Minnesota House Testimony:
Climate and Energy Finance and Policy Committee
3 March 2022

Natural Resources Research Institute
UNIVERSITY OF MINNESOTA DULUTH
Driven to Discover

Survey of Technology Options for Longer Duration Energy Storage in Minnesota

Discover the Economy of the Future

Examination of Non-Lithium Battery Energy Storage Concepts

D.R. Fosnacht, D.M. Peterson, E. Myers

June 2021

Funding:

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Problem Statement

To optimize renewable energy efficiency and minimize challenges, a portfolio of longer duration storage technologies beyond short duration battery storage is needed to reduce carbon dependency and enhance energy security.

Natural Resources Research Institute
UNIVERSITY OF MINNESOTA DULUTH
Driven to Discover

Report Organization

Part 1: Technology Survey

1. Li-Ion Battery (Energy contained in Electrodes)
2. Gravity (utilize topographic features)
3. Pressure (drive rotating mechanical equipment to produce energy)
4. Hydrogen and ammonia (chemical agents for energy)
5. Flow Batteries (energy contained in electrolytes)

Part 2: Technology Siting Analysis

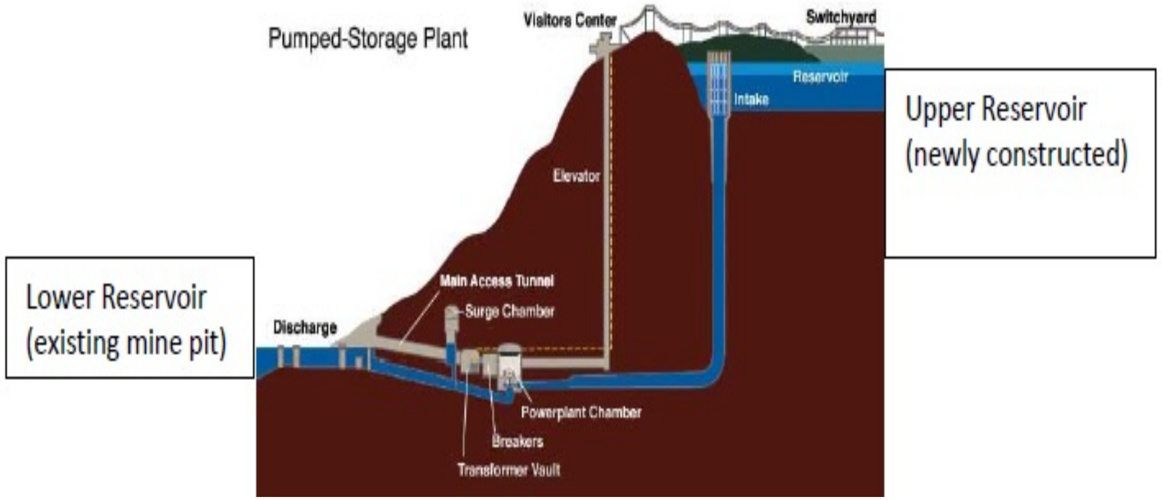
Base Comparison: Li Ion Batteries

Item	Parameter(s)
Components	Electrodes, electrolyte, integrated cells
Round Trip efficiency (%)	75-85
Project Costing ($/kWh)	367
Project Lifespan (Y)	5-10
Locatability	Anywhere
Capacity (MW)	1 to 300
Footprint (>35 MW)	Medium

Concerns:

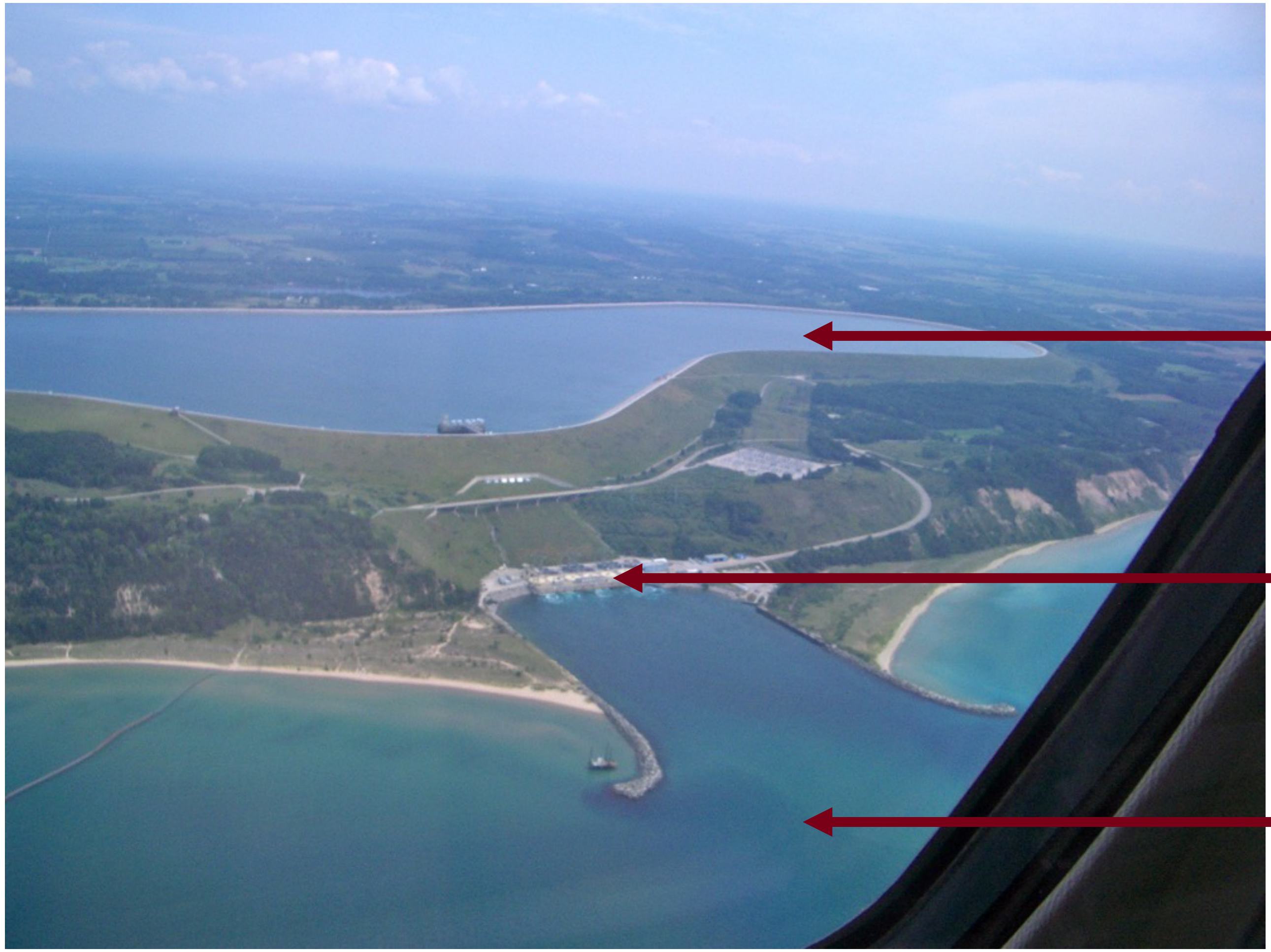
- Requires access to materials
- Longevity
- Safety

