POLICY STRATEGIES FOR ADVANCING THE MARINE AND HYDROKINETIC ENERGY INDUSTRY

By

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ABSTRACT

Policy Strategies for Advancing the Marine and Hydrokinetic Energy Industry

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Marine and hydrokinetic (MHK) electricity generation systems are one of the newest technologies to emerge in the renewable energy industry. In order for the MHK industry in the United States to develop and become competitive with fossil fuels and more mature renewable energy technologies, it needs to have a supportive policy environment. Much of the past success of renewable energy technologies (like wind and solar) can be attributed to government revenue support policies (e.g. tax credits and grants). Many of these policies have not yet been offered to the MHK industry or are not designed to adequately accommodate the unique characteristics of MHK projects.

This analysis focuses on identifying opportunities for enhancing or restructuring the production tax credit (PTC), investment tax credit (ITC), and cash grants to optimize the potential benefits to the MHK industry. An extensive literature review was conducted to compare the policy experiences of other, more mature, renewable energy technologies. Similarities were drawn between MHK and those technologies to develop a set of recommended strategies for accelerating the development of the MHK industry in the United States.

The results of the analysis revealed that the treasury cash grant is the ideal incentive policy for ensuring optimal growth opportunities for the MHK industry. The

next best policy option is a 5-10 year transitional program from a 30% ITC to a 2.2 ¢/kWh PTC, based on a “switch-over” installed cost target of approximately $1.65 million/MW (assuming a 7.5% discount rate). Additionally, the policies will be most beneficial if they are implemented through a stable, long-term framework that includes regular adjustments to account for changing economic conditions and fuel prices. These policy options will provide the best opportunity for increasing MHK’s competitiveness with other renewable energy technologies and fossil fuels.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

In the face of climate change, economic instability, and threats to national security, the United States government has begun to invest in renewable energy technologies to reduce dependence on fossil fuels and improve environmental quality. Marine and hydrokinetic (MHK) energy is a rapidly growing industry offering a new form of clean, reliable, and domestic renewable energy. It includes energy from waves, tides, currents, and thermal gradients. The MHK industry is in its infancy, and, in order for it to be as successful in the U.S. as more mature renewable energy and fossil fuel technologies, it needs to take advantage of the lessons learned from these predecessors.

MHK provides an opportunity for zero greenhouse gas (GHG) emissions energy while simultaneously creating domestic jobs, diversifying the U.S. energy portfolio, increasing national security, and decreasing fuel price volatility that results from resource shortages and political conflicts. It is one of the most abundant sources of renewable energy on earth, due to its high power density. According to Rogner and colleagues, the global theoretical energy potential for MHK technologies is estimated to be approximately 7,400 EJ/yr, compared to 6,000 EJ/yr for wind and 3,900,000 EJ/yr for solar (Rogner, et al., 2000). Though MHK resource assessments are in the preliminary phases, the theoretical potential for ocean energy easily exceeds present human energy requirements (Edenhofer, et al., 2011). The high power density of MHK means that the technologies require fewer and smaller devices than other renewable energy technologies, enabling smaller project footprints, reduced environmental impacts, and ultimately lower installed costs per kWh (Bedard, 2009). Additionally, some MHK resources offer a highly predictable and consistent form of renewable energy, which enable them to help balance grid load. Furthermore, preliminary studies have shown that MHK has the potential to be one of the most environmentally benign forms of renewable energy (Cada, et al., 2007). Lastly, according to a 2011 Intergovernmental Panel on Climate Change (IPCC) report, climate change is not anticipated to have significant impacts on the size or geographic distribution of ocean energy resources, so estimates of future generation capacity can be relied upon with confidence (Edenhofer, et al., 2011). This information is discussed further in the background information presented in Chapter 2.

Several barriers stand in the way of strong and continuous growth for the MHK industry in both the U.S. and abroad, including: regulatory authority/jurisdiction conflicts, permitting requirements and procedures, environmental impact uncertainties, high initial costs, technical performance challenges, lack of testing centers, and undefined performance and testing standards. These barriers increase the costs of renewables compared to fossil fuel technologies, which are further distorted by the market failure to value the public benefits of renewables. As renewable energy technologies work together to address several mutual barriers, incentive policies are also needed to overcome this market failure and ultimately enable cost-competitiveness between renewables and fossil fuel technologies. The potential policy mechanisms for overcoming this market failure will be the focus of this thesis.

The intention of this analysis is to identify opportunities for enhancing or restructuring the existing U.S. federal policy framework to optimize the potential benefits to the MHK industry. Recognizing that there are several potential policy options throughout the world that are aimed at increasing renewable energy development, this analysis choses to follow a simplified approach by focusing on a few select existing U.S. federal policies, and will not cover policy tools most commonly used at the state level. Therefore, a variety of state-level incentive programs that currently exist in the U.S. have been excluded from this analysis, including Renewable Portfolio Standards (RPS) and Feed-In Tariffs (FIT). The proposed approach, which is based on revising existing policies rather than proposing new ones, is intended to facilitate implementation. For example, expanding eligibility for existing tax credit incentive programs to new renewable energy technologies, instead of developing entirely new tax credit programs would likely avoid a great deal of opposition and a lengthy congressional approval process. As discussed in section 5.1 of the literature review chapter, it is advantageous to use the existing system, rather than develop an entirely new system, because the rules and administration structure are already in place. Additionally, for tax policies in particular, the limited transparency of the tax code may reduce budget scrutiny, which could increase the likelihood of congressional approval. This is due to the fact that a tax credit program leads to reduced tax revenue for the government, rather than increased spending. The amount of reduced revenue is typically based on the success of the particular tax credit program, and can be difficult to predict ahead of time. As a result, tax credit programs can appear to have a smaller upfront price tag than grants and loan programs, potentially enabling them to gain more political support.

This analysis attempts to make recommendations for future MHK incentive policies by doing an extensive literature review that compares the experiences of other, more mature, renewable energy technologies, and drawing conclusions based on similarities between MHK and those technologies. Much of the past success of renewable energy technologies (like wind and solar) can be attributed to government revenue support policies (e.g. tax credits and grants). Many of these policies have not yet been offered to the MHK industry or are not designed to adequately accommodate the unique characteristics of MHK projects. This analysis focuses on identifying opportunities for enhancing or restructuring the production tax credit (PTC), investment tax credit (ITC), and cash grant to optimize the potential benefits to the MHK industry. **Figure 1** shows the installed capacity and history of federal R&D funding in the U.S. for wind, photovoltaic (PV), ocean thermal energy conversion (OTEC), and MHK.

The results of the analysis revealed that the treasury cash grant is the ideal incentive policy for ensuring optimal growth opportunities for the MHK industry. The next best policy option is a 5-10 year transitional program from a 30% ITC to a 2.2 ¢/kWh PTC, based on a "switch-over" installed cost target of approximately $1.65 million/MW (assuming a 7.5% discount rate). Additionally, it is essential that these policies be implemented long-term and include regular adjustments to account for changing economic conditions and fuel prices. These policy options will provide the best opportunity for increasing MHK's competitiveness with other renewable energy technologies and fossil fuels.

The following chapters will begin by providing background information on the MHK industry. Next will be a discussion about the barriers facing MHK, the theory behind push and pull policies used to overcome renewable energy barriers, and an overview of the current policy options available in the U.S. Then an extensive literature review will be presented that examines several different renewable energy market development policy analyses. Lastly, the policies discussed in the literature review chapter will be analyzed with respect to MHK, and recommendations and conclusions will be provided.

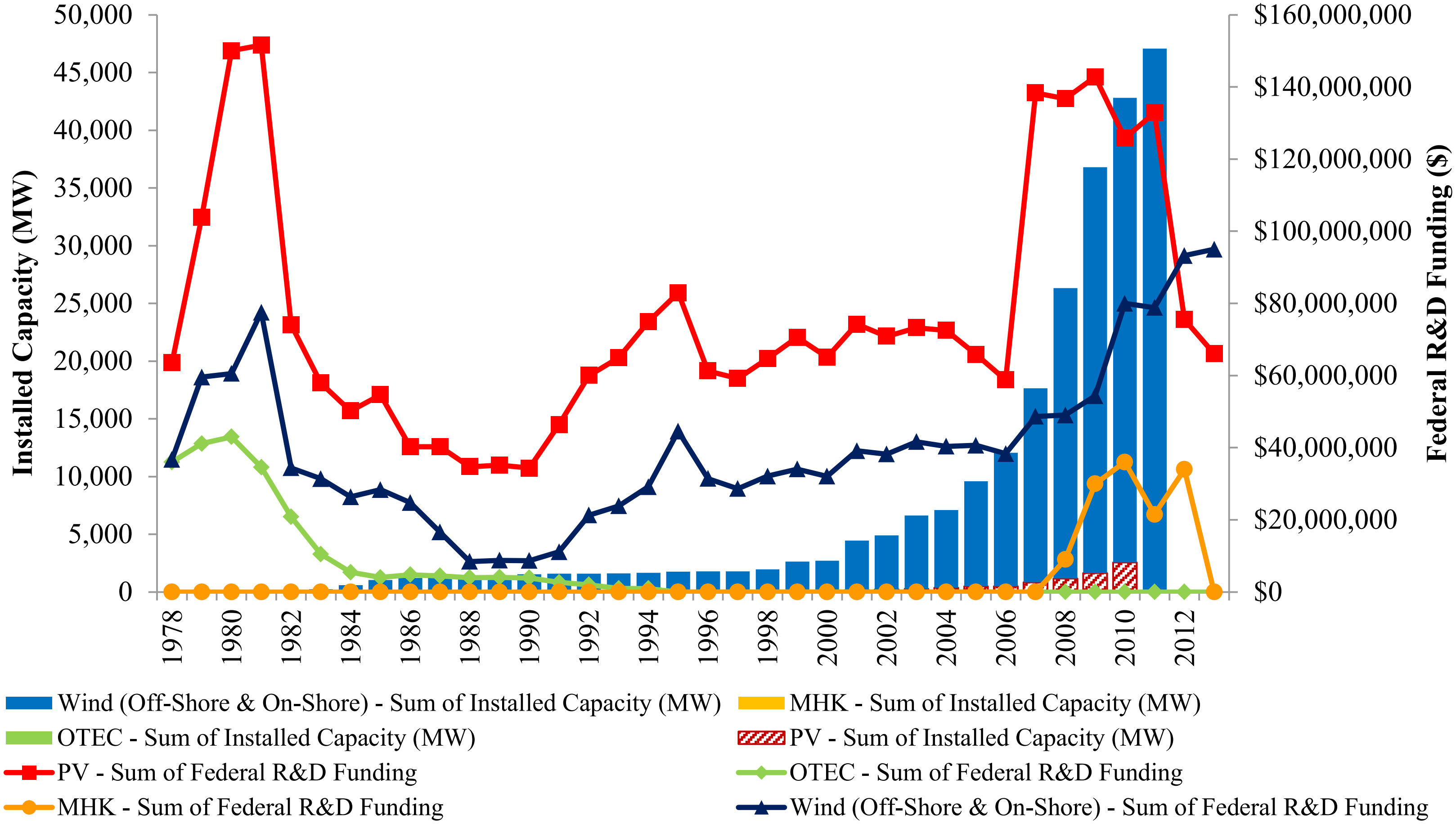

Figure 1: Installed capacity and federal R&D funding for wind, PV, OTEC, and MHK[1]

[1] See Appendix A for raw data and source information. Note – funding values are nominal and there is no installed capacity yet in the U.S. for OTEC or other MHK technologies.

2 BACKGROUND ON MHK

Marine and Hydrokinetic (MHK) energy resources are found in oceans, rivers, streams, estuaries, tidal areas, man-made waterways, and even some large lakes. The term MHK can be defined a variety of different ways, depending on who you ask. According to the Marine Renewable Energy Act of 2007, the United States considers MHK to include energy from waves, tides, currents, temperature gradients, and free-flowing water in man-made channels. The Act specifically excludes hydropower projects that use dams, divisionary structures, or impoundments. These excluded types of projects are generally grouped into a separate classification from MHK, called conventional hydropower. In addition to these resources, some organizations also consider off-shore wind and ocean salinity gradients to be a type of MHK resource (**Figure 2**).

Ocean energy is one of the newest forms of renewable energy being harnessed today. All ocean energy technologies, excluding traditional tidal technologies, are in the initial stages of development with no commercial scale deployments completed yet anywhere in the world. According to Edenhofer and colleagues, interest in these technologies began in the 1970s but progress was insignificant. In the early 2000s interest was again rejuvenated as climate change concerns grew. Currently, wave and tidal current technologies are the furthest along in development (Edenhofer, et al., 2011).

Despite being one of the most recent renewable energy resources being explored, MHK has always been one of the most abundant sources of renewable energy on earth, due to its high power density. For comparison purposes, the density of sea water is 832

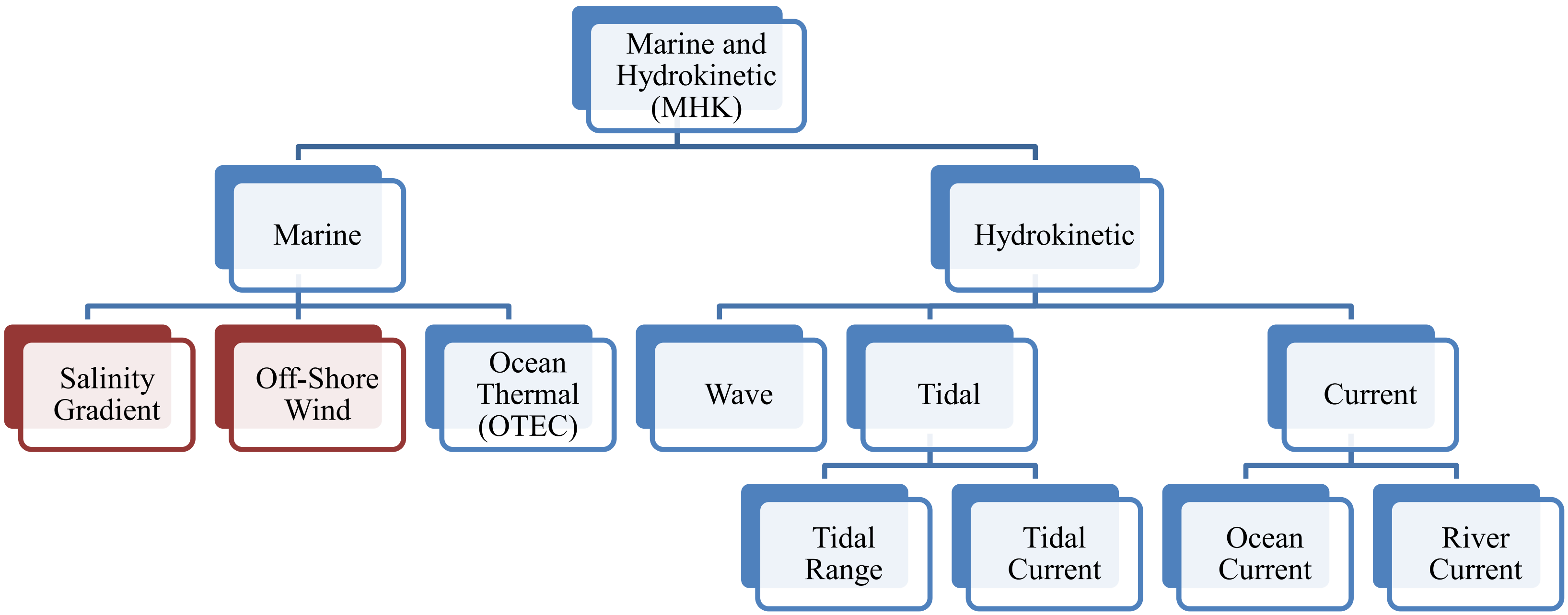

Figure 2: Marine and hydrokinetic energy classifications

times greater than air. To put this in context, water moving only 5 knots (5.8 mph) has the same force as air moving 350 km/h (218 mph). As a result, MHK devices can produce the same amount of energy as wind, but with fewer and smaller devices, leading to smaller project footprints and reduced environmental impacts (Global Marine Renewable Energy Conference, 2012). This suggests that MHK technologies have the potential to achieve a lower installed cost per kWh than wind once they have achieved a similar level of technological maturity (Bedard, 2009).

According to the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, the energy potential for ocean energy technologies is estimated to be approximately 7,400 EJ/yr (Edenhofer, et al., 2011). The report predicts that the 2050 global technical potential for ocean energy is estimated to range between 7 EJ/yr and 331 EJ/yr. Based on this information and projected deployments, an estimated 1,943 TWh/yr of electricity are expected to be delivered. The report notes that in 2009 approximately 10 MW of new ocean energy capacity was installed globally, bringing the total global ocean energy capacity to approximately 300 MW.

The IPCC report goes on to suggest that the variety of ocean energy technologies available can be used in complementary ways to meet energy demands. For instance, more consistent ocean energy technologies (e.g. ocean currents, ocean thermal energy, salinity gradients and, to some extent, wave energy) can satisfy base-load requirements (Edenhofer, et al., 2011). **Table 1** shows the integration characteristics for MHK and a variety of other renewable energy technologies.

Table 1: Summary of integration characteristics for a selection of renewable energy technologies[2] (Edenhofer, et al., 2011)

Technology		**Plant Size Range (MW)**	**Variability: Characteristic Time Scales for Power System Operation**	**Dispatchability**	**Geographical Diversity Potential**	**Predictability**	**Capacity Factor Range (%)**	**Capacity Credit Range (%)**	**Active Power, Frequency Control**	**Voltage, Reactive Power Control**
Bioenergy		0.1-100	Seasonal (depending on biomass availability)	+++	+	++	50-90	Similar to thermal and CHP	++	++
Direct Solar Energy	PV	0.004-100 modular	Minutes to years	+	++	+	12-27	<25-75	+	+
	CSP with Thermal Storage	50-250	Hours to years	++	+	++	35-42	90	++	++
Geothermal Energy		2-100	Years	+++	N/A	++	60-90	Similar to thermal	++	++
Hydropower	Run of River	0.1-1,500	Hours to years	++	+	++	20-95	0-90	++	++
	Reservoir	1-20,000	Days to years	+++	+	++	30-60	Similar to thermal	++	++
Ocean Energy	Tidal Range	0.1-300	Hours to days	+	+	++	22.5-28.5	<10%	++	++
	Tidal Current	1-200	Hours to days	+	+	++	19-60	10-20	+	++
	Wave	1-200	Minutes to years	+	++	+	22-31	16	+	+
Wind Energy		5-300	Minutes to years	+	++	+	20-40 onshore 30-45 offshore	5-40	+	++

[2] Notes: Assuming a CSP system with six hours of thermal storage in U.S. Southwest, in areas with direct-normal irradiance (DNI)>2,000 kWh/m2/yr (7,200 MJ/m2/yr)
Plant size: range of typical rated plant capacity
Characteristic time scales: time scales where significant variability for power system integration occurs
Dispatchability: degree of plant dispatchability (+ not dispatchable, ++ limited dispatchability, +++ fully dispatchable)
Geographical diversity potential: degree to which siting of the technology may mitigate variability and improve predictability, without substantial need for additional network (for example transmission and distribution infrastructure): +moderate potential, ++ high diversity potential.
Predictability: Accuracy to which plant output power can be predicted at relevant time scales to assist power system operation: + moderate prediction accuracy (typical <10% Root Mean Square (RMS) error of rated power day ahead), ++ high prediction accuracy.
Active power and frequency control: technology possibilities enabling plant to participate in active power control and frequency response during normal situations (steady state, dynamic) and during network fault situations (for example active power support during fault ride-through): + good possibilities, ++ full control possibilities.
Voltage and reactive power control: technology possibilities enabling plant to participate in voltage and reactive power control during normal situations (steady state, dynamic) and during network fault situations (for example reactive power support during fault ride-through): + good possibilities, ++ full control possibilities.

MHK offers additional unique advantages over other renewable energy technologies, including predictability, consistency, and minimized environmental impacts. According to a March 2011 presentation by the Pacific Northwest National Laboratory (PNNL) to the U.S. Department of Energy, MHK is even more consistent and predictable than wind or solar energy (Gerlofs, 2011). Because of the ability to forecast available energy days ahead of time, some MHK resources can help balance grid load. Another benefit of MHK technologies is location. Most MHK resources are located along coasts, and coastal cities tend to have higher electricity prices (**Figure 3**), making MHK more viable and attractive than other generation technologies located farther away, and with higher transmission costs. This could be particularly beneficial for remote and dispersed coastal communities and islands.

One of the primary benefits associated with utilizing renewable energy resources is their reduced environmental impact, when compared with traditional fossil fuels. Preliminary studies have shown that environmental impacts from MHK devices are expected to be minimal compared to both fossil fuels and other renewable technologies (Cada, et al., 2007). PNNL has developed a database and knowledge management system, called Tethys, which collects information on the environmental impacts from MHK technologies. In addition to minimizing impacts on marine animals, many MHK devices also have minimal impacts on humans. Compared to wind energy, several MHK devices are quieter (particularly devices that are fully submerged) because their parts move slower. MHK devices are also less visible from shore than wind turbines. Along with minimizing negative impacts on marine environments, MHK technologies may also

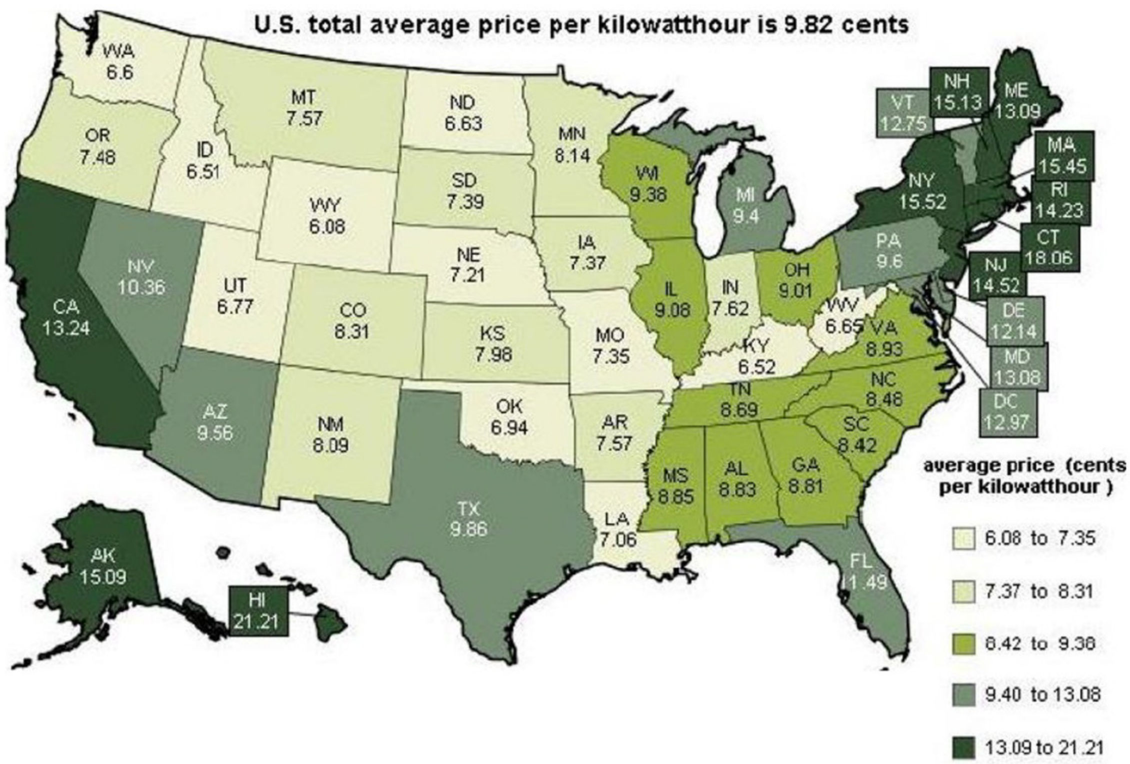

Figure 3: U.S. average price of electricity by state (2009) (Battey, 2011)

have a positive environmental impact due to their potential to reduce shore erosion (Global Marine Renewable Energy Conference, 2012). For instance, array effects of wave farms may impact coastal erosion and sediment transport (Hackett, 2008). Furthermore, the areas around MHK devices may increase biodiversity and attract fish, ultimately creating productive fishing grounds (Hackett, 2008). These are just a few of several potential positive socio-economic impacts from MHK technologies.

Climate change is often a significant motivator in the search for clean, renewable energy sources. The low GHG emissions associated with generation from renewable energy sources can help meet energy demands while slowing or even halting anthropogenic climate change. However, an often overlooked consideration is the impact of climate change on renewable energy technologies. Changes in precipitation and cloud cover may impact wind, solar, and biomass production (Edenhofer, et al., 2011). However, according to a 2011 IPCC report, climate change is not anticipated to have significant impacts on the size or geographic distribution of ocean energy resources (Edenhofer, et al., 2011).

Cost of Energy (COE) or Levelized Cost of Energy (LCOE) is one of the metrics used to determine the “success” of a renewable energy technology compared to other generation sources. COE/LCOE, which is typically measured in ¢/kWh, can be influenced by a number of factors, including: material costs, installation costs, operations and maintenance costs, resource intermittency, resource shortages of fossil fuels, foreign policy relations, etc. The difference between LCOE and COE is that LCOE takes into account the present value and future value of a product over its lifetime. LCOE is calculated by taking the total life cycle cost calculated over the anticipated service lifetime of the power plant, and dividing it by the present value of the electricity generated over the service lifetime of the power plant (Hackett, 2011). For a renewable technology to be successful, its COE/LCOE must be competitive with traditional fossil fuel technologies (e.g. coal, natural gas, petroleum, etc.); otherwise customers have no financial incentive to purchase their power from renewable resources. The sooner a renewable energy technology can become cost competitive with fossil fuels, the more successful it will be.

Learning curves (also known as experience curves) are often used to understand the cost competitiveness of renewable technologies by showing their COE/LCOE (¢/kWh) over time (typically several years).. **Figure 4** shows the DOE's target cost curves for MHK technologies. The estimated and target LCOEs identified by the DOE for MHK and other renewable technologies are shown in **Table D.1** and **D.2** of the appendix.

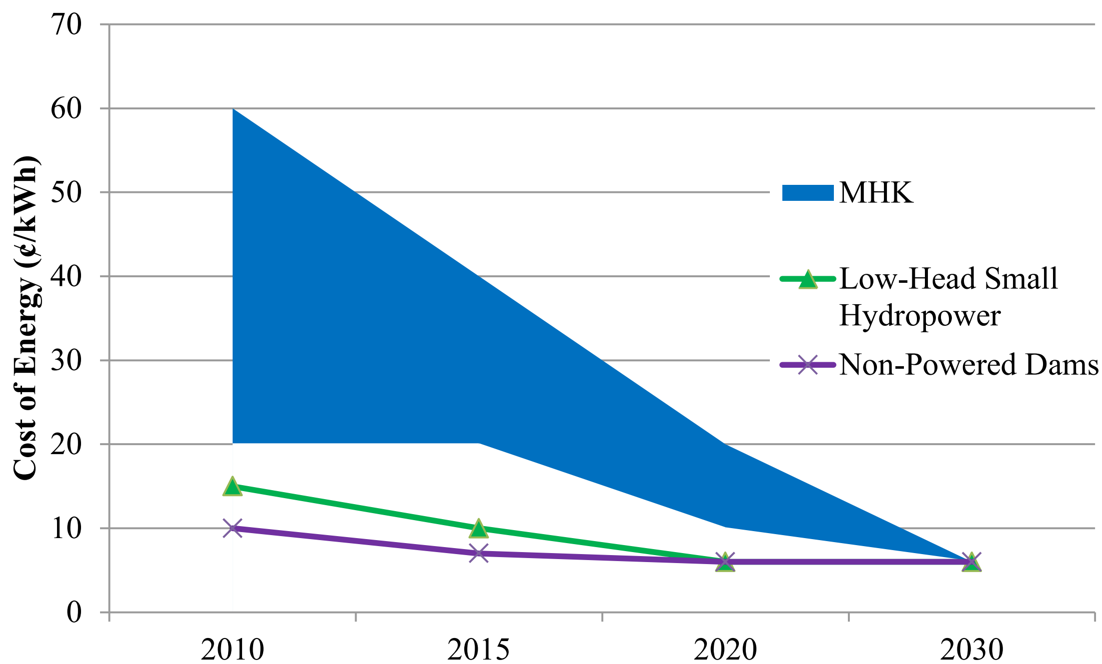

Figure 4: DOE target cost of energy for MHK (Zayas, 2012)

According to studies by the Electric Power Research Institute (EPRI), MHK will likely follow a similar learning curve as on-shore wind, and enter the market at a lower entry cost due to the advantage of higher power densities (**Figure 5**) (Bedard, 2009). Results of the studies revealed that on-shore wind technology experienced an 82%

learning curve, representing an 18% reduction for each doubling of cumulative installed capacity. Today, the status of MHK technologies can be compared to wind 15 to 20 years ago; close to starting its emergence as a commercial technology (Bedard, 2009).

