Thank you for allowing me to share my capstone project on Wind Power in the United States with you today. I'd like to start in the Iowa countryside at sunrise. When my brother sends me photos like this one, it's easy to become jealous of his career choice, but then I remember that he had to climb up over 300 ladder rungs, 312 feet in the air to the top of this wind turbine to capture this photo, and, on second thought, I think I'll stay on the ground behind my computer.

In 2016, when my brother had just started his training, the U.S. Bureau of Labor Statistics first named Wind Turbine Service Technicians the fastest growing occupation of the decade. It has remained near or at the top of this list since. Between 2019 and 2029, the number of jobs are expected to increase by 61%. But this wasn't always the case, the wind energy industry had a rather slow start in the U.S. So, how did we get here?

The principles used the generate electricity from the wind have been used since the middle ages to pump water and grind grains and it has been used in United States as a source of electricity since the late 1800s, especially in rural areas, but it wasn't until the 1970s when the price of gas skyrocketed that the nation began to see a need to focus on renewable energy sources. In 1980, the first large, utility scale wind farm was built in California. Throughout the 80s, the industry continued to innovate, but funding from the government waned, until 1992 when the Energy Policy Act was passed, which authorized a production tax credit of 1.5 cents per kilowatt hour of wind-power-energy generated. This encouraged the production and sale of wind energy so from 2000 to 2019 we see a steady increase in the number of kilowatt hours of electricity generated from wind turbines. In 2019, the United States reached 300 billion kilowatt hours.

Wind turbines generate electricity when wind turns the blades of a turbine around a rotor, which spins a generator, which creates electricity. The amount of electricity that is generated depends on the rated capacity of the turbine. Two components that have helped increase the rated capacity is rotor diameter, which is illustrated on the left side of this image, and hub height or the height from the turbine platform to the rotor or center of the blades, illustrated on the right. The following analysis focuses on utility scale, onshore wind turbines installed in the United States, and therefore does not include small residential wind turbines.

In the 1980s hub height was on average 78 feet and by the early 2000s average height was 205 feet or the height of the Tennessee State Capital Building. Today that height has increased to an average of 280 feet. Some even reaching 429 feet, which just a few feet taller than the Pinnacle Building in downtown Nashville. This is significant because wind speeds increase at higher heights above surface level and with higher wind speeds bring more electricity generating potential.

Higher hub heights also allow for larger rotor diameters. By 2005, we see average rotor diameters of 262 feet or approximately the size of a Boeing 747. And today the average is 369 feet with some over 500 feet wide.

This chart shows the relationship between rated capacity and rotor diameter of wind turbines. Using the averages from each year group we see that by doubling the rotor diameter from 92 feet to 194 feet, we see a quadrupling of the rated capacity from 0.25 megawatts to 1 megawatt. The average rated capacity of a turbine installed in the U.S. today is 2.3 megawatts, which can generate enough electricity in 70 minutes to power an average U.S. home for one month.

Now we've seen how technology has changed to allow for more electricity production, but another hurdle the industry has had to overcome is cost. Here we see the levelized cost of energy for onshore wind production in the United States. Levelized cost of energy takes into account the cost of building and operating a power plant over its lifetime and allows for comparison between energy sources. The cost for wind has fallen from nearly 30 cents per kilowatt hour in the 80s to less than 5 cents in 2019. Within the last few years the cost has become competitive with other sources of electricity and in many cases it is more cost effective to build new wind turbines than to continue operating coal-fired plants.

In 2019 wind accounted for 7% of electricity production in the United States and for the first time produced more electricity than hydropower. Although gas continues to increase, we see steady decrease in the use of coal. We know that replacing fossil fuels with renewable energy sources, leads to a reduction in co2 emissions. According to a study in the International Journal of Sustainable Manufacturing, the typical wind project repays its carbon footprint in six months or less.

Because wind energy provides zero-emission energy, it is also safer for humans than using fossil fuels. These death rates were measured as the number of deaths from both air pollution and accidents per terawatt-hour of energy production. We see that all renewable energy sources have a much lower death rate than fossil fuels.

The wind energy industry has also been working to mitigate the impact that wind turbines have on wildlife as well. Here is a map of a wind farm in California. In the 1980s turbines were installed close together, but over the years they were spaced farther apart to both allow for larger rotor diameters and to reduce the chance of a bird colliding with a turbine. Wind farm site planners spend years planning the construction of a wind farm to ensure turbines are installed in locations of optimal wind speeds, away from obstructions, and often work with wildlife agencies to minimize the risk to birds and bats, especially in their migration paths.

Wind turbines do kill approximately half a million birds in the U.S. each year, but that is far fewer than many other causes, like cats and buildings. Many wind farms have programs that track bird deaths and to help find ways to decrease these collisions in the future.

Bats are also affected by wind turbines. A study at the University of Colorado, reported that in 2012, 600,000 bat fatalities were cause by wind turbines in the United States during migration. This is particularly worrisome since white nose syndrome has also killed numerous bats in recent years. Unlike birds that collide with the turbines, bats can suffer 'barotrauma' if they fly into air to close to a turbine blade. The drop in pressure causes their lungs to rupture. Some wind turbines are now equipped with a device that transmits a sound to keep bats away from the turbines and engineers are also working on a machine learning algorithm to stop turbine blades from spinning during periods of high bat activity.

These innovations and more have made wind energy competitive and a safer alternative to fossil fuels. Although wind turbines have been a source of controversy, according to a Pew Research poll in 2019, nearly 80% of Americans agree that the more important energy priority should be developing alternative energy sources such as wind and solar power rather than increasing U.S. production of fossil fuels. Which is good, since wind power is predicted to provide 35% of our energy demand by 2050.

The industry will have to continue to innovate to reach that goal. This map shows the installed capacity in megawatts in each state. Leading the way we have Texas, Iowa and California. Notably, we see a distinct lack of wind turbines in the south east where wind speeds are slower. According to the National Renewable Energy Laboratory, wind turbines will need to be 360 to 460 feet tall to be feasible in these states. And we will have to look to the ocean. The first offshore wind farm in the United States was built off the coast of Rhode Island in 2016. The planning for more offshore wind turbines continues. According to the Department of Energy, offshore wind has the potential capacity of 2,000 GW, which could produce double our current electricity consumption. Although offshore wind is not yet as cost efficient, each turbine can have a much higher rated capacity than onshore wind turbines. General Electric's newest offshore wind turbine, the Haliade X, has a rated capacity of 12 MW and stands 853 feet tall, that's 230 feet taller than the batman building! With new ways to recycle wind turbine blades and battery storage of electricity becoming feasible we will be able to rely on wind energy more and more.

Before I close, I would like to shout out the Uptime Wind podcast for keeping me informed and inspired throughout this process. Last week's episode focused on the role data analytics plays in keeping wind turbines running efficiently. It is exciting to know that a variety of skill sets are needed to keep the industry moving forward and that we all don't have to climb wind turbines to make an impact on the industry and a more sustainable future.