Renewable sources, nuclear power, and energy storage alternatives to reduce UIUC Campus CO2 emissions

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Objectives

- Propose electricity generation alternatives for decreasing CO_2 emissions on UIUC campus.
  - Objective aligned with Illinois Climate Action Plan (iCAP) objectives.
- Understand the components of UIUC campus grid.
- Determine current CO_2 emissions in two representative months of the year.
- Calculate CO_2 emissions for different scenarios, including:
  - Increase in **wind** generation capacity.
  - Increase in **solar** generation capacity.
  - Addition of a **nuclear reactor** to UIUC campus grid.
  - Compare different electricity storage alternatives.

iCAP [1]

- American College and University Presidents' Climate Commitment (2008)
- Become carbon neutral as soon as possible, no later than 2050.
- Development of the iCAP (2010)
- Comprehensive roadmap toward a sustainable campus.
- iCAP list of goals, objectives, and potential strategies for several topical areas:
  - Energy Conservation and Building Standards
  - Energy generation, Purchasing, and Distribution
  - Transportation
  - Water and Stormwater usage
  - Purchasing, Waste, and Recycling (Zero Waste)
  - Agriculture, Land Use, Food, and Sequestration

UIUC Campus Grid [2]

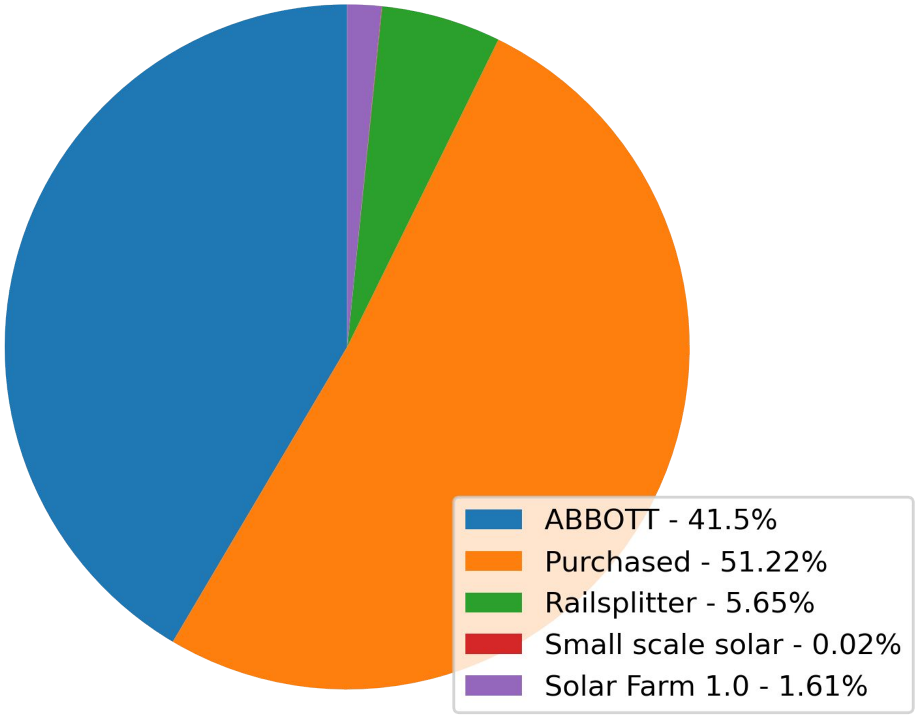


Figure. FY19 Electricity generation distribution.

ABBOTT Power Plant [3-4]

- Built in 1940.
- Supplies 70-75% of the campus energy demand.
- Types of energy sources:
  - Two gas turbines (natural gas or fuel oil)
  - Three gas-fired boilers (natural gas or fuel oil)
  - Three coal-fired boilers
- Cogeneration facility: steam and electricity
  - High-pressure steam spins a turbine to drive a generator and produce electricity.
  - Low-pressure exhaust steam for space heating, water heating, and space cooling.
  - Electrical capacity 85 MW.
- Free tours.

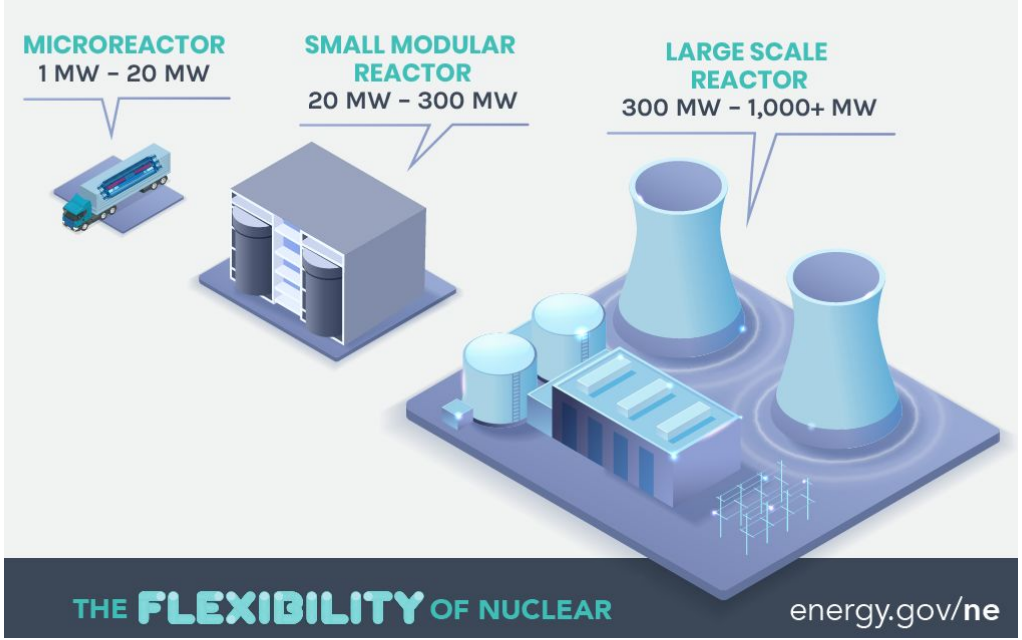
Rail Splitter Wind Farm [5-6]

- Operation began in 2009.
- Located in Tazewell and Logan Counties.
- Power output: 100.5 MW.
- 67 turbines of 1.5 MW.
- Power purchase agreement:
    - November 2016 - October 2026
    - 8.6% of the total wind generation

Solar Farm 1.0 [7-8]

- Operation began in 2015.
- Power output: 4.68 MWac.
- Total modules: 18,867.
- Land usage: 20.8 acres.
- Power purchase agreement: 2015-2025.
- Solar Farm 2.0: 12.32 MWdc, 54 acres.

