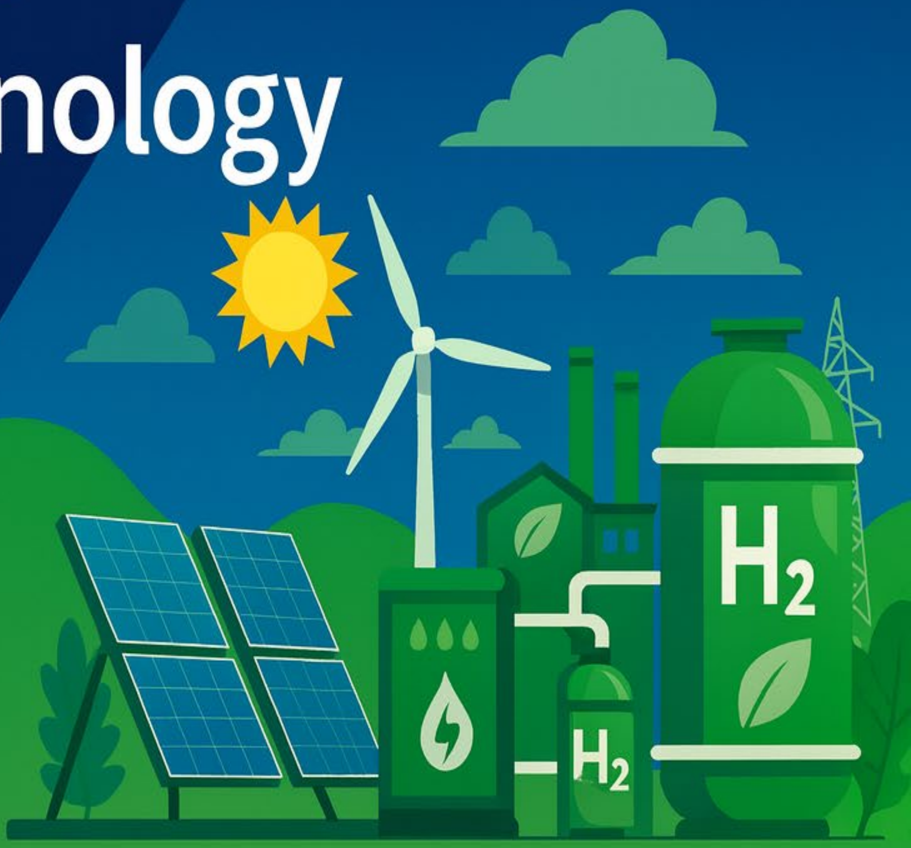
JTURBO

Hydrogen and LNG Liquefaction Technology



Introduction

Core Innovations

- 2 Patents in Liquid Hydrogen (LH_2) & LNG Liquefaction
- Proprietary Twin Turbo expander Reverse Brayton cycle

Superior Efficiency

- Lowest Specific Energy Consumption (SEC) in the market
- Performance near theoretical thermodynamic efficiency

Global Reach

- Clients across USA, EU, India, Africa, Australia & Middle East

Applications

- Green Hydrogen Liquefaction
- Green Ammonia & Methanol Production
- Industrial Decarbonization (e.g., Data Centers, Steel)

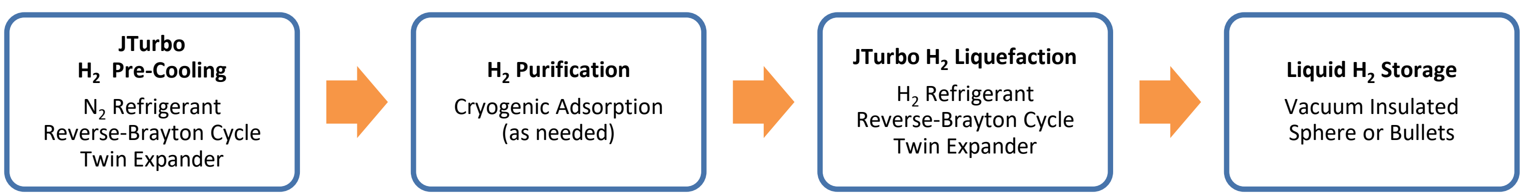
Strategic Advantage

- Ultra-efficient liquefaction tech enabling cost-effective liquid hydrogen
- storage & large-scale clean energy solutions for Industrial Applications
- (Ammonia, Steel, Refinery, Chemicals …)