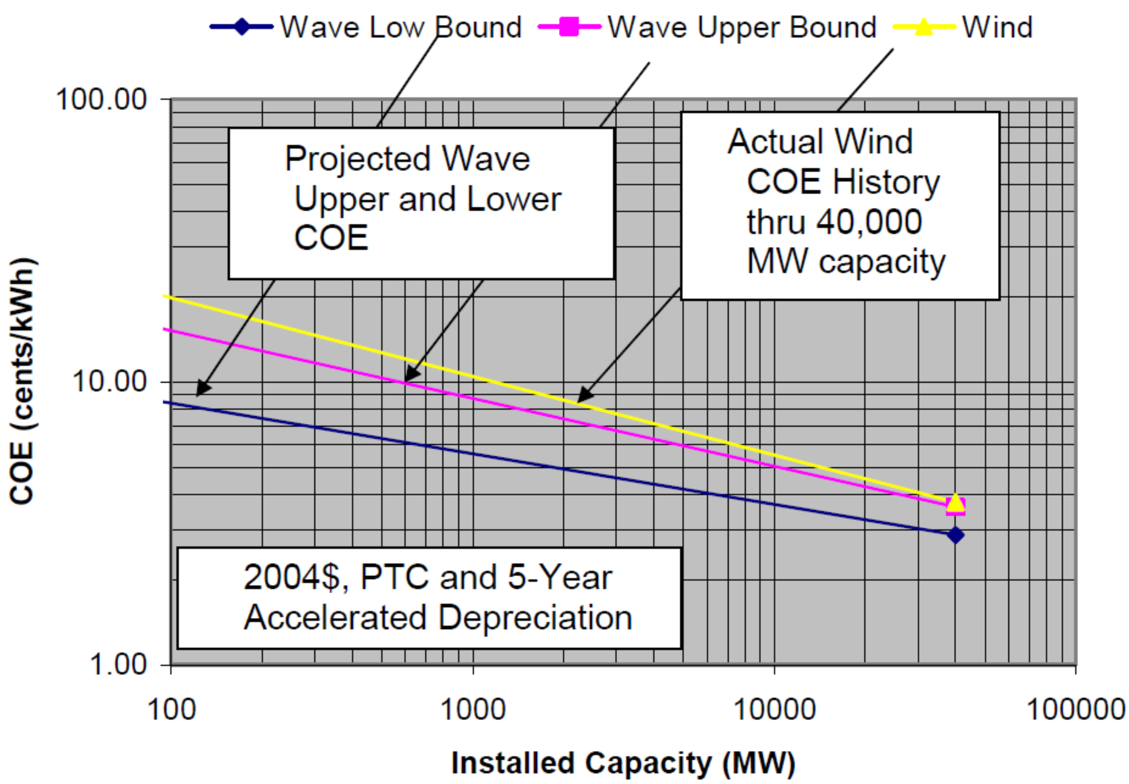

Figure 5: Projected MHK COE as compared to on-shore wind technology (Bedard, 2009)

Table 2 shows analysts Gauntlett and Asmus's anticipated and target LCOEs based on MHK installed capacity. According to DOE estimates, MHK needs to be between 6.2 ¢/kWh and 7.8 ¢/kWh (in $2009) in order to be competitive with fossil fuels (Battey, 2010). The DOE is currently working on creating roadmaps for each MHK technology to systematically bring down costs. A cost reduction cascade is shown for wave energy in **Figure 6**. Additionally, the DOE estimates for MHK component costs are shown in **Figure 7**.

Table 2: MHK Levelized Real COE (2012 U.S. dollars) (Gauntlett & Asmus, 2012)

Technology	**10 MW LCOE (¢/kWh)**	**100 MW LCOE (¢/kWh)**	**Target LCOE (¢/kWh)**
Wave	30	5 to 32	5
Tidal Stream	17	4 to 9	5
River Hydrokinetic	<65	~18	7 to 10
Ocean Current	~20-40	N?A	5
Ocean Thermal (OTEC)	>40	>20	15

Recently, interest in the MHK industry has been growing as the United States and other countries looks for clean, reliable, and domestic sources of energy (**Figure 8**).[3] MHK offers an opportunity for zero GHG emissions energy while simultaneously creating domestic jobs, diversifying the U.S. energy portfolio, increasing national security, and decreasing fuel price volatility that results from resource shortages and political conflicts. The following sections will summarize the differences between each of the different MHK resources, identify where these resources are located, and provide estimates of their available generation capacity. As of 2012, the U.S. DOE's 2030 target

[3] For more information see the U.S. Department of Energy Water Power Program's Marine and Hydrokinetic Technology Database http://www1.eere.energy.gov/water/hydrokinetic/default.aspx

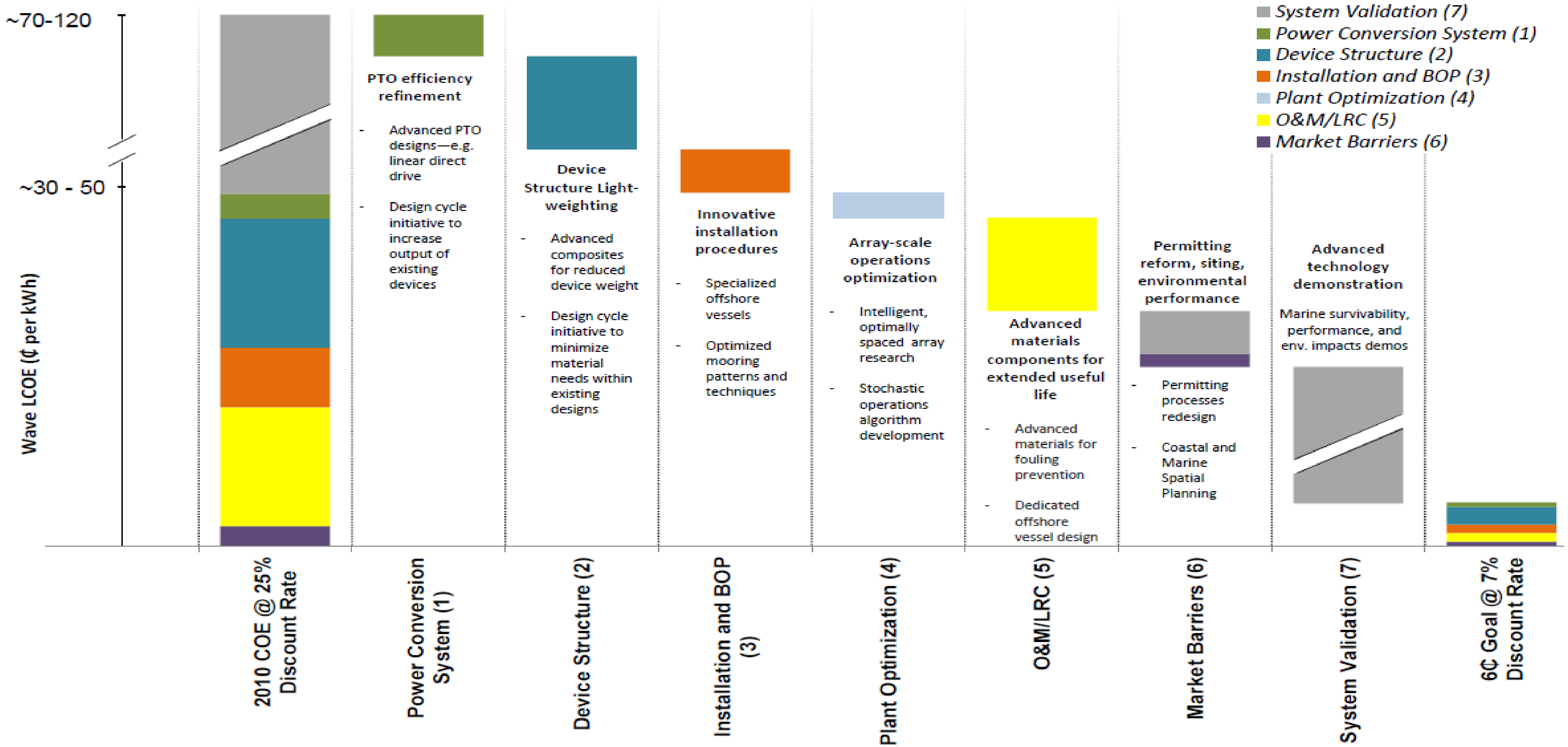

Figure 6: Wave energy cost reduction cascade (real 2011 U.S. cents) (Battey, 2011)

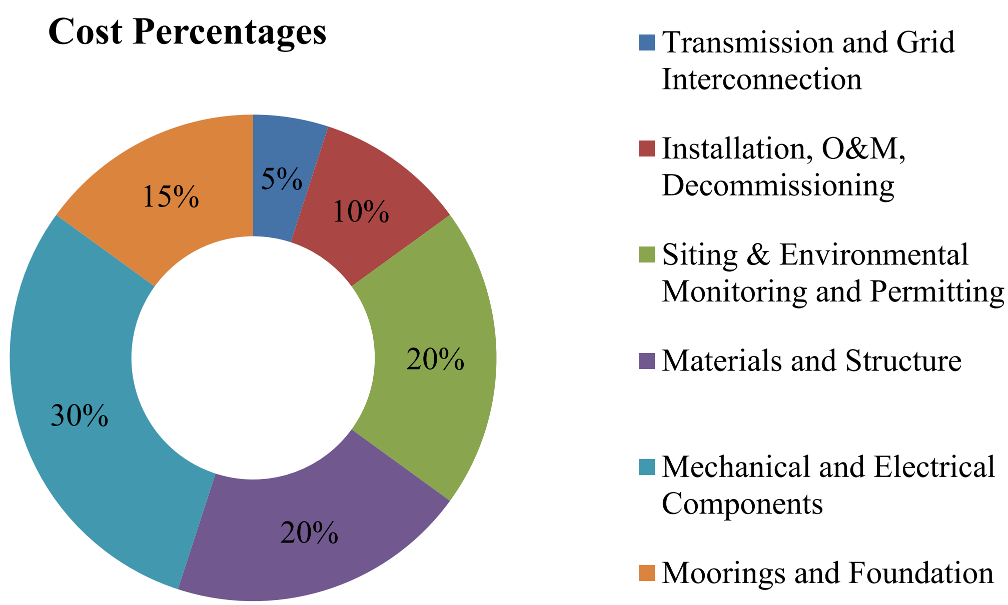

Figure 7: DOE estimates of future MHK component costs (Battey, 2010)

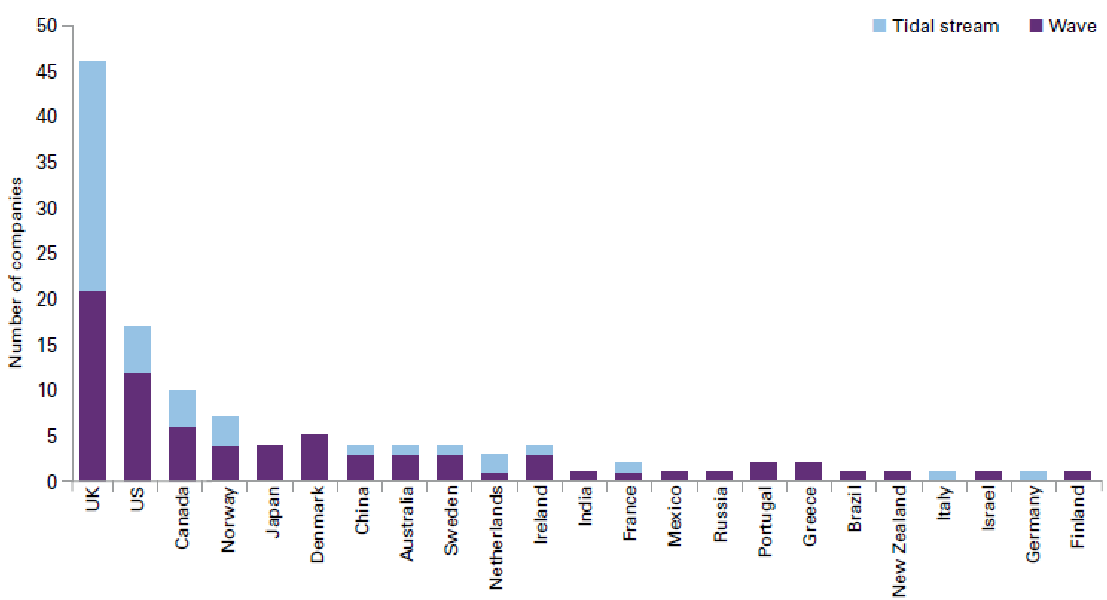

Figure 8: Global wave and tidal activity (Carbon Trust, 2011)

installed capacity for MHK technologies is 23 GW (Zayas, 2012). **Figure 9** shows the DOE's installed capacity goals for the U.S.

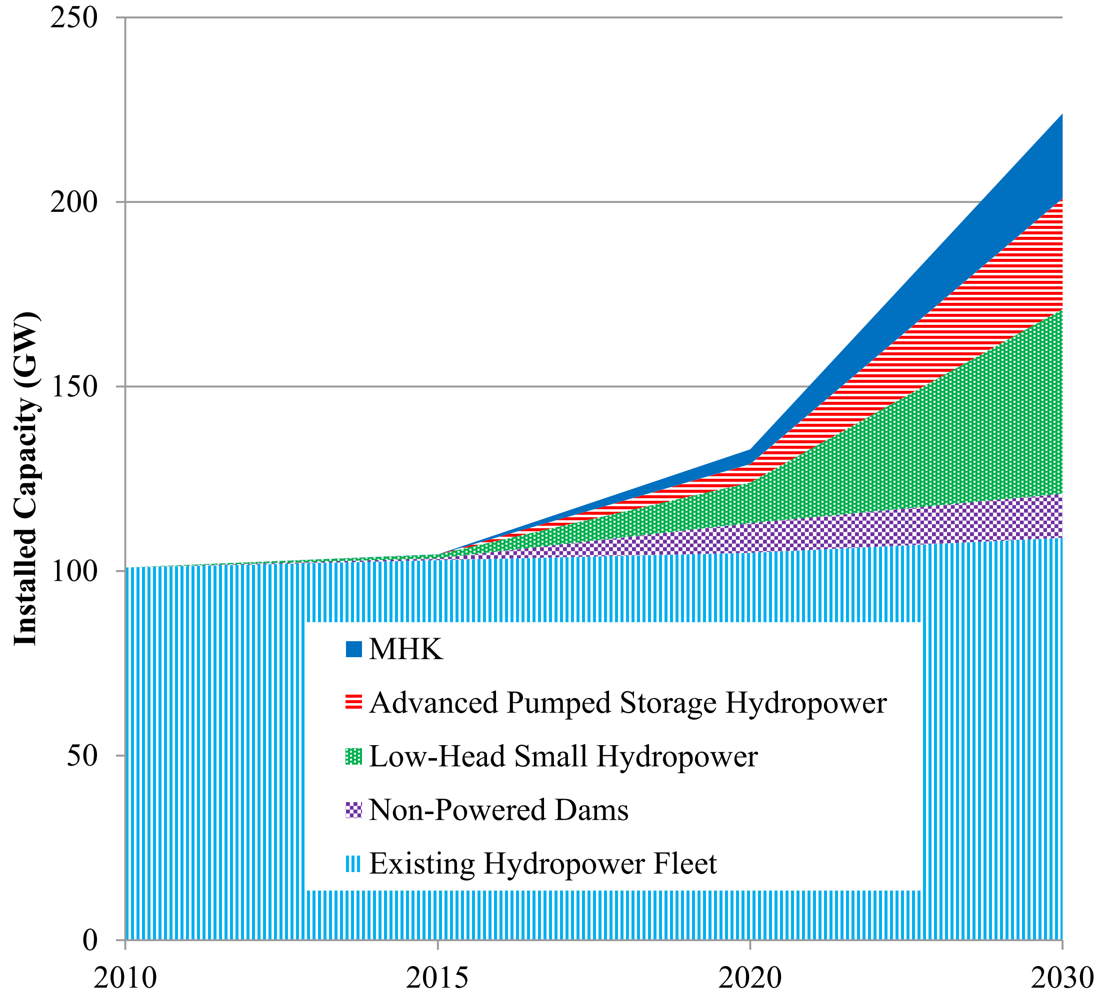

Figure 9: DOE Water Power Program installation goals for the U.S. (Zayas, 2012)[4]

[4] For raw data see **Table D.2** of the appendix

2.1 Wave Energy

Waves are caused by wind blowing over the surface of water. Wind comes from solar energy, so as long as the sun shines there will be wave energy available. This energy is available continuously - 24 hours a day, 365 days a year - though it varies in intensity. Even after the sun has set, wave energy is available because waves store energy and can transmit that energy thousands of miles with minimal losses. This continuity provides a unique advantage over wind and solar because wind velocities tend to decrease in the morning and solar energy is only available when the sun is up and when there are few clouds.

The type of energy available from waves is kinetic energy (i.e. energy from motion) and is derived from the changing height and speed of swells. The amount of energy available from waves, called the Wave Power Density or Wave Energy Flux, is approximated by the following equation:

Equation 1[5]: Wave Power Density (kW/m) $\boldsymbol{P \cong 0.5 \times H_s^2 \times \overline{T}_z}$

P = Wave Power Density (kW/m)
H_s = Significant Wave Height (m)
$\overline{T}_z$ = Mean Wave Period (s)

This formula is an approximation because it is based on statistically derived sea state parameters, while a more accurate formulate would take the product of the spectral

[5] (Bedard, 2010)

energy density and group velocity at a given frequency, and sum those products across all frequencies of the wave spectrum (Bedard, 2010). Waves oscillate at a low frequency whereby energy can be extracted and converted to a 60 Hertz frequency, and thus compatible with the electric grid. There are a variety of difference devices designed to capture wave energy: attenuators, overtopping devices, oscillating water column (OWC) devices, oscillating wave surge converters (OWSC), floating point absorbers, and submerged pressure differential point absorbers.

In general, the largest wave energy resources are located between the latitudes of 30° to 60° and along the west coasts of continents (**Figure 10**). In the U.S., the most significant wave energy resources are located along the coasts of the following areas: Alaska, Hawaii, Washington, Oregon, and California (**Figure 11**).[6] Wave energy resources vary seasonally and annually, depending on climate-driving factors such as El Niño and La Niña (Electric Power Research Institute, 2011). Historical wave power density variations for Eureka, CA and Nantucket, MA are shown below (**Figure 12** & **Figure 13**).[6]

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[6] For more information on wave energy resource locations and seasonal variations refer to the National Renewable Energy Laboratory's MHK Atlas http://maps.nrel.gov/mhk_atlas (The National Renewable Energy Laboratory (NREL), 2012)

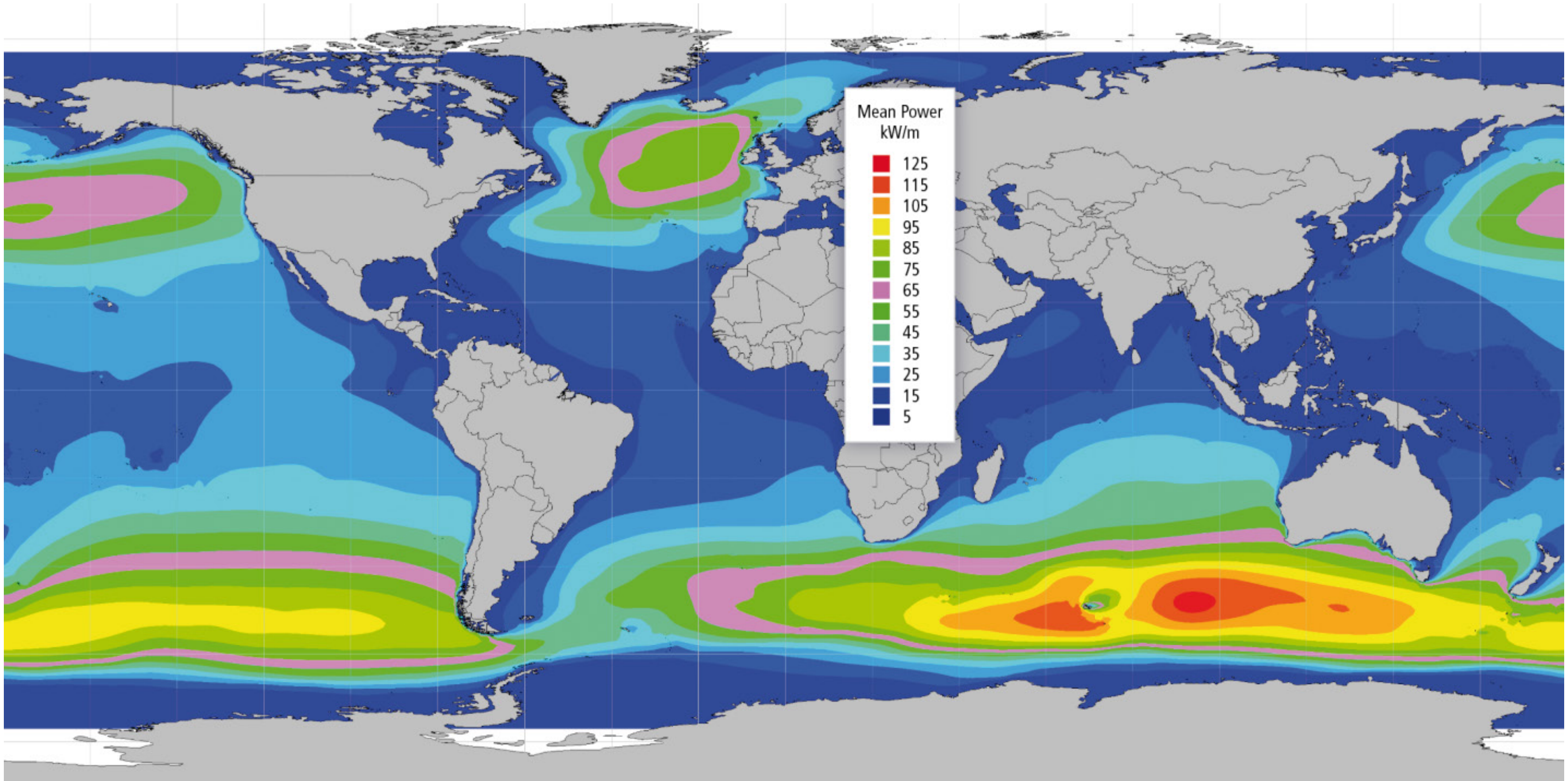

Figure 10: Global annual wave energy (kW/m) (Cornett, 2008)[7]

[7] From (Edenhofer, et al., 2011), original source (Cornett, 2008)

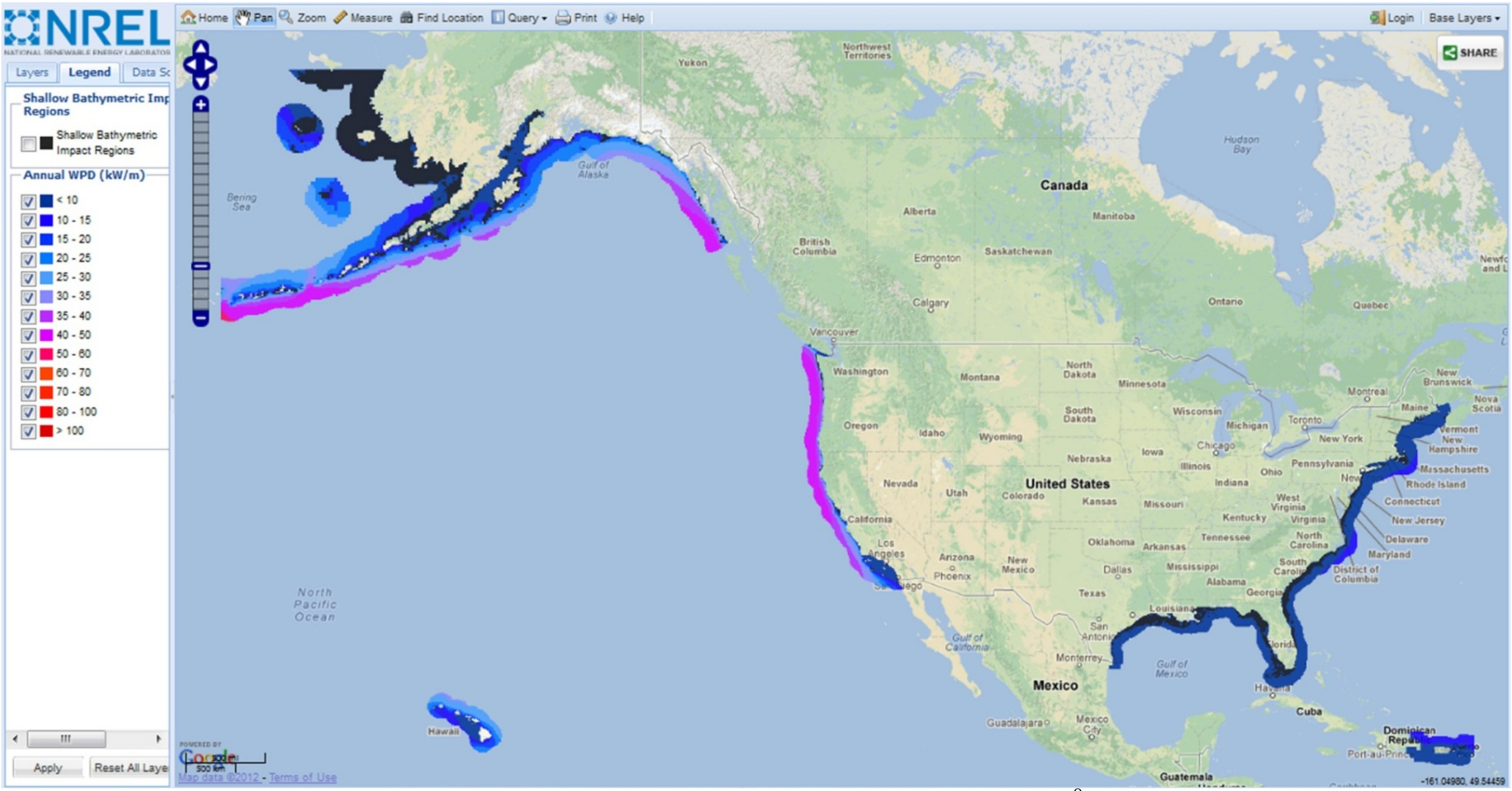

Figure 11: Map of U.S. Wave Power Density (kW/m)[8]