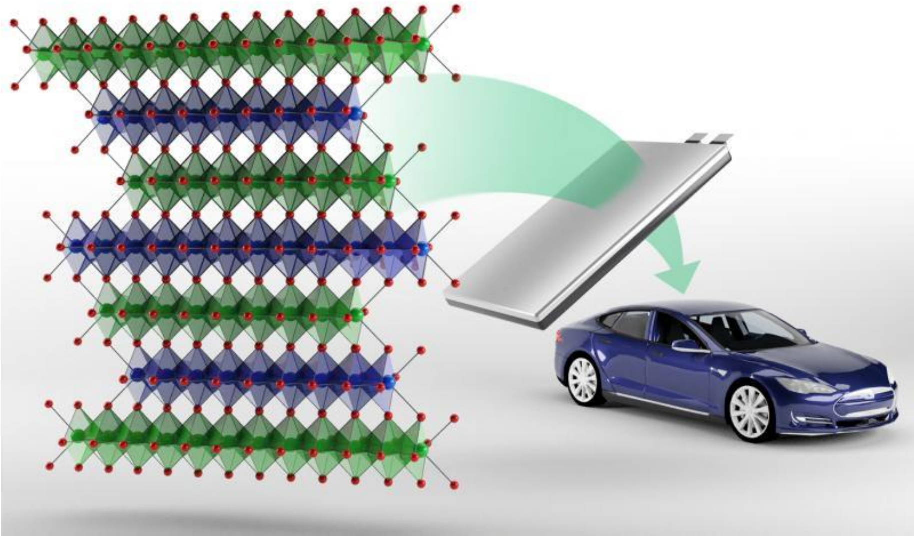
Small Modular Reactors and Microreactors [9-10]



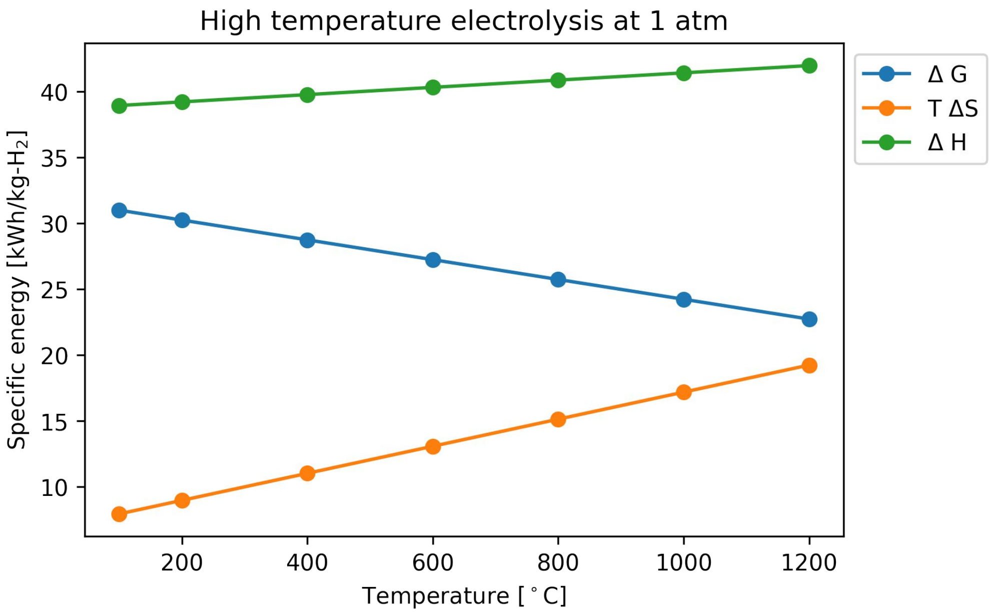
- UIUC Grid demand < 80 MW.
- Limited on-site preparation requirements.
- Factory-fabricated components.
- Components shipped out to generation site.
- Black starts and islanding operation mode.
- Passive safety systems, minimizing electrical parts.

Li-ion Batteries [11-15]

- Charge-Discharge Efficiency: 80-90%
- Rechargeable battery
- First prototype developed in 1985
- High energy density and low self-discharge
- Can cause explosions and fires
- Capacity fading over hundreds to thousands of cycles
- Applications:
  - Portable Power Packs: Laptops and cellphones
  - Electric Vehicles (EVs)
  - Uninterruptible Power Supply (UPS): computers, communication technology, medical technology
  - Solar power storage
- World largest Li-ion: 150 MW



Electrolysis [16]



