OCEAN RENEWABLE ENERGY'S POTENTIAL ROLE IN SUPPLYING FUTURE ELECTRICAL ENERGY NEEDS

BY ROBERT THRESHER AND WALTER MUSIAL

INTRODUCTION

The world is facing enormous environmental issues as human consumption has begun to stress Earth's resources, and thus, our ability to sustain our existence in the way we are accustomed. In parallel with finding ways to mitigate the impact of climate change, we must address the important issue of depletion of conventional energy supplies. A diverse portfolio of energy sources must be developed that also achieves the needed atmospheric carbon reductions. Earth's ocean contains large amounts of untapped clean renewable energy resources that can play a significant role in our future energy portfolio. These resources are found in the waves, currents, tides, and ocean thermal gradients. Indeed, ocean energy sources could become the primary energy source for some resource-rich coastal communities.

WORLD ENERGY USAGE

Throughout recorded history, humans have energized their development of civilization, first with wood for heating, then with water and wind for grinding grain and pumping water. Then, nearly two centuries ago, we began using coal for heating and powering steam-driven machines for doing work and transporting people and goods. This technological step sparked a rapid increase in the rate of industrial development and a technological evolution. The increased use of fossil energy fueled our productivity and our ability to produce goods and services. During the last century, we have further evolved our technological skills and begun to use more versatile fuels like oil and natural gas that are easier to store and handle and that have less tangible residue for disposal after combustion. The unintended consequence of this increased use of the planet's carbon-based fuels is that these

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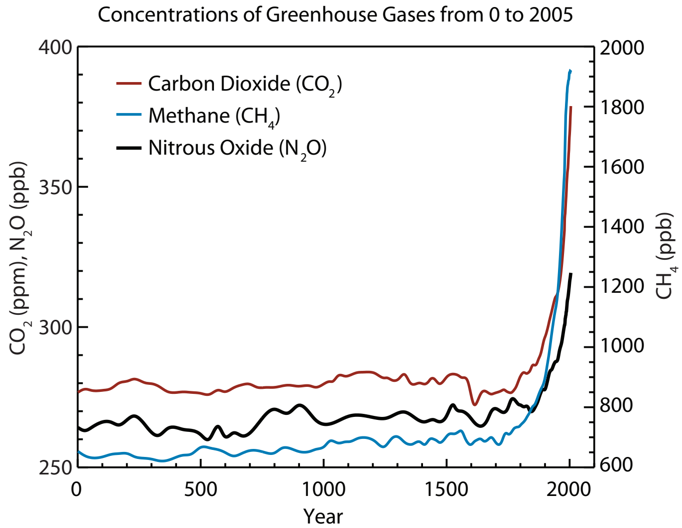

Figure 1. Concentration of important long-lived greenhouse gases in the atmosphere. Concentrations are given in parts per million (PPM) and parts per billion (PPB). *Source: FAQ 2.1, Figure 1 in Forster et al., 2007*

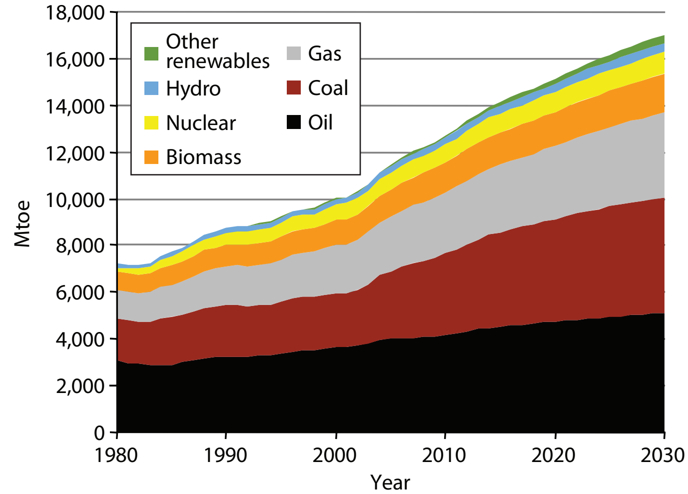

Figure 2. World primary energy demand from the International Energy Agency's World Energy Outlook reference scenario for 2008 (Tanaka, 2008).

combustion processes release great quantities of greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, that are mounting in the atmosphere (Figure 1). The higher the greenhouse gas concentration becomes, the higher the global mean temperature will rise. For this reason, it has become widely accepted that we must retard and stabilize the growth in CO_2 and other greenhouse gases, and there is much agreement that the best option for achieving stabilization is to deploy a portfolio of technologies, including ocean-derived energy, to achieve the target level.

