

National Wind Energy Workforce Assessment: Challenges, Opportunities, and Future Needs

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Revised March 2024





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National Renewable Energy Laboratory

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Errata

This report, originally published in January 2024, has been revised in March 2024 to allow for minor updates to the language and readability of the report based on feedback from workforce development subject matter experts. These revisions did not change the insights or key takeaways from the January 2024 publication. Specifically, the authors:

- Improved the clarity and specificity in the language leveraged throughout the report
- Specified that the terms “workers” and “employees” were used interchangeably throughout the report
- Revised the “Scenarios” section to report results more consistently across the tested model scenarios
- Consolidated and clarified the language surrounding apprenticeship program pathways
- Expanded the conclusion paragraph to include the modeling results and expand upon key takeaways.

Acknowledgments

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1 Purpose

Understanding the workforce needs to meet U.S. wind energy deployment goals is essential for successfully transitioning to a clean energy future. Recognizing how key levers, which are defined as actions that influence workforce supply and demand (e.g., automation, acceptance rates, perception of wind energy industry jobs), impact behaviors and estimations can provide insight into actions to equitably and sustainably develop the wind energy workforce. The increased need to further develop a domestic wind supply chain along with the ever-present wind workforce gap has revealed the urgency of enacting or expanding programs and policy to help grow a qualified wind industry workforce. The wind workforce gap is defined as the disconnect between employers having difficulty finding qualified candidates while potential wind energy workers report having difficulty finding jobs and educational institutions having difficulty placing students in industry.

For this assessment, a systems dynamic model—informed by a survey effort completed in 2022 and other anecdotal research—was created to better understand potential scenarios and actions that could be used to help close the workforce gap. The survey was conducted by the National Renewable Energy Laboratory (NREL), in collaboration with BW Research Partnership, to understand the perspective of wind industry firms, wind educators, current wind energy industry employees¹, and current renewable energy students on the workforce pathways into the wind industry. The information gathered through the survey effort was used to help develop workforce estimation scenarios, gain insight into why the workforce gap exists, and evaluate areas of opportunity to reduce barriers of entry into the wind energy industry. More information on the survey effort and systems dynamic model methodology can be found in the supplemental *National Wind Energy Workforce Assessment Methods Report: Surveys and System Dynamics Model* (McDowell and Stefek 2023). Through this analysis, we determined that to close the workforce gap collaborative actions between industry and education institutions are needed to ultimately connect more job seekers to careers in wind.

¹ In this report, the authors use the terms “workers” and “employees” interchangeably as the survey was sent to both and did not differentiate. However, we acknowledge that employees may receive different benefits than workers.

2 Background

The U.S. land-based and offshore wind energy markets are expected to grow significantly over the next few decades, thereby increasing the need for employment to meet the deployment demand. The White House has set targets of 80% renewable energy generation by 2030 and 100% carbon-free electricity by 2035 (White House 2021a) with wind energy potentially making up 20% of the U.S. electricity mix by 2030 and 35% by 2050 (Wind Energy Technologies Office 2017). Additionally, the Biden administration has set a goal to achieve 30 gigawatts of offshore wind energy by 2030, emphasizing that the creation of well-paying energy jobs will need to be a top priority (White House 2021b). Furthermore, the Inflation Reduction Act (IRA) and Infrastructure Investment Jobs Act have incentivized the creation and expansion of the domestic wind supply chain, increasing the demand for a locally available and properly trained wind energy workforce.

According to the NREL 2022 Standards Scenario Mid-case with nascent technology and current policy (Gagnon et al. 2022), the installed capacity in both the land-based and offshore wind sectors is estimated to reach nearly 317,000 megawatts (MW) by 2030 for land-based wind and 24,000 MW by 2030 for offshore wind (Figure 1). Therefore, helping develop the wind industry workforce and supply chain in the United States will be essential to reaching climate goals and is vital to the future success of the industry.

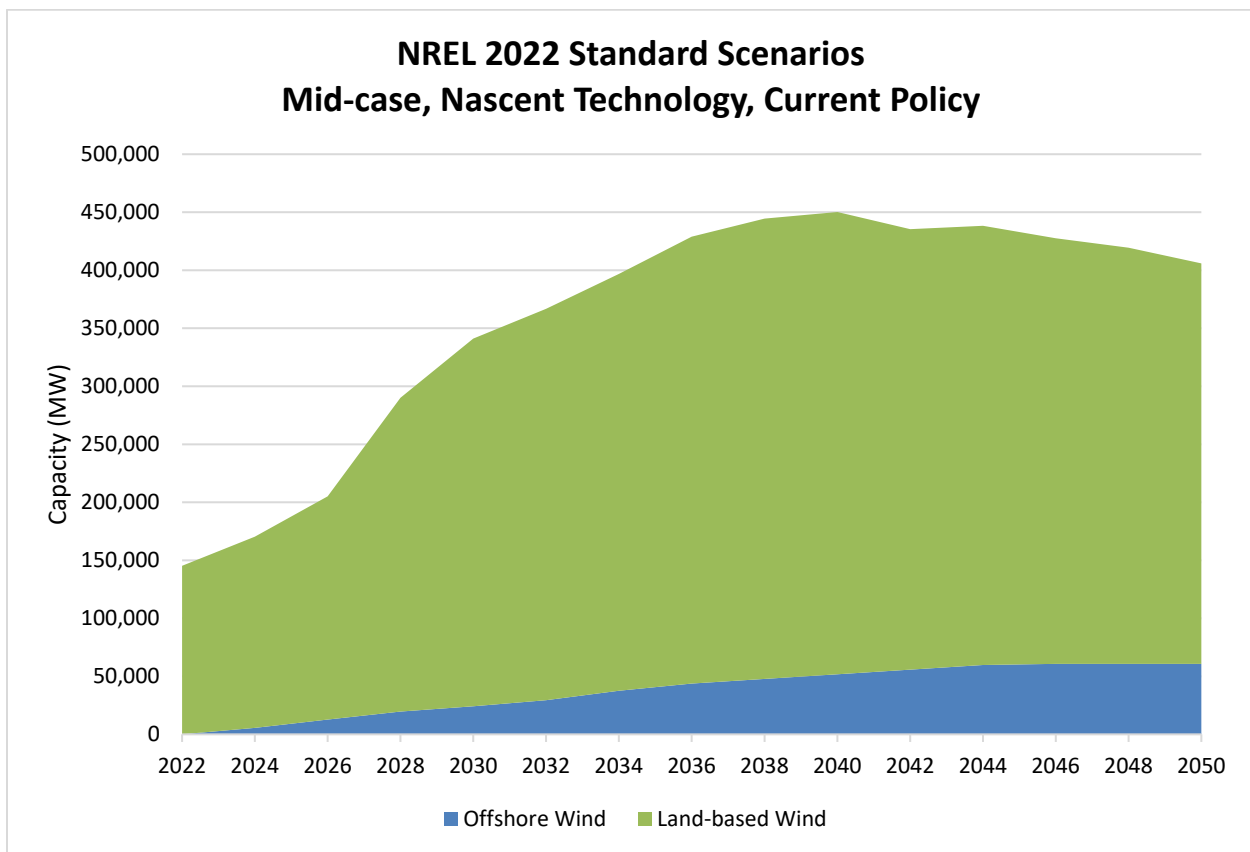


Figure 1. NREL 2022 Standard Scenarios Mid-case, nascent technology with current policy offshore wind and land-based wind installed capacity (MW). Graph from Gagnon et al. (2022)
Current State of the Wind Energy Industry Workforce

According to the 2022 *U.S. Energy and Employment Report*, wind energy technology was one of the few energy technologies to experience positive job growth from 114,774 in 2019 to 120,164 in 2021 (4.7%). The total number of workers wind energy companies employed in 2021 was up 3,347 workers from 2020 numbers (U.S. Department of Energy [DOE] 2022). The largest job gains were attributed to professional services with 1,374 recorded new jobs. Most of the wind energy workers (99.3%) are employed in land-based wind, whereas the remaining are in offshore wind, although involvement in this sector is expected to grow as deployment expands in the United States.² Additionally, it was reported that wind energy employers in five out of the six industries³ anticipate growth in 2022, with only wholesale trade, distribution, and transport projected to decrease in employment (Figure 2).

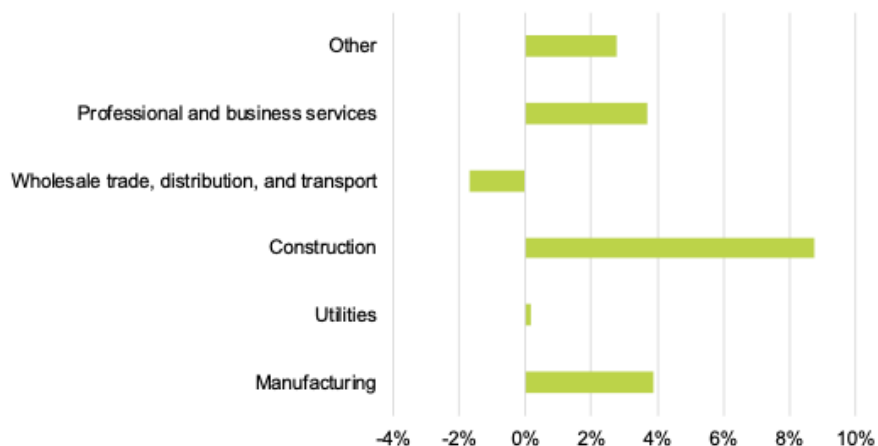


Figure 2. Wind power generation employment changes anticipated in 2021 for calendar year 2022. Graph from DOE (2022)

Amidst the anticipated growth in the wind energy workforce; however, wind energy firms reported difficulty in multiple industry segments. In 2021, construction employers reported the greatest difficulty hiring workers, with 98% reporting at least some difficulty finding qualified workers. Professional services had the lowest hiring difficulty, with 77% of employers reporting hiring to be somewhat or very difficult (Figure 3) (DOE 2022).

² Current employment for offshore wind energy in the 2022 *U.S. Energy and Employment Report* is largely underrepresented, accounting for only 877 of the 120,164 (estimated) total. More details regarding the U.S. offshore wind workforce can be found in the [U.S. Offshore Wind Workforce Assessment](#) (Stefek et al. 2022b).

³ The six industries in the 2022 *U.S. Energy and Employment Report* include other, professional services, wholesale trade, construction, utilities, and manufacturing. These industries were created by aggregating North American Industry Classification System codes to provide a standardized way of representing the workforce within the energy industry. This standardization helps allow for workforce changes to be more comparable across technologies.

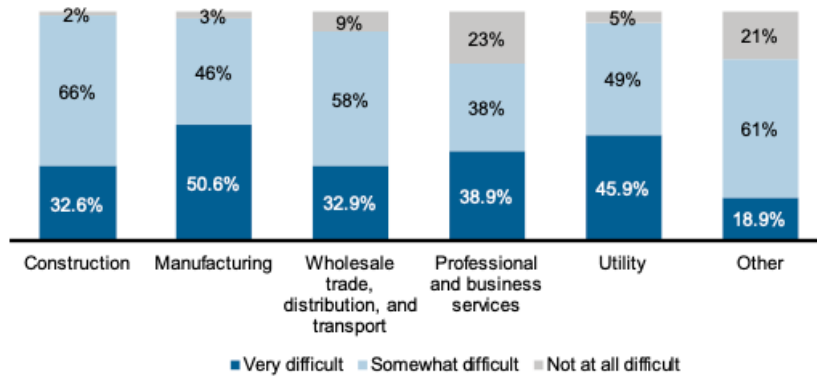


Figure 3. Hiring difficulty by wind energy industry. Graph from DOE (2022)

Similarly, in the 2022 NREL survey effort, employers were asked if they had experienced hiring difficulties across nine value chain segments. Wind energy firms reported that construction saw the greatest decrease in reported hiring difficulty for entry-level employees between 2020 and 2022 (BW Research Partnership 2023b). Based on the survey effort, Manufacturing reported the highest hiring difficulties for entry-level employees (67.4%). Furthermore, employers related to development and siting experienced the greatest hiring difficulties for nonentry level employees (75.0%) (Table 1).

