Natural Resources Research Institute

University of Minnesota Duluth

Driven to Discover

Innovative Research • Minnesota Value • Global Relevance.

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UNIVERSITY OF MINNESOTA DULUTH
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Bioenergy and Energy Storage Development

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NRRI Mission

Natural Resources Research Institute
University of Minnesota Duluth
Driven to Discover

Mission Driven and Project Focused

OUR MISSION:

NRRI delivers applied research solutions to balance our economy, resources, and environment for resilient communities.

OUR VISION:

NRRI is globally recognized as key partner to drive entrepreneurship, economic diversification and resource stewardship for Minnesota.

NRRI Overview

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OUR RESEARCH GOES TO WORK

As part of the University of Minnesota system research enterprise, NRRI employs over 140 scientists, engineers, technicians, staff and students in two industrial research facilities. Through collaborative partnerships, we deliver the innovative tools and solutions needed to utilize and sustain Minnesota's precious natural resources.

- **NRRI DULUTH** has 19 labs for land, wildlife, water, energy, and minerals research, as well as additive manufacturing and technology development.
- **NRRI COLERAINE** is a 27-acre industrial laboratory site focused on minerals, metallurgy and wood products, bio-based energy research.

Integrated Research Groups

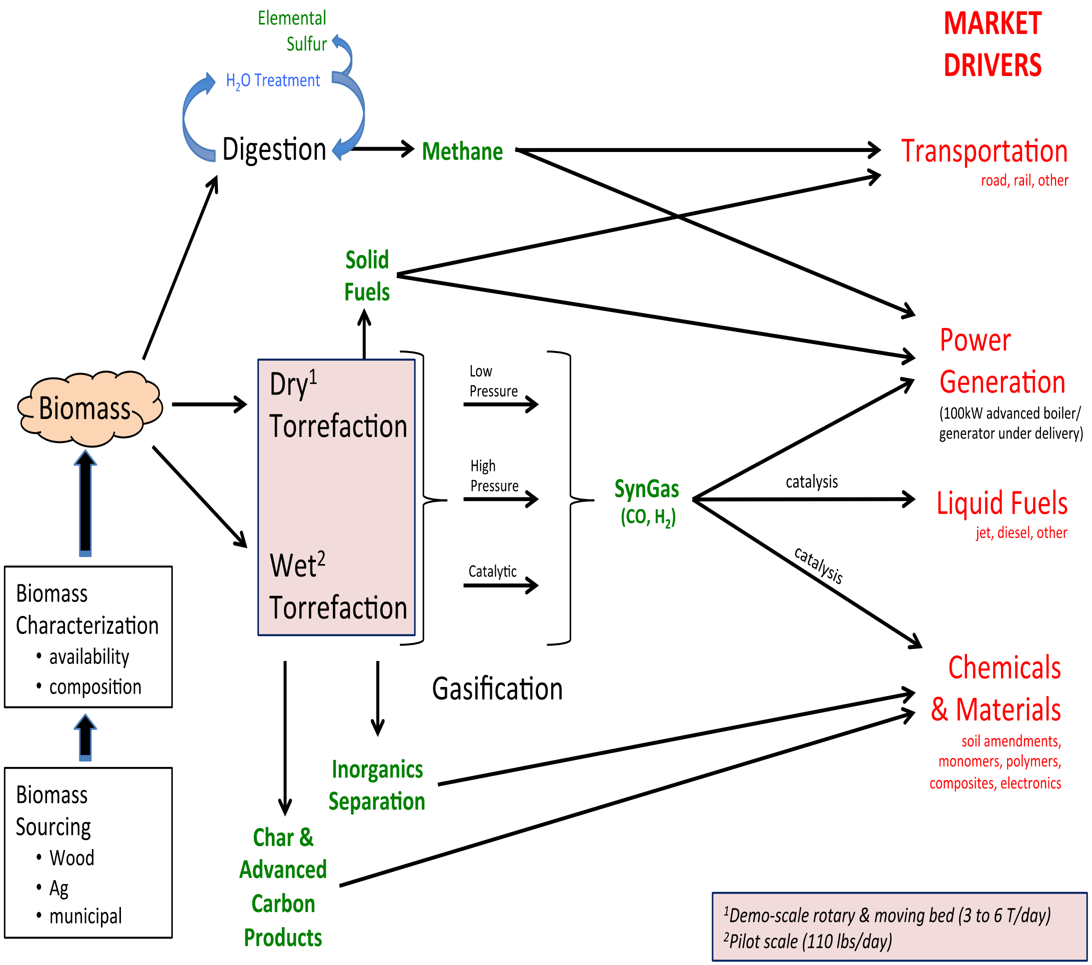
NRRI is:

