# A MODEL FOR EFFICIENT RESOURCE UTILIZATION: DEVELOPMENT AND VALIDATION

**B.V. Babu[1]* and V. Ramakrishna[2]**
Birla Institute of Technology & Science
Pilani – 333031

## Abstract

The population growth is increasing the demand and hence putting pressure on Natural Resources to cater to the needs of various requirements of the population in their day-to-day life. The Natural Resources are converted into an effective product/service through an appropriate Technology. Excess waste is generated in the process due to ineffective technologies and/or poor Management of technology implemented. An effective utilization of Natural Resources to useful product/service thus requires – appropriate Technology, effective Management, and low Waste emissions. An integrated and controlled approach in the Technology, Management, and Waste emissions (TMW) increases the efficiency of Natural Resource conversion.

In the present study, a **model** is developed based on the **TMW approach** for the conversion of Natural Resources into useful product/service. Numerous examples are cited where the proposed model can be successfully applied. The following cases are presented to illustrate and validate the model developed:

- The thermal efficiency of a low calorific value agricultural waste (Bagasse) is improved by mixing it with waste oil in the ratio of 4:1 without any changes in the stack height permitted for using Bagasse as fuel.
- A heat exchanger network is employed to impart indirect solar heating of water and reduce the scaling problems in the solar panel pipes occurred due to direct water heating.

In both the cases, the efficiency of product/services is improved by integrating and controlling the TMW options.

It is essential to achieve Sustainable Development by controlling the pressure on Natural Resources exerted due to the demands of growing population. The TMW approach is a **simple**, **novel** and **efficient model** for effective resources utilization.

***Key Words:*** *Modeling, Natural Resources, Technology, Management, Waste Emissions, Resource Utilization, Sustainable Development*

---

[1] Professor of Chemical Engineering, Incharge-Workshop & Group Leader (Head), Engineering Technology Group, Fax: +91-159-7644183; Phone: +91-159-7645073 Ext.: 205; E-mail: bvbabu@bits-pilani.ac.in

[2] Lecturer, Civil Engineering Group; E-mail: vrama@bits-pilani.ac.in

* Corresponding Author

# A MODEL FOR EFFICIENT RESOURCE UTILIZATION: DEVELOPMENT AND VALIDATION

## INTRODUCTION

The population growth (23,83,96,327 in 1901 to 102,70,15,247 in 2001 i.e., an increase of 330.80%, which has been increasing continuously) [MIB-GOI (2001)] is increasing the demand and putting pressure on natural resources to cater to the needs of various requirements of the population in their day-to-day life. The urban population is also increasing at a very rapid rate (13.9% in 1941 to 28.77% in 2001) [MIB-GOI (2001)]. The following details (Maudgal, 1995; TEDDY, 1999; Ramakrishna and Babu, 2001; Census, 2001) of accessibility, availability, & quality of some of the natural resources give vital statistical information and the effect of population growth on these resources in the country:

- **Water Resources**
    - Access to potable water: Rural – 31%; Urban – 77%.
    - Groundwater depletion in many regions.
    - Surface and groundwater quality deteriorating rapidly all over the country.
    - Cycle of floods and droughts became a regular feature.
    - Huge requirement of water for domestic and industrial needs.
- **Air Resources**
    - Acute air pollution problem in industrial regions and metropolitan cities.
    - Rapid industrialization in many parts of the country.
- **Land Resources**
    - Forest cover depletion: 0.19% decrease during 1989 to 1995 & 0.85% decrease during 1995 to 1997.
    - Population density in the country: 267persons/square km in 1991 & 324 persons/square km in 2001.
- **Energy Resources**
    - Industry and Transportation sectors require 71.40% of the commercial energy in terms of oil equivalent (1997-98 status).
    - Deficit of power scenario is continuing from 1990/91 onwards (Peak deficit: 11.50% in 1996/97; Average deficit per year: 8.475%).
    - Bulk of the coal reserves available in the country are of inferior grade forcing for the search of an alternate fuel.
    - The Ministry of Environment & Forests imposed restrictions on usage of coals of high ash contents in view of huge fly ash generation.
    - A large potential available in non-conventional fuels/energy sources is not completely utilized (Potential for bagasse based co-generation in India: 3500 MW).

