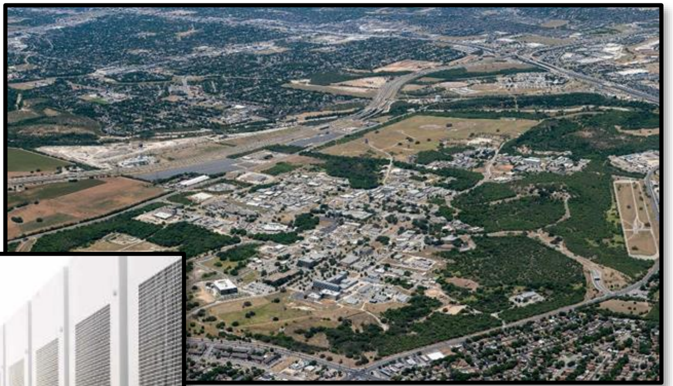
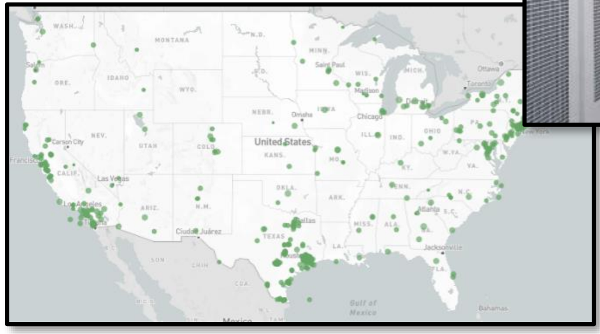
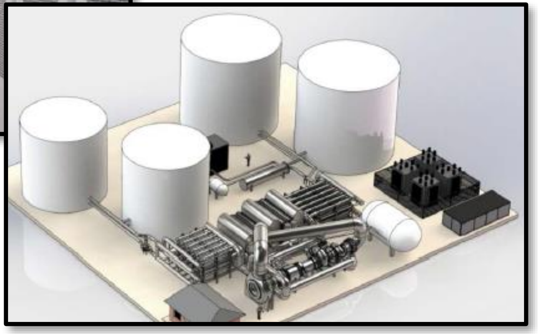
Techno-Economics of a Net-Zero Microgrid as a Scale-Up Platform for Energy Storage



July 31, 2024





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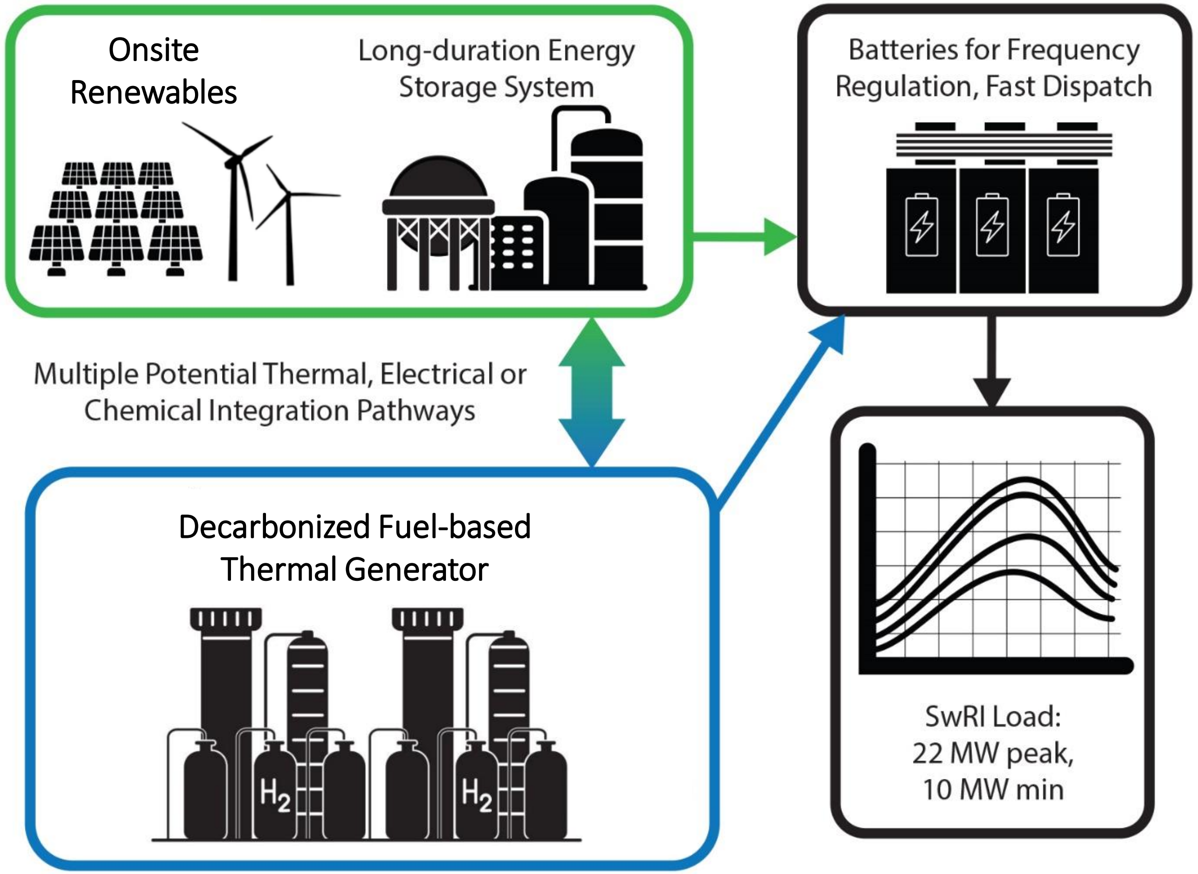
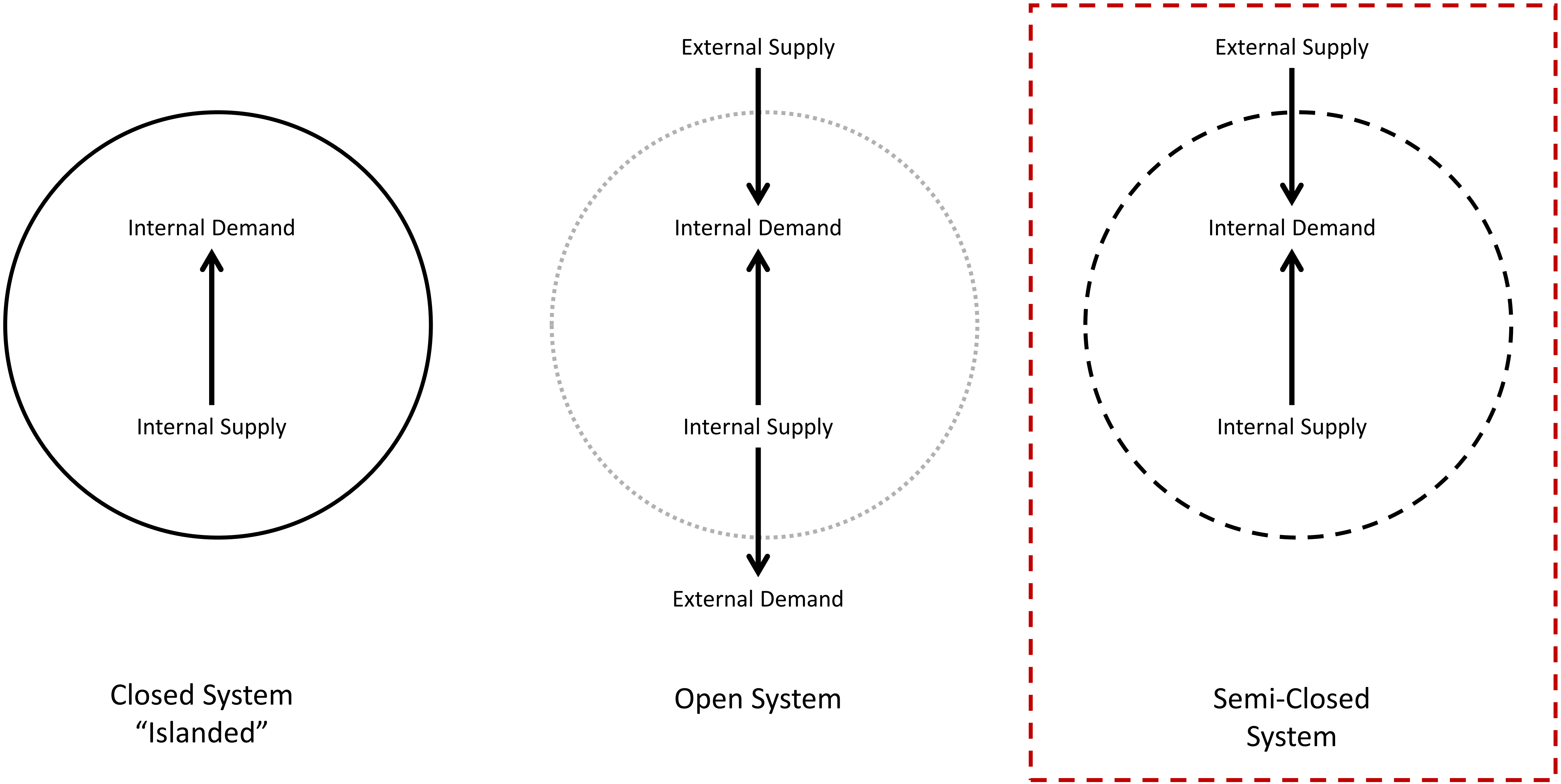
Net-Zero Electricity: Project Z Goals

- Clean energy generation & storage
  - Analyze dynamics of multiple interacting systems over time
  - Optimize costs & minimize emissions
- Roadmap to net-zero emissions
  - Characterize decarbonization steps
  - Assess opportunities
  - Track environment, social & governance trends
  - Estimate tax implications



What Type of System?



