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The likely adverse environmental impacts of renewable energy sources

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Abstract

The global attention has always been focussed on the adverse environmental impacts of conventional energy sources. In contrast nonconventional energy sources, particularly the renewable ones, have enjoyed a 'clean' image vis a vis environmental impacts. The only major exception to this general trend has been large hydropower projects; experience has taught us that they can be disastrous for the environment. The belief now is that minihydel and microhydel projects are harmless alternatives. But are renewable energy sources really as benign as is widely believed? The present essay addresses this question in the background of Lovin's classical paradigm, which had postulated the hard (malignant) and soft (benign) energy concepts in the first place. It critically evaluates the environmental impacts of major renewable energy sources. It then comes up with the broad conclusion that renewable energy sources are not the panacea they are popularly perceived to be; indeed in some cases their adverse environmental impacts can be as strongly negative as the impacts of conventional energy sources. The paper also dwells on the steps we need to take so that we can utilize renewable energy sources without facing environmental backlashes of the type we got from hydropower projects.

1. Introduction

Ever since the Club of Rome made public its prophesies [1], global attention has been focussed on the adverse environmental impacts of conventional energy sources. At the top of the 'hit-list' has been fossil fuels, and the three oil-shocks that rudely jolted the world in 1973, 1979 and 1990 have ensured that the ire remains focussed on the conventional energy sources, especially fossil fuels, as 'necessary evils' which

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have to be tolerated only as long as technological success does not catch up with non-conventional sources making them economically viable!

In contrast nonconventional energy sources, particularly the renewable ones amongst them, have had a 'clean' and 'benign' image. Whenever there is a public discussion on the pollution generated by such classical sources as thermal power plants, there is invariably a strident demand to switch over to non-conventional routes.

These concerns and general perceptions were given an elegant conceptual framework by Lovins [2] who introduced the terms 'hard paths' and 'soft paths' to define, respectively, the historical (or conventional) and the future (or favourable) energy policies. In Lovin's paradigm, the hard path denotes highly centralised and sustained expansion of energy production to meet a growing and inefficient use of energy. This strategy means a rapid expansion in coal utilisation, and an accelerated search for nuclear power. The synthetic fuels program promoted by the Carter Administration was an example of a hard path. The paradigm asserts that the continued implementation of hard energy technologies would lead to a more centralized and concentrated economy, and a more centrally controlled society. Centralization of technological facilities would create a vulnerability to sabotage, and disruptions and breakdowns of other types; it would also lead to the creation of elitist and dehumanized social control in which people would depend not on:

> people you know who are at your own social level, but rather from an alien, remote and perhaps humiliatingly uncontrollable technology run by a faraway, bureaucratized, technical elite who have probably never heard of you [3].

Thus, it is claimed, a hard path creates an elitist technocracy, concentrated political and economic power, technological vulnerability, as well as various inequities and other social, political and economic distortions.

In comparison, soft energy choices in Lovin's paradigm are premised on more restrained production of energy and more efficient use of energy. Soft energy choices are based on solar and other renewable energy. A soft energy path would purportedly lead to a future where small, decentralized systems form an increasingly large component of energy production and utilization. Soft energy technologies would be resilient, sustainable and benign. Specifically, the 'soft path', entailed:

1. dispersing, rather than geographically centralizing, energy production facilities;
2. providing individuals with their own sources of energy rather than having public utilities or private corporations control supply;
3. using renewable rather than exhaustible energy sources;
4. matching rather than mismatching energy supply to end use (with respect to size,thermodynamic quality,etc.);
5. developing solar power rather than coal and nuclear power;
6. aiming for technical simplicity rather than technical complexity;
7. enhancing conservation of energy rather than enhancing supply of energy
8. using environmentally benign rather than disruptive energy technologies.

Lovin's paradigm was sure to elicit very sharp and conflicting responses, and it did. Indeed the debate continues to rage with proponents of 'soft' option remaining sharply in disagreement with the believers of the 'hard' option; the intensity of the ongoing debate often clouding judgments to the extent that the exact points of disagreements get blurred and entangled. One major reason behind the extreme reactions has been the broader sociopolitical ramifications of Lovin's classification: the hard path has been thought of as representing centralised or 'totalistic' controls, while the soft path has been seen as propounding a decentralised system with 'power to the people'. In other words discussions on Lovin's paradigm can easily go beyond energy resources to the sensitive issues of 'right' vs 'left' or capitalism vs socialism.

Are non-conventional energy sources environmentally benign?

Leaving aside the broader connotations of the hard/soft options, the question we wish to address here is: are 'soft' or renewable energy sources as 'people-friendly' or environmentally benign as they are generally believed to be? In other words what are the possible environmental impacts of the Widespread and continuous utilisation of the popularly perceived environment-friendly and people-friendly energy resources? We would examine the likely impacts of large energy projects — comparable in capacities to the thermal or hydropower projects which dot the world map — as well as family-scale or highly dispersed but widely and continuously used systems. We emphasise wide and continuous use because only under those scenarios and not with the many present-day sporadically used 'experimental' or 'demonstration' systems that the impacts can become discernible.

2. Biomass energy — centralised (large scale) systems

Biomass is the general term used to include *phytomass* or plant biomass and *zoomass* or animal biomass. Sun's energy when intercepted by plants and converted by the process of photosynthesis into chemical energy, is 'fixed' or stored in the form of terrestrial and aquatic vegetation (Fig. 1). The vegetation when grazed (used as food) by animals gets converted into *zoomass* (animal biomass) and excreta. The excreta from terrestrial animals, especially dairy animals, can be used as a source of energy, while the excreta from aquatic animals gets dispersed as it is not possible to collect it and process it for energy production. In countries such as China and India, where per capita energy consumption is low and the number of dairy animals large, even the excreta of dairy animals has the potential to provide a sizeable fraction of the total energy requirement [4]. But, in general, animal biomass contributes very little to the overall biomass potential of the world. Therefore, subsequent discussion shall focus on phytomass and, as is popular convention, the term biomass shall be used to denote only the phytomass.

