Wind Power Project Repowering: Financial Feasibility, Decision Drivers, and Supply Chain Effects

Eric Lantz, Michael Leventhal,
and Ian Baring-Gould

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Technical Report
NREL/TP-6A20-60535
December 2013

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List of Acronyms and Abbreviations

BWE	Bundesverband WindEnergie (German Wind Energy Association)
DOE	U.S. Department of Energy
GW	gigawatt
IEC	International Electrotechnical Commission
kW	kilowatt
m	meter
MW	megawatt
MWh	megawatt-hour
NPV	net present value
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
PPA	power purchase agreement
PTC	production tax credit
SAM	System Advisor Model

Executive Summary

As wind power facilities age, project owners are faced with plant end-of-life decisions. This report is intended to inform policymakers and the business community regarding the history, opportunities, and challenges associated with plant end of life actions, in particular, repowering. Specifically, the report details the history of repowering, examines the plant age at which repowering becomes financially attractive, and estimates the incremental market investment and supply chain demand that might result from future U.S. repowering activities.

Repowering as defined here includes two types of actions. Full repowering refers to the complete dismantling and replacement of turbine equipment at an existing project site. Partial repowering is defined as installing a new drivetrain and rotor on an existing tower and foundation. Partial repowering allows existing wind power projects to be updated with equipment that increases energy production, reduces machine loads, increases grid service capabilities, and improves project reliability at lower cost and with reduced permitting barriers relative to full repowering and greenfield projects.

Repowering first emerged in the early 1990s in the California and Danish wind power markets and was followed by the Dutch and German markets in the 1990s and 2000s. Although repowering activity has occurred elsewhere, these locales remain the principal markets for repowering investments. Historically, repowering has been viewed as a means of increasing project productivity while offering an array of other potential attributes of interest. Fundamentally, however, profitability for a given project is the primary driver of repowering decisions. Given limited financing, the anticipated profitability at alternate greenfield sites is also relevant.

Two distinct analyses were conducted to understand the plant age when repowering becomes viable. These analyses utilized NREL's System Advisor Model (SAM), a tool that enables the user to predict estimated cash flows from a variety of electric power generation technologies. Net present value calculations were utilized to enable comparisons across time.

The first analysis involved creating "proto-typical" wind plants of four different vintages, with commissioning years of 1999, 2003, 2008, and 2012. Proto-typical plants are representative of the industry at the time of their construction and rely on market data from each of the commissioning years to derive installation and equipment costs, power purchase agreement revenue, net capacity factor, receipt of federal production tax credit payments, and operation and maintenance expenses. For each of these four plants, future investment decisions to repower, or build a nearby greenfield site, were evaluated for 2015, 2020, 2025, and 2030.

The second analysis focused on three actual wind plants operating in the United States. These plants were chosen for varying vintages and geographical diversity and include a Northeast wind plant (15–20 years old), a Midwest wind plant (10–15 years old), and a West Coast wind plant (20–25 years old). For these three plants, the decision to repower the current site or invest in a nearby greenfield site was assumed to occur in the 2012–2013 timeframe. Estimated costs to repower, expected revenue, and operational statistics were acquired from nearby sites that were recently placed in service or are in active development.

Both financial analyses concluded that repowering tends to become financially attractive, relative to investing in a nearby greenfield site, after approximately 20–25 years of service. Plants less than 20 years old are expected to be capable of generating a favorable revenue stream for several more years. However, there are a number of critical variables that could alter both the timing and attractiveness of repowering. These variables include the rate of technological advancement, availability of quality wind resource sites, wholesale market prices for electricity, durability and reliability of turbine equipment over time, and the extent to which owners are able to reuse existing infrastructure in the future.

A single partial repowering scenario—replacement of only the turbine drivetrain and rotor—was also examined. As defined here, partial repowering was estimated to reduce the cost of repowering by about 10%, while achieving about 50% of the energy production improvements associated with full repowering. Under these conditions, partial repowering was determined to be less economically attractive than full repowering. It should be noted however, that partial repowering can take many forms. If other concepts for partial repowering can be developed and offer reduced operation and maintenance costs or increased energy production at substantially lower costs than full repowering, such opportunities may well be financially sound.

Assuming a plant life of 20–25 years, demand for repowering is expected to be low over the next decade, reach a few hundred megawatts per year in the early 2020s, and achieve 1–3 gigawatts per year by the late 2020s. Total estimated value of the repowering market segment is estimated at $25 billion through 2030 (constant 2012 U.S. dollars) with the vast majority of this investment occurring in the latter half of the 2020s. Policy support in the form of financial incentives, as well as solutions to potential regulatory and contractual hurdles, would likely be necessary if an acceleration of repowering investment were desired.

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1 Introduction

As wind power facilities age, project owners are faced with plant end-of-life decisions. In many cases, technological advancement suggests that project owners might be able to increase their profits by refurbishing or replacing older equipment. However, end of life decisions are often far from straightforward. Older facilities are typically fully depreciated and paid for, leaving any remaining revenues after operation expenditures essentially as profit. In addition, the potential for new contractual or regulatory terms when making substantial alterations at an existing site can also present hurdles. This report is intended to inform policymakers and the business community regarding the history, opportunities, and challenges associated with plant end of life actions, in particular repowering.

Repowering as defined in this report entails two types of actions. Full repowering refers to the complete dismantling and replacement of turbine equipment at an existing project site, including the tower and foundation. With full repowering, some of the existing project infrastructure (e.g., roads, buildings, and interconnection equipment) is assumed to be utilized in the new project. There is also the potential to offset repowering costs by recycling or selling the older equipment. Partial repowering is defined as installing a new drivetrain and rotor on an existing tower (with an allowance for some structural tower modifications); some peripheral components, such as the power convertors and electronics, may also be replaced. Partial repowering allows existing wind power projects to be updated with equipment that increases energy production, reduces machine loads, increases grid service capabilities, and improves project reliability. Performance improvements associated with partial repowering are assumed to be lesser than under full repowering but greater than the original design of the machine.

The remainder of Section 1 entails a brief history of global wind plant repowering activities and trends, and summarizes the findings that have emerged from past research. In Section 2 and Section 3 financial analyses are conducted that examine the economic drivers of repowering with historical and projected cost and performance estimates and case studies. Estimates are carried out to better understand the expected lifetime of U.S. wind power plants. In Section 4 and Section 5, these results are used to derive estimates of the total repowering market and equipment demand resulting from repowering activities. Section 6 discusses policy considerations and other relevant decision drivers around repowering. The report concludes with a summary of key results and takeaways.

1.1 History and Status

Repowering first emerged in the early 1990s in the California and Danish wind power markets and was followed by the Dutch and German markets in the 1990s and 2000s (White and Gipe 1993; Knight 2004; Hulshorst 2008; Munksgaard and Morthorst 2008). There has also been interest in repowering in India and other parts of the world (e.g., Kharul 2008; Goyal 2010; GlobalData 2012; Filgueira et al. 2009). Based on the data reviewed, Denmark and Germany have generally been the most active repowering markets, followed by California.

Denmark was the first country to actively promote repowering (Wiser 2007; Sperling et al. 2010). Public policy support for repowering was first instituted there in 1994 (Sperling et al. 2010). In 2001, policy support was adjusted to provide an additional premium on top of the standard feed-in tariff for repowered projects that previously used turbines smaller than 100 kilowatts (kW) (Sperling et al. 2010; Wiser 2007). Additional incentives beyond the standard feed-in tariff remain in place for repowered projects that previously used turbines smaller than 450 kW (Sperling et al. 2010). Under the policy scheme in place from 2001 through 2003, it has been estimated that 1,208 turbines were replaced, resulting in an increase in capacity of 202 megawatts (MW) (Sperling et al. 2010). The stated goal under the policy scheme in place since 2004 (although modified in 2008) is for an additional 175 MW of existing capacity to be replaced by 350 MW of new capacity (Sperling et al. 2010). At least one source indicates that Denmark was the largest repowering market in 2011 with an estimated 213 MW of repowered wind generation (GlobalData 2012).

Suggested barriers to repowering in Denmark have been anecdotally observed to be greater capital requirements of modern wind power projects and shifting ownership models from community-based local ownership to larger corporate or utility players. Wiser (2007) also suggests that, similar to California, industry stakeholders see relatively limited economic incentive to replace a project that continues to operate and generate revenue.

Germany has been estimated to have the largest market potential for repowering, estimated at nearly 6,000 MW by 2015 (BWE 2011). However, in spite of more favorable treatment than greenfield projects due to the country's feed-in tariff laws, which incentivize repowering, repowering activities to date have still been limited (Wiser 2007; BWE 2008; BWE 2011). Through 2005, an estimated 59 MW of wind turbines were removed from service and replaced by 169 MW of new capacity (Wiser 2007). Since then, repowering activities have continued but remain modest. The German Wind Energy Association (BWE) reports (BWE 2008; BWE 2011) that in 2007, an additional 108 turbines (41 MW) were replaced with 45 new turbines (203 MW). In 2010, 183 MW of new equipment were installed at previously developed sites; in 2011, 170 turbines (123 MW) were replaced by 95 turbines (238 MW) (GlobalData 2012). The above annual repowering statistics represent a relatively small share of the potential installations that could be repowered in Germany (BWE 2008), and under the current energy policies, repowering appears not to be profitable until an installation has been operating for at least 15 years (Knight 2004).

Repowering in Germany has been limited by local hub and total turbine height restrictions as well as requirements for setbacks from existing residential areas (Wiser 2007). In addition, the BWE has noted that the existing incentives for wind power are insufficient to drive large-scale shifts in the repowering market in Germany (BWE 2008).

Despite its status as a pioneer in the repowering space, California has struggled to develop a robust repowering market due to a variety of policy and regulatory challenges. White and Gipe (1993) observed that repowering was likely affected by the contractual requirements negotiated in the original sales agreements under the Public Utility Regulatory Policy Act standard offer contracts of the 1980s. Stipulations around the federal production tax credit (PTC) also apparently stifled repowering efforts in California (Wiser 2007; Wiser et al. 2008).[1] Under all but the most conservative assumptions, prior analysis suggests that there is little economic incentive

[1] The literature occasionally refers to the "California Fix," whereby projects are ineligible for the PTC if after repowering they remain on their existing standard offer contract entered into prior to 1987.

for functioning California projects to pursue repowering (Wiser et al. 2008).[2] Through 2007, it was estimated that 365 MW of capacity had been repowered in California (Wiser et al. 2008) with more than 70% of that occurring before 1999 (Wiser 2007). Total repowered capacity through 2007 was equivalent to about 20% of the installed wind power capacity in the state in 1994, further suggesting that significant technical potential for repowering in the California market remains (Wiser et al. 2008).

