**Presentation Outline:**

Optimal Implementation of Offshore Wind Farms in the Gulf of Maine

Case Study: Gulf of Maine

Overview

Gulf of Maine has relatively good conditions for wind energy generation

Maine has relatively large projected shift to offshore wind

Solution

Operation Model

Strategy/Technology

Redox Flow

Dynamic model both meets

load requirements and maximizes revenue

Necessitates quick discharge (capitalization on market fluctuations) (Feature of RFB)

Financial Model

Estimated Cost

3 Revenue Streams

References

**The location and size of the offshore wind farm, including cost estimates.**

Bay of Fundy - intermittent winds

Energy vs. power: Maine: low power

Size:

$400/kwh - redox flow

Redox Flow (optimized for our large-scale system + intermittency of wind)

**1. What is the optimal battery size when co-located with an offshore wind farm and what are the key trigger points?**

* Intermittency of wind
* Demand: energy vs. power (duration)
* Location & proximity to metropolitan areas
* Business Model (ensure energy is being delivered, or to make profit)
  + Government vs. private corporation
* Power price variability
* 2 MW : 90 MW
* 1 MWh : 30 MW
* Hornsdale wind farm (South Australia) 129 MWh : 100 : 315 MW
  + <https://en.wikipedia.org/wiki/Hornsdale_Wind_Farm>

**The size (MW/MWh) and technology type (lithium-ion, flow batteries, mechanical, etc) of the energy storage system, including cost estimates.**

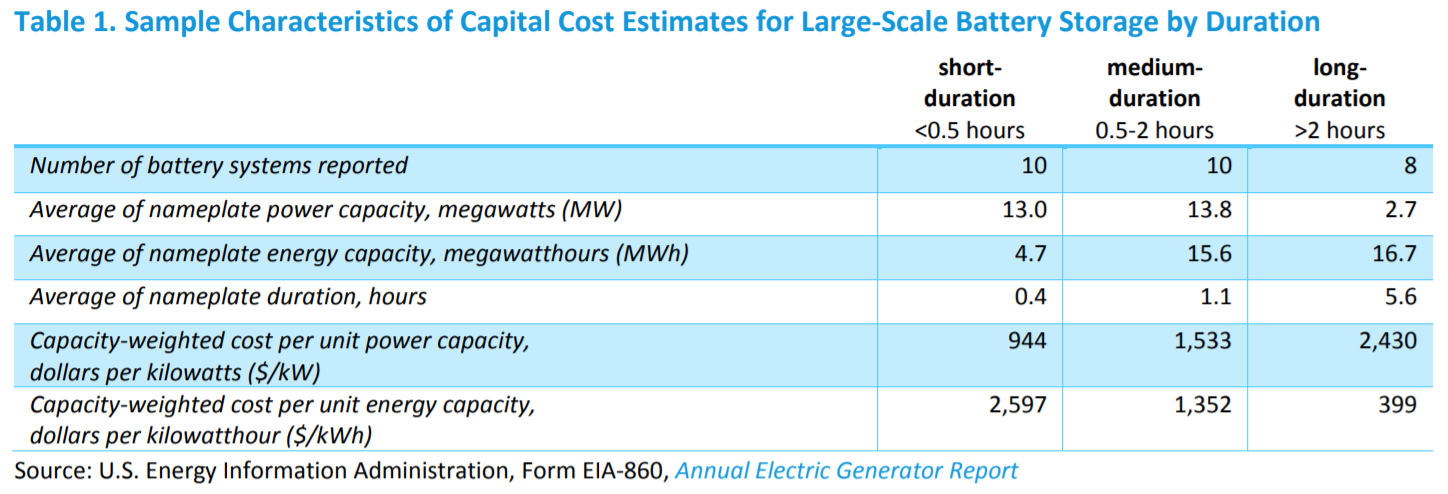
* *Criteria:* Scalable, instantaneous bidirectional energy flow (can take surplus/discharge quickly), low maintenance cost
* Redox Flow (better for large scale systems)
* Case: 600 MW off-shore wind site
  + Battery size: 12 MW, 8MWh (idk we don’t seem to need too high power because no nearby metros?)
* Cost estimate: (see table? - capital cost estimates)
* <https://spectrum.ieee.org/energywise/energy/renewables/underwater-energy-bags-for-the-london-array>
  + London Array (630 MW offshore wind site)
* <http://www.ipsnews.net/2018/06/masdar-equinor-inaugurate-worlds-first-battery-storage-facility-connected-offshore-wind-farm/>
  + “According to a recent International Renewable Energy Agency, IRENA, report from last October, the cost of installing battery storage systems could fall by two-thirds (66 percent) by 2030”
* <https://ieeexplore-ieee-org.ezp-prod1.hul.harvard.edu/document/6981515>
  + Optimal capacity of a large-scale BESS integrated with a grid-connected wind farm has been determined. It has been shown that the optimal size of all the batteries of the BESS decreases as the number of batteries increases. Furthermore, the optimal size of all the batteries of the BESS tends to some positive limit as the number of batteries approaches to infinity. We have proposed a constraint-based monotonic charge/discharge strategy of individual batteries of BESS with optimal capacity each. The two-fold benefits of the strategy lie in determining the overall optimal size of the BESS along with a strategy for charging and discharging of each individual battery of the BESS satisfying the given operating constraints. Simulation results prove the effectiveness of the proposed strategy. It has also been observed that the proposed strategy is robust against the variations in the system parameters.”
  + Also good for our strategy (more batteries, smaller size for each one)