The upper limit of capture efficiency of solar radiation in biomass may be as high as 15% but in most of the species it is generally 1% or lower [5,6]. The energy thus captured by photosynthesis is a small percentage of the total solar energy reaching our planet, but the total volume of biomass that can be created, theoretically, is still very large compared with our energy needs. The calculation of energy that is

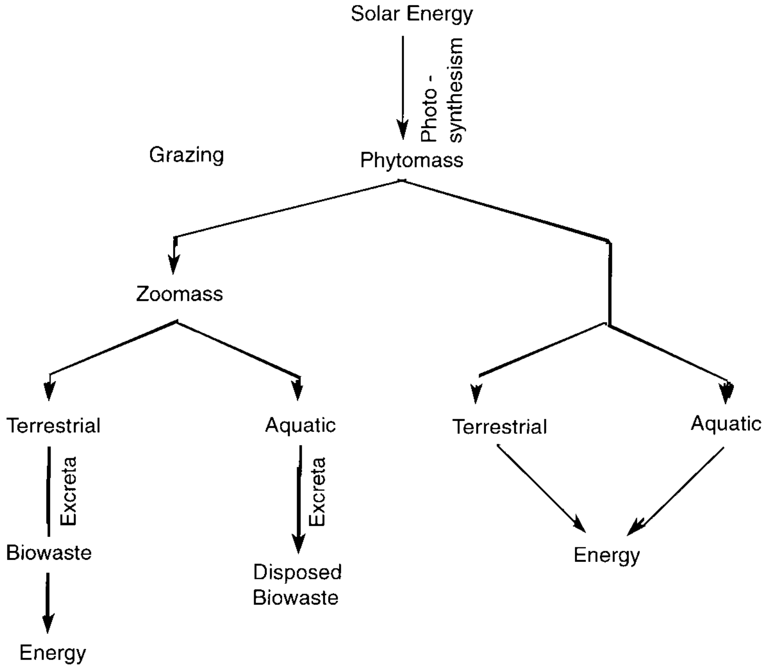

Fig. 1. The solar energy–biomass energy pathways.

waiting to be captured by planting biomass on the surface of the Earth (land as well as water) is easy to make and attractive to behold. Hidden from view in such exercises are the gigantic problems that shall emerge when the concept begins to be put into practice [7].

2.1. The proposed large scale systems

Three basic system-types have been propounded:

2.1.1. Hydrocarbon-rich-arid-land plants

These include species such as *Euphorbia lathyris* which can, as per liberal estimates, yield the energy equivalent of 25 barrels (1050 gallons) of petroleum per hectare. Johnson and Hinman [8] have estimated that it would require as much as 12 million hectares (46,000 square miles) of *E. lathyris* plantations to generate enough oil to meet a mere 10% of the petroleum demand of the USA. The stress such a massive plantation would cause on soil moisture — through uptake as well as evapotranspiration of precious water — has not been estimated but would obviously be quite great. There would be other impacts of a large magnitude — on soil productivity, microclimate, wildlife — some of which would be disastrous to the ecology of the region.

2.1.2. Aquatic weed farms

Fast-growing aquatic weeds such as water hyacinth (*Eichhornia crassipes*), salvinia (*Salvinia molesta*) and duckweed (*Lemna minor*) can attain very high productivities, especially when cultivated on nutrient-rich wastewaters such as domestic sewage [6,9–12]. The weeds, on anaerobic digestion, yield about 300 l of biogas per kg of dried (105°C) plant with a biogas of calorific value $\sim$ 600 BTU ft^{-3} [9,10,69,70]. It would require 8 million hectares (180,000 square miles) of primary-treated sewage pond surface to generate 1 quad of gross energy. The sewage from a city of population 5 million can supply sufficient nutrients to support a 260 km^2 water hyacinth pond but cities of such size are not located near such large areas of free low-cost land. Further, the engineering implications of constructing, operating, and managing such gigantic sewage ponds can be staggering. It would be difficult to prevent percolation of sewage from such large ponds to the underground aquifers and the dangers of groundwater contamination would be very real. There would be such other problems to contend with as mosquito menace and propagation of pathogens. Further, disposal of spent water hyacinth, after energy is extracted from it, would be a major problem.

2.1.3. Kelp farms

The marine giant brown kelp (*Microcystes pyrifera*) can attain productivities comparable to fast-growing sweet-water weeds such as water hyacinth [13,14]. The ocean biomass farm systems have been conceived around the culture of algae such as *M. pyrifera* by employing artificial upwelling techniques. The original plan developed by Wilcox [15] called for the culture of kelp *sporophylls* in an aquarium. The cultures would then be attached to plastic lines and divers would attach these lines to a large floating grid of pipes. The pipes would distribute nutrient-rich water, pumped (with wave-power) from 300-m (1000 ft) depths. Harvest ships would be quite similar to those already used by the Kelco Company of San Diego to gather 'wild' kelp: these ships back through the kelp bed and underwater clippers cut the fronds to a depth of 1.2 m (4 ft), while a system of rakes and belts hauls the cut fronds into the ships' holds. Each of the three ships now in operation has a 400–500 tonne capacity.

The project attracted wide interest and large funds especially in the USA.

Three test farms were installed [15]. The operations did not include artificial upwelling of deep-ocean water. The first farm, 7 acres in size, was placed in open ocean conditions about 1000 m (3000 ft) off the north-eastern tip of San Clemente Island, California, in 100 metres (300 ft) of water. About 100 *M. pyrifera* plants were taken from nearby natural beds and attached to the farm which was suspended approximately 10 m below the ocean surface. The plan was to observe this farm over 2 years. However, after 1 year, an anchor at one corner of the submerged grid came loose and the farm floated to the surface. A passing ship presumably tore the farm to pieces the next day, although the destruction might have been due to wave action [16].

The more recent efforts have centered around the Quarter-Acre Module (QAM), a concept of wire and rope lattice.The lattice would be suspended from a buoy, on which the plants would be attached and which would use diesel pumps to bring up water from a depth of 1500 ft [17]. A number of problems emerged when the concept was first put to practice. The OTA [16] reports: 'It was not certain that sufficient nutrients would be provided by the artificial upwelling to stimulate kelp growth. In any event, there was no way to monitor the actual exposure of an individual plant to the pumped water. Then, when the pumps shut down, there was a reverse flow which damaged plants by sucking them into the ports. Finally, in January 1979, a severe storm carried away essential parts of the system, which, in turn, caused the plants to become cut and tangled. All of the original 100 kelp plants were destroyed'.