Other repowering activities have been observed in a limited number of cases in the Netherlands and India (e.g., Grontmij; RWE Innogy; Ramesh), and analysis of the potential economics of repowering has been conducted in Spain (Filgueira et al. 2009). However, repowering activities in these countries have not been widespread.

Repowering efforts have overwhelmingly resulted in full turbine replacements as opposed to partial repowering (White and Gipe 1993; Knight 2004; Fairley 2009; Wiser et al. 2008; Ramesh; RWE Innogy; Grontmij).[3] This is a result of the rate at which wind power technology has improved. Even if existing equipment were refurbished, new turbines are often capable of generating much more energy than the existing equipment (Filgueira et al. 2009; Knight 2004). Moreover, the replacement of smaller turbines could allow some increase in the potential generating capacity from a given land area; as a result, countries with relatively few high-value wind resource sites are likely to prefer full repowering at these sites when wind power- or climate-related policy provisions are under consideration.

The literature has indicated two solutions for equipment removed from an existing site. California projects repowered in the early 1990s were largely forced to scrap the existing equipment due to dramatic improvements in technology (White and Gipe 1993; Knight 2004). Repowering efforts in the early 2000s in Europe (for projects using equipment that was approximately 10 years old) were more successful in their attempts to refurbish and sell the dismantled turbine equipment into emerging markets in eastern Europe and other parts of the world (Knight 2004).

1.2 Critical Variables Influencing Trends

Historically, repowering has been viewed as a possible means of increasing project productivity, improving grid support and grid interactions, extending the use of existing infrastructure investments, more efficiently utilizing high-value resource areas, and in some cases (e.g., single turbines or a single linear array), enabling greater installed capacity in a given land area (White and Gipe 1993; Kharul 2008; Hulshorst 2008; Fairley 2009; Filgueira et al. 2009; Wiser et al. 2008). Repowering has also been cited as a means of reducing the visual impact or clutter of wind power projects because for a given capacity rating, it reduces the number of turbines in a specific location (Knight 2004; Wiser et al. 2008; Filgueira et al. 2009; Meyerhoff et al. 2010). At the same time, it has been observed to potentially increase visual and aesthetic impacts by introducing new machines that are significantly larger and taller than their predecessors (Meyerhoff et al. 2010; Sperling et al. 2010). Repowering is generally anticipated to reduce

[2] Presently, no data are available detailing functioning versus nonfunctioning wind power plants in California.
[3] It should be noted, however, that partial repowering can in fact take many forms. It is feasible that more basic turbine upgrades incorporated through power electronics or other means could occur with much greater frequency than forms of partial repowering that involve more extensive overhaul and replacement of turbine components.

operation and maintenance (O&M) costs by deploying newer, more reliable equipment and by reducing the number of moving parts when moving to larger turbines (White and Gipe 1993; European Wind Energy Association 2009).[4] Repowering has also been noted to offer the possibility of reduced avian and wildlife impacts, at least for some species. However, broad-based data on the empirical change in impacts before and after repowering are not available, making it difficult to confirm this potential characteristic of repowered facilities (Wiser et al. 2008; Hotker 2006; Smallwood and Neher 2010).

Fundamentally, however, profitability for a given project is the primary driver of repowering decisions. Given limited financing, the anticipated profitability at alternate greenfield sites is also relevant. One's ability to extend, amend, or re-enter power purchase agreements (PPAs) with a creditworthy off-taker and to secure potential additional sources of revenue such as renewable energy certificates is another factor. These themes are consistent throughout markets for wind power around the globe.

Detailed financial modeling conducted by Wiser et al. (2008) suggests that the profitability of repowering is highly dependent on project-specific performance and annual operation expenditures. Wiser et al. (2008) also found that older projects can be expected to continue to operate profitably for many years, as long as the projects continue to function within a reasonable range of performance and are able to avoid dramatic upticks in annual operation expenditures. They conclude that in the absence of additional financial incentives, it is often in the project owner's interest to continue to produce power at an existing facility rather than to repower. Experience from Germany confirms this finding (Knight 2004).

[4] The parts counts of modern turbines relative to their predecessors are generally comparable; however, by reducing the number of machines required to achieve a specific rated capacity, one can reduce plant-wide moving parts by simply installing fewer turbines that are far greater in their rated capacity than the original equipment.

2 General Economic and Financial Feasibility

An initial assessment of the economics of repowering was developed from aggregate U.S. wind industry data. This analysis extends and updates prior work by Wiser et al. (2008), which focused on the California market. Although this approach does not capture the complete array of local and regional variabilities among projects, it provides a basic level of visibility—from the project owner's perspective—regarding the point at which repowering might be considered an attractive investment opportunity.

2.1 Methods

Repowering opportunities are examined through 2030 for existing plants. The analyses consider both full and partial repowering. The analyses presume capital is available to invest in wind infrastructure. Repowering is analyzed as a potential investment opportunity relative to developing a new adjacent greenfield. If neither of these options results in added value to the project owner, it is assumed the owner will simply maintain the existing plant and invest available capital in other opportunities.

Adjacent greenfields were chosen as the point of reference for alternative wind power investment opportunities based on anecdotal evidence and feedback from industry obtained through semi-structured interviews. These data sources indicated that new greenfield opportunities in proximate or adjacent locations to older facilities do exist. This suggests that the comparison to an adjacent greenfield is a realistic tradeoff considered by the development community. This approach also simplifies the analysis by eliminating the need to estimate wind resource conditions for the "typical" greenfield project at future points in time. It should be noted, however, that the ability to place a new greenfield in an adjacent site with essentially the same wind resource as the existing facility increases the attractiveness of the greenfield relative to repowering.

To understand how repowering opportunities might vary as technology and the industry have evolved, repowering is examined independently for plants commissioned at four points in the past: 1999, 2003, 2008, and 2012. Table 1 details the assumed plant parameters for projects completed in each of these years. Plant costs and performance are based on historical industry data (Table 2 and Table 3) reported by Wiser and Bolinger (2012). By emphasizing aggregate industry data, the analysis is representative of facilities commissioned in each of the respective years but not necessarily indicative any single plant's characteristics.

Table 1. Key Capacity-Weighted Average Turbine Parameters for Technology Considered for Repowering in This Analysis

Year Commissioned	Turbine Rating (MW)	Hub Height (m)	Rotor Diameter (m)
1999	0.7	56	48
2003	1.2	66	64
2008	1.7	79	79
2012	2.1	85	95

Full repowering is considered as a possibility for each of the existing plants at four points in the future: 2015, 2020, 2025, and 2030. In addition, for 2003-commissioned plants, the potential for partial repowering is also considered. Partial repowering is examined explicitly for this 2003 plant because of its relatively modern technology compared with 1999 plants (Table 1), and unlike plants commissioned later (e.g., 2008 and 2012), it was determined to be a viable candidate for full repowering within the time period considered in this analysis. For the 2003 facility, partial repowering is analyzed for 2025, the year in which full repowering becomes the preferred investment relative to an adjacent greenfield.

In order to analyze the viability of repowering, conceptual projects with specific cost and performance characteristics were evaluated and defined (for full repowering and new greenfield projects) at each of the prescribed future investment dates (2015, 2020, 2025, and 2030). Partial repowering costs and performance were estimated for 2025 (Table 2). Future plant costs, performance, and estimated PPA prices are based on historical trends, National Renewable Energy Laboratory (NREL) technological advancement projections detailed in Chapman et al. (2012), and semi-structured interviews with plant owners. Defining future technology cost and performance is critical, as repowering decisions are functions of current plant performance and the value added by investing in new state-of-the-art technology. Key financial modeling inputs are summarized in Table 3.

Table 2. Summary of Financial Modeling Inputs for Existing and Future Facilities by Year of Project Commissioning[a]

Plant Commission Date	Installed Capital Cost			Net Capacity Factor[b]			PPA Price[c]		Operations Expenditures (Year 1)	
	Greenfield 2012 $/kW	Repower 2012 $/kW	Partial Repower 2012 $/kW	Greenfield	Repower	Partial Repower	2012 $/MWh	PTC Available	Fixed 2012 $/kW-yr	Variable 2012 $/MWh
1999	1,672			28.1%			50	Yes	12.5	10.2
2003	1,402			29.8%			35	Yes	12.5	8.2
2008	1,998			33.7%			57	Yes	12.5	6.1
2012	1,890			35.6%			52	Yes	12.5	6.1
2015	1,862	1,769		41.0%	41.0%		63	No	12.5	6.1
2020	1,816	1,725		42.0%	42.0%		57	No	12.5	6.1
2025	1,770	1,681	1,504	43.0%	43.0%	37.2%	53	No	12.5	6.1
2030	1,712	1,626		43.0%	43.0%		51	No	12.5	6.1

[a] Historical data are derived from Wiser and Bolinger (2012); future data are derived from NREL cost projection analyses (e.g., Chapman et al. 2012; U.S. Department of Energy 2008), current industry trends, and semi-structured interviews with owner operators.

[b] Future net capacity factors are equivalent for greenfield and repowering developments, as the analysis assumes a proximate or adjacent facility in a comparable wind resource area; the apparent discontinuity between 2012 and 2015 is the result of recent technology advancements that have brought larger rotor and taller tower machines to the market. Historical data are intended to reflect the performance of plants installed in a specific year.

[c] The historical PPA prices shown in this table are reported contract values (Bolinger 2013). As a result, the PTC should be considered as an additional revenue stream above and beyond that reported here. This analysis assumes a one-year delay between PPA contract execution date and project commissioning.

Underlying data sources, trends, and justifications for the project cost, performance, and revenue characteristics summarized in Table 2 are described in greater detail here:

- **Installed capital cost:** Costs declined from 1999 to 2003 but then increased 2004–2010 (Wiser and Bolinger 2012). Today, however, costs have once again begun to decline with projects in development anticipated to have 20%–30% lower installed costs than during 2009 and 2010 (Wiser et al. 2012). Future assumptions include a continual, but slower, decline in installed costs in line with other independent projections in the literature (Lantz et al. 2012; Chapman et al. 2012).