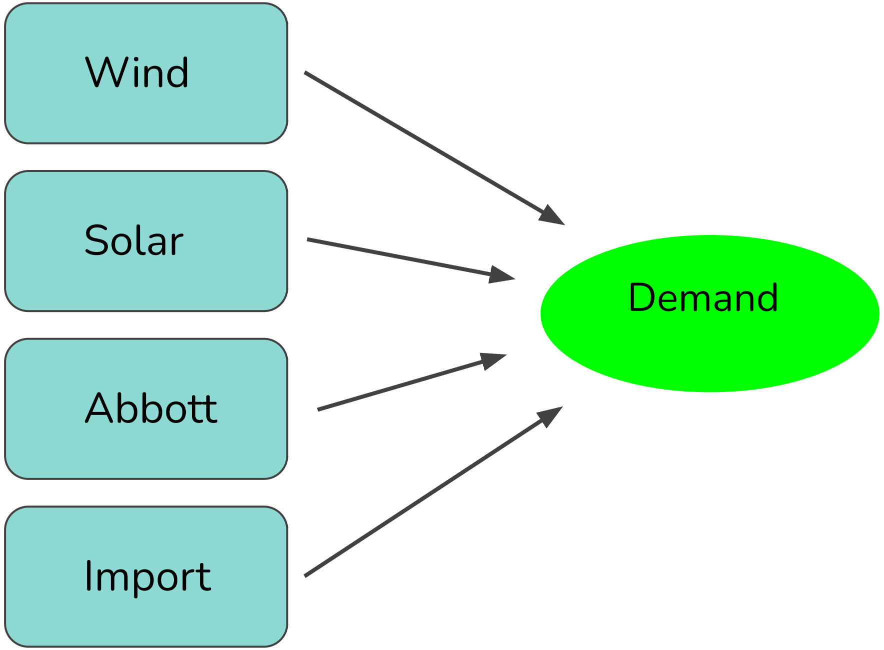
- Commercial use since 1890.
- Most common technologies:
  - Alkaline-based
  - Proton exchange membrane (PEM)
  - Solid Oxide (SOEC)
- Low temperature electrolysis (LTE)
- High temperature electrolysis (HTE)

Equation:

- $\Delta H = \Delta G + T\Delta S$
- ΔH: Specific total energy
- ΔG: Specific electrical energy
- $T\Delta S$: Specific thermal energy

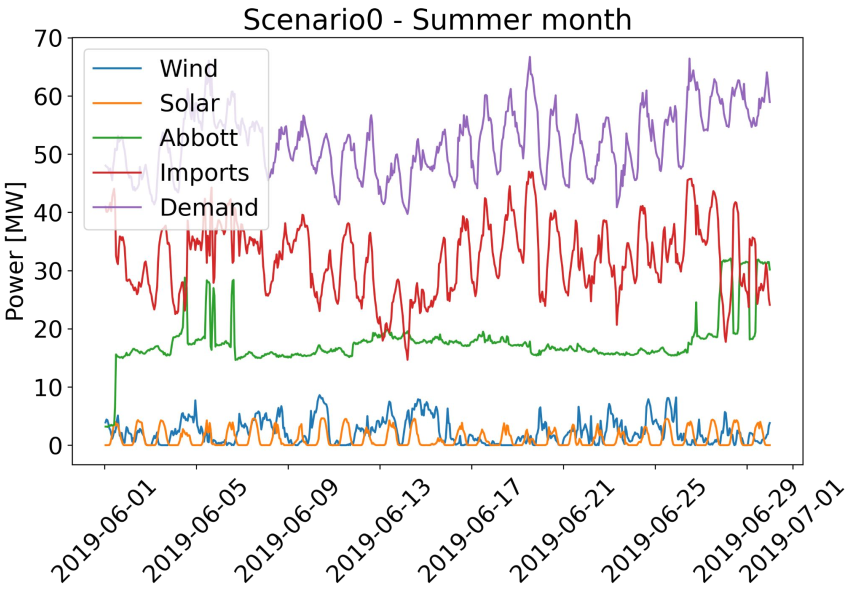
Scenario 0 - Business as usual

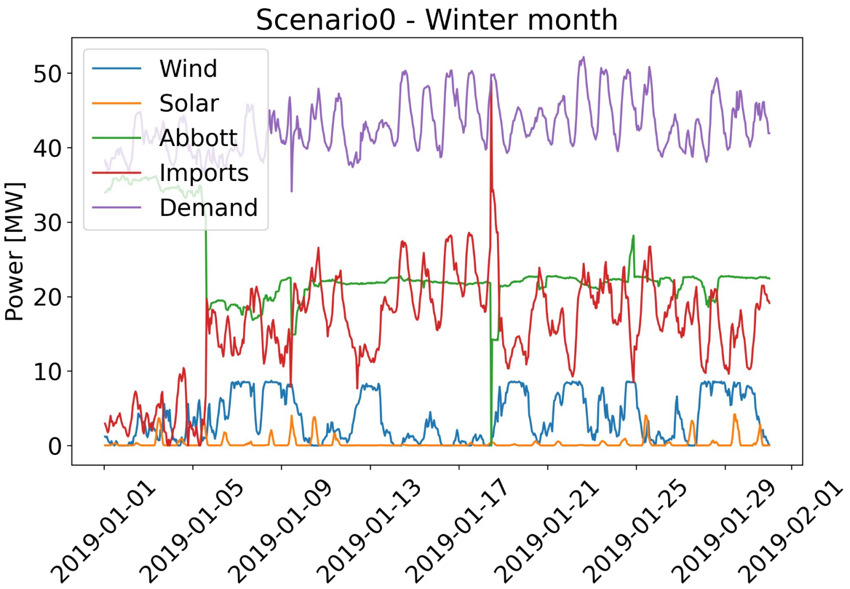
- We will focus in a summer month (June) and a winter month (January)
- Data available from F&S per request [17]
- Abbott: 0.26 tCO2/MW(th)h [1-2]
- Imports: 0.825 tCO2/MWh [1-2]



