ENERGY CONSERVATION THROUGH EFFICIENCY AND SUFFICIENCY

by Jørgen S. Nørgård

Physics Laboratory 3, Technical University of Denmark, 2800 Lyngby, Denmark

Abstract

The most severe environmental problems are related to our use of energy. What we want, however, is actually not the oil, gas, coal, electricity etc., but the energy services, which the energy-driven technology can provide. Fortunately, this technology can be designed to be roughly three times as energy-efficient as it is today. In other words, the present level of energy services can be maintained with only one third of today's energy consumption. The necessary technology changes are even cost-effective in socio-economic terms.

In order to reach sustainability in the global energy system, however, it is not adequate to look only for more efficient technology. We also have to combine efficiency with sufficiency. We have to consider reasonable target levels for energy services per capita in the future. Examples will be shown for electricity consumption. How much electricity is needed for a comfortable and decent standard of living, if highly efficient technology is employed? Electricity consumption per capita for one such example of a sustainable combination of efficiency and sufficiency is compared with today's use of electricity in various parts of the world.

How high a standard of living we can all enjoy in a sustainable future, depends on our willingness to share the general wealth, to stop population growth, and to make use of the energy-efficient technology options.

1. Introduction

The most severe environmental problems mankind is facing today are related to the demand for energy. These problems range from very local environmental health hazards of smoke from indoor woodstove cooking practiced in millions of homes, to the global threats of an increasing greenhouse effect from burning fossil fuels, and the risk of nuclear accidents. Other types of hazards are associated with mining of coal and uranium, the risk of oil tanker spills, acid rain from burning of coal and oil, and disposal of nuclear waste. Even though the use of renewable energy sources is the only sustainable energy supply in the long term, they too can cause environmental problems, when exploited to the extreme. For instance, hydropower has been a frequent target of environmental protests, due to its impact on nature and human settlements, and excessive utilization of biomass is causing desertification and other environmental problems.

2. The Energy Service Concept

Considering the environmental problems associated with the use of energy, it is fortunate that the consumption of energy - when excluding food - is of no direct value to human beings. Oil, coal, gas, uranium, petrol, electricity, etc. cannot be consumed directly. They are useful only as inputs to technologies, which then as outputs provide services, such as warm meals, convenient transport, comfortable rooms, illumination at the desk, clean clothes etc. These energy services are what can directly contribute to human welfare. The amount of energy input needed to provide the service depends on the energy efficiency of the technology involved, such as stoves, houses, trains, lamps, washing machines etc. Figure 1 illustrates the energy chain of technology involved in transforming the primary energy sources into energy services. Getting the full understanding, that the energy services constitute the real value, rather than energy itself, is one of the important prerequisites in energy planning for sustainability.

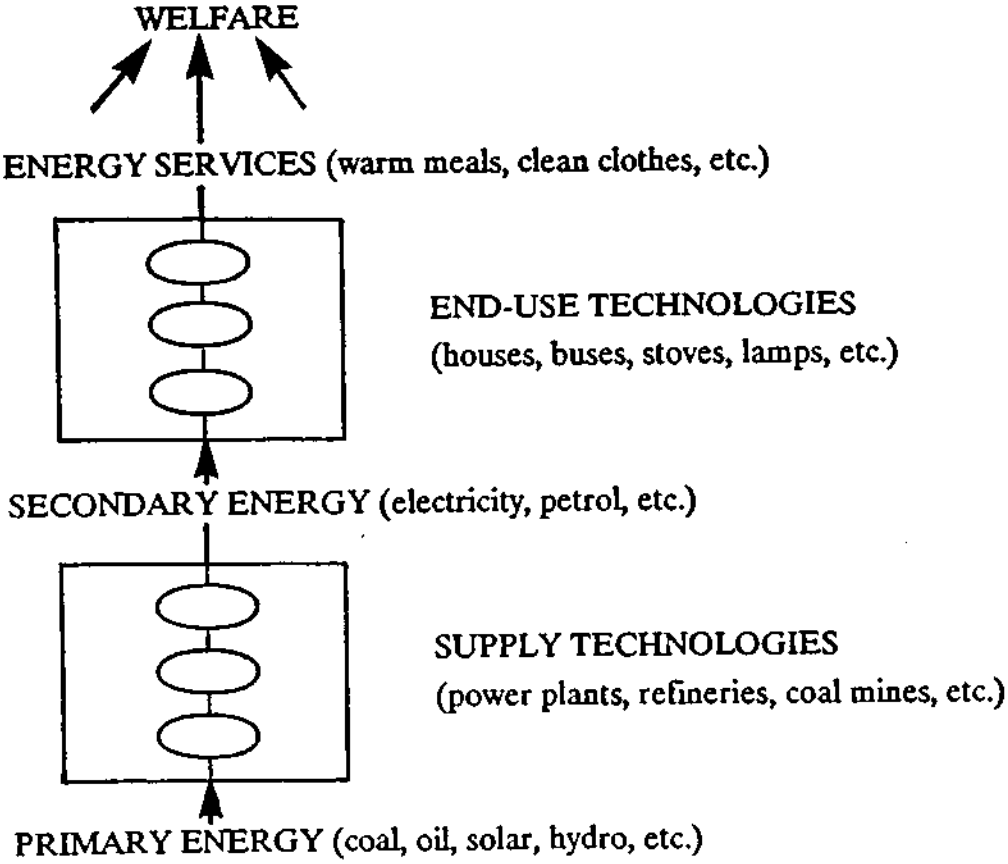


Figure 1: *A chain of technology converts the primary energy into energy services, which can contribute to human welfare. The technologies can be divided into two groups, as shown. End-use technologies are one focus of this paper.*

The various energy services usually cannot be measured in energy units, and not even in the same physical unit. Therefore, they can not easily be added up to one single indicator of energy service. Additionally, the efficiency of the end-use technology cannot be described by a dimensionless number in percentages. These characteristics may have led many natural science-oriented energy researchers to ignore the end-use technologies, compared to the supply technologies. There are various ways to overcome or avoid these problems of quantification of end-use savings, as described elsewhere [1,2]. In any case, such analytical problems ought not be an obstacle for making more efficient use of the energy in the end-use technology.

3. Technological Potential

The supply technologies, shown in the lower part of Fig. 1 can be improved considerably, both in terms of making them more efficient in converting primary energy into secondary energy, and in terms of designing them to use renewable energy sources. Examples of this are described by Williams [3]. In this paper, we will focus on the end-use technologies and possibilities for improving their efficiency.

Several studies have shown that there is an enormous potential for improvement in efficiency. In theory, the potential seems unlimited in many cases. For instance, around 35% of energy consumption in industrialized countries is spent on the passive task of just maintaining temperature differences. This includes keeping houses warm inside in a cold climate, or cool inside in a warm climate, or keeping refrigerators or freezers cold in a warm environment. If thermal insulation was perfect, such tasks would require no energy. Similar theoretical considerations can be applied to energy used for transport and for temporary changes in temperature, as in many industrial processes.

In real life, however, there are limits to the technical potential for conservation of energy. If the improvements are implemented in the natural course of replacing the technologies, it is estimated to be realistic to improve the end-use efficiency by a factor of three over a twenty-year period. In other words, we can enjoy the present energy service or material standard of living with just one third of our present consumption of secondary energy - or we can triple the energy service output without increasing our consumption of energy.

Examples from the four major uses of energy, namely transport, space heating, industrial processes and electricity use will briefly illustrate the technical potentials for saving energy.

4. Transport Technology

Most efforts toward improving the technical efficiency of transportation have been devoted to individual cars, which from a structural point of view constitute a rather inefficient means of transportation. Several large car manufacturers have for years been testing prototypes with fuel efficiency 2 to 4 times the present average [4,5]. The improvements consist of better aerodynamic design, lower weight, and several changes to make the engine more efficient.

Trains, trucks and buses have similar potential for efficiency improvement, but these options are in some cases not exploited and in other cases converted into higher speed, for example to make trains competitive with private cars and airplanes.

It is safe to assume that through better-designed vehicles, present levels of transportation service could be maintained in the future with less than half of the present level of energy consumption. If we then add the options for restructuring and reducing the demand for transportation, the per-capita energy consumption for transportation in the industrialized countries could easily be reduced to around one third of the present level, without reducing comfort.

5. Industrial Processes

For the more energy-intensive industrial processes, such as production of steel, aluminum, cement and paper, some efforts have continously been devoted to save energy, since it accounts for a relatively large proportion of the production cost. However, the penetration of new efficient technologies is rather slow, due to a long lifetime of the production facilities.

As an example, we will look at steel production [5,6]. Today steel is typically produced with an energy input ranging from 18 to 30 GJ/ton, including all processes from a 50/50 mix of iron ore and scrap to rolled steel. The individual steps in the traditional steel plant can be made still more efficient. But the interesting options are those which introduce completely new production systems. One way is to integrate the various processes so that the melted steel is cast directly into its final form as sheets, bars, wires, etc. Another option is the "dry steel-making", which from the iron ore produces steel in powder form without any melting. This powder can then be pressed directly into the final shape. This will also save material and energy compared to the conventional processes of shaping the product by various machines. Altogether, it seems likely that the same final steel products in the future can be produced with well below half of the energy used today.

Other options for saving energy in the production of steel consist of integrating the production of steel with the production of electricity, coal-gas, district heat or heat for low temperature industrial processes.

6. Space Heating

Better thermal insulation of buildings has already provided substantial energy savings in the industrialized countries in cold regions [7]. Together with some changes in habits toward lower average indoor temperatures and the use of heat from cogeneration, thermal insulation has since 1972 lowered the primary energy needed per square meter of floor space in Denmark by 40-50% [8]. However, much more can still be achieved.

New glazing materials, thicker thermal insulation, heat recuperating ventilation systems and better control systems can reduce the demand for space heating in new houses to 10-20% of what a typical house requires today [8]. It is important to implement as many of these options as possible in existing houses as well, since the turnover time of building stock is long, often 100 years or more.

7. Electricity Use

Electricity is used for hundreds of different tasks, most of which play an insignificant role in the budget of the home, institution, industry or wherever electricity is used. For that reason, savings options have often been ignored, even though electricity accounts for around 25% of the world's use of primary energy, and the proportion is growing fast. The following examples will illustrate the vast potential for technical electricity savings.

A very efficient refrigerator has been developed and is now being marketed, see Fig. 2. It consumes only 90 kWh per year for a 200-liter unit, or around 25% of what is typical for those refrigerators in use today [9]. Soon this unit will be available in a CFC-free version. Still higher efficiencies can be achieved for refrigerators, as shown. 90 | kWh/yr.

New light sources, compact fluorescent light bulbs, are 3-4 times as efficient as the normal incandescent light bulbs. Control systems, better fixtures, etc. can also contribute considerably to making lighting more efficient. 50

Ventilation systems can also be designed to provide the same indoor air quality with only around 15% of what present systems use [10].

More examples of improving electric end-use technologies can be found in refs. 10 and 11.

8. Costs of Saving

To save one unit of energy through more efficient end-use technology is today much cheaper than to provide one unit of energy. This is particularly the case when the improvements are introduced in the course of natural replacement of existing energy-consuming capital, as assumed in the following. Many studies find rather low cost-effective saving potentials, because the studies more or less are based on an immediate, forced replacement. For a long-term policy - 20-30 years - such methods for savings estimates are rather irrelevant, since most capital will be replaced within that time horizon.

Another pitfall in cost estimates of new energy-saving technology is to assume that the price reflects the production cost. This is the case only in a perfect free market with many independent and competing manufacturers. In the long run a higher price can reflect the extra cost, but in the first years after introducing a new energy-saving technology, the price charged is often determined by the manufacturer's expectations of what kind of payback time the consumer is willing to accept.

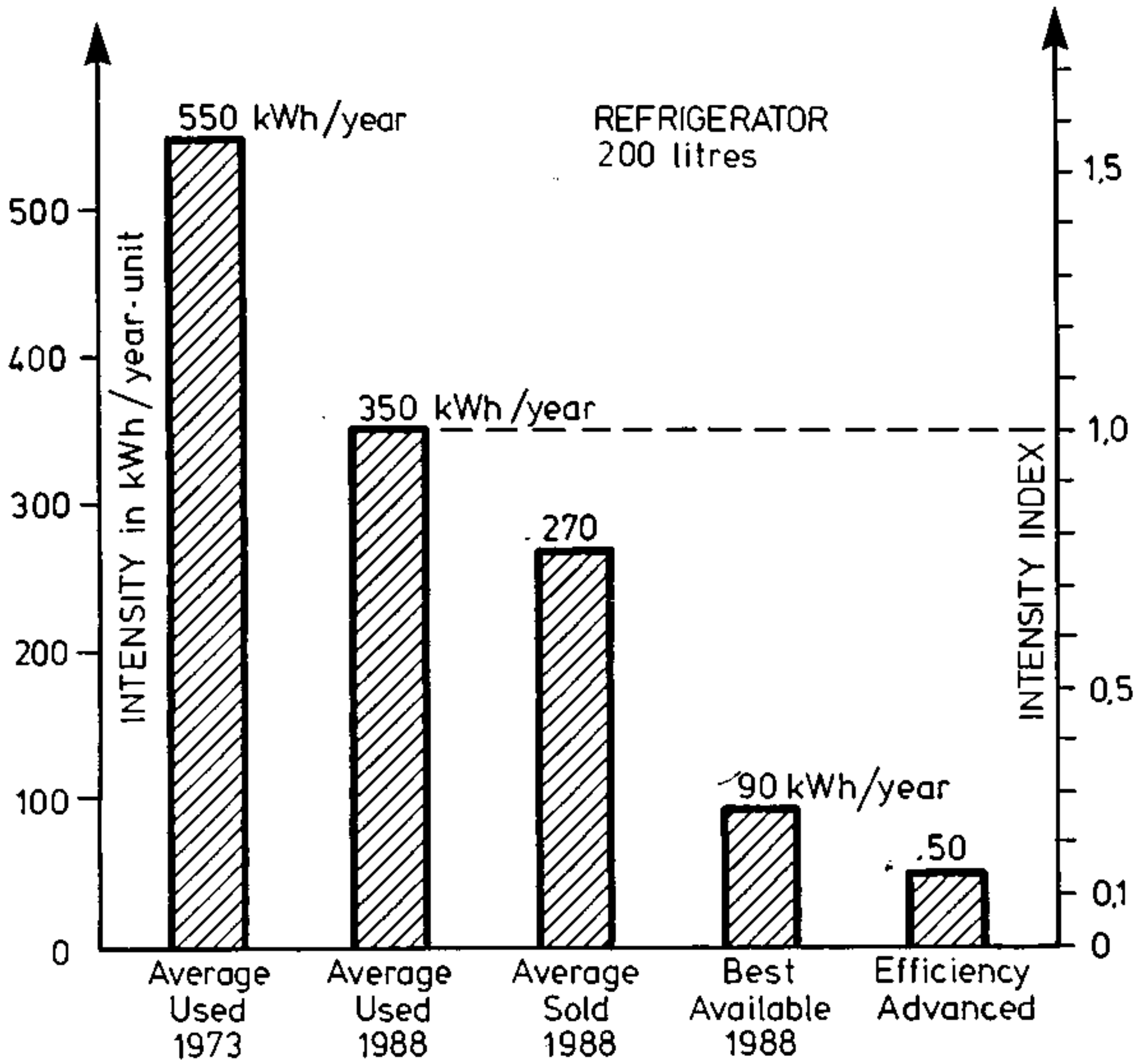


Figure 2. *Electricity consumption at European standard test conditions (25 degrees C outside, +5 degrees C inside) for various versions of a 200-liter refrigerator with no freezer compartment. The intensity index on the scale to the right illustrates the relative improvements, and is approximately transferable to other sizes of refrigerators, to freezers, and to combined units and commercial units in shops, etc. [From 10].*