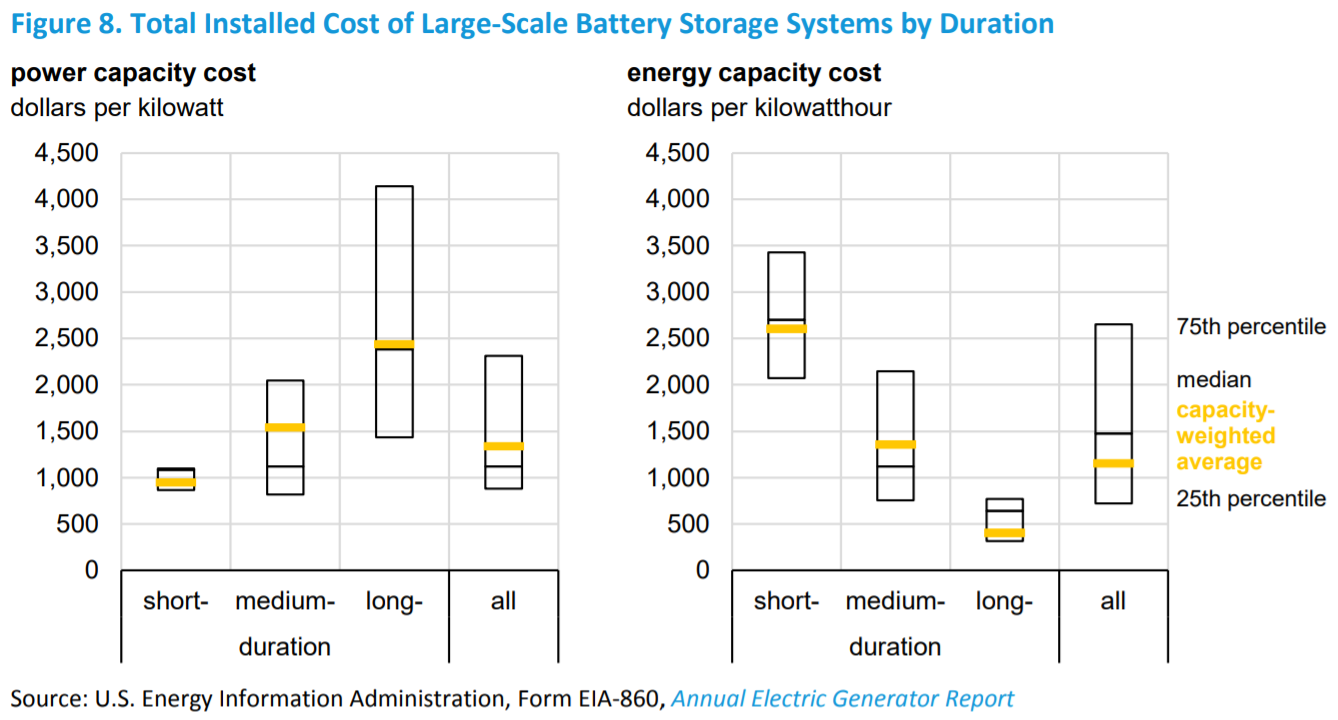
**The proposed energy storage utilization strategy, including any value or revenue streams that are to be stacked.**

