# TECHNO-ECONOMIC ANALYSIS OF RENEWABLE ENERGY GENERATION AT THE SOUTH POLE

Photo credit: A. Chokshi

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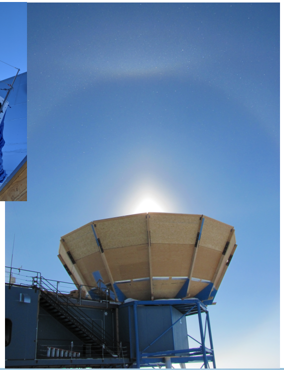
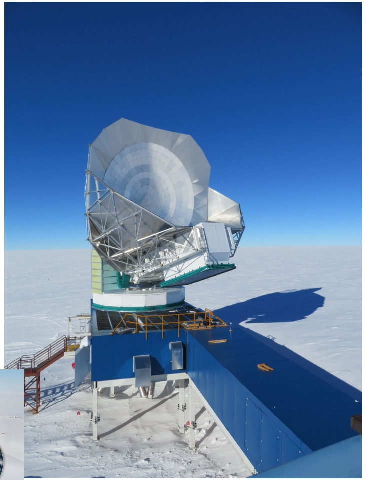
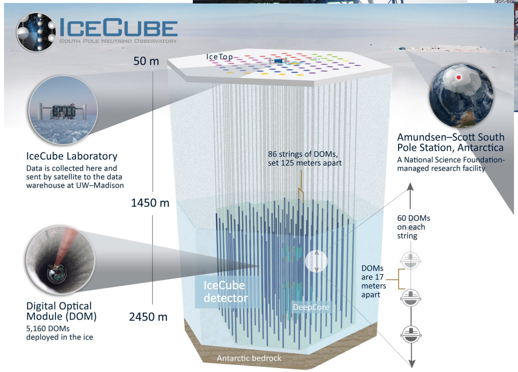
# HEP EXPERIMENTS AT THE SOUTH POLE

- The unique conditions at the South Pole enable HEP experiments
  - Cosmic microwave background (SPT-3G, BICEP Array)
  - Cosmic neutrino detection (IceCube, ARA)
- Electrical power is generated by traditional diesel generators that support the entire station (~600kW)
  - Fuel transport is costly and complex
  - Environmental stewardship is a key part of the Antarctic Treaty

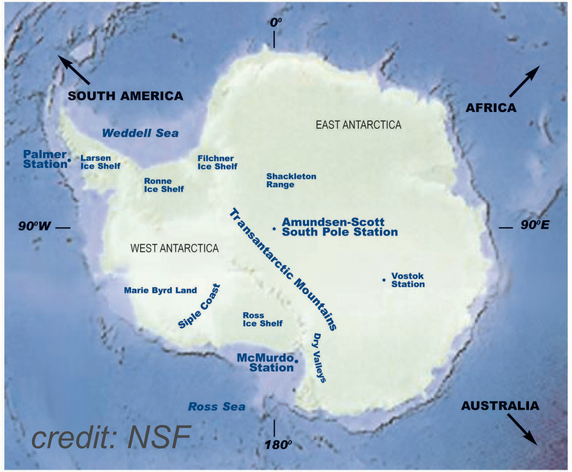






# SOUTH POLE CHALLENGES

- Sun is continuously above the horizon Sept 21 – March 21,  continuously below the horizon remainder of the year
- Temperatures as low a -80 ℃ in winter
- Transportation of personnel & equipment to the South Pole is through a combination of aircraft and overland traverse
- South Pole station is occupied year-round (~40 people in austral winter, 150 in austral summer)
  - Outdoor work occurs primarily during the short austral summer (Nov-early Feb)