The cost of saving energy also depends on what is already done in this area. The more energy is saved, the more expensive it becomes to save another unit, since the cheap options are used first. Figure 3 illustrates this rising marginal cost of saving a kWh of electricity, as compared to producing a kWh. It is estimated, as illustrated, that more than half of present consumption of electricity can be saved with cost-effective technological measures. Only thereafter will it become more costly to save than to produce electricity. Considering the environmental benefits of saving as compared to producing, we ought not hesitate to go beyond the limit of traditional economic cost-effectiveness. We should be prepared to pay something for a better environment. In the long run the environmentally benign policy of saving energy will also be the cheapest energy policy.

The fact that energy saving is cost-effective implies that the strongly-needed economic development in the South can be accelerated, if a higher priority is given to investment in more efficient end-use technology than in supply technology. Frequently the type and scale of the efficient end-use technology is in fact better suited for industrial production in the South than is large-scale power plant technology.

Despite all of the economic, environmental and social advantages, the energy-efficient technologies will not penetrate the market on its own, at least not at an acceptable rate. This reflects a lack of information on the part of decision-makers and also reflects large vested interests in energy supply technology. It will require a very determined policy to secure the future use of the efficient end-use technology.

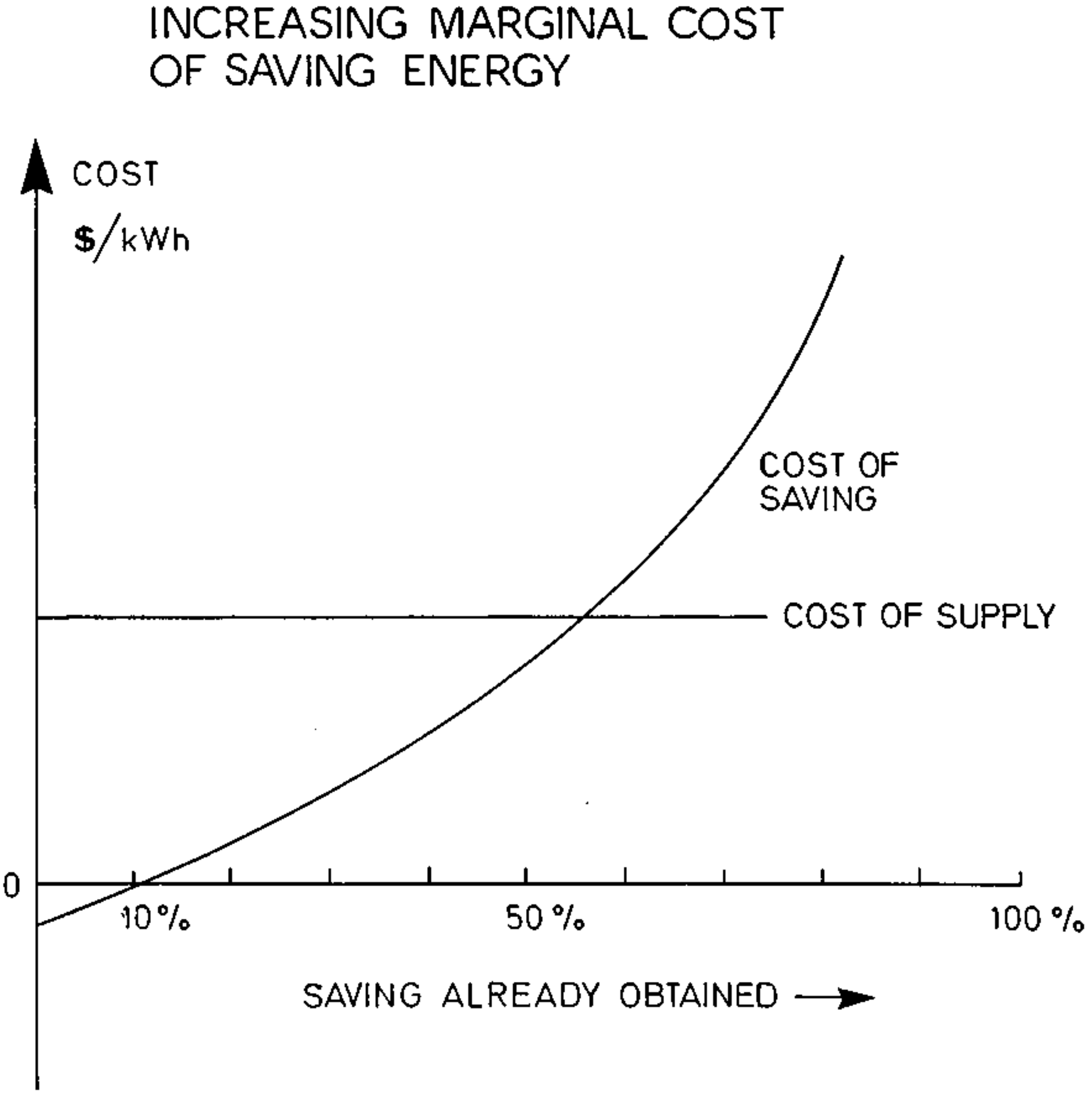


Figure 3. *The cost of saving another kWh becomes more expensive as more is saved. This marginal cost of saving is qualitatively illustrated here. At a certain level of saving it becomes more expensive to save than to supply energy.*

9. Efficiency: Important but Inadequate by Itself

The technical options described above for using energy more efficiently are enormous and not fully recognized. However, even these technical fixes are not adequate to secure a sustainable energy future, if we otherwise continue with business as usual.

One paradoxical aspect of focusing on just improving the technical efficiency is that efficiency can actually be accomplished by increasing energy consumption! If, for instance, a family replaces their house with a larger house with the same standard of insulation, indoor comfort, etc., the larger house will typically use less heat per square meter of floor space, because the ratio between the surface and the floor space is reduced. Therefore it would normally be considered more energy efficient, even though it consumes more energy. Similarly, a larger refrigerator unit will - everything else being equal -- consume more electricity than a smaller one, but nevertheless be technically more efficient, measured in electricity consumption per volume of storage space. In transportation the paradox also holds. Driving longer distances will obviously require more fuel, but usually produces better efficiency, measured as fuel per km.

These examples are not just accidental paradoxes. They illustrate a general view which dominates today's energy policy. It is acceptable to increase energy consumption as long as the output, - the energy service - grows even faster, so that efficiency increases. The absolute limits to the acceptable global energy consumption, expressed by CO_2-emission and other environment factors, make this fixation on efficiency an obsolete view on energy conservation.

In the materialistically rich North, we must now think in terms of combining efficiency with sufficiency. An ever-growing demand for energy services will, over a period, eat up the environmental advantages, which efficiency improvements could otherwise have provided [12]. With an open mind we must discuss what could be reasonable objectives for a material standard of living, for instance, expressed as a per-capita energy service level. One attempt at starting this is described later in this paper.

10. A Saturated Economy

A consequence of the above would be that future development in the industrialized North should be concentrated on qualitative improvements in the economy and everyday life, rather than as it is presently, on materialistic economic growth. The end of growth in BNP is not the end of the world (this could rather be the consequence of continuing growth!). An economy which at a macro level is in a stable state can at a micro level develop with just as much dynamic, competition, growth, decline and changes as do our present growth economies.

Most economists and policy-makers today act as if economic growth must and can go on forever, often because they are forced to work within a rather short time horizon and because they don't fully perceive the environmental repercussions. Their ancient idols, the pioneers in economic theory, such as John Stuart Mill, Karl Marx, Adam Smith, and John Maynard Keynes, had a wider and longer time perspective. Hence, they usually considered the economic growth period as a temporary phase, a transition to a state where the economic problems of humans were solved, and we could all enjoy the fruits of the technical development in a spiritually richer life [13,14,15]. This state seems to have been reached for the average person in many industrialized countries.

More recently some economists like H. Daly at the World Bank have pointed out how unrealistic and irrational it is to pursue economic growth as a primary goal [13]. Even the economic and material welfare is no longer indicated very well by the gross domestic product (GDP) [16]. Extended lifetime of durable goods, re-use of components, and recycling of materials are examples of economic policies which might lower GDP, but not impede welfare. Several surveys in Europe point toward a high preference by wage earners for more leisure time over more income, given the choice [17]. Such an increase in welfare in the form of more leisure time would not show up as a higher GDP either. Finally, a more equal distribution of wealth and income would increase the welfare obtained from a certain GDP. Consequently, a high degree of equity should be a basic element in a policy aimed at a sustainable welfare economy. The declining marginal benefit and the increasing social and environmental cost of continuing economic growth have even turned some top politicians away from economic growth as a goal. Oscar Lafontaine, who was the Social Democratic chancellor candidate in Germany in the 1990 election is one of them [18].

The above illustrates how the economy, just like the technology, can be made more efficient in providing welfare. This implies for instance that present energy services could be provided with a lower GDP.

11. Population

Every country should consider the population policy in the environmental perspective of sustainability. The only serious attempt to do this, so far, seems to have been in China [19]. Even this exemplary policy of China might turn out to be insufficient in the light of the global environmental problems we are facing today. In any case, a laissez-faire population policy seems irresponsible. It is now recognized that the traditional population policy of just assuming that increased standard of living will automatically halt the population growth is not going to work in many poor countries. This is because of the inverse relationship, namely that improving standard of living will require a reduced population growth. This "poverty trap" calls for other population policies like family planning programs, social security, etc.

Not only the developing countries should be concerned about population problems. The industrialized countries in Europe are among the most densely populated areas in the world. This puts a high pressure on the natural environment. It is encouraging that population is not presently growing in this part of the world, and in fact in some industrial countries it is declining. While this is advantageous from the point of view of sustainability the declining population is unfortunately often considered a problem by governments.

Population policy is a very emotional and sensitive area, and we will not go further into details here, except emphasizing this issue's extreme importance in a policy toward sustainability. The more people in a future world with limited sustainable energy supply options, the lower will be the average material standard of living.

12. Sustainability Through Sufficiency Plus Efficiency

The following describes in part an energy service level which could in the future be considered as a minimum human right. The energy services suggested belong to the domestic and the service sectors, two sectors which today typically account for between one - and two thirds of electricity consumption. For the domestic sector the suggested services are listed in Table 1.

Minimum domestic electricity service per household

Lighting:	As in Denmark today, 1000 lumen average, corresponding to 6 incandescent lamps, each 60 W, operating 6 hours per day.
Refrigeration:	200-liter refrigerator volume (+5 Degrees C) and 100 liter freezer (minus 18 Degrees C).
Washing:	200 laundry washings per year, each 4 kg,in an automatic electric washing machine. Possible need for warm water is assumed to be provided from non-electric energy.
Electronics:	Without specifying in details, the service suggested includes several hours of TV-watching, radio listening and computer use every day, as well as other minor uses of electronics.
Ventilation:	Supply of fresh air in high rise buildings plus some unspecified ventilation for cooling.
Other Uses:	Several other pieces of electric equipment can be added within this category as long as they are designed for high efficiency. Equipment with electric heating should generally be avoided.

Table 1. *List of the domestic electricity service level suggested as one example of a minimum human right level of energy services per household.*

The minimum electricity services for the service sector are not specified here, but the level corresponds roughly to that of Denmark in 1986, with a general material welfare among the highest in the world. Electricity service in the industrial sector is not included in this example, because the industrial structure varies a lot from country to country. A more thorough analysis of this area should include the electricity services embodied in imports and exports.

The end-use technologies suggested to provide these services are among the most energy-efficient models proposed [10]. This means, for instance, that the refrigerator is assumed to be like the one described as "efficiency advanced" in Fig. 2. Although these models are not always on the market, they could be developed and produced within a few years, if it was decided to do so.

The resulting demand for electricity is listed in Fig. 4, expressed as average power per capita in Watt. The average household size is assumed to be four persons. As shown, the required electricity in the domestic and service sectors in this combination of efficiency and sufficiency would be 70 Watt per capita. Without efficiency improvements this service level would require more than 200 Watt.