Table 1. Reported Difficulty for Finding and Hiring Qualified Entry-Level Applicants by Value Chain Segment

Entry Level	No Difficulty	Some Difficulty	Great Difficulty	Don't Know/Refused
Operations and Asset Management	30.1%	43.4%	20.6%	5.9%
Finance, Legal, and Insurance	33.0%	46.4%	16.5%	4.1%
Transportation and Logistics	37.5%	42.0%	19.3%	1.1%
Development and Siting	33.0%	42.0%	22.0%	3.0%
Construction	33.1%	42.3%	21.5%	3.1%
Government and Regulations	31.9%	45.1%	17.6%	5.5%
Education, Training, and Hiring	31.7%	40.7%	19.5%	8.1%

Entry Level	No Difficulty	Some Difficulty	Great Difficulty	Don't Know/Refused
Research and Development	32.8%	41.0%	18.0%	8.2%
Manufacturing	30.4%	43.5%	23.9%	2.2%

Table 2. Reported Difficulty for Finding and Hiring Qualified Nonentry-Level Applicants by Value Chain Segment

Nonentry Level	No Difficulty	Some Difficulty	Great Difficulty	Don't Know/Refused
Operations and Asset Management	23.5%	39.7%	32.4%	4.4%
Finance, Legal, and Insurance	25.8%	39.2%	32.0%	3.1%
Transportation and Logistics	31.8%	40.9%	25.0%	2.3%
Development and Siting	21%	41.0%	34%	4.0%
Construction	26.9%	45.4%	24.6%	3.1%
Government and Regulations	20.9%	42.9%	29.7%	6.6%
Education, Training, and Hiring	21.1%	39.0%	33.3%	6.5%
Research and Development	24.6%	41.8%	27.0%	6.6%
Manufacturing	28.3%	44.6%	25.0%	2.2%

3 Trends in the Wind Energy Workforce Gap

The idea of a wind energy workforce gap is not new. The 2019 report, *The Wind Energy Workforce in the United States: Training, Hiring, and Future Needs* (Keyser and Tegen 2019) defined the wind workforce gap as the disconnect between employers having difficulty finding qualified candidates while the potential workforce is having difficulty finding jobs and educational institutions are having difficulty placing students in industry. The assessment concluded that narrowing the gap would simultaneously reduce recruitment costs for employers, help education institutions fill classrooms, and grow the domestic wind energy workforce by properly communicating about careers to the potential workforce (Keyser and Tegen 2019). However, at the time, root causes for the workforce gap remained uncertain.

In the 2022 *Defining the Wind Energy Workforce Gap* report,⁴ wind industry firms were surveyed (in 2020) to gain more insight into the characteristics that cause the workforce gap. Wind industry firms were asked to select top reasons for hiring difficulty. In addition to a general lack of applications, the top reasons for difficulty hiring both entry- and nonentry-level workers were that not enough applicants had the right kind of education and training or relevant industry experience. When asked the same question, the total workforce reported that getting relevant experience, finding employment in a desirable geographic location, and developing technical skills were three of the primary barriers to successfully entering the wind energy workforce (Stefek et al. 2022a).

Between the 2020 survey effort and the most recent 2022 survey effort, difficulty for finding and hiring employees that are qualified for entry- and nonentry-level positions at wind energy firms remained high. Employers surveyed in 2022 reported greater hiring difficulty for entry- and nonentry level employees than in 2020 (Figure 4).

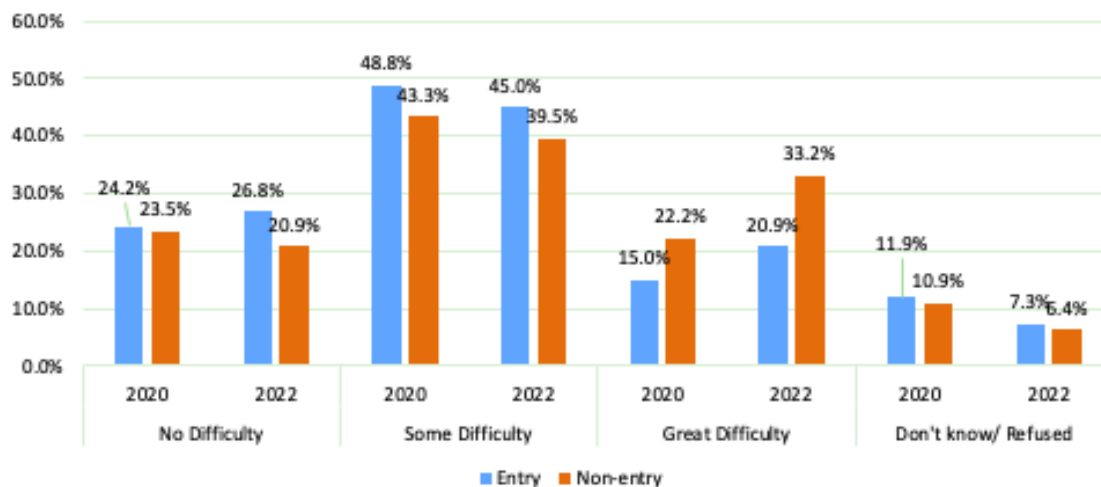


Figure 4. Employer hiring difficulty in 2020 and 2022. Graph from BW Research Partnership (2023b)

⁴ The 2022 *Defining the Wind Energy Workforce Gap* report used data collected in 2020. The 2022 survey effort used data that were collected in 2022.

Similar to hiring difficulty levels, many of the top reported reasons in 2022 for the workforce gap remained consistent, such as:

- A lack experience
- Education and training
- Quantity of applicants
- Desirable geographic location of jobs.

3.1 Experience

An inexperienced workforce continues to be a barrier to hiring as reported by wind energy employers. Overall difficulty for finding and hiring employees that are qualified for entry- and nonentry-level positions at wind energy firms remains high. Employers surveyed reported greater hiring difficulty for entry- (66.0%) and nonentry (72.7%) level employees in 2022 as opposed to entry-(64.0%) and nonentry (65.0%) in 2020 (Stefek et al. 2022a). The top reason for hiring difficulty for entry-level workers was reported to be a lack of experience for the job (22.7%). This amount has slightly decreased from the 2020 data that indicated 27.6% of wind energy firms reported difficulty hiring entry-level workers because of lack of experience (Stefek et al. 2022a). Three out of five students also indicated that getting relevant work experience was one of their challenges to obtaining employment in the wind industry. Even a majority of current industry workers (62.5%) reported that a lack of experience was a challenge when they tried to find employment in the wind industry. Through the survey effort, respondents indicated that although employees are entry-level, there is an expectation from employers that they have relevant experience before entering the industry. A better understanding of the level of experience needed and effective ways for job seekers to gain experience is important for developing a qualified, domestic workforce. NREL continues to research what experience means in the wind energy industry through internship and apprentice programs.

3.2 Education and Training

Obtaining education and training is still a reported difficulty by wind industry firms. Wind employers reported that they have some or great difficulty hiring entry-level (20.3%) and nonentry-level (18.8%) employees due to too many applicants not having the training or education needed for the job. In 2020, 29.7% of responding firms indicated that a lack of adequate education and training was a challenge when hiring job applicants (Stefek et al. 2022a). When students were asked about their greatest challenge to being hired, 79.2% indicated that getting technical training was somewhat or a considerable challenge. The survey results also indicated that 60.0% found that they had a lack of exposure to the wind energy industry within their coursework, 48.0% felt that their skills were not transferable to wind, and 54.0% were unsure what jobs made up the industry. Because workforce opportunities can be developed by different skill sets and educational trajectories, being able to bolster awareness and participation in opportunities such as apprenticeships, internships, research, and volunteer opportunities that have been reported by students to develop technical skills and expertise can help narrow the gap.

3.3 Quantity of Applicants

The top reason reported for hiring difficulty of nonentry-level workers by wind industry employers was due to a lack of job applicants. One in four employers found a lack of applicants as a challenge for nonentry-level workers, and one in five found this as a challenge for hiring

entry-level workers. Similar to past research, medium (10–49 employees) and large-sized (50+ employees) employers indicated that a lack of applicants was their top reported challenge for hiring (Stefek et al. 2022a).

When looking at students, only 24.4% had actively searched for work opportunities in the wind energy industry. Furthermore, 33.8% of students had considered working in the wind energy industry but never actively searched, and 37.5% had never considered working in the wind energy industry at all. When asked what the students' reasons were for not considering employment in wind energy, 71.2% stated they had found interest in other industries, 60.0% lacked exposure to the industry in course work, and 54.2% were unsure of the types of jobs available. Those that had looked for job opportunities reported that finding those opportunities in the wind energy industries (e.g., offshore, distributed, and land-based) was more difficult than other renewable energy industries. A lack of awareness of job opportunities and perceived difficulty finding job openings poses a two-sided barrier for both career seekers and employers in the wind energy industry when trying to increase the applicant pool.

3.4 Geographic Location of Jobs

According to respondents, physical location is an important attribute when looking for jobs. When students were asked about a wind energy employment attribute in comparison to other industries, around 16.5% of students on average felt that the wind industry had fewer opportunities to work in locations where they wanted to live when compared to other industries. This was the largest percentage of “worse than average” responses. Similarly, when students and current wind employees were asked about hiring challenges in the wind energy industry, 64.6% of students and 68.0% of current wind employees reported that finding employment opportunities that are near where they are willing to live was a hiring challenge. These levels of difficulty have remained consistent between 2020 and 2022 data. In 2020, students reported geography as their second-highest hiring challenge, with 67.0% reporting job location as a considerable challenge. Desirable job location was also ranked as the top challenge for current wind employees in 2022, with 64.0% reporting this factor to be a considerable challenge (Stefek et al. 2022a).

4 Current Workforce Estimations

Potential growth of the wind energy industry will need more qualified workers to support overall expansion. If industry is to progress in line with the NREL 2022 Standards Scenario Mid-case with nascent technology and current policy (Gagnon et al. 2022)⁵—one potential path for expansion—meeting the employment demand that is needed to reach deployment scenarios will not only require an increase in the number of the workers and program development, but also in the level of their relevant experience and training.

To estimate the total workforce demand, we applied multipliers calculated from information within the *2022 U.S. Energy and Employment Report* (DOE 2022) to the capacity projections of NREL 2022 standard scenarios (Gagnon et al. 2022). The full-time employee numbers produced for each industry segment were then further adjusted by the percent that automation is predicted to affect workforce demand. To estimate the workers in the wind industry at a given year, the anticipated working aged population was adjusted by:

- The percentage of people who are estimated to transition into the wind industry without needing formal education and training.
- The percent of people who need education and training either through a 2-year degree or certificate program, apprenticeship, or 4-year degree or higher education program.
- Application rates into education and training programs, acceptance rates into education and training programs, and enrollment rates into education and training programs.
- Application rates into wind industry jobs after transitioning or graduation.

The applicant pools were then hired into the industry using a constant hiring rate and further multiplied by an attrition rate, resulting in the estimated number of workers currently in the wind industry. We determined these model inputs through 2022 NREL survey effort data, Bureau of Labor Statistics data, and U.S. Department of Education data. More information about the methodology of the system dynamics model and survey effort can be found in the *National Wind Energy Workforce Assessment Methods Report: Surveys and Systems Dynamic Model* (McDowell and Stefek 2023).

4.1 Business As Usual

Under current assumptions, the number of workers in the wind industry is anticipated to increase steadily through 2050; however, it is not estimated to be at the rate that is needed to meet 2030 or 2050 wind workforce demand. Estimates show that the total number of workers in 2030 will be about 134,000, and the total workforce demand is about 258,500. Therefore, based on the business-as-usual (BAU) scenario, including current wind industry perceptions and baseline data, the model estimates that by 2030 there is a deficit of around 124,000 workers for both land-based and offshore wind deployment (Figure 5). These numbers are highly dependent on the assumption of the model and data gathered through the 2022 survey effort and should be used as a high-level estimate of scale and trend as opposed to an exact forecast.

⁵ We are not modeling the Inflation Reduction Act investment impacts to technology deployment; we are modeling the direct impact of the act to wind energy workforce supply.