credit: NSF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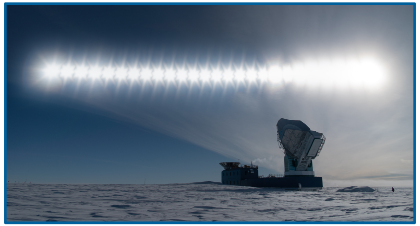
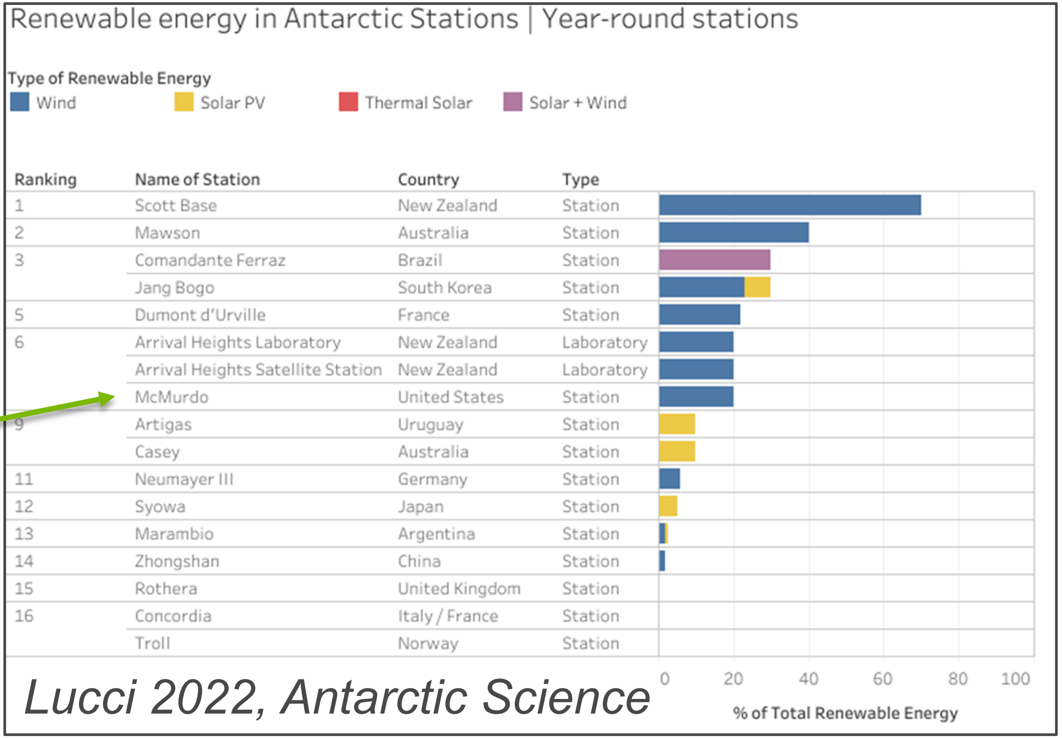


# RENEWABLE ENERGY IS ALREADY IN USE AT SOME ANTARCTIC STATIONS



Renewable energy in Antarctic Stations | Year-round stations

Type of Renewable Energy: Wind, Solar PV, Thermal Solar, Solar + Wind

| Ranking | Name of Station | Country | Type |
|---|---|---|---|
| 1 | Scott Base | New Zealand | Station |
| 2 | Mawson | Australia | Station |
| 3 | Comandante Ferraz | Brazil | Station |
| | Jang Bogo | South Korea | Station |
| 5 | Dumont d'Urville | France | Station |
| 6 | Arrival Heights Laboratory | New Zealand | Laboratory |
| | Arrival Heights Satellite Station | New Zealand | Laboratory |
| | McMurdo | United States | Station |
| 9 | Artigas | Uruguay | Station |
| | Casey | Australia | Station |
| 11 | Neumayer III | Germany | Station |
| 12 | Syowa | Japan | Station |
| 13 | Marambio | Argentina | Station |
| 14 | Zhongshan | China | Station |
| 15 | Rothera | United Kingdom | Station |
| 16 | Concordia | Italy / France | Station |
| | Troll | Norway | Station |

