Argonne NATIONAL LABORATORY

NREL Transforming ENERGY

A RENEWABLE ENERGY FUTURE AT THE SOUTH POLE

Photo credit: A. Chokshi

SUSAN BABINEC (ARGONNE)
AMY BENDER (ARGONNE)
RALPH MUEHLEISEN (ARGONNE)
RIK YOSHIDA (ARGONNE)

IAN BARING-GOULD (NREL)
NATE BLAIR (NREL)
XIANGKUN LI (NREL)
DAN OLIS (NREL)
SILVANA OVAITT (NREL)

U.S. DEPARTMENT OF ENERGY

Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

CMB-S4 Collaboration Meeting: 2023-04-04

EXECUTIVE SUMMARY

- ***Outcome: Renewable systems provide significant decarbonization and operations cost savings compared to diesel-only at the South Pole***
  - Example: For a 170 kW load with a 15 year lifetime, a solar+wind+storage+diesel system can reduce diesel consumption by 95%, save $10s of millions, with a ~2 year payback
  - Broad concept with identified applications
  - Technology is mature, South Pole specific implementation requires some developments

- System-wide optimization advises on component sizing & economics
  - Renewable resource (solar, wind) availability modeled from NOAA data
  - Singular, detailed inputs and technical constraints incorporated for South Pole
  - Note: Specific implementation choices such as location of equipment are *deliberately not made*. We do include requirements to mitigate any impact on science quality of the site.
- Argonne & NREL collaboration brings unique expertise to this detailed assessment of renewable energy opportunity at the South Pole

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

0 20 40 60 80 100

% of Total Renewable Energy

Lucci 2022, Antarctic Science

EXPERT & EXPERIENCED TEAM

Argonne NATIONAL LABORATORY

NREL Transforming ENERGY

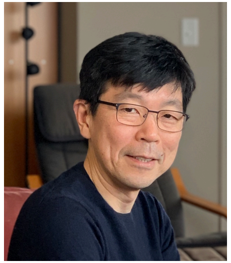
Susan Babinec
(energy storage)

Ralph Muehleisen
(solar modeling & system design)

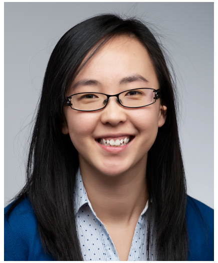
Nate Blair
(economics)

Ian Baring-Gould
(wind modeling)

Amy Bender
(CMB exp, S. Pole)



Rik Yoshida
(HEP experiments)



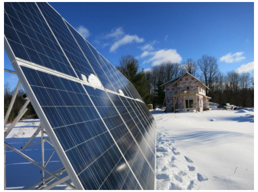
Xiangkun Li
(system optimization)

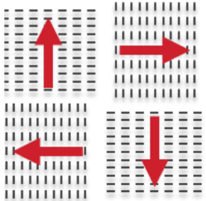
Dan Olis
(system optimization)

Silvana Ovaitt
(solar modeling)