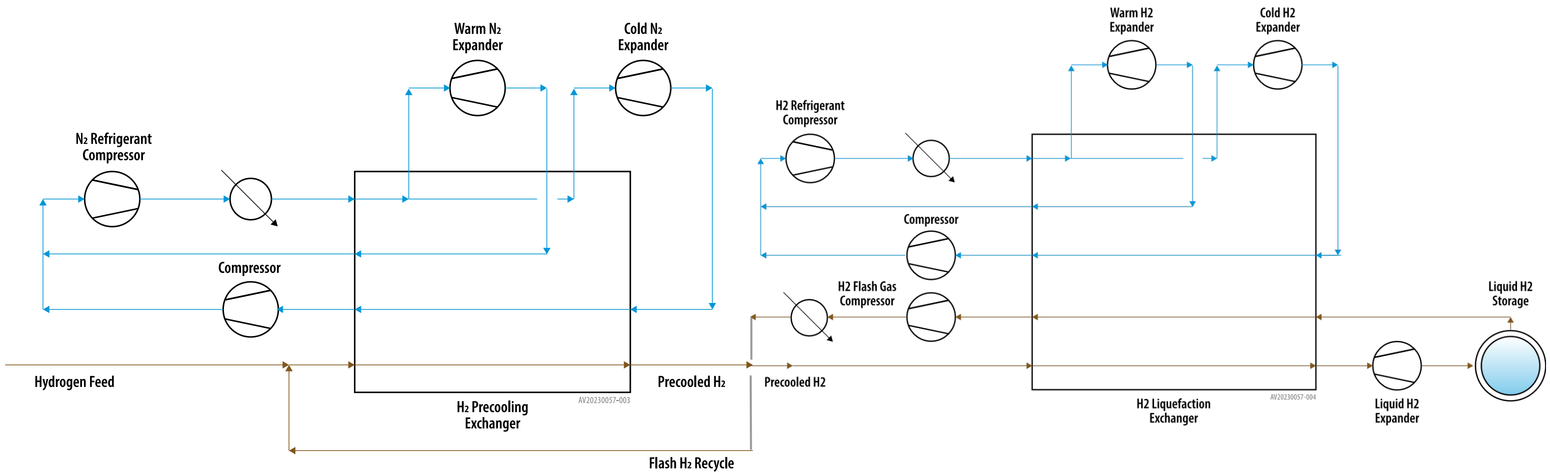
JTurbo Hydrogen Liquefaction Technology

Lowest Specific Energy Consumption in Hydrogen Liquefaction

- **Industry-Leading Efficiency**
  - Lowest Specific Energy Consumption (SEC) [kWh/kg LH_2]
  - **50% lower SEC** compared to current liquefaction technologies
- **Proven Thermodynamic Foundation**
  - H_2 Precooling & Liquefaction: Reverse-Brayton cycles
  - Built on established cycles & equipment technologies
- **High-Efficiency Equipment**
  - Twin expanders, plate-fin heat exchangers, refrigerant compressors
  - Sourced from reliable, established vendors
- **Flexible Refrigerant Options**
  - Primary: Nitrogen & Hydrogen
  - Alternatives (no loss of efficiency): H_2+Helium, H_2+ Neon mix



JTurbo Hydrogen Liquefaction Technology



Highly Efficient Design with Proven Elements (Stages 1 and 2)

- **Closed-Loop N_2 and H_2 Refrigeration Cycle**
  - Reverse-Brayton thermodynamic cycle
  - Single and multiple Turbo-expanders for high efficiency
- **Flexible Refrigerant Options**
  - Primary: Nitrogen & Hydrogen
  - Alternatives: Nitrogen & Helium or H_2+Neon mix
- **CAPEX & OPEX Reduction (≈30%)**
  - Integration with - LNG Terminal & LN_2 Air Separation units
- **Proven Equipment**
  - Turbo Expander-compressor design
  - Plate-fin heat exchanger technology
  - Established refrigerant compressor design
- **Efficiency Enhancements**
  - Water-cooling for final heat rejection
  - Efficiency depends on heat sink for ambient cooling

Current H_2 Liquefaction Technology Comparison

Comparison SEC for existing plants and JTurbo Liquefaction Technology using a consistent design basis