  Fully repowered plants are assumed to have slightly lower (5%) total installed capital costs as a result of the ability to reuse or repurpose existing plant infrastructure noted above. Although actual savings will vary from project to project, semi-structured interviews completed as part of this effort and the literature reviewed above suggest a 5% cost savings is feasible. Partial repowering is estimated to result in an approximately 15% cost savings as a result of reusing existing infrastructure as well as cost savings on towers and foundations.

- **Net capacity factor:** Historical net capacity factors were estimated for plants commissioned in a specific year and grounded in historical averages reported by Wiser and Bolinger (2012). However, larger rotors and taller towers, along with other technological advancements, have resulted in significant increases in net capacity factors for utility-scale wind plants over the past 13 years (Lantz et al. 2012). Changes are particularly evident when examined across fixed wind resource areas with an emphasis on performance resulting from the latest turbine models rather than fleet-wide data (Wiser et al. 2012). Future installations assume net capacity factor improvements as a result of increased turbine optimization for a given site as well as continued incremental technology improvements.

  Both repowered and new adjacent greenfield facilities are anticipated to bring about substantial (Wiser et al. 2012; Chapman et al. 2012) and equivalent improvements in net capacity factor. The latter is assumed as a result of comparing repowered facilities with adjacent greenfields where a comparable wind resource is likely. Partial repowering is assumed to achieve approximately 50% of the anticipated energy production improvement at a given site that results from full repowering. Energy production gains from partial repowering are assumed to be limited by the original assets that continue to be used (e.g., the tower and foundation).

- **PPA prices:** Existing plant revenues are approximated from historically bundled (renewable energy certificates and electricity) PPA price data reported by Bolinger (2013) and assume the PTC is utilized. Future project revenues assume current federal policy (PTC expiration at year-end 2013) and PPA pricing estimates that are aligned with wind power levelized cost of energy projections (Lantz et al. 2012). PPA escalation is estimated to increase about 1% (nominally) per year (Bolinger 2013). The PPA escalation rate is based on a composite mix of PPA contracts that escalate in line with inflation and others that have no stated escalation rate.

- **Operations expenditures:** Historical data (Wiser and Bolinger 2012) indicate that variable O&M costs have dropped over the past 13 years. Analyses conducted here assume year one total operation expenditures have fallen in the past but are constant into the future (Houston 2013). As facilities age, total operation expenditures are assumed to escalate at 2% above inflation (a 4.5% nominal escalation rate).[5] Operating costs are considered to be equivalent for new greenfield and repowered facilities (both full and partial).

Table 3. Financial Modeling Constants Across Scenarios

Inflation	2.5%
Discount rate (nominal)	9%
Cost of financing (nominal)	9%
PPA escalation rate (nominal)	1%
O&M escalation rate (nominal)	4.5%

Data Sources: Wiser et al. (2012), Bolinger (2013), Tegen et al. (2012), and the Bureau of Labor Statistics (2012)

The evaluation of investment options is based on a comparison of the net present value (NPV) of future after-tax cash flow. Specifically, the change in projected NPV for repowered facilities is compared with the change in projected NPV from future cash flows of an existing facility plus the NPV from a new adjacent greenfield plant. This comparison is appropriate because a greenfield investment decision allows the existing plant to continue generating revenue, while repowering replaces the existing plant's revenue stream with an alternate one (the repowered revenue stream). After-tax cash flows are included in the NPV as long as they remain positive or until 30 years of operation.[6] Potential positive cash flows estimated after 30 years of operation are not considered for any projects (existing, repowered, or greenfield) as a result of potential step functions for operating costs that are not captured by applying a generic operating expense escalation rate (Table 3).

NREL's System Advisor Model (SAM) was used to calculate expected future cash flow. Post analysis processing of these data allowed calculation of the NPV for a project's remaining cash flow and development of a uniform comparison in 2012 dollars for each of the potential future investment points.

2.2 Results

The data presented here represent the change in estimated NPV (2012 dollars) of after-tax cash flow resulting from the addition of a greenfield plant (i.e., the combined cash flows of the existing plant and the new adjacent greenfield) or repowering of each representative historical wind plant detailed above. In effect, the data illustrate value gained or lost as a result of a specific investment decision. As each of these plants is modeled at an equivalent size, plant-specific NPVs can be compared across time. However, caution is advised against any direct assessment of wind plant profitability or return on investment as the overall magnitude of NPV is highly correlated to plant size. Moreover, as the data presented represent the change in NPV

[5] This is the approximate annual inflation rate necessary to achieve a levelized pre-tax O&M cost comparable to the value assumed by Tegen et al. (2012).
[6] Negative after-tax cash flows are excluded based on the premise that plants will not be operated at a loss.

relative to simply maintaining the existing facility, they do not represent the full NPV from a given investment. Results from both the repowered and greenfield facilities assume a common reference project size of 100 MW.

Based on the inputs and analyses completed, wind power plants built in 1999 appear to be reasonably profitable moving into their 14th year of operation. In part, this is the result of relatively favorable PPAs signed during this time and relatively low capital costs. Nevertheless, the age of this facility and the advancements in technology that have occurred to date suggest that action in the near term is likely merited. Data analyzed here indicate that in 2015, after 15 full years of operation, overall profitability for a plant built in 1999 can be enhanced by repowering or by building an adjacent facility (Figure 1). If asked to choose the more lucrative option, this analysis indicates that developing an adjacent greenfield adds more value than simply repowering. By 2020, after 20 years of operation, the result is relatively similar with both alternatives adding value, but the combined assets of the new greenfield and the existing facility appear to be most profitable.

Full repowering becomes more attractive than an additional new greenfield sometime between 20 and 25 years of operation, for plants built in 1999; it is an increasingly attractive alternative as time progresses.

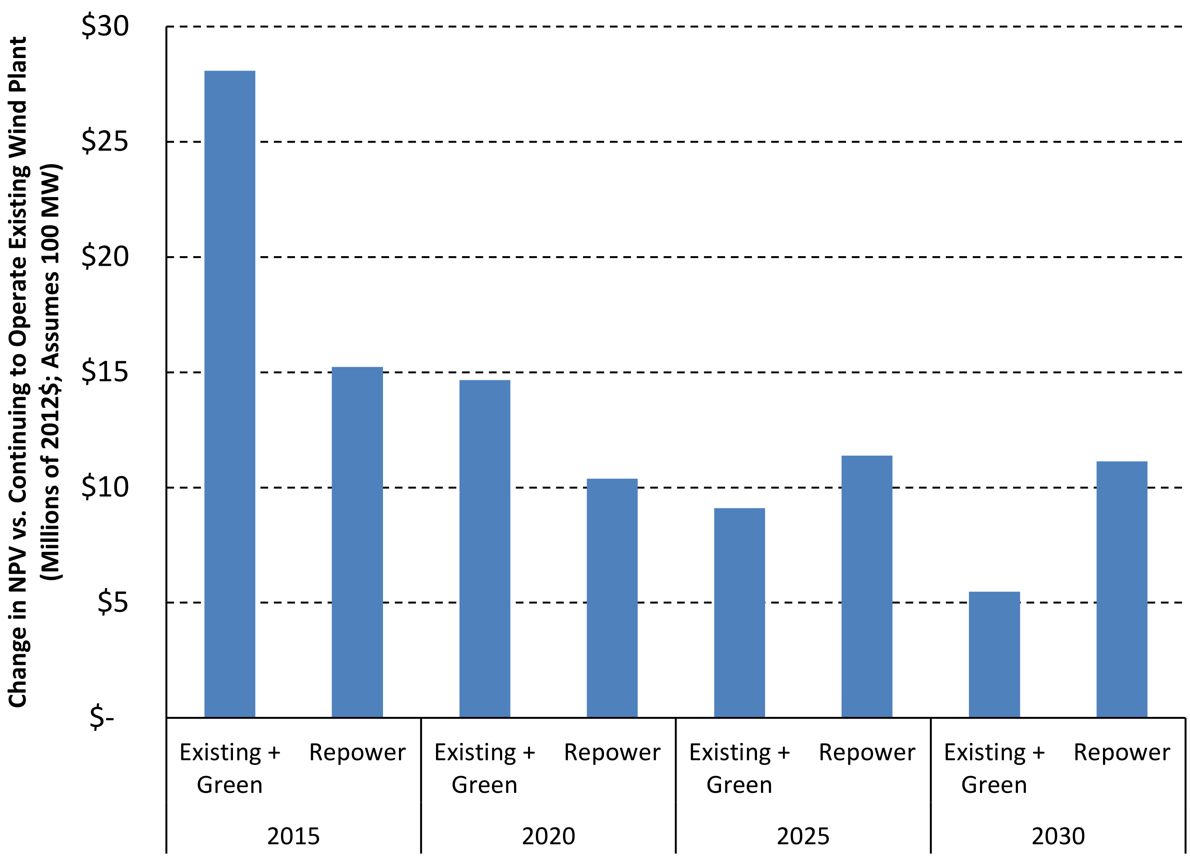

Figure 1. Value added to a 1999 wind plant as a result of investing in a new greenfield or full repowering

Note: Assumes common reference plant size of 100 MW

Figure 2 illustrates, in the same manner, the results for a wind plant commissioned in 2003. For this facility, analysis suggests that building an adjacent greenfield plant in 2015 and 2020 (after 11 and 16 years of operation, respectively) is again the preferred alternative relative to full repowering. However, in this case it is between 16 and 21 years of operation (2020–2025) that repowering becomes financially preferable, somewhat earlier in the life of the plant than for the 1999 plant. In part, the somewhat shorter anticipated life for the 2003 plant is a function of its lower estimated PPA price and the relatively slight improvement in net capacity factor observed for the 2003 facility relative to the 1999 facility. Combined with lower profitability overall for this plant, increasing operational costs begin to erode the value of 2003 vintage plants earlier in their life than plants commissioned in 1999 or later.[7]

