Painesville Municipal Electric Power
Vanadium Redox Battery Demonstration Project

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Ashlawn Energy LLC
US Produced Vanadium Redox Flow Battery for Bulk Storage, Peak Shaving

- 8 MW Hour redox flow battery (1MW 8 hours)
- To be installed at Painesville Municipal Electric Plant (PMEP), a 32 MW coal fired facility
- Most efficient PMEP operation is steady state at 26 MW (lowest emissions, lowest operating cost)
- Nominal PMEP power demand ranges from 19 MW to 37 MW
- 8 MW Hour battery to demonstrate benefits of energy storage at PMEP
History of Painesville Power

1885 - Established by the Globe Electric Company, the Painesville Council contracted for street lights at $6 per light per month.

1888 - Council sold bonds raising $12,500 to erect an Electric Light Plant on N. St. Clair near Main Street in back of the old Fire and Police Station (now public parking lot). The plant continued in operation until 1908. Municipal Electric Systems in Painesville and was adopted by Resolution 223.

1907 - Painesville Cider and Manufacturing Company property (site of present Light Plant) was purchased for $2,250.

1908 - A new plant was put into operation. The Commercial Electric Company phased itself out of operation around this time.

1923 and again in 1928, large general expansions of the plant facilities created by an increasing demand for electric power in the growing Painesville area.

1923 - A 1500 kilowatt steam turbine generator manufactured by Allis-Chalmers was installed to replace the existing reciprocating engine type generators and continued in operation until the late 1950s. This was the first large steam turbine at the Light Plant.

Additional Coal fired boilers steam turbines generators and allied equipment have been added to the Light Plant over the course of the years.

The American Public Power Association's grouping of Centennial Cities and Towns lists Painesville's system as the 10th oldest in the country of those communities that still operate their systems. In addition, it is one of 14 municipally-owned electric systems in Ohio still generating, and the oldest still in continuous operation.
Project has Multiple Objectives

• Establish/Use US Manufacturing Base
  – Stack components/stack fabrication
  – Electrolyte
  – Power Conditioning System

• Demonstrate Efficacy/Reliability of latest Vanadium Redox Flow Battery Design

• Cost Reduction

• Platform for Commercially Viable Product
Primary US Based Producers

- GrafTech International – Plates/Felt
- Strategic Minerals Corporation – Electrolyte
- DuPont and/or Other Producers – Membrane
- Innoventures – Stack Components/Stack
- American SuperConductor - Inverter
Original Top Level WBS

PMEP
Vanadium Redox Battery Demonstration Project
Top Level WBS

Phase I
Project Definition and Design

- Task 1.0 Update PMP
- Task 2.0 NEPA Compliance
- Task 3.0 Interoperability and Cyber Security Plan
- Task 4.0 Develop Metrics and Benefits Reporting Plan

- Task 5.0 Design, Scale up
  - Task 5.A Engineering and Design
  - Task 5.B Power Interface & Integration
  - Task 5.C Technology Transfer and Scale Up
  - Task 5.D Battery 1 Fabrication, Installation and Testing (540KW)

Phase II
Final Design and Construction

- Task 5.0 Design, Fabricate, Install, Test and Commission
  - Task 5.E Facility Construction and Preparation
  - Task 5.F Battery 2 Fabrication, Installation and Testing (540KW)
  - Task 5.G Release Final Operating and Maintenance Procedures

Phase III
Commissioning and Operations

- Task 6.0 Data Collection and Monitoring

Deliverables for all Phases

Hardware, Plans, Reports, Reviews
## Original Overall Schedule

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*Note: The diagram shows the timeline for each task with specific milestones and deadlines marked.*
Original Improvement Targets

• Vanadium Electrolyte from 1.75 M to 3.12 M
• Stack Size from standard 5 kW to 30 kW
• Power Inverter Efficiency (2% increase)
• Process System Efficiency (5% increase)
• Reduced foot print
Original Battery Layout

[Diagram showing the layout of battery systems with labels for positive and negative electrolyte, grouping of stacks, pumps, and interface connections.]
Modular Design

Painesville building block – 5 kw stack
1 Module below of 100 kw is made up of 20, 5 kw stacks

Continuous Discharge Rate (kW)

1 Module (100 kW)

2 Modules (200 kW)

3 Modules (300 kW)

10 Modules (1MW)
Painesville Storage time
The amount of Vanadium Electrolyte dictates storage time in hours

Capacity (kWh)