The world's primary energy demand is currently about 12,000 Mtoe (Mtoe = Million tonnes of oil equivalent), and approximately 85% of that is met by oil, coal, or natural gas. Primary energy is the intrinsic energy content of a naturally occurring fuel prior to being subjected to a conversion process. The remaining 15% of the world energy demand is met by nuclear energy and renewable energy resources, which are currently dominated by biomass and hydropower. Figure 2 shows the projected world energy demand from 1980 to 2030 from a reference case scenario in the International Energy Agency's (IEA) World Energy Outlook for 2008 (Tanaka, 2008).

The reference scenario can be thought of as an extrapolation of today's energy usage trends. The slope of the overall demand curve shows an average growth rate of about 1.6% per year, a continuously growing demand for all of the carbon-based fuels, and a very small increase in renewable energy usage. If that trend continues, overall energy demand would almost double between now and 2050, and, consequently, carbon emissions would continue to grow unabated.

UNITED STATES ENERGY FLOWS AND USAGE

Energy usage trends in the United States parallel world trends, but the Energy Information Agency's Annual Energy Outlook for 2009 (EIA, 2009) projects a lower average growth rate of 0.5% per year between now and 2030. Figure 3 shows the current picture of energy flows in the United States.

Renewable energy currently accounts for only about 7% of the US energy supply, with the bulk of the renewable energy being provided by biomass and hydroelectric power (Figure 4). The fastest growing renewable energy

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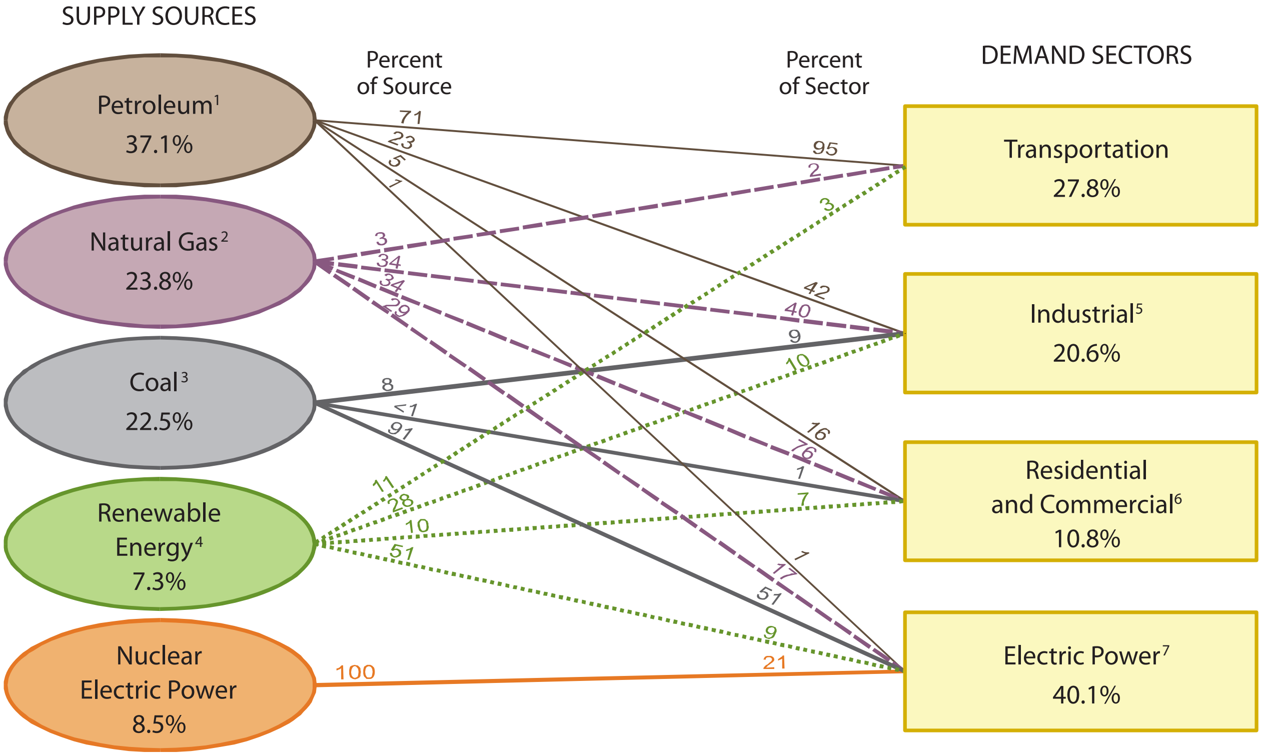