As the oil crisis began to ease in the 1980s, attempts were not made to try the QAM further. However, assuming that such technical problems can be solved, kelp farms would still require major construction efforts, far larger than any previous marine engineering project. A kelp farm, with an annual productivity of 22 dry tonnes/ha (10 tons/acre), would have to be very large in order to replace a significant fraction of the conventional energy. A set of modules covering 50,000 km^2 (30,000 square miles) of ocean surface would supply only one quad. This is the marine equivalent of multiple facilities gasifying 300,000 tonnes of coal each day [18].

2.2. The environmental impacts

From the foregoing discussion it is clear that only land-based biomass energy projects deserve serious consideration. The following environmental impacts of large, land-based biomass energy projects can be discerned.

2.2.1. Land and water resources

Implementing a substantial biomass energy production program would require large amounts of water resources and land. Horticulture is a massive water consuming activity; hectare for hectare, it requires more water by several orders of magnitude than is needed for domestic and industrial needs [19]. It also contributes significantly to water pollution via the pesticides and fertilisers that are inevitably needed in sustaining any intensive cultivation [20,21]. The land used for increased biomass production for energy would have to compete with crops, forests, and urbanization [22,23]. This competition can be illustrated by comparing the crop land needed to feed one person with that required to fuel one automobile for one year. If we assume that the average automobile travels 16,000 km per year and gets 6.2 km/l [24], then 2581 l of gasoline will be required per year for an automobile. Using straight ethanol, the total in equivalent kcal would be 3875 l. Assuming a zero energy charge (no high-grade fuel used) for the fermentation/distillation processes [25], then 4.2 ha of land would be required to provide this much fuel. In comparison, about 0.5 ha of crop-land is used to feed each person. Thus more than eight times more land is needed to fuel an automobile than to feed one person. Further, the demand for agricultural and forest products is certain to grow with time, thus increasing competition for land and water resources. The removal of biomass from land and water for energy production programmes may increase soil and water degradation, flooding, and removal of nutrients [19,26]. It might also affect wildlife and the natural biota. These and other threats to the environment from the production of biomass do not seem to have been widely understood.

2.2.2. Soil erosion and water run-off

Biomass energy production projects can exacerbate soil erosion problems [6,19,21,23]. Although the use of available technologies can minimize erosion, they are difficult and costly to implement. Producing energy crops such as corn for ethanol requires additional agricultural land. To do this, marginal cropland that is highly susceptible to soil erosion would have to be brought under corn cultivation [25]. Soil erosion contributes significantly in hastening water run-off, thus, retarding groundwater recharge; the nutrient-rich run-off can harm the quality of receiving rivers, lakes or estuaries by causing eutrophication.

2.2.3. Nutrient removal and losses

Significant nutrient loss will be incurred by the harvesting of crop residues for biomass energy. With the corn yield of 7840 kg/ha (125 bu/acre), the nutrients contained in both grain and residues are 224 kg N, 37 kg P, 140 kg K, and 6 kg Ca [27]; nearly half of the nutrients are in the residues. Thus, nitrogen as well as other nutrients must be replaced for each subsequent crop. The amount of energy needed to replace the nutrients lost when the grain and corn plants are harvested would be the equivalent of at least 460 l of oil per hectare [68].

2.2.4. Loss of natural biota, habitats and wildlife

Conversion of natural ecosystems into energy-crop plantations will change both the habitat and food sources of wildlife and other biota [23,27,28]. Alteration of forests and wetlands will reduce many preferred habitats and mating areas of some mammals, birds, and other biota.

Monoculture plantations of fast-growing trees reduce the diversity of vegetation and the value of the areas as habitats for many wildlife species [27,28]. These monocultures are less stable than climate forests and require increased energy inputs in the form of pesticides and fertilizers to maintain productivity. Trees in profitable plantations are 2–3 times as dense as those of natural forests; the high stand density may result in greater pest problems.

2.2.5. Social and economic impacts

The major social impacts will be shifts in employment and increases in occupational health and safety problems. Total employment overall is expected to increase if the nation's energy needs are provided by biomass resources [29]. The labour force would be needed in agricultural and forest production to cut, harvest, and transport biomass resources and in the operation of conversion facilities.

The direct labour inputs for wood biomass resources are 2–3 times greater per million kcal than coal [27]. A wood-fired steam plant requires [16] 4 times more construction workers and 3–7 times more plant maintenance and operation workers than a coal-fired plant [16]. Including the labour required to produce corn, about 18 times more labour is required to produce a million kcal of ethanol than an equivalent amount of gasoline [25].

Associated with the possibilities of increased employment are greater occupational hazards [30,31]. Significantly, more occupational injuries and illnesses are associated with biomass production in agriculture and forestry than with either coal (underground mining), oil, or gas recovery operations [30–35]. Agriculture reports 25% more injuries per man-day than all other private industries.

2.2.6. Price of biomass resources

Food and forest products have a higher economic value per kcal in their original form than when converted into either heat, liquid, or gaseous energy [16,25,32]. For example, when one million kcal of corn grain is converted to heat energy, its market value is reduced eight times. Producing liquid fuels (e.g. ethanol) is also expensive; what one would fetch in the market for the grain, one gets 20% less when the grain is converted to ethanol.

Some of the major limitations of biomass energy production include the relatively small percentage (average 0.1%) of light energy that is captured by plant material and that about half of the biomass of even developed countries like the USA is harvested as agricultural and forest products [33,34].

2.2.7. Conversion to utilizable energy

Production of biomass is only one dimension of the biomass-based energy systems; its conversion to utilisable energy is another and equally important dimension. Several technologies are available for biomass conversion (Table 1); of these the most widely used are direct combustion and pyrolysis. Broadly the impacts of conversion technologies are:

(a) air pollution — emissions of particulates, carbon oxides, sulphur oxides, nitrogen oxides;
(b) organic emissions — dioxin hydrocarbons, toxic irritants such as acid, aldehyde, phenol, and carcinogenic compounds such as benzopyrene;
(c) generation of solid wastes — bottom ash, flyash sometimes containing toxic substances with accompanying pollution problems;

Table 1
Technologies for converting biomass into energy

A. Thermal conversion
i. Direct combustion
ii. Pyrolysis
iii. Gasification
B. Thermomechanical conversion
i. Conversion of methanol
C. Fermentation
i. Aerobic fermentation
ii. Anaerobic digestion
D. Unproven novel concepts
i. Biophotolysis
ii. Extraction of hydrocarbons
iii. Hydrogasification
iv. Fuel cells

(d) water pollution — biological oxygen demand, chemical oxygen demand, suspended solids, trace metals;
(e) pressure on land and water resources;
(f) household hazards — accidental fires;
(g) occupational hazards — prolonged exposure to toxic and corrosive chemicals.