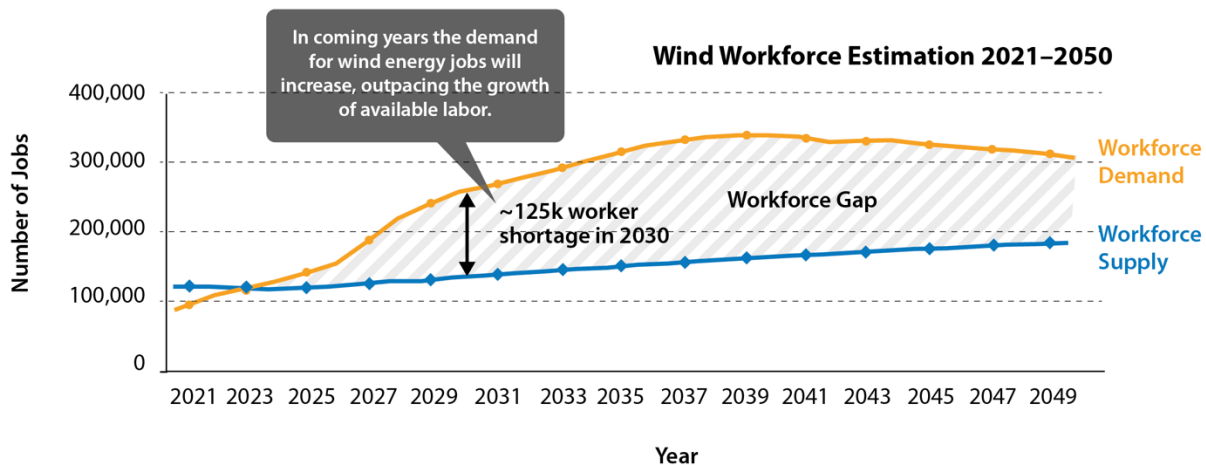


Figure 5. Workforce development estimations that show worker demand, supply, and the magnitude of a potential gap in workforce need under business-as-usual assumptions. Image created by John Frenzl, NREL

To help mitigate the workforce gap, the number of students applying for renewable energy education and training programs, and individuals applying for wind industry jobs will need to increase. The wind industry and education and training providers can encourage this growth by boosting training capacity, improving student perception of renewable energy education, and improving advertisement awareness of job opportunities.

4.2 Scenarios

To better understand the impacts of boosting training capacity, improving student perception of entering renewable energy education, and providing employment opportunities in the wind industry, we ran three scenarios to explore how different actions can affect the wind workforce gap estimations. Those scenarios include manipulation of key levers that affect:

- **Renewable energy education and training programs.** Application and acceptance rates into renewable energy education (Scenario 1)
- **Applicants to wind industry jobs.** The rate that graduates and workers who did not need further education or training apply for jobs in the wind industry (Scenario 2)
- **IRA.** Future workforce estimations based on assumptions of deployment of the IRA policy (Scenario 3).

We used the renewable energy education and training programs (Scenario 1) to test how varying the impact of factors like marketing, economic drivers, and societal drivers affects how many people apply for education or training programs. Additionally, this scenario tested how positively or negatively impacting education and training programs student teacher ratio, funding levels, infrastructure availability, and curriculum affect acceptance rates into these same education and training programs. The model assumed the full maturity of these policy changes happened at the end of the 30-year estimation. Figure 6 estimates that if the specific areas related to renewable energy education are adjusted to reach their maximum influence in the positive direction, by 2050 there could be a 14.5% decrease in the severity of the gap between the wind workforce supply and demand. The workforce demand stayed consistent to BAU estimations because no levers that affect the workforce demand variable were adjusted in this scenario.

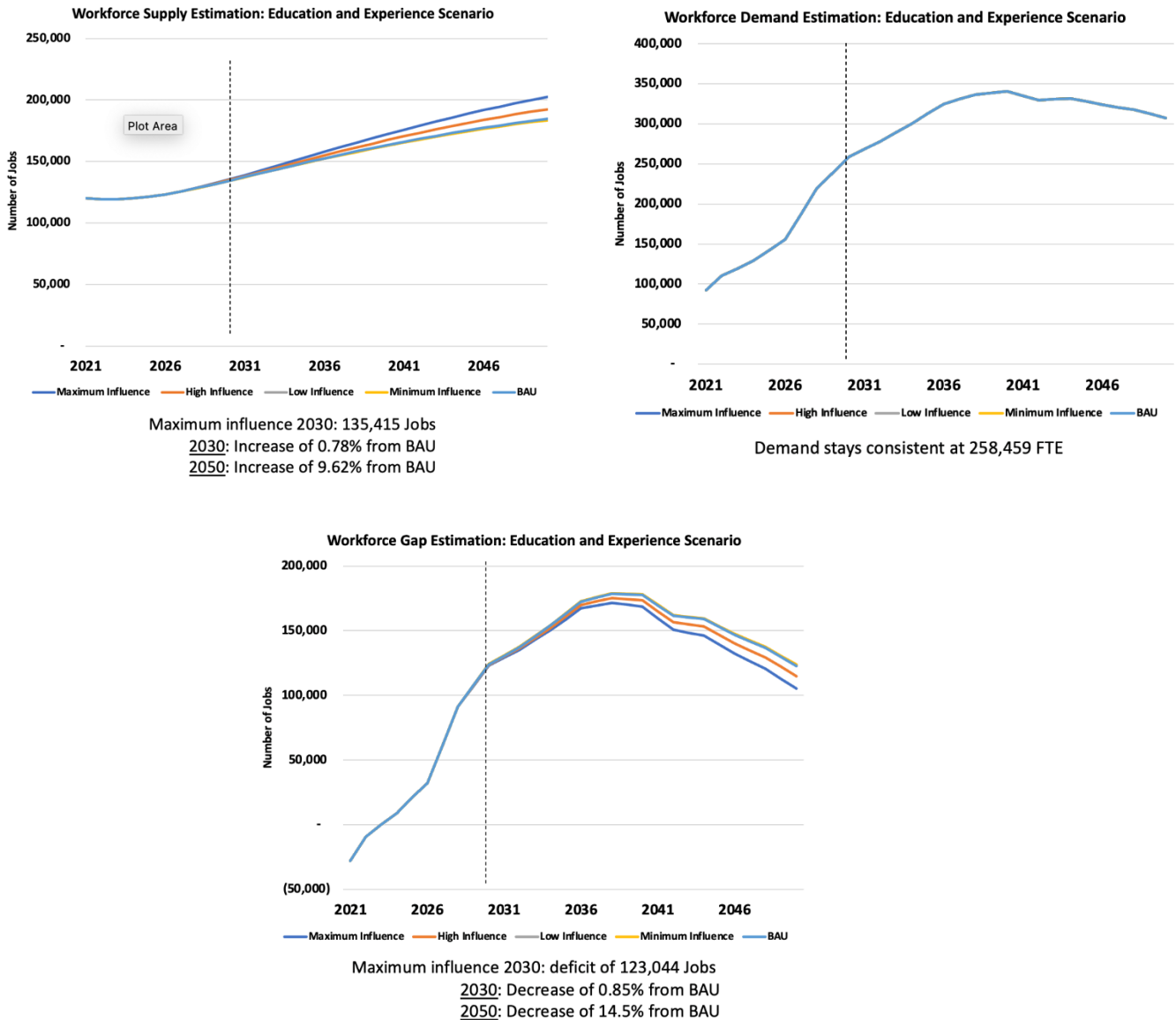


Figure 6. Workforce supply (top left), workforce demand (top right), and workforce gap (bottom) changes as affected by the renewable energy education and training program’s 30-year scenario.

Note: FTE = full-time equivalent

We also ran Scenario 1 with the assumption that the full maturity of the policy changes happened after 10 years as opposed to 30 years. This assumption was run in the model to explore timing effects and influence on the workforce estimations. Increasing the speed that policy was effective caused a larger decrease in the workforce gap estimation (Figure 7). If the maximum influence of the levers in Scenario 1 are recognized in 10 as opposed to 30 years, the workforce gap is estimated to decrease by 0.80% more in 2030 (1.64% total gap reduction) and 7.35% (20.9% total gap reduction) more in 2050. Thus, these results indicate the importance of quick and effective action.

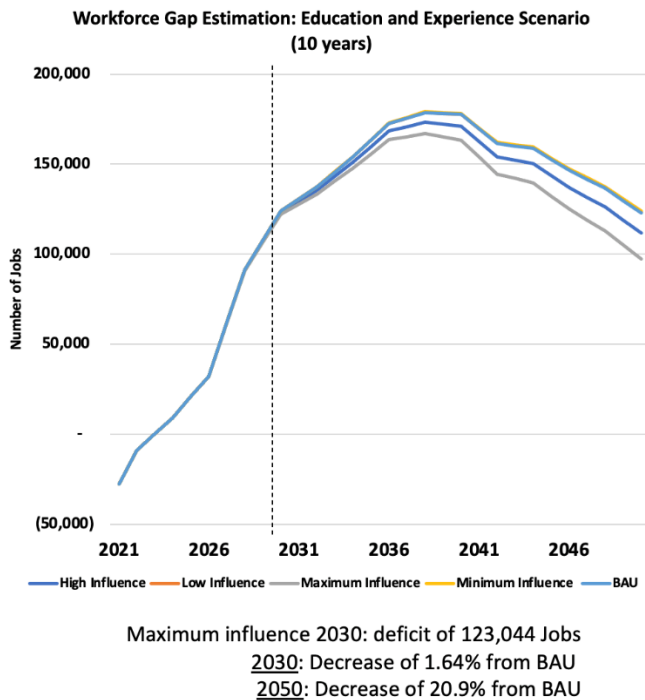
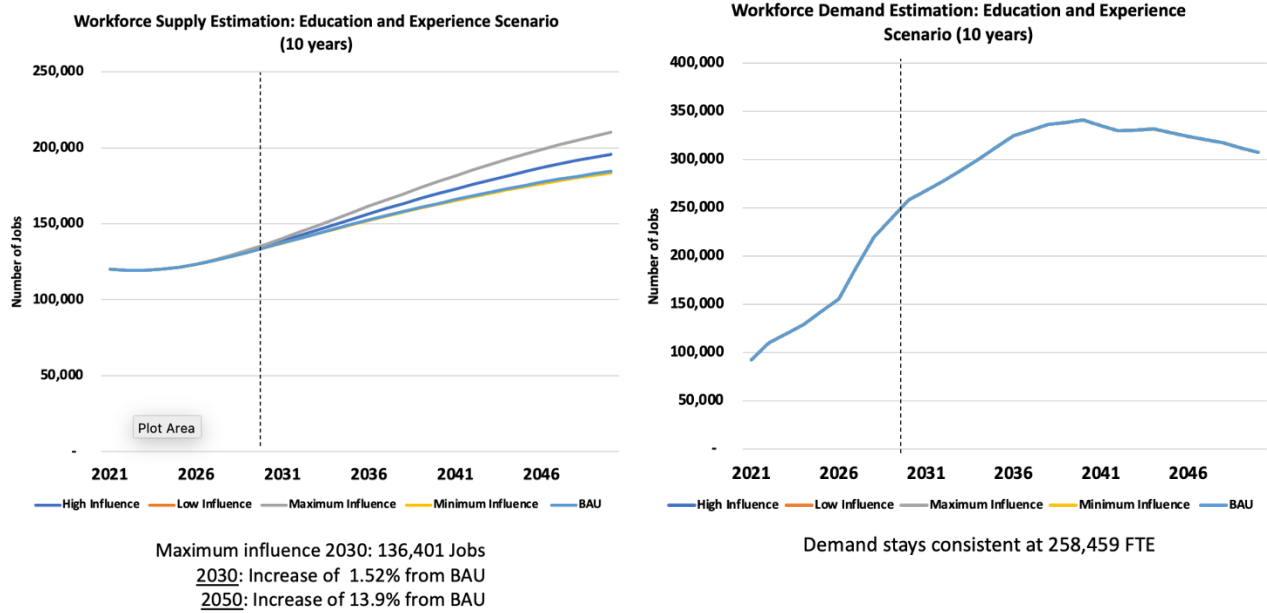


Figure 7. Workforce supply (top left), workforce demand (top right), and workforce gap (bottom) changes as affected by the renewable energy education and training program’s 10-year scenario

Scenario 2—applicants to wind energy industry jobs scenario—focuses on how increasing or decreasing job seekers’ perception of wind employment will affect the percent of applicants to wind energy industry jobs. Key levers that affect perception within the model include labor wages, job stability, and job location. The model assumes full maturity of these influences in 10 years. Additionally, the workforce demand stayed consistent to BAU estimations because no parameters that affect the workforce demand variable were adjusted in this scenario. Therefore,

because the demand stays constant if the supply increases or decreases, then the workforce gap also increases or decreases. Figure 8 indicates if the specific parameters related to perception are adjusted to reach maximum positive perception, the number of people in the workforce may increase by 3.23% in 2030 from BAU, and 9.06% in 2050 from BAU. If the parameters are adjusted to reflect a negative perception of the wind industry, there is an estimated decrease in workforce supply of 8.89% in 2030 and 21.1% in 2050 from BAU. The steeper decrease in supply from a more negative perception is due to the generally positive perception and attractiveness of the wind industry at BAU. If the parameters related to perception are adjusted to reach a maximum positive perception, the workforce gap is estimated to decrease by 3.49% from BAU in 2030 and 13.6% from BAU in 2050. If the parameters related to perception are adjusted to reflect a negative perception, then the workforce gap is estimated to increase by 9.62% from the BAU in 2030 and 31.7% from the BAU in 2050.

