An Introduction to Hydroelectric Power

As energy is most broadly defined as the ability to do work, it is obvious why it has become such an important focus of our everyday lives. Over the past century, human civilization has harnessed and utilized energy at an exponential rate, and the concern of sustainability has arisen. Most of our energy has come from the combustion of fossil fuels, which are organic chemical compounds that have compressed the energy from the sun into a combustible medium. By their nature, fossil fuels are limited in quantity as they take millions of years to replace, and recently have raised concerns about climate change. As demand for fossil fuels has climbed exponentially in a very brief period of history, there are worries if society has the time to develop a replacement to maintain the lifestyles that we have grown accustomed to. Renewable energy is a topic pushed by environmentalists and politicians alike as a solution to many of our problems, as well as the shortcut to a responsible future. Environmentalists romanticize the notion of widespread renewable energy as an opportunity to end global warming and save the environment. Politicians envision a self-sustaining economy capable of independence from the global economy, with no need to trade with political enemies. However, both of these views are fundamentally flawed, as the amounts of energy our societies consume will always require disturbing the natural state of the environment, and renewable energy resources are also finite in capacity. This paper will overview one of the first, and most utilized renewable energy resources, hydroelectric power. Its origins, process, potential, and limitations will be analyzed, in respect to human society.

First, it is important to differentiate between alternative and renewable energy, as they are not synonyms. Alternative energy sources are those which are not derived from the primary source of energy. Alternative energy has no implications of sustainability or pollution, as nuclear energy is considered alternative, and is also dependent upon finite fuel. Today's standard may also be tomorrow's alternative energy, as biomass was the staple of early human civilization in the form of wood burning. The first law of thermodynamics informs us that energy cannot be created or destroyed, which essentially says that there is no such thing as a free lunch. There will always be pollution from the method in which we harness energy, and there will always be a limit to it.

Hydroelectric was one of the first "modern" renewables utilized by humanity when water wheels were discovered. It is believed that the Sumerian civilization (~4,000 B.C.) was the first to harness the power of water to accomplish its work. (6) For nearly 6,000 years variations of the water wheel were made by various cultures, but all were used to transfer the kinetic energy of the water for other mechanical tasks. It wasn't until Michael Faraday's discovery of the homopolar generator (dynamos) in 1831 that a new way to harness hydropower would be possible. Faraday's experiments determined that a direct electric current could be generated from the rotation of a metallic disc through a magnetic field. (8) However, Faraday's original generator was inefficient due to issues with the counter flows of current, and was not fit for practical use for another 50 years when various improvements were made by other scientists to increase the efficiency. (9) It was around this time (~1880) that the first hydroelectric plants were being produced, most notably at Niagara Falls to power street lamps. Within 10 years, there were over 200 plants in the United States and Canada generating electricity from water. By 1907, 15% of all electricity in the United States was generated from hydropower, and by 1940 this grew to 40%. (10) In 2006, hydroelectric plants accounted for 19% of all of the world's electricity, and accounted for nearly two thirds of the world's renewable energy production. (Refer to Figures 1 and 2 for the U.S. consumption rates) It should be noted that 2006 was a record year for hydroelectric power due to high amounts of water available that year. (4)

As mentioned earlier hydroelectricity is generated by harnessing the power of falling or flowing water, which is mostly generated by the natural pull of gravity. As water is constantly being cycled to and from the atmosphere, in what is called the hydrological cycle, this makes hydroelectricity a renewable resource. (Refer to Figure 5). Hydroelectric power plants actually harness power in a similar fashion to a fossil fuel powered plant. The force of the water is used to turn a turbine connected to an electric generator, converting kinetic energy into electric. The only difference between a coal plant and a hydroelectric plant is the medium that spins the turbines. (Refer to Figure 4) The second law of thermodynamics tells us that every time energy is converted from one form to another, some of that energy is lost. Because of this, a hydroelectric plant wastes less energy, as there are less conversions than in a fuel fired plant, in only changing kinetic to electric versus transferring chemical to thermal to kinetic to electric. Beyond the dam style plants, variations have been created that harness the forces of waves and tidal flows, although the basic concept of using moving water to move a turbine remains. (7)

