Technologies for extracting valuable metals and compounds from geothermal fluids

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Simbol Mining Corp.
Specialized Materials and Fluids and Power Plants

This presentation does not contain any proprietary confidential, or otherwise restricted information.
Overview

- Simbol Mining Corp. (Simbol) will produce battery chemicals
  - Lithium
  - Manganese
  - Zinc
- Salton Sea hypersaline geothermal reservoir, Imperial Valley, Southern CA
- Each 50 MW geothermal plant can produce annually:
  - 16,000 tonnes of lithium carbonate equivalent
  - 24,000 tonnes of electrolytic manganese dioxide
  - 8,000 tonnes of zinc metal
- Simbol initial resource agreement
  - Four plus 50 MW plants

Representative brine chemistry

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<tr>
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<th>mg/kg</th>
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<tr>
<td>Na</td>
<td>53,000</td>
<td>Li</td>
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<tr>
<td>K</td>
<td>29,000</td>
<td>Mn</td>
</tr>
<tr>
<td>Ca</td>
<td>33,000</td>
<td>Zn</td>
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<tr>
<td>SiO₂</td>
<td>200</td>
<td>Cs</td>
</tr>
<tr>
<td>Fe</td>
<td>1,500</td>
<td>Rb</td>
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<tr>
<td>TDS</td>
<td>31 wt%</td>
<td>Cl</td>
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<td>pH</td>
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</table>
Metal extraction post-power production, pre-injection

Lowest cost of production and only green lithium production process

Source: DOE; Simbol analysis
Overview of R&D plan

Silica removal (Task 1)

Silica mgmt.

Improved Li extractants (Task 3)

Lithium extraction

Zn and MnO₂ lab tests (Task 6)

Mn / Zn precipitation

K (Task 8) Cs, Rb (Task 9) recovery

To injection well

Brine

Silica by-products: Colloidal silica (Task 1) Iron silicate (Task 2)

Lithium carbonate (Li₂CO₃)

Lithium hydroxide (LiOH)

Lithium chloride

Zinc metal (Zn)

Electrolytic manganese dioxide (EMD)

Manufacture of cathode materials (Task 7)

Lab tests and field pilot (Tasks 4, 5)
Overview

• Timeline
  – Start May 1, 2010
  – End April 30, 2012 (pre-award activities post-Oct. 22, 2009)

• Budget
  – Total $9,633,543
  – DOE share $3,000,000
  – Simbol match $6,633,543 (69%)
  – $0 funding received to date
  – $7,397,268 planned FY10 expenditures
Relevance/Impact of Research

• Project goals
  – Demonstrate geothermal mineral extraction
  – Demonstrate technical and economic feasibility
  – Produce products for market development
  – Generate operational data and scale up data so a commercial scale plant can be designed and built

• Despite its economic potential, mineral extraction from geothermal brines has not been successfully commercialized

• Simbol’s business model puts mineral extraction into a separate company, shielding the geothermal operator from risk and letting each company focus on its core competencies

• Simbol will fully commercialize its technology by partnering with geothermal developers and operators
Relevance/Impact of Research

• This project may improve the economics of geothermal projects by creating new revenue streams for the geothermal operator through royalties from the sale of geothermal by-products
  – Offset the cost of geothermal electricity by up to 0.5¢/kWh per mineral
  – Provide mineral royalties of about $4MM annually per 1% royalty to the geothermal operator
  – Annual revenues will be multiples larger than those from electricity sales

• U.S. geothermal power plants can satisfy the nation’s need for an environmentally friendly and domestic source of lithium and other chemicals which are key components of batteries for electric vehicle and energy storage technologies
 Scientifi c/Technical Approach

• Initial target: lithium extraction
  – Build a demonstration plant - 15 tonnes/year (6 gpm of brine flow)
  – Technical proof of process- at least 1,000 hours of operation
  – Economic proof of process- validate operating cost/capital estimates
  – Produce commercial grade products customer qualification
  – Demonstrate scalability
  – Optimization
  – Operations discipline & training
Scientific/Technical Approach

- Lab-based extraction technology development with surrogate brine (e.g. Li, K, Cs, Rb)
  - Technology ID
  - Bench scale testing: capture and recovery
    - Go/no go decision (e.g. > 80% selectivity)
  - Bench scale columns: capacity and lifetime
    - Go/no go decision (e.g. adequate physical stability)
  - Small Pilot Optimization
    - Operating parameters for scale-up
    - Go/no go to field testing (30-50% economic improvement over existing technology)