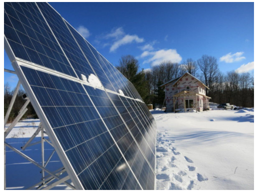


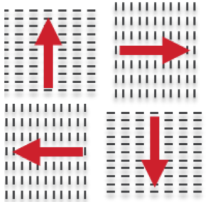
*Lucci 2022, Antarctic Science*



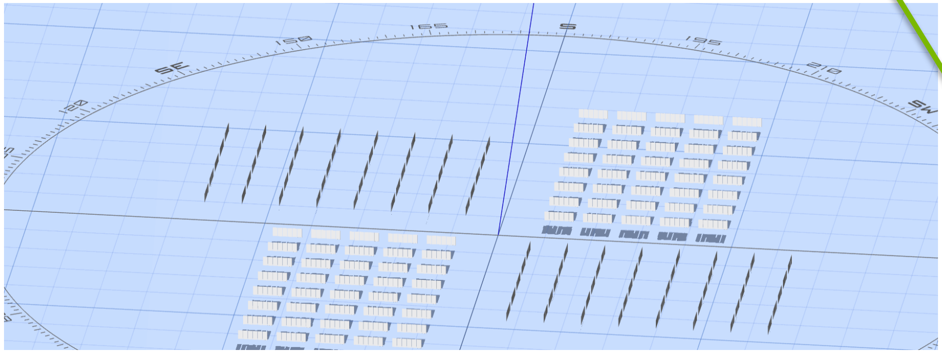
# ENERGY GENERATION RESOURCES: SOLAR

- NOAA data from the past decade is used to inform solar availability over the year
  - 2016 is an ‘average’ year used in this analysis
  - Polar longitude dictates unique panel configuration and power generation profile

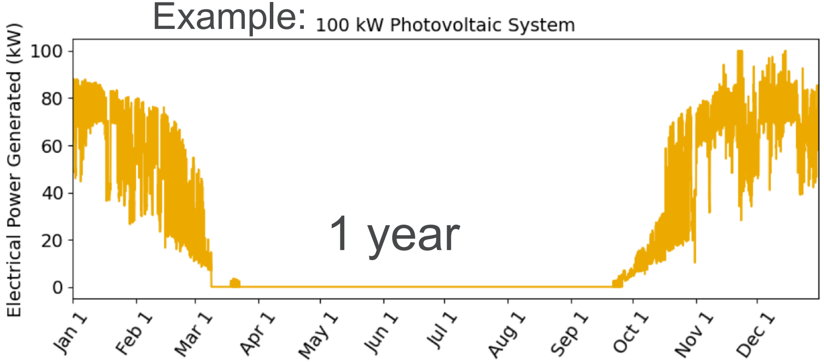


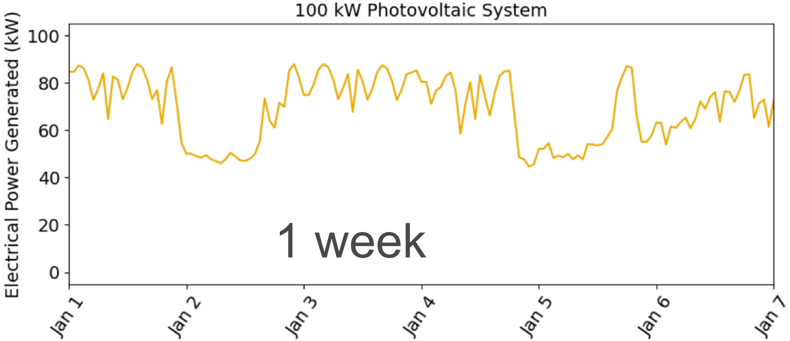


4 subarrays of bifacial vertical panels oriented facing
azimuth = 0, 90, 180, 270 degrees

