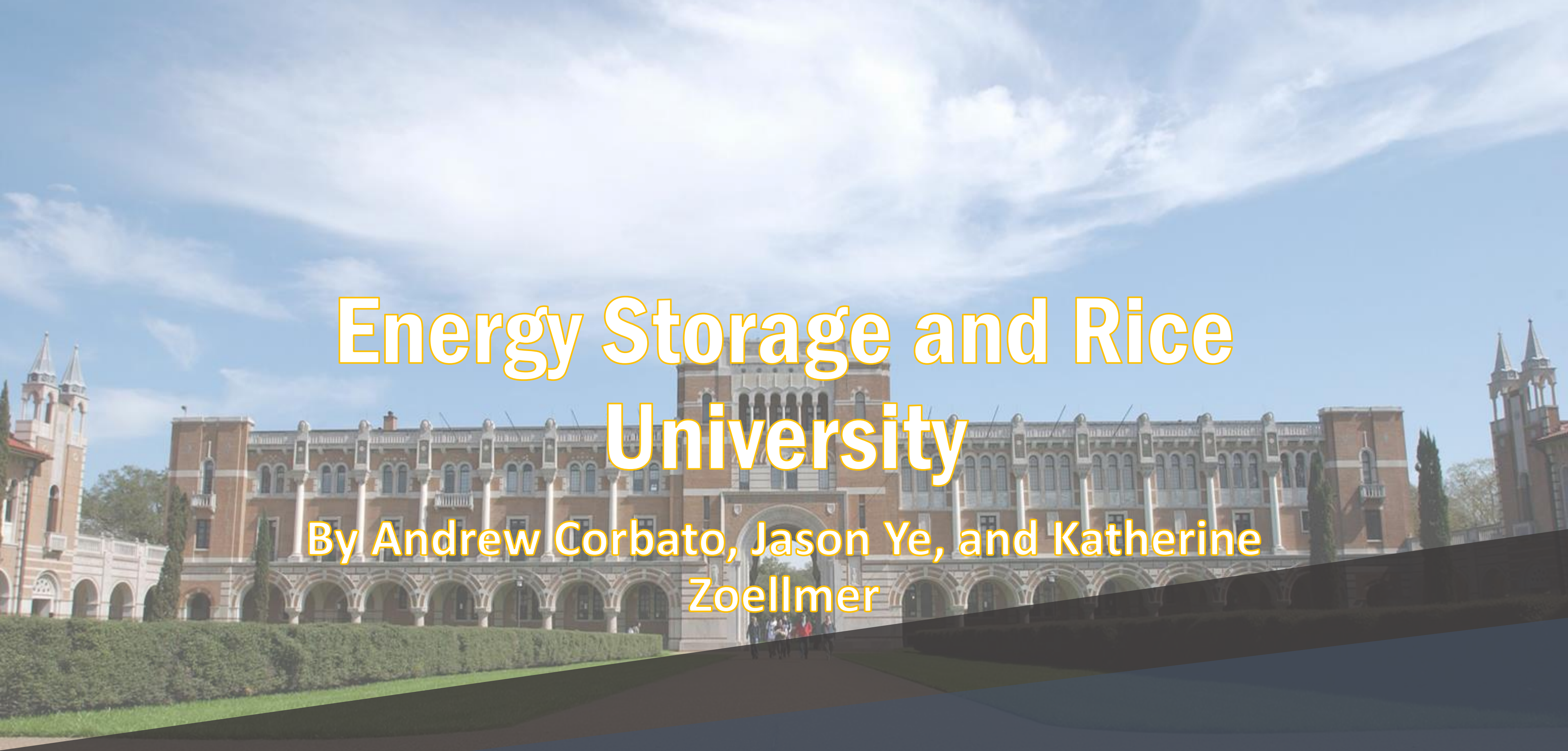


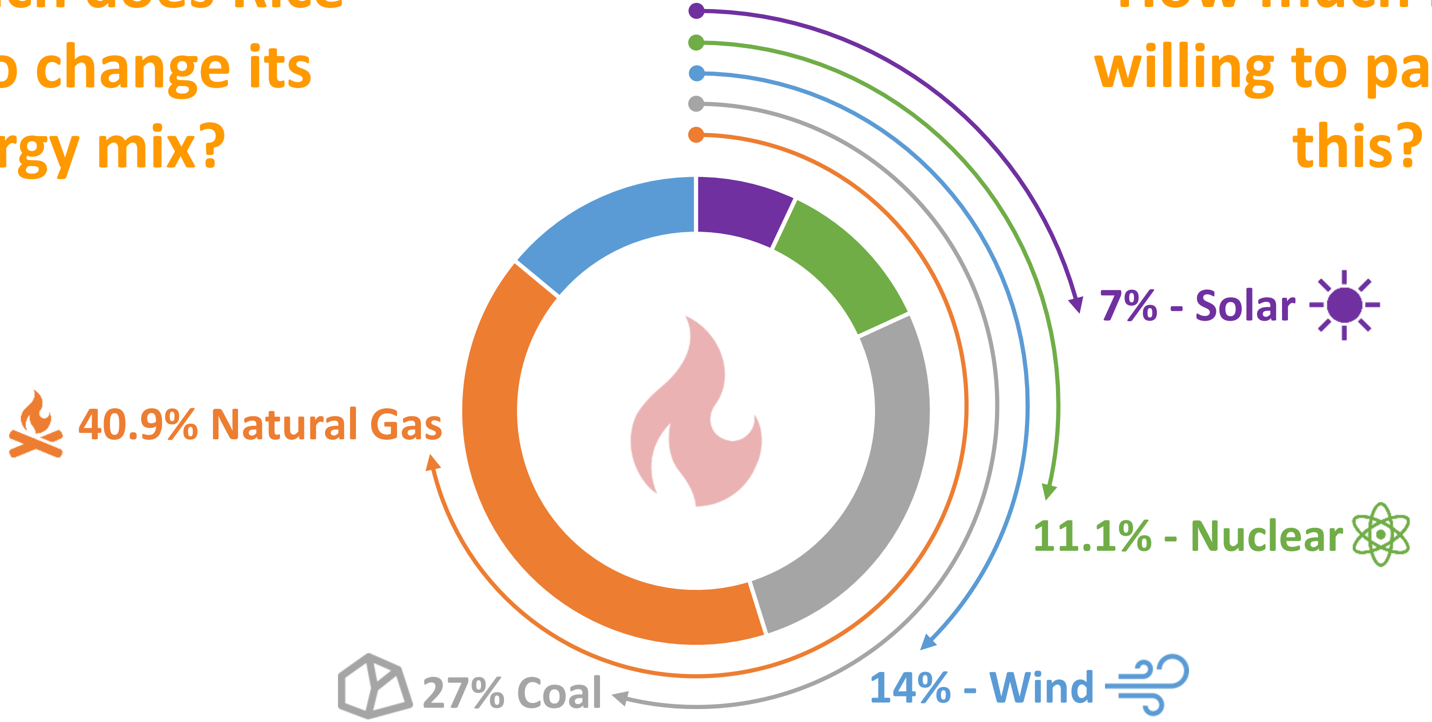
Energy Storage and Rice University

By Andrew Corbato, Jason Ye, and Katherine Zoellmer

Rice's Current Electricity Portfolio

How much does Rice want to change its energy mix?

How much is Rice willing to pay to do this?