Scenario 0 - Results

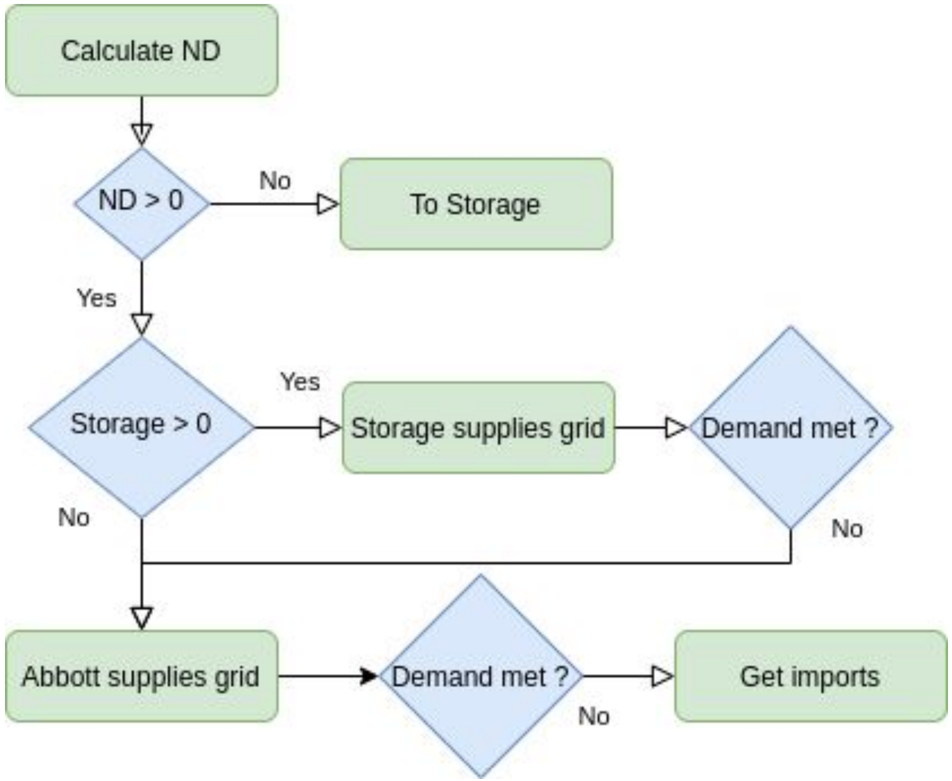
10^3 MT CO_2	Abbott	Imports	Total
Winter	6.6	8.5	15.1
Summer	4.8	16.7	21.5





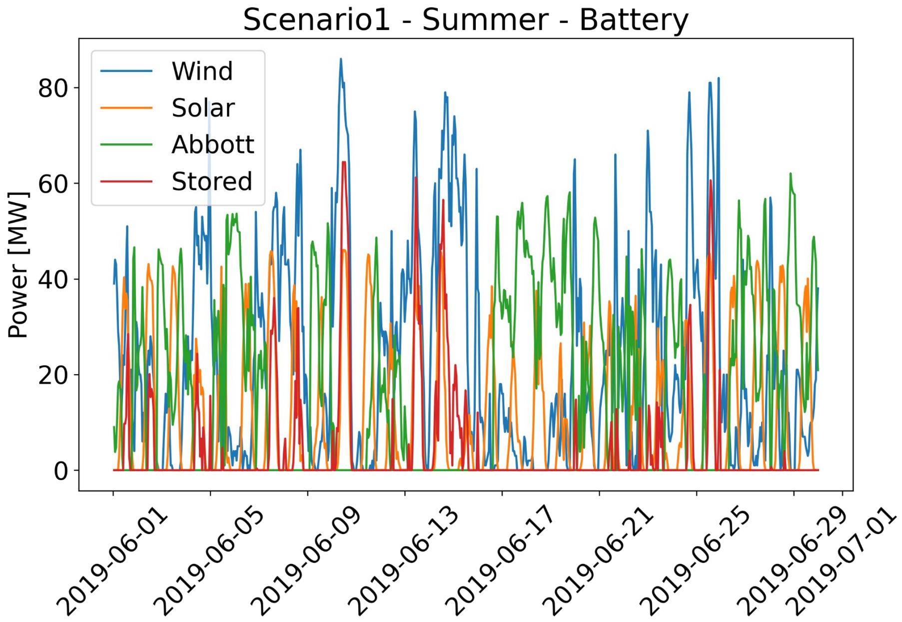
Scenario 1

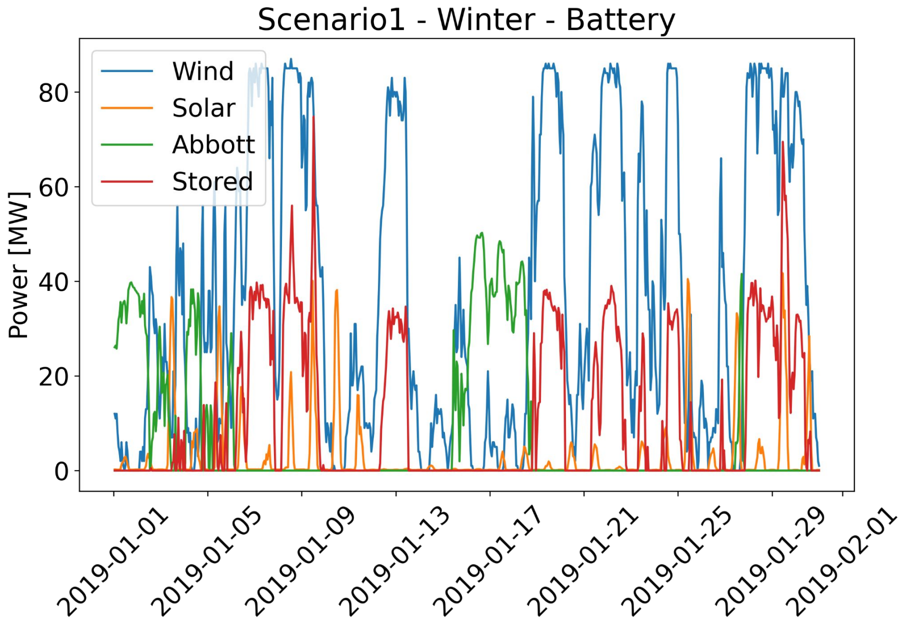
- Dispatch model
  - Wind and Solar
  - Storage
  - Abbott
  - Import
- Increase in Wind and Solar capacity
- Net Demand (ND) = Demand - Wind - Solar
- Necessity for storage mechanisms



