

# Large LNG plant capabilities for capacity >2 MTPA

## Benefit from economies of scale and proven technology



Air Products' natural gas liquefaction processes and main cryogenic heat exchangers are the world's standard for baseload LNG.

## Liquefaction capabilities and support:

We provide a complete range of products and services for the successful design, construction, start-up, and operation of your LNG facility:

- Feasibility studies
- Project development studies
- Detailed liquefaction process designs
- Coil wound heat exchanger design and fabrication
- Installation and start-up advisory services
- Technical support services during plant operations
- Debottlenecking studies

## Benefits to our customers:

### Economical Production

- Readily available refrigerants
- Large train sizes for economies of scale
- High efficiency/low feed gas consumption

### High Reliability

- Fewer process components
- Proven performance, demonstrated by plant onstream records
- Robust CWHE (Coil Wound Heat Exchanger) design and construction

### Improved Operation

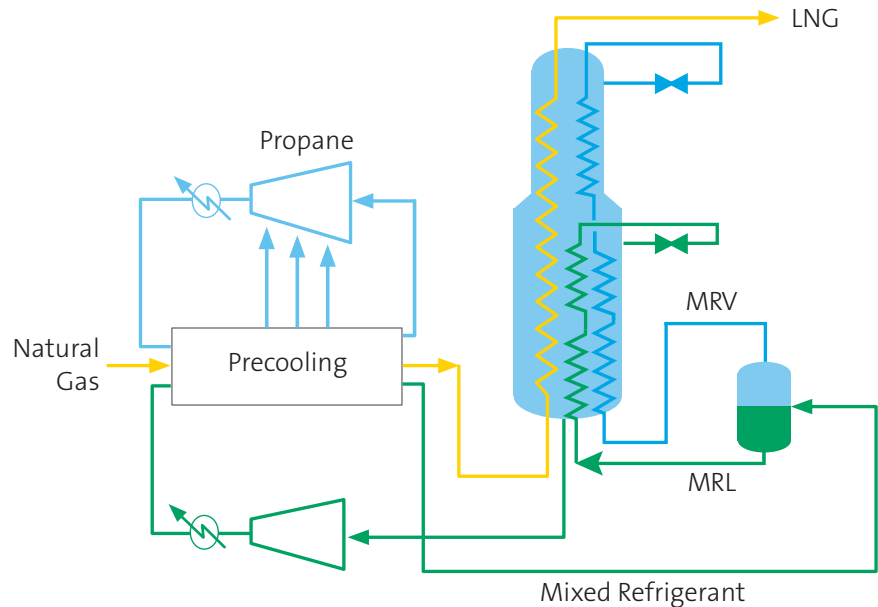
- Ease of start-up to minimize the time to achieve full capacity
- Flexibility to operate at high efficiency over a wide range of feed gas compositions and conditions
- Efficient and stable turndown even at very low feed rates

**The result is improved profitability due to faster project completion, higher availability of the process, and maximum efficiency.**



The bundle winding process for each coil wound heat exchanger manufactured by Air Products.

## The most prevalent liquefaction technology used today is Air Products' AP-C3MR™ LNG Process



## MCR® LNG Processes:

### Maximum production with high efficiency and low CAPEX/MTPA

More LNG is produced using Air Products' mixed component refrigerant and liquefaction processes than any other processes in the world. They have proven to be the highly reliable, flexible, and easy to operate. Air Products invented propane precooled mixed refrigerant process (AP-C3MR™), which has become the industry standard. To meet specific liquefaction requirements, we also offer several variations, including dual mixed-refrigerant (AP-DMR™) processes and the AP-X® LNG Process utilized by the industry's largest LNG trains in Qatar.

