The Oil Drum: Net Energy

Discussions about Energy and Our Future

Wave/Geothermal - Energy Return on Investment (EROI) (Part 6 of 6)

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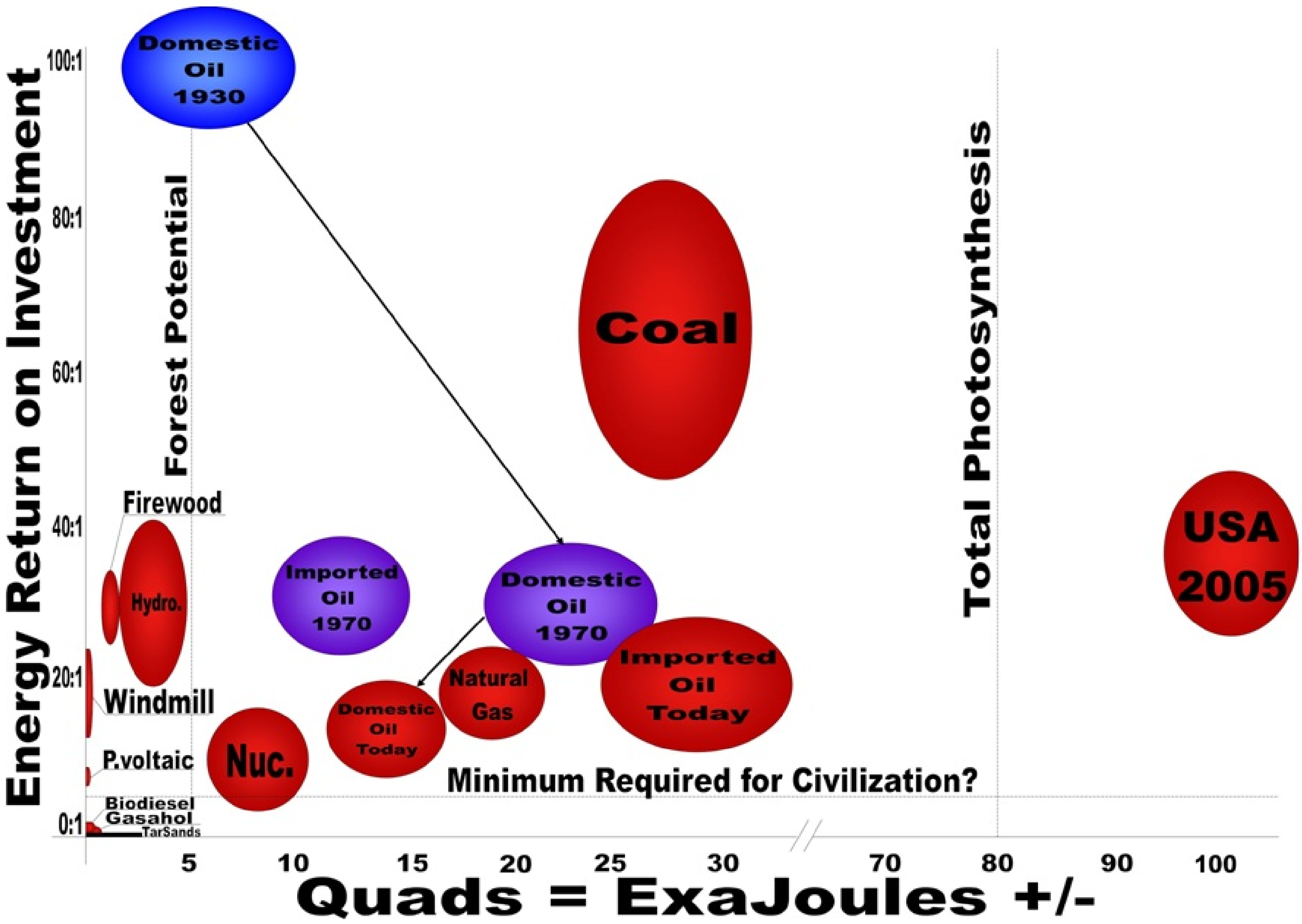
This is the final piece of a series on Energy Return on Investment from Professor Charles Hall's EROI Workshop at SUNY. Today's papers outline the energy technologies of wave and geothermal power, concluding a 5 part series that has looked at Why EROI Matters, Natural Gas and Imported Oil, Tar Sands and Shale Oil, Nuclear Power, and Passive Solar, Photovoltaic, Wind, and Hydro-electric. Previously, Professor Hall also wrote the thought provoking, At $100 Oil, What Can the Scientist Say to the Investor. Forget not about the simple 'balloon graph' below of EROI x Scale for fossil and renewable energy sources that this project is attempting to update with the help of theoildrum.com readership.



