Final Papers for Energy & Energy Policy
Fall 2011

TEAM 1

Phase 1 of the Chicago South Works Development Project: a Benefit-Cost Analysis of Energy Savings to the City of Chicago

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Autumn 2011

Abstract

The City of Chicago recently approved a large (580 acres) urban development project on the City's South Side on the site of the South Works steel mill. Construction of the initial phase of this development (87 acres) will begin in 2013 with an overall budget of $396,693,757. The City of Chicago has agreed to provide a $95,885,584 subsidy for this phase of the project through Tax Increment Financing (TIF). In return for the City's funding, the project's developers, McCaffery Interests Inc. and U.S. Steel Corporation, have agreed (1) that the development will be built in accordance with the Leadership in Energy and Environmental Design Neighborhood Development (LEEDND) standards, (2) that all buildings in the project will be LEED-certified, and (3) that a majority of the buildings in the development will have green roofs. In this paper, we conduct a benefit-cost analysis from the perspective of the City of Chicago of the energy savings realized by this specific development compared to a theoretical and comparable development that does not adhere to the above LEED standards. We analyze the project over a time horizon of 100 years and discount the benefits of energy savings over time. Our results suggest that this project is net beneficial even though we only consider the development's energy savings.

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1 Introduction

In this paper, we will analyze the approved South Works Leadership in Energy and Environmental Design Neighborhood Development (LEEDND) project. By converting the largest brownfield in Chicago into a sustainable neighborhood, this project presents us with a unique opportunity to examine how the energy use of LEED-certified buildings compares with that of non-LEED buildings at a large, neighborhood scale. The South Works development is an ideal case to investigate since specific information about the number and types of buildings that will be constructed at the site are available for the first phase. Access to the phase 1 plan allows us to approximate the total energy usage of these buildings and the cost of that energy. We show that it is feasible to identify and quantify the energy efficiency benefits to the city of Chicago for all the buildings in South Works as LEED-certified in comparison to being non-LEED.

Our paper is structured in five major sections: §2 discusses the history and specifics of the South Works Development Project, §3 presents an overview of the LEED certification framework, §4 addresses the energy savings benefits of the South Works project thanks to it being LEED-certified, §5 provides a discussion of the Tax Increment Financing (TIF) method by which the City of Chicago is supporting the South Works development, and §6 displays our benefit-cost analysis calculations and results. A conclusion and reference list conclude the essay.

2 The South Works Development Project

2.1 Environmental History of the South Works Site

The Chicago South Works site (Figure 1) sits on the shores of Lake Michigan between 79th and 91st Streets, bordered by the mouth of the Calumet River on its southern end. From 1882 to 1992, the U.S. Steel Company housed a steel production plant at the site. In 1882, the original South Works site covered only 74 acres of sandy land that jutted out into Lake Michigan (Great Lakes Dredging Team, 2005). Over the next century, U.S. Steel filled in 500 acres of the lake as the company expanded its production. Shortly after the plant closed, U.S. Steel removed the old blast furnaces, refining mills, and all of the buildings that were used for steel production (Great Lakes Dredging Team, 2005). The site has sat vacant since 1992, with only a gatehouse and two large concrete ore walls as a reminder of the vast plant that once occupied the site (Illinois Sustainable Technology Center, 2011). At 580 acres of land, the South Works site is by far the largest brownfield[1] in Chicago. Although the physical aspects of the plant may have been removed, the environmental status os South Works reflects a lasting mark on the site.

Figure 1: The South Works Site

[1]A brownfield is an area previously used for industrial purposes that has been abandoned and not yet re-developed.

The infill that expanded the South Works site to 580 acres in area came at an environmental cost. U.S. Steel filled the lake by dumping construction debris combined with slag, a byproduct of steel production, along the shore (Great Lakes Dredging Team, 2005).[2] Slag is composed of large amounts of metal mixed with calcium silicate minerals and can have adverse effects on the surface water, groundwater, and plants that are found in areas where it is present (Roadcap et al., 2005). Slag can create elevated concentrations of ammonia, barium, chromium, potassium, tin, cyanide, silica, copper, mercury, vanadium, iron, and zinc in the water and plants nearby (Roadcap et al., 2005).

Since the South Works site was deemed a superfund site, the U.S. Steel Company was required by law to remediate the area after removing buildings and ceasing steel production. The company's remediation included reducing the levels of classified toxic chemicals at the site to meet EPA standards (Great Lakes Dredging Team, 2005). U.S. Steel also removed toxic sediment found in the slip of Lake Michigan waterway stretching through the middle of the site, along the shores of Lake Michigan itself, and in the Calumet River at the southern end of the site (Great Lakes Dredging Team, 2005). After the company finished conducting its environmental remediation of the site, the Illinois EPA approved the South Works site for redevelopment in 1997 (Great Lakes Dredging Team, 2005).

One of the main challenges with converting the former U.S. Steel South Works site into an urban development will be creating infrastructure on top of the slag, concrete building foundations, and roads that remain there (Illinois Sustainable Technology Center, 2011). The Illinois Department of Natural Resources took a step towards redeveloping the site by covering part of the land with mud from Lake Peoria in 2004 (Illinois Sustainable Technology Center, 2011). The Illinois DNR transported 100,000 tons of mud from nearby Lake Peoria to the South Works site, covering about 30 acres of proposed Chicago Park District parkland on the lakefront with 2-3 feet of topsoil (Illinois Sustainable Technology Center, 2011). The

[2]Slag is created when limestone and impurities in iron ore are combined (Roadcap et al., 2005).

first barge load of soil was placed at the site on April 14, 2004, and by September 2, 2004, scientists had found 79 species of plants growing on the newly placed soil (Illinois Sustainable Technology Center, 2011). The diverse vegetation (Figure 2) observed within 6 months of depositing soil at the site suggests that South Works can be transformed from an industrial wasteland to parkland or urban neighborhood within a few years of the onset of construction.

Figure 2: South Works Site Vegetation

The developer of the first phase of the South Works project, McCaffery Interests, Inc., will be responsible for redeveloping the 87 acres of land from an industrial wasteland to a sustainable neighborhood (Kamin, 2010). In order for McCaffery Interests to build, much more soil will be required to cover the remnants of the steel industry that remain throughout the South Works site. Covering the current slag and concrete that exists at the South Works site will be a costly task, but the previous remediation project has shown that the land can be successfully restored.

2.2 LEED Neighborhood Development Program

LEED is an internationally recognized green building certification system developed by the U.S. Green Building Council (USGBC). In addition to certifying individual buildings, the USGBC has recently developed a standard for neighborhood development known as LEED Neighborhood Development or LEEDND. In this section, we will discuss the relationship between the South Works project and LEEDND. We will discuss the LEED certification system more broadly later in §3.

In order to encourage more sustainable developments that integrate land uses, the USGBC launched LEEDND as its most recent LEED certification system. This new certification system is based on principles of smart growth, green buildings, and green infrastructure that can reduce a neighborhood's impact on the environment (Benfield, 2011). The goal of the LEEDND program is to establish a national standard for assessing and rewarding environmentally superior neighborhood development practices (Benfield, 2011). The program is mostly used for the planning and development of new neighborhoods, but it can also be used for retrofitting or redesigning existing neighborhoods (U.S. Green Building Council, 2009).

According to LEEDND definitions, a neighborhood is considered a planning unit of a town, and by itself should be its own village with amenities available for its residents (U.S. Green Building Council, 2009). A well-functioning neighborhood should possess an identifiable center/downtown area and edges, walkable streets, sites for public use and social interaction, and maintain connections with its surroundings (U.S. Green Building Council, 2009). A mix of uses is often integral to the vitality of a neighborhood. "Mixed-use" can include not only residential and commercial buildings, but also a variety of retail establishments, services, community facilities, and more (U.S. Green Building Council, 2009). A single neighborhood need not encompass all of these functions, since they may instead be found within adjacent neighborhoods.

Recently, especially in suburban sprawl type environments, neighborhood development has consisted of segregated land use (Ewing, 2008). Houses are concentrated in large blocks, with retail establishments concentrated in separate blocks. In order to shop, attend school or work, or participate in almost any activity outside of their home, residents must drive their cars because public transportation is severely limited. This sprawling type of city planning increases greenhouse gas emissions because residents of these developments are heavily reliant upon automobiles (Ewing, 2008).

In contrast to sprawling developments that segregate land use, the mixed-use development seen in LEEDND neighborhoods places residences and jobs in the same area. The neighborhood planning arranges residential and commercial spaces amongst one another in order to limit automobile usage and its associated greenhouse gas emissions (Benfield, 2011). LEEDND neighborhoods encourage walking, bicycling, and the use of public transportation for daily commuting and errands. A green neighborhood such as South Works benefits both the community and the environment by making residents' commutes easier and reducing their impact on the environment. The combination of integrated urban planning and environmentally efficient buildings and infrastructure can significantly reduce energy consumption for LEEDND developments compared to non-LEED developments (Benfield, 2011).

The LEEDND program uses a rating system to classify the level of sustainability for newly developed neighborhoods. Five environmental categories are used to rate the health, durability, affordability and general condition of the building design and construction: smart location and linkage, neighborhood pattern and design, green infrastructure and buildings, innovation and design process, and regional priority credit (U.S. Green Building Council, 2009). Unlike other LEED rating systems, LEEDND focuses on site selection, design principles, and construction elements that relate the neighborhood to its landscape as well as its local and regional context (U.S. Green Building Council, 2009).

The LEEDND program particularly promotes the redevelopment of aging brownfield sites into revitalized neighborhoods (U.S. Green Building Council, 2009). This brownfield redevelopment is incentivized by the regional priority credits within the LEEDND rating system that are given for particularly "green" efforts that are specific to the area's environmental issues (U.S. Green Building Council, 2009). The South Works development thus fits perfectly into LEEDND's mission of revitalizing brownfields, in this case a former steel plant, into sustainable neighborhoods.

2.3 First Phase of the South Works Project

Out of the 580 acres that make up the South Works site, 369 acres will eventually be developed for retail, residential and commercial uses (Kamin, 2010). Of the remaining land, 95 acres will be converted into a lakefront park, and 35 additional acres of parks will be spread throughout the development (Kamin, 2010). However, the entirety of the site will be developed throughout different phases.

The first phase of development for South Works will include 87 acres and construction is set to begin in June of 2013 (City of Chicago, 2011a). The phase 1 development will be located in the Northwest corner of the site, bounded by a newly renovated U.S. Route 41 to the North and East, 83rd Street to the South, and Brandon Avenue to the West (City of Chicago, 2011a). See Figure 3 for a plan of the South Works Development. McCaffery Interests is set to construct a mix of retail space, apartments, and townhomes/two-flat residences for the first phase of the project (City of Chicago, 2011a).

The initial phase will consist of two major components that will be set aside for different uses: the Vertical Development Area and the Pad Sale Area (City of Chicago, 2011a). The Vertical Development Area will function as the town center or downtown area, and will include 844,000 square feet of ground-level retail space, as well as 250 residential units above the retail spaces (City of Chicago, 2011a). This development will create an urban

Figure 3: South Works Site Plan

environment with retail that will be easily accessible by pedestrians from the surrounding residences (City of Chicago, 2011a). The developer of the site will construct all necessary improvements to infrastructure in the Vertical Development Area, as well as the buildings in this area (City of Chicago, 2011a).

The Pad Sale Area will function as the residential neighborhood area. It will include sites that are prepared for the construction of approximately 136 townhome or 2-flat units and 3 high-rise buildings adjacent to Route 41 that will house approximately 598 residences (City of Chicago, 2011a). The developer will construct the necessary infrastructure for the

Pad Sale Area and prepare the sites to be built upon. The finished pads will be sold to residential developers, who will then construct the buildings upon them (City of Chicago, 2011a).

As a condition of the developer's agreement with the City of Chicago, all buildings in the South Works development will attain LEED certification (City of Chicago, 2011a). These buildings may have varying ranges of energy efficiency with their different uses, but one objective of the program is that the entire neighborhood will be "energy efficient" as decreed by the City of Chicago. In addition to the energy efficient buildings in the development, 100% of the roof area of the buildings in phase 1 shall be constructed with green roofs or 50% of the roof area will be constructed with green roofs and 50% of streets and parking lots will be shaded within 5 years of completing construction (City of Chicago, 2011a).

The South Works neighborhood development will also exhibit energy efficiency by providing public transportation options for its residents so that they can drive their cars less. The neighborhood developers have proposed providing a shuttle to the nearby Metra station, possibly extending the CTA green line to reach the new neighborhood, and adding bus routes through South Works (Kamin, 2010). The lakefront bike path will also be extended along the rerouted South Shore Drive that will skirt the western edge of the development (Kamin, 2010). In the larger South Works project, some have also proposed providing a ferry on Lake Michigan that would take residents downtown (Kamin, 2010). All of these options will make it easier for residents of the South Works neighborhood to drive less, and the environmental impact of the neighborhood and its citizens will thus be reduced.

In §4 and §5 we will discuss the quantification of benefits and costs of this development.

3 LEED Certification — An Overview

As explained in §2, 100% of the buildings to be built in the South Works project will be LEED-certified. The additional price tag associated with "green" design and development has made the choice to exclusively develop LEED certified buildings a controversial one. Thus, the higher-priced choice to construct LEED-certified buildings as opposed to non-LEED buildings must be examined. In order to fully evaluate this decision, one must first understand the potential energy costs of a development project of this magnitude, and why energy efficiency is a suitable policy. Subsequently, a review of LEED's energy efficiency objectives, standards, strategies and outcomes will demonstrate LEED's capacity to fulfill the project's energy efficiency requirements and, thus, justify its incorporation into the project.

3.1 Energy Consumption in the U.S. and the Rationale of Energy Efficiency

In 2007, 3706 terrawatt-hours of electricity, 21.12 trillion cubic feet of natural gas, and 20.25 million barrels per day of liquid fuels were consumed in the U.S. (Committee on America's Energy Future et al., 2009). Of the 99.4 quadrillion Btu consumed the next year, the building sector (residential and commercial combined) accounted for 41% (U.S. Energy Information Administration, 2011). More specifically, of the nearly 4000 TWh of electricity consumed yearly, the building sector alone accounts for 70%. That is, nearly half of the energy used in the U.S. is used for building maintenance. While the building sector uses all three forms of energy, 73% is electric (U.S. Energy Information Administration, 2011). Figure 4 shows total U.S. energy use by sector in 2008.

Considering the significant role of the building sector in U.S. energy consumption, the specific manner in which buildings use energy is material to the discussion. While the building sector includes commercial, industrial, and residential buildings, this paper will

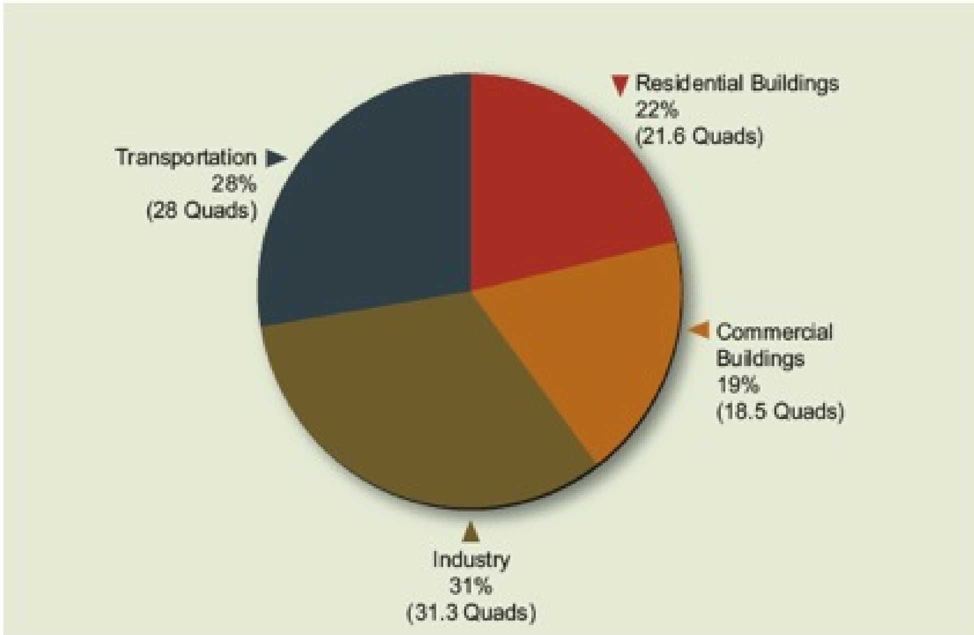

Figure 4: Total U.S. Energy Use by Sector, 2008. Source: DOE, 2009.

focus on residential and commercial buildings, as these are the proposed structures in phase 1.

The amount of energy consumed in any given household is generally due to 7 contributing factors: space heating, water heating, air conditioning, ventilation, appliances and lighting, and regional or climatic factors. First, often considered together and designated by the acronym HVAC, heating, ventilation and air conditioning combined account for approximately a third of the total electricity consumed in U.S. households (U.S. Energy Information Administration, 2005). In total, HVAC systems accounted for 356 billion kWh of energy use in 2001. The three central functions are interrelated, particularly because of the need to provide thermal comfort and healthy air quality, both of which require an integrated system that evenly ventilates and distributes air of any temperature. HVAC does not include space or water heating, which each separately account for 10% of the total residential energy use (U.S. Energy Information Administration, 2005). Next, according to the same study, household appliances and electric equipment accounted for 387 billion kWh of energy, 156 billion of which (40%) are from refrigerators alone. Despite innovations in the refrigerator design in the last 20 years in order to improve energy efficiency, refrigerator energy use has remained elevated. This is mainly due to the fact that the U.S. has experienced an upward trend in the number of households with more than one refrigerator. In 2001, 17% of households had more than one refrigerator, having increased 40% since 1984 (U.S. Energy Information Administration, 2005). In comparison, lighting represents less than 9% of the total electricity consumption in households (U.S. Energy Information Administration, 2005). The disparity between the energy use of a refrigerator and that of lights may lead one to wonder why green campaigns focus on turning off lights instead of fighting for a standard of one refrigerator per household.

Energy consumption in households is largely determined by regional factors. Variation in energy consumption between regions can be explained by regional climate — hot summers and cold winters like those in Chicago both require greater energy consumption than the moderate seasons of the Mediterranean or subtropical climates. Furthermore, electricity consumption is also affected by the nature of the population density of the area — an urban or metropolitan setting implies fewer individual household appliances, central heating and cooling systems, and an elevated average temperature known as the urban heat island affect. Thus, HVAC, space heating, water heating, appliances and lighting, and regional factors contribute to the nation's high rate of energy consumption. Figure 5 shows electricity consumption by end use in U.S. households in 2001.

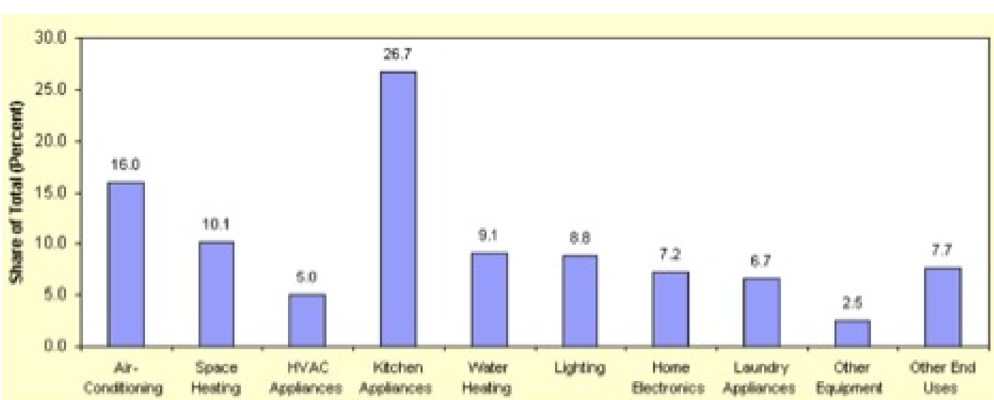

Figure 5: Electricity Consumption by End Use in U.S. Households, 2001. Source: EIA, 2001.

While it is clear from both a geopolitical and environmental standpoint that the total U.S. energy consumption must be reduced, there are various theories as to how this could be achieved. Energy efficiency, however, has become the most widely used narrative. The logic of energy efficiency is appealing because its deployment is the nearest-term and lowest-cost option for moderating our nation's demand for energy, especially over the next decade (Committee on America's Energy Future et al., 2009). Energy efficiency becomes a resource in and of itself, as the stretching of resources produces more while using less. Investing in the development of energy efficiency has been valued at over $170 billion a year (Farrell & Remes, 2008). This figure was found by estimating the market price of all investments needed to realize the possible energy productivity opportunities associated to improving energy efficiency in lighting, cooling and heating systems. Thus, it is in the nation's best interest to invest in energy efficiency as a solution to its high rate of energy consumption. Furthermore, because of the weighty role of the building sector, the greatest capability for energy efficiency savings is in said building sector. As was summarized in one NRC report:

> Improvements in the energy efficiency of residential and commercial buildings — through the accelerated deployment of efficient technologies for space heating and cooling, water heating, lighting, computing, and other uses — could save about 840 TWh per year by 2020... Further continuous improvements in building efficiency could save about 1300 TWh of electricity per year by 2030. (Committee on America's Energy Future et al., 2009)

This report goes on to explain that this increase in energy efficiency could be realized by the replacement of old appliances and systems with more efficient models, as well as the reconfiguring of larger infrastructures. Figure 6 displays capital requirements for capturing global energy productivity in billions of dollars per year.

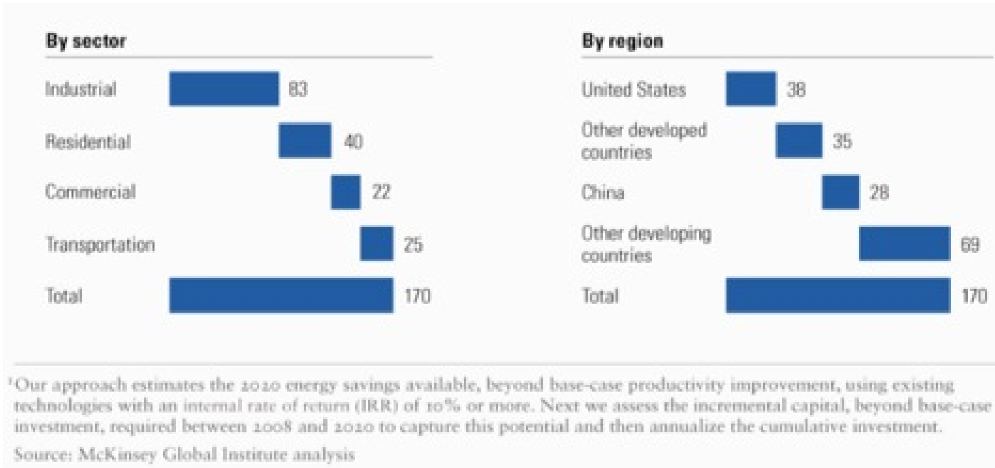

Figure 6: Capital Requirements for Capturing Global Energy Productivity, $ billion per year. Source: McKinsey Global Institute analysis.

3.2 Energy Efficiency within LEED

Created by the U.S. Green Building Council, LEED provides a national energy efficiency standard that developers looking to save energy and costs may follow. The LEED objectives include lowering operating costs and increasing asset value, reducing waste, conserving energy and water, allowing for healthier and safer living standards and reducing harmful greenhouse gas emissions (U.S. Green Building Council, 2011b). Within the LEED certification process, a project may receive points in 9 key areas, all of which promote a whole-building approach to sustainability.

The LEED rating system varies between building types (i.e. commercial, residential, schools), but for homes a project must achieve a minimum of 45 points out of 136 to be LEED certified. Of these 136 available points, the two areas devoted to energy efficiency account for 48 points, or 35% of the total (U.S. Green Building Council, 2008). In comparison, water efficiency accounts for a meagerly 15 points, or 11% of the total. Thus, energy efficiency is a primary concern, and accounts for the largest portion of credits possible in the LEED rating system. The two categories concerned with energy efficiency are Location & Linkages (LL) and Energy & Atmosphere (EA). LL is relevant because much of a home's impact on a given environment comes from where it is located and how it fits into the community. Thus, the category encourages building on previously developed or infill sites instead of sensitive areas, and gives credits to homes that are built near pre-existing infrastructure because the proximity reduces automobile use. Furthermore, EA is important because LEED recognizes that buildings use 70% of the electricity produced each year in the U.S. and 39% of the energy more generally. Thus, this category encourages the implementation of "energy-wise strategies" (U.S. Green Building Council, 2011b). Additionally, most of the categories are directly correlated to the project's Energy Star Performance, meaning that the LEED certification also takes into account the energy efficiency standards of Energy Star (U.S. Green Building Council, 2008). It is, therefore, clear that LEED prioritizes energy efficiency in its rating system. Figure 7 shows the prerequisites and minimum point requirements for all LEED home categories.

Credit category	Prerequisites (mandatory) measures	Minimum point requirements	Maximum points available
Innovation & Design Process (ID)	3	0	11
Location & Linkages (LL)	0	0	10
Sustainable Sites (SS)	2	5	22
Water Efficiency (WE)	0	3	15
Energy & Atmosphere (EA)	2	0	38
Materials & Resources (MR)	3	2	16
Indoor Environmental Quality (EQ)	7	6	21
Awareness & Education (AE)	1	0	3
Total	**18**	**16**	**136**

Figure 7: Prerequisites and Minimum Point Requirements for all LEED Home Categories. Source: USGBC, 2008

In order to carry out these standards of energy efficiency, LEED implements various energy saving strategies, including: commissioning; energy use monitoring; efficient design and construction; efficient appliances, systems and lighting; the use of renewable and clean sources of energy, generated on-site or off-site; and other innovative measures. The following paragraphs describe some of these strategies.

First, smart or intelligent metering involves an electrical meter that records energy consumption and communicates this information to both the consumer and the utilities facility for monitoring and billing purposes. This allows the consumer to be aware of price peeks and how much energy is being used. Consequently, it both allows the consumer to better manage his/her energy use and encourages curtailment of energy use. Smart meters have been estimated to save up to 30% of energy used when combined with consequent behavioral changes among consumers (European Commission: Intelligent Energy-Europe, 2005).

Next, the concept of building design focuses on integrating low-energy concepts into the design process. For example, the strategic placement of windows, light shelves and skylights allows for greater use of natural sunlight, and thus decreased daylighting costs. Buildings can be designed to enhance natural ventilation, a design that may incorporate induced stack-effect ventilation such that cooling and heating loads are reduced, the solar-heat gain or temperature is stabilized, and costs are curtailed. Other such low-energy concepts integrated into LEED designed buildings are the elongation of buildings in an east-west direction so as to benefit from natural sunlight and heat, the implementation of occupancy sensors, greater insulation through new construction materials, and more.

As discussed in §2, a final energy efficiency strategy used by LEED is the creation of a national standard for neighborhood developments (LEEDND) that establishes the same energy efficiency practices as LEED but on a larger, more influential scale. In order to receive LEEDND certification, a project must be in accordance with LEEDND's objective of reducing segregated land use and increasing mixed-use development such that commercial and residential buildings are closer to one another. Thus, LEEDND certification encourages commercial/residential proximity and stimulates walking, biking, and public transportation use over individual automobiles (U.S. Green Building Council, 2009).

Many of the energy efficiency strategies discussed thus far are illustrated in the example of Pearl Place housing development in Portland, Maine. Pearl Place is a Gold certified residential LEED project that achieved 68.5/104 credits. More specifically, this project acquired: 14/14 credits for sustainable sites, 7/13 for water efficiency, 11/36 for energy and atmosphere, 6.5/11 for material and resources, 11/11 for indoor environmental quality, 10/10 for location and linkages, 2/2 for awareness and education, and 7/7 for innovation and design process (U.S. Green Building Council, 2011a). These numbers provide a lot of additional information. First, while energy and atmosphere accounts for 35% of possible point, these buildings achieved less than a third of the energy and atmosphere credits possible. This is demonstrative of one of LEEDs limitations: while a large portion of the credits possible is attributed to energy efficiency, a lack of points in this category can be compensated by other categories, thus allowing the project to achieve Gold certification despite insufficient energy efficiency strategies. Nonetheless, this project still managed to achieve the following goals: (1) exceed energy star for homes standards, (2) implement super-insulation and a tight building envelope, (3) minimize ozone depletion and global warming contributions, and (4) implement energy-efficient fixtures, mechanical equipment, and appliances.

3.3 Energy Consumption: LEED vs. non-LEED

With the implementation of all of these strategies, LEED projects hope to quantifiably reduce energy use by increasing energy efficiency. Are these strategies successful? What have been the outcomes? Is achieving LEED certification directly correlated to concrete energy savings? Prepared for the U.S. Green Building Council as a final report on the energy performance of LEED and assembled by the New Buildings Institute, the *Energy Performance of LEED for New Construction Buildings* (Turner & Frankel, 2008) report provides concrete answers.

Energy Performance of LEED for New Construction Buildings is a study that measured energy performance in 121 LEED new construction buildings, producing the information necessary to link the energy efficiency efforts of LEED and the true outcomes. The study was measured by 3 different metrics: energy use intensities, energy star ratings, and measured performance in relation to modeling. First, in terms of energy use intensities, LEED buildings averaged 69 kBtu/sf, or 24% below (better than) the Commercial Building energy Consumption Survey national average for all commercial building stock. Similar relationships were observed when comparing by building type. Second, the average Energy Star rating of LEED buildings was 68, meaning that they are better than 68% of similar buildings. In fact, nearly half of LEED buildings had Energy Star ratings of at least 75. As a comparison, the average for the national building stock is 50. Lastly, the performance in relation to modeling is measured on the basis of predicted energy cost savings compared to modeled code baseline building. The average measured energy savings for the buildings in this study was 28% compared to the baselines, which compares to the average 25% savings that was predicted in the designs and proposals. Thus, not only do LEED buildings successfully achieve their energy savings goals, they also exceed them.

Thus, as observed through all three measurements, the average LEED energy use is 25-30% better than the national average. These results show that these 121 projects — and by extension, all LEED certified projects — average significant energy performance improvements in comparison to non-LEED buildings. In §4, we more thoroughly and explicitly identify energy savings realized by LEED-certified buildings and quantify these energy savings benefits.

4 Benefits: Energy Savings from LEED-Certified Buildings

4.1 Summary of Methods

In this section, we will conduct an analysis of the benefits of LEED-mandated increases in energy efficiency as well as those of the Tax Increment Financing (TIF) mandated green roofs in the phase 1 South Works buildings. To do so, we will compare average energy savings found in similar LEED buildings to baseline energy usage statistics for non-LEED like-buildings. We then estimate savings for green roofs using data from the Federal Energy Management Program. Finally, an analysis of CO_2 equivalent greenhouse gas reduction will be performed to determine yearly emissions reductions realized by the South Works development. These data will be compared to price history for both gas and electricity in the Chicago area. We then project the benefits of energy savings and carbon emissions reduction over the period from 2012-2112 since we assume 100 years to be a reasonable life span of the buildings to be built.

4.2 Projection of Electricity Prices

From recent historical data on electricity price fluctuation in Chicago over the past half-decade (see Figure 8), energy prices have been increasing in a close to linear-upwards trend, increasing by a price of around $0.0094 per kilowatt-hour per year (U.S. Bureau of Labor Statistics, 2011). For our analysis, we will assume this trend to continue over the next 100 years. While this is certainly a contestable assumption, we believe it is conservative and an appropriate assumption for this analysis.

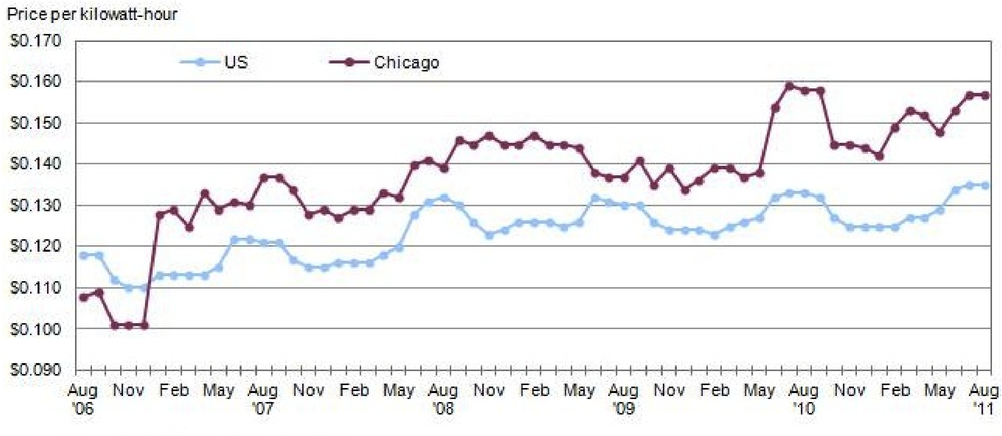

Figure 8: Average Prices for Electricity, United States and Chicago Area, August 2006 – August 2011. Source: U.S. Bureau of Labor Statistics, 2011

4.3 Projection of Natural Gas Prices

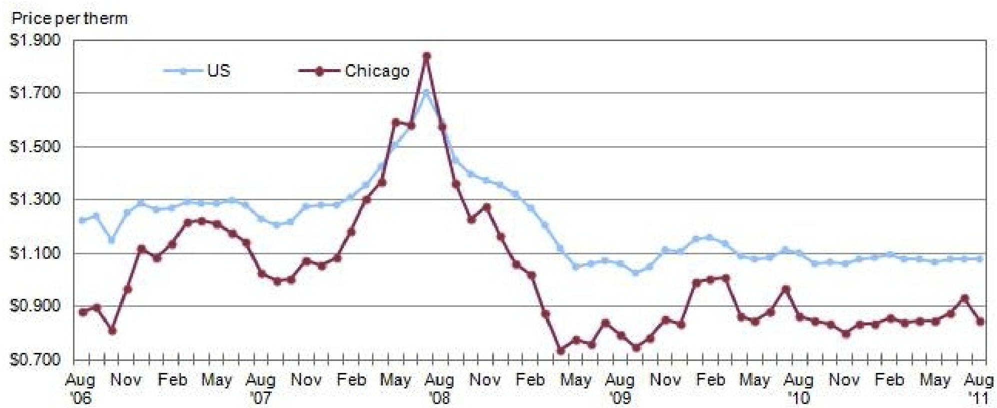

Figure 9: Average Prices for Utility (Piped) Gas, United States and Chicago Area, August 2006 – August 2011. Source: U.S. Bureau of Labor Statistics, 2011

Piped gas prices in Chicago historically have been more volatile than electricity (Figure 9), and this is the product of many factors that cannot be taken into account here. For the purposes of this analysis, gas prices will be projected to stay the same ($0.85 per therm), adjusted for inflation, over time (U.S. Bureau of Labor Statistics, 2011).

4.4 Summary of phase 1 Residential Units and Commercial Space

As was discussed in §2, there will be 598 rental residential units, 136 two home flats (272 residential units) and 250 residential units above the proposed commercial space in phase 1 of the South Works project. While the type of residential unit does affect energy consumption, a lack of data on the specifics of the proposed units, as well as a lack of good information on energy consumption compared between these types of units, warrants the use of an aggregated residential unit. Thus, 598+272+250=1,120 residential units. Additionally, the phase 1 commercial space is 844,000 square feet.

4.5 Energy Savings

According to the U.S. Green Building Council, the average energy savings of a LEED-certified building over the baseline energy consumption of non-LEED equivalent buildings is 25% (U.S. Energy Information Administration, 2006). This figure was found to be similar across building types (Turner & Frankel, 2008).

