A Multidisciplined Systems Approach to the Study of Renewable and Nonrenewable Energy

by

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Abstract

The issue of energy has assumed increasing economic and political importance. Experts predict this will be more so in the future with a more significant role for renewable energy sources and systems. This requires the design of optimal energy solutions and systems. To do so, a comprehensive multidisciplined and comparative study of energy sources and systems both renewable and nonrenewable, storage issues, cost-effectiveness, effects on health and the environment, the pros and cons of each solution, the state of the art in research and development and predictions for future developments in technology are presented. Such a comprehensive approach is found to be lacking in the current literature. It is shown that optimal energy solutions will be generally hybrid and customized specifically to the particular resources of the locality, the type of application, and the magnitude of power demand. This study provides a solid multidisciplined basis for developing and implementing courses and for research in energy systems with a focus on renewable energy.

Introduction

The energy issue plays increasingly a prominent role in contemporary life. The advent of the industrial revolution, which was enabled by significant progress in the sciences, has led to the development of an energy-intensive technology on a worldwide scale. The dominant source of energy has been hydrocarbons, i.e., oil, coal, and natural gas, all of which are known to be non-renewable. The approach used by industry was not ecological, and was wasteful, in that little attention was paid to energy efficiencies at an ecological level, perhaps because the science of ecology itself was not developed yet. Recycling, which is fundamental to the way ecosystems work, was minimal until recently. The increasing scarcity of energy supplies has led to many conflicts. The development of efficient renewable energy systems is therefore a necessity. Solar energy systems have the potential to provide the ideal energy solution in the future, and depending on the region, contribute as subsystems of hybrid systems based on a mix of primarily renewable energy sources. The author believes that the results of his research herein summarized would help provide a comprehensive *ecological* approach to developing renewable energy curriculum and research as to what is the *optimal* energy solution in a given locality. Based on his research, the author concludes that the *golden mean* is the correct approach and philosophy which should abide by basic principles of ecology and health, while using the appropriate mix of hybrid solutions most suitable and economical to a given locality and application. As in nature, the overall system must be *sustainable* and *integrated* in the ecosystem. This requires all products to be *recyclable*, *compatible* with the *environment* and *health*, and involve the most efficient and least wasteful designs, as is the case in all *natural* processes.

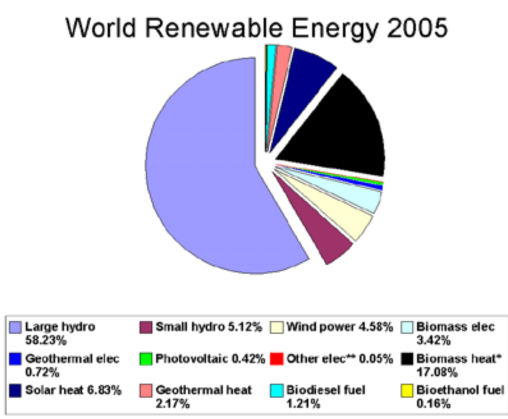
The sources of electric power

Energy is a fundamental requirement for life. It takes many forms, such as thermal, mechanical, electromagnetic, including light, chemical and biochemical. A fundamental law of physics states that although energy *changes forms continuously*, *it is conserved and may not be created*. Heat from solar energy or combustion of hydrocarbons may be converted to mechanical kinetic energy through heat engines. When heating is the desired result, solar energy may be most efficiently directly converted into heat. Electric technology is powered by electric energy which is obtained through the transformation of other forms, such as mechanical energy of rotation in generators or from the transduction of solar light by photovoltaic cells. Non-renewable sources include the hydrocarbons. Another non-renewable form is nuclear energy. The proportion of each energy type currently in use is shown in Fig. 1 [1]. It is seen that the hydrocarbon sources dominate, and next nuclear energy sources. The major advantage of the hydrocarbon-based energy systems is that electricity produced from hydrocarbons is currently the most cost-effective, in that the price per kWh is the lowest [1]. Another advantage is their high energy density making them ideally suited for transport. One disadvantage is that the hydrocarbons are nonrenewable and therefore these energy systems are not sustainable. This not only results in increasing prices, as is currently experienced, but ultimately this source of energy is expected to end as it is not replenished because of the *excessive* consumption rate. Another disadvantage of the hydrocarbon-based energy generation is that it produces pollution, which in the long term has its costs in its negative effects both on the ecosystem and health.