[1] Does not include the fuel ethanol portion of motor gasoline—fuel ethanol is included in "Renewable Energy."
[2] Excludes supplemental gaseous fuels.
[3] Includes less than 0.1 quadrillion Btu of coal coke net imports.
[4] Conventional hydroelectric power, geothermal, solar/PV, wind, and biomass.
[5] Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.
[6] Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
[7] Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.
Note: Sum of components may not equal 100 percent due to independent rounding.
Sources: Energy Information Administration, *Annual Energy Review* 2008, Tables 1.3, 2.1b-2.1f , 10.3, and 10.4.

Figure 3. The primary energy sources and demands by sector for the United States from the Energy Information Agency's (EIA) Annual Energy Review for 2008 (EIA, 2008a). The energy sources and demands are given in quadrillion Btu.

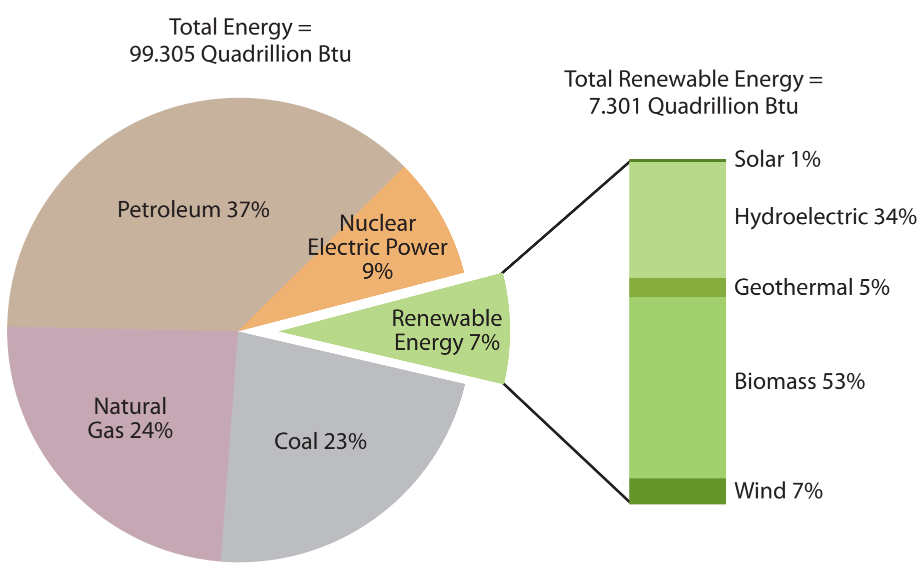

Figure 4. Energy sources in the United States in 2008 (EIA, 2009).

source in the electrical system is wind energy, which has demonstrated a yearly growth rate of 20% to 30% for the past decade, yet it only accounts for one-half quad of US energy in 2008 (1 quad = 1.06×10^{18} joules or a quadrillion BTUs; current US consumption is roughly 100 quads per year). Wind is considered a cost-competitive commercial technology, but even with 10,000 MW of new capacity added to the US grid in 2009, it is still just a tiny fraction of our energy supply. This example illustrates the enormity of the task of changing the resource base for our energy supply. To accomplish a significant change, and to accelerate the move away from carbon-based resources, we need to begin shifting sooner rather than later, and draw from differing resources to prevent a single source bottleneck.