- Unique
- Anticipatory
- Comprehensive
- Integrated

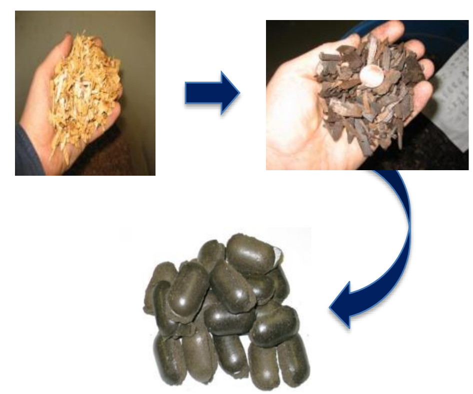
Our Partners:

- Industry
- Business
- Agencies
- NGOs

Integrated, System-based Biomass Processing Research Platform



Rotary Kiln System



Bioenergy Development Overview

- Pretreat Biomass to Ease its Use in Subsequent Processing
- 3 Pretreatment Paths Available
  - Rotary Dryer/Indirectly Heated Kiln (Demo-scale)
  - Moving Bed Using Super heated Steam (Demo-scale)
  - Hydrothermal Carbonization (Pressure, Temperature) (Pilot-scale)
- Collaborate with Key Partners for Use of the Pretreated Materials
- Demonstrate power conversion with newly designed boiler/generator system at 100 kW scale