Current Hydrogen Liquefaction Technology and Proposed New Developments					
Technology	**Status**	**Pre-cooling Cycle**	**Liquefaction & Sub-cooling Cycle**	**Specific Energy Consumption (SEC) kWh/kg**	**Exergy Efficiency (%)**
Linde–Ingolstadt	Operating	LN2	H2 - Claude	13.60	28.82
Linde–Leuna	Operating	LN2	H2 - Claude	11.90	32.94
Air Products	6 × operating	LN2	H - Claude	12 - 15	33 - 26
Praxair	4 × operating	LN2	H2 - Claude	12.5 - 15	31 - 26
Air Liquide	5 × operating	LN2	H2 - Claude	12 - 15	33 - 26
	Patent No. US 11,391,511 B1	N2 - Reverse Brayton	He - Reverse Brayton	5.35	73.22
		N2 - Reverse Brayton	H2 - Reverse Brayton	5.29	74.10
		N2 - Reverse Brayton	H2+Ne - Reverse Brayton	5.20	75.46
		LN2 / LNG	H2 - Reverse Brayton	3.6 / 4.5	108 / 87

Notes:

1. H_2 Plant Feed Gas & Liquefaction Pressure @ 1160 psi (80 bar) and H_2 Storage @ 14.5 psi (1.0 bar)

2. Specific Energy Consumption (SEC) does not include a constant value of 527 kJ/kg, Ortho-Para H_2 Conversion (OPC) heat duty for consistency with other Technologies that has not been included in the published SEC.

JTurbo Hydrogen Liquefaction Technology

JTurbo Hydrogen Liquefaction Technology Summary

Hydrogen Liquéfaction & Réfrigération Summary (Avenage Ambient Température 25 °C)					
Pre-Cooling Cycle	Twin-Exp N_2 (1) (1+1) Cycle	Twin-Exp N_2 (2) (1+1) Cycle	Twin-Exp N_2 (3) (1+1) Cycle	LNG (4)	LN_2 (5)
Liquefaction & Subcooling Refrigeration Cycle *	Twin-Exp H_2 (1+1) Cycle	Twin-Exp H_2 (2+1) Cycle	Twin-Exp H_2 (3+2) Cycle	Twin-Exp H_2 (3+2) Cycle	Twin-Exp H_2 (3+2) Cycle
Hydrogen Feed Gas (Nm3/h)	23,168	46,331	69,491	69,491	69,491
Liquid Hydrogen Loading (ton/day)	50	100	150	150	150
Specific Energy Consumption (kWh/kg)	6.8	6.0	5.7	4.5	3.6
Exergy Efficiency (%)	57.4	65.3	68.5	87.0	108.0
Total Power (kWh)	14,235	25,011	35,799	28,402	22,722
Total CAPEX (US $ / kg LH2 / Day	1,300	900	800	650	600

Notes

(1) Twin-Exp JTurbo N_2 / H_2 (1+1) Exp H_2 Cycle: Twin-Exp JTurbo Nitogen Precooling and H_2 (1+1) Exp Cycle H_2 Liquefaction

(2) Twin-Exp JTurbo N_2 / H_2 (2+1) Exp H_2 Cycle: Twin-Exp JTurbo Nitogen Precooling and H_2 (2+1) Exp Cycle H_2 Liquefaction

(3) Twin-Exp JTurbo N_2 / H_2 (3+2) Exp H_2 Cycle: Twin-Exp JTurbo Nitogen Precooling and H_2 (3+2) Exp Cycle H_2 Liquefaction

(4) LNG / H_2 (3+2) Exp H_2 Cycle: Twin-Exp JTurbo LNG Precooling and H_2 (3+2) Exp Cycle H_2 Liquefaction

(5) LN_2 / H_2 (2+1) Exp H_2 Cycle: Twin-Exp JTurbo LN2 Precooling and H_2 (2+1) Exp Cycle H_2 Liquefaction

* H_2 Feed Gas from H_2 Storage & H_2 Liquefaction @ 580 psig (40 bar) and H_2 Storage @ - 418.4 °F (-250 °C) and 29 psig (2 bar)

Current H_2 Liquifaction Industry Status

Challenges

- Outdated technology (based on decades-old designs)
- Limited efficiency & scalability improvements
- Lack of R&D investment & cryogenic expertise
- Inefficiencies at scale – viable only for ≤30 TPD setups