4.6 Energy Use for Residential Units

Average residential unit consumption of piped gas in the Cook county area is reported to be 1,084 therms per year (CNTenergy, 2009, pg. 14). Average residential unit consumption of electricity in the Cook county area is reported to be 7,935 kilowatt hours. Electricity usage converts to 270.75 therms per year (CNTenergy, 2009). These data will be used later in our quantification of benefits realized.

4.7 Energy Use for Commercial Space

Average commercial space data was best described in national data. Among the 6,478.33 square feet of commercial space in one study, 582 million btu was used in one year (U.S. Energy Information Administration, 2006). This averages to 89,838 btu per quare foot per year, or .898 therms per square foot per year. 0.469 therms of electricity are used per square foot per year, and piped gas accounts for 0.429 therms per square foot per year (U.S. Energy Information Administration, 2006).

4.8 Green Roof Energy Savings

The South Works project has also committed to building a number of green roofs (see §2). While the Federal Energy Management Program reported an average of 11% savings of all air-conditioning costs with the presence of green roofs (Department of Energy Efficiency and Renewable Energy, 2004), this can only be matched with data reporting square footage of phase 1 roofs as well as data demonstrating whether this energy comes from natural gas, electricity or some other source. Without these specific energy breakdowns and with a broad range (50-100%) of roofs in phase 1 having the potential to be green roofs (as mandated by the City subsidy), it is not possible at this time to calculate the exact benefits of this part of the South Works project. Therefore, while we acknowledge the presence and benefit of green roofs in the South Works project, these benefits are not factored into our calculations, making our results even more conservative.

4.9 Determining Benefits of Emissions Reduction

The average US household emits 6,800 pounds or 3.4 tons of CO_2 equivalent each year (U.S. Environmental Protection Agency, 2011). There are 60 billion square feet of commercial space in the United States (Diamond, 2001), averaging 2.46 billion tons of CO_2 per year (Energy Star, 2011). This amounts to .041 tons of CO_2 per square foot of commercial space per year. Given an expected 25% energy use reduction, which we draw from the literature in §3.3, we will assume a 25% emissions reduction. This is a simplified assumption as it does not reflect the specific mix of energy sources for the Chicago area. However, it is a good conservative estimate that allows us to look at the general effect of CO_2 emissions reductions without addressing the minutia of Chicago area power sources. A recent study published in the Proceedings of the National Academy of Science (PNAS) valued a ton of CO_2, in order to be offset, at $1.33 per ton (Kindermann et al., 2008). As this is a highly divisive and volatile price estimation, this will be assumed to remain stable, plus inflation, over time. Since this is a very debatable component of the South Works project's benefits, we will conduct our analysis both with and without CO_2 emissions reductions in order to provide a stress test for our results.

4.10 Projection of Energy Savings - in therms per year

4.10.1 Variables

Here, we list all the variables we will use in our calculations for projections of energy savings below. Each of these variables has been discussed in the above sections, but this presentation allows for easy referencing. **All of these variables assume the South Works project is *not* LEED-certified. We will quantify the effect of being LEED-certified (an energy savings of 25%, explained in §4.5 above) in §4.10.2.**

- E_R is electricity use in the residential units of South Works phase 1 (303,240 therms/year)
  - 270.75 therms/year/unit (CNTenergy, 2009)
  - 1,120 units (City of Chicago, 2011a)
- E_C is electricity use in the commercial space of South Works phase 1 (395,836 therms/year)

- 0.469 therms/year/square foot (U.S. Energy Information Administration, 2006)
- 844,000 square feet (City of Chicago, 2011a)

- E_T is total electricity use in South Works phase 1 (699,076 therms/year)
  - Sum of E_R and E_C
- NG_R is natural gas use in the residential units of South Works phase 1 (1,214,080 therms/year)
  - 1,084 therms/year/unit (U.S. Energy Information Administration, 2006)
  - 1,120 units (City of Chicago, 2011a)
- NG_C is natural gas use in the commercial space of South Works phase 1 (362,076 therms/year)
  - 0.429 therms/year/square foot (U.S. Energy Information Administration, 2006)
  - 844,000 square feet (City of Chicago, 2011a)
- NG_T is total natural gas use in South Works phase 1 (1,576,156 therms/year)
  - Sum of NG_R and NG_C
- TE_R is total energy use (electricity plus natural gas) in the residential units of South Works phase 1 (1,517,320 therms/year)
  - Sum of E_R and NG_R
- TE_C is total energy use (electricity plus natural gas) in the commercial space of South Works phase 1 (757,912 therms/year)
  - Sum of E_C and NG_C
- TE_T is total total energy use (electricity plus natural gas) in South Works phase 1 (2,275,232 therms/year)
  - Sum of TE_R and TE_C
- C_R is energy-related CO_2 equivalent emissions from the residential units of South Works phase 1 (3,808 tons/year)
  - 3.4 tons/year/unit (U.S. Environmental Protection Agency, 2011)
  - 1,120 units (City of Chicago, 2011a)
- C_C is energy-related CO_2 equivalent emissions from the commercial space of South Works phase 1 (34,604 tons/year)
  - 0.041 tons/year/square foot (Diamond, 2001)
  - 844,000 square feet (City of Chicago, 2011a)

- C_T is total energy-related CO_2 equivalent emissions from South Works phase 1 (38,412 tons/year)
  - Sum of C_R and C_C

The above values are presented again here in table form:

Variable	**Value**	**Units**
E_R	303,240	therms/year
E_C	395,836	therms/year
E_T	699,076	therms/year
NG_R	1,214,080	therms/year
NG_C	362,076	therms/year
NG_T	1,576,156	therms/year
TE_R	1,517,320	therms/year
TE_C	757,912	therms/year
TE_T	2,275,232	therms/year
C_R	3,808	tons of CO_2 equivalent emissions/year
C_C	34,604	tons of CO_2 equivalent emissions/year
C_T	38,412	tons of CO_2 equivalent emissions/year

4.10.2 Calculations

The following tables rely on the variables introduced in §4.10.1 to distinguish between "non-LEED" energy use and emissions and "with LEED" energy use and emissions.

South Works Phase 1 **Electricity** Use		
	non-LEED (therms/year)	with LEED (therms/year)
Residential	E_R = 303,240	$(0.75)E_R$ = 227,430
Commercial	E_C = 395,836	$(0.75)E_C$ = 296,877
Total	E_T = 699,076	$(0.75)E_T$ = 524,307

South Works Phase 1 **Natural Gas** Use		
	non-LEED (therms/year)	with LEED (therms/year)
Residential	NG_R = 1,214,080	$(0.75)NG_R$ = 910,560
Commercial	NG_C = 362,076	$(0.75)NG_C$ = 271,557
Total	NG_T = 1,576,156	$(0.75)NG_T$ = 1,182,117

South Works Phase 1 **Total Energy** Use (Electricity + Natural Gas)		
	non-LEED (therms/year)	with LEED (therms/year)
Residential	TE_R = 1,517,320	$(0.75)TE_R$ = 1,137,990
Commercial	TE_C = 757,912	$(0.75)TE_C$ = 568,434
Total	TE_T = 2,275,232	$(0.75)TE_T$ = 1,706,424

South Works Phase 1 Total Energy-Related **CO_2 Emissions**		
	non-LEED (tons CO_2/year)	with LEED (tons CO_2/year)
Residential	C_R = 3,808	$(0.75)C_R$ = 2,856
Commercial	C_C = 34,604	$(0.75)C_C$ = 25,953
Total	C_T = 38,412	$(0.75)C_T$ = 28,809

One observation to draw from the above tables is that natural gas use is much more important in residential buildings than commercial buildings, while this is not true of electricity use. (Compare the difference between E_R and E_C with the difference between NG_R

and NG_C.) **Also, note that the *savings* from being LEED-certified is the difference between the left-hand and right hand columns in each of the above tables.** When we quantify energy savings in §4.11, we will use values like $(0.25)E_T$ as the electricity savings from being LEED-certified. Notice that $(0.25)E_T = E_T - (0.75)E_T$, which is the difference between the two columns.

4.11 Quantification of Energy Savings - in dollars per year

In this section, we draw from the quantified benefits in the tables above and convert these benefits into dollar amounts through projections of energy prices.

We define three prices: p_e is the price of electricity per therm, p_g is the price of natural gas per therm, and p_{CO_2} is the price of one ton of CO_2 offset. We quantify these variables below: (note that all prices are in "per year" terms.)

p_e = \$0.158/kWh/year × 29.3kWh/therm = \$4.63/therm/year
(p_e is assumed to rise over time by \$0.0094/kWh/year×29.3kWh/therm = \$0.275/therm/year)
(See §4.2 for more discussion of this variable)

p_g = \$0.85/therm/year (p_g is assumed constant across years) (See §4.3 for more discussion of this variable)

p_{CO_2} = \$1.33/ton/year (p_{CO_2} is assumed constant across years) (See §4.9 for more discussion of this variable)

Energy savings benefits will be accrued over the lifetime of the South Works project (assumed to be 100 years) at the prices above. Therefore, starting in the year 2012, the flow of benefits can be defined as follows, with B_t as the energy savings benefit in year t:

$$B_t = \begin{cases} 0 & \text{for } t \in [0,5] \\ ((0.25)E_T)(p_e + 0.275t) + ((0.25)NG_T)p_g + ((0.25)C_T)p_{CO_2} & \text{for } t \in [6,100] \end{cases}$$

Plugging in numbers for the energy use variables (drawing from the tables in §4.10.2), this expression becomes:

$$B_t = \begin{cases} 0 & \text{for } t \in [0,5] \\ (174769)(p_e + 0.275t) + (394039)p_g + (9603)p_{CO_2} & \text{for } t \in [6,100] \end{cases}$$

Plugging in p_e, p_g, and p_{CO_2} from above, we get:

$$B_t = \begin{cases} 0 & \text{for } t \in [0,5] \\ (174769)(4.63 + 0.275t) + (394039)0.85 + (9603)1.33 & \text{for } t \in [6,100] \end{cases}$$

This simplifies to B_t in dollars:

$$B_t = \begin{cases} 0 & \text{for } t \in [0,5] \\ 1156886 + 48061t & \text{for } t \in [6,100] \end{cases}$$

In §4.9, we mentioned that we would conduct our analysis without CO_2 emissions reductions as a stress test. If we remove the benefit of CO_2 emissions reductions, our benefit function becomes:

$$B_t = \begin{cases} 0 & \text{for } t \in [0,5] \\ 1144114 + 48061t & \text{for } t \in [6,100] \end{cases}$$

While B_t estimates savings at any given year after construction, LEED certified results have been documented to vary greatly about a mean energy savings of 25%, with over 50% of buildings varying over 35% from the expected output (Diamond et al., 2006). This will also affect emissions reduction, but we find this to remain a good estimate as these deviations are equally likely to be higher or lower than the mean, and we were able to average this over the several units and commercial spaces proposed in phase 1.

5 Costs: Tax Increment Financing and Chicago's Support of the South Works Project

In this section, we discuss the City of Chicago's contribution of $95,885,584 to the South Works Development Project as a cost. This city expenditure is being funded through Tax Increment Financing (TIF) — a somewhat contentious public financing technique. We address this funding method in this section and discuss how it relates to this project.

The costs of the phase 1 project are expected to total approximately $396,693,757, the budget for this phase of the development (City of Chicago, 2011a). These total costs can be broken down into equity ($75,000,000), lender financing ($225,808,173), and "net proceeds of bonds" or the City's subsidy ($95,885,584) (City of Chicago, 2011a). In September of 2010, the Chicago City Council approved the $95,885,584 in net proceeds of City bonds for the project, and this amount could possibly increase to but not exceed $96,859,748 depending upon what happens throughout the construction of the project (City of Chicago, 2011a). This funding, roughly a fourth of the total construction budget, can be viewed essentially as a subsidy to encourage desirable development characteristics such as energy efficiency in the new development.

5.1 Public Sponsorship of the South Works Project

The conversion of South Works from a brownfield to a sustainable neighborhood is undoubtedly ambitious and costly. The overall plan is estimated to take three decades and approximately $4 billion to complete (Sharoff, 2010). The full plans by Skidmore, Owings & Merrill calls for accommodations for 50,000 residents, 17.5 million square feet of commercial and retail space, a 1,500-slip-marina and a high school (Sharoff, 2010). As discussed in §2, this development will ideally be a thriving South Side neighborhood that works with the existing city grid and improves the surrounding area. Despite the continued oversupply of homes in Chicago from the housing bubble, the Chicago Metropolitan Agency for Planning anticipates that over the next 30 years Chicago's population will increase by 2.4 million residents (Sharoff, 2010). Phase 1 of the South Works redevelopment project, which will begin construction in 2013, aims to create approximately one thousand mixed-income residences and about a million square feet of commercial space. Some negligible level of commercial activity is expected as soon as 2014 when retailers are anticipated to settle into what currently stands as a no-man's land (Baker, 2010). Additionally, all buildings will all have to meet LEED certification standards to be successfully part of the City's three LEED pilot projects. Almost a quarter of phase 1's nearly $400 million price tag will be sponsored by the City of Chicago as part of a projected 25 year effort to revitalize Chicago's South Side.

The City's $95,885,584 contribution makes this the City's largest publicly subsidized private development (Baker, 2010). Although the subsidy seems sizable and especially generous for a project that is not purely public, the use of the City's funds will only serve as a stepping stone to realize the South Works plan. All public funds will likely be exhausted by base improvements which are claimed to be necessary for any potential developer. Chicago developer Dan McCaffery argues that the City's "money given to South Works would all go towards... a dearth of water supply, streets, power grid and other infrastructure requisites... [which] must be met before the first foundation can be laid" (Baker, 2010). As previously mentioned in §2, South Works' infertile status has already been aided by the Illinois Department of Natural Resources with tons of topsoil moved from the Illinois River (Baker, 2010). The limitations on the use of the subsidy places all additional costs to complete phase 1 on developers McCaffery Interests Inc. and U.S. Steel Corporation.

Although green buildings are on average 2% higher in cost to construct than traditional structures, these buildings' positive externalities of financial savings and possible health and social benefits show that consumers are willing to pay a premium for green architecture such as LEED projects (Kats, 2009). The upfront higher cost of a LEED certified building is offset by an average reduction in energy use of 33% (Kats, 2009). More green-friendly developments are a step towards improved energy efficiency as residential and commercial buildings make up 41% of America's energy consumption as shown in Figure 4.

5.2 Funding through Tax Increment Financing

The public financing mechanism known as Tax Increment Financing (TIF) is the City of Chicago's source of funding for the revitalization of the former U.S. Steel site. The funds for TIF programs are generated by increases over a 23 year period in the Equalized Assessed Valuation (EAV) of a declared TIF district (City of Chicago, 2011b). The EAV base amount is determined by the current level of property tax that a district generates when it is declared TIF. Revenue allocated to bodies such as schools and parks are frozen at the current level of when a TIF district is declared. Funds for TIF are then raised from increases in the property taxes above the EAV base when the district's property values rise. The bonds issued to pay the upfront costs of a TIF program are then reimbursed through the increment (City of Chicago, 2011b). The City's sponsorship just shy of $96 million reflects very optimistic projections of South Works' impact on property values in the surrounding areas of the South Side.

The City of Chicago's official site states that TIF funding is intended to "build and repair roads and infrastructure, clean polluted land and put vacant properties back to productive use" (City of Chicago, 2011b). The official site also declares that "areas proposed for TIF designation must possess numerous blighting factors to be eligible" (City of Chicago, 2011b). Among the dozen factors named obsolescence, excessive land coverage, lack of community planning and excessive vacancies can be argued to be true of the current state of South Works. As we discussed in §2, the South Works site has remained vacant since U.S. Steel fully closed operations in 1992 and has been rendered a three-quarters landfill of slag deposits from over a century of smelting (Sharoff, 2010).

The TIF program was implemented in Chicago during the 1980s by Mayor Harold Washington with the purpose of improving blighted areas of the City that would otherwise be left untouched in the private market (Joravsky & Dumke, 2009). The location of the sizable South Works site at the mouth of the Calumet River and the shores of Lake Michigan has worked to convince many, including the Chicago City Council, that South Works is a neighborhood that could be successfully integrated into Chicago. In short, the immediate financial assistance afforded through TIF is intended to catalyze sustained future economic activity for the aided site and the surrounding area.

5.3 Criticism of TIF

Although TIF has become a popular device since the 1970s for local governments to finance projects without the assistance of federal funds, it is still a controversial means of subsidizing. The main criticism of TIF is that funds for current projects are dependent upon future tax revenues from increasing property taxes. Given the recent housing bubble, the means by which TIF provides funds for projects can seem unsound. While issues over the City's deficit have caused attacks on TIF, the issue becomes how these taxpayer-funded subsidies are allocated rather than whether if TIF should be used as a public financing mechanism.

Although TIF has been defended as the "city's chief tool for bringing economic development and infrastructure investment to neighborhoods that couldn't otherwise attract them," the allocation of funds among the 152 Chicago TIF districts have tended to not reflect the program's declared agenda (Joravsky & Dumke, 2009). The budget for TIF funds shown in Figure 10 reflects a lopsided distribution towards improvements on already financially thriving neighborhoods in the city center rather than to the south and west sides, which make up the majority of TIF districts.

AREA	2009 BALANCE	NUMBER OF TIF DISTRICTS	AVERAGE BALANCE PER DISTRICT
Central	$308,787,563	16	$19,299,223
South Side	$174,866,721	56	$3,122,620
Northwest Side	$147,869,113	35	$4,224,832
North Side	$101,328,944	21	$4,825,188
Southwest Side	$47,764,318	16	$2,985,270
West Side	$44,650,300	11	$4,059,118

Figure 10: Chicago Tax Increment Financing (TIF) Budget. Source: Joravsky & Dumke, 2009.

The use of taxpayer dollars to subsidize projects such as a French Supermarket in the West Loop as an "economic opportunity" that Mayor Daley claimed to reflect TIF's objective have caused the program to be criticized as inefficient (Joravsky & Dumke, 2009). The alleged waste caused by many TIF sponsorships is that funds are diverted to developments that likely would have gone ahead and in turn reduce financing for other public goods like the local school district (Joravsky & Dumke, 2009). The vagueness of what constitutes "economic development" has been the primary source of debate over Chicago's TIF program, which has even been called an abuse of the public coffers (Baker, 2010). Furthermore, subsidies awarded to for-profit ventures, such as the French market, in prosperous neighborhoods have made opponents question the City's political motivations.

5.4 What the City has at Stake

The unprecedented amount of the South Works TIF sponsorship has the potential to restore the program's image but also risks even further attacks on the City's use if the development faces obstacles such as delays and failing to meet LEED standards. While the subsidy will only plant the seeds for the South Works vision, the project is receiving more than half of the combined funds that 56 South Side districts were granted in 2009 (Joravsky & Dumke, 2009). In other words, South Work's nearly $96 million grant is tremendously higher than the average TIF sponsorship on the South Side of $3 million and even central Chicago's average of $19 million (Joravsky & Dumke, 2009).

The costs to create the South Works project, which is comparable to the Loop in size, are especially high given the economy's current state. However, the City does believe that it will see a long-run return on the taxpayer-funded subsidy. In Mayor Daley's ordinances supporting housing opportunities and business expansion, he stated that the "Chicago Lakeside[3] Development Tax Increment Financing (TIF) District [establishes] a way to revitalize residential and commercial investment in the South Shore community... [and] will work to stimulate new development and provide local residents with increased job opportunities and shopping options" (Sullivan, 2010). The plans for phase 1 alone address issues of land segregation with the integration of residential and commercial spaces. Paul Vogel praised South Works as a positive step to reduce the "understored" problem that has rendered the South Side neighborhoods such as Roseland and Englewood food deserts (Sharoff, 2010).

Major improvements like bringing more grocery stores and creating a business district on the South Side are reason enough to make South Works an attractive TIF program. The planning of the development with full LEED certification helps to increase energy efficiency through the mix of residential and retail buildings. The proximity of neighborhood needs naturally promotes walking, biking and public transportation over driving, which is not only more cost-effective for residents but also increases energy efficiency. The full plans for South Works also incorporate energy alternatives such as wind power generation. South Works has the potential to stimulate economic activity while creating a model for sustainable neighborhood development.

[3]The term "Lakeside" is a proposed neighborhood name and refers to the South Works project.

6 Benefit-Cost Analysis

In this section, we outline and conduct a benefit-cost analysis of the South Works project using the data outlined in the previous sections.

As we have noted, this analysis only considers the energy savings of the South Works project from being LEED-certified. A comprehensive benefit-cost analysis would need to include estimations of community building, reduced transportation, gentrification, remediation of the South Works site, and other factors. These all lie outside the scope of this paper, but it is important to remember them when thinking about the City's decision to make its subsidy to this project.

6.1 The Benefit-Cost Analysis Framework

There are 5 major components to any benefit-cost analysis: (1) the "with and without" principle, (2) "present value" calculations, (3) specification of those individuals or groups who actually benefit and/or bear costs from a project, (4) quantifying the seemingly unquantifiable, and (5) allowing for uncertainty. Below we briefly discuss each of these components in relation to our study.

6.1.1 The *With* and *Without* Principle

In this analysis, we are comparing the first phase of the South Works development against another hypothetical development of the site that is *not* LEED-certified. By doing this, we are isolating the costs and benefits of the development project being LEED-certified rather than the costs and benefits of the project overall. This allows us to piece out the energy savings of the project and clarifies our scope of analysis. However, we could also imagine that were this development not to be built, other developments would begin around the City of Chicago rather than a similarly-sized development on the South Works site. In either case, we must realize that some of those developments might be LEED-certified themselves, so our with-and-without analysis is not quite perfect. However, it would be difficult to predict with any certainty what percentage of other developments might incorporate LEED standards into their designs.

6.1.2 Present Value

Present Value is a calculation that allows comparison of a project's immediate costs to future benefits that accrue over time. Central to the present value calculation is the identification of the discount rate — a measure of how much we value costs and benefits in the future compared to costs and benefits in the present. We explicitly discuss our discount rate below in §6.2 and calculate the present value of the energy savings of the South Works Development Project in §6.3.

6.1.3 Whose Benefits? Whose Costs?

We are conducting our analysis from the perspective of the City of Chicago. This choice situates our benefits and costs on a relatively local scale, and does not mire us in massive global-scale calculations. The City of Chicago, while being a bureaucratic entity itself, is in effect a proxy for the citizenry of Chicago. All of the city's actions are taken (theoretically) on behalf of and funded by the taxpayers of Chicago. Therefore, when we say that our analysis is from the perspective of the City, we are simultaneously saying our analysis is from the perspective of Chicago taxpayers. However, it is much simpler to quantify the City's interaction with the South Works project rather than individual taxpayers' interactions, so this is an effective proxy.

In other words, we are analyzing this project from the perspective of "society." However, in this case, "society" is particularly local in scale (the City of Chicago) and not necessarily the whole world.

6.1.4 Quantifying the Seemingly Unquantifiable

Central to the benefit-cost analysis framework is measuring all benefits and costs in dollar amounts. This allows for direct comparison of all aspects of a given program or action. However, it is often difficult or off-putting to quantify certain benefits, such as carbon emission reduction, in dollar terms. In this study, we have quantified all costs and benefits, specifically using the benefit-transfer method. You can find our estimations of benefits above in §4.11 and our analysis of costs above in §5.

6.1.5 Allowing for Uncertainty

Inherent in predicting future benefits is a certain amount of uncertainty. Future events are unpredictable, and the costs and benefits of the South Works Development Project over the next 100 years are impossible to quantify with certainty. Therefore, in the above quantifications of the project's benefits and costs (§4.11 and §5), we have discussed the existence of high and low estimates that give us a range of possible outcomes. We will analyze these different estimations and end up with a range of present values representing various possible results. While a range of results is less specific than a single number, the range is much more helpful because the future is much more likely to fall within the range than meet a specific prediction. For more detail about how we allow for uncertainty in our analysis, see §6.3 below: "Calculation of Present Value."

6.2 The Discount Rate

Selecting a discount rate is a topic of much debate. In this analysis, we draw from Professor George Tolley (2011) to determine our discount rate. Since roughly two thirds of the economy's investment is in regular businesses, which have an average before-tax return of about 9%, and the other third of investment is in housing, which has a before-tax return of 3%, we take a weighted average of these returns to determine our short-run discount rate: $(2/3)(0.09) + (1/3)(0.03) = 0.07$ or 7%.

While 7% is a good discount rate for the short-term (roughly a 25-year time horizon), discount rates should drop significantly for longer-term time horizons. Therefore, we assume a 1% discount rate for all years after 75 years have passed. For the period between 25 and 75 years, we assume a linearly decreasing discount rate falling from 7% to 1% over 50 years by 0.12% each year.

6.3 Calculation of Present Value

Here we calculate the present value (PV) of the South Works development. To do so, we compare the costs at $t = 1$ with the discounted benefits of the project accrued over 100 years. B_t represents the benefits of the development in year t, r is the discount rate, and C is the project's cost to the city. Note, C is an up-front cost paid in $t = 1$ from the City to the developer. The general form of the present value calculation is here:

$$PV = -C + \sum_{t=1}^{T} \frac{B_t}{(1+r)^t}$$

Once we specify for the particular discount rates we have outlined above in §6.2, the present value equation becomes:

$$PV = -C + \sum_{t=1}^{25} \frac{B_t}{(1.07)^t} + \sum_{t=26}^{75} \frac{B_t}{(1.07 - (0.0012)(t-25))^t} + \sum_{t=76}^{100} \frac{B_t}{(1.01)^t}$$

Now, we plug in costs ($C = \$95885584$) and benefits (two different calculations of B_t from §4.11) to calculate present value:

With CO_2 emissions reductions included:

$$PV = \$11131032$$

Without CO_2 emissions reductions included:

$$PV = \$10775949$$

7 Conclusion

In this paper, we have exclusively analyzed the energy savings benefits of the South Works Development Project's initial phase — not all the benefits of the development. Despite this, we have found a positive net present value for the project. This suggests that the City's roughly $96 million subsidy is more than "worth it" — even if only the benefits of energy savings are taken into account. As a stress test, we ran our analysis both with and without CO_2 equivalent emissions reductions factored in. The difference between our two cases was $355,083, suggesting that CO_2 emissions are a relatively small component of the benefits from LEED certification. (Note that $355,083 is only 3.2% of the total net present value of $11,131,032 we find in our first case.)

Our analysis demonstrates that, if the South Works project is developed as planned and is successful (i.e. the units sell and the neighborhood is successfully revitalized), the City's subsidy will have been a cost-effective and net-beneficial way to achieve energy savings in this major development. The fact that the South Works development will result in other benefits to the City — such as community building and improved transportation — is an additional benefit on top of the energy savings. (In more colloquial terms, it is all gravy.) In short, we believe the City's decision to subsidize the South Works project is justified from a benefit-cost analysis perspective.

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TEAM 2

A Lerner Curve Analysis of Solar Photovoltaic Grid Parity in California

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December 2011

Abstract

Solar energy has long been recognized as one of the most promising alternatives to grid power. Until cost parity is achieved, however, the market will not large-scale shift towards PV. This paper analyzes when cost parity for PV will be achieved in California, one of the most abundant sources of solar energy in the U.S. Previous studies suggest that new technologies decrease in cost as production increases, due to increased efficiency and refined technology. This paper applies the Lerner experience curve model to predict this price decrease. The past 10 years of California solar data is regressed to fit the model, and then various growth rates are applied to the model to predict future cost trends. At a growth rate of 50% per year – which matches previous growth rates - grid parity is achieved in 2030, at 20% per year – our conservative estimate - it is achieved at 2050, and at 50% for the first ten years followed by 20% for subsequent years – the rate we believe will be closest to reality - parity is achieved in 2042. Further research on the effects of government subsidies and technological initiatives could shed light on how to make this time frame more accurate, and possibly closer to present.

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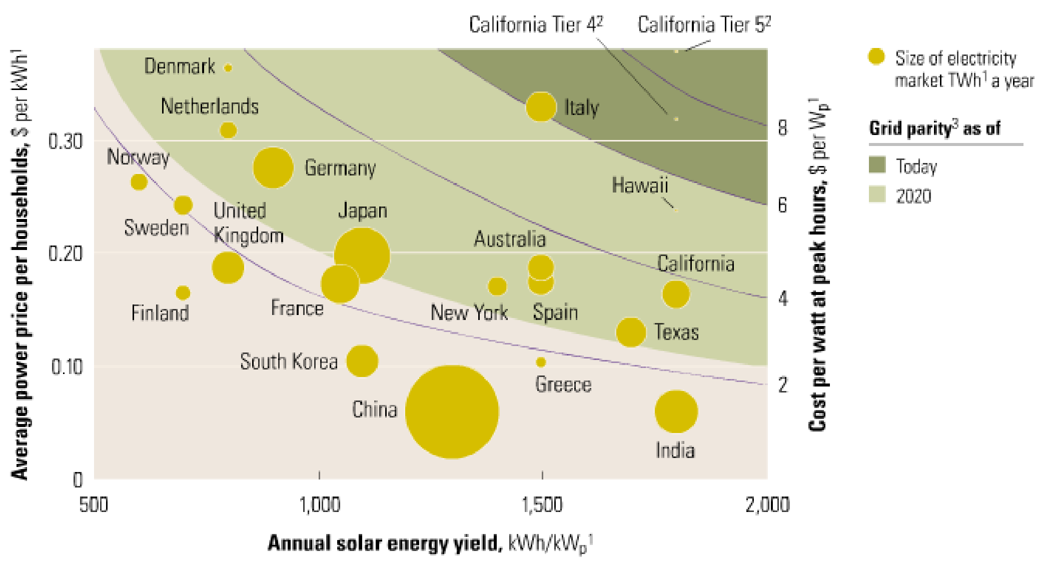
I. Introduction

Renewable energy technologies for producing electricity have received greater attention in recent years due to increases in fossil fuel prices and concerns over greenhouse gas emission and global climate change. There is an urgent need to develop and implement renewable energy technologies that can make a substantial contribution to the increasing energy demand. Solar photovoltaic (PV) is one of such technologies. PV technology for electricity generation has already proven its multi fold applications and is accepted worldwide. PV offers possibilities to better match electricity supply and demand by generating electricity during day time, when demand of electricity and its price is also high. Additionally, PV technologies have some other technical advantages compared to other electricity generating technologies i.e. they require low maintenance and can operate for long periods unattended. Moreover, if necessary, additional generating capacity can be readily added, which makes them a good choice for electricity generation in remote applications.

Many countries, such as Germany, have already included different PV promotion programmes (e.g. subsidies, feed in tariff, etc.) in their national electrification plans. The PV industries are focusing their efforts in the promotion of more PV systems worldwide. Focuses are also concentrated in increasing the technical and economic performances of PV modules and systems, developing new technologies, and enacting effective government regulations and policies. However, high cost often associated with solar PV systems is still hindering its market competitiveness preventing it from competing in the market without subsidies and supports. Nevertheless, costs are decreasing rapidly since its commercial application started in 1980s. It is believed that, because of rapid increase in prices of the electricity from conventional fuels on the one hand and improvements and further experiences in PV technology leading to mass production on the other hand, a day will come in future when the price of grid electricity generated from conventional fuels will be same or even higher than the price of electricity generated from solar PV. There are many market factors that may determine the occurrence of this time point. Although many countries have significant potential for solar energy production – as seen in the figure below - this paper will restrict itself to the largest potential market in the United States, California.



[1]kWh = kilowatt hour; kW_p = kilowatt peak; TWh = terawatt hour; W_p = watt peak; the annual solar yield is the amount of electricity generated by a south-facing 1 kW peak-rated module in 1 year, or the equivalent number of hours that the module operates at peak rating.

Figure 1. The International Solar Energy Market
Source: University of California at Merced

The objective of this paper is to find out the ‘‘Grid Parity Year,” that is the time point in future when the electricity from grid connected PV will be able to compete with the grid electricity generated from conventional fuels in the state of California, and to assess the relevant market parameters necessary for occurrence of grid parity. For this purpose, experience curves for solar PV systems available in the literatures have been analyzed, and these curves are extrapolated for the future with certain assumptions on annual growth rates of PV installations, annual growth rate of electricity prices, presence of single connected grid, and assurance of subsidy and other federal support. We decided to consider California as geographical area of our study as it exemplifies all the above factors. Grid parity can be defined as the time point when a kWh electricity generation cost using solar PV becomes equal to a kWh electricity price from grid.

The paper is organized in the following sections. Section II covers the history of solar PV in California and the govt. support it receives; Section III explains our methodology to estimate grid parity and net benefit; Section IV presents our findings, and Section V concludes and discusses the implications of our results.

II. Solar PV Market Structure

Solar energy has long been considered one of the most promising alternative energy sources. Although differences in climate make it unlikely to be universally adopted, it is still one of the fastest growing sources of alternative energy. Additionally, photovoltaic cells have seen an approximate 35 percent decrease in cost over the past 12 years; the cost per kilowatt in 1998 was $10.87, whereas by 2010 it was approximately 7$ [1]. Taking inflation into account, this decrease in cost is even more dramatic. These decreases can be attributed to government subsidies, increased efficiency of PV panels, and larger scale manufacturing [1]. Many researchers are optimistic that these prices will continue to fall, although there is considerable debate concerning how much [2,3].

If such decreases in cost continue, price parity will soon be achieved for PV against traditional grid power. Some researchers have even suggested that it may be achieved as soon as 2013, although the more common estimates run closer to 2020 [2,3]. One of the main goals of this paper is to explore whether and how the price of PV will continue to drop in the future, in order to determine a range of possible years by which grid parity may be attained.

Presence & Support in California

California is widely considered one of the most fertile states for solar energy production [3]. Not only does it have an abundance of sunshine, but the political climate strongly favors alternative energy and large scale PV investment has already been undertaken [4]. In 2009, 11.6 percent of the state's energy was supplied by alternative energy, with nearly 9 percent of that from solar energy [4].

In 1998, following deregulation of utilities in California, the California Energy Commission was put in charge of the Renewable Energy Program, aimed at facilitating California's switch to Renewable Energy. The Renewable Energy Program has a statewide goal of achieving 3,000 MW energy production through Solar Energy by 2016 [4]. Additionally, California enacted the

California Solar Initiative, with the goal of increasing Solar Production by 1940MW within the next 5 years [4]. The Commisions's New Solar Homes Partnership, with a budget of $400 million, aims to help Californians add solar energy production to their personal homes through taxes and subsidies.

In light of California's favorable climate, political climate, and current solar infrastructure, our paper will focus specifically on when California might achieve grid parity.

III. Methodology

As outlined earlier, costs have historically dropped for Solar Energy, a trend that is common across most new technologies. In our paper, we adopted a **Lerner experience curve model** regressing previous solar energy cost data to measure California's future cost decreases and grid parity timeline. It has been successfully applied to the German solar industry [6].

Experience curves describe how cost declines with cumulative production, where cumulative production is used as an approximation for the accumulated experience in producing and employing a technology. A specific characteristic of experience curves is that cost declines by a constant percentage with each doubling of the total number of units produced. Data on PV installation/generation capability in California covering the period 1998-2007 reveal such a characteristic (See Figure 2 and Table 1).