Torrefaction Research Timeline

2010

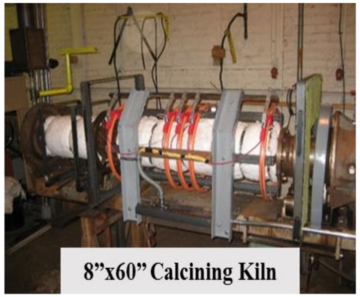
350 cm³ Reactor

Rocket Reactor

2011

2012-2013

"Pig Roaster" Rotary Torrefaction



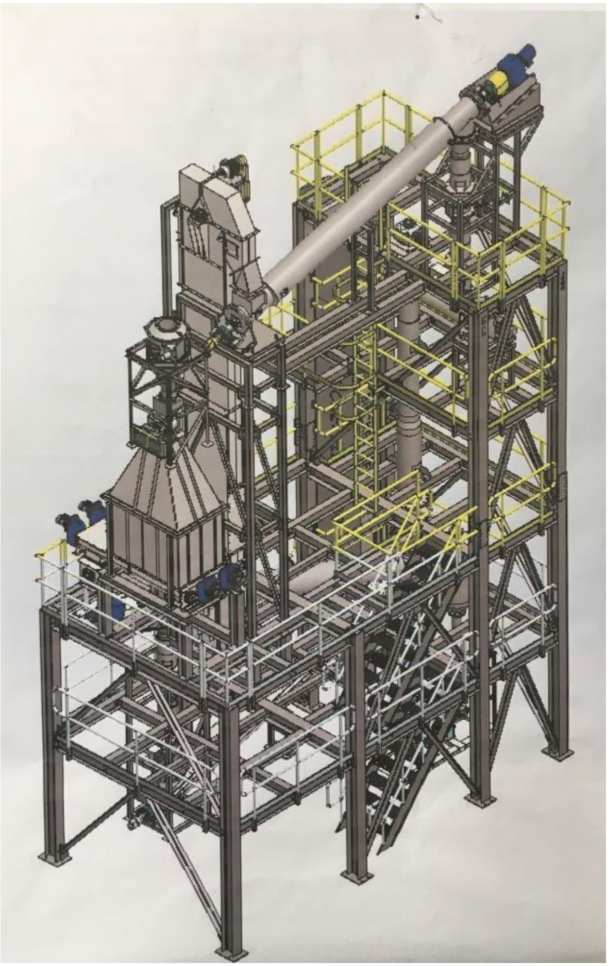
Pilot 8" Kiln SYLVA Kiln

2014

2015-2018

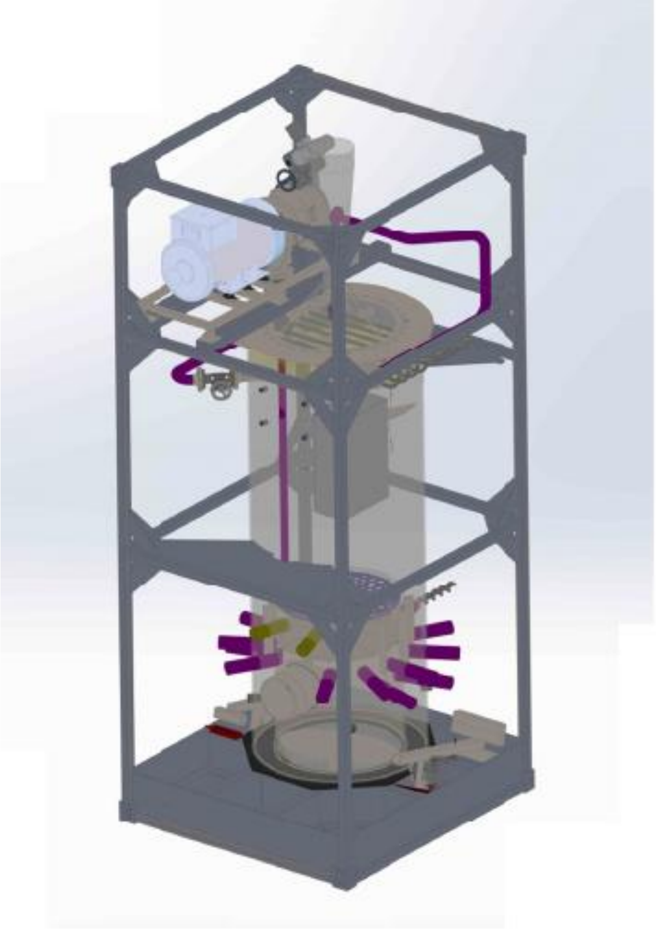
REL – Coleraine H&P Kiln

Overview of Kiln Reactor for Torrefaction and Char



Moving Bed Design and Construction

Moving Bed Torrefaction Reactor

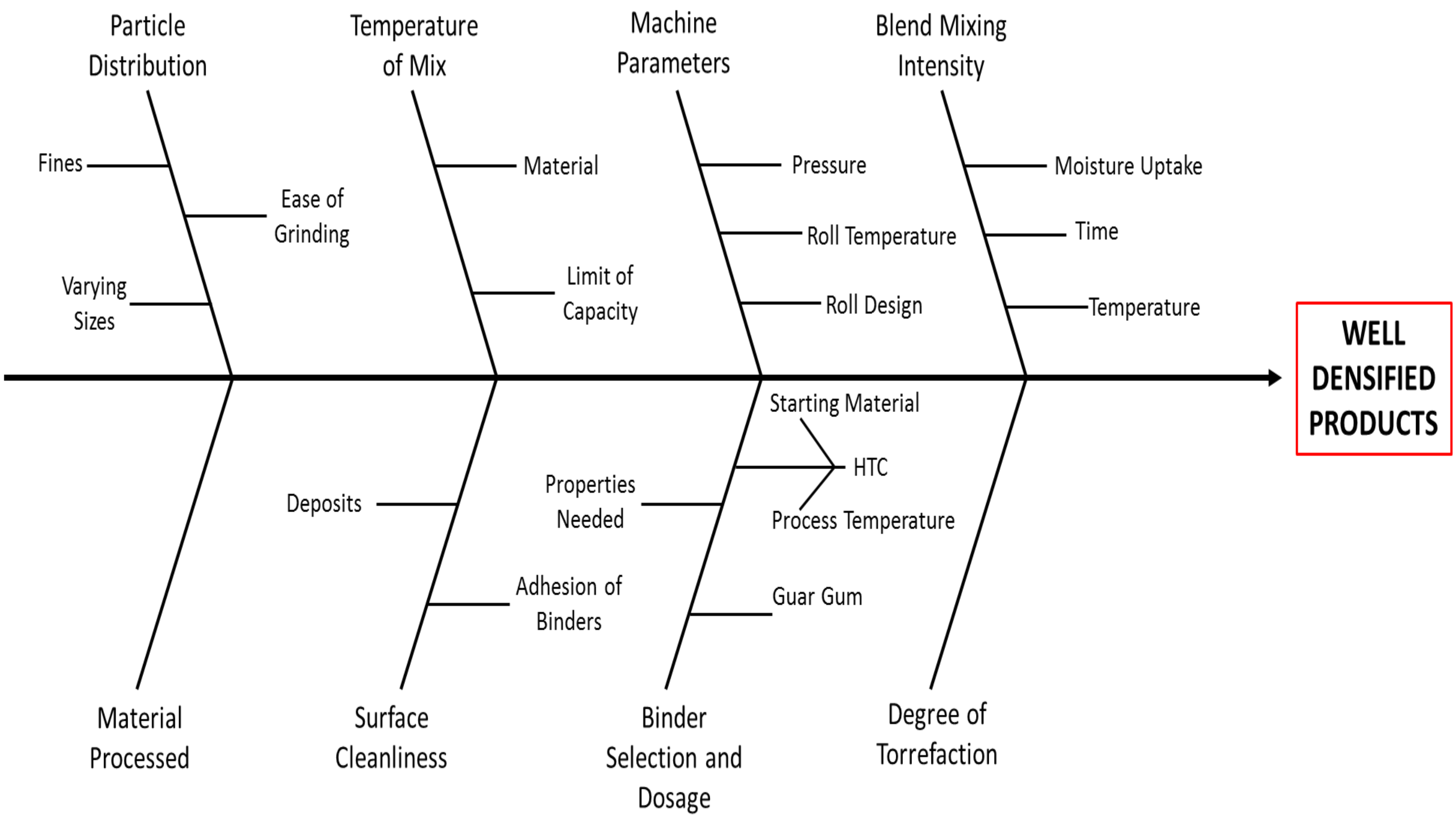


100 kW Boiler/Generator Schematic

Moving Bed View and Boiler/Generator Design