Rice’s Past Energy Decisions

Market Interactior
Consumer and Pro

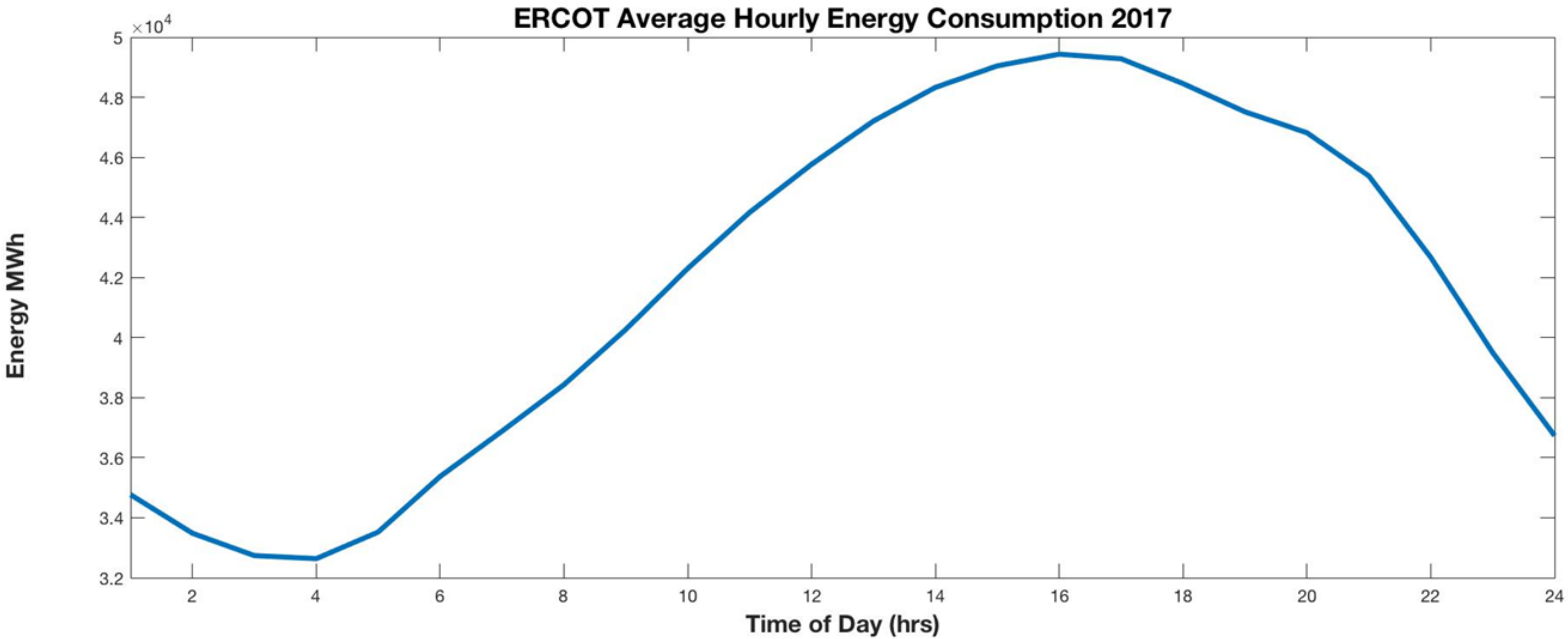
Variable Pricing - N

Takeaway: Rice is willing to spend on sustainability, but the price must match the benefits