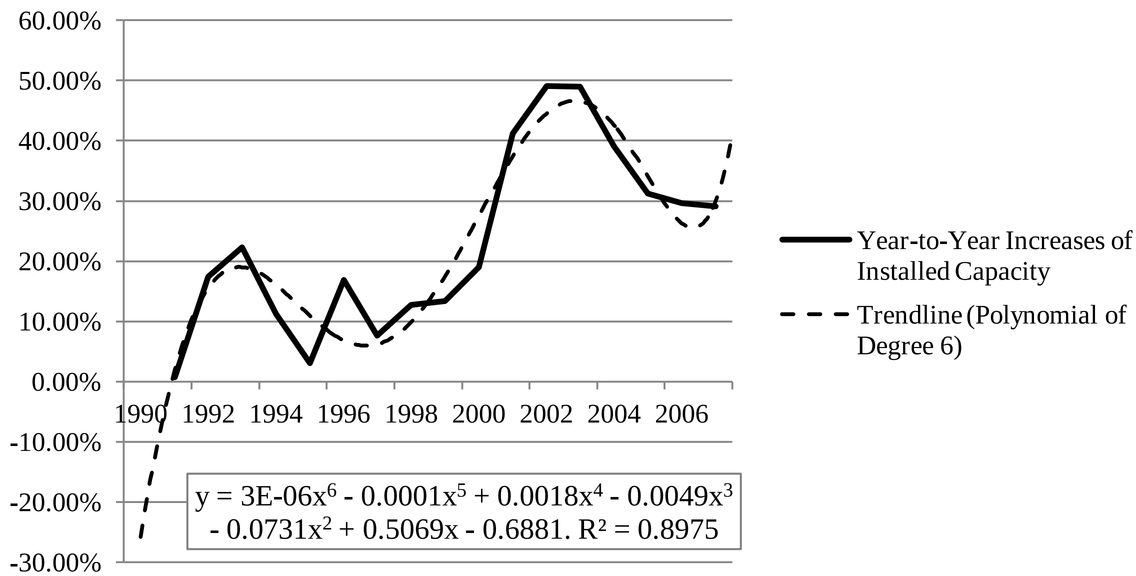


Figure 2. Year-to-Year Percentage Increase in Installed Capacity of Solar PV in California from 1990-2007. Our trendline indicates that capacity growth rates beyond 2007 appear to eventually hover or exceed 20-50%.

Year	Total Installed Capacity (kW)	Cumulative Installed Capacity (kW)
1990	15	2,295
1991	17	2,312
1992	489	2,801
1993	806	3,606
1994	458	4,064
1995	128	4,193
1996	854	5,046
1997	418	5,465
1998	798	6,263
1999	965	7,228
2000	1,701	8,929
2001	6,251	15,180
2002	14,640	29,820
2003	28,640	58,460
2004	37,525	95,984
2005	43,532	139,516
2006	58,741	198,257
2007	81,206	279,463

Table 1: Solar PV Capacity Installed in California from 1990-2007
Source: energyalmanac.ca.gov

We consider 2007 the base year from which to extrapolate for the next 60 years (during which time we believe grid parity is likely to occur), going by the availability of data. The equation for learning curve is written as [7]:

$$C_t = C_0 \left(\frac{Q_t}{Q_0}\right)^b$$

where,

C_t is levelized cost of given cumulative electricity production at time t,

C_0 is levelized cost at t = 0 (in our study 2007),

Q_t is cumulative production capacity at time t,

Q_0 is cumulative production capacity at t = 0 (in our study 2007),

b is rate of innovation or learning parameter. As the cost decreases with increase in production, value of b is negative.

This parameter is calculated as*:*

$$b = \frac{\ln \frac{C_t}{C_0}}{\ln \frac{Q_t}{Q_0}}$$

where,

C_t = levelized cost of given cumulative electricity production in 2007

C_0 = levelized cost of given cumulative electricity production in 1998

Q_t = cumulative production/capacity in 2007

Q_0 = cumulative production/capacity in 1998

In order to determine the grid-parity timeframe, electricity price trends for the state of California were also considered [Table 2]. This also helped to determine projected revenues and conduct a benefit-cost analysis to determine the timeline for net benefit in solar PV electricity, given the cost of PV electricity-generating installations 2007 onwards. Costs figures were incorporated from yearly data available at the Open PV Project database and adjusted for annual inflation of 3% [8].

Average Retail Electricity Prices
Historical (1982-2010)
In Nominal Cents/kWh

Year	IOUs	Municipal
1997	7.5	7.4
1998	7.5	7.6
1999	7.5	7.6
2000	8	7.7
2001	11.5	8.1
2002	12.3	10.4
2003	12.3	11.8
2004	12	8
2005	11	8.1
2006	12.4	8.2
2007	11.4	8.4
2008	11.5	9
2009	12.5	10.3
2010	12.7	10.1

Table 2: Average Electricity Prices in California [1982-2010]
Source: energyalmanac.ca.gov

We make the following assumptions in our model:

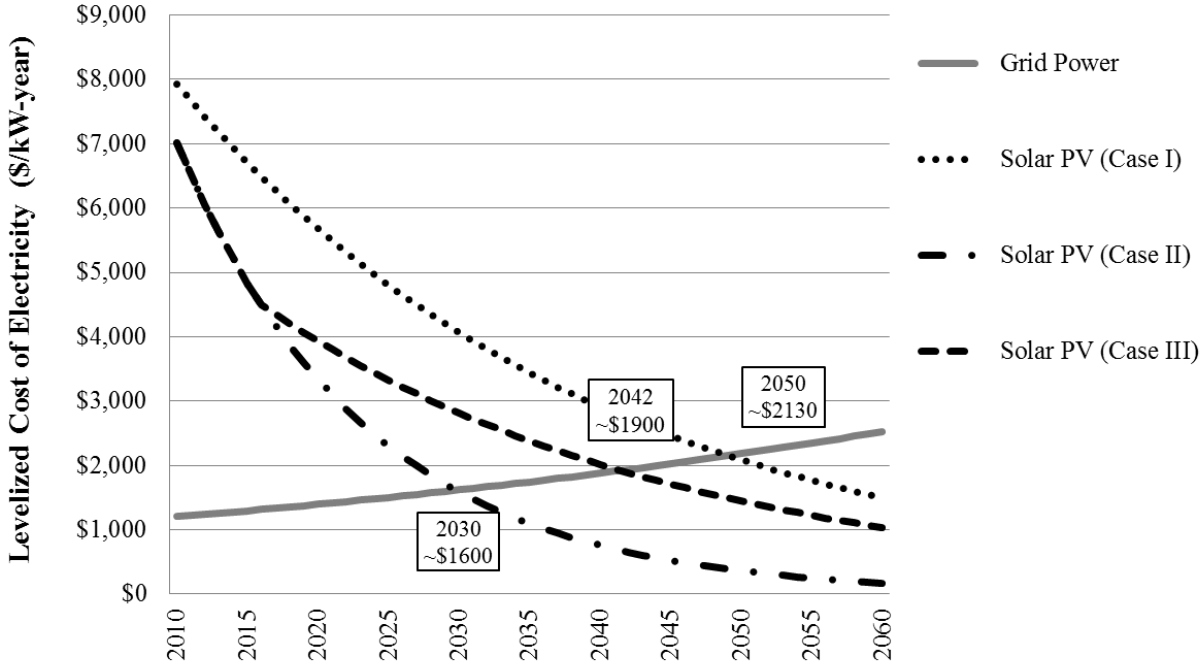
- The PV installation capacity for California is shown to be growing at range of 1.2 to 1.9 times annually as observed in the years preceding 2007. Given the uncertainly of precisely determining this growth rate in future years, we look at three different cases — *the lower bound rate of 1.2, an averaged growth rate of 1.5, and a mixed 1.5 for the first ten years (from 2007) followed by a 1.2 rate then on*. Our unit of measurement is in kW/year.
- Data reveals that for the same period of 1998-07, California electricity prices have been growing at a rate of 1.015% averaged over the growth rates for each of those years. This is the same rate used in the extrapolation for predicting price fluctuations in future years. Unit of measurement is $/kW-year.
- Current federal and state regulations which have been and are inherent in determining California electricity prices are assumed to remain unchanged.

IV. Findings

These calculations are based on our assumed rates and formulae in the previous section. Our result for the innovation parameter comes out as:

$$b = \frac{ln\frac{8760}{18504}}{ln\frac{279463}{6263}} = -0.1968$$

Using this result, looking at the period 2007 onwards, we received results for the following three cases.



Note: Price of grid power assumed to grow at 1.015% per year in California.
Case I: Capacity growing at 1.2 times/year. Grid Parity Achieved in year 2050
Case II: Capacity growing at 1.5 times/year. Grid parity achieved in year 2030
Case III: Capacity growing at 1.5 times/year for the first ten years and then at 1.2 times/year from 2019 onward. Grid parity achieved in year 2042

Figure 3. LCOE Estimations of Solar PV versus Grid Power Over Time

Correspondingly, for each year, based on respective estimated (prevailing then) electricity price, capacity installed, and levelized cost, the net benefits were calculated as follows (see Table 3).

	Case 1			Case 2			Case 3		
Year	Revenue	Cost	Net Benefit	Revenue	Cost	Net Benefit	Revenue	Cost	Net Benefit
2008	0.39	2.84	-2.45	0.49	3.41	-2.92	0.49	3.41	-2.92
2010	0.58	3.83	-3.25	1.13	6.61	-5.48	1.13	6.61	-5.48
2012	0.86	5.16	-4.30	2.63	12.83	-10.20	2.63	12.83	-10.20
2014	1.28	6.94	-5.67	6.09	24.88	-18.79	6.09	24.88	-18.79
2016	1.89	9.35	-7.46	14.11	48.26	-34.15	14.11	48.26	-34.15
2018	2.81	12.60	-9.79	32.70	93.60	-60.90	20.93	65.00	-44.08
2020	4.17	16.97	-12.81	75.79	181.55	-105.76	31.05	87.56	-56.52
2022	6.18	22.86	-16.68	175.69	352.14	-176.45	46.06	117.95	-71.89
2024	9.17	30.80	-21.63	407.25	683.03	-275.78	68.33	158.88	-90.55
2026	13.60	41.49	-27.88	944.01	1,324.83	-380.82	101.36	214.01	-112.65
2028	20.18	55.88	-35.70	2,188.22	2,569.68	-381.45	150.37	288.28	-137.91
2030	29.94	75.27	-45.33	**5,072.31**	**4,984.22**	**88.09**	223.08	388.32	-165.24
2032	44.42	101.40	-56.98	11,758	9,668	2,090	330.95	523.08	-192.13
2034	65.90	136.58	-70.69	27,254	18,751	8,503	490.97	704.61	-213.64
2036	97.76	183.98	-86.22	63,176	36,371	26,805	728.37	949.12	-220.76
2038	145.03	247.83	-102.80	146,441	70,546	75,895	1,081	1,278	-197.94
2040	215.15	333.83	-118.68	339,452	136,833	202,619	1,603	1,722	-119.14
2042	319.19	449.68	-130.50	786,853	265,406	521,446	**2,378**	**2,320**	**58.32**
2044	473.52	605.73	-132.21	1,820,000	514,790	1,310,000	3,528	3,125	403.17
2046	702.48	815.94	-113.46	4,230,000	998,503	3,230,000	5,234	4,209	1,025
2048	1,042	1,099	-56.95	9,800,000	1,940,000	7,860,000	7,765	5,670	2,095
2050	**1,546**	**1,481**	**65.54**	22,700,000	3,760,000	19,000,000	11,519	7,638	3,881
2052	2,294	1,994	299.32	52,700,000	7,290,000	45,400,000	17,089	10,288	6,801
2054	3,403	2,686	716.26	122,000,000	14,100,000	108,000,000	25,351	13,858	11,493

Note: Figures are measured in billions (USD $). Price is assumed to grow at 1.015% per year.
Case I: Capacity grows at 1.2 times/year. Net benefit in 2050.
Case II: Capacity grows at 1.5 times/year. Net benefit in 2030.
Case III: Capacity grows at 1.5 times/year for 10 years, and then sinks to 1.2 times/year. Net benefit in 2042.

Table 3: The revenue, cost, and net benefit figures for three cases of solar PV production, assuming different capacity growth rates. See Note above.

V. Conclusion

This study produced a wide range of dates from 2030 to 2050 based on fluctuations in solar photovoltaic growth rates in California. Currently, the growth rate for Californian solar PV installations approximately doubles in fewer than two years making our estimate of 50% growth per year a somewhat optimistic estimate for future trends. However, this estimate is often perceived to be unsustainable due to factors such as limited land available, fiscal constraints, and a lack of adequate energy storage options, causing a decrease in the future. In order to accommodate for this decline, this study used the conformist figure of 20% growth in order to get a baseline conservative estimate. Under these scenarios, we predict grid parity to be achieved in 2050 and 2030 respectively.

Our best model, however, uses a hybrid of both previously mentioned models and assumes the current growth rate of around 50% will continue for the next ten years and then decrease and continue by 20%. Thus, the best approximation for grid parity of solar PV in California using this model turns out to be the year 2042. Parallely, the net benefits derived from our benefit-cost analysis corresponding to the prices, costs and quantities we utilized are also shown in magnitude, thereby being an indicator of the sustaninability of this business to investors, utilities, and policymakers in the years ahead.

State and federal subsidies and incentives for solar PV installations were not taken into account for this model due to the lack of control over this variable. Thus, by calibrating our data over a ten-year period, this model accounts for the historical average of the effects of these regulations, and it is assumed that these regulations will continue and improve in the future. Some areas of further research could include analyzing the decreasing utility for each new installation and could also look at research covering a larger geographical area with multiple grids such as the larger southwestern region of the United State. We assumed that the existing solar PV installations have been installed in the most ideal locations that include the highest solar radiation and the lowest cloud cover. Therefore, if future installations are placed in less ideal locations, they may generate lower revenue, and hence the marginal benefit of new installations would fall – this could also be having a significant impact. Alternatively, further studies could examine the benefits of additional ideal locations outside of California such as the Mojave Desert.

Lastly, technological improvements in PV design and electricity storage for the grid would greatly influence this model, as the potential applications for solar technology would be greatly increased. This study is meant to be used as an simple estimate for grid parity and may be influenced in either direction based on outside sources.

VI. Acknowledgements

The authors would like to express their gratitude to the course instructors Professor Stephen Berry & Professor George Tolley for their helpful guidance in accomplishing this project. Additional comments and informational assistance from Dr. Roland Winston of the University of California, Merced and course TA Ruinan Liu are also appreciated.

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TEAM 3

SMALL MODULAR REACTORS: TECHNOLOGICAL, ECONOMIC, AND SOCIAL FEASIBILITY*

by

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Abstract

Small Modular Reactors: Technological, Economic, and Social Feasibility. TRAVIS DIETZ (University of Chicago, Chicago, IL, 60637) MAX KRASITY (University of Chicago, Chicago, IL, 60637) KELLI MALECKAR (University of Chicago, Chicago, IL, 60637) THOMAS WANG (University of Chicago, Chicago, IL, 60637) STEPHEN BERRY (Chemistry Department, University of Chicago, Chicago, IL, 60637) GEORGE TOLLEY (Economics Department, University of Chicago, Chicago, IL, 60637)

While the practice of standardization in the United States outside of the commercial sector has been fundamentally found to be successful, as displayed by the United States Navy Nuclear Reactor Program, it is currently on the verge of being an important part of the future of commercial nuclear power in the United States, and possibly the world, through the creation of small modular reactors (SMRs). To determine the feasibility of SMRs, this paper looked at the technological, economic, and political barriers and their possible solutions. The development of small modular reactors displays benefits such as increased amount of experience with a single type of reactor by all personnel involved in its construction and operation, a possibility of a more efficient approval process of new reactors by the Nuclear Regulatory Commission, and a greater amount of locations where nuclear power can be installed. Overall, both the design of SMRs and possibility of increased personnel experience will increase the safety of these reactors and thereby help with public acceptance of an increased nuclear power industry. A cost analysis of SMRs, using Babcock and Wilcox's mPower reactor as a base case, yielded a levelized cost of energy which was on the high end of cost competitiveness with current large reactor nuclear power generation, although it was still found to be more costly than were traditional fossil fuels. However, a brief calculation of the impact of a carbon tax was undertaken to project a scenario in which SMRs could be economically feasible. Although it seems SMRs might not be the most cost effective energy source, there are many extenuating factors that boost the feasibility of SMRs. These factors range from infrastructure benefits to environmental benefits and their impact supports SMRs as a means to appease the country's growing demand for energy, while also serving as a viable replacement for older power plants. When all the factors are taken into account, it becomes clear that SMRs can become a environmental and economical solution to the country's growing need for cleaner energy.

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List of Abbreviations

B&W - Babcock and Wilcox
CRDM - Control rod deployment mechanism
DOE - Department of Energy
FOAK - First of a Kind
LCOE - Levelized Cost of Energy
IAEA - International Atomic Energy Agency
LOCA - Loss of coolant accident(s)
NRC - Nuclear Regulatory Commision
O&M - Operation and Maintenance
PWR - Pressurized Water Reactor
SMR - Small Modular Reactor
TVA – Tennessee Valley Authority

1. Introduction

1.1 Overview of Small Modular Reactors (SMR)

A small modular reactor or SMR can be most easily described through its component parts, “small,” “modular,” and “reactor.” An SMR is a nuclear reactor, which implies the heat used to generate steam and therefore power through the use of steam turbines is produced by a nuclear reaction. In the case of SMRs, this nuclear reaction is the fission reaction that occurs between a single neutron and most often an atom of Uranium-235, which subsequently produces three more neutrons and heat. Since the original commercialization of nuclear power, it has been more popular to construct nuclear reactors with power outputs of greater than 500 MW of power.[1] This popularity was based on economies of scale, and it was not until environmental, safety, and energy concerns began to take hold that SMRs were considered economically sound due to their benefits in all of these fields. Environmentally, SMRs have all the benefits of larger nuclear power operations such as practically zero carbon emissions, but also all the consequences such as radioactive waste. As a result of these factors, SMRs are being designed with the ability to place multiple units at the same site to allow for increased power usage in a surrounding area, and with power outputs closer to 200 MW or lower, which is very important for safety considerations.

Even before the recent Fukushima disaster, SMRs were being developed to include a series of safety features that are only available to plants with smaller power outputs. The size of these reactors will also allow for a new method of deployment that was unavailable to much larger reactors. The modular portion of “small modular reactor” alludes to the fact that companies currently in the process of applying for reactor licenses from the NRC for their SMR

[1], Vladimir Kuznetsov and Alexey Kohov, *Current Status, Technical Feasibility, and Economics of Small Modular Reactors*, Nuclear Energy Agency, http://www.oecd-nea.org/ndd/reports/2011/current-status-small-reactors.pdf, 3.

designs intend to produce their reactors in a factory setting and ship the components to the construction site of the plant. Larger reactors were often severely hampered by construction costs due to fact that very few reactors had the same design due to site differences and developments in technology. These costs were also increased by underestimated construction times, and as a result, at least in the United States, the front-heavy costs for nuclear reactors resulted in the reduction of new plant construction to the point where there has not been a new plant built in the United States since 1996 with the Watts Bar nuclear plant unit 1 located in Tennessee.[2]

1.2 Practice of Standardization

The practice of modularity and standardization in the United States Nuclear Industry is only a new concept in terms of commercial use. Soon after the development of the nuclear weapons program during the second World War, nuclear power was considered as a possible method of propulsion for seagoing vessels in the United States Navy. This effort culminated in the United States naval reactor program, which produced over 125 nuclear-powered ships[3] all with reactors smaller than the proposed commercial SMRs but following the same concepts such as the use of a pressurized water reactor (PWR), unified teaching and operations manuals, and scalability. In fact, one of the companies currently developing an SMR, Babcock and Wilcox (B&W) (whose mPower SMR will be used as a focal point for the calculation of the LCOE), actually designed some of the earliest naval reactors, indicating their already extensive experience in developing standardized reactors.

The commercialization of small modular reactors will certainly benefit from the techniques and subsequent advantages of the United States naval reactor program. Most of these advantages are derived from greater amounts of experience that would be gained by both the construction and operations teams that would interact with the reactor components directly. First and foremost, safe operation of reactors and accident responses would not be complicated by intricacies in design that would not have been present in other reactors. By unifying the design of a reactor, one would also be unifying the accident responses which would decrease the amount of time needed to respond to a reactor problem, saving what could be valuable minutes or hours.

[2] United States Nuclear Regulatory Commission. "Watts Bar Nuclear Plant, Unit 1 ." United States Nuclear Regulatory Commission. Accessed December 6, 2011. Last modified December 6, 2011. http://www.nrc.gov/info-finder/reactor/wb1.html.
[3] Office of Technology Assessment. *Nuclear Powerplant Standardization*. Washington, D.C.: U.S. Government Printing Office, 1981, 43.

Experience with constructing the same reactor also benefits from the "learning by doing" effect.[4] Basically, as more SMR units are produced the production time will decrease. This could also lead to cheaper methods of assembly, and perhaps advancements in the reactor design. Another significant example of standardization in practice is the French Nuclear Program. Unlike the United States, France has many elements that made standardization easier to achieve such as firm government support and a single electric utility.[5] The benefits the French obtained from their standardization however can still be applied to an American effort to standardize even within a small portion of the American nuclear industry. The French Nuclear Program has recognized four key advantages to standardization, most of which are directly related to safety: a greater understanding of reactor safety is achievable with multiple units of the same reactor, personnel experience in all aspects of reactor operation and design can be transferred from module to module, new generation reactor designers can spend more time on a single design rather than splitting it between multiple designs, and regulators can spend more time analyzing the safety of operations at different sites given site-specific considerations. Importantly though, the French have also recognized three key difficulties with standardization that need to be addressed: any issue with one module will probably have propagated to other modules which may result in expensive retro-fitting of a multitude of plants, site considerations might require differences in design, and technological upgrading may prove to be costly and difficult.

However, the modern technology of the smaller sized reactors planned on being incorporated into the American SMR program have key features that would address some of these concerns - at least in part. First of all, the passive safety features of SMRs will prevent any issue in the reactor from becoming too serious before the issue can be addressed across all the reactors already deployed. While this does not solve the issue of expense if all of the reactor modules need to be corrected, it does prevent serious accidents from occurring in multiple locations, and would hopefully help to buffer any kind of social opinion setback. Second, the fact that the SMR considered for this paper, B&W's mPower, will be buried underground, any extra costs concerning site considerations would most likely be roughly the same. Finally, while technological upgrading may prove difficult with these smaller reactors, SMRs allow for the long-term possibility of site expansion through the construction of new, technologically

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[4] George S. Tolley and Donald W. Jones, *The Economic Future of Nuclear Power*, S-4, accessed December 6, 2011, http://www.ne.doe.gov/np2010/reports/NuclIndustryStudy-Summary.pdf, 92.
[5] Office of Technology Assessment, *Standardization*, 46.

upgraded reactors at the same site. According to the Office of Technology Assessment, "the French are satisfied with their choice and consider that the advantage of standardization (especially those related to safety and economics) far outweighs those difficulties."[6] Combined with the Naval reactor program experience of the companies involved with the American SMR program, the possible larger size of the commercial SMR program in the United States should not affect the program in such a way as to somehow develop a different conclusion from the one reached by the French Nuclear Program.

One of the key elements to a successful standardization program will be its ability to allow the Nuclear Regulatory Committee (NRC) to more easily approve new reactor sites due to a unified reactor design that would be the foundation of any standardization program involving SMRs. The NRC currently does not have a standardization program, although it is currently seeking one: "The NRC has long sought standardization of nuclear power plant designs, and the enhanced safety and licensing reform that standardization could make possible."[7] There have been recent suggestions made by such organizations including the Tennessee Valley Authority's "One Design -- One Review Approach," which is aimed at accelerating the application process for the B&W mPower design they are planning on purchasing.[8] The NRC has also aimed at implementing four other standardization programs based on different methods of plant standardization.[9] The most applicable of these programs include the "Duplicate Plant Concept," the "Manufacturing License Concept," and the "Replicate Plant Concept." The "Duplicate Plant Concept" would allow the NRC to receive multiple applications for practically the same plant to be built in different locations, but would allow these applications to grouped together at two stages, the construction permit and operating license application stages. While the initial design for this concept would not have benefited SMRs past the first wave of SMR purchases due to the fact that it would need all the duplicate plants to have site applications submitted within a few month of each other, the new design for the concept allows greater flexibility, "the [modified] concept allows NRC staff to issue a preliminary duplicate design approval (PDDA) for the first

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[6] Office of Technology Assessment, *Standardization*, 48.
[7] Office of Corporate Affairs. "Background on New Nuclear Plant Designs ." United States Nuclear Regulatory Commission. Accessed December 6, 2011. Last modified June 2008. http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/new-nuc-plant-des-bg.html.
[8] Tennesse Valley Authority to U.S. Nuclear Regulatory Commission, November 5, 2010, accessed December 6, 2011, http://pbadupws.nrc.gov/docs/ML1031/ML103120558.pdf.
[9] Office of Technology Assessment, *Standardization*, 33.

duplicate plant approved at the CP (construction permit) stage and a final duplicate design approval (FDDA) at the OL (operating license) stage."[10] While this concept may only accelerate two parts of the NRC application process, it is still a significant development in reducing the approval process.

Another concept that would most readily apply to SMR commercialization in the United States is the "Manufacturing License Concept," which as its name suggests allows the NRC to approve an application that involves the construction of multiple, duplicate plants at different sites whose components would manufactured and shipped from a single site. This design concept accurately describes the desired method of SMR implementation at the very least with the mPower design. The final applicable NRC standardization concept, called the "Replicate Plant Concept," "involves the submittal of an application by a utility applicant for a nuclear powerplant of essentially the same design as one in which the staff's review has resulted in the issuance of a safety evaluation report."[11] The initial plant reviewed by the NRC is termed the base plant, and any subsequent new plant is called the replicated plant within this concept for standardization. This concept has its own merits for the SMR program such that it is very similar to the "Manufacturing License Concept," but it does not require the plants to be built at a single site. These two standardization concepts both have elements that when put together would allow for the NRC to greatly accelerate the licensing of new plants and thereby both reduce the cost of developing a new plant and the time required to deploy it.

1.3 Current Pressurized Water Reactors versus SMRs

In order to understand the unique and important differences between SMRs and their conceptually similar relatives, the larger nuclear reactors, one must first understand the basic design layout of a nuclear reactor. The design for the mPower reactor focused on in this paper is based on a pressurized water reactor (PWR) that uses pressurized water at temperatures above boiling as a coolant (a substance that both cools the reactor core and carries its heat to a heat exchanger) and moderator (a substance that helps to control the rate of fission in the reactor core) for its reactor core. A PWR, as seen if Fig. 1, is composed of three separate loops.

[10] Office of Technology Assessment, *Standardization*, 34.
[11] Office of Technology Assessment, *Standardization*, 35.

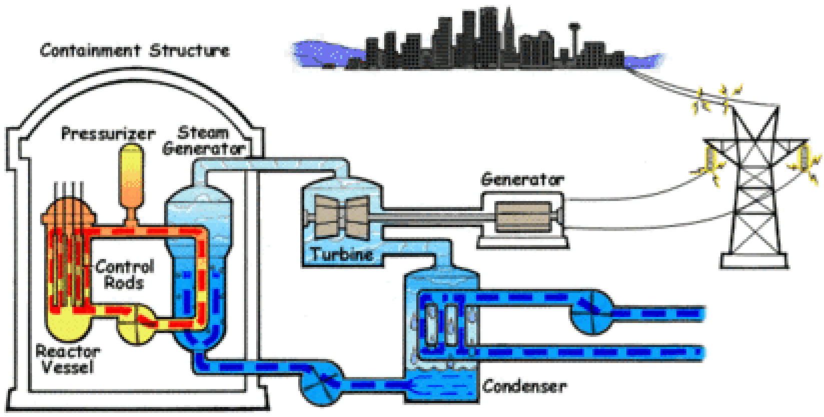

Fig. 1 - A pressurized water reactor[12]

The first loop, which includes the reactor core and pressurizer, is known as the primary loop and, in the case of a PWR, contains water passing through the reactor core. This loop passes through a heat exchanger, which is part of the secondary loop that carries hot water to a steam turbine, which then powers a generator. The secondary loop and primary loops under normal operation do not exchange fluids, due to the fact that water in the primary loop will be irradiated due to the reactor core. The final, and aptly named, tertiary loop in a PWR is serves a source of cool water to condense the water in the secondary loop. Once again, water is not exchanged between the secondary and tertiary loops. A few key design elements of a PWR versus a more compact SMR based on a PWR design can be seen in Fig. 1, such as the external location of both the pressurizer and the control rod deployment mechanism (CRDM, located above the control rods). The mPower SMR design mainly focuses on condensing this PWR design which allows for greater safety and efficiency in terms of space, as can be seen in Fig. 2.

[12] United States Nuclear Regulatory Commission. *Pressurized Water Reactor*. From Wikimedia Commons. GIF, http://www.nrc.gov/reading-rm/basic-ref/students/animated-pwr.html (accessed on December 6, 2011)

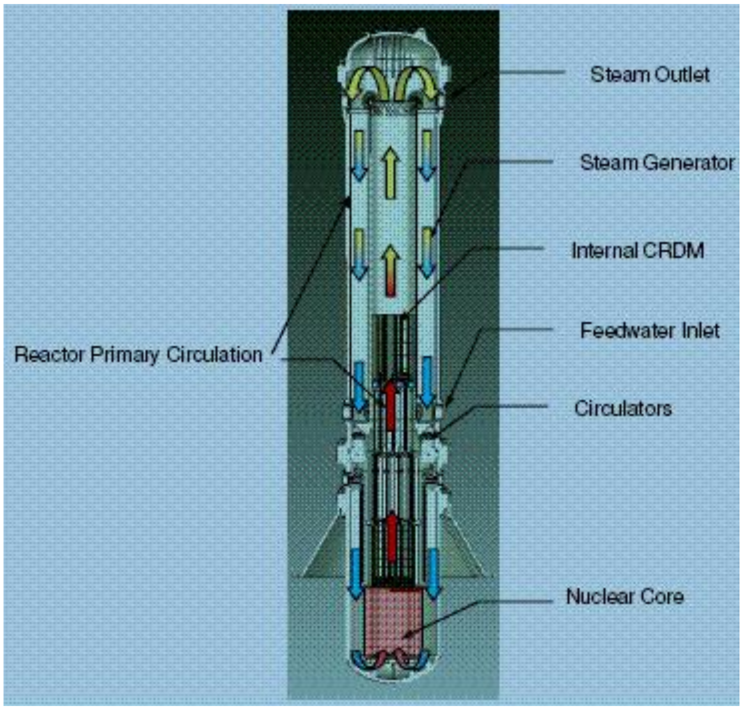

Fig. 2 - mPower Reactor Core Design[13]

As this reactor design shows the circulators (indicated by a black cross surrounded by a round part of piping in Fig. 1), the steam generator (which is used in conjunction with a pressurizer), and the majority of the CRDM are all included in the primary reactor vessel. The internalization of these components adds to the safety of the SMR by helping to prevent significant loss of coolant accidents (LOCAs). The other safety benefits of this and other SMRs will be explored in the next section.

1.4 Safety of SMRs

One of the key benefits to modern SMRs is their seamless integration of passive and active safety features, most of which are based on the design and smaller power output of the reactors. These safety features are specifically important for the application review process by the NRC and for creating a higher level of public acceptance of nuclear power. The International Atomic Energy Agency (IAEA) examines reactors based on their ability to convey "defense in depth," which involves the inclusion of multiple, redundant, and independent layers of safety systems and attributes to prevent any accidents involving the reactor from ultimately releasing radioactive

[13] United States Nuclear Regulatory Commission. *mPower*. JPG, http://www.nrc.gov/reactors/advanced/advanced-files/mpower.jpg (accessed on December 6, 2011)

material into the environment. There are five different levels of the defense in depth strategy, each one detailing specific intentions of the safety measures incorporated at these levels all of which focus on the normal operation of the reactor core. This focus is obviously due to the fact that the source of both heat and radioactivity in a nuclear reactor is its core, which needs to be kept cool and at or below critical status especially in the case of a plant malfunction. In order to most accurately determine the advantages to safety presented by the mPower reactor focused on within the context of this paper, the safety features specifically applicable to this reactor will be briefly described in the course of the defense in depth strategy description.

The first level of defense in depth focuses on the "prevention of abnormal operation and failure" of the reactor core and is not as focused as much on loss of coolant accidents (LOCA) as it is on the prevention of LOCA.[14] As previously mentioned, the condensed design of the mPower SMR includes integrated steam generators, CRDM, and primary coolant circuit in its primary reactor shell. Alongside the fully immersed pumps and circulators of the mPower design, the location of the most important elements of the reactor in the primary pressure boundary will prevent cracks or burst pipes or pumps from causing a loss of coolant from around the reactor core. The second level of defense in depth focuses on the "control of abnormal operation and detection of failure" of the reactor core.[15] While this level of defense relies heavily on modern instrumentation across all sizes of reactors, specifically with SMRs, the negative reactivity coefficients of the reactor core and the high heat capacity of the reactor installation will allow for increased emergency response time even in the case of instrumentation or redundant and diverse passive or active shutdown system failures. The negative reactivity coefficient of the reactor denotes the ability of the reactor to slowly reduce its rate of neutron production, implying that the nuclear reaction in the reactor will actually cease in a period of time if normal reactor function is interrupted. The high heat capacity of the reactor installation implies that it has the capacity to store large amounts of the thermal radiation that would continue to emit from the radioactive isotopes present in the nuclear fuel even after the fission reactions in the reactor had come to a halt. This is extremely important for extending the allowed response time to a reactor issue before the heat from the reactor begins to melt structural components of the core.

[14] International Atomic Energy Agency. *Design Features to Achieve Defense in Depth in Small and Medium Sized Reactors*. IAEA Nuclear Energy Series, NP-T-2.2. Accessed December 4, 2011. http://www-pub.iaea.org/books/IAEABooks/8094/Design-Features-to-Achieve-Defence-in-Depth-in-Small-and-Medium-Sized-Reactors-SMRs, 11.
[15] International Atomic Energy Agency, *Design Features*, 15.

The third level of the defense in depth strategy accounts for the,"control of accidents within design basis."[16] The safety features associated with level of defense in depth are generally built into the reactor itself and focus on reactor self-control, the reduction of the effect of perturbations in design basis events, and the incorporation of at least two redundant and diverse shutdown systems. Examples of these features include the insertion of the control rods by either a gravity or spring driven mechanism and the transfer of heat around the reactor due to natural convection. It should be noted that in the case of the mPower design, natural convection will not be effective enough to completely remove all the latent heat of the reactor in case of an emergency shut down. In order to prevent any unnecessary increase in the rate of the increase in core temperature, the mPower's compact design also ensures that the core will not become uncovered due to a loss of coolant in its primary reactor shell.

The fourth and fifth levels of defense in depth preclude the "control of severe plant conditions, including prevention of accident progression and mitigation of consequences of severe accidents" and "mitigation of radiological consequences of significant release of radioactive materials," respectively.[17] The fourth level of defense in depth focuses mainly on reactor features that postpone or prevent the reactor core from melting and possibly releasing radioactive materials into the environment. This level includes safety features such as a second protective shell and design features to prevent the build up and combustion of hydrogen. The fifth level of defense in depth does not directly deal with physical features of the reactor design, and focuses more on administrative responses to reactor accidents.

Protection of the reactor from external accidents such as natural disasters, accidents like plane crashes, or purposeful attacks on the reactor is provided by both internal features and external structures. The double shell of most reactors, including the mPower design, and the location of the primary shell underground will help protect the reactor from accidental or purposeful attack on the external structure of the reactor. The passive safety features of the reactor core and the emergency, redundant safety features of the reactor will also provide safety in case of natural disaster and/or power loss to the reactor site.

The greater amount of integrated safety features based on the defense in depth strategy planned for SMRs like the mPower design as a result of the smaller power output and condensed

[16] International Atomic Energy Agency, *Design Features*, 18.

[17] International Atomic Energy Agency, *Design Features*, 20.

design will allow for reduced risk of LCOA or other serious accidents. These safety features should lead to an easier approval process and strengthen the confidence in the performance of the reactor.