Overview of Densification Room

Key Variables and Densification Parameters for Acceptable Briquettes



Both 100% Biomass and Coal/Biomass Blends can be Produced

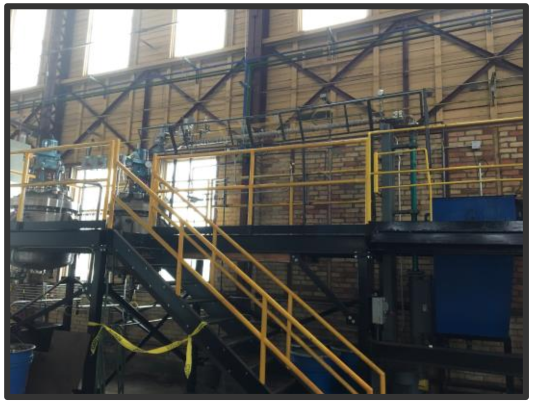
100% Torrefied Wood

50% Sub-bituminous coal/50% torrefied Wood

Evolution of Hydrothermal Carbonization System – Wet Torrefaction

2 liter (g)

5 liter (kg)



Pilot Unit (Multi-kg)

Hydrothermal Carbonization Pilot Plant

Centrifuge

Product Tanks

Pressure Reactor

Feed Tank and Pump

Excellent process for conversion of Agricultural and Wet Biomass to Energy and Chemical Products