Nuclear power is produced by converting energy released by the fission of uranium nuclei in nuclear reactors into heat that drives generators to produce electricity. Nuclear energy has, by far, the most negative effects of any energy system [3]. These include the potential danger of uncontrollable explosion of nuclear reactors [4], [5]. Another problem with nuclear power is that it produces highly radioactive wastes whose half-life exceeds the billion years. These wastes can not be recycled and no effective storage for them is known. Another disadvantage of nuclear power is that it is not portable and therefore cannot be used to power freely moving devices such as cars and planes. From an ecological point of view, nuclear energy is the most unsuitable in that according to our current understanding in geophysics, the ecological role of uranium is to heat Earth interior, safely far from the biosphere. Indeed, according to biology, not only are uranium and other radioactive elements not required for life, but they have also been proven to be highly destructive to life. Finally, nuclear power is *not* cost-effective as it is sometimes claimed by its proponent, since it is heavily subsidized by the government [3]. In addition, there has been credible research that has documented radiation pollution in and around nuclear reactors [6]. Finally nuclear energy is at the root of nuclear weapons proliferation which puts the biosphere in a permanent threat of annihilation.

Renewable sources of energy include solar, wind, hydroelectric, biomass, geothermal, and tides. At a fundamental level, physicists have shown they all originate from solar energy. The proportions of each currently in use are shown in Fig. 1. Fig.2 shows that though renewable energy sources still represent a very small fraction, the use of solar energy has been dramatically increasing. Wind energy is currently the most mature and competitive renewable energy source. It is ecological in that it uses in a non-polluting way the *free* kinetic energy of the wind to drive a generator to produce electricity. The main limitations of wind energy are its restricted and unpredictable availability and its non portability, which therefore requires some form of storage. Biomass involves the combustion of fuels obtained from dead organisms such as wood, or the biochemical production of ethanol and other biofuels such as obtained from the fermentation of corn. The problem with this is that this can be used in a sustainable and ecological way only on a very reduced and local scale, and should not compete with a source *normally* used as food. The result of using this source on a larger scale, for example, is the rapid increase of the price of corn over the last years as more corn has been diverted for the production of ethanol. A less publicized danger is the alarming decrease in soil fertility due to the intensive monoculture that dominates modern agriculture. Therefore, though on a small local scale biofuels may be produced through ecological means, for a household consumption for example, this cannot be a major source of energy in the future.

Hydro-electric power is renewable and non-polluting, but it suffers two disadvantages: It is very limited in that it is available in relatively few areas in the world, it is not portable, so that it cannot power moving systems, and it is not ecological in that the long-term consequences of interfering with the natural course of river water has been shown to have a significant impact on the ecosystems, and sometimes cause outright disasters. Such a form may be used on a small scale in an ecologically sound manner. Geothermal energy that uses the hot water from the interior of the Earth and tides is a good renewable source of energy but they are also not widely available and portable.



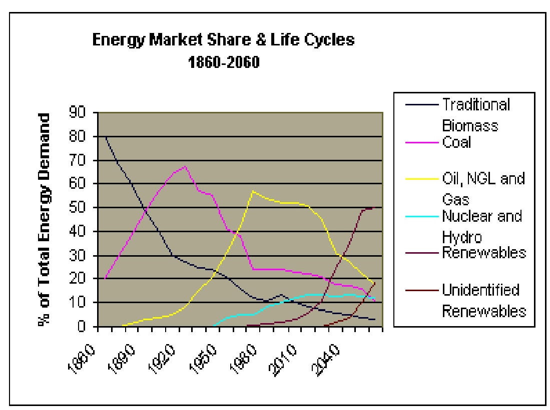


Fig. 1: (Solarbuzz) (a) proportions

Fig. 2: (Solarbuzz) future trends

Solar energy

Most experts agree that solar energy has the potential to be the “ideal” energy solution in the future. Physicists also believe all other forms of energy ultimately *derive* from solar energy. The

main stumbling block is that it is currently not cost-effective, costing as much as 4 times the cost per Watt of hydrocarbon-based electricity [1].
Solar energy has the following advantages:

- It is an unlimited renewable source. It is available *free* everywhere.
- It is non polluting. On the contrary it is a fundamental requirement for life.
- It provides elegant scalable and perfectly distributed solutions that can be scaled according to local needs by addition of modules. Therefore, the generation of energy being local and in dc form there is no need for ac transmission lines which are believed t cause potentially harmful low-frequency electromagnetic radiation [8]-[9].
- Solar power systems, particularly photovoltaic, require comparatively little maintenance; this improves the system reliability, so in the long run more savings are made than with current technology such as diesel generators.
- Solar power systems are long-lasting, especially photovoltaic (the most costly component, the solar panel, may last up to 30 years)
- It is economical in the long run as will be explained below
- Being modular and scalable, solar energy is a highly ecological energy solution as the system is scaled according to need. This is another ecological principle whereby living organisms *use what they strictly need, tolerating no waste*.
- Easy installation: being scalable modular and local, the solar power system installation is a one-time relatively low cost.
- It is absolutely safe in that there is no danger of unpredictable catastrophe such as with nuclear reactors.
- It is portable. Therefore, it can provide portable scalable power supplies anywhere, though an efficient energy storage device must be used as needed. Centralized power generation on the other hand produces harmful electromagnetic pollution [8]-[9].
- There has been tremendous progress in fuel cell technology. Fuel cell technology being perfectly ecological in that its “waste” is the most valuable life-sustaining element, water, and that water is simply used in a *recyclable* manner. Thus, the use of fuel cells with solar power which would produce hydrogen fuel through electrolysis represents one promising ideal solution in the future based on current knowledge.

To summarize, various energy sources of electric power may be used depending on local availability. The pros and cons of each were discussed. Fig. 2 indicates that experts predict that with time the use of renewable sources will increase.

Solar power systems

There are two basic types of solar electric power systems: Thermo-solar and photovoltaic. Thermo-solar systems involve concentrating the sunlight through large spherical or cylindrical (Fig 3) parabolic mirrors. The focused light heats water to steam at around 800 °C and the steam drives a generator as in the conventional hydrocarbon-based power generation. In areas with a lot of sunlight this could be an attractive cost-effective solution as costs will be distributed among the population. This system, because it has moving parts, is not as reliable as the PV system.

Fig. 3: Thermo-solar power generator

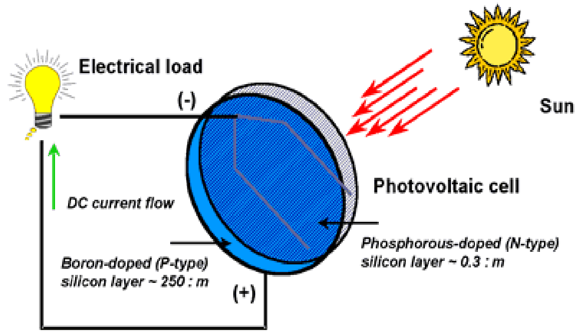


Fig. 4: Transduction of solar light into electricity

Photovoltaic (PV) power systems:

The basic components of the PV system are the PV array, where solar energy is transduced into electricity (Fig. 4), a storage device, usually a lead-acid battery bank, and the power electronics that interface with the load, including possibly the utility grid. Figs. 5 and 6 summarize the main components of a PV system. Currently the highest PV cell efficiency is close to 40%. The target according to the 2005 DOE Workshop [10] is 50%. However, the current high-efficiency cells are expensive. Active research is recommended [10] aiming at a better understanding of biological light electro-transduction such as in photosynthesis and application of those insights to the design of more efficient solar transduction systems.