Since all the developmental activities utilize natural resources in one form or the other, the efficiency of converting the resources into useful products becomes the key parameter for estimating the waste and pollution generated. There is a need to identify a mechanism that can improve the conversion efficiency of natural resources into useful product/service. The present study focuses on understanding the intricate relationship among various affecting parameters, and subsequently developing a model in order to address the above problem.

## MODEL DEVELOPMENT

Maudgal (1995) discussed in detail various factors affecting the conversion of natural resources into a useful product/service. The waste generation from a particular process operation in the developing countries is often much more than that in developed countries (Maudgal, 1995) because of over-dependence on few ineffective Technologies or poor Management of Technology implemented.

The information given earlier about the accessibility, availability, & quality of some of the natural resources in the country reveals that, there is a need to bridge the gap between the availability and efficiency of utilization of Natural Resources. At the same time, it is also imperative on everyone to ensure that the Natural Resources are not exhausted and alternate sources are identified.

From the detailed and critical analysis of the above observations, it is found that the efficient usage of resources depends upon many parameters and the intricate relationship among them. A simplified schematic diagram representing the inter-relationship among the major parameters is presented in Fig.1. Effective management of the technology implemented reduces the waste generation and increases the conversion efficiency of natural resources into a useful product/service. For a given Natural Resource, the parameters affecting the Resource Utilization (RU) are Technology (T) and Management (M), subject to Minimum Waste emissions (W) and Maximum Desired Product/Service (P). This relationship is mathematically represented as a generalized TMWP model and given below:

$$\text{Max } RU = f(T, M, W, P) \qquad \text{-------}\ (1)$$

$$\text{Subject to the constraints:} \quad \text{Min } W \ \& \quad \text{Max } P$$

The above model has the flexibility of meeting both the constraints of Min W & Max P or meeting either of the constraints depending upon the specific need. For a specific case where minimization of waste emissions become a major constraint (from the environmental pollution point of view), the above model reduces to the TMW model as:

$$\text{Max } RU = f(T, M, W) \qquad \text{-------}\ (2)$$

$$\text{Subject to the constraints:} \quad \text{Min } W$$

In the present study, emphasis is given to the waste emissions and so the TMW model is considered. As evident from equation (2) and Fig. 1, the TMW model is based on an integrated and controlled approach in the Technology, Management, and Waste emissions. The TMW model is a **simple**, **novel, flexible,** and **efficient** for effective resources utilization. The model developed on TMW approach can improve the efficiency of the product/services from natural resources that subsequently increases the life of natural resources.