Energy Storage

- Two Major Studies Completed by University on Pumped Hydro and Compressed Air Energy Storage
  - PUMPED HYDRO ENERGY STORAGE (PHES) USING ABANDONED MINE PITS ON THE MESABI IRON RANGE OF MINNESOTA
  - COMPRESSED AIR ENERGY STORAGE (CAES) IN NORTHERN MINNESOTA USING UNDERGROUND MINE WORKINGS AND ABOVE GROUND FEATURES
- For Pump Hydro – Results show that topography and water resources exist at various sites that to support a 100 to 200 MW facility
- For CAES – Hybrid Technology (Hydrostor) identified that holds promise for brown field sites for advanced compressed storage at large scale (>100 MW)

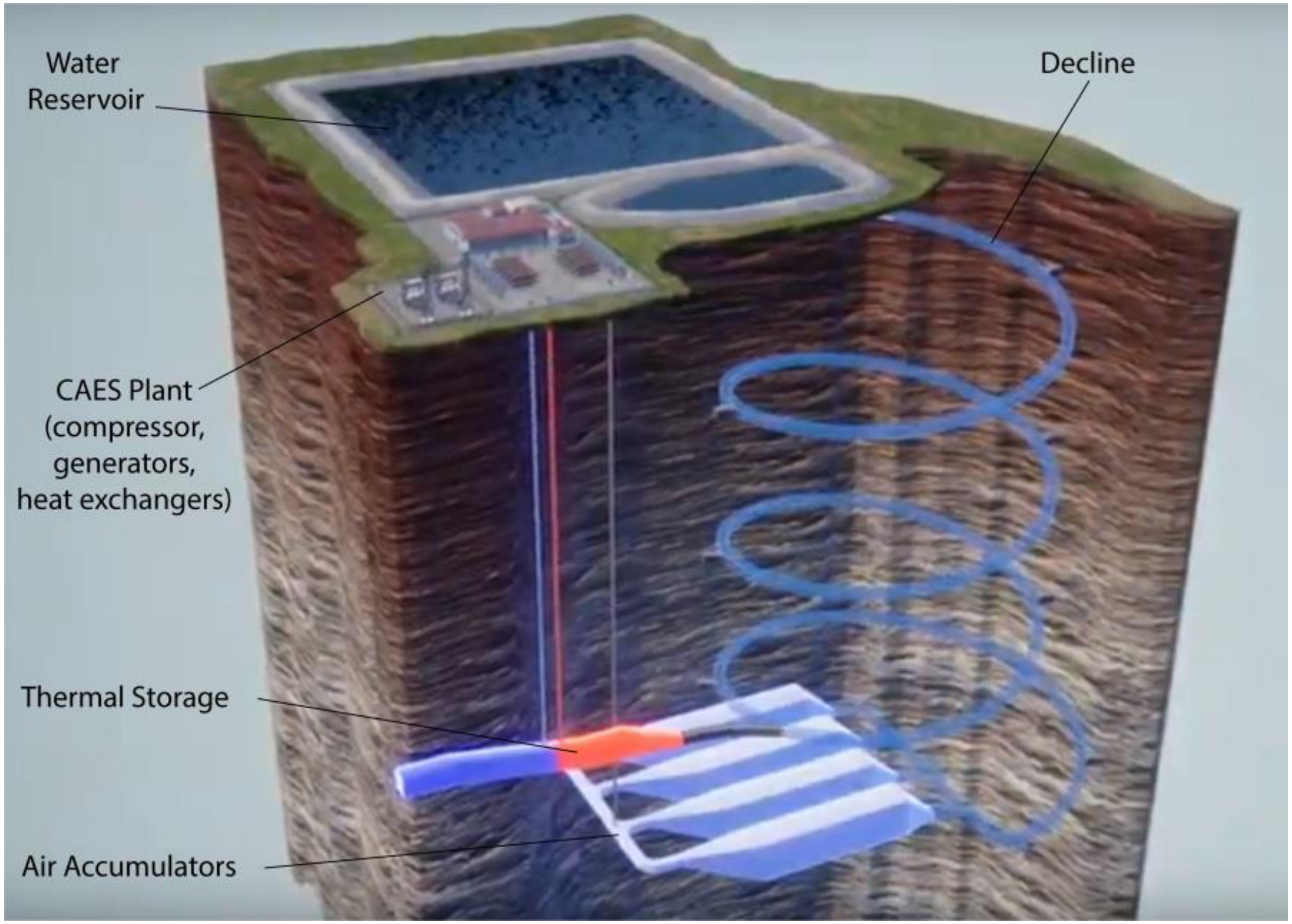
PHES Scenarios

1. Existing pit upper reservoir to existing pit lower reservoir (EPUR TO EPLR);
2. Constructed upper reservoir to existing pit lower reservoir (CUR TO EPLR);
3. Constructed upper reservoir in stockpile to existing pit lower reservoir CURS TO EPLR);
4. Existing tailings pond upper reservoir to existing pit lower reservoir (ETPUR TO EPLR);
5. Constructed upper reservoir to existing tailings pond lower reservoir (CUR TO ETPLR);
6. Constructed upper reservoir to constructed lower reservoir (CUR TO CLR);
7. Existing pit upper reservoir to excavated/mined underground lower reservoir (EPUR TO E/MULR);
8. Existing tailings pond upper reservoir to excavated/mined underground lower reservoir (ETPUR TO E/MULR);
9. Constructed upper reservoir in tailings basin to excavated/mined underground lower reservoir (CURTB TO E/MULR); and
10. Existing pit upper reservoir to existing underground mine lower reservoir (EPUR TO EUMLR).