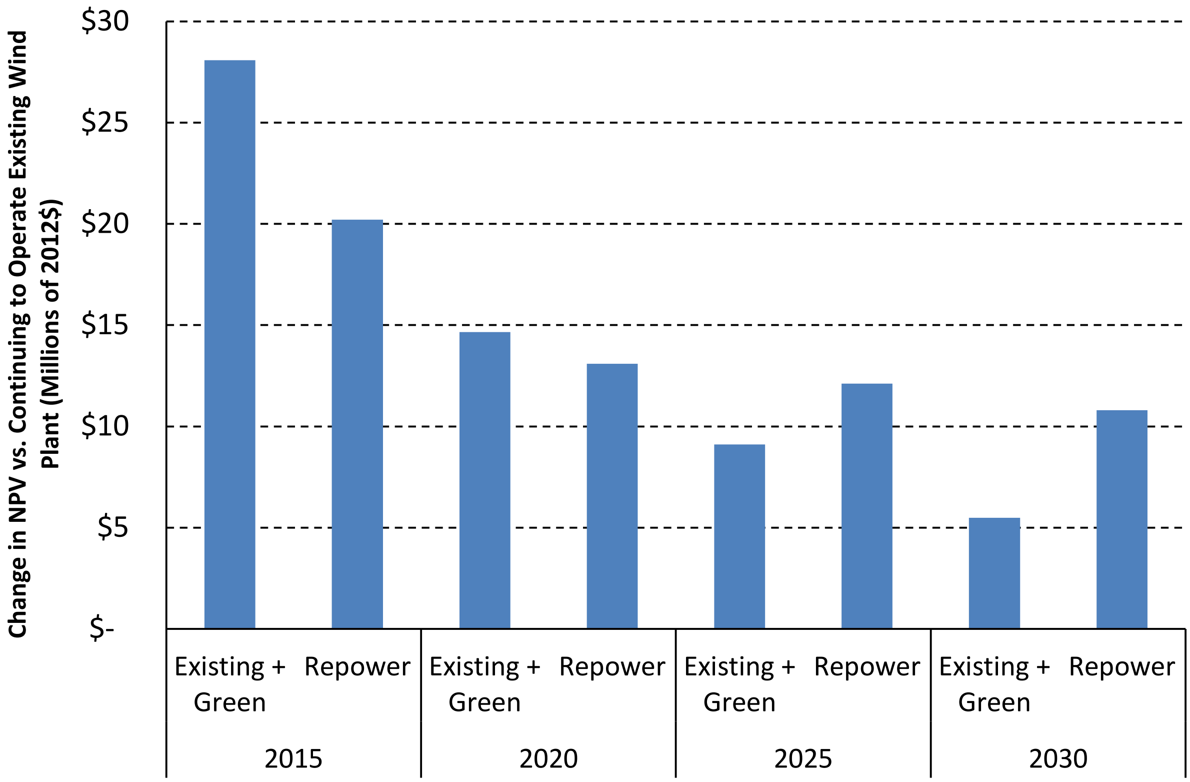

Figure 2. Value added to a 2003 wind plant as a result of investing in a new greenfield or full repowering

Note: Assumes common reference plant size of 100 MW

Results for the plants commissioned in 2008 and 2012 are presented in Figure 3 and Figure 4, respectively. For both the 2008 and 2012 plants, building an adjacent new greenfield project is the financially preferable option through 2030. In fact, throughout this time period (as many as 21 and 17 years of operation, respectively), full repowering results in a reduction in the NPV of future after-tax cash flows. For the 2008 facility, this is in part the result of historically high

[7] The authors note, however, that even though this analysis indicates that repowering might be financially attractive after only 16–21 years, owners/operators might not ultimately choose to repower within this timeframe as a result of project-specific financing, depreciation, or other constraints.

PPAs signed during this period. Also playing a role are the assumed declines in PPA pricing associated with future technology advancements and cost reductions. Regardless of drivers, more recent plants appear to have substantial value remaining beyond 20 years. Accordingly, these projects could delay repowering investments until 25 years of operation or beyond.

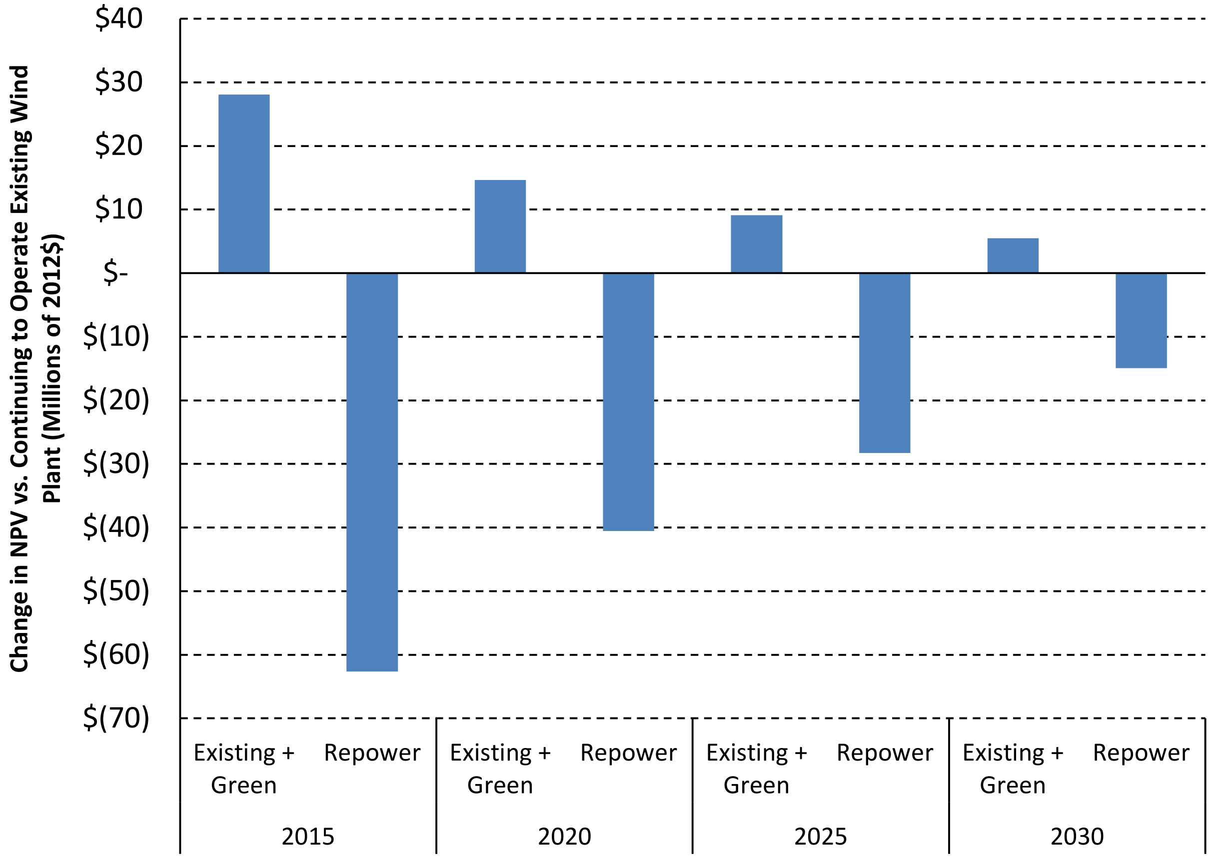

Figure 3. Value added or lost as a result of investing in a new greenfield or full repowering for a 2008 wind power plant

Note: Assumes common reference plant size of 100 MW

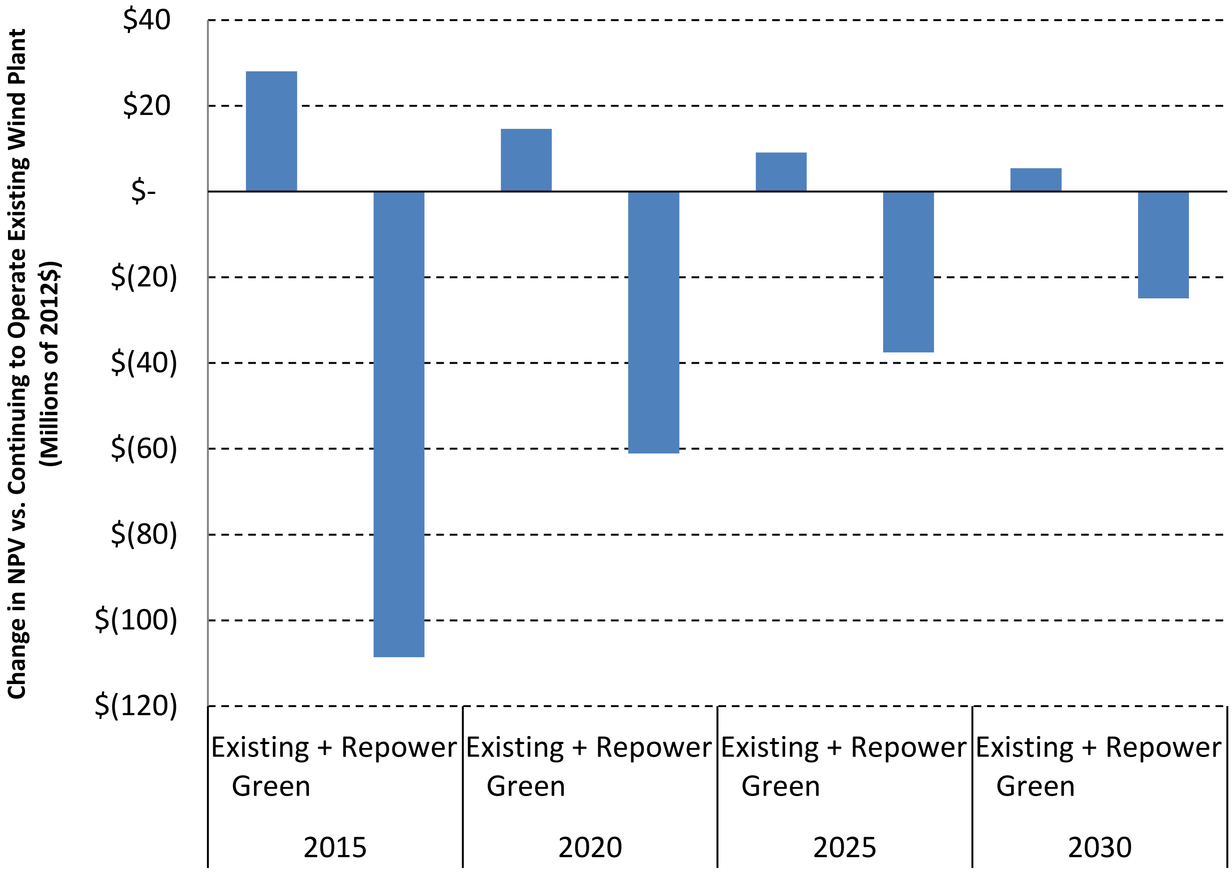

Figure 4. Value added or lost as a result of investing in a new greenfield or full repowering for a 2012 wind power plant

Note: Assumes common reference plant size of 100 MW

Partial repowering is examined for the 2003 plant only. Figure 5 demonstrates the results for partial repowering relative to full repowering as well as building a new adjacent greenfield facility. Results are shown specifically for 2025 when full repowering was determined to be the preferred alternative. Based on the inputs summarized in Table 2 and Table 3, partial repowering offers less added value to an owner/operator than either full repowering or building an adjacent greenfield. This is primarily due to the lower net capacity factor resulting from not replacing the tower, and hence not accessing stronger winds aloft, coupled with the modest additional cost savings to be gained by keeping the existing tower and foundation intact. It should be noted that this conclusion is based on the concept of partial repowering that was identified and defined earlier. Were innovations to emerge that boost the productivity of aging equipment at less cost than estimated here, partial repowering could be more attractive.