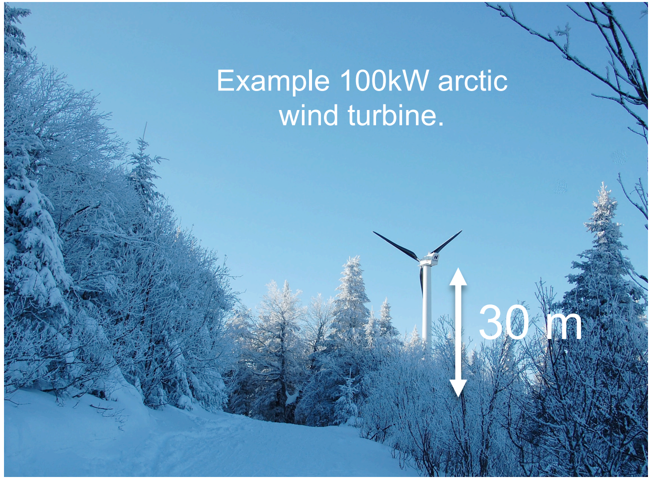


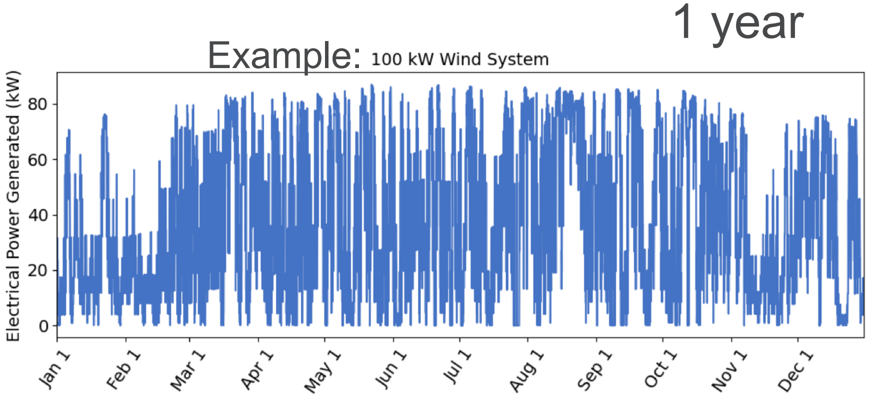

Example:

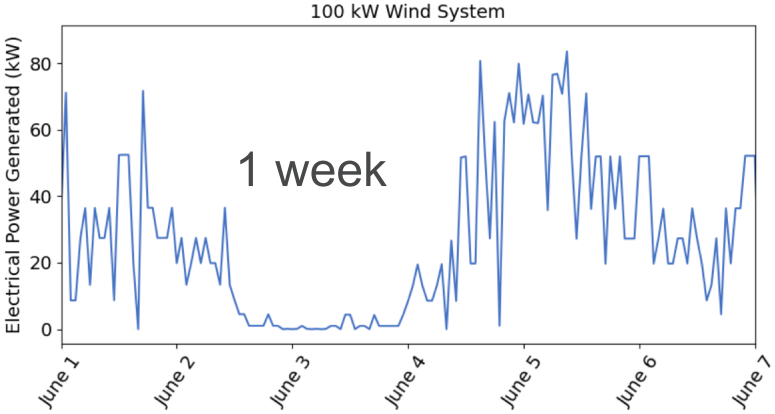


# ENERGY GENERATION RESOURCES: WIND



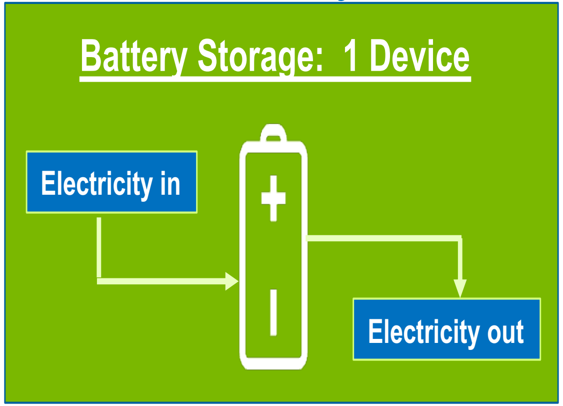




Assume turbine operates to -70ºC, below which it shuts down.