All in all the problems of air pollution associated with conversion of lignous biomass to energy are no less significant than the ones we are familiar vis a vis conversion of coal and oil. These are significant even at the very small scale of residential wood-burning. The smoke has harmful levels of carcinogens and other toxicants. Lastly in terms of a million kcal output, forest biomass has several times more occupational injuries and illnesses than coal and oil mining [35].

3. Biomass energy — dispersed systems

Dispersed biomass energy utilisation systems can be of two types:

(a) household systems using biomass directly as a fuel;
(b) community sized electricity/heat producing systems based on pyrolysis, gasification or liquifaction.

The first type of dispersed systems is widely used in developing countries, including India [36–38]. It has been estimated [39–41] that nearly 90% of India's cooking energy requirement, and about 40% of all energy requirements, is met with biomass. Even more startling are the findings that as much as one-fourth of the household income in Indian villages may be coming from biomass extracted from common lands [23,42]. Though crop wastes form a part of this supply, the bulk of the supply comes from firewood. Extraction of wood from forests to meet this requirement is one of the major factors responsible for the loss of forests in developing countries [41,43]. It has been estimated that, in India alone, the current annual withdrawal of fuelwood from forests is of the order of 220 million tonnes whereas the sustainable production capacity is only about 28 million tonnes. There are no quantitative studies on the impact that firewood extraction of this magnitude exerts on the underground water and soil productivity but considering the size of the extraction, the extent of the adverse impact is not difficult to imagine. Fuelwood can be sustainably derived from any unit of land only if the rate of regrowth equals or exceeds the rate of extraction. But such favourable dynamics are not possible if the essential energy needs of a populous country like India are to be met, more so when fuelwood has to compete with agriculture for the limited land available.

Moreover, the use of fuelwood directly in the homes is a very serious source of air pollution, and a major health-hazard for women and children who are exposed to this pollution for significant lengths of time. It has been reported [44–46] that the emissions of air pollutants such as carbon monoxide, sulphur dioxide, nitrogen oxides, organics, and particulates are much larger — compared to other sources — from the burning of biomass.

As for community sized biomass-based energy sources the pollution problems are similar to large installations such as thermal power plants. But, whereas in the latter, the centralised nature of the problem and the economics of scale make the problem more manageable, these advantages are unavailable in the former. Dispersal can, infact, entail serious drawbacks. For example, a large number of small backyard, neighbourhood, or even community-sized coal gasification or liquifaction plants would probably be ecologically more harmful than a centralized facility with the same total output of synfuel. It is doubtful that as stringent a level of air and water treatment would be possible in the dispersed systems. And even if the dispersed plants dispose of the same total quantity of pollutants into the environment as the centralized plants, it is likely that a greater reach of the habitat would be effected.

Moreover, the damage is not likely to be significantly more diluted by dispersal than by centralisation; in dispersed use the quantity of waste generated at a site is small but then the preparedness to handle the waste is either very little or not at all. Whereas centralised systems are subjected to surveillance by regulatory agencies and can afford to take pollution control measures, such regulation is not possible in dispersed use. These considerations may appear speculative, but are not far fetched if we take into account the seriousness of air pollution problems already noticed during dispersed biomass utilization [38,45].

4. Direct solar energy based systems

4.1. Centralised systems

Solar energy is the largest of the renewable energy sources and if viewed out of context of the problems of energy storage and large-scale power generation, direct solar energy based systems appear the easiest and cleanest means of tapping renewable energy. But no sooner do we begin taking cognisance of the energy requirements and pollution generation associated with materials needed to tap solar energy — primarily steel, glass, and cement — and the environmental stresses a large solar-collector would cause on water resources (in terms of the need for cooling water) and land, the entire picture begins to acquire an altogether different complexion.

Direct conversion of solar radiation into utilizable energy can be accomplished in many ways. These include solar architecture, solar thermal systems and photovoltaics (PVs).

Centralised systems for large-scale power generation through direct solar energy utilization are based on thermal or photovoltaic technologies. Both need large tracts of land on which to locate collectors. Such tracts of land should be ideally situated in areas receiving high solar radiation fluxes and where the land is inexpensive. They also need to be preferably located on tracts of land which are not usable for agriculture or do not have a forest cover. Further, one would also need to locate them not too distant from population centres (to reduce distribution losses and expenses on installing transmission lines) and near ample supplies of water (for cooling purposes). To a large extent these objectives are at cross purposes as the most ideal locations for central receiver systems are likely to be in the arid northwest of India where copious sunshine is available on large areas of barren land. It thus, becomes imperative to assess ecological impacts of large-scale central solar stations on desert ecosystems. In addition, because of the large materials requirements (primarily cement, steel, and glass) for the collectors themselves and for structural support, analysis of the pollutant emissions expected during the *manufacturing process* has also to be made. In a recent report [47] it has been estimated that material requirements for central solar thermal systems are larger than for fossil fuel plants per unit energy. It is also estimated that central photovoltaic-based systems require exotic inputs, some of which — such as cadmium sulphide — are toxic and explosive. According to this report both types of solar energy systems would generate significant concentrations of problematic water pollutants, including antifreeze agents, rust inhibitors, and heavy metals leached from the system. Both would generate significant quantities of boiler blowdown.

There shall also be indirect generation of water pollutants via the use of herbicides to deter excessive vegetation growth around the collectors. Some other adverse impacts of central solar systems are:

(a) permanent use of a large land area; no reclamation until the plant is decommissioned;
(b) generation of non-recyclables during decommissioning: fiberglass, glass, coolant, insulations; in PV-based systems, additional disposal problems would be caused by cadmium and arsenic;
(c) aesthetic impacts: would be similar to fossil plants including steam but excluding air emissions;
(d) hazard to eyesight from reflectors, hazard from toxicants in coolant fluids;
(e) soil erosion and compaction; wind diversion; potential decrease in evaporation rate from soil.