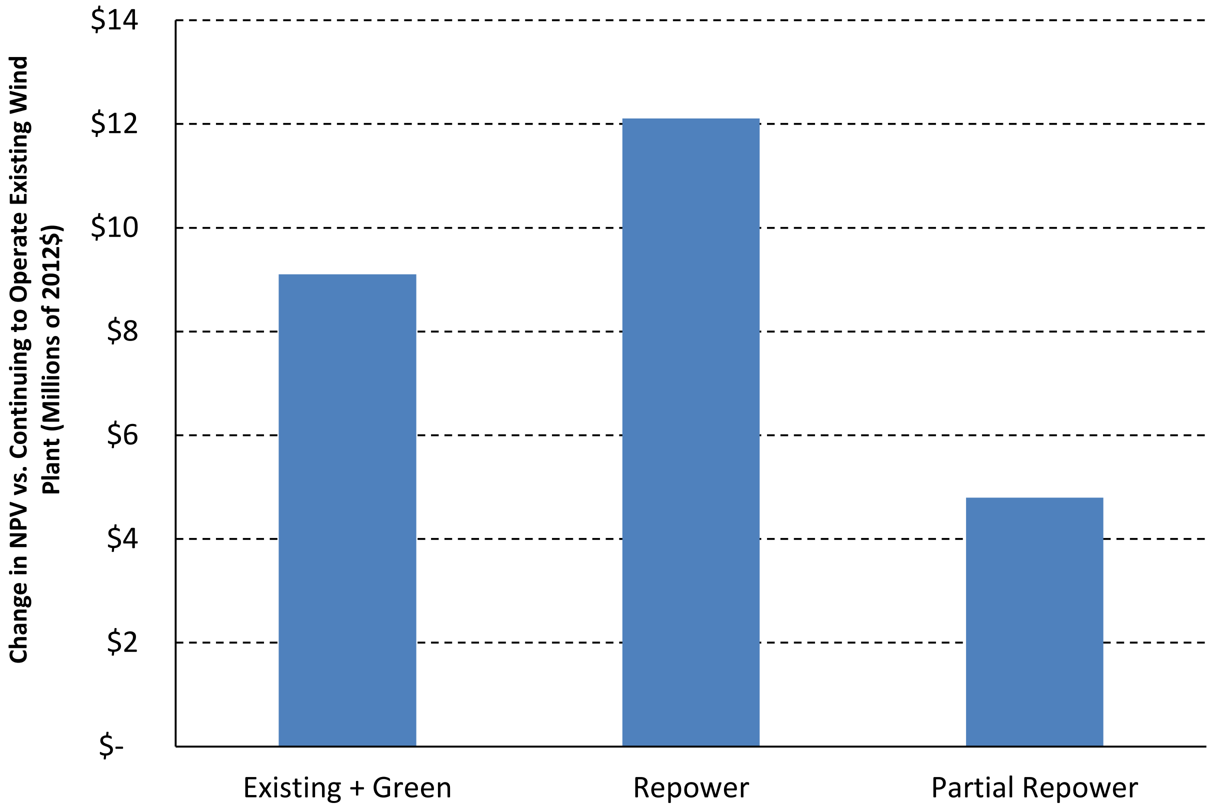

Figure 5. Value added to a 2003 wind plant as a result of investing in a new greenfield, full repowering, or partial repowering in 2025

Note: Assumes common reference plant size of 100 MW

3 Case Study Analysis

The financial modeling completed within the general economic feasibility assessment is supplemented by additional modeling and semi-structured interviews with project owners. These efforts focus on repowering opportunities within three specific regions of the United States: the Northeast, Midwest, and West Coast. This approach offers a more nuanced perspective on the repowering opportunity. In addition, this supplemental work serves as a check on the more general conclusions drawn from industry-wide analysis covered in Section 2.

3.1 Methods

Analytically, the case study analysis was carried out in an equivalent manner as the more general economic analysis. Modeling was performed using SAM, and the change in NPV of after-tax cash flows was compared across the two specific investment opportunities (repowering or developing an adjacent greenfield). Notably, the case study analysis focuses only on full repowering, as partial repowering was determined to offer less added value than full repowering (Figure 5). However, unlike the more general assessment, which emphasized aggregated industry data, the case study approach developed modeling inputs for existing plants that were specific to actual projects within the three regions considered. Table 4 summarizes the general characteristics and modeling input variables for the plants chosen for analysis.[8]

Criteria for plant selection included geographic diversity, an operation history of at least 10 years, and the presence of recent, or ongoing, development at an adjacent greenfield site. Choosing existing wind plants with new greenfield sites in active development provided a more refined look at real-world factors such as installation costs, expected performance, and PPAs that were appropriate for those locations at the present time. In principle, this approach ties the case study analysis to more realistic conditions faced by project owners.

To gather relevant data for these sites, a three-step process was undertaken. First, Web-based inquiries were conducted with the intent of extracting key project characteristics for the existing plants and the adjacent greenfield projects. Characteristics such as number of turbines, nameplate capacity, and expected initial net capacity factor were collected from project websites and archived news articles. Second, spreadsheet forms were distributed to contacts at all of the companies that own or operate the respective wind plants or those who are developing the nearby greenfield sites. Owner/operator contacts were asked to provide supplemental data to fill in the gaps that were missing from publicly available sources. Third, relevant modeling input data were solicited from the industry databases maintained by Lawrence Berkeley National Laboratory and summarized by Wiser and Bolinger (2012). Where data were not available, estimates based on comparable projects (both in terms of age and technology type) were developed to allow for completion of the financial modeling. Given some persistent data gaps, follow-up semi-structured interviews with plant owners/operators were conducted to obtain reactions and review of results. Final modeling input data and assumptions are summarized in Table 4 and Table 5.

[8] Note that Table 4 contains ranges to protect the confidentiality and anonymity of the specific plants being analyzed.

Table 4. Key Characteristics and Assumptions for the Three Case Study Wind Plants

	Commercial Operation Date	Turbine Size (MW)	Plant Rated Capacity	Average Annual Net Capacity Factor	PPA Price/ MWh	Installation Cost 2012$/kW	Federal Incentive Utilized	Year 1 OpEx	
								Fixed (2012$/ kW-yr)	Variable (2012$/ MWh)
Northeast Wind Plant									
Existing	1995–2000	0.5–1.0	5–10 MW	20%–25%	91	2,400–2,900	PTC	12.5	11.2
Nearby greenfield	2010–2015	1.5–2.5	25–35 MW	32%–37%	88	2,400–2,900	PTC	12.5	6.1
Repower existing[a]	2010–2015	1.5–2.5	25–35 MW	32%–37%	88	2,300–2,800	PTC	12.5	6.1
West Coast Wind Plant									
Existing	1988–1993	< 0.5	45–55 MW	17%–22%	135	2,300–2,800	None	12.5	13.3
Nearby greenfield	2010–2015	1.5–2.5	95–105 MW	25%–30%b	115	2,900–3,400	PTC	12.5	6.1
Repower existing[a]	2010–2015	1.5–2.5	95–105 MW	28%–33%	115	2,700–3,200	PTC	12.5	6.1
Midwest Wind Plant									
Existing	1997–2002	0.5–1.0	10–15 MW	32%–37%	69	1,700–2,200	PTC	12.5	10.2
Nearby greenfield	2010–2015	1.5–2.5	25–35 MW	35%–40%	68	1,700–2,200	ITC/1603 Cash Grant	12.5	6.1
Repower existing[b]	2010–2015	1.5–2.5	25–35 MW	35%–40%	68	1,600–2,100	ITC/1603 Cash Grant	12.5	6.1

[a] Installation costs for "Repower existing" were again assumed to be 5% less than building a nearby greenfield site based on semi-structured interviews with developers/owners.

[b] For the West Coast case study, interviews with owners/operators indicated that finding a nearby greenfield site with as strong a wind resource as the existing wind site was unlikely given the large number of wind plants that have already been installed in this location.

Table 5. Financial Modeling Constants Across Case Study Scenarios

Inflation	2.5%
Discount rate (nominal)	9%
Cost of financing (nominal)	9%
PPA escalation rate (nominal)[a]	1%
O&M escalation rate (nominal)[b]	4.5%

[a] The Midwest plant PPA's escalation rate was assumed to be 0.2% for the existing plant, and 0% escalation for the greenfield and repower scenarios per guidance from semi-structured interviews. Moreover, as reported by Bolinger (2013) there are many PPAs signed today that are consistent with this approach and are constant in nominal terms with time.

[b] O&M escalation rate for the existing West Coast wind plant was assumed to be 5.5% given its earlier commissioning date.

3.2 Results

For the Northeast wind plant, which has 15–20 years of operation, both building a new greenfield site and repowering would increase the NPV of projected after-tax cash flows (Figure 6). Moreover, these two possible investment opportunities result in very similar NPVs, within 1%. Thus, although repowering does appear to be a viable option, one cannot conclude it is clearly favorable to building a new greenfield site.