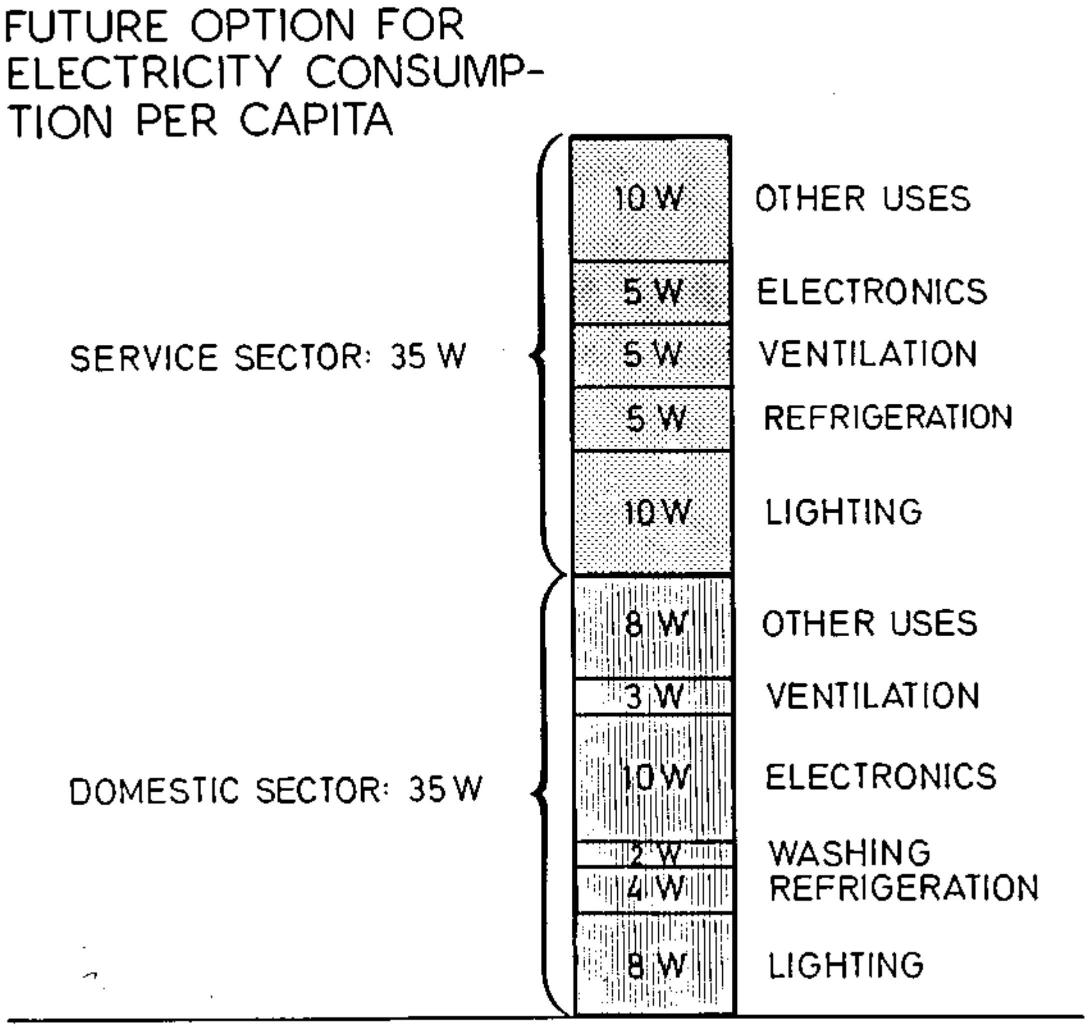


Figure 4. *Electricity required per capita to provide the level of energy service suggested in Table 1 as a minimum human right. The example is based on an average family size of four persons. Electricity consumption is here expressed as the corresponding average power in Watts. One Watt = 8.76 kWh per year. If today's typically used technology were applied, the electricity required per capita would be 200 Watts for the two sectors rather than 70 Watts.*

In the mid-eighties a similar energy service level example was proposed by Goldemberg et al., as a possible goal for developing countries only [5]. Since this one kilowatt-scenario, as it was called because it required around 1000 Watt per capita, was established, two trends have been observed. First, the technical efficiency options have increased. Second, this increase is more than outweighed by the fact that the environmental sustainability today is found to require a deeper cut in energy demand than anticipated in the mid-eighties. There are now indications that continuous economic growth is unrealistic and incompatible with a sustainable development in the world [20, 21].

The concrete example used here is not meant as a model for how everyone should live. First of all, the energy services illustrate only the material part of our welfare, and an extensive cultural and individual diversity could easily be imagined within the same material basis. Second, different cultures or individuals can have different preferences in terms of combinations of energy services. The list of energy services put forward here can serve as a guideline for estimating an overall level per capita, which can ensure a material basis for a good life.

In Figure 5, the graphic illustration of Figure 4 is scaled down and compared to present electricity consumption per capita in various parts of the world. The higher per capita use of electricity in Western European domestic and service sectors is mainly due to: 1) lower technical efficiency; 2) smaller average family size; and 3) use of electricity for domestic heating. Additionally for the USA the following factors apply: 4) higher level of electricity services in general; and 5) high use of air conditioning in particular. It is interesting to observe that a developing country like Brazil probably need not expand its actual electricity supply per capita in order to reach a service level such as the one outlined above, unless Brazil chooses to develop a very electricity-intensive industry.

13. Concluding Remarks

There is no doubt that every person on the Earth could be provided with a decent material standard of living on an environmentally sustainable level. Over the next decades this will require:

1. Restricting population growth;
2. Stabilizing GDP in the North;
3. Distributing more evenly the material wealth; and
4. Implementing high-efficiency technologies.

The more successful we are in these four actions, the higher total welfare can be enjoyed. In a global collaboration we in the North can contribute by transferring energy efficiency to the South. Stabilizing our own production and consumption in the North could, however, be a more significant contribution to a sustainable development, by leaving more environmental elbow-room for the much-needed material growth in the South.

While we in the North have been rather successful in the technological development of efficiency, we could benefit in learning from the diversity of cultures in the South about sufficiency. How can we exist as individuals and as societies without an ever-growing excessive consumption and production? In short: how to be happy without a dishwasher?

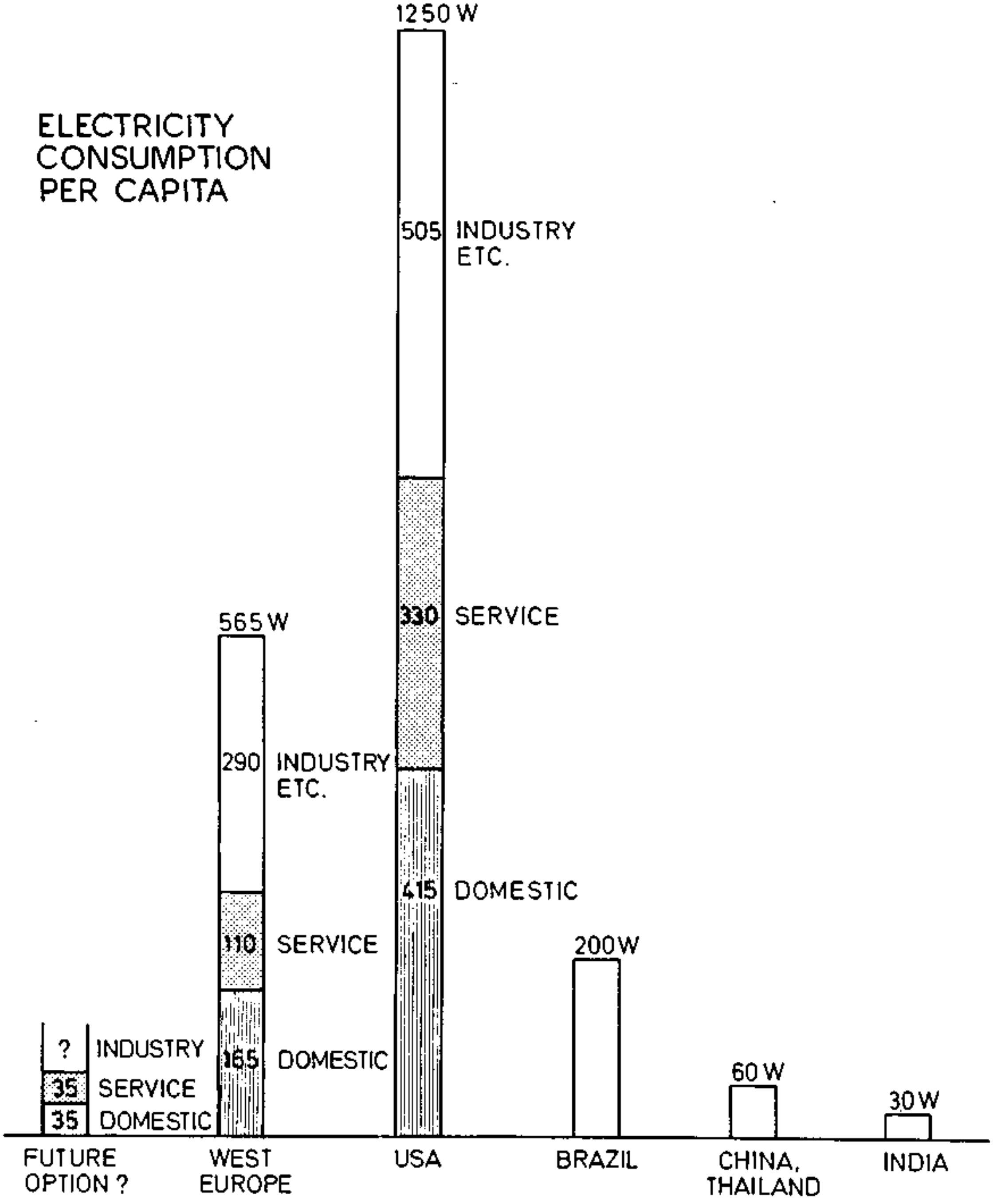


Figure 5. *The column in Figure 4 showing future options for sustainable electricity consumption in the domestic and service sectors is here scaled down and compared to present consumption in various parts of the world. Without efficiency improvements the future option would require three times as much electricity.*

References

1. J.S. Nørgård: "Methods and Concepts in Electricity Planning", Physics Laboratory III, Technical University of Denmark, DK 2800 Lyngby, Denmark, 1991.

2. B. Bodlund, E. Mills, T. Karlson, and T.B. Johansson: "The Challenge of Choices: Technology Options for the Swedish Electricity Sector", in the book entitled "Electricity," edited by T.B. Johansson, B. Bodlund and R.H. Williams, Lund University Press, Sweden, 1989.

3. R. H. Williams: "The Outlook for Renewable Energy", in these proceedings, 1991.

4. "Öko-Polo", IAV-ingenieurgesellschaft für Aggregatetechnik und Verkersfahrzeuge mbH. Report from Volkswagen AG, D 3180 Wolfsburg 1, Germany, 1987.

5. J. Goldemberg, T.B. Johansson, A.K.N. Reddy, and R.H. Williams; "Energy for a Sustainable World", Wiley Eastern Limited, New Dehli, India, 1988.

6. S. Eketorp: "Electrotechnologies and Steelmaking", in the book entitled, "Electricity," edited by T.B. Johansson, B. Bodlund, and R.H. Williams, Lund University Press, Sweden, 1989.

7. L. Schipper and A. Ketoff: "Explaining Residential Energy Use by International Bottom-Up Comparison", Am. Rev. Energy, Vol. 10, pp. 341-405, 1985.

8. "Energy 2000 - A Plan of Action for Sustainable Development" and Danish background report no 1, Danish Ministry of Energy, Copenhagen, April 1990.

9. T. Guldbrandsen, and J.S. Nørgård: "Achieving Substantially Reduced Energy Consumption in European Type Refrigerator", Presented at 37th Annual International Appliance Technical Conference, Purdue University, USA, May 1986.

10. J.S. Nørgård: "Low Electricity Appliances - Options for the Future", in the book entitled "Electricity", edited by Johansson, Bodlund, and Williams. Lund University Press, Lund, Sweden, 1989.

11. T. Flanigan, A. Lovins, et al.: "Competitek - Advanced Techniques for Electric Efficiency", Information Service, August 1990 Edition, Rocky Mountain Institute, 1739 Snowmass Creek Rd., Snowmass, Colorado, 81654, USA.

12. J. S. Nørgård: "Technological and Social Measures to Conserve Energy", Research Program on Technology and Public Policy, Thayer School, Dartmouth College, USA, 1974.

13. H.E. Daly and J.B. Cobb: "For the Common Good", Beacon Press, Boston, USA, 1989.

14. J.S. Mill: "Principles of Political Economy", Revised edition, Volume II, Colonial Press, New York, 1900.

15. J.M. Keynes: "Essays in Persuasion", MacMilland and Co., London, 1931.

16. J.S. Nørgård: "National Product or Welfare?", (in Danish) in EVA-report 1991, "Det Rene Svineri", Samfundsfagsnyt, Copenhagen, 1991.

17. J. S. Nørgård and B.L. Christensen: "Individual Attitudes in Scandinavia points towards a Low-Energy, Saturated Society", Vol F, Proceedings from ACEEE 1984 Summer Study on Energy Efficiency in Buildings, Santa Cruz. ACEEE, 10001 Conn. Ave. N. W., Washington D.C., USA, 1984.

18. O. Lafontaine: "Der andere Fortschrift: Verantwortung statt Verwei gerung", Hoffmann and Campe Verlag, Hamburg, Germany, 1985.

19. N. Keyfitz: "The Population of China", Scientific American, Volume 250, No. 2, February 1984.

20. L. Brinck et al: "Environment and Energy in Scandinavia - energy scenarios for the year 2010" (in Scandinavian), Environmental and Energy Systems Studies, University of Lund, Gerdagatan 13, S-223 62 Lund, Sweden, December 1990.

21. O. Benestad et al: "Energy 2030 - Low Energy Scenarios for Denmark, Norway and Sweden" (in Norwegian), Preliminary report, March 1991. Alternative Framtid, Hausmannsgatan 27, N-0182, Oslo 1, Norway.

THE OUTLOOK FOR RENEWABLE ENERGY

by Robert H. Williams

Center for Energy and Environmental Studies, Princeton University, USA

The following is a summary of the paper by Robert H. Williams illustrated by his viewgraphs and short comments.