INTRODUCTION

by Charles A. S. Hall

Most of the energy sources that we use or might use are dependent directly or indirectly upon the sun. This includes wave energy which is derived from wind (e.g. the sun). Nuclear, geothermal and tidal energies are different in that they depend upon nuclear decay within the Earth or Earth's materials or, in the case of tidal, the processes of celestial motions. The advantage of these energies are that they are truly immense. The main disadvantages are that they are, with a few exceptions, dilute and hence very difficult to extract energy from. Another issue is that for some forms (e.g. heat from the ground) high quality energy (electricity) must be invested to extract low quality energy (heat), which can be a losing proposition even if the direct EROIs are positive. These issues for many situations imply generally low EROIs and hence low profitability. On the other hand some hot steam procedures in very favorable sites have high EROI and generate high quality electricity via investment of general engineering and materials, which implies lower quality investment energy. So unless these most favorable circumstances can be applied more generally or better methods are derived it is likely that development will be quite slow. On the other hand if and as EROIs from other fuels continue to decline they might be increasingly attractive. Tidal energies are likewise potentially enormous but there are few operational plants and we have not examined them. Daniel Halloran summarizes here such information as he could find on EROIs of various geothermal and wave energies. They are interesting but remain more as potential than realized energy and appear unlikely to effect our energy situation significantly for decades, if ever. As usual we seek your critiques and, especially, other hard literature that we missed.

APPENDIX H.

GEOTHERMAL ENERGY SUMMARY

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Definition: Geothermal energy is the heat within the earth, which can be "mined" by extracting hot water or steam, either to run a turbine for the generation of electricity or for direct use of the heat itself (Brown and Garnish 2004; Dickson and Fanelli 2005).

Resource Base

Theoretical: The heat content of the earth has been estimated to be about 13 trillion EJ (Dickson and Fanelli 2005). That heat comes from radioactive decay inside the Earth. Obviously, most of this is not practical to exploit.

The 2000 World Energy Assessment estimates that "140 million EJ per year" could theoretically be tapped within a depth of 5 kilometres", with 5,000 EJ/yr being economical within 50 years (UNDP 2000). A recent MIT study estimated a stored thermal energy of 14 million EJ between 3 and 10 kilometers (Tester et al 2006). This energy could be tapped with enhanced geothermal systems (EGS), also known as Hot Dry Rock (HDR), which exploits the heat available at greater depths in the absence of groundwater.
Geopressured-geothermal systems could theoretically provide thermal energy from hot brine, mechanical energy from highly pressured fluid, and chemical energy from confined methane. The Gulf Coast of the United States has an estimated stored thermal energy of 11,600 EJ in

geopressured sedimentary basins (John et al. 2006).

There is not a consensus in the literature regarding resource base estimates.

Actual: World-wide capacity for direct use of geothermal heat is about 16-17,000 MWt and world-wide installed capacity of geothermal electricity generation is about 9,000 MWe. Currently, the only places being exploited for geothermal power generation are places where hydrothermal resources exist. In a hydrothermal resource, heat is transferred to groundwater at depths penetrable by drilling technology. No power is generated commercially using HDR. The world leader in geothermal electricity is the United States with a capacity of over 2800 MWe, which accounts for 0.36% of U.S. electricity production (GEA 2007). Growth of geothermal power capacity worldwide has slowed from 9% per year in 1997 (EERE 1997) to 2.5% per year in 2004 (Dickson and Fanelli 2005).

