Assessing the costs of energy storage: An integrated wind turbine and energy-storage system

April 28, 2009

Clayton Barrows
Alisha Fernandez
Brian Marpoe
Luke Witmer

Objective

To design a profitable energy storage system that is suitable for integration with utility scale wind electricity generation in Pennsylvania.

Problem Statement

As intermittent generation increases, development of energy storage is necessary to ensure the reliability of the system; however the technical and economic feasibility of new storage is not proven in Pennsylvania.

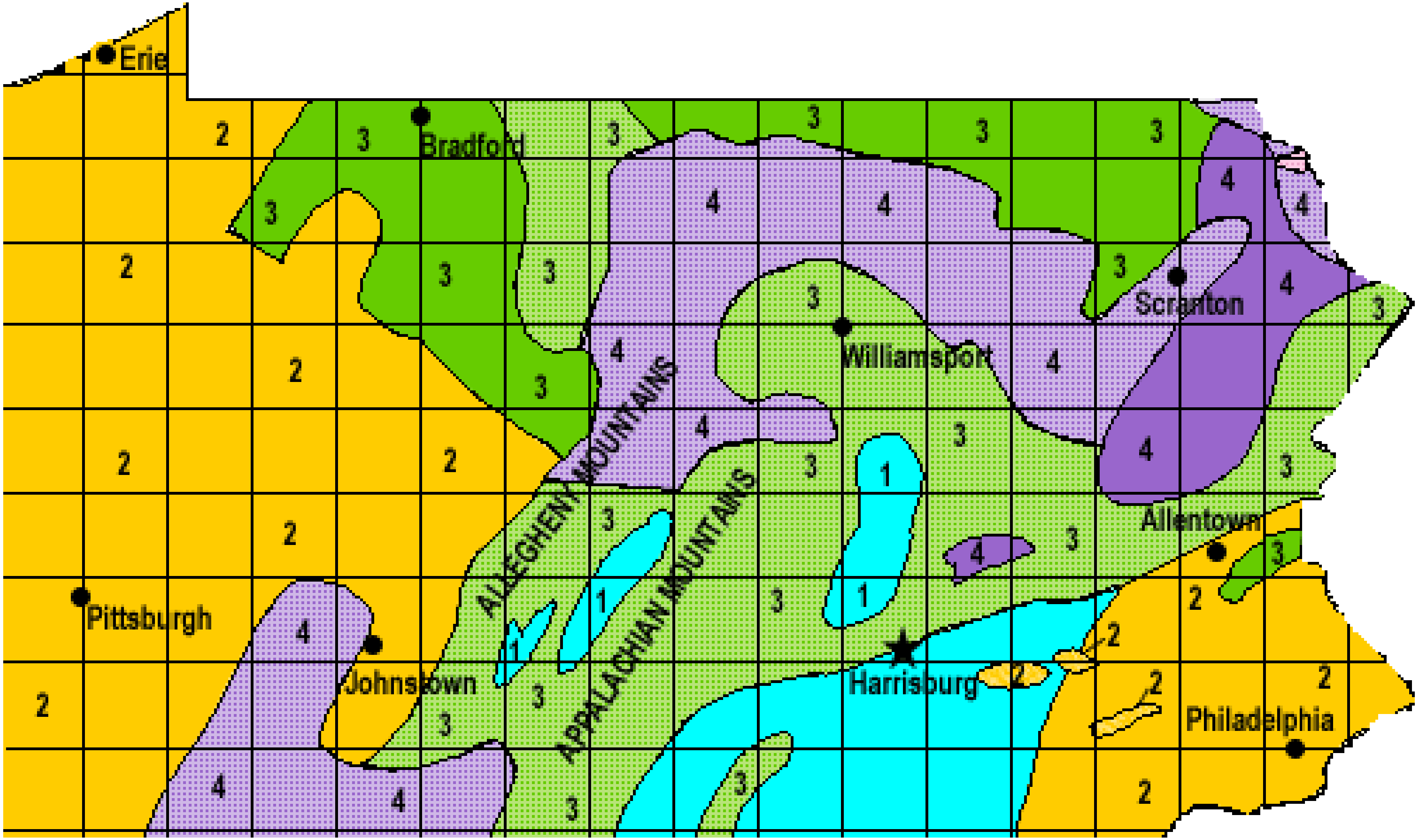
Outline

- Selection of generation technologies
- Selection of storage technologies
- Designing a Greenfield system
  - Locations
  - Operation
  - Sizing
- Profit Optimization: Size sensitivity
  - Wind Integrated Storage System Model (WISSM)
  - Stand-Alone Storage System Model (SASSM)

