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“VX™ Cycle”

Patented

Lower-Cost, Higher-Efficiency

LNG Production Technology

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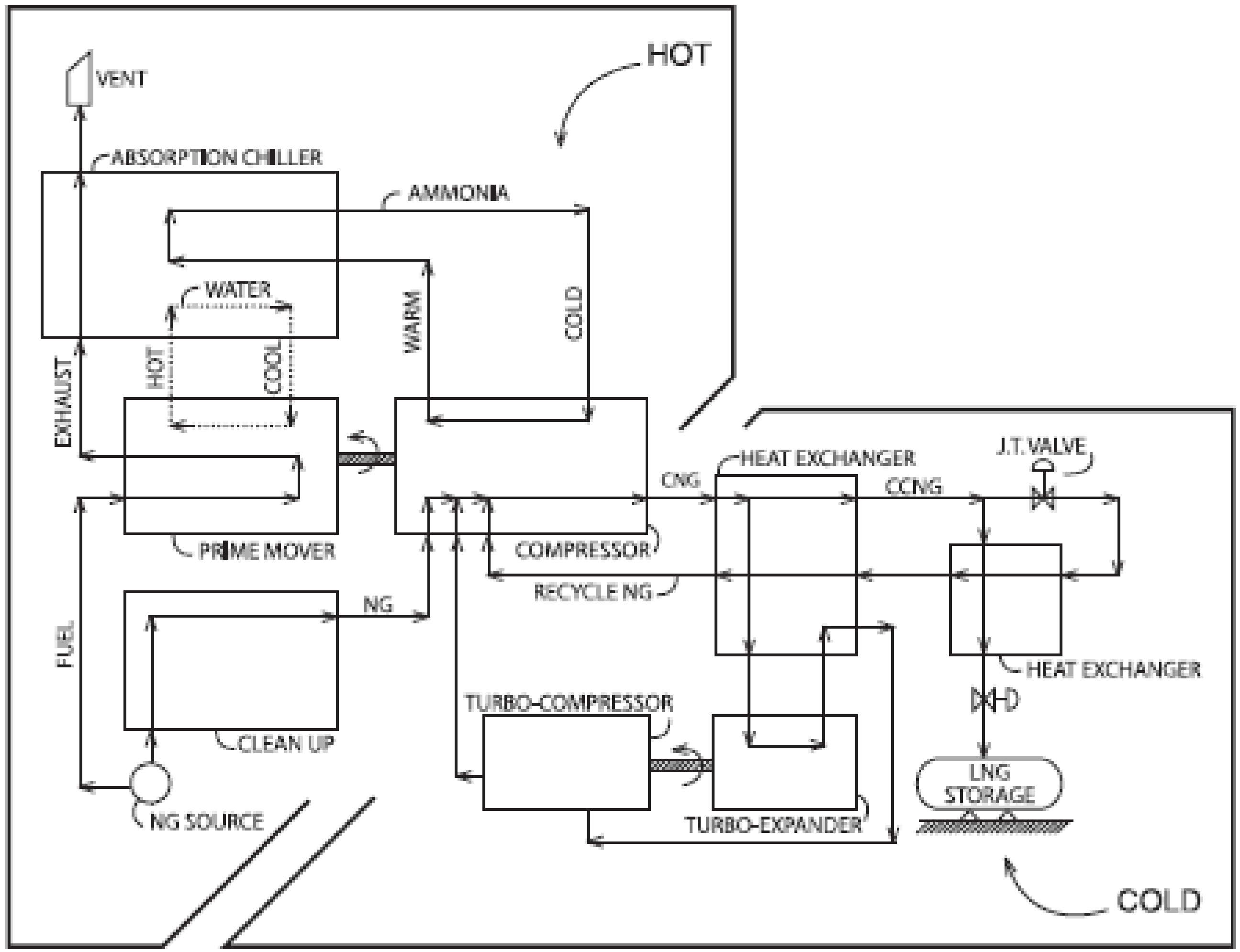
"VX^{TM} Cycle" LNG Production Technology – Background

