2023 CU Boulder Collegiate Wind Competition Team
Wind Turbine Technical Design

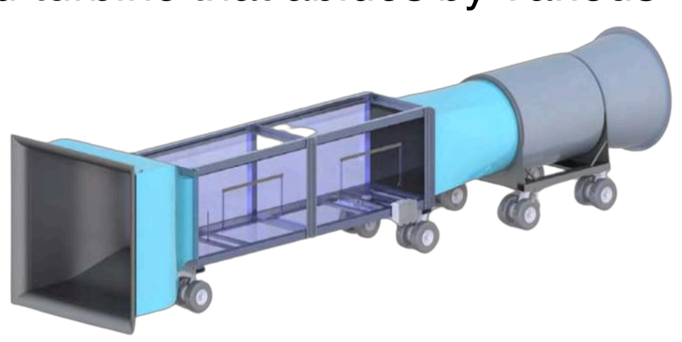
Regan Barton | Ariana Carmody | Chris Holladay | Will McConnell | Lauren Mullen | Luis Munoz | Rhett Nutter | Jeremiah Pare | Ethan Smith | Amanda Shields | Ryan Stoltz | Ryan Tasto | Heather Walker

Competition Summary

As the third annual CU wind team, we are competing in the Collegiate Wind Competition (CWC) hosted by the National Renewable Energy Lab (NREL) in Boulder from May 15 – 19, 2023. Thirteen teams will design a small-scale offshore wind turbine that abides by various design constraints as one of the three sub-competitions.

Design Objectives

- Convert kinetic energy from wind into electrical energy
- Withstand continuous wind speeds of 22 m/s
- Abide to various design constraints set by the CWC

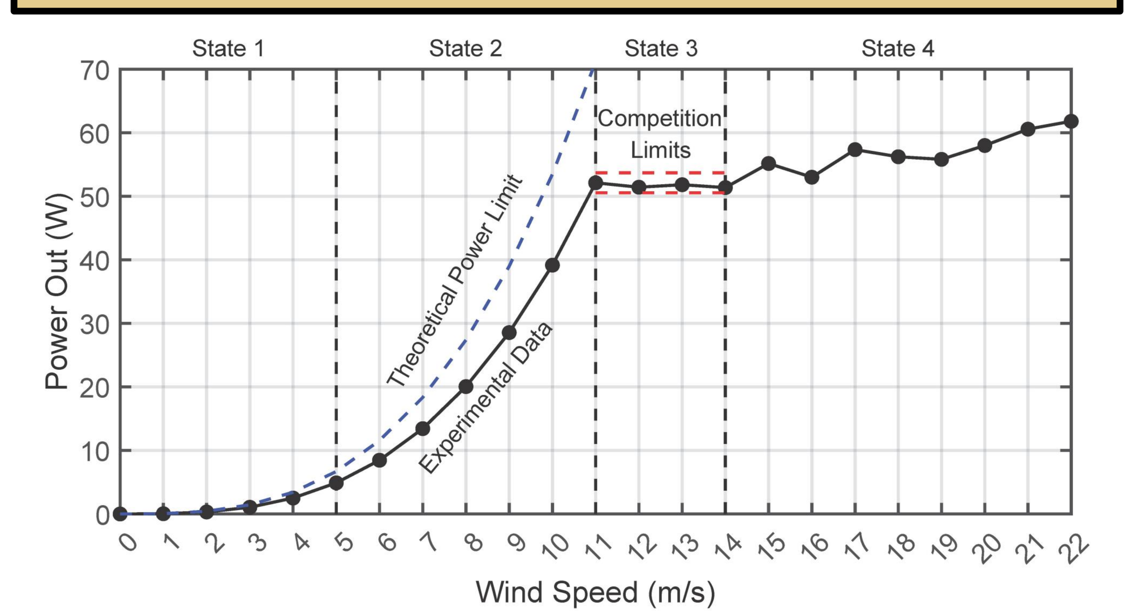


Competition Wind Tunnel Diagram

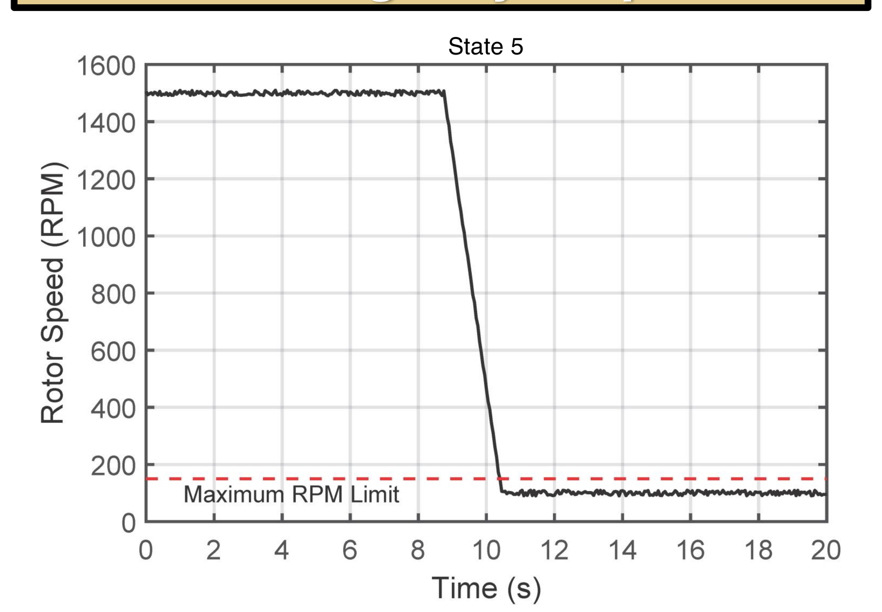
Controls

State 1: < 5 m/s	State 2: 5 m/s to 11 m/s	State 3: 11 m/s to 14 m/s	State 4: > 14 m/s	State 5: Emergency Stop
Encourage rotor to begin spinning	Maximize the power output of the turbine	Keep rotor speed below a specified value and keep power output similar to a specified value	Manage rotor speed to stay within safe operational limits	Slow rotor down below a specified RPM value at any time