Selecting generation technologies in PA

- Wind
- Hydro
- Geothermal
- Solar
- Biofuels

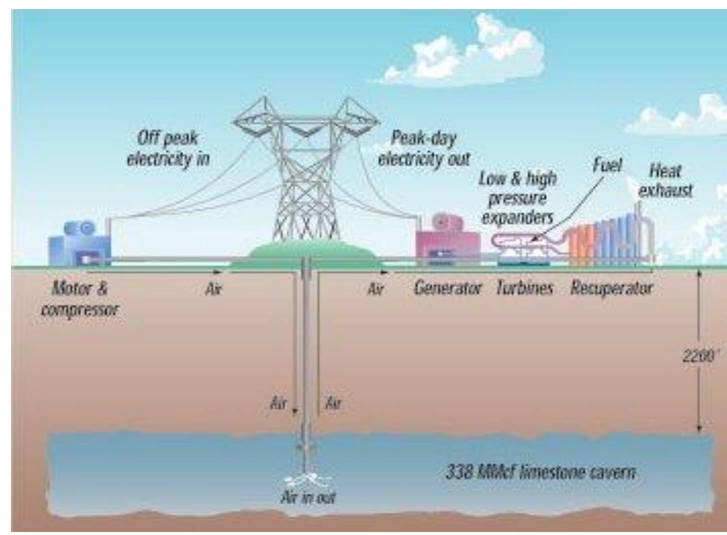
Wind Resource Map



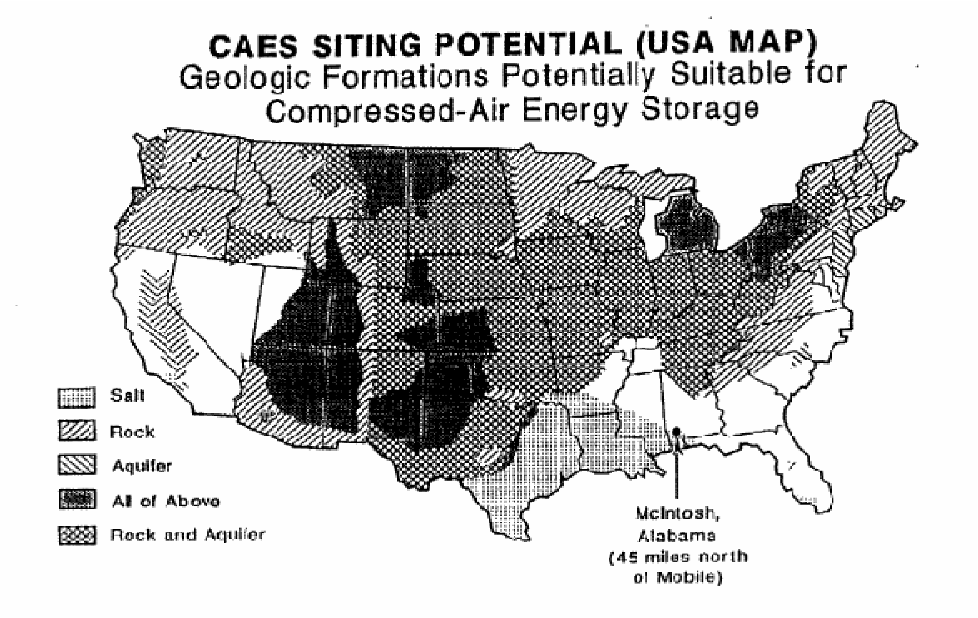
http://www.wppsef.org/wind.html

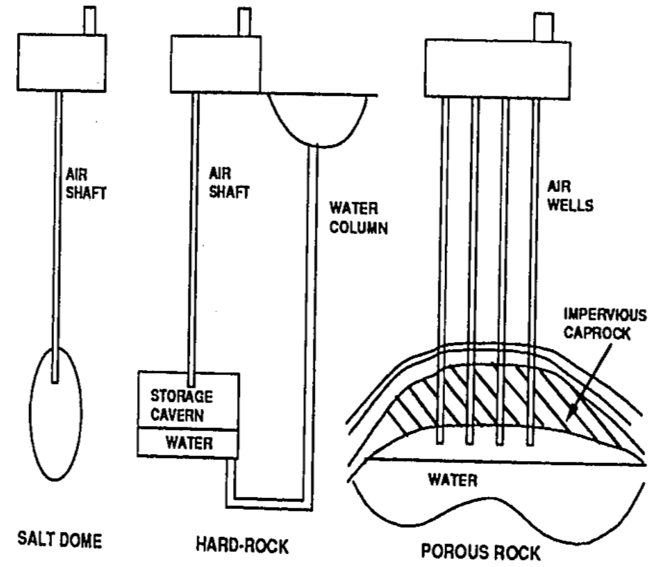
Selecting storage technologies in PA

- PHS
  - 70-75 %
  - NW and SE
  - 435 to 1110 MW
  - > 6800 MWh
- CAES
  - 80 %
  - West and North
  - 50 to 350 MW
  - 2500-17,500 MWh



CAES: Storage Potential





Ridge Energy Storage & Grid Services L.P. (2005). *The Economic Impact of CAES on Wind in TX, OK, and NM.* Texas State Energy Conservation Office.

Schainker, R. B., Mehta, B., & Pollak, R. (1993). Overview of CAES Technology. *American Power Conference*, (pp. 992-997).

