MEETING ENERGY NEEDS IN THE TWENTY-FIRST CENTURY

Robindra Nath Basu Ph.D., P. Eng.
ARAM International, Calgary, AB, CANADA T2L 2L2

Keywords: energy, exergy, fossil fuels, sustainable, renewable, fission, fusion, solar, wind, nuclear, hydrogen, fuel cell, conservation, efficiency, geothermal, space power, cogeneration

Contents

Summary

A review of the current energy situation -- supply and demand -- has shown that resources are adequate to meet the rising demand for energy from the increasing population and their change of lifestyles. But the present methods of meeting energy needs are not sustainable.

Pollution and sustainability are the key factors in choosing the mode of energy supply in the new century. These factors have made the non-polluting renewable energy forms very important elements in the energy equation. Reliance on nuclear power is

decreasing in the advanced industrial countries but increasing in the developing countries. Coal and oil remain as leaders of energy fuels but chemical processes are emerging which make coal-burning less polluting than before. At the same time buildings and their heating and cooling utilities are being made more energy efficient.

Next to the electric power supply, the second largest polluter is the automobile on the road. The old internal combustion engine burning oil or gas is being modified or replaced to lower pollution.

Both the form of transportation fuel and the prime mover are being changed. Cars and buses powered by fuel cells and electric motors are on trial in different countries. Soon they will be in public usage. Technologies for using hydrogen as an industrial fuel are developing fast to make the twenty-first century the era of hydrogen.

Renewable energies -- i.e. photovoltaics, wind, biomass and hydrogen -- are ready to meet the new energy needs in the twenty-first century with much less pollution. But mankind needs a new philosophy i.e. Waste not, Want not. Cogeneration, conservation and efficiency are essential creeds for sustainable development and use of energy in the twenty-first century.

1. Introduction

Energy is a fundamental component of all life support systems. It is crucial to the modern way of life. It fuels the technology that governs the nature of our society, our lifestyle, even our health and happiness.

Energy is not a thing or substance, but a concept developed to describe in specific terms the state of a body: hot or cold, lively or morbid, dynamic or static etc. In simple terms it means capacity to do work.

Energy may also be considered as the ultimate resource because it drives everything. Energy is essential to the metabolism of any living system. Zero energy is death. We need energy even to breathe and the energy has to come from somewhere.

Energy comes in many forms i.e. chemical energy, electrical energy, kinetic energy, potential energy, thermal energy, light energy, sound energy, etc. Some of these energies are available in abundance in nature.

Some forms are not readily available but have to be obtained by engineering methods. An important physical law of conservation states that energy can neither be created nor destroyed, only transformed. The total energy remains constant.

Energy is bountiful in nature surrounding us. There is energy in the wind shaking the tree, in the sunlight heating the exterior of our building; energy in the greening leaf, in the ripening fruit; energy in the flowing river, in the rolling ocean. There is energy in everything we eat and secrete.

Source	Energy (cal kg^{-1})	Energy (KW-hr $lb.^{-1}$)	Cost (per 1000Kw hr^{-1})
Coal (stove coal)	7200	3.86	5.20
Fuel oil	10 800	5.72	4.30
Natural gas	11 000	5.86	5.46
Gasoline	11 530	6.10	10.00
Alcohol (denatured)	6400	3.42	10.25
Alcohol (Scotch, 80 proof)	2580	1.37	2920.00
Bread	2660	1.42	220.00
Butter	7950	4.20	200.00
Sugar	4100	2.16	68.00
Beef steak (sirloin)	1840	0.97	1640.00
Electricity	N/A	N/A	20.00

Table 1 Values for Some Fuels and Foods (Retail Prices)

The problem is that this natural energy is mostly distributed in space and time. What the industrial society wants is a large dollop of energy, wherever and whenever necessary, at the press of a button. Nature does not provide that. Hence we have to manipulate nature by converting, concentrating, storing and other methods to suit our needs.