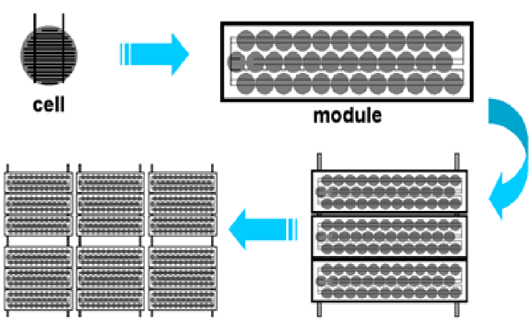


Fig. 5: PV array

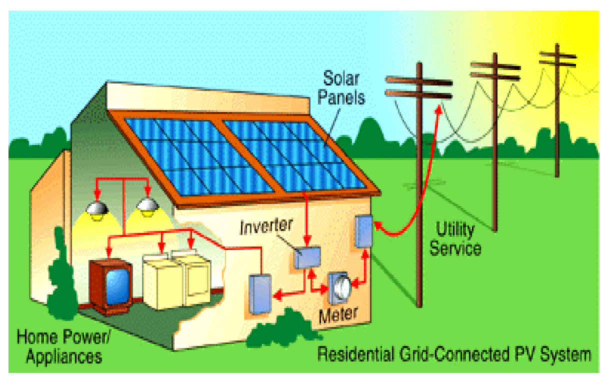


Fig. 6: Hybrid PV system

Concentrated Photovoltaic Systems (CPV):

The cost of the solar cells of the PV array typically represents about 50% of the total upfront cost of the PV array. Concentrated PV (CPV) systems [11], [12] provide a means to significantly reduce this cost. This is achieved by replacing the solar cells with Fresnel lenses which are relatively cheap acrylic sheets. The lens focuses incident solar light into either a narrow line or a small disc. A solar tracker must be used, which typically costs up to $1000, depending on the size of the array. Because of the potential of CPV to significantly reduce the price of PV systems, there has been a continued research effort to find alternative ways of concentrating light and avoid using a tracker [10].

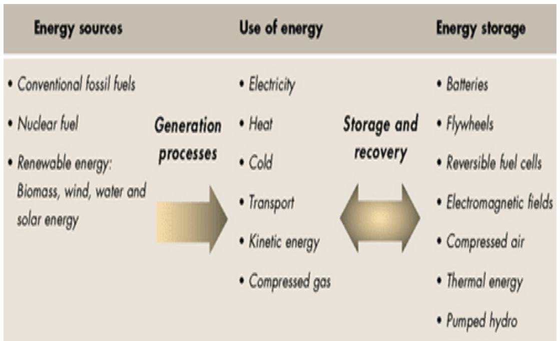
Energy storage

Since solar energy like wind power is not available on demand and continuously, solar power systems usually require a storage system. Since the economics of the solar power systems require the highest possible overall system efficiency, the storage element must be most efficient. Table1 lists the various types of storage elements currently available. There is active on-going research [10] to improve the design and efficiency of all of them. Batteries, typically the lead-acid batteries, are the most commonly used storage elements. Energy storage of hydrogen is the subject of active research and development involving the participation of the automotive industry. Fuel cells "burn" hydrogen and the oxygen from air to *efficiently* produce electricity and water as a "waste." Another form of energy storage is electromagnetic. This includes super-capacitors, where energy is stored in the capacitor electric field, and superconducting coils where energy is stored in the magnetic field of the lossless superconducting coils, which require cooling at very low subzero temperatures. Flywheels store energy as mechanical kinetic energy of rotating wheels, which is retrieved on demand to drive a generator. Pumped hydro uses solar energy to pump water to a higher level, thereby transforming the energy into gravitational potential energy of the water, which is then used on demand to drive a generator. The compressed air method involves storing the solar energy as elastic potential energy of compressed air, and the thermal energy method involves storing the heat from solar energy in a material. In both cases, the energy is retrieved on demand to drive a generator or use in another form.

Cost Analysis

Solar power systems are already considered *the most cost-effective energy solution in remote areas* [1]. As mentioned above, a proper scientific cost analysis must be performed on a systems basis with the long-term ecological and health costs factored in. Also, the cost analysis should be performed both in the short and long term. Fig. 8 shows that though the upfront cost for a solar power system is high, in the long run the payback becomes significant. Fig 9 shows that in Japan where heavy investments in mass manufacturing were made the cost of solar panels has been significantly dropping over the years. Fig. 10 shows the breakdown of component prices for PV solar systems and how it evolves over time. In the first year the % cost of the solar panel is the highest, about 50%. With time the percentage from the battery bank becomes dominant.

