Alternative energy sources for electricity generation: Their "energy effectiveness" and their viability for undeveloped and developing countries

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Abstract

Many sources of alternative energy have been proposed due to increasing prices of fossil fuels and the international call for cleaner electricity production. The most important of these are solar, wind, geothermal, nuclear, and hydroelectric; their processes and costs are discussed in this paper. Geothermal is included with the caveat that it is only feasible in geothermally active areas. Promising technologies in both solar and wind power coupled with their low environmental impact make them an attractive option for rural parts of undeveloped and developing countries where no 'grid' exists, but are not viable for industrial scale or large urban areas. Using these self sufficient technologies will save countries the immense costs of building a 'grid' to rural communities. For industrial and urban areas where demand for electricity is great, nuclear and hydroelectric power are the best options, taking into account that they are used safely and regulated for environmental and social reasons. For all of these alternative options to succeed, these countries need to focus on long term benefits because the start up costs may be higher than fossil fuels. Also, a combination of these alternative energy sources along with fossil fuels will be necessary for the world's burgeoning economies – focusing on only one type may prove to be quite myopic.

Introduction

Alternative energy (hereinafter 'AE') sources have become an increasingly more popular subject as more and more researchers have shown that indeed global warming has rapidly increased from anthropogenic causes. A large portion of global CO2 emissions is produced in the process of making electricity by burning fossil fuels. Natural gas and coal are the feedstocks of the industry, natural gas being cleaner than coal. Since coal is much cheaper than natural gas, it is used most in developing countries. Many large cities in these poorer countries (e.g. Beijing, China) that burn mainly coal are paying dearly with elevated pollution levels and a high rate of respiratory inflictions.

AE has been promoted as clean energy and a way to lower global CO2 emissions by supplementing fossil fuel usage to make electricity. Many of these energies use natural conditions like gravity, wind, and geothermal heat to produce electricity and it are truly clean forms of energy.

Many advocates of AE sources push for only one type of alternative energy to edge out fossil fuels, but in reality no AE can single-handedly fuel the world's growing energy needs. For example, solar energy will not be effective in high latitudes or where the largest energy needs are at night when the sun is not out. It is unclear whether or not nuclear energy will make it through the regulatory framework in the U.S. (not to mention the waste disposal/Yucca Mountain problem). The wind doesn't blow all the time nor do rivers have a constant discharge. It must be a combination of all these types of AE plus fossil fuels to fuel the world's needs and mitigate the effects of global warming.

Although AE seems to be the solution, it has received bad press about many different issues. Many people that are worried about AE energy effectiveness (i.e. 'net energy') – that it doesn't cost more energy to produce than they themselves will produce through their lifetime.

These people state that they are not efficient enough and are too technologically intensive to produce and use. Also, many AE's are subsidized by the government to make them even feasible or competitive (see wind energy section below).

This paper intends to explore all the positive and negative aspects of AE sources, their energy effectiveness (net energy) and their feasibility and viability in developing and undeveloped countries.

Alternative energy electricity production – pros, cons, and 'net energy'

Solar Energy (Photovoltaic cells)

Solar energy has been a long touted AE resource, but has historically never been efficient or a cost effective alternative to traditional fuels for electricity generation on a large scale. AT BEST, 30% of photon energy that hits a solar panel is converted to energy in a traditional photovoltaic (PV) cell (Service, 2005). These cells employ the use of poly crystalline silicon in a fairly thick wafer. The silicon has to be formed and cut into wafers, introducing large manufacturing costs to solar cells. However, recent advances in photovoltaic construction and the chemical nature of its components may lead to greater efficiencies or cheaper production of solar energy cells.

