“VX™ Cycle”

Patented

Lower-Cost, Higher-Efficiency

LNG Production Technology

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“VXTM Cycle” LNG Production Technology – Background

• Patented technology for producing LNG (liquefied natural gas) and CCNG™ (cold compressed natural gas)
  – Developed and owned by Expansion Energy LLC

• **Scalable:** Production scales from ~ 2,000 gallons/day (GPD) to > 1,000,000 GPD

• VX Cycle technology is **available for license**

• VX is a methane expansion cycle that achieves:
  – Lower capital costs—as much as **35% lower CAPEX** vs. other LNG cycles
  – Lower operating costs—typically **20-30% lower OPEX** vs. other LNG cycles
  – Higher production efficiencies (higher NG-to-LNG conversion efficiency)
  – Simpler logistics & operations / fewer process inputs
  – Improved safety & environmental benefits
  – Less sensitive to hot ambient temperatures
  – Ability to **shop-fabricate** entire plant → **Faster time-to-completion** vs. field-constructed plants
“VX™ Cycle” Block Diagram
“VX™ Cycle” Technology Overview

• A methane expansion cycle – **Methane (NG) is both the product & the refrigerant**
  – First commercially viable methane expansion cycle that does not require a low-pressure gas “sink”

• VX plants can be **factory-built and shipped to the deployment site in modules**
  – Pre-engineered, containerized modules are connected at the deployment site
  – A “turnkey” approach that lowers cost and minimizes risks
  – Shorter time-to-completion vs. custom-designed, field-erected LNG plants
  – Easier to finance

• Each VX plant uses a single compressor for the feed gas + refrigerant stream
  – Lowers capital costs & operating costs
  – Competing LNG cycles need multiple compressors

• Can utilize **low-pressure** (e.g., 50 psia) or high-pressure feed gas

• For VX plants > 100,000 GPD, **gas-to-LNG conversion efficiency can exceed 85%**
  – Efficiency is even higher with higher-pressure feed gas

• Produces its own power → No connection to the electrical grid is required

• Can be fully automated → No continuous labor required

• Uses “off-the-shelf” equipment + **does not require a “cold box”** (a long lead-time item)
VXTM Cycle Technology Advantages

• High efficiency (NG-to-LNG conversion efficiency)
  – Uses an optimal balance of refrigeration & compression
  – Utilizes waste heat & waste cold (through multiple thermal recovery steps)

• Low capital cost—as much as 35% lower CAPEX vs. other LNG cycles
  – Requires only 1 compressor (vs. 2 compressors for other LNG cycles: 1 for NG + 1 for refrigerant(s))

• Low operating costs—typically 20-30% lower OPEX vs. other LNG cycles

• Simplifies LNG production vs. other LNG technologies such as:
  Nitrogen Cycles / Mixed Refrigerant Cycles / Cascade Cycles
  – Less complex equipment
  – Fewer process inputs (e.g., no separate refrigerants to ship in; no “make-up” refrigerants)
  – Less sensitive to ambient temperatures

• Can utilize low-pressure or high-pressure feed gas (or any pressure in between)
  – Pipeline gas from local gas distribution systems or interstate pipelines
  – Well gas / stranded gas
  – Allows VX plants to be deployed at virtually any feed gas source

• Shop-built, modular VX plants allow for incremental plant expansion with lower capital risk
• Use of multiple modules ensures higher % uptime + more efficient “turn-down”
• Modular VX plants can be moved & re-deployed (if necessary)
VX™ Cycle LNG Product Advantages

- VX Cycle plants produce a differentiated LNG product: “sub-cooled LNG”
- Sub-cooled LNG is several degrees colder than “standard” LNG at the same pressure
- Sub-cooled LNG is not “on the bubble” between NG’s liquid and vapor state
  - Allows for less “flashing” of LNG when transferred from stationary tanks to on-vehicle fuel tanks
  - Sub-cooled LNG has a longer “shelf life” in stationary storage tanks and on-vehicle fuel tanks
- VX Cycle plants achieve sub-cooled LNG without sacrificing production efficiency

- VX Cycle plants also produce CCNG™ (cold compressed natural gas)
  - CCNG is a dense, near-liquid state of NG—above its “critical pressure” and colder than its “critical temperature”
  - Requires substantially less energy to produce than LNG, but is nearly as dense
  - Pumpable (like a liquid) by standard cryogenic liquid pumps
  - See the following slides
CNG/CCNG/LNG Continuum