Gravity: Pump Hydro Energy Storage



Item	Parameter(s)
Components	Higher, Lower reservoir, Pump/turbine, penstock
Round Trip efficiency (%)	80 (Similar)
Project Costing ($/kWh)	165 (Lower)
Project Lifespan (Y)	50 (Longer)
Locatability	Specific Geology
Capacity (MW)	100 to 2,000
Footprint	Very Large

Example of Pump Hydro Facility



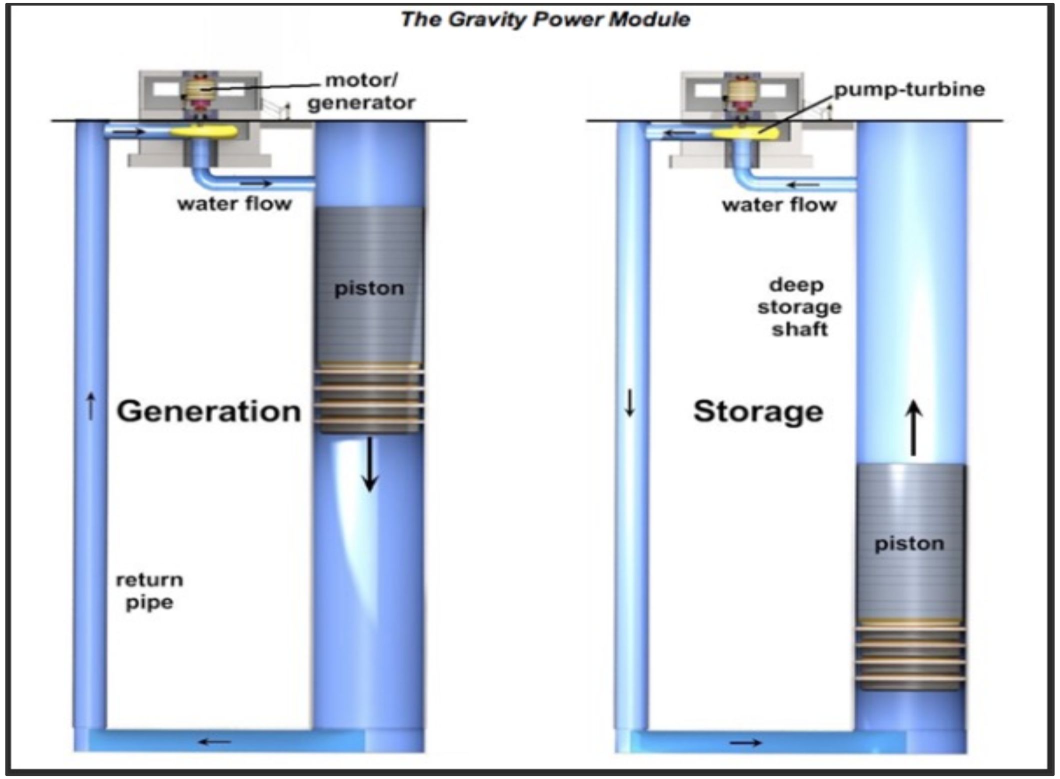
1.9 TW Facility in Ludington, MI

Man-made Upper Reservoir

Six Pump/Turbines

Lake Michigan

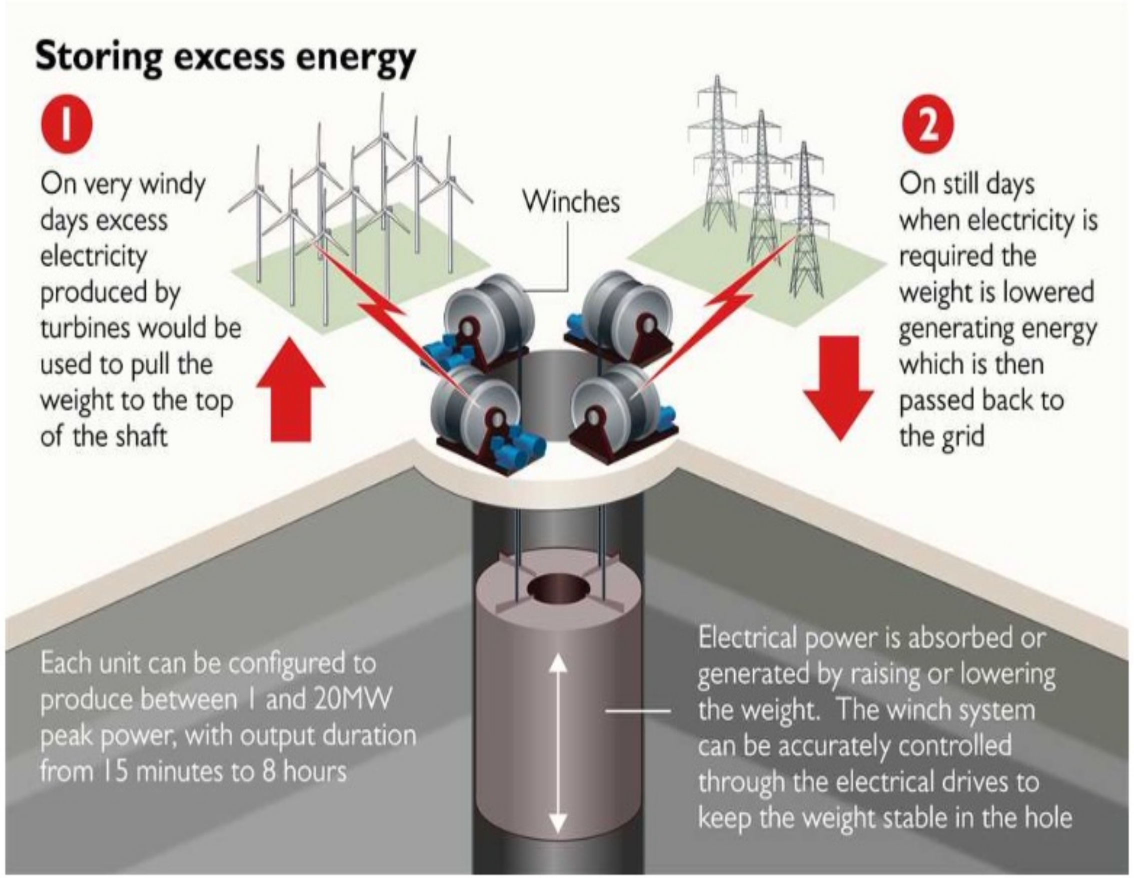
Gravity: Gravity Power



Item	Parameter(s)
Components	Sealed shaft, water return pipe, weighted piston, piston seals, pump/turbine, water as media
Round Trip efficiency (%)	60 (Lower)
Project Costing ($/kWh)	125-543
Project Lifespan (Y)	60 (Longer)
Locatability	Anywhere a shaft can be driven
Capacity (MW)	>40
Footprint	Small to Medium