MAJOR ENERGY-RELATED ENVIRONMENT/SECURITY PROBLEMS

CONCERN	CAUSE
REGIONAL AIR POLLUTION	INADEQUATE emission controls
URBAN AIR POLLUTION	INADEQUATE emission controls + OVERDEPENDENCE on liquid hydrocarbon fuels
GLOBAL INSECURITY	OVERDEPENDENCE on Middle East oil
GREENHOUSE WARMING	OVERDEPENDENCE on fossil fuels
NUCLEAR PROLIFERATION	OVERDEPENDENCE on nuclear power

THESIS: CREATIVELY CRAFTED environment/security policy can SPEED UP PACE OF TECHNOLOGICAL INNOVATION and thus adoption of energy technologies that not only IMPROVE ENVIRONMENT/SECURITY but also offer MULTIPLE ADDITIONAL BENEFITS

"Band-aid" solutions for coping with the environment and security problems that will face the energy system in the coming decades will be inadequate in many instances. Instead, fundamental changes in the energy system will often be needed. The challenge to public policy is to find how to address these problems in ways that will speed up the pace of technological innovation for energy and the adoption of energy strategies that not only improve the environment/security situation, but also offer multiple additional benefits.

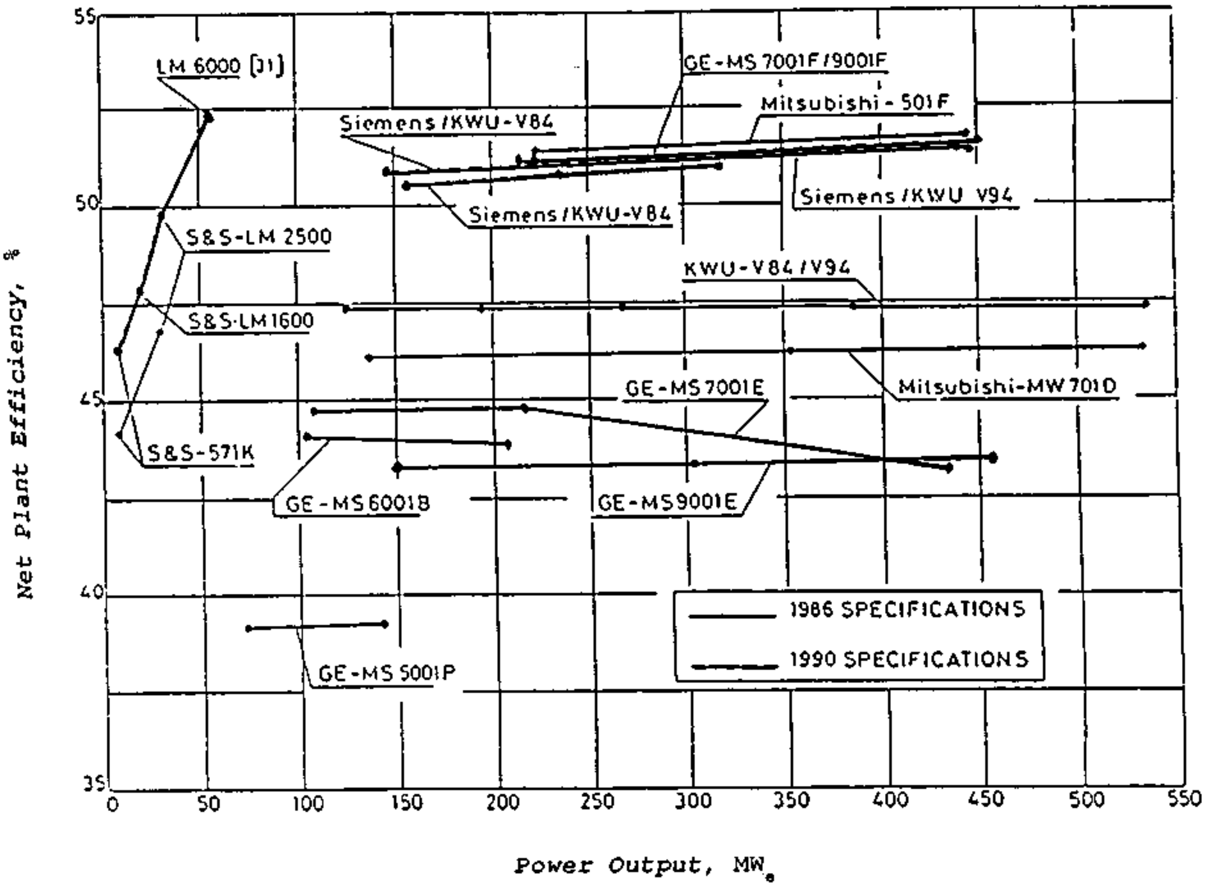
ENERGY STRATEGIES FOR COPING WITH ENERGY-RELATED ENVIRONMENT/SECURITY PROBLEMS

- MORE EFFICIENT USE OF ENERGY
- NATURAL GAS AS THE FOSSIL FUEL OF CHOICE
- MODERNIZATION OF BIOMASS (Green Plant Matter) AS AN ENERGY SOURCE
  - Power Generation
  - Liquid and Gaseous Fuels
- ELECTRICITY FROM INTERMITTENT RENEWABLE SOURCES
  - Wind Power
  - Solar Thermal-electric Power
  - Photovoltaic Power
- HYDROGEN AS AN ENERGY CARRIER
  - Hydrogen from Coal (Thermochemical Gasification w/CO_2 Sequesterin
  - Hydrogen from Biomass (Thermochemical Gasification)
  - Solar Hydrogen (Electrolytic, from Wind Power, PV Power)

A promising approach to dealing with these environment/security challenges is the above 5-part energy strategy. The elements of this strategy are listed in order of their temporal priority, with the more efficient use of energy offering the largest near-term payoff, and a shift to hydrogen as an energy carrier being the furthest off but offering perhaps the greatest long-term potential for displacing conventional energy sources. All elements of this strategy, however, could be initiated before the end of this century.

In this presentation the focus is on four elements of this energy strategy - natural gas as the fuel of choice in the transition to the post-fossil fuel era, wind power, biomass for power generation, and hydrogen from biomass.

RAPID PACE OF TECHNOLOGICAL IMPROVEMENT
FOR
GAS TURBINE/STEAM TURBINE COMBINED CYCLE POWER SYSTEMS
(With Natural Gas Firing)



COMPARISON OF 1986 AND 1990 SPECIFICATIONS FOR COMBINED CYCLES

The facts that natural gas is the cleanest of the fossil fuels and that the global reserve/production ratio is much larger for gas than for oil suggests greatly expanded roles for gas in the decades immediately ahead.

In particular, natural gas-fired, gas turbine cycles will be increasingly used for power generation, offering the advantages of low unit capital cost, high efficiency, and low pollutant emissions.

The pace of technological change for gas turbines is rapid, with the efficiencies of the most-efficient gas turbine/steam turbine combined cycles now offered commercially being more efficient by almost 5 percentage points than the most efficient cycles offered commercially five years ago, as indicated in this graph.

Efficient combined cycle plants emit 60% less CO_2 per kWh than coal-fired steam-electric plants with flue gas desulfurization.

Busbar Cost of Electricity from Wind Turbines[a]

NEW WIND FARMS AT ALTAMONT PASS[b]

In-Service Year	Capacity Factor	Installed Cost ($/kW)	Busbar Cost (cents/kWh) Capital	O&M	Total
1981-82	0.034	2440	81.1	4.9	86.0
1983	0.089	2110	27.2	3.8	31.0
1984	0.13	1840	16.2	3.2	19.4
1985	0.18	1550	9.9	2.7	12.6
1986	0.23	1220	6.1	2.1	8.2

ADVANCED TECHNOLOGIES[c,d]:

Year	Technology	Capacity Factor	Installed Cost ($/kW)	Busbar Cost (cents/kWh) Capital	O&M	Total
2000	BAU	0.28	1040	4.3	1.2	5.5
	R,D&D	0.30	990	3.8	1.0	4.8
2010	BAU	0.29	1000	4.0	0.9	4.9
	R,D&D	0.33	885	3.1	0.8	3.9

---

[a] The 30-year levelized cost in 1989 dollars, with a levelized annual capital charge rate of 0.1007 (EPRI TAG accounting rules).

[b] The entries are actual costs (without subsidies) for new wind farms installed at Altamont Pass in California (D.R. Smith, "The Wind Farms of Altamont Pass," Annual Review of Energy, pp. 145-183, 1987).

[c] Projections for the years 2000 and 2010 are for sites with 13 mph annual average wind speeds for the Business-As-Usual (BAU) and Research, Development, and Demonstration Intensification (R,D&D) Scenarios presented by the US Department of Energy, Office of Policy, Planning, and Analysis, in its Interlaboratory White Paper, "The Potential of Renewable Energy," March 1990 (SERI/TP-260-3674).

[d] The DOE projections for 2000 are consistent with what could be achieved with a 340 kW variable speed wind turbine being developed jointly by US Windpower, the Electric Power Research Institute, and the Pacific Gas and Electric Company, in a program that will be completed in 1993 (E. Lucas, G. Montgomery, E. DeMeo, and W. Steeley, "The EPRI-Utility-USW Advanced Wind Turbine Program--Status and Plans," paper presented at WindPower '89, the 1989 American Wind Energy Conference, September 25-27, San Francisco, California). The capital cost is expected to be $0.36/kWh/yr (see Figure 3. Optimization Curve for the USW 33-300). The targeted energy capture rate is 807 MWh/yr, the installed cost is ($0.36/kWh/yr)*(807,000 kWh/yr) = $290,000 ($855/kW), and the corresponding capacity factor would be 27%. The capital charge would be 3.63 cents/kWh, and the total busbar cost 4.73 cents/kWh (see page 182), for an average wind speed of 15 mph in Altamont Pass applications.

One of the major advantages of most renewable energy technologies is the potential for cost-cutting through "organizational learning", the process of improving economic efficiency, in effect, by getting better organized. The modest scale of most renewable technologies makes it feasible to mass-produce identical units. Moreover, the time required from initial design to operation is characteristically so short that needed improvements can be determined by field testing and quickly incorporated into modified designs.

The 10-fold reduction in the busbar electricity cost achieved for new wind farms at Altamont Pass in California in the 1980s (see above) can be attributed mainly to organizational learning, as there was little technological improvement in this period. There was organizational learning in the factory (where the techniques of mass production were learned) and organizational learning in the field (where wind producers learned how to site turbines to better exploit the local wind resource and to schedule maintenance during periods of low wind). While the prospects for further cost reductions through organizational learning are limited, technological improvements are expected in the 1990s that will reduce the wind busbar cost to below that for coal-fired steam-electric plants.

HYPOTHETICAL WIND TURBINE/GAS TURBINE HYBRID

One 50 **MW GAS TURBINE COMBINED CYCLE**
(w/hot-air gas turbine bottoming cycle)
48% efficient (LHV basis); $450/$kW_e$

+

One Hundred Fifty 340 **kW_e VARIABLE-SPEED WIND TURBINES**
(US Windpower/PG&E/EPRI development)
$850/$kW_e$, 27% capacity factor

=

WIND TURBINE/GAS TURBINE HYBRID

$1300/$kW_e$ (w/no wind capacity credit)
"Effective" gas-turbine-equivalent efficiency = 75%
Capacity Factor = 75%

Competitive with baseload coal steam-electric power
for gas prices up to $30/barrel of oil-equivalent

CO_2 emissions/kWh 75% less than for coal steam-electric power
Extremely low levels of other pollutants

Low capital-cost gas turbines can be effective complements to intermittent renewable electric technologies - e.g., wind power, photo voltaic power, and solar thermal-electric power. Very low-cost simple cycle gas turbines can be used in conjunction with intermittent renewable technologies in meeting peak electric demand. High efficiency gas turbine cycles can be combined with intermittent renewable technologies to provide even baseload power cost-effectively, with extraordinarily low pollutant emissions.

The latter possibility is illustrated above with a gas turbine combined cycle coupled to a "farm" of variable-speed wind turbines.

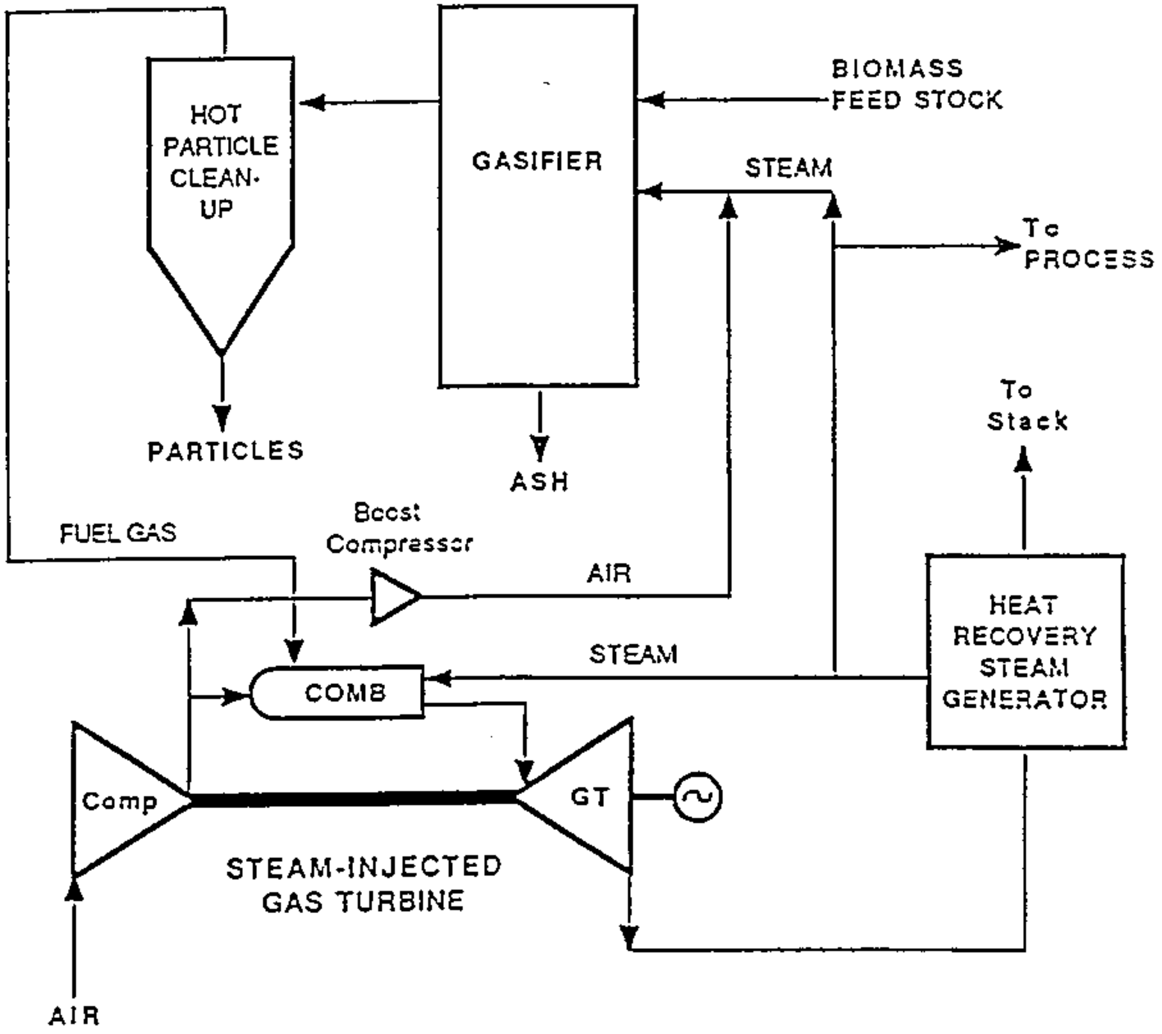
IMPORTANCE OF BIOENERGY

- BIOMASS IS WIDELY AVAILABLE RESOURCE
- BIOENERGY OFTEN CHEAPER THAN IMPORTED OIL
- BIOENERGY WELL-SUITED FOR RURAL INDUSTRIALIZATION, RURAL EMPLOYMENT GENERATION
- NO NET ATMOSPHERIC CO_2 BUILDUP IF BIOMASS GROWN RENEWABLY