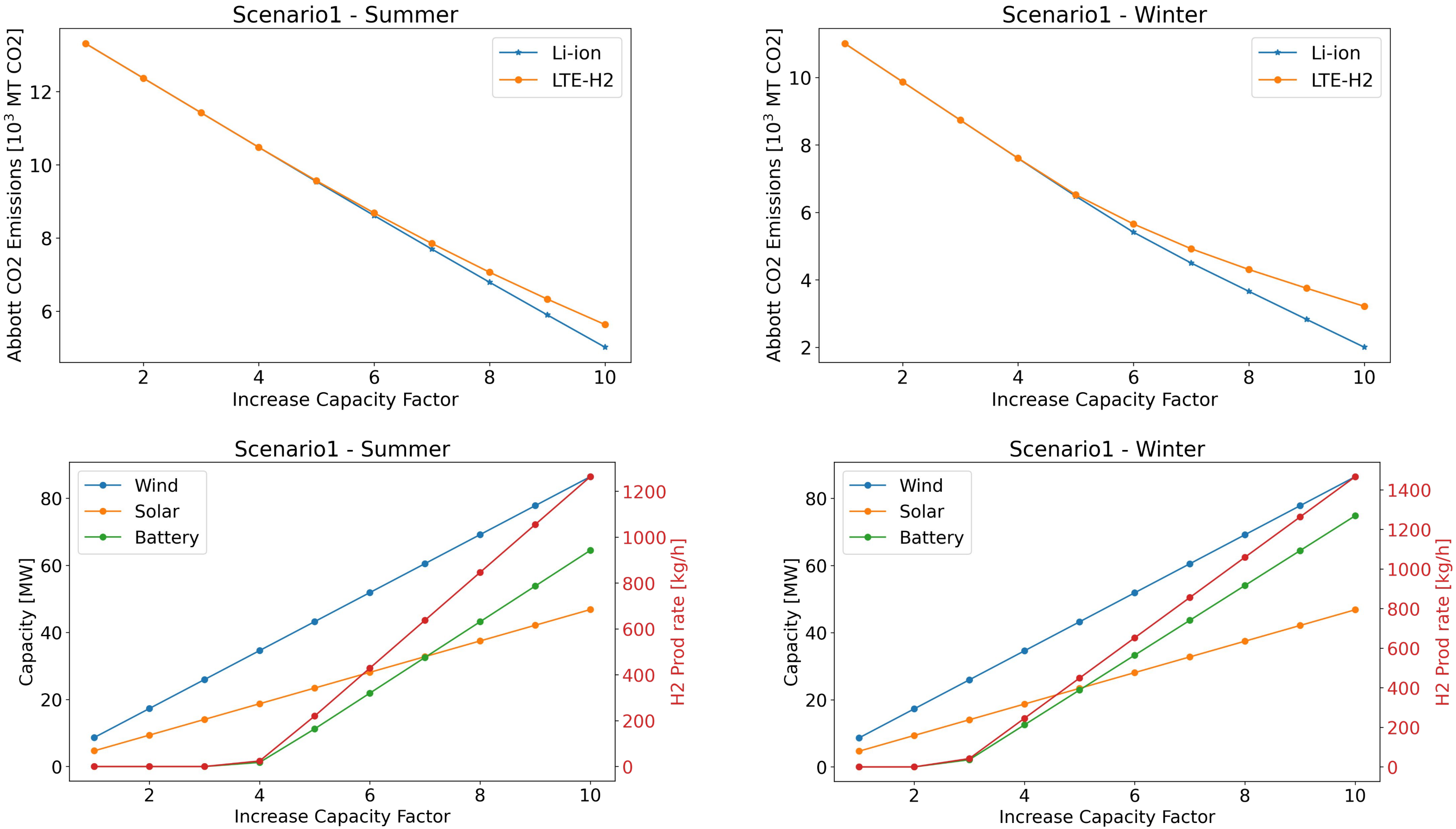
Scenario 1 - Results

- Capacity increase by 10, Wind: 100.5 MW, Solar: 46.8 MW



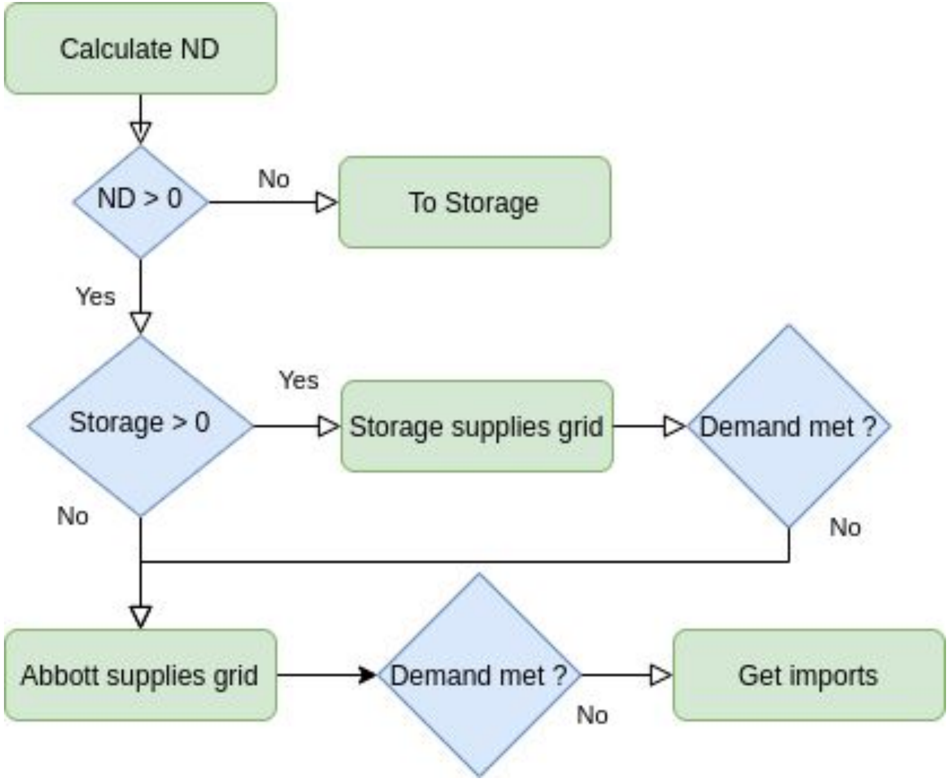


Scenario 1 - Results

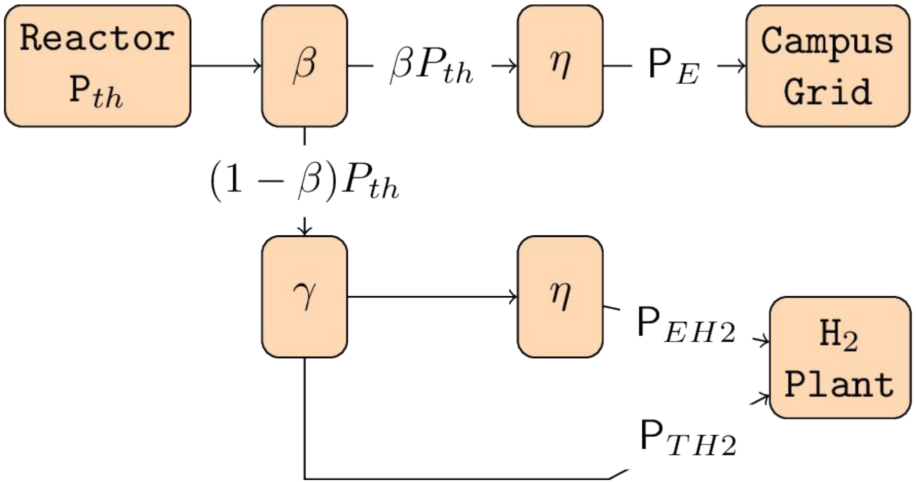


Scenario 2

- Dispatch model
  - Wind and Solar
  - Nuclear Reactor
  - Storage
  - Abbott
  - Import
- Increase in Wind and Solar capacity
- Increase in Reactor Capacity
- Net Demand (ND) = Demand - Wind - Solar - Reactor