Beyond their simple nature, hydroelectric plants have another aspect making them attractive energy options: their cost. After the initial startup costs of creating the plant, the operating and maintenance costs are relatively low compared to other renewable sources, and are even competitive with fossil fuels in some areas as service life of a plant can exceed 100 years. (Refer to Figure 3 for a comparison of costs for renewable sources of energy) An important aspect to note is that the smaller the hydroelectric plant is, the costlier the energy will be (economies of scale). The globally accepted standard of "large" hydropower plants are those greater than 10MW of capacity, although projects in the U.S. and Canada can be classified as small up to 30 MW. (4) Aside from these large projects, options are now available to individual consumers (pico-scale plants), with small scale generators capable of generating 5 kW, which is enough to power a modest single family dwelling. The power generated through these pico-hydro plants would not be competitive with larger scale hydro or fossil plants, and are most attractive to small remote communities. (11)

However, despite the many benefits hydropower can offer an area, it is not without detrimental effects upon the environment. Hydroelectric systems require large dams in order to harness the power of the water effectively, and this will disrupt the aquatic ecosystem. From the spawning habits of fish, to the erosion of river beds due to sediment removal, various factors get changed by the dam and can be disastrous for the ecosystem as it once was. The effects have been documented well enough that many environmentalists are actually lobbying for shutting down hydroelectric plants (although few realize they would be replaced by increased generation from nuclear and fossil fuel plants). Another overlooked aspect in which hydroelectric plants can pollute is the emission of greenhouse gases. While the dynamo process itself is combustion-free and therefore emission-less, organic material will gather in the dam's reservoir. When this organic matter decomposes, greenhouse gases such as methane are released, and these gases will contribute to global warming. While some technological solutions have been found for some of the environmental issues above, adding them will come at an additional cost, which inevitably makes it less competitive against "dirtier" options. From a political standpoint, hydroelectric dams can be a risk as they will make easy military targets. Dam failure is an aspect that should go into planning before the dam is constructed, as a poor location choice can be disastrous should the dam fail structurally. The final consideration of the limits of hydropower is the inherent limits of water availability. While hydropower is more reliable than other renewables like solar or wind, the plant is limited to the water available at a particular location. Some countries are better endowed than others with water sources capable of damming, so there is an upper maxim for the amount of hydropower a country can produce. Furthermore, water supply can vary greatly from year to year and a dry year can leave an area without critical power. One of the major factors behind the 2000 California Energy Crisis was a lack of hydropower due to a dry year. (1)

Given the above, what implications does hydropower hold for mankind's energy future? While it is clearly one of the oldest, most reliable, and widely utilized renewable energy sources at society's disposal today, many could argue that hydropower's potential has piqued. New environmental concerns and demonstrated unreliability as a main energy supply demonstrate that with the current technology hydropower is best utilized as an alternative energy. While the costs associated with hydropower can be competitive with fossil fuels, the low costs are subject to natural resources (water bodies suitable for damming) and affect the natural environment. As the technology has been utilized for nearly 130 years now, nearly all non-protected large water resources have already been tapped. In conclusion, without a radical development in dynamo technology, or a reduction/stagnation of the growth of energy demand hydropower cannot be the sole solution to human society's needs regardless of cost.