## MCR® Cryogenic Heat Exchangers (MCHEs):

### Flexible and Robust

The typical exchanger may be as large as 5 meters (16.5 feet) in diameter and 55 meters (180 feet) high and weigh 450 metric tonnes (500 tons). The large size of the individual heat exchanger tube bundles facilitates the design of large process trains. In addition to providing economies of scale, this leads to simple piping and control systems and, consequently, to reductions in installation, operation, and maintenance costs. Heat exchangers we supplied more than 45 years ago are still operating, many at production rates well in excess of their original design capacity.

### Integrated Manufacturing

Air Products is the world's leading supplier of large coil wound heat exchangers (CWHEs). Each CWHE is manufactured by skilled craftspeople at our state-of-the-art facilities in the United States, convenient to U.S. ports for shipping to site. We fabricate the units with internal piping and components, and complete with transition joints or flanged connections so that no aluminum welding is required once the unit reaches the LNG plant site.

## Air Products Mid and Large-Scale LNG plant experience

Country	Location/Project	Initial Start-Up	Trains	LNG Capacity per Train (MTPA)	LNG Process
Abu Dhabi (UAE)	Das Island	1977	2	1.7	AP-C3MR™
		1994	1	2.6	AP-C3MR
Algeria	Arzew	1977	6	1.3	AP-C3MR
		1981	6	1.4	AP-C3MR
		2014	1	4.7	AP-C3MR/SplitMR®
	Skikda	2013	1	4.5	AP-C3MR/SplitMR®
Australia	NWS	1989–1992	3	2.5	AP-C3MR
	Gorgon	2016	3	5	AP-C3MR/SplitMR®
	Prelude (FLNG)	2017	1	3.6	DMR
	Ichthys	2017	2	4.2	AP-C3MR/SplitMR®
Brunei	Lumut	1972–1974	5	1.3	AP-C3MR
China	Ningxia Hanas	2012	2	0.4	AP-SMR™
	Shaanxi Yangling	2015	1	0.5	AP-SMR
	FengZhen	2017	1	0.3	AP-SMR
Egypt	SEGAS	2004	1	5	AP-C3MR/SplitMR®
Indonesia	Bontang	1977–1997	7	2.6	AP-C3MR
		1999	1	3	AP-C3MR
	Arun	1978–1986	6	2	AP-C3MR
	Tangguh	2009, 2020	3	3.8	AP-C3MR/SplitMR®
	Donggi	2015	1	2.1	AP-C3MR
Libya	Marsa el Brega	1970	4	0.8	AP-SMR
Malaysia	Satu	1982	3	2.5	AP-C3MR
	Dua	1995	3	2.8	AP-C3MR
	Tiga	2003	2	3.8	AP-C3MR
	Petronas 9	2016	1	3.6	AP-C3MR/SplitMR®
	PFLNG Satu	2016	1	1.2	AP-N™
	PFLNG Dua	2018	1	1.5	AP-N
Nigeria	Bonny Island	1999–2002	3	3.2	AP-C3MR
		2005–2007	3	3.7	AP-C3MR
Oman	Oman LNG	2000–2006	3	3.3	AP-C3MR
Papau New Guinea	PNG LNG	2014	2	3.3	AP-C3MR
Peru	Peru LNG	2010	1	4	AP-C3MR/SplitMR®
Qatar	Qatargas	1996–1999	3	3.3	AP-C3MR
		2009–2011	4	7.8	AP-X®
	Rasgas	1999–2000	2	3.3	AP-C3MR
		2004–2006	3	4.7	AP-C3MR/SplitMR®
		2009–2010	2	7.8	AP-X®
Russia	Yamal	2018	3	5.5	AP-C3MR
United States	Cove Point	2017	1	5.25	AP-C3MR
	Freeport	2018–2019	3	4.4	AP-C3MR
	Cameron	2018–2019	3	4.4	AP-C3MR/SplitMR®
Yemen	Bal-Haf	2009	2	3.4	AP-C3MR/SplitMR®
Total Trains			107		

## Air Products experience: Industry leader

We helped pioneer the LNG industry, supplying our first LNG process and equipment over 45 years ago. Today, we are on the leading edge of LNG technology and provide quality, reliability, performance, and the best return on capital.