[8] Data sources: http://maps.nrel.gov/mhk_atlas; (Electric Power Research Institute, 2011)

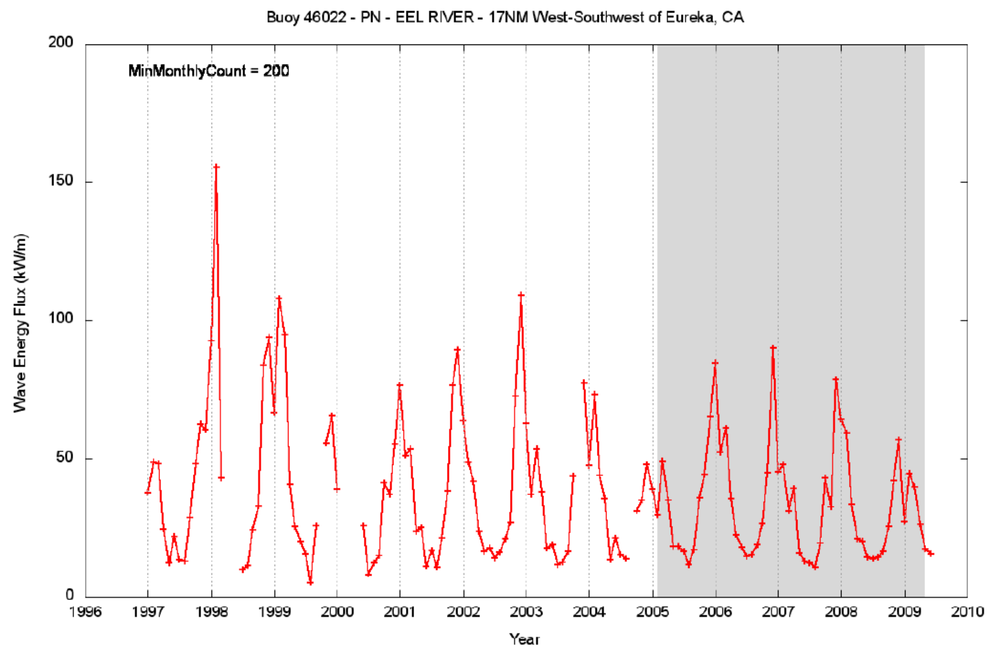

Figure 12: Historical wave power density (kW/m) variation for Eureka, CA (Electric Power Research Institute, 2011)

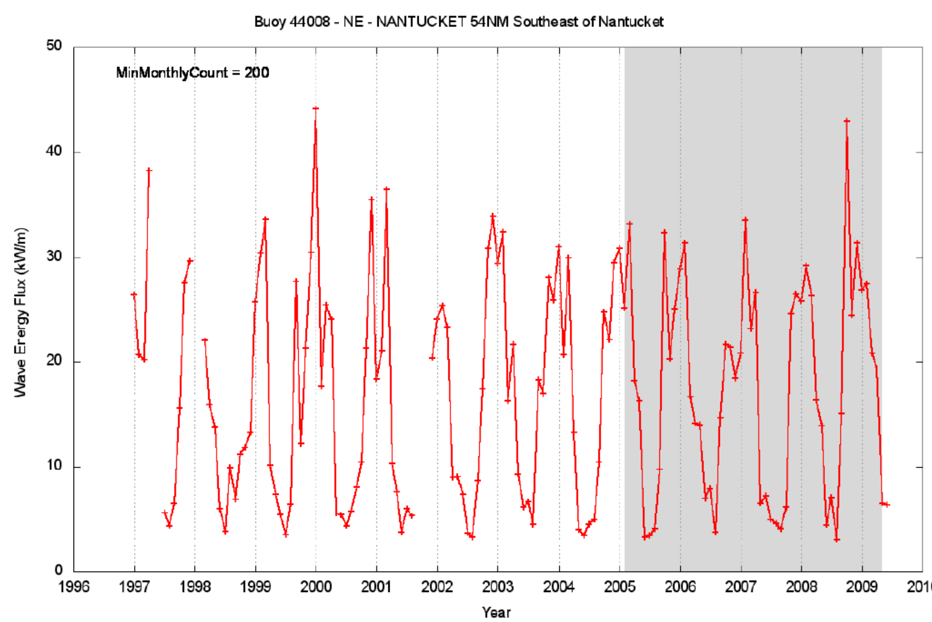

Figure 13: Historical wave power density (kW/m) variation for Nantucket, MA (Electric Power Research Institute, 2011)

The following tables provide a summary of the theoretically available (aka potential) and recoverable wave energy resources, both globally and in the U.S. The total theoretical wave energy potential is estimated to be 32,000 TWh/yr (Mørk, et al., 2010).[7] The global regional potential is shown in **Table 3**. Additionally, **Table 4** and **Table 5**, respectively, show the available and recoverable wave energy resources along the U.S. continental shelf edge (Electric Power Research Institute, 2011). The difference between available and recoverable energy is attributed to the fact that not all available wave energy can be recovered economically. In other words, it may be both technically and financially prohibitive to recover a portion of the available energy. Furthermore, **Table 5** shows only one of several possible combinations of capacity packing densitites, threshold operating conditions (TOC), and maximum operating conditions (MOC). Capacity packing densities range between 10, 15, and 20 MW/km. The range of threshold operating conditions are based on the following criteria:

TOC = 1 kW/m	Mildly energetic wave climates (annual average wave power density < 10 kW/m)
TOC = 2 kW/m	Moderately energetic wave climates (10 kW/m ≤ annual average wave power density < 20 kW/m)
TOC = 3 kW/m	Highly energetic wave climates (annual average wave power density ≥ 20 kW/m)

The device operational range is constrained to a 100-fold difference between the TOC and MOC in terms of wave power density, which is consistent with the operating range of proven offshore wind turbines. This means that the MOC is 100 times the the TOC (Electric Power Research Institute, 2011).

Table 3: Regional theoretical potential of wave energy (Mørk, et al., 2010)

Region	**Wave Energy TWh/yr (EJ/yr)**
Western and Northern Europe	2,800 (10.1)
Mediterranean Sea and Atlantic Archipelagos (Azores, Cape Verde, Canaries)	1,300 (4.7)
North America and Greenland	4,000 (14.4)
Central America	1,500 (5.4)
South America	4,600 (16.6)
Africa	3,500 (12.6)
Asia	6,200 (22.3)
Australia, New Zealand and Pacific Islands	5,600 (20.2)
TOTAL	**29,500 (106.2)**

Table 4: Total available wave energy resource breakdown by U.S. region (Electric Power Research Institute, 2011)

Coastal Region	**EPRI 2004 Estimate**	**Present Estimate Outer Shelf[a]**
West Coast (WA, OR, CA)	440 TWh/yr	590 TWh/yr (34% greater)
East Coast (ME thru NC)	110 TWh/yr	200 TWh/yr (82% greater)
East Coast (SC thru FL)	NOT ESTIMATED	40 TWh/yr
Gulf of Mexico	NOT ESTIMATED	80 TWh/yr
Alaska (Pacific Ocean)	1,250 TWh/yr	1,360 TWh/yr (9% greater)
Alaska (Bering Sea)	NOT ESTIMATED	210 TWh/yr
Hawaii	300 TWh/yr	130 TWh/yr (not comparable[b])
Puerto Rico	NOT ESTIMATED	30 TWh/yr
TOTAL	**2,100 TWh/yr**	**2,640 TWh/yr (26% greater)**

[a]Rounded to the nearest 10 TWh/yr for consistent comparison with EPRI 2004 estimate.
[b]EPRI's 2004 estimate for Hawaii was along the northern boundary of the U.S. Exclusive Economic Zone[9], as far west as the Midway Islands. The present estimate extends only as far west as Kauai, and encompasses the entire islands (not just their northern exposures).

[9] An exclusive economic zone (EEZ) is an offshore area where a country has special rights over the exploration and use of marine resources, including production of energy from water and wind. It spans outward 200 nautical miles from the coast.

Table 5: Total recoverable wave energy resource breakdown by U.S. region for capacity packing density of 15 MW per km and regionally optimal maximum and threshold operating conditions[a] (Electric Power Research Institute, 2011)

Coastal Region	**Outer Shelf Recoverable Resource (%)**	**Inner Shelf Recoverable Resource (%)**	**TOC[b]**	**MOC[c]**
West Coast (WA, OR, CA)	42	48	3	300
East Coast (ME thru NC)	65	81	2	200
East Coast (SC thru FL)	76	87	1	100
Gulf of Mexico	77	79	1	100
Alaska (Pacific Ocean)	39	52	3	300
Alaska (Bering Sea)	49	59	3	300
Hawaii	64	56	2	200
Puerto Rico	76	83	1	100

[a]Given as a percentage of available resource; multiply by values in **Table 4** to obtain TWh/yr.
[b]Threshold Operating Conditions
[c]Maximum Operating Conditions

2.2 Tidal Range Energy

Tidal range energy is characterized by the energy available from the difference between high and low tides. Changing tides are caused by the gravitational forces of the moon and sun, and the rotation of the Earth. The influence of these forces on tides are known, even centuries in advance, and the data are readily available (Ocean Energy Council, 2012). Thus, tidal energy is highly predictable, more so than wind, solar, and even wave energy (Gerlofs, 2011; Ocean Energy Council, 2012). Since tides are mainly dependent on planetary gravitational and rotational forces, they are not expected to be affected by climate change (Edenhofer, et al., 2011).

Traditionally, tidal range energy is extracted by building semi-permeable structures across areas with a high tidal range. The approach has been well developed over the past several decades and commonly utilizes tidal barrage technology (Ocean Energy Council, 2012). Tidal barrages function by allowing water to flow through sluice gates into a bay or river during high tide, closing, and then releasing the sluice gates when the low tide creates a significant pressure head on either side of the gates. This traditional form of tidal range energy extraction is sometimes excluded from MHK categorization, because it involves impoundments that disrupt the natural flow of water (Ocean Renewable Energy Coalition, 2012). Instead, the more modern approach that uses unimpounded tidal current stream flows is typically included with MHK categorization.

There are two high and low tides each day, which results in maximum tidal power plant generation every twelve hours, with no generation at the six hour mark in between (Ocean Energy Council, 2012). Unfortunately, one disadvantage of traditional tidal power is that the tidal cycle does not produce power in sync with demand schedules. Another drawback is its low capacity factor. For tidal energy to be economical there typically needs to be a tidal range of at least 7m (~23ft) (Ocean Energy Council, 2012).

2.3 Tidal Current Energy

Tidal current technology differs from tidal range technology in that it utilizes high velocity currents generated by tides (Georgia Tech Research Corporation, 2011). As tides ebb and flow, currents are generated. These currents are often magnified by topography and bathymetry, forcing water to flow through narrow channels or around headlands. The flowing water generates kinetic energy that can be extracted using a variety of devices. The following equation shows that the hydrokinetic power of a tidal current (or river current) is proportional to the cube of the current velocity (Bedard, Marine and Hydrokinetic Curriculum, 2010).

Equation 2: Tidal Current Power $\boldsymbol{P = \frac{1}{2} A\rho|V|^3}$

P = Tidal Current Power (kW)
A= Area (m^2)
ρ= Density of Water ($\frac{kg}{m^3}$)
V = Velocity ($\frac{m}{s}$)

As a result, small increases in current velocity can provide substantial increases in power (Bedard, 2010). One key advantage of this technology is that its energy production potential can be precisely forecast well in advance using astronomy (Georgia Tech Research Corporation, 2011). The ability to predict when slack water will occur can also assist deployment and maintenance activities (Georgia Tech Research Corporation, 2011).

Tidal current energy is typically extracted using arrays of slow moving horizontal or vertical axis turbines (e.g. tidal fences) or oscillating hydrofoils (Battey, 2010). In contrast to traditional tidal barrage technology, tidal fences are not dependent on tidal amplitude which makes them feasible in more locations (Alternative Energy Tutorials, 2012). Additionally, the open and free-flowing designs of turbine arrays reduce environmental impacts (Alternative Energy Tutorials, 2012). Tidal fences are also cheaper to install than tidal barrages (Alternative Energy Tutorials, 2012).

The tidal current resource in Europe is estimated to be 48 TWh/yr (Commission of the European Communities - Directorate-General for Science Research and Development, 1996). According to a 2011 report by Georgia Tech, the production potential from tidal streams in the U.S. is approximately 50 GW, with the majority of that potential located in the state of Alaska (see **Table 6**) (Georgia Tech Research Corporation, 2011). The data from this report were also used to create a national GIS database of tidal stream energy potential, shown below in **Figure 14** (Center for GIS at Georgia Tech, 2012).

Table 6: U.S. total theoretical available tidal current power (Georgia Tech Research Corporation, 2011)

State	**Max Power (MW)**
Alaska	47,437
Washington	683
Maine	675
South Carolina	388
New York	280
Georgia	219
California	204
New Jersey	192
Florida	166
Delaware	165
Virginia	133
Massachusetts	66
North Carolina	61
Oregon	48
Maryland	35
Rhode Island	16
Texas	6
Alabama	7
Louisiana	2
Total U.S.	**50,783**

Figure 14: Map of U.S. Tidal Current Mean Kinetic Power Density (W/m^2) [10]

[10] Data Sources: http://www.tidalstreampower.gatech.edu/; (Georgia Tech Research Corporation, 2011)

2.4 Ocean Current Energy

Though similar to tidal current technology, ocean current technology differs in a variety of ways. Due to the greater size of the resource the devices are larger than tidal and river current turbines (Battey, 2010). Additionally, the devices are designed for unidirectional flow and have different mooring configurations to accommodate deeper waters (Battey, 2010).

Ocean currents are caused by a combination of solar heating, wind, and gravitational forces. Strong ocean currents are typically found in shallow water areas with a large tidal range (American Council on Renewable Energy, 2012). Accordingly, ideal ocean current energy locations are typically located in narrow straights, around headlands, and between islands where a significant tidal phase difference exists (Ocean Energy Council, 2012). **Figure 15** shows the locations and directions of global ocean currents.

Because of the tremendous volume and high energy density of ocean water, ocean current energy systems are ideally suited for large-scale deployments of multiple gigawatts (American Council on Renewable Energy, 2012). According to EPRI's Roger Bedard, Florida's Gulf Stream is one of the best locations in the world for ocean current energy with a power production potential estimated to be between 4 and 10 GW (Bedard, 2010). These continuously strong currents move close to shore in areas with high power demand, making the technology even more attractive than generation sources located farther away. The flow from these currents exceed the combined flow rate of all freshwater rives in the U.S. The global power potential from ocean current energy is estimated to be over 450 GW (Bedard, 2010).

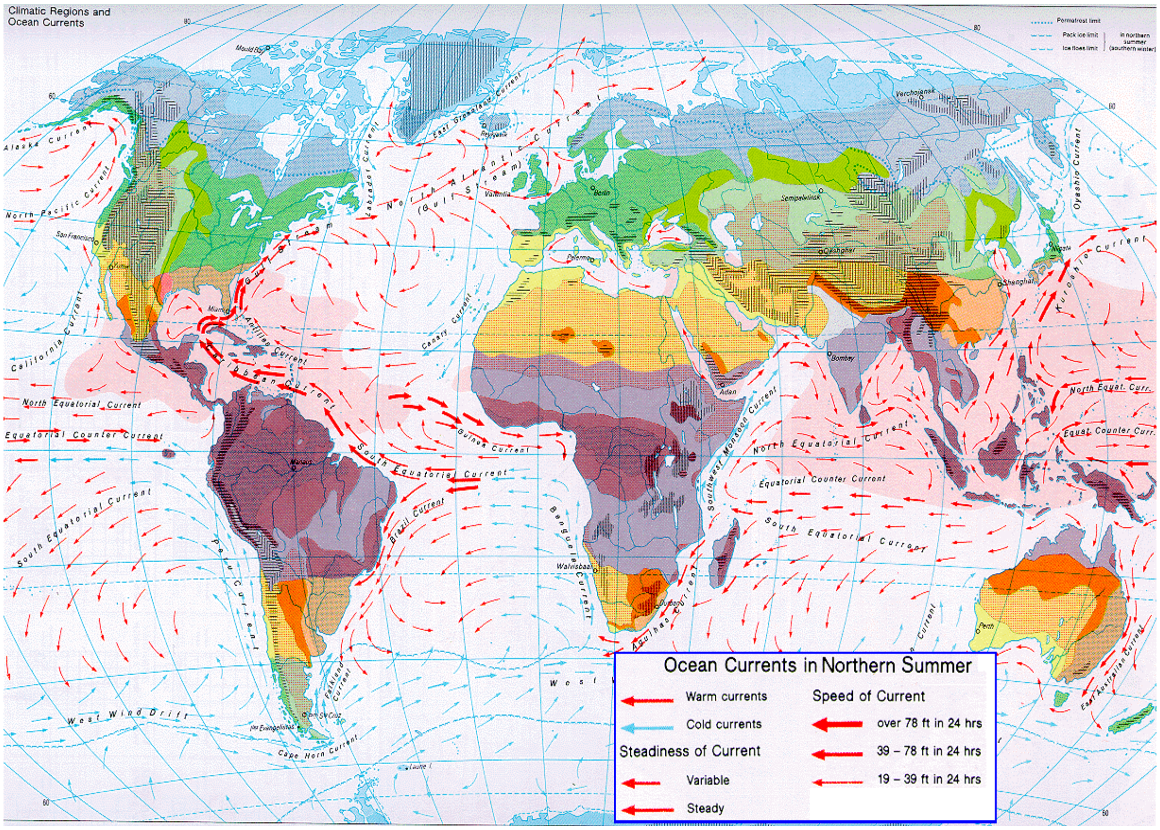

Figure 15: Map of ocean current flows (Florida Atlantic University)

2.5 River Current Energy

River currents come from seasonally varying precipitation, flowing downward due to gravity. Similar to tidal and ocean current energy, river current energy extraction takes advantage of the kinetic energy available in the unidirectional flow of rivers (Battey, 2010). The primary consideration for a river energy conversion site is the strength of the current. Preferred sites are those with high kinetic power densities (kW/m^2), which is calculated from the strength and distribution of current velocities (Bedard, 2010). One advantage of river current energy is that the devices are placed in freshwater, potentially eliminating many of the obstacles that tidal and ocean current energy face due to the harsh corrosive environments of saltwater bodies. Additionally, river current energy primarily varies seasonally (rather than daily or hourly), further supporting the assertion that MHK is a more consistent and reliable resource than wind and solar (Gerlofs, 2011). Of the various MHK technologies in development, relatively little information is known about river current energy potential in the U.S. (Bedard, 2009). What is known, are the discharge rates of major rivers in the U.S., as shown in **Figure 16**.

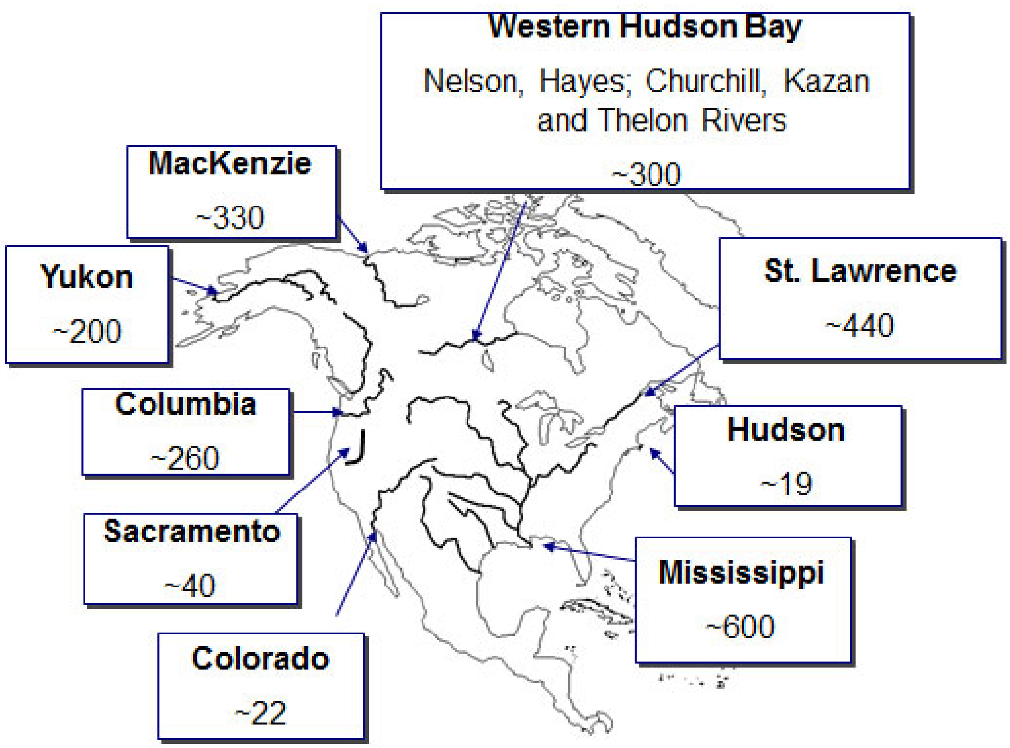

Figure 16: Discharge rates of major rivers in the U.S. (km^3/yr) (Bedard, 2010)

2.6 Ocean Thermal Energy

Oceans cover over 70% of the Earth's surface, and as such, are the largest solar energy sink in the world (Solar Energy Research Institute, 1989). Ocean Thermal Energy Conversion (OTEC) is made possible by the temperature difference between warm surface water (heated by the sun), and colder temperature deep water. Three types of Rankine cycle systems can be used for OTEC: open cycle, closed cycle, and hybrid systems (Ocean Energy Council, 2012). The difference between the two systems is that in the closed cycle the working fluid (such as ammonia or chlorofluorocarbon) remains enclosed and is continuously recycled. In the open cycle system the working fluid is sea water and is not enclosed. According to a paper published in 2007 by the University of Hawaii, the available maximum steady-state global OTEC electrical power, based on standard OTEC conditions (A_{OTEC}=100 million km^2, ΔT=20°C, T_{design}=25°C), is approximately 5 TW (Nihous, 2007). This estimate takes into consideration the fact that OTEC systems can interfere and alter the ocean temperature profile, potentially causing negative environmental consequences (such as changes to nutrient concentrations and dissolved gases). According to the U.S. Energy Information Administration, in 2009 the total global and U.S. average power consumption was approximately 16 TW and 3 TW, respectively. These values correspond to total global and U.S. primary energy consumption quantities of approximately 482.972 quadrillion BTUs and 94.547 quadrillion BTUs, respectively. The 5 TW available from OTEC resources could provide approximately 31% of average global power consumption, or 158% of average U.S. power consumption. See **Figure 17** for a map of global OTEC annual average net power (MW).

Some limitations of OTEC systems are that devices must be in stable environments with temperature differences of at least 20°C (36°F), and be located no more than 1,000 m (3,280 ft) below the surface. However, a benefit of OTEC systems is that they have a wide variety of applications (in addition to electrical energy production), including: water desalinization, refrigeration, air-conditioning, deep-water mariculture, and mineral extraction (National Renewable Energy Laboratory, 2012).

Ideal OTEC locations are typically found between latitudes 20°N and 20°S (Solar Energy Research Institute, 1989). Hawaii is the only U.S. area that falls within these boundaries, but some areas around Florida also have some OTEC potential. The growing population and reliance on expensive imported power make Hawaii even more attractive for OTEC applications than other areas. In 1974 the Natural Energy Laboratory of Hawaii (NELHA) was established (National Renewable Energy Laboratory, 2012). From 1978 to 1995 the U.S. DOE funded the Ocean Energy Systems Program targeted specifically toward OTEC (see **Figure 1** for OTEC funding amounts) (National Renewable Energy Laboratory, 2012). A handful of demonstration projects have been launched in the U.S. since the founding of NELHA but no commercial scale projects exist yet (Global Marine Renewable Energy Conference, 2012).

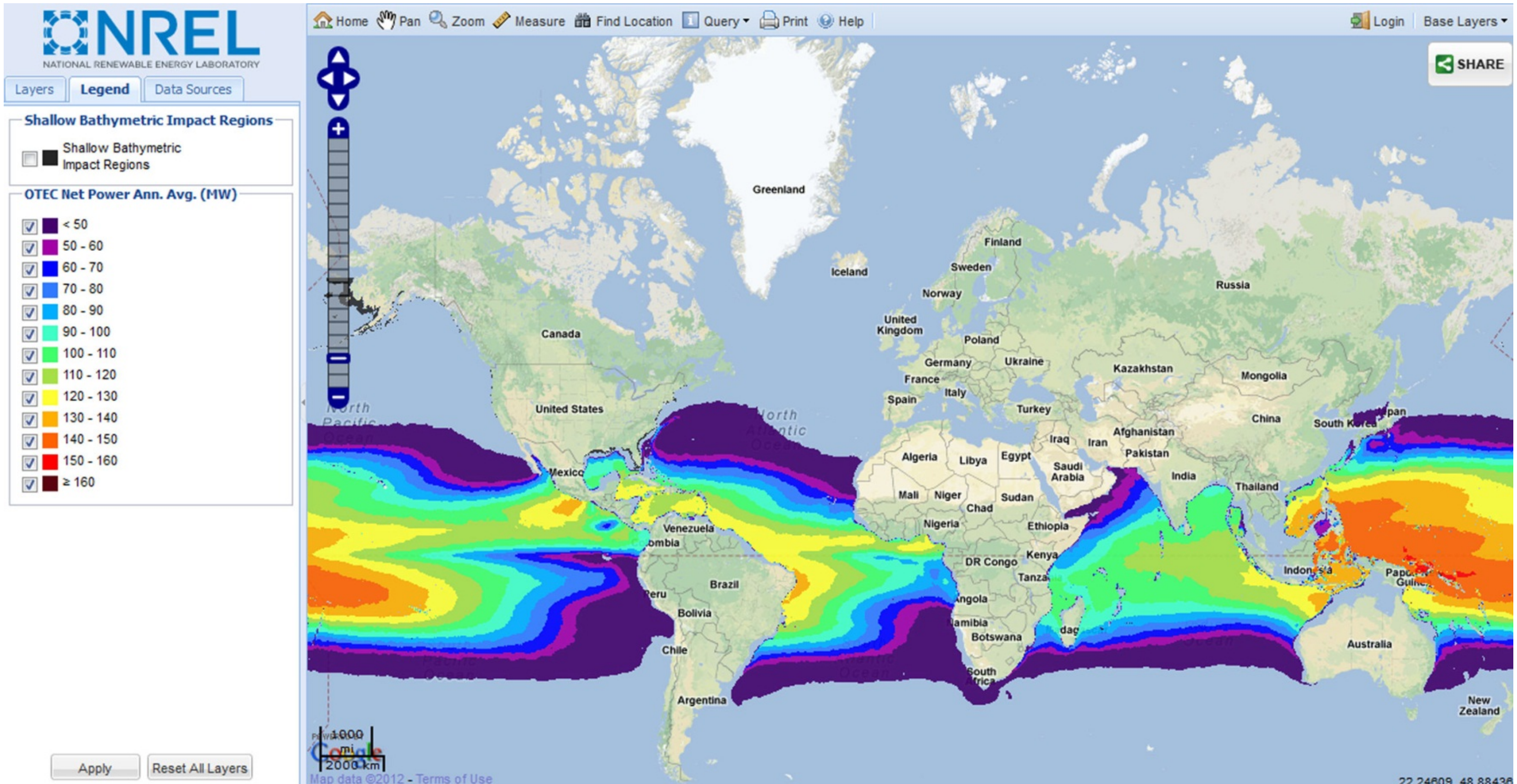

Figure 17: Map of Global OTEC Annual Average Net Power (MW)[11]

[11] Data Source: http://maps.nrel.gov/mhk_atlas; (The National Renewable Energy Laboratory (NREL), 2012)

Despite the abundant resource capacity for MHK, the relatively long history of awareness about the resource, and increasing efforts to mitigate anthropogenic climate change, the MHK industry is still in its infancy compared to other renewable technologies. The reason for this is because the MHK industry is facing several barriers that challenge its continued growth. The following chapter will discuss some of the most significant barriers.