Figure 1

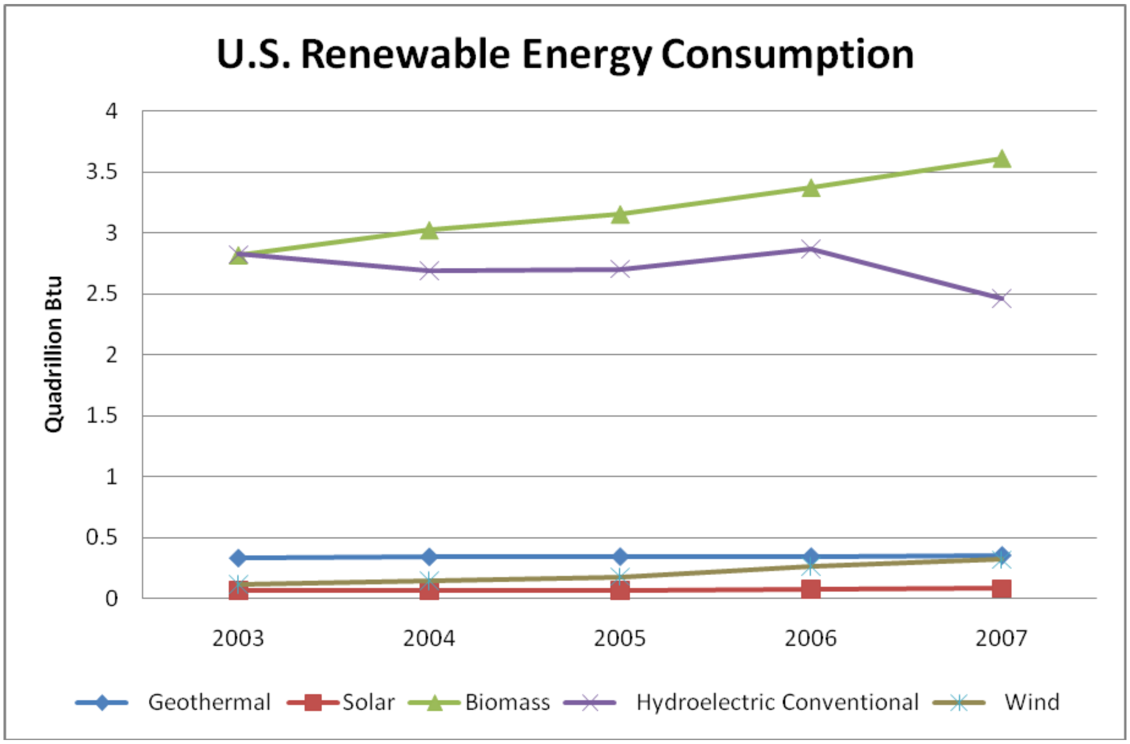