2. Cost Analysis

2.1 Overview

To determine the economic feasibility of building and operating an SMR it is necessary to establish the costs that such a project would incur. To do this an examination of the levelized cost of electricity (LCOE) associated with SMRs will be undertaken. The LCOE represents the costs associated with all the factors necessary to build and operate an SMR over its entire lifetime. This analysis will be tailored specifically towards the Babcock & Wilcox mPower reactor, but will have wider applicability as well. The mPower reactor, scheduled to open in 2020, was chosen as a primary unit of analysis primarily because of the high likelihood that it will be the first SMR put into commercial production. Other reasons for focusing on the mPower reactor are that its technological framework is already established, and that as a 160 MWe reactor it is middle of the range of power outputs of proposed SMRs.[18] Furthermore, the Tennessee Valley Authority (TVA) has filed a letter with the NRC stating its interest in purchasing up to six mPower reactors to place at its Clinch River site in Rome County Tennessee.[19] Other relevant general statistics for the mPower reactor are a 60 year operating lifetime[20] and a 4 year fuel cycle.[21]

To calculate the levelized cost of energy, we used the equation laid out in a report by the Nuclear Energy Agency (NEA) of the Organisation of Economic Cooperation and Development (OECD) on the current status of SMRs[22]:

[18] "Small Nuclear Power Reactor," World Nuclear Association, accessed November 30, 2011, last modified November 21, 2011, http://www.world-nuclear.org/info/inf33.html.
[19] Tennesse Valley Authority to U.S. Nuclear Regulatory Commission.
[20] "Small Nuclear Power Reactor."
[21] "Modular Nuclear Reactors," The Babcock & Wilcox Company, accessed December 4, 2011, last modified 2011, http://www.babcock.com/products/modular_nuclear/.
[22] Kuznetsov and Lakhov, *Current Status*, 71.

$$\text{LCOE} = \frac{\sum_t \left(\frac{(\text{Investment}_t + \text{O\&M}_t + \text{Fuel}_t + \text{Decommissioning}_t)}{(1+r)^t} \right)}{\sum_t \left(\frac{(\text{Electricity}_t)}{(1+r)^t} \right)}$$

Figure 2.1 – LCOE Equation

2.2 Energy Output

The electrical output of the mPower reactor is the first factor that must be determined. Although mPower is a 160 MWe reactor, as outlined by its producer Babcock & Wilcox, the capacity factor must also be determined to calculate its real energy output.[23] Capacity factor is the realistic expectation of the percentage of power output which a reactor generates that will be utilized commercially. This value takes into account energy lost due to maintenance, errors, and the generation of excess power which is not demanded. The average capacity factor over all US nuclear plants in 2010 was 91.2%, but it is important to note that this number has been trending upwards in recent years.[24] Newer reactors, such as mPower, incorporate technological and procedural improvements in their design and operations which lead to greater efficiency, and this generally leads to greater capacity factors. Babcock & Wilcox claim that the mPower reactor will operate at a capacity factor greater than 95%.[25] However, to employ a fairly conservative estimation scheme a 95% capacity factor was chosen for incorporation into the final calculation of energy production. This yields a 1,331,520 MW/year total power production.

2.3 Investment

Construction costs, and the associated financing of these costs, are the single most important element in determining the economic viability of a nuclear reactor.[26] Although the initial capital requirements for SMR construction are much smaller than what is necessary for

[23] "Modular Nuclear Reactors."

[24] "US Nuclear Power Plants," Nuclear Energy Institute, accessed December 6, 2011, last modified 2011, http://www.nei.org/resourcesandstats/nuclear_statistics/usnuclearpowerplants/

[25] Doug Lee, "Introduction to B&W mPower™ Program" (Powerpoint, IAEA Interregional Worksho, Vienna, Austria, July 7, 2011).

[26] Tolley and Jones, *Economic Future*, S-4,

large reactor construction, these costs still have a large effect on determining the LCOE for an SMR. Furthermore these capital costs become much larger when economies of scale are considered, as investment costs per kilowatt hour for SMR power generation are higher than for comparable large reactors. This is due to the fact that the small size of SMR internal reactors leads to less efficient power generation. Given the high costs associated with reactor construction, only a fraction of these costs can be directly shouldered by the firm undertaking construction, and the rest must be financed by borrowing. Accordingly, not only are construction costs of paramount importance, but the rates at which a firm can borrow are also vital.

As no SMRs have been built in the United States to date, a precise determination of the construction costs is difficult. Vague estimates have been put forth, making claims that the construction costs for the first mPower unit should not exceed $1 billion[27], but more concrete values must be established for a meaningful LCOE to be calculated. However, the obvious solution to this problem, of simply taking a large reactor which resembles the SMR in question and linearly reducing the costs to model the smaller power output and size of the reactor, is not a valid methodology given decreasing economies of scale. A small reactor which generates 10% of the power of a large reactor does not simply incur 10% of the capital costs of a large reactor, as large reactors can more efficiently generate power than can small reactors and many of the same construction elements are needed. To this end the "scaling law," as outlined by the NEA, was utilized.[28] This scaling law allows for the estimation of SMR construction costs while taking decreasing economies of scale into account. The scaling formula is as follows:

$$\mathrm{Cost}(P_1)=\mathrm{Cost}(P_0)\left(\frac{P_1}{P_0}\right)^n$$

Figure 2.2. Construction cost scaling formula

To engage in this analysis, a large reactor which is similar in design and location to the LWR mPower reactor was selected. The TVA run Sequoyah reactor best seems to match the mPower's relevant characteristic, as it located 18 miles north of Chattanooga, Tennessee and is

[27] Craig Welling, "SMR Financing and Economics" (Powerpoint, Office of Nuclear Energy, US Department of Energy, December 2010), accessed December 6, 2011, http://www.uaf.edu/files/acep/ Craig-Welling---SMR-Financing-Alaska-December1010-v2.pdf.
[28] Kuznetsov and Lakhov, *Current Status*, 71.

also a PWR.[29] The cost and power production of Sequoyah was provided by the TVA.[30] Furthermore a scaling factor of .51 was assumed, a value obtained from the NEA report which averages over a number of scaling factors found throughout the literature.[31] The relevant statistics are as follows:

$$\text{Cost}[P_1] = \text{Cost of mPower reactor} = \text{unknown}$$

$$\text{Cost}[P_o] = \text{Cost of Sequoyah reactor} = \$3{,}629{,}095{,}957$$

$$\text{Power}[P_1] = \text{Total Power Output of mPower reactor} = 160 \text{ MWe}$$

$$\text{Power}[P_o] = \text{Total Power Output of Sequoyah reactor} = 2274 \text{ MWe}$$

$$n = \text{Scaling factor} = .51$$

This calculation yields a cost of construction of the mPower reactor (taking into account decreasing economies of scale in small reactors) of $937,424,949. This puts overnight costs at 5858.90 $/kW for mPower, compared to an overnight cost of 1595.91 $/kW for Sequoyah, clearly showing the vastly differing economies of scale.

However this number does not take into account the costs associated with building a new reactor design for the first time. Although the mPower design is a PWR, it will also with all likelihood be the first reactor of its size to be deployed commercially, which will likely entail additional costs. These costs are generally termed first of a kind costs (FOAK), and are meant to capture the increased cost of doing anything for the first time. As a firm builds additional reactors they are able to do so more and more efficiently - essentially learning by doing. However, this paper is attempting to analyze the costs associated with the earliest SMRs, and thus we must examine the effect these FOAK costs will have on LCOE.

Clearly, as no SMRs have been manufactured to date there would certainly be additional costs associated with building the first one. Nonetheless, SMRs also have several inherent characteristics that would lower the costs of production. First, SMRs employ simplifications in their design that lead to lower costs, but which are not reflected in the scaling function that was utilized previously. For instance in the mPower reactor, previously external elements of the primary loop, such as the circulator, control ride drive mechanism, and pressurizer, are integrated

[29] "Sequoyah Nuclear Plant," http://www.tva.gov/sites/sequoyah.htm, accessed December 6, 2011, last modified 2010.
[30] "Tennessee Nuclear Profile," U.S. Energy Information Administration, accessed December 6, 2011, last modified September 2010, http://www.eia.gov/cneaf/nuclear/state_profiles/tennessee/tn.html.
[31] Kuznetsov and Lakhov, *Current Status*, 71.

into the reactor vessel itself, creating a more compact and simpler design. Moreover, SMRs can also be fabricated in large sections in factories, shipped to the building locations on barges or railways, and assembled on site. Conversely, large reactors must be built on site. This means that materials and workers must be brought to the building zone, which is an expensive process. Once again, factory fabrication of SMR components would decrease construction costs of SMRs in a manner that is not captured in the scaling formula.

The quantification of these effects is difficult and varies for each reactor, but the NEA once again has provided a reasonable place to start. It estimates that FOAK costs can contribute anywhere from an additional 10%-40% to the construction costs of a new reactor, even once design simplification and factory fabrication cost savings are taken into account.[32] However, due to the fact that Babcock & Wilcox has considerable experience in the nuclear industry, particularly in the fabrication of nuclear submarines, the FOAK costs are certain to be lower than for an entirely new technology.[33] Thus, the FOAK costs would likely fall on the lower end of the above range. To reflect this, as well as any unforeseen difficulties in licensing or regulatory processes, an additional 20% was added to the construction costs of the mPower reactor, yielding a final construction cost of $1,124,909,939. This places the overnight cost at 7030.69 $/kWh.

The last significant aspect of investment relates to financing and the debt repayment scheme. Given B&W's deal with the TVA, as well as their market cap and other assets, it is likely that B&W will self-finance a portion of the reactor. A study jointly conducted by the International Conference on Nuclear Engineering and Westinghouse proposes a conservative self-financing rate of 19%.[34] At this percentage, B&W would need to pay $212,732,888 over the three years of construction, with a majority of the costs coming in the first year. Given their market capitalization of approximately $4 billion, this estimate should be fairly sound.[35]

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[32] Kuznetsov and Lakhov, *Current Status*, 147

[33] "Babcock & Wilcox Nuclear Operations Group, Inc." The Babcock & Wilcox Company, accessed December 6, 2011, last modified 2011, http://www.babcock.com/about/business_units/ nuclear_operations_group/.

[34] Sara Boarin and Marco E Ricotti, "Cost and Profitability Analysis of Modular SMRs in Different Deployment Scenarios," in *Proceedings of the 17th International Conference on Nuclear Engineering - 2009* (Brussels, Belgium: ASME, 2009), 3: 948.

[35] "Management Team." The Babcock & Wilcox Company, accessed December 6, 2011, last modified 2011, http://www.babcock.com/about/bethards.html.

The rate at which B&W repays the loan on mPower is equally important to determining total investment cost. The borrowing rates imposed on Babcock &Wilcox will certainly be higher than the average borrowing rates for other non-nuclear projects. The financial failure of several reactors in the past has branded nuclear as a risky investment, and groups will only lend to firms building reactors if they pay high borrowing rates to offset this risk. Although SMRs are smaller projects, and thus would entail less money be put in danger in the case of a default, the fact that they are new and commercially untested would insure that borrowing rates would remain high. To reflect this, we modeled the LCOE in multiple scenarios: a 7.5% and a 10% borrowing rate. Given these rates, we assumed a moderate time-span of between 15 and 25 years for loan repayment, with a constant repayment sum for each scenario.

2.4 Operations & Maintenance

Though initial capital costs for any nuclear reactor are extremely high, the costs of keeping a reactor running are quite low. The main factor which keeps operation and maintenance (O&M) costs down is the nature of the fuel cycle and the degree of mechanization. Nuclear plants require relatively low amount of fuel necessary to generate significant amounts of power which only needs to be replaced every four years. Additionally, a large part of the operation process in general is mechanized. This means that relatively few employees are needed to engage in the processes that go towards actually generating power. On the other hand, the need for a large number of safety personnel to be present and for many safety protocols to be followed, as necessitated by federal safety guidelines, means that nuclear reactors have large fixed costs that must be observed when operating a plant.

The industry-wide average O&M cost associated with operating a large nuclear reactor was 1.49 ¢/kWh in 2009.[36] Small modular reactors would likely have a lower O&M cost because of their smaller size and, more importantly, their inherent and passive safety features, making the actual process of operation much simpler.[37] Despite these features, current regulations have no special dispensation for SMRs, meaning that they would have to engage in safety procedures equally as onerous as those followed by large reactors. This would obviously cause higher O&M costs for a small reactor in dollars per kilowatt hour when compared to

[36] "Costs: Fuel, Operation and Waste Disposal," Nuclear Energy Institute, accessed December 6, 2011, last modified 2011, http://www.nei.org/resourcesandstats/nuclear_statistics/costs/.
[37] Kuznetsov and Lakhov, *Current Status*, 16

reactors with larger outputs. This current regulation, an essentially "one size fits all" policy, is difficult to justify. Given both the decreased likelihood of an accident in an SMR due to the greater ease and the greater number of mechanisms by which a potential dangerous situation could be diffused, and the lower damage that would result if an accident were to occur, it seems likely that regulation will be amended to lower the onus of safety costs on SMRs. Estimates specifically tailored to SMRs have been made which place the O&M costs at 1.27 ¢/kWh.[38] Given the uncertainty of the regulatory position an SMR will find itself in in 2020, we elected to use a conservative value of 1.38 ¢/kWh, yielding yearly O&M costs of $19,342,080.

2.5 Fuel

Although less important than both investment and O&M, fuel cost do contribute to the LCOE in a non-negligible manner. When compared to coal or natural gas power plants, nuclear reactors are far more cost efficient when it comes to fuel due to the immense power-generating capabilites of uranium. While uranium, and the processes necessary to make it reactor ready, is more expensive than coal or natural gas on a kilogram per kilogram basis, uranium also generates vastly more power.

When determining uranium prices it is first necessary to determine the costs associated with all of the steps for making it suitable for nuclear power generation. Spot prices for natural uranium (U_3O_8) in December 2011 are around \$52/kgU_3O_8, but that this value was around \$73/kgU_3O_8 as recently as January 2011 highlights the volatility of this market.[39] Beyond short term fluctuations, uranium prices are also sensitive to long term market shifts regarding the number of uranium mines, their outputs, and the amount of fuel demanded by nuclear plants. The International Atomic Energy Agency has projected that in 2020, given a scenario with moderate growth in the number of nuclear capacity and a relatively steady mining pattern, uranium will cost between \$52-\$78/kgU_3O_8.[40] This number implicitly entails a growth in demand, but also projects a moderate rise in the number of open uranium mines and their outputs, particularly in Kazakhstan.[41] The NEA, when considering a similar situation entailing moderate

[38] Boarin and Ricotti, "Cost and Profitability Analysis," 947.
[39] "UxC Nuclear Fuel Price Indicators." The Ux Consulting Company, accessed December 6, 2011, last modified December 6, 2011, http://www.uxc.com/review/uxc_Prices.aspx.
[40] International Atomic Energy Agency, *Analysis of Uranium Supply to 2050* (Vienna, Austria: International Atomic Energy Agency, 2001), 4.
[41] International Atomic Energy Agency, *Uranium*, 27.

growth in nuclear capacity, estimates that uranium prices will be $60/kgU_3O_8$ in 2020.[42] Given these estimated values, and a desire to use a somewhat conservative estimation for uranium costs in 2020, a value of $65/kgU_3O_8$ was employed in our analysis. To obtain one kilogram of usable uranium, 8.9 kilograms must be purchased, giving a total purchasing price of $578.50.[43]

The uranium spot price only captures a small part of the total fuel cost for nuclear reactors. The three-tiered process of conversion, enrichment, and fabrication adds very significant additional costs. Natural uranium must first be converted to uranium hexafluoride to enable the enrichment process. The conversion market has experienced a slow decline in prices over the last few decades due to technological improvements, though in the last ten years the price has increased significantly. The current spot price for converting natural uranium oxide is $13/kgU.[44] The long term price projections for the conversion market place the price in a range of $5/kgU to $15/kgU.[45] To account for further technological improvements and an increased market for uranium while still maintaining a conservative estimate, we chose the average of these two numbers being $10/kgU, which is slightly lower than the current spot price. To obtain one kilogram of usable uranium, 7.5 kilograms must be converted, giving a total conversion price of $70.50.

Uranium that has been converted is finally in an ideal state to be enriched. The price of enrichment was unusually low over the last two decades of the twentieth century, mostly due to over-capacity. However, like conversion prices, the enrichment market has recently seen an upswing in prices, leading to a current spot price of $155/SWU.[46] However, this price increase is seen by many as temporary, and it is expected to drop once the vastly more efficient gas centrifuge or laser separation technologies replace diffusion technology.[47] A paper by the NEA estimates that the price of enrichment could be as low as $105/SWU in next few decades, but to account for slow technology adoption and uncertainty in the market, we adopted a more conservative estimate of $130/SWU, which falls at the high end of the NEA's range.[48] To obtain

[42] Economic Modeling Working Group of the Generation IV International Forum, *Cost Estimating Guidelines for Generation IV Nuclear Energy Systems*, ed. OECD Nuclear Energy Agency, 86.
[43] "The Economics of Nuclear Power," World Nuclear Association, accessed December 6, 2011, last modified December 2011, http://www.world-nuclear.org/info/inf02.html.
[44] "The Economics of Nuclear Power."
[45] Economic Modeling Working Group, *Guidelines,* 86.
[46] "The Economics of Nuclear Power."
[47] "GE Hitachi Nuclear Energy Selects Wilmington, N.C. as Site for Potential Commercial Uranium Enrichment Facility," Business Wire, accessed December 6, 2011, last modified April 30, 2008, http://www.businesswire.com/news.
[48] Economic Modeling Working Group, *Guidelines,* 87.

one kilogram of usable uranium, 7.3 SWU must undergo enrichment, giving a total enrichment price of $949.

Once uranium hexafluoride is enriched, it must be fabricated into uranium dioxide powder, which is then formed into pellets for final use in the reactor core. The fabrication process is fairly expensive at a current price of $240, but given that it is applied to a smaller volume of uranium and is a final add-on price rather than a per kilogram price, it contributes much less to the total fuel price than enrichment or purchasing.[49] Fabrication prices are also not forecasted to change much over the next few decades, as the NEA's predicted fabrication price is also $240. Thus, we adopted a fabrication price of $240.

The final contributor to fuel cost is the price dealing with spent fuel. The amount of fuel needed by SMRs is so low compared to a large reactor that they are able store all spent fuel on site. This provides a unique challenge for estimating spent fuel costs, given that other estimates take into account interim storage, transportation, and away-from-reactor costs and must deal with uncertainties surrounding nuclear depositories. For our purposes, we have adopted the cost estimate most likely to be similar to an SMRs storage capacity, the interim storage estimate. Though this might seem low as it doesn't take any costs specific to long-term storage into account, but since the structure of an SMR's on-site storage is inherently simpler and safer than a large power reactor, which would certainly bring down these costs. Thus, a storage number of $40/kgU was adopted.[50]

In sum, our final calculations of fuel costs are as follows, leading to a total cost of $1,883/kgU:

Purchasing	8.9 kg U_3O_8 x $65/kg	$579
Conversion	7.5 kg U x $10/kg	$75
Enrichment	7.3 SWU x $130/SW	$949
Fabrication	$240	$240
Storage	1 kg UO_2 x $40/kg	$40
		$1,883

Figure 2.3 - Fuel Calculation

[49] "The Economics of Nuclear Power."
[50] Economic Modeling Working Group, *Guidelines*, 88.

To calculate the exact amount of uranium needed to supply the mPower reactor with fuel over its entire lifetime, we used the burn-up rate to determine the kilograms of uranium needed per year. The NEA estimates that burn-up for an SMR would fall between 30 MWd/kg and 45MWd/kg.[51] We adopted the lower number to account for the decreased burn-up efficiency of SMRs, and to fit with B&W's estimate of a fuel cycle length of four years.[52] This burn-up rate, combined with the output of 160 MW, requires 1,946 kg of uranium per year. When the stated lifetime of 60 years is taken into account, the total cost of fuel per year is $3,664,318. This yields a value of .27 ¢/kWh.

2.6 Decommissioning

As no SMRs have yet been constructed, it is obvious that none have yet been decommissioned. Once again decommissioning costs must be estimated from figures available from large reactors. Currently the per plant decommissioning costs are around $300 million, which takes into account restoration and management costs associated with both of the reactor site and of spent fuel.[53] SMRs would almost certainly have lower costs than would large reactors with respect to decomissioning. The overall amount of space used, and the amount of fuel processed, are both much lower in an SMR than they would be in a large reactor. The main factor when determining decommissioning costs is the amount of fuel that must be processed, and that amount is much lower in an SMR such as mPower when compared to a large reactor.

Taking these factors into account, estimates have been made which place the decommissioning costs for an SMR with the output of the mPower reactor at $125 million, but this figures seems overly optimistic.[54] Given the high fixed costs associated with sterilizing a site and keeping it secure, a more conservative value of $175 million was chosen for decommissioning costs. This would correspond to a very low value of .22 ¢/kWh. An important issue to note when considering decommissioning costs is that given that they are taken into account so far into the future, that varying the value selected will actually have little impact on determining the LCOE. Given the discount rate and the large time horizon, the varying of

[51] Economic Modeling Working Group, *Guidelines*, 88.
[52] "Modular Nuclear Reactors."
[53] *Fuel, Operation and Waste Disposal*
[54] Boarin and Ricotti, "Cost and Profitability," 947.

decommissioning costs can safely be considered the least important factor when estimating the LCOE.

2.7 LCOE Results

To calculate the LCOE, we started by calculating a base case with all of the assumptions shown below. In order to conduct a sensitivity analysis later on, we also illustrate the highest and lowest estimates of each factor:

Assumptions for Each Independent Factor

	Base Case	Lowest	Highest
Discount rate	10%	5%	10%
Overnight construction cost	7030.69 $/kW	6444.80 $/kW	8202.47 $/kW
Borrowing rate	7.50%	7.50%	10%
Self-financing	19%	19%	19%
O&M	1.38 ¢/kW	1.27 ¢/kW	1.49 ¢/kW
Fuel Costs	.2692 ¢/kW	0.2406 ¢/kW	.3097 ¢/kW
Energy output	160 MW	160 MW	160 MW
Capacity factor	95%	91%	>95%
Decommissioning	$175,000,000	$125,000,000	$300,000,000

Figure 2.4. Assumptions

Using our base case assumptions, we arrived at a levelized cost of energy of 10.3819 ¢/kWh . As other estimates for nuclear power place large reactor LCOEs within the range of 6-13 ¢/kWh, this result of 10.3819 ¢/kWh seems quite reasonable.[55]

Although the LCOE of the mPower reactor is increased by decreasing economies of scale and FOAK costs, which increase overall initial construction costs, the decreased size of the project keeps mPower's LCOE competitive when compared to larger reactors. The single most important factor in determining the cost competitiveness of a nuclear reactor is initial investment costs, and although scale issues and FOAK costs raise costs when compared to a large reactor, the absolute magnitude of these costs is much lower for SMRs such as the mPower reactor due to the smaller scope of such projects. Because firms must borrow at quite high rates to construct reactors, having much lower initial capital requirements, even if the reactor is less efficiently

[55] George S. Tolley, "Energy, the Environment and National Goals" (Powerpoint, University of Chicago, October 5, 2011).

constructed, greatly reduces overall costs. In the following analysis these two factors have more or less cancelled each other out, and the LCOE for the mPower reactor appears competitive with large reactors.

Although the mPower reactor LCOE is competitive when compared to current large nuclear reactors, it is still more costly to run than are coal or natural gas plants. Coal plants currently operate with LCOEs around 5-7.5 ¢/kWh while natural gas plants operate at around 5-9 ¢/kWh.[56] The base case estimate for the mPower reactor LCOE of 10.3819 ¢/kWh is not cost competitive with these technologies.

However, the possibility of the implementation of a carbon tax in the future could render nuclear plants cost competitive with other power producing alternatives. For instance, although a coal plant currently generates power with an LCOE at an average of 6.25 ¢/kWh, it also creates about 1.4 tons of CO_2 per megawatt hour of electricity generated.[57] [58] Accordingly, for a coal plant with a power output similar to the mPower reactor, a carbon tax of $29.5/ton of CO_2 would result in equivalent LCOEs between a standard coal plant and the mPower reactor. This tax of $29.5/kWh also falls within the range of currently enforced carbon taxes.[59]

2.8 Sensitivity Analysis

Although the assumptions made when determining the base case scenario reflect the most likely LCOE given current data, the speculative nature of the calculation means that looking at alternative cost scenarios may prove productive. The most influential variables on LCOE calculation cost are borrowing and discount rates, as they affect how important future costs are to the investor. We conducted a sensitivity analysis using four different scenarios. The lowest LCOE in the table below illustrates a scenario in which B&W is able to pay back their debt at a very low interest rate and in which future discounting is high. The highest LCOE in the table below illustrates the opposite scenario, with a high interest rate and low future discounting.

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[56] Tolley, *National Goals*
[57] Tolley, *National Goals*

[58] "Voluntary Reporting of Greenhouse Gases Program Fuel Emission Coefficients," US Energy Information Administration, accessed December 6, 2011, last modified January 31, 2011, http://www.eia.gov/oiaf/1605/coefficients.html.
[59] Jenny Sumner, Lori Bird, and Hillary Smith, *Carbon Taxes, A Review of Experience and Policy Design Considerations*, ed. National Renewable Energy Laboratory, page v.

Levelized Cost of Electricity (¢/kWh)

Discount Rate \ Borrowing Rate	7.5%	10%
5%	7.5446	9.5134
10%	10.3819	11.8427

Figure 2.5 Borrowing & Discount Rates

By varying O&M costs we can examine other possible outcomes, particularly outcomes where possible variations in regulation being put into place by 2020 are considered. The 1.27 ¢/kWh value in figure 2.6 represents a case where regulation is fully adjusted to take into account the lower active safety demands required by SMRs. It also reflects the lower number of employees needed in general to operate a smaller facility. The 1.49 ¢/kWh value from figure 2.6 represents a case where O&M costs for SMRs remains equal to that of large reactors, despite their smaller size and inherent safety features. The variation of these values also illustrates how different estimations of O&M costs have a relatively minor, though significant, effect on the overall LCOE.

O&M (¢/kWh)	Levelized Cost of Energy (¢/kWh)
1.27	10.2721
1.38	10.3879
1.49	10.5036

Figure 2.6. O&M

As the single most important factor in determining the LCOE for a nuclear reactor is the investment costs, a sensitivity analysis regarding this value has been undertaken. The high and low estimates take into account variations in the scaling factor and FOAK costs to determine the initial capital cost. The lower estimate represents a case in which economies of scale would have a smaller impact and most FOAK costs are already covered. The higher estimate represents the opposite case, where economies of scale become more important and a higher percentage of FOAK costs are placed on the builder. Each total investment cost only differs by about $100,000,000, but the LCOE goes up by almost an entire cent/kWh. This shows the enormous impact investment costs can have on estimates of LCOE, and just reiterates their importance as a factor determining the cost of building a small modular reactor.

Overnight Cost ($/kW)	Levelized Cost of Energy (¢/kWh)
6444.80	9.6711
7030.69	10.3879
8202.47	11.7196

Figure 2.7. Overnight Cost

These results are all calculated using numbers specific to B&W's mPower reactor, but they could easily be generalized to almost any pressurized water SMR. As the reactor power output decreases, the LCOE will likely go up due to economies of scale. Similarly, as the power output increases (up to 500 MW to still be classified as an SMR), the LCOE will likely go down. However, these results are only applicable to reactors using pressurized water technology. Any design adjustments would put the entire calculation in question, since the scaling law and FOAK costs would no longer be applicable.

3. Unquantifiable Analysis

3.1 Energy Market

In the LCOE analysis, it is still unclear how small modular reactors can be a viable part of the energy market. The costs of producing electricity through coal, natural gas, and most large nuclear reactors are still cheaper than the price of using a small reactor. However, there are extenuating circumstances and outside factors that make SMRs a more viable option.

To explain the viability of SMRs, it is important to first analyze their role in the United States' energy market.

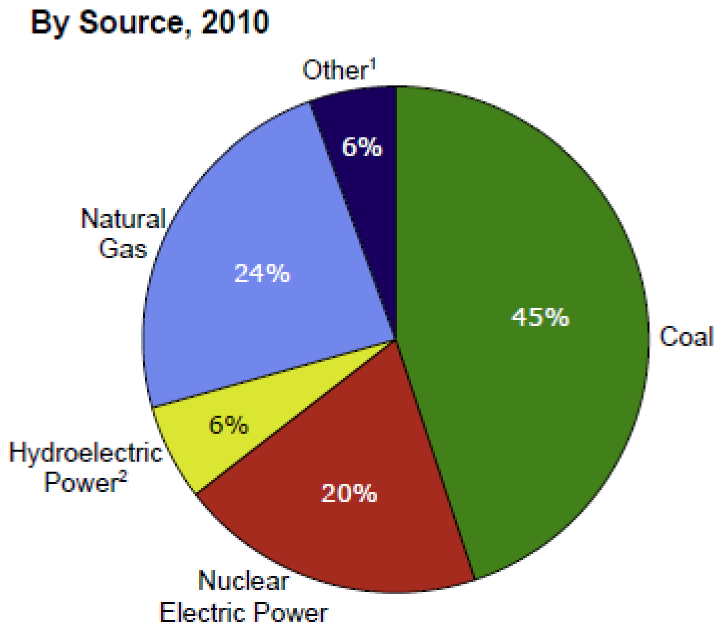

Figure 3.1 – Energy Share[60]

According to the U.S. Energy Information Administration, nuclear energy accounts for roughly one-fifth of total U.S. energy production, whereas coal and gas together constitute nearly 70%. This is relevant because the goal of SMRs is not to be the dominant player in the energy market or even within nuclear power, but rather to fill specific niche roles that other sources of energy cannot provide.

One of the most important assets of SMRs is their unique intended locations. SMRs, unlike large reactors, could be suitable for more remote areas that are disconnected from large electrical grids.[61] These generally more rural locations have growing energy needs, and the practicality of installing a SMR as opposed to significantly extending electrical grids weighs heavily in favor of the smaller reactors. The SMR that is the furthest along in its stages of development, B&W's mPower, has already signed contracts with the Tennessee Valley Authority to build reactors in Rome County, Tennessee. Rome County is a relatively remote area with a growing need for energy. The lack of a major electrical grid in Rome County means the implementation of a SMR could alleviate the county's growing need for energy in a manner that other energy sources could not achieve.

[60] "Electricity." U.S. Environmental Information Agency. Accessed December 6, 2011. Last modified October 2011. http://38.96.246.204/electricity/.

[61] Kuznetsov and Lakhov, *Current Status*, 24.

3.2 Infrastructure

SMRs also have many infrastructure benefits that promote viability. Most of the electrical grids in rural locations do not have the capability of sustaining the power output from a large nuclear reactor. This means SMRs could be integrated into existing electrical grids without major overhaul or construction, which would greatly reduce building costs and the timeline of SMR implementation.[62] This could make SMRs very feasible in locations such as Alaska, or rural areas in the south or midwest, where electrical grids tend to be older. This potential benefit does not only exist for the United States; SMR technology can also be applied to existing electrical grids in other nations.

3.3 Technology

The technology that Babcock & Wilcox's mPower reactor involves is derived from modern-day PWRs. This is beneficial because PWRs are a tested and proven form of technology. Currently, roughly 61% of all nuclear reactors in the world follow the PWR design.[63] This means the amount of uncertainty with plant operation greatly diminishes, and safety becomes less of an issue as it has mostly been dealt with. Furthermore, future research and operation costs should be minimized as there already exists a platform for PWRs.

In the case of modular PWRs, there are even more benefits for B&W. Large reactors generally require on-site construction, which is both costly and time-consuming. In the case of Sequoyah, a PWR built for the TVA, construction took nearly 11 years, from 1969 until 1980.[64] This was partly due to the difficulty of building a reactor on-site and partly due to the sheer size of the reactor. On the other hand, SMRs take roughly three to five years to build and become fully operational.[65] This would lower overnight capital costs and greatly shorten timelines for implementation. The shorter construction time can be attributed both to the smaller size of the reactor as well as the modular characteristics of the reactor.

Unlike large reactors, SMRs can be built on an assembly line. This means the reactors can be built far away and be shipped on-site, which would greatly lower construction costs. SMRs also have beneficial modular characteristics. As communities grow and demand more

[62] Kuznetsov and Lakhov, *Current Status*, 38.
[63] Kuznetsov and Lakhov, *Current Status*, 34.
[64] Sequoyah Nuclear Plant," TVA.
[65] Kuznetsov and Lakhov, *Current Status*, 74.

energy, a new plant does not have to be built. Instead, the communities can request more modular SMRs and increase the size of the plant, thus increasing output without requiring a whole new project. B&W is already experienced in creating nuclear reactors on an assembly line because they build engines for the Navy, and the transition from building submarine cores to SMRs would be simple and cost effective. One of the key characteristics of modular reactors is that they can address the United States' ever-growing need for energy in smaller communities. As these small communities require more energy, SMRs can be increased in size by building another module on an assembly line and adding it to the plant, saving the firm the trouble of creating an entirely new project and power plant.

Another benefit of SMRs is the ability to produce potable water. Nuclear reactors have long taken part in desalination of water and production of fresh drinking water for cities. SMRs could also perform this function for their local communities. Because SMRs may be placed in remote locations, potable water may be a scarcer resource of which SMRs could help produce more. Japan has already linked many desalination factories to their PWRs with great success. Locations such as Alaska could take advantage of such a feature to further boost the viability of SMRs in the United States.[66]

3.5 Clean Energy

Furthermore, SMRs can serve as both environmental and cost-efficient solutions to coal and nuclear power plants that were built in the 1950s and are now set for decommissioning. Many such plants produce roughly the same amount of power as a SMR (although even more modules can be added to SMRs as necessary) and exist in electrical grids with which SMRs are compatible. Experts at the DOE stated that "small reactors could be built in an advanced factory in the United States and delivered across the globe to replace coal-fired power plants," which addresses Congress's demand to lower the DOE's carbon footprint by 28 percent.[67] This would allow a fast and smooth transition for new energy production as opposed to continuing to rely on the environmentally hazardous coal and natural gas plants. SMRs can also serve as a replacement for newly planned natural gas and coal plants, thereby further decreasing the release of

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[66] "Nuclear Desalination." World Nuclear Association. Accessed December 2011. Last modified October 2011. http://www.world-nuclear.org/info/inf71.html.

[67] Wald, Matthew L. "Administration to Push for Small 'Modular' Reactors." *New York Times*, February 12, 2011. Accessed December 6, 2011. http://www.nytimes.com/2011/02/13/science/earth/13nuke.html?_r=1.

greenhouse gases. As older and less powerful commercial nuclear reactors become decommissioned, modular reactors can take their place, producing the same amount of energy but with modern safety features and technology. Replacing these old sources of electricity with modern SMRs can prove beneficial both economically and politically. The United States' desire to drastically lower reliance on carbon-emitting energy sources is just another factor that would support the nuclear industry.