POLICIES IN THE UNITED STATES

Although there is not yet legislation in the United States that mandates carbon control and stabilization, there is a clear intent to develop new energy policies that limit carbon dioxide emissions. The Obama Administration has set forth its intentions and put forth specific targets, or goals. In major addresses and speeches given during the past nine months, President Obama (Obama, 2009) laid out the following clean energy objectives and goals for the nation:

- Double the United States' supply of renewable energy in the next three years
- Invest 15 billion dollars a year to develop technologies like wind power and solar power, advanced biofuels, clean coal, and more fuel-efficient cars and trucks
- Cut our carbon pollution by about 80% by 2050, and create millions of new jobs
- Lease federal waters for projects to generate electricity from wind, as well as from ocean currents and other renewable sources
- Put Americans on the path to generating 20% or more of our energy from renewable sources by 2020

Figure 5 shows that to limit the increase in global temperature to only 2°C at best, we must follow the lowest (green) trajectory for carbon emissions. Following this lowest trajectory means that we must keep global carbon emissions below 490 ppm by cutting our carbon pollution by 80% by 2050, as indicated in the North American Leaders' Declaration on Climate Change and Clean Energy (http://www.whitehouse.gov/the_press_office/North-American-Leaders-Declaration-on-Climate-Change-and-Clean-Energy).

To summarize the energy and climate challenge, global energy demand is expected to almost double between now and 2050, and during the next 40 years we must transform our entire energy system to reduce carbon emissions to less than half of the 1990 level. To meet this daunting challenge, we will need to identify, evolve, and utilize the best low-carbon energy-generation technologies as rapidly as possible.

CO_2 emissions and equilibrium temperature increases for a range of stabilization levels