REQUIREMENTS OF BIOENERGY SYSTEM

- RENEWABLE PRODUCTION OF BIOMASS
- CONVERSION OF BIOMASS TO MODERN ENERGY CARRIERS
- EMPHASIS ON HIGH-EFFICIENCY CONVERSION PROCESS
- EMPHASIS ON HIGH-EFFICIENCY END-USE TECHNOLOGIES
- CONVERSION TECHNOLOGIES OFFERING FAVORABLE ECONOMICS AT MODEST SCALES

Biomass is likely to provide the basis for much of the renewable energy development in the decades immediately ahead. While biomass already accounts for about 1/7 of energy use globally and 1/3 of energy use in developing countries, a significant role for biomass in the future global energy economy will require that biomass be transformed from its present status as the inefficiently used "poor man's oil" into a modern energy source - by utilizing advanced technologies for efficiently converting raw biomass into electricity and gaseous and liquid fuels.



BIOMASS INTEGRATED GASIFIER/STEAM-INJECTED

GAS TURBINE (BIG/STIG)

A first generation biomass-integrated gasifier/gas turbine (BIG/GT) power system may well involve coupling a fixed bed gasifier (suitable for gasifying densified biomass feedstocks - e.g. wood chips or briquetted bagasse) to a steam-injected gas turbine (STIG) that could be used for cogeneration (the combined production of heat and electricity) in industrial applications.

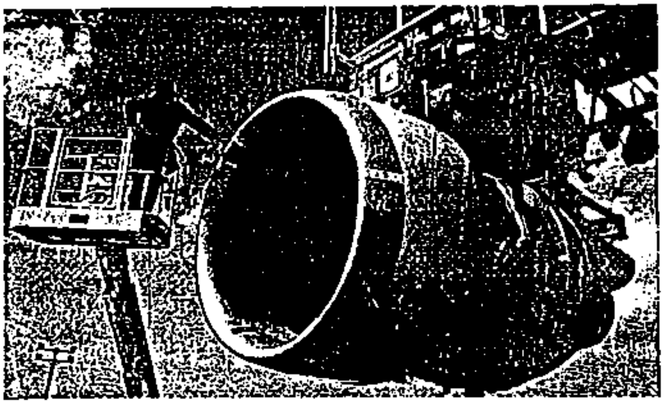
BIOMASS-BASED POWER GENERATION

PRESENT TECHNOLOGY: STEAM TURBINE

COST-EFFECTIVE ONLY FOR VERY LOW BIOMASS COSTS
AT MODEST SCALES NEEDED FOR BIOMASS

ADVANCED TECHNOLOGY: BIOMASS GASIFIER/GAS TURBINE

CAN USE AERODERIVATIVE GAS TURBINES
-> HIGH EFFICIENCY, LOW UNIT CAPITAL COST AT MODEST SCALE



The most powerful GE product, a CF6-80C2, gets a final check before testing at an Ohio plant

CAN ADAPT COAL-GASIFIER/GAS TURBINE TECHNOLOGY TO BIOMASS.
-> EASIER TO GASIFY BIOMASS, USUALLY NO SULFUR CLEANUP NEEDED

At the present low world oil price the most promising route for modernizing biomass involves making electricity. An approach that will probably be commercialized in the 1990s involves gasifying the biomass thermochemically and using the gas on site to provide electricity in aeroderivative gas turbine-based power cycles. Such cycles offer the potential for achieving high efficiency and low unit capital costs at the modest scales (typically tens of MW) needed for biomass operations.

Some of the advances that have been made in marrying coal to the gas turbine through the use of coal gasifiers that are closely coupled to the gas turbine power plant can be adapted to biomass at low incremental development cost. The biomass version of these coal-integrated gasifier/gas turbine technologies are likely to be commercialized more quickly than the coal versions, both because biomass is more reactive than coal and thus easier to gasify, and because biomass generally contains negligible sulfur - the efficient and cost-effective removal of which is the major obstacle to making coal-integrated gasifier/gas turbine (CIG/GT) technology competitive with coal steam electric power with flue-gas desulfurization.

SUGAR CANE PLANT

968×10^6 TONNES OF SUGAR CANE PRODUCED IN 1987--MOSTLY IN DEVELOPING COUNTRIES

SUGAR - TRADITIONAL PRODUCT OF SUGAR CANE

FUEL ALCOHOL (ETHANOL) ALSO PRODUCED FROM CANE IN BRAZIL (12 BILLION LITERS/YR)

TREND WILL BE TOWARD THE COPRODUCTION OF:

SUGAR + ELECTRICITY
ALCOHOL + ELECTRICITY

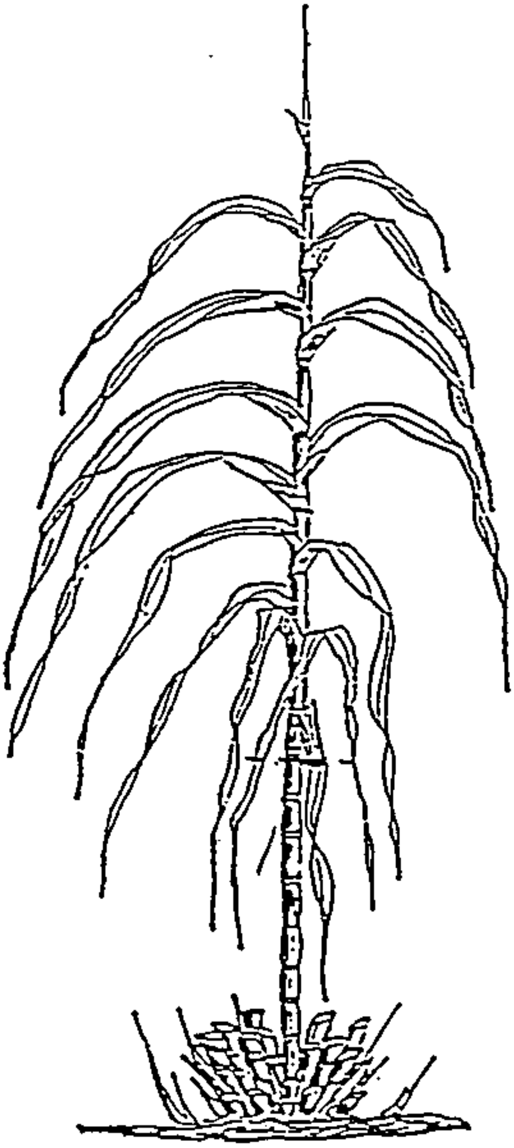
ELECTRICITY CAN BE PRODUCED USING "SUGAR CANE RESIDUES" AS FUEL:

BAGASSE: SAWDUST-LIKE RESIDUE LEFT AFTER CRUSHING CANE TO EXTRACT SUGAR JUICE [PRESENTLY USED TO PROVIDE FUEL NEEDS FOR SUGAR FACTORY OR ALCOHOL DISTILLERY--BUT USED INEFFICIENTLY)

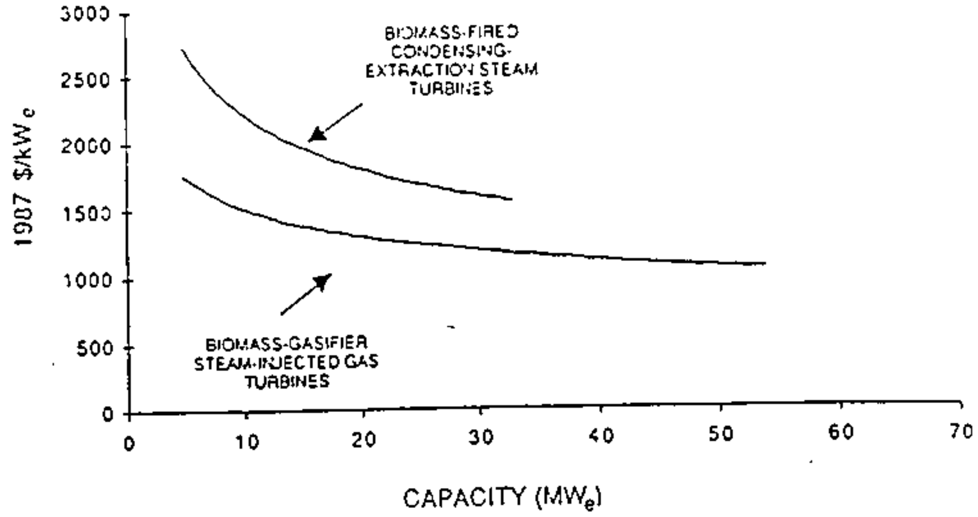
BARBOJO: TOPS AND LEAVES OF SUGAR CANE PLANT (TODAY OFTEN BURNED OFF THE SUGAR CANE STEM BEFORE HARVESTING)

USING MODERN STEAM-TURBINE POWER PLANTS BYPRODUCT ELECTRICITY IS PRODUCED TODAY IN:

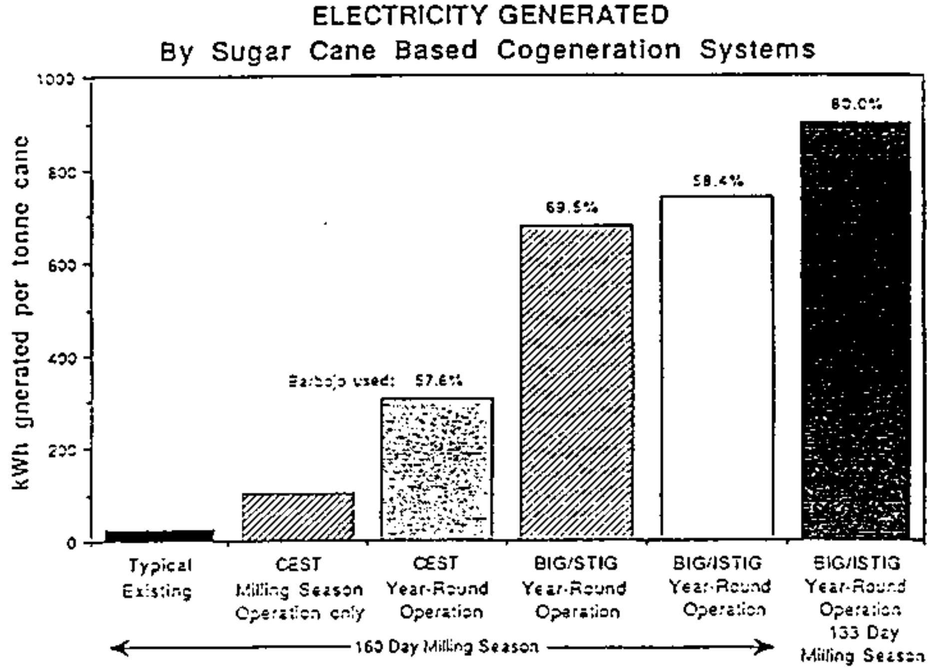
- MAURITIUS
- REUNION
- BRAZIL
- HAWAII



Initial applications of BIG/GT technologies will probably be for cogeneration using as fuel the biomass residues of existing forest product and agricultural industries. For industrialized countries, some of the most promising applications will be in the pulp and paper industry - using hog fuel, black liquor, and forest residues as fuel; for developing countries, in the sugar cane industries - using bagasse and barbojo as fuel.