* Dynamic system to store energy & sell at higher power price
* Predictive models that take into account:
  + Supply:
    - Weather
    - Charge level
    - Time of day
  + Demand:
    - Tracking Power Price (propose LSTM Algorithm)
    - Natural disasters / power outages / anomalies
* “Specifically, we’ve equipped Batwind with our intelligent Y.Q software, which ensures that the battery ’learns’ the optimal storage conditions. Our software tells the battery when to store electricity and for how long, and when and how much to inject back onto the grid.”

**2. What is the preferred technology (quick charge/discharge vs. large capacity) considering the revenue potential?**

Quick charge / discharge

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* Revenue Potential:
  + Selling to grid (Central Maine Power) when high
    - <https://www.eia.gov/electricity/state/maine/>
    - <https://www.electricitylocal.com/states/maine/>
    - “Residential electricity consumption in Maine averages **531 kWh/month**, which ranks **51st in the U.S.”**
    - Energy consumption is 27th
    - <https://www.energy.ca.gov/almanac/electricity_data/us_per_capita_electricity.html>
    - 10th lowest for electricity consumption per capita in 2016
  + Selling to corporations instead of power companies
  + Selling to other neighboring states (like Connecticut) (Denmark Model)

**A mock financial and operational model of storage and offshore wind production. You may include several scenarios if desired.**

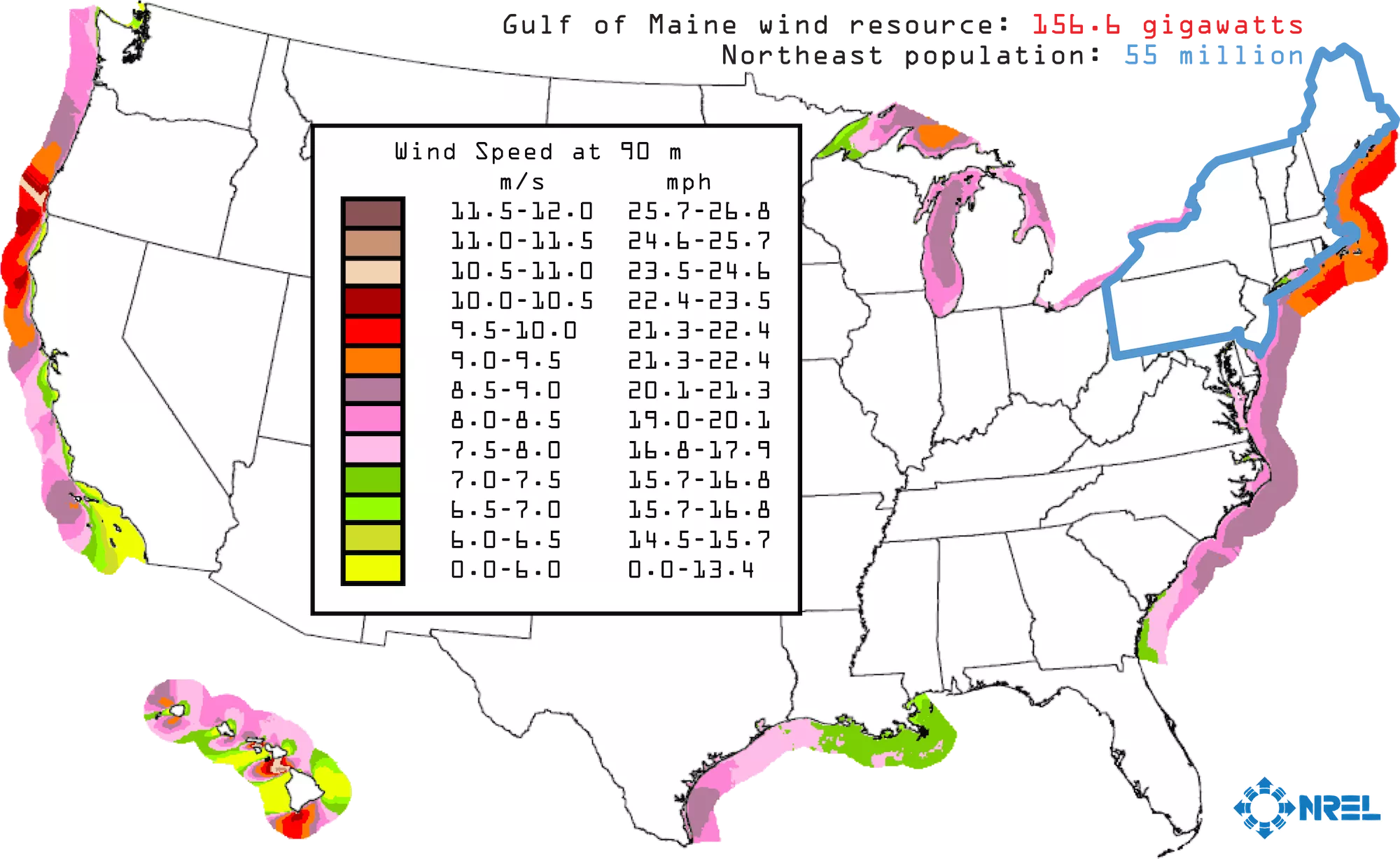
How much energy wind farm produces, costs at which it’s sold