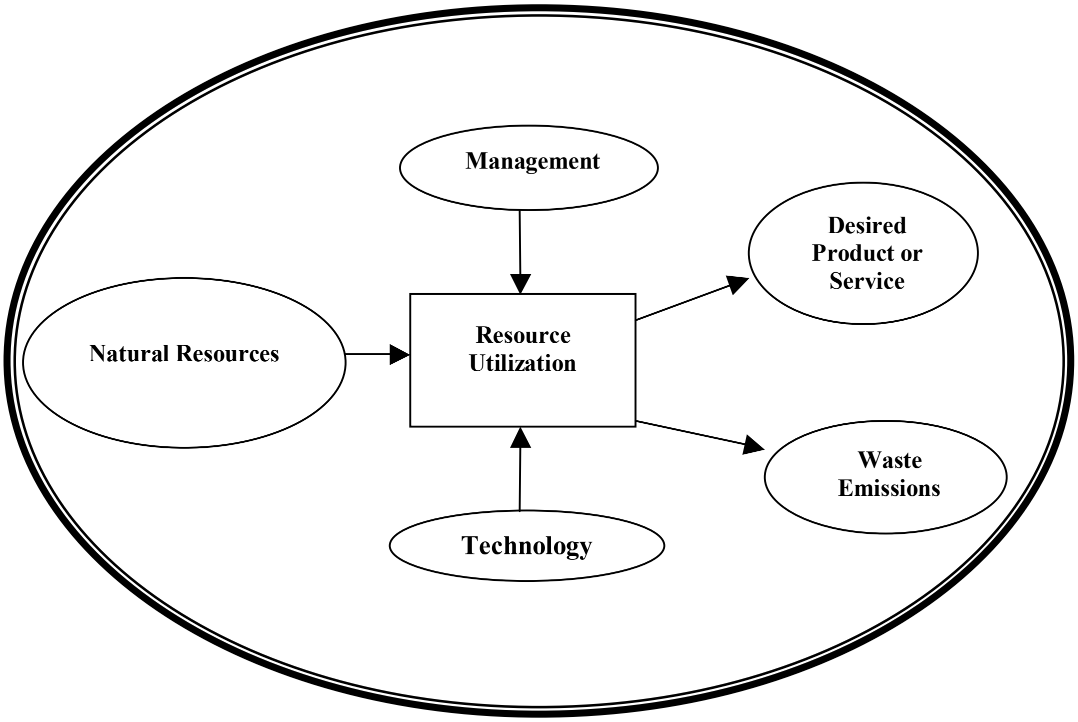

**Fig.1**. **Factors affecting the Resource Utilization**

## RESULTS & DISCUSSION

A number of examples where the TMW model is effective are briefly explained (Refer Table-1). Further, two case studies are presented in this paper to illustrate the TMW model in detail to validate the effectiveness of the model. It is found that, in both the case studies, the compact and robust approach adopted by integrating and controlling the TMW options is effective in improving the efficiency of the resource utilization. The details of the two case studies are given as follows:

**Table-1 Summary of examples for TMW Model application**

| S.No. | Application | Description |
|---|---|---|
| 1 | Water harvesting approach | Diversion of rainwater/run-off to groundwater through percolation pits; Diversion of treated wastewater and wastewater from kitchen to groundwater through percolation pits. |
| 2 | Integrated approach for wastewater treatment & Solid waste management | The treated wastewater is discharged to agricultural fields/irrigation purposes. The sludge from wastewater treatment plants is used to increase the moisture content and C/N ratio of solid waste for composting. The compost generated is used in the agricultural/irrigation fields. The groundwater table may also get raised due o application of treated wastewater on land. |
| 3 | Common Effluent Treatment Plant (CETP) approach | The wastewater generated from several industrial sources is treated at a common location. The CETP can offer improved technological options. The high cost involvement in the implementation of technologies can be affordable and better management practices are anticipated. |

| S.No. | Application | Description |
|---|---|---|
| 4 | Integrated approach for municipal solid waste disposal practices | The conventional practices in India are Landfilling with or without gas recovery and composting. Under composting, aerobic, anaerobic, and vermi-composting options are available. These options can be judiciously used to reduce the land requirement for landfilling operation. Alternately, the organic portion of the solid waste can be segregated to prepare Refuse-Derived Fuel (RDF), which has an encouraging Calorific Value. The RDF can be independently used as a fuel or can be fired in gasifiers and the heat can be recovered. The Landfilling of the share of the solid waste can gradually reduced in order to reduce the load on land requirement. |
| 5 | Biogas generation from garbage | The garbage (kitchen waste) can be separated from the municipal solid wastes and can be anaerobically converted to biogas. |
| 6 | Treatment, Storage and Disposal Facility (TSDF) | This is suitable for solid waste in general and hazardous waste in particular, where the solid waste is collected at a common facility, treated and disposed. The TSDF can offer improved technological options. The high cost involvement in the implementation of technologies can be affordable and better management practices are anticipated. |
| 7 | Bagasse based co-generation | It can offer reduced pollutant emissions compared to that of using fossil fuels. Further, this option can satisfy the needs of captive requirements of the generator and the excess power generated can be supplied to National/State level grids. This option is a part of implementing the National policies for encouraging the usage of Renewable energy sources. |
| 8 | Common Incinerator facility | Installation of incinerator for disposal of biomedical waste is mandatory for all the hospitals above 30-bed capacity. A common incinerator facility can also be created for the benefit of more than one user. The common incinerator facility can offer improved technological options. The high cost involvement in the implementation of technologies can be affordable and better management practices are anticipated. |
| 9 | Reuse of demolition waste (Houthoofd, 1995) | Recycling of metal, wood, cardboard, rubbish etc. available after demolition can reduce both the waste generation and the cost of construction. |
| 10 | Usage of rubber for laying the pavement (Houthoofd, 1995) | Usage of scrap tires in road paving in the form of rubberized asphalt. Though this option is little expensive than that of regular asphalt, it lasts 80-100% longer and results in a 76% noise reduction. |

## Case study-I: Improved thermal efficiency of bagasse

In this case study, the TMW model is applied to the investigations carried out on improving the thermal efficiency of bagasse with the following objectives:

- To find out the optimum mix ratio of bagasse & waste oil for improving the energy content, which ensures the stack height requirement for emissions within the permissible height specified by the Central Pollution Control Board.
- To address the related techno-economical aspects for the above.
- Comparative study of the economic viability with those using different grades of coal.