- Field testing with live geothermal brine at CalEnergy’s Elmore geothermal power plant
  - Small pilot testing in field
    - Next generation silica management
    - Next generation lithium extraction
  - Demonstration plant testing (6 gpm)
    - Silica management/lithium extraction
    - Lithium carbonate and lithium hydroxide production
Accomplishments, Expected Outcomes and Progress

• Accomplishments to date
  – Manufacturing and lab testing of next generation lithium extraction materials
  – Developed and validated end-to-end process to producing lithium chloride at lab scale
  – 1/1,000-scale pilot operating with surrogate brine (6 gpm)
  – Secured site access agreement with CalEnergy for on-site testing

Task 3: Manufacturing next generation of lithium extractants and conducting lab testing
  – Created 7 new materials and tested 5 in bench scale tests
    • Up to 2,600 cycles
    • Mass selectivity of Li vs. divalent cations is > 500
    • Extraction varies from 50 to 90% depending on media
  – Scaled two materials to field pilot scale
Accomplishments, Expected Outcomes and Progress

Task 5: Demonstrated silica management and lithium extraction technologies

- Surrogate geothermal brines (30 wt.% TDS)
- Constructed 6 gpm pilot
- Operated for >500 hours
- Silica decreased to ND
- Achieved >50% lithium extraction
- Confirmed chemical consumption and process efficiencies
Accomplishments, Expected Outcomes and Progress

Task 6: SGS reports on manganese and zinc extraction
  – Key steps in the process demonstrated at the bench scale
  – Awaiting technical and economic reports from Independent Engineers

Task 8: Potassium extraction
  – Begun synthesizing and characterizing variations of existing ion-exchange materials for potassium extraction
<table>
<thead>
<tr>
<th>Project Management/Coordination</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
<th>Q7</th>
<th>Q8</th>
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<tbody>
<tr>
<td>Silica mgmt- next generation technologies</td>
<td>Process optimization in lab</td>
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<td>Conversion of silica ppt to product</td>
<td>Removal of toxic elements</td>
<td>Pilot testing</td>
<td>Ppt dissoln.</td>
<td>LiFePO4 lab tests</td>
<td>Pilot testing</td>
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<td>New materials for Li extraction</td>
<td>Design and testing</td>
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<td>Pilot testing</td>
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<td>Lab piloting of Li2CO3 and LiOH production</td>
<td>Design and build pilot</td>
<td>Optimize unit ops</td>
<td>Continuous operation</td>
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<td>Li extraction field pilot</td>
<td>Design and build</td>
<td>Demo using surrogate brine</td>
<td>Li extraction at geothermal plant</td>
<td>Li2CO3, LiOH production at geothermal plant</td>
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<td>Mn, Zn lab tests</td>
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<td>Li-ion battery cathode manufacturing</td>
<td>Impurity testing</td>
<td>Make cathode materials</td>
<td>Cathode performance tests</td>
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<td>K extraction</td>
<td>Loading, unloading tests</td>
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<td>Column tests</td>
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<td>Cs, Rb extraction</td>
<td>Loading and unloading tests</td>
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<td>Project management and reporting</td>
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- ▲ Task completion
- ▲ Subtask completion
- ▲ Go/no go decision point
- ▶ Economic evaluation
- ▲ Progress to date
### Project Management/Coordination

<table>
<thead>
<tr>
<th>Task #</th>
<th>Task</th>
<th>Total funding (excl. indirect and fringe)</th>
<th>% of total project</th>
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<td>Silica mgmt – next generation</td>
<td>$449,892</td>
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Simbol match: 69%
Project Management/Coordination

Spending plan per task and quarter

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<th>Description</th>
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<th>Q2</th>
<th>Q3</th>
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Total: $9,633,543
Project Management/Coordination

Spending plan per category *

- Task 1 - New silica mgmt
- Task 2 - Silica product
- Task 3 - New lithium extractants
- Task 4 - Lab Li2CO3, LiOH production
- Task 5 - Lithium ext. field pilot
- Task 6 - Mn, Zn lab tests
- Task 7 - Cathode manufacturing
- Task 8 - K extraction
- Task 9 - Cs, Rb extraction
- Task 10 - Project mgmt/reporting

* excluding fringe and indirect
Future Directions & Summary

- Start Tasks 1, 2, 4 & 9
- Continue scale-up of Li extraction materials (Task 3)
- Li extraction (Task 5)
  - Transfer demo plant to CalEnergy’s Elmore power plant
  - Operate 3rd quarter 2010
- Complete Task 6

✔ Simbol has made significant progress during 90 day pre-award period
✔ Ahead of schedule for field testing of first generation technologies in the demonstration plant
✔ Ready to commence remaining laboratory-based R&D activities