assessment methods and improved sedimentation management.

d) Standards for small/ mini/ micro hydro power projects and systems.

7 Hydrogen Energy and Fuel Cells

7.1 A broad based research and development programme covering different aspects of hydrogen energy, including its production, storage, transportation, delivery, applications and safety aspects needs to undertaken through industry in conjunction with national laboratories, universities, IITs, NITs and other research organizations. The focus of RD&D efforts in this area will be directed towards development of new materials, processes, components, sub-systems and systems.

7.2 It is proposed to set up a Hydrogen and Fuel Cell Facility in the premises of Solar Energy Centre of the Ministry. This facility will undertake and co-ordinate RD&D on hydrogen and fuel cell technologies with other R&D groups and industry

7.3 Hydrogen Production/ Supply

a) Tapping by-product/ spare hydrogen.

b) Design and Development of skid-mounted small scale steam methane reformers (SMR) for distributed generation of hydrogen.

c) Design and Development of high efficiency water electrolysers, including solid polymer electrolyte water electrolyser (SPEWE), for distributed hydrogen production.

d) Purification, pressurization and storage.

e) Design & Development of small reformers for on-site and on-board reformation.

f) Pilot scale generation of hydrogen by biological processes.

g) Pilot scale demonstration of hydrogen production from carbohydrate bioorganic waste by different processes.

h) Pilot plant for low temperature water splitting by biological route.

i) Pilot plant for production of hydrogen and synthetic fluid fuel by adopting IGCC technology for Indian coal as well as biomass.

j) RD&D on high temperature steam electrolysis (HTSE).

k) Design and development of 1 Nm^3/hr HTSE and 5 Nm^3/hr indigenously developed SPEWE.

l) Design and development of solar based water splitting processes.

7.4 **Hydrogen Storage**

a) Development of inter-metallic hydrides with storage efficiency: 5 wt% & cycle life of 1,000 cycles.

b) Development of high pressure (~500 bar) gaseous cylinder.

c) Development of Nano-materials, including carbon nano-tubes/ nano- fibres.

d) Development of alanates, including Na and Mg alanates.

e) Exploration of unusual storage modes like depleted mines.

7.5 **Hydrogen Delivery**

a) Decentralized distribution through high pressure (>200 bar) gaseous cylinders employing trucks.

b) Decentralized distribution through hydrides canisters.

c) Decentralized distribution through high pressure (500 bar) gaseous cylinders employing trucks.

d) Pipeline network.

e) Decentralized distribution through hydrides canisters.

7.6 **Hydrogen Application in Transport, Power Generation & Other Applications**

A) IC Engine Route

a) Design & Development of hydrogen IC engines and components for transport, portable and stationery applications.

B) Fuel Cell Route

C) Low Temperature Fuel Cells

i) Design and development of PEMFC and AFC.

ii) PEMFC:

a) Low-cost 'proton exchange' membranes as a substitute to costly imported membrane.

b) Low-cost bipolar plates (graphite based, high conductivity, impervious) preferably with flow grooves incorporated during molding itself.

c) Higher CO tolerant anode catalyst.

d) Cheaper cathode catalyst.

e) Electrode support substrate (graphite paper).

iii) AFC:

a) Compact, low-power electrolyte re-circulating system.

b) Low cost CO_2 scrubber & alkali-water heat exchanger.

c) Low-cost catalysts (Ni-Co spinel, MnO_2/ C).

d) Low-cost, resin based mono-polar plates/ cell enclosures.

e) Regenerative CO_2 scrubbing system.

iv) Optimize design of various components (bipolar plates, MEAs etc for PEMFC and electrode frames, seals, CO_2 scrubbing/ electrolyte re-circulating systems for AFC).

v) Assemble and test the stacks.

vi) Integrate the AFC and PEMFC stacks with other subsystems.

vii) Design & development micro power rating/ size Fuel Cells (like pencil cells/ batteries) for small/ micro power applications for laptops, mobile phones and other small power requiring gadgets/ systems.

D) High Temperature Fuel Cells

(i) Design and development of SOFC stacks (5 kW) and of MCFC stacks (10 kW) :

a) Decide which SOFC technology is to be pursued (Planar or Tubular);

b) Develop and optimize component and stack design for SOFC and MCFC. Identify fuel to be used.

(ii) Design and development of SOFC stacks and of MCFC stacks:

a) Develop various components (electrodes, electrolyte, seals) including identifying the materials to be used & processing techniques to be adopted. Design inter-connects (between adjacent cells) and overall current collectors.

b) Design mechanical systems (clamping / stacking arrangements, flow field design etc.) Finalize stack assembly & testing procedures. Integrate the complete system and test.

c) Design C&I and inverter systems and incorporate safety systems.

d) Design skid mounted sub-assemblies / systems for ease of transportation to site.

e) Install, Commission & test the integrated system.

8 Battery Operated and Hybrid Vehicles

a) Development of high power, energy density batteries for BOVs and HEVs.

b) Design and development of ultra capacitors.

c) Design and development of control systems, power electronics and electric drive systems.

d) Design and development of chassis.

e) Development of BOVs with long operating range.

f) Development of HEVs, based on IC engine and storage batteries to significantly reduce the emissions and improve the performance range of the vehicles.

g) Development of HEVs, based on IC engine and fuel cells to significantly reduce the emissions and improve the performance range of the vehicles.

9 Geothermal Energy

9.1 In India, 340 hot spring sites have been identified with a maximum temperature recorded at the surface being 92°C. A 5 kW binary cycle power plant which was set up at Manikaran, Himachal Pradesh was damaged on account of a land slide. Magnetotelluric studies are being conducted through a National Geophysical Research Institute, Hyderabad to assess the potential at Puga Valley in Jammu & Kashmir.