- Necessity for storage mechanisms
- HTE at 3.5 MPa



Scenario 2 (2)



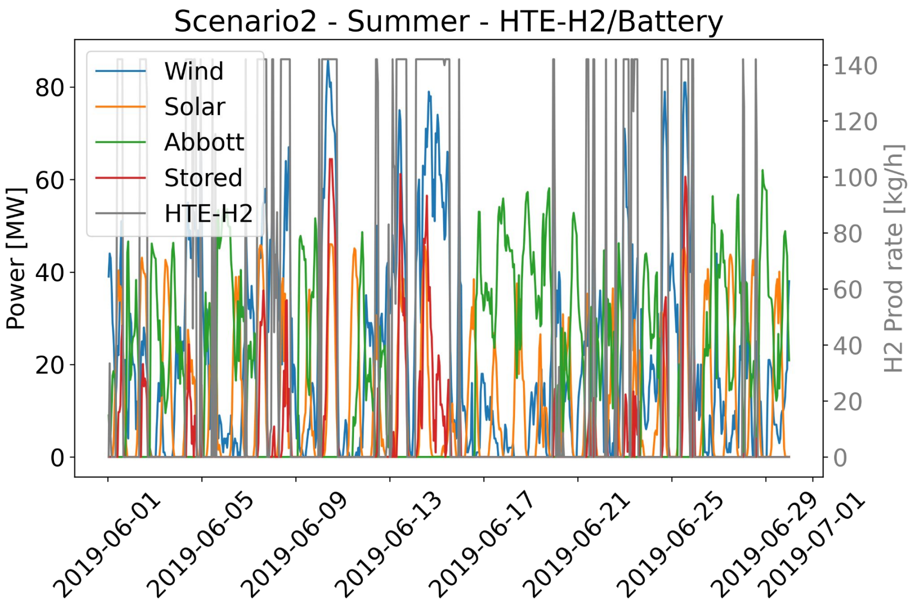
	γ	P_{EH2}	P_{TH2}
LTE	1	≠ 0	0
HTE	(0-1)	≠ 0	≠ 0

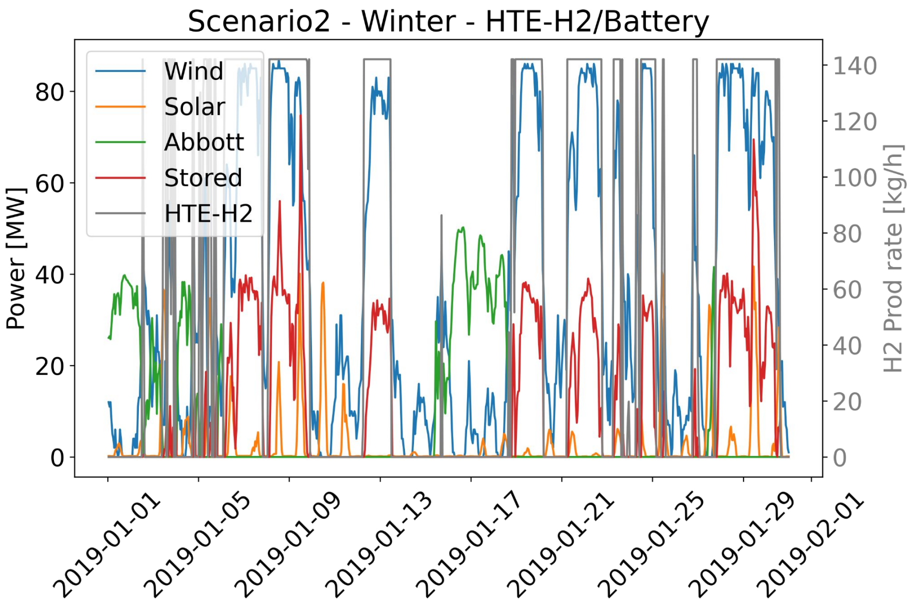
- $P_E = \eta\, \beta\, P_{TH}$
- $P_{EH2} = \eta\, \gamma\, (1 - \beta)\, P_{TH}$
- $P_{TH2} = (1 - \gamma)\, (1 - \beta)\, P_{TH}$
- $\eta = \eta(T_O)$
- η: conversion efficiency
- T_O: reactor outlet temperature