Harte [49] has conducted an analysis of pollution emissions associated with the material requirements for central direct solar receiver systems by comparing these emissions with those of an oil or coal burning plant producing the same average power, and operating over the lifetime of the solar plant. The comparison shows that, for those pollutants considered environmentally harmful, the emissions associated with the central receiver system are lower by about an order of magnitude as compared with an oil or coal-fired plant. The findings of a more recent study are less favourable towards central solar systems [50]. In this study the impact of greenhouse-gas emissions, environmental degradation, and human health and safety of solar energy systems have been compared with the nuclear and fossil-energy options. After accounting for all direct and indirect aspects of the different energy production and delivery systems the study concludes that:

1. given current technologies, on a standardized energy unit basis, solar energy systems may initially cause more greenhouse-gas emissions and environmental degradation than do conventional nuclear and fossil-energy systems;
2. an ambitious programme to utilize solar energy systems in place of nuclear and fossil-fuel systems could, for the next four or five decades, actually increase

environmental degradation. In addition, the production of materials for these technologies involves hazardous substances that must be handled cautiously to avoid environmental damage;
3. in comparing solar energy systems with the conventional alternatives, it is important to recognize the substantial costs, hazardous wastes, and land-use issues associated with solar technologies;
4. based upon risk perceptions and current technologies, the health and safety risks of solar energy systems may be substantially larger than those associated with some fossil and nuclear energy resource options.

The situation vis a vis impacts on desert ecosystems may also not augur well for large-scale photovoltaic power generation systems. Strong negative ecological effects would stem from both increased water consumption for cooling purposes and from disruption of ground and surface water flow patterns. Further, there would be direct destruction of desert habitats for burrowing animals and other desert wildlife (including several rare and endangered species). There will also be ecological effects resulting from possible local climate alteration due to the presence of collectors. Lastly, the power generated through such large-scale systems will have to be transmitted over large distances to reach populous cities or industries. This would entail significant transmission losses.

4.2. Dispersed systems

4.2.1. Solar space heating and cooling

There is little to question here as solar energy for space heating and cooling, passive as well as active, must be among the most ecologically benign sources of energy. Studies to date have identified aesthetic problems as the only ones of potential consequence. In particular, the incompatibility of solar home heating with the existence of evergreen trees near homes could become a consideration in some locations. Rooftop collectors, if used in profusion as is often suggested [48], may change the albedo and therefore may affect the weather. These changes, while difficult to predict, are not likely to be significant nor are they expected to pose threats to ecosystems. The only environmental costs of significance are the ones incurred in the manufacture of the material needed to fabricate solar heating devices. Barring these, the dispersed solar systems are really a 'clean' energy option with little, if any, dormant environmental dangers.

5. Wind energy

5.1. Centralised systems

In terms of causing stress on water resources, wind energy is one of the most benign sources of energy. A major advantage of wind energy relative to nuclear, geothermal, fossil, and solar central receiver systems is that wind-based generation of electricity does not need cooling water.

On the debit side wind generators can interfere with habitats, cause noise pollution, aesthetic degradation, and interference with bird flight. Large-scale generation of electricity through windmills can reduce wind-speeds and cause stress to ecosystems. Lakes that are downwind from the windmills might become warmer because of reduced evaporation from their surface. Soil moisture might also increase. Nevertheless, these impacts may not be of great consequence except in certain sensitive areas and wind may prove to be one of the most ecologically benign sources of energy for electricity production.

5.1.1. Human safety hazards

Human safety related hazards associated with wind energy generators are similar to those in the building industry, including the risk of falling from high buildings during construction and repairs or the failure of parts through fatigue or design. Turbine blades sometimes fail, but no serious accidents are known to have resulted from this. Large wind machines are generally located in sparsely populated areas and the risk of human accidents is not great. More accidents are likely with the large number of small wind machines located within higher population densities.

5.1.2. Wild life

Wind turbines pose a threat to birds. Bird strikes, particular of raptors, have caused concern in parts of California, USA, and at Tarifa in Spain. These birds tend to swoop from a great height and cannot evade a fast moving blade. During a recent survey of the area adjacent to Blyth Harbour windfarm [51], which has a large population of birds including rare purple sandpipers, about 1000 animals were found dead.

5.1.3. Noise

There are two principal sources of noise in the wind turbine [52]: (a) the machinery in the nacelle, which can be avoided by good design and acoustic insulation and (b) the swishing sound from the rotating blades which is unavoidable: being an integral part of the aerodynamic energy transfer process which generates vortices from the blade surfaces.

Movement of wind also generates sounds but, except when the windspeeds are uncomfortably high, these sounds are mellow and pleasant. More often than not, wind turbines make a lot more noise than the wind does. In 1979, the National Aeronautics and Space Administration (NASA), USA, installed a 2 MW turbine, called MOD1 having a 200 foot rotor and 131 foot tower, at Howard's Knob in Boome, North Carolina. A shivering low frequency noise wafted downwind from the turbine, causing annoyance to the residents of houses in a small valley near the machine. The valley sides not only shielded the residents from the pleasant murmur of the natural wind which masks noise but also amplified the sound from the wind turbine [52].

The noise generated by a wind machine increases with the wind speed. Some of this noise is of infrasound, at frequencies below the audible range. This infrasound may cause houses and other structures to vibrate. The infrasound is generated by the turbulence that is set up by the rotating blades and interacts with the tower structure. These low-frequency waves can be eliminated only in new buildings after careful design considerations.

5.1.4. Television interference

Wind turbines can create a generally broad signal that can interfere with television reception. The problem is caused by the rotor blades, which intercept the television beam, and by the tower structure, which scatters the beam.

The phenomenon is variously called *television interference*, *electromagnetic interference* or *microwave interference*. In the NASA station mentioned above, serious interferences of this type were encountered. The residential area in Block Island is quite close to the turbine and the rotating blades chopped the TV signals to an irritating degree. The Department of Energy had to install a cable system to assuage the feelings of the small local community. This type of mitigatory measures may prove very costly for larger communities and improving TV signal reception with powerful antennas has been proposed as an alternative [53].

The interference windmills may cause, with the free movement of wind across the landscape, may perturb precipitation or evaporation patterns. However, it has been claimed that no serious effects will occur, other than in strictly localized ones that will happen within a couple of rotor-diameters of the machine [52]. The use of wind energy is likely to require auxiliary storage systems or some back-up supply of energy. The backup source generally will be more ecologically damaging than the wind source itself. The storage facility also could pose serious ecological risks if, for example, pumped storage is employed. The storage needs of centralized and dispersed wind systems will depend upon the statistical distribution of wind speed at a given centralized site and upon the correlations of wind speed across a variety of dispersed sites.