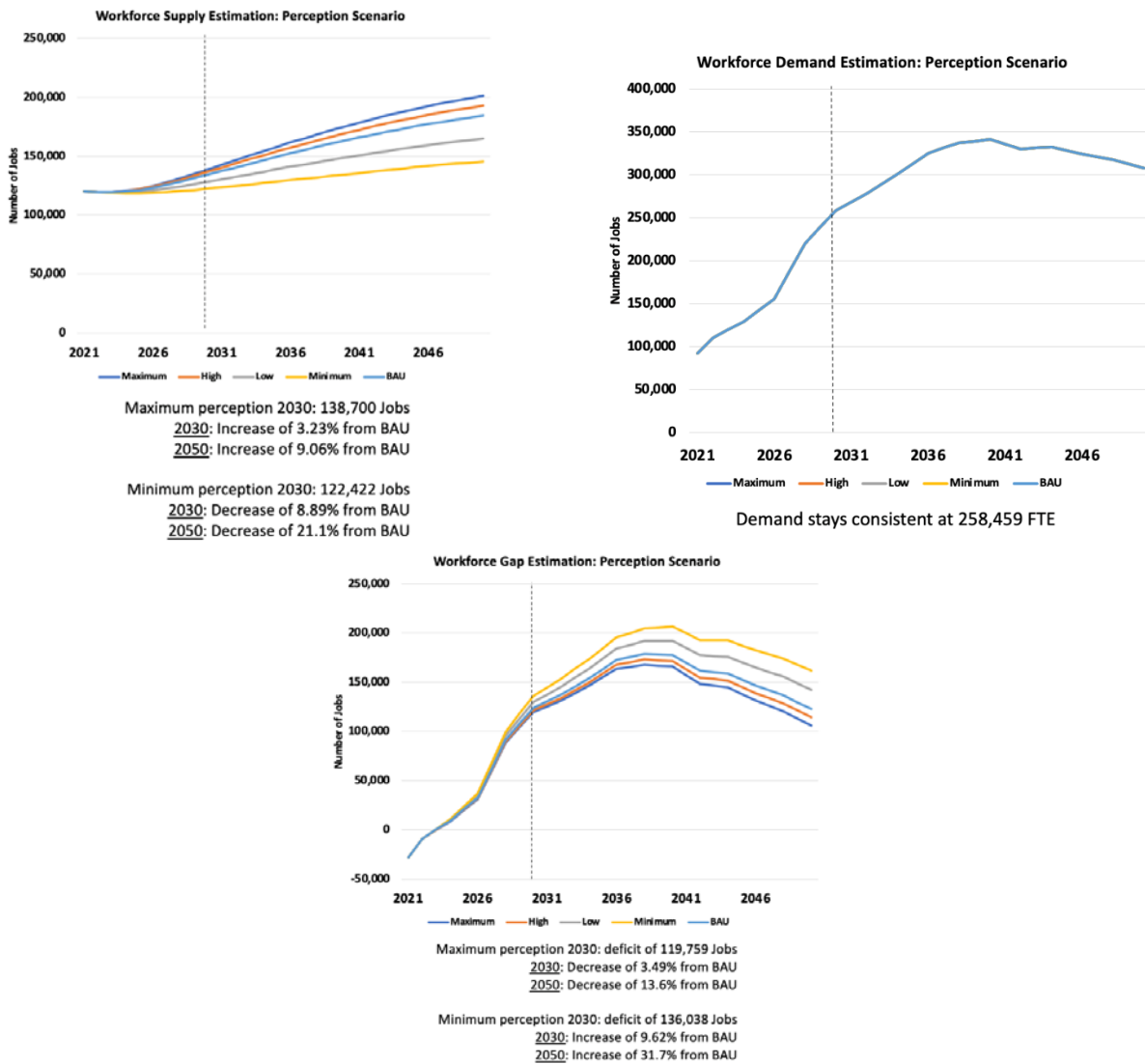


Figure 8. Workforce supply (top left), workforce demand (top right), and workforce gap (bottom) changes as affected by the applicants to wind industry jobs scenario

The IRA (Scenario 3) tested how their apprenticeship requirements, prevailing wage, and domestic content incentives affect workforce estimations. Within this model, the primary impacts of the IRA are accounted for on the demand side of the model through increased wind energy deployment. NREL 2022 Standards Scenario Mid-case with nascent technology and current policy (Gagnon et al. 2022)—the wind energy deployment scenario used on the demand side of the model—assumes that the production tax credit will be applied for land-based wind energy and the investment tax credit will be used for offshore wind energy and that one of the two bonus credits will be claimed by 2028. Further, the NREL 2022 Standard Scenario assumes qualifying projects will meet the prevailing wage and apprenticeship requirements to claim the tax credit multiplier⁶; however, it does not explicitly represent the manufacturing tax incentives in the IRA.⁷

While manufacturing incentives are not considered in the capacity deployment scenario, increased domestic manufacturing was built into the model under the assumption that as domestic manufacturing increases, so will the demand for a domestic workforce. The model assumed that domestic content percent will only affect the full-time equivalents attributed to manufacturing, primarily workers in skilled trades, and that the other wind industry segments are not affected. Because only the full-time equivalents related to manufacturing are affected, Figure 9 displays a modest increase in the workforce demand chart.

Conversely to the demand side of the model, increasing the supply of the workforce is considered an indirect outcome related to the IRA's ability to increase workforce demand. Therefore, many of the impacts to supply will not be accounted for in this scenario.

On the supply side of the model, we assumed that more people would enter apprenticeship training in occupations that could be applicable to the renewables industry as the workforce gains more awareness of these opportunities⁸. Furthermore, we assumed that as more projects use the prevailing wage, the positive perception of employment in the wind industry, and therefore, the number of people applying for careers in the wind energy industry, will increase for occupations affected by the prevailing wage requirement.⁹ Additionally, Scenario 3 assumes that the IRA will not cause a decrease in the supply of the workforce as it is being implemented, and that full maturity of these policies occur over 10 years, as this is when many of the tax incentives are scheduled to retire.

⁶ More information on the good faith effort exemption and 5-times tax credit multiplier can be found here: <https://www.irs.gov/credits-deductions/frequently-asked-questions-about-the-prevailing-wage-and-apprenticeship-under-the-inflation-reduction-act#prevailing>.

⁷ More information on the assumptions within the NREL 2022 Standards Scenario can be found here: <https://www.nrel.gov/docs/fy23osti/84327.pdf>.

⁸ There are many reasons for an apprentice to be placed or choose to go into the wind industry. This model only exhibits one of those assumptions.

⁹ “For purposes of complying with the prevailing wage provisions of the Inflation Reduction Act, the prevailing wage refers to the minimum wage rates that taxpayers must ensure are paid to laborers and mechanics performing construction of a facility, project, property, or equipment (hereafter referred to as a facility) and, in some cases, alteration or repair.”

<https://www.dol.gov/agencies/whd/IRA#:~:text=The%20prevailing%20wage%20is%20the,in%20an%20applicable%20wage%20determination>.

Figure 9 estimates that deploying IRA policies could cause the supply of the workforce to increase anywhere between 0.25% and 1.04% from BAU in 2030, and between 0.77% and 3.35% from BAU in 2050. The increased workforce demand, however, does have a slightly counteracting effect to the increased workforce supply's ability to decrease the workforce gap. Therefore, increasing the supply through education and training program expansion and development, and recruiting qualified transitioning workers at a quicker rate will be needed to offset the increasing demand.

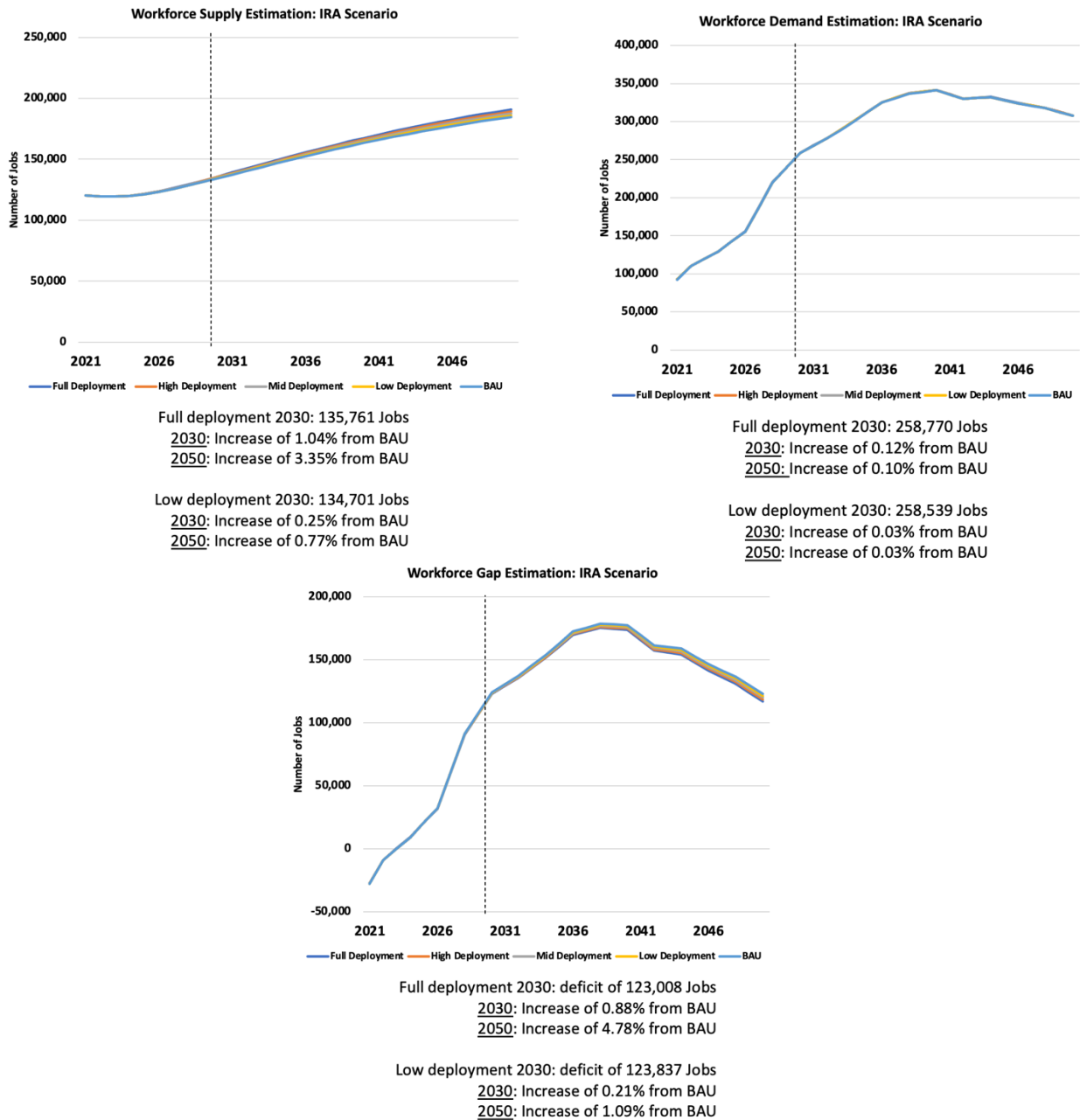


Figure 9. Workforce supply (top left), workforce demand (top right), and workforce gap (bottom) changes as affected by the IRA scenario

These estimated ranges indicate that taking actions that increase the number of the people going into renewable-energy-related education and training, and the number of job seekers applying into wind industry jobs can help lessen the workforce gap. However, taking actions to increase the supply of education and training program applicants and job applicants will not be enough to mitigate the gap. The applicants to wind energy must also have the correct experience and qualifications to align with industry needs and hiring preferences to ultimately secure jobs. Timing can also vary the workforce estimations greatly as it is assumed that faster implementation and maturity of policy will increase the supply of the wind workforce faster and have sustained effects. Therefore, showing that increasing the workforce supply, if demand is kept constant, will decrease the gap between supply and demand.