# ENERGY STORAGE OPTIONS

## $e^-$ in ⟺ $e^-$ out: Two basic approaches

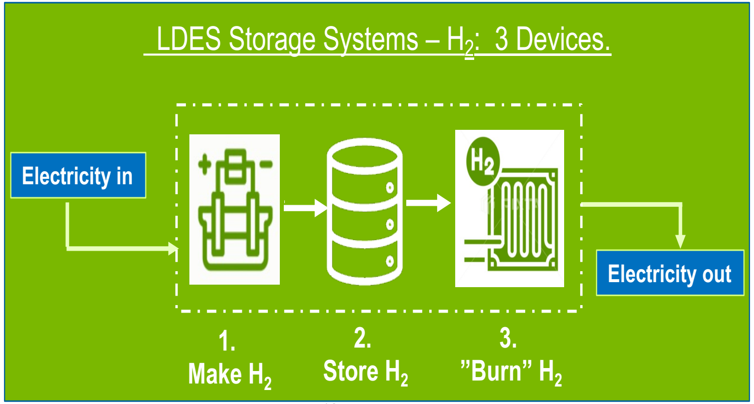
### ”Battery”




Shorter durations: 1 -100 hours

*Nonflammable Li-ion*
*Flow cells*
*Fe/air battery*
*MgMnOx (thermal)*
*Liquid metal battery*

### “Energy Storage System””

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Longer duration: 100 hours - ”seasonal”

*$H_2$ system*
*MeOH system*
*$NH_3$ system*

Shorter duration storage technologies have higher technical readiness levels

LDES = long duration energy storage

# COMMERICAL-GRADE TOOL, UNIQUE INPUTS

## Renewable Energy Integration & Optimization (REopt)

- REopt is a constrained optimization tool developed by NREL
  - **Advises on cost-effective way to meet energy needs given available resources**
  - REopt can answer different questions depending on the inputs & constraints applied
  - **Decades of development on this tool**
- Inputs:
  - Load requirements of application ( Example: **170 kW**)
  - Site specific renewable resource profiles (solar and wind)
  - Capital materials and labor estimates
  - Operations and maintenance cost estimates
  - **Site specific cost estimates (e.g., shipping cost to South Pole, fuel cost)**
  - Lifetime of system (Example: **15 years**)
- Outputs:
  - **Optimized sizing** of each component (solar, wind, storage)
  - **Upfront capital,** lifetime cost, net present value
  - ***Time to payback***

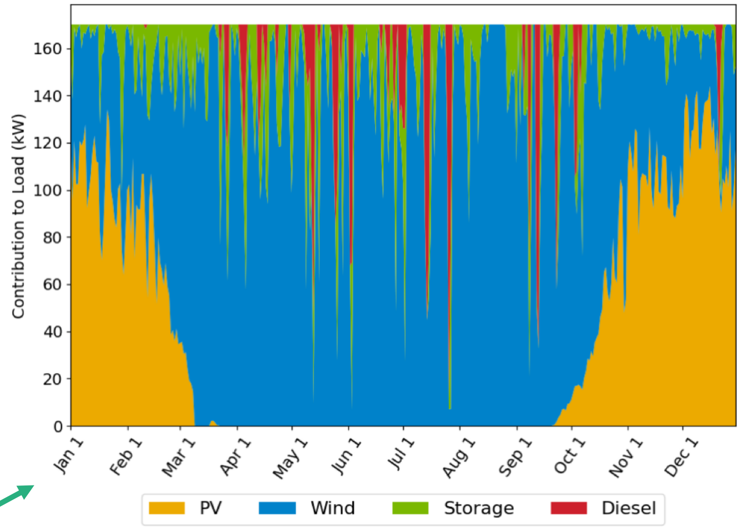
| **Combined expertise of the team evaluated many assumptions & inputs** |
|---|
| Solar panel geometry |
| Temperature rating of components vs cost |
| South Pole logistical constraints |
| Housing of batteries |
| Position & number of inverters for batteries |
| Battery round trip efficiency |
| Battery cycling approach & system sizing |