under development

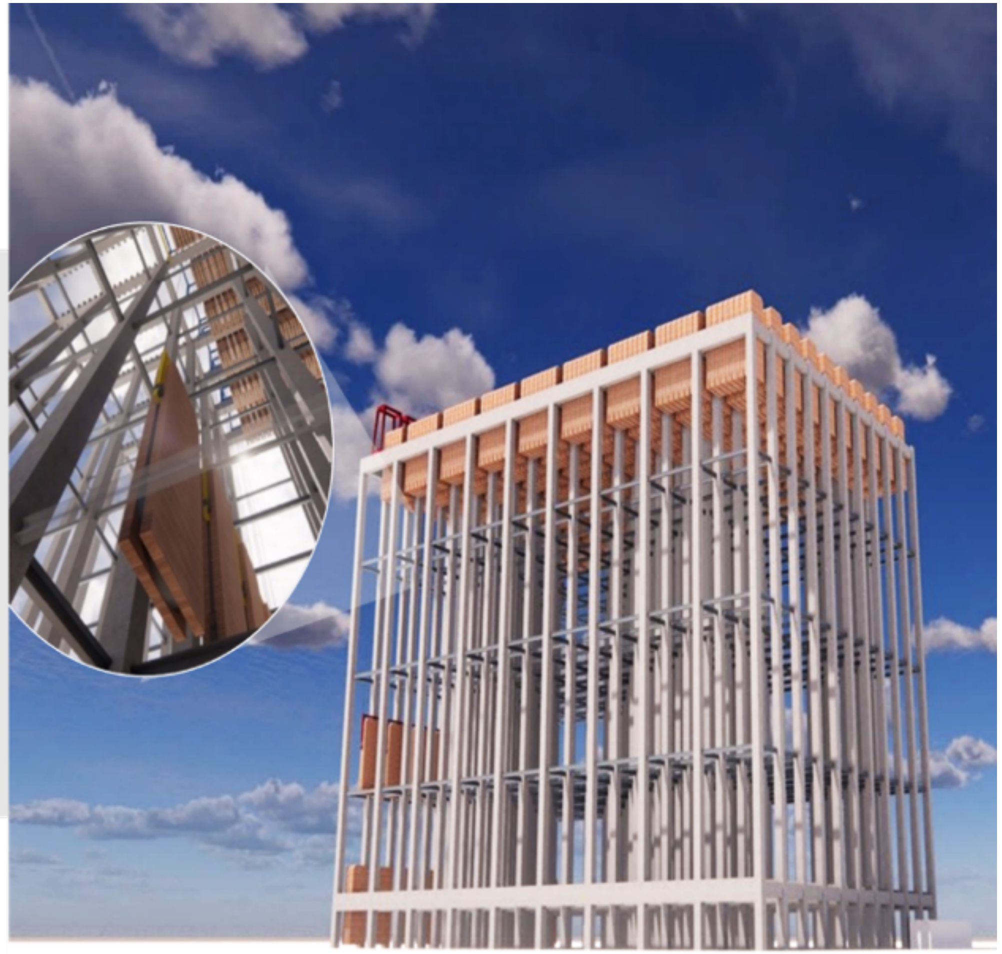
Gravity: Gravitricity



Pressure cap: hydrogen storage
Heat pump: in lower part of shaft

Item	Parameter(s)
Components	100 m to 1000 m deep shaft, weights and cabling with motor/generators, Quick change weight reservoir at top, pressurized shaft for hydrogen storage, deep heat exchanger for heat pump service
Round Trip efficiency (%)	80-90 (Better)
Project Costing ($/kWh)	$171 (Lower)
Project Lifespan (Y)	50+ (Longer)
Locatability	Anywhere a shaft can be driven
Capacity (MW)	1-20, but other services provided
Footprint	Small

Gravity: Energy Vault (Ev_x Configuration)



Can sequester coal ash power plant waste in blocks

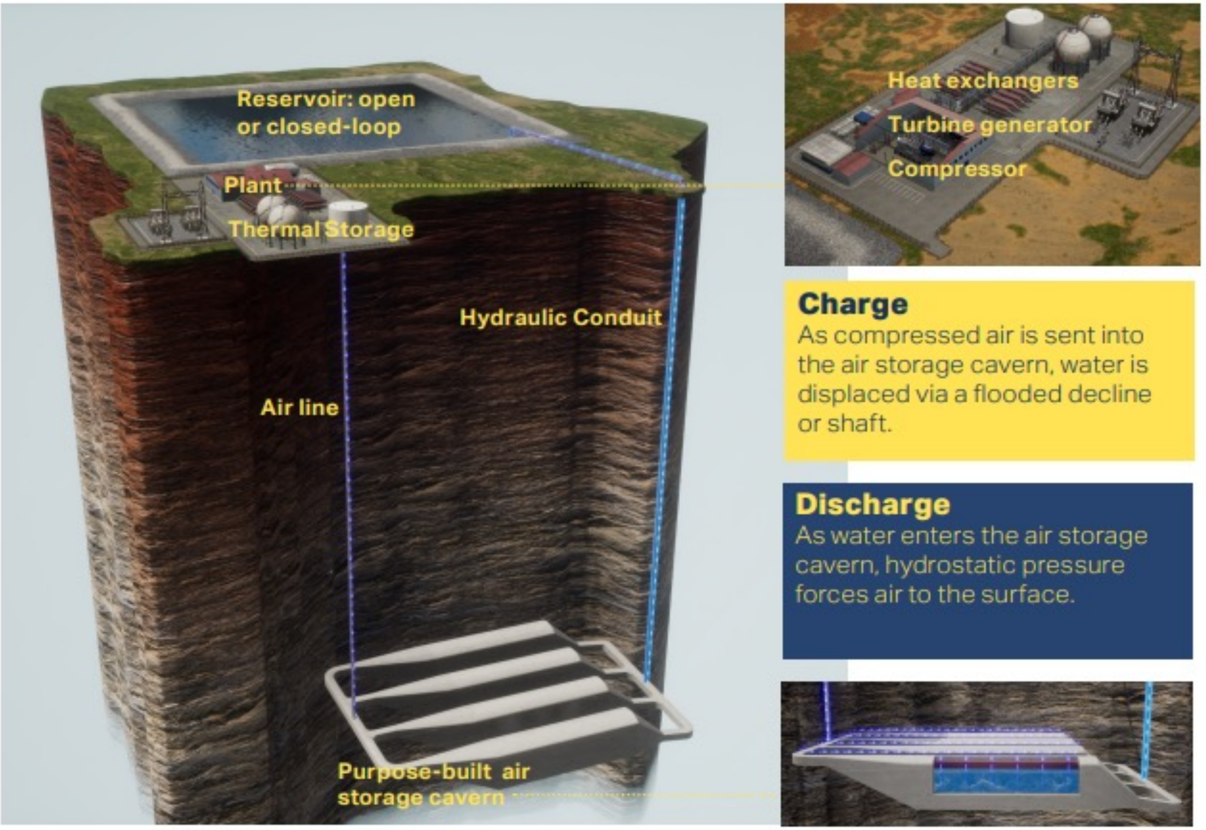
Item	Parameter(s)
Components	Electric motor/generator, 36 T weights, 120 m high structure, modular construction
Round Trip efficiency (%)	78-80
Project Costing ($/kWh)	$200 -350 depending on desired duration and waste revenue (Lower)
Project Lifespan (Y)	40+ (Longer)
Locatability	Specific Geology
Capacity (MW)	1-35 and modular
Footprint	Small

