By co-locating cryogenic industries for mutual benefit

Recovering Cryogenic Refrigeration Energy From LNG Terminals for Data Center Cooling and Power

Technology Presentation

Datacentres Europe 2014

May 2014
Cooling and Power Opportunity – LNG Terminals

• **Liquefied Natural Gas (LNG) terminals**
  – LNG – mostly methane – a cryogenic liquid at −162° C (-260° F)
    • Expands 600x during liquid to gas phase change
  – Massive energy stored during liquefaction is lost
  – Mission-critical, continuous operation for natural gas send-out
    • **~15-700 MW/hr refrigeration capacity typically unused**
  – Some terminals burn ~1.75% of supply to heat LNG to 60° F for send-out
  – 20-40 year contracts for LNG delivery and gas pipeline send-out

• **LNG industry growth**
  – Production doubling 2005-2015
  – 4.5% annual growth projected 2015-2025
  – New shale gas supplies create expanding market for LNG
  – Political uncertainty driving growth in Europe (e.g. Ukraine)
TeraCool Technology

**Heat Exchange**
- Recover “waste cold” from LNG terminals to cool data centers
- Waste heat from data centers lowers LNG vaporization costs and emissions

**Expansion Turbines**
- Generate emissions free, base-load power for data centers via non-combustion expansion turbines

• Flexible and standard design approaches
• Best fit where power costs and/or ambient temps are high and sustainability goals are present

_TeraCool - at nexus of two critical and rapidly growing sectors:_

*LNG Terminals and Data Centers*
Selected technologies used in LNG cold recovery:
• Air and condensate cooling for CHP and CCGT
• Air separation and liquefaction (industrial gas production)
• Chemical manufacturing
• Clean power generation via expansion turbines
• Frozen food, cold warehouse, dry ice, aquaculture

Selected countries using LNG cold recovery:
• Belgium
• China
• France
• India
• Japan
• Netherlands
• South Korea
• Spain
• Taiwan
• UK
Interconnection between storage tank and vaporizer, supplementing existing LNG vaporizers.
Terminal Safety Measures

In ~70+ years of modern commercial LNG use, no major accidents, safety or security problems have occurred in port or at sea

- **Hazards mitigation:**
  - Primary containment – high nickel steel surrounded by 3 foot thick concrete
  - Secondary containment (has never been utilized)
  - Redundant safeguard systems
  - Separation distances (Data Center outside of separation zone)

- **International safety example:**
  - Japan Earthquake – March 2011
    - 28 LNG terminals [1/3rd of world’s total]
      - Only one temporarily off-line
    - No other incidents

- **In U.S.:**
  - Highly regulated by several Federal safety agencies for construction and operations
  - Evaluated by Homeland Security Dept. No additional measures needed
Existing LNG Terminals - Global
Heat Exchange Process

• ~90% efficient heat exchange refrigeration loop

• LNG terminals have enough cold to cool largest data centers

• Refrigeration/heat can travel up to two km between facilities
  – Further separation lowers efficiency and increases costs

• Patent pending
Schematic: Heat Exchange

Note: Other non-toxic and non-flammable refrigerants or glycol/water can be used instead of ammonia.
Electrical Power Generation

- Excess refrigeration available at most LNG terminals beyond data center cooling needs

- Temperature gradient between LNG and ambient can drive expansion turbines generating non-combustion, zero-emissions electrical power
  - 2.5 MW and up
  - Japan ~ 45 MW installed capacity at LNG terminals

- 25-30% overall energy efficiency

- Patent pending
Available via Non-Disclosure Agreement
Case Studies

Singapore – Singapore LNG

France – Fos Cavaou LNG

Portugal – Sines LNG
## Case Study: 30 MW Data Center Example

<table>
<thead>
<tr>
<th>Data Center Size:</th>
<th>30 MW IT + 10 MW Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COOLING ONLY</td>
</tr>
<tr>
<td>Capital Costs:*</td>
<td>$ 9 million</td>
</tr>
<tr>
<td>Gross Annual Savings:</td>
<td>$ 19.1 million</td>
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<tr>
<td>Annual Operating Costs:</td>
<td>$ 2.8 million</td>
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<tr>
<td>Net Annual Energy Savings:</td>
<td>$ 16.3 million</td>
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<tr>
<td>Internal Rate of Return:</td>
<td>187%</td>
</tr>
</tbody>
</table>

- Does not include TeraCool or LNG terminal fees or savings
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<td></td>
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<tr>
<td>Capital Costs:*</td>
<td>$ 7.0 million</td>
</tr>
<tr>
<td>Gross Annual Savings:</td>
<td>$ 7.3 million</td>
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<tr>
<td>Annual Operating Costs:</td>
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<tr>
<td>Net Annual Energy Savings:</td>
<td>$ 5.7 million</td>
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<tr>
<td>Internal Rate of Return:</td>
<td>68%</td>
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Benefits + Environmental – 30 MW IT & 10 MW cooling