Designing the Greenfield system

- Site selection
- Data collection
- Operating characteristics
- Levelized costs

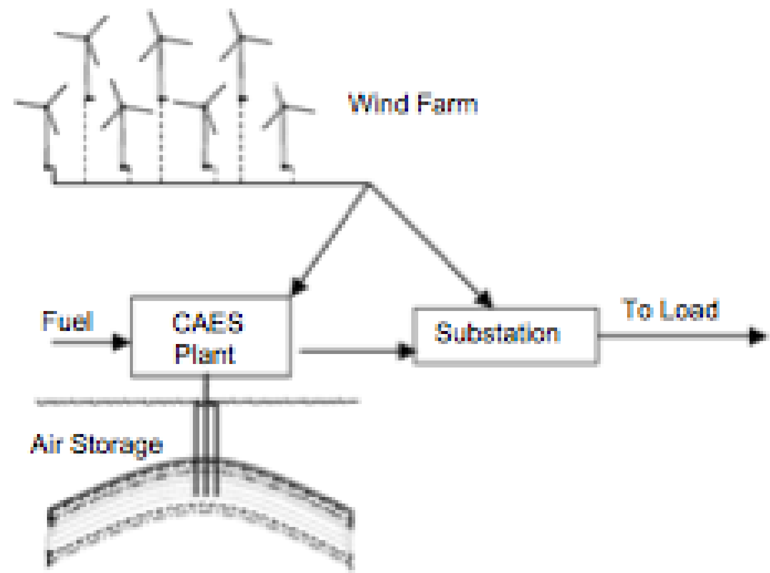
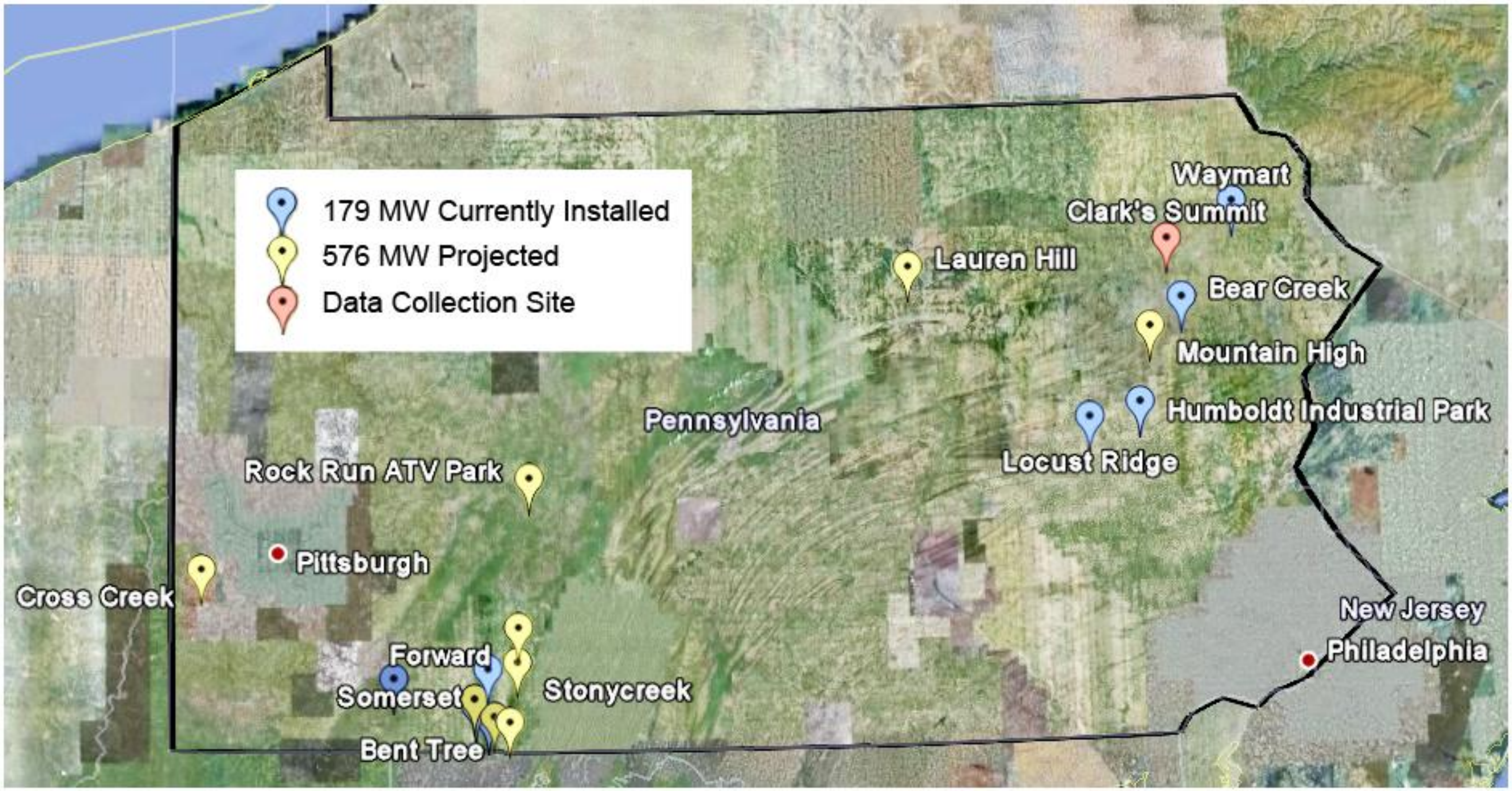


Fig. 1. Simplified schematic of a wind/CAES power plant.