## About Air Products

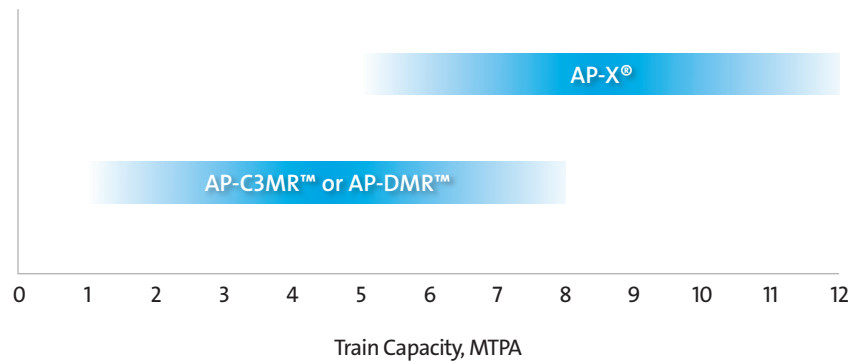
Air Products is a world-leading Industrial Gases company celebrating 75 years of operation. The company's core Industrial Gases business provides atmospheric and process gases and related equipment to manufacturing markets, including refining and petrochemical, metals, electronics, and food and beverage. Air Products is also the world's leading supplier of liquefied natural gas process technology and equipment.

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## Large LNG plant liquefaction process capacities



For the AP-X® LNG Process, in addition to liquefaction process design and CWHEs (Coil Wound Heat Exchangers), Air Products designs and manufactures cryogenic nitrogen compressors (compressor turbo-expander machinery), and nitrogen economizer heat exchanger cold boxes.



A large Air Products' custom designed coil wound heat exchanger.



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# Mid-scale LNG capabilities World-class LNG technology applied to mid-scale LNG plants



Each coil wound heat exchanger is custom designed and delivered with performance guarantees.



Mid-scale LNG plants producing from 0.25–2.0 MTA are gaining acceptance as a way to serve niche markets for LNG and to monetize smaller gas volumes at reduced cost. Air Products meets the need for mid-scale LNG plants with liquefaction processes and equipment designed for simplicity while delivering lower unit costs.

## Mid-size plants: track record of success

While the LNG industry trends in past years have been toward larger plants, it is important to recognize that a significant number of the operating LNG plants around the world today are in the capacity range of what is currently being categorized as the “mid-scale LNG market.” Notably, Air Products’ coil-wound heat exchangers have been successfully applied for more than 45 years to mid-scale plants and demonstrated high reliability, operability, turn-down stability, and productivity.





Shaanxi LNG Investment Development Co. LTD. Yangling, Shaanxi, China plant utilizes Air Products' single mixed refrigerant (AP-SMR™) process.

## Air Products' coil wound heat exchanger technology and equipment: efficient and robust

Air Products offers proven natural gas liquefaction technologies to support customer-specific project requirements for the land based mid-scale LNG market; most notably Air Products' proprietary single mixed refrigerant (AP-SMR™) and propane pre-cooled mixed refrigerant (AP-C3MR™) process cycles have been applied. Each liquefaction unit is delivered with performance guarantees on LNG production, specific power and quality. Each coil wound heat exchanger (CWHE) is custom designed by our engineers to address the full spectrum of economic factors, feed gas compositions, ambient conditions, and LNG product specifications.

Our CWHEs contain helically wound tube bundles housed within an aluminum or stainless steel pressure shell. The CWHE provides efficient liquefaction and containment of hydrocarbons, both LNG and refrigerants. The heat exchangers may consist of one-, two-, or three bundles, each made up of several tube circuits with the tube circuit areas being matched to the process requirements. The CWHE can be fully modularized to minimize fieldwork. Our dedicated experts work with clients from conceptual development through project execution, commissioning and start-up, and continue through the life of the LNG facility.