Highest Sustainable Data Center Solution via Industrial Ecology: waste streams = resources

• Eliminates data center cooling power and can supply nearly 100% of IT power
  – Uses zero-emissions, expansion turbine power generation

• GHG reductions from offset power demand:
  – GHG credits may have significant market value
    • Singapore ~170,000 TPY
      – Equivalent to removing 30,000 cars per year
    • Sines, Portugal ~36,000 TPY
    • Fos Cavaou, France ~25,000 TPY

• If LNG terminal included, GHG credits can be higher
  – Additional seawater environmental quality benefits
Potential Business Structure

Data Center

- Capital
- Cooling & Electricity Savings

TeraCool
- Technology (Operations)
- License Fee

JV

- Vaporization Savings
- Refrigeration

LNG Terminal
Progress

• Discussions ongoing with top ten data center partners
• Interest from major LNG terminals for cold recovery in:
  – U.S.
  – Mexico
  – Chile
  – France
  – U.K.
  – Spain
  – Portugal
  – Taiwan
  – Japan
  – China
  – S. Korea
  – Singapore
  – India
  – Others
• Potential Fortune 500 strategic partner that services data centers
• Request to participate by Singapore EDB in EIO for uses of cold from Singapore LNG - 2014
• Participating in Green Grid working groups
• Peer reviewed recognition:
  – Datacentres Europe presentation – France 2013 & Monaco 2014
  – Winner Uptime Institute Green IT Audacious Idea Award – 2013
Management Team

**Robert Shatten – President**
Principal, Boreal Renewable Energy Development; AES; U.S. EPA; Arthur D. Little Inc.; hazardous/radioactive waste recycling startup.

**Eric Grunebaum – Chief Business Dev’t Officer**
20+ years experience building enterprises, initiating strategic partnerships, assembling and directing teams, managing projects, developing communications.

**J.D. Jackson – Chief Technology Officer**
35+ years in market development/commercializing cryogenic applications for Linde Industrial Gases and Praxair; Member, National Fire Protection Assn. technical standards committee.

**MIT Prof. John Brisson – Co-founder/Advisor**
Professor of Mechanical Engineering at MIT with over 20 years experience in the fields of fluid mechanics, heat transfer and thermodynamics. Director MIT Cryogenic Engineering Lab.

**Joe Grabmeier – CPA|CFO**
25+ years experience in senior financial positions in establishing and building emerging companies.
TeraCool Can Achieve Corporate Missions

Facebook
• Our goal is to power all of our operations with clean and renewable energy
• Siting policy states a preference for access to clean and renewable energy

Microsoft
• Instituting a companywide commitment to achieve carbon neutrality
• Long-term capital investment in new renewable energy projects, and data centers with on-site innovative renewable energy sources

Google
• Our efforts in efficiency, buying clean energy, and purchasing offsets bring our carbon footprint down to zero
• We're going beyond carbon neutral by committing over $1 billion to renewable energy projects that create far more renewable energy for the world than we consume as a company

Yahoo!
• Yahoo! is committed to being an environmentally responsible company
• Pushing the industry standards for energy-efficiency in data centers

Amazon Web Services
• Corporate goal to offer services in:
  – “an environmentally friendly way in all of our regions”
• Amazon employees at all levels dive deep to identify waste and design alternative solutions that are more energy efficient.
Audacious or Consistent with Corporate Mission?

Digital Realty Trust

- DRT has made sustainability and energy efficiency a central focus of how we design, build and operate our datacenter facilities.

Rackspace

- Incorporate energy conservation & efficiency into decision making in the way we build, buy and operate.
- Committed to providing the world with access to the most efficient infrastructure designs.
- We weight facility-siting investments that avoid the use of power and/or rely primarily on renewable energy as a source of electricity over those that do not.

eBay

- Committed to accelerating more sustainable, more vibrant commerce.
- Core belief that a rapid transition to a 21st century, low-carbon economy will create new jobs and stimulate economic growth while stabilizing our planet’s fragile climate.
- Our opportunity is to think about the role sustainability plays in that future — and how we can advance it through engaging people, building a greener company, embedding sustainability into commerce, and shaping the industry.
- Driving efficiency and sustainability across every facet of our business operations.
Next Steps

• Preserve TeraCool IP in Japan?
• Multi-site Feasibility Study?
• Strategic partnership?
Contact Information

Bob Shatten

President, TeraCool LLC
Cell: 617.905.5757
bob@teracool-llc.com
Concord, Massachusetts