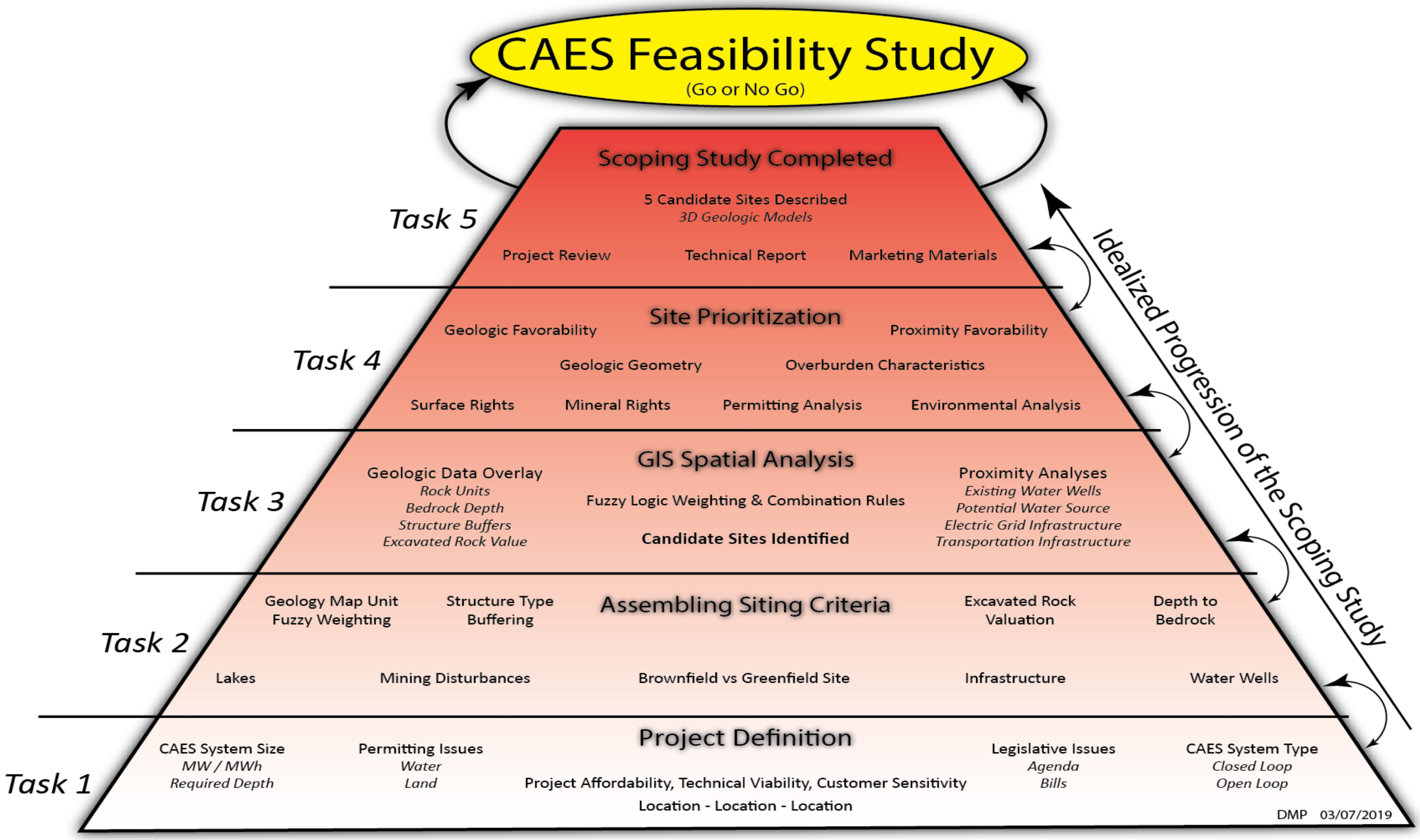
Identified Pump Hydro Sites

			Least expensive sites to develop								
Deal Breaker	**Criteria**	**Requirements/Concerns**	**Morton-South Agnew**	**Hibtac**	**Chisholm-Buhl (Hartley)**	**Keetac-North**	**Alpena-Minorca**	**Virg Horn - South (Laurentian Mine)**	**Virg Horn - North**	**Minntac (East and West pits)**	**Arcturus**
definitely	Head	R	~350 feet	~350 feet	~350 feet	~350 feet	~350 feet	~350 feet	(needs to be calculated)	~350 feet	~350 feet
definitely	Volume	R	Y	Y	Y?	Y	Y	**Y - need to wait for mine closure**	(needs to be calculated)	Y	Y
possible	Adj. to current mining/blasting	C	Y	Y	N	Y	Y - could be mined to west	currently Laurentian Pit	N	Y	N - remote
possible	faults/fractures	C	likely	likely	likely	likely	Y- very close to known fault system	likely	likely	likely	likely
possible	Water Quality/Hydrology	C	N	?	**Y? - Fraser Pit is Chisholm's water supply**	N	process water; close to Virginia water source	N	? - use old tailings basin	? - Mt. Iron water source?	**adjacent to Hill Annex State Park**
possible	Land Acquisition Problems	R	N	N - Hibtac	N - some USS, mostly state	N - USS	Y - RGGS & Private	N	Y - Superior Natl Forest	Y - USS	N (oxtac potential?)
possible	Environmental Concerns	C	N	N	N	N	Y - close proximity to drinking water source	N	? - use old tailings basin	Y - reuse of Process water	N? (adjacent to State Park)
no	Local Construction materials	R	Y	Y	Y - lots	Y	Y - tails	Y	Y	Y - lots	Y