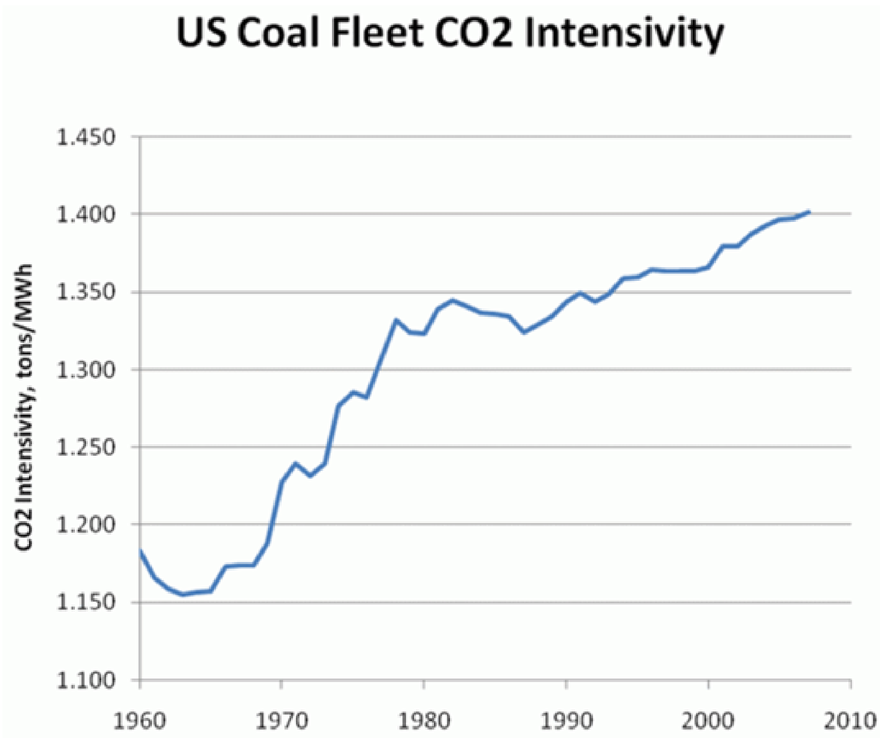

Figure 3.2 – CO_2[68]

Coal plants in the U.S. release approximately 1.4 tons of carbon dioxide per megawatt hour of electricity produced, whereas nuclear energy production releases nearly no carbon dioxide. Natural gas also releases very high amounts of carbon dioxide. As society understands more about the ramifications of greenhouse gases on the environment, policy changes have been put in place to find alternative sources of energy that release lower amounts of carbon dioxide. The replacement of old coal and natural gas plants with new SMRs could help the DOE lower its carbon footprint immensely, as required by Congress, without having to significantly sacrifice energy output.

[68] Casten, Sean. "How much CO2 do our nation's coal and gas plants actually produce?" Grist. Accessed December 5, 2011. Last modified July 6, 2009. http://www.grist.org/article/

The environmental factors of SMRs extend beyond lower greenhouse gas emissions. Coal plants release significantly more radiation than nuclear power plants. Studies have shown that areas around coal plants contain radiation levels that are roughly 50-200% higher than areas surrounding nuclear reactors.[69] People who live within 50 miles of a nuclear reactor are exposed to merely another 0.1 μSv of radiation, while the average human receives 260 μSv from sun exposure alone.[70] In addition, coal ash has been known to generate large amounts of sulfur dioxide, nitrous oxide, and acid rain. Many scientists believe these side effects are significantly more detrimental to the environment than the minimal radiation release by nuclear reactors. In essence, short of a major catastrophe, which is unlikely in the case of SMRs thanks to the passive and thorough safety features, SMRs would have a significantly better impact on the environment than coal and natural gas power plants.

3.5 Proliferation

Nuclear proliferation is major concern for nuclear power. Although it is not a significant issue in the United States, SMRs still manage to address the concern and lower the possibility of proliferation. The fuel used by the mPower is identical to its large counterpart, which is lightly enriched uranium.[71] This uranium requires significant change to become weapons grade. In terms of the reactor itself, B&W's mPower contains a localized fuel system, which means that the fuel stays in one place throughout its cycle; this fact drastically lowers the possibility of proliferation. Waste produced by SMRs can be stored on-site until the SMR becomes decommissioned, meaning that the spent fuel and currently used fuel will be on site. The minimal exposure of fuel to outside sources and minimal transportation of fuel both help lower proliferation, which can help especially in smaller countries that do not invest as much into avoiding proliferation.

3.6 Subsidies

Another factor that could further increase the feasibility of SMRs is government subsidies. It is currently impractical to fund a nuclear reactor in the U.S. without substantial government

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[69] Hvistendahl, Mara. "Coal Ash Is More Radioactive than Nuclear Waste." *Scientific American* (December 2007). Accessed December 6, 2011. http://www.scientificamerican.com/ article.cfm?id=coal-ash-is-more-radioactive-than-nuclear-waste.

[70] "Radiation Dose Chart." American Nuclear Society. Accessed December 6, 2011. Last modified 2009. http://www.new.ans.org/pi/resources/dosechart/.

[71] Kutnetsov and Lakhov, *Current Status*, 134.

assistance. Large reactors can run upwards of $5 billion dollars, and many firms do not have the capital or desire to take on so much risk. The DOE has roughly eight billion dollars set aside for nuclear power as well as another $67 million specifically intended for the licensing and support of SMRs.[72] This year, SMRs were included in the DOE budget for the first time, which signifies the government's support of such a project. It is also important to note that SMRs cost roughly one-fifth the price of large reactors, so subsidies can help substantially, and firms can take smaller risks when investing in SMRs.

Subsidies that directly target SMRs are beneficial, but SMRs should also capitalize on other government funding. Carbon taxes will not apply to SMRs since they release little to no carbon dioxide, which is very beneficial when considering the amount of carbon dioxide that coal and natural gas release, as explored in Section 2.7. If the government was to implement a subsidy for low carbon energy sources, the LCOE for SMRs could be further decreased. Also, as the U.S. pushes towards cleaner energy sources, incentives could be added to support the replacement of old carbon-producing energy sources with cleaner ones such as nuclear power. The largest issue in nuclear power is financing the plants, and because of the cheaper prices of SMRs and assistance from the government, SMRs can have LCOE's that compete directly with coal and natural gas while avoiding the harmful side effects to the environment.

4. Public Policy

4.1 Government Policy

Public policy also greatly impacts the practicality of SMRs in the United States. Currently, the Obama administration has been openly supportive of nuclear power and is attempting to increase nuclear power's budget to $37 billion from the $18.5 billion allowed in 2005. Congress is also in the process of levying a carbon tax on energy sources that emit large amounts of carbon dioxide[73]. This would indirectly impact nuclear power as it releases no carbon dioxide at all. SMRs have finally been included into the DOE budget, which signifies that the government is aware of the benefits SMRs can provide both economically and environmentally. Finally, Congress has a general consensus that nuclear power is an important means of supporting the country's growing demand for energy.

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72 US Department of Energy 2012 Budget Breakdown, ed. DOE Congressional Budget, 4.
73 Associated Press, "Obama renews commitment to nuclear energy," MSNBC, accessed December 6, 2011, last modified February 16, 2010.

4.2 Public Opinion Trends

In the wake of the Fukushima disaster in Japan, the question arises as to whether or not public opinion could seriously affect the construction of new SMR sites once designs are approved by the NRC. Due to the limited data available for public opinion of nuclear power following Fukushima, publlic opinion trends following the Three Mile Island accident in 1979 could be used based on the fact that the situation of the Three Mile Island accident in the United States would balance the fact that the accident was a level five on the International Nuclear Event Scale, while Fukushima was raised to a level seven from a level five but occurred outside the United States.[74] [75] Based on this conclusion, one could conclude that following Fukushima or another nuclear accident or disaster, public opinion concerning whether or not additional nuclear power plants should be built in the the United States would experience a roughly 10% increase in opposition and 10% decrease in favor, with neither favor or opposition returning to pre-accident levels even two years after the actual event.[76] While this is not encouraging for the implementation of SMRs in the near future, there are key aspects of the SMR industry that will allow for continued growth even in the face of these trends.

One of the most important trends in the United States following the Three Mile Island accident (TMI) involves the public opinion concerning whether or not the nuclear industry as a whole should be shut down. As it turns out, even after TMI, the American public were strongly opposed to the permanent closure of all nuclear power plants. Within a year following TMI, more than 70% of Americans polled were opposed to the permanent closure of all nuclear power plants.[77] SMRs by their nature have the capacity to expand off of a single site which would take advantage of the fact that the public, while opposed to the opening of new nuclear power plant sites, would not be as opposed to the expansion of an already existing nuclear power plant site. Another key benefit to the development of the SMR industry is the public opinion's attitude

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[74] Internation Atomic Energy Agency, *The International Nuclear and Radiological Event Scale*, Information, 08-26941 /(International Atomic Energy Agency),2 , accessed December 6, 2011, http://www.iaea.org/Publications/Factsheets/English/ines.pdf.

[75] Shinichi Saoshiro and Yoko Nishikawa, "Japan says nuclear crisis stabilizing, time to rebuild," *Reuters*, April 12, 2011, accessed December 6, 2011, http://www.reuters.com/article/2011/04/12/us-japan-idUSTRE72A0SS20110412.

[76] Nealey, Stanley M, Barbara D Melber, and William L Rankin. *Public Opinion and Nuclear Energy*. [Washington D.C.?]: D.C. Heath and Company, 1983, 17-18.

[77] Nealey, Melber, and Rankin, *Public Opinion*, 27.

toward the time and money it takes to construct a nuclear power plant. In general, when the public is informed of the added cost due to delays in application processing or protesting their opinion is favorable to decreasing the time required for a plant to become operational, “a 60 percent majority of the public underestimated how long it takes and how much it costs the consumer, and when provided this information a plurality of the public favored speeding up the process.”[78] This trend will allow the NRC to more easily incorporate standardization procedures in their existing application process, and perhaps even encourage them to do so. Finally, one the key issues of public opinion that SMRs address is the focus on safety, “When respondents were asked why they opposed nuclear power, what harmful consequences might come from building more power plants, and disadvantages of nuclear power, the majority of the responses dealt with safety-related issues.”[79] Based on the greater integrated safety features of SMR designs such as mPower, if this information can be successfully conveyed to the public, opposition to the expansion of the nuclear industry, at least with increased SMR construction, should decrease.

5. Future Implementation and Steps toward Generation IV Reactors

An important possible consideration for the success of a SMR program in the United States based on water-moderated designs is the development of Generation IV nuclear power plants. With the development of standardization licensing procedures, the benefits of smaller capacity sodium cooled and lead cooled fast reactors for example could provide enough incentive to continue the development of already designed SMRs based on these Generation IV concepts.[80] The benefits of smaller capacity to these types of reactors are based on the removal of decay heat and high heat capacity of the primary coolant system. If these Generation IV SMR designs can be implemented, they could lead to a greater understanding of these designs through experience, and possible future implementation at larger scales. In general Generation IV plants have significant benefits over current nuclear reactor designs (considered Generation III or Generation III+ plants), which include a great reduction in reactor waste lifetime, greater efficiency in terms of power production, an ability to use current nuclear waste as fuel, and overall an increase in

[78] Nealey, Melber, and Rankin, *Public Opinion*, 123.
[79] Nealey, Melber, and Rankin, *Public Opinion*, 170.
[80] International Atomic Energy Agency, *Design Features*, 29, 35, 46.

safety due to minimal pressure in the primary loop.[81] Overall, the success of a SMR program in the United States will strengthen the nuclear power industry, and thereby lead to greater improvements in nuclear reactor design.

[81] International Atomic Energy Agency, *Design Features*, 37.

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TEAM 4

Can we achieve 20% Wind Energy by 2030?
A Critical Factor Analysis

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This paper examines whether the assumptions incorporated into the Department of Energy's report, 20% Wind Energy by 2030, are congruent with the real world situations. We find that the critical factors used in the Department of Energy's report for a modeled wind scenario are flawed from economic, social, political and technological perspectives. Our analysis indicates that to make more meaningful predictions, several factors, including the probability and scale of financial breakdowns; the extent of influence of government decision making; possible selection bias during research; and improved modeling of economic factors concerning investment and deployment of wind and competing technologies, should be better incorporated into subsequent research which attempts to evaluate the future of wind energy.

Introduction

Concerns over energy prices, supply uncertainties, environmental impacts, and other factors surrounding energy production have driven interest in wind in the past and continue to provide a significant justification for its continued study; however, much of the prominent literature on the topic, such as the Department of Energy's report 20% Wind Energy by 2030, falls short of providing a meaningful exploration of the topic.[1] Such an assessment is corroborated by the 20% Wind Energy by 2030 report which acknowledges that it explores but "one specific scenario for reaching the 20% level," conducts "no sensitivity analyses…to estimate the impact of changes in assumptions" which "may be considered optimistic," and "does not compare the wind scenario to other energy portfolio options, nor does it outline an action plan."[2] This reality, however, has provided the motivation for the work at hand. With a thorough isolation, analysis, and exploration of the critical assumptions made for the modeled wind scenario in the report, we hope to provide a more robust understanding of each realm of assumptions and inspire more comprehensive energy studies, particularly regarding wind, which come closer to solving the aforementioned problems by incorporating more realistic

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[1] U.S. Department of Energy. 2008. 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply. 1-7.
[2] Ibid., 1-7

assumptions through in depth sensitivity analyses.

This report adopts a structure similar to much of the literature on the topic, addressing economic, social, technological, and political perspectives. This organization allows for comparison and discussion which is clear, systematic, and in direct dialogue with the literature, specifically the Department of Energy's report. The individual treatment given to each of the aforementioned frames should not, however, be taken as an indication that future studies can view them most effectively in isolation. In fact, much to the contrary, we believe that a broad, eclectic approach which meshes the considerations of each perspective, would best serve the function of providing a more thorough and meaningful investigation of wind energy.

Returning to the specific motivation of this paper and the evaluation of *20% Wind Energy by 2030's* assumption, our ultimate findings may be concisely, though not completely, understood as follows: 1. Economically, the report's model was greatly disrupted by the financial crisis of 2008; 2. Politically, the model failed to incorporate how the wind industry and related markets have been dominated primarily by federal, but also by state, legislation and the interests which influenced them; 3. Socially, the model suffered from a selection bias and lacked significant generalizability; 4. Technologically, the report has numerous shortcomings and makes several fatal assumptions particularly with regard to the growth of competing renewable energies and the conventional generation technology cost, performance, and fuel prices; 5. Future studies should strive to assess and incorporate: the probability and scale of financial breakdowns; the extent of outside influence on government decision making; possible selection bias during research; and improved modeling of economic factors concerning investment and deployment of wind and competing technologies.

1. The Effects of the Turbulent Economy on Wind Energy

The aim of the 20% in 2030 report was to provide a feasible scenario by which wind energy, a renewable and independent energy source, could be implemented as one of the largest providers of energy in the U.S. With the current uncertainties of energy in regards to prices and environmental concerns, the contents of the report would show that such a scenario could be accomplished by the year 2030. Although the authors acknowledged certain associated challenges of such a task, their assumptions were greatly affected by many unanticipated challenges including the 2008 financial crisis; which had drastic and compounding effects on the projections of the 20% 2030 report.

In the 20% Wind Energy by 2030 report, many assumptions played a key role in the realization of the determined goal of 20% wind energy in the United states. The scenario would require the U.S. wind power capacity to grow from 11.6 GW in 2006 to more than 300 GW in

2030.[3] By this assumption, the authors projected that wind installations would grow 20% annually until 2018 before maintaining annual installments of 16GW per year until 2030.The incremental investment cost of the installation in the scenario was predicted to increase total capital costs by $197 billion and $20 billion (net present value) in addition for transmission expansion.[4] Though these costs seemed reasonably anticipated, they were prepared without the foresight of the turbulent effects of the upcoming crisis of 2008.

Though these predictions seemed optimistic and somewhat reasonable, they were disrupted by the effects of the 2008 financial crisis. In 2008 numerous of banks and insurance companies including key players were forced into bankruptcy triggering a financial crisis which would effectively halt global credit markets and require unprecedented US government intervention.

Prior to the financial crisis US wind industry was on record pace with 8,558 MW installations in 2008 increasing the generating capacity by 50% in a single year. This pace was linear to the predicted trend of installations by the 20% in 2030 report. Similarly, in 2007, the US wind industry increasing by 45% with installations amounting to 5,244 MW. These increases would bring the average growth rate in the wind industry to 32% annually over the past previous five years.[5] Such an accomplishment would solidify wind energy's stance as a mainstream energy source for the country, number one ahead of new natural gas in net new generating capacity, and second to natural gas in new generating capacity. This achievement would also place wind ahead of schedule to the 20% in 2030 report.

After modest growth and continuous record breaking increases, the impacts of the financial crisis of 2008 was greatly witnessed by the renewable energy sector particularly in the flow of debt from banks to renewable energy developers. Though drivers that propelled the sector so successfully such as: climate change, energy insecurity, fossil fuel depletion, new technologies, and more were still in play, clean energy including wind energy was unable to resist the credit crunch of 2008.

In the years preceding the economic crisis, investment in early stage technology and expansion dedicated to renewable energy by venture capital and private equity firms saw a growth off 60% from $11.1 billion to $17.7 billion. 2009 saw a drastic decrease as the quarter began with only a $1.8 billion dollar investment by these same firms in the first quarter.[6] This was in large part due to the performance of the VC and PE firms, which were also struggling to weather the economic storm. Amidst the credit crunch bank lending almost came to a complete halt in the late 2008 as key financial institutions found it nearly impossible to price and provide loans during the highly volatile period of the markets.

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[3] Ibid., 7
[4] Ibid., 7-9
[5] Wiser, Ryan, and Mark Bolinger. *2008 Wind Technologies Market Report. Pg.3*
[6] Morgenthal, Sebastian, Crhis Greenwood, Carola Menzel, Marija Mironjuk, and Virginia Sonntag-O'Brien. *The global financial crisis and its impact on renewable energy finance*. Pg. 9

Prior to the credit crunch, the top financers of wind energy included, AIG, Lehman Brothers, JP Morgan, GE Energy Financial, Nobel Environmental Power, and First Wind were all hit hard by the crisis. Nobel Environmental Power and First Wind, two of the larger wind developers based in the U.S. were forced to delay their initial public stock offerings as means of raising cash and surviving the economic crisis. In June 2009, Noble Environmental Power withdrew its offering altogether.

In 2008, investments in clean energy firms as denoted by the global stock markets dropped 51% from $23.4 billion to $11.4 billion.[7] This drop was exemplified through the performance of the WilderHill New Energy Global Innovation Index (NEX), the benchmark index of 88 clean energy stocks. In the midst of the 2008 crisis, NEX dropped from 457.6 to 350.5, a 23.4% decrease. It would continue to trade in the 250-450 range until another drop later in 2008.[8] These decreases were in large part due to many factors including the collapse of the energy prices which caused a relayed effect on energy stocks. Similarly, with the economic crash, investors shied from stocks with technological or execution risk in favor of the stocks of longer established businesses (blue chip companies).

With the last few months of 2008, investments in renewable energy power projects slowed down greatly with the anticipation of the effects of the financial crisis. The number of new deals reached a two year low of 207, with volume of new investment tumbled 21% to $20.5 billion in 2008. The year of 2009 saw an even worse report, with only 88 deals completed.[9]

The immediate effects of the crisis in 2008 and early 2009 caused a major break in the plans proposed by the *20% in 2030* report as seen in the poor performance of the first quarter of 2009. After the worst start to the year in Q1 with investments dropping to $1.8 billion from $17.7 billion (real in 2008 dollars) and $11.1 billion (real in 2007 dollars) in 2008 and 2007 respectively, wind energy investment rallied back with another record setting year.[10] Wind power additions included 9,994 MW of new installed capacity amounting to a cumulative total of more than 35,000 MW nationwide reflecting $21 billion invested (real in 20009 dollars).

The increase in installations in 2009 resulted from the execution of several projects in 2009 which were initially scheduled for 2008 but were postponed after the poor credit status of the nation. In addition, the government played a crucial player in jump starting the failing sector with the implementation of the American Recovery and Reinvestment Act which stirred an increase in renewable energy investment.

Following the rebound in 2009 with record installations of 9,994 MW of wind power, the wind energy sector saw the biggest stumble in 2010. Wind energy production power was cut in half with 5,115 MW of new installations amounting to 40,180 MW cumulative capacity,

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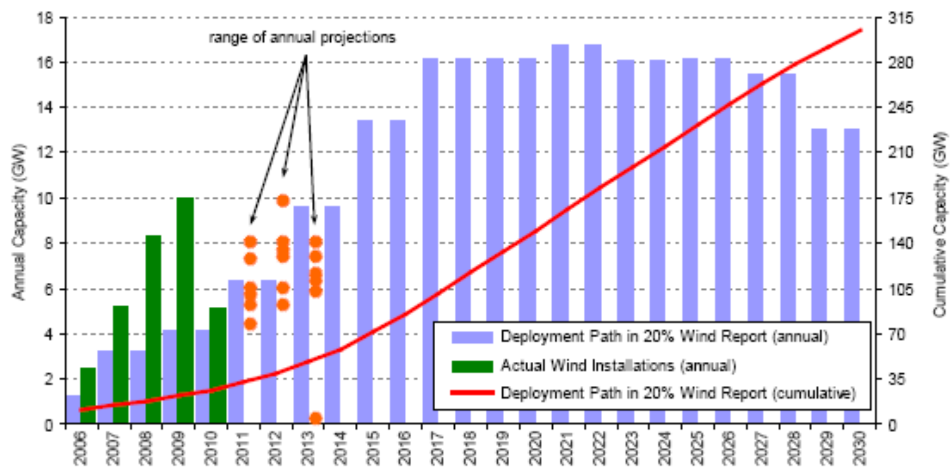
[7] Ibid., 10
[8] Ibid., 11
[9] Ibid .,11
[10] Wiser, Ryan, and Mark Bolinger. *2009 Wind Technologies Market Report*. Rep. pg. 3

reflecting the investment of about $11 billion (real in 2010 dollars).[11] This dramatic decrease was attributed to the delayed impact of the financial crisis which caused relatively low wholesale electricity prices, including natural gas, wind energy's direct competitor. These two effects were enough to offset the many realized benefits of the American Recovery and Reinvestment Act as felt in 2009.

Although the 2010 installations grew by 15%, they were down nearly half the size of the previous year's growth. Factors for such a decrease were ascribed to the lagging effect of the financial crisis which impacted the availability of capital for 2010 projects which were developed in 2009; since these project decisions were determined amidst the peak of the crisis in 2008 and early 2009. The relatively low natural gas and wholesale electricity prices also slowed this growth with a drop in the development of merchant projects. Also, 2010 saw a slump in the demand for energy which as a result paralleled the lowered demand for wind energy.



Source: DOE (20% wind scenario); AWEA (historical additions); Table 8 (projected additions)

With the effects of the crisis, the wind energy sector has experienced a turbulent and unpredictable growth period. "Ramping up to an annual installation rate of 16 GW per year, and maintaining that rate for a decade, is far from pre-determined, as demonstrated by the lull experienced in 2010 and the moderate growth expected for 2011-13.[12] Though 8.5 GW of wind energy was installed amidst the crisis in 2008, they were a direct result of the carryover of projects from 2007, the year before the crisis.

In 2009, much of the effects of the crisis were felt in the overall energy sector as wholesale electricity prices plummeted and demand for renewable energy as whole lowered; thus affecting the wind power industry. These effects would continue to the manufacturing sector as well, with fewer orders for new turbines placed and large the announcement of large layoffs by component manufactures. The poor performance of the first quarter of 2009 would be a direct reflection of the aforementioned factors along with low investing activity for wind energy. As mentioned earlier in the report, the American Recovery and Reinvestment Act enacted by the government in 2009, would delay the looming effects of the crisis by reviving investment activity in the market; resulting in the best year for wind despite earlier declines. With the introduction of the American Recovery Reinvestment Act, the U.S. government was

[11] Wiser, Ryan, and Mark Bolinger. *2010 Wind Technologies Market Report*. Rep. pg. 3
[12] Ibid., 75

successful in prolonging the effects of the crisis until the following year.

The year 2010 would mark the true effects of the crisis as the wind power installation additions fell below every market predictions for 2010. The immediate effects of the crisis in 2008 which compounded to create skewed conditions in 2009 as a result of the PTC extension, would finally catch up to the energy sector in 2010 as only 5,223 MW of wind energy was installed. This benchmark hadn't been reached since before the wind energy sector boom of 2006, reflecting the lowered demand for renewable energy. This achievement would mark the changing tide, as the effects of the crisis would be evident in the success of the wind energy department, outweighing all government incentives included in the ARRA. As an enhancing factor to wind energy's lowered demand, natural gas (wind energy's primary competitor) has become more economically attractive as current prices and predicted future prices have lowered.

Although, it may appear that wind energy is still on the trajectory to reach the goal as depicted by the authors of 20% in 2030, the outcome of 2010 may mark the complete undoing of the success experienced by the sector in 2007-2009. According to the AWEA, all future annual predictions for 2013 with the incorporation of the financial crisis have fallen far shorter than the annual growth as predicted by the 20% in 2030 report; implying that that the goal as predicted by the report will not be met.[13] In essence, the effects of the crisis would have finally outpaced the historical success of the wind energy sector. There are many uncertainties which surround the wind energy sector, but an unpredicted factor which has caused much havoc and will continue to affect all renewable energies is the effect of the crisis and the uncertain future effects.

2. Social Acceptability of Wind Energy and Problems of Selection Bias

With the intentions of drastically increasing the share of renewable energy used by the U.S, the advancement of wind energy has become a national priority. When considering the feasibility of implementing a change, technological advancements as well as the political and economic atmospheres are closely scrutinized. However, social acceptance is commonly given only a cursory glance. As wind turbines begin to spread across the country it has become evident that social acceptance can be a powerful barrier to the achievement of 20% wind energy by 2030.

The Department of Energy (D.O.E) created the 20% of U.S electricity by 2030 scenario with an eye towards the environmental benefits renewable resources deliver. With the climate warming and threatening our current environment, reduction of greenhouse gases has become a crucial issue. Wind energy, as a zero-emission energy source, holds significant promise for the reduction of CO_2, which is the majority cause of global warming. "Compared with the current U.S average utility fuel mix, a single 1.5 MW wind turbine displaces 2,700 tons of CO_2 per year,

[13] Ibid., 74

or the equivalent of planting 4 square kilometers of forest every year"[14]. If the U.S were to reach the 20% by 2030 benchmark, wind energy would avoid putting 825 million metric tons of CO_2 into the atmosphere annually.[15]

In addition to providing cleaner air, switching our energy consumption to wind energy will conserve water. As the nation's population continues to grow the severity of the current water shortage, especially in arid locations like the southern Midwest and interior West, will only get worse. It is not commonly known that water is an important resource of thermoelectric power plants. 48% of all water withdrawals are used in the production of energy. While most of this water can be recycled, the amount evaporated during the process totals 68 billion liters per day. Reaching 20% wind energy would provide an 8% reduction in water consumption. This is equivalent to 4 trillion gallons of water through 2030[16]. In many arid locations a reduction of such magnitude could literally be life changing.

These benefits are widely known creating a positive image of wind energy, which pervades society. Initial studies and opinion polls reflect this knowledge giving results of an overwhelming percentage that support the expansion of wind energy. In a poll conducted by Yale University in 2005, "more than 87% wanted expanded wind energy development"[17] . Seeing such a high level of support for wind energy, many developers were mis-led to believe that actually constructing the wind farms, after the financial, political and technological aspects were worked out, would be very easy and straight forward. However, they were taken by surprise when they were greeted with heavy resistance as they began choosing construction sites for turbines. The problem they were encountering was one of a lack of social acceptability at a different level than their previous polls had researched.

To gather a more properly informed understanding of the problem developers were encountering, social acceptance needs to be examined in three sub-categories: socio-political acceptance, market acceptance and community acceptance. Socio-political acceptance and market acceptance are large scale concepts that deal with the society as a broad general entity. Market acceptance is the adoption of wind energy by the market. Community acceptance is focused on the small group that is more intimately impacted by the installation of the wind turbines. The first two sub-categories of social acceptance both deal with wind energy on a level which removes the construction and location of the wind turbines from the consideration. On the societal level, wind energy is a very accepted concept. However, when you examine the community surrounding the wind farm you encounter a very different sentiment. This is the resistance developers encountered as they began the process of turning policy into reality. Community acceptance deals with the specific acceptance of siting decisions by local residents and authorities. At this level of acceptance, many residents change their support for wind energy as its installation affects them so intimately. It is this area where the common sentiment

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[14] Ibid., 107

[15] Ibid., 107

[16] Ibid., 16

[17] Ibid., 116

of “not in my backyard” emerges.

While in policy people support the expansion of U.S renewable resources they do not approve of placing the technology in their own backyard. Not in my backyard is not a concern unique to the wind energy sector but it is an even more prevalent in wind energy because building wind farms impact more individuals than conventional power plants. Whereas a typical coal power plant has a capacity of over 600 megawatts (MW), a wind turbine only has a capacity of 1.5 MW[18]. Clearly for every one siting decision surrounding a power plant, wind energy must make countless more.

Residents in areas near proposed wind farm sites are concerned with a decrease in their quality of life. Local residents are concerned that the external costs of the wind turbines. Some of the most common resistance surrounding the installation of wind farms is concerned with the visual impact the turbines have. For many people the location and views that come with that location are the two most important parts of their property. In addition to tarnishing the visual landscape, the constant noise emitted by the wind turbines act to ruin the sense of nature. Another concern is the negative effect that wind turbines have on the local ecosystem, most specifically birds and bats. A final concern that many residents have is that there will be a decrease in their property value when the turbines are installed.

While there are external costs to every type of energy source many people are blissfully ignorant of those surrounding conventional power plants. Because conventional power plants are out of the general public’s eye the external costs they carry with them are not as significant to the general person. It is a hard change to ask a resident to accept the external costs of the wind turbines at such an intimate level as he is essentially getting his current power from a plant whose external costs are invisible to him. In addition to this, many residents feel that by having a wind turbine in their backyard they are bearing an unfair burden as they receive the same benefits as everyone who doesn’t share these costs. The push for renewable resources is an international movement designed to increase air quality and slow the rate of global warming. As the benefits of wind energy are felt around the world it seems unfair that the residents are the only ones who should have to experience the external costs of the turbines.

While these concerns seem very persuasive they are no longer accurate. Wind turbine technology has advanced to eliminate most of these concerns that the residents have. Technology has created larger wind turbines with blades that rotate at a slower rate. This helps with two issues: noise and the impact on the local ecosystem. With slower spinning blades the avian fatalities have dropped to less than 1 out of every 10,000 deaths caused by human activity. House cats alone kill over 1000 times as many as wind turbines do[19]. Additionally form 350 meters away modern turbines register at only 35-45 decibels. That’s just slightly louder than a rural night-time background. The D.O.E reported studies that found no change in

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[18] Public Service Commission of Wisconsin. *Electric Power Plants.* Psc.wi.gov. 2008.

[19] Department of Energy. *20% Wind Energy by 2030: Increasing Wind Energy’s Contribution to U.S. Electricity Supply.* July 2008. 112

property values at existing wind farm sites. Rather than a decrease in property value, residents can enjoy receiving $2000 to $5000 per turbine per year paid by the wind turbine owner[20]. The hardest issue for the D.O.E to overcome is the visual change on the landscape. However, through working with the developer and the community the projects can be rearranged to accommodate specific concerns. If it is economically feasible the turbines can even be shielded using trees.

Through programs and interactions between officials and the community the D.O.E plans to inform the impacted residents of the realities of the modern wind turbines. The D.O.E assumes that informing the community impacted by the turbines of the new information and realities of the modern wind turbines, many concerns mentioned above can be alleviated and social acceptability will increase enough to allow the wind energy market to expand to 20% by 2030.

The D.O.E. supports this assumption that educating the public will work with a study performed by The British Wind Energy Association (BWEA). The BWEA polled a community near a small wind farm before and after the wind farm was constructed. Of those who initially opposed the wind farm 60% had changed their mind and now supported the wind farm that they initially opposed[21]. Based on this study the D.O.E assumed that simply educating the public would raise the social acceptability enough to reach its goal of 20% by 2030.

However, the research performed on the social acceptability of wind energy by the D.O.E was severely lacking. They referred to only two studies of social mentality and one of them was performed in the UK. The U.S and the UK are two very different social atmospheres and therefore using data from a study performed on the social mind of a UK resident will not accurately portray how a U.S resident may react. Additionally, the research did not cover the variability that is found across the country. The trouble in creating one single solution to deal with social resistance lies in that each community values things differently. For example a study by the National Renewable Energy Laboratory found that when presented with the same plan for offshore wind farms, 78% of Delaware residents supported it versus 25% of the Cape Cod residents. This difference was rooted in a difference of values. Delaware residents valued air quality and electricity rates while Cape Cod residents valued aesthetics and marine life[22]. Such variability weakens any generalizations drawn from a few sample studies.

There are too many shortcomings of this assumption to be able to concretely state that educating the community will allow the wind energy to expand enough to reach 20% by 2030. Social acceptance at a community level is a powerful enough barrier to prevent any further wind energy expansion. For such a powerful barrier the D.O.E did not perform enough research to make a properly educated assumption. The information that they used in their assumption

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[20] Ibid., 118

[21] Ibid., 116

[22] Lantz, Eric. National Renewable Energy Laboratory. *Wind Energy Update and Social Acceptance Analysis in the U.S.* March 20, 2009. 12

lacked applicability, depth and varied greatly across the nation. Drawing generalizations from this data to apply to the entire nation led the D.O.E to make an incorrect assumption, which can prevent the achievement of the 20% by 2030 scenario.

3. A Case of Fatal Assumptions: Wind Technology and Critical Considerations Regarding Competing Technologies

Numerous factors must be considered from the perspective of technology in terms of its relation to modeled wind scenarios. In all, the modeled wind scenario incorporated in the Department of Energy's *20% Wind Energy by 2030* report makes numerous technological assumptions encompassed in nine broad categories.[23] While an exhaustive analysis of every category and assumption would certainly be useful to some extent, the scope and motivation of this report limits us to a discussion of those which seem most critical in the catalyzation of more thorough works with more sensitive assumptions. As such, we will focus the discussion in this section around five, aggregated and streamlined areas of assumptions which we have deemed critical. They are: 1. Renewable technologies other than wind; 2. Land and shallow offshore wind technology costs; 3. Wind technology performance; 4. New transmission; 5. Conventional technology Cost/Performance and Fuel Prices. Overall, we find that in the case of D.O.E.'s modeled wind scenario, there are several shortcomings of assumptions; however, several particularly fatal assumptions are made in addressing the relative growth of competing renewable energies as well as conventional generation technology cost/performance and fuel prices, which render the scenario implausible and demonstrate the need for improved modeling and assumptions of economic factors concerning investment and deployment of wind and competing technologies

The main assumption in the first category, renewable energy technologies other than wind, is that "contributions to U.S. electricity supply from renewable energy (other than wind) are held at 2006 levels through 2030."[24] While someone new to the study of renewable energy production may perceive this assumption as relatively innocuous, it is perhaps one of the most fatal assumptions made in the D.O.E. report and future literature should carefully consider their treatment of this issue.

The first point of analysis regarding this assumption is a seeming inconsistency with documented trends in renewable energy production. For example, around the time this constancy assumption was made, the U.S. Energy Information Administration published data from previous years showing significant growth in the contributions that other energies made to the total renewable sector of U.S. Energy Production.[25] In 2005-2006 there was a 27% growth in biofuels' contribution to renewable energy production as well as growth of approximately 7% in each of the contributions of both solar and hydroelectric.[26] Additionally,

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[23] Ibid., 147
[24] Ibid., 140-147
[25] "EIA Renewable Energy-" Renewable Energy Consumption and Electricity Preliminary 2006 Statistics"." *U.S. Energy Information Administration (EIA)*. Web. 05 Dec. 2011.
[26] "EIA Renewable Energy-" Renewable Energy Consumption and Electricity Preliminary 2006 Statistics"." *U.S.*

more contemporary research reveals that such trends have continued with around 4% growth in solar energy's 2009-2010 contribution, 10% growth in biofuel/biomass contribution, and an anticipated rapid decline in solar energy production capital costs, as described by Thomas Blum a venture capitalist at G.C. Andersen Partners, LLC., which will likely result from cut-throat competition in the solar energy industry in China and the U.S..[27] [28]

While the aforementioned empirical observations are indeed interesting and revealing, discussion would be incomplete without a more theoretical understanding of the mechanisms at work which would make this assumption implausible. This premise ignores numerous factors including the competitive nature of the renewable energy industry, existing inequalities in production which may shape consumer preferences and demand, numerous incentives/disincentives for certain types of renewable energy production, and the erratic nature of technological development which may lead to certain technologies assuming positions of primacy for years at a time. These factors will be explored individually, but may also interact and combine in numerous ways. Overall, the failure to account for these factors may ultimately perpetuate false information across the entire timeline of projections and render them superficial/myopic at best.