Near term active projects

Gravity: Advanced Rail

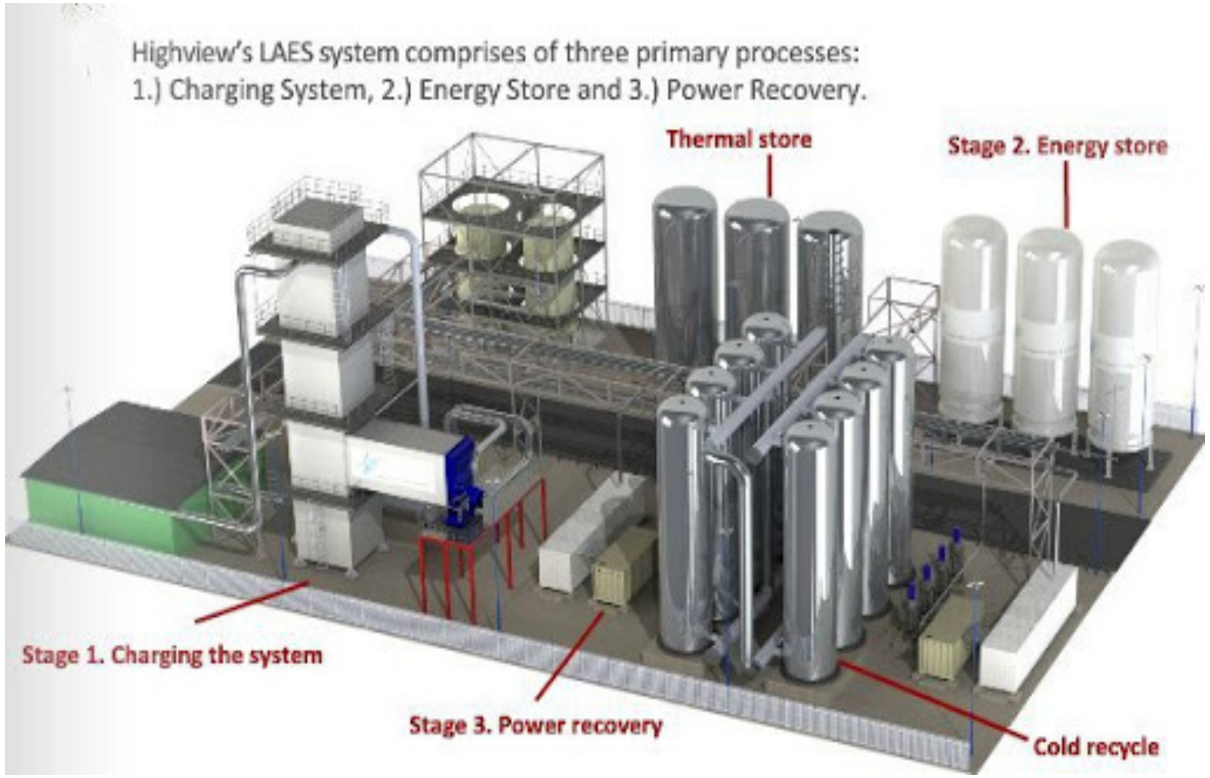
Item	Parameter(s)
Components	Height differential on land from 6^o to 50^o slope; rail system or cable system, motor, weighted cars or designed weights
Round Trip efficiency (%)	70-80 (Similar)
Project Costing ($/kWh)	168 (Lower)
Project Lifespan (Y)	40+ (Longer)
Locatability	Specific Geology
Capacity (MW)	>50-700
Footprint	Medium to Large

Pressure: Advanced Compressed Air (Hydrostor)



Item	Parameter(s)
Components	Compressor, turbine, heat recovery equipment, upper water source, air storage cavern, hydraulic connection
Round Trip efficiency (%)	>60 (Lower)
Project Costing ($/kWh)	150-300 (Lower)
Project Lifespan (Y)	40+ (Longer)
Locatability	Specific Geology
Capacity (MW)	>50-many hundreds
Footprint	Medium

Pressure: Liquid Air (Highview Power)