Current and Projected Wind Farms



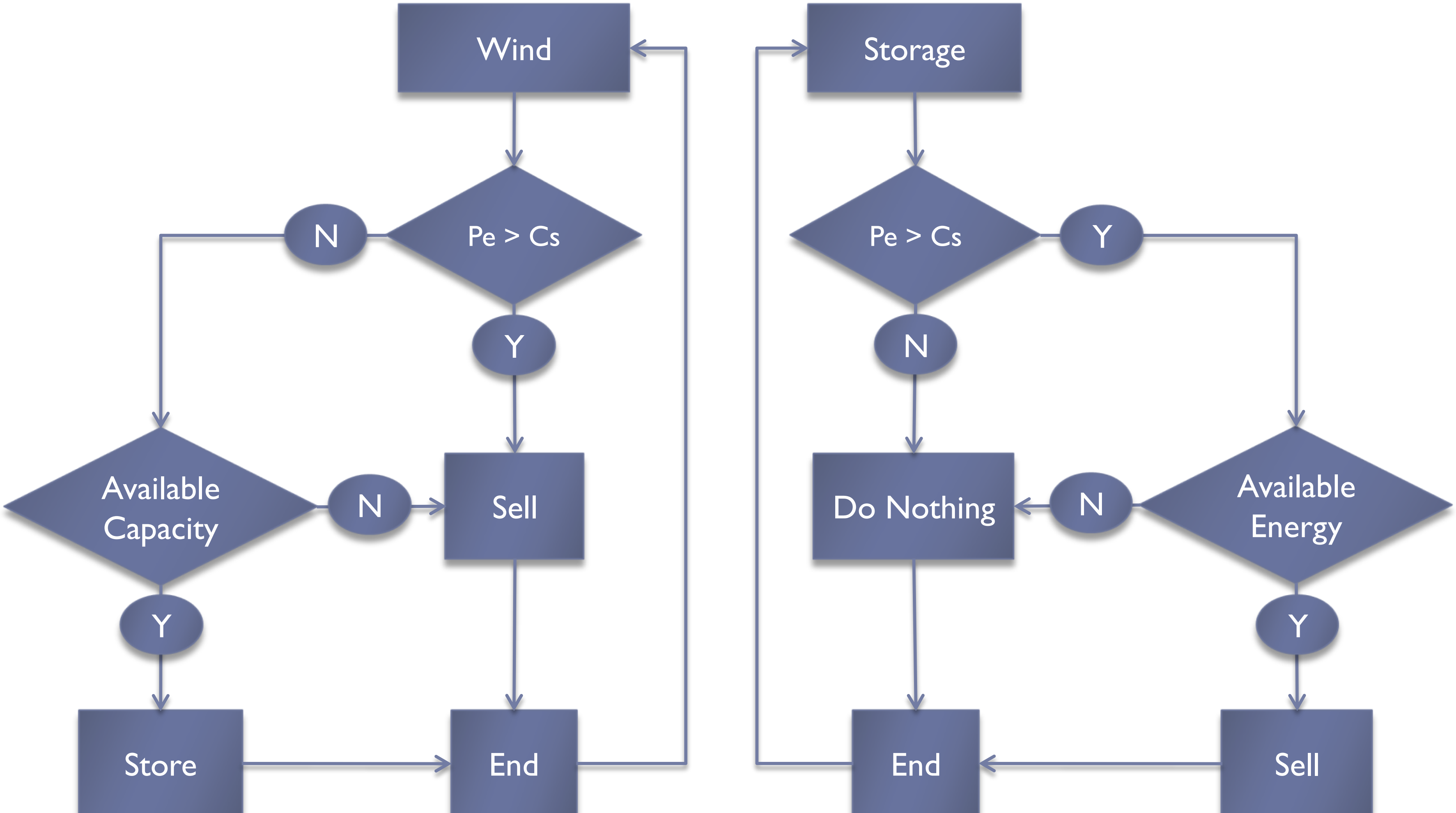
Levelized Costs of Energy

Energy Generation or Storage Option	Levelized Cost of Energy [$/kWh]
Pumped-hydro Storage (PHS)	$0.010/kWh
Compressed Air Energy Storage (CAES)	$0.034/kWh
Wind Generator	$0.026/kWh
Natural Gas Non-Peaking Generator	$0.038/kWh
Coal Generator	$0.045/kWh
Natural Gas Peaking Generator	$0.387/kWh

How to size a storage system?