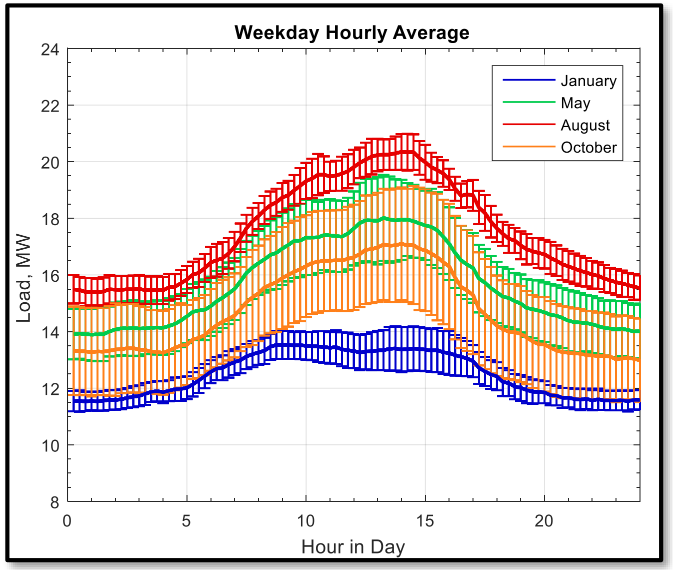
Closed System
"Islanded"

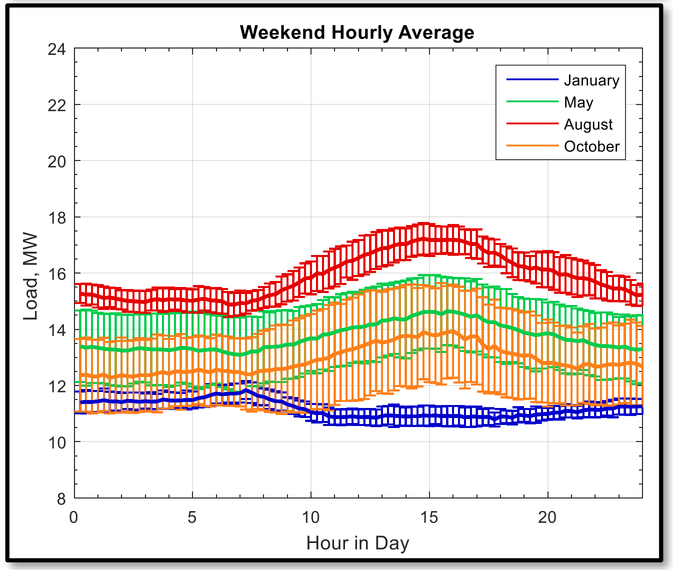
Open System

Semi-Closed
System

Why is SwRI a Good Match?

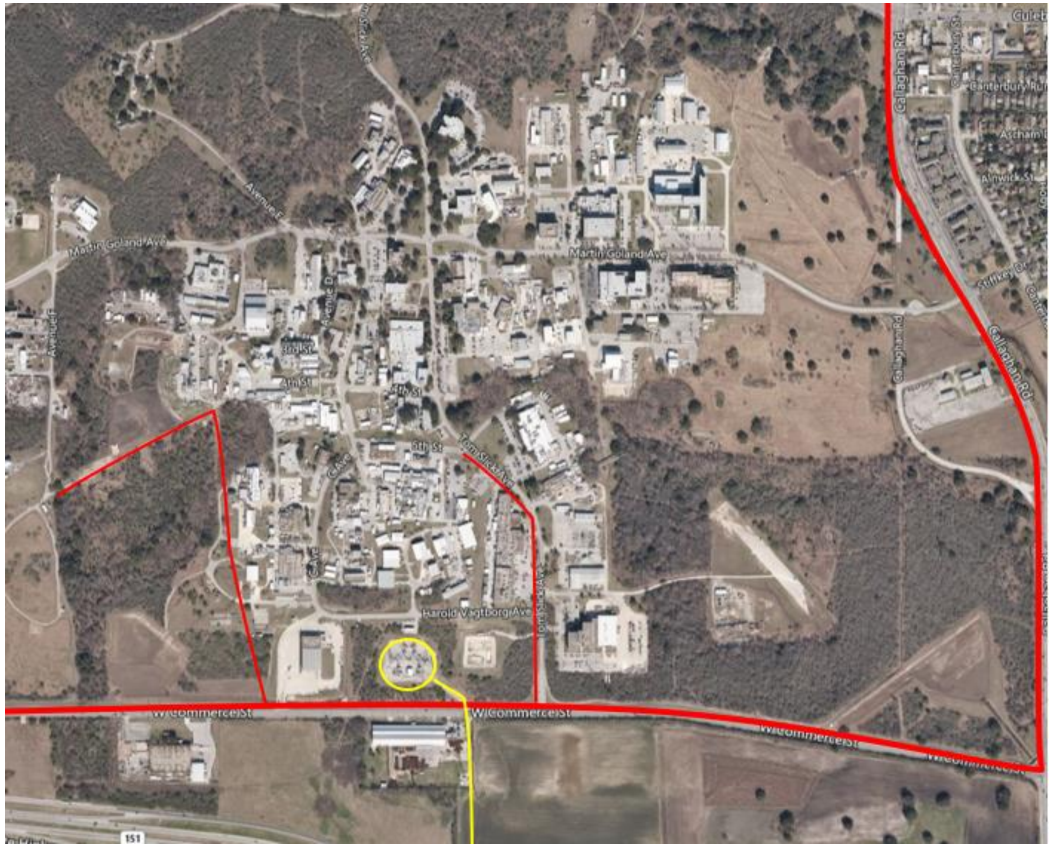
- Campus distribution network & land availability could support microgrid
- Megawatt-scale demonstrations provide hours of run time
  - Large-scale demonstrations
  - Eligible for grants
- “Grid of the future” possible using baseload and variable power sources
- State-of-the-art opportunity for emerging technology R&D



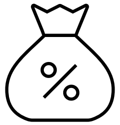


Feasibility and Technology Assessment

- Gathered data on electric usage, contractual agreements, existing infrastructure
- Compared renewable generation options for further analysis
  - Solar PV most available
  - Wind a good secondary resource
- Wide assessment of different renewable technologies
  - Estimating Performance
  - Examining cost
  - Assessing risk



