Bioenergy and Energy Storage Development

Donald R. Fosnacht, Ph.D.

Presented to: United States Energy Association
Date: July 17, 2019
NRRI Mission

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

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 COLERAIN**E is a 27-acre industrial laboratory site focused on minerals, metallurgy and wood products, bio-based energy research.
INNOVATION THROUGH INTEGRATION

Integrated Research Groups

NRRI is:
• Unique
• Anticipatory
• Comprehensive
• Integrated

Our Partners:
• Industry
• Business
• Agencies
• NGOs
Integrated, System-based Biomass Processing Research Platform

Biomass

- Biomass Characterization
  - availability
  - composition

- Biomass Sourcing
  - Wood
  - Ag
  - municipal

Dry\textsuperscript{1} Torrefaction

Wet\textsuperscript{2} Torrefaction

Elemental Sulfur

H$_2$O Treatment

Digestion

Methane

Solid Fuels

MARKET DRIVERS

- Transportation
  - road, rail, other

- Power Generation
  - (100kW advanced boiler / generator under delivery)

- Liquid Fuels
  - jet, diesel, other

Low Pressure

High Pressure

Catalytic

SynGas (CO, H$_2$)

catalysis

catalysis

Gasification

Chemicals & Materials

- soil amendments,
  - monomers, polymers,
  - composites, electronics

Inorganics Separation

Char & Advanced Carbon Products

Rotary Kiln System

\textsuperscript{1}Demo-scale rotary & moving bed (3 to 6 T/day)

\textsuperscript{2}Pilot scale (110 lbs/day)
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 Superheated 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

- **2011**
  - Rocket Reactor

- **2012-2013**
  - "Pig Roaster" Rotary Torrefaction

- **2014**
  - Pilot 8” Kiln

- **2015-2018**
  - REL – Coleraine H&P Kiln

NRRI • Innovative Research • Minnesota Value • Global Relevance • www.nrri.umn.edu
Overview of Kiln Reactor for Torrefaction and Char
Moving Bed Design and Construction
Moving Bed View and Boiler/Generator Design

Moving Bed Torrefaction Reactor

100 kW Boiler/Generator Schematic
Overview of Densification Room
Key Variables and Densification Parameters for Acceptable Briquettes

- Particle Distribution
  - Fines
  - Varying Sizes
- Temperature of Mix
  - Ease of Grinding
- Machine Parameters
  - Material
  - Limit of Capacity
- Blend Mixing Intensity
  - Pressure
  - Roll Temperature
  - Roll Design
  - Moisture Uptake
  - Time
  - Temperature
- Material Processed
- Surface Cleanliness
  - Deposits
  - Properties Needed
  - Adhesion of Binders
- Binder Selection and Dosage
  - Starting Material
    - HTC
    - Process Temperature
    - Guar Gum
- Degree of Torrefaction