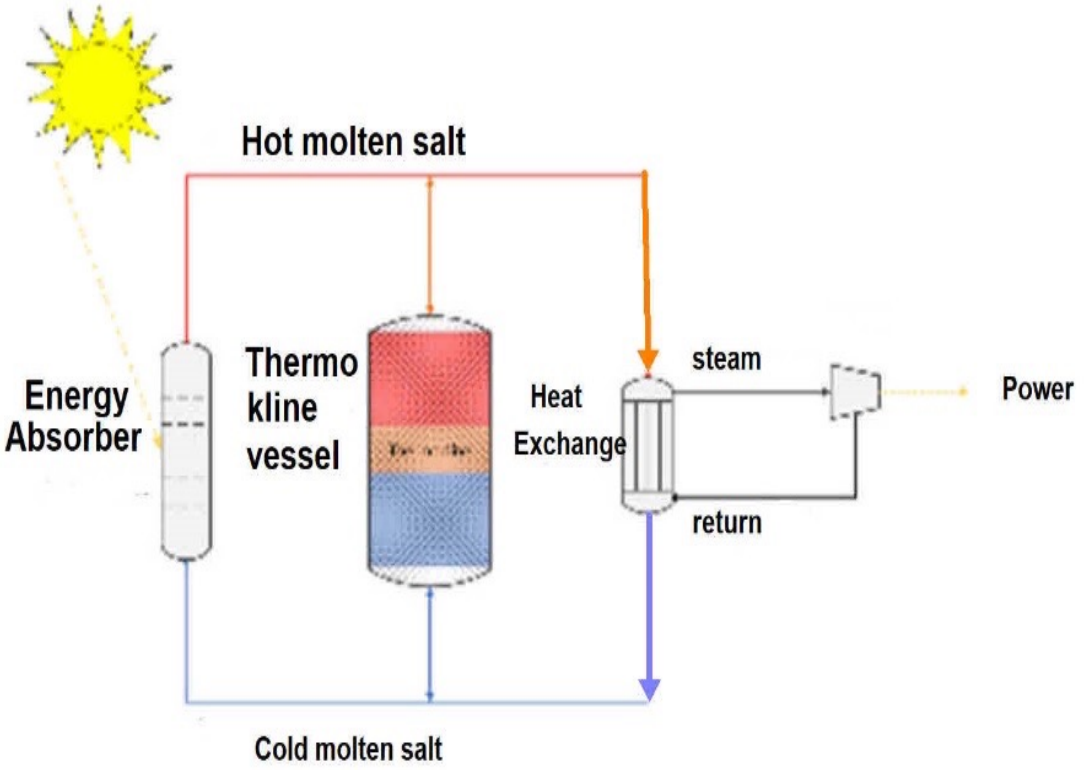


Use of Waste Heat can increase efficiency

Employs largely Conventional Equipment Used in Gas Separation

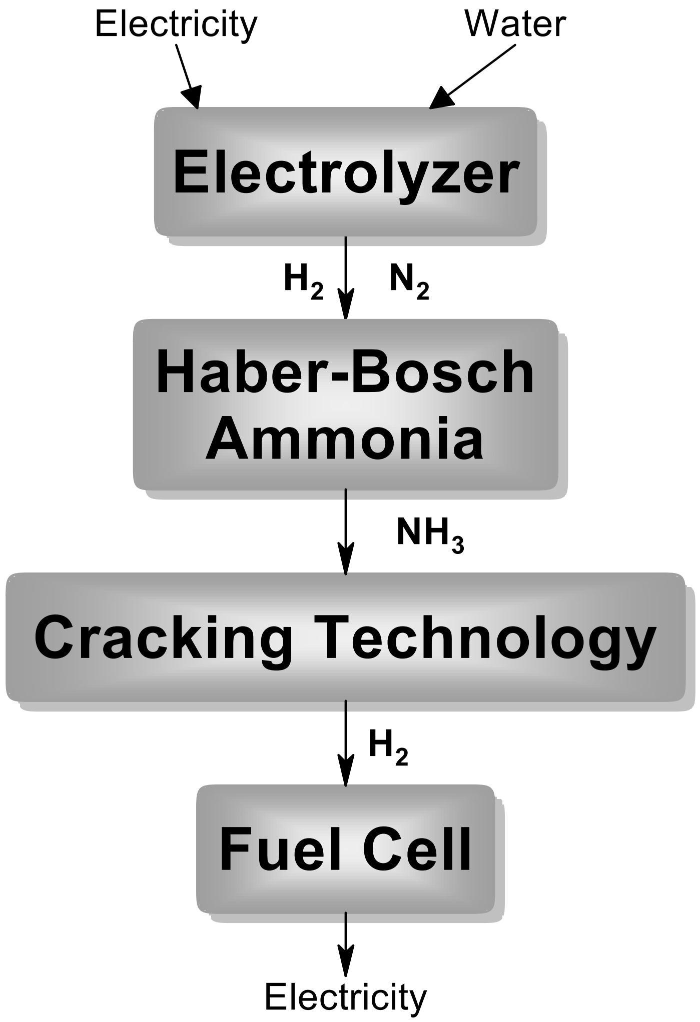
Item	Parameter(s)
Components	Cryogenic compression, heat capture, liquid storage tanks, evaporator, turbine
Round Trip efficiency (%)	60 to >75 (Lower)
Project Costing ($/kWh)	54 (Lower)
Project Lifespan (Y)	30-50+ (Longer)
Locatability	Anywhere, better efficiency if source of waste heat available
Size (MW)	>50
Footprint	Medium to Large

Heat Storage



Item	Parameter(s)
Components	1 to 2 insulated tanks, heat exchangers, piping, heat source, turbine, working fluid - molten salt, steam or super critical CO_2
Round Trip efficiency (%)	>70 (Lower)
Project Costing ($/kWh)	? Depends on heating source, heat storage and thermal transfer media
Project Lifespan (Y)	30 (Longer)
Locatability	Anywhere, but waste heat source advantageous
Capacity (MW)	>15 depending on heat source and tank sizes
Footprint	Small to Medium

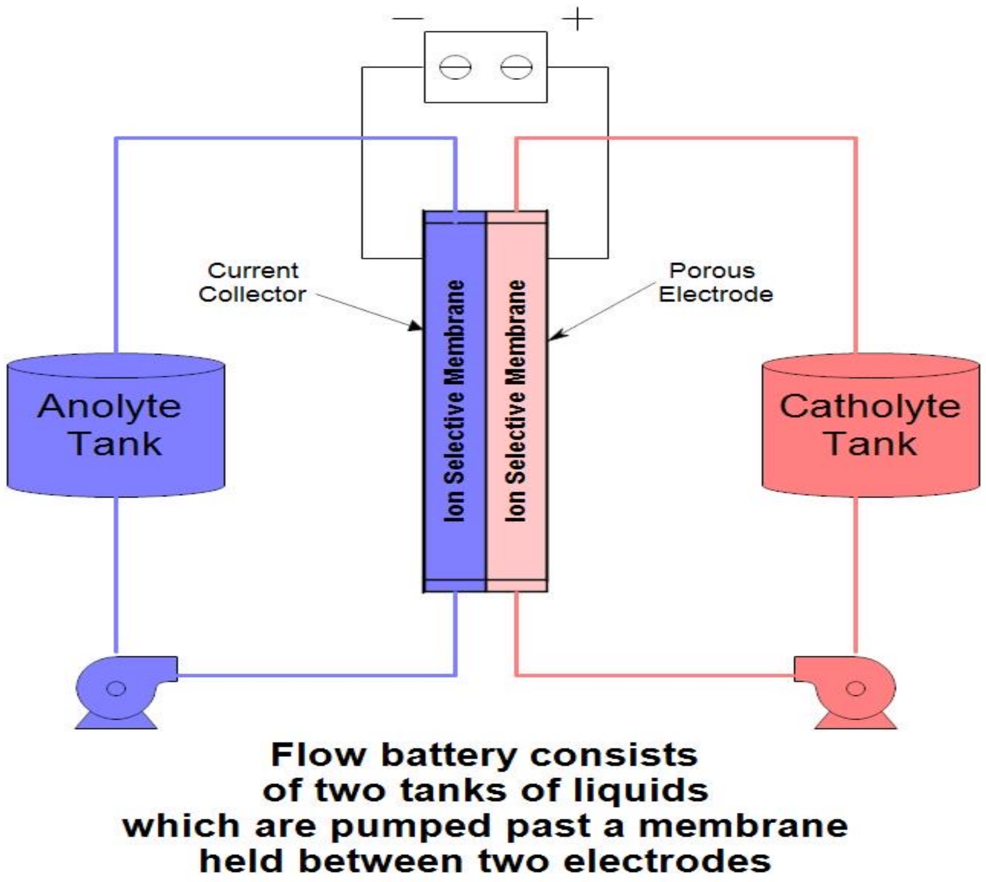
Hydrogen: Hydrogen and Ammonia Use



Item	Parameter(s)
Components	Electrolyzer, Storage Tanks, Fuel cells or conventional boiler, pipeline, or conversion to ammonia with cracking facility
Round Trip efficiency (%)	65 to >75 (Lower)
Project Costing ($/kWh)	?
Project Lifespan (Y)	30 (Longer)
Locatability	Anywhere
Capacity (MW)	1 to >1,000
Footprint	Small to Medium

Flow Batteries

Reagents stored in Tanks (M^{n+}/M^{n+1})



Item	Parameter(s)
Components	2 electrolyte storage tanks, electron acceptors, membranes, pumps, chemical reactants, electrolytes
Round Trip efficiency (%)	65 to 70 (Lower)
Project Costing ($/kWh)	20 to 120 (Lower)
Project Lifespan (Y)	20 (Longer)
Locatability	Anywhere
Size (MW)	Variable depending on tank size
Footprint	Small to Medium