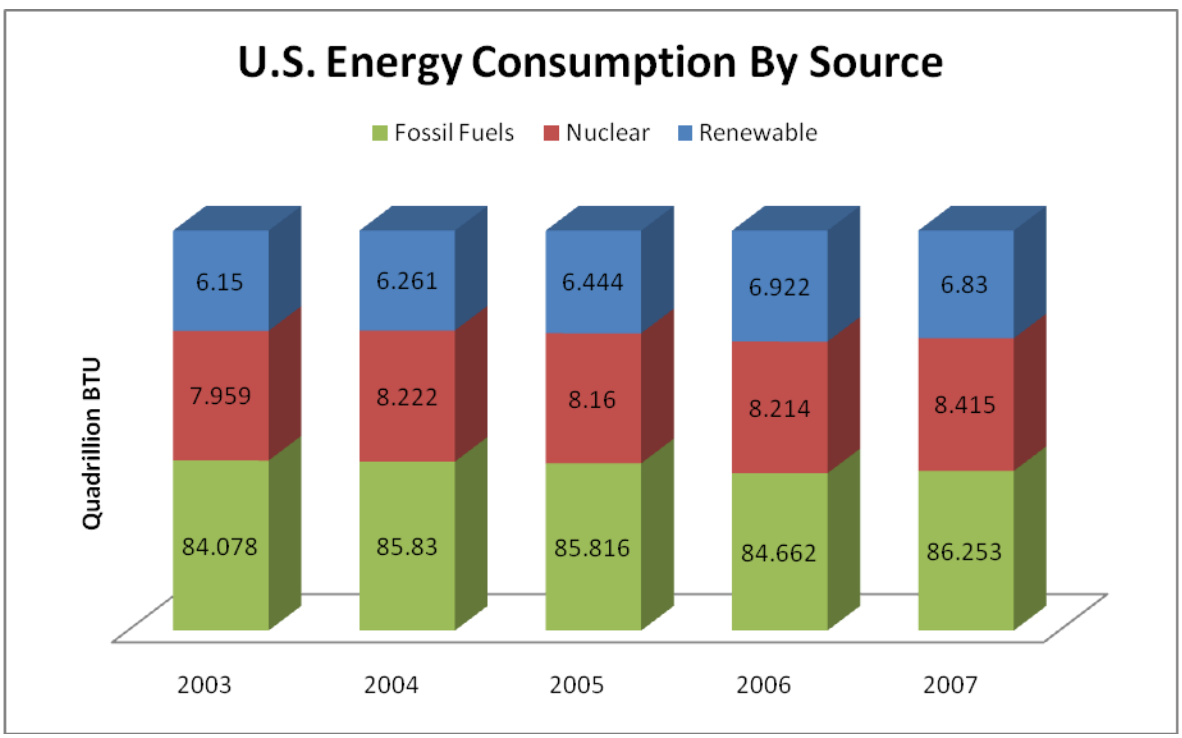
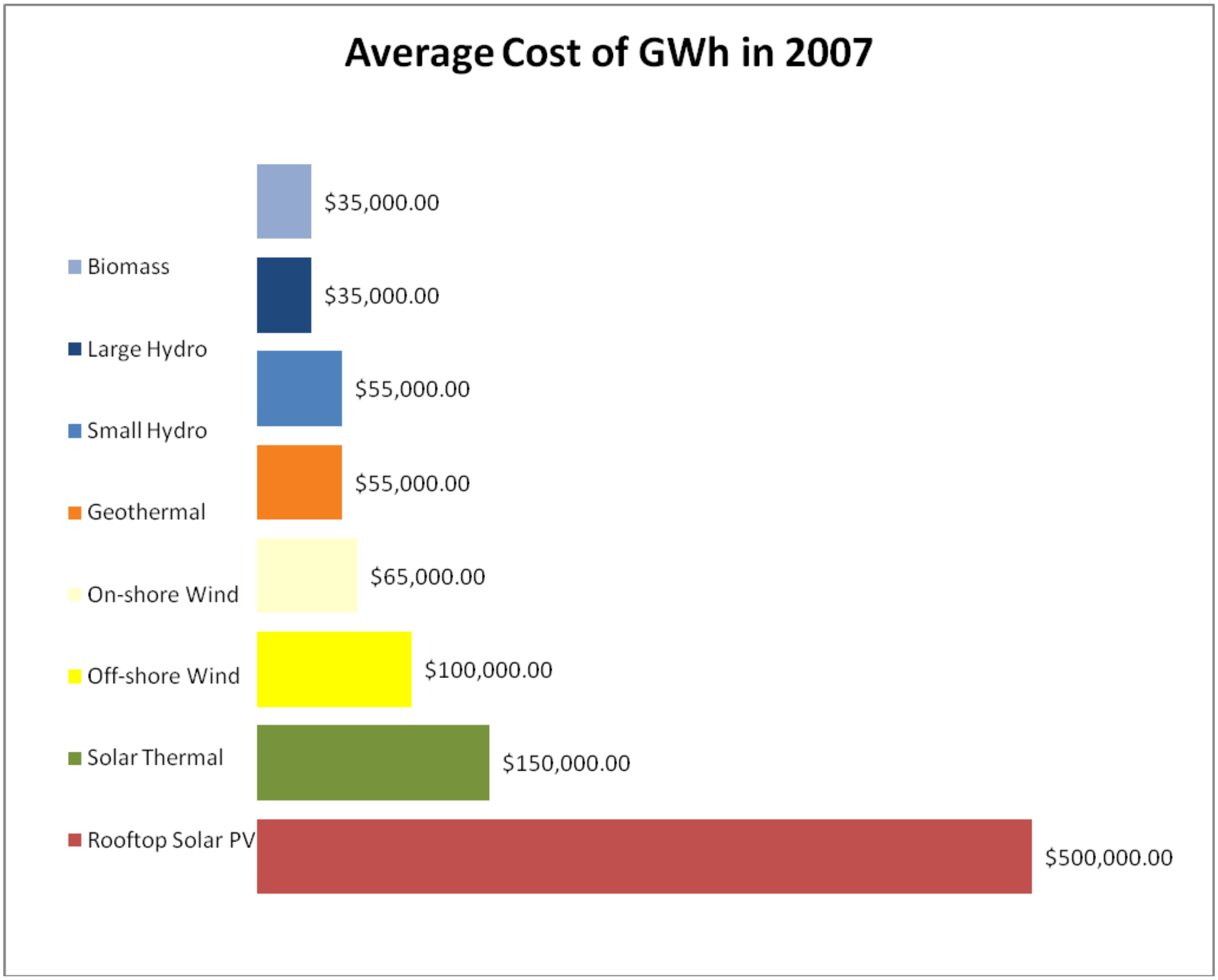