- $\beta = P_E/\eta \,/\, (P_E/\eta + P_{TH2}/(1-\gamma))$
- $\gamma = P_{EH2}/\eta \,/\, (P_{EH2}/\eta + P_{TH2})$

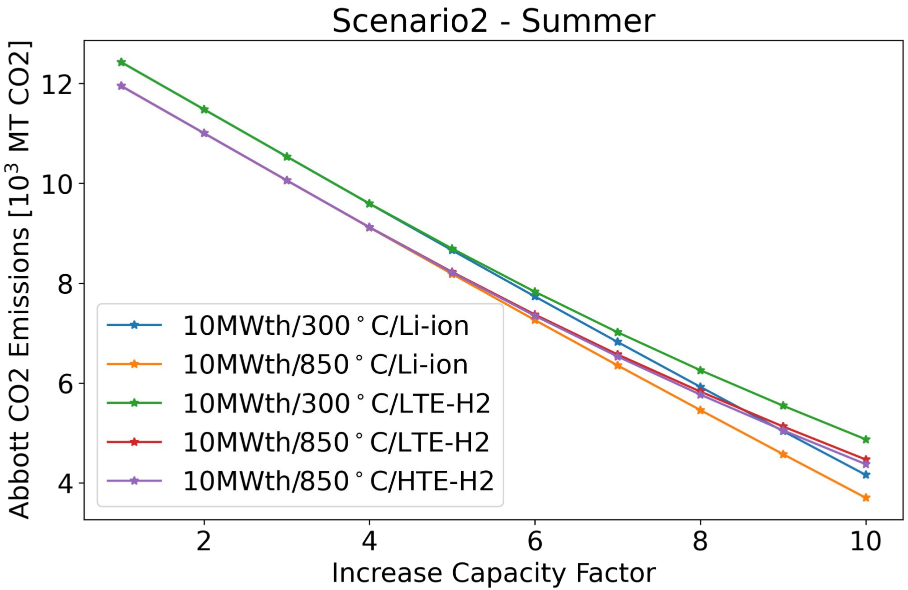
Scenario 2 - Results

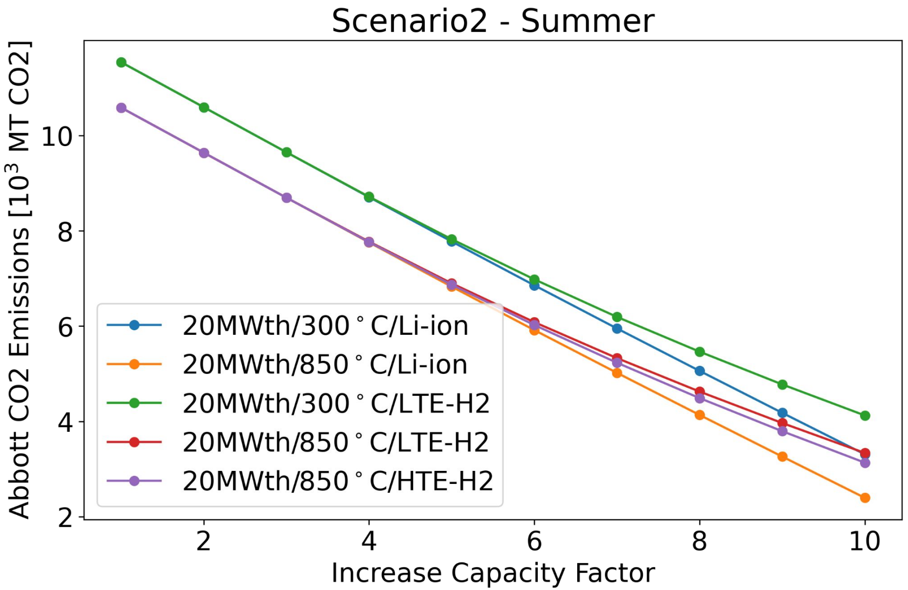
- Capacity increase by 10, Wind: 100.5 MW, Solar: 46.8 MW, Reactor: 10 MWth