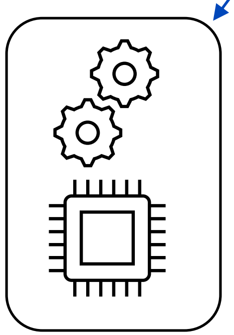
Detailed Python Model Toolset



Federal Tax Incentives

Custom Dispatch Strategies

Campus Load Data

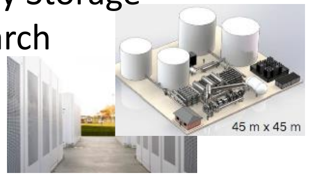


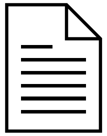
PyZ Model

Generalized toolset developed under SwRI IR&D Project Z

On-Site Generation

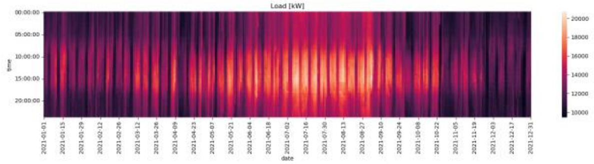
Energy Storage Research





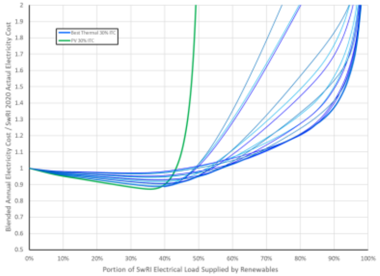
Utility Bills

Hourly energy balance for campus grid



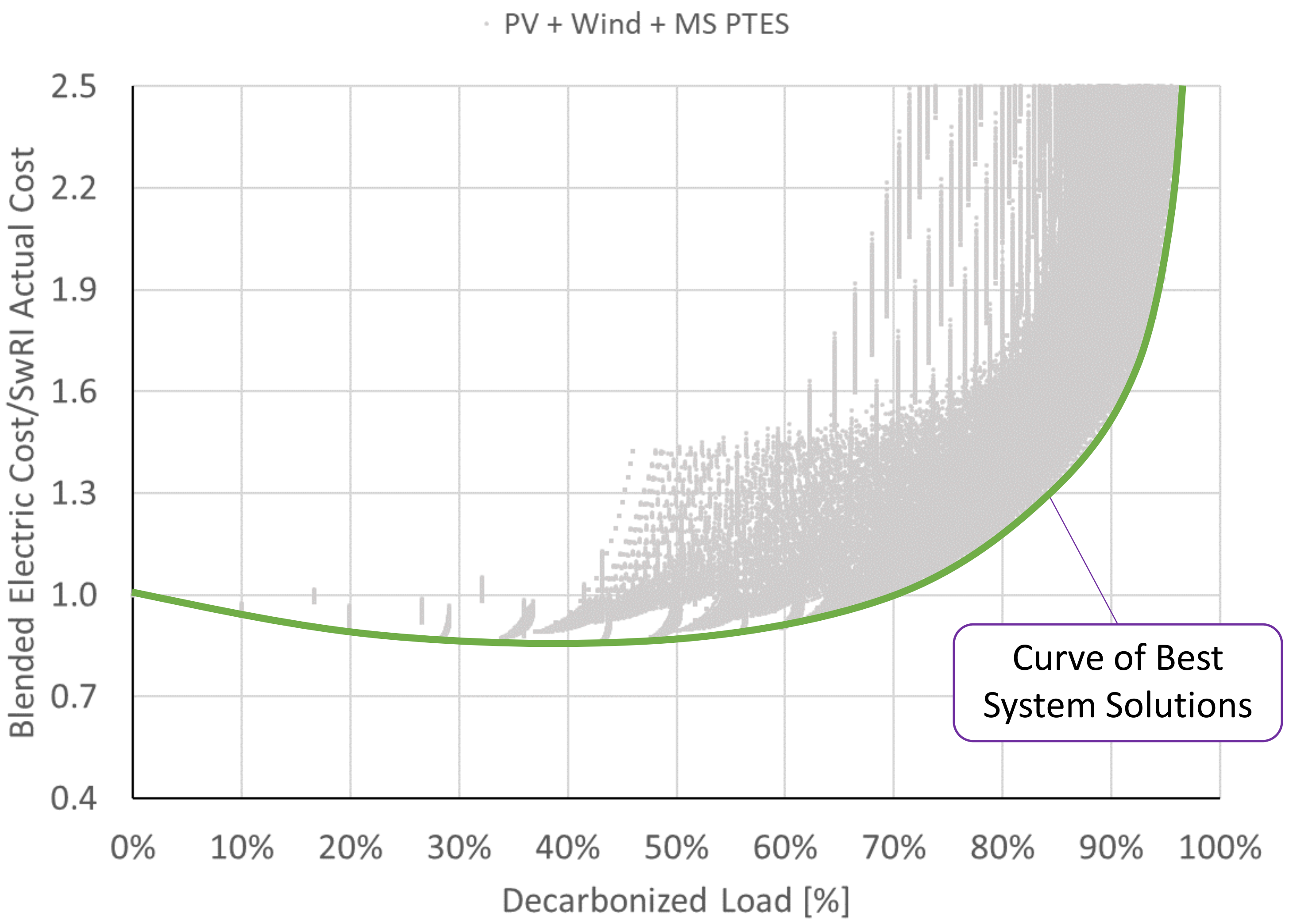
Techno-Economic Analysis of

- On-site generation
- Storage Options



Curve of Best Solutions for Mixed Systems

- Parameterize the sizing of mixed systems
- Results in a curve of best solutions for minimum cost option
- Best system depends on desired decarbonization
- "Curve of Bests" will be shown in all subsequent trends



Cost and Performance for Renewable Generation

- 30-year life of plant
- Considerations in modeling cash flow
  - No financing of the project
  - Inflation, escalation, and cost of capital (factored into net present value (NPV) of cash flow
  - Discount rate is based on the average treasury bond rate
- Federally offered income tax credit (ITC) available for installing renewables
- Compare a calculated blended electric cost normalized to current electric costs

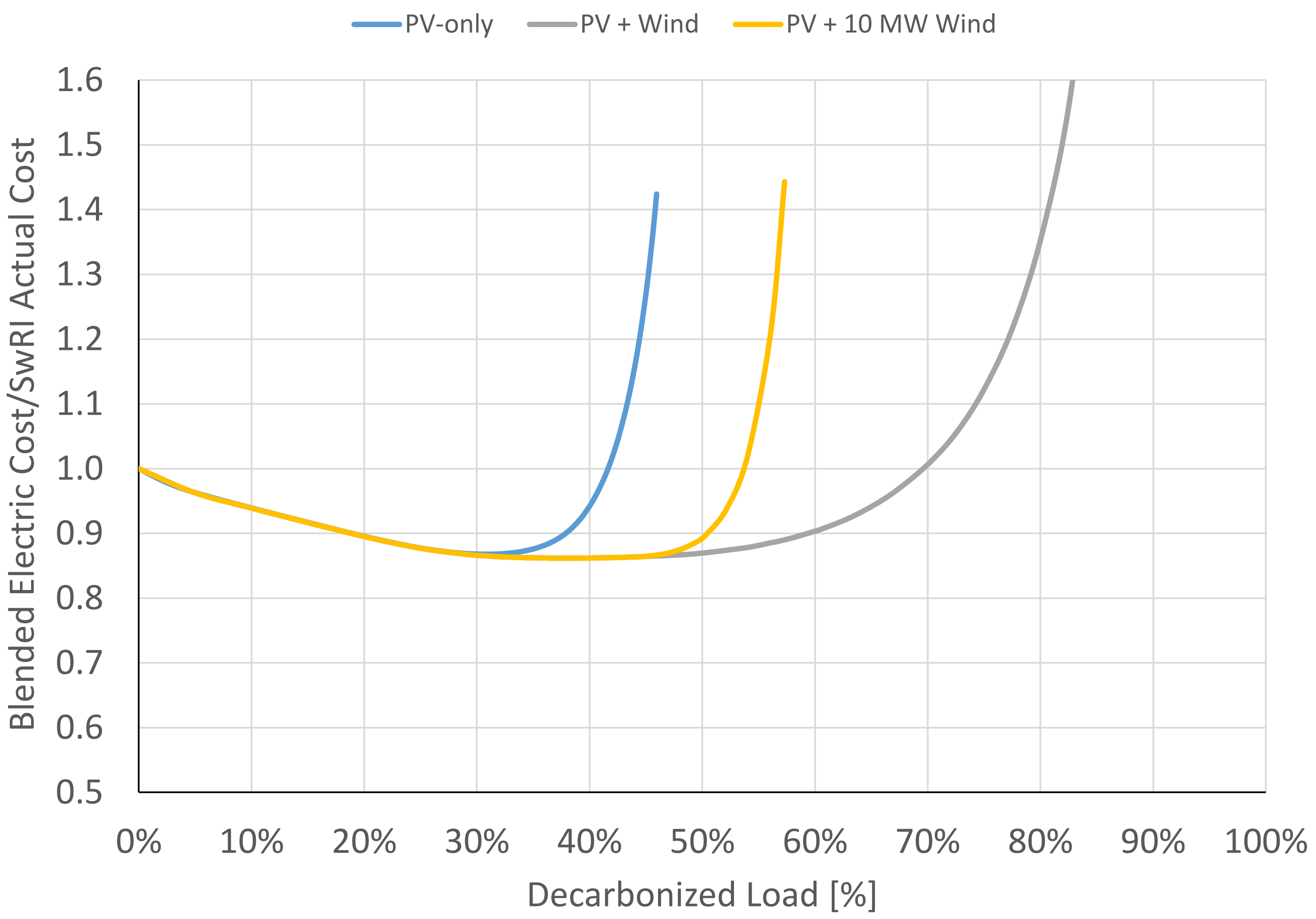
Parameter	Value
PV Installed cost ($/kW$_{DC}$)	961
PV Levelized O&M ($/kW$_{DC\text{-}yr}$)	16
Preinverter derate (%)	85.9
Inverter efficiency (%)	96
Inverter loading ratio	1.1
Array Type	1-axis backtracking
PV Degradation (%/yr)	0.7
Wind Installed cost ($/kW$_{AC}$)	3,270
Wind Levelized O&M ($/kW$_{AC\text{-}yr}$)	39
Wind Degradation (%/yr)	0.7
Inflation Rate (%)	2.5
Discount Rate (%)	4.74

$$NPV\ (\$) = \sum_{i=1}^{n} \frac{Net\ Cash\ Flow_i(\$)}{(1 + Discount\ Rate)^i}$$

$$Blended\ Electric\ Cost\ \left(\$/_{kWh}\right) = \frac{CAPEX(\$) + NPV\ Utility\ Costs(\$) + NPV\ OPEX(\$)}{NPV\ Generation\ and\ Import\ (kWh)}$$

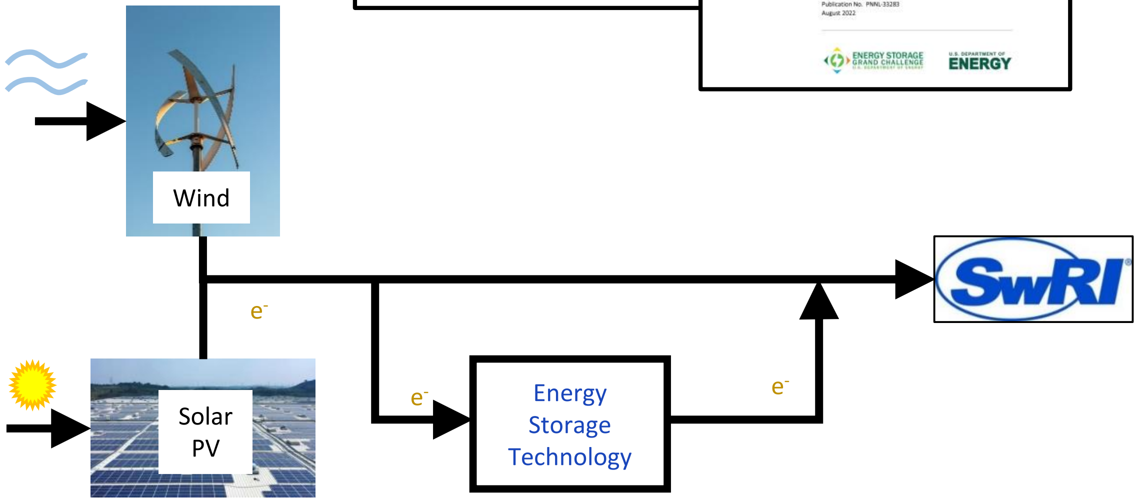
Analysis Results for PV and Wind

- PV only costs grow exponentially beyond 40% decarbonization
- PV with wind can push decarbonization to 70% before current costs are exceeded
    - 42 MW solar and 34 MW wind at cost parity
- Wind limited to a maximum of 10 MW to represent real limit of SwRI property
    - Pushes decarbonization past 50% with no storage
    - Starts adding wind after about 30 MW of solar are installed