Power Curve

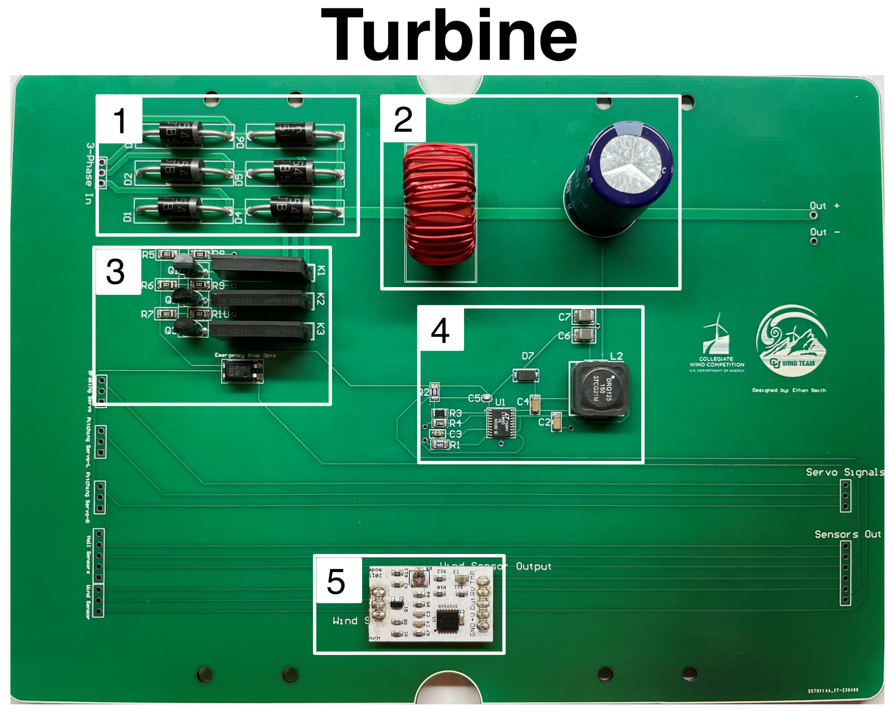


Emergency Stop



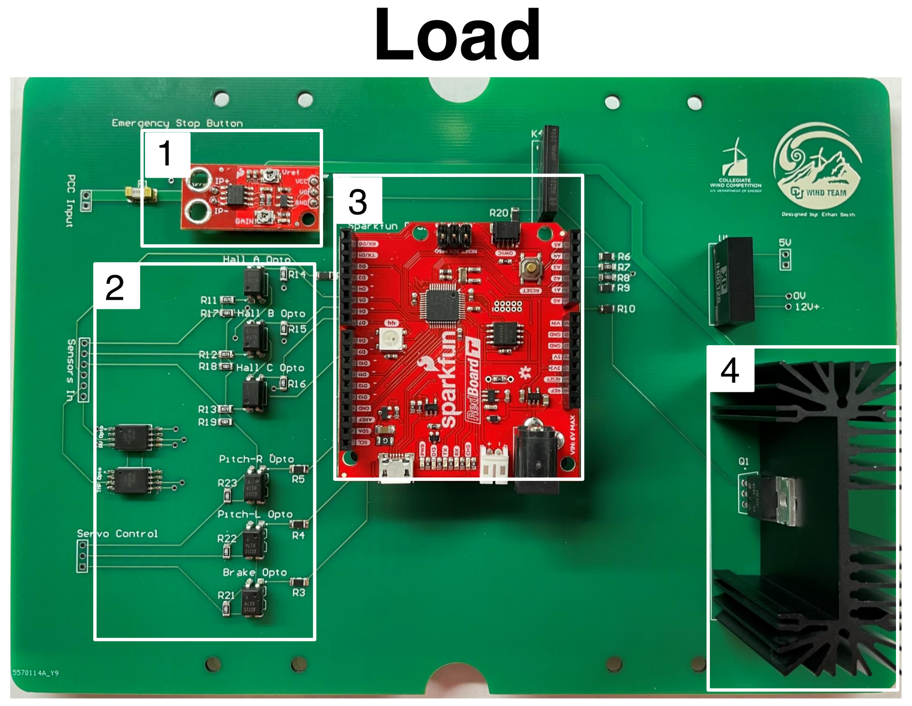
Electrical Components

Turbine



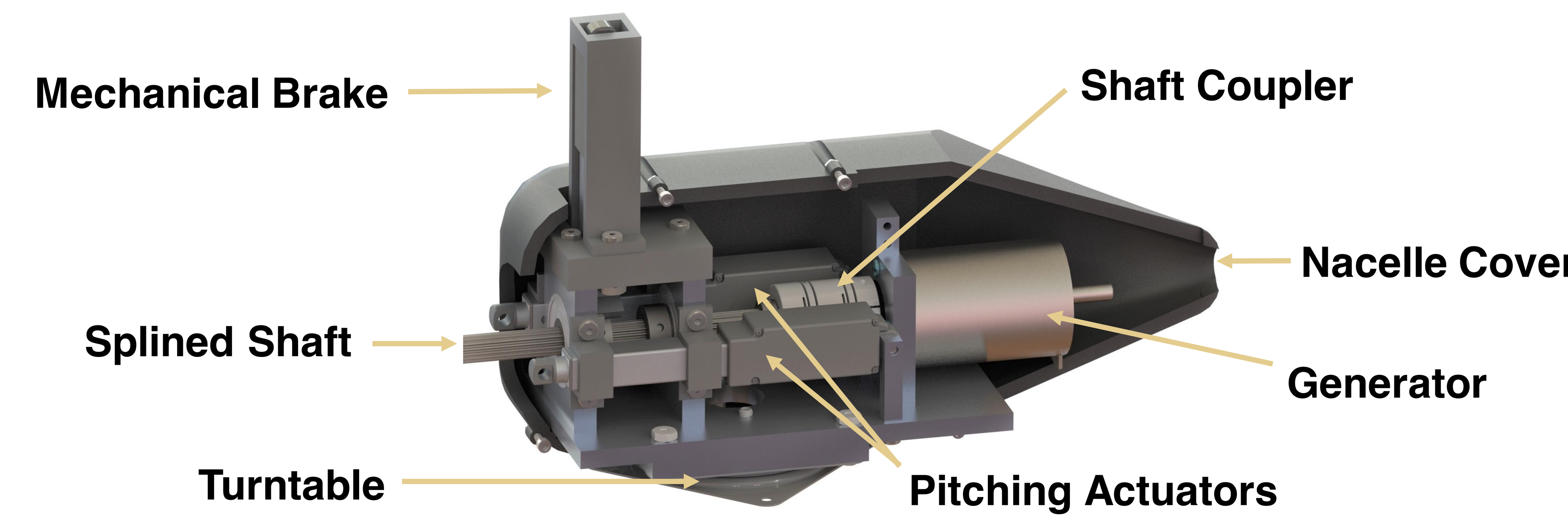
1. 3-Phase Rectifier – Convert 3-phase AC power into DC power
2. LC Filter – Smooth out voltage and current ripple
3. E-stop Solid State Relays – Switch for each phase of generator
4. SEPIC – Regulate voltage
5. Anemometer – Collect wind speed data

