The Darwin LNG Plant – Pioneering Aeroderivative Turbines for LNG Refrigeration Service

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Bayu-Undan Development

Phase I: Offshore gas recycle project
- Condensate and natural gas liquid recovery
- Gas reinjection
- 400 million barrels condensate
- 3.4 trillion cubic feet of gas

Phase II: Gas Commercialization
- Natural gas pipeline to shore
- Darwin LNG plant
- US $1.5 billion development
Darwin Design Requirements

- Reliable plant design
- Short and certain schedule
- Cost certainty
- Safe and efficient
- Low carbon dioxide emissions
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>Bayu-Undan field discovered</td>
</tr>
<tr>
<td></td>
<td>Delineation drilling</td>
</tr>
<tr>
<td>1999</td>
<td>LNG marketing begins in earnest</td>
</tr>
<tr>
<td>2000</td>
<td>Recycle gas project approved</td>
</tr>
<tr>
<td>2002</td>
<td>LNG sales agreement heads of agreement signed</td>
</tr>
<tr>
<td>June 2003</td>
<td>Bechtel given notice to proceed</td>
</tr>
<tr>
<td>Feb 2004</td>
<td>Bayu-Undan began production</td>
</tr>
<tr>
<td>Feb 2006</td>
<td>First LNG cargo loaded</td>
</tr>
<tr>
<td></td>
<td>(32 months from notice to proceed)</td>
</tr>
</tbody>
</table>
Darwin LNG Features

- 3.7 million tonne per annum capacity
- Optimized Cascade℠ LNG process
  - Two-in-one turbine design
- Inlet gas in carbon dioxide and nitrogen is high
- Based upon ConocoPhillips-Bechtel Collaboration
  - Bechtel performed design and EPC
  - Lump sum turn key approach
- Completed ahead of schedule and on budget
- LNG marketed to Tokyo Gas and Tokyo Electric
COP Two-Trains-in-One Approach

Overall Plant Production Efficiency  >95%

Operating Range (% of design)

- **Full Plant**: 80 – 105%
- **One Turbine Offline**: 60 – 80%
- **Three Turbines Offline**\(^*\): 30 – 60%

\(^*\)At least one turbine on each cycle must be operating

- **Plant Idle**: 0 – 30%

*Maximum plant availability with operating flexibility*
Darwin Firsts

• Aeroderivative turbines for refrigeration
  – Water injection for low NOx
  – Media based evaporative cooling for power augmentation

• Integrated nitrogen rejection facilities

• Process heat supplied from turbine exhaust
  – Amine regeneration
  – Molecular sieve regeneration
  – NGL recovery system
  – Inlet gas pre-heater

• Propane sub-cooling integration

• Loading and vapor lines of vacuum insulated pipe
Advantages of Aeroderivatives

- **Low fuel consumption**
  - Lower fuels costs, more LNG
  - Less carbon dioxide emissions

- **High availability**
  - Turbine replacement in a few days, rather than weeks

- **Lower weight**
  - Less handling equipment

- **Two shaft machines provide operating flexibility**
  - Excellent starting torque
    - Startup under settle out conditions
  - Wide speed range provides flexibility
Advantages of Aeroderivatives in the Optimized Cascade Process

- Available turbine sizes match those used in process
- Short scheduled maintenance periods
  - Plant continues to operate with one or more units down
- Plants operate well at 0 to 100% of capacity
  - Turbine maintenance can be opportunistic
- No starting motors required
  - Small power generation requirement
# Representative Turbine Performance

<table>
<thead>
<tr>
<th>Turbine</th>
<th>Shaft</th>
<th>Power (kW)</th>
<th>Efficiency</th>
<th>Fuel Consumption (Indexed)</th>
<th>Scheduled Downtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame 5D</td>
<td>Dual</td>
<td>32,580</td>
<td>29.4%</td>
<td>100</td>
<td>2.6%</td>
</tr>
<tr>
<td>LM2500+</td>
<td>Dual</td>
<td>31,364</td>
<td>41.1%</td>
<td>72</td>
<td>1.6%</td>
</tr>
<tr>
<td>LM6000</td>
<td>Dual</td>
<td>44,740</td>
<td>42.6%</td>
<td>69</td>
<td>1.6%</td>
</tr>
<tr>
<td>Frame 7E</td>
<td>Single</td>
<td>86,225</td>
<td>33.0%</td>
<td>89</td>
<td>4.4%</td>
</tr>
<tr>
<td>Frame 9E</td>
<td>Single</td>
<td>130,100</td>
<td>34.6%</td>
<td>85</td>
<td>4.6%</td>
</tr>
</tbody>
</table>

Values are representative.
Impact of Ambient Temperature on LM2500 Turbines

Power (MW)

Inlet Air Temperature (C)
Turbine Performance

Power and Heat Rate Index (ISO=100)

Inlet Air Temperature (°C)

Aeroderivatives are more sensitive to ambient conditions
Darwin Ambient Conditions

Coincident hot and dry conditions occur frequently
Future Improvements

• Upgrade to LM2500+ G4
  – Additional 10% power
  – Less sensitive to high ambient conditions

• New turbine possibilities
  – LM6000

• Additional inlet air cooling strategies

• Use in floating LNG
## Aeroderivative Plant Configurations

<table>
<thead>
<tr>
<th>Turbine (No. x Model)</th>
<th>Number of Turbines By Service (Propane/Ethylene/Methane)</th>
<th>Nominal Train Size (MTPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 x LM2500+</td>
<td>2 / 2 / 2</td>
<td>3.5</td>
</tr>
<tr>
<td>8 x LM2500+G4</td>
<td>3 / 3 / 2</td>
<td>5</td>
</tr>
<tr>
<td>6 x LM6000 DLE</td>
<td>2 / 2 / 2</td>
<td>5</td>
</tr>
<tr>
<td>9 x LM6000 DLE</td>
<td>3 / 3 / 3</td>
<td>7.5</td>
</tr>
</tbody>
</table>
First Year Performance

• First LNG two months ahead of schedule
• Few issues during turbine startup
• LNG production in 2006 exceeded target
• Plant production efficiency exceeded 95% since turnover
Summary

- Darwin LNG has met the goals
  - On time
  - On budget
  - Reliable
  - Efficient
- New technology deployed at Darwin and extensions of them are available for future plants
  - Aeroderivatives
  - Inlet air humidification
  - Nitrogen rejection units
  - Propane sub-cooling integration
Thank You