Figure 2



Graphs: Scott Templeman **Source: Energy Information Agency 5/08 (1)**

Figure 3



Graph: Scott Templeman **Source: REM21 (5)**

Figure 4

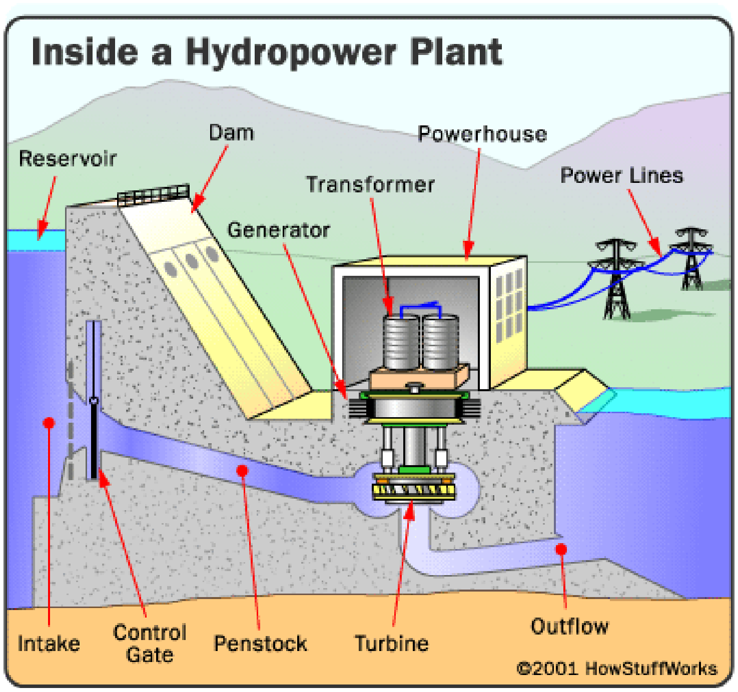
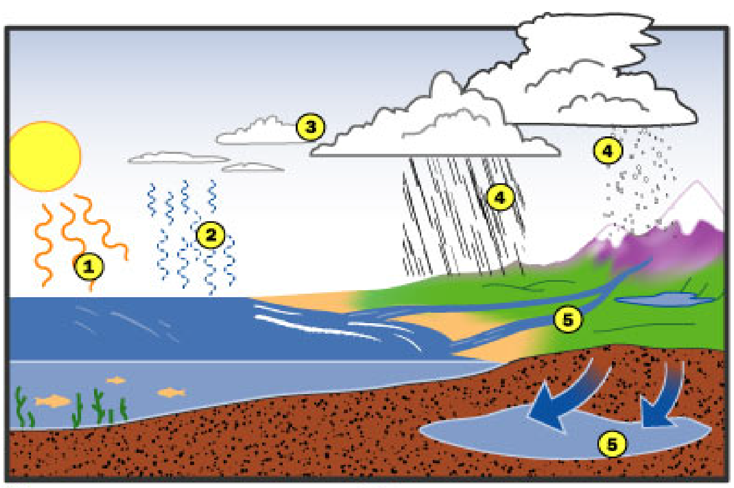


Figure 5



1. The sun heats the ocean.
2. Ocean water evaporates and rises into the air.
3. The water vapor cools and condenses to become droplets, which form clouds.
4. If enough water condenses, the drops become heavy enough to fall to the ground as rain and snow.
5. Some rain collects in groundwells. The rest flows through rivers back into the ocean.

Source: Howstuffworks.com (3)

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