WELL DENSIFIED PRODUCTS
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

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

<table>
<thead>
<tr>
<th>Deal Breaker</th>
<th>Criteria</th>
<th>Requirements/Concerns</th>
<th>Morton-South (Agnew)</th>
<th>Hibtaq</th>
<th>Chisholm-Buhi (Harley)</th>
<th>Keetac-North</th>
<th>Alpena-Minora</th>
<th>Virg Horn - South (Laurentian Mine)</th>
<th>Virg Horn - North</th>
<th>Minnac (East and West pits)</th>
<th>Arcturus</th>
</tr>
</thead>
<tbody>
<tr>
<td>definitely</td>
<td>Head</td>
<td>R</td>
<td>~550 feet</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y - need to wait for mine closure</td>
<td>(needs to be calculated)</td>
<td>~350 feet</td>
<td>~350 feet</td>
</tr>
<tr>
<td>definitely</td>
<td>Volume</td>
<td>R</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y - need to wait for mine closure</td>
<td>(needs to be calculated)</td>
<td>~350 feet</td>
<td>~350 feet</td>
</tr>
<tr>
<td>possible</td>
<td>Adj. to current mining/blasting</td>
<td>C</td>
<td>Y</td>
<td>Y</td>
<td>Y?</td>
<td>N</td>
<td>Y</td>
<td>Y? - Fraser Pit is Chisholm's water supply</td>
<td>currently Laurentian Pt</td>
<td>N</td>
<td>Y - remote</td>
</tr>
<tr>
<td>possible</td>
<td>Fault/fractures</td>
<td>C</td>
<td>likely</td>
<td>likely</td>
<td>likely</td>
<td>likely</td>
<td>likely</td>
<td>Y - very close to known fault system</td>
<td>likely</td>
<td>likely</td>
<td>likely</td>
</tr>
<tr>
<td>possible</td>
<td>Water Quality/Hydrology</td>
<td>C</td>
<td>N</td>
<td>Y</td>
<td>Y?</td>
<td>N</td>
<td>N</td>
<td>process water; close to Virginia water source</td>
<td>N</td>
<td>? - use old tailings basin</td>
<td>? - lift iron water source?</td>
</tr>
<tr>
<td>possible</td>
<td>Environmental Concerns</td>
<td>C</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y - close proximity to drinking water source</td>
<td>N</td>
<td>? - use old tailings basin</td>
<td>Y - reuse of Process water</td>
</tr>
<tr>
<td>no</td>
<td>Local Construction materials</td>
<td>R</td>
<td>Y</td>
<td>Y</td>
<td>Y - lots</td>
<td>Y - small</td>
<td>Y</td>
<td>Y - lots</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>possible</td>
<td>Site Costs (infrastructure, etc.)</td>
<td>R</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High - upper reservoir on granite knob</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>no</td>
<td>Underground Mining Potential</td>
<td>C</td>
<td>N</td>
<td>Y?</td>
<td>Y - surface in future</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>possible</td>
<td>existing basins</td>
<td>R</td>
<td>2 good lower reserves</td>
<td>both basins</td>
<td>lower</td>
<td>3 lower reservoirs</td>
<td>both basins</td>
<td>lower - need to wait for mine closure</td>
<td>lower = tailings basin; upper = on granite hill</td>
<td>4 lower reservoirs</td>
<td>Upper reservoir = wetland</td>
</tr>
<tr>
<td>possible</td>
<td>existing underground mines</td>
<td>C</td>
<td>Y - drift from south (could be cemented)</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y - very close</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Fatal Flaws</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>East Pit - will be mixed into future</td>
<td>Upper reservoir = wetland</td>
</tr>
<tr>
<td>FINAL RANKING</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6 (future site after mine closure?)</td>
<td>7</td>
<td>8 = West Pit</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**NRRI** • Innovative Research • Minnesota Value • Global Relevance • www.nrri.umn.edu
Advanced-CAES Example
Typical Assessment

CAES Feasibility Study
(To go or not to go)

Task 5
Scoping Study Completed
- 5 Candidate Sites Described
- 3D Geologic Models
- Project Review
- Technical Report
- Marketing Materials

Task 4
Site Prioritization
- Geologic Favorability
- Proximity Favorability
- Geologic Geometry
- Overburden Characteristics
- Surface Rights
- Mineral Rights
- Permitting Analysis
- Environmental Analysis

Task 3
GIS Spatial Analysis
- Geologic Data Overlay
  - Rock Units
  - Bedrock Depth
  - Structure Buffers
  - Excavated Rock Volume
- Fuzzy Logic Weighting & Combination Rules
- Candidate Sites Identified
- Proximity Analyses
  - Existing Water Wells
  - Potential Water Source
  - Electric Grid Infrastructure
  - Transportation Infrastructure

Task 2
Assembling Siting Criteria
- Geology Map Unit
  - Fuzzy Weighting
- Structure Type Buffering
- Excavated Rock Valuation
- Depth to Bedrock
- Lakes
- Mining Disturbances
- Brownfield vs Greenfield Site
- Infrastructure
- Water Wells

Task 1
Project Definition
- CAES System Size
  - MW / MWh
  - Required Depth
- Permitting Issues
  - Water
  - Land
- Legislative Issues
  - Agenda
  - Bills
- CAES System Type
  - Closed Loop
  - Open Loop
- Project Affordability, Technical Viability, Customer Sensitivity
- Location - Location - Location

NRRI • Innovative Research • Minnesota Value • Global Relevance • www.nrri.umn.edu
Other Non-Battery Technologies

Introduction to the EV Storage System

- EV towers store energy in the form of potential energy and releases it using gravity/kinetic energy
- EV towers are built by a computer controlled six-arm crane that orchestrates the movement to absorb/release uninterrupted power

- 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

Donald R. Fosnacht, Ph.D.
Associate Director
email: dfosnach@d.umn.edu