Table 1: Forms of energy storage



"Diagram of energy sources, use of energy and energy storage"

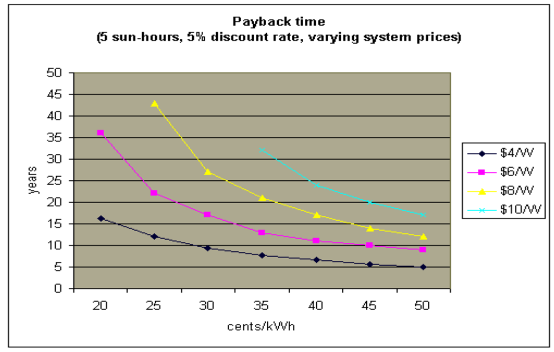
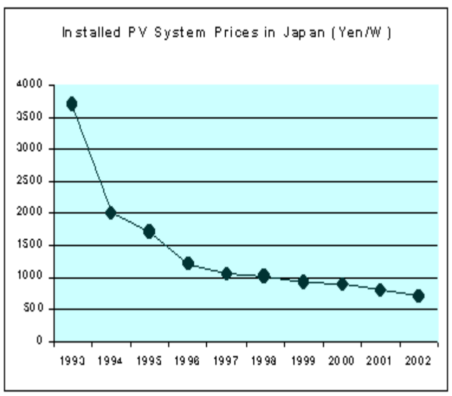


Fig. 8: Payback time for PV systems



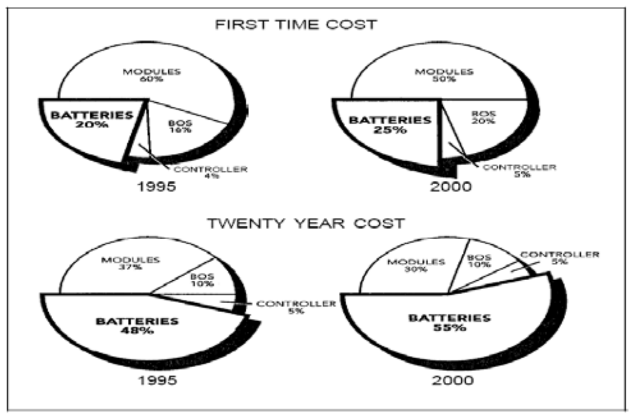


Figure 1. PV System Cost Breakdown.

Fig. 9: Price trends of PV systems in Japan **Fig. 10**: Cost of components of a PV system

Conclusion

Because the current dominant hydrocarbon-based electric power generation systems use non-renewable sources of energy which are increasingly costly and polluting, experts agree that the only sustainable energy solution is the use of renewable energy sources. Nuclear energy, the other type of non-renewable energy source is by far worse in all respects as discussed above, especially for being the most dangerous energy system and for producing non-recyclable radioactive wastes. Among all the renewable energy sources, solar energy is the most abundant, unlimited in supply and totally free. It is available throughout all regions of Earth. It is the cleanest and most ecological source of energy. Based on the above discussion, the following may be concluded: The energy systems of the future will be mostly solar and, depending on the region, in the form of hybrid systems as solar in combination with other renewable sources, and limited hydrocarbon such as diesel generators. One advantage of hydrocarbons is their high energy content and power output. In the medium transition period hybrid systems such as solar and the current utility grids will also be used. Solar electric power systems are the most ecological, most sustainable, health promoting and safe in that they produce no electromagnetic pollution in the form of potentially harmful low frequency electromagnetic radiation. Together with fuel cells and hydrogen produced from electrolysis by solar power, solar energy may be used to power vehicles and other movable objects. Based on the above discussion, to improve the cost effectiveness of solar power systems as standalone or part of a hybrid system, the following is needed:

- Use of energy-efficient appliances such as refrigerators, and lighting
- Recycle energy wastes such as the heat produced in various devices
- Larger-scale manufacturing of solar power equipment especially PV arrays
- Local collective power generation in the form of PV solar and thermo-solar
- More active government support in the form of significant tax incentives both to users and manufacturers and more subsidized extensive R&D addressing all aspects of solar power and hybrid systems
- Green building design, whereby materials and building orientation are chosen in such a way as to optimize natural heating and cooling throughout the year
- Research and development in solar power systems must be a multidisciplinary and interdisciplinary endeavor with a focus on both the ecological and health aspects.

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