Bagasse is a by-product obtained during the manufacture of sugar from sugar cane. The average bagasse generated is around 25-30% of the sugar cane. It contains about 50-55% moisture, 2% ash content and a Calorific Value (CV) of 8021 kJ/kg. It is used as a fuel in a boiler to generate steam for industrial purposes. The waste oil (CV: 42481 kJ/kg) discarded from plant operations is often recovered in the industry from wastewater drains. The options generally adopted by the industry for disposal of waste oil are:

1. Storing in drums and selling for downstream uses.
2. Mixing with boiler ash to fill the low-lying areas.

3. Discarding on the ground forming oil-mud pools.
4. Mixing of waste oil with bagasse and firing as fuel. The technical aspects involved in firing the mix of bagasse and waste oil are not clearly understood.

The first three options do not completely utilize the energy potential of waste oil. The third option is not recommended due to aesthetic and hygienic reasons also. The energy potential of waste oil can only be effectively utilized using the fourth option. Simultaneously, the waste emission (oil) is reduced and the generated waste is recycled for productive use. The fourth option is studied in detail (Babu and Krishna, 1998; Ramakrishna and Babu, 2001) keeping in view of the objectives as mentioned earlier. The fourth option is in accordance with the TMW model because:

- The waste oil is effectively managed (*M of TMW model*) for improving the energy content by mixing with bagasse and firing (*T of TMW model*).
- The waste emissions are reduced (*W of TMW model*).

It is found from the results that, if bagasse and waste oil are mixed in the ratio of 4:1, the emissions from the mix are satisfying the minimum stack height requirements. By using the Bagasse and Waste Oil (BWO) mix, the CV and the steam generation are improved by 6902 kJ/kg (186% increase) and 2.26 kg/kg (172% increase) respectively over usage of bagasse alone as a fuel. The techno-economic aspects of BWO mix are compared with that of three different grades of coal reported (Patil, 1996) and bagasse alone. The economic returns involved in the alternate usage of BWO mix as fuel for coal and/or bagasse are compared using the cost factors given in literature (Douglas, 1988; Perry and Green, 1984; Peters and Timmerhaus, 1981; Babu and Krishna, 1998). The Net Utility Value (NUV) of each fuel is calculated as the difference of its steam utility value (SUV) and purchase costs and the details are given in Table-2. The variation of NUV obtained is studied over two aspects viz. various BWO mix ratios & quantity of fuel fired. The Net Utility Savings (NUS) are calculated based on relative comparison between the NUV of an alternate fuel and BWO mix or bagasse alone. For example, the NUS for the BWO mix (4:1) over C1 and C2 type coals (Ramakrishna and Babu, 2001) resulted Rs. 143.84 & Rs. 299.12 respectively.

The results from the above analysis are extrapolated assuming 21 working hours a day and 30 working days per month and are as follows:

- The usage of optimum BWO mix in place of bagasse alone results in a net savings of Rs. 1.915 lakhs per month or Rs. 22. 98 lakhs per annum.
- The financial loss to the user due to the non-usage of bagasse as fuel is Rs. 1.726 lakhs per month or Rs. 20.716 lakhs per annum.
- If the user purchases C1-grade coal despite the availability of bagasse, the net expenditure incurred is Rs. 2.904 lakhs per month or Rs. 34.85 lakhs per annum.

The cost aspects obtained in this study can vary due to many factors and are discussed in detail by Ramakrishna and Babu (2001). It can be concluded from the above case study that, the effective utilization of bagasse can only be achieved subject to its mixing with waste oil in the ratio of 4:1. However, purchase of bagasse for commercial C1 type (F-grade) coal is not economical. Though the optimum BWO mix is slightly expensive when compared with a F-grade coal, its usage is strongly recommended as an alternative to coal in view of the increasing demand of coal and its limited availability.

## Advantages gained

- The thermal efficiency of bagasse improved.
- Load on the fossil fuel decreased.
- Pollution load decreased.
- Utilization of agricultural waste such as bagasse is achieved.