New Challenge : Renewables

- Intermittent solar & wind → energy volatility
- Grid limitations restrict continuous H_2 production

Opportunity

- Liquid Hydrogen storage as an energy buffer
- JTurbo uniquely positioned to enable large-scale (50-150 TPD) liquefaction

Liquid Hydrogen as Power & Cold Energy Buffer

- **LH_2 Handling**: Liquefy and Store hydrogen with renewable energy; use during unavailability
- **LN_2 Handling**: Recovered cold energy from LH_2 vaporization for producing LN_2 to be used later in hydrogen precooling cycle

- **Optimized ASU Operation**
- **Nighttime GAN**: Meets Industrial demand(Ammonia, Steel, Refinery, Chemicals …) + recovers cold energy
- **Daytime GAN**: Covers above Industrial demand, deducts LN_2-derived GAN

- **Key Advantages**
- No loss of cold energy → lower OPEX
- Liquid Hydrogen as storage buffer = highly cost-effective

Advantages of Twin Turboexpander Cycle

Efficiency & Energy Savings

- SEC: 5.2 kWh/kg LH_2 vs. 11+ industry standard → >50% savings

CAPEX Advantage

- $800–1300 per kg LH_2/day at 50–150 TPD scale
- Industry: $2500+ per kg LH_2/day
- ~50% lower capital cost

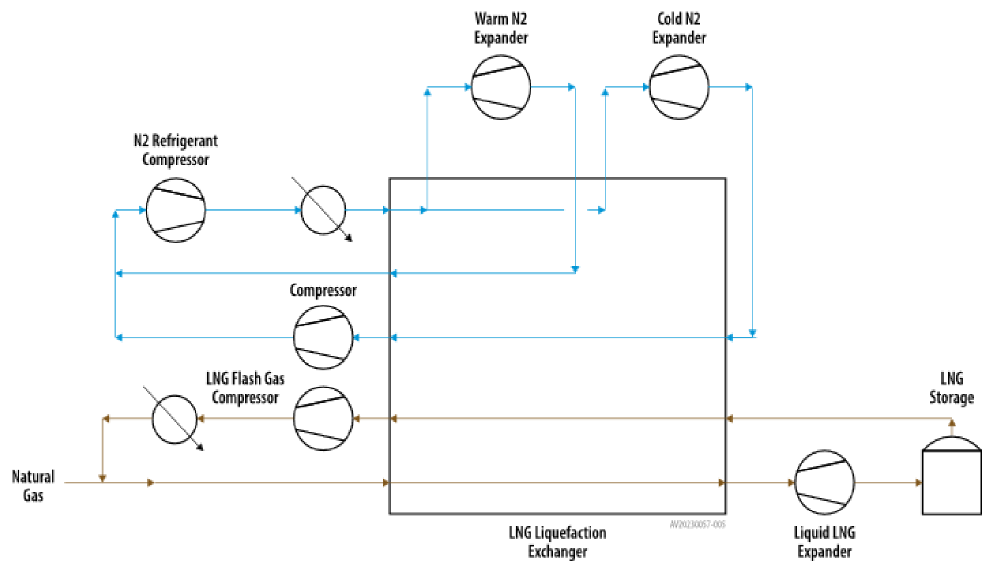
Proven Technology

- Backed by OEMs Performance Guarantees
- Submitted proposals to license several LH_2 units with key partners across the U.S., Middle East, India, Africa, Europe, and Australia—powering cleaner mobility and high-value industrial applications

JTurbo LNG Liquefaction Technology

Highly Efficient Design, Proven Elements

- Reverse-Brayton thermodynamic refrigeration cycle
    - Twin turbo-expanders for high efficiency
- Demonstrated plate-fin heat exchanger technology
- Established refrigerant compressor design
- Water or air-cooling for final heat rejection
- Efficiency depends on available ambient heat sink



LNG Liquefaction Cycle Current Technology

JTurbo's Twin Expander Nitrogen Cycle LNG Liquefaction Technology as an SMR-free system that uses **pure nitrogen** as the refrigerant. Nitrogen expander cycles are indeed common for **small to mid-scale** LNG / Bio-LNG, and floating LNG (FLNG) and **modular LNG plants** because of their lower cost, simplicity, safety, and environmental friendliness (no hydrocarbon refrigerants).