3 MHK BARRIERS

There are several barriers standing in the way of emerging renewable energy technologies. This analysis will focus on the main barriers to MHK technologies exacerbated by market failures that lead to distorted costs in comparison to non-renewable resources. Most of these barriers can be grouped into three categories: technical, financial, and political. To bring down the high costs of renewables to a level competitive with fossil fuels will require both incentive policies and a shared effort among all renewable technologies to collaboratively tackle mutual barriers. As this chapter will discuss, the extremely high initial costs that MHK and other renewables face can be reduced through efforts across multiple renewable energy industries. However, the ultimate barrier to reducing the costs of renewables results from the inability of renewable technology developers to receive a reasonable return on their investment. Currently, the market fails to incorporate all the benefits from renewables (i.e. positive externalities) and costs from fossil fuels (i.e. negative externalities) into the price of energy. As a result, developers are unable to sell renewable energy at a price high enough to recoup their investment costs. This could be ameliorated with appropriate incentive policies (e.g. tax credits, production payments, etc.). This chapter will begin by identifying some of the barriers facing the MHK industry and other renewable energy technologies and conclude with a discussion about the potential policy mechanisms that could be used to overcome these barriers.

3.1 Renewable Energy Industry Shared Barriers

Emerging renewable energy technologies are typically faced with technical, financial, and political barriers that inhibit their development. Many of these barriers are technology, location, and time (i.e. maturity level) specific, but some can be applied broadly to multiple renewable energy technologies. These shared barriers provide an opportunity for more mature renewable energy technologies to smooth the path for more nascent technologies and ensure strong and stable market growth. Fortunately for a technology like MHK - whose resource potential is spread across the globe rather than concentrated in a handful of select countries – there are numerous teams dedicated to finding solutions to overcome these barriers. This section will identify past experiences of other renewable energy technologies that have helped the MHK industry grow, and provide explanations for why some achievements of other renewable energy technologies are not applicable to the MHK industry.

Early stage renewable energy technology barriers can include: technical barriers, such as design constraints and technically recoverable resource limitations; financial barriers, such as extremely high capital costs and financing limitations; and policy barriers, such as regulation and permitting complications (Global Marine Renewable Energy Conference, 2012). The technical barriers facing the MHK industry include: limited testing centers to collect device performance data, lack of testing standards, and lack of performance standards (Global Marine Renewable Energy Conference, 2012). Financial barriers are particularly burdensome for the MHK industry, and tie in with the permitting barriers. The high capital costs that the emerging MHK industry faces are exacerbated by the expenses associated with lengthy and complicated permitting processes (Copping & Geerlofs, 2010).

According to a 2010 report published by the Pacific Northwest National Laboratory, the most significant early stage technology development barriers facing the MHK industry are regulatory barriers, lack of R&D investment for pilot projects, and lack of environmental impact studies (Copping & Geerlofs, 2010). The report noted that regulatory barriers result from the fact that stakeholders have limited knowledge of the regulatory needs for siting and permitting processes, and that regulators are struggling to develop the appropriate siting and permitting processes. These struggles stem from the lack of environmental data available to determine the effects of MHK development. Not only is there very little environmental data available, but there is limited knowledge about what types of environmental information are needed to be able to make these determinations. The current regulations governing the use of oceans and shorelines were not designed to accommodate MHK, but rather shipping, fishing, oil and gas exploration, and recreation. Complicating the situation in the U.S. specifically is the fact that there are many key agencies involved with regulation, including: the Federal Energy Regulatory Commission (FERC); the Bureau of Ocean Energy Management (BOEM)[12]; the National Oceanic and Atmospheric Administration (NOAA); the U.S. Fish and Wildlife Service (U.S.FWS); the Department of Energy (DOE); and state and local agencies. These organizations have overlapping jurisdictions which are now being brought to light as developers struggle through the lengthy and expensive permitting

[12] Formerly the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) and the Minerals Management Service (MMS)

process. Moreover, these jurisdictional complications further exacerbate the already tense relationships between the severely undercapitalized U.S. MHK industry, regulatory agencies, and other stakeholders (Copping & Geerlofs, 2010).

Fortunately for the MHK industry, efforts by the DOE to mitigate early stage technology barriers are already underway (see **Table 7**). This work is being aided by efforts in other renewable energy industries to overcome several shared barriers, including: permitting regulations, grid integration, transmission line ownership, and technical performance data collection.

Regulatory barriers are being addressed by efforts in the off-shore wind industry, which is slightly further along than MHK in development. Several off-shore wind projects have already secured permits and power purchase agreements (see **Figure 18** & **Table 8**). Additionally, off-shore wind efforts have led to memorandums of understanding (MOUs) between federal agencies and simplifications to the permitting process. As noted by Copping and Geerlofs (2010), a March 2009 MOU signed between the Department of the Interior (DOI) and FERC, established that:

> FERC has jurisdiction to issue licenses and exemptions from licensing for the construction and operation of MHK projects on the Outer Continental Shelf (OCS) and will conduct necessary analyses, including those under NEPA related to those actions. FERC's licensing process involves other relevant federal land and resource agencies, but FERC will not issue a license or exemption for an OCS MHK project until the applicant has first obtained a lease, easement, or right-of-

Table 7: U.S. Department of Energy MHK technology barriers (Battey, 2011)

<table>
<tr><th>Subprograms</th><th>Barriers</th><th>Solutions</th></tr>
<tr><td>SYSTEM DEVELOPMENT</td><td rowspan="2">Technologies are not yet cost competitive; Device functionality is not yet demonstrated</td><td>Establish and verify baseline LCOE for each resource class and device type by FY 2013 - Quantify key cost drivers</td></tr>
<tr><td>RESEARCH, TOOLS & MODELS</td><td rowspan="2">Develop tools, models, and materials to maximize efficiency and ensure survivability</td></tr>
<tr><td>TEST FACILITIES</td><td rowspan="2">Cost and performance data does not yet exist to establish baseline LCOE</td></tr>
<tr><td>CHARACTERIZATION & EVALUATION</td><td>Support comprehensive testing at progressive technology stages to quantify cost and performance drivers</td></tr>
<tr><td>RESOURCE ASSESSMENTS</td><td rowspan="2">Resource assessments are very basic and incomplete; show moderate resource size</td><td rowspan="2">Integrate resource assessments, technology cost and performance data, advanced cost/performance models to identify critical drivers to reduce overall COE</td></tr>
<tr><td>ENVIRONMENT & SITING</td></tr>
<tr><td>ECONOMIC ANALYSIS & MARKET DEVELOPMENT</td><td>Lack of data on environmental risks to permitting and deployment</td><td>Develop and disseminate environmental data to reduce siting and permitting costs; incorporate siting costs into LCOE</td></tr>
</table>

way from MMS for the site. The MOU also eliminated FERC's preliminary license process.[13]

In 2012 BOEM and FERC announced revised guidelines for MHK developers pursuing permitting and licensing on the U.S. Outer Continental Shelf. The revisions clarify the regulatory process and help streamline the procedure for authorizing research and testing of MHK devices. Additionally in 2012, the National Ocean Council, established by President Obama in 2010, released a Draft Implementation Plan for a new national ocean policy to facilitate efforts to plan for ocean energy generation. Furthermore, BOEM has established task forces in Oregon and Hawaii to identify lease blocks for ideal wave energy development locations.

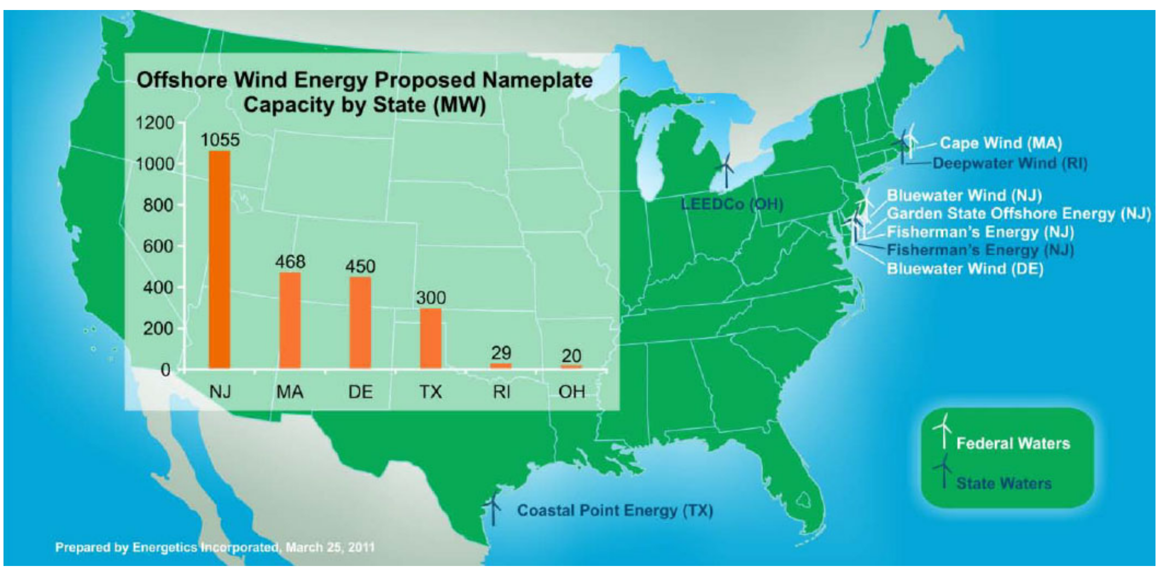

Figure 18: Proposed off-shore wind power projects in a relatively advanced state of development (Wiser & Bolinger, 2011)

[13] For a more detailed summary of the off-shore wind industry's permitting progress see the 2011 Wind Technologies Market Report (Wiser & Bolinger, 2012).

Table 8: Power purchase agreements for proposed off-shore wind power projects (Wiser & Bolinger, 2011)

Seller (Location)	Purchaser	Amount	Contract Details (Bundled Price)
NRG Bluewater Wind (Delaware)	Delmarva	200 MW	25-yr contract for electricity, capacity, and a portion[a] of the RECs: $114.25/MWh plus $70.23/kW-yr in 2007 dollars, escalating at 2.5 %/yr since 2007; approved by regulatory commission in July 2008, and amended in August 2010
	University of Maryland	55 MW	Not available
	Delaware Municipal Electric	38 MW	20-yr contract
Deepwater Wind (Rhode Island)	National Grid	28.8 MW	20-yr contract for electricity and RECs: Not to exceed $235.7/MWh in 2012, escalating at 3.5 %/yr; approved by regulatory commission in August 2010
Cape Wind (Massachusetts)	National Grid	Up to 234 MW (50% of project)	15-yr contract for electricity and RECs: base price of $187/MWh in 2013, escalating at 3.5 %/yr; option to extend 10 yrs; approved by regulatory commission in November 2010

[a]Delmarva would receive 28.6% of the renewable energy certificates (RECs) generated by this 200 MW portion of the project, while NRG Bluewater would retain the remaining 71.4% of RECs and could see those RECs into the market for further revenue support.

Though off-shore wind has faced similar permitting barriers as MHK, the on-shore wind industry has not. Most wind projects are located on private land (e.g. farms); therefore, they are not subject to the same permitting requirements as projects located on the OCS or further out to sea. In fact, the passage of the Public Utility Regulatory

Policies Act (PURPA) in 1978 was the major catalyst for the start of the on-shore wind industry, but it wasn't until the National Energy Policy Act (NEPA) of 1992 that on-shore wind projects receiving federal funding were required to meet federal permitting requirements.

Although the on-shore wind industry was unable to ease the permitting process for the future MHK industry, it was, however, able to assist in other ways. The intermittent nature of many renewable energy technologies complicates issues with grid integration, and thanks to early renewable technologies (like wind and solar) grid integration issues have already been studied for several years. The National Renewable Energy Laboratory's (NREL) Grid Integration Group has published several studies that evaluate the impacts of wind and solar renewables on the electrical grid. For example the "Eastern Wind Integration and Transmission Study" evaluates the costs and benefits of a 20% wind integration scenario in the U.S. by 2030 (EnerNex Corporation, 2011). A complementary report released by the same NREL group is the "Western Wind and Solar Integration Study", which evaluates how high levels of wind and solar impact the western electrical grid (Lew, et al., 2010).

Another common barrier that the wind industry still faces today involves issues over who should pay for new transmission lines (Wiser, 2007). Similar to the permitting issues already mentioned, transmission line ownership is complicated by those same regulation and authority confusions. Fortunately, all energy technologies – renewable or fossil - are facing this barrier together. For the on-shore energy industry, as more solar, wind, and natural gas projects come on-line, river current projects may have the advantage of being able to use those same transmission lines.

Lastly, the mechanics of how energy is captured are similar for wind and some MHK technologies (e.g. ocean/tidal/river current energy), potentially enabling MHK technologies to adopt many of the same design elements as wind turbines (e.g. blade design, axis positioning, etc.) (Global Marine Renewable Energy Conference, 2012).

Though many renewable energy industries are able to collectively address several shared barriers, there still exists one overarching market failure that creates the most significant barrier to renewable energy technologies – the failure to internalize the environmental benefits of clean energy technologies in the costs. The following section will briefly discuss the theory behind this most significant renewable energy market barrier and the potential policy mechanisms that could be used to overcome it.

3.2 Policy Mechanisms to Address Market Barriers

The most significant renewable energy market barrier is the market failure to internalize the environmental benefits of clean energy technologies in their cost, which is necessary to bring the cost of renewables down to a level competitive with fossil fuels (Hackett, 2011). In this context, market failure refers to the cost of energy failing to take into account the indirect benefits or damages resulting from consumption of an energy resource. By failing to internalize (i.e. incorporate into the cost) the environmental benefits of renewable energy resources, the price of renewables is higher compared to less environmentally friendly fossil fuel resources (Hackett, 2011). One example of an environmental benefit not internalized by the market would be the improved air quality associated with replacing fossil fuel technologies with renewable energy technologies, leading to better health and reduced healthcare costs for everyone. Nogee and colleagues note that additional benefits of renewable technologies include the ability to create jobs, diversify fuel supplies, stabilize fuel prices, and generate other indirect economic benefits that apply to society as a whole (Nogee, et al., 1999). Since markets are primarily driven by profits and bottom lines, there exists an opportunity for incentives to overcome these market failures with policies that internalize the positive externalities from renewables (e.g. renewable energy tax credits and other incentives), or internalize the negative externalities associated with fossil fuels (e.g. taxes, emissions caps, or tradable emissions permits).

Currently, the tax benefits afforded to the MHK industry lack parity with other renewables. The MHK industry is only eligible for half the production tax credit (PTC) value (1.1 ¢/kWh vs. 2.2 ¢/kWh), while wind, geothermal, and closed-loop biomass are eligible for the full PTC value. Additionally, only MHK projects larger than 150kW are eligible for the PTC. Another defect in the current design of the PTC is that it has historically only been enacted in 1 to 2-year increments, causing disruptions to growing renewable energy industries (Wiser, 2007). Unstable policies create uncertainty and undermine the ability of renewable energy technologies to attract capital from investors. MHK is also ineligible for the 5-year modified accelerated cost recovery system (MACRS) depreciation, but PV, wind, geothermal, and many other renewable technologies are not (Database of State Incentives for Renewables & Efficiency, 2012;

Ocean Renewable Energy Coalition, 2012). MACRS is an accelerated 5-year tax depreciation schedule for a property dedicated to the production of renewable energy, and enables a project to save money using tax deductions.

From a policy perspective, perhaps the most significant contribution that a more mature renewable technology has made to the MHK industry is its experience with the production tax credit (PTC). Past experience in the on-shore wind industry has demonstrated the significance of the PTC in helping to grow the industry, and the damage that the 1 to 2-year expirations have had. With regard to costs, the PTC reduced the cost of wind by approximately 2 ¢/kWh, and preliminary analyses by Lawrence Berkeley National Laboratory (LBNL) in 2006 suggest that longer-term PTC extensions may be able to reduce installed costs for wind by 5% to 15% (Wiser, 2007). Furthermore, the short term extensions of the PTC have had significant negative impacts on the wind industry. These impacts include slowed wind development, higher costs, greater reliance on foreign manufacturing, difficulties in rationally planning transmission expansion, and reduced private R&D expenditures (Wiser, 2007). With regard to a 5 to 10-year PTC extension, the installed cost reduction potential is significant, between 8% and 15% (Wiser, 2007).

As case studies later in this analysis will show, historical experience with these policies have allowed analysts to identify their weaknesses and recommend improvements. Using that information this analysis aims to identify opportunities for enhancing or restructuring the existing U.S. federal policy framework to optimize the potential benefits to the MHK industry. Recognizing that there are several potential policy options throughout the world that are aimed at increasing renewable energy development, this analysis will only focus on existing U.S. federal policies. By restructuring existing policies, this approach is intended to be more effective than proposing new policies, which could face a great deal of opposition and a lengthy congressional approval process. This is evidenced by the ongoing debate between advocates of the proposed carbon tax and cap-and-trade programs, which are generally agreed to be useful tools for climate change mitigation, but have yet to be implemented. The following chapter will summarize the current federal renewable energy policy environment in the U.S. and examine several case studies that evaluate the effectiveness of current and potential policies on increasing renewable energy capacity.

4 RENEWABLE ENERGY POLICY ENVIRONMENT

Despite the increasing growth of renewable energy capacity in the U.S. and the country's vast available resources, it is uncertain whether or not the U.S. will be able to reach target levels identified for climate change mitigation using the renewable energy incentives currently in place. Studies have shown that ongoing supportive federal policies (like the PTC) will be necessary for continued growth (Wiser, 2007). As discussed in the previous chapter, the need for these policies arises from the fact that several barriers increase the cost of renewables compared to fossil fuel technologies, and these high costs are further exacerbated by the market failure to value the public benefits of renewables. As a result, many renewable energy technologies have very high capital costs - generally with high construction costs but low operating costs – and, as such, are more sensitive to the availability of financing than other energy technologies (Bolinger, et al., 2009). **Figure 19** shows the growth in installed capacity for selected renewable energy technologies possessing attributes similar to MHK (wind and PV), as identified previously in **Table 1**. The following chapter will discuss the theory behind push and pull policies used to overcome technology barriers, and then provide a brief overview of the current PTC, ITC, and cash grant policies that will be the focus of this analysis.

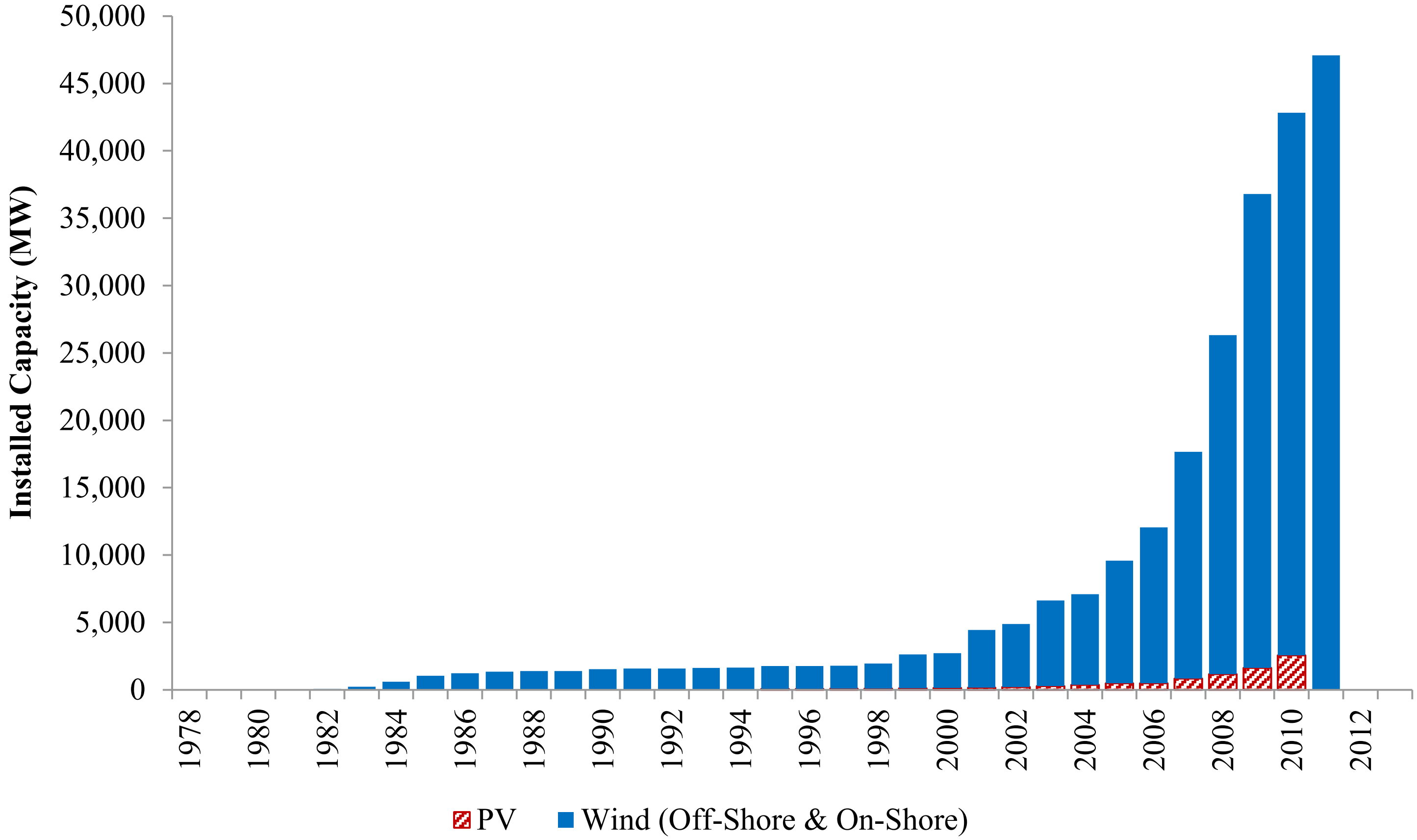

Figure 19: U.S. installed capacity of wind and PV[14]

[14] See Appendix A for raw data and source information

4.1 Renewable Energy Policy Theory: Technology-Push vs. Demand-Pull

Renewable energy policies are established to help further a technology's development along a learning curve when direct investments are not enough to support sustained, long-term growth. They are intended to bring technologies to a point where subsidies are no longer needed, typically when prices have dropped sufficiently to allow the technology to be cost competitive with fossil fuels or other renewable energy technologies. These policies should be designed to foster, or at least not impede, environmental and technological innovation (Taylor, 2008). There are a variety of different policy designs available, each aimed at achieving specific goals. Typically, these policies are separated into two categories: (1) technology-push and (2) demand-pull (aka market-pull).

Generally, and for the purpose of this thesis, technology-push policies are defined as policies aimed at spurring early stage technology development (e.g. R&D funding), while demand-pull policies increase the market demand for a technology (e.g. end-user rebates). Within the policy community, however, there exists some disagreement about the exact definitions of these terms, and which policies fall under their headings. Guerin and Schiavo define demand-pull instruments as "supporting the production of electricity through renewable energy sources," and technology-push instruments as "supporting the production of corresponding [renewable energy] technologies" (Guérin & Schiavo, 2011). The key distinction being that technology-push instruments encourage the development of renewable technologies regardless of the amount of energy produced. The article by Margaret Taylor, discussed in section 5.2, defines "technology-push" as instruments that influence the supply of new knowledge, and “demand-pull” as instruments that affect the size of the market for a new technology (Taylor, 2008). She provides evidence of discrepancies in the terminology with an example from the California Public Utilities Commission’s (CPUC) interim decision regarding a new solar energy incentive program. The CPUC stated that solar energy technologies should be supported with “a ‘push’ from an incentive program” (in this case, upfront rebates) and a “‘pull’ [from] a program design that encourages technological improvements” (in this case, R&D support). She notes that the CPUC’s language implies that the agency considers rebates to be a “technology-push” instrument, even though they do not directly support the supply of new knowledge in a technology, but rather foster a market for that technology. Instead, she notes that considering it as a “demand-pull” mechanism would be more appropriate. Conversely, the “pull” mechanism used to encourage technological improvements would typically be considered a “technology-push” mechanism. Guerin and Schiavo categorize a variety of demand-pull and technology-push policies in **Table 9**.

Table 9: Categorization of demand-pull and technology-push policies (Guérin & Schiavo, 2011)

Demand-Pull	**Technology-Push**
Tax incentives for end-users	Special financing, loan guarantees
Tradable green certificates, quotas	Producer tax incentives
CO_2 tax	Research and development funding
Cap-and-trade systems	
Feed-in tariffs, feed-in premiums	

Some of these policies operate as both demand-pull and technology-push because they reduce developer costs, which also trickle down to the consumer (e.g. production tax incentives). Despite the disagreements over terminology and classification, Guerin and Schiavo argue that neither policy category is effective without the other (Guérin & Schiavo, 2011). Rather, they assert that combining push and pull policies for renewable energy technologies is the most effective way to address climate change. They state that in the absence of private benefits conferred to industries by push policies, no one country has an incentive to develop renewable energy technologies, but rather to wait for others to develop the technologies and then adopt them. Alternatively, no country has an incentive to implement only pull policies, because, if for instance, they were to rely mainly on feed-in tariffs (i.e. a pull policy) they would face a high risk that renewable technologies would be imported.

Three main incentive policies will be the focus of this discussion, including: the PTC, ITC, and treasury cash grant. This analysis choses to follow a simplified approach by focusing on a few select existing U.S. federal policies and will not cover policy tools most commonly used at the state level (e.g. RPS and FIT). By restructuring existing federal policies (e.g. expanding eligibility to new renewable energy technologies), this approach is intended to be more effective than proposing new policies, which could face a great deal of opposition and a lengthy congressional approval process. As discussed in section 5.1 of the literature review chapter, it is advantageous to use the existing system, rather than develop an entirely new system, because the rules and administration structure are already in place. Additionally, for tax policies in particular, the limited transparency of the tax code may reduce budget scrutiny, which could increase the likelihood of congressional approval. Tax credit programs lead to reduced tax revenue for the government, rather than increased spending and can appear to have a smaller upfront price tag than grants and loan programs, potentially enabling them to gain more political support. As discussed later in this analysis, the PTC, ITC, and treasury cash grant have typically been credited for spurring growth in other renewable energy industries (e.g. on-shore wind). All three of these policies involve allocation of government funds, but differ in how they are delivered to the recipient. Each of the policies serves the same purpose – to incentivize the development of clean energy technologies and make them economically competitive with fossil fuel technologies.