Energy Source	Calories	Btu
Energy in 1 photon of red light (λ = 7,000 A) [a]	6.8×10^{-23}	27.0×10^{-23}
Energy in 1 photon of blue light(λ = 4,000 A) [a]	11.8×10^{-23}	46.8×10^{-23}
Energy converted (per reaction) in photo synthesis	19.0×10^{-23}	75.4×10^{-23}
Energy in 1 photon of ultraviolet light (λ = 2,250 A) [a]	21.2×10^{-23}	84.2×10^{-23}
Energy (gravitational) of 1 lb. of mass at 1 mi above sea level	~2	~8
Energy to melt 1 lb. Of ice (at O°C)	36	140
Energy to evaporate 1 lb. of water	245	970
Energy (chemical) released by exploding 1 lb. of TNT	520	2065
Energy (chemical) released by burning 1 lb. of wood	1250	4965
Energy (chemical) released by burning 1 lb. of sugar	1860	7385
Energy (chemical) released by burning 1 lb. of coal	3300	13100
Energy (chemical) released by burning 1 lb. of gasoline	5250	29840
Energy needed to manufacture an automobile	5.2×10^{6}	20.6×10^{6}
Energy needed to send Apollo 17 to Moon [b]	1.42×10^{9}	5.64×10^{9}
Energy (nuclear) released by fusing 1 lb. of deuterium	37×10^{9}	147×10^{9}
Energy (nuclear) released by fission of 1 lb. of U^{235}	137×10^{9}	544×10^{9}
Energy equivalent of 1 lb. of mass ($E = mc^2$)	9.8×10^{12}	38.0×10^{12}
United States daily energy consumption (1970)	47×10^{12}	189×10^{12}
World daily energy consumption (1970)	140×10^{12}	556×10^{12}
Energy needed to boil Lake Michigan [c]	$\sim 400 \times 10^{12}$	$\sim 1600 \times 10^{12}$
Solar, earth's daily total at top of atmosphere	3.6×10^{18}	14.3×10^{18}
Total energy in fossil fuels [d]	$\sim 2.5 \times 10^{19}$	$\sim 10 \times 10^{19}$
Sun's daily output	7.1×10^{28}	28.2×10^{28}

Table 2 Some Representative Energy Data

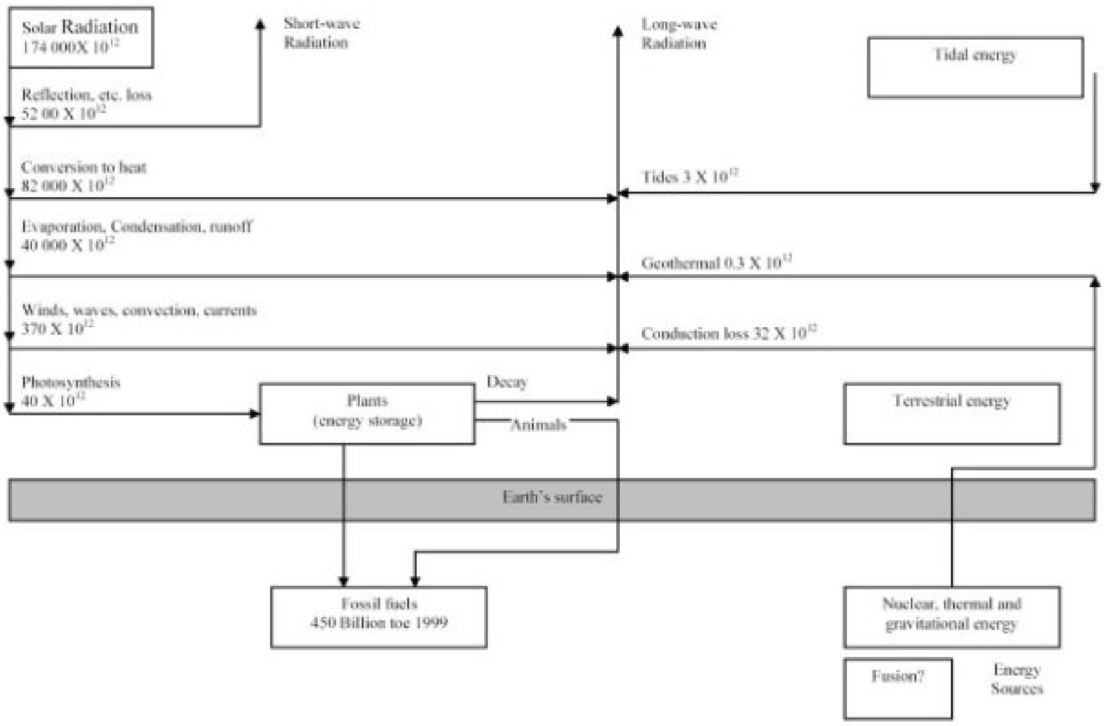


Figure 1: World Energy Flow – Annual Amounts in Watts

Much of the manipulation is to obtain a convenient heating fuel and electricity. Electricity is the "magic medium" which improves the quality of life. It is not a prime energy but generated by conversion from mechanical energy, chemical energy or solar energy. In general, the five prime energies used by mankind are chemical energy, tidal energy, nuclear energy, geothermal energy and solar energy. Out of these only solar energy is continuous and available everywhere.