possible	Site Costs (infrastructure, etc.)	R	Low	Low	Low	Low	Low	Low	**High - upper reservoir on granite knob**	Low	Low
possible	Regulatory Issues	R	N	N	N? - nearby small wetlands	N	? - Treaty Lands	N	**Y - Superior Nat'l Forest plans?**	? - Treaty Lands	**Y - State Park; upper reservoir=wetlands**
possible	Safety Issues	C	N	N	Y - dams/banks	N	Y - Coffer Dam	N	on granite knob/Dam safety	Y - banks for upper reservoir	Y - Coffer Dam
no	Underground Mining Potential	C	N	N	Y - surface in future	N	N	N	N	N	Y
possible	existing basins	R	2 good lower reservoirs	both basins	lower	3 lower reservoirs	both basins	**lower - need to wait for mine closure**	lower = tailings basin; upper = on granite hill	4 lower reservoirs	**Upper reservoir = wetland**
possible	existing underground mines	C	Y - drift from south (could be cemented)	N	Y	N	Y - very close	Y	N	N	unknown
	Fatal Flaws		None	None	None	None	None	Need to wait for Laurentian mine closure	None	East Pit - will be mined into future	Upper reservoir = wetland
	Potential Fatal Flaws		Hibtac's Mine Plans? Laurentian Vision Plans?	Hibtac's Mine Plans? Laurentian Vision Plans?	reservoirs straddle Laurentian Divide; Chisholm water supply?	USS's Mine Plans? In Mississippi drainage?	Mining to west? / Arcelor-Mittal's Plans?	Arcelor-Mittal's reclamation plans; Gilbert water source close-by?	Superior Nat'l Forest Plans; Arcelor-Mittal plans for future tailings?	West Pit - USS's Mine Plans	Water Source for Essar?
	FINAL RANKING		**1**	**2**	**3**	**4**	**5**	**6 (future site after mine closure?)**	**7**	**8 = West Pit**	**9**