250 kWh = 3,000 G

500 kWh = 6,000 G

1 MWH = 12,000 G
Major Cost Drivers at Start

- Electrolyte: 36%
- Building: 13%
- Other Stack Costs: 15%
- Process System: 9%
- Power Converter: 5%
- Membrane (US): 9%
- Other: 1%
- Engineering: 8%
- Project Management: 4%
Project Risk Analysis

• 10 kW stack prove out and electrolyte pricing are key to meeting cost targets
• Process design schedule confirmation is key to meeting building schedule
• Higher molar electrolyte is key to storage time target
• Process design changes will demonstrate round trip efficiency improvements
Progress To Date

• Status in Selected Areas
  – 250 watt, 2.5 kW and 10 kW prototypes Fabricated
  – Battery Test Bed System Operational
  – Electrolyte Prototype Production/Conversion Line Complete
  – Target Building Footprint Achieved/Building Site/Design Complete
  – Building Contract Awarded
  – Flow Frame Mold Steel Released for Purchase
  – Various Membranes, Bi-Polar Plates and Felt Tested
  – Improved Flow Frame Design/Fabrication Complete
  – 7 Potential Patents Identified/2 in Process

• 10 kW Stack Milestone Test to Complete End October

• Lower Cost Components in Queue for Testing
Cyber Security & Interoperability

• Cyber Security/Interoperability Plan Submitted and Accepted by DOE
  – CISO (Chief Information Security Officer) employed and active
  – Member: NIST Smart Grid Interoperability and Cyber Security Working Group (SGIP/CSWG)
  – Program represented at DOE Cyber Security Information Exchange in Chicago, Summer 2011

• Cyber Security Plan in effect
  – Incident Response Team assembled: contact information posted
  – Administrative team assembled: coordinates with CISO
  – Cyber Security best-practices distributed to team and potential vendors
• Threat Reduction / Risk Analysis

  – Project will be air-gapped from plant SCADA (No Remote Data Communications)
  – Not enough current to cause ripple electrical disturbance at PMEP
  – Battery Control System will be locked and secured per applicable NERC standards
  – DOE-approved security policies will be in effect for all information systems
Painesville Municipal Electric Power Plant

Battery Building Site
Various Stacks & Prototype Lines

Ashlawn Energy Battery Pilot Line

Ashlawn Energy Prototype Stack Design

Ashlawn Energy Prototype Stack Design for Painesville Battery Project

Ashlawn Energy Electrolyte Conversion Pilot Line

Ashlawn Energy Prototype Stack Design
Project Approach Changed Based on the Outcome of Tests on Various Design Improvements
Current Improvement Targets

• Operational Stack Size from 10 kW to 20 kW
• 30 kW Prototype Prove Out
• Power Inverter Efficiency (2% increase)
• Process System Efficiency (5% increase)
• Mixed Acid Vanadium Electrolyte
Current Overall Schedule
Modular Design

Stack Modules - Higher Power

Painesville building block – 20kw stack
1 Module below of 400 kw is made up of 20, 20kw stacks

Continuous Discharge Rate (kW)

1 Module (400 kW)

2 Modules (800 kW)

2.5 Modules (1 MW)
Modular Design
Vanadium Electrolyte Modules-Higher Molarity

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<th>Capacity (kWh)</th>
<th>250 kWh = 2,100 G</th>
<th>500 kWh = 4,200 G</th>
<th>1 MWH = 8,800 G</th>
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Painesville Storage time
The amount of Vanadium Electrolyte dictates storage time in hours
Distribution of Cost Factors

- Molded Flow Frames
- Lower Membrane Costs
- Graphite-Coated Collector Plates
- Bonded Felt
- Composite End Plates
- 10 kW Stack Prove Out
- 20 kW Stack Design
Summary/Conclusions

• Project will complete well ahead of original schedule and is currently over budget

• Test bed confirmation of higher molarity electrolyte is key to storage time target

• Design Improvements have reduced costs

• Test bed confirmation of process design changes will demonstrate round trip efficiency improvements
Future Tasks

- Complete Operational Testing of Prototypes
- Building Construction
- Long Lead Orders on Manufacturing Equipment/Components
- Balance of Plant Final Design
- Inverter Design Modifications
- Competitive Bids on Components (all US)
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Questions?