9.2 During the 11th Plan resource assessment for estimating potential of geothermal for power generation will be continued using magnotelluric techniques. Chemical analysis of hot springs where power generation is feasible will also be carried out. Power plants utilizing low grade steam and water need to be developed indigenously. Drilling at a few selected sites will also be carried out for power generation. Hot waters could be used for space heating, industrial, poultry, green houses and other applications.

10 Tidal Energy

10.1 RD&D for the design, development and testing of 3.65 MW tidal power project at Durgaduani Greek in Sunderbans in West Bengal is proposed. In addition, other potential sites will be identified.

11 Solar Energy Centre

11.1 It is proposed to strengthen the Solar Energy Centre as a lead centre for solar energy with necessary links with other national organizations. Major activities proposed to be carried out during the 11th Plan are given overleaf:

11.1.1 Solar Photovoltaic

a) High efficiency solar cells.

b) Solar Cell characterization Laboratory.

c) System engineering

11.1.2 Solar Thermal

a) Solar Thermal Power Generation (STPG) through Stirling engine.

b) High temperature solar thermal research facility.

c) Solar air conditioning and refrigeration.

d) Activities on energy efficient buildings to be continued.

e) RD&D work on solar water heating systems, solar desalination systems, solar dryers, solar detoxification and solar cookers etc. to be continued.

11.1.3 Testing

System and Component Testing for RD&D purposes.

12. Centres for Wind Energy Technology (C-WET)

12.1 The research activities of the Centre are classified into the following three generic areas:

a) Design, Development and facilitating manufacture of MW-scale WEGs for low wind regimes.

b) Component and System Testing.

c) Standards development.

12.2 Resource Assessment

12.2.1 Wind resource assessment is proposed to be expanded and refined for higher heights.

13 National Institute of Renewable Energy (SSS NIRE)

13.1 The Sardar Swaran Singh National Institute of Renewable Energy (SSS NIRE) is being established as an autonomous institution at Wadala Kalan, Distt. Kapurthala, Punjab with an approved outlay of Rs.37.68 crore. Buildings are expected to be completed by 2006-07. Scientific and Technical Advisory Committee (STAC) is being reconstituted to prepare a road map for various activities of NIRE.

13.2 The NIRE will focus on:

a) RD&D in bio-energy, bio-fuels and synthetic fuels.

b) Bio-energy / bio-fuel component and system testing.

c) Development of standards for bio-energy and bio-fuel based products, systems and devices.

d) Bio-energy resource assessment.

14 Renewable Energy Resource Assessment

14.1 It is proposed to focus on creation, updation and validation of database on Renewable energy resources during the 11th Plan through a systematic approach in association with expert and specialized institutions. in addition to SEC, C-WET, NIRE and AHEC.

15 RD&D in Hybrid Renewable Energy Technologies

15.1 The nature of the renewable energy sources are such that many a time one renewable energy source is not able to address the need for ensuring electricity supply round the clock and round the year. At some times surplus electricity is generated by the same plant and some other time of the year electricity is required from the grid. This has necessitated RD&D activities to be taken up for the development of a suitable electronics, software and power management systems for automatic inter-connections of various renewable energy systems. Further, in order that renewable electricity supply becomes dependable from the consumers perspective this area of RD&D activity is to be provided a serious impetus and accordingly for the 11th Plan a separate budget provision has been recommended.

16 Energy Storage Systems

16.1 At present storage batteries are widely being used to store energy generated by various renewable energy systems, when used in decentralized manner. In addition, capacitors are also being used to store energy, specially in fuel cell vehicles. However, batteries require periodic replacement. Therefore, it is necessary to focus R&D efforts on development of improved storage techniques and develop alternate / additional methods of storage such as super conducting bearing based fly wheel etc. It is proposed to study the prospects of new and improved methods of storage of energy from renewable energy sources. Collaborative research will be taken-up in co-ordination with specialized R&D centres working in the country on different storage methods.

ANNEXURE-X (MENTIONED IN THE SECTION-XI ON RENEWABLE ENERGY R&D)

PROPOSED FINANCIAL OUTLAY ON RESEARCH, DESIGN AND DEVELOPMENT FOR 11TH PLAN

(Already projected in the proposed outlay of the Ministry of New and Renewable Energy for the eleventh five year plan)

Sl. No.	Area	Amount (Rs. in crores)
1.	**Bio-Energy:**	**100**
	i) Bio-solid and gaseous Fuels	60
	ii) Bio-Liquid Fuels	40
2.	**Solar Energy:**	**360**
	i) Solar Thermal	140
	ii) Solar Photovoltaic	220
3.	**Wind Energy:**	**100**
	i) Large WEGs	90
	ii) Small Aero-generators / Wind Pumps	10
4.	**Small Hydro Power:**	**30**
	i) Small Hydro Power	25
	ii) Mini / Micro Hydro Power	5
5.	**New Technology:**	**300**
	i) Hydrogen / Fuel Cells	50
	ii) National Hydrogen and Fuel Cell Centre at SEC	50
	iii) National Bio-fuel Board	25
	iv) Transport Applications	100
	v) Power generation	50
	vi) Geothermal Energy	10
	vii)Tidal Energy	20
6.	**Hybrid Energy Systems**	**20**
7.	**Energy Storage**	**20**
8.	**Electricity from Animal Energy and other new concepts**	**25** **3**
9.	**TIFAD**	**10**
10.	**NETCOF**	**2**
11.	**Solar Energy Centre**	**25**
12.	**C-Wind Energy Technology**	**25**
13.	**National Institute of Renewable Energy**	**25**
14.	**Alternate Hydro Electric Centre**	**10**
15.	**National Renewable Energy Certification Centre(NRECC)**	**20**
16.	**Renewable Energy Resource Assessment**	**10**
	Total	**1085**