4.3 Additional Considerations for the Workforce Gap

Students who are U.S. citizens but have a non-U.S.-based education were included in the previously mentioned workforce estimation. For example, a high school or undergraduate student from a U.S. institution could attend an international training program, be awarded a degree, move back, and get hired by a U.S.-based firm. Looking specifically at U.S. wind firms hiring from non-U.S.-based education and training institutions, previous research has indicated that one-quarter of wind energy firms have considered hiring applicants with non-U.S.-based education or experience for jobs in the United States (Keyser and Tegen 2019). However, to best focus on the domestic wind workforce need, we did not include foreign workers who are hired by U.S. wind industry companies as an element of the supply side of the model (for example, a foreign student or tradesperson who attends an international training program and is hired for the U.S. wind industry).

Another factor that could affect the size of the wind workforce gap would be a decrease in worker demand due to automation and digitalization. Automation could involve processes that use software, hardware, or other technologies to automate tasks, improve quality control, and reduce time. Automation was a limiting factor in the workforce estimations as it was applied as an assumption related to the speed of deployment for wind energy. Based on research performed by the Massachusetts Institute of Technology and Boston University, it is assumed that 1 robot unit¹⁰ decreases the workforce demand in the United States by 3.3 full-time employees (Acemoglu and Restrepo 2020). The model also assumed that the specific number of robot units used for the manufacturing, construction, and utilities sectors increases by 3.0% annually.

According to the 2022 survey results, more than two-thirds of the overall respondents reported that they had implemented automation (Figure 10). When asked why, respondents stated it was for quality control (55.2%), safety of workers (37.2%), and to reduce operational costs within the firm (37.2%) (Figure 11).

¹⁰ A robot unit or industrial robot is defined by the International Federation of Robotics in compliance with [\(ISO 8373:2021\)](#) as an “automatically controlled, reprogrammable multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or fixed to a mobile platform for use in automation applications in an industrial environment.” <https://ifr.org/industrial-robots#:~:text=The%20IFR%27s%20use%20of%20the,platform%20for%20use%20in%20automation.>

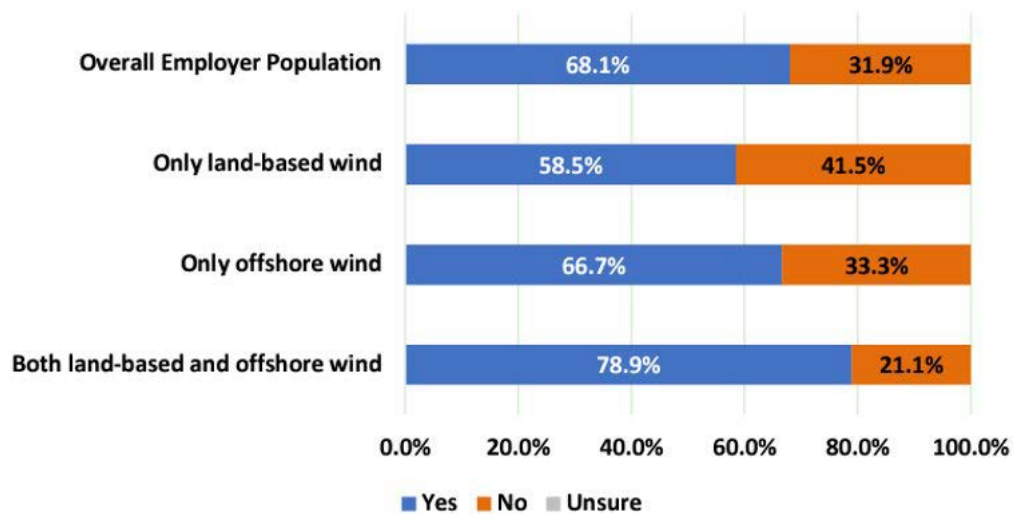


Figure 10. Implementation of automation technologies at wind energy firms. Graph from BW Research Partnership (2023a)

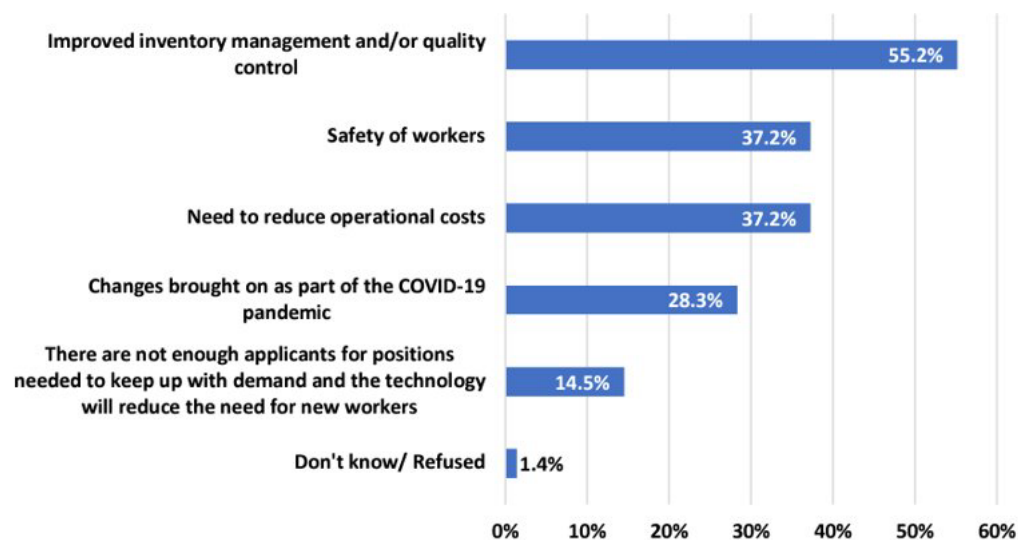


Figure 11. Reasons for implementing automation technologies at wind energy firms. Graph BW Research Partnership (2023a)

While only 14.5% reported that there are not enough applicants for positions needed to keep up with demand as their primary reason for initially implementing automated technologies, firms have reported that these technologies have allowed them to better manage the lack of available workers and reduced the need to hire new workers (Figure 12). The top three occupations believed to be impacted from automation within wind energy firms were those related to operations and maintenance, accounting and administrative occupations, and manufacturing and assembly. More research on the effects automation and digitalization will have on the wind workforce demand is needed; however, it is expected that automation in the wind industry will increase, so training the future workforce in skills related to digitalization will be important for future adaptability.

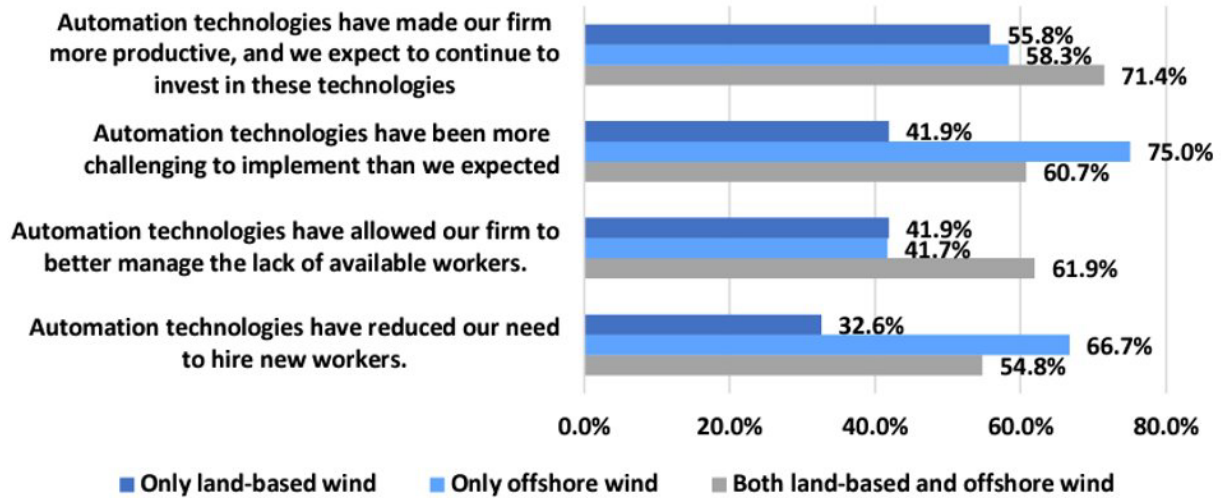


Figure 12. Agreement with statements about automation technologies at wind energy firms by wind industry segment. *Graph BW Research Partnership (2023a)*

5 Summary of Presentations

Due to the amount of information gathered through the survey and modeling efforts, four presentations have been created to provide more insight into findings and focus on specific stakeholder groups. These groups include:

- Educators
- Wind industry firms
- Students
- Current wind industry employees.

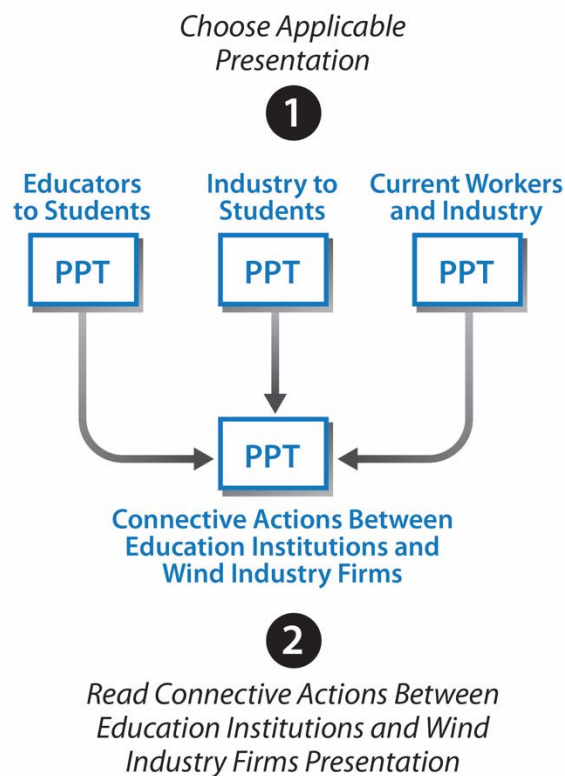


Figure 13. How to utilize the stakeholder presentations. Image created by John Frenzl, NREL

5.1 Educators to Students

This presentation, “[National Wind Workforce Assessment: Educators to Students](#),” (McDowell, Smith, and Stefek 2023a) is intended for use by educators and students looking to gain insight into key areas that can influence wind energy hiring difficulty and actionable steps that can be taken to help narrow the workforce gap. The presentation includes the current student perception of the wind industry, hiring difficulties faced by wind energy firms, and hiring difficulties faced by the potential workforce. The hiring difficulties for wind industry employers are divided by entry-level employees and nonentry-level employees and by firm size, location, value chain segment, and wind industry sector. Hiring challenges faced by students trying to enter the wind industry are divided according to 2-year degree and certification programs, 4-year degree programs, and current wind employees.

5.2 Industry to Students

This presentation, “[National Wind Workforce Assessment: Industry to Students](#),” (McDowell, Stefek, and Smith 2023) is intended for use by wind industry employers looking to gain insight into key areas that can influence hiring difficulty and actionable steps that can be taken to help narrow the workforce gap. The presentation includes the current perception of the wind industry by the potential workforce, hiring difficulties faced by wind energy firms, and hiring difficulties faced by the potential workforce. The hiring difficulties for wind industry employers are divided by entry-level employees and nonentry-level employees and by firm size, location, value chain segment, and wind industry sector. Hiring challenges faced by students trying to enter the wind industry are divided according to 2-year degree and certification programs, 4-year degree programs, and current wind employees.

5.3 Current Workers and Industry

This presentation, “[National Wind Workforce Assessment: Current Workers to Industry](#),” (McDowell, Smith, and Stefek 2023b) is intended for use by wind industry employers and current workers, including recent graduates, looking to gain insight into key areas that can contribute to the narrowing or widening of the wind workforce gap. This presentation highlights the perception that current workers and recent graduates have regarding hiring barriers to enter the wind energy industry. In addition to the current perception, it covers hiring challenges by wind energy firms as well as prospective workers and discusses automation and its contribution to narrowing the wind workforce gap.