Load



1. Current & Voltage Sensor – Measure power
2. Opto-Isolators (Digital & Analog) - Isolate 5V signals from 3.3V inputs
3. Microcontroller – Process control state code and signal inputs from various components
4. Resistive Load and Heat-Sink – Operate MOSFET in ohmic region

Nacelle



Rotor

Pitching System

Objective:

- Allow for active control of produced power
- Achieve negative pitch to allow for emergency stop

How it works:

- Swash plate design
  - Translate linearly with sides having independent rotation
- Linear actuators control translation
- Push rods rotate the blade bushing about the hub

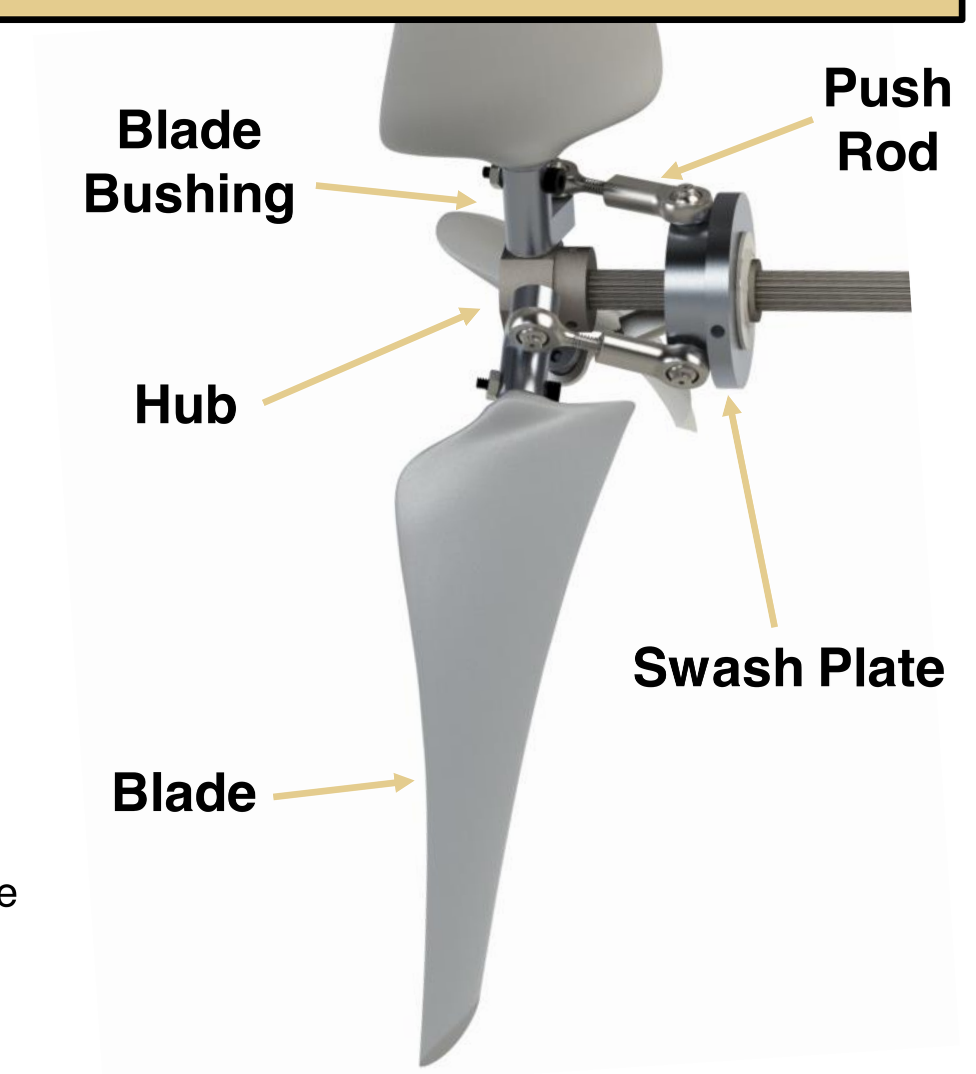
Blades

Objective:

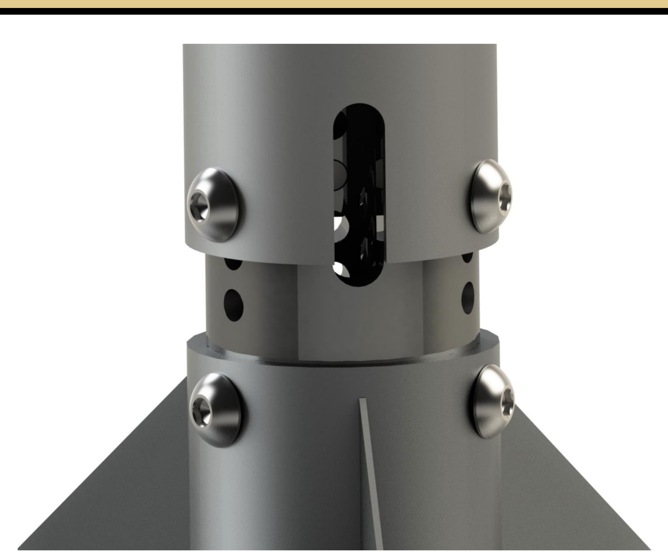
- Maximize power output
- Maximize lift and minimize drag forces