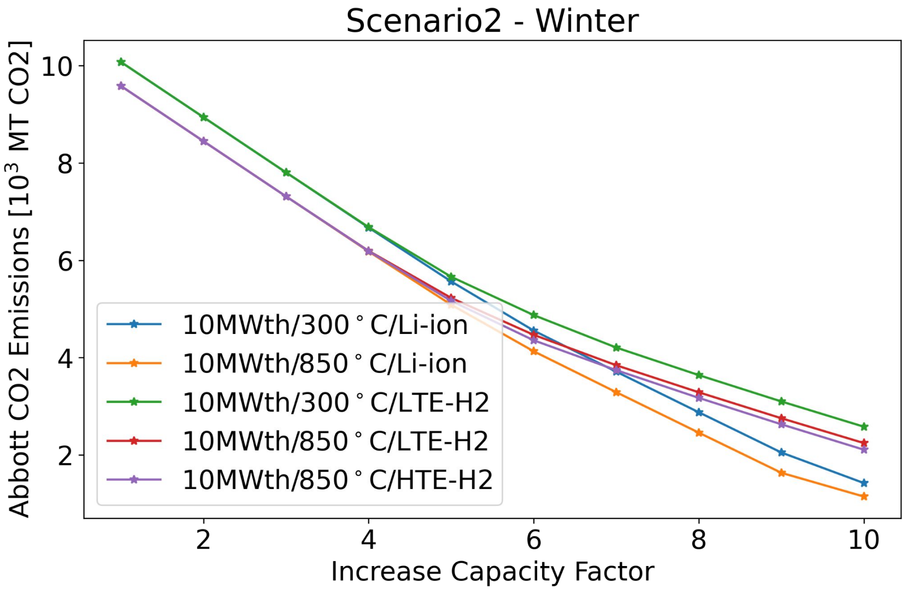


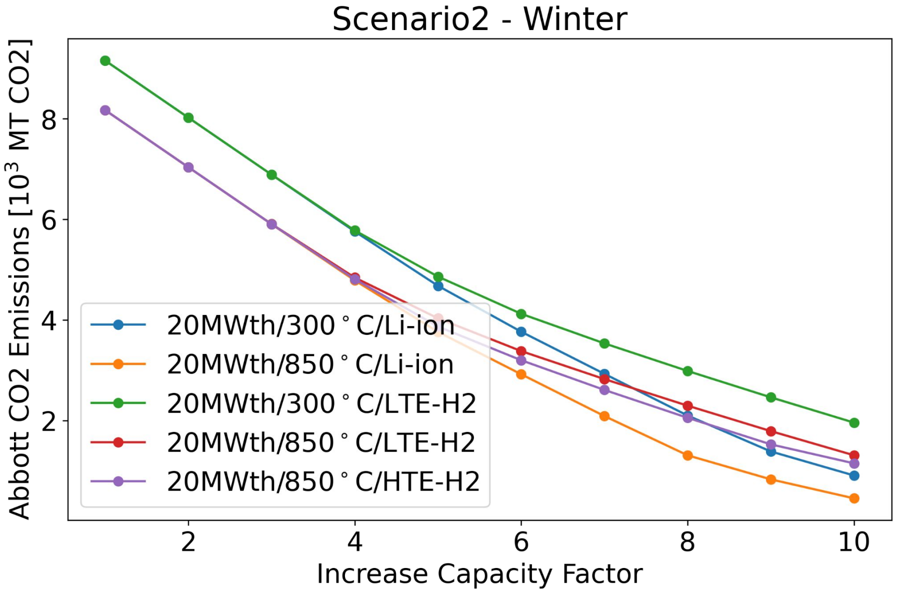
Scenario 2 - Results - Summer





Scenario 2 - Results - Winter





Conclusions

- UIUC campus grid is a good example of a diverse microgrid.
- Winter CO2 emissions are lower to Summer CO2 emissions.
  - Total demand is lower as well.
  - Future work may include the same analysis using February dataset.
- Decreasing the imported electricity considerably reduces CO2 emissions.
- Abbott steam production may limit max electric capacity.
- Increase in renewables capacity linearly decreases CO2 emissions if no storage mechanism is needed.
- In Scenario 1, increasing wind and solar capacity requires:
  - Battery of around 70 MW.
  - Hydrogen plant that can support 1400 kg/h.
- Larger reactor capacities reduce further the CO2 emissions.
- Larger reactor outlet temperature increases storage efficiency.
- HTE-H2 production is limited by the size of the reactor, secondary method required.
- Li-ion is the most efficient storage mechanism.

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References

[1] - https://icap.sustainability.illinois.edu/files/project/2634/2015iCAPweb.pdf

[2] - https://icap.sustainability.illinois.edu/files/project/5293/iCAP-2020-FINAL-WEB.pdf

[3] - https://fs.illinois.edu/services/utilities-energy/production/abbott-power-plant

[4] - https://fs.illinois.edu/docs/default-source/utilities-energy/abbottbrofinal.pdf?sfvrsn=90b1f9ea_4

[5] - https://icap.sustainability.illinois.edu/files/project/2235/RailSplitter-Wind%20Farm-9.6.16.pdf

[6] - https://fs.illinois.edu/services/utilities-energy/production/renewable-energy

[7] - https://fs.illinois.edu/docs/default-source/utilities-energy/solar-farm-project-fact-sheet_with-faqs_104171bbba4c36b8160c2ad00ff2500358aeb.pdf?sfvrsn=813ac4ea_0

[8] - https://icap.sustainability.illinois.edu/project/solar-farm-20

[9] - https://www.energy.gov/ne/downloads/ultimate-fast-facts-guide-nuclear-energy

[10] - https://twitter.com/govnuclear/status/1282822874865242117

References (2)

[11] - http://large.stanford.edu/courses/2010/ph240/sun1/

[12] - https://www.ornl.gov/news/new-class-cobalt-free-cathodes-could-enhance-energy-density-next-gen-lithium-ion-batteries

[13] - https://relionbattery.com/blog/the-seven-top-uses-for-rechargeable-lithium-ion-batteries

[14] - https://en.wikipedia.org/wiki/Lithium-ion_battery#Battery_life

[15] - https://www.tesla.com/videos/powerpack-hornsdale?redirect=no

[16] - Fairhurst-Agosta R. MULTI-PHYSICS AND TECHNICAL ANALYSIS OF HIGH-TEMPERATURE GAS-COOLED REACTORS FOR HYDROGEN PRODUCTION. MS Thesis. University of Illinois at Urbana-Champaign. 2020. https://www.ideals.illinois.edu/handle/2142/109439

[17] - UIUC F&S. Private Communications. 2019. 2020.

Thank you!

Questions?