https://reopt.nrel.gov/

# SYSTEM CO-OPTIMIZATION

- Assumptions:
  - Example load = 170 kW
  - Example lifetime = 15 years
  - This is a representative example, these assumptions are flexible
- Multiple configurations of renewable technology evaluated for least-cost solution

| | DIESEL | SOLAR | WIND | Lithium-Ion | LDES |
|---|---|---|---|---|---|
| BAU | • | | | | |
| A | • | • | | • | |
| B | • | | • | • | |
| C | • | • | • | • | |
| D | | • | • | • | |
| E | • | • | • | | • |

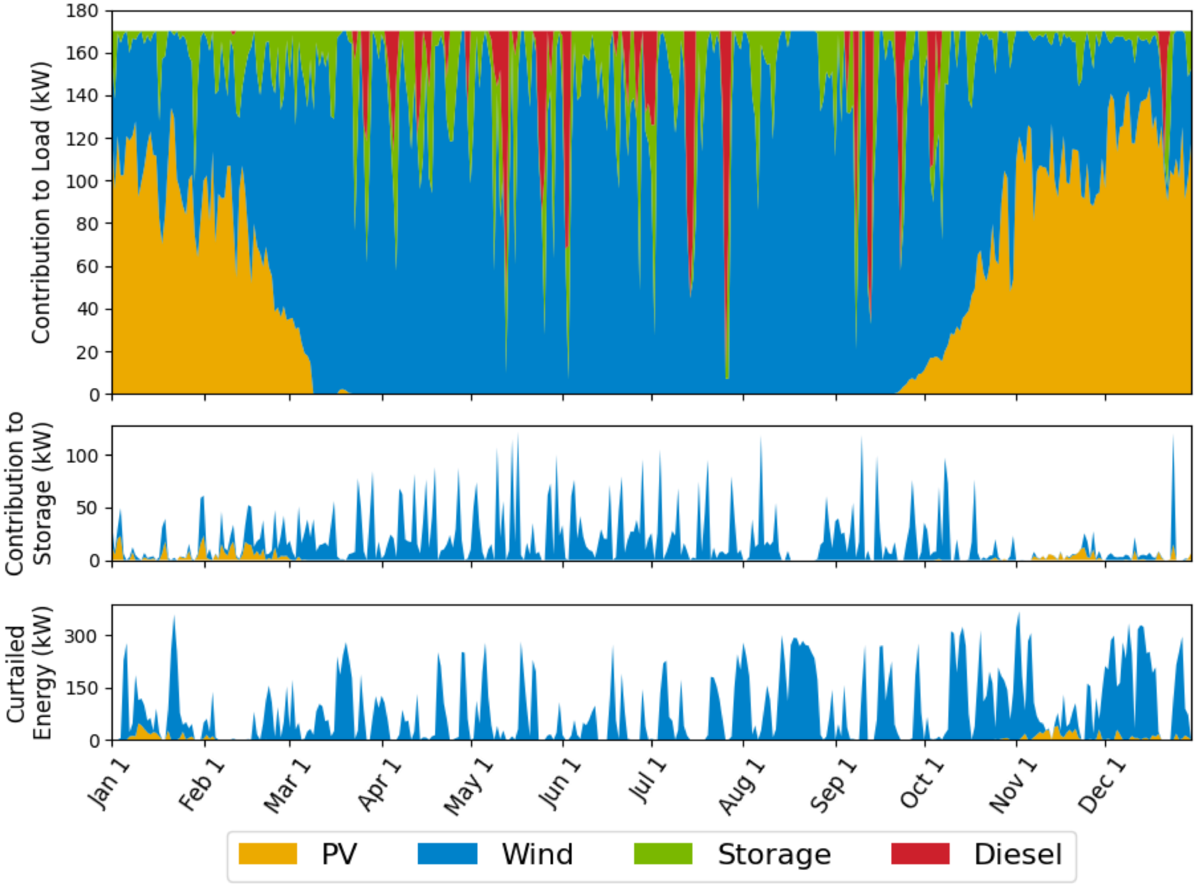



Example output from REopt shows how each technology meets the load requirement throughout the year for Scenario **C**.