Two of these advances have been 'thin film' cells and 'organic' cells. Menanteau (2000) advocates the usage of "thin film" inorganic solar cells using innovative new compounds, such as amorphous silicon, copper indium diselenide (CIS), copper gallium diselenide (CGS), and Cadmium-Telluride. These compounds make more efficient PV cells (greater than 75% in some cases). Using these compounds in a nearly uni-molecular layer on the PV cell conserve expensive raw materials and yield flexible and durable cells, a large advance over traditional silicon wafer cells. Also, these thin film cells benefit from a positive feedback mechanism (see Menanteau 2000 for details), which yields much greater efficiency than traditional PV cells.

Nelson (2001) discusses the second major technological advance, organic solar cells and its efficiency. She states that blended organic compounds used in a solar cell can approach the efficiency of those made with inorganic compounds. On an industrial scale, using these cells may lessen the need for raw materials like silicon and rare earth metals (Cu, Ga, In, etc.) that are used in traditional and thin flim solar cells. These organic PV cells are still in their infancy, but look to be promising as a future PV cell that is much more efficient than those at present.

Solar energy is also harnessed for many other purposes besides electricity generation. It is commonly used to heat water for residential use by installing a 'radiator' on the roof of one's house. Also, houses and other buildings have recently been designed to be 'solar-ergonomic' – two examples are: the overall floor plan of the house keeps it cool in the summer and warm in the winter and natural skylighting is used to avoid usng electricity to light the building during the daytime.

Wind Energy

Wind energy has become increasingly popular in the last decade because of its clean electricity production and ease of operation. Each machine is composed of a steel *tower*, a *generator-gearbox*, and a fiberglass-reinforced polyester *rotor* that is made to be very lightweight (www.awea.org). The generators are quite complex and made efficient by the use of fully automated controls that control the rotor blades to be most efficient with different wind speeds and directions. The turbines need little maintenance and are quite durable. They can also recoup the original cost within 6 – 15 years of emplacement and seem to be a direct competitor to traditional energy sources.

However, wind energy benefits from many tax breaks and incentives that may deceptively bolster its viability as an alternative. Toby Carlton states that "one thing that's made it economic is that there's an investment tax credit of 1.9 cents per kilowatt hour, which is good for the next 10 years" (Brown 2006). Without this tax credit wind energy would be, on average, half again as expensive as other electricity options. Inevitably wind energy will become more efficient, but only the future will tell if it will be able to directly compete without tax breaks.

Although wind energy seems to be quite a viable form of AE, many social and environmental concerns have been raised. Large wind farms have been constructed onshore in many countries, but are deemed an eyesore by many. The typical turbine is 300 ft tall with 130 ft blades – quite a large blemish indeed! As an alternative, wind farms are being planned in many shallow offshore areas (North Sea, Cape Cod, etc.). These farms seem to be the best design – out of sight and benefit from more reliable wind conditions (more powerful and constant winds). Secondly, many birds are killed by these wind turbines – as of yet, no feasible preventative measures have been suggested to alleviate this problem, although advocates of wind energy say that many more birds die from building impacts (www.awea.org). Other minor problems like soil erosion, shadow flicker, and noise have been solved through better engineering or planning of wind farm sites.

Geothermal Energy

Iceland is a wonderful example of how geothermal energy can be used to decrease dependence on traditional electricity production. Iceland derives nearly one quarter of its electrity from geothermal power plants (the other 80% is mainly hydroelectric). Even more impressive, nearly 100% of houses in Iceland are heated with geothermal waters (http://www.energy.rochester.edu/is/reyk/ and www.os.is).

Although a wonderful resource, geothermal energy is only viable in geographic locations that have geothermal potential. This is restricted to locations near subduction zones, hot spots, mid ocean ridges, and other geothermally active areas. Unfortunately, these areas do not include most of the land surface and therefore geothermal energy is not a focus of this paper.

Nuclear Energy

Electricity production from nuclear reactors was touted as a clean form of AE but has turned into an international dispute in recent years. With disasters like Chernobyl, contentious storage facilities like Yucca Mountain, and the doubtfulness that many countries only want nuclear materials for peaceful electricity generation, the future of nuclear energy remains on shaky ground.