5.2. Dispersed systems

If windmills were located in farmland scattered over the entire country side, and connected to an existing grid system, there will be little about them that would be offensive. Thus, dispersed wind energy systems do seem to be more environmentally benign than any other alternative source of energy.

6. Hydroelectric power

Large hydroelectric power projects represent ‘renewable’, albeit conventional, energy sources but minihydel and microhydel projects are non-conventional. Here, we briefly recapitulate mankind’s past experience with major hydel projects before discussing the likely impacts of mini and microhydel projects, as in many cases the impacts may be similar though lesser in scale and more dispersed.

6.1. Centralised systems

Hydroelectric power projects are the most extensively studied power generation options vis a vis environmental impacts, alongside thermal power plants [39,44,54–57]). There is general agreement that large hydroelectric projects cause major adverse environmental impacts, especially on water quality, and there have even been suggestions [49] that large hydel may well be the most ecologically damaging of all power generation alternatives.

One prime reason why today we are so sure about the environmental hazards of large hydroelectric projects is that we have the wisdom of hindsight. The perceptions were entirely different earlier, when hydroelectric projects had not been actually used on a wide scale. In the 1950s, when there were only a few such projects functioning across the world, hydroelectric power was perceived as the most clean, obvious, and all purpose energy production option. Water is one of the precious natural resources — arguably *the most* precious — and dams promised to provide this resource in abundance and in a manner that it could be used many times over. It was believed that dams would store water for year round use (public water supply, fisheries, recreation). Then, after electricity has been derived from it, the water would irrigate agricultural fields downstream. In that process, it would also recharge underground aquifers. And all this without a whiff of smoke that thermal power plants generated, or the paranoia of catastrophe that came with nuclear power plants. It was clean energy all right and Jawaharlal Nehru, the then Prime Minister of India and a major global personality associated with the *non aligned movement*, was moved deeply enough by the sheer appeal of hydel power plants to call them ‘temples of modern India’.

Fortyfive years later, i.e. today, the same hydel projects are considered as the abodes of evil! All over the world environmental activists go up in arms whenever a hydroelectric power project is planned. In India, right now, a person (the noted environmentalist S.L.Bahuguna) is on the verge of laying down his life through the Gandhian means of fast-unto-death in protest against a hydel project. The lesson to learn from these experiences with large hydel projects is to carefully evaluate the likely environmental impacts of *large scale* use of any of the renewable energy systems before advocating it.

Major ecological impacts are caused by hydropower projects in all the four habitats associated with the projects — the reservoir catchment, the artificially created lake, the downstream reaches of the dammed river, and the estuary into which the river flows.

The environmental stresses are caused by altered timing of river flow, increased evapotranspiration and seepage water losses, barriers to aquatic organism movement, thermal stratification, changes in sediment loading and nutrient levels, and loss of terrestrial habitat to artificial lake habitat. There is an enhanced tendency towards eutrophication of the impounded lake and downstream sections of the river. Estuarine organisms are effected due to disruption of the natural mix of salt water and inflowing freshwater. The nesting, mating, and other behavior of riparian organisms is affected as a result of altered river flow and barriers to movement. Impounding, and increased human activity in the reservoir catchment leads to deforestation and loss of wildlife. There is often an increase in the incidence of waterborne diseases. Above all the damming is associated with serious problems of rehabilitation for those who were living in the reservoir area [54].

A recently expressed and serious concern is the release of greenhouse gases, especially methane, from manmade reservoirs created for hydropower generation. Some authors have gone to the extent of suggesting that, per unit of electrical energy produced, greenhouse gas emissions from some hydroelectric reservoirs may be comparable to emissions from fossil-fuelled power plants [58]. Predictably the large size of these emission estimates of have been disputed but there is no disagreement on the fact that the greenhouse emissions from manmade reservoirs are not inconsiderable. This adds some more weight to the already buldging dossier of adverse environmental impacts associated with hydroelectric power projects.

6.2. Dispersed systems

Mini and microhydel systems result from the dispersal of hydel power generation. The dispersal is achieved either by constructing a number of low-head dams or in-stream generators. China is the leader in small-hydro, with 0.1 million turbines in operation supplying electricity to rural areas [47]. The Phillippines had $\sim$ 4 MW of mini-hydro plants in 1980. It is estimated that the *potential* of small hydro-systems in several countries (Nepal, Madagascar, Papua New Guinea and some Latin American countries) exceeds the total installed power generation capacity in these countries from all other energy sources.

Problems that result from a dispersed approach are numerous and appear no less serious, *per kilowatt generated*, than those from centralized hydropower. Among the factors to consider in making a comparison are the reach of river habitat affected by the interruption of water flow, barriers to animal movement in the water, water loss from evaporation, wilderness quality of the sacrificed portion of river, and the amount of access road needed. With smaller dams, storage is an increasingly important problem and could lead to the necessity for constructing more low-head systems than anticipated. The problems of siltation and eutrofication which are common with major reservoirs are likely to be even more serious with smaller and shallower bodies of water created by mini and micro projects. Lastly the emission of greenhouse gases is as likely to occur from shallow reservoirs, which are similar to paddy fields known to contribute substantially to methane emissions [59,60] — as from large reservoirs, if not more. All in all, the environmental impacts of smaller and dispersed hydropower projects are not likely to be insignificant. It is a moot point whether they would be as severe as of 'known devils' — large hydropower projects.

7. Ocean thermal energy

Ocean thermal energy conversion (OTEC) power plants have the potential to cause major adverse impacts on the ocean water quality. Such plants would require entraining and discharging enormous quantities of seawater. The plants will displace about 4 m^3 of water per second per MW electricity output, both from the surface layer and from the deep ocean, and discharge them at some intermediate depth between 100 and 200 m. This massive flow may disturb the thermal structure of the ocean near the plant, change salinity gradients, and change the amounts of dissolved gases, nutrients, carbonates, and turbidity. These changes could have adverse impacts of magnitudes large enough to be highly significant.