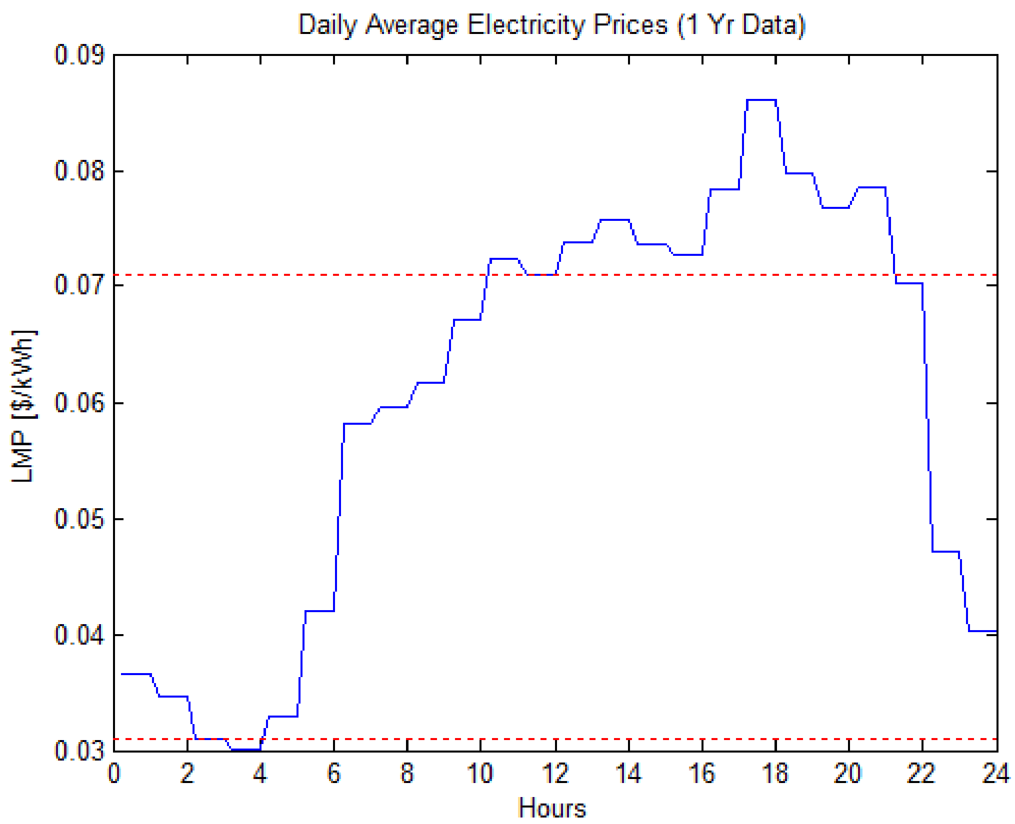
- Technical characteristics
  - Power rating
  - Discharge time
  - Recharge time
- Economic goals
  - Costs: Capital, and operations
  - Timeframe when storage or generation is profitable

Operating characteristics WISSM



Operating characteristics SASSM

- $P_E > C_S$
  - Sell to grid
- $P_E < C_S$
  - Buy for storage



Results sizing sensitivity analysis

- Capital and operating costs for CAES always exceed revenues
  - WISSM yields negative profits from poor wind data
  - SASSM yields negative profits from small price variability
- For Greenfield site
  - Storage is not profitable
- Necessary for profitable site
  - Higher price peaks
  - More consistent daily wind