A nuclear power plant is very technologically advanced – the construction and materials used are only able to be produced by enrichment of uranium or plutonium, a complicated process. The plants also require specially trained workers to maintain it. A plant works on the principle of nuclear fission: a uranium (U) core produces heat energy by fission (β and γ decay from neutron emission and atom splitting) and control rods that absorb neutrons are used to restrain the nuclear reaction. The heat energy is kept constant by raising or lowering the rods and that energy is used to heat water to drive steam turbines (http://www.iaea.org/).

If the control rods are not managed correctly, the chain reaction escalates out of control and causes a disaster like what happened at the nuclear power plant in Chernobyl, Ukraine in 1986. Safety procedures were unheeded and others failed, causing Reactor #4 to have a total meltdown. The U core and control rods melted into radioactive 'lava' and the 1000 ton sealing cap of the reactor was blown off in an immense explosion (www.chernobyl.info). This explosion is believed to have released more radioactive nuclides than both atomic bombs dropped on Japan in WWII (Pflugbeil and Checherov 2002). Due to this disaster, Chernobyl style power plants were all dismantled and replaced with much safer varieties and none oare in use today (Richter 2006).

If there are no accidents and the reactors run smoothly, there is still a lot of high level radioactive waste that is produced that needs to be stored indefinitely in a contained manner. Yucca Mountain in Nevada was chosen in the early 1980's to house the U.S.'s nuclear waste, but due to difficulty in planning & regulation of the long term storage and bad public opinion, it is not due to open until 2015, and according to Dyer (2006), even this date may be unattainable.

An innovative method to minimize the amount of waste is being used in France now: separate and reuse the waste in light water reactors and 'fast' reactors before disposing of it (Richter 2006). This reduces both the amount and the toxicity of the waste that must be stored in facilites like Yucca Mountain.

Recent news (BBC April 2006) shows that the countries like Iran and North Korea are starting to enrich U and Pu with supposed peaceful nuclear intentions. However, the UN fears that these countries are enriching to make nuclear weapons and therefore is trying to stop that enrichment by imposing sanctions. Recently (April 2006), Libya has agreed not to enrich any more and UN sanctions were lifted; Iran and North Korea are recommended by the UN to stop enriching for fear of nuclear proliferation.

Hydroelectric Energy

Hydroelectric power generation was pioneered by the U.S. in the 1880s and escalated in the 1930s during the Great Depression, employing many people to build dams and turbines. The entire process, including construction of the dam and the turbines is comparatively simple, making it a viable source of AE in undeveloped countries. This type of AE also has the added benefit of water storage, especially for desert areas. However, the riparian ecosystems of dammed rivers, especially downstream, are severely degraded by the power generation process.

Hydroelectric power generation works from a simple gravity driven process. A river is dammed, and water is redirected through the dam to turn large water turbines that are connected to vertical axis generators that produce electricity (www.tva.gov). Since its inception, the basic technology has not changed, but efficiency has greatly improved. One great example of hydroelectric power benefiting an area is Hoover Dam and associated Lake Mead, which provides much of the electricity and water for nearby Las Vegas, Nevada. The dam also provides flood control to the Colorado River and irrigation water to Las Vegas and much of Arizona's farm country.

However, with all the benefits come tradeoffs, usually in the form of environmental degradation. The Colorado River is a prime example of riparian degradation following dam construction. Many thousands of acres were flooded to make Lake Mead, destroying river riparian habitat. The downstream ecosystems are the ones most severely affected by many things, including: loss of nutrients due to settling on the upstream side of the dam, drastic water level changes as the dam releases large amounts of water for irrigation or electricity generation (Stevens et al 2000). So the need for water level management is quite apparent and very important to the downstream habitats of our rivers and lakes. Stevens et al (2000) shows that with proper timing and controlled water release, the effects of the flood on the ecosystem are minimal.