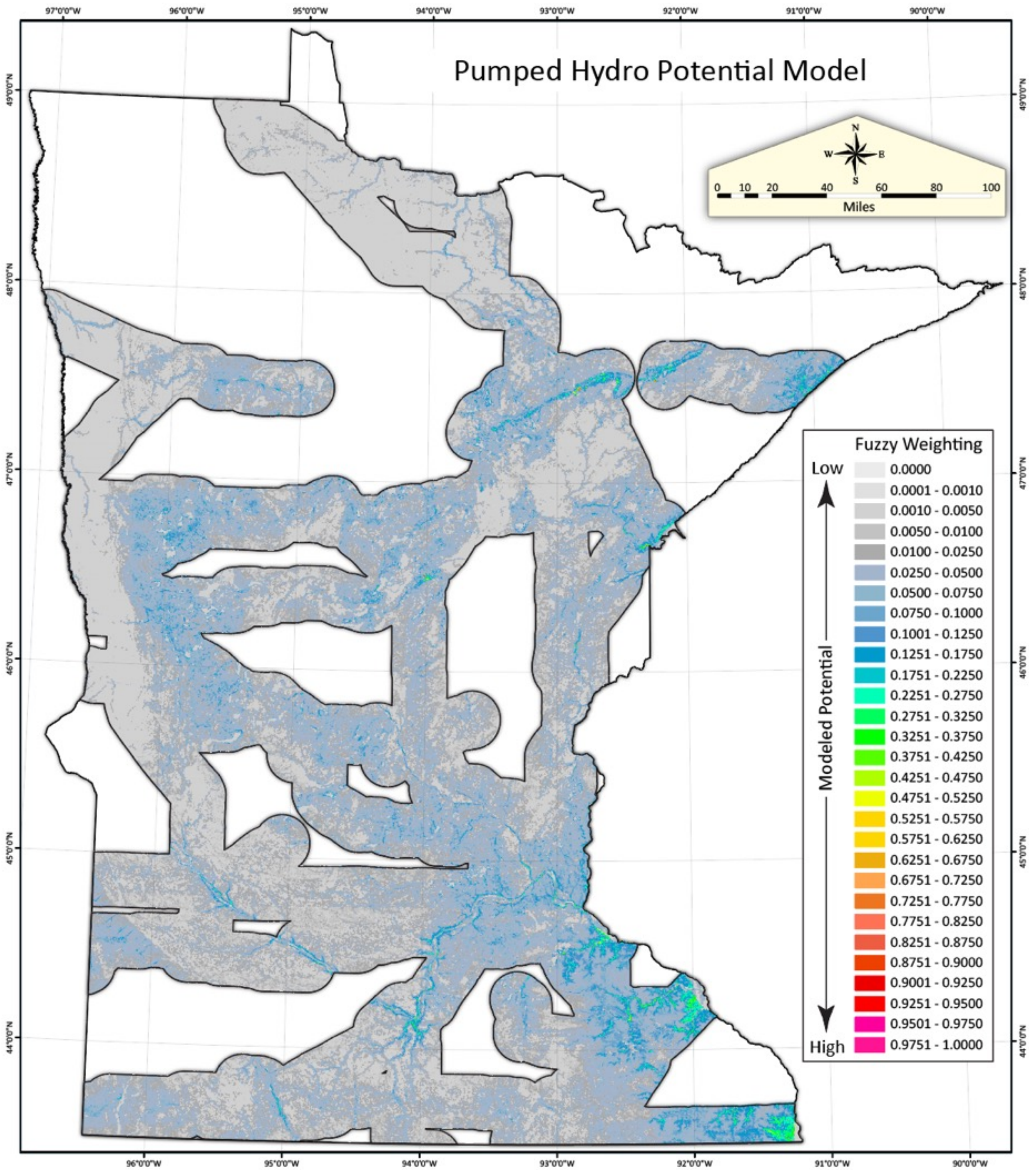
Needs inexpensive reagents – Mn iron?

Part 2: Technology Siting Analysis

Natural Resources
Research Institute
University of Minnesota Duluth
Driven to Discover

Factors Considered in Location Analysis

- Nearness to the Grid
- Topography
- Depth to Bedrock
- Faults in the Rock
- Water Resources (lakes and rivers)
- Mining features (past and present)
- Closeness to national and state parks
- Native American reservations
- Geology of location



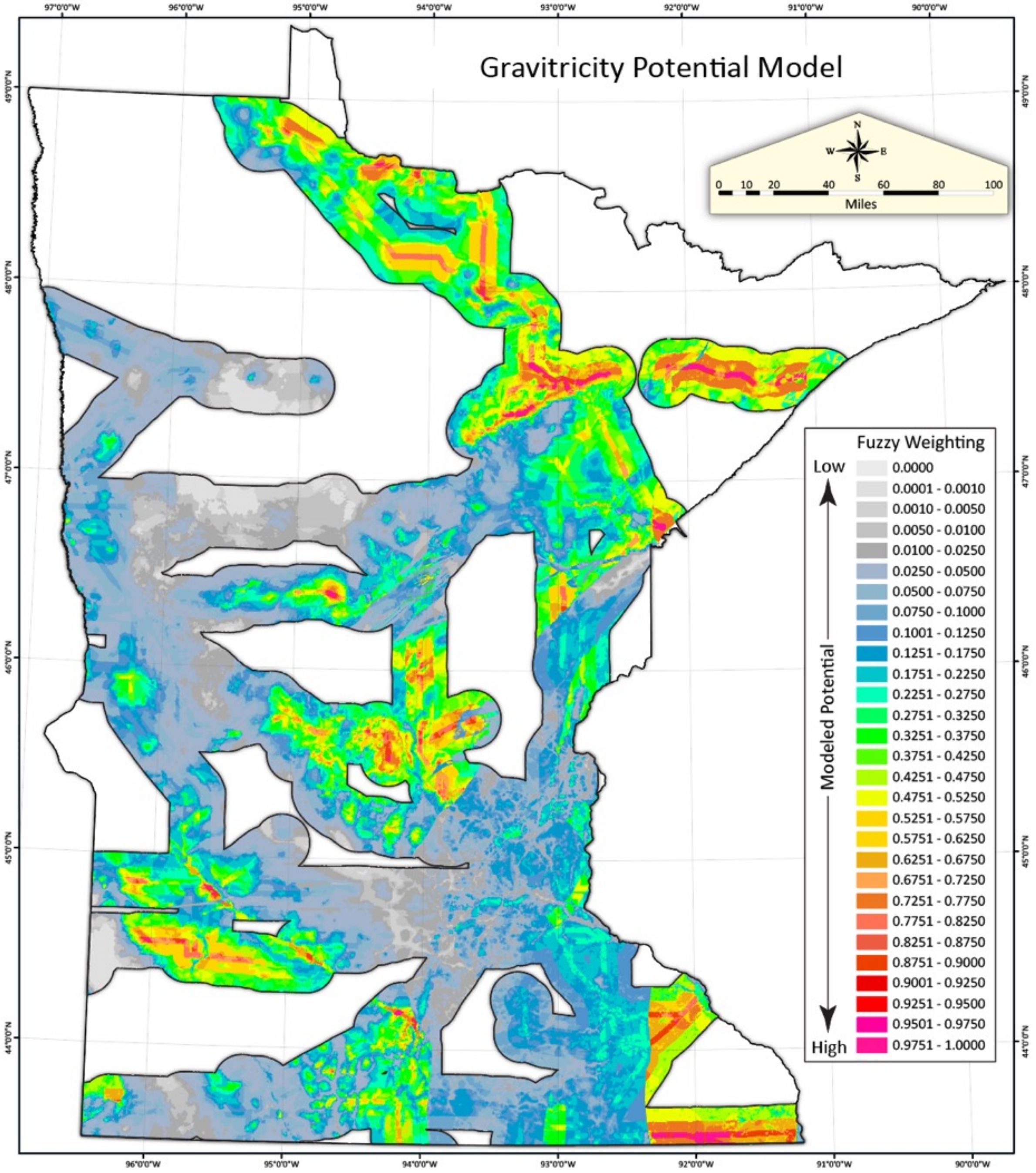
Pumped Hydro

Requires 350' of relief and water sources for an upper and lower reservoir.