How it works:

- Difference in air pressure across blade causes it to rotate
- Airfoil has high C_{Lift}/C_{Drag} ratio
- Qblade optimizes chord length and angle of twist
- Made from Nylon 12 on SLS printer



Structure



Height Adjustment

Objective:

- Allow for foundation to fit under wind tunnel
- Rotor at center of wind tunnel

How it works:

- Concentric steel insert with 3 threaded holes and 5 different configurations allows for a total of 31.8 mm of adjustment

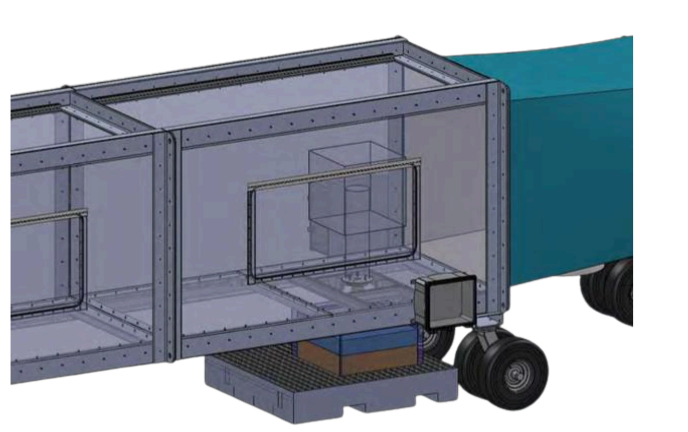
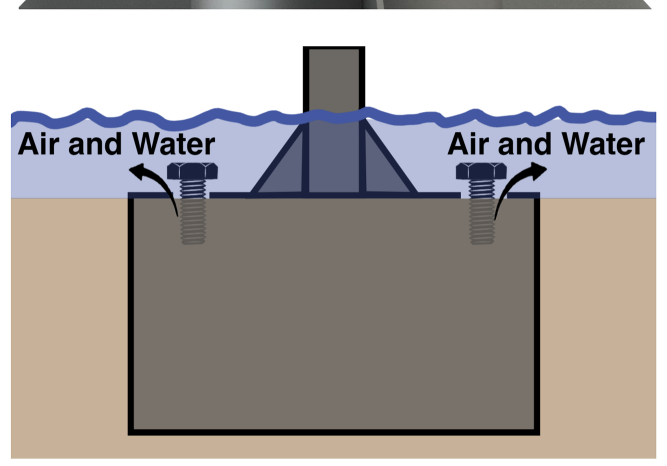


Diagram of Foundation Installation Constraints



Foundation

Objective:

- Support the weight of the wind turbine in a "seabed" environment, while keeping horizontal deflection to less than 25 mm

How it works:

- Suction Bucket Foundation, once sealed, a pressure differential keeps the foundation in place

Acknowledgments: Roark Lanning, Julie Steinbrenner, Daria Kotys-Schwartz, Guillermo Blandon, Idea Forge Staff, Design Center Colorado, Engineering Excellence Fund, Mission Zero, CU Wind Club

2023 CU Boulder Collegiate Wind Competition Team Project Development Report

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Future of Offshore Wind in the USA

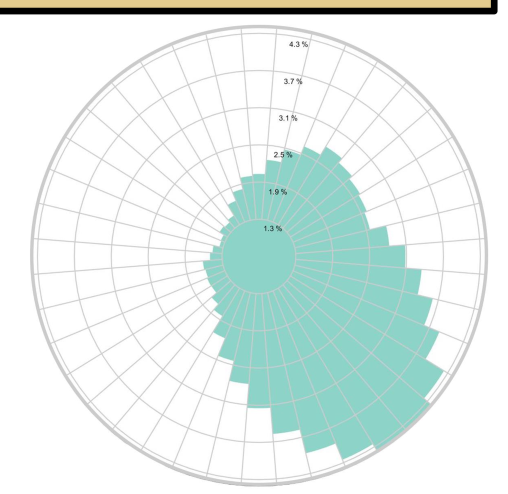
- U.S. DOI announced goal of **30 GW** of offshore wind energy by 2030
  - Annual projected average of 58,000 workers from 2023-2030
- Current capacity = **42 MW** (7 total turbines)
  - Larger-scale projects planned for MA, NY, NJ, VA by 2025