**Table-2 Comparative characteristics of alternate fuels**

| Fuel | Calorific Value kJ/kg | Steam generation kg/kg | QOF KPH | PC Rs. | SUV Rs. | NUV, Rs. (SUV-PC) |
|---|---|---|---|---|---|---|
| Bagasse | 8021 | 3.12 | 432 | 64.80 | 338.83 | 274.03 |
| Optimum BWO mix (4:1)* | 14924 | 5.80 | 346 | 51.90 | 629.88 | 577.98 |
| C1 type coal | 18426 | 7.18 | 108 | 44.82 | 779.75 | 734.93 |
| C2 type coal | 20970 | 8.16 | 135 | 56.03 | 886.18 | 830.15 |
| C3 type coal | 23669 | 9.21 | 185 | 110.00 | 1000.21 | 890.21 |

* 0.8 x 0.432; QOF = Quantity Of Fuel; PC = Purchase Cost; SUV = Steam Utilization Value; NUV = Net Utility Value

## Case study-II: Modified Solar Water Heating System using Heat Exchanger

In this case study, the TMW model is applied to improve the performance of solar water heating system at Birla Institute of Technology & Science (BITS), Pilani.

The hot water requirement in student hostels in BITS campus is met by using the Solar Water Heating Systems (SWHSs). The systems used earlier consist of a heat transfer mechanism where the cold tap water is directly heated in the very narrow (approximately 10 mm in diameter) solar panel tubes. These tubes are made of copper and very costly. Due to the quality of water available at Pilani (high salt content and hard), there used to be thick and hard scale formation inside the tubes, making the maintenance of the system extremely difficult. This also led to significant decrease in thermal efficiency of the systems due to the resistance offered by thick scaling inside the tubes. In order to overcome the above problem, these systems are replaced with the Heat Exchanger type SWHSs, which work on thermo-siphon principle. In these systems, cold tap water is indirectly heated in a Double Pipe Heat Exchanger (DPHE). Instead of tap water as in the earlier systems, the distilled water is sent through the panel tubes that gets heated up. The hot distilled water flows through the shell side (approximately 600 mm outer diameter) and the cold tap water flows through the tube side (approximately 300 mm outer diameter) achieving indirect heating in the DPHE (Refer Fig. 2). The Heat Exchanger (HE) tubes are larger and cheaper compared to solar panel tubes. They can be easily cleaned or even be replaced as they are cheap in case the cleaning during regular maintenance becomes difficult. The heated distilled water moves up into the shell-side of DPHE (Thermo-siphoning principle) and relatively cold water from shell side of DPHE comes down and flows through the panel tubes completing the closed loop of the distilled water cycle. A make-up water tank is provided in the system to periodically fill and maintain the level of distilled water to take care of the evaporation losses. The thermal efficiency of these systems found to be much higher in spite of indirect heating than that in the earlier systems. This is attributed to the fact that the resistance offered by scaling in the panel tubes of earlier system is much higher than the resistance offered in DPHE due to indirect heating.