Data Modeled includes:

1) Proximity to major power lines
2) Lakes
3) River systems
4) Open pit mines

(High and Low ground differences and source of water)

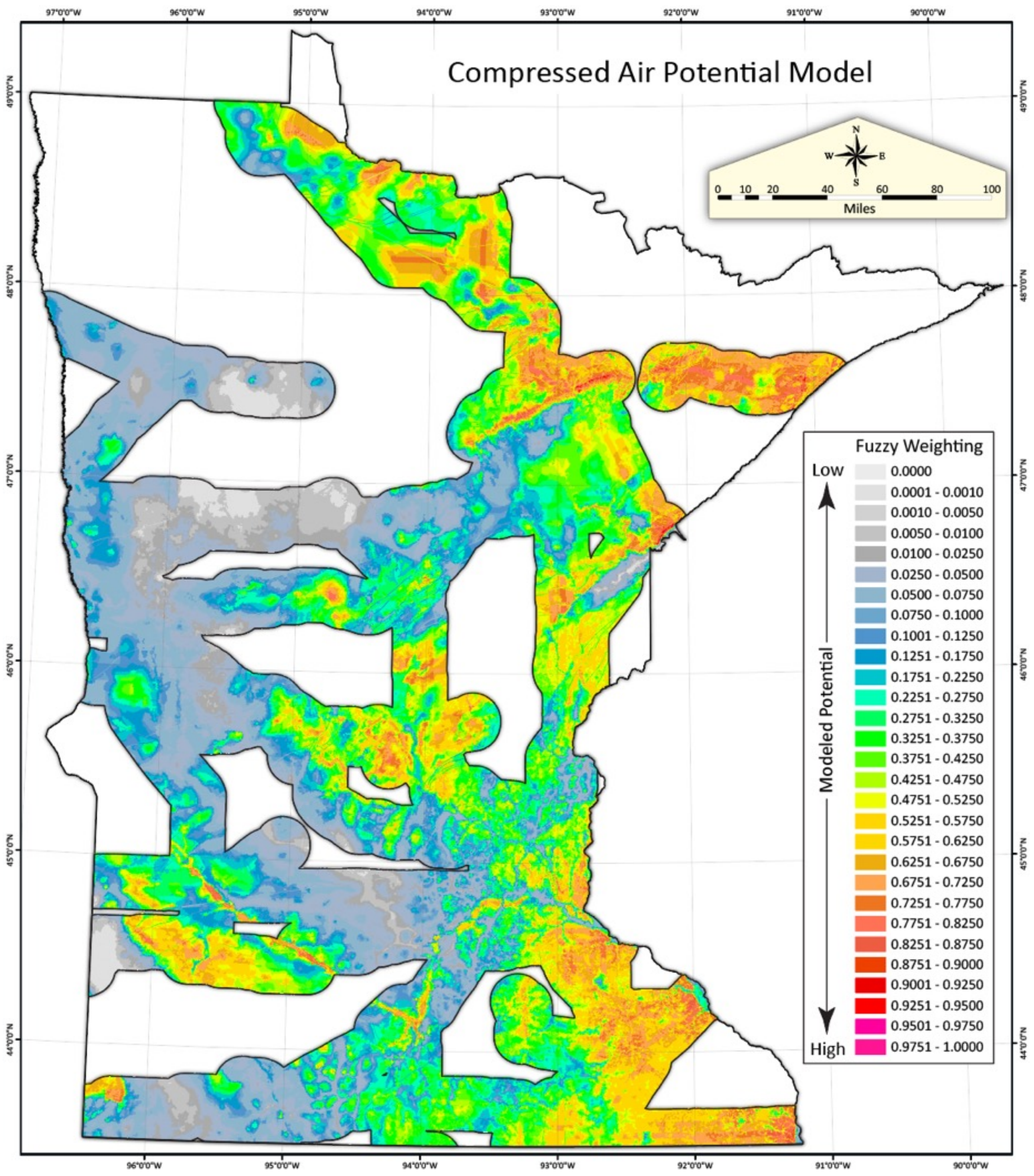


Gravitricity

Requires a new or repurposed mine shaft

Data Modeled includes:

1) Proximity to major power lines
2) Location of historic shafts
3) Depth to bedrock
4) Bedrock geology (strength)