The sun showers continuously 174 trillion kW of radiation on the earth and its atmosphere. Thirty-five percent is reflected back into space. The remainder warms the atmosphere, drives the wind, tides and the weather cycle. The energy reaching the earth is partly the energy in the direct beam and partly in the diffuse energy from the sky. Nearly half of the incoming solar radiation heats the clouds and greenhouse gases, which then reradiate it to the earth's surface. An energy flow diagram is shown in:

The sun is the ultimate powerhouse. Most of the energy used on earth has a solar connection. Fossil fuels (natural gas, petroleum and coal) are products of photosynthesis followed by underground burial over millions of years. These resources as well as radioactive minerals, e.g. uranium, are subject to depletion hence called nonrenewable or capital sources of energy. Other solar-derived resources, e.g. wind, running water, photovoltaic (PV) electricity etc., can not be depleted and are hence called renewable.

2. Current Energy Situation -- Supply and Demand

With the continuous rapid growth of global population, the demand for energy is rising fast. Simultaneously, the developing countries are becoming more industrialized, thereby increasing their need for energy. Also the standards of living of millions of people are rising. Everyone needs electricity for more lights and TV sets. This has caused an energy crisis in the developing world. Frequent power cuts are necessary at the peak power hours.

Figure 2.1 shows the global distribution of energy use in 1987, i.e. 5 years before the Earth Summit in Rio. The size of each pie chart corresponds approximately to the energy use in each part of the world. In most developing countries, by definition, there are two parallel economies: a) the rural economy which is agrarian; b) the urban economy which is industrial/commercial.

The patterns of energy use in the two sectors are different. The commercial energy market comprising petroleum, coal, gas and electricity is based in the cities. The rural sector in contrast, consumes mostly energy from biomass and employs animal and human power. Household demand, especially for cooking and heating, dominates energy consumption in the developing countries.

During the last century there has been a sequential replacement of domestic fuels: wood by coal, then coal by oil and natural gas. However the pattern of global electricity supply has not changed much. The bulk still comes from large, centrally located, coal-fired, electric and hydroelectric power stations.

There are also about 565 nuclear power stations distributed in 30 countries including Canada & USA. In 1990 there were 22 nuclear power units in Canada and 125 in USA.

Nuclear fission is the method used in all the nuclear reactors currently in operation. Uranium (U 238) and Thorium (Th232) and their derivatives are usual fuels in different types of reactors. Largest reserves of uranium, a nonrenewable resource, are in USA, Canada and South Africa.

Although hailed initially as a clean energy solution, high costs and safety problems have turned public opinion in many countries against further growth in the use of nuclear energy. In fact some nuclear power stations have been shut down or cancelled in Canada and USA.

Despite improvements in the safety systems in nuclear plants, the Nuclear Regulatory commission estimates that the chances of a nuclear accident in USA in the next 20 years are fifty-fifty. The explosion and subsequent fallout of radioactive material from the Chernobyl disaster in Russia on 26 April 1986 remains fresh in people's minds.

The cost of dismantling and shutting down a nuclear station is very high. For instance, a newsflash on TV on August 6 1999 reported that it cost US $ 23 million to dismantle the large nuclear reactor of the Trojan power station in Portland, OR, USA. It had to be sealed with special concrete, wrapped in plastic and taken by barge on Columbia River to Hanford station in Washington State for burying in deep water.

Nuclear fusion remains a sought-after technology with the potential to provide an environmentally acceptable alternative to fossil fuel combustion. Fusion power occurs when light nuclei are fused together to form reaction products whose total mass is less than that of the initial particles; the difference is converted into reaction energy.

The energy released from these reactions is very great, about ten times greater than typical fission reactions, per gram of fuel. Since the electric charges in the nuclei provide strong repulsive forces, the energy of the particles must be very high to achieve a sustained reaction.

It can be achieved in a very hot gas (plasma) by allowing sufficient residence time for the particles to collide. A concerted R & D program is going on in several IEA (International Energy Agency) countries. Target year for a marketable nuclear fusion reactor is held at 2050.

The work potential that can be obtained from fossil fuels and nuclear fission is called exergy, alternatively defined as the work capability of heat. According to the laws of physics, it is always less than the thermal energy that is spent.

Using state-of-the-art technologies, large power plants can achieve an exergy value which is equal to 50-58 percent of the energy (lower heating value) spent through the combustion of fossil fuels; when used directly for heating, 90 to 100 percent of the energy can be used. High-efficiency heating plants can be realized by combining power stations with heat pumps. In such cases, at least some of the electricity generated by the power station will be needed to drive the heat pumps.

The share of electricity (excluding losses during generation) in the total energy use in USA has risen from 6 percent in 1960 to 12 percent in 1991. This is a modest growth achieved by the emphasis given to energy conservation and "demand-side management" introduced by the power utilities in North America. They have been giving consumers energy-saving tips to avoid troublesome shortage of power and to reduce pollution.