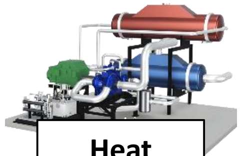
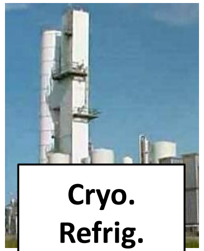
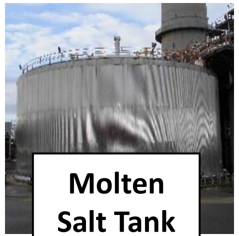
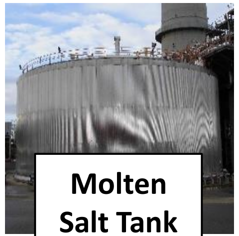


Long Duration Energy Storage Analysis Setup

- Grid purchases from CPS are given a carbon emission amount
  - CPS reported electric carbon intensity of 850 lbs/MWh
  - SwRI decarbonization calculated based on increase and decrease from base number
- Compare a wide range of LDES systems designed for 6+ hours of duration
- Wide range of technologies examined



LDES Systems Overview

On-Site Generation ↓	LDES Systems						
	Lithium-Ion Battery (BES)	Molten Salt Pumped Thermal (MS PTES)	Sand TES with SCO2 Power (Sand+SCO2)	Molten Salt TES with SCO2 Power (MS+SCO2)	Concrete TES with SCO2 Power (Concrete+SCO2)	Gas Hydrogen with Fuel Cell (GH2+FC)	Liquid Air Energy Storage (LAES)
Storage Charging ↓	 Battery Package	 Heat Pump	 Resistive Heating	 Resistive Heating	 Resistive Heating	 H2 Electrolyzer	 Cryo. Refrig.
Storage System ↓	 Battery Package	 Molten Salt Tank	 Packed Sand	 Molten Salt Tank	 Concrete Blocks	 High Pressure Tank	 Cryo. Tank
Storage Discharging ↓	 Battery Package	 Expander Machinery	 SCO2 Power Cycle	 SCO2 Power Cycle	 SCO2 Power Cycle	 H2 Fuel Cell	 Expander Machinery

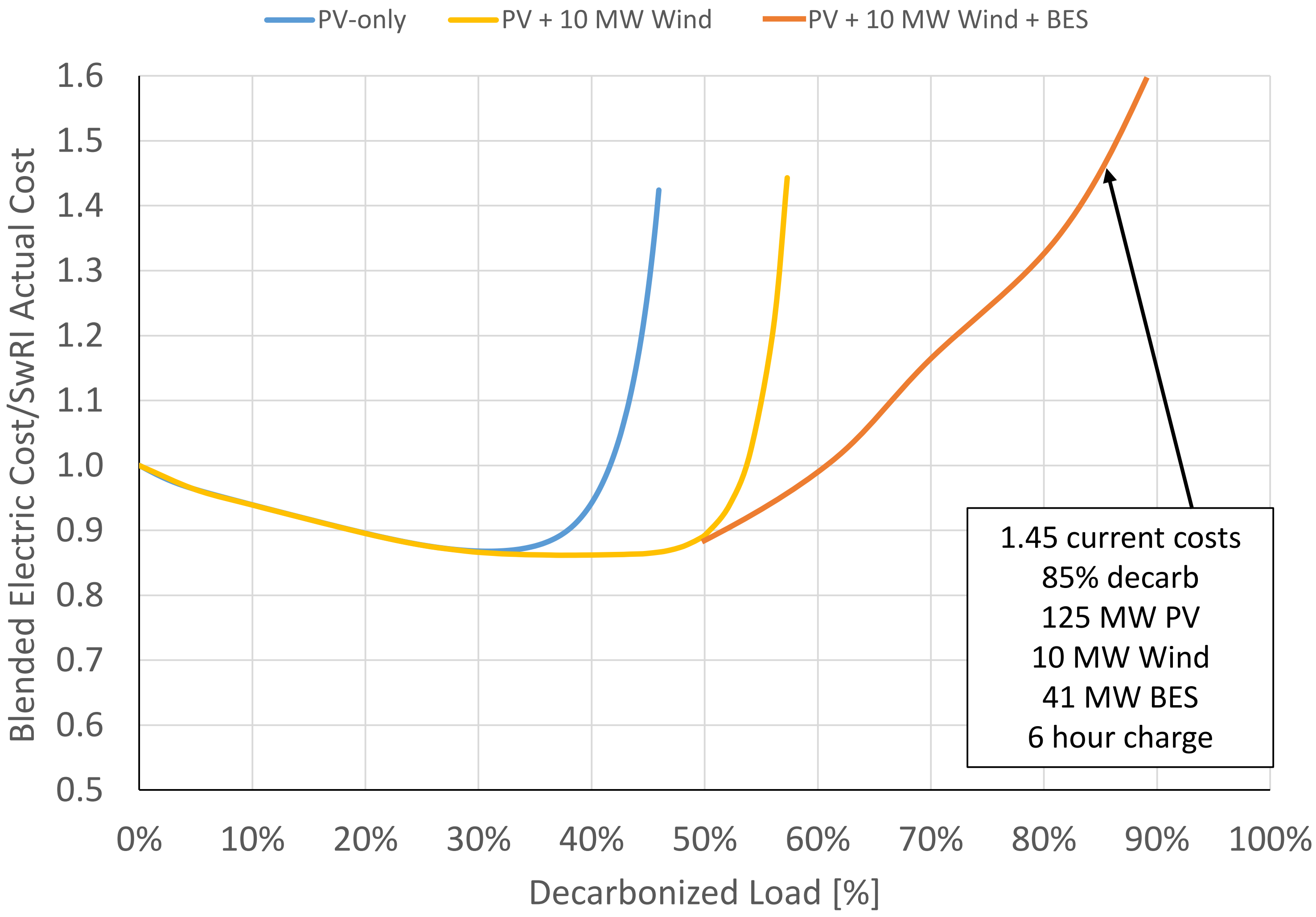
On-Site Load

Cost and Performance for LDES Systems

	Li-Ion BES	MS PTES	Sand +SCO2	MS +SCO2	Concrete +SCO2	GH2+FC	LAES
Total Storage Cost ($/kWh$_e$)	**366**	**127**	**94**	**115**	**81**	**107**	**252**
Total Power Cost ($/kW-AC)	**106**	**1,532**	**1,760**	**1,760**	**1,760**	**2,894**	**1,612**
Charging Power Costs ($/kW-AC)	53	935	126	126	126	1,485	806
Discharging Power Costs ($/kW-AC)	53	597	1,635	1,635	1,635	1,408	806
O&M Costs ($/kW-yr)	4.59	53.7	22.1	53.7	14.7	23.2	30.0
Storage Replacement Cost ($/kWh)	113.6						
Round Trip Efficiency (%)	**82.8%**	**50.0%**	**47.6%**	**45.2%**	**45.2%**	**34.9%**	**50.1%**