With regard to the assumption in question and competitiveness of the renewable industry, firms may saturate certain renewable energy markets to the point where output increases, market supply meets or exceeds demand, and profit is eventually eliminated. Thus, entrepreneurs/firms might be driven to enter different renewable markets that cater to similar skill sets as they search for profits arising from situations more closely resembling those of oligopolistic or monopolist firms. This phenomenon was witnessed to a partial extent in the case of solar energy component production where, as described by Thomas Blum, firms engaged in "cut-throat" competition and ultimately benefitted consumers greatly at the expense of their own ability to turn a profit.[29] In such a scenario, the competitiveness within the renewable energy market could force internal transitions/movements within between types of renewable energy and thus render such an assumption as the constancy of other renewable energy production methods, useless.

Moreover, in terms of existing inequalities in production, consumer preferences, and demand, certain renewables have a certain degree of inertia which may render the aforementioned constancy assumption useless. The process might work in the following manner, consumers may be accustomed to using a certain renewable energy, such as ethanol in their vehicles, and/or may even have invested in hardware, such as a new biofuel vehicle, which may cause their continued use of a certain renewable energy production method out of habit, preference, or financial necessity. For example, a University of Michigan report highlights the

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Energy Information Administration (EIA). Web. 05 Dec. 2011.

[27] Shahan, Zachary. "11% of U.S. Energy Production from Renewable Resources in 2010."*Cleantechnica.com*. Web. 5 Dec. 2011.

[28] Blum, Thomas. Lecture. November 2011. University of Chicago.

[29] Blum, Thomas. Lecture. November 2011. University of Chicago.

fact that of 2008 U.S. renewable energy consumption, biomass and hydro-electric power constituted 50% and 34% respectively.[30] Inequalities such as these in total contributions can play a powerful role in shaping preferences and demand and should be incorporated into scenario assumptions rather than ignored.

Next, in the case of various incentives and disincentives for sundry renewable energy production methods, there are numerous reasons why consumers would not exclusively seek wind energy or why other renewable energy methods contributions to national energy consumption would not remain constant. For example, the Environmental Working Group discusses an Energy Information Administration report and incentives saying, "the corn-based ethanol industry received $3 billion in tax credits in 2007, more than four times the $690 million in credits available to companies trying to expand all other forms of renewable energy, including solar, wind and geothermal power… [ethanol received] 76% of all Federal Renewable Energy Tax Credits in 2007."[31] This is powerful evidence in support of the idea that various incentives will necessarily promote the adoption of a diversity of renewable energy production methods. Furthermore, Renewable Portfolio Standards (RPS), which differ from state to state (and are discussed more extensively in later portions of this report), motivate the use of a diversity of renewable energies through established minimums of renewable energy production generally, or from specific sources. They are considered some of the most powerful drivers for renewables and if they are adhered to, they alone will demonstrate the limitations of the D.O.E. renewable assumption including the power of various incentives and disincentives.[32] As such, further studies should inform themselves regarding the numerous incentives and disincentives in their attempts to formulate sufficient assumptions and make useful evaluations of wind.

Last in the case of the renewables assumption, the erratic nature of technological development necessarily means that a constancy of renewable technologies other than wind is extremely unlikely. For example, small improvements in the production methods of solar cells which already exist in laboratory settings may result in costs much lower than other renewable energy production methods and initiate a rapid proliferation and the primacy of certain technologies for short periods.[33] Moreover, because wind energy is relatively mature, it is unlikely that technological developments will occur which enhance its appeal to the point where it would have established renewable hegemony consistent with the D.O.E. assumption.[34]

Overall, the examples above, as well as discussion of mechanisms and hypotheticals, essentially demonstrate the limitations, uselessness, and fatal implications of the D.O.E.'s renewable constancy assumption. Furthermore, they reveal the necessity for sensitivity as well as a thorough knowledge of realities and potential as they consider such economic factors as competitiveness, current inequalities in production, various incentives and disincentives, and

[30] "U.S. Renewable Energy." University of Michigan. Web. 5 Dec. 2011.
[31] "Ethanol's Federal Subsidy Grab Leaves Little For Solar, Wind And Geothermal Energy." *Environmental Working Group*. Web. 05 Dec. 2011.
[32] Blum, Thomas. Lecture. November 2011. University of Chicago.
[33] Worthington, David. "New Solar Technology Could Be Mass Produced." *Smart Planet*. Web. 5 Dec. 2011.
[34] *Quadrennial Technology Review*. Rep. Department of Energy, Sept. 2011. Web. 5 Dec. 2011.

the nature of technological development in the category of renewable energies other than wind.

The next main category, regarding the land and shallow offshore wind technology costs, stipulates the following assumptions: 1. Land based costs of $1,730/kW in 2005 and 2010, decreasing 10% by 2030 with regional cost variation with population density and an additional 20% in New England; and 2. Offshore costs of $2,520/kW in 2005, decreasing 12.5% by 2030 (Offshore).[35] These assumptions are fairly sound in several respects; however, there are also some notable deficiencies.

The land based wind assumptions are at their best in the sense that there is demonstrated comprehensiveness and applicability; however, there is a simultaneous lack of variability in the analyses considered and a certain problems with methodology. Such thoroughness of the report is demonstrated when it is revealed that the stated cost is calculated in a manner that claims to consider "turbines, towers, foundations, installation, profit, and interconnection fees."[36] Furthermore, in the case of applicability, the report describes that industry experts from the American Wind Energy Association were consulted in developing costs.[37] This U.S. industry – specific insight moves the model towards a situation where projections are adjusted to the realities present in the situation being considered. However, a concurrent lack of variability in considered analyses is exposed when the report revealed that the assumptions are based on the research of a single firm, Black and Veatch Analysts.[38] This does not necessarily invalidate the findings or render assumptions invalid; however, it leaves a greater opportunity for peculiarities in the particular firm's methods, which are not adjusted for through aggregation and averaging with other firms' results, to skew outcomes. Lastly, in the case of regional cost variation, the AWEA calculations provide a certain degree of applicability; however, it also contributes to the weakness of the assumption in that, as far as can be discerned from the report, the assumptions are very generic, vague, and arbitrary. They are said to be made by consulting industry experts, but how did they come to these conclusions? What about variation within the region mentioned (e.g. New England as large region with millions of people and huge differences, etc.)?[39] Why is only one region mentioned? Furthermore, how exactly does population density interact with variation/is there a certain amount of predictability in this area adjusting for other factors such as demonstrated preferences? The fact that these questions go largely unanswered is not necessarily indicative of problems, but such questions should be consulted in the formulation of better assumptions and explanations so as to make them more sensitive and realistic.

Next, in the case of shallow offshore wind technology, there are several things to consider. Regional cost variation considerations are largely irrelevant because of fairly

[35] Ibid., 147
[36] Ibid., 140-153
[37] Ibid., 140-157
[38] Ibid., 3-7, 140-153
[39] "U.S. Census Interactive Data Map." U.S. Census Bureau. Web. 5 December 2011.

consistent cost of water-installations.[40] Next, there are shared strengths and weaknesses with land based production estimates because of constant approaches, including comprehensiveness and analysis variability respectively. However, a notable difference appears in the case of applicability. Offshore estimates were calculated using European offshore wind installation data.[41] This creates a problem for modeling in the sense that extrapolation/generalization made by the model is based on a sample which may not be representative of the larger population because of complex consequences of trade, trans-national technology exchange, nation specific industry practices (e.g. labor, financing, etc.), etc. And thus, estimates may deviate greatly from reality.

Overall, this category of assumptions has a variety of strengths and weakness which may lead to mixed effects on outcomes. Improvements in assumptions should be considered regarding variability, thoroughness, disaggregation, and applicability; however, these factors do not exhibit the same, severe potential for problems as the renewable energy category assumption.

The next main category of assumptions is wind technology performance. "Capacity factor improvements of about 15% on average over all wind classes between 2005 and 2030" is the primary assumption made in the area of wind technology performance.[42] This category of assumption is similar to the previous in the sense that strength in some areas is countered by weaknesses in others. This leads to a mixed-potential for accuracy in this portion of the D.O.E. scenario and highlights those factors which should be considered in the corresponding assumptions of future works for enhanced sensitivity. First, the strength of the assumption comes in that there are indeed several promising areas of research. For example, the report, as well as another D.O.E. publication, The Quadrennial Technology Review, highlight the cross-cutting" nature of carbon fiber and energy storage technologies which may find applications in wind energy, as cost, weight, or intermittency/dispatchibility solutions, or in other cases such as the automobile industry, with hybrid cars, production costs, and/or fuel efficiency.[43][44] In contrast to this significant strength, two main weaknesses are present in this area of assumption – maturity and economic trend sensitivity. Of various renewable energy technologies, wind is relatively mature which limits the potential for further profitable technological development before smaller discoveries may have a larger impact in competing industries and subsequently draw greater investment because of larger returns.[45] Next, the lack of economic considerations, as discussed in the initial section, may limit this assumption in the sense that overall investment in research and development is closely tied to the state of the economy and thus may not accurately account for long term results based on the limitations for industry in this area.

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[40] Ibid., 153-157
[41] Ibid .,153-157
[42] Ibid., 147
[43] *Quadrennial Technology Review*. Rep. Department of Energy, Sept. 2011. Web. 5 Dec. 2011.
[44] Ibid., 147-153
[45] Blum, Thomas. Lecture. November 2011. University of Chicago.

In sum, this category of assumptions has a mixed impact on projections, but future studies should attempt to incorporate further accommodations in their assumptions for economic variations such as the financial crisis and its impacts on research and development as well as the maturity of wind energy technology and subsequent implications for investment.

New transmission is the fourth main category of assumptions. This section of the report's scenario assumes that transmission will be expanded, the cost will average $1,600/MW-mile, 50% of cost will be covered by the wind project, and regional cost variations are prescribed as follows: 40% higher in New England and New York, 30% higher in Pennsylvania-New Jersey – Maryland (PJM) East interconnection, 20% higher in PJM West, 20% higher in California.[46] The assumptions in this area can be improved greatly, but also have a certain degree of strength which might be maintained to benefit future research. The area of transmission in energy production is an area of significant potential, but also of notable uncertainty.

The strength of the report comes mainly in the sense that the American Wind Energy Association was consulted and thus sensitivity to the realities of the U.S. wind energy industry should be built into the model to a certain extent.[47] Alternatively, there are significantly more weaknesses when it comes to aggregation, cost sharing estimates, and regional variation assumptions. Offshore and land generation cost assumptions are aggregated, yet they are inherently different. By developing two distinct assumptions for each, not only would methods be more clear, but models might be more sensitive to how specific growth predictions in one or the other (i.e. land or offshore) wind production method would change the overall picture. For example, the current method could throw projections of dramatically if say, averaging the cost of land or offshore wind brought the particular cost of one or the other wind production methods up or down significantly yet it was expected to grow significantly greater than the other production type. Next, cost sharing estimates also seem to be an area where significant improvement can be made. The ratepayer share of the cost, 50%, seems unrealistic and was calculated according to Midwest specific industry practice.[48] As with the case of using European wind farm data in previous assumptions, building in data from a sample, in this case Midwest industry, that does not necessarily represent the population you are generalizing to (i.e. the U.S. wind industry as a whole) may lead to problems with the projection as sample-specific eccentricities grow, rather than diminish through aggregation, randomization, and ultimately representativeness, when projecting for the entire population. Lastly, with regard to the regional variation calculations, similar questions arise as with land and offshore wind technology costs. How can these seemingly vague, overly broad, and arbitrary assessments be considered reliable? What about variation within these large regions which may be greater than variation between regions not specified? How will future population growth and relocation trends change these assumptions over the period of longer projections? It is indeed tough to make good assumptions, but reflection on these questions will likely yield improvement in their sensitivity and realism.

[46] Ibid., 143-157
[47] Ibid., 143-157
[48] Ibid., 150-169

In conclusion, the transmission category assumptions, as they stand in the D.O.E.'s model, have some strength, but should be redesigned for future studies with an eye towards distinct wind production type cost estimates, more generalizable cost sharing estimates, and more thorough regional variation estimates.

The final, major set of assumptions made in the 20% Wind Energy by 2030 report in the category of conventional generation technology cost/performance and fuel prices were numerous and specifically addressed the performance of natural gas, coal, and nuclear energy. Ultimately they assumed: 1. Natural gas plant cost ($780/kW in 2005) and performance flat through 2030; 2. Coal plant capital cost ($2,120/kW in 2005) and increases approximately 5% through 2015 and then remains flat through 2030; 3. Coal plant performance improvement of about 5% between 2005 and 2030; 4. Nuclear plan capital cost ($3,260/kW in 2005) decreases 28% between 2005 and 2030; 5. Nuclear plant performance stays flat through 2030; 6. Natural gas prices follow AEO high fuel price forecast; 7. Coal prices follow AEO reference fuel price forecast; 8. Uranium fuel price is constant.[49]

This category of assumptions, along with that which deals with renewable technology other than wind, is perhaps one of the most important and fatal for the model incorporated in the D.O.E. report. It is beyond the scope of this project to speak about the numerous strengths and weaknesses of all of the assumptions above. As such, we will try to evidence the claim made above by focusing primarily on those made regarding natural gas. The selection of natural gas is based mostly on convenience with regard to the ready availability of data. It is our hope that the exposition of problems in this specific sub-category will also improve the overall methods in the formulation of sensitive, realistic assumptions for this category of technological assumptions in future studies.

In the process of trying to explain the necessary steps that would have to occur in order to reach 20% wind energy by 2030, the D.O.E. made assumptions about the future of fossil fuel prices. For their study, the D.O.E. assumed that, "Fossil fuel technology costs and performance are generally flat between 2005 and 2030"[50] and that, "Natural gas prices follow AEO high fuel price forecast".[51] As, we now know, this was not what happened. In order to give a more realistic analysis of the development of wind energy in the U.S. we must not neglect the effect fossil fuel prices have on the demand for wind energy.

In 2009 and 2010 the trend of increasing natural gas prices come to a halt. Not only did the increase stop, we saw a drop to some of the lowest natural gas prices in the past six years. The electric power price of natural gas in 2009 dropped to $4.93 per thousand cubic feet and was still low in 2010 at $5.29 per thousand cubic feet.[52] These two prices are the lowest since 2002. Since natural gas is a competitor with wind, it caused a decrease in the demand for the

[49] Ibid., 147-153
[50] Ibid., 2-4
[51] Ibid., 147-153
[52] "U.S. Natural Gas Prices." *U.S. Energy Information Administration (EIA)*.

development of wind energy. Natural gas prices were climbing and reached an all time high in 2008 at $9.26 per thousand cubic feet.[53] The high increasing natural gas prices had a significant impact on the development of wind farms. With natural gas prices continually rising there was greater demand for alternative renewable energy sources. This meant an increase for more wind energy production during the years when natural gas prices were on the rise.

Due to the changes that occurred with regards to natural gas prices, 2010 was the first year that wind energy prices were higher than wholesale electric prices. Although these wind energy prices are affected by incentives and tax credits, it still shows how the decline in demand for wind due to a decrease in the price of natural gas affects the price and production of wind energy. This shift in wholesale electric prices and wind energy prices also affects the incentives and tax credits awarded from the federal and state government. The public's demand consequently has an effect on government actions on both the state and federal level, and if Americans are content with their energy prices they have little motivation to demand change from their politicians.

In summation, the D.O.E.'s modeled wind scenario possesses several shortcomings of assumptions from a technological perspective which might be treated with general improvements in applicability of research to make better generalizations (e.g. Use of European wind farm data for U.S.), variability of assumptions to correct for firm-specific eccentricities (e.g. Black and Veatch Analysts idiosyncrasies), methodological thoroughness to eliminate arbitrariness (e.g. AWEA regional variation estimates), and/or specificity to prevent gross miscalculations through aggregation of dissimilar things (i.e. land and offshore wind production technology).   However, several particularly fatal assumptions are made in addressing the relative growth of competing renewable energies as well as conventional generation technology cost/performance and fuel prices. These render the scenario implausible and demonstrate the overwhelming need for improved modeling and assumptions which incorporate economic factors concerning investment and deployment of wind and competing technologies.

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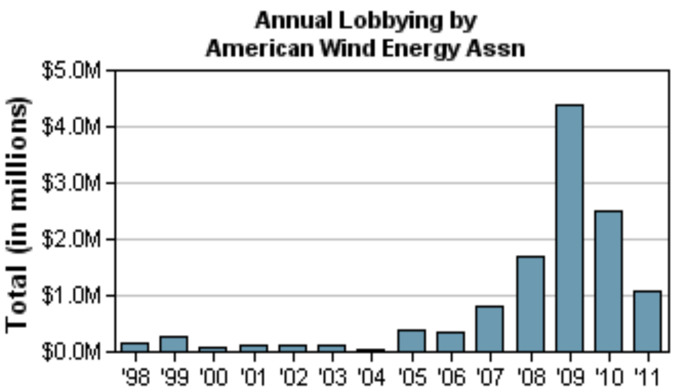
[53] Ibid., 147-153

4. The Politics that Control the Wind Industry in America

Another factor that may have contributed to the decrease in wind development and an increase in natural gas is the impact of lobbying. In 2009, when wind energy production was at an all time high in the U.S., the American Wind Energy Assn. contributed its highest amount ever towards lobbying, $4,366,620.[54] Figure 2 shows the history of the American Wind energy Assn. lobbying in dollars. The graph looks very similar to yearly wind energy production graphs.



A lot of the development over the past years is contributed to incentives and tax credits; therefore it is reasonable to believe that the years that we see the most development also have the greatest amount of lobbying. With this idea in mind, 2010 would have more wind energy development than 2008. However, this was not the case. This disparity can be due to the fact that the Natural Gas Assn. also ramped up its lobbying efforts in 2010, in an effort to possibly counter the wind lobbing in 2009.

Lobbying records for America's Natural Gas Alliance do not show up until 2009, suggesting there was not much of a need for a natural gas lobby. In 2009, America's Natural Gas Alliance recorded $1,660,000 spent on lobbying.[55] This is far less than the $4,366,620 that the American Wind Energy Assn. spent in that same year. However, in 2010, America's Natural Gas Alliance increased it lobbying effort to $3,360,000, over $1,000,000 more than the wind lobby recorded in 2010.[56] Since political legislation has played a critical role in the development of wind energy, it is important to factor in the significance of lobbying when evaluating the production of wind energy.

In the *20% Wind Energy by 2030* report, the D.O.E. had to make a lot of assumptions in order to show how they believe the U.S. could potentially achieve 20% wind energy by 2030. One of the areas that they neglected was the political aspect of the wind industry in the United States. They over looked the importance that federal tax credits and incentives have had on the development of wind energy. As they stated, "The 20% Wind Scenario does not include policy incentives such as a production tax credit (PTC) or carbon regulation".[57] They assumed no policy changes from those that were in place up until 12/31/08. While they could have used this to express the importance of certain policies that have helped with the development of wind

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[54] "Lobbying Spending Database - American Wind Energy Assn, 2011 *OpenSecrets.org*
[55] "Lobbying Spending Database – America's Natural Gas Alliance, 2011 *OpenSecrets.org*
[56] Ibid.
[57] U.S. Department of Energy. 2008. 20% Wind Energy by 2030. Pg. 145

energy, they chose to assume just business as usual from a policy standpoint. They overlooked the fact that in the short history of the wind industry, lawmakers have been able to control the market and development of wind energy in the U.S. In order to give a more realistic analysis of the future of wind energy and the potential to reach 20% wind by 2030 we analyzed the political factors that affect the wind industry.

A common trend in wind energy development for each fiscal year is that the largest gains in wind farm production come in the fourth quarter. This is caused by on-again, off-again short-term federal incentives for wind energy production. Since wind farms can be built rather quickly, their development is heavily impacted by state and federal legislation. In the fourth quarter of both 2008 and 2009 wind farm production increased by more than 4,000 MW, which is a considerable amount considering that the totals for those years were about 8,000MW and 10,000MW respectively.[58] Then in 2010, where we only saw an additional 5,000MW added, over 3,000 of those MW came in the fourth quarter alone.[59] These trends show the impact that federal incentives have on wind energy development. Developers wait until they know that a policy will be extended and then they go through with the completion of their wind farm. One federal policy has had the greatest effect on wind energy production, the Renewable Energy Production Tax Credit.

The Renewable Energy Production Tax Credit (PTC) offers corporate tax credit for completed renewable energy projects on the basis of kilowatt-hours produced. In the case of wind, the PTC offers 2.2 cents per kilowatt-hour, which in most cases applies for the first ten years that the project is in full operation.[60] There has also been a carryover provision added, which allows unused credits to be carried over for up to 20 years following the year they were generated or they can be carried back one year if the taxpayer files and ammended return. In 2009, under the Recovery and Reinvestment Act, the Production Tax Credit for wind energy production was extended until December 31, 2012.[61]

The PTC was implemented in 1993 after the Energy Policy Act of 1992. The PTC has caused a lot of market volatility due to the fact that it is consistently voted on for only one- or two- year terms, and there have been years when congress let the PTC expire. When the PTC has been allowed to expire it has had damaging effects on wind energy development. In 1999, 2001, and 2003 congress allowed the PTC to expire, and the years after expiration saw decreases in wind development ranging from 73% to 93%.[62] The threat of an expiring PTC has significant impacts on the wind industry, and in many ways the wind industry has not been a natural market. It is controlled by policies and tax credits like the Renewable Energy Production Tax Credit. The one- to two- year periods have created a boom and bust cycle hinders the chances for wind energy to establish itself as a competitor to fossil fuels.

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[58] "Fiscal Year 2010 Budget-in-Brief." *U.S. Department of Energy: Energy Efficiency and Renewable Energy*
[59] Ibid.
[60] "Federal Renewable Electricity Production Tax Credit (PTC)." *DSIRE: DSIRE Home*. Web.
[61] Ibid.
[62] "The Reality of U.S. Energy Incentives." *American Wind Energy Association*.

With the PTC in place, the wind energy industry in America has been very productive in all aspects. There are 400 facilities across 43 states that manufacturer parts for the wind industry. In 2005, America proudced 25% of a wind turbines value, now America produces 60% of a turbines value. Also, since 1980, there has been a 90% drop in the price of wind energy and more than $60 billion has been invested since 2005 alone.[63] However, the current threat of the PTC expireing in 2012 is hindering the development of wind energy in the U.S. With the threat of an expiring PTC and the fact that the industry is very dependent on government legislation, wind project developers are not mking plans in the U.S. like they used to. A lot of the development and production is moving overseas.

In a recent effort to extend the PTC and other federal incentive programs, a new bi-partisan piece of legislation has been introduced in the House of Representatives. A Republican, Dave Reichert (Wash.), and a Democrat, Earl Blumenauer (Ore.), introduced a legislation that would extend the PTC until 2016. This is a very important piece of legislation because it is coming from a Republican and a Democrat.[64] The two parties in the past have generally not agreed on issues evolving federal tax credits of incentives for renewable energy sources. If this bill is passed it can be a step in the right direction to stabilize the wind industry and allow it to grow.

If the United States and the D.O.E. were serious about making wind a signifcant energy competitor than their would need to be a significant extenstion to the Renewable Energy Production Tax Credit and establish a long-term policy. "To creat a real market for wind energy and manufacturingin the U.S. to compete globally, the U.S. needs to provide a long-term, clear and consistent policy signal".[65] If Congress wants to make wind a significant contributor, then they have a lot of work to do to ensure manufacturers and investors that their will be consistant policies in place. This would remove a great deal of the uncertanty that has been created by changing policies. Fossil fuels were given longterm policy incentives. These policy incentives allowed fossil fuels to establish themselves in the U.S. and dominate the energy market when there were no competeing energy sources. However, now we know that there are potential competitors, like wind, that offer a renewable energy source that does not have the damaging effects on the enviornment like fossil fuels.

Another area that we believe needs more attention in order to creat a more realistic analysis of wind development in the United States, is the role of state legislation. State's have established their own goals and projections in developing renewable energy sources. In order to promote the development of renewable energies, they have offered their own form of incentives and standards pertaining to private energy providers. While these efforts are good in the sense of developing renewable energy, they differ from state to state and make it harder for the country as a whole to reach goals on a federal level. The seperation of goals and incentives from the federal level to the state level also causes a unnatural market that is controlled by lawmakers.

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[63] "The Reality of U.S. Energy Incentives." *American Wind Energy Association*.
[64] Lacey, Stephen. "Will Congress Cut Off Key Clean Energy Incentives?" *ThinkProgress*.
[65] "The Reality of U.S. Energy Incentives." *American Wind Energy Association*.

As of 2010 there were 29 states that had implemented their own RPSs and six states had set up goals.[66] As the E.P.A. states, "A Renewable Portfolio Standard provides states with a mechanism to increase renewable energy generation using a cost-effective market-based approach that is administratively efficient."[67] The main goal of these RPS is to stimulate both technological and market development that will allow renewable energy sources to be economically competitive with fossil fuel energy production. An RPS is essentially a way to force electric utility and retail electric providers to supply a certain amount of their customers electricity from renewable energy sources. This has both positive and negative effects. While it is good for renewable energy companies and manufacturers, it is a hinderance to the elecricity providers that have to deal with such a forced market. They are no longer able to let the consumer decide, and they are forced to change their prices in order to ensure that a certain amount of their output comes from renewable energy sources. There are three things that energy providers can do to comply with their states RPS; own a renewable energy facility and its production, purchase renewable energy certificates, or they can purchase electricity from a renewable facility inclusive of all renewable attirbutes.[68] These demands cause unrealistic controlled prices and an unnatural market that energy providers have to adhere to.

However, despite creating an unnnatural market, this force may be necessary to close the gap between fossil fuels and renewable energy sources. Although the assumptions for the *20% Wind Energy by 2030* scenario are unrealistic from a political standpoint, the legislation that will be discussed and voted on in the coming months will greatly affect the future of wind energy in the United States.

Conclusion

There are many considerations that require reevaluation and inclusion for more accurate predictions and projections. By analyzing the history of the wind energy industry, government intervention is crucial to wind development. The wind energy industry has been controlled by year-to-year policies that have dictated the production and market for wind energy. If the U.S. is serious about making wind energy a significant contributor to our nations energy consumption a long-term policy is needed to ensure market stability. While wind energy itself cannot compete with the cheap prices of coal and natural gas, the tax credits and incentives allow it to become an economic competitor. These tax credits are needed if the country is serious about developing wind energy as a substantial energy source. The largest gains in wind energy have come when investors and manufacturers had confidence in the policies that allow them to compete with fossil fuel prices. By reestablishing large investment trends it would directly increase the amount of activity in the wind energy sector (i.e. Research and development), and as a result promote growth and annual installations. The D.O.E also needs further reevaluation of their predictions for the future growth of annual installations in

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[66] "Renewable Portfolio Standards Fact Sheet | Combined Heat and Power Partnership | US EPA." *US Environmental Protection Agency*. Web.
[67] Ibid.
[68] Ibid.

light of the conditions created by the financial crisis. With such a turbulent growth pattern over the last few years, the annual installations can no longer be accurately predicted to increase by 20% each year until 2018, as witnessed by the year 2010 and predictions for 2011-2013. The D.O.E should also revaluate their goals set in 2008 based on that period's energy demand trends, which have also been greatly affected by the crisis of 2008. From a social standpoint, many Americans support the idea of wind energy but reject it at the community level. These social implications could affect the lawmakers who hold a large portion of the wind industry in their hands.

The D.O.E. report's modeled wind scenario possesses several shortcomings of assumptions from a technological perspective which might be treated with general improvements in applicability of research to make better generalization, variability of assumptions to correct for firm-specific eccentricities, methodological thoroughness to eliminate arbitrariness, and/or specificity to prevent gross miscalculations through aggregation. However, several particularly fatal assumptions are made in addressing the relative growth of competing renewable energies as well as conventional generation technology cost/performance and fuel prices. These render the scenario implausible and demonstrate the overriding necessity for improved modeling/assumptions that are more sensitive to the real world by incorporating economic factors concerning investment and deployment of wind and competing technologies.

Overall, our evaluation of the assumptions made by the D.O.E. as well as the current status of the wind energy industry have revealed that the *20% Wind Energy by 2030* scenario is unrealistic and neglects several critical factors. It is beyond the scope of this paper to offer an alternative scenario and we acknowledge that doing so is a difficult undertaking with numerous uncertainties. It is our belief that with an improved consideration that takes into account the economic, social, technological, and political factors that contribute to the development of wind energy, future literature on the topic can produce a more realistic assessment of how the wind energy industry will progress in a larger energy industry context.

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TEAM 5

Technological, Sociopolitical, and Economical Barriers for Algae Fuel—A Case for Greater Government Investment

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12/7/2011

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Abstract

In today's world of clean technology and alternative fuel development, there are significant barriers and drivers to success that require public and private cooperation. Algae biofuel is a promising alternative choice for energy that is "green" in every sense, and has the potential to displace fossil fuel as a liquid source. The driving factors for algal fuel were considered here in the context of social, political, technological, and economic forces. All of these factors, including high production costs and insufficient government investment, are major deterrents for algal commercialization and pose a risk for private sector investment. Assuming, as the head of the Algal Biomass Organization claimed, algae fuel can reach price parity with oil in 2018 if granted production tax credits. Therefore we estimate that the U.S. government and the private sector need to invest $86.76 billion and $11.8 billion per year respectively in order to cover the costs of replacing 25% of oil consumption by that time. We recommend higher algae fuel investment levels than what is currently being provided in the overall clean energy sector.

Social Drivers for Algae Fuel

The public is becoming increasingly aware of issues like climate change, resource scarcity, and energy security. For these reasons, alternative fuels like algae fuel have the power to gain widespread support from those in society who value the health of their environment. Algal fuel has the ability to displace fossil as a liquid source and lower carbon emissions, which is a huge advantage when compared to other renewables like wind, which can only be utilized for electricity. The need for a viable liquid fuel is critical and the public preference for reduced foreign oil and cleaner air is growing. As populations expand and resources run thin, green issues will be at center stage in society. There will be a challenge to meet increased energy demand—thus pushing renewable fuel forward.

Another major advantage of algae is that it is a second generation fuel that does not come from a food source—unlike first generation ethanol—which is favored by society. People in general do not want to see food displacement for energy, as many people around the world face hunger. Instead of food crop displacement, algae fuel is engineered from microorganisms, and has the added societal appeal of utilizing clean and innovative sources for energy. People who are more aware of alternative fuels will be more willing to pay to advance science and consume cleaner energy.

Social factors also affect investment behavior in the public and private sectors. If society is in favor of a technology, it will more likely be supported politically and financially. With increased public support, investors will be more likely to take risks on technology like algae fuel for its ability to appeal to society, as it may be more easily commercialized. Bigger players in the private sector are also aware of this "green appeal" so they too have invested in research and development. Even oil companies, such as Exxon Mobil, have been doing heavy R & D into algae to increase their green market share and diversify their energy portfolio. The private sector will also be more driven to invest if the government is willing to support projects—and the government supports what their constituents want. Increased public awareness and education are strong drivers for renewable energy development, and algae fuel has room to grow in this space (http://www.exxonmobil.com/Corporate/energy_vehicle_algae.aspx).

Overall, social factors are a positive driver for algae fuel, due to its potential benefits of increasing environmental and public health. Assuming that people in society are rational actors, they will adapt to future fossil limitations and consequences. Many are now moving beyond "climate change" to "climate adaption", as people anticipate significant environmental changes in the future. Biofuel development has the appeal to solve environmental and energy issues, while maintaining the integrity of our ecosystems for future generations. If a solution has future benefit, society will be more willing to pay for that solution—prompting government and business to take action.

I. Policy Support

The green energy sector, including advances biofuels, sees many failures in the attempts for market entry—falling victim to the "valley of death". This is due to the fact that fossil prices are still low and clean technology investments require a lot of capital. For these reasons, the private sector of biofuel development needs support from the government in order to become a sustainable industry that is cost competitive with traditional fuels. The US federal government is aware of this issue and has provided policy support for environmental and energy security reasons.

The American Petroleum Institute estimates that the United States currently spends about $1 billion each day on oil imports (http://www.api.org/Newsroom/upload/Nov_11_Petroleum_Facts_at_Glance.pdf). More than 70% of imports are consumed by the U.S. transportation sector, according to the Energy Information Agencies Annual Energy Review. Therefore, reducing oil dependence is a priority of the government—for major economic reasons. It requires developing technologies to replace gasoline, diesel, jet fuel and heavy distillates, and produce a range of bio-based chemicals and products. Algae fuel has the ability to supply these different transportation sectors, which gives it potential to be a valuable resource commodity. For energy security reasons, politicians will increasingly support algae fuel into the future.

To reduce oil dependence, Congress passed energy legislation to support renewable fuel with the Energy Independence and Security Act of 2007. This law raised standards for vehicle fuel economy and renewable fuel supply. The law mandates that transportation fuel must utilize 36 billion gallons of total renewable fuel by 2022. The requirements are divided up so that 21 billion gallons must come from advanced biofuels and 16 billion gallons to come from cellulosic biofuel. The legislation further requires that these biofuels must achieve at least a 50% reduction in life-cycle greenhouse gas emissions (US DOE, http://www1.eere.energy.gov/biomass/federal_biomass.html). This mandate is a major driver for advances algal fuels.

The EPA estimates that the increased use of renewable fuel needed to meet the 36 billion gallons mandated—relative to market projections in the absence of the mandate—will displace about 13.6 billion gallons of petroleum-based gasoline and diesel fuel. This represents about 7% of expected annual gasoline and diesel consumption in 2022. Furthermore, we expect the rule to decrease oil imports by $41.5 billion, and to result in additional energy security benefits of $2.6 billion (US EPA, http://www.epa.gov/otaq/renewablefuels/420f10007.htm).

The U.S. Department of Energy (DOE) is the major federal body behind biofuel development. The Department supported algae fuel for nearly two decades with R&D investment under the DOE Aquatic Species Program, which focused largely on the development of algal biodiesel but was discontinued in 1996 (http://www1.eere.energy.gov/biomass/pdfs/biodiesel_from_algae.pdf) . They have recently initiated a program to maximize the potential for collaboration between the public and private sectors. The program began in December 2008 with an “Algal Biofuels Workshop”, in which all interested parties were invited to help set the collective research agenda. The resulting the *National Algal Biofuels Technology Roadmap*, released in 2010, provides an overview of the current state of the art, concluding with recommendations on the role that partnerships can play in the development of this industry (http://www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf). The DOE gave a grant allocation to provide a total of $85 million to support the collaborative research projects in the Roadmap (U.S. Dept. of Energy, Biomass Program, *DOE Announces Recovery Act Funding of up to $85 Million for Algal and Advanced Biofuels*, July 16, 2009, http://www1.eere.energy.gov/biomass/news_detail.html?news_id=12670).

The DOE also has their infamous Loan Guarantee Program for renewable projects, which has recently faced scrutiny over the Solyndra debacle. Despite conflicts over the bankrupt company who received money from the government, Energy Secretary Steven Chu stated, "When it comes to the clean energy race, America faces a simple choice: compete or accept defeat," he said. "I believe we can and must compete." Based on these words, it is clear that Secretary Chu believes that the government must get involved in order to facilitate clean energy competitiveness—despite failures (http://www.nytimes.com/2011/11/18/business/energy-environment/energy-secretary-defends-solyndra-loan.html).