On/Off Campus Solar Arrays

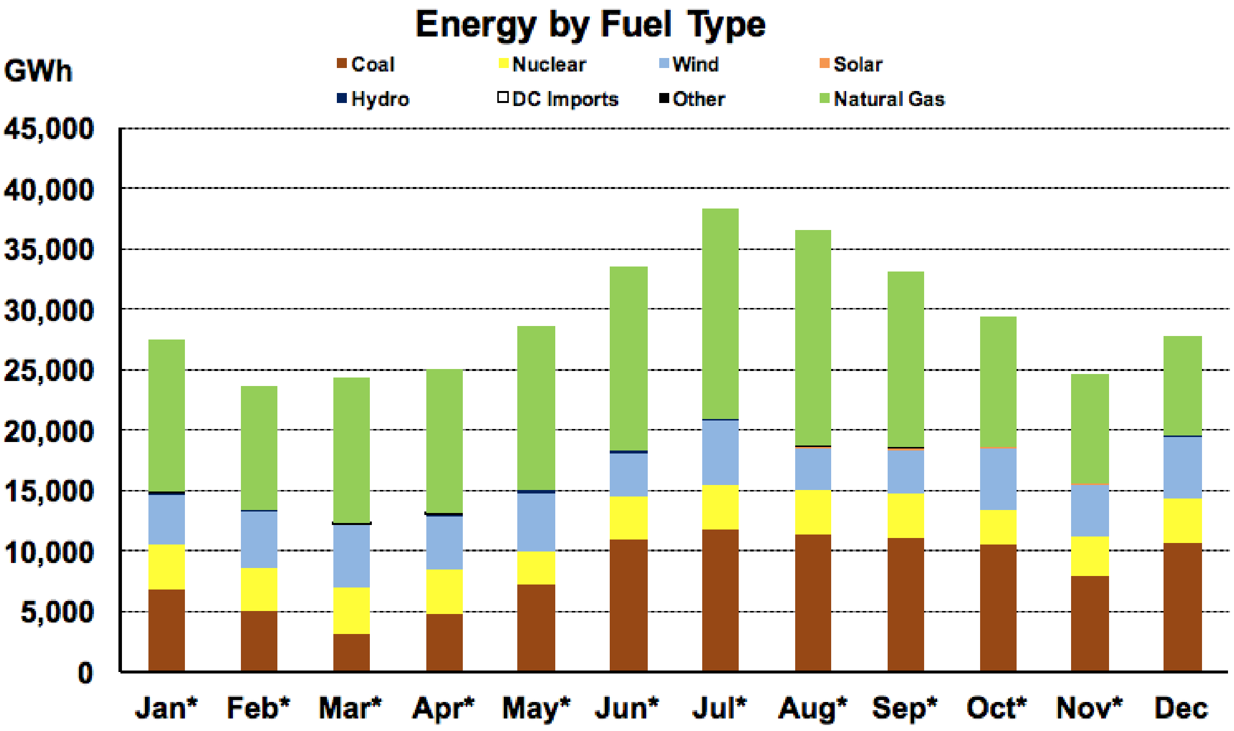
American College and University Presidents Climate Committee Signee