- Patented technology for producing LNG (liquefied natural gas) and CCNG^{TM} (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

“VXTM Cycle” Block Diagram



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"VX^{TM} 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)

VX™ 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^{TM} 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

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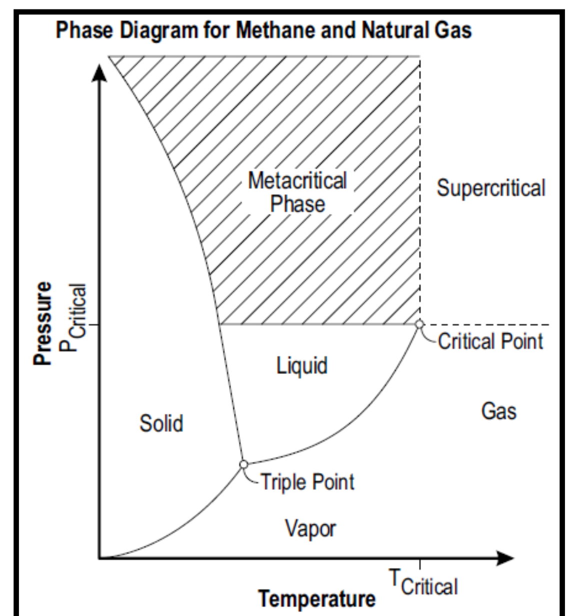
- VX Cycle plants also produce **CCNG^{TM}** (cold compressed natural gas)
  - CCNG is a dense, near-liquid state of NG—**above its "critical pressure"** and **colder than its "critical temperature"**
  - Requires substantially less energy to produce than LNG, but is nearly as dense
  - Pumpable (like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