The following sections will provide a brief overview of the PTC, ITC, and treasury cash grant. Due to the highly complex nature of tax programs, this section is not intended to be a comprehensive reference detailing all the unique facets of each policy.[15]

4.2 Production Tax Credit

The PTC was originally enacted by the Energy Policy Act of 1992. It has expired and been reinstated on numerous occasions (see **Table 10**). The current value of the PTC has been continually adjusted for inflation, and the values for different energy technologies are shown in **Table 11**. The PTC is a ¢/kWh tax credit "for electricity generated by qualified energy resources and sold by the taxpayer to an unrelated person

[15] For more information see the Database of State Incentives for Renewables and Efficiency (DSIRE) http://www.dsireusa.org/

Table 10: History of the wind PTC and related development activity[16]

Legislation Date	Enacted	PTC Eligibility Window	Total Duration (months)[a]	Capacity Built (MW)[b]	MW/month
Section 1914, Energy Policy Act of 1992 (P.L. 102-486)	10/24/1992	1994-June 1999	80	894	11
Section 507, Ticket to Work and Work Incentives Improvement Act of 1999 (P.L. 106-170)	12/19/1999	July 1999-2001	24	1,764	74
Section 603, Job Creation and Worker Assistance Act (P.L. 107-147)	3/9/2002	2002-2003	22	2,078	94
Section 313, The Working Families Tax Relief Act, (P.L. 108-311)	10/4/2004	2004-2005	15	2,796	186
Section 1301, Energy Policy Act of 2005 (P.L. 109-58)	8/8/2005	2006-2007	24	7,702	321
Section 201, Tax Relief and Health Care Act of 2006 (P.L. 109-432)	12/20/2006	2008	12	8,337	695
Energy Improvement and Extension Act of 2008 (H.R. 1424)	10/1/2008	2009	12	9,993	833
American Recovery and Reinvestment Act of 2009 (H.R. 1)	2/1/2009	2010-2012	36	11,928[c]	497[c]

[a]Cumulative duration, including lapses due to expirations and reinstatements
[b]Wind capacity built in PTC window
[c]2010 and 2011 only

[16] Updated from original source (Wiser, 2007) using data from (Wiser & Bolinger, 2011; Wiser & Bolinger, 2012)

Table 11: Inflation-adjusted PTC credit amounts for the 2011 calendar year (Database of State Incentives for Renewables & Efficiency, 2012)

Resource Type	**In-Service Deadline**	**Credit Amount (¢/kWh)**
Wind	December 31, 2012	2.2
Closed-Loop Biomass	December 31, 2013	2.2
Open-Loop Biomass	December 31, 2013	1.1
Geothermal Energy	December 31, 2013	2.2
Landfill Gas	December 31, 2013	1.1
Municipal Solid Waste	December 31, 2013	1.1
Qualified Hydroelectric	December 31, 2013	1.1
Marine and Hydrokinetic[a]	December 31, 2013	1.1

[a]150 kW or larger

during the taxable year" (Database of State Incentives for Renewables & Efficiency, 2012). Projects are generally eligible to receive the tax credit for the first 10 years of operation. The addition of MHK as a PTC eligible technology was introduced by the Energy Improvement and Extension Act of 2008 (H.R. 1424). More recently the American Recovery and Reinvestment Act (ARRA) of 2009 (H.R. 1) extended and revised the credit to enable eligible technologies to elect to take the ITC or the treasury cash grant instead of the PTC.

4.3 Investment Tax Credit

The ITC for energy projects has been enacted through numerous pieces of legislation, each designed differently and providing varying amounts of credit (see **Table 13** in section 5.3). The first time an ITC was implemented for renewable energy was in 1978. The design of the current ITC is set-up as a one-time, upfront tax credit taken as a percentage of the project's capital cost. The value of the ITC is 30% for solar, fuel cell, and wind technologies, and 10% for geothermal, microturbine, and combined heat and power (CHP) technologies (Database of State Incentives for Renewables & Efficiency, 2012). The specific incentive amount for MHK is 30% (Ocean Renewable Energy Coalition, 2012).

4.4 Treasury Cash Grant (§1603)

ARRA, enacted in February 2009, created a renewable energy grant program that is administered by the U.S. Department of the Treasury. It is a one-time, upfront grant calculated as a percentage of the "basis of the property" (Database of State Incentives for Renewables & Efficiency, 2012). The Internal Revenue Service (IRS) defines "basis of the property" as "cost" - "the cost is the amount you pay in cash, debt obligations, other property, or services. Your cost also includes amounts you pay for the following items: sales tax, freight, installation and testing, excise taxes, legal and accounting fees (when they must be capitalized), revenue stamps, recording fees, and real estate taxes (if assumed for the seller)" (Internal Revenue Service, 2012). The amount of the grant is 30% for qualified fuel cells, solar, qualified small wind, and other "qualified facilities".

Qualified facilities include: wind energy, closed-loop biomass, open-loop biomass, geothermal energy, landfill gas, trash, qualified hydropower, and marine and hydrokinetic renewable energy. The amount of the grant is 10% for all other properties.

The following chapter will provide a literature review of various renewable energy market development policy analyses. As mentioned earlier, the policies discussed here have typically been credited for spurring growth in other renewable energy industries (e.g. on-shore wind). The intention is to draw conclusions based on similarities between MHK and those technologies, and make recommendations for future MHK incentive policies.

5 LITERATURE REVIEW OF RENEWABLE ENERGY MARKET DEVELOPMENT POLICY ANALYSES

The following chapter provides an extensive literature review of past renewable energy market development policy analyses. It will begin by discussing the roles of renewable energy policies and their modes of implementation in the U.S. Following this discussion will be numerous analyses that examine which renewable energy policies are most effective in terms of their implementation cost and their ability to increase renewable energy capacity and generation, reduce emissions, and reduce energy prices. Furthermore, these policies will be evaluated based on their value (quantitative and qualitative) to various renewable energy technologies and the particular design flaws that have hindered their potential effectiveness. The intent of this chapter is to provide the information necessary to (1) understand the policy experiences of other, more mature, renewable energy technologies, (2) draw similarities between MHK and those technologies, and (3) develop a set of recommended strategies for accelerating the development of the MHK industry in the United States.

5.1 "Good Government Investments in Renewable Energy" by the Center for American Progress, 2012

The 2012 article by the Center for American Progress called "Good Government Investments in Renewable Energy," discussed the historical importance of government energy policies and provided an explanation for one aspect of their current design strategies (Caperton, 2012). As the article noted, in the U.S., the federal government has a long history of intervention in domestic energy markets. For over a century the government has granted access to resources on public land, helped build transportation networks for fuels, built damns for electricity, subsidized the exploration and extraction of fossil fuels, financed the electrification of rural America, assumed the risk for nuclear power plant construction, and funded R&D for almost all energy sources. Recently, much of the federal government's intervention in energy markets has come in the form of subsidy programs directed toward the fossil fuel industry and implemented using the tax code. In other words, the fossil fuel industry receives large benefits in the form of tax credits, deductions, or rebates that create price distortions between fossil fuels and renewables. **Figure 20** shows that approximately half of all government energy tax expenditures (i.e. foregone tax revenues resulting from these tax credits, deductions, and rebates) and about 10% of direct spending (e.g. investment in R&D) are directed toward fossil fuel industries. One of the reasons these benefits are implemented through the tax code (as mentioned previously) is because it is advantageous for policy developers to use the existing tax system, rather than develop an entirely new system, and because the tax rules and administration structures are already in place. Additionally, the decreased transparency of the tax code reduces budget scrutiny, and makes it easier to pass new legislation through Congress. The fossil fuel industry is able to maintain substantial tax benefits because it has a large base of stakeholders (far beyond the realm of the fuel producers and refineries), making them very powerful both politically and economically. As a result, the large stakeholder base has afforded the fossil fuel industry a very effective lobbying campaign to ensure that it continues to receive these benefits year after year. Advocates of renewable energy argue that continuing to subsidize fossil fuels creates an un-level playing field for competing energy technologies, and is counterproductive to America's energy and climate change goals (Caperton, 2012). Instead, they suggest that fossil fuel subsidies be eliminated while subsidies for renewables be increased. However, before that can happen there needs to be an adequate evaluation of existing policies, as discussed in the next section.

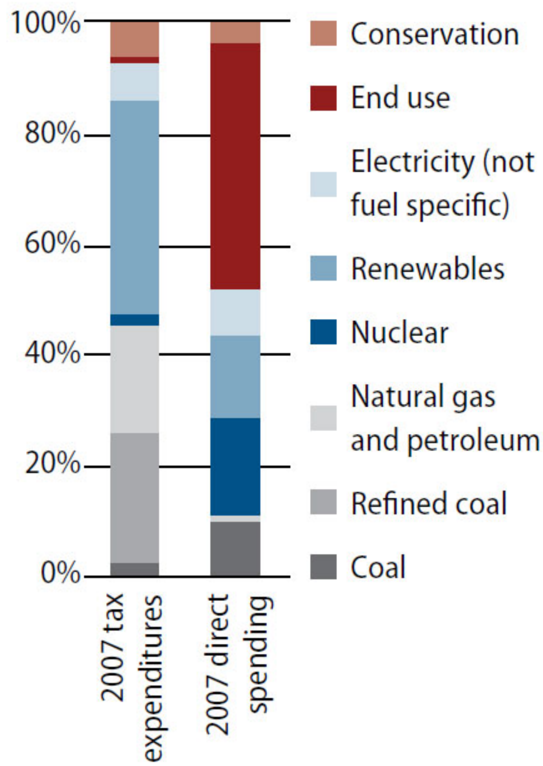

Figure 20: Proportion of government tax expenditures and direct spending for different energy sectors, 2007 (Caperton, 2012)

5.2 "Beyond technology-push and demand-pull: Lessons from California's solar policy" by Margaret Taylor, 2008

Margaret Taylor's 2008 article, titled "Beyond technology-push and demand-pull: Lessons from California's solar policy" discussed discrepancies in categorizing various renewable energy policies as either technology-push or demand-pull (Taylor, 2008). She instead offered three new categories: (1) upstream investment, (2) market creation, and (3) interface improvement (see **Table 12**). She recognized that "there is a weak empirical basis for policy design recommendations due to a lack of systematic, retrospective policy evaluation." In response, she went on to review the origins, strengths, and weaknesses of technology-push and demand-pull solar policies in California, and analyzed their impacts on innovation in the solar industry.

Her conclusions about market creation policies for centralized solar facilities are most applicable to this analysis, and she found that these types of policies fell into two categories: "carrots" (financial subsidies) and "sticks" (mandates or standards with penalties). Her analysis revealed that the two most significant "carrot" and "stick" policies for solar thermal electricity (STE) projects were the long-term contracts (i.e. Standard Offer Contracts) and power purchase agreements (PPA) established as result of the California Public Utilities Commission's (CPUC) implementation of the 1978 federal Public Utility Regulatory Policy Act (PURPA) and the California renewable portfolio standard (RPS) that required investor owned utilities (IOU) to purchase a legislated percentage of their total retail electricity sales from renewable sources, respectively. Further investigation revealed that the RPS favored wind over STE and PV, despite the technological flexibility of the RPS program.

Regardless of the relative successes of these programs that were made possible by PURPA, within the programs existed design flaws that hindered them from reaching their full potential in helping the California solar industry grow. For example, Taylor noted

Table 12: Types of solar policies employed in California (Taylor, 2008)

Policy Category	Government Action
Upstream Investment	Invests in R&D, sometimes in partnership with private sector. Recently, utility surcharges have provided resources for publicly administered R&D program. Provides capital to support solar companies, sometimes in partnership with private sector. Uses monopoly-regulating power to compel utilities to invest in solar R&D.
Market Creation	Acts as a customer for solar technologies through procurement policies for public properties. Creates customers for solar technologies, either through subsidies or through mandates/standards. Uses monopoly-regulating power to make utilities become or create customers for solar technologies.
Interface Improvements	Performs the role of installer. Ensures quality installers through decentralized policies like training and certification programs. Ensures quality installations through decentralized policies like inspection programs and warranty requirements.

that Standard Offer Contracts (particularly ISO4) helped the entrepreneurial southern California firm, Luz, to produce 95% of the world's solar-generated electricity during the years 1984 to 1991, bringing the LCOE down from 24 ¢/kWh to 8 ¢/kWh ($U.S.), respectively (Lotker, 1991) & (Mariyappan & Anderson, 2001). However, in a 1980 FERC ruling, the high purchase prices for qualifying facilities was set to revert back to the actual avoided cost after ten years, creating what was referred to as the “11-year cliff”. This, in combination with the 1995 FERC decision to disapprove California’s Biennial Resource Plan Update (BRPU), created financial uncertainty for Luz. Furthermore, a legislative detail of PURPA created a size limit on one of the two categories of qualifying facilities, ultimately constraining Luz from “designing a plant sized at an optimal level” to take advantage of economies of scale (Lotker, 1991). Two pieces of temporary legislation attempted to raise the size limit, but their short-term duration did not provide any comfort to long-term investors who were aware of the inevitability that plants would be limited to sub-optimal size.

Taylor concluded by stating that historically, “carrots” have been the preferred policy option for solar projects in California. She attributed this to the fact that it was likely more difficult for governments to implement “stick” policies (like mandates) than “carrot” policies (like subsidies), due to the mixture of private and public value inherent in renewable energy technologies. The design failures of these policies further emphasize her point; that legislators need to “design climate policy to foster, or at least not impede, environmental innovation.” Moreover, she asserted that California “has not reached its full potential as a niche market for solar energy technologies, in part due to compromises in program design and implementation.”

5.3 “Demand-pull, technology-push, and government-led incentives for non-incremental technical change” by Gregory F. Nemet, 2009

Further studies have investigated the effects of federal renewable energy incentive programs on the growth of renewable energy industries. A 2009 article by Gregory F.

Nemet of the University of Wisconsin, Madison called "Demand-pull, technology-push, and government-led incentives for non-incremental technical change" investigated the correlation between demand-pull policies on non-incremental (i.e. radical) technological innovation, using wind energy between 1975 to 1991 as an example (Nemet, 2009). He considered non-incremental innovation to be the development of radically different wind turbine design concepts. In contrast, he considered incremental innovation to be technological improvements and refinements of a single wind turbine design concept. His intention was to reveal whether or not demand-pull policies led to increased incremental innovation or non-incremental innovation, enabling policy makers to create the appropriate policies based on the desired outcome.

The results of his analysis indicated that incremental innovation is more likely to respond to demand-pull, while non-incremental innovation is more likely to respond to technology-push. Incremental innovation was the approach taken by the wind industry, evidenced by the single design concept (three-blade, horizontal axis, upwind of support tower) that emerged early on and remained relatively unchanged throughout the industry's development. His analysis also included a review of the impacts from tax credits on the success of the wind industry, and found that growth and profitability were highly dependent on the demand-pull policies listed in **Table 13**. **Figure 21** shows that despite the fact that the majority of investment in wind energy occurred during the mid-1980s, unsubsidized wind energy remained profitless up through 2005. Only a few unsubsidized projects (in windy locations with high energy prices) began to see profits starting around the year 2000. Alternatively, subsidized wind projects were profitable in the late 1980s and early 1990s, indicating that the demand-pull policies in place leading up to that time were the true cause of the industry's success. The effect of the investment tax credit was to reduce project capital costs. The Standard Offer Contracts in California were particularly generous to wind energy due to the fact that rates were based on the anticipation of high future electricity prices, caused by increasing natural gas prices and high nuclear power construction costs. These rates led to increased revenues for wind farm developers that were well above their short run average cost of electricity, and were locked into place for several years into the future (≥10 years).

Table 13: Demand-side policies relevant to wind power in California (Nemet, 2009)

Policy	Subsidy Level	Begin	End
Federal Investment Tax Credit	10% of capital cost	1978	1985
Energy Tax Act Credit	10 % of capital cost	1978	1980
Oil Windfall Profits Tax Credit	15% of capital cost	1980	1985
CA Alt. Energy Tax Credit	25% of capital cost	1978	1986
Standard Offer Contracts	Price = 14 ¢/kWh	1983	1992
Production Tax Credit	1.8 ¢/kWh tax credit	1994	-

To further support his conclusions, Nemet stated that the timing of investments in the wind industry suggests that these demand-pull policies created strong incentives for firms to develop wind power projects. The bar graph on the bottom of **Figure 21** shows that significantly more investment in the wind industry occurred during the mid-1980s than in the early 2000s, despite the fact that over three times more capacity was installed during the early 2000s than the mid-1980s. This indicates a large drop in installed cost during that time. Specifically, Nemet stated that the capital cost of wind turbines fell by a factor of four, due to a combination of economies of manufacturing scale and economies of unit size.

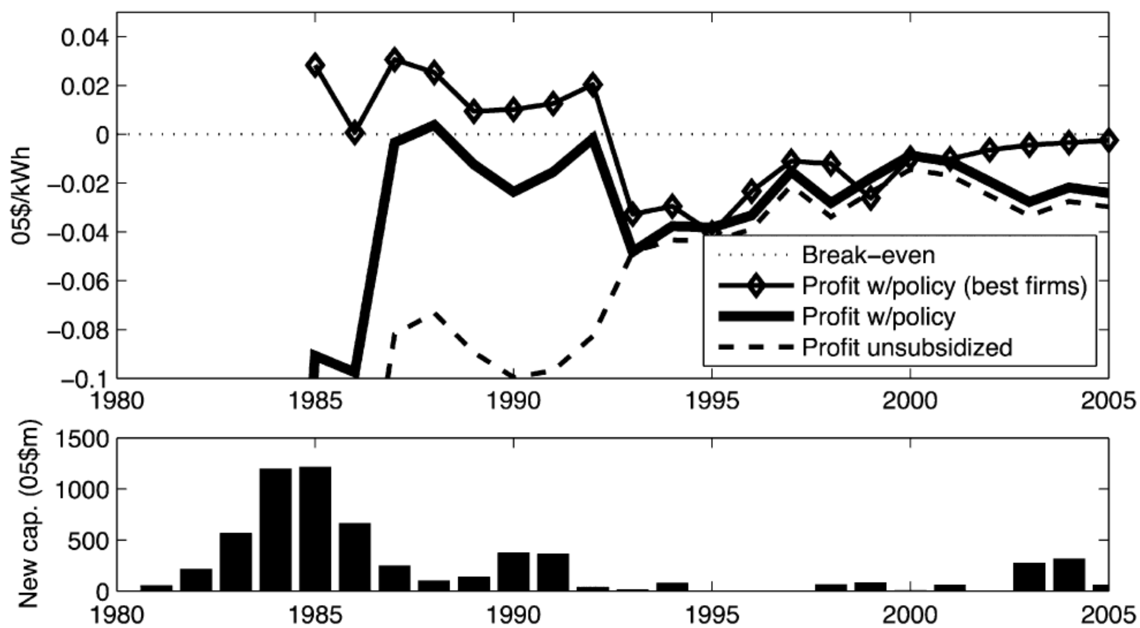

Figure 21: Investment in new capacity and the difference between levelized cost and revenue (Nemet, 2009)[17]

Lastly, Nemet's analysis explained that despite the success of demand-pull policies on incremental innovation, the effectiveness of these policies on non-incremental technological innovation was diminished by their own volatility. For instance, the short

[17] Values are in $2005 adjusted for inflation

duration of the tax credit programs and the uncertainty regarding their reinstatement made it more financially feasible to construct wind farms utilizing existing technology, rather than invest in non-incremental technological innovation (e.g. invent new design concepts). This was because the long project times required for non-incremental technological innovation could not provide investment returns during the short 1-2 year tax credit windows.

5.4 "Cost-Effectiveness of Renewable Electricity Policies" by Karen Palmer and Dallas Burtraw (Resources for the Future), 2005

To investigate the impacts of demand-pull policies further, Karen Palmer and Dallas Burtraw of Resources for the Future wrote an article in 2005 titled "Cost-Effectiveness of Renewable Electricity Policies" (Palmer & Burtraw, 2005). The study evaluated the federal PTC, various state-level RPS programs, and a federal cap-and-trade program. The policies were compared based on their cost, effectiveness at reducing carbon emissions and energy prices, and effectiveness at increasing renewable capacity.

The RPS in the model included a standard variety of renewable technologies, for which each kWh generated received a tradable energy credit. The model divided the production tax credit into two categories, REPC-E and REPC-G. The REPC-E only included wind and closed-loop biomass technology. The REPC-G included all technologies that were considered eligible for the RPS in the model. The third policy that the study evaluated was a carbon cap-and-trade program with allowance allocation based on generation.

The results of the study concluded that the RPS raised electricity prices, lowered total generation, reduced natural gas generation, and lowered carbon emissions. The scale of these impacts grew with increasingly stringent RPS requirements. Additionally, the RPS was more cost-effective than either of the production tax credit scenarios at increasing renewable capacity and reducing carbon emissions. This cost-effectiveness at reducing carbon emissions was partially due to the fact that the production tax credit lowered electricity prices at the expense of the taxpayers, leading to increased generation and increased emissions. However, the RPS was less effective (in absolute terms and cost) at reducing carbon emissions than a carbon cap-and-trade program. Ultimately, the RPS would be the most effective policy at promoting renewables, but the cap-and-trade policy would be more effective at reducing carbon emissions. In terms of selecting the best policy for promoting a particular technology, the authors note that the production tax credit could be valuable in supporting new and immature technologies and the RPS could set targets for specific types of technologies. This suggests that MHK, as a new and immature technology, could benefit from the production tax credit.

5.5 "Federal Tax Policy Towards Energy" by Gilbert E. Metcalf (MIT Joint Program on the Science and Policy of Global Change), 2007

Another interesting study on renewable energy tax policies was conducted in 2007 by Gilbert E. Metcalf of the MIT Joint Program on the Science and Policy of Global Change. The study was called "Federal Tax Policy Towards Energy" and modeled the impacts of the PTC, ITC, and depreciation on various energy generation technologies (Metcalf, 2007). The ultimate goal of the study was to identify which technologies benefitted most from these incentives and what were the impacts on energy supply and demand. LCOE is the electricity price (¢/kWh) that is necessary to cover all project costs and provide a reasonable rate of return to investors. The study modeled the impacts of these three incentives on the LCOE for the following eight electricity generation sources: nuclear, conventional (pulverized) coal, clean coal using an integrated gasification combined cycle (IGCC) process, natural gas combined cycle, biomass, wind, solar thermal, and PV. The parameters included in the model were: capacity factor (%), construction time, fuel cost ($/MMBtu), heat rate (Btu/kWh), fixed and variable operations and maintenance (O&M) ($/kWh), decommissioning ($ million), capital increment ($/kW), K increment (years 30+), overnight cost ($/kW), debt finance (%), equity finance (%), discount rate (%), economic life, Modified Accelerated Cost Recovery System (MACRS), inflation rate (%), state tax rate (%), PTC ($/kWh), and the Section 48 ITC (%). LCOE results from the study are shown below in **Table 14**. Unlike accelerated depreciation, economic depreciation was modeled as a straight line over the project lifetime. A "level playing field" referred to a scenario where the technology qualifies for economic depreciation but no production or investment tax credit.

The results of the analysis indicated that the PTC benefitted nuclear energy more than wind and biomass, with observed LCOE increases of 29%, 4%, and 4%, respectively, in the absence of the PTC. The ITC primarily benefitted solar (thermal and PV) and IGCC, with observed LCOE increases of 36%, 42% and 14%, respectively. Solar PV, solar thermal, and wind were the primary beneficiaries of accelerated depreciation. The model showed that replacing accelerated depreciation with economic

Table 14: Real levelized costs of electricity[a] (Metcalf, 2007)

Technology	Current Law	No PTC	No ITC	Economic Depreciation	Level Playing Field	No Tax
Nuclear	4.31	5.55	4.31	4.7	5.94	4.57
Conventional Coal	3.53	3.53	3.53	3.79	3.79	3.1
Clean Coal (IGCC)	3.55	3.55	4.06	3.8	4.37	3.53
Natural Gas	5.47	5.47	5.47	5.61	5.61	5.29
Biomass	5.34	5.56	5.34	5.74	5.95	4.96
Wind	5.7	5.91	5.7	6.42	6.64	4.95
Solar Thermal	12.25	12.25	16.68	13.74	18.82	13.84
Photovoltaics	22.99	22.99	32.6	26.34	37.39	26.64

[a]Cost are reported in ¢/kWh in 2004 prices

depreciation lead to LCOE increases of 15%, 13%, and 13%, respectively. Similar to the results of the Palmer and Burtraw article, the authors noted that a carbon tax would be a more effective policy mechanism for encouraging renewable energy generation than the production and investment tax credits. This is in part due to the fact that tax credits must be financed by raising other distortionary taxes or through reduced spending elsewhere in the budget. In contrast, a carbon tax would contribute to making renewables more cost competitive with fossil fuels while also raising revenues.

5.6 “PTC, ITC, or Cash Grant? An Analysis of the Choice Facing Renewable Power Projects in the United States” by Bolinger, et al., 2009

The following case study compared the PTC, ITC, and the treasury cash grant. The study was written in 2009 by Mark Bolinger and Ryan Wiser of Lawrence Berkeley National Laboratory (LBNL), and Karlynn Cory and Ted James of the National Renewable Energy Laboratory (NREL), and is titled “PTC, ITC, or Cash Grant? An Analysis of the Choice Facing Renewable Power Projects in the United States.” (Bolinger, et al., 2009) The study analyzed both the quantitative and qualitative aspects of the PTC, ITC, and cash grant for a variety of renewable energy technologies to determine which policy would provide the greatest financial value to a project developer or owner. The following technologies were included: on-shore wind, open-loop biomass, closed-loop biomass, geothermal, and landfill gas. The quantitative analysis depended on two project-specific factors: installed project costs and capacity factor. The qualitative analysis included the following considerations: option to elect equivalent cash grant, performance risk, tax credit appetite, liquidity, subsidized energy financing, power sale requirement, and owner/operator requirements.

The results of the study concluded that projects with higher capacity factors and lower installed costs favored the PTC over the ITC. This is due to the fact that higher capacity factors mean greater production, and thus more PTCs are generated. Additionally, lower installed costs mean that the value of the PTCs will be higher and account for a higher percentage of the project’s installed cost. The quantitative analysis revealed that open-loop biomass received the greatest benefit from the ITC, geothermal received the greatest benefit from the PTC, and the remaining three technologies (wind, closed-loop biomass, and landfill gas) received only a slight benefit from the PTC over the ITC. When qualitative variables were considered, only investment liquidity favored the PTC, while all other considerations favored the ITC. When both quantitative and qualitative factors were considered, the results of the analysis suggested that only geothermal favored the PTC, while all other technologies favored the ITC. However, exceptions include projects with extremely low installed costs and high capacity factors, which would quantitatively favor the PTC.

5.7 "Wind Power and the Production Tax Credit: An Overview of Research Results" by Ryan Wiser (Lawrence Berkeley National Laboratory), 2007

Another interesting piece of literature pertinent to this analysis is a 2007 testimony by Ryan Wiser of LBNL to the Senate Finance Committee titled "Wind Power and the Production Tax Credit: An Overview of Research Results" (Wiser, 2007). In his testimony Dr. Wiser stated that the PTC was one of the most significant drivers of growth in the wind industry. He also summarized the impacts of the "boom-and-bust" cycle that resulted from the PTC enactments and expirations. Based on his research results, Dr. Wiser provided a set of recommendations for redesigning the PTC to promote increased renewable energy development.

The results presented in his testimony stated that the short term (1-2 year) extensions of the PTC have had negative impacts on the wind industry. These impacts include slowed wind development (see **Figure 22**), higher costs, greater reliance on foreign manufacturing, difficulties in rationally planning transmission expansion, and

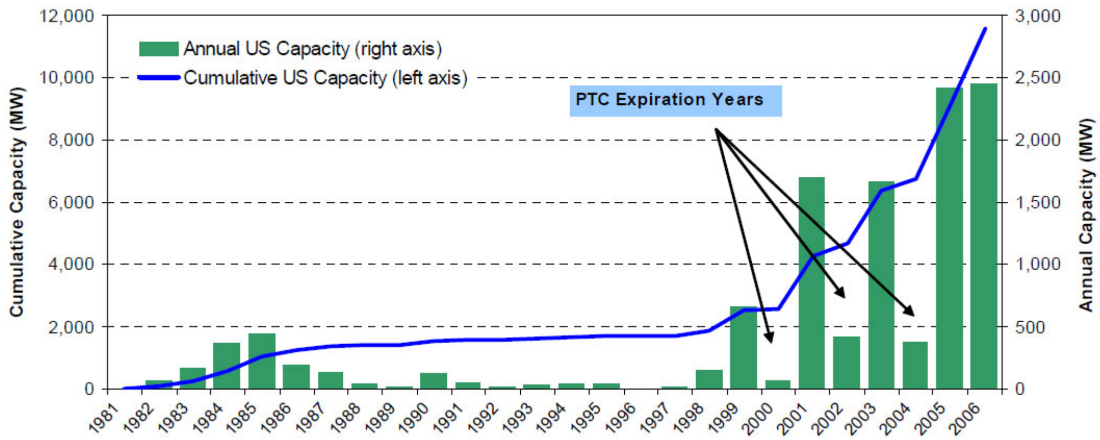

Figure 22: Wind power capacity (annual and cumulative) (Wiser, 2007)

reduced private R&D expenditures. With regard to costs, Dr. Wiser noted that the PTC reduced the cost of wind by approximately 2 ¢/kWh, and that preliminary analyses by LBNL in 2006 suggested that longer-term PTC extensions may be able to reduce installed costs for wind by 5% to 15%. To support the results of the 2006 analysis, Dr. Wiser also provided findings from a survey of wind industry members, which listed the potential benefits from an improved PTC policy and ranked them in order of importance (see **Figure 23**). With regard to a 5-10 year PTC extension, the key findings of the survey were as follows: (1) the benefits to the wind industry are expected to be diverse, (2) the PTC extension may encourage growth in domestic wind turbine manufacturing, (3) the installed cost reduction potential is significant between 8% to 15%, and (4) the benefits of a 10-year PTC extension are likely to be greater than a 5-year extension.