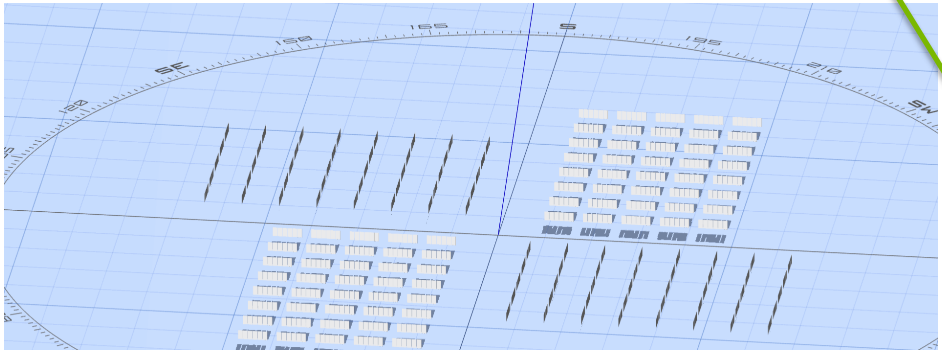
ENERGY GENERATION RESOURCES: SOLAR

- 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

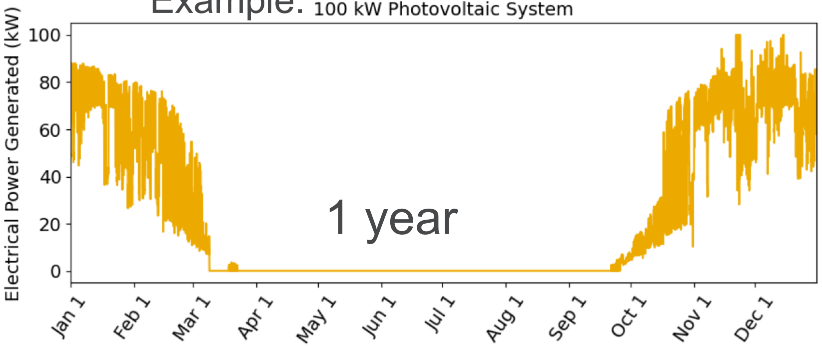


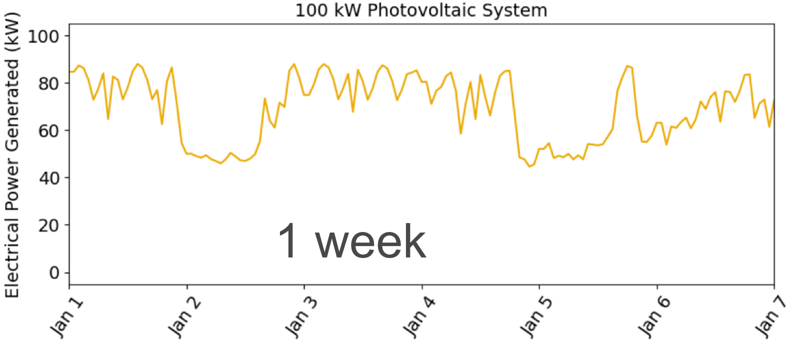


4 subarrays of bifacial vertical panels oriented facing
azimuth = 0, 90, 180, 270 degrees

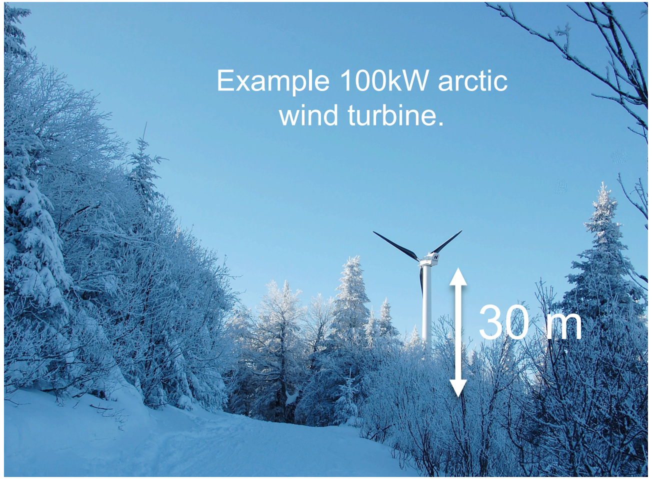


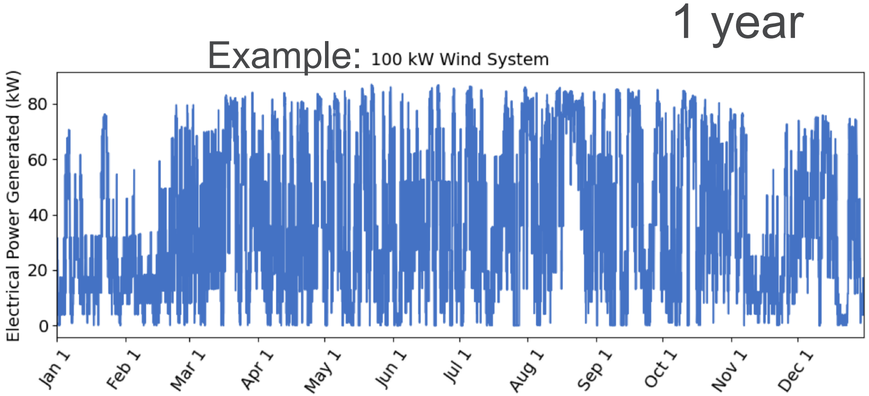
Example:

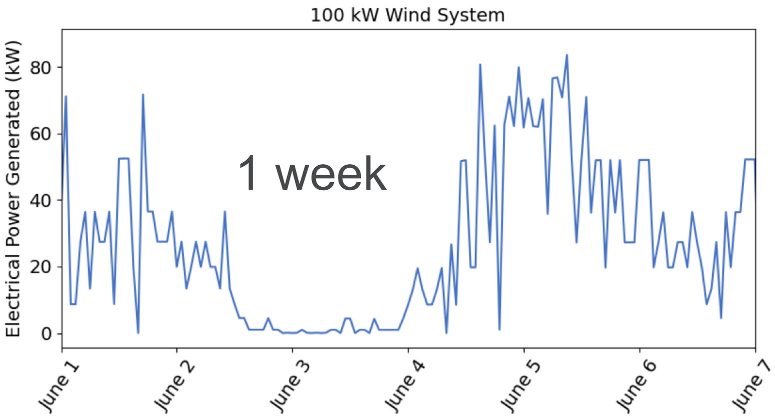




ENERGY GENERATION RESOURCES: WIND





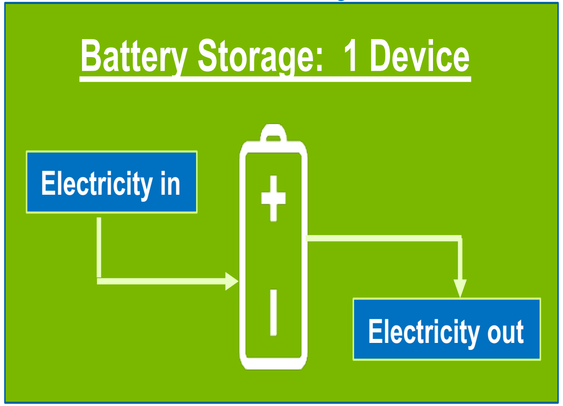


Assume turbine operates to -70ºC, below which it shuts down.

ENERGY STORAGE OPTIONS

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

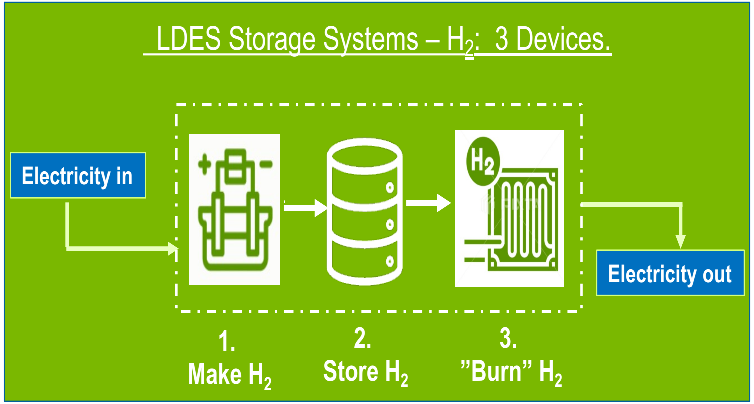
”Battery”



Shorter durations: 1 -100 hours

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

“Energy Storage System””



18

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/

CONFIGURATION OVERVIEW

Example load = 170 kW
Example lifetime = 15 years

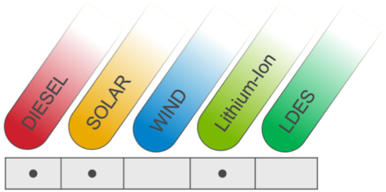
17 configurations have been run. These tell a clear story of the unique site constraints and the opportunity of RE.

	DIESEL	SOLAR	WIND	Lithium-Ion	LDES
Baseline Existing	●				
RE Configuration 1	●	●		●	
RE Configuration 2	●	●	●	●	
RE Configuration 3	●	●	●		●

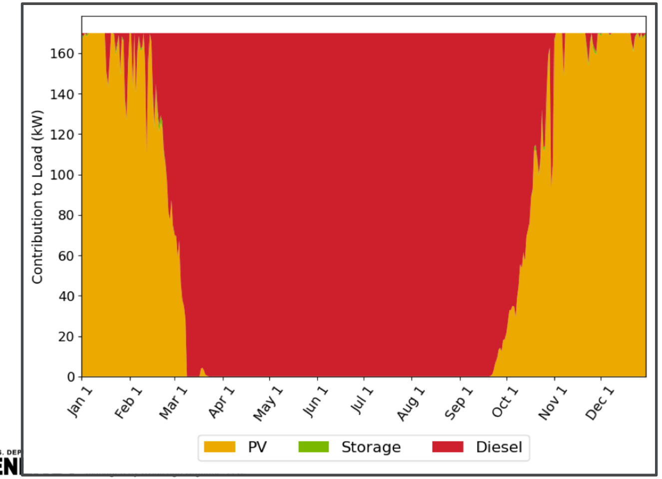
Configurations 1-3 all include diesel which REopt shows as beneficial.