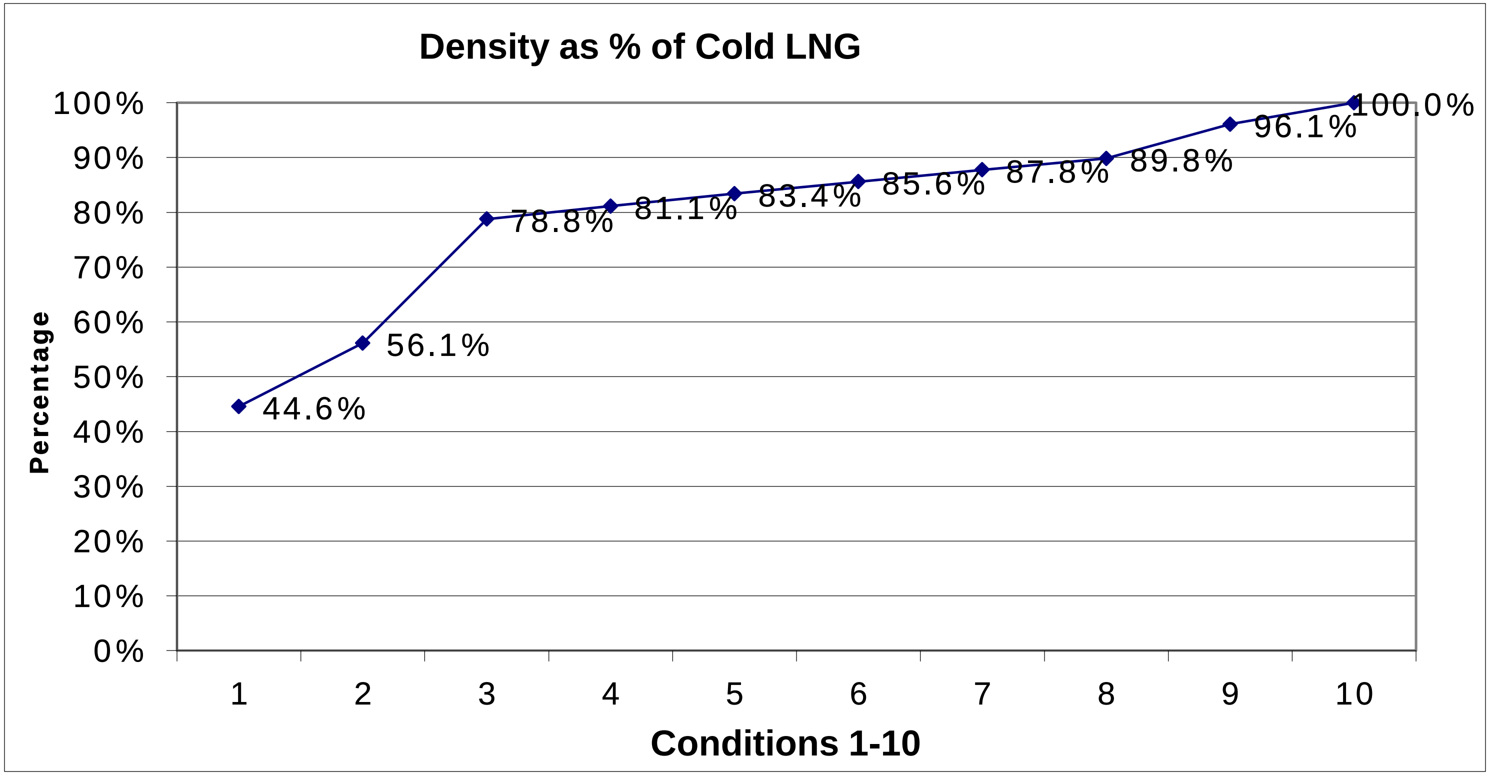


CNG/CCNG/LNG Continuum

A ***range*** of combinations of Temperatures & Pressures

	1	2	3	4	5	6	7	8	9	10
USE	CNG		**STORABLE & PUMPABLE DENSE PHASE NATURAL GAS**							
CONDITION	H-Press.	H-Press.		**"Warm"**	**"Warm"**	**"Warm"**	**"Warm"**	**"Warm"**	**"Cold"**	**"Cold"**
"NAME"	CNG	L/CNG	**CCNG**	**LNG**	**LNG**	**LNG**	**LNG**	**LNG**	**LNG**	**LNG**
Pressure (psia)	3,600	3,600	700	600	500	400	300	200	60	45
Temp (Deg. F)	+95	+30	-150	-160	-170	-180	-190	-200	-230	-250
Pounds/Cubic Ft.)	12.13	15.28	21.44	22.08	22.70	23.30	23.89	24.45	26.15	27.22
% Density of LNG	44.6%	56.1%	78.8%	81.1%	83.4%	85.6%	87.8%	89.8%	96.1%	100.0%
Sub-cooled (Deg. F)			37.5	25.7	23.0	25.9	28.0	35.5	6.0	14.4

Energy per Density Achieved: CNG vs CCNG vs LNG



Energy per Density for 1MM DTH of NG			**STORABLE & PUMPABLE DENSE PHASE NATURAL GAS**							
Conditions 1-12	1	2	3	4	5	6	7	8	9	10
Energy Input Reqd. (kWH)	333	775	500	516.7	534.5	553.6	574.1	589.4	673.9	738.1
kWH to Density Ratio	27.45	50.72	**23.32**	**23.40**	**23.55**	**23.76**	**24.03**	**24.11**	25.77	27.12
		WORST CASE	**LOW POINTS = Least kWH per Density Achieved**							

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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., **"VCCS™"** (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: "VCCS™ Cycle"

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- All LNG cycles need clean feed gas to function properly
  - Even pipeline-quality feed gas needs to have CO_2 and H_20 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—CO_2, H_2S, H_2O
- Expansion Energy offers a patented, robust gas clean-up technology: **"VCCS™"**
  - VCCS can be used on the front-end of a VX Cycle LNG plant (or other LNG or gas processing plant)
  - "Captures" CO_2, H_2S and H_2O 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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