In his testimony Dr. Wiser also provided numerous considerations and suggestions for redesigning the PTC. First, he noted the incongruity between state and federal financial incentives with regard to the "credit offset" or "anti-double-dipping"

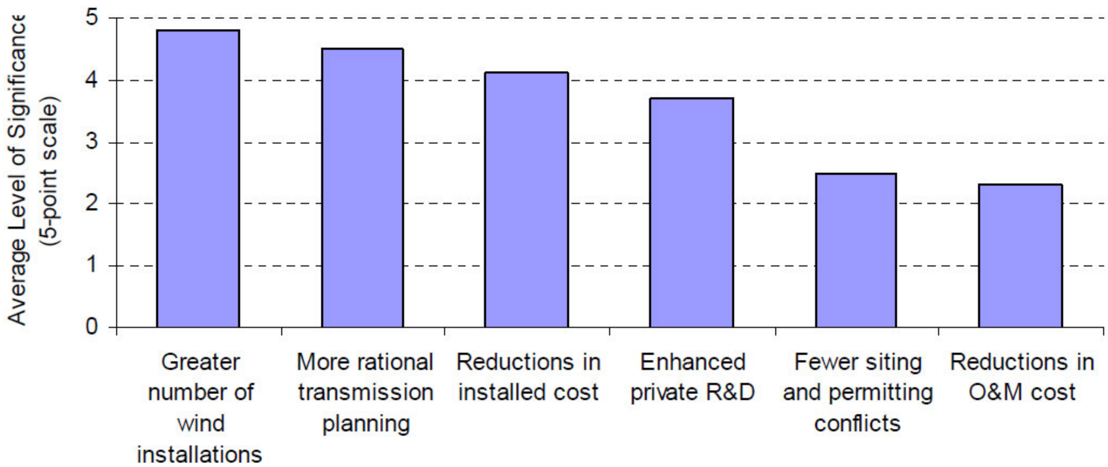

Figure 23: Potential benefits to the wind industry of a 5-10 year PTC extension (Wiser, 2007)

provisions, which disqualify or reduce the amount of PTC available to projects that also receive other types of federal assistance (e.g. grants, bonds, other tax credits, etc.). State programs are often designed to avoid triggering the offset provisions, while federal programs are not. He suggested eliminating the credit offset provisions, exempting certain smaller renewable energy projects from the offset provisions, or restructuring the incentives so that they do not trigger the offset provisions (e.g. making the payment performance based).

Additionally he suggested restructuring the PTC to increase the types of investors that can use it, specifically to include “passive” investors – those who require additional income not in the form of wages, interest payments, or dividends to use the PTC - and investors that do not pay taxes (e.g. publicly owned electric utilities, rural electric cooperatives, government bodies, and non-profit groups). Furthermore, he suggested that the PTC should be allowed to be traded or sold for cash to enable excluded investors to more easily and directly realize value from the credit.

5.8 "Using the Federal Production Tax Credit to Build a Durable Market for Wind Power in the United States" by Wiser, et al., 2007

As discussed earlier, the potential value of extending the PTC by 5 or 10 years is substantial. Dr. Wiser noted that some renewable technologies require longer development periods than wind, and thus a longer-term PTC is necessary to provide an equivalent value to those industries as it does to the wind industry. In a report released later in 2007 by Wiser, Bolinger, and Barbose of LBNL titled "Using the Federal Production Tax Credit to Build a Durable Market for Wind Power in the United States," the implications for other renewable technologies were discussed in greater detail (Wiser, et al., 2007). The report noted that since some renewable technologies had only recently become eligible for the PTC, the short duration of the PTC activity window had made financing difficult. Furthermore, the varied incentive levels of the PTC with respect to different renewable technologies suggested that some renewable technologies would be unlikely to see much growth even with a longer-term PTC policy. The solution, the authors suggested, would be to "tune" the PTC incentive levels to each technology based on maturity and level of economic competitiveness.

Many opponents to the PTC have raised concerns about the policy's high cost and budgetary impacts. Dr. Wiser suggested that to contain costs, the level of the PTC should gradually decrease over time, and in proportion to the maturation rate of the technologies.

Furthermore, he noted that the value of the PTC should still be substantial enough to support new project development.

5.9 “Reassessing Renewable Energy Subsidies” by the Bipartisan Policy Center, 2011

Taking things one step further, the staff of the Bipartisan Policy Center (BPC) identified additional options for renewable energy incentives in the 2011 report titled “Reassessing Renewable Energy Subsidies” (Bipartisan Policy Center, 2011). The report evaluated the value of tax credit programs, compared to the cash grant option, and then provided alternatives for modifying or replacing the tax-based incentive system.

Drawing on the conclusions of a 2009 study by Hudson Clean Energy Partners (Auerbach, 2009) which found that the premium charged for tax equity financing increased project installed costs ($/kW), the BPC commissioned Bloomberg’s New Energy Finance (BNEF) to evaluate how effectively the renewable energy tax-based incentives were utilizing taxpayer resources. The results of the assessment concluded that the cash grant is significantly more effective than the PTC. Additionally, the results of the study suggested that one dollar in cash is nearly twice as valuable as one dollar in credits (see **Figure 24**). When considering these results, it is important to note that the authors of the report specifically stated that their intention was not to dispute that the tax-based incentive system has been hugely beneficial for renewable technologies, but rather to point out that it is a “sub-optimal tool” when compared to alternative options.

One of the alternative options recommended in the report was to enable renewable energy developers to utilize a financing/ownership structure called a master limited partnership (MLP). This would allow for limited liability ownership and access to tax benefits that permit selling of securities (e.g. stocks). The result would be that the general public could invest in renewable energy projects by buying stock in MLPs and then use the equity to develop more projects, ultimately reducing liquidity by broadening the pool of eligible investors.

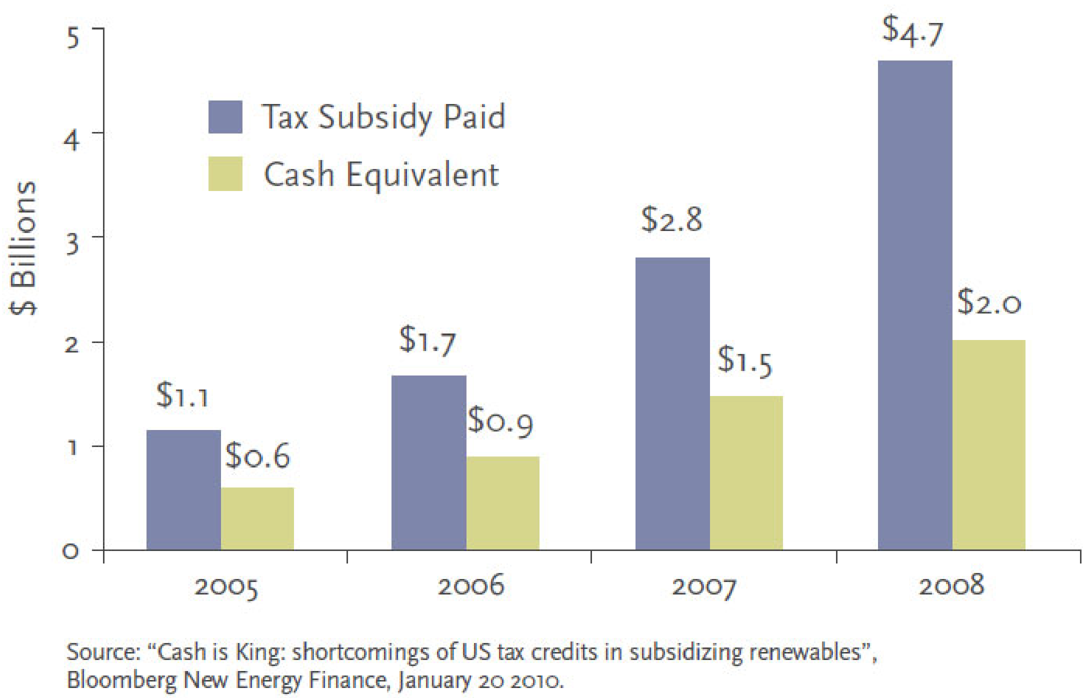

Figure 24: Cost to federal government of subsidizing wind (tax credits vs. cash grants) (Bipartisan Policy Center, 2011)

Another option that the report provided involved modifications to the cash grant program. Rather than provide the cash grant to any eligible project, the BPC recommended holding a reverse auction, whereby projects are selected based on which ones require the least amount of upfront funding to produce the desired amount of energy. However, the study noted that reverse auctions tend to favor existing least-cost technologies rather than more expensive - but potentially more efficient - nascent technologies. Accordingly, the study suggested establishing separate programs based on technology maturity level. The study also suggested that mechanisms be put in place to even the playing field between disadvantaged small firms and larger more experienced firms.

To ensure that the funding further incentivize improvements in operating capacity and efficiency, the study suggested that competition for the incentives could also be coupled with declining incentive amounts over time. The report noted a similar policy proposal called Incentives for Renewable Energy Generation (IREG), which utilizes a declining production-based incentive program. PTC eligible projects would receive PTC-equivalent cash payments on a quarterly basis for 10 years that gradually decrease over time. ITC eligible projects would receive a one-time ITC-equivalent payment and then would gradually shift to a declining production-based payment, which would be intended to reward and encourage increased production. To provide funding for the above-mentioned options, the BPC recommended reducing or eliminating fossil fuel subsidies, creating an oil import fee, or collecting a wires charge on electricity sales.

In summary, this literature review chapter compared a variety of renewable energy policies (both quantitatively and qualitatively) to provide the information necessary to develop a set of recommended strategies for accelerating the development of the MHK industry in the United States. The following chapter presents these recommendations.

6 POLICY ANALYSIS AND RECOMMENDATIONS FOR MHK

Drawing on the information presented in the previous literature review, this chapter analyzes the aforementioned policies and attempts to make policy recommendations for the MHK industry. The following chapter presents the analysis methods and results.

6.1 Analysis Methods

The relative infancy of the MHK industry leaves very little historical data (e.g. capacity, costs, policy programs, etc.) available for review. This analysis attempts to make recommendations for future MHK incentive policies by doing an extensive literature review of past case studies that examine the experiences of other, more mature, renewable energy technologies, and draw conclusions based on similarities between MHK and those technologies.

Table 10 (shown in section 4.2) and **Figure 25** (shown in section 6.2) are used to demonstrate the success of the PTC on the on-shore wind industry. The 1994-2005 data were referenced from a previous report (Wiser, 2007) and updated from 2006 onward using new information (Wiser & Bolinger, 2011; Wiser & Bolinger, 2012). Monthly installed capacity data were available for the 1994-2005 years, making it easy to calculate the exact amount of capacity installed during a partial year PTC window. However, installed capacity data were only available in annual increments starting in 2006. Therefore, the data presented in **Table 10** and **Figure 25** are verified using **Table 15**, which compares capacities installed during the PTC window using both monthly data and

Table 15: Comparing monthly and annual data used to calculated wind capacities installed during PTC windows[18]

Legislation Date	Enacted	PTC Eligibility Window	Duration[a]	Capacity Installed Using Monthly Data (MW)[b]	Capacity Installed Using Annual Data (MW)[d]
Section 1914, Energy Policy Act of 1992 (P.L. 102-486)	10/24/1992	1994-June 1999	80	894	894
Section 507, Ticket to Work and Work Incentives Improvement Act of 1999 (P.L. 106-170)	12/19/1999	July 1999-2001	24	1,764	1,764
Section 603, Job Creation and Worker Assistance Act (P.L. 107-147)	3/9/2002	2002-2003	22	2,078	2,078
Section 313, The Working Families Tax Relief Act, (P.L. 108-311)	10/4/2004	2004-2005	15	2,796	2,395
Section 1301, Energy Policy Act of 2005 (P.L. 109-58)	8/8/2005	2006-2007	24	-	7,702
Section 201, Tax Relief and Health Care Act of 2006 (P.L. 109-432)	12/20/2006	2008	12	-	8,337
Energy Improvement and Extension Act of 2008 (H.R. 1424)	10/1/2008	2009	12	-	9,993
American Recovery and Reinvestment Act of 2009 (H.R. 1)	2/1/2009	2010-2012	36	-	11,928[c]

[a] Effective duration in months (considering lapses)
[b] Wind capacity built in PTC window using exact monthly capacity installation data, data not available beyond 2005 (Wiser, 2007)
[c] 2010 and 2011 only
[d] Wind capacity built in PTC window using data from annual capacity additions regardless of partial year PTC windows (Wiser & Bolinger, 2011; Wiser & Bolinger, 2012)

[18] Updated from original source (Wiser, 2007) using data from (Wiser & Bolinger, 2011; Wiser & Bolinger, 2012)

annual data. **Table 15** shows good agreement between the monthly and annually calculated installed capacities, confirming the practicality of this approach. The referenced report does not specify how the monthly data were obtained for the years leading up to 2006.

The data in **Table 16** (shown later in section 6.2) present the results of a previous case study that compared the effectiveness of the ITC vs. the PTC for several alternative energy technologies (Bolinger, et al., 2009). Conclusions about the effectiveness of the ITC and PTC for MHK were made by drawing comparisons between MHK and these technologies. Due to the nascent state of MHK technologies, no reliable published data were found presenting installed costs ($/kW) for MHK. Costs used in this analysis are based on data presented by European project developers at the 2012 Global Marine Renewable Energy Conference, hosted by the Ocean Renewable Energy Coalition.

6.2 Analysis Results

Drawing on the conclusions of the Nemet article, it stands to reason that R&D funding is effective at stimulating radical technological innovation, but tax credits are more effective at spurring growth in an industry that has reached the point of fine-tuning a limited number of design concepts. Currently the focus of the MHK industry in the U.S. is on government R&D spending, with the intention of exploring a variety of drastically different design concepts. Once R&D funding has enabled a preferred design to be chosen for each applicable resource (e.g. wave, tidal, current, OTEC) and the focus shifts to deployment, efforts by the government would be more effective if funding were redirected toward demand-pull mechanisms. However, some degree of R&D funding remains valuable to stimulate further innovation and improvement.

There are a variety of demand-pull policy options available; selecting an ideal set of options depends upon the desired outcome. Some policy options are most effective (in absolute terms and cost) at reducing emissions, while other policy options are most effective at increasing renewable energy generation. As discussed in section 5.4 of the literature review chapter, RPSs can achieve greater renewable generation and at lower cost than a cap-and-trade program, but a cap-and-trade program can achieve greater emissions reductions and at lower cost (Palmer & Burtraw, 2005). Of all the policy options evaluated in the case studies (PTC, ITC, cash grant, RPS, cap-and-trade, and carbon tax) the tax credits and cash grants were less effective at increasing renewable generation and decreasing emissions than the other policies. Unfortunately these sub-optimal policies are the only incentive policies that currently exist at the federal level in the U.S.,[19] so – as mentioned in the barriers analysis section – rather than reiterate the already well known potential benefits of carbon tax and cap-and-trade programs, this analysis aims to identify opportunities for modifying or enhancing the existing tax credit policies to maximize the potential benefit for the MHK industry. As this analysis will show, the current designs of tax credit policies could and should be improved as soon as possible to provide the best growth opportunities for the MHK industry in the U.S.

Based on the results of the policy case studies discussed earlier, MHK technologies would benefit more from an ITC than a PTC. Though the PTC has

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[19] RPSs currently exist at the state level only. No national RPS exists yet.

historically been the incentive policy credited for the success of the wind industry – and would be the assumed policy preference for the MHK industry - relatively recent changes to the design of renewable energy incentive programs and eligibility requirements (e.g. increased value of the ITC and introduction of the cash grant) have made the ITC more attractive to MHK. It is likely that if these changes had been implemented simultaneously with the introduction of the PTC (1992) most wind developers would have elected the ITC over the PTC. Instead, the overwhelming selection of the PTC over the ITC throughout the history of the wind industry can be attributed to the fact that the value of the ITC was much lower than it is now (see **Table 13**). The changes to the ITC through ARRA have since increased the value of the ITC to certain types of renewable energy project developers, particularly nascent technologies with very high capital costs. On-shore wind projects will likely continue to benefit more from the PTC than the ITC due to the fact that the technology has matured enough to bring down capital costs. The effectiveness of the PTC on increasing installed capacity for the on-shore wind industry is shown in the figures below. Each time the PTC was reinstated, the capacity installed per month increased substantially (**Figure 25**). Each time the PTC expired, the annual percent capacity growth dropped significantly (**Figure 26**).

ARRA was passed in response to the 2008 financial crisis. It extends the PTC timeframe and allows taxpayers eligible for the PTC to instead elect to take the ITC or to receive a grant from the U.S. Treasury Department. This legislation has profound implications for previously ITC-ineligible technologies that are only eligible for half the value of the PTC. Additionally, the ability to elect the cash grant option is significant

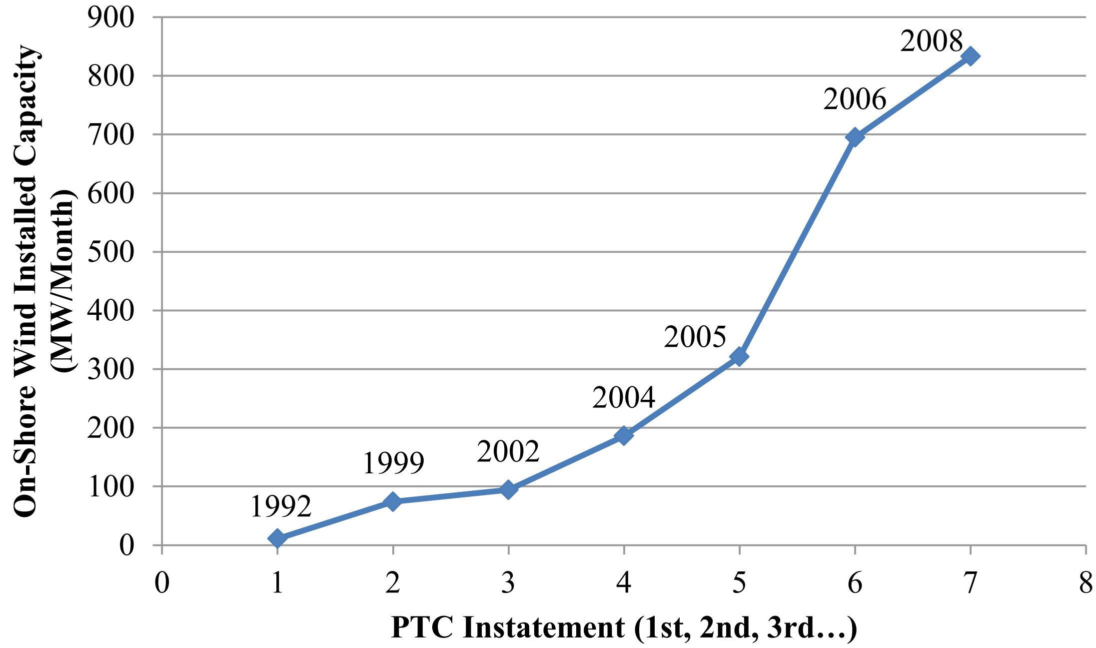

Figure 25: Average monthly on-shore wind capacity installed during each PTC instatement window[20]

because the financial crisis has reduced the number of tax equity investors in the renewable energy market, making tax credit programs relatively useless (Bolinger, et al., 2009). Unfortunately, the benefits provided to the MHK industry by ARRA are set to expire on January 1st, 2014. As discussed previously, without stable, long-term incentive policies, investment uncertainty will rise, and MHK industry development will slow as the expiration date approaches.

For projects than can make use of the PTC and ITC it is worthwhile to evaluate which tax credit benefits each technology more. A comparison of wind, open-loop biomass, closed-loop biomass, geothermal, and land fill gas technologies revealed that

[20] Data from (Wiser, 2007) and (Wiser & Bolinger, 2011). For more information see the Analysis Methods section.

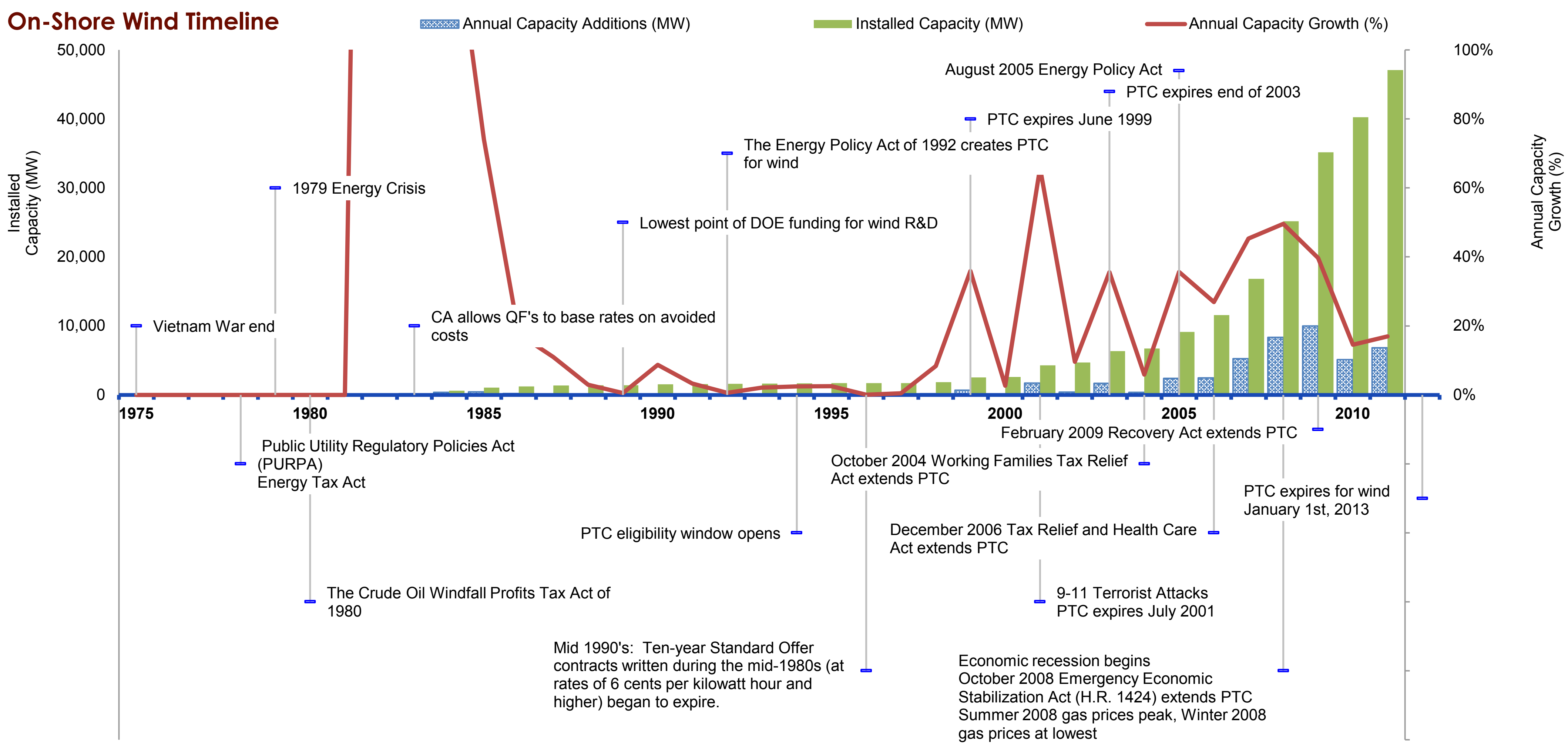

Figure 26: U.S. on-shore wind capacity growth and policy enactment timeline[21]

[21] See Appendix A for raw data and source information

only open-loop biomass favors the ITC over the PTC, based on quantitative considerations (Bolinger, et al., 2009). This is due to the fact that open-loop biomass is only eligible to receive half of the PTC value, has relatively high installed costs, and is eligible for the full 30% ITC. Landfill gas also only receives half the value of the PTC, but due to the low installed costs of these projects, the technology benefits relatively equally from either the PTC or ITC. With regard to PTC or ITC preference, MHK projects most closely resemble the attributes of open-loop biomass projects (given that they are also only eligible for half the PTC and have high installed costs) and wind projects (given that they have similar capacity factors). See **Table 16** for the results of the technology and policy comparisons.

The conclusion that MHK would benefit more from the ITC than the PTC is further supported by the following table (17) and figures (27-30), which demonstrate the lifetime costs and PTC/ITC benefits for an example on-shore wind project and an MHK project (using **Equation 3**). **Figure 27** shows that the lifetime cost for an MHK project is significantly lower when using the ITC versus the PTC (~ $38mil, 23%). This difference in lifetime cost is drastically larger for MHK than for on-shore wind (which is only ~ $10mil, 16%). It should also be noted that, as discussed in the literature review, extending the PTC by 5-10 years could provide cost reductions between 8-15% (Wiser, 2007). Presumably, these same cost reductions would apply for a 5-10 year extension of the ITC as well. Additionally, **Figure 27** shows that if the PTC were 2.2 ¢/kWh for MHK, rather than 1.1 ¢/kWh, the lifetime cost of an MHK project would be reduced by ~ $10mil (6%). **Figure 28** shows that the ITC becomes more attractive than the PTC with

Table 16: Results of policy and technology quantitative comparisons, using 7.5% nominal discount rate (Bolinger, et al., 2009)

Metric	Wind	Open-Loop Biomass	Closed-Loop Biomass	Geothermal	Landfill Gas	MHK
Installed Cost ($/kW)	1,500-2,500	3,000-5,000	3,000-5,000	3,000-6,000	1,000-3,000	$4,000+[d]
Capacity Factor (%)	25-45	60-90	60-90	70-95	60-90	30-57[b]
2.2 ¢/kWh PTC Eligible	✓		✓	✓		
1.1 ¢/kWh PTC Eligible		✓			✓	✓
30% ITC Eligible	✓	✓[c]	✓[c]	✓[c]	✓[c]	✓[c]
% ITC eligible for MACRS	95	95	95	75	95	0[e]
Preference	PTC > ITC (slightly)[a]	ITC	PTC	PTC	PTC = ITC	Likely ITC

[a]For wind technology, projects < $1,500/kW benefit more from PTC, while projects > $2,500/kW benefit more from ITC. In between these values capacity factor is more likely to be the determinant.
[b]Sources: (Bedard, 2009); (Tribal Energy and Environmental Information, 2012)
[c]Temporarily made possible by the 2009 Recovery Act
[d]Source: (Global Marine Renewable Energy Conference, 2012)
[e]See **Table C.1** in the appendix

increasing installed costs. In other words, as the installed cost increases, the ITC is able to lower the lifetime cost of a project more than the PTC. Therefore, the ITC is more appealing to MHK than to wind because MHK installed costs are much higher. As the installed costs decrease, the appeal of the ITC over the PTC diminishes. Once installed costs drop to approximately \$1.65 million/MW (assuming a 7.5% discount rate) the benefits of the ITC and PTC become equal. (Using a discount rate between 5-10% yields a target installed cost range of \$1.9-\$1.5 million/MW, respectively). This should be used as the basis for developing a transitional ITC to PTC program. Furthermore, **Figure 27** shows that even if MHK were eligible for the full PTC, as wind is, the ITC still provides a lower lifetime cost than the PTC.