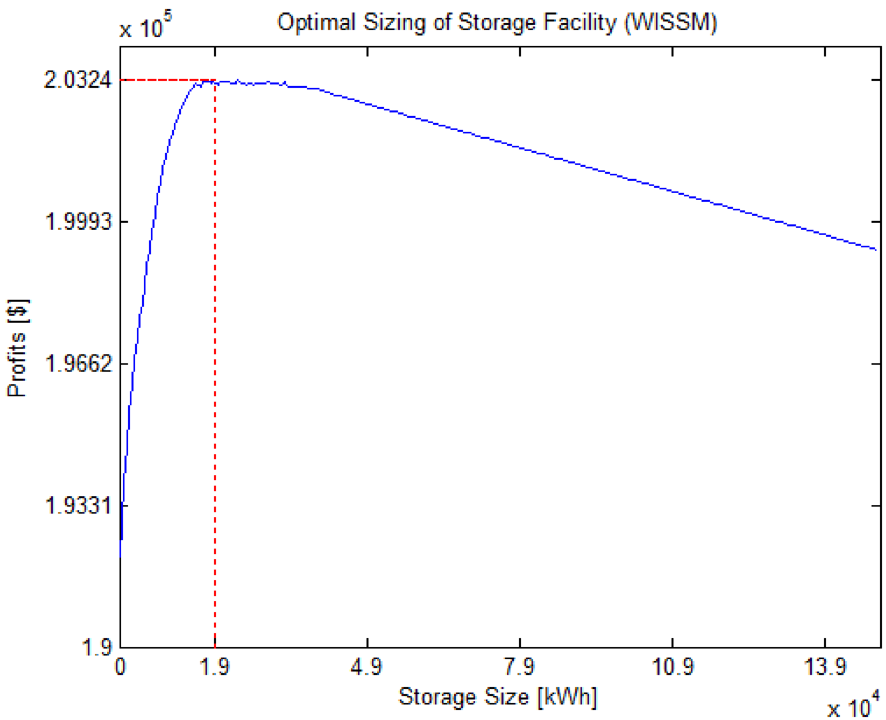
Policy

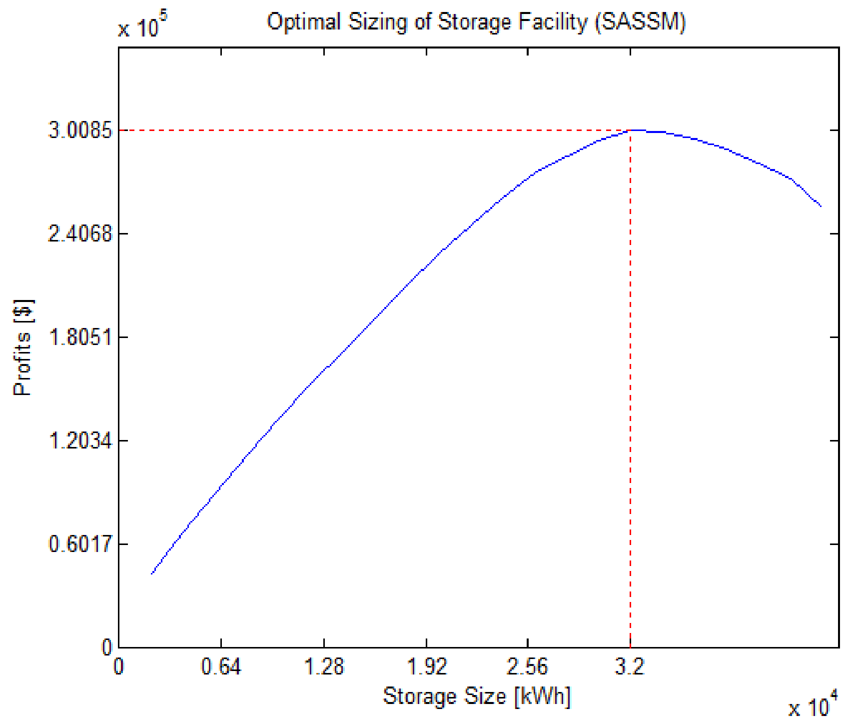
- Goals:
  - Mandate the construction of storage
    - Necessary for reliability
  - Improve the profitability of storage
    - Construction cost subsidies
    - CO_2 tax

Technology	CO_2 emissions (lbs/kWh)
Wind-storage	0.00050
NG Turbine	0.00134

Policy

- By adjusting the cost structure





Summary

- With increasing amounts of intermittent generation, energy storage becomes crucial to maintain a reliable system
- CAES is the most promising storage technology
- Storage is not profitable in PA
- Incentivize construction of storage
  - CO_2 tax