Global proportions of the various primary energy usages in 1987 are shown on the pie chart in Figure 2.

Another chart, Figure 3 shows global energy consumption in 1993. Due to the continually increasing demand for primary energy, it is felt that the limited resources of nonrenewable energy and its environmental effects will become an impediment to global development.

According to one assessment, with present technologies, the economically recoverable global reserves of crude petroleum amount to 120 billion tonnes and those of natural gas to 100 billion toe (tonnes of oil equivalent). Improved extraction technology and more discoveries may push this to 450 billion toe.

If the current oil and gas production continues at a rate of 5 billion toes per year, these resources will be exhausted by the middle of the next century. Coal reserves are estimated to last longer but its associated pollution problems makes coal an undesirable choice for replacing other fuels.

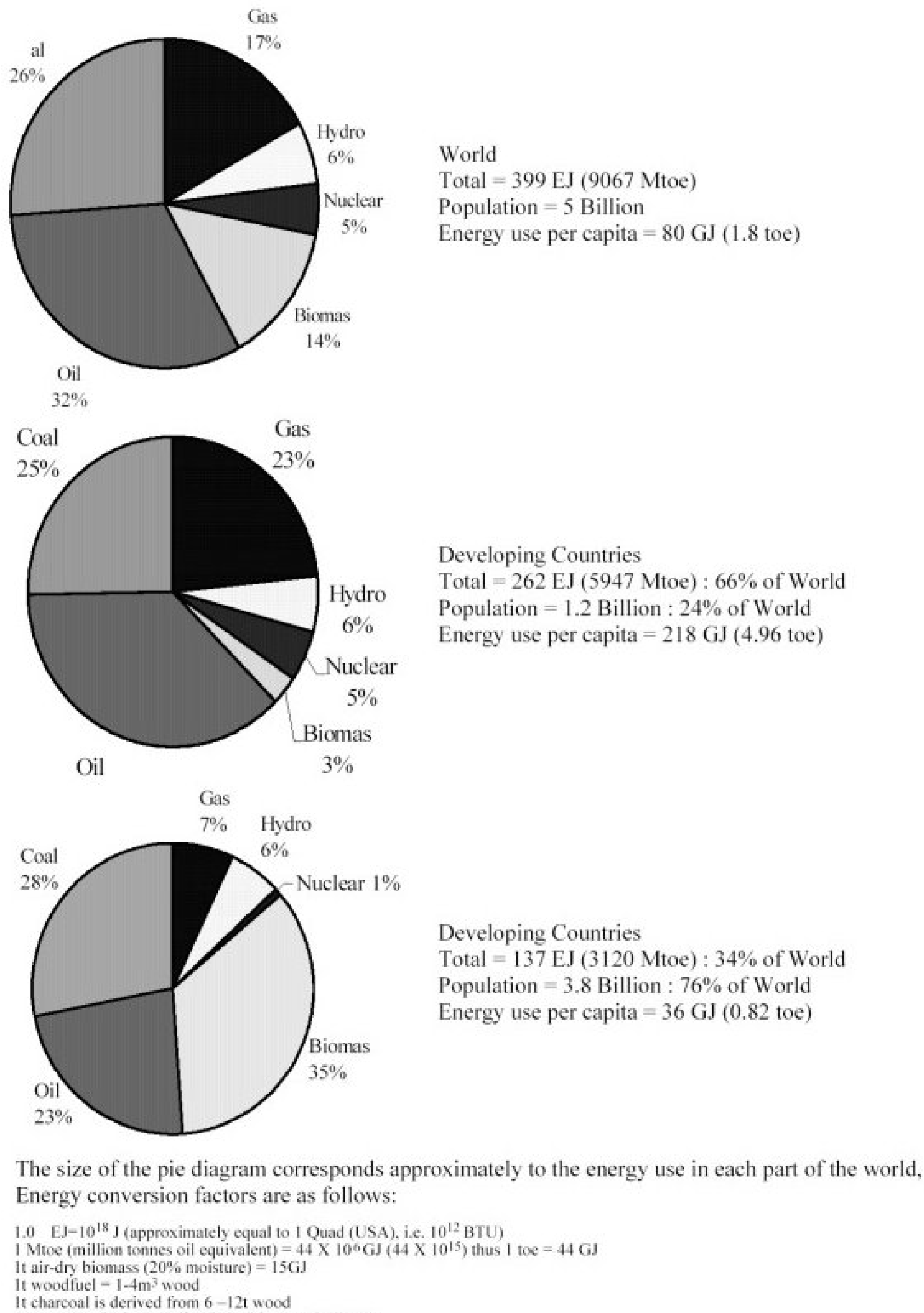
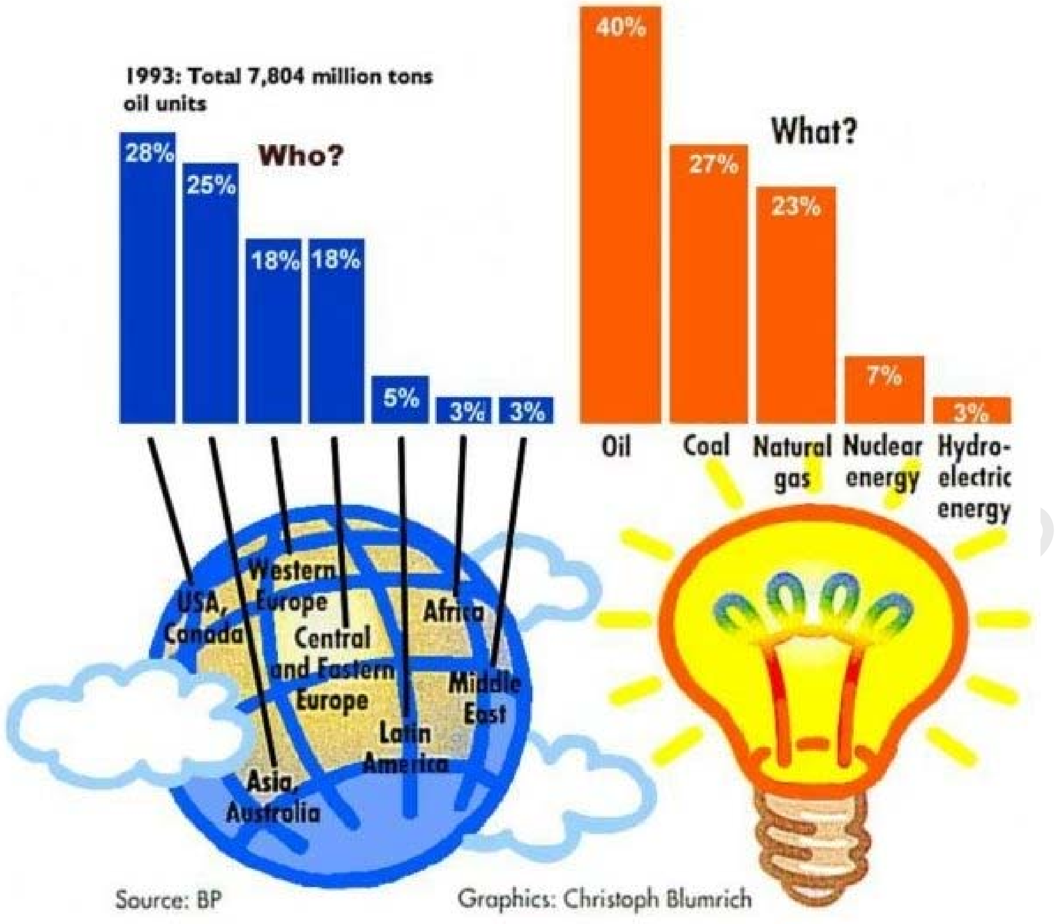