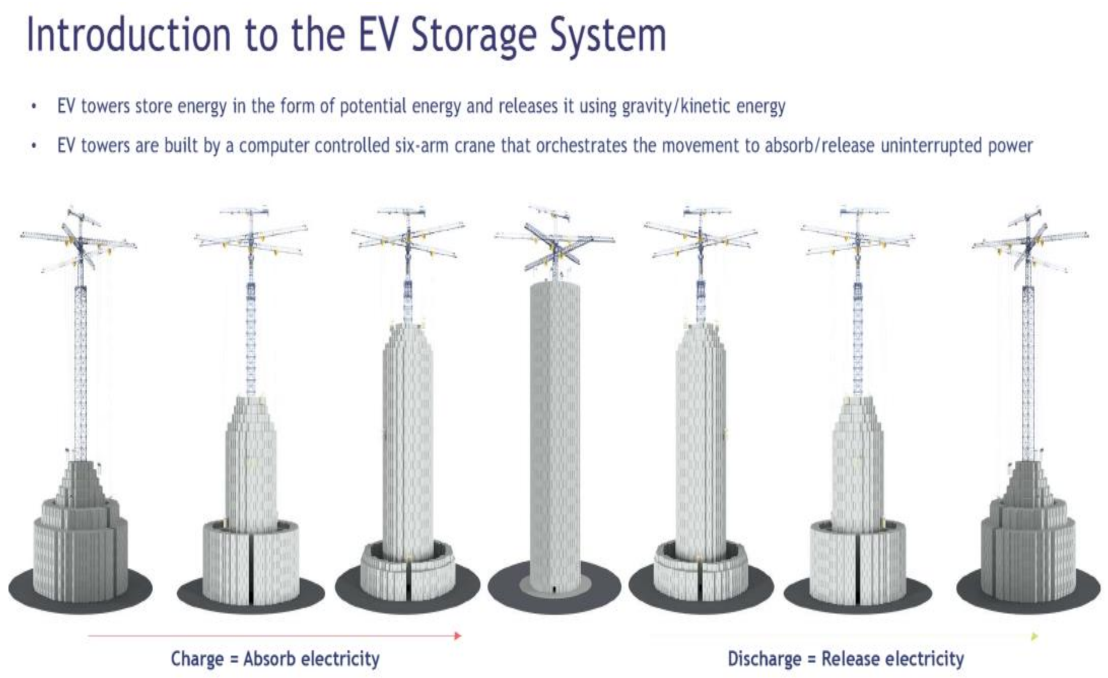
Advanced-CAES Example



Typical Assessment



Other Non-Battery Technologies



Energy Vault Concept for Long Duration Storage

- Use Potential Energy and Gravity to Generate Power
- Employ Already Known Technology and New Control Logic

Projected Costs Comparisons per Installed Capacity

- $350/$400 per kWh for Batteries
- $300 per kWh for Pumped Hydro
- $250 per kWh for Energy Vault

Many options need to be considered depending on local situation and storage needs

Thank You

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