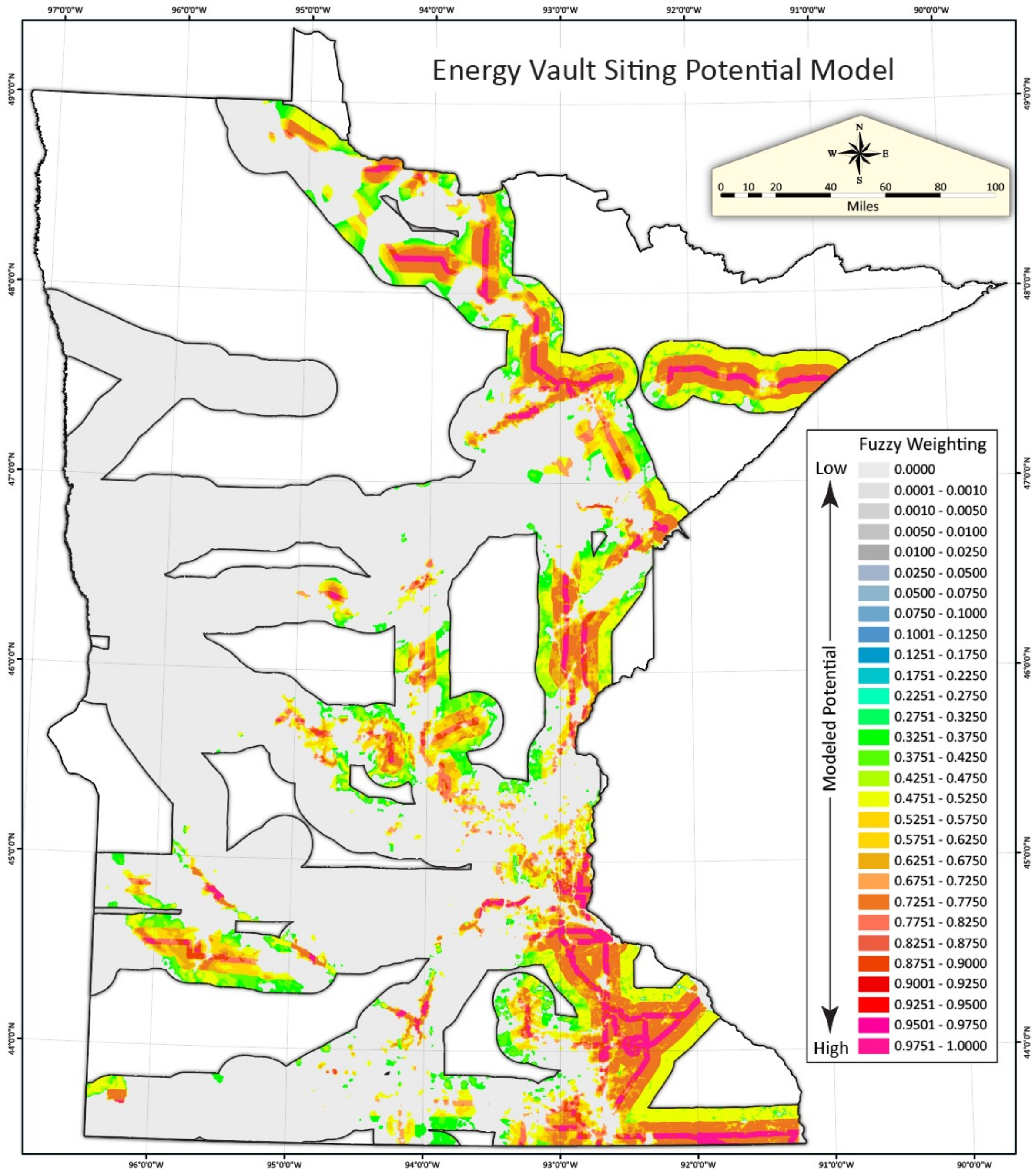


Advanced Compressed Air (Hydrostor)

Requires a purpose-built underground cavern surface reservoir.

Data Modeled includes:

1) Proximity to major power lines
2) Depth to bedrock
3) Precambrian geology
4) Paleozoic geology
5) Faults
6) Topographic relief

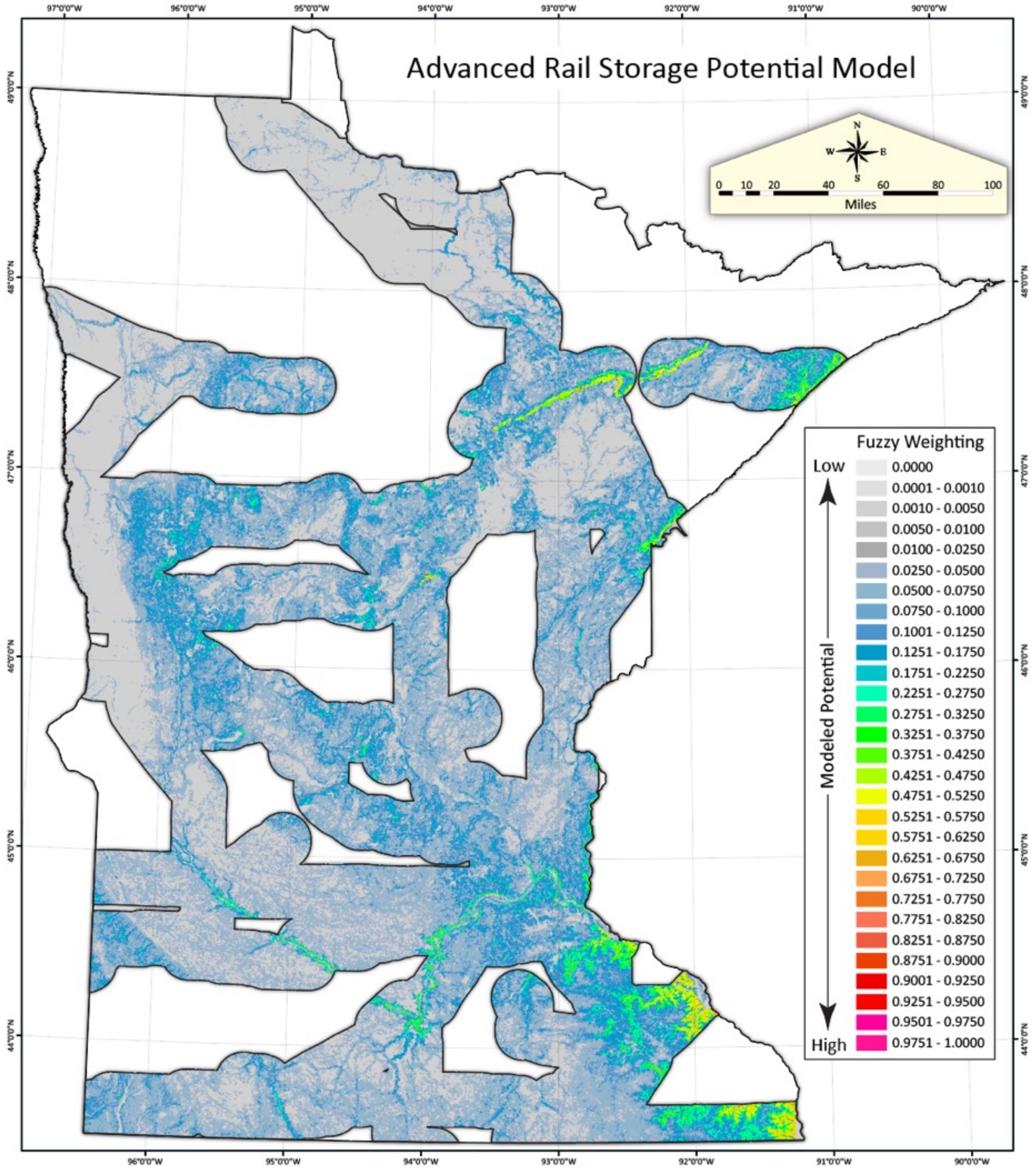


Energy Vault

Requires 3-5 acres of land as well as minimum depth to bedrock to support the system.

Data Modeled includes:

1) Proximity to major power lines
2) Depth to bedrock



Advanced Rail Storage

Requires 800’ of relief and 20% to 50% grades.

Data Modeled includes:

1) Proximity to major power lines
2) Topographic relief
3) Open pit mines

Example: Incline railroad – if Duluth only still had one

Conclusions

- A variety of non-Li battery technologies are under active development/demonstration
  - Offer short and longer duration storage
  - Unique siting requirements
  - High efficiencies, reduced cost
  - May utilize waste materials
- Most emerging technologies are applicable to MN landforms & geology
  - Opportunity for use of under-utilized brownfield assets
- A data base and online tool pin-points the most promising locations across Minnesota for the various technologies

Next Steps

- Policies to incentivize creation and installation of portfolio of energy storage options
- Ongoing review and update of technology platforms; continued dialog with developers and interested stakeholders
- Refinement of location criteria for the various technologies

FOR WHAT'S AHEAD

Natural Resources Research Institute

UNIVERSITY OF MINNESOTA DULUTH

Driven to Discover

WWW.NRRI.UMN.EDU

Thank You