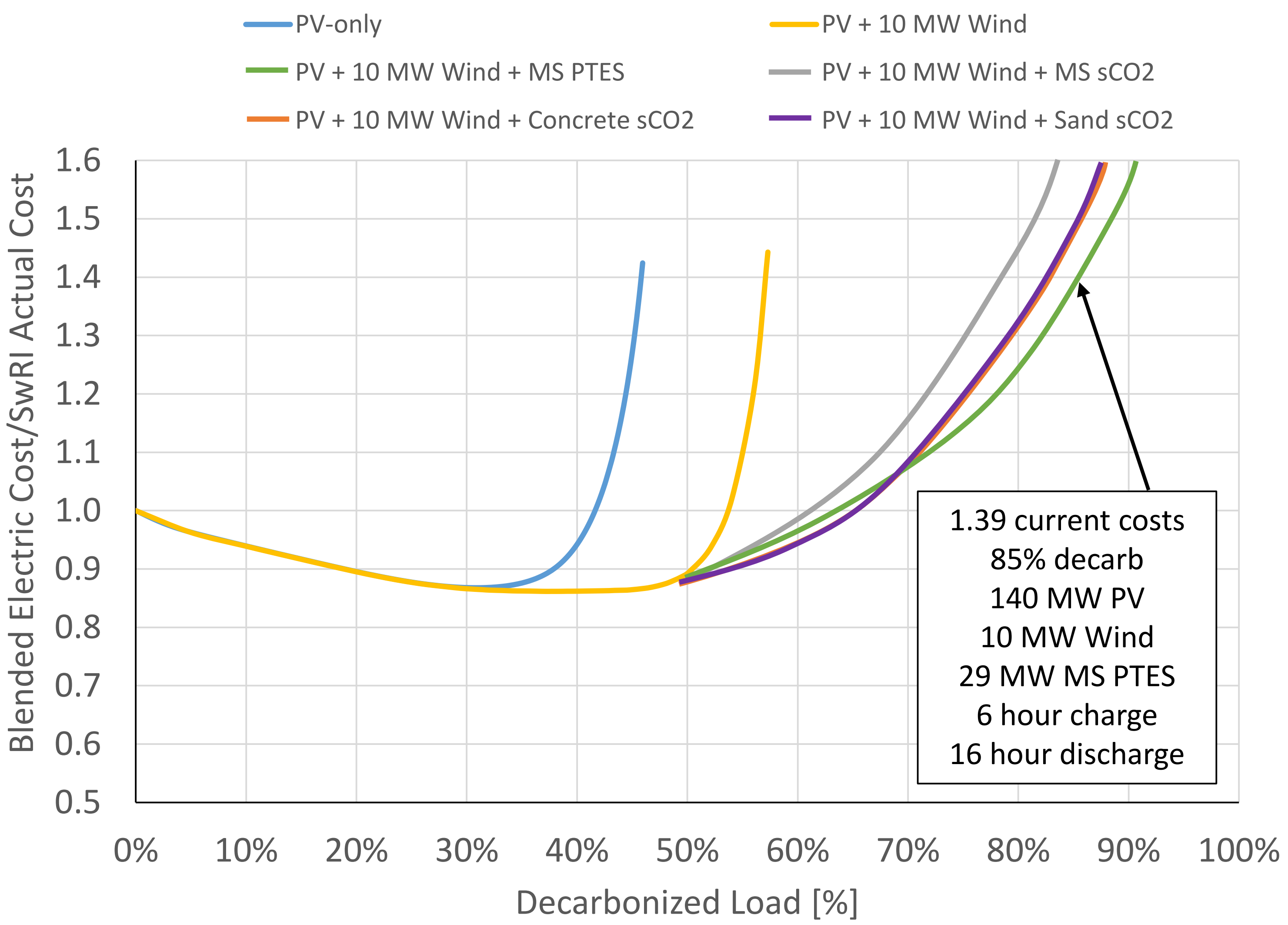
Analysis Results for Battery

- System should install only renewables up to the minimum cost point
- BES constrained to equal charge and discharge duration
  - 6, 8, or 10 hours
- BES allowed to maximum of 10 hours of duration due to current technology limits



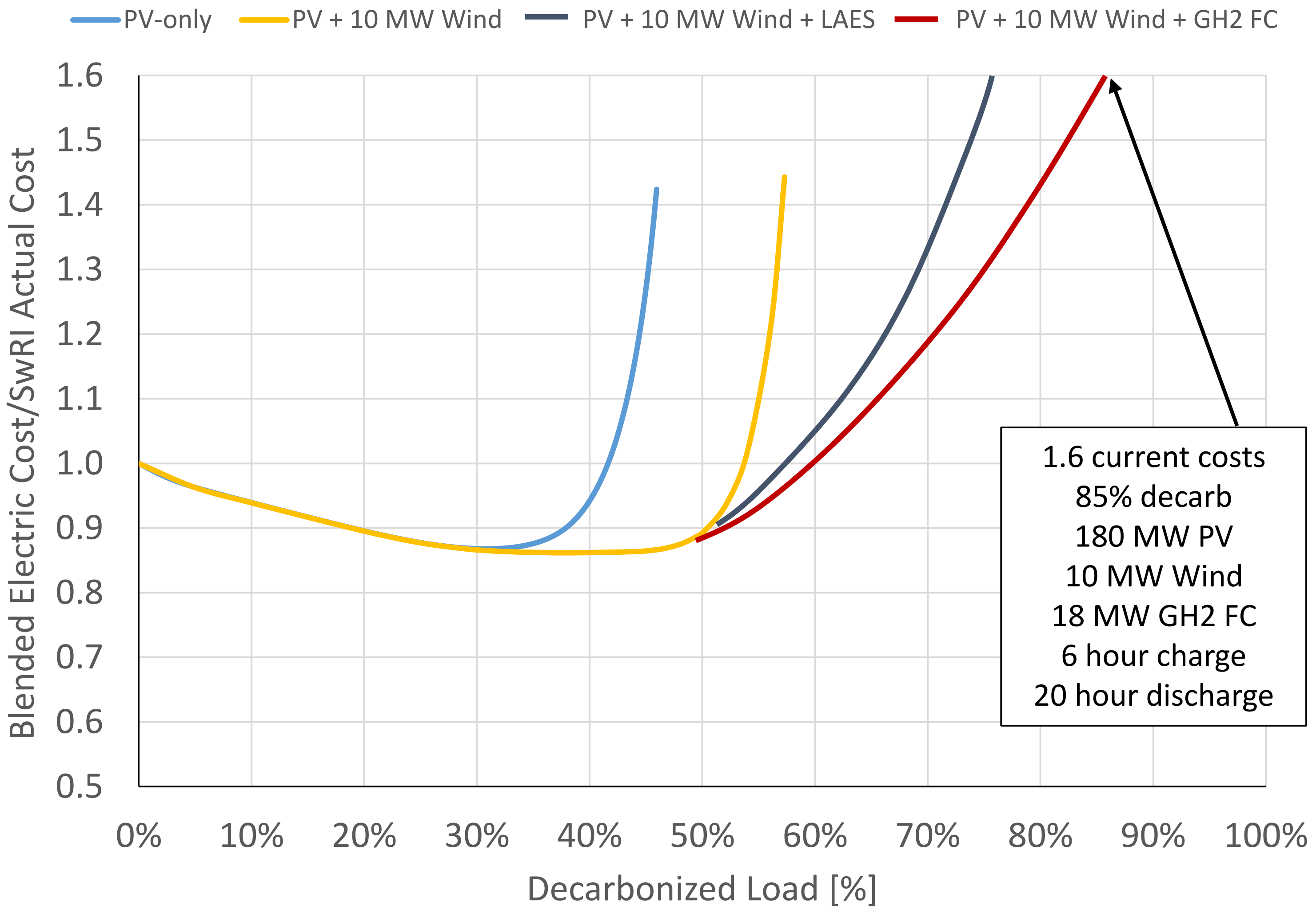
Analysis Results for Thermal LDES

- Molten Salt is storage in the best and worst cases
  - Best case has higher RTE of PTES
  - Lower RTE of SCO2 favors cheaper storage media
- Packed sand and concrete with SCO2 perform similarly
  - Sand is preference going forward due to ease of construction