For the West Coast plant, which is 20–25 years old, both building a new greenfield site and repowering also increase the NPV of projected cash flows above and beyond those resulting from simply maintaining the existing plant. However, in this case, repowering the existing wind plant was notably more lucrative than building a new greenfield site (Figure 6). In part, this is a result of the slightly lower net capacity factor assumed for a nearby greenfield site relative to a repowered facility. This assumption was applied in this specific case as a result of interviewees observing that the West Coast plant would have difficulty acquiring land to build an adjacent greenfield site with a similar high-quality wind resource.[9] However, the more critical factor is likely the overall age of the facility and its relatively low remaining cash flow. Under these conditions, the incremental cost savings from use of a portion of the existing infrastructure coupled with the slightly better wind resource at the repowered site result in repowering being the most attractive investment opportunity.

As in the previous two cases, building a new greenfield site and repowering the existing wind plant both resulted in an increase in the NPV of projected after-tax cash flows for the Midwest wind plant. However, as this facility has been in operation for only 10–15 years, and there are presumably many years of substantial profitability from this plant, building a new greenfield site is more lucrative than repowering the existing plant.

[9] This location is already extensively developed, making it relatively difficult to acquire adjacent land.

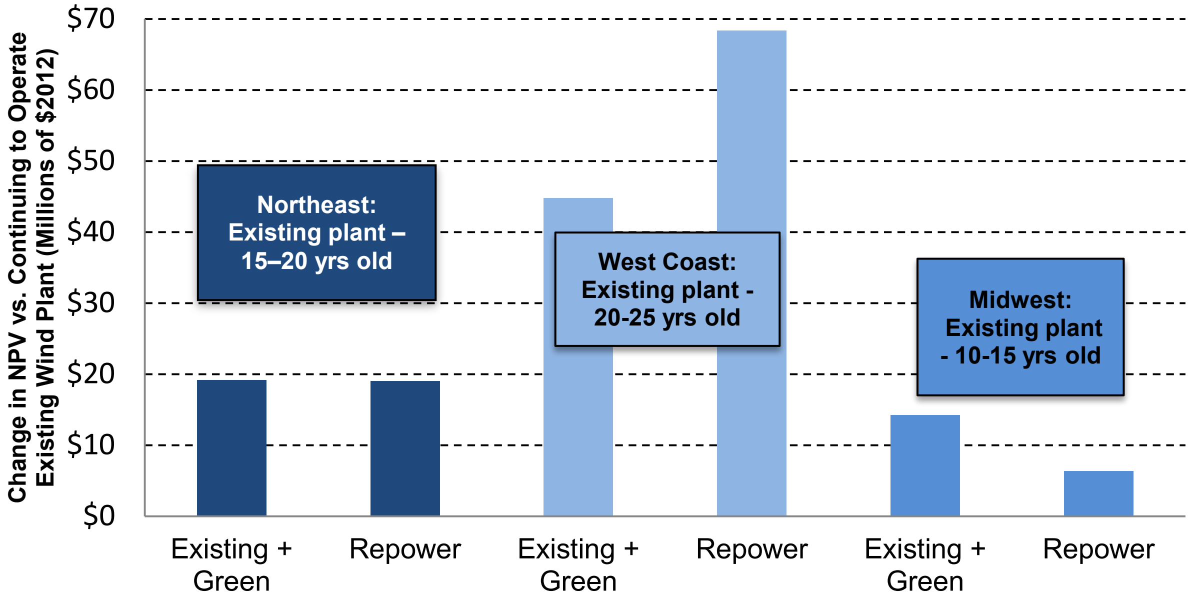

Figure 6. Value added to each case study wind plant as a result of investing in a new greenfield or full repowering

Note: Comparing the NPV across the three case studies is not appropriate. The absolute magnitude of the NPV is highly correlated with the size of the wind plant, as larger wind plants require higher levels of investment. Within each case study, it was always assumed that both greenfield and repowering decisions would be of the same size (i.e., same rated capacity) and thus can be fairly compared.

The results of these case studies support the findings generated by the economic analysis summarized in Section 2. Only after a wind plant has been in operation for more than 20 years does repowering provide a clear financial advantage relative to building a nearby greenfield site. Interestingly, the simulated results compiled here appear to align relatively well with current owner/operator financial assessments. Only one of these three plants—the West Coast plant—has been repowered to date.

4 Market Opportunity

Both the general economic assessment and the more specific regional case study analysis suggest repowering is likely to become attractive after 20–25 years of operation.[10] An anticipated plant life of 20–25 years is generally consistent with the typical contract life for wind facilities. Historically, wind power contracts have been 20 years in length with 15- and 25-year contracts signed as well (Bolinger 2013). Having identified the expected timeframe in which projects will consider repowering, the next element of this analysis is to quantify the market opportunity provided by repowering activity through 2030.

4.1 Methods

The market opportunity was quantified in terms of annual repowered capacity and expected value in constant 2012 dollars. Estimates are premised on 25% of existing facilities repowering after 20 years of operation and 50% repowering after 25 years of operation. The remaining 25% of the existing fleet is assumed to either continue to operate after 25 years or be decommissioned. As empirical data on actual repowering behavior are extremely limited, these estimates are intended for hypothetical purposes only. Given this timeframe, only existing plants will be making repowering decisions by 2030. Accordingly, this task relied on installations contained in the U.S. industry projects database (American Wind Energy Association 2012) to determine the potential installed capacity that might be repowered on an annual basis over the next two decades. Annual installed capacity estimates are calculated assuming a 1:1 replacement of capacity. However, if repowering results in increased capacity at a given site, as has been observed in Germany and Denmark, additional demand could result. The total repowering market value is estimated based on the calculated plant lifetime, projected turbine pricing, and installed cost estimates.

This approach represents a high-level estimate of the potential repowering opportunity. The actual magnitude of the repowering market will likely vary; nevertheless, the results presented here are anticipated to capture the general order of magnitude of the market segment in terms of both installed capacity and dollar value.

4.2 Results

The estimated plant life applied here suggests that repowering could be considered for about 40 gigawatts (GW) of the operating wind power fleet within the next two decades (i.e., plants commissioned by year-end 2010). Moreover, it suggests that there will be a substantial increase in repowering activity in the early 2020s as turbines installed in the late 1990s and early 2000s begin to approach the 20- to 25-year threshold where repowering begins to be attractive. Assuming 25% of the existing fleet repowers at or around year 20 of operation and 50% repowers at or around year 25 of operation, annual repowering activity in terms of megawatts repowered through 2030 are highlighted in Figure 7. With these conditions the effect is that 75% of the fleet does not repower before 25 years of operation; accordingly, the cumulative repowered capacity by 2030 is estimated to be slightly less than 14 GW.

[10] If technological advances are more rapid, costs for repowering are substantially lower relative to a new greenfield plant, or if capacity factors at new greenfields are notably lower than at repowered facilities, repowering could occur earlier than projected in Section 2 and Section 3.

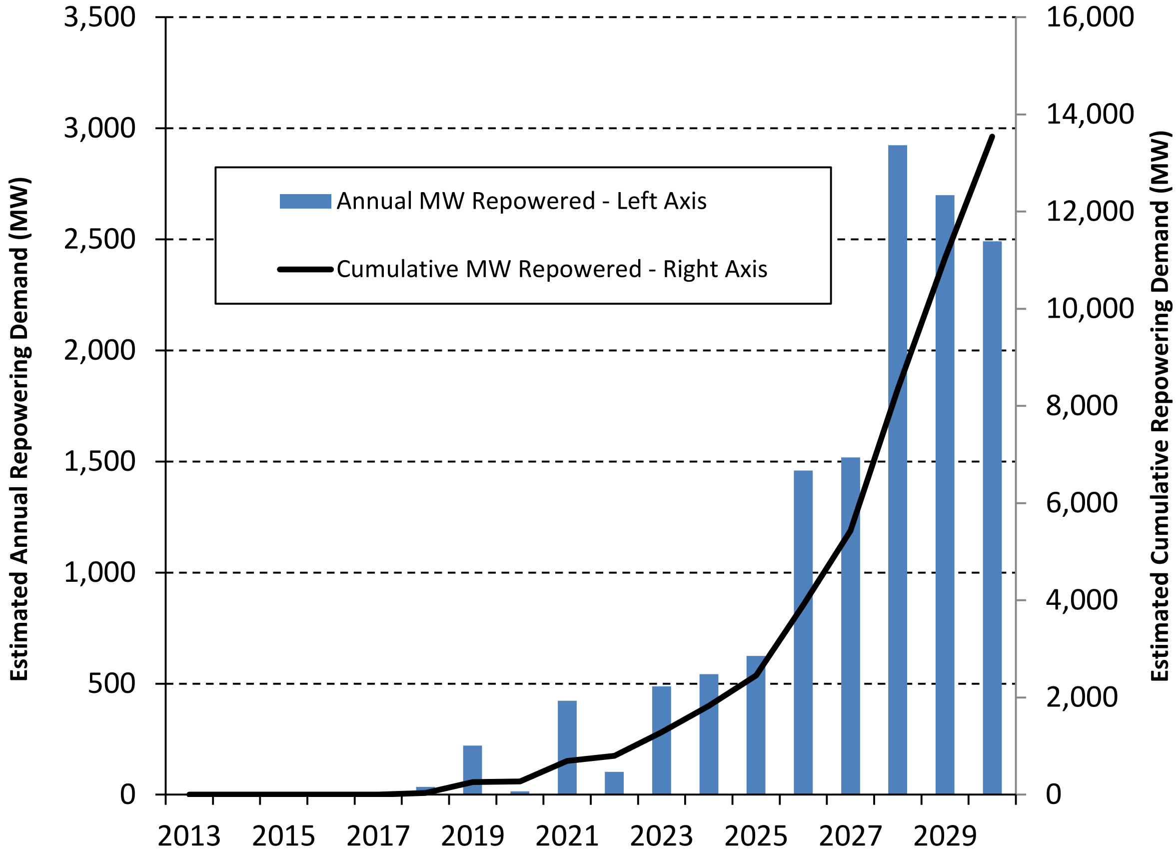

Figure 7. Estimated annual capacity repowered by year

Note: Results assume 1 MW of existing capacity is replaced by 1 MW of repowered capacity.