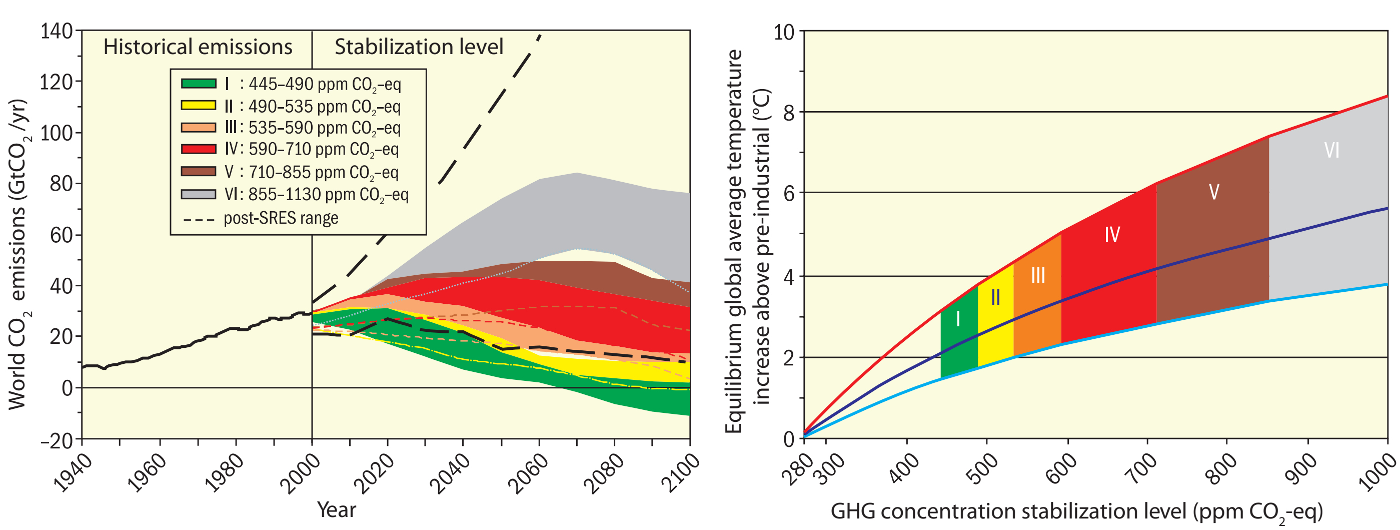

Figure 5. (Left panel) Global CO_2 emissions for 1940 to 2000 and emissions ranges for categories of stabilization scenarios from 2000 to 2100. (Right panel) The relationship between the stabilization target and global average temperature increase above preindustrial levels. Source: *Figure SPM 11 in IPCC, 2007*

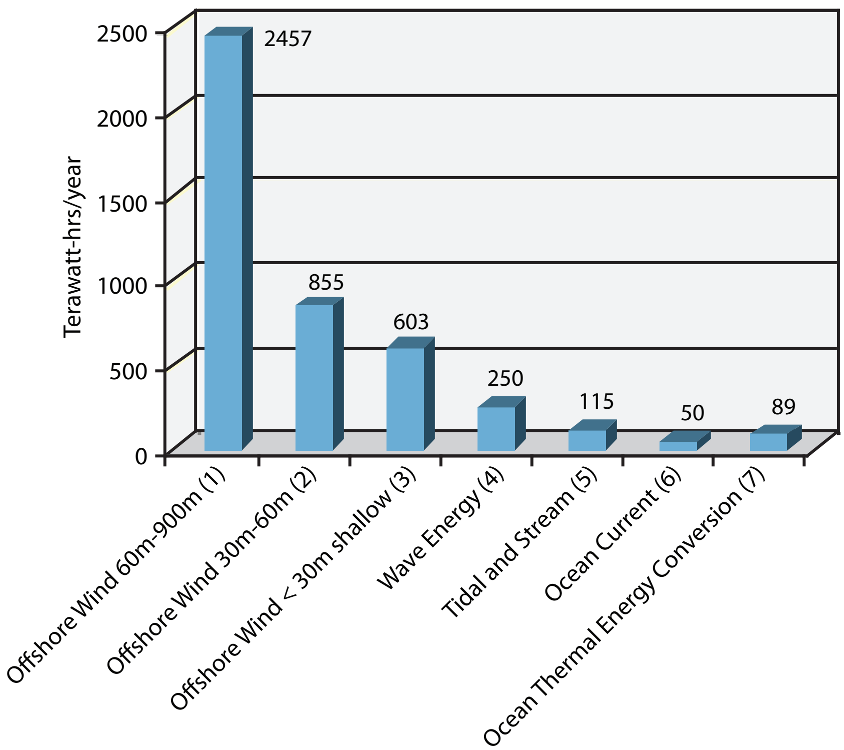

Figure 6. Estimated electric potential for US ocean renewable energy resources.

OFFSHORE RENEWABLE ENERGY

Offshore renewable energy sources include waves, tidal currents, ocean and river currents, ocean thermal gradients, and offshore wind. Worldwide, the potential to generate energy from offshore renewable resources is vast because many of the most populated regions with the greatest need for electricity are adjacent to the ocean and other major bodies of water. Thirty states in the United States border an ocean or one of the Great Lakes, and these states generate (and consume) 75% of the nation's electricity, that is, 3,108 terawatt-hours (TWh) of 4,157 TWh generated nationally (EIA, 2008b). Although the offshore renewable energy resources surrounding the borders of the United States are abundant, they are largely untapped because harsh ocean environments make the long-term survival of machinery more difficult and investments riskier. However, advanced ocean engineering and new technologies used for offshore oil and gas exploration, such as computers and controls, materials, better corrosion prevention, and improved energy storage and generation methods, are already enabling ocean devices to be technically viable and economically practical. Compared to dealing with the daunting challenges that accompany climate change, the difficulty of exploiting these low-carbon ocean energy sources is easily within our technical grasp.