5.4 Connective Actions for Education Institutions and Wind Industry Firms

This presentation, “[Connective Actions for Education Institutions and Wind Industry Firms](#),” (McDowell, Smith, and Stefek 2023c) is intended for wind industry firms and educational institutions looking to gain insight into key areas and actionable steps that can be taken to help narrow the workforce gap. This presentation includes data and guidance on how wind industry firms and education institutions can collaborate to:

- Grow the number of graduates applying into wind occupational roles by building awareness of opportunities in the industry.
- Increase the quality of applicants applying into wind energy through relevant opportunities like internships and apprenticeships.
- Reduce barriers for applicants into the wind energy industry through diversity, equity, and inclusion (DEI) practices.

6 Connective Actions

As the wind energy workforce gap continues to be a challenge, all stakeholders have an essential role to play in successfully closing it. Collaboration among wind workforce development stakeholders to increase awareness of industry jobs, effectively develop opportunities to gain experience such as internships and apprenticeships and reduce barriers of entry into the wind industry are vital steps in ensuring that there is an adequate (in numbers) and properly trained wind workforce.

Wind industry firms are reporting difficulty finding entry- and nonentry level workers due to a shortage of applicants and a lack of the experience desired. Education institutions, which include both wind-energy-specific programs and renewable-energy-focused programs, are reporting that despite 89.2% of students having jobs after 6 months of graduation, only 47.9% of those students had jobs in the wind industry. These results exemplify the gap between qualified workers and entrance into the wind energy industry.

Meanwhile, 37.5% of students and recent graduates surveyed have never considered working in the wind energy industry with their top reasons being interest in other industries (71.2%), lack of exposure to the wind industry in coursework (60.0%), and unsure of what jobs make up the wind industry (54.2%). Of the students and recent graduates who are currently working in the wind industry getting technical training and experience, along with finding employment opportunities that are near where they are willing to live, were reported as top challenges to getting hired.

Through the workforce estimation scenarios, we determined that proactive efforts, such as recruiting students for education programs and building awareness of opportunities and encouraging individuals to apply to jobs in the wind industry are needed. Additionally, establishing more opportunities to gain experience and training that meet industry requirements can help adequately prepare the potential workforce for a career in wind. Industry employers and educators can work together to mitigate the workforce gap by:

- Conducting outreach and providing opportunities to participate in programs that build awareness of the wind energy industry and connect with students.
- Establishing effective internship and apprenticeship programs and pipelines
- Reducing barriers into the wind industry for historically underrepresented populations and transitioning workers.

6.1 Outreach and Participation in Programs To Build Awareness

Enhancing awareness of wind industry opportunities among students and recent graduates is an opportunity for attracting more people to apply to wind industry jobs. One way to increase student awareness is through increased connection between wind industry firms and educational or training institutions. Survey respondents indicated that wind industry employers and educational institutions are underutilizing resources between one another that could be used to connect current students with wind careers. In addition, 58.8% of wind energy firms reported underutilizing education institutions to find job candidates (Figure 14).

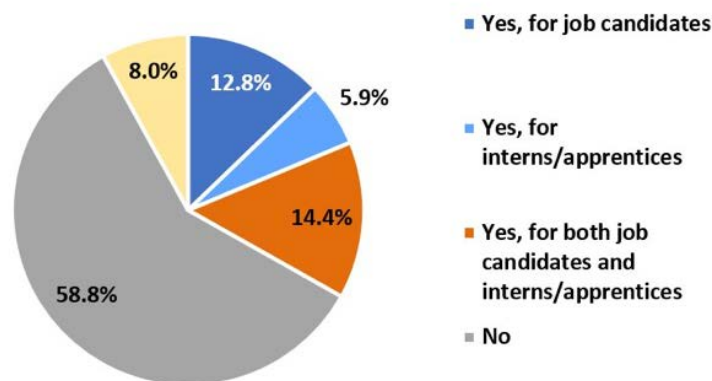


Figure 14. Utilization of educational institutions by wind energy firms (2022 [n = 187]). *Graph BW Research Partnership (2023a)*

To increase collaboration and awareness of wind energy opportunities, partnerships between educators and wind industry firms could be established. In addition to building awareness, these partnerships could also be leveraged to provide wind energy related professional experiences through education and training programs. Educators surveyed indicated offering a range of opportunities that help students gain experience through their programs. Industry guest speakers were the most prevalent opportunity, which was offered by an education institution who took the survey (95.2%). Internships (76.2%) and research (76.2%) were the next two biggest opportunities indicated. Most of the students reported being aware of these types of opportunities, indicating how partnership between education and industry could allow for industry to have more interaction with the potential workforce, therefore, building more awareness of future career pathways in wind energy (Figure 15).

Awareness of Experience Opportunities Offered By Educators to Students

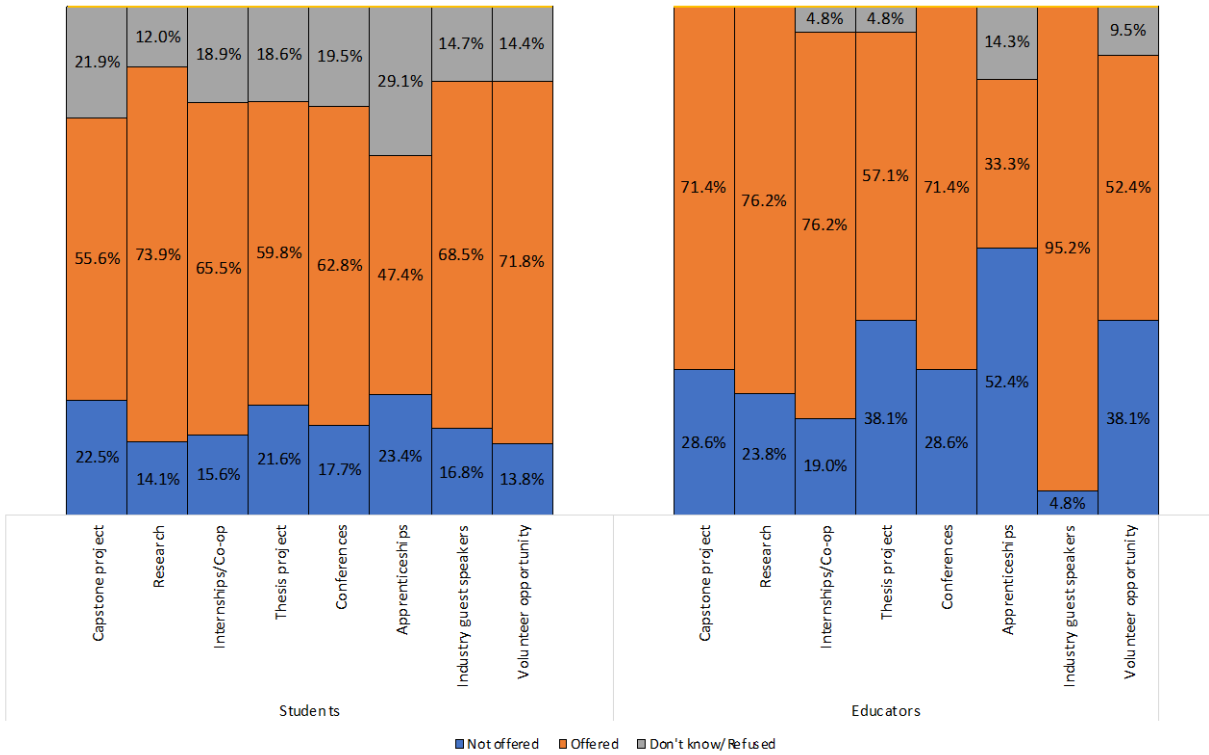


Figure 15. Awareness of opportunities that provide experience by educators to students

Another way to have increased collaboration between wind energy firms and education institutions is through participation in programs that build awareness of careers in the wind energy industry and provide relevant experience like DOE’s Collegiate Wind Competition (CWC). The CWC is a program funded by DOE’s Wind Energy Technologies Office to provide undergraduate students focused on careers in fields such as engineering, business, finance, and environmental studies with real-world wind application and experiential learning and build partnerships between educators and students and wind energy firms. According to the survey effort, 55.0% of employers reported that the CWC has a positive influence in the wind energy industry. Additionally, analysis done by BW Research indicated that recent CWC participants were between 1.42 and 1.50 times more likely to be interested in building a career across the wind industry than non-CWC participants, and currently employed workers who participated in CWC were 1.57 to 1.81 times more likely to be employed in the wind industry than non-CWC participants (BW Research 2022). This is one example of a connective program that helps develop a robust wind workforce pipeline and encourages participants to apply to wind-energy-related jobs.

6.2 Internship and Apprenticeship Programs and Pipelines

Internships and apprenticeships offer a pathway for students and recent graduates to gain technical skills and expertise and for wind industry firms to enhance the experience level of the workforce. According to survey data, student respondents who participated in internships and/or apprenticeships were highly satisfied with their experiences (Figure 16). Student respondents were most satisfied with their ability to get training and develop technical skills and expertise,

which was also reported as being the number-one challenge to being hired into the wind industry. Additionally, nearly 75% of current or recent wind employees surveyed participated in an internship or apprenticeship before entering the wind industry and agreed that their experience helped prepare them for their career.

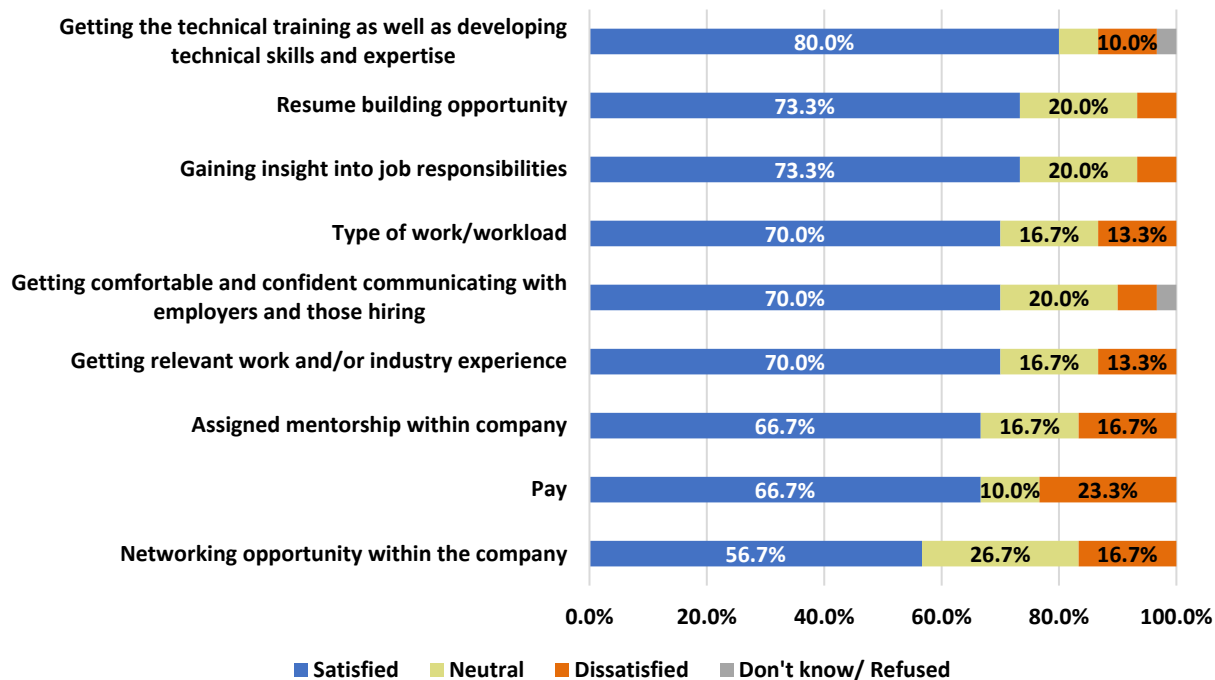


Figure 16. Level of satisfaction internship and apprenticeship experiences (2022 [n=30]) Graph BW Research Partnership (2023a)

Of wind energy firm respondents, 32.8% reported having an internship program, 12.0% reported having an apprenticeship program, 19.1% reported having both an internship and apprenticeship program, and 33.9% reported having neither. Students are recognizing the importance of internships and apprenticeships when entering the wind industry, with nearly 94% of respondents reporting that they have considered and/or actively searched for internship and apprenticeships in the wind energy industry.