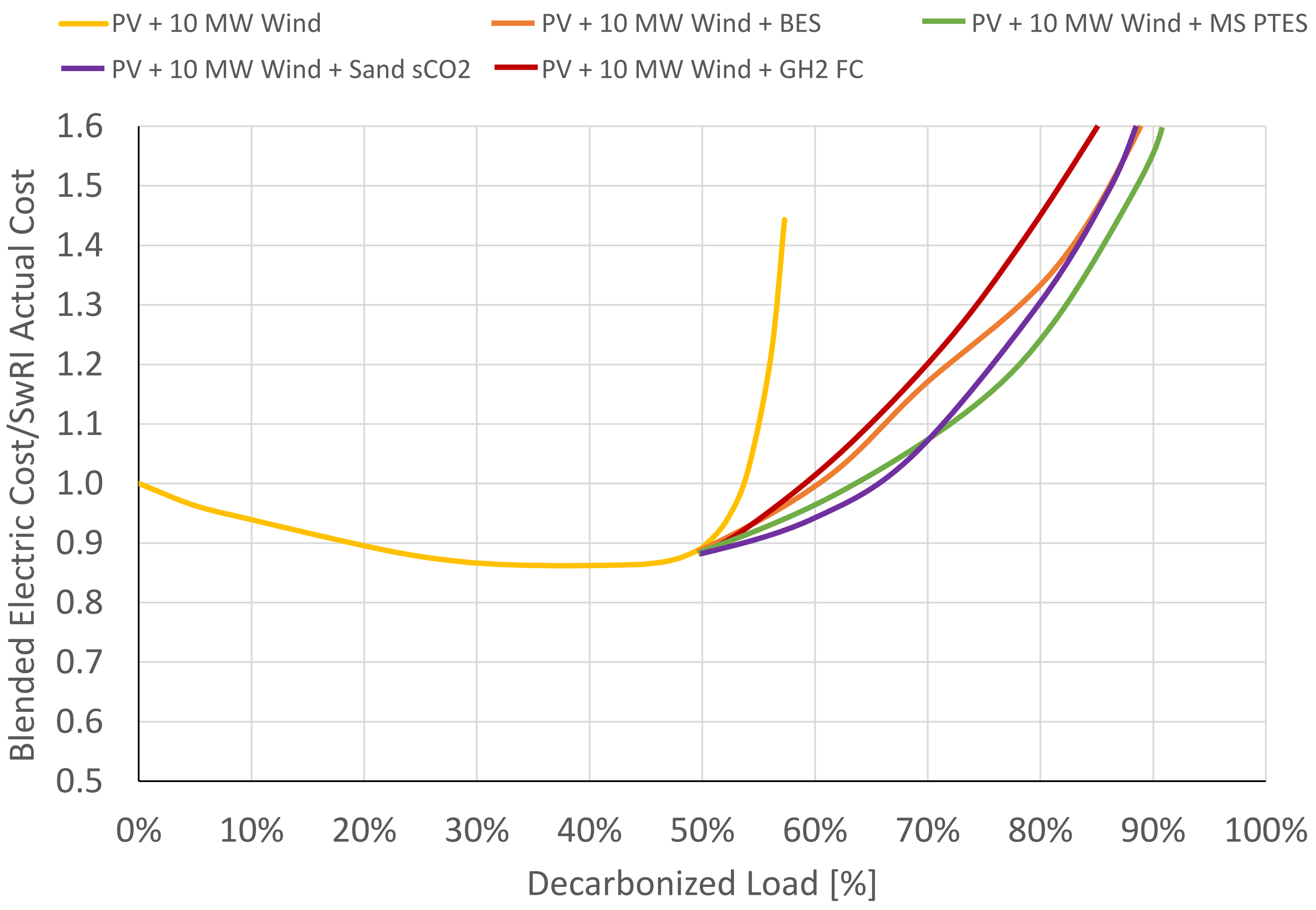
Analysis Results for Hydrogen and LAES

- LAES showed higher cost than thermal or hydrogen
- GH2 with fuel cell performs better
  - Reaches 85% decarb at 1.6 times the current electric costs
- Previous work considered combustion of hydrogen
  - RTE was worse, driving up cost
  - Primary driver of cost and low performance is electrolyzers



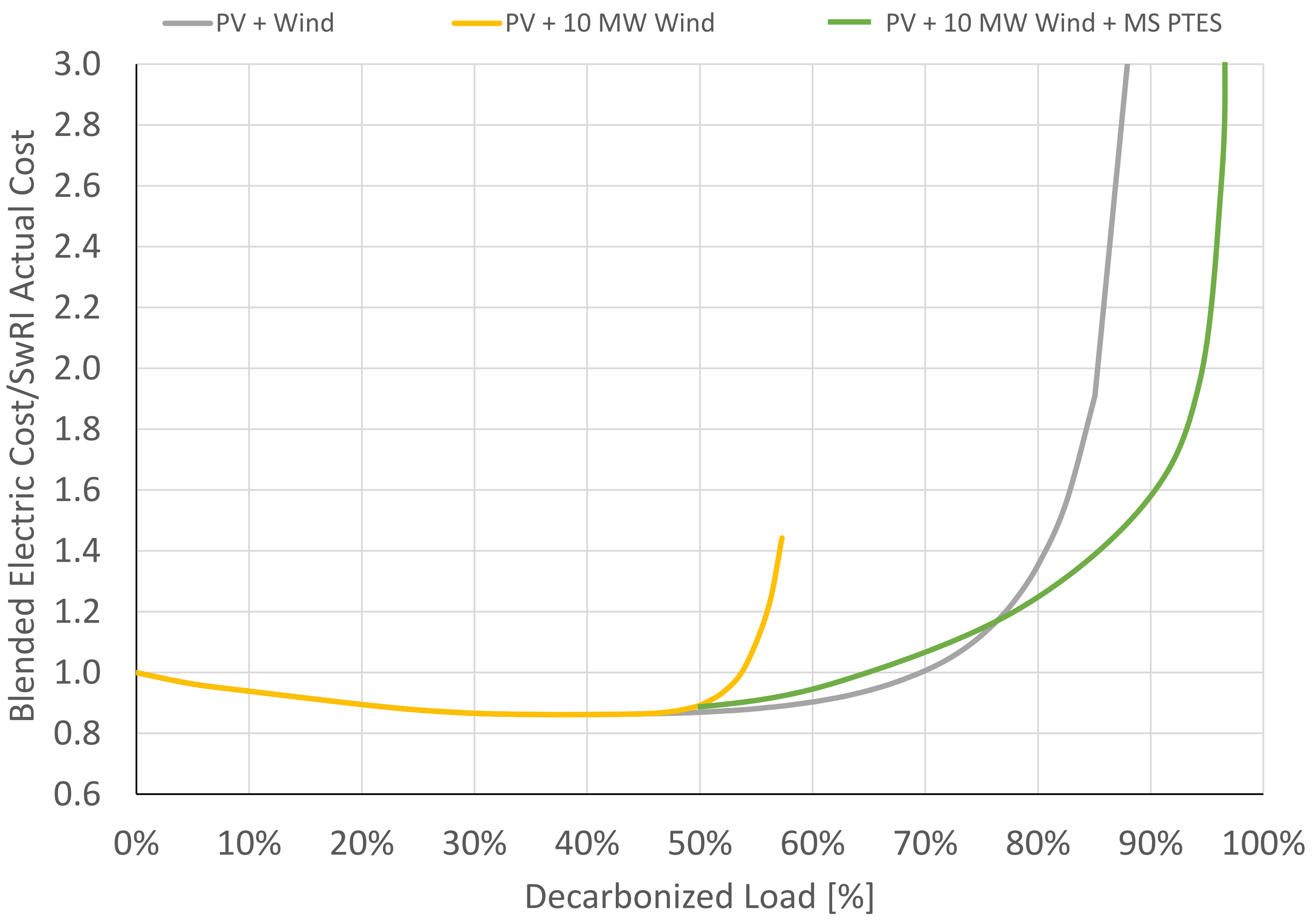
Analysis Results for Select Storage Systems

- Costs of unrestricted PV+Wind still grows quickly past 80% decarb
- BES starts similar to hydrogen at smaller sizes, but ends up closer to Sand+SCO2
- MS PTES is best storage from a cost perspective
  - Other LDES should seek ways to improve RTE above 50%



The Cost of Large Systems

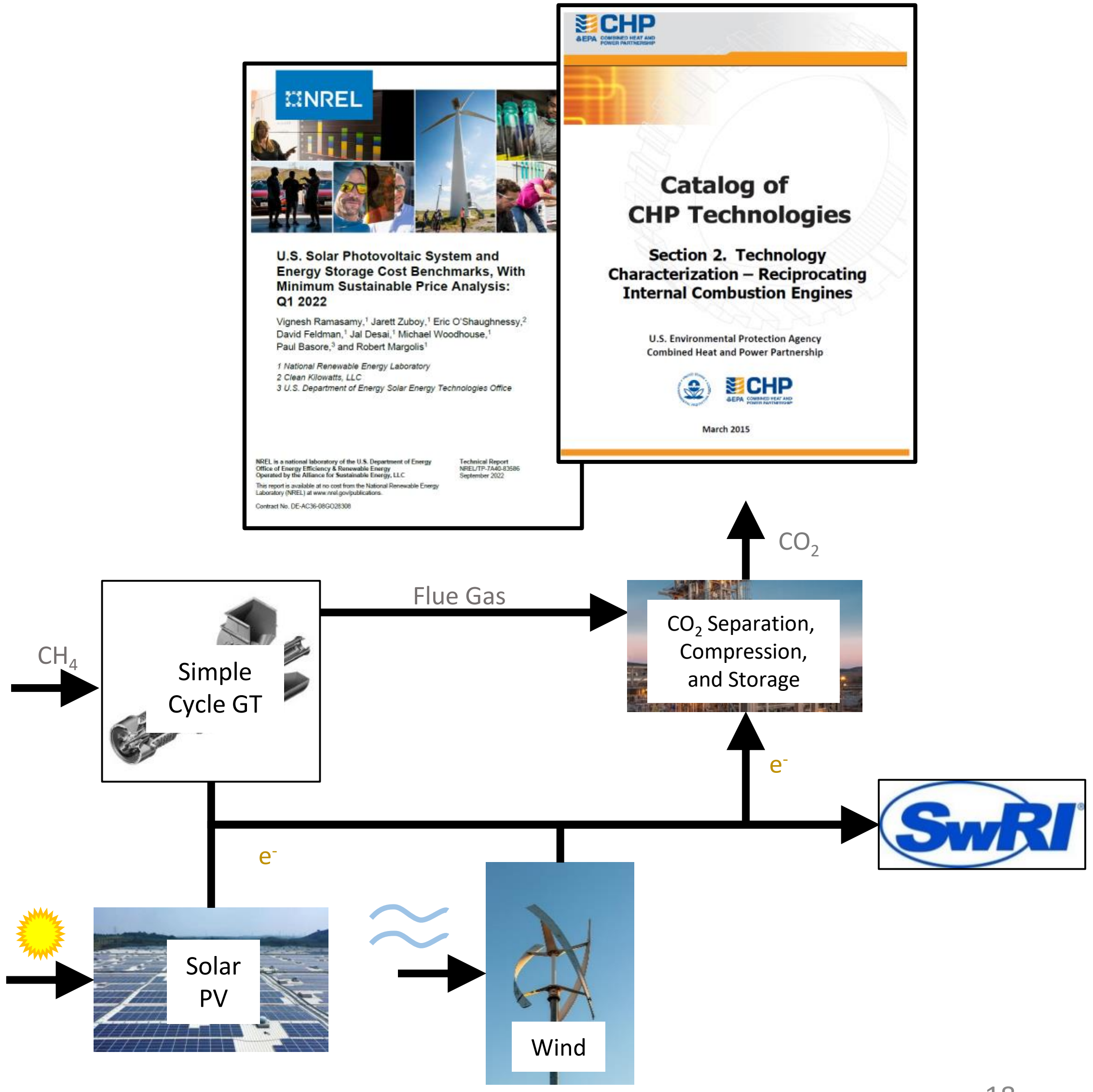
- Changing y-axis of cost scaling to 3x current costs
- Costs increase asymptotically with or without storage
- Best performing storage can't bridge the last 3% of decarbonization