# TOTAL ENERGY

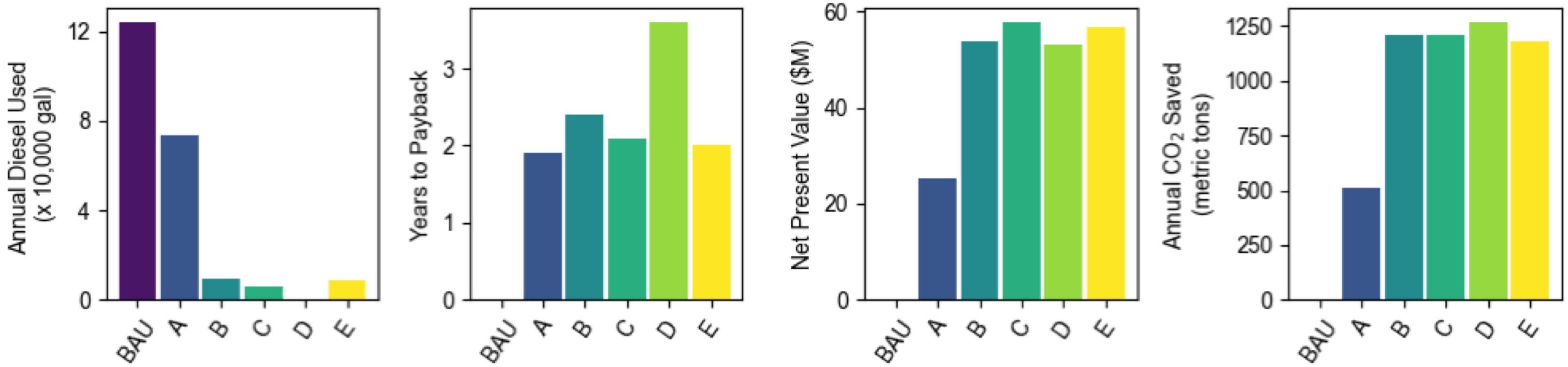
Power used to charge the energy storage

Optimization results in curtailed energy: Extra power that we could use or provide to another user (~0.8 GWh)



# COMPARATIVE RESULTS

| | DIESEL | SOLAR | WIND | Lithium-Ion | LDES |
|---|---|---|---|---|---|
| BAU | • | | | | |
| A | • | • | | • | |
| B | • | | • | • | |
| C | • | • | • | • | |
| D | | • | • | • | |
| E | • | • | • | | • |




- Diesel fuel reduction ranges from 40-100%
- All options have significant net present value (cost savings over life cycle)
- Additional configurations and constraints have been modeled to
  - characterize sensitivity to assumptions
  - determine payback at different system sizes
  - explore impact of LDES future projections

# SUMMARY

Babinec et al 2024, RSER

- Direct collaboration with renewable energy experts to perform quantitative analysis for renewable at the South Pole
- A significant reduction in diesel consumption is possible using mature renewable energy technology and energy storage
  - Directly translates into significant reductions in both carbon footprint and cost of operations
  - Time to pay back on initial investment ~2 years
- Future engineering developments have been identified
  - Snow drift modeling & mitigation; cold turbine development, ice foundation development, EMI/RFI & vibration impacts
- 'Alternative energy' is discussed in the recently released draft South Pole Master Plan
  - Link to South Pole Master Plan & Comment Instructions
  - Currently open for public comment

Frimannslund 2021