Parameters:

1. Traffic (energy yield) (Using the power prices we get from the data)
2. Capital costs (we can get this from table?)
   1. $600-1500 kW cost on VRB
   2. $150-1000 kWh
   3. Per annum revenue: $180 million
3. Operational expenses (including expected depreciation? Maintenance?)
   1. 20-25 year useful life (matches up w/ wind turbine lifespan)

**Why Maine?**

[**https://composites.umaine.edu/offshorewind/resourcemapwhitebg/**](https://composites.umaine.edu/offshorewind/resourcemapwhitebg/)

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**List of any assumptions and cite resources utilized in developing the model.**

[**https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery\_storage.pdf**](https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf)

NOTES for utilization strategy:

Use demand response (or demand-side management) to shift flexible loads to a time when more renewable energy is available, and away from times when renewable generation is low. This requires that loads be capable of receiving and responding to price or control signals from the local utility or grid operator.

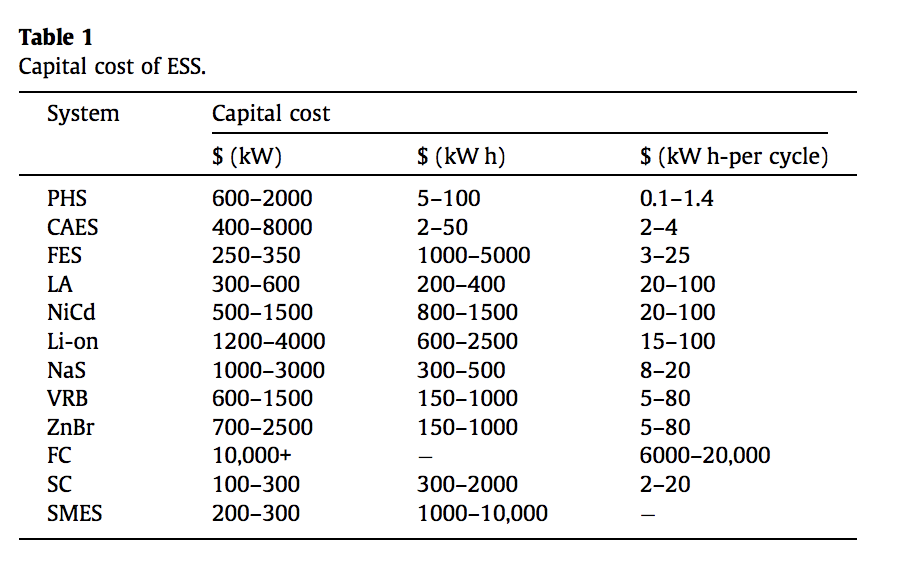
**Other References**

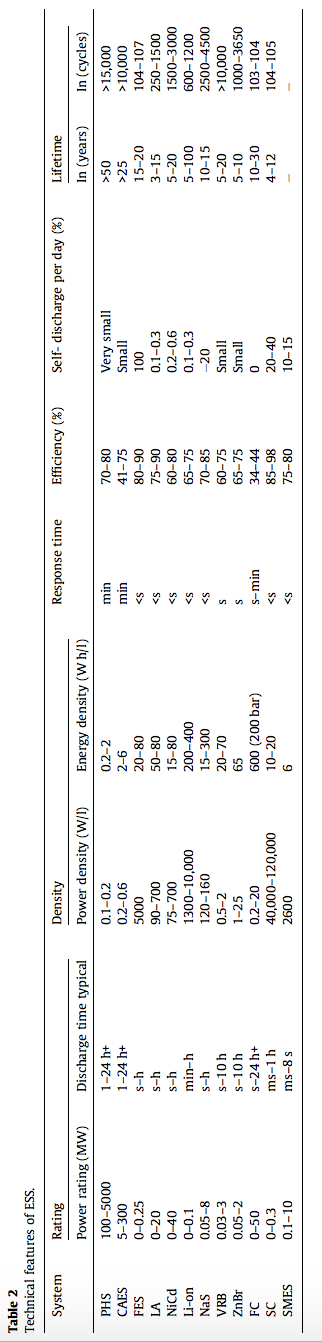