The Texas Power Story: Demand



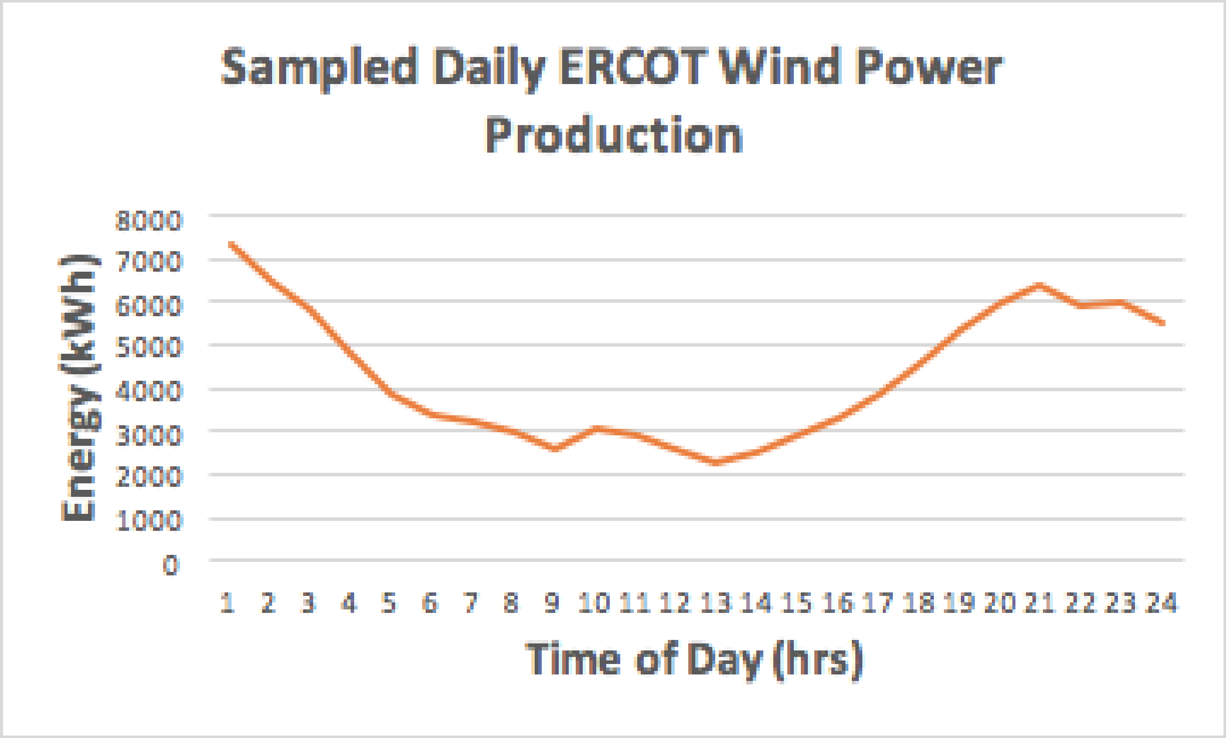
Data Courtesy of ERCOT

The Texas Power Story: Supply



Data Courtesy of ERCOT

The Texas Power Story: Wind



Data Courtesy of ERCOT

The Missing Link: Energy Storage

5 Improved Selling Power

Improve selling power position due to enhanced flexibility with excess power

4 Increased Responsiveness

Increase responsiveness to power outages and power blips including third party disruptions

3 Operational Cost Savings

Reduce and lower operational costs

2 Peak Demand Shifting

Alleviate peak demand by shifting demand to off-peak times

1 Price Capitalization

Capitalize on variable energy prices i.e. cheap wind power at night to lower costs

Energy Storage Options for Rice

Battery Storage

Electricity Storage

Thermal Storage

Air Conditioning

Battery Storage: Lithium-Ion

https://financialtribune.com/articles/energy/74284/world-power-storage-capacity-to-rise-threefold-by-2030

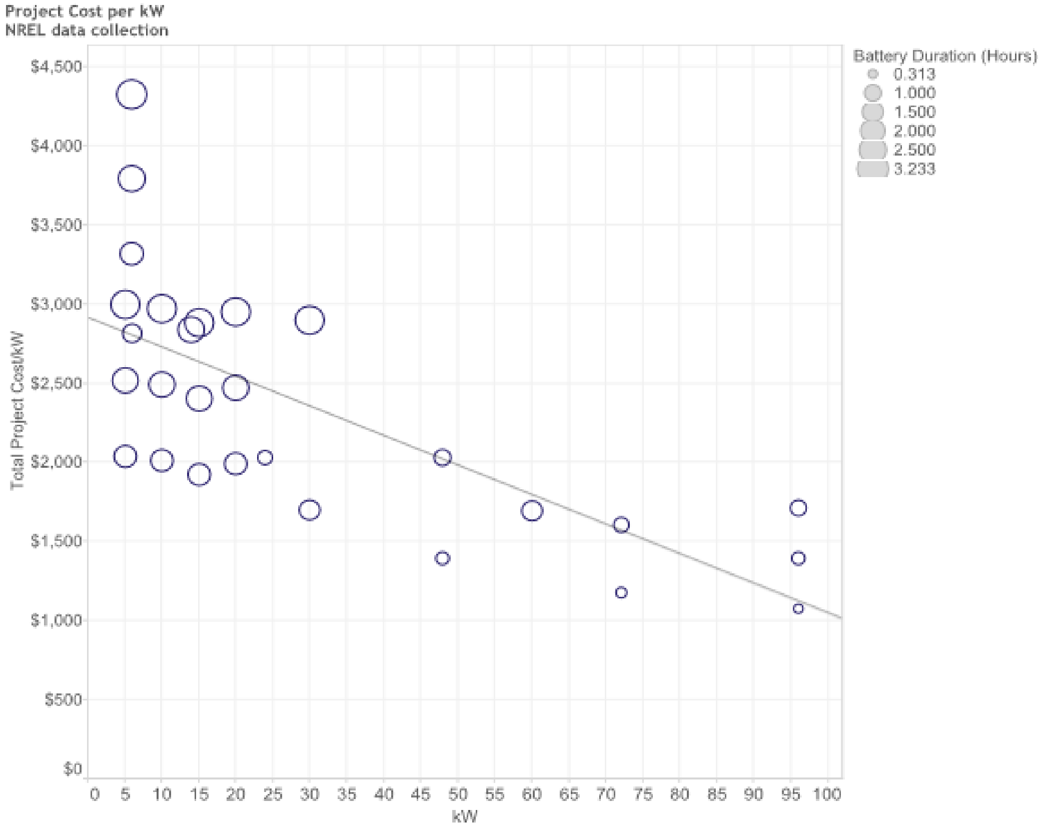
- Vary in size to fit residential and commercial needs
- Flexible, can quickly react to changes in the grid
- Average total project cost: $2,338/kW
  - Average Power Rating: 30 kW
  - Average Energy Rating: 37 kWh
  - Average Duration: 1.9 hours
- Cost of commercial size 500 kW/1000 kWh: $883,427