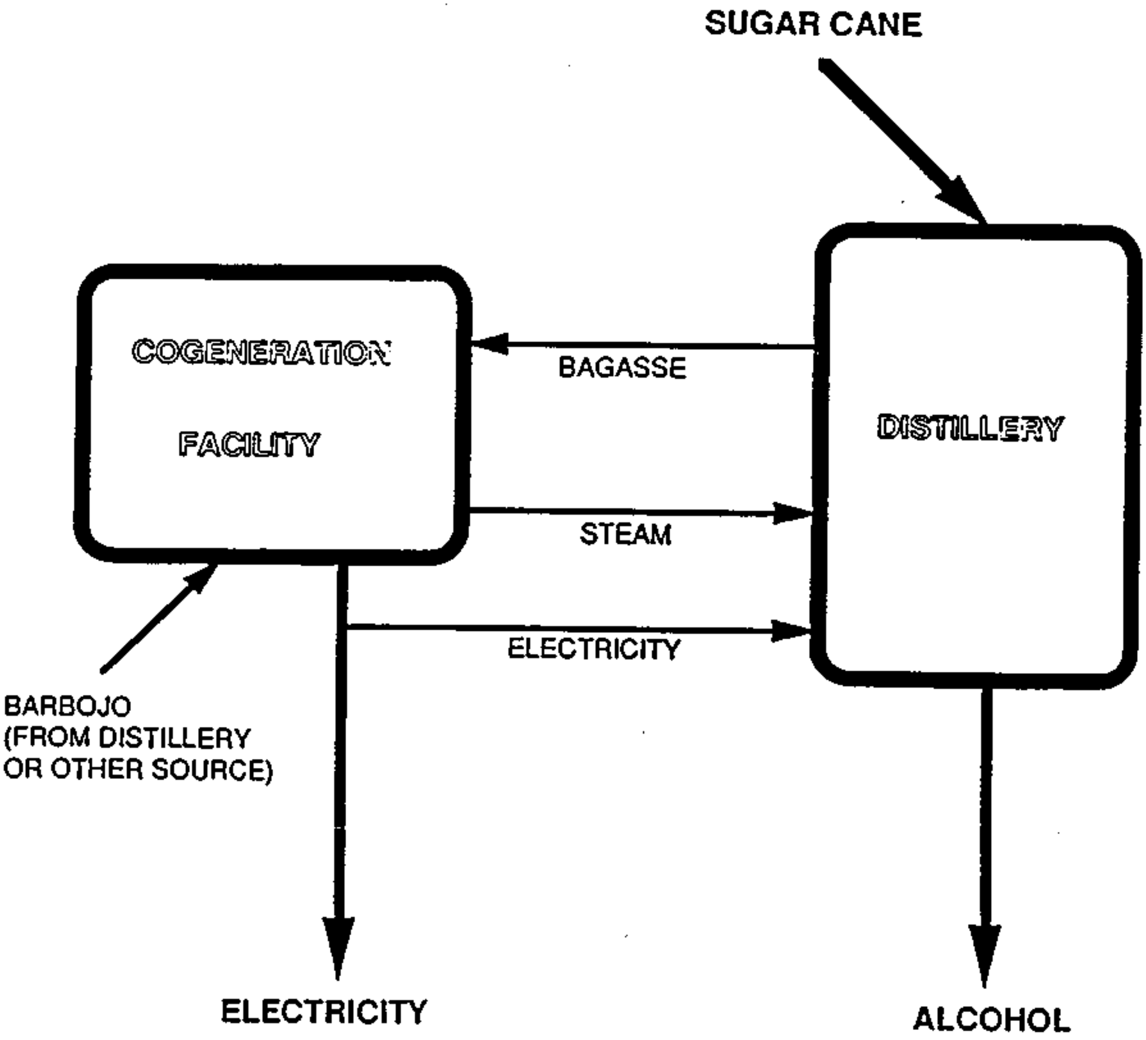
Estimated installed capital costs (1987 $/kW$_e$) for biomass-gasifier steam-injected gas turbine and condensing-extraction steam turbine cogeneration systems



When BIG/GT technologies are used to produce electricity as a byproduct of sugar at cane sugar factories, more than twice as much electricity could be produced per tonne of cane as with modern condensing/extraction steam turbine (CEST) systems that are inherently much less efficient (bottom). Also, unit capital costs for BIG/GT technologies are expected to be both much lower and much less scale sensitive than for CEST technologies (top).

With BIG/GT technologies, electricity could be produced from cane residues at rates of the order of 40 times onsite electricity needs, while still meeting the onsite steam requirements of the factory. If electric utility rules were such that cogenerators at sugar cane factories could sell their excess electricity to the electric utility at competitive prices, sugar factories could become major exporters of electricity. At the present level of cane production in the 80 sugar cane-producing developing countries, electricity could be produced from cane residues at a rate equivalent to half of all electricity now produced by electric utilities in those countries.

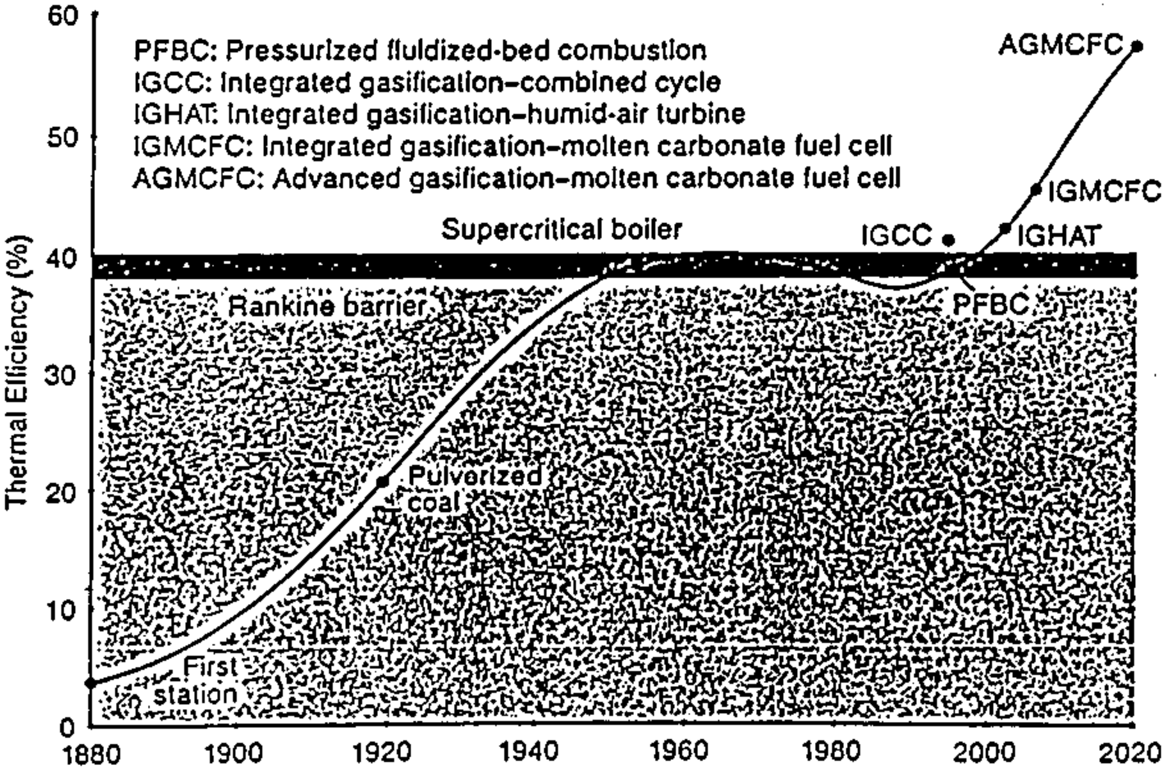
AUTONOMOUS DISTILLERY SETUP



If BIG/GT technologies were used to cogenerate electricity at sugar cane-based alcohol distilleries, electricity would become the primary product, and alcohol the byproduct of the sugar cane. With co-production it would be possible in Brazil to simultaneously produce electricity at a cost competitive with new hydro power plants ($1500/kW) and alcohol at a cost competitive with gasoline for a world crude oil price of $20/barrel.

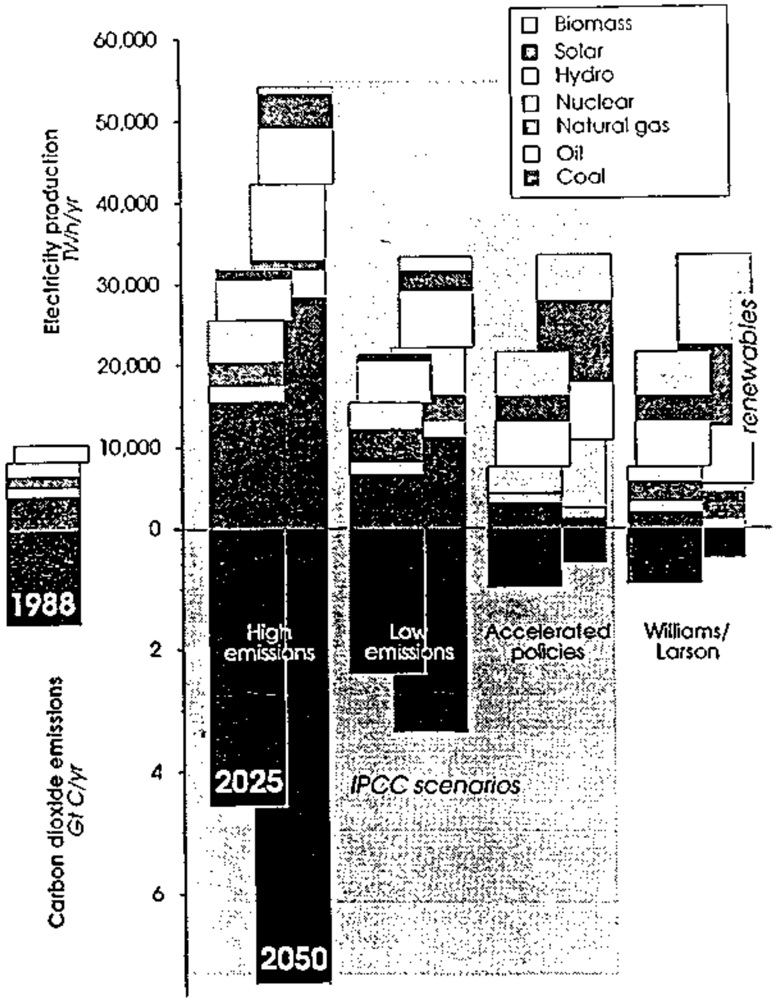
Evolution of Coal-Fired Power Plants

The efficiency of steam-based (Rankine cycle) power plants increased steadily for 80 years, nearing theoretical limits in the 1960s. Since then, efficiency has decreased somewhat because of the need to use energy to remove pollutants formed during combustion. Breaking the Rankine barrier of practical limitations on efficiency will require innovative approaches based on chemical energy conversion, such as coal gasification, and electricity generation by means of advanced combustion turbines and fuel cell technologies.



While gas turbine cycles will probably be the dominant means of providing electricity efficiently from fuels over the next couple of decades, even further efficiency gains are likely to be realized with fuel cells. For example, in the above graph the Electric Power Research Institute projects that by 2020 the advanced coal-integrated gasifer/molten carbonate fuel cell (ACIG/MCFC) could be providing utility electricity at coal-to-busbar efficiencies approaching 60%. As in the case of coal-integrated gasifier/gas turbine (CIG/GT) these fuel cells could be used with biomass (ABIG/MCFC) as well as coal (ACIG/MCFC).

Alternative scenarios for global electricity production



The global potential for reducing CO_2 emissions from the power sector with renewables plus natural gas is suggested by scenarios prepared by the Response Strategies Working Group of the Intergovernmental Panel on Climate Change (IPCC). Shown above are three of the IPCC global electricity scenarios for conditions of high GNP growth.

The "business-as-usual" High Emissions (HE) Scenario involves three-fold and five-fold increases in global electricity demand by 2025 and 2050, respectively, with corresponding increases in CO_2 emissions relative to 1988.

In the Low Emissions (LE) Scenario, global electricity demand only doubles by 2025 and triples by 2050, as a result of emphasis on efficient electricity use and natural gas for power generation; in this case CO_2 emissions increase 50% by 2025 and double by 2050.

In the Accelerated Policies (AP) Scenario, emphasis on energy efficiency is combined with emphasis on nuclear and renewable power sources, so that CO_2 emissions decline 1/3 by 2025 and 2/3 by 2050.

The Williams/Larson Scenario is a modified AP Scenario (with the same level of energy efficiency and renewable supplies other than biomass as for the AP Scenario) that makes it possible to extract more electricity from biomass without increasing biomass supplies, through the use of BIG/GT and ABIG/MCFC technologies. By producing more electricity from biomass as well as from natural gas, CO_2 emissions in the Williams/Larson Scenario are reduced to 60% of the 1988 level by 2025 and to 30% of the 1988 level by 2050, without expanding nuclear power above the 1988 level and with sharp reductions in coal use.

HYDROGEN FROM BIOMASS

1. GASIFICATION:

BIOMASS

$$CH_{1.37}O_{0.6} + H_2O_{(g)} + HEAT \longrightarrow CO,\ H_2,\ CH_4,\ H_2O_{(g)}$$

2. STEAM-REFORMING OF METHANE:

$$CH_4 + H_2O_{(g)} + HEAT \longrightarrow CO + 3H_2$$

3. WATER-GAS SHIFT REACTION:

$$CO + H_2O_{(g)} \longrightarrow CO_2 + H_2$$

4. OVERALL REACTION:

$$CH_{1.37}O_{0.6} + H_2O_{(g)} + HEAT \longrightarrow CO_2,\ H_2$$

5. SEPARATE CO_2 FROM HYDROGEN (physical absorption process)

OVERALL ENERGY EFFICIENCY OF CONVERTING BIOMASS TO HYDROGEN ~ 80%

WHOLESALE COST OF HYDROGEN

~ $1 PER GALLON OF GASOLINE-EQUIVALENT

COST OF HYDROGEN DELIVERED TO "GAS STATION"

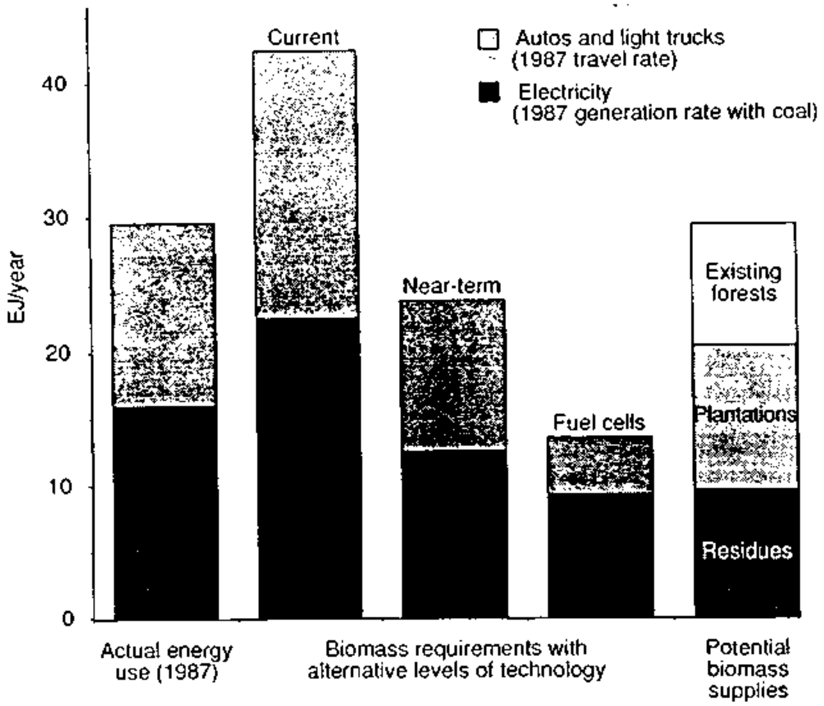
~ $1.65 PER GALLON OF GASOLINE-EQUIVALENT

Most analysts think that it will prove to be much easier to reduce CO_2 emissions from the power sector than from the fuels sector of the energy economy. However, ongoing advances relating to hydrogen as a transport fuel could make the fuels problem more tractable.