A *range* of combinations of Temperatures & Pressures

<table>
<thead>
<tr>
<th>USE CONDITION &quot;NAME&quot;</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<tbody>
<tr>
<td>CNG</td>
<td>H-Press.</td>
<td>H-Press.</td>
<td>&quot;Warm&quot;</td>
<td>&quot;Warm&quot;</td>
<td>&quot;Warm&quot;</td>
<td>&quot;Warm&quot;</td>
<td>&quot;Warm&quot;</td>
<td>&quot;Cold&quot;</td>
<td>&quot;Cold&quot;</td>
<td>&quot;Cold&quot;</td>
</tr>
<tr>
<td>Pressure (psia)</td>
<td>3,600</td>
<td>3,600</td>
<td>700</td>
<td>600</td>
<td>500</td>
<td>400</td>
<td>300</td>
<td>200</td>
<td>60</td>
<td>45</td>
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<tr>
<td>Temp (Deg. F)</td>
<td>+95</td>
<td>+30</td>
<td>-150</td>
<td>-160</td>
<td>-170</td>
<td>-180</td>
<td>-190</td>
<td>-200</td>
<td>-230</td>
<td>-250</td>
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<tr>
<td>Pounds/Cubic Ft.)</td>
<td>12.13</td>
<td>15.28</td>
<td>21.44</td>
<td>22.08</td>
<td>22.70</td>
<td>23.30</td>
<td>23.89</td>
<td>24.45</td>
<td>26.15</td>
<td>27.22</td>
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<tr>
<td>% Density of LNG</td>
<td>44.6%</td>
<td>56.1%</td>
<td>78.8%</td>
<td>81.1%</td>
<td>83.4%</td>
<td>85.6%</td>
<td>87.8%</td>
<td>89.8%</td>
<td>96.1%</td>
<td>100.0%</td>
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<tr>
<td>Sub-cooled (Deg. F)</td>
<td>37.5</td>
<td>25.7</td>
<td>23.0</td>
<td>25.9</td>
<td>28.0</td>
<td>35.5</td>
<td>6.0</td>
<td>14.4</td>
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Energy per Density Achieved: CNG vs CCNG vs LNG

Density as % of Cold LNG

Energy per Density for 1MM DTH of NG

<table>
<thead>
<tr>
<th>Conditions 1-12</th>
<th>Energy Input Reqd. (kWH)</th>
<th>kWh to Density Ratio</th>
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<tr>
<td>1</td>
<td>333</td>
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<tr>
<td>2</td>
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<td>3</td>
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<td>5</td>
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<td>6</td>
<td>553.6</td>
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<td>7</td>
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<td>8</td>
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<td>9</td>
<td>673.9</td>
<td>25.77</td>
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<tr>
<td>10</td>
<td>738.1</td>
<td>27.12</td>
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STORABLE & PUMPABLE DENSE PHASE NATURAL GAS

LOW POINTS = Least kWh per Density Achieved

VX™ Cycle – LNG Production Technology
**VX™ Cycle Safety Advantages**

- Fewer pieces of equipment → fewer moving parts
- Optional: Electric motor can be used as the prime mover instead of a gas engine
  - Eliminates on-site combustion
  - Requires a robust gas clean-up system that produces no sweep gas—e.g., “VCCSTM” (see next slide)
- VX requires virtually no refrigerants other than methane
  - Refrigerants used by Mixed Refrigerant LNG cycles are typically flammable hydrocarbons
  - Only VX’s auxiliary chilling systems require (a small amount of) refrigerants
- Simpler logistics & operations reduces probability of accidents
- VX operates at lower pressures → less prone to valve & seal leaks or stress fractures
- VX plants can be designed to automatically shut down during certain incidents
- Meets NFPA standards and compliant with typical state & local codes

**VX™ Cycle Environmental Advantages**

- High efficiency (high NG-to-LNG conversion ratio)
- Electric motor-driven VX plants have zero emissions
- Gas engine-driven VX plants can use low-emissions prime movers (low NOx, etc.)
Complementary Gas Clean-Up Technology: “VCCSTM Cycle”

• All LNG cycles need clean feed gas to function properly
  – Even pipeline-quality feed gas needs to have CO₂ and H₂O removed
• Front-end gas clean-up systems are especially important for:
  – Unprocessed natural gas, landfill gas (LFG) and anaerobic digester gas (ADG)
  – Electric motor-driven LNG plants (which do not have gas-fired prime movers to burn the sweep gas)
• Other gas clean-up systems (such as mole sieves & membranes) have significant drawbacks:
  – Expensive
  – Need to be frequently regenerated by significant volumes of sweep gas
  – Not cost-effective or robust enough for gas with a high % of impurities—CO₂, H₂S, H₂O
• Expansion Energy offers a patented, robust gas clean-up technology: “VCCSTM”
  – VCCS can be used on the front-end of a VX Cycle LNG plant (or other LNG or gas processing plant)
  – “Captures” CO₂, H₂S and H₂O by subjecting feed gas to alkaline materials, forcing a chemical reaction that “neutralizes” these impurities and “pulls” them from the feed gas
• Unlike other clean-up systems, VCCS does not require regeneration or produce sweep gas
• VCCS can be easily scaled for the volume of feed gas and/or level of impurities
• The VCCS Cycle is available for license from Expansion Energy
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