Figure 2: Global distribution of energy use (1987)



Courtesy "Deutschland", September 2000

Figure 3: World energy consumption

There is an enormous gap between the developed and developing countries in per capita energy consumption. As shown on OECD table 2.1 of energy consumption in 1981, Canada had the highest i.e. 107 toe per capita followed by Luxembourg at 9.5 and Australia at 8.6 LDC (Less Developed Countries) group as a whole recorded 06 toe.

The figures have no doubt changed over the years but Canada -- as a rich cold country -- is still the top per capita consumer and LDC is still at the bottom. But energy consumption is also related to GDP (Gross Domestic Product). Hence as the GDPs of LDCs are increasing fast in some cases; their energy demand is rising fast as well.

This is the case for India and China. These two most populous countries are hungry for energy in all forms, renewable and nonrenewable. Luckily these countries are in the sunny tropics and hence have an exuberance of solar energy round the year. But they have been late in exploiting this great resource technologically.

-
-
-

Bibliography

Active Solar Heating in Canada to the Year 2010, Energy, Mines and Resources, Canada

Balamiento E.C. (1993) Philippine Program on Research & Development, Promotion and Commercialization of Solar PV Technology, SOLAR' 93, Dec.

Bara, M.F., S.K.Agrawal, A.Gadem, A.A.Zaalan & R.C.Yadav Power Plant Load Management -An Effective Tool for Energy Conservation. Proceedings of ENERGEX 88, Tripoli, Libya

Barbir, F. & M. Padki, Solar Hydrogen Energy System for Adriatic Islands, 9th Miami IntnL Con. On Energy & Environment, Dec. 89

Barra, L. & D. Coiante (1993) Hydrogen-Pv Stand-alone Power Stations- A Sizing Method, Inti. Hydrogen Energy, Vol.18, No.4, pp337- 44

Basu, R.N. et al, Cooling by Solar Energy, Journal of Australian Refrigeration, Air-conditioning & Heating, Vol. 39, No. 2

Basu, R.N. et al, Integrated Approach to Cogeneration Planning Using Renewable Energies, New Directions in Energy Technology, Association of Energy Engineers

Basu, R.N. Generation/Cogeneration with PV Modules in Remote Areas; Proceedings of SOLAR '87 Conference, American Solar Energy Society

Basu, R.N. PV Solar R &D in Europe -A Status Report, Siddhartha Communications

Basu, R.N. Field Studies of Performance & Reliability of Heterogeneous PV Modules for Optimum Array Design, Proc. of 22nd IEEE PV Specialist's Conference, IEEE

Braun, G.W. (1991) Improving Efficiency in Electricity Generation: Advanced Conversion Systems ESETT, Milan, Italy

Braun, G.W., A. Suchard & I. Martin (1991) Hydrogen & Electricity as Carriers of Solar & Wind Energy for 1990s and Beyond, Solar Energy Materials, **24**

Buildings that Save Money with Efficient Lighting, Green Lights Program, US DOE, National Renewable Energy Laboratory

Butterfield, C.P. New Eyes for Wind Turbine Designers

Cetron, M. & 0. Davies Crystal Globe –The Haves & Have-Nots St. Martin's Press

Chatteri, M. (ed) Energy and Environment in the Developing Countries, John Wiley & Sons;

China & India -The Dilemma of Coal- fired Power, IEEE Spectrum November 1999

Chou, S.K. and W.L.Chang (1993) Development of an Energy-Estimating Equation for Large Commercial Buildings, International Journal of Energy Research Vol. 17,759-773

Clarke, J.A. Advanced Design Tools for Energy Conscious Building Design, 1st World Renewable Energy Congress, Sep. 90

Connell, R.M. Solar Cell Research Leads to Better Superconductors

Conover, (1991) K & D. Eppler, Status of Wind Energy Developments and Technology in the United States AsiaEnergy

Costa, H.S. et al (1992) Evaluation of Amorphous Silicon Module Outdoor performance, Solar Energy Materials & Solar Cells, Vol. 27 p 59-68

Dalpane, E., B. Berard, and C. Stork; Wind Energy Converters for Developing Countries, ESETT'91, Int'l. Symp. On Environmentally Sound Energy Technologies, Milan, Italy, Oct 1991

Dept. of Mechanical Engng., Midnight Sun- a Solar Electric Car project, University of Waterloo, Ont., Canada

Dostrovsky, I. (1991) Chemical Fuels from the Sun, Scientific American, December

Dubois, D. (1988) Solar fuels research has dual benefits Science & Technology in Review, Sep-Oct 1988

Durand, S.J., D.R.Bowling & V. V. Risser, Lessons Learned from resting Utility Connected PV Systems, 21st IEEE PV Specialists' Conference, May 90

Electricity from Space, EPRI Journal, Spring 2000

Energy Technology Support Unit (ETSU) The Small Scale Use of Poultry Litter as a Boiler Fuel; UK

Fowler, John M. Energy and The Environment McGraw-Hill Book Co.

Frutschi, H.U. Optimizing how fuels and renewable energy are utilized for heating, ABB Review, Issue 5/96, Asia Brown Bovery Ltd.

Geothermal Heat Pumps (GHP) -Special issue, GEO-Heat Center Quarterly Bulletin, April 1997

German Aerospace Research Establishment. Hysolar-Solar Hydrogen Energy

Gewell, W. & R. Rmakumar, (1987) The Effects of Moving Clouds on Electric Utilities with Dispersed Photovoltaic Generation, IEEE Trns. On Energy Conversion, Vol. EC-2, No.4, Dec.

Gianto, H. (1993) Evaluation of PV Household Rural Electrification Project, SOLAR ' 93, Dec.

Grossman, Karl (1999) Alternative Energy meets Main Street, New Age, July / Aug.