Gas Generator with Carbon Capture

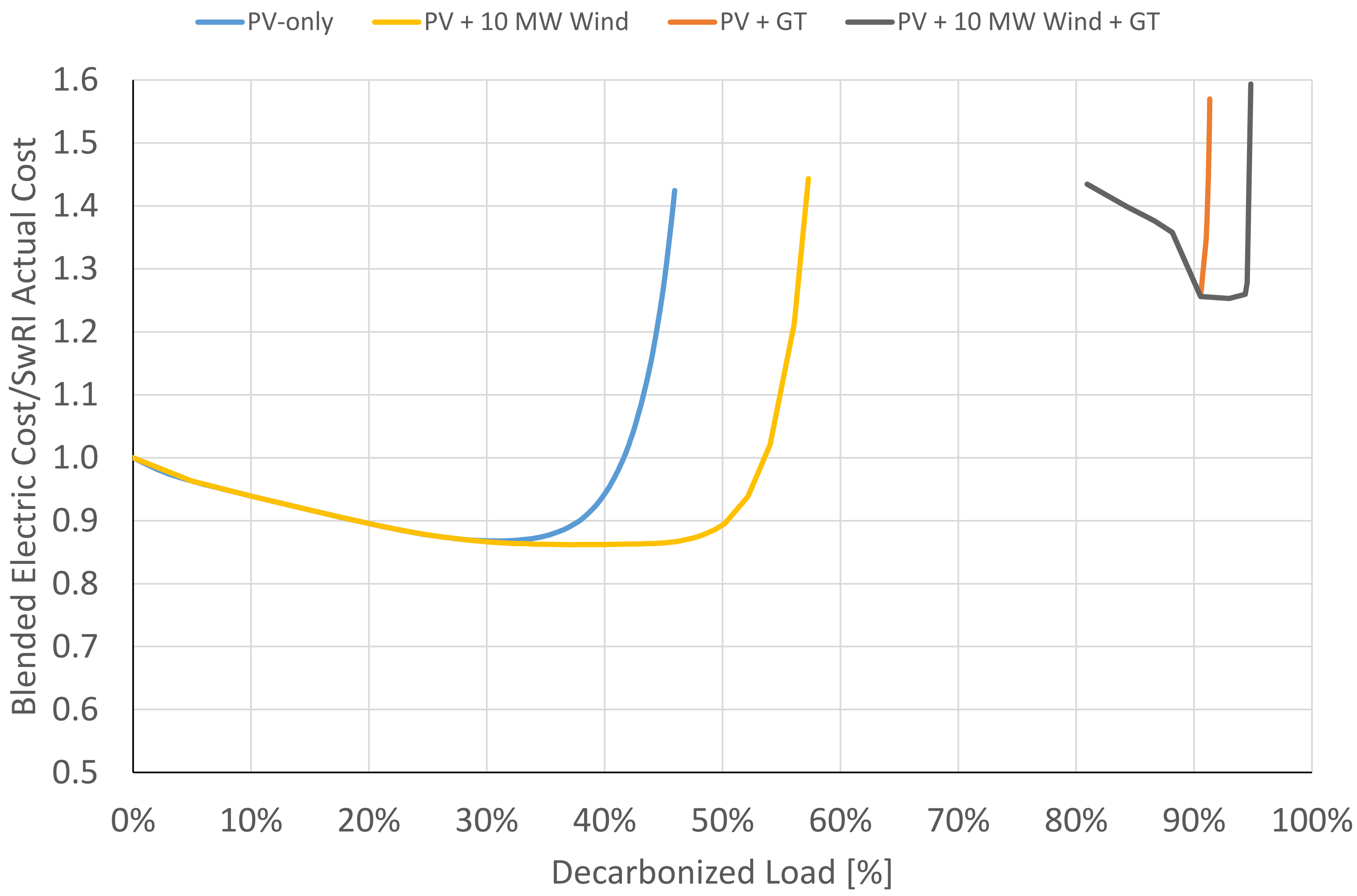
- Add carbon capture and storage (CCS) to improve decarbonization of a gas turbine (GT)
- Gas costs based on SwRI utility gas costs
- Cost and performance from internal estimate
  - High TRL amine plant
  - 95% of CO2 produced by the GT is captured
  - Promising cryogenic CCS technologies could achieve this
- Capture tax credits not added as revenue because disposal costs are not known and may offset credits

	Gas Turbine	Carbon Capture and Storage
CAPEX ($\$$/kW-AC$_{GT}$)	1,079	1,518
Non-Fuel OPEX ($\$$/kW-yr$_{GT}$)	30.7	81.5



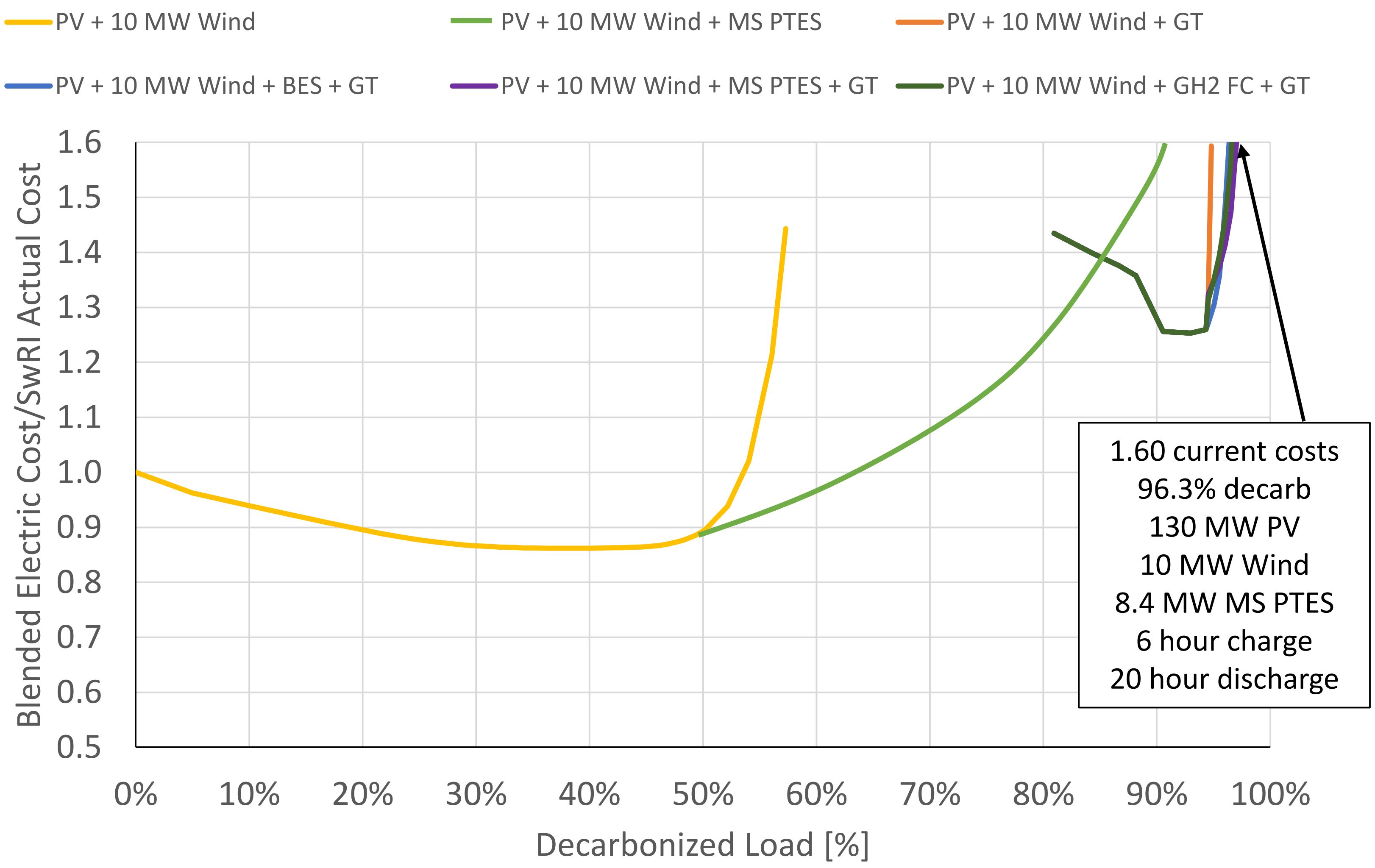
Analysis Results for Renewable with GT+CCS

- Adding GT with CCS to balance renewables
- Would need to ramp up and down with renewables
  - May require an hour of storage to allow ramping
- A mix of renewables improves cost and decarbonization