Beyond loans, the government provides several different tax credits for renewable energy sources. These credits listed below are not permanent, and depend on the changing political cycles:

Tax Credits:

1. Renewable Electricity Production Tax Credit (PTC)- IRC Section 45
    - 2.2 ¢/kWh for closed-loop biomass v. 1.1 ¢/kWh for open-loop
    - Duration is generally 10 years after the date the facility is places in service
    - In service deadline is December 31, 2013
2. Business Energy Investment Tax Credit (ITC)- IRC Section 48
    - 30% (of cost) tax credit for renewable investment through December 31, 2013
3. Grant in lieu of Investment Tax Credit- Section 1603 of the ARRA of 2009
    - 30% of property that is part of a qualified facility, 10% of all other property
    - Credit termination date for biomass: January 1, 2014

Source: http://www.dsireusa.org/incentives/index.cfm?state=us&re=1&EE=1

These tax credits are very beneficial to alternative fuel development, but they unfortunately are not in place long term. A major drawback of the US government is that there is no secure and long term energy policy, causing hesitance for private sector investment.

The advanced biofuel industry suffers from the "chicken-and-egg" problem in regards to infrastructure. Oil companies and car manufacturers don't want to invest in new technologies to distribute and utilize biofuel until there is widespread supply, but biofuel producers don't want to invest in more production until they are sure it is feasible for use by vehicles on the road and the gas stations that fuel them. Algae fuel in particular, which requires investment in R&D before it can be cost competitive with grain-based ethanol, will be supported by the widespread adoption of new distribution systems and automotive technologies. Without government support from tax credits and grants for investment, this infrastructure will not be developed.

Overall, political factors have the potential to be a driver and a barrier to algae fuel. With government support from tax credits and grants, this fuel will have a promising future. Without government help, fuel industry players will be slow to invest in this market. Energy and environmental issues are unfortunately heavily politicized; therefore it may not be in policymaker's best interest to support clean energy funding unless they have support from their party and constituents. For those politicians who lie on the right (conservative) end of the spectrum, government spending on green energy is not favorable, as they say the government should not pick winners and losers in this market. However, the government still supplies subsidies to oil and gas companies—which does not get as much attention and seems to have been forgotten on the right.

Economic Factors: Public Sector

The Department of Energy (DOE) and National Renewable Energy Laboratory (NREL) are the two most prominent governmental organizations in the US with regards to investments in algae fuel. They mainly promote algae fuel as a potential source of energy in the future for its unique advantages over other source of renewable source of energy and oil (Roadmap p. 2). Hence, looking at the investment decisions and feedback made in the past by the DOE and NREL provide insightful information on the economical inducements and barriers with regards to algae fuel technology.

Aquatic Species Program (ASP)

The DOE's office of Fuels Development funded a program called the Aquatic Species Program (ASP) to further specialize in the R&D of algae fuel technology from 1987 to 1996 providing valuable in depth information with respect to algae fuel that worked as a catalyst for much of the research done at present time. The following table summarizes the two main research methodologies on algae:

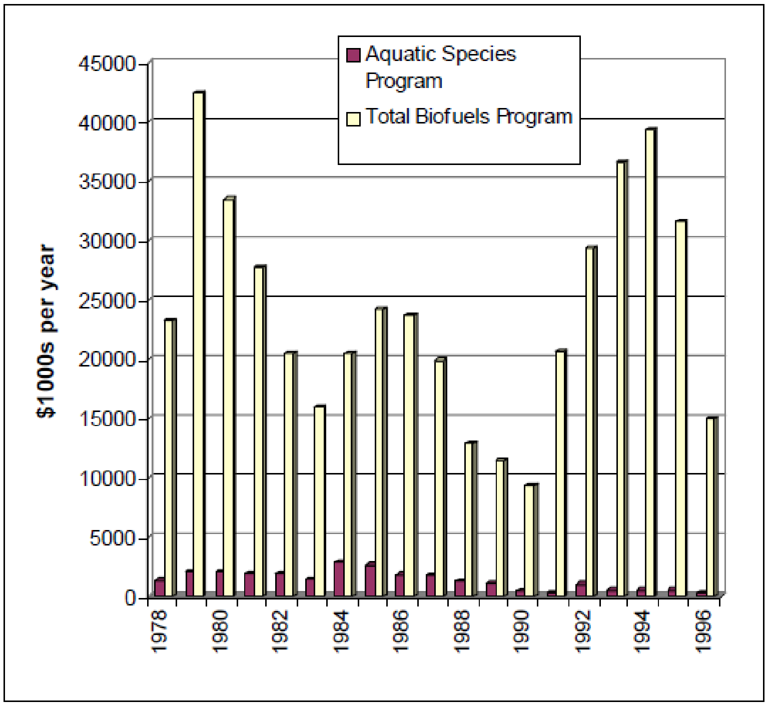
<Figure 1. Laboratory and Outdoor Studies

Laboratory Studies	Outdoor Studies
Focused on the scientific and technological aspects of turning algae into a source of energy/fuel	Concerned with the economics of algae technology such as economies of scale and cost-efficiency

The “Laboratory Studies” deal with the technological issues in converting algae into a renewable source of energy. Initially the ASP focused in the identification and classification of algae and later on proceeded on the genetic engineering (GE) of algae to produce methods in converting algae into environmentally friendly source of energy. Moreover, “Outdoor Studies” was centered with the economical aspects of the technology such as economies of scale and scaling technology prices down so that it is competitive to current energy prices. Hence, concurrently carrying out R&D in both of these sectors many promising study results of some of the main findings entailing the high cost of algae production and the development of an open pond system as a means of large scale production of algae (Sheehan et al., p. ii) has come to the public’s attention. Even today these findings are of high value despite its finding dates.

The DOE funded the ASP during the 20 active years a total sum of $25.05M. Compared to the total Biofuels program investment, $458M, over the same period, the ASP has worked at a relatively low budget. For example, the ASP was only endowed 14% of the Biofuels Program budget at its peak. For the rest of the years the average endowment was 5.5% per year (Sheehan et al., p 20). Nonetheless, for the input the ASP has been successfully able to yield results of higher value than its total investment.

<Figure 2. Biofuels Program investment and ASP investment from 1978 to 1996>



(Source: Sheehan et al., p 20)

This has brought a positive impact in the biofuel community and harnessed greater interest and investment value. As a comparison consider DOE's Biomass Program which invests in three main categories: (i) Grain-based Ethanol, (ii) Cellulosic Ethanol, and (iii) Other Advanced Biofuels. Algae fuel is included in the third section and a sum of $68.8M (71% funded by the DOE and 29% Cost Share) is invested over a three-year period. However, other Fungible advanced biofuels, also in the third category, is only endowed with $45.8M (74% funded by the DOE and 26% Cost Share) is invested over a three year period. Thus, the Algae fuel investment is rewarded $23M more than the Fungible advanced biofuels, 50% of the Fungible advanced biofuels investment.

DOE Roadmap & PPP

After the ASP the DOE continuously promoted further programs to overcome the economical barriers that have hindered the commercialization of algae fuel. Currently algal biofuel production cost is $8/gallon, which is twice the price of production cost of soybean oil at $4/gallon. Even after 14 years after the closing of the ASP, the challenge remains on whether the technology may be available at a competitive pricing level to other biofuel sources (Algal Biofuels, p2). The technology exists at present time but the main challenge is whether these can be scaled down to a price that outweighs its drawbacks. To do so, further financing is required from the public sector to carry out the research needed to find an optimal solution.

Then why does the DOE not make, for example, soybean oil cheaper? Why keep on investing more on something that already has the technology but is harder to scale down? This is one of their tasks. To convince the private sector that if algae fuel actually is an economically feasible source of energy, then it will benefit everyone from its outstanding benefits. Therefore, one of the concepts presented at the DOE Roadmap in 2010 is the "Public-Private Partnership (PPP)", which aims to tackle the barriers to algae fuel by joining the private and public sector together. The PPP is presented as an inducement for algae fuel investment. This is not a new concept, but has been since the 1980's. However, the PPP itself has its own inducements and barriers that hold back both the public and private sector from easily forming a partnership (Ferrell et al., p.7). The DOE plans to form such partnerships by emphasizing the shared benefits that are engendered through the PPP so that investors become actively interested in algae fuel technology (Ferrel et al., p.109).

The major inducement of the PPP is that more financing sources may be acquired from both economic sectors driving overall investment level in algae fuel up. For example, in the DOE's Biomass Program presented above, the DOE funded a sum of $48.8M out of $68.8M. The rest was covered by academic institutions and laboratories. If along with the DOE and academic sector the private sector invested in such programs the overall level of investment would go up. This is an explicit advantage. However, by allowing successful ventures to participate in the investment process will potentially create a competition in the private sector to invest further in algae fuel. Such competition will not only increase both the awareness and importance of algae fuel but also reduce private investment risks to the participant firms (Ferrel et al., p. 109). Moreover, since the public and private sectors work closely together, some regulations that are restricting private investment decisions could easily be amended upon agreement to facilitate investment processes.

Nonetheless, these agreements are not easily arranged as conflicts are bound to occur between the public and private sector due to issues on who to give the intellectual property right (Ferrel et al., p.7). Before the PPP's inducement would foster competition within the private sector; however, competition between the public and private sector is a potential problem that reduces the possibility of PPP. In the short term, the process of setting up a partnership between the two sectors might flow seamlessly. In the long term, after the partnership has been setup, cooperation between the two will raise conflicts due to the imbalance of information. New observations and results from experiments are crucial and is one of the main constituents of the common interest. Without the willingness to share such information to win the claim on intellectual right will only disturb the partnership. Note that even without a partnership, such disagreement is a hindrance to algae fuel investment.

In spite of being an economic inducement by itself, the PPP has its own benefits and costs. Failure to reach equilibrium between the two sectors will cause considerable trouble in financing algae fuel programs.

As shown above, the ASP and PPP are both inducements to algae fuel investment by the public sector. However, barriers in investing in algae fuel are also present due to the lack of cooperation between the two sectors. A main similarity is the public sector's involvement in the investment process as a means to attract private sector investments. The ASP has been influential and successful case, whereas the PPP remains questionable as to its ability to captivate the private sector's attention.

A Technological and Biochemical Perspective

The IEA chief economist, Fatih Birol, once stated that we should prepare to "leave oil before it leaves us." An increasingly promising way comes from an unexpected source—microphytes which produce fatty oils in their cells. Microalgae are single-celled photosynthetic organisms that grow suspended in water. They effectively fix carbon dioxide (responsible for over 40 % of global carbon fixation) and have the capacity to increase its biomass rapidly, with many species doubling in as few as 6 hours. All algae have the capacity to produce energy-rich oils, although lipid content varies drastically in different strains. The most promising microalgal species under study for biofuel are diatoms, green algae, and cyanobacteria (it should be noted that cyanobacteria are strictly not algae but photosynthetic bacteria, but energy products are grouped under the term algae fuel for practical reasons).

Beginning from a thermodynamic perspective, the question of algal fuel is essentially starts from the biochemical conversion of solar energy. Given the first law of thermodynamics (energy cannot be created or destroyed), the upper limit to the theoretical amount of energy captured for fuel synthesis is directly limited by the rate of solar irradiance into the system. This immediately poses restrictions on the maximum limit. Assuming full irradiance of sunlight for 12 hours a day, the bioreactors are still sitting inert without absorbing energy during the night. Also, considering the factors of atmospheric absorption and clouds, sunlight as a feeding source of energy can be restrictive and unpredictable. Here, two factors are at play: photon transmission efficiency and photon utilization efficiency. The former is determined by the geometry of the reactor, while the second is determined by the conditions of algal culture. An ideal reactor will minimize losses in solar energy capture due to reflection or absorption by the structure of the system. This applies to both open and closed systems. The utilization efficiency depends on the brightness of the light irradiated, as well as the temperature. An ideal system will induce the culture conditions for complete photon absorption. Excessively high light conditions or less-than-optimal temperatures lead to absorbed photons being remitted in heat form.

The transition from solar energy to chemical energy becomes a turning point that depends on photosynthetic efficiency:

$$CO2 + H2O + 8 \text{ photons} \rightarrow CH2O + O2$$

The photosynthetic efficiency of theoretically perfectly efficient algae is calculated to be around 26.7%. In reality, it is far less, with outdoor cultures of chlorella attaining up to 2.7% efficiency in optimal sunlight (Weyer et al, p. 18). We must also consider the fact that algal cells will use up some of the energy fixed for various functions to sustain itself, such as photosynthesis.

With these figures, the thermodynamic efficiency of the algal synthesis process may appear dismal. However, the upper bound of convertible energy can be drastically heightened by introducing a sugar feed to the oil-producing algae, introducing glucose as another major source of energy (glucose is produced by the consumption of solar energy from plant biomass, so this also ultimately traces back to the question of solar thermodynamics). As an example, Solazyme does not grow algae with photosynthesis but rather use a genetically modified strain that feeds on sugar in a fermentation process. Also, gallons of oil produced per acre is several hundred-fold higher than corn, and by far greater than all the leading biofuels produced from crop feedstock. Challenges and costs associated with thermodynamic uncertainties, mostly involved with fixing solar energy, seem to be common for the biofuel industry in common, and not just algae fuel.

From a biological perspective, the species of algae used, and the strain used, is also one of the key factors of variability. The two major ways to address high production costs is either to obtain the raw materials for synthesis at a lower cost, or to increase the yield of oil produced. The second, more straightforward way is a biological question unique to algal fuel production—how to increase the amount of lipid a cell can produce? The implied variability depending on the organism of choice can sway the industry.

<Figure 3. Composition of Microalgae in Starved and Enriched Conditions (Dry Weight %)>

	growth conditions		organic component (dry wt %)					
species	NaCl level (molar)	nutrients	ash	lipid (triglyceride)	protein	carbohydrate	glycerol	unknown
Botryococcu braunii	0	enriched	5.6	44.5	22.0	14.1	0.1	19.3
	0	deficient	7.8	54.2	20.6	14.3	0.1	10.8
	0.5	enriched	59.6	46.3	15.0	13.3	0.1	25.3
Dunaliella bardawil	2.0	deficient	14.7	10.4	9.7	40.4	16.4	23.1
Dunaliella salina	0.5	enriched	8.6	25.3	29.3	16.3	9.4	19.7
	0.5	deficient	7.7	9.2	12.5	55.5	4.7	18.1
	2.0	enriched	21.7	18.5	35.9	12.5	27.7	5.4
Ankistrodesmus sp.	0	enriched	4.5	24.5	31.1	10.8	0.1	33.5
Isochrysis sp.	0.5	enriched	12.0	7.1	37.0	11.2	0.1	44.6
	0.5	deficient	52.0	26.0	23.3	20.5	0.1	30.1
	1.0	enriched	65.9	15.3	34.7	15.5	0.1	34.4
Nanochloris sp.	0	enriched	13.6	20.8	33.1	13.2	0.1	32.8
Nitzschia sp.	1.4	enriched	20.4	12.1	16.8	9.2	0.1	61.8

(Adapted from Klass et al.)

Here, we are interested in the dry weight percent of lipid, which is the substance extracted and transesterified to produce a fuel source. It has been found that starved cells yield proportionately greater amounts of lipid. Thus, another problem emerges—the trade-off between growth and lipid content. Open pond systems struggle to find the most profitable compromise between fast growth and lipid content, which are at odds with each other. Another aspect to note from the graph is the varying lipid content between different species of microalgae, with strains such as Botryococcu Braunii yielding more than 50 % of its dry weight in pure triglyceride and Dunaliella yielding less than 10%. A benefit to microalgae as lipid harvesting molecules is that its genetics is readily manipulable. Not mentioned in this chart are cyanobacterial strains, which produce much lower levels of lipids but are at the same time more genetically manipulable. Co-harvesting multiple strains together is an idea to be further explored—nitrogen-fixing cyanobacteria along with high-lipid-yield microalgae species could reduce the cost of adding nitrates to the system.

Not only does lipid content vary between species of algae, but between strains of algae that have been genetically engineered. With tools such as RNAi (RNA interference), geneticists are able to target certain genes impeding lipid synthesis and create a double-stranded RNA for the region, effectively "silencing" the coding region of choice. Because the genomes of many cyanobacterial and microalgal strains have already been sequenced, they are also easily able to manipulate.

The biology behind algal fuels is intrinsic to the economic perspective. The costs involved with inducing each pathway, esterification, and polymerization are ultimately going to affect the price of oil per barrel that comes from algal fuel. What is the cost of the most effective, yet cheap solvent for transesterification? How shallow should open ponds be if you want to minimize the land area while maximizing light efficiency to drive photosynthesis? Cyanobacteria, for example, have evolved to absorb much more light energy than they actually need for photosynthesis. This means that a pond depth of over

30 cm is not going to be efficient in capturing light energy for cells at lower levels, leading to the need for a broad expanse of level terrain.

The first fundamental decision to make when building an algal fuel bioreactor is whether to employ an open pond system or a closed loop system. With productivity falling in the range of 25–35 g/m^2 per day (Sheehan et al.), the open pond is often the system of choice because of its comparatively low capital cost. However, the open pond needs constant measures against contamination (from competing natural algal strains, debris, and predatory species), evaporative water loss, and vast areas of flat land. In addition, open pond facilities require rigorous measures to contain recombinant strains from the outside environment, as regulation standards are high. In contrast, the closed loop system is much more effective in eliminating environmental factors such as contamination by other microorganisms or unwanted chemicals. The yield has been reported to up to 170 g/m^2 per day in some photobioreactors, such as GreenFuel Technologies Corp. in 2007. However, the closed loop system has much higher capital costs for construction materials and circulatory system. Because of the distinct cost and benefits of each system, it is likely that the most economically efficient method will be a combination of both systems, such as closed-loop system for inoculum (seed algae) generation, and open pond for mass product generation. This method allows the closed-loop system to be used intermittently, reducing costs of halted production while cleaning interior surfaces and eliminating accumulated oxygen levels. Unlike the open pond system, the closed bioreactor cannot take advantage of evaporative cooling, leading to heat accumulation with continued use.

The nature of facilities used and products generated would also vary depending on the species and strain of microorganism used. There are two distinct biological pathways involved in energy production from microalgae and cyanobacteria. The former involves the conversion from cellulose to sugars to methanol, whereas the second converts carbon dioxide directly into isoprene, with oxygen as a side product. A commonality of both is the chemical feedstock—copious amounts of carbon dioxide.

Dr. Haselkorn, an expert specialized in cyanobacteria research at the University of Chicago, believes that cyanobacteria, rather than microalgae, hold better prospects for providing expedient fuel for two reasons. Firstly, although various strains of algae may be harvested in hatcheries, they are less genetically manipulable. Also, algae cannot produce isoprene, a hydrocarbon that yields more calories per gram than coal. In contrast, genome sequences of cyanobacteria can be varied, producing infinite possibilities of mutant strains increasing the yield of fatty molecule produced. With cyanobacteria, it is possible to alter the genome so that enzymes related to fatty acid biosynthesis (such as acetyl CoA carboxylase) is upregulated, and usage of the stored fatty acid in the form of energy is downregulated.

The second advantage of cyanobacteria is its ability to convert the CO_2 feedstock directly into isoprene form, a useful form of fuel because of its versatility. Isoprene is a five-carbon ring that is readily polymerized. As a dimer, it can function as a form of gasoline. As a trimer, it can be used as jet fuel. The MEP pathway in cyanobacteria has been identified to produce the precursor to isoprene—DMAPP. Dephosphorylating this molecule will yield isoprene, along with oxygen. Dr. Haselkorn mentions that a unique cost of this synthetic method would be the rapid separation of isoprene from oxygen, given its high volatility.

The expected cost for pure isoprene is calculated to be $1600-$2300 per ton, with a global market estimated at up to $2 billion. This puts bioisoprene in the $5.80-$8.40 per gallon range, signifying 2.5 to 3.5-fold greater margin compared to standard fuels. It is also believed that cyanobacterial production of isoprene holds great potential for relieving oil dependence, as it takes about seven gallons of crude oil to make a gallon of fossil-based isoprene.

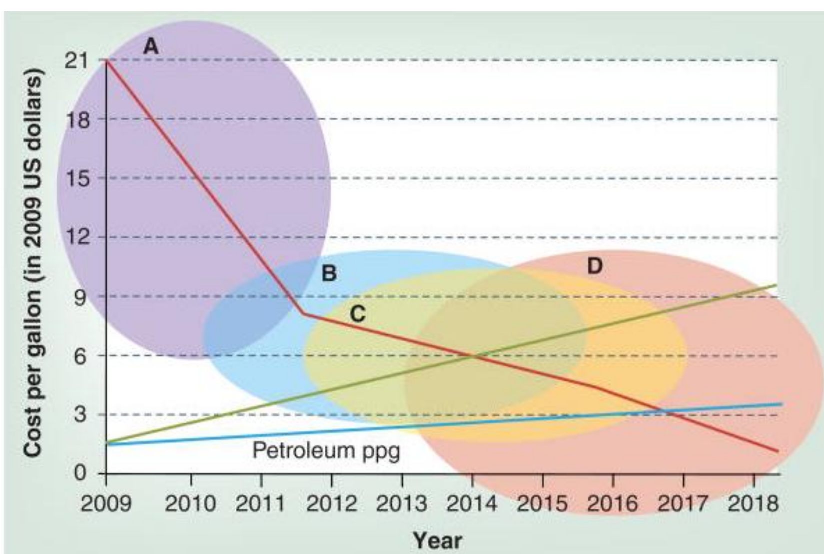
So, where do most of the costs associated with making synthetic fuel come from? There are several hurdles to overcome in terms of technology, most of them coming from feedstock and solvent. During the harvesting process, the initial delimiting factors for proliferation is the amount of phosphorus and nitrogen available in the water. Nitrogen is added to ponds in the form of ammonia or nitrate, at 0.8% of the dry weight of the algae in the pond, while phosphate comprises 0.6% of the dry weight (Benemann, 2006).

Then comes the cost of CO_2 input. In dry weight, microalgae is about 50% carbon—requiring constant input of carbon dioxide. It is estimated that 100 t of algal biomass produced fixes approximately 183 t of carbon dioxide (Chisti et al, 2007). Of the total cost for producing biomass algae, $185/metric ton, the cost for carbon dioxide comprises 20-30% of the total cost (Huber et al.). After the algae synthesize fatty acid chains, the intermediate product, triacylglyceride, must undergo the process of transesterification. This essentially converts fat, or triglyceride, into biodiesel with the aid of methanol or ethanol and catalyst. The usual catalyst of choice is an alkali catalyst such as NaOH or KOH.

Currently, the price of CO_2 as the chemical feedstock is one of the highest components—higher than even the costs for other nutrients or solvents. However, carbon emissions from nearby smokestacks have proven to work well in supporting algal strains, and options for algae harvesting near factories or smokestacks can greatly reduce costs.

With triglyceride production rates that are 45-220 times higher than terrestrial biomass such as corn, algae is by far the best candidate in terms of fuel yield. However, the setback is that while production costs of lignocellulosic biomass is at less than $40/metric ton, cost for algal biomass production is at around $185/metric ton (Huber et al.). Because algae is receptive to utilizing waste carbon dioxides from smokestacks, as well as growing in wastewater (while purifying the water it grows in), algae is sustainable as well as economical once production costs are lowered by improvements in technology.

<Figure 4—Factors required for algae fuel to become cost competitive with petroleum> -adapted from Hannon et al.



***(A)** bioprospecting for high-oil-producing, low-input-requiring species; **(B)** engineering to improve growth, harvesting and nutrient recycling; **(C**) further strain improvement through breeding, selection and random mutagenesis; and **(D)** bioengineering to improve fuel traits, produce co-products and crop protection

In this comparative graph adapted from Hannon et al. (2010), we are able to see that initial costs are greatly reduced by choice of efficient strains, while further competitiveness can be improved with genetic engineering such as mutagenesis via RNA silencing, or upregulation of pathways involved in lipid synthesis.

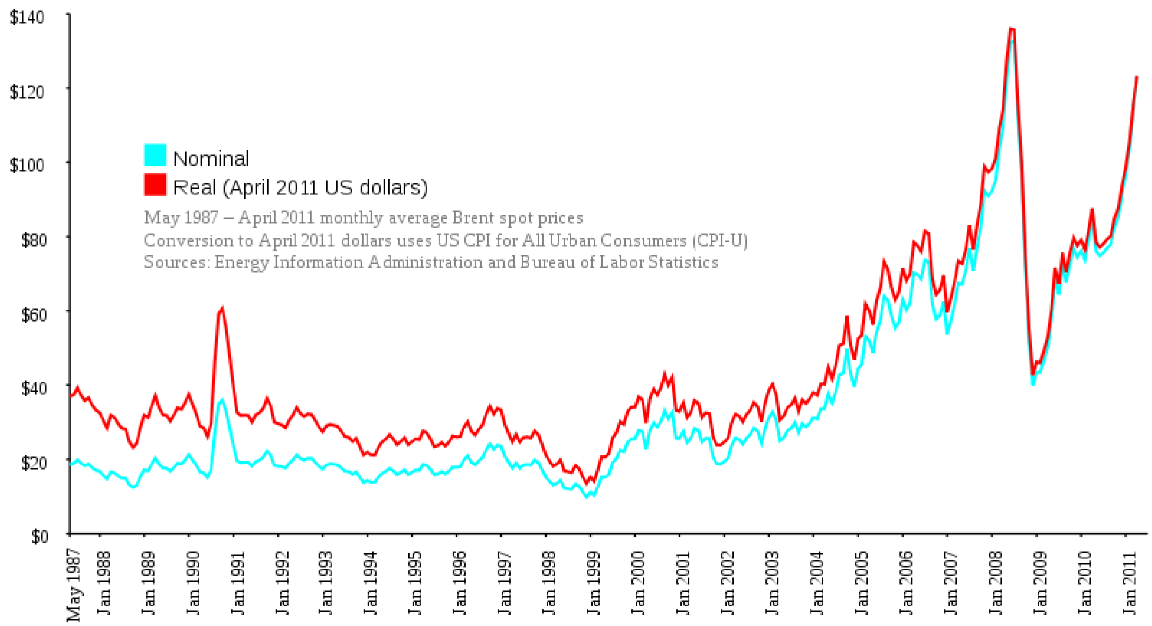
Given the methods and costs of what ultimately is the process of fixing solar energy, harvesting algal biomass may initially not seem to be the most straightforward method. Thermodynamically efficient methods of capturing energy from natural sources, such as sunlight and wind, are canonical, currently more stable ways to produce energy. However, it is interesting that while these are the straightforward methods generate electric energy, the extra step of harnessing these sources to produce liquid biofuels is many times more cost-intensive, painstaking in terms of research, and risky in terms of benefit return. The chemical, physical, and genetic implications of algae technology cannot be abandoned when addressing the question of scalability of algae fuel, essentially because the product is liquid material that may finally help alleviate our total dependence of oil.

Economic Factors : Private Sector

In addition to the technological, social and political drivers, there are several economic barriers and inducements to the development and commercialization of algae fuel in the United States.

Perhaps the most prominent of these is the rising price of oil. Although there have been fluctuations over the past several decades, the long-term price trend of crude oil has been a sharp increase—the Brent spot price of a barrel of oil was just over $18 in May of 1987, while today it is slightly under $110. The oil price increase has been most prominent over the past decade, as a barrel of oil began to rise above $30 in 2003 and doubled to $60 just two years later on August 11, 2005. Increasing prices are largely a result of declining supply due to limited global petroleum reserves, rapidly increasing demand due to growing middle classes in developing countries like China and India, speculation on the part of long-term investors, as well as tensions around volatile Middle East geopolitics and energy insecurity.

<Figure 5. Price of Oil from 1987-2011>



Rising oil prices is a key inducement to the development and commercialization of biofuels such as algae fuel. As oil becomes more expensive as a result of reduced supply and the uncertainty and volatility of Middle Eastern imported oil, the United States at both the private and public sector levels will be induced to invest more in fuels that could replace our dependence of foreign oil in the long-run, be naturally replenished so that supply challenges can be overcome, at a price that is affordable for all of our citizens and all around the world. Algae fuel could certainly meet all of these criteria. However, the price of oil could also be a barrier to its development due to potential unforeseen price reductions and fluctuations. During the 2008 financial crisis, for instance, the price of oil fell from a July 2008 high of $147 per barrel to a low of $32 per barrel in December 2008. Events like this in the future could cause large drops in algae fuel investment and are is therefore a potentially significant barrier to its commercialization.

Another significant economic driver is the high capital costs of algae fuel. A company with a desire to enter the algae fuel space would have to raise of large sum of money to pay the high upfront cost of facilities to convert algae to biofuels. As with most other clean technologies, algae fuel is highly capital-intensive and therefore cannot simply rely on one source of funding, as could start-up companies in the Internet sector back in the 1990s. In order for more early-stage algae fuel companies to enter the market, they would need to be financed by an wider array of both private investors and public institutions so that, in the aggregate, they can meet their necessary upfront capital requirements. Private investors in clean technologies such as algae fuel fall primarily into two categories: venture capital firms and strategic investors—big companies with lots of cash as well as industry and personal connections that can lead to greater investment.

Venture capital investment in algae fuel start-ups has been relatively measured compared to the rest of VC investment in clean technologies. This is primarily due to high capital and operational costs of algae fuel as well as the fact that venture capital place of majority of their capital in later-stage rather than early-stage funding, and relatively few algae fuel start-ups have reached later-stage yet. However some notable venture investments in algae fuel startups have been made:

<Figure 7. Recent VC Investments in Algae Firms>

Algae Firm	Investors	Funding
Synthetic Genomics	Exxon	$300M over several years
Sapphire	ARCH Venture Partners, the Wellcome Trust,Venrock	$50M
Aurora	Oak Investment Partners, Gabriel Venture Partners, Noventi	$20M Round B
GreenFuel	Polaris, Access Private Equity, DFJ	$14M Round B add-on
Sapphire	Cascade Investments	$50M Round B
Solazyme	Braemar Energy Ventures, Lightspeed, The Roda Group, Harris & Harris	$45.4 Round C
Solazyme	Lightspeed Venture Partners, Braemar Energy Ventures, The Roda Group, VantagePoint Venture Partners, et al.	$11.6M Round C add-on
BARD	Undisclosed	$40M
Solix	I2BF Venture Capital, Bohemian Investments, Valero Energy, Infield Capital, et al.	$10.5M
Solix	Shanghai Alliance Investment, I2BF Venture Capital, Bohemian Investments, Southern Ute Alternative Energy, Valero Energy, Infield Capital	$16.8M Round A

(http://www.greentechmedia.com/green-light/post/hot-algae-nights/)

The biggest barrier with venture algae fuel investment in the United States is that very few investors are willing to be the first to invest in a new, unproven algae fuel company's business model. Dr. Robert Haselkorn, Fanny L. Pritzker Professor at the University of Chicago, is the co-founder of an algae fuel company based in the United States that has moved some of its operations to China. When asked about what some of the company's biggest challenges were, Dr. Haselkorn stated "We've met with several investors who seem interested in our model, but none are willing to take the first step, to be the first to invest." Vinod Khosla, perhaps the most prominent venture capitalist in clean technologies and the founding partner of Khosla Ventures, stated, "We looked at two dozen algae business plans and have not found one that was a viable plan."

(http://www.bloomberg.com/news/2010-06-03/exxon-600-million-algae-investment-spurs-khosla-to-dismiss-as-pipe-dream.html) At the same time, however, some early-stage algae fuel companies have received strong financing from venture capital investors with higher risk-profiles. Sapphire Energy raised more than $100 million Cascade Investment, Bill Gates' VC firm, as well as others. (http://gigaom.com/cleantech/investors-fuel-solazyme-with-52m-for-algae/) South San Francisco-based Solazyme has raised $52 million from Braemer Energy Ventures and others venture capital firms. (http://gigaom.com/cleantech/investors-fuel-solazyme-with-52m-for-algae/)

Due to the unpredictability of venture capital investment in algae fuel, algae start-ups have had to rely on investment from large strategic players in the energy industry as well. For the most part, these strategic investors have been the big oil super majors—BP, Total, Shell, ExxonMobil, ConocoPhillips and Chevron. In July 2009, ExxonMobil invested $600 million in algae fuel technologies. (http://www.bloomberg.com/news/2010-06-03/exxon-600-million-algae-investment-spurs-khosla-to-dismiss-as-pipe-dream.html) Solazyme has received significant funding from Chevron and has partnered with the big oil company to make algae fuel more cost-effective. (http://www.portfolio.com/views/columns/natural-selection/2009/01/07/Algae-as-Alternative-Fuel-Source/index1.html)

Perhaps the greatest potential economic inducement to the development and commercialization of algae fuel, however, is the success of existing algae fuel companies in coming down the cost curve and becoming profitable. This will cause more start-ups to enter the space and create similar business models to successful algae fuel companies, which in turn will lead to even greater private sector investment on the part of venture capital firms and big oil companies.

<u>A quantitative scenario</u>

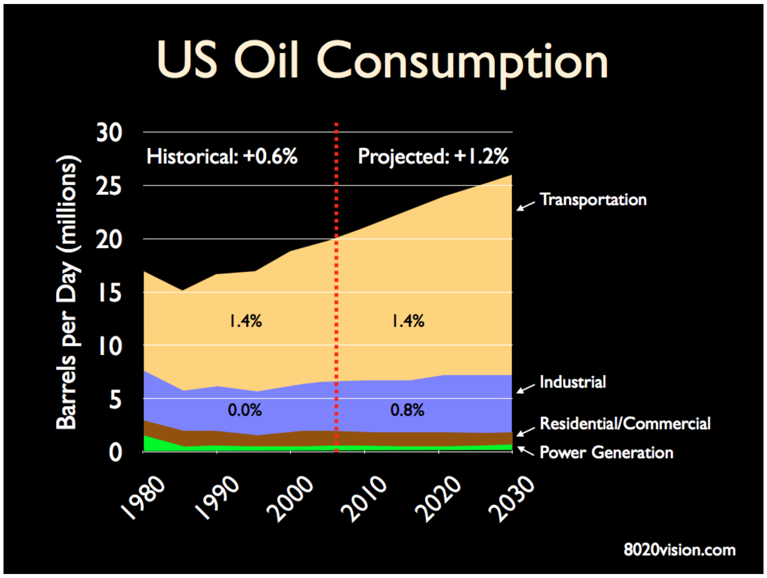
The following is a scenario for 2018 under a set of assumptions showing that funding from both the public and private sector is required much more than current levels.

Assumptions:

1) Price parity between oil and algae fuel will reach in 2018

- "We're hoping to be to be at parity with fossil fuel-based petroleum in the year 2017 or 2018, with the idea that we will be at several billions of gallons," Mary Rosenthal told SolveClimate News in a phone interview" **[1]**
- Hence, taking this statement of the future as a feasible possibility, in 2018 the preference between oil and algae fuel will be indifferent to each other as there are no significant difference in prices between the two source of energies

2) The total consumption of oil in 2018 will be 22.5M barrels/day (or 8212.5M barrels/year)



<Figure 7. US Oil Consumption Predictions>

(source: http://8020vision.com/2010/07/13/us-energy-use-the-big-picture/)

From the graph above, US oil Consumption in 2018 will be approximately 22.5M barrels/day.