The enrichment of the near-surface waters with the nutrient-rich cold water brought up from a depth of 1000 m is of particular significance. Natural upwellings of cold water from great depths in the ocean produce sites that are enormously rich in marine life. One of the well-known natural upwelling sites is where the Humboldt current off Peru enriches the surface waters. The productivity there is so high that almost one-fifth of the world's fish harvest comes from this region. It would be possible to use the cold water effluent from an OTEC plant for the cultivation of algae, crustaceans, and shellfish. In the nutrient-rich water, unicelluar algae grow to a density 27 times greater than the density in surface water and are in turn consumed by filter-feeding shellfish such as clams, oysters, and scallops.

However, abundance of nutrients in aquatic ecosystems can spell serious trouble as it can lead to eutrophication and all the adverse consequence associated with eutrophication.

Further, if the algal blooms caused by artificial upwelling include certain dinoflagellates, there may be other problems. For example shellfish consume dinoflagellates and if these shellfish are consumed by humans, it can lead to serious illness. OTEC advocates hope that, by designing the OTEC plant to discharge its water below the photic zone (the region in the surface waters where photosynthesizing organisms live), the surface waters will not be enriched. Furthermore, the fish living below the photic zone do not feed on these nutrients. However, these are unknowns and, given the magnitude of disturbances that would be caused by OTEC, may not be as easily controllable as the proponents of OTEC may like to believe. If nutrient-rich water is discharged anywhere near the surface water intake valves, it could cause biofouling inside the pipes.

Marine biota may be impinged on the screens covering the warm and cold water intakes of an OTEC plant. Small fishes and crustaceans may be entrained through the system, where they will experience rapid changes of temperature, salinity, pressure, turbidity, and dissolved oxygen. A major change occurring in the cold water pipe is the depressurization of up to 10^7 pascals in water coming from a depth of 1000 m to the surface.

Sea surface temperatures in the vicinity of an OTEC plant could be lowered by the discharge of effluent from the cold water pipe. This will have impacts on organisms and microclimate. The pumping of large volumes of cold water from depths of the ocean to the surface will release dissolved gases such as carbon dioxide, oxygen, and nitrogen to the atmosphere. This would influence water pH and DO status, causing stress to marine life.

Biocides, such as chlorine, used to prevent biofouling of the pipes and heat exchanger surfaces may be irritating or toxic to organisms. If ammonia is the working fluid and it leaks out, there could be serious consequences to the ocean ecosystem nearby. In summary, there is lot more to OTEC than mere utilisation of the thermal gradiant across ocean depth. The large-scale utilisation of this phenomenon can profoundly disturb the fragile marine ecosystems. Further, the disturbance being 'non-point' in nature, can be very difficult to control or mitigate. All this puts serious question marks before the viability of OTEC.

8. Geothermal energy

There are three types of geothermal resources: hydrothermal, dry hot rock, and geopressures. Currently, only hydrothermal resources have been exploited. The main producers of power from geothermal energy are the Philippines, New Zealand, Iceland, and the United States. Global installed capacity is more than 4700 MW electric (MWe) [61].

The likely adverse environmental effects of geothermal energy sources are: surface disturbances, physical effects (such as land subsidence) caused by fluid withdrawal, noise, thermal pollution, and release of offensive chemicals [62]. These are highly site-dependent and technology-dependent (open system or closed system) as geothermal reservoirs have a wide range of geothermal and chemical properties. For this reason, it is not possible to describe a typical geothermal energy system. The environmental impacts and the use and effectiveness of mitigation techniques can be realistically considered only on a site-by-site basis.

A primary concern vis-a-vis harnessing geothermal energy is land subsidence following the withdrawal of hot water or steam from an underground field. Several potential pollutants are associated with geothermal sources, including hydrogen sulfide, carbon dioxide, ammonia, methane, and boric acid, along with trace amounts of mercury, arsenic, and other elements. In order to extract energy from hot, dry rocks, from molten magma, or from the normal temperature-differences underground, it is necessary to force water down boreholes as a working fluid and to return it to the surface for use in a turbine or for direct heating. The chief environmental problem is that very large quantities of water are needed. This problem can be presumably alleviated by using geothermal concentrate as cooling water; this is indeed done at several geysers, but the polluted and foul smelling water is responsible for a good part of the aesthetic problems of these geysers. The amount of water required is less if the geothermal reservoir is very hot so that it converts the water to steam. If the underground reservoir is highly permeable, there is no way to know how much water will need to be injected before a useful amount of steam or hot water is returned to the surface.

Axtmann [63] has studied the environmental effects associated with the geothermal power plant at Wairakei, New Zealand. He chose this plant to study because it is a hot water rather than a dry steam geothermal source. He found that the Wairakei plant discharges approximately 6.5 times more heat, 5.5 times more water vapour, and one-half as much sulfur per unit of power produced as would a modern coal plant in New Zealand. It also contaminates the Waikato river with hydrogen sulfide, carbon dioxide, arsenic and mercury at concentrations that have adverse, if not calamitous, effects. Because the Wairakei plant was initiated prior to the expression of much of the current environmental concern, it was allowed to have a greater environmental impact than would be acceptable or necessary today. Reinjection of the waste water into the geothermal field would reduce that plant's environmental impact greatly. Ground subsidence is not a serious problem at Wairakei, but may prove to be so at the nearby Broadlands field. In studying the Wairakei site, Axtmann did not take into account impacts during the development of the borefield and construction of the plant, the effects of well blowouts, changes in the natural habitat, land use considerations, and aesthetic factors. All these issues need to be considered when using any geothermal resource. Geothermal water at the geysers in Northern California is cooled as it flows through cooling towers. Apparently this highly minieralized water is killing vegetation in deposition zones downwind from the power stations there. Shinn [67] reported a higher deposition of cooling-tower minerals at a distance of 1200 m than would be expected from liquid aerosol transport and concluded that dry deposition is also playing a role. He also reported significant increases in the levels of minerals in run-off water collected at the confluence of streams draining the area.

9. Energy from urban waste

Urban wastes are made up of an assortment of materials, not all of which are renewable, but most are. The amount of urban wastes that have to be landfilled can be considerably reduced by the adoption of recycling and composting, and a growing number of cities around the world are integrating material recovery and energy recovery into their waste management plans. Material recovery can indirectly lead to energy saving: for example production of aluminum is an extremely energy intensive process, but recycling aluminum requires just 5% as much energy as producing it from bauxite [64]. The most prevalent method of generating energy from urban waste is incineration. Incineration has the advantages of greatly diminishing solid wastes for landfill and killing pathogens. Depending on their location, incineration plants may also reduce the distance that municipal wastes have to be hauled. But these advantages are offset by emissions of carbon oxides, sulfur oxides, particulates, heavy metals, and other pollutants from the incinerators. Particular attention has been focussed on the emissions of dioxins and furans [65], which are more toxic and costlier to control than other pollutants. Concern has also been mounting over the disposal of the ash residues from incinerators. Because the ash often contains heavy metals from discarded batteries, lighting fixtures, and other sources, Sweden brackets it as hazardous waste [66].