RE = Renewable Energy

RE CONFIGURATION 1



- System size optimized for Nov 1 –Jan 31 period, then analysis expanded to full year solar collection at that size
- 98% less fuel consumed during austral summer optimization period; **36% reduction in diesel fuel consumed when full year considered**
- PV panels and Lithium-Ion batteries are mature, commercially available, low-risk technologies



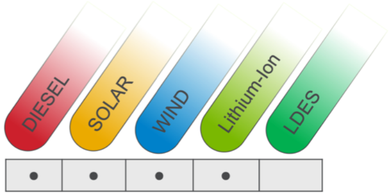
Upfront Capital	**$1.93 M**
% Diesel Reduction	36%
Years to Payback	**1.1**
Lifetime cost	$48.9 M
Net Present Value	**$23.8 M / 32%**
PV Size	354 kW
Wind Size	0 kW
Battery Size	8 kW for <3.6> hours
Yearly Diesel Used	79,800 gal

savings compared to 100% diesel

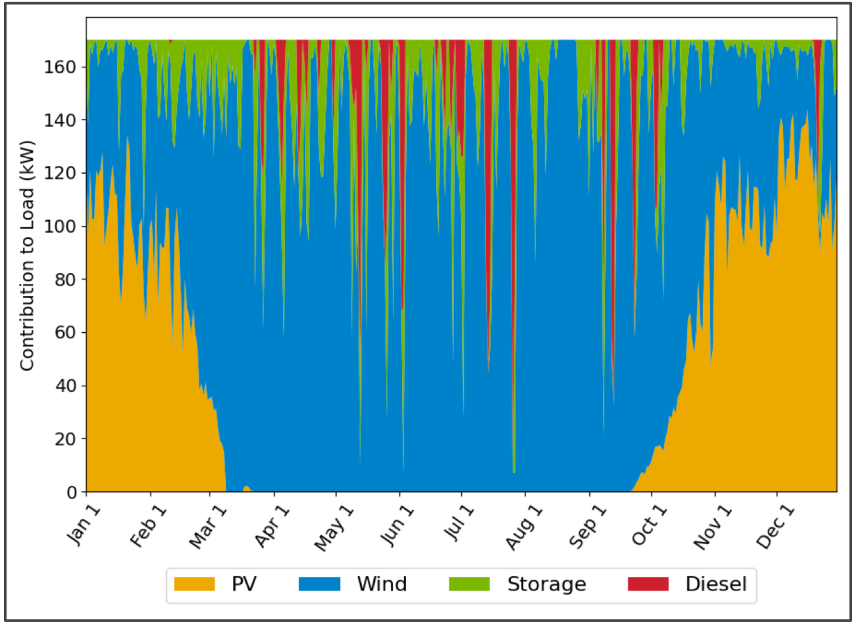
15 year lifetime assumed.

Configuration produces energy in addition the required load (170kW) shown here.

RE CONFIGURATION 2



Wind provides resource when sun is unavailable.



Configuration produces energy in addition the required load (170kW) shown here.

These are all mature technologies!

15 year lifetime assumed.