3) Price of production of algae fuel is $8/gallon in 2018

- At the technology given at present day the production cost of algae fuel yields a minimum of $8/gallon.
- Assuming that this will become the maximum cost by 2018, which is still far mor e expensive than other renewable source of energy at present day ($4/gallon for s oybean oil), this would be the hypothetical upper bound of the price of algae fuel in 2018. **[2]**

4) 25% of US oil consumption will be replaced by algae fuel in 2018

- "Under Energy Independence and Security Act's (EISA) calendar of benchmarks, at least 9 billion gallons of renewable fuel must be included in the gasoline sold in the United States in 2009. In 2022, the last year on its schedule, EISA mandates a minimum of 36 billion gallons of renewable fuel.” **[3]**

- Even with EISA’s stipulation this assumption may be highly presumptuous. However, this assumption will highlight the lack of funding from both the public and private sides.

5) Private and public sector divide total costs into: 12% private sector and 88% public sector

- From the table below, the total US investment in renewables in 2010 was $34 billion. In addition, $3.98 billion was invested by Venture Capital (VC) in 2010.
- Assuming the VC fairly represents the total private sector, 3.98/34 = 0.117, approximately 12% is invested from the private sector. Hence, 88% from the public sector. **[4]**

6) All production cost in algae fuel will be financed entirely between the private and public sector:

<Figure 8. Top 10 Countries in Clean Energy Investment, 2010>

2010 Rank	Country	2010 Investment (billions of $)	2009 Investment (billions of $)	2009 Rank
1	China	54.4	39.1	1
2	Germany	41.2	20.6	3
3	United States	34.0	22.5	2
4	Italy	13.9	6.2	8
5	Rest of EU-27	13.4	13.3	4
6	Brazil	7.6	7.7	7
7	Canada	5.6	3.5	9
8	Spain	4.9	10.5	6
9	France	4.0	3.2	12
10	India	4.0	3.2	11

(Source: PEW Charitable Trusts) **[5]**

From the assumptions, 25% of 8212.5M barrels/year is approximately 2053.125 barrels/year and in gallons this would be 86231.25 gallons/year. Therefore, $8/gallon as a production cost will be the equivalent of $689850M in 2018 (= $690 billion in 2018). Using the ratio from assumption (5), this would require a sum of $82.8 billion from the private sector and $607.2 billion from the public sector. Furthermore, if these costs were split up in the next 7 year period beginning 2012 and ending in 2018, a financing of $11.8 billion/year from the private sector and $86.74 billion/year from the public sector will be required to meet the above assumptions.

The following table is a summary of the results:

<Figure 9> Summary of Total Investments 2012~2018 (predictions)

	Percentage	Cost in 2018	Yearly (2012 to 2018)	2010 total investment
Private Sector	12%	$82.8 billion	$11.8 billion/year	$3.98 billion
Public Sector	88%	$607.2 billion	$86.74 billion/year	$30.02 billion

The results show that clearly at 2010 private and public funding levels for clean energy overall, ($3.98 billion and $30.02 billion from the private and public sector respectively) it is not even enough to cover the annual payment requirements from 2012 to 2018. In fact, it requires about 3 times more than the 2010 investment figures.

Conclusion

In this paper, we have addressed the sociopolitical, economical, and technological barriers and inducements of developing fuel from microalgae. In order for fuel from microalgae to enter competition with oil, a great reduction of total production cost is needed. From the technological perspective, this mainly comes down to reduction of costs for chemical feedstock, in addition to bioengineering to increase yield. Public interest in renewables is expected to drive government investment, yet currently the U.S. is lacking a long-term clear energy policy for algae fuel. Meanwhile, predictions on the algae fuel market are not isolable from the price of oil, which is still the cheaper competitor. Together, these results indicate that greater investments from both the private and public sector will enable microalgae to enter competition with oil, currently impeded by high production cost. Eventually, more successful companies will lead to greater private investment, which will further stabilize the industry. The success of algal fuel industries will be amplified in a feed-forward loop, the first trigger being government investment.

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TEAM 6

Hydraulic Fracturing of the Marcellus Shale:
A Technological, Economic, and Environmental Analysis

Bryanne Halfhill
Alice Li
Anthony Pence

Table of Contents

Abstract

Natural gas as an energy source comprises of roughly a quarter of the United States' energy consumption, and is cost-efficient, widely available domestically, and has lower carbon emissions per unit- therefore, natural gas is a crucial energy source for the United States. "Fracking," short for "hydraulic fracturing" and also known as "fracing" or "hydrofracking," is a method of obtaining natural gas that has been hotly debated in the recent years. The main concerns with fracking are over its environmental impacts, and subsequently, the potentially detrimental health effects arising from environmental changes. In this study, we will seek to objectively lay out the benefits and detriments of using fracking as a way of obtaining natural gas, focusing specifically on the Marcellus Shale region in Pennsylvania. Based on this analysis, fracking can be a feasible and safe method of acquiring natural gas- in conclusion; we will offer several policy measures that ought to be taken in order to ensure that fracking is conducted properly.

Policy and Literature Review

Although hydraulic fracturing is not a new technological development, drilling in residential and urban areas via horizontal wells is new. As a result, the environmental and social costs of fracking the Marcellus Shale have been under-researched. The little research that has been published about the sites has not been widely accepted by scientists as the researchers publishing the studies had a conflict of interest with fracking companies. For example, Pennsylvania, the central figure in fracking the Marcellus Shale, designated Pennsylvania State University as the research university in charge of gathering data for the environmental and social costs of fracking. Soon after Penn State was chosen, it received an $88 million gift from a company interested in fracking the Marcellus Shale in Pennsylvania.

The federal government also had its work dismissed by academics. In 2004, the EPA's only major study on the environmental consequences of fracking, the primary researchers chose to collect no original data and instead relied on data that was not properly vetted by other academics. The study concluded that there were no real environmental and social risks associated with fracking in Pennsylvania (EPA 2004: ES1). As a result, fracking was not added to the Clean Drinking Water Act and was not added to the list of industries required to release their chemicals under the "right to know clause of the Superfund law (Davis 2011: 5)

However in 2011, many prominent researchers published widely accepted data on the possible consequences of fracking the Marcellus Shale. The most recognized of which was published by Duke University. This study was focused on water pollution related to fracking and sampled water from numerous wells in the region. It was one of the first to perform a before and after water analysis of wells near active drills and it also compared water quality to local high-quality aquifers (Osborn *et al* 2011). Similarly, in early 2012 the EPA will release the first part of a new study on fracking in Pennsylvania. This study will have original data collected over the last two years and will be continued over the next several years. New Jersey and New York are waiting to see the results of the study before they consider lifting their drilling moratoriums.

Introduction

Keeping warm in the Chicago winter at home. Frying eggs for breakfast. Using the dryer. Keeping cool in the Chicago summer at the office. What do all of these actions have in common?

They all use natural gas.

Natural gas, due to its cleaner nature (in terms of lower carbon emissions per unit) than other energy sources such as coal, its relative abundance domestically, and relatively low capital construction costs, has grown to be one of America's premier energy sources. According to the Department of Energy (DoE), Electricity's contribution from natural gas is projected to grow from 23% in 2009 to 25% in 2035. The U.S. produced roughly 21 trillion cubic feet of natural gas in 2009 with about 14% coming from shale gas, and the DoE projects that by 2035, natural gas production will exceed 25 trillion cubic feet, with roughly 40% coming from shale gas (DOE 2011: 3).

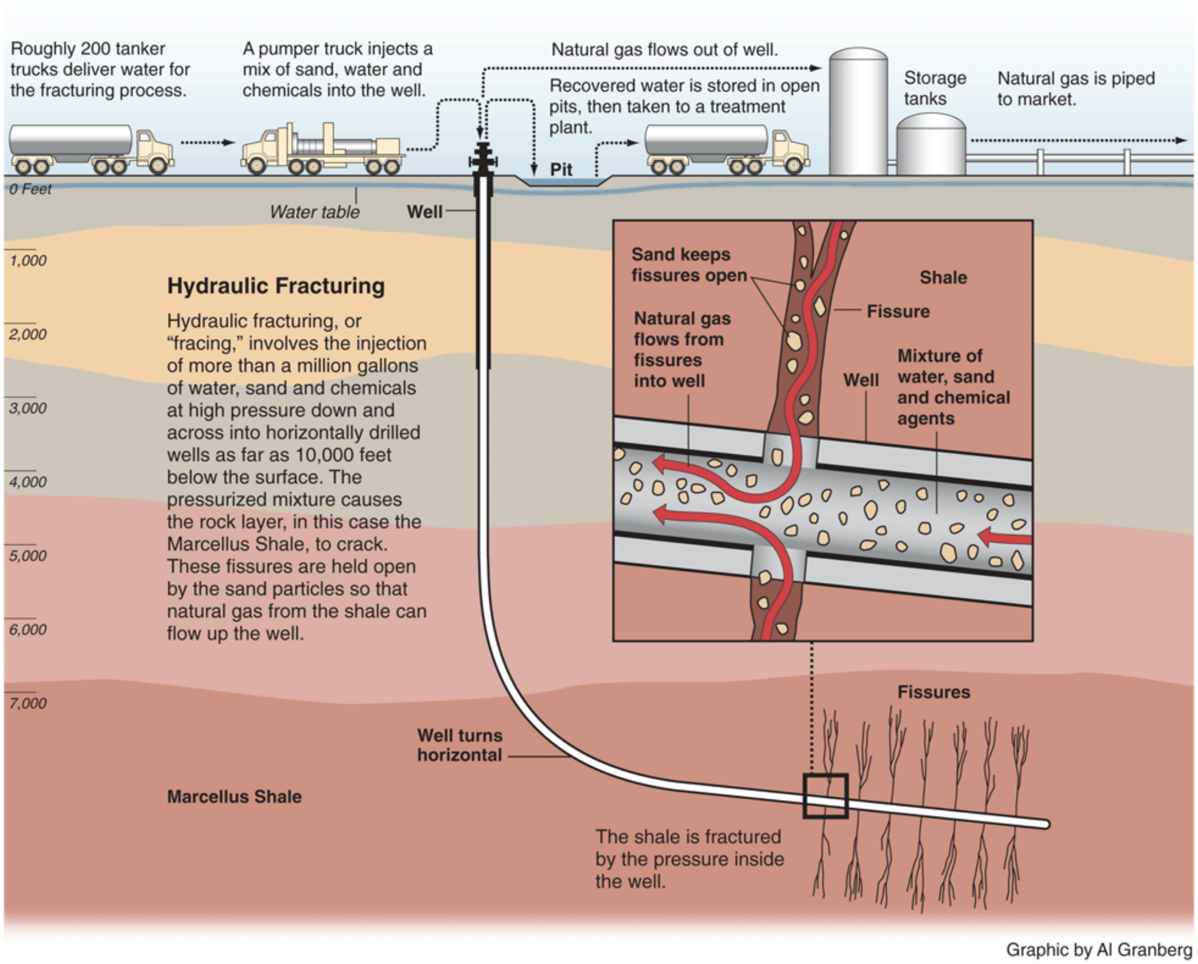
This paper will focus on the extraction of shale gas from the Marcellus Shale (named for a distinct outcropping in Marcellus, NY), a region extending from most of Pennsylvania and New York to eastern Ohio, Maryland, and most of West Virginia. According to Terry Engelder, a professor of geosciences at Penn State, "The Marcellus Shale may contain 490 trillion cubic feet of gas- enough to heat U.S. homes and to power electric plants for two decades," making it the world's second largest gas field, and largest in the U.S (Efstanthiou Jr and Chipman 2011).

Shale gas refers to natural gas extracted from shale. Shale is a type of mature petroleum source rock where high heat and pressure converted the petroleum into natural gas. Since shale has low permeability, fractures in shale allow for the extraction of natural gas- shale is fairly rigid and brittle, so once these fractures are created (either naturally or through man-made means), they are able to stay open. Other sources of natural gas include tight gas, lower 48 onshore/offshore, and coalbed methane. However, as shale gas is projected to be the main source of natural gas for the United States in the near future, shale gas will be the primary focus of this paper.

With recent developments in technology, shale gas has become easier to extract than ever before. Before horizontal fracturing was invented, shale gas was only able to be extracted through natural fractures or a single deep fracture, limiting the amounts of gas to be obtained. However, with improvements in directional drilling technologies, the amount of shale gas to be extracted has grown exponentially.

Technological Overview

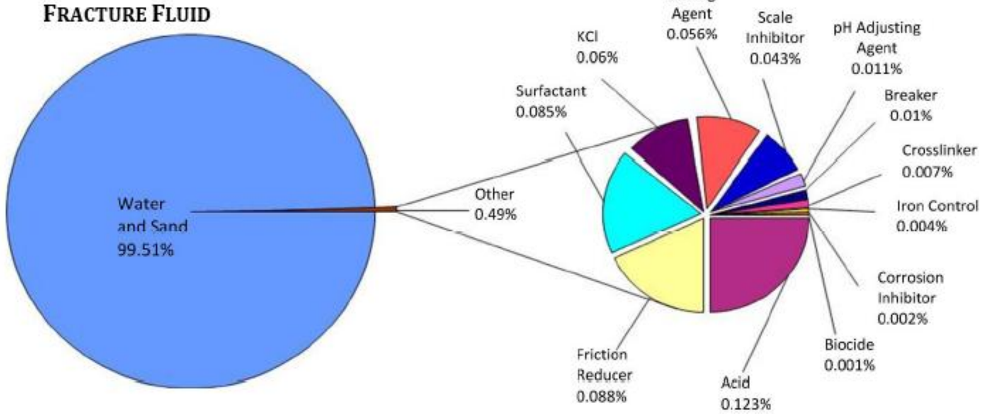
"Fracking," also known as "hydrofracking" or "fracing," is the controversial method of obtaining shale gas and is currently in use by over 90% of natural gas wells in the United States. Fracking is loosely defined as the process of initiating a fracture within a layer of rock and then propagating it (called a "frack job") by using a pressurized fluid. Manmade fracking typically starts from the borehole and extends into the targeted formations. A borehole is a long narrow shaft into the ground. These wells are usually drilled to a depth of 1500m-6100m#. The pressurized fluid (called "fracking fluid" injected into these wells is about 98%-99% water, with the remaining 1%-2% consisting of "proppant", material such as sand, ceramic, and other particulates that help keep the fractures open.



Fracking fluid may contain acid to increase permeability of the rock, or radioactive tracers to measure the depth of the well. A point of contention between environmentalists and industry is that fracking fluid recipes are currently considered trade secrets, making it difficult for regulators to control what amounts of chemicals companies are putting into their fracking fluids.

MODERN SHALE GAS DEVELOPMENT IN THE UNITED STATES: A PRIMER

EXHIBIT 35: VOLUMETRIC COMPOSITION OF A FRACTURE FLUID



Source: ALL Consulting based on data from a fracture operation in the Fayetteville Shale, 2008

A typical fracking job has four stages: an acid stage, where water and dilute acid are used to clear cement debris and provide an open conduit for other frac fluids, followed by a pad stage where slickwater fills the wellbore to open the formation, and then the prop sequence stage, where water and proppant keep the fractures open, and finally the flushing stage, where fresh water is used to flush the excess proppant from the wellbore (DEP: 2011).

To be clear, fracking is neither a new technology, nor is it solely used for extracting natural gas. Conventional fracking methods have been in use for the past 40 years. Fracking has also been used for: stimulating groundwater wells, conditioning rock for mining, disposing of waste, measuring stress in the earth, and for heat extraction to produce electricity in Enhanced

Geothermal Systems. It is the fairly new process of horizontal drilling that is the cause of consternation. Horizontal fracking takes it one step further by turning the fracture horizontal and then doing lateral fractures to capture more gas. The problem arises when these fractures occur near water aquifers and sources of drinking water where contamination by fracking fluid is a potential threat, or when fracking causes gas such as methane to rise to the surface and contaminate wells.

Another source of concern with fracking is the more recent technological developments that have not been thoroughly tested for environmental impact. For instance, “slickwater” or fracking fluid that has friction reducers to increase fluid flow from 60bbl/min to as high as 100bbl/min. These friction reducers can be a host of chemicals, including benzene, chromium, and other toxic compounds. Slickwater fracturing also uses more water than conventional fracking methods: 5-6 million gallons per lateral compared to 2-4 million gallons, respectively (DEP: 2011).

Several technological advances have been made in reducing the environmental impacts of fracking. The first of which would be to place drill rigs on raised platforms to protect the underlying landscape as well as to accommodate blowout prevention equipment that affixes to the wellhead during drilling. While this is required in certain states, like Michigan, it ought to be a national measure (Godbold: 2009). Second, rubber pools should be used to catch spilled fluids before they could seep into the soil and have potentially harmful effects through contamination- going along with that, waste enclosed in steel tanks rather than open pits reduce possible air and water contamination by more than 50%. Finally, the government should prevent companies from using diesel fuel (benzene) in fracking fluid solutions, as there are other, safer chemicals that can replace benzene. The industry should continue to fund and invest in research and development of safer and more efficient equipment and fracking practices.

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Environmental Assessment of Fracking the Marcellus Shale

The most debated aspect of hydraulic fracturing, or fracking, of the Marcellus Shale is the possibility of extremely detrimental environmental consequences. Some scholars argue that although there is a risk to the environment involved with fracking, these risks are often overstated and the possibility of environmental degradation is lowered by properly drilling the shale. However, there are few statutes regulating fracking and horizontal drilling for natural gas. Without these regulations, it is necessary to examine to possible consequences of fracking the Marcellus shale. This section will look at the environmental consequences - air and water pollution, and the possibility of surface spills. Then we will discuss the various health consequences related to these forms of pollutions. Lastly, this section examines the federal and state policies that regulate drilling for natural gas.

Environmental Concerns

"These (environmental) impacts (from hydraulic fracturing in Pennsylvania) result from changes in land use, road building, water withdrawals, improper cementing and casing of wells, over-pressurized wells, gas migration from new and abandoned wells, the inability of wastewater treatment plants to treat flowback and produced water, underground injection of brine wastewater, improper erosion and sediment controls, truck traffic, compressor stations, as well as accidents and spills." – Michaels, C. *et al* 2010: 3

Michaels *et al* (2010) outlines major problems with fracking that could potentially lead to environmental degradation. The above issues are likely to lead to air and water pollution and demonstrate the possible long-term problems associated with fracking the Marcellus Shale. As the quote shows, all aspects of drilling – preparation work, drilling, recovery, and clean up –

require a large amount of resources and monitoring; all parts pose potential dangers to the environmental and public health.

Air Pollution

Fracking also makes considerable contributions to localized CO_2 emissions by increasing the number of high tonnage commercial trucks in towns. Not only do these semi-trucks and construction vehicles emit more than other vehicles, they also require towns to replace roads. Replacing and expanding roads requires increased mining for rock and production of asphalt. However, studies have had mixed results as to the exact amount of air pollution that occurs at drilling sites. Some studies show that drilling sites are well above air pollution levels based on the amount of nitrogen oxide (NO_x) and volatile organic compounds (VOC) released, others show that some sites are well below EPA requirements for close monitoring. Currently, the EPA requires a minimum of 10 – 250 tons of air pollutants per year (the exact number depends on the pollutant being released) for close regulation at a single source emission site (Schmidt 2011: 352). However, as discussed in the literature review, the only study done by the EPA was performed during the Bush administration in 2004 and did not collect its own data. Today many scientists argue that emission levels need to be closely monitored since drilling occurs in residential areas in Pennsylvania.

Water Usage

Fracking is incontestably a resource intensive project. Each fracking well requires up to four million gallons of water from nearby lakes, rivers, or underground aquifers (Davis 2011: 4). If you account for all 35,000 drilling wells in the US, hydraulic fracturing currently uses more water than five million Americans in a single year (Schmidt 2011: 352). Although withdrawing this amount of water in Pennsylvania is currently less of an issue than at other sits in Texas or

Colorado, after its withdrawn, water, along with fracking proppant are then pumped back into the ground where it has the potential to pollute groundwater. Finally, some of the water returns to the surface as flowback and must be stored in wastewater pools and treated at an offsite location. The wastewater must then be treated via energy intensive processes to ensure the removal of all chemicals and potential carcinogens from the water.

Water Pollution

A 2009 report, the US Geological Survey states, "While the technology of drilling directional boreholes, and the use of sophisticated hydraulic fracturing processes to extract gas resources from tight rock have improved over the past few decades, the knowledge of how this extraction might affect water resources has not kept pace (USGS 2009: 5)." Although water usage and air quality remain critical issues with fracking, with over 750 chemicals being mixed into water and injected into the ground (Schmidt 2011: 350), the most important environmental and public health issue is water pollution.

As discussed in the drilling technology section of this paper, wells are usually drilled 1000 meters or more below the water table. The drilling industry claims that because the water table and fracking zones are separated by such great distance and by rock that it is very difficult for fracking fluids to pollute local waters. However, numerous studies have reported large amounts of water pollution as a result of fracking and communities have even found fracking fluids as far as a kilometer away from the nearest well (Lee *et al* 2011, Michaels *et al* 2010, Schmidt 2011).

Currently, the most documented problem with fracking in residential areas is the sudden accumulation of methane in drinking water. There are many several videos on YouTube documenting residents of Pennsylvania with flammable water. Duke University's study[1] of drinking water contamination found that methane contamination of drinking water was 17 times higher in drinking wells located within 1 km of an active well. In the 26 drinking wells near active drillings sites that were examined, the study found 21 of them to be contaminated with higher than normal levels of methane (Osborn *et al* 2011: 2). The study also could not rule out the possibility of fluid migration as a result of displacement of gas in coal seams, leaky well casings, and the creation of unexpectedly large or enlarging existing fractures (Osborn *et al* 2011: 4).

However, the same study also compared 68 drinking wells in the Marcellus Shale region to 124, presumably clean, drinking wells in Catskill and Lockhaven aquifers. The study specifically looked at the levels of inorganic compounds, stable isotopes of water ($\delta^{18}O$, $\delta^{2}H$), and isotopes of dissolved constituents ($\delta^{13}C$-DIC, δ-B, and ^{226}Ra). Importantly, the study did not find the wells in the Marcellus Shale region to be polluted with compounds typically found in fracking fluids (Osborn *et al* 2011: 4).

Although huge amounts of water pollution have not been verified, the wastewater storage ponds are one of the top concerns for citizens living near drilling cites and for environmentalists. When water and chemicals are pumped into the ground to extract natural gas, a large percentage of it returns to the surface as flowback. Flowback is highly concentrated with dissolved solids and contaminants and must be contained and treated before reusing the water or pumping it back into local waterways (Rogers 2011: 133). In its "Fractured Communities" report, *Riverkeeper* lists six major fracking fluid spills in Pennsylvania in 2010. The companies were fined $3,500 to $140,000 for breaking state laws. The largest fine resulted from spilling 250 barrels of diluted

[1] It should be noted that the Duke University, "Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing", is currently considered to be the most thorough and academically respected study on water pollution as a result of fracking in the Marcellus Shale Region.

fracking fluid into a tributary of Brush Run River in Pennsylvania. This river was set-aside as a high quality, warm water waterway until the spill occurred. At least 168 aquatic animals were found dead in the days immediately after the spill. The waterway flows directly through Hopewell Township, PA and has had unknown consequences on the town (Michaels *et al* 2010: 11).

After sitting in containment ponds, the water must be treated before it can be pumped back into local waterways or repurposed. However, fracking fluids are known to contain many carcinogens, especially benzene (Schmidt 2011: 351). This raises many concerns about purifying fracking water in existing water treatment plants - the possibility of contaminating other water at treatment facilities, and the ability for existing plants to rid the water of all of the fracking chemicals. Currently, water is being held in storage ponds or is lightly treated before being reused in wells. This effects of this has not been researched and has unknown consequences.

Health Concerns

As mentioned above, fracking fluids are filled with carcinogens and unknown compounds. Although there have been no known leaks or exposure to these chemicals, the consequences of exposure would be tremendous. However, there are known and well documented instances of ingesting methane. But, the toxicology of ingesting methane has never been fully study. Regardless, the potential for widespread public health consequences is very high given the chemicals used in the fracking process and the lack or regulation and oversight of the process.

A major cause for concern stems from fracking's omission from the 2005 Safe Drinking Water Act and from the "right to know" clause from the 1986 Superfund law (Davis 2011: 5). This allows companies to claim fracking fluids as "trade secrets" and therefore officials and regulators are ill prepared for potential problems with fracking. Although no formal health studies have been performed, the 2010 documentary *Gasland* interviewed people living near drilling sites that complained of headaches, diarrhea, nosebleeds, dizziness, blackouts, and muscle spasms ever since drilling began near their homes. Since 2009 the Texas Commission on Environmental Quality (TCEQ) has monitored water wells and air quality throughout Texas, where hydraulic fracturing is also used. They have yet to release conclusive reports on their findings.

Benefit-Cost Analysis

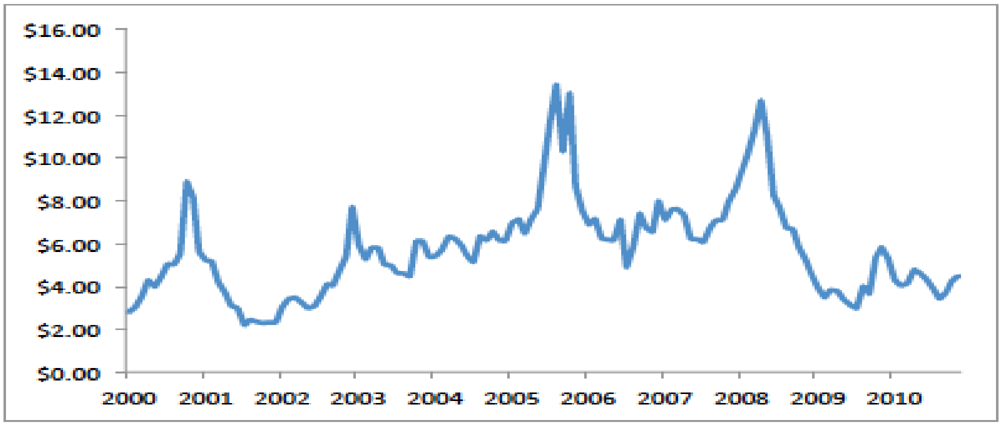
A cost benefit analysis is a quantitative economic comparison that checks the feasibility of a proposed action by observing the costs and benefits of the specific project. As I continue with my analysis, it will become evident that not only will the benefits outweigh the costs but also that using natural gas will be the smarter choice as we look ahead to the future.

Benefits of Natural Gas

With our natural gas obtained from fracking, it would be possible to replace all coal powered electricity generation. It is also evident that we have enough natural gas reserves to last for approximately 100 years (EIA - Use of Natural Gas - Energy Explained). Without fracking, we would still be able to obtain our natural gas, however it would be at a higher price and would need to be in a variety of different ways in order to obtain the amount we need.

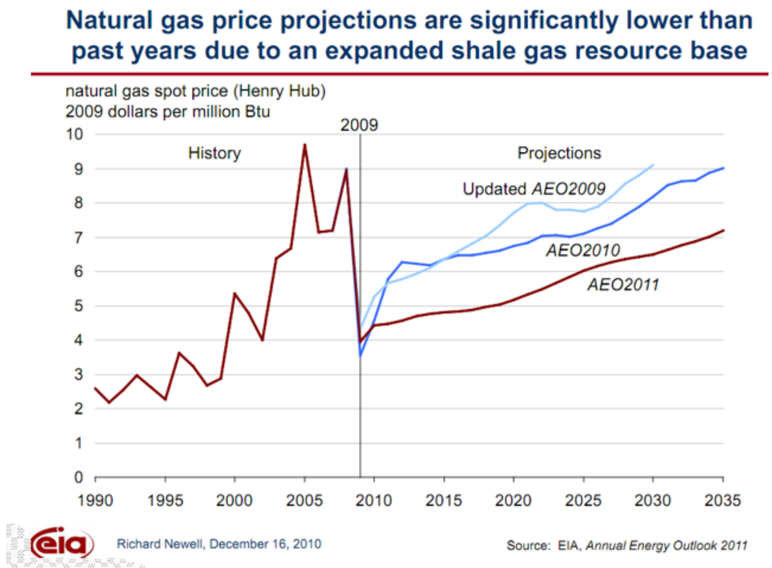
Gardner Pinfold Consulting Economics did a study in 2002 that concluded a long term oil price of $24.00 per barrel and natural gas prices at $4.54/MMBtu. In 2010 and 2011 oil prices increased to over $100.00 a barrel while natural gas still averaged out to be about $4.93/MMBtu (Nova Scotia 2003). In the figure below you can see the cost of natural gas throughout the past 10 years.

Natural Gas Spot Price 2000-2010

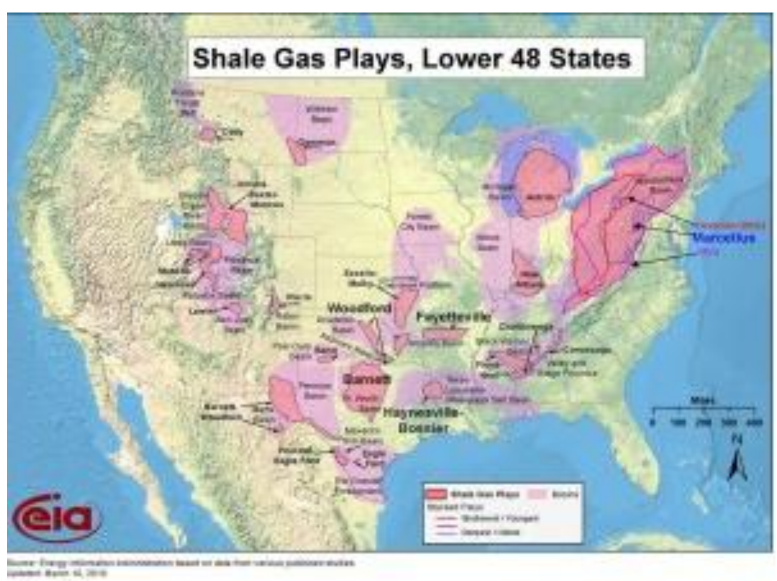


Source: U.S. Energy Information Administration, 2011

As we can see from the figure, in the past couple of years, natural gas prices seem to level out and become lower. This will benefit each individual living in the United States with lower everyday living costs. It will reduce the cost of heating for people using natural gas to heat their homes and provide us with low cost electricity. There is an overall consensus from various different sources that the price of natural gas will stabilize and remain at a constant moderate level for an extended period of time. This is because there is so much potential and so much natural gas reserves readily available for fracking to take place. We can below the natural gas price projections.



The graph also predicts the next twenty-five years. The EIA estimates that Marcellus Shale in Pennsylvania may have enough reserves to power the entire US for about seventy years. In the following picture, we can see all of the gas deposits and where natural gas is readily available for fracking.



Business Week states,

> "In Pennsylvania, where 2,516 wells have been drilled in the last three years, $389 million in tax revenue and 44,000 jobs came from gas drilling in 2009, according to a

> Penn State report. Perhaps best of all, natural gas emits had the carbon emissions of oil" (Efstathiou 2011).

So not only will this provide us with natural gas for the next said to be 100 years, but it will also bring about jobs to our starving economy.

In addition, although some have tainted views of fracking and natural gas, it is actually true that it has many environmental benefits and is proven to be the better choice. Natural gas is the least chemically complex of all of the fuels and is easily combusted. According to the EIA, natural gas produces about 117,000 pounds of carbon dioxide per billion Btu while coal produces 208,000 pounds of Carbon Dioxide per billion Btu. Natural gas is also the clear winner with producing only 40 pounds of carbon monoxide per billion Btu and 0.6 pounds of sulphur dioxide per billion Btu while coal produced 208 pounds per billion Btu of carbon monoxide and sulphur dioxide. These three with many other pollutants proves that natural gas creates fewer pollutants than any other fossil fuel.

Costs

When evaluating costs, we will first consider the conversion costs of companies to switch from coal powered or whatever type of gas they are currently using to natural gas. This is obviously a big concern for companies, hospitals and universities who are considering making the switch. Although the cost can be seen as a multi million-dollar investment, The Gas Market Development Fund is an energy program supported by gas producers who aid in the process of converting big companies and universities to natural gas. Therefore, since universities, companies and hospitals could expect and would be given support and financial assistance, the cost of converting energy is really not one that we are concerned with.

First, we will need to account for the cost of the pipeline and the actual drilling process. When constructing the pipeline, we must consider the cost of the steel for the pipe and the cement to seal and lock the natural gas into the pipe. The cement used for the pipe is a very important part of the process, therefore we need to make sure that we are using a significant amount of cement and top of the line steel to make sure this process is environmentally safe. We also need to consider the fact that the costs will increase as the diameter of the pipe increases. Increasing the diameter will raise the initial cost, but this will also allow the capacity inside the pipe to increase, which will make this project even more economically sensible, because it will allow us to obtain more gas more quickly.

A study was done at Massachusetts Institute of Technology in the Oil and Gas Journal on fracking and natural gas stated that the pipeline will be approximately $33,853 for ever inch of diameter per mile. If we use a standard six-inch pipe for approximately sixty-five miles the total initial cost will be equal to about $13.25 million (Sung Lee, Herman 2011).

The cost of the project is weighed against future cost and benefits which will leave us with our present value of the project. When calculating the present value for the project, if we end up with a positive number, the project is feasible. The PV will be calculated for the next five years at a four percent discount rate.

After the initial cost of the actual pipeline, there will be maintenance costs that need to be accounted for. FGA Consultants and Engineers estimate that maintenance and management costs of the pipeline will estimate to be about $2,554 to every 0.7 mile. This will lead to the total cost of about $322,000 per year. We also need to consider the cost of drilling, which will cost about $1 million per year for a vertical well.

Present Value

PV = [(energy cost savings – (maintenance costs + drilling costs)) / (1+discount rate^t)] – initial construction costs

This will give us a present value equation of:

($13.25million – ($322,000+1million)) / (1/0.4)^5 = 122,142.72

As stated before, if we end up with a positive number in our present value equation, then the project is feasible. As our present value equation portrays a positive result, we can assume that our project is indeed possible.

Unquantifiable Factors

We also need to account for the unquantifiable factors in this project. As when writing an analysis there are still things that cannot be calculated until the project is actually occurring. Although all of these prices listed above are accurate estimates and were reached through observations and research, we also need to account for the fact that we are not able to predict an exact situation. There are many factors that will differ in different areas were we plan for the fracking to take place. For example, we do not know how much pipeline we actually need until we know the grounds of the area. It is also crucial to note that prices vary in different areas of the Unites States, therefore, the cost of drilling, the cost of cement the cost of workers, etc. varies.

Allowing for Uncertainty

We also do need to account for cleanup costs in our cost equation. We realize that if a pipeline were to bust or were to leak from faulty cement sealing, there would be a cost environmentally and also a cost for the actual cleanup process. We need to account for situations in which things do not go as planned in the particular fracking process.

Conclusion

It is important for regulators and citizens to understand the difference between conventional fracking, which has been in use for over 40 years and with which most natural gas consumed is obtained, and unconventional fracking practices such as horizontal drilling and the use of slickwater, which are the practices in controversy. The first thing that needs to be done is a strict and formal defining of hydraulic fracturing, so time is not wasted squabbling over word nuances. Secondly, more research needs to be done on measuring the environmental impact and health effects of hydraulic fracturing as well as pinpointing which practices are the most harmful. Finally, the industry needs to be mindful of communities living near fracking sites and invest in safe equipment and conduct fracking in an environmentally conscious manner.

Based off of much research done to determine the costs of setting up a fracking site, it is clear that the benefits outweigh the costs. We can see from the present value equation that the project is feasible and will save every American money. However, there are important environmental and public health concerns that must be considered as the project moves forward. Specifically, researchers and regulators must do more to learn about the possible environmental degradation being done by fracking fluids that are injected. Similarly, more research needs to be done on the toxicology of ingesting methane and other fracking chemicals. Lastly, research based policy should be approved to ensure that fracking is a safe alternative for domestic natural gas drilling.

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