Energy Storage (Battery) Comparables

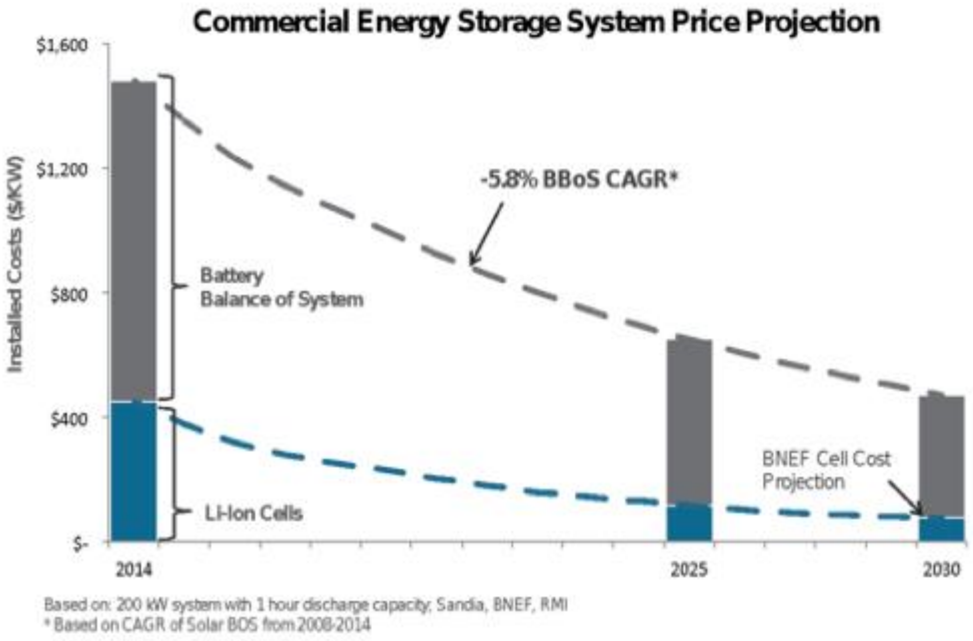
Demo Case	Cost (Upfront)	Capacity (kw)	kwH	Cost per KW	Cost per kwH	Notes
UCSD		2500	5000			
UBC		1000	1000			
SUNY	$3,000,000.00	500	2000	$6,000	$1,500	
Cal State		1000	6000			Tesla Powerpacks
Carnegie Mellon	$1,040,000.00					
Clemson		50	160			
NREL Benchmark	$883,427.00	500	1000	$1,767	$883	
NREL Average	$55,282.00	30.7	37.1	$1,800.72	$1,490.08	
NREL Minimum	$10,200.00	0.3	8			
NREL Maximum	$164,131.00	96	90	$1,709.70	$1,823.68	
Tesla Megafarm	$100,000,000.00		80000		$1,250.00	
Mean	$858,840.00	630.7777778	9529.51	**$2,819.32**	**$1,424.30**	
Median	$523,779.00	500	1000	**$1,783.79**	**$1,495.04**	