Site Resource

Location: Southern coast of Louisiana

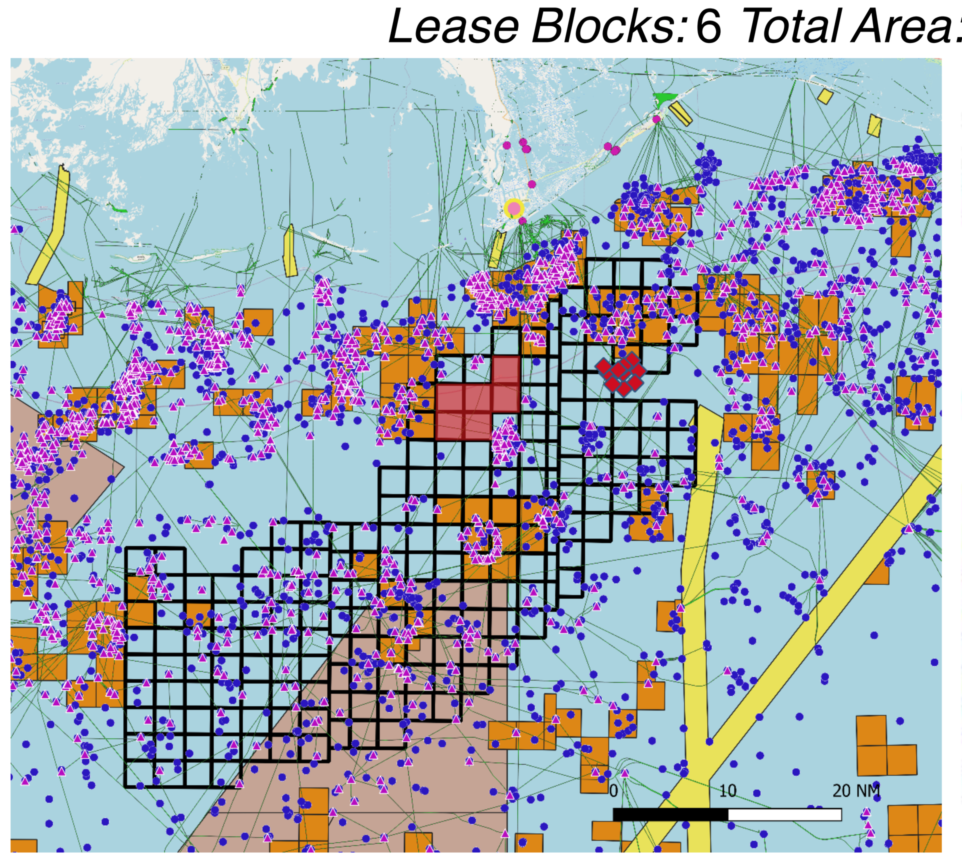
Wind Resource:
Average Wind Speed: 6.4 m/s
Average Wind Direction: 135° (SE)

Bathymetry:
Max Depth: 25 m


Wind Rose

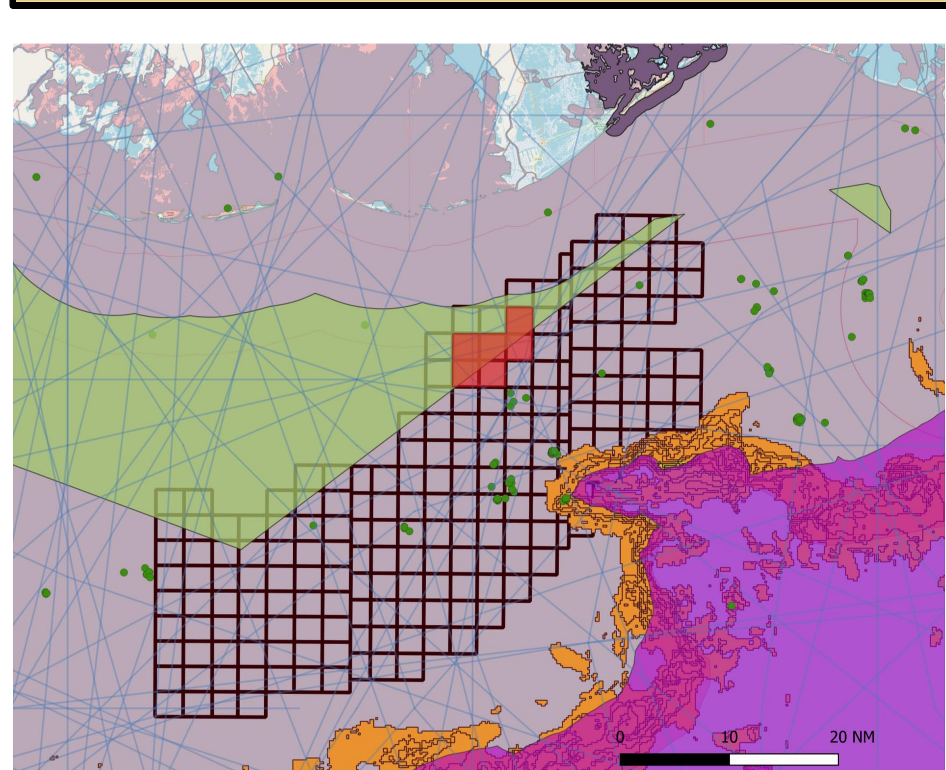
Site Selection Map

Lease Blocks: 6 *Total Area:* 30,000 acres



- Available Lease Blocks
- Selected Lease Blocks
- O&G Platform
- O&G Well
- Deepwater Port
- Substations
- Port
- Pipeline
- Shipping Fairways
- Active O&G Lease Sites
- Military Special Use Airspace

Sensitive Environmental Areas



- Available Lease Blocks
- Selected Lease Blocks
- Essential Fish Habitat
- Habitats of Particular Concern
- Reef Fish Stressed Area
- Cetacean Biologically Important Area
- Deep Sea Coral Habitat Suitability
- Artificial Reef
- Historic Tropical Storm Tracks

Environmental Considerations

Impact Areas	Mitigation Actions
Avian Species Take	Paint one blade on turbine black, use of Aircraft Detection Lighting System on turbines
Construction Disturbance to Marine Wildlife	Slow start of construction – wildlife will return after completion, limit floodlighting
Electromagnetic Sensitive Species	Bury transmission cables at 2 m depth
Onshore Communities	No action – negligible visual and sound impacts
Reef Fish Stressed Area	Formation of artificial reefs around foundations and scour protection

Relevant Regulations	Compliance Actions
Bald and Golden Eagle Protection Act	Apply for Incidental Take Permit with Fish Wildlife Service
Endangered Species Act	Conduct pre-construction surveying, prepare Biological Assessment
Magnuson-Stevens Act	Complete Essential Fish Habitat Assessment
Marine Mammal Protection Act	Apply for Incidental Harassment Authorization
Migratory Bird Treaty Act	Apply for Incidental Take Permit with Fish Wildlife Service
National Environmental Policy Act	Prepare range of alternatives to ensure impacts to fishing and marine trust resources are fully considered, community outreach