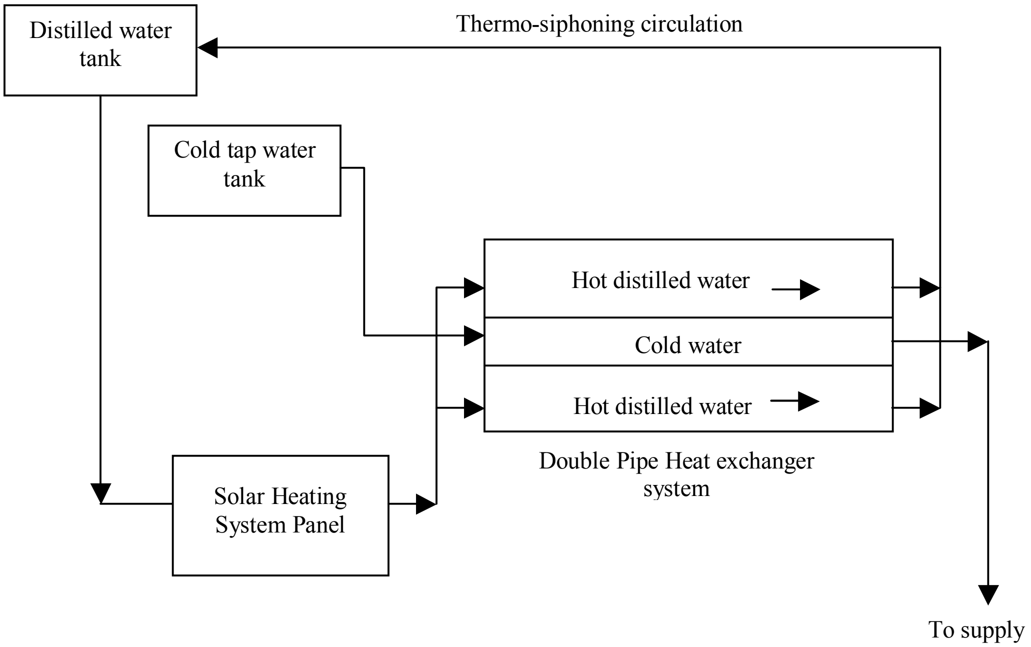

**Fig. 2 Schematic diagram of Heat Exchanger based Solar Water Heating System**

The above case study is in accordance with TMW model such that:

- The DPHE based SWHS is being used in place of a simple SWHS (*T of TMW model*).
- Availability of large diameter of tube in DPHE compared to that of narrow tubes in earlier systems enabling easy maintenance and management of the system (*M of TMW model*).
- Scaling (Total Dissolved Solids) is reduced due to indirect heating of cold tap water (*W of TMW model*).

## Advantages gained

- Maintenance problem is rectified.
- Cost of replacement for the tubes reduced.
- The overall thermal efficiency of the system is increased.

It may be noted from the results of above two case studies that there is a perfect control and integration of Technology, Management, and Waste emissions resulting in improved resource utilization. The TMW model can also be successfully applied to the examples given in Table-1 in a similar way as discussed in detail in the above two case studies. The description given for these examples in Table-1 is self-explanatory.

## Summary and Conclusions

Excess waste is generated in any process operation due to use of ineffective Technologies and/or poor Management of Technology implemented. In order to utilize the natural resources effectively, an integrated and controlled approach of Technology, Management, and Waste emissions (TMW) is essential. A model is developed based on TMW approach and is illustrated with a number of application areas. Two case studies based on TMW approach are also presented in this study and are discussed in detail. It is found that, the conversion efficiency of natural resources into valuable product/service is increased in both the case studies. From the examples and case studies addressed in this study, it is concluded that, the model developed on TMW approach is a simple, novel, flexible, and efficient model for effective resource utilization that is very essential in order to satisfy the requirements of growing population.

## References

Babu B.V. and V. Rama Krishna (1998). “Optimum utilization of waste oil for Improved thermal efficiency of bagasse”, Journal of Indian Association for Environmental Management, 25 (1998), pp. 59-65.

Census (2001). *Official website on Census of India,* the URL of which is www.censusindia.net as on 10.02.2002.

Douglas J.M. (1988). *Conceptual Design of Chemical Processes*, Mc. Graw Hill Book Company, New York (International edition), pp. 36-37.

Houthoofd J.M. (1995). “Pollution prevention applications in Construction and Water resource management”, Environmental Progress, 14 (4), 254-258.

Maudgal S.C. (1995). “Waste Management in India”, Journal of Indian Association for Environmental Management, 22 (1995), pp. 203-208.

MIB-GOI (2001). *India 2001 – A Reference Manual*, Publications division, Ministry of Information and Broadcasting, Government of India, New Delhi, pp. 8, 15.

Patil M.A. (1996). “Industrial pollution in urban areas and possible solutions - A case study of boilers”, Energy, Environment and Monitor, 12 (2), Tata Energy Research Institute, New Delhi, pp. 79-87.

Peters M.S. and K.D. Timmerhaus (1981). *Plant design and economics for Chemical Engineers*, 3rd edition, ISE, McGraw Hill International Book Company, Tokyo, pp. 160-161.

Ramakrishna V. and B.V. Babu (2001). “Bagasse as an alternate fuel to coal for industrial uses – A comparative study”, Indian Chemical Engineer, Section-B, 43 (2), 123-126.

TEDDY (1999). *Teri Energy Data Directory & Yearbook, 1999/2000*, Tata Energy Research Institute, New Delhi, pp. 15, 105,145, 335.