Two little known and exciting forms of hydroelectric power that may become viable as AE sources are tidal channel power and wave power (Trapp & Watchorn 2001). Both these sources are low impact on the environment and may be used in many geographic locations. Tidal channel power uses vertical axis turbines installed in deep tidal channels to drive generators without disturbing the tidal cycle or the environment. This is a large improvement over the 'tidal fence' idea, which is disastrous to tidal ecosystems. These systems may be used in macrotidal (4-6 m range) environments with deep and robust tidal channels (i.e. Baltic Sea, New Zealand, Sea of Cortez, etc.). Wave power harnesses hydraulic wave energy and converts it to electricity at or near the shore. Many of these units are already in place in Japan and the UK and have far surpassed original electricity production forecasts.

AE's viability for developing and undeveloped countries

Newly emerging economies like China and India and many undeveloped countries (like Saharan African countries) have the opportunity to benefit from AE sources in many ways. These burgeoning economies could base their economy upon AE and not be reliant on fossil fuels; already developed economies must make the painful and expensive switch. This would save these new economies huge sums of money and would help to bring them up to 'first world' standards. Also, rural communities could use AE sources that are self sustainable and eliminate the need for constant delivery of fossil fuels for generators or the money and infrastructure of running power lines ('the grid') out to rural areas. The main hurdle that these economies will have to overcome is the cost of AE – at the moment they are still more expensive than fossil fuels. It must be thought of as a long term investment, not a short term fix, a difficult choice for a rising economic power to make.

Each topic introduced in the first part of this paper (with the exception of geothermal energy) will be examined here for its viability in developing and undeveloped countries.

Solar

At the moment, industrial scale solar power generation is still cost prohibitive. But the promising new technologies discussed above shed light on a hopeful future for solar energy. Menanteau (2000) states that these new solar technologies "open up considerable possibilities in developing countries where a large proportion of rural populations are not connected to an electricity grid." Indeed, solar energy already represents the most cost effective way to make electricity or pump water in many rural locations. The rural community of Terlingua, TX, where no power 'grid' exists for hundreds of miles, is powered solely by photovoltaic cells. Menanteau also concludes that *while* PV cells may never be competitive for housing that is connected to the grid (because of the cost), the use of PV cells in these rural applications *can save* tremendous amounts of money and resources by not having to establish a 'grid.'

Using solar energy and common sense can be accomplished by any economy. Building 'solar-ergonomic' housing can save impressive amounts of energy and can be instituted most effectively by economies that are just starting to build housing and urban buildings on a massive scale.

Wind

Because of the comparative engineering simplicity of wind energy, it should be a widely used source of AE in the future for developing and undeveloped economies. Like solar energy, it will be very useful for rural communities that are not connected to the grid and will save the resources of running the grid out to those rural places. Already, some companies sell small scale residential turbines that recoup their cost in ~ 6 years (www.awea.org). For industrial applications, it is most favorable to put wind farms with large scale turbines (300 ft diameter) offshore where they are not an eyesore and where wind is the strongest and most predictable.

Nuclear

Nuclear energy is the most efficient AE source for industrial and widespread application in developing countries. However, the technological complexity, the proliferation problem, and the produced waste continue to plague it. Developed countries are hesitant to let developing countries enrich U and Pu in the fear that they will then use it to make nuclear weapons. A scheme has been devised by Richter (2006) to make nuclear energy be a sort of a commodity with an international organization to regulate it. In other words, developing countries would be able to buy enriched U and Pu, use it, and then give back the waste (under careful supervision, of course). This would negate the worry of proliferation and make sure that the waste is stored properly and safely.

Sadly, nuclear energy is not an option at all for undeveloped countries unless implemented by a developed country. The technological barrier is too great for undeveloped countries to cross – fortunately, wind and solar energy are simple and easy to implement in undeveloped countries, especially in rural areas.