Turbine Selection

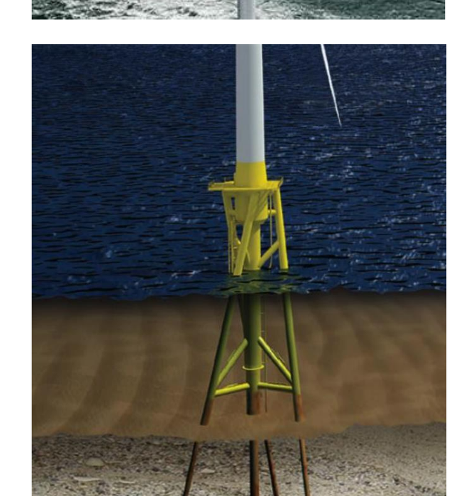
Nominal Power Selection

- Initially sought larger, 15 MW turbines to maximize power output
  - Significant capacity factor losses due to low wind speeds, lower profit
- 10 MW turbines found a balance between capacity factor and profit
- Need similar specifications to NREL IEA 10MW reference turbine

Siemens Gamesa 10.0-193 DD

- *Nominal Power Rating:* 10.0 MW
- *Rotor Diameter:* 193 m
- *Estimated Lifespan:* 25 years
- *Power Regulation:* Pitch-regulated, variable speed

Twisted Jacket Foundation

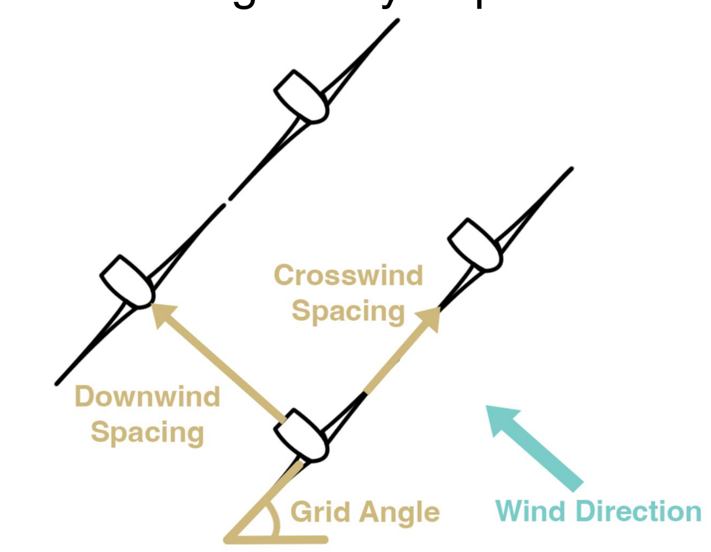


- *Max Depth:* 60 m
- Lowest impacts to habitat loss, wake effect, acoustic effect
- Artificial reef addition
- Widely used in Gulf of Mexico for O&G
- Can withstand hurricane-strength winds

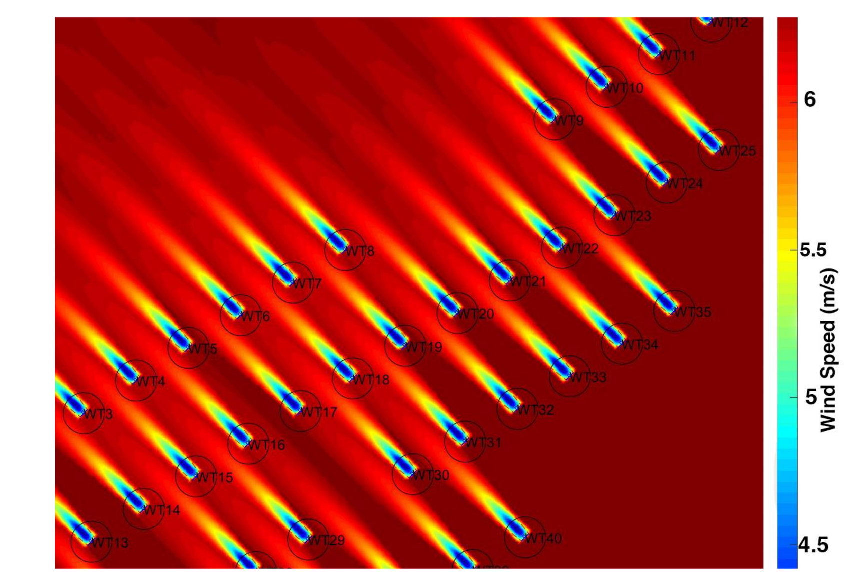
Layout Optimization

Goals:
- Maximize capacity factor
- Maximize use of leasing blocks
- Minimize installation costs
- Meet regulatory requirements

Variables:
- Crosswind spacing: 4D, 5D, 6D
- Downwind spacing: 10D, 11D
- Grid angle: 0-90 degrees