Current LNG Liquefaction Technology Comparison				
Licensor Technology	**LNG Liquefaction Cycle**	**Maximum Capacity per LNG Train (TPD)**	**Specific Refrigerant Power (SRP) kWh / ton LNG**	**Notes**
Air Products (APCI)	SMR / C_3MR / DMR	Base Load	270 - 300	Used for large base-load LNG. Highest efficiency but complex system.
Air Products (APCI)	Dual N_2 Expander	1,000 – 1,500	500 - 650	Simpler, scalable, but lower efficiency than MR system
Linde	Dual N_2 Expander	1,000 – 1,500	500 - 650	Compact modular designs available. Lower efficiency but robust
Black & Veatch (PRICO)	Dual N_2 Expander	1,000 – 2,-000	500 - 650	Used in small FLNG and distributed LNG. Low maintenance
Chart (IPSMR) N_2	Dual N_2 Expander	1,200 – 1,800	500 - 650	Integrated power recovery; good for small-scale LNG.
JTURBO US Patent 12.181.214	Twin N_2 Expander	50 - 3,000	300	Higher efficiency than conventional N_2 expanders; performance approaching MR efficiency. Modular and scalable for 50–3,000 TPD.

50 - 3,000 TPD LNG & Bio-LNG Liquefaction

Why N_2 Expander Cycle?

- Safe & Simple: Pure nitrogen, inert & non-flammable → no hydrocarbon risk
- Compact & Modular: Ideal for space-limited platforms/vessels; skid-mounted design
- Flexible Operation: Handles variable gas, rapid start/stop for intermittent use
- Lower CAPEX: Fewer equipment, simpler process → $400 ton LNG vs. >$800 for mixed refrigerant cycles
- Backed by OEMs Performance Guarantees

50 - 3,000 TPD LNG & Bio-LNG Liquefaction

Commercial Examples

- EXMAR Caribbean FLNG: 0.5 MTPA, nitrogen expander cycle (PRICO-N_2)
- PFLNG Satu (Petronas): First FLNG (dual mixed refrigerant); smaller FLNGs <1 MTPA often use N_2 cycles
- Black & Veatch PRICO-N_2: Widely adopted in small FLNG, barge, and peak shaving units (100–200 tpd / 0.05–0.1 MTA)

Conclusion

- JTurbo N_2 Expander Cycle = safe, efficient, compact LNG solution
- Ideal for modular LNG, Bio-LNG & offshore projects
- Delivers low CAPEX + fast deployment

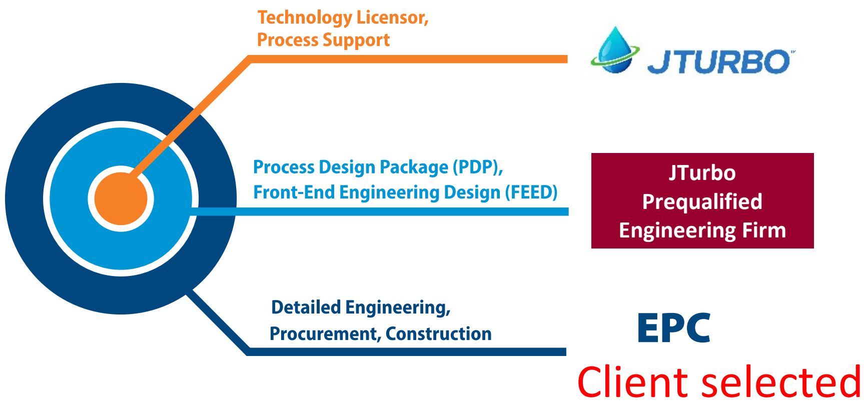
JTurbo’s Execution Approach

JTURBO: PRODUCTIZING MOST ENERGY EFFICIENT HYDROGEN & LNG LIQUEFACTION TECHNOLOGY

JTurbo licenses and delivers the liquefaction technology including the material balance, process flowsheet, and critical specifications.

JTurbo engages Top-tier EPC firm to complete and deliver an appropriately detailed Process Design Package (PDP) or Front-End Engineering Design Package (FEED) based on project needs.

This execution approach brings state-of-the-art technology together with quality engineering to deliver cost-effective, efficient, and reliable hydrogen liquefaction technologies.



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