Geothermal heat pumps, which extract heat from the normally "warm" shallow soils or their water, have grown to over a million units world-wide, led by the U.S. with 600,000 (Lund et al 2004), accounting for most of the four-fold increase in direct use capacity between 1992 and 2000 (Brown and Garnish 2004). While the heat pump industry has continued to grow, total geothermal direct use has slowed to 6 or 7% growth (Bronicki and Lax 2004). Total use of geothermal energy world-wide was an estimated 2 EJ in 2000 (Sawin 2004). Geothermal heat is regional in availability. Countries such as Iceland, Japan, the Philippines, Costa Rica, and the United States, have successfully exploited the shallow geothermal energy available at plate boundaries (Huttrer 2001). Most of the terrestrial Earth does not have those conditions.

Although in theory ground heat is indefinitely renewable there is concern about the sustainability of geothermal systems. Technically, geothermal resources are not renewable, because heat is always removed faster than it is replenished by the heat source (Brown and Garnish 2004; Lee 2004). The most important US site is The Geysers in California which has shown signs of cooling with heavy use. Nevertheless, geothermal energy sources are constant and require no storage other than the earth.

Technology: The general technology is that of steam turbine power generation, with rare "dry-steam" reservoirs (vapor-dominated) being the ideal type of resource. Because most resources are not dry steam, technological improvements are necessary for the geothermal industry to continue to grow (Brown and Garnish 2004), possibly including improvements in enhanced geothermal systems.

EROI

The EROI for electricity generation from hydrothermal resources has been reported by a handful of researchers with a range of 2.0 to 13.0 (Table 1). Some conceptual EROI values have been calculated for HDR ranging from 1.9 to 39.0, and for geopressured systems with a range of 2.9 to 17.6. The ranges represent the lack of a unified methodology for EROI analysis and disagreements about system boundaries, quality-correction, and future expectations. No EROI values of geothermal direct use were found. Because they exploit and use lower-temperature resources rather than electricity generation, and are more universally applied, it is probably safe to assume higher EROI values for most direct use applications.

Economics

In addition to geography and technology, high capital cost and low fossil fuel costs are major limiting factors for geothermal development, especially for HDR and geopressured systems which are still in the developmental phases. A kilowatt-hour of electricity generated at The Geysers, the largest field in California, sells for 3-3.5¢, and many other plants are economically competitive at about 9¢ (MDEQ 2007). Economic feasibility could be potentially improved in the U.S. with an extension of the Production Tax Credit (Gawell 2007) and with cascading geothermal systems, which use lower temperature waste fluids in succession for secondary applications (Lee 2004).

Environmental and Social Impacts

Positives: Reduced emissions and low land area compared to fossil fuel plants, employment benefits, decreased dependence on foreign energy for countries rich in geothermal resources (EERE, No Date).

Negatives: Small danger of air, water, thermal, and noise pollution, erosion and solid waste buildup. Subsidence, hydrothermal eruptions, aesthetic disruptions, local or indigenous objection, and changes of surface manifestations are rare and site-specific. There is also a controversial possibility of induced seismicity.

Prospects: The limited hydrothermal resources are unlikely to become a silver bullet solution to meet increasing global energy needs but could continue to be important regionally. If HDR were to become economically feasible, much larger, less-depletable geothermal resources would be opened up worldwide, potentially increasing EROI, geographic relevance, and long-term sustainability of geothermal power, with an estimated increase in production of a factor of ten or more (Tester 2006). Geothermal heat pumps already seem to be generating net thermal energy on small scales and are nearly limitless geographically.