LNG heat exchanger bundle winding process.

## Selected Air Products mid-scale LNG plant experience

Location	Initial Start-Up	No. of Trains	LNG Capacity (mtpa)	Air Products' Process
Libya	1970	4	0.8	AP-SMR™
Brunei	1972	5	1.3	AP-C3MR™
Abu Dhabi	1977	2	1.7	AP-C3MR™
<b>Algeria</b>				
Arzew GL1Z	1977	6	1.3	AP-C3MR™
Arzew GL2Z	1981	6	1.4	AP-C3MR™
<b>Indonesia</b>				
Arun	1978–1986	6	2.0	AP-C3MR™
Donggi	2014	1	2.0	AP-C3MR™
<b>China</b>				
Ningxia Hanas	2012	2	0.4	AP-SMR™
ShaanXi Yangling	2014	1	0.5	AP-SMR™
Fengzhen City Wanjie Gas	2017	1	0.3	AP-SMR™
<b>Total</b>		<b>34</b>		

## Experience you can trust

Air Products is the premier global LNG technology and equipment supplier, with 85 LNG trains in operation, all of which successfully passed their performance test the first time. No matter how small your capacity requirements, maintaining production is key to a profitable project. Air Products' proprietary liquefaction equipment is robust, reliable, compact and efficient with many CWHEs still in service today and producing well over their original design capacity.



Ningxia Hanas Natural Gas Co. Ltd., Ningxia, China plant utilizes Air Products' single mixed refrigerant (AP-SMR™) process.



Air Products' first LNG plant for Sirte Oil Co., Libya was a mid-size plant utilizing the single mixed refrigerant (AP-SMR™) process.

## About Air Products

Air Products is a world-leading industrial gases company celebrating 75 years of operation. The company's core industrial gases business provides atmospheric and process gases and related equipment to manufacturing markets, including refining and petrochemical, metals, electronics, and food and beverage. Air Products is also the world's leading supplier of liquefied natural gas process technology and equipment.



Donggi-Senoro LNG, Indonesia utilizes Air Products' propane pre-cooled mixed refrigerant (AP-C3MR™) process.

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# Small plant and peak-shaving LNG processes:

## Designed for simplicity and delivering lower unit costs



Air Products' peak-shaving LNG plant on Long Island, New York.

Small and peak-shaving LNG plants producing up to 0.5 MTA are being promoted as the way to monetize stranded gas reserves at reduced cost, to replace inefficient aging assets, and to provide fuel for the mining and transportation industries. Air Products helped pioneer the LNG industry, and we have contributed to the success of more LNG operations around the world than any other liquefaction company. Today, we are meeting the need for smaller scale and peak-shaving plants.

### Air Products' LNG processes:

#### Proven design

No matter how small your capacity requirements, you want the ability to liquefy natural gas on demand. Air Products' efficient and reliable process designs have proven to be robust and reliable in natural gas liquefaction service. Small liquefaction plants that we manufactured more than 40 years ago are still in service today, with many producing well over their original design capacity.

### Nitrogen recycle:

#### Extensive experience

Air Products has used the nitrogen recycle refrigeration system as the primary liquefaction process in air separation for more than 50 years. These liquefaction systems cover a large range of plant capacities. Air Products also owns and operates over 100 nitrogen recycle (or air recycle) liquefiers. Year in and year out, our system-wide plant availability exceeds 99 percent, while operating and maintenance costs are the industry's lowest. The high reliability and low maintenance we build into the plants we own and operate carries over to the design practices and equipment selection in plants we build for natural gas liquefaction.