  - Construction cost subsidies
  - Generation dispatchability mandates

Questions?

Thermodynamics

$$\left(\frac{T_2}{T_1}\right)_{S_{Const}} = \left(\frac{P_2}{P_1}\right)^{\left(\frac{k-1}{k}\right)}$$

$$k_{air} = 1.4$$

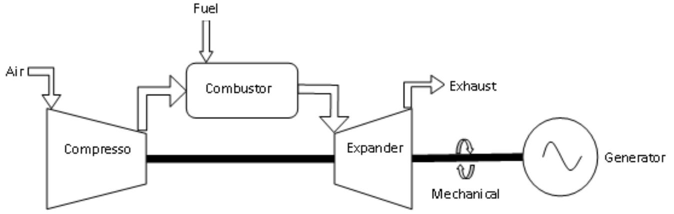
$$T_1 = 60^\circ F = 15^\circ C = 288K$$

$$P_1 = 50Bar = 5MPa$$

$$P_2 = 0.1MPa$$

Assumptions:

1) Isentropic Turbine (Adiabatic-Reversible)
2) Steady State
3) $T_{1,air}$=60° F
4) P_1=50Bar=5MPa
5) P_2=1atm=0.1MPa



$$\rightarrow \left(\frac{T_2}{288K}\right)_{S_{Const}} = \left(\frac{0.1MPa}{5MPa}\right)^{\left(\frac{1.4-1}{1.4}\right)} \rightarrow T_2 = 92.5K = \underline{\underline{-180^\circ C}}$$