Layout Spacing

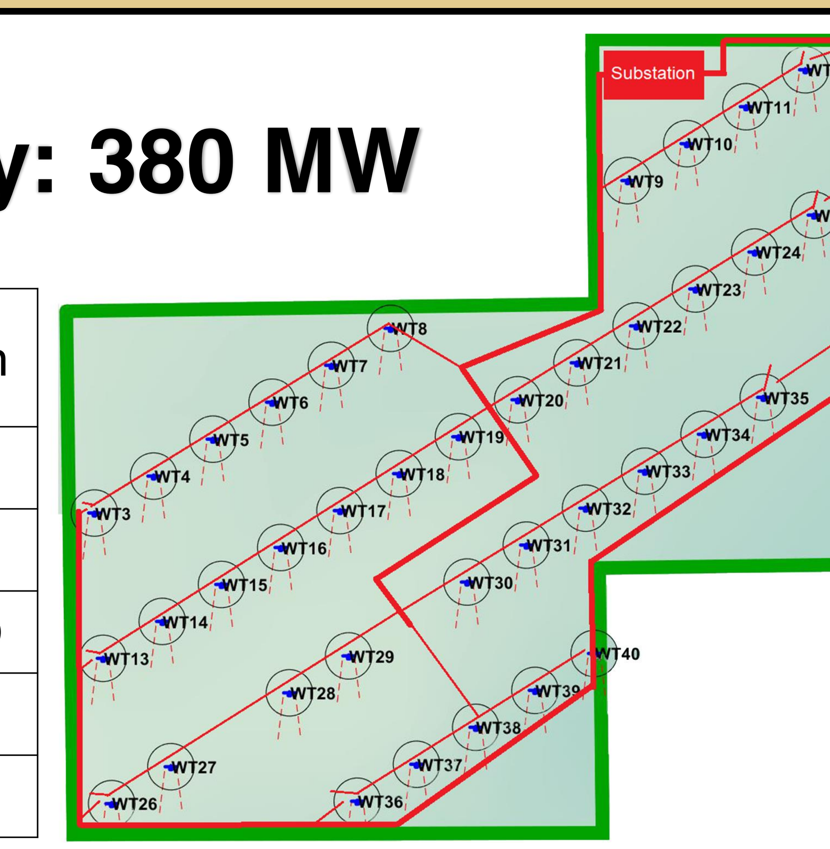


Wake Effect Map

Final Layout

Total Capacity: 380 MW

Net Annual Energy	995 MWh
Capacity Factor	32.8%
Wake Loss	5.55%
Spacing	6D x 11D
Angle	68°
# of Turbines	38

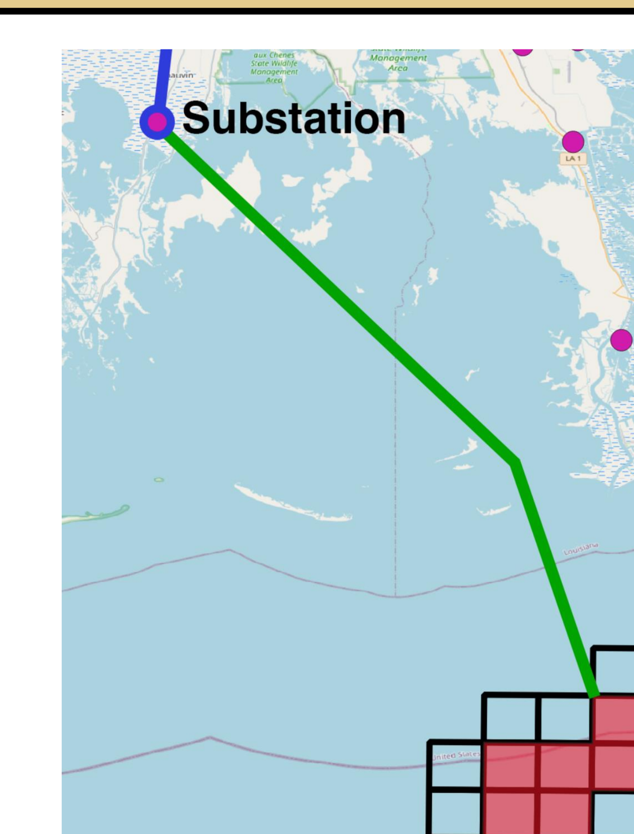


Transmission

Goals:
- Minimize power transmission losses
- Reliable and cost-effective collection system

Transmission:
- HVAC (High Voltage Alternating Current)
  - Single return with single hub collection system
  - 66 km of 320 kV transmission line

Substation:
- Chauvin Substation
  - 260 kV export transmission



Acknowledgments: Roark Lanning, Dr. Julie Steinbrenner, Dr. Daria Kotys-Schwartz, Julie Lundquist, Daniel Kaffine, Mission Zero

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Proposed Timeline

2022 (Q3, Q4) | 2023 (Q1–Q4) | 2024 (Q1–Q4) | 2025 (Q1–Q4) | 2026 (Q1–Q4) | 2027 (Q1–Q4) | 2028 (Q1–Q4) | 2029 (Q1–Q4) | 2030 (Q1–Q4) | ~ | 2055 (Q1–Q4)

- Community Outreach
- Publish Leasing Notices
- Pre-Survey Meetings/Plan
- Site Assessment and Surveys
- BOEM Environmental and Tech Review
- Onshore Duct Bank and Export Cable
- Onshore Substation Commissioning & Test
- Offshore Export Cables Installation
- Scour Protection
- Install Foundations
- Turbine Installation
- ESP Install & Commissioning
- Wind Farm Lifetime (25 Years)

Pre-Construction | Construction | Wind Farm Duration

*Decommissioning not pictured

Pre-Construction

Site Assessment and Surveying Campaign

- Accurate wind data collection is essential to the wind farm's success
- Floating LIDARs campaign will be executed over two years
- Environmental and geotechnical surveys will be done using O&G vessels equipped with sensors

Community Outreach Plan

- A community outreach task force will meet with local community members to educate citizens and local entities about the benefits of renewable energy
- Allows community members to ask questions and express their views on the wind farm's potential impacts.

Construction and O&M

Staging of Components:

- Port Fourchon - Heavy duty wharf, large lay-down areas, overall ability to improve facilities

Active Construction:

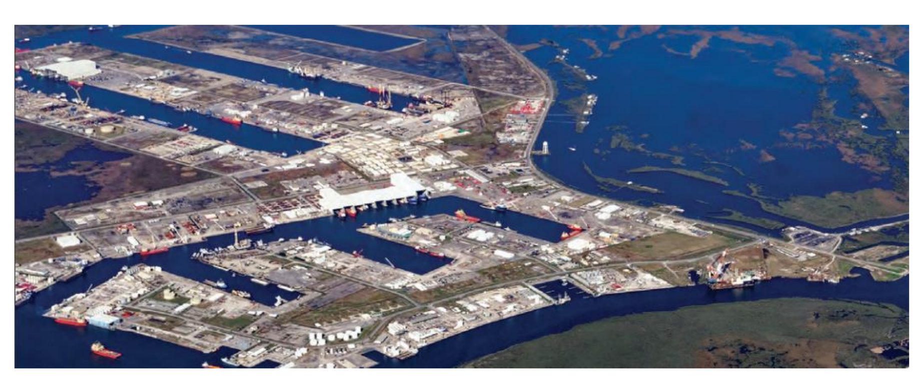
- Jones Act Compliance
- WTIV: *Feederdock*
- Additional Vessels: Surveying vessels (environmental, geophysical, geotechnical) and cable laying vessels (contract with Royal IHC)

Ongoing Maintenance:

- Vessels: Personnel Transport Vessels (PTVs) and Service Operation Vehicles (SOVs)

Decommissioning:

- Occurs at the end of the 25-yr project lifetime
- Two main end-of-life options: Repower or Decommission
- Steel from the turbines can be recycled and sold
  - Estimated possible salvage value of $40,000/MW



Port Fourchon in Lafourche Parish, LA

Digital Rendering of the *Feederdock*

Financial Analysis

Financing Options

- Partnership Flip with Debt
- Partnership Flip without Debt
- ***Single Owner with Debt***

Incentives

Inflation Reduction Act (IRA) 2022 – PTC or ITC

- Production Tax Credit (PTC) - 2.6 ¢/kWh
- ***Investment Tax Credit (ITC) – 30% federal tax credit***

Power Purchase Agreement (PPA) entergy

Full Cost, "Break-Even"

9.69 ¢/kWh	
IRR	5.29%
NPV	$0
LCOE	$95/MWh

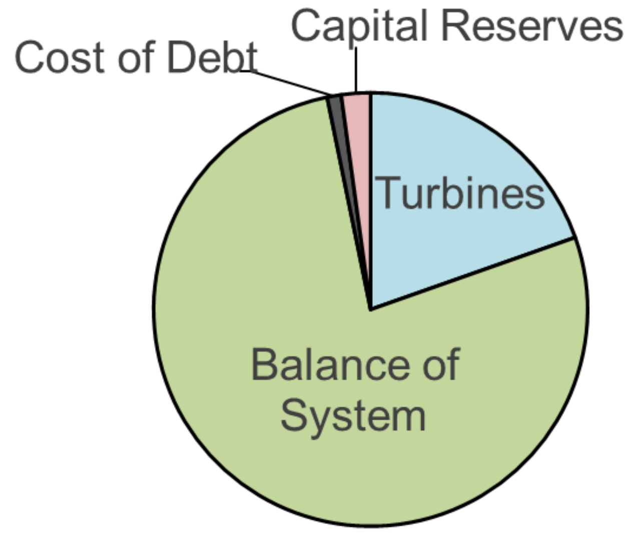
Net Capital Cost: $2.2 billion

80% BOS Cost Including Bid

8.70 ¢/kWh	
IRR	5.47%
NPV	$11 million
LCOE	$84/MWh

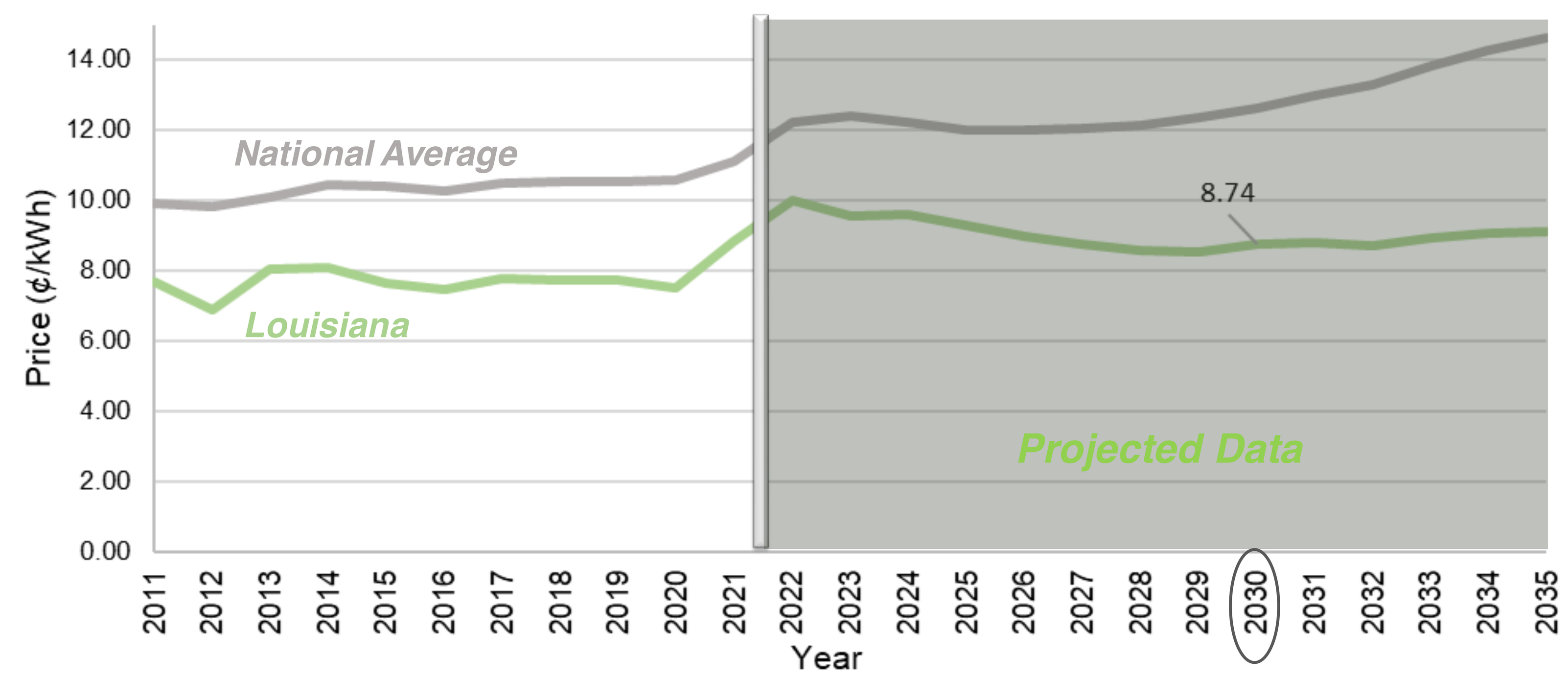
Net Capital Cost: $1.8 billion

Capital Costs



Utilizing NREL's System Advisory Model (SAM)

Electricity Prices in Louisiana Compared to the National Average



Data from EIA.gov

Bid Proposal:
$30 million

$1,000/acre

$79/kW

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