Haruni, M.M. The Solar pilot project in Qatar, Solar & Wind Technology Vol.1, No.2

Hawlader, M.N.A., K. S. Novak & B.D. Wood (1993) Unglazed Collector/Regenerator Performance for a Solar-Assisted Open Cycle Absorption Cooling System, Solar Energy, VoL 2, No.1

Hug, W. & W. Seeger (in German), Alkaline Test Electrolyzer of New Technology with Integrated Gas Separators in Intermittent Operation Inst. For Technical Thermodynamics, DFLVR Stuttgart

Hughes, L. & S. Scott, Using Hydrogen from Hydro-Electricity to Alleviate Carbon Dioxide Emissions in Eastern Canada Energy Conserv, Vo133, No.2, Pergamon Press

Ibrahim A.R.B. Energy Efficiency and New Energy in Singapore, APEC New Energy Seminar, Nov. 1992

Kabakov, V.I. & Ye. I. Yantovsky (1993) Solar Pond Magnetohydrodynamic Generator for Hydrogen Production, Int. J. Hydrogen Energy Vol.18, No.1

Kalaitzakis, K.C. & G.J. Vachtsevanos, On the Control and Stability of Grid Connected Photovoltaic Sources, IEEE Trans. On Energy Conversion, Vol.EC-2, No.4, Dec. 1987

Kentfield, L.A.C. The Delta-Turbine, A Decade of Development, 8th Miami Intnl. Conf. On Alternative Energy Sources, Miami, FL, Dec. 1987

Khalifa, A.M.A., MM.A. Taha & M.Akyurt An Energy Thrifty Solar Cooker -the Mina oven, Solar & Wind Technology Vol.l No.2

Kirtikara K. & P. Wibulswas (1993) Review of Solar PV Energy Developments in ASEAN, SOLAR '93, Dec.

Klose, W. & V. Stuke (1992) Studies for Hydrogen Storage in Mg/MgH System (in German) VCH Verlagsgesellschaft Weinheim

Kolbenev, I.L., Hydrogen Fuel in Automobiles & Tractors, Int J. Hydrogen Energy, Vol. 18, No3

Koner, P.K. (1993) A Review on the Diversity of Photovoltaic Water Pumping Systems, RERIC Intnl. Energy Journal, Vol.15, No.2, December

Kreith, F. & J. F. Kreider Principles of Solar Engineering McGraw -Hill Book Co.

Kroeker, E.J., H.M.Lapp, D.D.Schulte J. D. Haliburton & A.B. Sparling Methane Production from Animal Wastes II -Process Stability presentation at 1976 Annual Meeting, Canadian Soc. of Agricultural Engineering, Halifax, N.S.

Natural Gas -An Increasingly Popular Fuel, (1993) CANMET Technology Focus, Vo15, No3, Dec.

Lapp, H.M. Utilization of Biogas from Livestock Waste, Waste Treatment and Utilization, Pergamon Press

Leng, G. et al, Overview of The Worldwide PV Industry, EDRL 96-41, CANMET publication

Lienau, P.J. Factors Influencing Greenhouse Heating Geo-Heat Center Quarterly Bulletin Vo118, No 1

Lim, J.T. and N.H.Yeong, A Method of Estimating Coastal Winds in the Equatorial Region, 3rd ASEAN S&T Week, Sep. 1992

Malchy, B. (1986) Business Aspects of Renewable Energy, bio-joule, May

Maning, Jeanne, The Coming Energy Revolution, Avery Publishing Group

Ogden, J.M. & R.H. Williarns Solar Hydrogen -Moving Beyond Fossil Fuels, World Resources Institute

Pacheco, F. Autoelectrolytical Generation of Hydrogen from Sea Water: Cogeneration of Surplus Electrical & Thermal Energy, 8th World Hydrogen Energy Conference, July 1990

Peleg, U. & E. Shaviv, Integrated Computer-Aided Passive Solar Architectural design System, 1st World Renewable Energy Congress, Sep. 90

Photron Canada Inc., Feasibility and Cost Competitiveness of PV/Diesel Generator Hybrid Power Systems for Arctic Sites, EMR Canada, Renewable Energy Branch, Ottawa

Rajvanshi A.K. (1990) Ethanol from Sweet Sorghum: An Energy Alternative, Biomass Users Network News Vol. 4, No2, March-April

Saievar-Iranizad, E. Colloidal Semiconductors in Solar Hydrogen Production, 1st World Renewable Energy Congress, Sep, 1990

Sairan, S. Electricity through Cogeneration from Biomass, Proc. of ASEAN Conf. on Energy from Biomass, 1986

Scheer, H. For a Global Ecological Solar Development Initiative Program, EuroSolar Journal No. 9/89

Schneider, Stephen H. Global Warming Sierra Club Books

Selvam, P. Energy and Environment-An All Time Search, Int. Jour. of Hydrogen Energy, Vol.**16** No1

Siebenmorgen, T.J., D.A.Kottwitz & D.D.Schultel Cogeneration of Electricity and Hot Water, Fact Sheet #7, the Energy Farm, Univ. of Nebraska-Lincoln

Smith, E.M. (1991) Hydrogen in Transport, Energy World, Vol.186, March

Stanford, Q. The Global Challenge -A Study of World Issues, Oxford University Press

Starr, M.R. PV Plant Monitoring in Europe, European PV Plant Monitoring Newsletter No 1,Oct 1986

Strong, Steven, An Overview of Worldwide Development Activity in Building -integrated Photovoltaics, Solar Design Associates, Harvard, Massachusetts, USA.