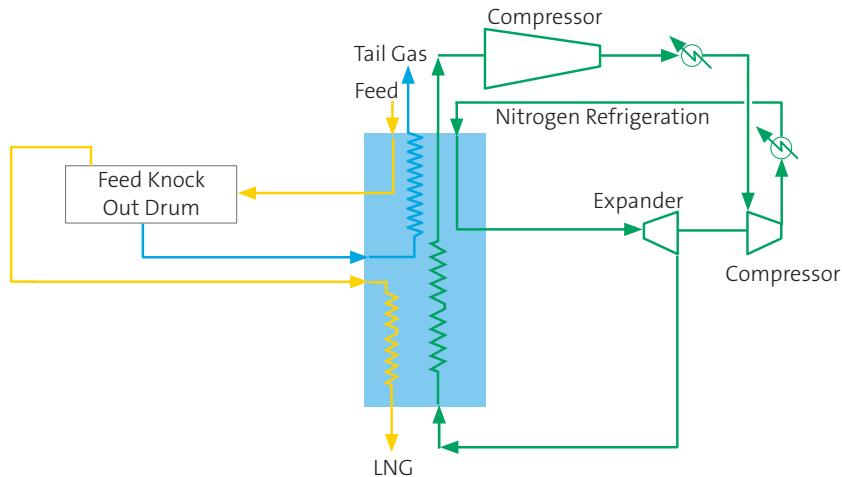
### Nitrogen recycle LNG liquefier:

#### Efficient process design and lower cost

As the world's leading supplier of LNG technology, Air Products designed and built the first LNG peak-shaving plant in 1965. We have designed and built all major types of LNG liquefaction plants, including cascade, mixed refrigerant, precooled mixed refrigerant, nitrogen recycle, and feed gas expander cycles. Our preferred product offering for LNG liquefaction applications at capacities of 5 MMSCFD to 30 MMSCFD is the nitrogen recycle liquefier. Nitrogen recycle plants in this size offer several benefits:

- Inherently lower capital cost than competing mixed refrigerant technologies while providing comparable energy efficiency
- Simple operation and superior turn-down efficiency
- Nonflammable and environmentally benign nitrogen refrigerant
- Low cost and ready availability of nitrogen
- Modularized design of nitrogen recycle liquefier, with three basic components, minimizes field construction cost

## Simple N<sub>2</sub> Recycle Process



Air Products cryogenic expander typically used in the production of a small LNG plant.

## Single mixed-refrigerant process:

### An option for enhanced performance

Depending on your project, Air Products' single mixed-refrigerant (SMR) LNG process may also be an option for your small plant. The AP-SMR process incorporates our unique coil-wound heat exchanger (CWHE), offering an attractive and straightforward solution that minimizes process equipment and provides enhanced performance and reliability. The CWHE can be fully modularized to minimize fieldwork. Air Products' mixed refrigerant process cycles with coil-wound heat exchangers benefit from years of experience and "know-how" gained in the LNG industry.

## Air Products' capabilities:

### Comprehensive resources

Air Products is the leader in supplying process technology and equipment to the LNG industry. Air Products has contributed to the success of more LNG operations than any other company and brings its full capabilities to LNG projects of any scale. From peak-shaving plants producing less than 0.1 MTA to the largest baseload facilities, on land or off-shore, our LNG team can help you get a plant up and running at the highest efficiency, on time, on budget, and in any climate. As an owner and operator of hundreds of process facilities worldwide, Air Products can provide full support to the LNG plant owner, including spare parts management, short and long term O&M services, plant optimization studies, and upgrades for existing facilities. If you need LNG production capacity—today or in the future—and you want to obtain it efficiently and cost-effectively, please contact us. We'd love to tell you more.

## About Air Products

Air Products provides atmospheric, process and specialty gases; performance materials; equipment; and technology. For over 70 years, the company has enabled customers to become more productive, energy-efficient and sustainable. More than 20,000 employees in over 50 countries supply innovative solutions to the energy, environmental and emerging markets. These include semiconductor materials, refinery hydrogen, coal gasification, natural gas liquefaction, and advanced coatings and adhesives. In fiscal 2012, Air Products had sales approaching \$10 billion.