<https://www-sciencedirect-com.ezp-prod1.hul.harvard.edu/science/article/pii/S0196890413005517> -- if someone can get access to this (Harvard library doesn’t have it)

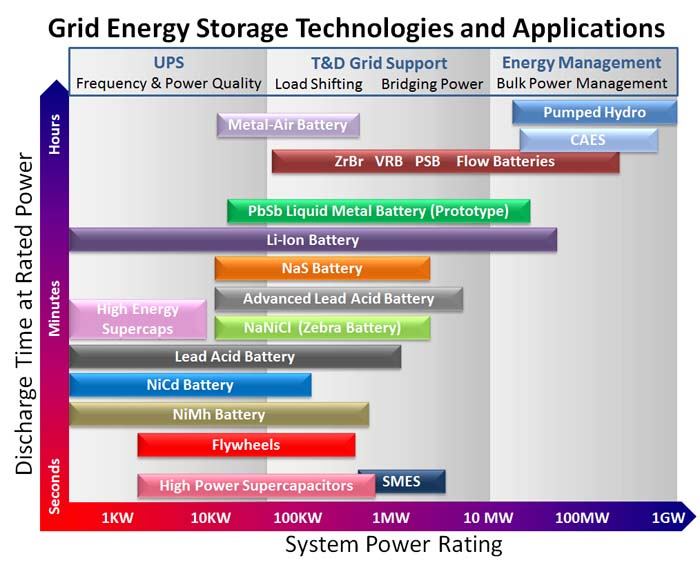
<https://www-sciencedirect-com.stanford.idm.oclc.org/science/article/pii/S0306261918304811>

<https://onlinelibrary-wiley-com.ezp-prod1.hul.harvard.edu/doi/epdf/10.1002/er.3858>

<https://pdfs.semanticscholar.org/1750/7c614c7d5379c6698dd61d3fcb7f28e10f9f.pdf>







* Among battery storage systems, VRBs are among lowest capital cost
* Low self-discharge,

https://www.nature.com/articles/nenergy2017110.epdf?author\_access\_token=kgQRHDjvTRhV1d-1kLgOZtRgN0jAjWel9jnR3ZoTv0OOdK-8yUasIZW74rQ\_v4V4XTBr1xnvw3cTRJey3GxvJFmyOGgB9\_IdmWXkHYu-5WEfsmZY2jniD4TvrTE9rfDV4i3\_ogxKTpG8QfmQdEhRaw%3D%3D

* It showed redox flow batteries achieving a ‘competitive’ capital cost threshold of USD$650 per kWh of capacity by 2019, once around 7GWh or $4bn of projects had been installed.
* Lithium-ion batteries, in contrast, would require at least 33GWh of installations to reach the same level. This would take until 2023 and cost $94bn, the authors concluded.
* The $650 price point was chosen as a level at which energy storage systems could be competitive based on their ability to deliver multiple services simultaneously