While internships and apprenticeships have been reported to be successful in providing entry-level employees with the experiences desired by wind industry firms, the benefits that internships and apprenticeships bring to the wind industry rely on job seekers' ability to locate opportunities, and the employer's ability to find qualified applicants. In Fiscal Year 2022 and Fiscal Year 2023, NREL performed internal analysis and stakeholder engagement interviews to research the best practices and challenges within wind industry's internship and apprenticeship programs. Regarding internships, it was found that inconsistencies within company landing pages, entry-level job labeling, and recruitment practices used for internships hinder a job seeker's ability to

find and apply for opportunities in the wind industry.¹¹ Additionally, challenges such as limited human resource department capacity, a lack of a standardized recruitment time frame, and a lack of DEI initiatives have been shown to be institutional challenges for recruitment into wind industry firms. From this effort, the following seven best practices for improving internship programs in the wind industry were identified:

- Expand the capacity of the human resources department.
- Develop a company landing page for the internship program.
- Standardize the recruitment time frame for the fall.
- Diversify recruitment strategies to attract a variety of job seekers .
- Increase accessibility to internship programs through wrap-around services.
- Create an early engagement program with first- and second year students.
- Identify and implement efficient methods for building relationships with universities.¹²

Concerning apprenticeships in the wind energy industry, NREL researchers conducted stakeholder interviews with many organizations such as labor unions, preapprenticeship programs, policy groups, and community colleges to evaluate trends and challenges. The findings were categorized by three key areas: recruitment strategies, program structure, and policy.

Regarding recruitment strategies, it was found that the maturity of recruitment approaches varied across interviewed stakeholders. However, it was reported amongst stakeholders that traditional recruitment strategies into training programs are increasingly becoming inadequate for meeting skilled trades workforce demand. It was indicated that one possible solution to this barrier was to tailor recruitment strategies to targeted locations and demographics; however, three main systemic challenges were identified as barriers to this approach. These challenges include a workforce skills and occupation awareness gap, societal barriers, and workforce demand uncertainty. To address these barriers, apprenticeship programs reported developing and expanding youth-focused recruitment pipelines like preapprenticeship and youth apprenticeship programs and offering supportive services to ensure success once the individual has become an apprentice. Youth apprenticeship programs are registered programs intended to support individuals ages 16 to 24; however, this does not disqualify those individuals from participating in a traditional, nonyouth, registered apprenticeship program. Preapprenticeship programs are leveraged to prepare an individual for entering a registered apprenticeship program. Within preapprenticeship programs, it was found that comprehensive curriculum, supportive wrap-around services, and sustainable partnerships are important factors for preparing individuals who were interested in entering a registered apprenticeship program.

The apprenticeship ecosystem structure comprises both registered and nonregistered apprenticeship programs. Registered apprenticeship programs are approved by the U.S.

¹¹ Information compiled based on internal analysis of large wind energy industry and adjacent industry webpages, conducted by National Renewable Energy Laboratory (NREL) staff Heidi Tinnesand, Matthew Kotarbinski, and Chloe Constant (2022).

¹² Information compiled based on internal analysis of 12 interviews with wind energy industry human resource representatives, conducted by NREL staff Heidi Tinnesand, Brinn McDowell, Bailey Pons, Matthew Kotarbinski, and Chloe Constant (2023).

Department of Labor or select state approved agencies and may or may not be affiliated with a union. Nonregistered apprenticeship programs are often not affiliated with a union. Whether a program is or is not registered, in addition to what occupation it is training for, influences the program design and what requirements are needed for completion. Specific to registered apprenticeship programs, the analysis revealed that:

- Effective curriculum development must be created collaboratively with relevant stakeholders and employers such as industry members, labor unions, and community colleges.
- Mentors for program participants must provide support and guidance throughout the program.
- Partnerships between training programs and employers are key to the trainee's success.

Regarding policy initiatives, there was uncertainty around whether policy or programs should be developed first, as well as how the IRA will affect employers in the industry. Additionally, it was found that grant funding often has regulations regarding how funds can be used, and in some cases, those regulations can prevent the money from being effectively allocated to DEI initiatives and wrap-around services used by preapprenticeship and apprenticeship programs. As a result of the extensive research and analysis, researchers developed the following five best practices that wind industry firms could use to further develop and expand apprenticeship programs:

- Collaborate with key stakeholders to ensure accountability, trust, and transparency.
- Address program recruitment needs through increased involvement and transparency with apprenticeship programs and their sponsors.
- Establish contract-based tools early in the project development timeline.
- Integrate DEI initiatives into apprenticeship program recruitment and program design through wrap-around services and supportive policies.
- Build awareness of job opportunities in the wind industry and leverage registered apprenticeship programs as a pipeline to those opportunities.¹³

6.3 Reducing Barriers to the Wind Energy Industry

Reducing barriers for traditionally underrepresented populations looking to enter wind industry education programs and employment is essential to improving the workforce gap. While the wind workforce continues to increase, intentional inclusivity and equity practices will help to not only promote accessibility, and inclusion in the wind energy industry, but also ensure local benefits, such as job creation, are available to the communities where development is occurring.

Currently, worker representation within the wind energy sector varies based on demographics and characteristics. In terms of gender, the wind industry is disproportionately male, with nearly 70.0% of workers identifying as such. The U.S. average for male workforce representation is around 53.0%. Additionally, the portion of people who identify as Black, African American, Asian, or having a disability all have lower representation than the national average. However, the wind energy industry does have a higher-than-average representation of veterans (9.0%) and

¹³ Information compiled based on internal analysis of 17 interviews with stakeholders related to wind energy apprenticeship programs, conducted by NREL staff Brinn McDowell, Matthew Kotarbinski, Bailey Pons, Heidi Tinnesand, and Chloe Constant (2023).

union members (11.0%) when compared to the national average representation of veterans (6.0%) and those represented by a project labor agreement or union in the private sector (6.0%) (Table 3).

Table 3. Wind Electric Power Generation Workforce Demographics and Characteristics. From DOE (2022)

Table 8. Wind Electric Power Generation Workforce Demographics and Characteristics

	Number of Workers	Wind Electricity Average	National Workforce Averages	Energy Workforce Averages
Male	83,564	70%	53%	74%
Female	36,444	30%	47%	25%
Gender non-binary	156	<1%	Unknown	0%
Hispanic or Latino	22,264	19%	18%	17%
Not Hispanic or Latino	97,900	81%	82%	83%
American Indian or Alaska Native	1,336	1%	1%	2%
Asian	11,878	10%	7%	7%
Black or African American, not Indigenous	8,724	7%	12%	8%
Black Indigenous	1,061	1%	insufficient data	1%
Native Hawaiian or other Pacific Islander	1,370	1%	<1%	1%
White	84,431	70%	78%	74%
Two or more races	11,365	9%	2%	8%
Veterans	10,330	9%	6%	9%
55 and over	17,773	15%	24%	17%
Disability	2,982	2%	4%	2%
Formerly Incarcerated	2,225	2%	2%	1%
Represented by a Union or Project Labor Agreement	13,743	11%	6%	10%

National sources: BLS (2022a, 2022b, 2022c, 2022d), Jobs EQ (2021), Prison Policy (2022)

Wind industry firms that participated in the 2022 survey were asked if they feel there is difficulty hiring specific populations of people. Wind energy firms reported the highest difficulty in hiring was for people who identify as American Indian or Alaskan Native (31.3%). Additionally, one in four wind firms felt that there was difficulty in hiring a person that identifies as a woman. Of the employers who responded, 22.5% were unsure or refused to answer if there was difficulty when trying to hire a person that identifies as nonbinary (Figure 17).

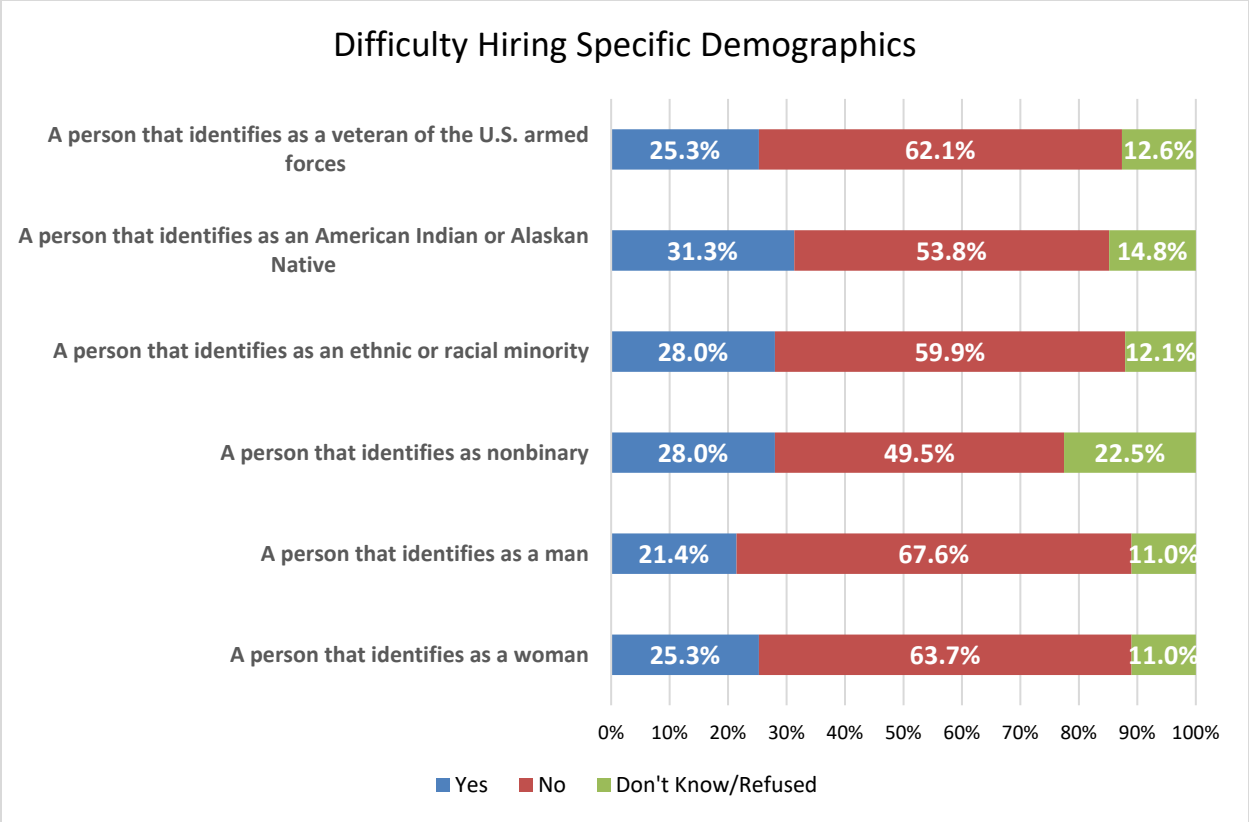


Figure 17. Difficulty faced by wind industry firms when hiring specific demographics (n=182)

The majority of firms who participated in the survey also reported that they did not have hiring initiatives or programs to increase the number of employees for specific demographic groups. People who identify as an ethnic or racial minority, woman, or veteran of the U.S. armed forces were reported to have the most hiring programs or initiatives developed for them at 38.7%, 37.6%, and 32.6%, respectively (Figure 18).