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# Air Products' experience: Mid-scale to large LNG plant projects



Country	Location/Project	Initial Start-Up	Trains	LNG Capacity per Train (MTPA)	LNG Process
Abu Dhabi (UAE)	Das Island	1977	2	1.7	AP-C3MR™
		1994	1	2.6	AP-C3MR
Algeria	Arzew	1977	6	1.3	AP-C3MR
		1981	6	1.4	AP-C3MR
		2014	1	4.7	AP-C3MR/SplitMR®
	Skikda	2013	1	4.5	AP-C3MR/SplitMR®
Australia	NWS	1989–1992	3	2.5	AP-C3MR
	Gorgon	2016	3	5	AP-C3MR/SplitMR®
	Prelude (FLNG)	2017	1	3.6	DMR
	Ichthys	2017	2	4.2	AP-C3MR/SplitMR®
Brunei	Lumut	1972–1974	5	1.3	AP-C3MR
China	Ningxia Hanas	2012	2	0.4	AP-SMR™
	Shaanxi Yangling	2015	1	0.5	AP-SMR
	FengZhen	2017	1	0.3	AP-SMR
Egypt	SEGAS	2004	1	5	AP-C3MR/SplitMR®
Indonesia	Bontang	1977–1997	7	2.6	AP-C3MR
		1999	1	3	AP-C3MR
	Arun	1978–1986	6	2	AP-C3MR
	Tangguh	2009, 2020	3	3.8	AP-C3MR/SplitMR®
	Donggi	2015	1	2.1	AP-C3MR
Libya	Marsa el Brega	1970	4	0.8	AP-SMR
Malaysia	Satu	1982	3	2.5	AP-C3MR
	Dua	1995	3	2.8	AP-C3MR
	Tiga	2003	2	3.8	AP-C3MR
	Petronas 9	2016	1	3.6	AP-C3MR/SplitMR®
	PFLNG Satu	2016	1	1.2	AP-N™
	PFLNG Dua	2018	1	1.5	AP-N
Nigeria	Bonny Island	1999–2002	3	3.2	AP-C3MR
		2005–2007	3	3.7	AP-C3MR
Oman	Oman LNG	2000–2006	3	3.3	AP-C3MR
Papua New Guinea	PNG LNG	2014	2	3.3	AP-C3MR
Peru	Peru LNG	2010	1	4	AP-C3MR/SplitMR®
Qatar	Qatargas	1996–1999	3	3.3	AP-C3MR
		2009–2011	4	7.8	AP-X®
	Rasgas	1999–2000	2	3.3	AP-C3MR
		2004–2006	3	4.7	AP-C3MR/SplitMR®
		2009–2010	2	7.8	AP-X®
Russia	Yamal	2018	3	5.5	AP-C3MR
United States	Cove Point	2017	1	5.25	AP-C3MR
	Freeport	2018–2019	3	4.4	AP-C3MR
	Cameron	2018–2019	3	4.4	AP-C3MR/SplitMR®
Yemen	Bal-Haf	2009	2	3.4	AP-C3MR/SplitMR®
Total Trains			107		

# Air Products' experience: Small-scale/peakshaver LNG plant projects

Country	Customer	Start-Up	LNG Capacity MMSCFD (TPD)	Air Products Process
England	British Gas Council	1981	11 (227 TPD)	AP-SMR
Japan	Japex	2004	7 (144 TPD)	AP-N
		2007	10 (206 TPD)	AP-N
United States	Alabama Gas Co.	1965	5 (103 TPD)	Cascade
	Massachusetts LNG	1973	8 (165 TPD)	AP-SMR
	Hopkinton LNG Corp	1977	19 (392 TPD)	Cascade
	Cove Point LNG	1994	15 (310 TPD)	AP-SMR
	Keyspan LNG	2001	6 (124 TPD)	AP-N
	Philadelphia Gas Works	2002	16 (330 TPD)	NG Expander
	National Grid	2017	20 (412 TPD)	AP-N

## About Air Products

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