Median $1783.79 cost per kW and Median $1495.04 cost per kWh

Lithium-Ion Battery Cost



Lithium-Ion Future Cost Projections



Source: Energy Storage Association (2015)

Lithium-Ion Battery Storage on Campuses

- UC San Diego:
  - 2.5 MW, 5 MWh
  - Incorporated into their microgrid
  - Uses no heavy metals or toxic electrolytes
- Randolph-Macon College
  - Integrated solar and battery system
  - Installing 265 solar panels for 50 kW of electricity
  - Currently testing two options for battery storage
- Clemson University
  - 50 kW, 160 kWh

Battery Storage in Texas

- No tariffs or retail charges on power used to charge battery
- Eligible for Texas Emission Reduction Plan Grants

- Treated as generator when selling back into grid

Thermal Energy Storage

https://cleantechnica.com/files/2016/02/Crescent-Dunes-1.1-GW-hour-storage-capability-is-almost-40-times-the-size-of-the-largest-battery-storage-project-in-construction-or-built-to-date..jpg

- **Sensible Heat Storage:** heat is stored in a liquid or solid medium
- **Latent Heat Storage:** where the storage medium changes phase
- **Thermo-Chemical Storage:** pairs chemical reactions with heat storage

Sensible Heat Storage: Chilled Water

http://www.tmc.edu/news/2017/06/powering-the-tmc/

- Chilled water during the daytime is used for air conditioning
- Water chilled at night stored in a TES tank when electricity prices are lowest
- Shift in demand time allows the grid to use more renewables
- Optimizes Combined Heating and Power Turbines, such as Rice's Cogeneration Turbines

Chilled Water Storage On-Campus

UCF (2010)

- Shifts 2MW of peak cooling to non-peak times
- $320k/yr savings

USC (2013)