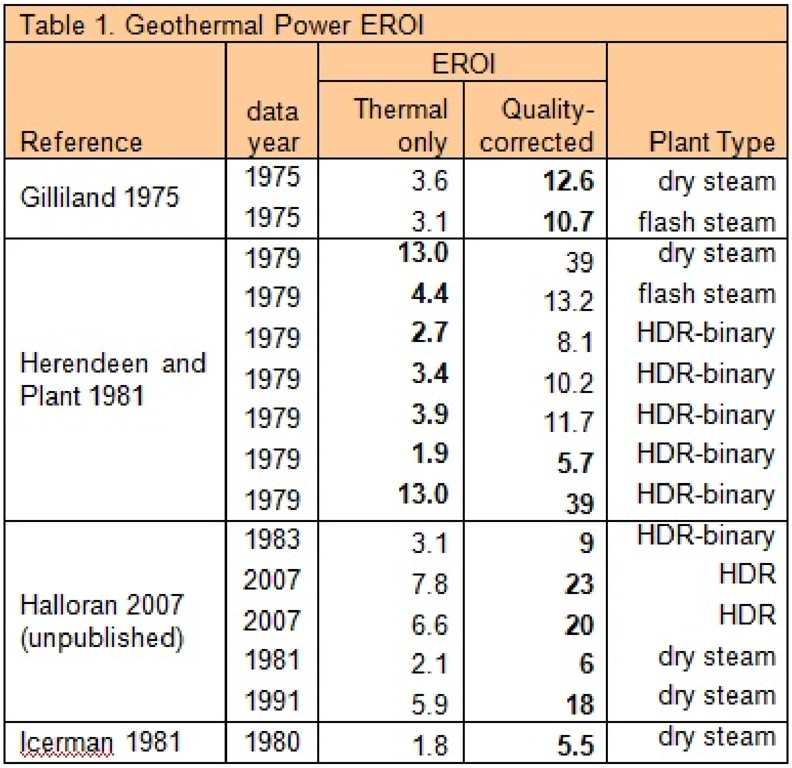

Table 1. Geothermal Power EROI

Reference	data year	EROI		Plant Type
		Thermal only	Quality-corrected	
Gilliland 1975	1975	3.6	**12.6**	dry steam
	1975	3.1	**10.7**	flash steam
Herendeen and Plant 1981	1979	**13.0**	39	dry steam
	1979	**4.4**	13.2	flash steam
	1979	**2.7**	8.1	HDR-binary
	1979	**3.4**	10.2	HDR-binary
	1979	**3.9**	11.7	HDR-binary
	1979	**1.9**	**5.7**	HDR-binary
	1979	**13.0**	39	HDR-binary
Halloran 2007 (unpublished)	1983	3.1	**9**	HDR-binary
	2007	7.8	**23**	HDR
	2007	6.6	**20**	HDR
	1981	2.1	**6**	dry steam
	1991	5.9	**18**	dry steam
Icerman 1981	1980	1.8	**5.5**	dry steam

Table 1. Geothermal Power EROI

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APPENDIX I.

WAVE ENERGY: Potential, EROI, and Social and Environmental Impacts

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INTRODUCTION

Wave energy is solar energy concentrated by the wind (Thorpe 2004), which can be converted into mechanical energy for the generation of electricity. Wave energy has been a part of the renewable energy discussion since the 1970s (Duckers 2004), but has yet to materialize as a viable option for large-scale power generation. It can have a high power density (storm waves up to 1700 kW per meter of wave crest length) depending on the speed, duration, and fetch (unimpeded distance over water) of the wind (Duckers 2004). Because of this high power density, and more recently, its relatively low environmental impact, wave energy research and development continues in many countries, most notably the UK, Japan, Norway, and Portugal (Thorpe 2004).

HISTORY

During the energy shocks of the 1970s, wave energy research was mainly government funded and academic in nature. After tapering off for a few decades, it is beginning to reemerge, this time led by small engineering companies (Thorpe 2004).