Resource estimates for ocean energy sources are not well understood, but the world's ocean renewable energy resources are vast compared to our energy needs. However, it is the practical extraction potential—the amount of energy that can be effectively converted to electricity—that is currently most difficult to estimate. Because of the very nascent stage of the industry, projections of extractable energy from the world's ocean resources cannot be considered very accurate.

In the United States, the resource has been better quantified, but the resource estimate should still be considered preliminary. Figure 6 shows the major ocean energy sources and compares the estimated extractable energy potential. The Electric Power Research Institute (EPRI) and the National Renewable Energy Laboratory (NREL) estimate that the total combined potential for all ocean renewables in the United States exceeds national electric energy use. These sources include: offshore wind in three categories based on water depth—shallow water between 0 m and 30 m[1], transitional depths between 30 m and 60 m[2], and deep water between 60 m and 900 m[3]; wave energy[4]; electric

[1] Resource includes: Class 5 (approximately 7.5 m/s) wind or better; water depths between 0 m and 30 m; 60% resource area excluded; HI and AK not included; 0 to 50 nm from shore; 45% capacity factor. Source: NREL.

[2] Resource includes: Class 5 (approximately 7.5 m/s) wind or better; water depths between 30 m and 60 m; 60% resource area excluded; HI and AK not included; 0 to 50 nm from shore; 45% capacity factor. Source: NREL.

[3] Resource includes: Class 5 (approximately 7.5 m/s) wind or better; depths between 60 m and 900 m; 60% resource area excluded; HI and AK not included; 0 to 50 nm from shore; 45% capacity factor. Source: NREL.

[4] 15% of incident wave energy; 20% conversion losses; AK and HI included; wave climate 10 kW/m or better Source: EPRI.

energy from kinetic tidal and in-stream water currents[5]; open ocean currents[6]; and energy from ocean thermal gradients[7]. Other ocean energy sources such as salinity gradients at river mouths and marine biomass could also have some promise in the future, but the potential for these new resources has not yet been estimated.

Although most engineers and scientists would consider these numbers to be upper bounds to the actual extractable potential, the ocean energy potential is still highly significant if only a fraction were extracted. In 2008, the American Wind Energy Association and the Department of Energy published an energy deployment vision for wind energy to supply 20% of US electricity by 2030 (USDOE, 2008). In this scenario, 54 GW of the 20% electric capacity is provided by offshore wind, and most of this capacity does not begin to tap the vast deepwater wind resources. In 2007, EPRI estimated that marine hydrokinetic technologies, including wave and water current turbine technologies, could potentially provide a similar contribution to the current electricity supply provided by conventional hydroelectric power plants (EPRI, 2007)[8]. The EPRI report estimated that 13 GW of new hydrokinetic technologies could be deployed by 2025. Of course, ocean energy industries are not likely to mature until after 2025, so these deployment estimates are likely to be low compared to the resource potentials that are estimated in Figure 6. Based on these approximations, ocean energy could ultimately provide at least 10% of the electric supply of the United States. In coastal areas, where these resources are plentiful, these indigenous sources may, on a regional basis, represent a much larger fraction of the local energy supply and may indeed be the best long-term energy option.

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- http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-in-Newton-IA;
- http://www.whitehouse.gov/the-press-office/president-obama-announces-34-billion-investment-spur-transition-smart-energy-grid

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[5] Estimated from aggregate siting studies; 15% extraction permitted; in-stream river kinetic estimated by EPRI.

[6] Estimated from Coriolis Study, Aquantis, and Florida Atlantic University; Miami/Gulf Stream region only, 57% capacity factor; 10-GW rated capacity.

[7] OTEC resource is up to 2.5TW worldwide but most of the feasible areas with high thermal gradients are not in close proximity to US electric loads. US estimates were derived from (Nihous, 2007).

[8] EPRI wave, tidal, and in-stream study reports developed over the last five years are available online at: http://www.epri.com/oceanenergy/ (accessed April 6, 2010).