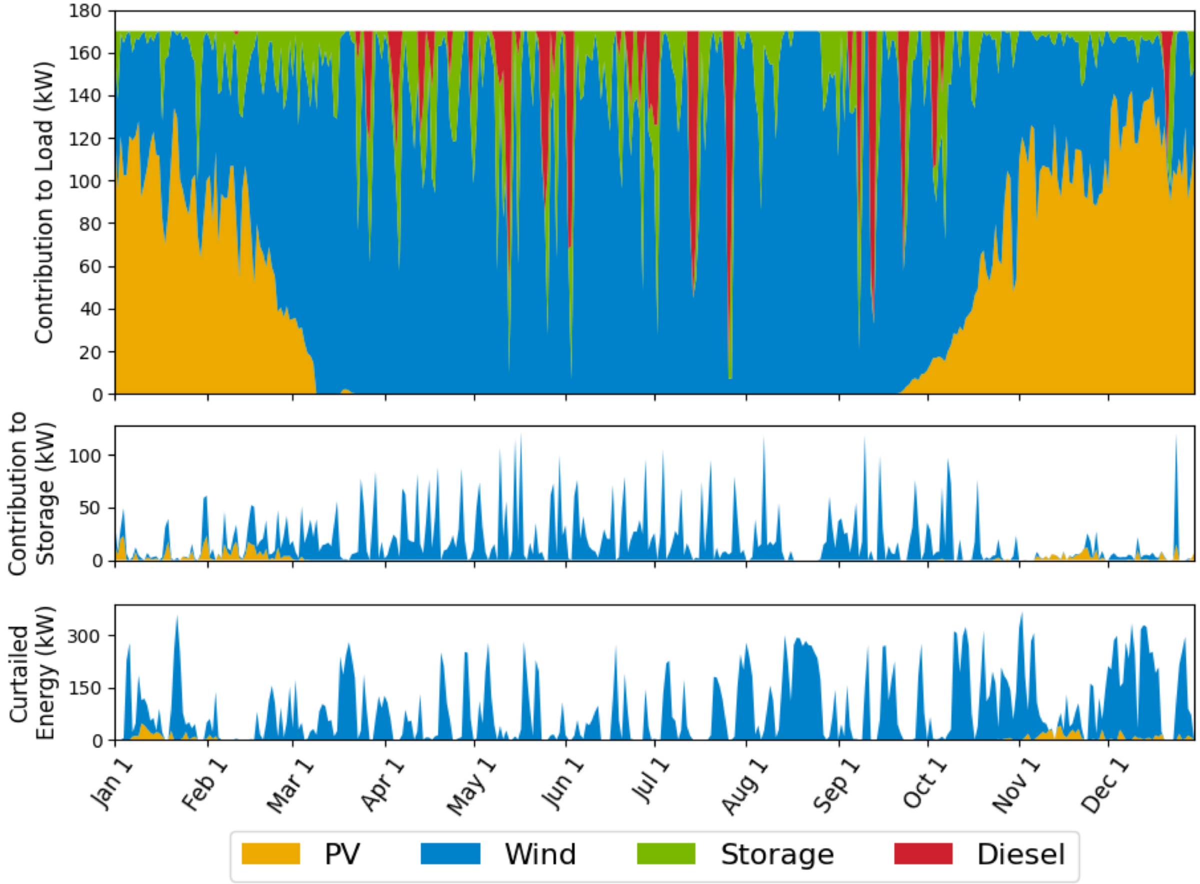
Upfront Capital	**$9.68 M**
% Diesel Reduction	95.5%
Years to Payback	**2.1**
Lifetime cost	$14.9 M
Net Present Value	**$57.8 M / 79%**
PV Size	182 kW
Wind Size	569 kW
Battery Size	180 kW for <18.9> hours
Annual Diesel Used	5,600 gal

RE Configuration 3 (LDES instead of lithium-ion) has very similar economics due to emerging technologies. LDES should continue to be considered in the future.

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)



SIDE BY SIDE COMPARISON

	Baseline Existing	RE Config 1 (PV + Li-Ion)	RE Config 2 (PV + wind + Li-Ion)	RE Config 3 (PV + wind + LDES)
Upfront Capital	0	$1,926,806	$9,681,999	$8,903,020
% Diesel Reduction	0	36%	95.5%	93.1%
Years to Payback	-	1.1	2.1	2.0
Lifetime cost	$72,745,453	$48,941,401	$14,938,109	$15,944,373
Net Present Value	0	$23,804,052	$57,807,344	$56,801,080
PV Size	0	354 kW	182 kW	199 kW
Wind Size	0	0 kW	569 kW	576 kW
Battery Size	0	8 kW for <3.6> hours	180 kW for <18.9> hours	203 kW for <10.9> hours
Yearly Diesel Used	124,095 gal	79,831 gal	5,553 gal	8,540 gal
Yearly CO_2 Emission Saved	0	432 metric tons	1156 metric tons	1127 metric tons

STAGED IMPLEMENTATION

Stage 1: Pre-prototype demonstration of PV + Li-Ion

Stage 2: Demonstration of single wind turbine

Stage 3: LDES implemented with existing wind & PV

Stage 4: Partial scale-up of targeted configuration

Stage 5: Full system operates

Renewable technology is modular, therefore ***this plan is flexible***. For example, earlier scale-up of solar generates economic savings to offset wind & storage upfront capital costs.

FUTURE RESEARCH & DEVELOPMENTS

- Solar
  - Durability
  - Snow drift maintenance
- Wind
  - Durability (demonstrate operational temperature down to -70º C)
  - Foundation engineering (work with CRREL)
  - EMI for all telescopes, sidelobe modeling for SPLAT
  - Improved wind measurements
- Energy Storage
  - Predict durability of Lithium-Ion over time in this scenario
  - Understand power : energy ratio & time constants (noise in power in and out of the storage)
  - As long-duration technology (LDES) increases maturity, characterize impact
- Diesel
  - Understand impact of noisy load profile on diesel system
- Development of safety technology, standards, and mitigations

RENEWABLE ENERGY IS VIABLE AT THE SOUTH POLE.

- A **significant reduction in carbon footprint and cost of operations** is possible using mature renewable energy technology.
  - Payback time on capital investment is ~ 2 years
- Primary risk is durability in extreme environment
  - Risks can be mitigated with engineering development and demonstrations
- A staged, flexible implementation will reap economic benefits while retiring technical risks