Hydroelectric

This form of AE can produce many gigawatt-hours per year of electricity for undeveloped and developing countries, but it must be regulated correctly to mitigate environmental disaster. The construction of a dam is relatively simple and the turbines can be purchased or constructed. Once built, it needs relatively little maintenance and can produce electricity for a long period of time. China, with the new Three Gorges dam, has shown the world that developing countries can be successful with hydroelectric power generation. This dam is five times the size of the immense Hoover Dam and will produce much more electricity. It dams up the Yengtze River (which is notorious for flooding) for irrigation and water storage. As with all hydroelectric projects, the cons are in the environmental sector. Worries abound about how the dam will affect the river ecology and much habitat will be lost due to the formation of a lake behind the dam (BBC April 2006b). Also, a million people will lose their homes and land to the lake. Do the benefits outweigh the harm?

Tidal channel power and wave power also promise to be a good source of hydroelectric AE in the future.

CONCLUSION

According to recent projections, alternative energy will become increasingly more important over the next ~ 50 – 100 years. However, historically, estimates about energy in general and especially AE have proven to be quite inaccurate (both over and under projected), so only time will tell.

For developing countries, nuclear and hydroelectric energy promise to produce the most electricity with practically no CO2 emissions. These types of AE require substantial investment and planning for them to be useful and safe. Also, the country must be technologically advanced enough to enrich their own U and/or Pu (see caveat below). With nuclear energy, the challenges to overcome will be the radioactive waste and the proliferation scare. Burning the waste in other reactors will help to reduce the waste and an international organization made to regulate nuclear energy and its products as a commodity will negate the proliferation scare and help countries obtain nuclear energy that cannot enrich by themselves. With hydroelectric energy, the challenge will be to work in close conjuction with environmentalists to avoid an ecological riparian disaster.

For rural parts of developing countries and undeveloped countries (which can be largely rural), wind, solar, and wave & tidal channel power are the most viable alternatives to fossil fuels for electricity production. These simple technologies can be implemented cheaply and quickly without the investment and planning required for nuclear and hydroelectric. Especially favorable is the notion that they are self sufficient and no money is wasted by installing a grid to these rural areas. If the areas are on the coast, wave or tidal channel power also may be an option. Also, geothermally active undeveloped countries like the countries near the East African Rift may benefit greatly from geothermal energy.

Finally, all of these energy sources must be used in unison to meet the growing demand for electricity – favoring only one type may prove to be very shortsighted in the future.

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Transportation

"Hydrogen Economy"

- Clean, but Producing hydrogen is energy intensive
- Efficiency?
- Very techno intensive to produce and upkeep
- Hydrogen infrastructure (pipeline, H producing plants, etc.)
- STILL USES PETROLEUM!
- Steam methane reforming,
- Steam reforming of methanol
- Partial oxidation of heavy oil.
- Biomass gasification (produces CO_2 also, but may be fed back to plants)
- Electrolysis of water
- Requires electricity (usually from petroleum)

Biodiesel

- Direct use of frying oil doesn't work – must be filtered and processed
- Relatively easy process (transesterification) but requires petroleum (methanol) in large ratios
- By product is glycerol, which can be used for various purposes

Ethanol

- Corn? Come on . . .
- Using precious crop and grazing fodder for fuel production?
- Biomass however . . .

- Biological production from lignocellulosic biomass
- Uses anaerobes to separate lignin from cellulose and then cellulose converted to sugars for fermentation
- Biomass natural gas
- Landfills, lignocellulose

Still have to deal with CO_2

Electric

- Where does the electricity come from?
- Miles per charge (no roadtrips)
- HEAVY batteries
- This is where a technology breakthrough needs to be

Hydrogen

- Too techno intensive (ie who fixes the car when it breaks in the middle of Africa?)
- Production
- Steam methane reform and water electrolyzer on small scale home by home basis, but cost prohibitive (cost and energy used)

Biodiesel

- Process easy enough?
- If no waste oil, grow oil seed crops - is this viable?
- Simple conversion from diesel trucks (as compared to hydrogen or electric)

Ethanol

- Crop space?

- Distillation process?
- Might be better only as an additive, not as a replacement . . .