Advances in solid polymer electrolyte fuel cell technology may make it possible to begin to introduce hydrogen fuel cells in transport applications by the turn of the century. Fuel cells and electric drive trains used in conjunction with small batteries (for peaking power) could provide the environmental benefits of the electric car without its range limitation. The fuel economy of the fuel cell car is expected to be more than twice that of the internal combustion engine car, and maintenance costs are expected to be much less.

Hydrogen could ultimately be produced via electrolysis from wind and photo voltaic power sources. However, the cheapest way to produce hydrogen from renewable energy sources over the next decade or so will probably involve the thermochemical gasification of biomass, as indicated above.

US Bioenergy Strategies for Electricity Generation and Light-duty Vehicles



Current technology
Biomass steam-electric power @ 15.4 MJ/kWh
Methanol from biomass in ICE autos (light trucks) @ 12.3 l/100 km
(18.2 l/100 km) gasoline-equivalent

Near-term technology
Biomass-integrated gasifier/gas turbine power @ 8.55 MJ/kWh
Methanol from biomass in ICE autos (light trucks) @ 7.0 l/100 km
(10.4 l/100 km) gasoline-equivalent

Fuel cells
Biomass-integrated gasifier/molten carbonate fuel cell power @ 6.33 MJ/kWh
Hydrogen from biomass in fuel cell autos (light trucks) @ 3.6 l/100 km
(5.4 l/100 km) gasoline-equivalent

The potential role of biomass in meeting energy needs depends sensitively on the efficiencies of the conversion and end-use technologies used, as illustrated here. If the 1987 levels of driving and coal-based power generation in the US (first bar), had instead been provided by biomass with currently available technologies, the overall biomass fuel requirements (second bar) would be 1/3 more than total potential long-term US biomass supplies (fifth bar), as estimated in 1989 by the Oak Ridge National Laboratory. With improved technology, biomass requirements could be reduced dramatically. In particular, with fuel cells used for both power generation and light duty vehicles (fourth bar), the amount of biomass supplies needed for these end-use activities at the 1987 activity levels would be less than half of potential biomass supplies (fifth bar). If biomass-fueled fuel cell technologies had been used for these activities in 1987 and if the biomass fuel had been produced renewably, total US CO_2 emissions would have been half as much as they actually were.

Energy strategies for a Sustainable Development in India

by Amulya K.N. Reddy

Department of Management Studies, Indian Institute of Science, Bangalore 560012, India

Abstract

A new paradigm for energy planning, which is necessary because the conventional paradigm is in serious trouble, must be shaped by the goal of sustainable development. The focus on development necessarily means an emphasis on providing the energy services required for the satisfaction of basic needs. The stress on energy services, rather than energy consumption per se, means that there must be an emphasis on the end-uses of energy and therefore on the end-use devices that convert the final energy delivered to consumers into the required energy services. Hence, there must be an end-use orientation to energy planning. What is required therefore is a development-focused end-use-oriented service-directed paradigm that we shall refer to by the acronym DEFENDUS.

DEFENDUS approaches for the electricity and oil sectors in India are presented - they appear far more conducive to sustainable development than the conventional paradigm.

The DEFENDUS scenario for electricity demand and supply in the state of Karnataka focuses on people-based development through the promotion of energy services, identifies technological opportunities for better utilization of energy through a scrutiny of the end-uses of energy, and adheres to a least-cost approach to the mix of energy supplies. The DEFENDUS scenario turns out to be as promising as the conventional plans are gloomy. In particular, even though the DEFENDUS scenario involves the illumination of all homes in Karnataka, an emphasis on employment-generating industry, the energization of irrigation pumpsets up to a limit imposed by the groundwater potential, and the establishment of decentralized rural energy centres in villages, it comes out with energy and power requirements in the year 2000 which are only about 38% and 42% respectively of the conventional demand. This reduction in requirement is partly (59 %) due to the development focus and partly (41 %) due to the simple efficiency improvement and carrier substitution measures. These measures consist of the replacement of inefficient motors and incandescent bulbs with efficient motors and compact fluorescent lamps respectively, the substitution of solar water-heaters and LP Gas stoves for electric water heaters and electric stoves, and the retro-fitting of irrigation pumpsets with frictionless foot-valves and HDPE piping.

To meet the extra demand, the DEFENDUS least-cost supply scenario involves a mix of efficiency improvements and electricity substitution measures, decentralized generation technologies and conventional centralized generation technologies in an approximately

40:40:20 ratio. The replacement of inefficient motors with efficient ones is the cheapest technology, and therefore, it comes out as the first element of the mix, then improvement of irrigation pumpsets, followed by small hydel, compact fluorescent lamps, cogeneration from bagasse fuel in sugar factories, biogas, producer gas and then natural gas.

While providing more services to the people, the DEFENDUS supply scheme is only about one-third of the cost of the centralized supply scheme. The DEFENDUS scenario also involves a shorter gestation time and is about 200 times more environmentally benign in terms of millions of tonnes of CO_2 pumped into the atmosphere every year. Thus, the DEFENDUS electricity scenario is cheaper, quicker, more environmentally sound and more equitable.

A DEFENDUS approach to the identification of technologies for reducing India's oil dependence is presented next.

The fundamental cause of India's current oil crisis is the country's unchecked appetite for diesel, kerosene and gasoline due to railway freight being de-emphasized, homes not being electrified and personal transportation being preferred.

A four-pronged DEFENDUS strategy for resolving India's oil crisis has, therefore, been suggested. It is based primarily on reducing the demand for diesel, kerosene and gasoline. The strategy consists of:

a. implementing efficiency improvements in the use of petroleum products,

b. shifting passenger traffic from personal vehicles to public transportation,

c. shifting freight traffic from road to rail, and

d. replacing oil with alternative non-oil fuels, particularly biomass-derived fuels.

The crux of the proposed strategy is a massive programme of <u>home</u> electrification. When <u>all</u> homes are electrified, kerosene becomes unnecessary as an illuminant. Once this is done, the subsidy on diesel can be removed and its price can be brought on par with that of gasoline. The increase of diesel prices would create a favourable environment in which supporting policy measures can be adopted. For the railways to exploit the situation and increase their freight haulage, there must be substantial investments in the improvement of the railways' freight operations. These funds can come from the diversion of the implicit subsidies on kerosene and diesel. This strategy of shifting freight from trucks to rail can reduce drastically the diesel demand in the transport sector.

The next component of the strategy consists of the provision of high-efficiency cooking fuels and/or devices in rural and urban areas and would make available large amounts of wood provided that all the firewood being used today for cooking can still be collected. This saved fuelwood can be converted into methanol. If diesel fuel in trucks and buses is replaced with methanol, then the only diesel demand from the transport sector will come from the railways.

As in the case of economic growth, energy planning is meaningless unless one asks: "energy for whom?" and "energy for what?" In the case of India, it appears that the country has been engulfed by a grave oil crisis because it has ignored two crucial basic needs of poor households: efficient energy sources for lighting and for cooking. The DEFENDUS oil strategy proposed here shows that by the provision of electric lighting and efficient cooking fuels/devices to all homes, India can move towards a virtually oil-free road transport system and reduce drastically its dependence on oil. The lesson is simple: "Look after the people, and energy will look after itself!" This translates to mean that the choice of energy technologies must be derived from a development-focused end-use-oriented service-directed perspective, i.e., a DEFENDUS perspective.

1. Introduction

1.1. The search for energy strategies for a sustainable development has perforce to begin against the background of the conventional paradigm for energy planning. According to this paradigm, development is equated with economic growth which, in turn, is assumed to depend upon increasing energy consumption, which requires an ever-increasing supply of energy. So, it is a growth-oriented supply-sided consumption-directed paradigm for which a possible acronym is GROSSCON even though, according to the Little Oxford Dictionary, "gross" means "flagrant" and "con" means "confidence trick".

1.2. This conventional paradigm for energy planning has resulted in three crises:
* the <u>economic</u> crisis of impossible costs;
* the <u>environmental</u> crisis of intolerable impacts on the local and global environment; and
* the social crisis of people located at the energy generation sites being subjected to displacement, pollution, hazards, etc.

Due to these crises, the conventional paradigm is in serious trouble and it has become clear even to conservative planners that alternatives approaches are essential.

2. A DEFENDUS Perspective for the Indian Energy System

2.1. The search for energy technologies must turn therefore to a new paradigm shaped by the <u>goal</u> of the Indian energy system.

2.2. The goal of the Indian energy system may be taken to be <u>sustainable development</u>. Accordingly, the energy system must become an instrument for sustainable development. The perspective here is that, though economic growth is a necessary condition for sustainable development, it is not a sufficient condition. In addition, the process of growth must be directed towards:
* the satisfaction of basic needs, starting from the needs of the neediest;
* the strengthening of self-reliance; and
* environmental soundness.

2.3. The focus on development necessarily means an emphasis on providing the energy services required for the satisfaction of basic needs. The true indicator of development is therefore the level of energy services enjoyed by the population, particularly by its poorest sections. This standpoint generates the challenge of making the poorest sections the main beneficiaries of the energy system.

2.4. The stress on energy services - rather than energy consumption per se - means that there must be an emphasis on the end-uses of energy and therefore on the end-use devices that convert the final energy delivered to consumers into the required energy services. The level of energy services is determined by the magnitude of "useful" energy, i.e., how much of the input energy is converted by the end-use device into energy that is actually used for the task. In turn, the useful energy depends upon two factors - the input energy and the efficiency of the end-use device. Hence, there must be an end-use orientation to energy planning.

2.5. What is required therefore is a development-focused end-use-oriented service-directed paradigm that we shall refer to by the acronym DEFENDUS.

2.6. There are three well-known options for increasing energy services. The first one is based on the conventional GROSSCON paradigm of maintaining current efficiencies and ensuring that the supply and input of energy are increased. This is a supply-based approach. The second option also stresses an increase of energy, but there is an insistence that the supply should come from so-called "clean" sources, i.e., renewable and environmentally benign sources of energy, and not from the conventional centralized and environmentally malign sources. Then, there is the third option of the conservation purists who argue that all that is required is an increase of efficiency.

2.7 According to the DEFENDUS paradigm, all three options are extreme positions that must be rejected. What is required is a holistic integration of the three options, i.e., the increase of energy services, which is the essential basis of development, must be achieved through a mix of efficiency improvements, decentralized renewable sources and centralized sources. It is this mix that defines the set of energy technologies that promote sustainable development.

2.8. The basic approach to the identification of the elements of the mix is the technique of "least-cost planning" that is being increasingly adopted by the electricity utilities in the United States. The technique involves the construction of least-cost curves in which the Y axis is the unit cost of the energy technology (irrespective of whether it is a source of generation or a conservation measure) and the X-axis is the magnitude of energy that is saved/generated by that technology. Before such a curve can be constructed, it is necessary to make a comparison of the costs of different ways of saving and generating energy and to rank them according to increasing cost. The procedure in least-cost planning is to take the cheapest technology and make it the first element of the mix. This technology enables a partial advance from the present energy demand to the energy goal. When its potential is exhausted, the procedure is repeated with the next technology, and in this manner, the cost-supply staircase is climbed until the energy goal is reached.

2.9. All the technologies lying on the cost-supply staircase up to the energy goal are the components of the supply mix that has to be used to meet the demand requirements. In this process, there must not be any favoured technologies. If, for instance, a conservation measure comes into the mix, it is accepted. If it is too expensive, it rules itself out.

2.10. An important precaution has to be observed in specifying the energy goal at which the cost-supply staircase ends. Efficiency improvement and energy saving are like a cheque that can be cashed only once. The cheque can either be cashed on the demand side or on the supply side. It cannot be cashed both on the supply and demand sides. If the energy goal has already taken into account energy conservation measures, then the inclusion of these measures in the construction of the cost-supply curve involves "double-counting". This problem does not arise in the case of the frozen-efficiency goal where it is assumed that energy efficiencies are frozen at current levels. It is preferable, therefore, to adopt the frozen efficiency energy goal because it does not assume efficiency improvements so that even conservation measures become ordinary candidates for a place on the cost supply-staircase.

2.11. Costs, however, cannot be the only criterion for deciding the appropriateness of technologies. Other criteria must be taken into account. For instance, environmental impacts must also be considered. Where such impacts can be quantified, it is possible to pursue least-impact planning by constructing impact-supply curves similar to cost-supply curves.

2.12. Attention will now be turned to the electricity and oil sectors in India where attempts at pursuing a DEFENDUS approach have identified sets of energy technologies to promote sustainable development.

3. A DEFENDUS Electricity Scenario for Karnataka State in India

3.1. The recent efforts at electricity planning in Karnataka State, South India, in particular the May 1987 report of the Committee for preparing a "Long Range Plan for Power Projects in Karnataka 1987-2000 AD" (LRPPP), are clear-cut examples of the failure of the conventional GROSSCON approach to energy planning. The LRPPP plan demanded that, in order to meet its energy requirement of 47.5 TWh and 9.4 GW in 2000, the state should spend an astronomical sum of about $17.4 billion, develop a great deal of infrastructure (better transmission lines, coal transportation linkages, railway facilities, etc.), construct massive centralized power generation facilities (including a 1 GW super-thermal coal-based power station and about 2 GW of nuclear power), raise funds from the World Bank and the Central Government, divert at least 25% of Karnataka State's Plan for power and appeal to private industry to set up generation facilities. In return, the LRPPP plan promised that energy shortages will continue up to, and into, the next century. In other words, conventional plans are no longer solutions; they are exercises in profligacy.