Equation 3: Uniform present worth $\boldsymbol{P = A\frac{(1+d)^n-1}{d(1+d)^n}}$

P = Uniform present worth (\$)
A = Annual cost (\$)
d = Discount rate (%)
n = Project lifetime (years)

Table 17: Data and calculations for the PTC and ITC benefits comparisons of on-shore wind and MHK

	On-Shore Wind		**MHK**	
Rated power (MW/turbine)	1	1	1	1
Number turbines	40	40	40	40
Capacity factor (%)	31%	31%	37%	37%
Installed cost ($mil/MW)	$1.5	$1.5	$4.0	$4.0
Annual O&M ($/MWh)	10	10	10	10
Turbine life (years)	20	20	20	20
Net discount rate (%)	7.50%	7.50%	7.50%	7.50%
PTC ($/kWh)	***$0.022***	***$0.011***	***$0.011***	***$0.022***
ITC (%)	30%	30%	30%	30%
Annual Energy Output (MWh)	108,624	108,624	129,648	129,648
Installed Cost ($mil)	$60.0	$60.0	$160.0	$160.0
Annual O&M Cost ($mil)	$1.09	$1.09	$1.3	$1.3
Annual PTCs Received ($mil)	$2.39	$1.19	$1.43	$2.85
One-Time ITC Received	$18.0	$18.0	$48.0	$48.0
Uniform Present Worth (Lifecycle Cost, $mil)	$71.07	$71.07	$173.22	$173.22
Uniform Present Worth of PTCs Received (Over first 10 years, $mil)	$16.4	$8.2	$9.79	$19.58
Lifetime Cost w/ PTC ($mil)	$55	$63	$160	$150
Lifetime Cost w/ITC ($mil)	$53	$53	$130	$130

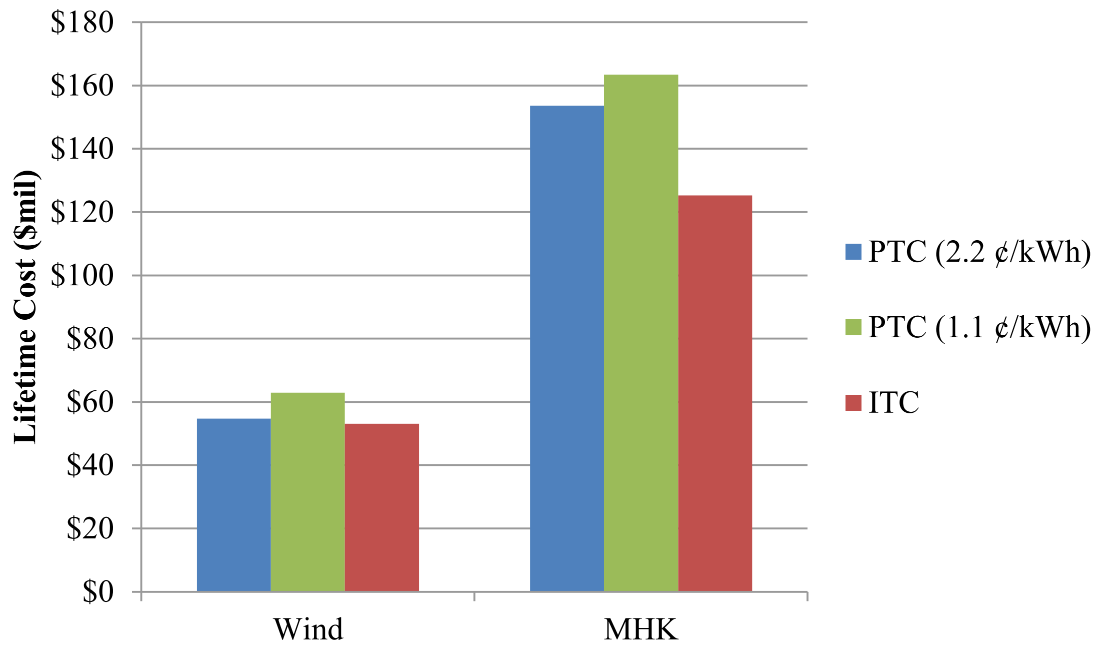

Figure 27: PTC and ITC lifetime cost benefits compared for on-shore wind and MHK

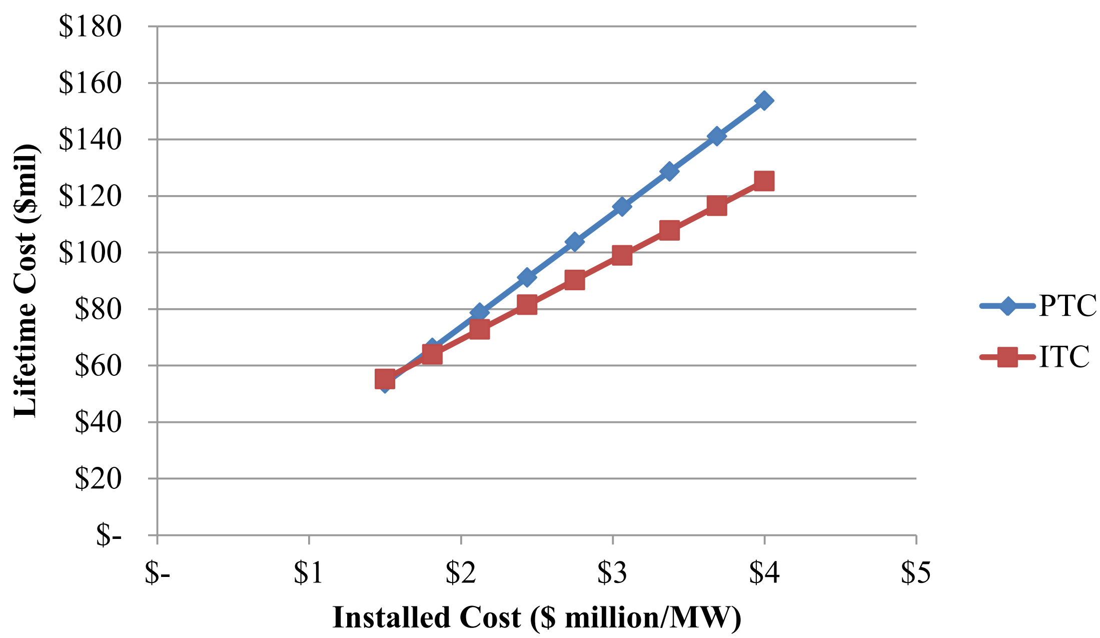

Figure 28: Influence of MHK installed cost on lifetime cost, compared for the ITC and PTC

In addition to installed cost, another factor that influences the ability of the PTC and ITC to lower a project's lifetime cost is the capacity factor. Lower capacity factors mean reduced production output, and correspondingly lower revenues from the PTC. Wind and MHK both have similar capacity factor ranges - which are low relative to the other technologies compared in the study – and wind shows only a slight preference for the PTC. If wind and MHK had higher capacity factors, the PTC would be more appealing than it currently is. **Figure 29** shows that in order for an MHK project to benefit more from the PTC than the ITC, the value of the PTC must be 2.2 ¢/kWh instead of 1.1 ¢/kWh, and the capacity factor must be over 90%. Furthermore, **Figure 30** shows that increasing the value of the PTC still does not provide a lower lifetime cost than projects using the ITC. Since the value of the PTC for MHK is currently only 1.1 ¢/kWh, and 90% capacity factors are highly unlikely, the ITC is the preferred policy option for MHK.

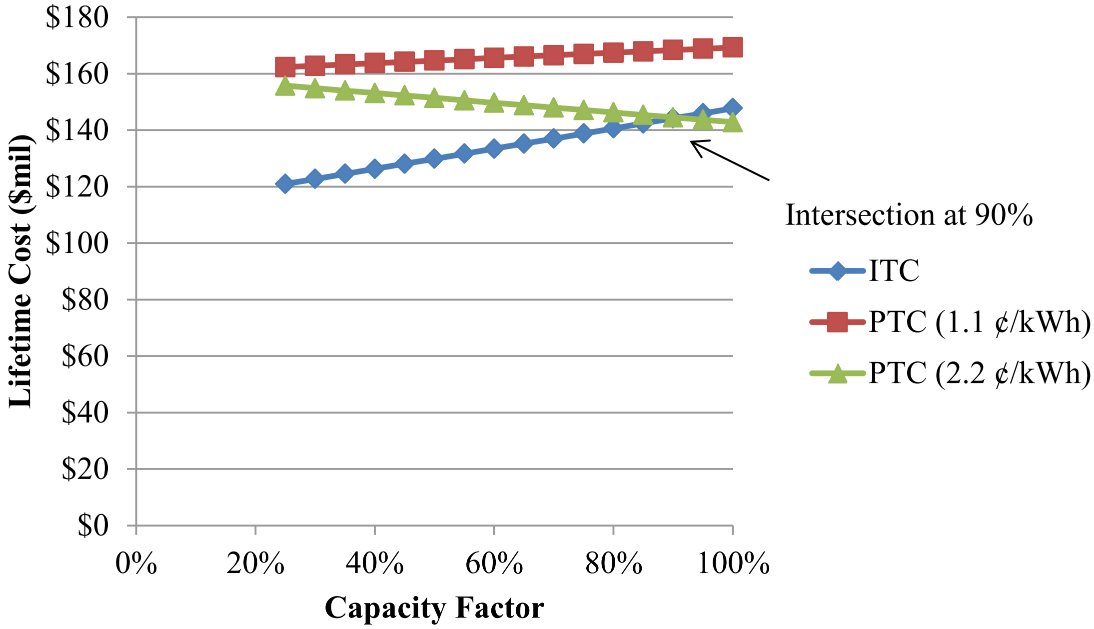

Figure 29: Influence of capacity factor on PTC and ITC lifetime cost for MHK

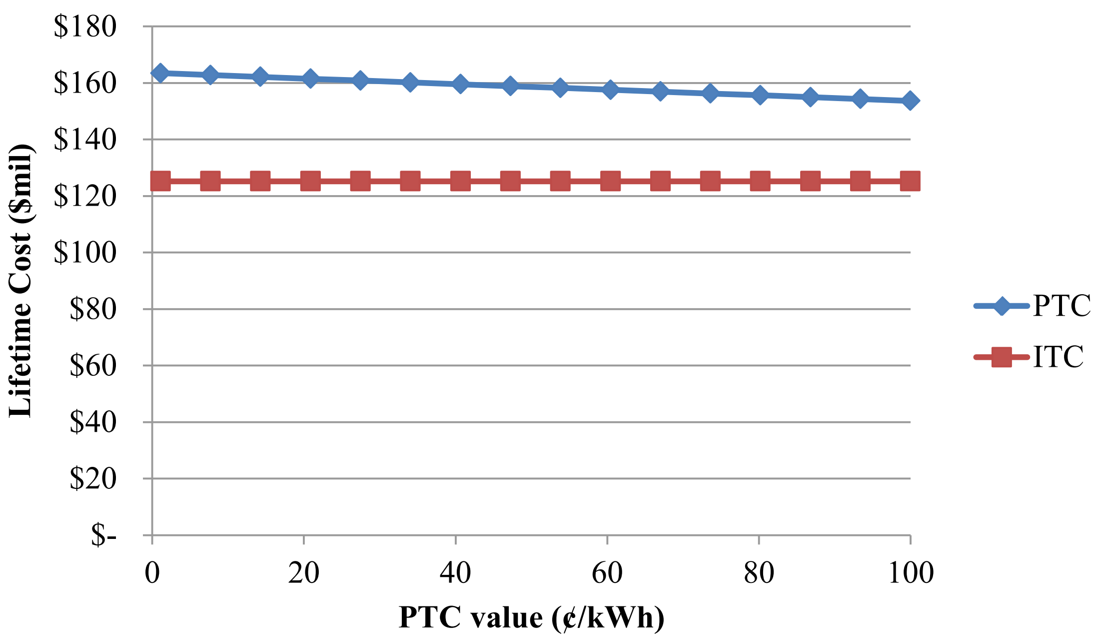

Figure 30: Influence of PTC value on lifetime cost for MHK

In addition to the quantitative benefits of the ITC over the PTC, there are several qualitative benefits as well. One potential benefit is that the ITC provides developers with an opportunity to develop less energetic sites, because the ITC does not depend on how much energy a project generates (Wiser & Bolinger, 2011). For MHK developers, this may provide an opportunity to prioritize the development of sites that are easier to access, closer to shore, or in shallower waters. These more easily accessible sites might be able to use less robust mooring systems (due to the shallower waters), ultimately reducing project costs for critical pilot projects. Additionally, these sites might require shorter transmission lines, further reducing project costs. However, transmission infrastructure is not eligible for inclusion as "qualifying property" defined by the ITC rules, "only the property that is integral to the production of the energy is qualifying" (Idress, 2012).

Comparing MHK to off-shore wind (rather than on-shore wind) provides further support that the ITC is preferable over the PTC. From an economic perspective off-shore wind is the most similar renewable energy technology to MHK. Both technologies are in their infancy, face similar barriers with off-shore permitting, and have very high upfront costs. Off-shore wind benefits more from an ITC than a PTC because it is a largely unproven technology, and - in the eyes of investors – discounts returns in the capital market (Caperton, 2012). As an unproven technology its production capability is unpredictable. The durability and reliability of off-shore equipment is unknown, so maintenance costs are uncertain. This uncertainty makes the value of the PTC also unpredictable (Caperton, 2012). Even though MHK is most economically comparable to off-shore wind, from a tax credit policy perspective it is treated very differently. Off-shore wind reaps the benefits of on-shore wind experience by receiving the same treatment with regard to tax credits. Both on-shore and off-shore wind are eligible for the full 2.2 ¢/kWh PTC and 30% ITC amount, and subsequently the full 30% treasury cash grant amount. This kind of treatment is good for the off-shore wind industry but unfair to the MHK industry, which only receives half the PTC amount (1.1 ¢/kWh). Both MHK and off-shore wind technologies face many of the same barriers, risks, and high costs, but off-shore wind is favorably treated in the policy environment the same way as its more mature cousin, on-shore wind.

An even more valuable policy incentive to MHK is the treasury cash grant. Research has shown that cash grants are twice as valuable to renewable energy project developers as tax credits (Auerbach, 2009). Since renewable energy projects are typically capital-intensive, project developers often partner with tax equity investors (e.g. large investment banks and insurance companies) through special financing structures. Considering the harsh economic conditions that have reduced the number of tax equity investors in the market, tax-base policy incentives have become less valuable to investors. However, the cash grant virtually eliminates the need for these tax equity investors, who project developers have relied on so heavily in the past (Bolinger, et al., 2009). The allure of cash has some intrinsic value of its own, which could be particularly appealing to MHK project developers who are understandably cautious given the high-risk nature of up-and-coming MHK technologies. An additional benefit of the cash grant is that it is more transparent than a tax credit, because developers who claim cash grants must submit much more detailed information about their project than when they file for tax credits (Caperton, 2012).

Unfortunately the benefits of the PTC, ITC, and cash grant are only temporarily available to MHK. The provisions of ARRA state that MHK projects must be placed in service before January 1st, 2014 to be eligible. Therefore, it is crucial to have a long-term (5-10 years or longer) policy in place that allows MHK to be eligible for the full 2.2 ¢/kWh PTC and 30% ITC - and subsequently the treasury cash grant – if maximum growth opportunities are to be realized. Additionally, it is vital to have stable, long-term tax credit and grant policies in place before the expiration of the current ARRA regulations. Historically, gaps in incentive policies have created significant volatility in renewable energy markets and slowed their potential growth (Wiser, et al., 2007). Furthermore, a long-term policy should be continually revised and updated based on the current economic needs of the U.S. The value of the PTC has been updated numerous times since its original enactment to account for inflation. This trend should be continued for the PTC. Additionally, when updating the PTC and ITC values a technology's maturity rate should be considered (Wiser, et al., 2007), as well as the current price of conventional fuels.

7 CONCLUSIONS

The most critical issue for MHK incentive policy is having a stable, long-term (5-10 years or longer) program in place. Current tax credits and grants extended or enhanced by the 2009 ARRA are set to expire for MHK on January 1st, 2014. Stable, long-term incentives must be enacted before the current ones expire to avoid the same development lulls that the wind industry experienced with the expirations of the PTC. Long-term policies must be designed to include regular review processes that adjust incentive amounts based on the current economic environment, technology maturity level, and competing conventional fuel prices.

A key component of a successful policy program for MHK is prioritizing the policy option that provides the most benefit to the MHK industry. Of the three incentive policies examined, the best incentive identified for MHK is the treasury cash grant. MHK advocates should focus their lobbying efforts on extending the current cash grant program by at least 5 years - the minimum time suggested for the PTC extension, (Wiser, 2007). Since this policy was only temporarily extended to MHK technologies to counteract the effects of the U.S. financial crisis and economic recession, it is unlikely that this particular policy will receive an extension from Congress.

The next best policy option that should be considered for long-term reinstatement is the 30% ITC. The program should be designed to gradually transition over 5-10 years from the 30% ITC to the full value 2.2 ¢/kWh PTC as costs come down, because the benefits of the ITC vs. PTC are primarily only valuable for projects with high capital costs (like MHK), and PTCs provide a long-term incentive for efficiency improvements (Wiser, et al., 2007). The transitional ITC to PTC program should be based on a "switch-over" installed cost of approximately $1.65 million/MW (assuming a 7.5% discount rate), as identified in the Analysis Results section. Unfortunately, MHK is currently only eligible for half the value of the PTC, which was enacted in 2008 prior to the 2009 ARRA, and is set to expire on January 1st, 2014. If a 5-10 year, transitional program from ITC to PTC is to be developed, it is critical for MHK supporters to convince Congress to increase the PTC value from 1.1 ¢/kWh to 2.2 ¢/kWh. Since MHK is most economically similar to off-shore wind, it is unreasonable that MHK receives only half the PTC value while off-shore wind receives the full 2.2¢/kWh PTC value. Enabling MHK to receive the full 2.2 ¢/kWh PTC value will provide a level playing field in the competitive renewable energy market.

In summary, the results of this analysis show that stable, long term policies are crucial in order for the growth of the U.S. MHK industry to continue. The prioritized policy options identified here will provide the U.S. MHK industry with the best opportunities to be competitive and successful in energy markets, ultimately helping to reduce greenhouse gas emissions and improve environmental quality, while simultaneously creating domestic jobs, diversifying the U.S. energy portfolio, increasing national security, and decreasing fuel price volatility that results from resource shortages and political conflicts.

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APPENDIX A. CAPACITY AND FEDERAL R&D FUNDING INFORMATION FOR RENEWABLE AND TRADITIONAL ENERGY SOURCES

The information presented here in Appendix A includes installed capacity and federal R&D funding data (nominal $) for renewable and traditional energy technologies. The data are presented graphically to show trends over time. The raw data tables are also provided.

Notes for **Figures A.1** & **A.2** and **Tables A.1-A-9**:

Capacity Sources:

- Coal, Petroleum, Natural Gas, Nuclear, Hydroelectric (Table 8.11a Electric Net Summer Capacity: Total (All Sectors), 1949-2010) (U.S. Energy Information Administration Office of Energy Statistics, 2011; U.S. Energy Information Administration Office of Energy Statistics, 2012)
- PV (Bolcar & Ardani, 2011)
- On Shore Wind (Wiser & Bolinger, 2011; Wiser & Bolinger, 2012)

Capacity Notes:

- Coal - Anthracite, bituminous coal, subbituminous coal, lignite, waste coal, and coal synfuel.
- Petroleum - Distillate fuel oil, residual fuel oil, petroleum coke, jet fuel, kerosene, other petroleum, and waste oil.
- Natural Gas - Natural gas, plus a small amount of supplemental gaseous fuels.

- Hydroelectric - Through 1988, hydroelectric pumped storage is included in "Conventional Hydroelectric Power."
- PV - Cumulative installed PV power, includes Off-Grid Non-Domestic, Grid-Connected Distributed, and Grid-Connected Centralized. Excludes Off-Grid Domestic.

Additional Capacity Notes:

- Data are at end of year. For plants that use multiple sources of energy, capacity is assigned to the energy source reported as the predominant one.
- Through 1988, data are for electric utilities only. Beginning in 1989, data are for electric utilities, independent power producers, commercial plants, and industrial plants.
- Web Page: For related information, see http://www.eia.gov/electricity/

Financial sources:

- (National Renewable Energy Laboratory, 2009)
- (US Department of Energy - Office of the Chief Financial Officer - Office of Budget, 2002-2013)
- Budget tables created by Fred Sissine of Congressional Research Services (FSISSINE@crs.loc.gov)

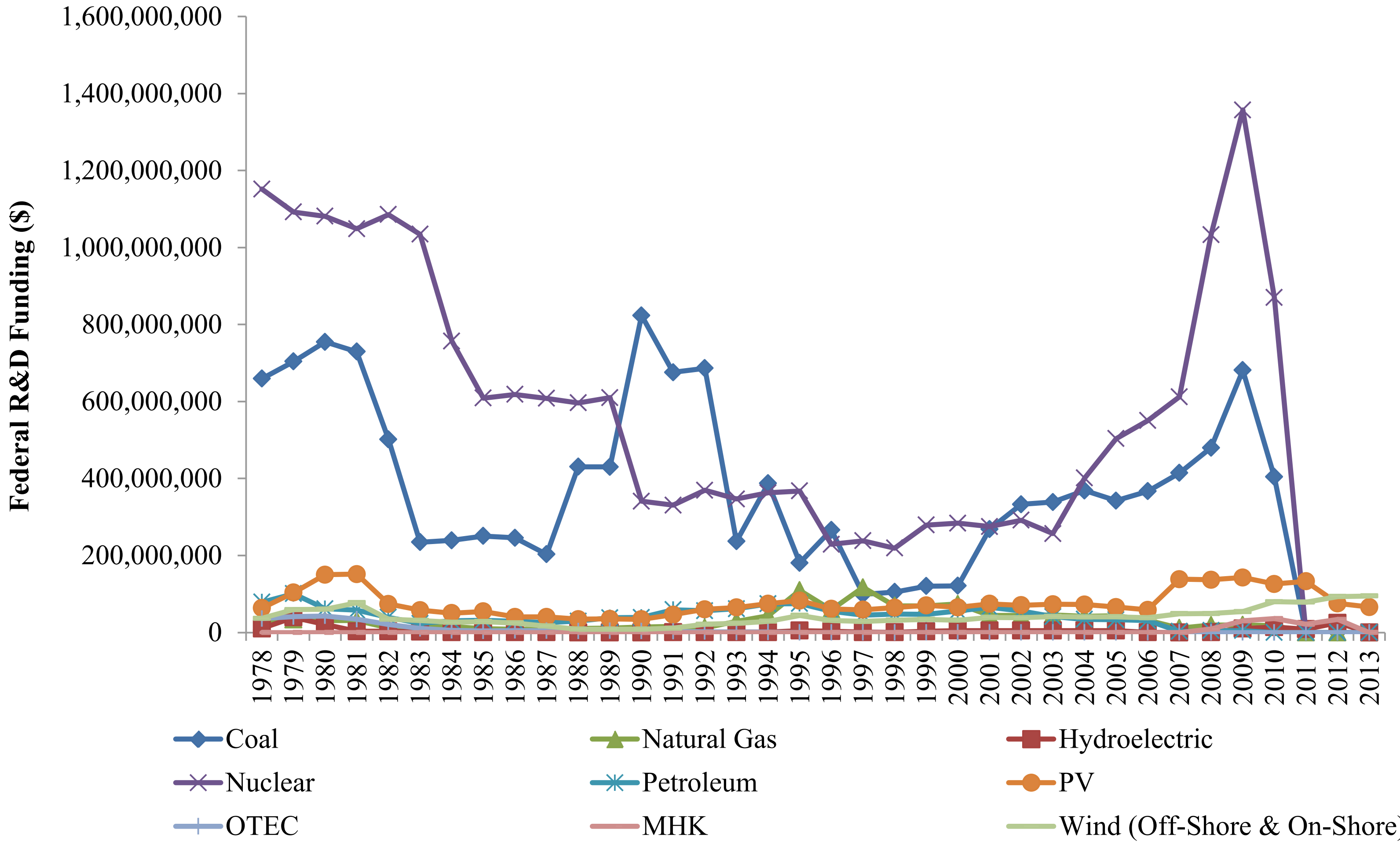

Figure A.1: Federal R&D funding for traditional and renewable fuel technologies

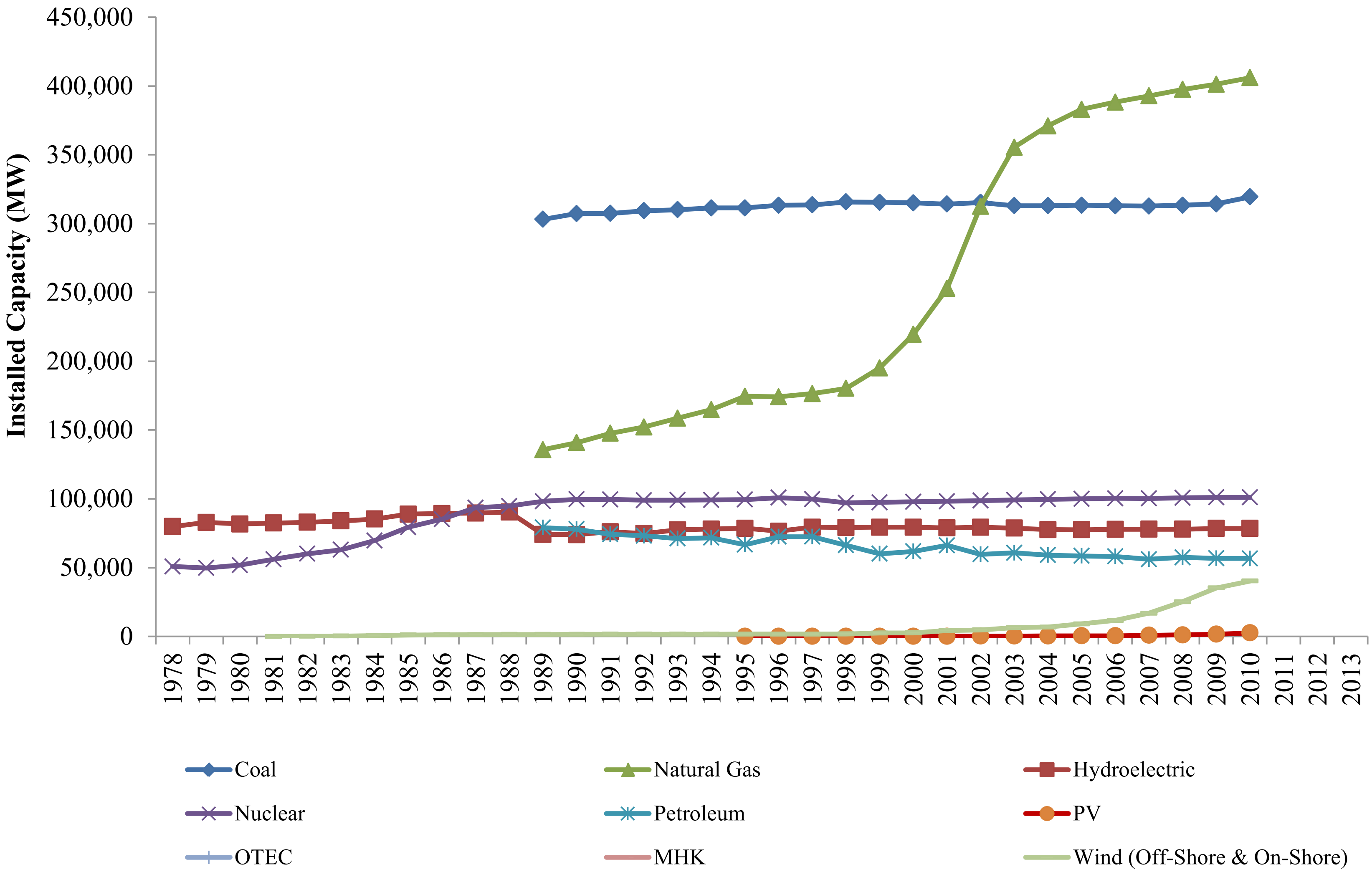

Figure A.2: Installed capacity for traditional and renewable fuel technologies

Table A.1: Capacity and funding data for coal

Year	Resource	Installed Capacity (MW)	Annual Capacity Additions (MW)	Annual Capacity Growth (%)	Federal R&D Funding ($)
1978	Coal				$659,315,000
1979	Coal				$703,941,000
1980	Coal				$754,898,000
1981	Coal				$729,713,000
1982	Coal				$501,964,000
1983	Coal				$234,500,000
1984	Coal				$239,249,000
1985	Coal				$250,679,000
1986	Coal				$246,015,000
1987	Coal				$203,126,000
1988	Coal				$430,635,000
1989	Coal	303,108			$430,096,000
1990	Coal	307,361	4,253	1%	$823,494,000
1991	Coal	307,438	77	0%	$675,979,000
1992	Coal	309,372	1,934	1%	$686,484,000
1993	Coal	310,148	776	0%	$236,701,000
1994	Coal	311,415	1,267	0%	$387,378,000
1995	Coal	311,386	(29)	0%	$180,737,000
1996	Coal	313,382	1,996	1%	$266,370,000
1997	Coal	313,624	242	0%	$98,821,000
1998	Coal	315,786	2,162	1%	$105,291,000
1999	Coal	315,496	(290)	0%	$120,579,000
2000	Coal	315,114	(382)	0%	$121,200,000
2001	Coal	314,230	(883)	0%	$268,277,000
2002	Coal	315,350	1,120	0%	$332,970,000
2003	Coal	313,019	(2,331)	-1%	$338,588,000
2004	Coal	313,020	1	0%	$368,835,000
2005	Coal	313,380	360	0%	$342,502,000
2006	Coal	312,956	(425)	0%	$366,762,000
2007	Coal	312,738	(218)	0%	$414,438,000
2008	Coal	313,322	583	0%	$479,871,000
2009	Coal	314,294	973	0%	$681,264,000
2010	Coal	316,800	2,506	1%	$404,000,000
2011	Coal	319,245	2,445	1%	
2012	Coal				