RESOURCE BASE AND USE

The wave energy resource base is highly regional in potential. Estimates of the global potential vary widely for reasons that we do not know (Table 1) but many agree that there is a significant exploitable energy source in the waves, especially between 30 and 60 degrees latitude. Wave intensity at these latitudes is greatest in the winter, corresponding with the seasonal peak in electricity demand (Lemonis 2004). Tropical regions have some potential because of the prevailing steady trade winds, but power densities are generally not as high (Thorpe 2004). As with most "environmental" energies a large problem is that the supplies cannot be counted upon, but is at least partially intermittent.

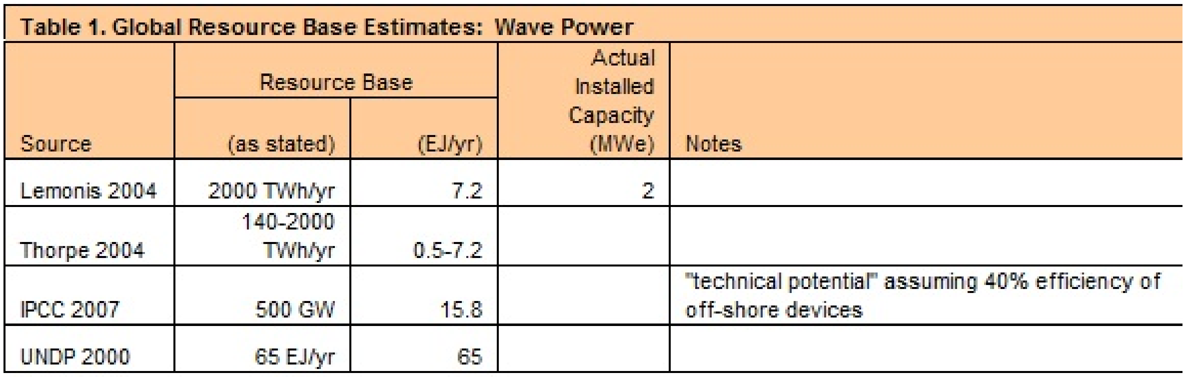

Table 1. Global Resource Base Estimates: Wave Power

Source	Resource Base (as stated)	Resource Base (EJ/yr)	Actual Installed Capacity (MWe)	Notes
Lemonis 2004	2000 TWh/yr	7.2	2	
Thorpe 2004	140-2000 TWh/yr	0.5-7.2		
IPCC 2007	500 GW	15.8		"technical potential" assuming 40% efficiency of off-shore devices
UNDP 2000	65 EJ/yr	65		

Table 1. Global Resource Base Estimates: Wave Power

Regional differences in the direction, duration, and fetch of wind across the ocean combined with differences in ocean depths near shore cause certain areas to have greater wave power densities than others. Greater wave power densities (or levels) are more feasibly converted into useful mechanical energy. The illustration below shows the semi-latitudinal pattern of wave power density.

Average annual wave power levels as kW/m of wave front (Thorpe 2004)

Presently, there is very little wave power being generated anywhere in the world. Recently, a

Pelamis off-shore unit developed by the Scottish firm Ocean Power Delivery (OPD) was deployed off the coast of Portugal with a grid-connected capacity of 2.25 MW (Power tech 2007). This installment approximately doubled the previous worldwide capacity of about 2 MW that had existed in demonstration projects (Table 1).

There is significant wave potential in the Northeastern Pacific, and the State of Oregon has begun looking into options for exploiting it using technology developed at Oregon State University (Profita 2007). The United States is well behind Europe and Japan, despite estimates that the U.S. wave potential is twice that of Japan and nearly five times that of Great Britain (OEC 2006).

TECHNOLOGY

There are over 1000 patented techniques under development for converting wave energy into mechanical energy that can be used to generate electricity (Lemonis 2004). The challenge is the precise engineering required to enable a turbine or other moving part to move relative to the central structure (Duckers 2004). Because the physics of waves varies geographically and temporally, many technological solutions have been proposed, tested, and in few cases, implemented. They are generally classified according to their relative distances from shore.