3.2 An alternative scenario for the electricity sector of Karnataka has, therefore, been developed on the basis of the DEFENDUS paradigm. This DEFENDUS scenario for energy demand and supply focuses on people-based development through the promotion of energy services, identifying technological opportunities for better utilization of energy through a scrutiny of the end-uses of energy, and adhering to a least-cost approach to the mix of energy supplies. The DEFENDUS scenario turns out to be as promising as the LRPPP and other conventional plans are gloomy. In particular, even though the DEFENDUS scenario involves the illumination of all homes in Karnataka, an emphasis on employment-generating industry, the energization of irrigation pumpsets up to a limit imposed by the groundwater potential, and the establishment of decentralized rural energy centres in villages, it comes out with energy and power requirements in the year 2000 which are only about 38% and 42% respectively of the LRPPP demand.

3.3. This reduction in requirement is partly (59 %) due to the development focus and partly (41 %) due to the simple efficiency improvement and carrier substitution measures. These measures consist of the replacement of inefficient motors and incandescent bulbs with efficient motors and compact fluorescent lamps respectively, the substitution of solar water-heaters and LP Gas stoves for electric water heaters and electric stoves, and the retro-fitting of irrigation pumpsets with frictionless foot-valves and HDPE piping.

3.4 To meet its demand, the DEFENDUS least-cost supply scenario involves a mix of efficiency improvements and electricity substitution measures, decentralized generation technologies and conventional centralized generation technologies in an approximately 40:40:20 ratio. The replacement of inefficient motors with efficient ones is the cheapest technology, and therefore, it comes out as the first element of the mix, then improvement of irrigation pumpsets, followed by small hydel, compact fluorescent lamps, cogeneration from bagasse fuel in sugar factories, biogas, producer gas and then natural gas.

3.5. As the energy requirement increases, i.e. as the demand escalates, the environmentally malign and harsh technologies become more inescapable. As the demand goes down, it becomes possible to avoid some of these harsh technologies. So, the technologies that must be invoked are very much dependent upon the magnitude of the demand target. In other words, the technologies that find a place in the least-cost mix are very much a function of the magnitude of the energy goal. This is the reason why the demand targets are often manipulated to high values, so that they justify some of the harsh technologies that would not come into the mix with lower demand targets. In the specific context of Karnataka, the reduced demand for centralized generation technologies means that the technologies that have become environmentally controversial in the state - nuclear power plants, coal-based thermal power plants and large hydroelectricity plants - can be largely avoided.

3.6. Instead of the least-cost mix, the conventional LRPPP plan starts with nuclear, coal and hydel and leads to what we may call "maximum-cost planning". Since the area under a cost-supply curve [(\$/kWh)*(kWh/year)] yields the annual cost (\$/year) for the mix of technologies defined by the curve, we can compare the cost of the DEFENDUS least-cost mix with the cost of the official maximum-cost plan. It turns out that the DEFENDUS supply scheme is only about onethird of the cost of the centralized supply scheme. At one third the cost, the energy goal can be met while providing more services to the people. Thus, the area between the maximum-cost and least-cost curve represents the squandering of public funds that results from adopting, not the least-cost mix of appropriate energy technologies, but an arbitrary mix of energy technologies that has obviously been arrived at by considerations other than cost. There could be many vested interests that derive advantages from maximum-cost planning and large projects.

3.7. Even allowing for a five-year preparation period before efficiency improvements and electricity distribution measures are introduced, the DEFENDUS scenario involves a shorter gestation time. This is because it depends largely on efficiency improvements and electricity substitution and on decentralized technologies that can deliver energy and power almost immediately.

3.8. And finally, the DEFENDUS scenario is about 200 times more environmentally benign in terms of millions of tonnes of CO_2 pumped into the atmosphere every year.

3.9. The cheaper, quicker, more environmentally sound and more equitable DEFENDUS electricity scenario is so obviously superior that it (or some variant of it) should be chosen without hesitation if rationality prevailed. Energy decision-making, however, is not done on the basis of rationality alone; there are powerful vested interests that have grown along with the conventional electrical supply industry. But, it appears that the supply lobby can no longer procure the capital to carry through its exorbitantly expensive schemes as easily as before. This is because the bankability of these schemes is being eroded by rising costs and environmental safeguards. Further, the funders are being confronted with alternative scenarios presented in increasingly quantitative detail. Whether these funding institutions will be able to resist these more cost-effective and environmentally sound alternatives may well depend upon the fact that development-focused end-use-oriented scenarios may be difficult to implement, but the conventional plans are impossible to sustain.

4. A DEFENDUS Strategy to Reduce India´s Oil Dependence

4.1. Even before quantitative least-cost planning can be carried out, it is necessary to list the technologies that have to be considered in the least-cost mix. In contrast to the conventional supply technologies, the decentralized supply technologies (providing the same energy services as the conventional ones), are not so self-evident. Similarly, the identification of technologies that save energy - and therefore result in effects that are equivalent to energy generation - can only emerge from a careful end-use analysis. In other words, the listing of technologies for a least-cost planning exercise is a creative challenge in which a heuristic approach (that reduces the complexity of the search for solutions) is an extremely valuable precursor. An example of such a heuristic approach to the identification of technologies for reducing India's oil dependence will now be presented.

4.2. India is currently facing a serious oil crisis. Further, it is not likely that India's current oil crisis will go away like the previous crisis of the 1970s. India is in a much graver situation today than ten years ago. The fundamental cause of the current oil crisis is not the Gulf War; it is the country's unchecked appetite for diesel, kerosene and gasoline due to railway freight being de-emphasized, homes not being electrified and personal transportation being preferred.

4.3. India's transport sector is a major oil consumer, but, quite unlike the industrialized countries, the country's transport runs mainly on diesel which accounts for 70% of the oil used in the transport sector. Diesel consumption is mostly due to trucks which are far less energy efficient than railways in hauling high-bulk-density goods. Despite this, the share of total freight transported by trucks has increased enormously because of the low price of diesel which has been subsidized and pegged at a price slightly above that of kerosene. Diesel prices cannot be increased without roughly equal increases in kerosene prices because, if the price of kerosene is very much lower than that of diesel, trucks adulterate their diesel fuel with kerosene and immediately create a kerosene shortage. These shortage causes great hardship to the poor because kerosene is used almost wholly in the household sector for lighting and cooking. And, for the same reason, kerosene prices cannot be increased under present conditions.

4.4. Though electrical illumination is far more energy-efficient than kerosene lamps, the number of <u>un</u>-electrified homes in the country is increasing at the rate of about a million households per year. Under these conditions, the country has been forced to increase kerosene consumption at the rate of 7.8% per year.

4.5. India's oil problem, therefore, is primarily a problem of the two middle distillates, diesel and kerosene, in that order. Together, they account for as much as half of India's oil consumption, and incidentally account for the bulk of the country's imports of petroleum <u>products</u>.

4.6. In contrast, gasoline is currently a small problem because it represents less than one-tenth of the oil consumption. But, it is a rapidly growing problem in India because the decision-makers have not only failed to provide the funds necessary for public transportation, but also encouraged the proliferation of mopeds, scooters, motor-bikes, cars, and three-wheeler autorickshaws. <u>De facto</u>, the planners and government have "chosen" personal and hired vehicles as the preferred mode of intra-city passenger movement.

4.7. On the basis of this analysis, a four-pronged strategy for resolving India's oil crisis is suggested. It is based primarily on reducing the demand for diesel, kerosene and gasoline. The strategy consists of:

1. implementing efficiency improvements in the use of petroleum products,
2. shifting passenger traffic from personal vehicles to public transportation,
3. shifting freight traffic from road to rail, and
4. replacing oil with alternative non-oil fuels, particularly biomass-derived fuels.

4.8. Efficiency improvements in the transport sector can be achieved straightaway by better house-keeping and by long-term measures such as improvement in the fuel efficiency of the vehicle fleet. In addition, there are several long-term measures that can play a major role.

4.9. In the case of diesel, for instance, the long-term measures would involve:

* improvement in the fuel efficiency of the truck fleet through better engines (e.g., direct-injection stratified-charge or DISC diesel engines), transmissions and drives;
* reduction in chassis weight;
* better streamlining;
* greater payload capability by using multi-axle vehicles that consume one-third less fuel than the conventional Indian two-axle 10-tonne payload trucks;
* better traffic flow on existing roads;
* land-use changes;
* better roads, etc.;

In addition, the fuel efficiency of diesel buses can be improved by having special lower-power (90 BHP) bus engines to carry the smaller payloads (3-4 tonnes) of passenger buses compared to freight trucks which use 110 BHP engines to haul 10 tonne payloads.

Immediately, however, 10-15% reduction in diesel consumption can be achieved through training truck and bus drivers with regard to fuel-conserving driving habits. And of course, proper and timely maintenance yields significant fuel savings.

Substantial diesel conservation can also be achieved in diesel pumpsets where as much as 30% savings are possible with improved footvalves and plastic piping.

Kerosene savings in cooking are possible through more fuel-efficient stoves, better cooking practices and the use of pressure cookers. These measures are also useful in reducing LPG consumption.

4.10. In the case of gasoline, the reduction of gasoline consumption also requires a change in the modal mix for passenger traffic away from personal vehicles to public transportation through overall measures that include steps such as massive investments in the infrastructure for public transportation. But, for intra-city passenger movement, special supplementary measures such as major increases in the number of buses, and where possible, suburban trains, are also necessary.

4.11. The crux of the third prong of the proposed strategy is a massive programme of home electrification. When all homes are electrified, kerosene becomes unnecessary as an illuminant. To make kerosene completely redundant, additional measures are required for replacing kerosene as a cooking fuel in cities. Once this is done, the subsidy on diesel can be removed and its price can be brought on par with that of gasoline.

4.12. The increase of diesel prices is a necessary, not sufficient, cost for decreasing truck freight; it would, however, create a favourable environment in which supporting policy measures can be adopted. For the railways to exploit the situation and increase their freight haulage, there must be substantial investments in the improvement of the railways' freight operations. These funds can come from the diversion of the implicit subsidies on kerosene and diesel.

4.13. The combination of this strategy of shifting freight from trucks to rail along with a strategy of shifting short-distance inter-city passenger traffic from diesel locomotives to buses can reduce the diesel demand in the transport sector from about 36 million tonnes in the year 2000 just projected by the Planning Commission of the Government of India to about 21 million tonnes, which is only about 10% above the present consumption.

4.14. Even with this combination of strategies, the oil problem would not be eliminated. Intra-regional or short-haul traffic would still require road transport, and therefore, a considerable amount of oil. So, in order to advance the objective of sustainable development, the possibility must be explored of the dependence of road transport on non-renewable oil resources being eliminated completely. In other words, a comprehensive oil-reduction strategy requires, over the longer term, the much more radical solution of shifting to alternative fuels for road transportation.

4.15. Producer gas and biogas have limited scope for use in road transport. Since natural gas is more abundant than oil, much cheaper, far less polluting and as easily distributed, the compressed natural gas (CNG) option is an attractive alternative for urban fleets of vehicles - buses, taxis, city delivery vehicles. Though hydrogen produced by solar photovoltaics may well turn out to be the transport fuel of the future, it is only the liquid fuels - ethanol and methanol - that are widely applicable alternative fuels in road transport. They can be distributed through the nation-wide network already established for gasoline and diesel. Mixtures of ethanol and gasoline - so-called "gasohol" - can be used widely as gasoline extenders. And pure methanol, although never used extensively, is, like pure ethanol, an excellent fuel for internal combustion engines.

4.16. Producer gas, biogas, ethanol and methanol can all be obtained from biomass sources. A synergistic coupling between the transport sector and the agricultural sector is therefore possible whereby "fuel farms" can be established to supply fuels for transportation in the same way that rural farms produce food for urban demands.

4.17. The fuel-food conflict can be avoided by turning to non-agricultural land for cellulosic resources, particularly fuelwood, to produce methanol and/or ethanol. But, the alcohol-from-fuelwood solution to the oil crisis can aggravate the domestic fuelwood problem, particularly for the poor. Cooking fuel for homes, however, is one of the basic energy needs, and the satisfaction of this need has to be an essential feature of an overall development-oriented energy strategy. Hence, the solution to the oil crisis must be compatible with the solution to the fuelwood problem.

4.18. One way of achieving such a compatible solution is to extend in two steps the synergism between the agriculture and transport sectors to include the domestic sector also.

4.19. The first step is based on the fact that, if alternative high-efficiency fuels are provided for cooking, or the efficiencies of fuelwood stoves are radically improved, then the resulting drastic reductions in fuelwood consumption can free a vast fuelwood resource base for the production of liquid fuels for the transport sector. Either the biogas or high-efficiency fuelwood-stove options or a mix of them can be introduced in villages. In cities and towns, the LP Gas option can be adopted, since there is considerable scope for the expansion of LP Gas supplies. And, once the pressure on forests as a source of cooking fuel decreases, conditions become established for managing the growth of forests, and dramatically improving their fuelwood yields. In other words, silvicultural practices - agriculture in the general sense - can be implemented to increase fuelwood availability. This is the second step in the extension of the synergism; it consists of including agriculture in the domestic-transport synergism.

4.20. In all, therefore, the provision of high-efficiency cooking fuels and/or devices in rural and urban areas would make available large amounts of wood, provided that all the firewood being used today for cooking can still be collected. This saved fuelwood can be converted into methanol. If diesel fuel in truck and buses is replaced with methanol, then the only diesel demand from the transport sector will come from the railways.

4.21. As in the case of economic growth, energy planning is meaningless unless one asks: "energy for whom?" and "energy for what?" In the case of India, it appears that the country has been engulfed by a grave oil crisis because it has ignored two crucial basic needs of poor households: efficient energy sources for lighting and for cooking. The DEFENDUS oil strategy proposed here shows that by the provision of electric lighting and efficient cooking fuels/devices to all homes, India can move towards a virtually oil-free road transport system and reduce drastically its dependence on oil. The lesson is simple: "Look after the people, and energy will look after itself!" This translates to mean that the choice of energy technologies must be derived from a development-focused end-use-oriented service-directed perspective, i.e., a DEFENDUS perspective.