Table A.2: Capacity and funding data for petroleum

Year	Resource	Installed Capacity (MW)	Annual Capacity Additions (MW)	Annual Capacity Growth (%)	Federal R&D Funding ($)
1978	Petroleum				$78,617,000
1979	Petroleum				$100,854,000
1980	Petroleum				$61,713,000
1981	Petroleum				$57,791,000
1982	Petroleum				$39,360,000
1983	Petroleum				$23,750,000
1984	Petroleum				$30,200,000
1985	Petroleum				$31,694,000
1986	Petroleum				$29,113,000
1987	Petroleum				$25,920,000
1988	Petroleum				$29,464,000
1989	Petroleum	79,061			$38,314,000
1990	Petroleum	77,921	(1,140)	-1%	$39,034,000
1991	Petroleum	74,248	(3,673)	-5%	$59,194,000
1992	Petroleum	73,114	(1,133)	-2%	$56,491,000
1993	Petroleum	71,102	(2,012)	-3%	$61,613,000
1994	Petroleum	71,710	608	1%	$74,274,000
1995	Petroleum	66,622	(5,088)	-7%	$75,211,000
1996	Petroleum	72,518	5,896	9%	$54,935,000
1997	Petroleum	72,463	(54)	0%	$45,184,000
1998	Petroleum	66,282	(6,182)	-9%	$47,708,000
1999	Petroleum	60,069	(6,213)	-9%	$47,344,000
2000	Petroleum	61,837	1,768	3%	$55,747,000
2001	Petroleum	66,162	4,325	7%	$65,095,000
2002	Petroleum	59,651	(6,512)	-10%	$56,244,000
2003	Petroleum	60,730	1,079	2%	$40,983,000
2004	Petroleum	59,119	(1,611)	-3%	$34,107,000
2005	Petroleum	58,548	(571)	-1%	$32,985,000
2006	Petroleum	58,097	(450)	-1%	$30,805,000
2007	Petroleum	56,068	(2,030)	-3%	$2,625,000
2008	Petroleum	57,445	1,377	2%	$4,817,000
2009	Petroleum	56,781	(664)	-1%	$4,860,000
2010	Petroleum	55,647	(1,133)	-2%	
2011	Petroleum	55,608	(-39)	0%	
2012	Petroleum				

Table A.3: Capacity and funding data for natural gas

Year	Resource	Installed Capacity (MW)	Annual Capacity Additions (MW)	Annual Capacity Growth (%)	Federal R&D Funding ($)
1978	Natural Gas				$27,401,000
1979	Natural Gas				$33,811,000
1980	Natural Gas				$30,742,000
1981	Natural Gas				$31,013,000
1982	Natural Gas				$11,712,000
1983	Natural Gas				$13,680,000
1984	Natural Gas				$15,400,000
1985	Natural Gas				$10,142,000
1986	Natural Gas				$8,503,000
1987	Natural Gas				$7,971,000
1988	Natural Gas				$10,534,000
1989	Natural Gas	135,678			$11,384,000
1990	Natural Gas	140,849	5,171	4%	$14,429,000
1991	Natural Gas	147,610	6,761	5%	$15,868,000
1992	Natural Gas	152,177	4,568	3%	$12,422,000
1993	Natural Gas	158,598	6,420	4%	$29,019,000
1994	Natural Gas	164,780	6,182	4%	$43,710,000
1995	Natural Gas	174,482	9,702	6%	$109,472,000
1996	Natural Gas	174,135	(347)	0%	$58,553,000
1997	Natural Gas	176,471	2,336	1%	$117,261,000
1998	Natural Gas	180,288	3,817	2%	$69,305,000
1999	Natural Gas	195,119	14,831	8%	$69,346,000
2000	Natural Gas	219,590	24,471	13%	$73,894,000
2001	Natural Gas	252,832	33,242	15%	$43,925,000
2002	Natural Gas	312,512	59,680	24%	$44,069,000
2003	Natural Gas	355,442	42,930	14%	$45,860,000
2004	Natural Gas	371,011	15,569	4%	$41,836,000
2005	Natural Gas	383,061	12,050	3%	$43,632,000
2006	Natural Gas	388,294	5,233	1%	$31,801,000
2007	Natural Gas	392,876	4,582	1%	$11,709,000
2008	Natural Gas	397,460	4,584	1%	$19,270,000
2009	Natural Gas	401,272	3,812	1%	$19,440,000
2010	Natural Gas	407,028	5,756	1%	$17,833,000
2011	Natural Gas	413,116	6,087	1%	
2012	Natural Gas				

Table A.4: Capacity and funding data for nuclear

Year	Resource	Installed Capacity (MW)	Annual Capacity Additions (MW)	Annual Capacity Growth (%)	Federal R&D Funding ($)
1978	Nuclear	50,824	4,521	10%	$1,151,957,000
1979	Nuclear	49,747	(1,077)	-2%	$1,092,295,000
1980	Nuclear	51,810	2,063	4%	$1,081,135,000
1981	Nuclear	56,042	4,232	8%	$1,048,810,000
1982	Nuclear	60,035	3,993	7%	$1,085,794,000
1983	Nuclear	63,009	2,974	5%	$1,034,269,000
1984	Nuclear	69,652	6,643	11%	$756,978,000
1985	Nuclear	79,397	9,745	14%	$608,863,000
1986	Nuclear	85,241	5,844	7%	$618,231,000
1987	Nuclear	93,583	8,342	10%	$608,334,000
1988	Nuclear	94,695	1,112	1%	$596,359,000
1989	Nuclear	98,161	3,466	4%	$609,889,000
1990	Nuclear	99,624	1,463	1%	$340,808,000
1991	Nuclear	99,589	(35)	0%	$330,720,000
1992	Nuclear	98,985	(604)	-1%	$369,401,000
1993	Nuclear	99,041	56	0%	$346,801,000
1994	Nuclear	99,148	107	0%	$362,685,000
1995	Nuclear	99,515	367	0%	$367,599,000
1996	Nuclear	100,784	1,270	1%	$229,059,000
1997	Nuclear	99,716	(1,069)	-1%	$238,334,000
1998	Nuclear	97,070	(2,646)	-3%	$219,280,000
1999	Nuclear	97,411	341	0%	$279,088,000
2000	Nuclear	97,860	449	0%	$283,927,000
2001	Nuclear	98,159	299	0%	$275,223,000
2002	Nuclear	98,657	498	1%	$291,713,000
2003	Nuclear	99,209	552	1%	$256,854,000
2004	Nuclear	99,628	419	0%	$401,349,000
2005	Nuclear	99,988	360	0%	$503,792,000
2006	Nuclear	100,334	346	0%	$550,226,000
2007	Nuclear	100,266	(68)	0%	$612,230,000
2008	Nuclear	100,755	489	0%	$1,033,161,000
2009	Nuclear	101,004	249	0%	$1,357,263,000
2010	Nuclear	101,167	164	0%	$869,995,000
2011	Nuclear	101,423	256	0%	
2012	Nuclear				

Table A.5: Capacity and funding data for hydroelectric

Year	Resource	Installed Capacity (MW)	Annual Capacity Additions (MW)	Annual Capacity Growth (%)	Federal R&D Funding ($)
1978	Hydroelectric	79,900	1,300	2%	$10,413,000
1979	Hydroelectric	82,900	3,000	4%	$39,172,000
1980	Hydroelectric	81,700	(1,200)	-1%	$20,939,000
1981	Hydroelectric	82,400	700	1%	$3,198,000
1982	Hydroelectric	83,000	600	1%	$3,000,000
1983	Hydroelectric	83,900	900	1%	$1,996,000
1984	Hydroelectric	85,300	1,400	2%	$750,000
1985	Hydroelectric	88,900	3,600	4%	$447,000
1986	Hydroelectric	89,300	400	0%	$481,000
1987	Hydroelectric	89,700	400	0%	$450,000
1988	Hydroelectric	90,300	600	1%	$0
1989	Hydroelectric	74,111	(16,189)	-18%	$0
1990	Hydroelectric	73,923	(188)	0%	$0
1991	Hydroelectric	76,036	2,113	3%	$993,000
1992	Hydroelectric	74,773	(1,264)	-2%	$1,028,000
1993	Hydroelectric	77,410	2,638	4%	$1,043,000
1994	Hydroelectric	78,041	631	1%	$1,039,000
1995	Hydroelectric	78,562	521	1%	$4,810,000
1996	Hydroelectric	76,437	(2,124)	-3%	$3,483,000
1997	Hydroelectric	79,415	2,977	4%	$973,000
1998	Hydroelectric	79,151	(264)	0%	$729,000
1999	Hydroelectric	79,393	242	0%	$3,210,000
2000	Hydroelectric	79,359	(34)	0%	$4,861,000
2001	Hydroelectric	78,916	(443)	-1%	$4,936,000
2002	Hydroelectric	79,356	440	1%	$4,986,000
2003	Hydroelectric	78,694	(662)	-1%	$5,016,000
2004	Hydroelectric	77,641	(1,053)	-1%	$4,772,000
2005	Hydroelectric	77,541	(100)	0%	$4,880,000
2006	Hydroelectric	77,821	280	0%	$495,000
2007	Hydroelectric	77,885	64	0%	$0
2008	Hydroelectric	77,930	46	0%	$1,000,000
2009	Hydroelectric	78,518	588	1%	$10,000,000
2010	Hydroelectric	78,825	307	0%	$14,000,000
2011	Hydroelectric	78,927	102	0%	$8,500,000
2012	Hydroelectric				$25,000,000

Table A.6: Capacity and funding data for PV

Year	Resource	Installed Capacity (MW)	Annual Capacity Additions (MW)	Annual Capacity Growth (%)	Federal R&D Funding ($)
1978	PV				$63,500,000
1979	PV				$103,800,000
1980	PV				$150,045,000
1981	PV				$151,600,000
1982	PV				$74,000,000
1983	PV				$57,915,000
1984	PV				$50,182,000
1985	PV				$54,649,000
1986	PV				$40,301,000
1987	PV				$40,253,000
1988	PV				$34,685,000
1989	PV				$35,146,000
1990	PV				$34,332,000
1991	PV				$46,386,000
1992	PV				$59,995,000
1993	PV				$64,898,000
1994	PV				$74,881,000
1995	PV	67			$82,935,000
1996	PV	77	10	15%	$61,268,000
1997	PV	88	12	15%	$59,210,000
1998	PV	100	12	13%	$64,691,000
1999	PV	117	17	17%	$70,561,000
2000	PV	139	22	18%	$65,107,000
2001	PV	168	29	21%	$74,260,000
2002	PV	212	44	26%	$70,855,000
2003	PV	275	63	30%	$73,249,000
2004	PV	376	101	37%	$72,537,000
2005	PV	479	103	27%	$65,844,000
2006	PV	483	4	1%	$58,802,000
2007	PV	830	347	72%	$138,372,000
2008	PV	1,169	339	41%	$136,744,000
2009	PV	1,633	465	40%	$142,793,000
2010	PV	2,549	916	56%	$125,778,000
2011	PV				$132,844,000
2012	PV				$75,554,000

Table A.7: Capacity and funding data for OTEC

Year	Resource	Installed Capacity (MW)	Annual Capacity Additions (MW)	Annual Capacity Growth (%)	Federal R&D Funding ($)
1978	OTEC				$36,000,000
1979	OTEC				$41,145,000
1980	OTEC				$43,000,000
1981	OTEC				$34,600,000
1982	OTEC				$20,800,000
1983	OTEC				$10,490,000
1984	OTEC				$5,465,000
1985	OTEC				$4,008,000
1986	OTEC				$4,767,000
1987	OTEC				$4,460,000
1988	OTEC				$3,966,000
1989	OTEC				$4,070,000
1990	OTEC				$3,883,000
1991	OTEC				$2,663,000
1992	OTEC				$1,970,000
1993	OTEC				$993,000
1994	OTEC				$959,000
1995	OTEC				
1996	OTEC				
1997	OTEC				
1998	OTEC				
1999	OTEC				
2000	OTEC				
2001	OTEC				
2002	OTEC				
2003	OTEC				
2004	OTEC				
2005	OTEC				
2006	OTEC				
2007	OTEC				
2008	OTEC				
2009	OTEC				
2010	OTEC				
2011	OTEC				
2012	OTEC				

Table A.8: Capacity and funding data for MHK

Year	Resource	Installed Capacity (MW)	Annual Capacity Additions (MW)	Annual Capacity Growth (%)	Federal R&D Funding ($)
1978	MHK				
1979	MHK				
1980	MHK				
1981	MHK				
1982	MHK				
1983	MHK				
1984	MHK				
1985	MHK				
1986	MHK				
1987	MHK				
1988	MHK				
1989	MHK				
1990	MHK				
1991	MHK				
1992	MHK				
1993	MHK				
1994	MHK				
1995	MHK				
1996	MHK				
1997	MHK				
1998	MHK				
1999	MHK				
2000	MHK				
2001	MHK				
2002	MHK				
2003	MHK				
2004	MHK				
2005	MHK				
2006	MHK				
2007	MHK				
2008	MHK				$9,000,000
2009	MHK				$30,000,000
2010	MHK				$36,000,000
2011	MHK				$21,500,000
2012	MHK				$34,000,000

Table A.9: Capacity and funding data for on-shore and off-shore wind

Year	Resource	Installed Capacity (MW)	Annual Capacity Additions (MW)	Annual Capacity Growth (%)	Federal R&D Funding ($)
1978	On-Shore Wind				$36,700,000
1979	On-Shore Wind				$59,555,000
1980	On-Shore Wind				$60,555,000
1981	On-Shore Wind	10			$77,500,000
1982	On-Shore Wind	70	60	600%	$34,400,000
1983	On-Shore Wind	240	170	243%	$31,390,000
1984	On-Shore Wind	597	357	149%	$26,367,000
1985	On-Shore Wind	1,039	442	74%	$28,355,000
1986	On-Shore Wind	1,222	183	18%	$24,786,000
1987	On-Shore Wind	1,356	134	11%	$16,606,000
1988	On-Shore Wind	1,396	40	3%	$8,464,000
1989	On-Shore Wind	1,403	7	1%	$8,760,000
1990	On-Shore Wind	1,525	122	9%	$8,687,000
1991	On-Shore Wind	1,575	50	3%	$11,110,000
1992	On-Shore Wind	1,584	9	1%	$21,282,000
1993	On-Shore Wind	1,617	33	2%	$23,841,000
1994	On-Shore Wind	1,656	39	2%	$29,151,000
1995	On-Shore Wind	1,697	41	2%	$44,545,000
1996	On-Shore Wind	1,698	1	0%	$31,420,000
1997	On-Shore Wind	1,706	8	0%	$28,646,000
1998	On-Shore Wind	1,848	142	8%	$32,128,000
1999	On-Shore Wind	2,511	663	36%	$34,076,000
2000	On-Shore Wind	2,578	67	3%	$32,085,000
2001	On-Shore Wind	4,275	1,697	66%	$39,132,000
2002	On-Shore Wind	4,686	411	10%	$38,211,000
2003	On-Shore Wind	6,353	1,667	36%	$41,640,000
2004	On-Shore Wind	6,725	372	6%	$40,386,000
2005	On-Shore Wind	9,121	2,396	36%	$40,631,000
2006	On-Shore Wind	11,574	2,454	27%	$38,333,000
2007	On-Shore Wind	16,824	5,249	45%	$48,659,000
2008	On-Shore Wind	25,161	8,337	50%	$49,034,000
2009	Off & On-Shore Wind	35,154	9,993	40%	$54,370,000
2010	Off & On-Shore Wind	40,267	5,112	15%	$80,000,000
2011	Off & On-Shore Wind	47,083	6,816	17%	$78,834,000
2012	Off & On-Shore Wind				$93,254,000

APPENDIX B. DATA FOR U.S. THEORETICAL AVAILABLE TIDAL CURRENT POWER

The following table presents results from the 2012 Georgia Tech Report, "Assessment of Energy Production Potential of Tidal Streams in the United States." The data shown here are the total theoretical available tidal current powers, organized by U.S. region.

Table B.1: U.S. regional total theoretical available tidal current power (Center for GIS at Georgia Tech, 2012)

State	Theoretical Available Tidal Current Power (MW)
Alaska	47,437
Washington	683
California	204
Oregon	48
Region Total	935
Maine	675
New York	280
New Jersey	192
Delaware	165
Massachusetts	66
Rhode Island	16
Region Total	1,394
Maryland	35
Virginia	133
North Carolina	61
South Carolina	388
Region Total	617
Georgia	219
Florida	166
Region Total	385
Texas	6
Alabama	7
Louisiana	2
Region Total	15

APPENDIX C. MHK TAX INCENTIVE PROGRAM DETAILS

The following tables list the tax incentives available to MHK. The data were gathered from the Ocean Renewable Energy Coalition website.

Table C.1: MHK Tax Incentives (Ocean Renewable Energy Coalition, 2012)

	Program	Funding	Additional Info
Federal Income Tax Programs	Production Tax Credit	§ 45 of Internal Revenue Code of 1986, as amended by H.R. 1 (Recovery Act) tax Credits in Lieu of PTC provisions.	To qualify, facility must have a nameplate capacity rating of at least 150 kilowatts, and was originally placed in service on or after October 3, 2008 and before January 1, 2014. As of 2012, the PTC is 2.2 ¢/kWh for most renewables, adjusted for inflation, multiplied by the number of qualified kW hours of electricity produced and sold by the taxpayer during the year. **Currently, the PTC for MHK is 1.1 ¢/kWh, half the amount of other renewables.** The PTC runs for ten years after a project is placed in service, but will be reduced by 50% if a project has already received tax exempt financing, a grant or another federal tax credit. IRC sec. 45(b)(3). It is possible that the sunset date could be extended beyond January 1, 2014.
	Investment Tax Credit	§ 46 and § 48 of the Code	ITC may be claimed in lieu of the PTC by owners of a qualified ocean power facility that is placed in service on or after January 1, 2009 and before January 1, 2014, and is taken entirely in the year the project is placed in service. The ITC is a one-time credit against income tax that is based on the amount invested in a facility rather than on the amount of electricity produced and sold. The amount of the ITC for a qualified MHK facility is 30% of the tax basis of the qualifying property that is placed in service during the taxable year. No PTC allowed with ITC. To qualify for the ITC, a facility must be placed in service before January 1, 2014.
	US Treasury Department Grants	See § 1603 of ARRA	No ITC or PTC may be claimed with respect to property for which a grant has been claimed.
	Bonus Depreciation and MACRS Depreciation		An owner of a qualifying property placed in service in 2009 is entitled to deduct 50% of the adjusted basis of the property in 2009. The remaining 50% of the adjusted basis of the property is a bonus depreciation of the regular tax depreciation schedule. For an ocean power facility, qualifying property generally includes the turbines and their structural components. Modified accelerated cost recovery system (MACRS) depreciation is an accelerated five year depreciation schedule for property dedicated to production of renewable energy. **Currently, the MACRS five year depreciation schedule does not apply to MHK.**

Table C.1: MHK Tax Incentives (Ocean Renewable Energy Coalition, 2012) (continued…)

	Program	Funding	Additional Info
Additional Financial Incentives	Clean Renewable Energy Bonds (CREBs)	Varies	The IRS is not currently accepting applications for CREB allocations. CREBs are issued -- theoretically -- with a 0% interest rate. The borrower pays back only the principal of the bond, and the bondholder receives federal tax credits in lieu of the traditional bond interest.
	Qualified Energy Conservation Bonds (QECBs)	Varies	QECBs may be used by state, local and tribal governments to finance certain types of energy projects. QECBs are qualified tax credit bonds, and in this respect are similar to new CREBs. The tax credit may be taken quarterly to offset the tax liability of the bondholder. The tax credit rate is set daily by the U.S. Treasury Department under 26 USC § 54A. In contrast to CREBs, QECBs are not subject to a U.S. Department of Treasury application and approval process.
	Renewable Energy Production Incentive (REPI)	2.1¢/kWh (subject to availability of annual appropriations in each federal fiscal year of operation)	REPI provides incentive payments for electricity generated and sold by new qualifying renewable energy facilities that are publicly owned. Qualifying systems are eligible for annual incentive payments of 1.5¢ per kilowatt-hour in 1993 dollars (indexed for inflation) for the first 10-year period of their operation, subject to the availability of annual appropriations in each federal fiscal year of operation. REPI was designed to complement the federal renewable energy production tax credit (PTC), which is available only to businesses that pay federal corporate taxes.
American Recovery and Reinvestment Act Tax Programs	Advanced Energy Manufacturing Tax Credits	$2.3 billion in ARRA (§ 48C)	Worth up to 30% of each planned project; oversubscribed; Administration has requested additional $5B.
	Tax Grants in Lieu of Credits for Energy Projects	>$1 billion in ARRA (§ 1603)	Under this program, the federal government provides a cash payment in lieu of a tax credit totaling 30% of the qualifying cost of the project, for each federal dollar spent in payments, more than two dollars are spent in private sector investments.

APPENDIX D. DOE RENEWABLE ENERGY CAPACITY AND LCOE ESTIMATES AND TARGETS

The following information presents the U.S. DOE actual and target LCOE estimates for PV, on-shore wind, off-shore wind, and MHK.

Notes for **Table D.1**:

LCOE is for Fiscal Year

PV LCOE:

- The range in the targets corresponds to different U.S. geographic regions
- Module cost goal of $0.50 per watt
- Power electronics cost goal of $0.10 per watt
- Balance of system cost goal of $0.40 per watt
- By 2020, demonstrate the commercial viability of PV technologies at multiple scales:
    - Utility (100 MW) - $1.00/W
    - Commercial (200 kW) - $1.25/W
    - Residential (5 kW) - $1.50/W
- NREL runs this LCOE analysis annually based on best known industry data
- Prior to the launch of the SunShot Initiative, the program goals included existing federal tax credits (30% ITC). FY12 and FY13 targets are rebaselined to exclude

subsidies since the goal of the SunShot Initiative is to achieve unsubsidized grid parity (~ 5-6 cents/kWh) at utility scale by 2020.

On-Shore Wind LCOE:

- Unsubsidized land-based wind cost of energy (DOE influence-adjusted), in cents per kWh, in Class 4 wind speed areas (7.25 m/s mean wind speed at 50m above ground) from a 2010 baseline of 8.2 cents/kWh. LCOE validated via annual, independent NREL analysis of actual installed U.S. wind plants, normalized for Class IV wind speed, 30 year useful life, standard Federal and State taxes, and with other updated EERE standardization assumptions (updated from prior years.)

Off-Shore Wind:

- Unsubsidized cost of offshore wind energy, in cents per kWh, in Class 6 wind speed areas (9.25 m/s mean wind speed at 50m above ground) from a 2010 baseline of 25.3 cents/kWh.

Table D.1: DOE renewable energy LCOE estimates and targets (US Department of Energy - Office of the Chief Financial Officer - Office of Budget, 2002-2013)

Year	Technology	Min Target LCOE ($/kWh)	Max Target LCOE ($/kWh)	Min Actual LCOE ($/kWh)	Max Actual LCOE ($/kWh)
2009	PV	$0.017	$0.019	$0.017	$0.019
2010	PV	$0.014	$0.024	$0.015	$0.020
2011	PV	$0.015	$0.020	$0.018	$0.024
2012	PV	$0.014	$0.018		
2013	PV	$0.013	$0.017		
2020	PV	$0.050	$0.060		
2010	On-Shore Wind			$0.082*	$0.082*
2011	On-Shore Wind	$0.081	$0.081	$0.077	$0.077
2012	On-Shore Wind	$0.079	$0.079		
2013	On-Shore Wind	$0.077	$0.077		
2020	On-Shore Wind	$0.060	$0.060		
2010	Off-Shore Wind			$0.253*	$0.253*
2011	Off-Shore Wind	$0.251	$0.251	$0.251	$0.251
2012	Off-Shore Wind	$0.235	$0.235		
2013	Off-Shore Wind	$0.217	$0.217		
2020	Off-Shore Wind	$0.093	$0.093		
2030	MHK	$0.060	$0.0600		

*2010 baseline

Table D.2: DOE Water Power Program LCOE and GW installation goals (Zayas, 2012)

	2010		**2015**		**2020**		**2030**	
	COE (¢/kWh)	**GW**	**COE (¢/kWh)**	**GW**	**COE (¢/kWh)**	**GW**	**COE (¢/kWh)**	**GW**
MHK	20-60	0	20-40	0.05	10-20	4	6 (EERE Goal)	23
Advanced Pumped Storage Hydropower	n/a	0	n/a	0	n/a	5	n/a	30
Low-Head Small Hydropower	15	0	10	1	6	11	6	50
Non-Powered Dams	10	0	7	0.5	6	8	6	12
Existing Hydropower Fleet	n/a	101	n/a	103	n/a	105	n/a	109