In planning disposal options for urban waste (recycling and incineration), programme planners should include assessment of the net energy gains from various materials. Wastes that are of more value when recycled than incinerated should be separated from the waste stream rather than burned. Overbuilding incinerator capacity can result in a desire to meet the designed capacity by increasing the waste stream through the curtailment of recycling: a policy option that could waste more energy than it produces.

10. Impacts of alternative energy utilization

Environmental impacts of *generating* energy from alternative sources constitute one dimension of the problem. What about the impacts of utilizing energy produced from alternative sources?

Harte [49] briefly surveyed four end-use activities — agriculture, transportation, housing and industry, and concluded that ecological damage initiated by the end use to which energy is put is not negligible compared to direct ecological damage initiated by fuel combustion, effluents, mining of fuels, and conversion. Moreover, because the indirect impacts are independent of the type of energy supply, he concluded that development of a cheap, unlimited, and clean source of energy is not the end of energy-related environmental problems; in other words generation of 'clean' energy is but one aspect of the environmental implications of energy-use and unless equal emphasis is given to the pollution caused by actual *consumption* of energy, development of alternative (and 'clean') sources of energy may mean fulfilling only half the mission of environmental friendliness.

11. Concluding remarks

In this write-up we have dwelt at length on the adverse environmental impacts of renewable energy sources. The situation is summarized in Table 2.

Are we, then, advocating that renewables be discarded? No, because such a view would be as irrational as the one which we have questioned in this write-up; the one which proclaims renewable energy sources as a totally safe and viable answer to the pollution-generating non-renewables.

Rather the purpose of this chapter is to generate awareness towards the adverse environmental impacts of various renewable energy options so that we acquire a balanced view of their virtues (already well-known) as well as shortcomings (not *that* well-known) and the sad euphoria-turned-despair history of hydel power projects is not repeated.

We have catalogued the already studied and documented impacts in addition to the ones which are highly likely. This exercise is envisaged to achieve the following objectives:

(a) help us to do elaborate environmental planning based on 'preventive adverse impact assessment' before any renewable energy system is actually installed;
(b) help us in rational site selection for a renewable energy project so as to ensure maximum compatibility with the environment and minimum adverse impacts;
(c) help us in generating awareness towards the niches of various renewable energy systems; an energy generation system which is ideal for one type of use, or for a given region, need not be so in all situations;
(d) ensure that we do not 'burn our fingers' as we did in case of hydel power presupposing the geniality of an energy source and using it in a big way only to curse it later.

There have been instances in the recent history when major natural resource development activities were taken with only the benefits in view. In the 1960s, India and some other countries were swept by 'green revolution' during which high-yielding dwarf varieties of plants and intensive agricultural practices were used on a very large scale to produce massive stocks of food-grains. This enabled food-deficient countries to be in food-surplus in a matter of 3–4 years. At that time, the scientists who worked for the green revolution, were heralded as Messiahs. Then, as years rolled by and the adverse impacts of intensive agriculture began to surface in the form of waterlogging, salinization, depleted soil productivity, pollution — the very same scientists who were lionised earlier were made targets of public ire and ridicule.

Table 2
A summary of the possible adverse environmental impacts of renewable energy sources and their relative magnitudes

Renewable energy sources	Adverse impact	Relative magnitude
1. Biomass production: centralised systems	Adverse impacts common to any very large-scale plantation: degradation of land, consumption of water, harm to water quality, stress on the ecosystem, etc	Major
2. Biomass production: dispersed systems	Depletion of forests, human encroachments	Medium
3. Biomass burning	Air pollution	Major
4. Direct solar: centralised systems	Degradation of large tracts of land covered by reflectors	Major
	Loss of habitat due to above	Major
	Indirect pollution during manufacture of collectors and storage devices	Major
	Generation of hazardous pollutants on decommissioning	Major
	Impact on micrometeorology	Medium
5. Direct solar: dispersed systems	Adverse albedo	Minor
	Clash with presence of trees, interference with the canopies around buildings housing solar collectors	Medium
6. Wind energy: centralised systems	Noise due to generators	Minor
	Aesthetic degradation	Minor
	Interference with bird flights	Medium
	Stress on the ecosystem due to reduced wind-speeds downstream	Minor
	Television interference	Medium
7. Hydroelectric power: centralised system	Loss of habitats	Major
	Loss of water quality	Major
	Loss of forests	Major
	Generation of greenhouse gases	Major
	Impediment in river flow, stress on aquatic life	Major
8. Hydroelectric power: mini & micro hydel system	Impacts similar to large-scale systems	Major
9. Ocean thermal energy conversion (OTEC) system	Impact on the marine ecosystem in terms of: altering thermal structure altering water chemistry eutrophication & algal blooms	
	Introduction of xenobiotics in the form of biocides	Major
10. Geothermal energy	Surface distributions	Medium
	Land subsidence	Major
	Noise	Minor
	Thermal pollution	Major
	Air pollution	Medium to major
	Water pollution	Medium to major
11. Urban waste incineration	Air pollution (especialy dioxins, furans, and toxic metals)	Major

When eucalyptus was initially brought to India it was dubbed 'wonder tree'. It grew easily, it grew rapidly, and each cell of it was utilizable. Some even saw in it the embodiment of the mythical *kalp vriksha* — the tree capable of giving everything one asks from it! A few decades from then, eucalyptus has become the favourite object of attack for environmental activists. It has been called an enemy of water, soil, wildlife, and all other constituents of environment. It is even portrayed as an agent of the bourgeoisie!

In both the above mentioned instances, the fault did not lie with the instruments of change (green revolution/eucalyptus) but with the total lack of any environmental impact forecasting before those instruments were put to large-scale use.

We wish that similar faith does not befall renewable energy sources and hope write-ups such as this would contribute towards truly environment-friendly utilization of the renewables.

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