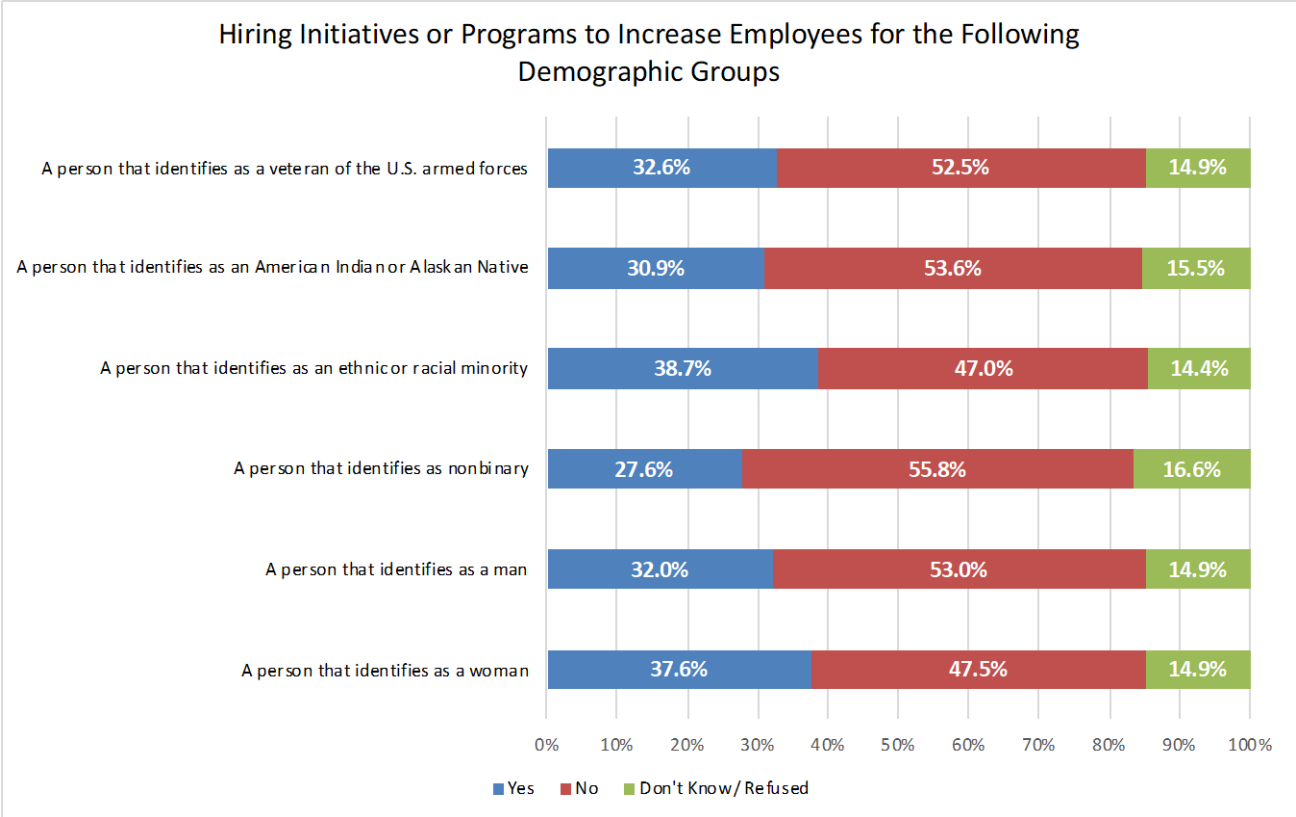


Figure 18. Percent of wind industry firms who have hiring initiatives or programs to increase representation of specific demographics (n = 181)

Wind energy firms that reported difficulty hiring employees of the following demographic groups (Figure 19) reported having more initiatives and programs to increase recruitment numbers for those specific groups than all wind firms in general. This distribution could potentially be attributed to awareness of DEI practices and tracking of demographics and hiring initiatives within the specific wind energy firms.

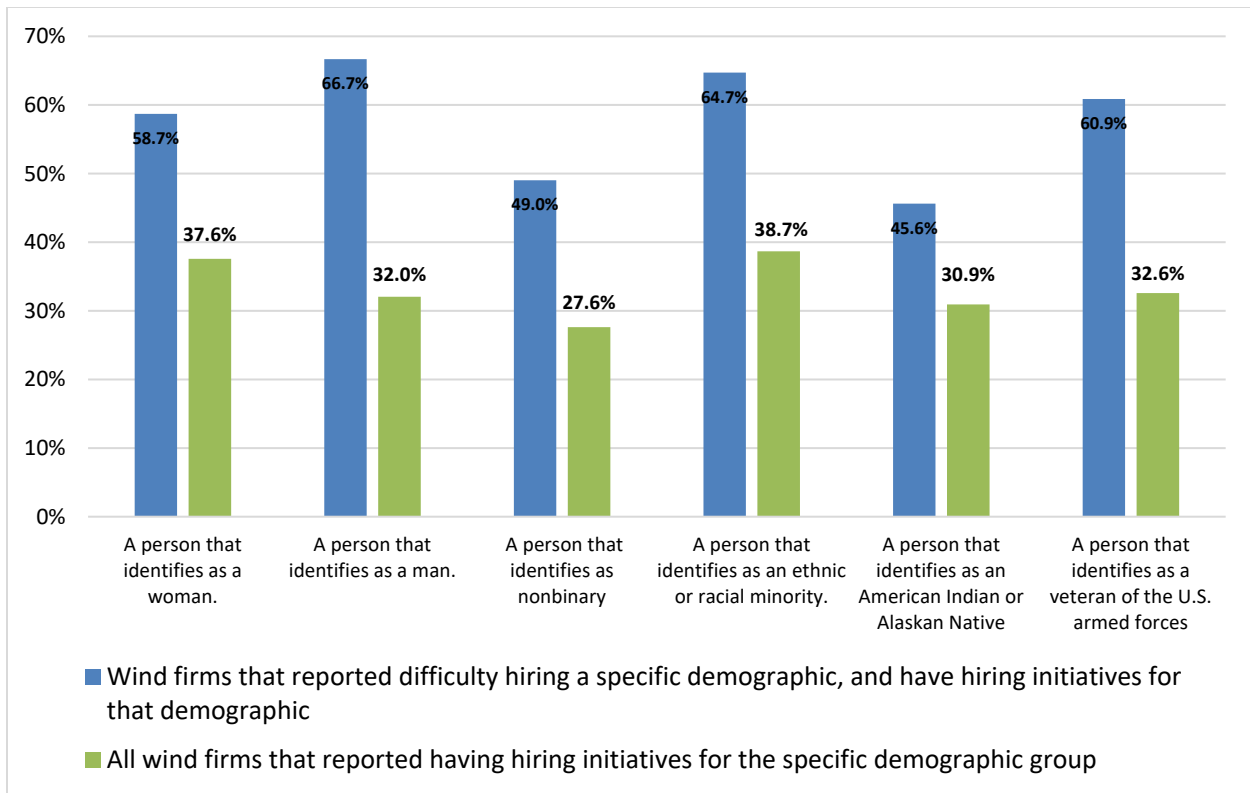


Figure 19. Percent of all wind firm respondents with reported hiring initiatives for specific demographic groups compared to the percent of firms who reported having hiring difficulties and have initiatives for hiring specific demographic groups

Collecting meaningful wind energy workforce data and metrics is one of the first steps to ensuring progress is being made by the programs created. Through internal NREL analysis, several challenges to collecting meaningful wind energy workforce data have emerged that could hinder the development of DEI programs and initiatives.¹⁴ Some of these challenges include:

- A lack of funding and standardized framework for reporting practice
- Dependence on voluntary reporting
- Employee privacy and data collection practices
- A low response rate from industry employers on DEI topics.

In addition to collecting meaningful metrics, one way wind energy industry firms and education and training institutions could reduce some of the barriers to entry is through partnerships with DEI-focused, community-based organizations and programs. To create more diversity, equity, and inclusion in the wind energy industry, there must be an intentional understanding of socio-economic and systemic barriers that have influenced these historical inequities. The process of creating a DEI partnership must first involve understanding why diversity is important in the workforce. Furthermore, ensuring that the economic benefits of wind energy development get distributed in a way that does not perpetuate historical inequities and supports the economic development of local wind communities is essential for future success. As the wind industry

¹⁴ Information compiled based on literature review and interview with BW Research Partnership, conducted by NREL staff Jeremy Stefek, Sabina Maniak, and Chloe Constant (2023).

grows, it is imperative to involve diverse perspectives, which can be achieved through long-term DEI-focused partnerships.

Goals and concerns for creating effective DEI partnerships were discussed during virtual interviews held between NREL researchers and various community-based organizations and programs. Interviewees expressed a clear desire to provide wind-energy-related educational and professional opportunities to the youth and minority groups they serve, and overall excitement for partnership. However, interviewees also expressed concerns. The main topics interviewees discussed include:

- The need for direct communication
- Understanding these opportunities and creating objectives that complement their organizations' goals.
- Intentionality in continuing to work together on projects until goals are met.

7 Conclusion

As wind energy installations continue to increase in the United States, mitigating barriers and challenges to establish a properly trained wind energy workforce will be essential for meeting deployment goals. Currently, wind energy employers are reporting difficulty finding qualified job candidates, and potential wind energy workers report challenges finding jobs in the wind energy industry resulting in a workforce gap.

According to the BAU scenario, by 2030 there is an estimated wind workforce gap of nearly 124,000 workers for both land-based and offshore wind. While this workforce gap poses a potential barrier to wind energy development, there are connective actions that educators and industry firms can take to close this gap in the future. Based on our modeling of key levers for the renewable energy education and training programs, applicants to wind industry jobs, and IRA scenarios (Section 5.2), the following actions have the greatest impact in decreasing the wind workforce gap:

- Positively impacting education and training programs student teacher ratio, funding levels, infrastructure availability, and curriculum to increase acceptance rates into relevant education and training programs
- Positively affecting key metrics such as labor wages, job stability, and job location to increase job seekers' perception of wind energy employment.

Furthermore, increasing students' awareness of job opportunities in the wind energy industry through deepening connections between postsecondary educational institutions and industry firms, and providing experience-gaining opportunities through internship and apprenticeships or collegiate competitions have been reported to be effective tools for influencing qualified job seekers to apply, and be hired into, the wind industry, thereby helping to close the workforce gap.

7.1 Key Takeaways

Wind energy employers have continued to indicate a level of difficulty in hiring for entry and nonentry-level workers. Entry-level employees were reported as not having the experience and qualifications desired by employers, whereas industry firms looking to hire nonentry-level employees often did not have enough applicants for positions available. Employers also reported difficulty in hiring employees of certain demographics, and our survey effort indicated that wind firms had the highest difficulty in hiring Native American or Alaska Natives. Additionally, most firms that responded to the survey reported that they did not have hiring initiatives to increase the number of employees across different demographic groups, which is an area with room for improvement. Similarly, enhancing collaboration and awareness of wind energy opportunities between wind employers and educational institutions has the potential to increase the number of qualified people applying for these types of jobs. In addition, the CWC was reported by employers as a strength of the wind industry, with currently employed workers who participated in the competition to be 1.57 to 1.81 times more likely, dependent on wind technology, to be employed in the wind industry than non-CWC students (BW Research Partnership 2022).

Deepening connections between post-secondary educational institutions and the wind energy industry is necessary, as the demand for workers grows to meet wind capacity goals. Based on the firms that responded to the survey, more collaboration is needed to encourage wind energy firms to use educational institutions to find qualified candidates for job opportunities. While firms reported difficulty in hiring workers, 59.0% did not use educational institutions to find workers. Therefore, increased collaboration and awareness of job opportunities and partnerships between these parties can help firms find qualified workers.

Internships and apprenticeships can also help by providing students with the technical and transferable skills they need to qualify for positions in the wind energy industry. Students who responded to our surveys that had participated in either an internship or apprenticeship were satisfied with their experience. Overall, almost 75% of the current or recent wind employees hired had participated in an internship or apprenticeship and found that their experience prepared them for their position in the wind industry.

7.2 Future Initiatives and Research

Future research and initiatives are still needed to develop a sizeable and qualified workforce to meet the deployment goals of wind energy.

Areas for future analysis research could include:

- Developing a better understanding of how educational and training institutions, such as apprenticeship programs and community colleges and wind employers can deepen their connection with one another to meet workforce development needs
- Evaluating the effects that digitalization and automation could have on the wind energy workforce demand and skills required to meet deployment goals
- Identifying how wind energy is integrated into educational programs and analyzing why students study wind energy can help educational institutions better develop their curricula to increase student interest
- Examining how opportunities like apprenticeships and internships are being used to overcome hiring challenges within the wind energy industry, such as gaining a better understanding of the regional workforce implications of the IRA, including availability and use of wind-related registered apprenticeships programs and the effects of the prevailing wage on workers and labor markets.
- Catalogging the direct investments by federal agencies into federal programs and organizations while evaluating the implications of the funding on wind workforce development initiatives, programs, and awareness levels.
- Investigating techniques and best practices that could be used to overcome the reported undesirable geographic location of wind industry jobs.

Areas for future programming and initiative development could include:

- Creating regional collaborative working groups that include various stakeholders, such as state governments, local municipalities, community-based organizations, labor organizations, and educational and training institutions focused on reducing the economic and cultural barriers in the wind energy industry

- Developing a common platform to increase awareness of industry jobs and education and training opportunities related to wind energy by connecting pathways between educational and training institutions, wind industry firms, and job seekers
- Advancing intentional and inclusive hiring practices into wind career opportunities
- Creating curriculum and resources for middle and high school students that build awareness of wind career pathways.

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