The total future value of repowering activity through 2030 is estimated at $20–$25 billion. Once repowering begins to take an active foothold in the market around 2023, the annual value of the market segment is anticipated to be roughly $1 billion per year through 2025 and increases to about $5 billion per year in 2028.

5 Supply Chain Impacts

Based on the potential range of incremental new demand resulting from repowering activities, impacts to the supply chain are calculated in terms of demand for new blades, drivetrains, and turbines. As a result of the uncertainties noted above—in terms of the percentage of eligible sites that actually repower and the percentage of partial versus full repowering—this analysis seeks simply to provide a basic order of magnitude estimate for changes in demand, given the estimated levels of repowering and assuming that all repowering activity is full repowering.

5.1 Methods

Projected technological advancement[11] is coupled with anticipated repowering activity to estimate total repowering demand and demand for specific component sizes. Given the relatively strong wind resource areas where those facilities projected to repower over this timeframe are located (Wiser and Bolinger 2012), the majority of demand is expected to be for International Electrotechnical Commission (IEC) Class II turbines. The results are briefly compared with the existing U.S. wind manufacturing base to inform the ability of the current supply chain to serve the repowering market.

5.2 Results

Total turbine demand is estimated from the installed capacity estimates presented in Section 4. Assuming 2- to 3-MW turbines constitute the bulk of capacity during the late 2010s and early 2020s, an average of approximately 60 turbines per year will be needed to serve repowering investment from 2018 to 2021. Assuming that 3- to 4-MW turbines become more prevalent after 2021, an average of approximately 230 turbines per year will be needed to serve the repowering demand from 2022 to 2027. From 2028 to 2030, an average of about 730 turbines per year will be needed (Figure 8).

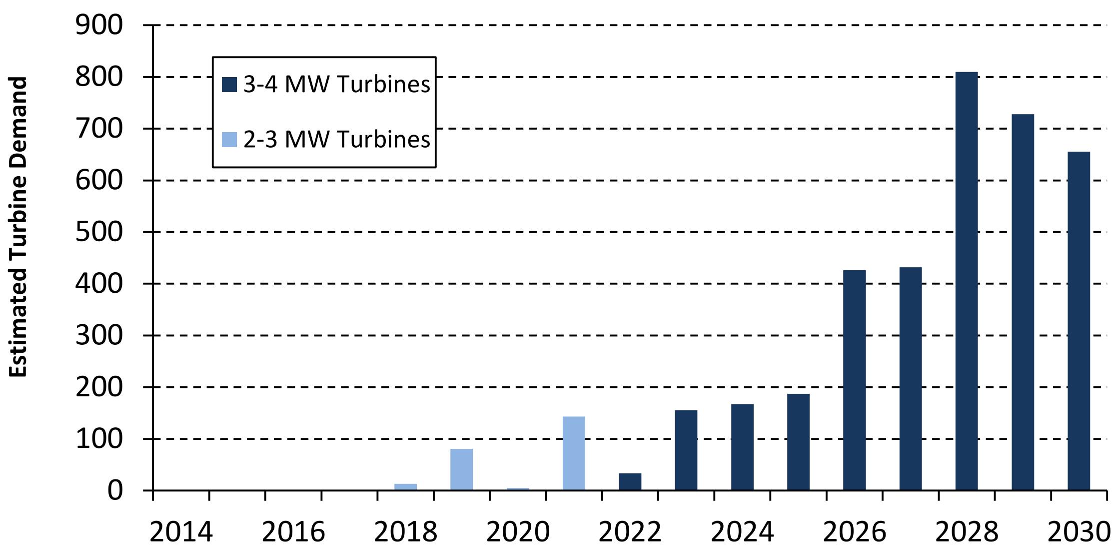

Figure 8. Estimated turbine demand by nameplate capacity resulting from potential repowering activity

[11] Based on extrapolation of historical trends as well as analysis and research summarized by Cohen et al. (2008) and Chapman et al. (2012).

Blade and tower demand by size are presented in Figure 9 and Figure 10, respectively. Based on the technology projections applied here, the majority of blades could be on the order of 50–60 meters (m) with some IEC Class III turbines being utilized in the late 2020s and subsequently requiring longer 70- to 80-m blades. Similarly, the majority of towers required for sites that are repowered (i.e., Wind Power Class 5 and above wind resource sites) are expected to be 80- to 100-m towers with some 120- to 130-m towers in the later years.

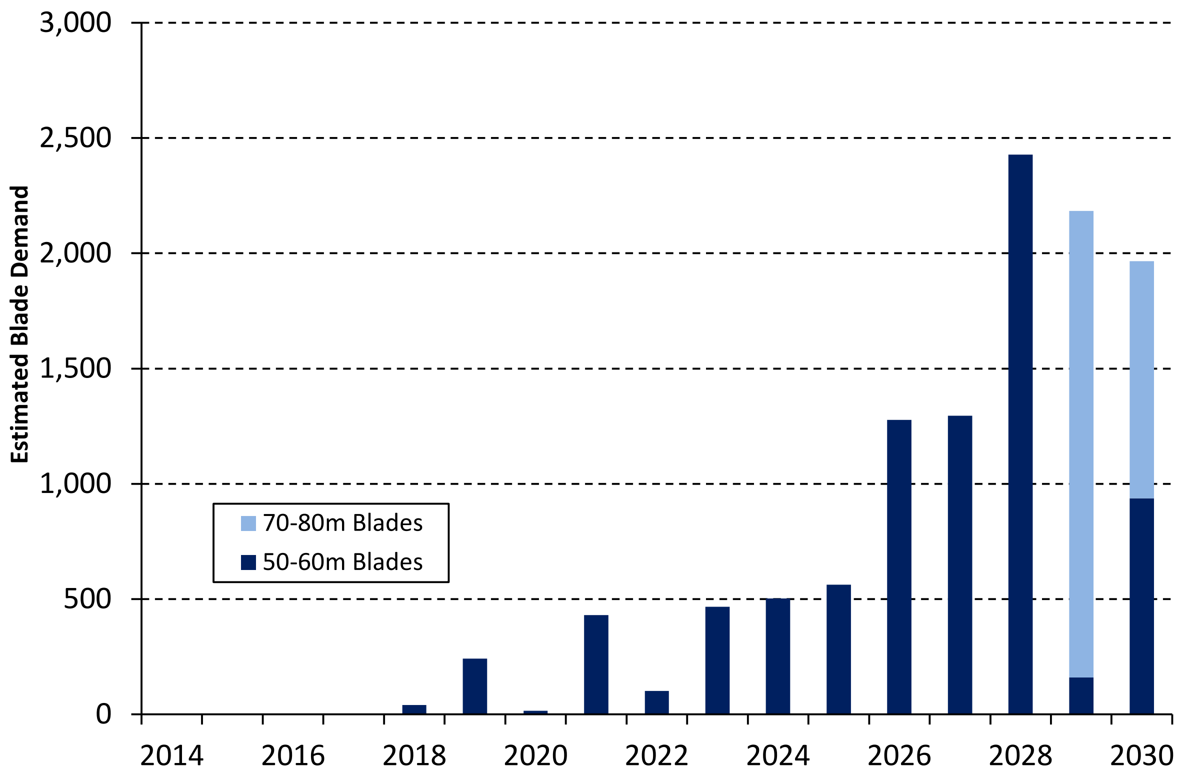

Figure 9. Estimated blade demand by length (meters) resulting from potential repowering activity

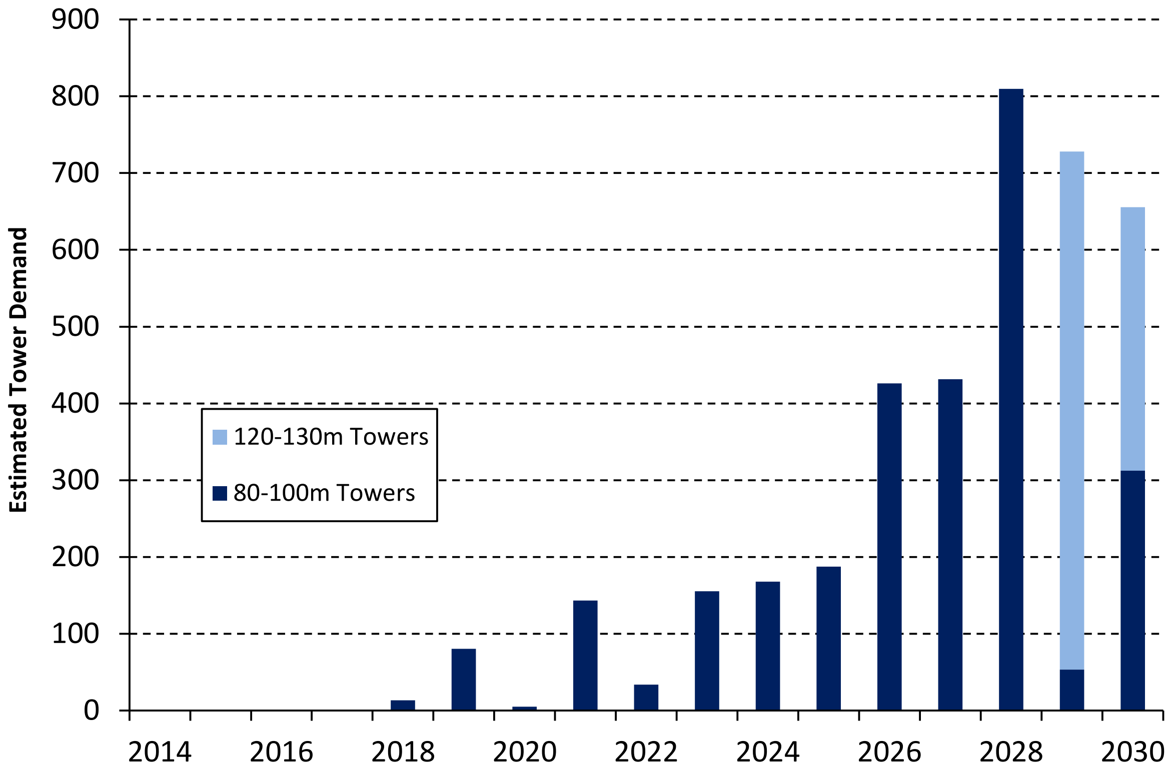

Figure 10. Estimated tower demand by height (meters) resulting from potential repowering activity

U.S. wind installations topped 13 GW per year in 2012. With incremental demand from repowering expected to be below 500 MW through the early 2020s and only about 3 GW by the late 2020s, supply chain constraints are not expected to be a major impediment to repowering. Were partial repowering to become more viable than observed here, production capacity for somewhat smaller components geared toward refurbishing older equipment might need to be developed. However, as this analysis suggests that repowering will be dominated by full repowering efforts utilizing the same state-of-the-art technology being installed on greenfields, such additional investment is not foreseen. At the same time, repowering cannot be expected to create notable supplemental demand in the U.S. supply chain until at least the early to mid-2020s. Were the U.S. supply chain forced to downsize dramatically between today and the mid-2020s, supply chain constraints could emerge as repowering demand picks up once again in the latter half of the 2020s. Assuming a 20- to 25-year life suggests that repowering demand will jump again in the early 2030s. Nevertheless, as these increases can be anticipated and predicted, they are not expected to result in significant supply chain hurdles.