EROI

Net energy analysis of wave energy appears to be non-existent. One study (Banjeree et al 2006) reports life cycle emissions of 21.67 g CO2 per kWh and energy payback time of just over one year for the Pelamis off shore device. Therefore, with an expected lifetime of 15 years per device, the Pelamis could be a sustainable net energy producer with an EROI of nearly 15:1. It is not known how much this would be reduced by including maintenance and other costs. This analysis does not account for the small scale of wave energy production and the inability to demonstrate significant commercial production to date.

ECONOMICS

There is optimism in the field about wave energy becoming economical in the near future (Duckers 2004; Margolis 2007), although the capital costs are very large. A kWh of wave energy costs about 20 to 30 cents to generate, but one expert compared the wave energy cost to that of wind 20 years ago (Profita 2007). Wind is now down to 4 to 6 cents per kWh. Reportedly, the best technology in the UK is producing at an average of 7.5 cents (OEC 2006). Although waves are more predictable than wind, the variability of the wind causes wave power stations to run at relatively low capacity factors, perhaps around 40% (Duckers 2004), compared to 95% or higher for geothermal energy, for example. This threatens the ability of production to pay back high costs. However, the capacity factor for wind power systems is lower than for wave energy, and the wind industry has been able to reduce costs significantly. In addition, waves are much more dense than moving air, meaning smaller turbines can generate the same amount of electricity (Profita 2007; Lemonis 2004). Smaller turbines should imply smaller cost. However, a major economic consideration is durability and plant lifetime, which may be greatest at near-shore pressure plants such as OWCs with fewer moving parts and less susceptibility to storm damage. In addition salt water implies a very difficult corrosion environment.

Overall there is little experience with wave energy and although the EROI appears moderately favorable the lack of experience and the irregular nature of the resource appears to have resulted in very little research. We have heard that there was one system built in Portugal that was destroyed by a storm but we cannot find a reference even from our Portuguese colleagues.

ENVIRONMENTAL IMPACTS

Positives: Little to no chemical pollution during operation and little to no land use (Lemonis 2004). These devices would have very low greenhouse gas emissions estimated at 11g of CO2 per kWh for near-shore schemes (Duckers 2004), and 21.67g per kWh for the off-shore Pelamis device (Banjeree et al 2006). This compares to a release of about xx KG of CO2 per kWh for coal-fired electricity production.

Negatives: These devices require very high construction costs. From a net energy perspective, the energy required to build the infrastructure may outweigh the small amount of electricity wave projects are capable of producing in the short term. Sever storms have dashed the hopes of some earlier projects, probably before serious energy has been returned. They may also alter coastlines by changing energetic patterns of waves (Lane 2007 may generate various environmental impacts, most of which are unknown. Other potential impacts, such as disruption of marine habitat and fish migration patterns, and sedimentation, are generally agreed to be minimal, but important considerations on an individual project basis.

SOCIAL IMPACTS

Noise pollution is usually low (Duckers 2004), but could be a problem in some situations (Thorpe 2004). There has been some concern about aesthetics (Lane 2007) and disruption of fishing, shipping, and boating (Lane 2007). These impacts would occur in both construction and operation.

PROSPECTS

Wave energy has yet to be demonstrated as a possibility for large-scale commercial power generation. However, with the rising costs of fossil fuels and increasing environmental concerns, a competitive wave industry, if developed, could be one of the most environmentally benign of the renewables. The most practical application for wave energy in the short to medium term could be on small, remote islands without easy access to fossil fuel shipments or the need for long transmission lines. The potential for these sorts of small but locally important projects seems highest in the UK, where wave power density is high and much of the research is centered. Ocean Power Delivery, the Scottish company that provided the 2.25 MW installation in Portugal, is planning a 3 MW project in Orkney, the small island systems off the north coast of Scotland (OPD 2007). There has also been research into potential uses for wave energy other than electricity, most notably desalinization and hydrogen generation.

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