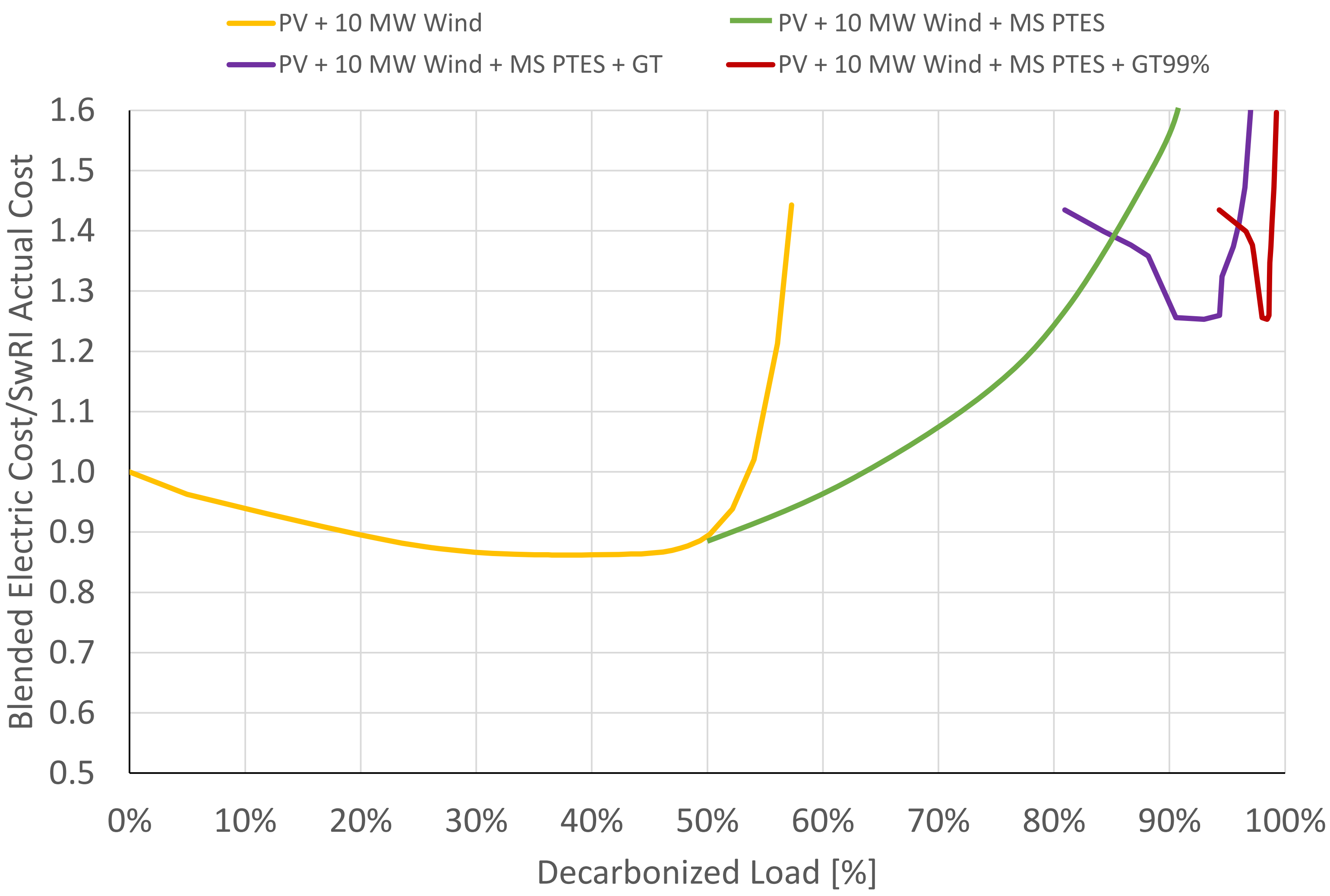
Analysis Results for Mixed Systems

- Little differentiation in storage systems
- Lower power requirement on storage discharge
- True closed microgrid achieved at 1.6x current costs



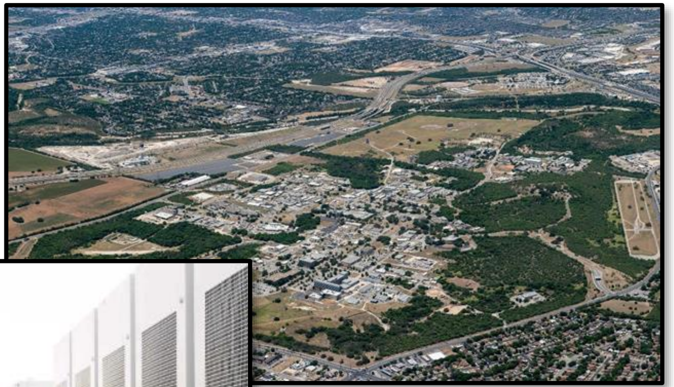
Pushing Decarbonization to Net-Zero

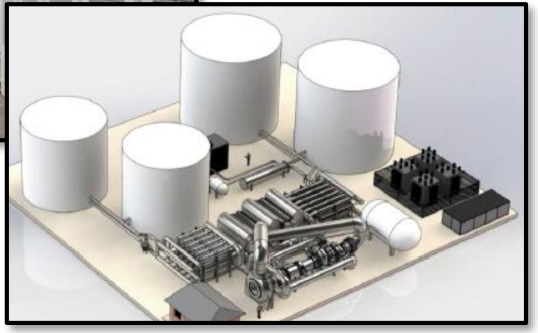
- CCS should be pushed to 99%+ to be true net-zero system
  - Air-breathing generator CO2 intake can be balanced with emissions
  - Gas turbine with 99.5%+ capture efficiency is net neutral
- 99.5% capture at low cost is a critical need
  - Cryogenic CCS may provide a solution



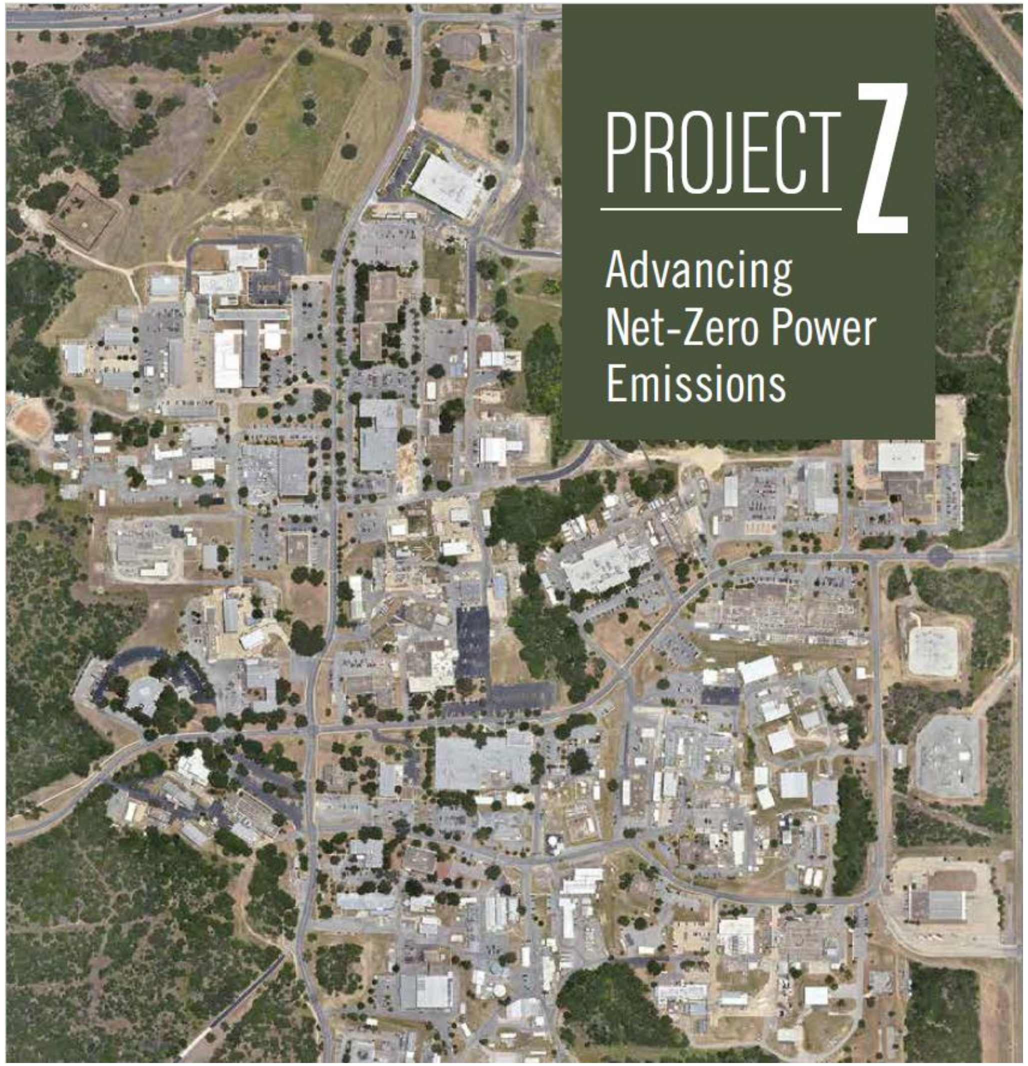
Conclusion

- A diverse set of technologies is required to achieve net-zero decarbonization
  - Renewable generation
  - Low-cost long duration energy storage
  - Decarbonized dispatchable generators
- The analysis of the SwRI microgrid reveals broader trends in decarbonization
  - SwRI is a good fit for testing storage technologies of the future
  - Mixing technologies allows for full decarbonization without dramatic cost escalation
- A roadmap to decarbonization is realistic, achievable, and considers the impact to the grid as technologies are added





Questions?



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