The Gravity Power Module (GPM)

Storing Energy
The Gravity Power Module (GPM)

Generating Power
The Gravity Power Module (GPM)

- Modular pumped storage
- Much lower cost/kW installed versus conventional PSH
- Low cost materials (cement, iron ore, steel)
- No exhaust stack
- Flexible siting
- Very little land use
- Quiet
- Fast permitting
- Rapid construction
- Excellent dynamic response
- Short time to revenue
- Patents Pending
Single-Piston Design

- Piston carved from native rock
- 250m piston in 500m shaft
- 500m piston in 1000m shaft
- $\approx 2500 \text{ kg/m}^3$
- Reinforced concrete lining
- Reinforced concrete baseplate
- Smooth piston outer lining
- Sliding seals
- Dynamic balancing (no positioning wheels)
Small GPM – 40 MW, 160 MWh

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Shaft Diam.</td>
<td>33.2 m</td>
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<tr>
<td>Shaft Depth</td>
<td>500 m</td>
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<tr>
<td>Power System</td>
<td>Francis pump-turbine Synchronous AC M/G</td>
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<tr>
<td>Operating Pressure</td>
<td>375 meters of head (3.7 MPa, 533 psi)</td>
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<td>RT Efficiency</td>
<td>~80%</td>
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<tr>
<td>Storage Mass</td>
<td>436,000 tonnes</td>
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<tr>
<td>Water Volume</td>
<td>245,000 cubic meters</td>
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</table>
Big GPM – 1000 MW, 4000 MWh

- **Shaft Diam.**: 80 m
- **Shaft Depth**: 1000 m
- **Power System**: Francis pump-turbine
  Synchronous AC M/G
- **Operating Pressure**: 750 meters of head
  (7.35 MPa, 1065 psi)
- **RT Efficiency**: 83+% 
- **Storage Mass**: 5.4M tonnes
- **Water Volume**: 2.75 Million cubic meters
1,000 Megawatt GPM (4,000 MWh)
High Throughput Shaft Excavation

- Large diameter allows open-pit mining technology:
  - High throughput excavation equipment
  - Drill & Blast
  - Large crew size

- Potential for rapid excavation
- Potential for very low cost
Blasthole Drilling
Blasthole Drilling
Blasthole Drilling
Blasthole Loading
Pre-splitting to Limit Blast Damage
Controlled Blast

Minimal projectile danger
Open Pit Muck Removal

100 tonnes per scoop
10,000 Tonnes per Hour...

...but not shaft compatible.
Deep Shaft Muck Removal

- **Medium size equipment**
  - Can be hoisted
- **Conveyors instead of trucks**
  - Similar capacity & cost
Loaders

- Inexpensive
- High capacity
- All sizes
Rock Crusher

Smashes rock to conveyor-compatible size
Vertical Conveyor

- Very high throughput
  (Up to 4000 m$^3$/hour per conveyor)
- 500 meter vertical lift
- 1000 meter lift possible
- Low cost
Construction Sequence

1. Prepare site
2. Excavate top half of shaft
3. Rock bolt & shotcrete shaft wall
4. Excavate annulus around piston
5. Rock bolt & shotcrete piston & annulus wall
6. Excavate & line return tunnel
7. Excavate & line return shaft
8. Incrementally mine under piston and replace with reinforced concrete base
9. Line piston & shaft wall with reinforced concrete
10. Cover piston with smooth liner
11. Install seals
12. Fill with water

80m x 1000m GPM at correct scale
Shaft Excavation

vertical conveyor

Rock bolts and shotcrete
Piston Release

Annulus cut using drill & blast and/or mining machines

Tunnel also cut this way
Tunnel Under Piston
Install Roof Bolts & Floor

- Rock bolts
- Steel plate
- Concrete
Install Reinforcement

- Rebar
- Steel plate
Baseplate-Floor Close-up

Rebar

Baseplate steel

Floor steel
Prepare for Grouting

Casting form
Place Initial Support

Concrete fill
Widen Tunnel
Repeat Under Entire Piston

- Support
- Floor
Slip-form Final Liners

- Shaft
- Piston
Completed Piston Baseplate

Rock Piston

Steel & Concrete Baseplate
Hydraulic Force
Piston Cutaway Close-up
GPM Products Planned

Ancillary Services GPM
• 25MW capacity x 20 min.
• Cost/kw: $1,000

Intermediate Peaking Plant
• 40MW capacity x 4 hours
• Cost/kw: $1,900

Business Model: Gravity Power will sell and construct turnkey power plants

GPM Price Assumptions: Costs shown assume a 20% contingency and 15% profit

2010 EIA Costs for PSH equal $5595/kW at 250MW of capacity: GPMs will be much less expensive on a $/kW basis and more flexibly sited

Eventual Peaking Plants
• 150-1000+MW capacity x 4+ hours
• Cost/kw: $1000
Pump-Turbine

- Proven technology
- Operates at fixed pressure in GPMs and thus its best efficiency point most of the time
- Sits at ground level
- Expert PhD pump-turbine engineer on staff, formerly of Hitachi
## Company Milestones

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<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
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<td><strong>GPM System Design</strong></td>
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<td><strong>B-Round Financing Complete</strong></td>
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<td><strong>Commercial Demo</strong></td>
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Early-Stage Target Markets

Priority

- Germany
- Middle East
- China
- South Africa
- United States
Team

- Tom Mason, CEO
  - Former EVP of Calpine, Responsible for 92 power plants

- David Anthony, Board of Directors
  - 21Ventures/Quercus Trust, Portfolio of >40 cleantech companies

- Jim Fiske, Founder and CTO
  - Serial Entrepreneur, R&D Engineer

- Chris Grieco, Executive VP
  - Extensive experience in Renewable Energy

- Dr. Jingchun Wu, Chief Scientist
  - PhD with experience in pump-turbine hydraulics
Tom Mason, CEO

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