Swannakum, T., K. Kirtikara & P. Yord-Ovart, (1993) Effects of Cell Temperatures on Long-term Efficiency of Photovoltaic Arrays in a PV-Hydro Hybrid System, SOLAR ' 93, Dec.

Tam, K.S., P. Kumar & M. Foreman (1989). Enhancing the Utilization of Photovoltaic Power Generation by Superconductive Magnetic Energy Storage, IEEE Trans. On Energy Conversion, Vol **4**, No3, Sept.

Thiessen, Tracy When Technology is Not Enough: A Social Perspective on Solar-Powered Water Pumping, GEOS, Communications EMR Canada, V 01.19, No.4

Tsukamato, K & K. Tanaka Photovoltaic Power System Interconnected with Utility, Proceedings of the American Power Conference '86

Tung, E.M.R. Canadian Small Hydropower Handbook: B.C. Region Canada;

Walker, C.E., R.L.Ogden & B. K.Rein Producing Fuel Alcohol from Sweet Sorghum Juice, Fact Sheet #2, The Energy Farm, Univ. of Nebraska-Lincoln

Wereko-Brobby, C. (1991) Less Charcoal for Cooking, Biomass Users Network News, Vo15, No.6 Dec.

Williams, R.H. (1992) Powering the Future, EPA Journal, Vol. 18, No 4, Sept./Oct.

Wilt, G. (1998) Tracing the Role of Carbon Dioxide in Global Warming, Science & Technology Review, March

Xiansheng, G. Crop Residue Gasifier-Cooking Stove System: A Novel Design from China, Biomass Users Network News, Vol. 6, No.1

Zmeureanu, R. (1992) A New Method for Evaluating the Normalised Energy Consumption in Office Buildings, Energy Vol.17 , No.3

Biographical Sketch

Robindra Nath Basu Ph.D., M.Sc., B.E. E., M.I. Inf. Sc., M.I.E.E.E., PEng.

Robin Basu is a polyglot scientist and professional engineer from Calcutta, India, with three decades of wide band experience of energy-related research and development and also design of energy systems on earth and in space. As a highvoltage engineer, in his early twenties he was involved in design of power transmission lines when he pioneered the application of aluminium alloys for lighter line hardware and insulator fittings.

Later at C.A. Parsons' works in England, he developed test methods for quality control of large turbo-alternators and transformers. In this context, he patented a method of detection and location of partial discharges in insulation by combination of electronic and ultrasonic signals. This was followed by his study of EMC/EMI of different switchgear at Elliott Automation also in U.K.

He pursued these studies also in Germany where he worked for Siemens and Fichtners. He was also used as a liaison person on overseas projects because of his linguistic skills. As a result, he worked on power station projects in several countries He participated as a volunteer in planning the North South Dialogue under Dr Willie Brandt, the Nobel-Laureate.

In the sixties, he became the technical director of a multidisciplinary company called Technoimpex Ltd. Its main purpose was to transfer beneficial technologies to developing countries in exchange for the country's cash crops like jute, coffee etc. The company was successful in helping new industries in several countries.

In 1976, Robin came to Canada as a consultant and decided to stay. He worked as a maintenance consultant and systems designer for various concerns ranging from automobiles to zoological gardens. In 1980 he joined Montreal Engineering as a senior engineer in the design team of Sheerness and other power stations. He led the magnetic induction study of the Calgary LRT. In 1984 he started a Solar Energy Research project at the University of Calgary Under this project, the properties and uses of solar energy in various forms were studied. Robin developed courses on Renewable Energies and lectured at the university and abroad. Lecturing comes easily to him because he has been a teacher, on the side, right from his graduate days.

His research at the university has been accredited by UNESCO in Paris and recorded in the database for Energy Information Sources and Research Centers. He is recognized by IEEE as PV specialist and a consultant in EEHS (Energy Environment Health & Safety). He has reported his work on various fields in 30 papers at conferences and journals. He has contributed to books and was an editor of Science Abstracts at the Institution of Electrical Engineers, London, for five years. As a founding member of the Institute of Information Science (I. Inf. Sc.), he has analyzed and abstracted many patents and papers from German, and French into English databases.

As president of the SPHERE GROUP of organizations, he advises architects, Governments, industries, cities and NGOs directly and via UN Centre for Technology Transfer. He was a UN-accredited observer at the Earth Summit in Rio in 1992. He is an active supporter of UNICEF and other international organizations promoting Sustainable Development.