- 400MWh energy savings from increased system flexibility
- $400k/yr savings

https://www.dntanks.com/projects/the-university-of-central-floridas-tes-tank/

http://facilities.usc.edu/leftsidebar.asp?ItemID=462

Combined Chilled Water & Seasonal Cold Storage

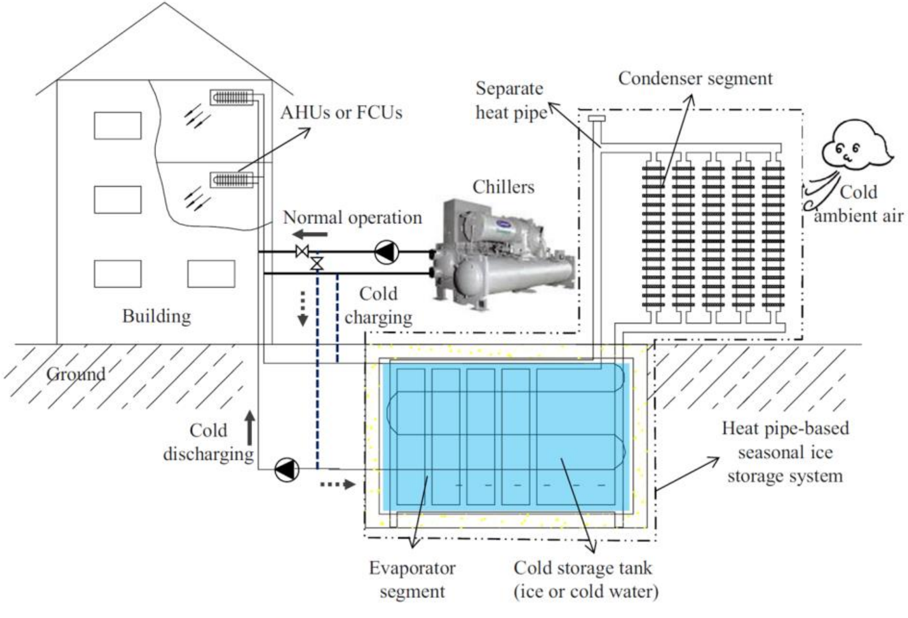


Fig. 1. Schematic of the compound cold storage system.

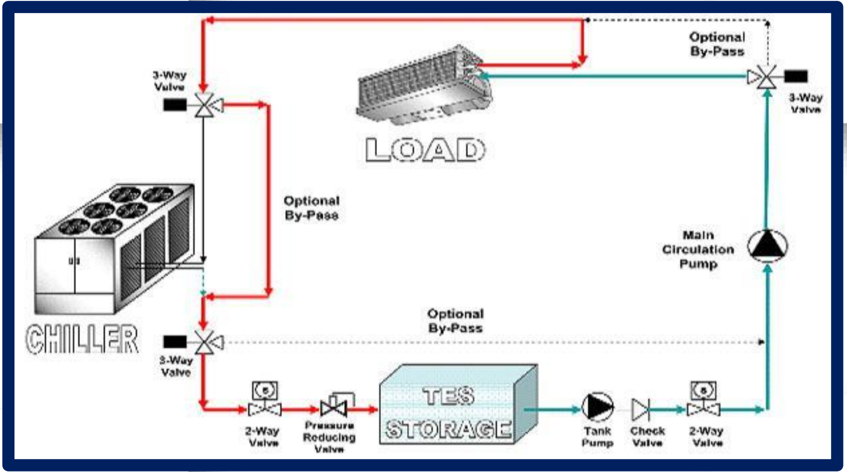
Yang et al (2015)

- Natural cold energy is extracted from the air in the winter, condensing into water and then ice
- Melting, collected ice is then used as chilled water for air conditioning
- Water is then re-used as medium for chilled water storage
- Bypasses portion of cost of electricity to chill water, reducing long-term costs
- Reduces storage capacity needed for utilization in small-scale buildings

Chilled Water Cost Considerations: Components

Water Tank Construction

Pumps



Centrifugal Chillers (Compressors)

Piping

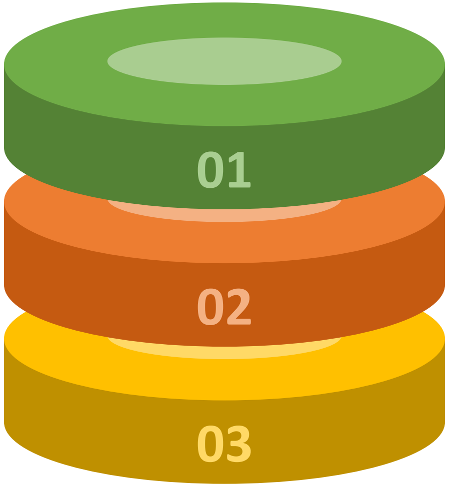
Storage at Rice: Benefits

Both Battery and Thermal

- Optimizes electricity market interaction
- Takes advantage of cheap Texas wind prices
- Operational flexibility with cogeneration facility

Battery

- Pairs nicely with on-campus solar generation
- Incentives from ERCOT/GOV



Thermal

- Low maintenance costs
- Option to transition from cogeneration

Future Trends

Energy storage market expected to grow to $2.5bn — $2.5bn

Average installation size of 40 gigawatts by 2020 — 40gW

Component cost reduction to $120 per kW — $120pkW

Energy storage market is predicted to 47% for 2017 — 284%

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