6 Policy and Other Relevant Considerations

The analyses conducted here suggest that repowering activity will remain modest in the United States through the early to mid 2020s; however, repowering decisions are not often driven by economic considerations alone. The following discussion highlights the perspectives of wind industry professionals with regard to the impacts of current policy on repowering decisions as well as areas where future policy may be applied to facilitate or discourage repowering.

Semi-structured interviews indicated that current federal policy has only a modest impact on repowering decisions. In some instances, repowering investment may be accelerated to take advantage of the PTC or accelerated depreciation provisions similar to other wind power development activity, but generally, no substantial impact was observed. Similarly, Environmental Protection Agency rules under development that may encourage the retirement of existing generation capacity could create more demand for wind power generally but are unlikely to directly affect decisions specific to repowering.

Multiple interview respondents observed that repowering could offer the possibility for expedited permitting because development is occurring at a previously permitted site and these sites have a much longer track record of historical environmental data. Existing plants also tend to have increased local familiarity, which might also facilitate the permitting process. The ability to expedite the permitting process would suggest, perhaps, that repowering could take place somewhat sooner than envisioned by the financial analyses above. However, development costs, including permitting, are low relative to the total capital expenditures associated with modern wind facilities (Tegen et al. 2011) suggesting that this effect may be relatively modest. It was also observed that where endangered species live or other environmental damage has occurred, permitting would likely be more complex and drawn out, with the likely effect of postponing repowering activity. Repowering activity was also noted to be likely to occur later in a plant's life if local siting requirements become more stringent over time.

Along with more general policy considerations, respondents noted that the contractual language around an existing PPA could potentially raise a number of red flags when considering repowering. For example, wind professionals expressed concern about potential outage clauses and minimum generation thresholds as the physical act of repowering would likely involve substantial plant downtime. Respondents were also concerned about the contractual implications resulting from potential changes in production associated with putting new more productive technology at a specific site or from the potential addition of more capacity at a site. It was also noted that past PPAs tended to be more generous, so project owners are hesitant to take any action that would jeopardize an existing set of terms, conditions, and payments. Such a condition is comparable to that described earlier as the "California Fix," whereby repowered plants that take the federal PTC are anticipated to result in the loss of relatively generous standard offer contracts for many California wind projects built in the 1980s.

Within this context, if the various attributes of repowering are valued, repowering activities could be accelerated. However, encouraging and accelerating repowering investment is likely to require a shift in policy. Policy changes would likely need to address the current economic incentives around repowering, but may also consider the various permitting, regulatory, and contractual risks associated with repowering.

7 Summary and Conclusions

In line with prior work, this report's principal conclusion is that wind power plants that continue to generate a positive after-tax cash flow are unlikely to pursue repowering in the immediate future. Based on the analysis completed here, it is estimated that existing plant viability remains strong up until 20–25 years of operation, at which point repowering becomes more attractive than a new greenfield addition. Before this time, the continuing revenue stream from the existing plant augments any new greenfield site's future revenue stream, making repowering less viable. This timeframe for repowering was supported both by our aggregated representative wind plant financial analysis and by our case studies. Once the after-tax cash flow falls below a given threshold (after 20–25 years), the installed cost savings associated with repowering and resulting from the ability to use existing infrastructure, including roads, buildings, and electrical equipment, shifts the balance in favor of repowering.

As defined here, partial repowering appears to offer less value than full repowering. Estimated cost savings of approximately 10% relative to full repowering that result from reusing the existing tower and foundations did not offset the reduction in energy generation due to the lower hub height and smaller rotor anticipated for the partially repowered turbine. Accordingly, partial repowering is unlikely to be pursued unless innovations emerge that can boost plant productivity or reduce operating costs with less investment than was anticipated here.

In brief, wind industry investors looking to expand their profitability over the next decade are likely to see a greater increase in NPV from developing adjacent new greenfield sites than from repowering.[12] Nevertheless, there is an array of variables that could affect the attractiveness of repowering and either extend or shorten operating plant life including:

- **Technological advancement:** More rapid advancement will encourage repowering while slower advancement will reduce the viability of repowering.
- **Wind resource regime for greenfield plants:** A wind resource that is lower quality than that of existing facilities will encourage repowering while higher-quality wind resource areas potentially opened up by new transmission will encourage further greenfield investment.
- **PPA prices:** Both higher prices for future repowered plants and, alternatively, lower PPA prices for existing plants would encourage repowering to occur earlier.
- **Operation expenditures:** More rapid cost escalation as facilities age will make repowering more attractive earlier.
- **Repowering cost savings (relative to a greenfield project):** The ability to capture > 5% cost savings from repowering activities will encourage repowering; potentially higher costs (than modeled here) for repowering will discourage repowering investment.

[12] Assuming, of course, that new greenfield plants are viable investments independent of the repowering considerations.

Assuming a plant life of 20–25 years, repowering demand is expected to be low over the next decade, reach a few hundred megawatts per year in the early 2020s, and achieve 1–3 GW by the late 2020s. The total estimated value of the repowering market segment is estimated at $25 billion through 2030 with the vast majority of this investment occurring in the latter half of the 2020s. Turbine demand is anticipated to range from well below 100 turbines per year in the early 2020s to slightly more than 700 turbines per year by the late 2020s. Tower and blade demand is anticipated to be concentrated on the state-of-the-art IEC Class II turbine designs suggesting that repowering could support an incremental increase in supply chain activity.

Policy support in the form of financial incentives, as well as solutions to potential regulatory and contractual hurdles, is likely to be necessary if there is value placed on the acceleration of repowering investment.

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Appendix A: Interview Guide for Wind Owner Operators

Semi-structured interviews with plant owners and operators provided insights into their reasons for having repowered or not, as well as an opportunity to acquire feedback on earlier modeling inputs and results. This appendix includes the interview template and summarizes the themes that emerged from these discussions. In total, extended interviews were completed with eight wind power professionals, representing the financial community, owner/operator/developer firms, and utility owners.

Template

Part 1: Experiences and Perspective on Repowering

1. Project Overview
    A. Explanation of our project
    B. Why we are calling
    C. What we mean by repowering
2. Have you been involved in any projects involving repowering of older wind plants? (**if no, move down to #3**)

(If yes), please describe what was done in the repowering process.

A. How many turbines were removed? Rated capacity of each?
B. How many new ones were installed? Rated capacity of each?
C. Was the plant's total rated capacity increased? How much?
D. Were the towers replaced?
E. What other components, if any, of the balance of plant was modified?
F. Which of the following, if any, were reasons supporting this repowering decision? You may choose more than one response.
    i. Increasing total plant rated capacity
    ii. Lowering O&M costs
    iii. Increasing net capacity factor
    iv. Adhering to environmental regulations
    v. Technology was outdated
    vi. Equipment was at the end of its useful life
G. Was a new environmental impact study conducted before the repowering was approved?
H. What was done with the old nacelle, rotors, and towers when the plant was repowered?
    i. Refurbished and sold?

ii. Recycled?

iii. Landfill?

3. What are the primary benefits of repowering an existing wind plant?
4. What major obstacles, if any, should a wind plant owner consider when evaluating the feasibility of repowering?
5. When evaluating the decision whether to invest in a new nearby greenfield site versus repowering an existing wind plant, what are the major factors that an owner/operator should consider?
   I. Describe the advantage of repowering an existing wind plant relative to investing in a new greenfield site.
   J. Conversely, describe the advantage to investing in a new nearby greenfield site relative to repowering an existing wind plant.
6. At what age do you think it is most appropriate to repower a wind plant?
7. Please discuss what impact, if any, the structure of current government incentives supporting wind energy have on the decision to repower an older wind plant?
8. What impact, if any, does a wind plant's current PPA agreement for an existing wind farm have on the decision to repower?
9. What should be done with older wind plant equipment (nacelle, rotors, and tower) when taken down?

Part 2: Case Study Examples

Now we would like to hear your perspective on the three case studies we prepared. We compared the financial projections for three possible investment decision paths for each case study:

1. Maintaining an existing wind plant
2. Building a new greenfield site in addition to maintaining the existing plant
3. Repowering an existing site.

We created three case studies (Northeast, West Coast, Midwest), all of which were run with these three investment decision paths. If we could not find publicly available information for key inputs, we used industry averages described in the *Wind Technology Market Report 2011* (Wiser and Bolinger 2012). Modeling was performed with SAM.

4. Have you had a chance to review our preliminary results of the case studies file we sent you on Friday evening? **(if no, ask them to review it)**
   K. What are your initial thoughts?
   L. Do these results match what you would expect? Why or why not?
5. In the case study results we highlighted three important input assumptions that drove repowering's NPV advantage over building a new greenfield site. Please consider each of these three assumptions and describe whether you feel they are reasonable or not and why you feel that way.

M. 5% better wind resource for repowered sites versus greenfield
N. 5%–10% lower installation costs due to already existing infrastructure for repowering
O. Costs of removal of old equipment can be offset by selling it.

6. Does your company have any employees devoted to assessing the market potential of repowering? Please describe.
7. What other thoughts do you have on the feasibility of repowering that you would like to share?
8. What questions would you like answered to help your company make informed decisions concerning repowering older wind plants?
9. Is there anything else you would like to tell us to inform this project?
10. Are there any other wind energy professionals, either within or outside of your company, that you would recommend we speak with on this topic? **Request specific contact details**.