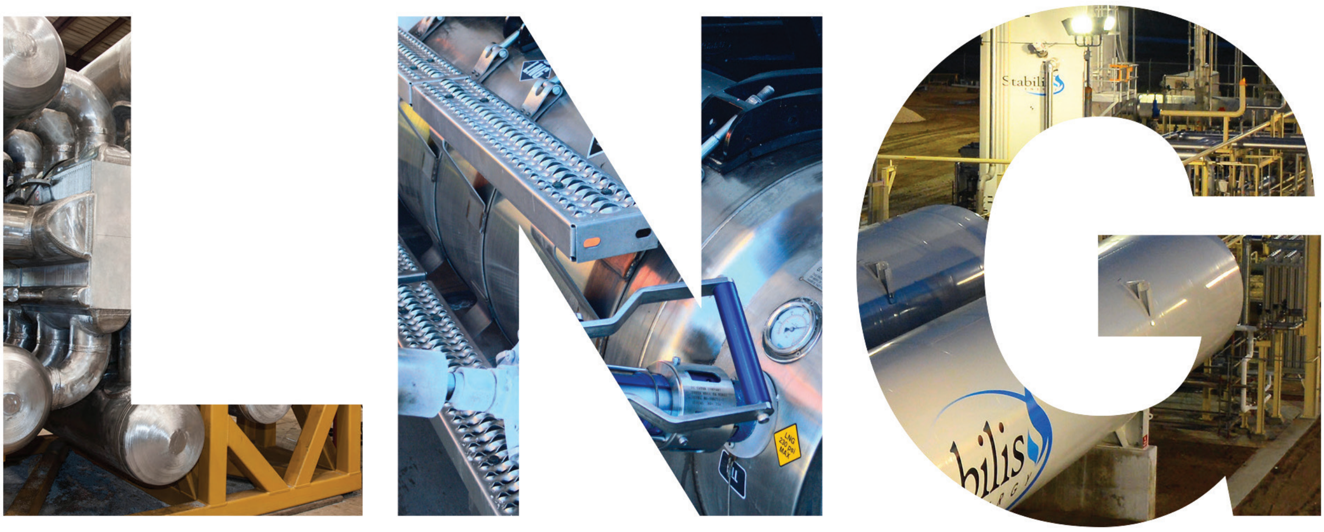
LNG INDUSTRY

October 2015



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What shall we do with all this gas

Paul Shields, Chart Industries Inc., USA, looks at how small and mid scale LNG is providing answers to this question.

The development and application of drilling and fracturing technology is responsible for the significant escalation in natural gas production from non-conventional sources. Similarly, it is the development and application of liquefaction technology that is enabling this environmentally friendly source of energy to be used as a substitute for diesel and bunker fuel and a valuable export for North America.

In particular, standard and modular plant solutions are overcoming the economies of scale traditionally associated with world scale facilities, and answering the economic question. The Stabilis facility in George West, Texas, US, which opened earlier this year, is strategically located at the heart of the Eagle Ford Shale and produces LNG used to fuel high horsepower engines that are used in the oilfield, as well as in other sectors, including transportation and asphalt, that would otherwise use diesel and other distillate fuels. With a liquefaction capacity of 100 000 gal./d, it is an excellent demonstration of the standard plant approach. A modular solution is favoured by many of the North American export projects, currently in various stages of approval.

From the earliest days of commercial natural gas liquefaction, brazed aluminium plate-fin heat exchangers (BAHX) have been selected for LNG trains, ranging in size from the very smallest, to some of the largest at approximately 5 million tpy. This trend has continued with small and mid scale LNG, where the combination of optimised process technology and the BAHX provide plant

Definition of small and mid scale LNG

Although the terms small scale LNG and mid scale LNG have been adopted into common industry parlance, there are no defining liquefaction capacities to denote either, or indeed a fixed point at which the cross-over between the two occurs. For the purposes of discussion, it is useful to reference plant size. However, it is perhaps more useful to consider plant characteristics when attempting a definition of small and mid scale LNG (Figure 1).

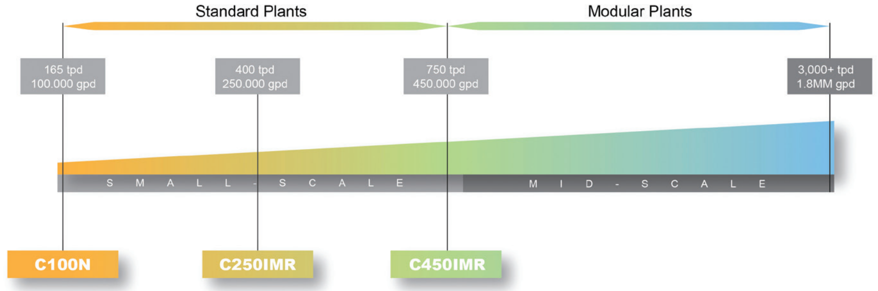

Figure 1. Working definition of small and mid scale LNG.

In terms of economic cost and the time-scale of building a plant, standardisation sits at the opposite end of the spectrum to the custom design of base-load LNG plants, and somewhere in between lies modularisation. If these traits are aligned with the generic descriptors of LNG plant sizes, then small scale = standard, mid scale = modular, and base load = custom, which is a good foundation for an overall definition.

The use of brazed aluminium heat exchangers is neither economical, nor feasible, for cryogenic liquefaction plants producing less than 100 tpd (62 000 gal./d). Therefore, 100 tpd is Chart's starting point for small scale LNG. The upper limit for small scale LNG is more arbitrary, but is predominantly based on demand experience from China, where such facilities are prevalent, and the practicality of maximising standard equipment packages within a fixed mechanical design for a portfolio of capacities. This lead to Chart developing three standard plant solutions, each with nominal liquefaction capacities of approximately 100 000 gal./d (165 tpd), 250 000 gal./d (400 tpd) and 450 000 gal./d (700 tpd), respectively.

Increased mid scale capacities are achieved through multiple identical liquefaction modules rather than a single custom plant. The modular approach is proven to deliver reduced capital cost and faster project execution through maximised shop fabrication and reduced field construction. Each single mid scale module would generally be engineered to provide between 900 000 gal./d and 1 800 000 gal./d.

In summary, although it can be useful to think in terms of plant capacities when defining small and mid scale LNG, it can also be easy to apply the following:

- Small scale LNG = standard cryogenic plant.
- Mid scale LNG = modular cryogenic plant.

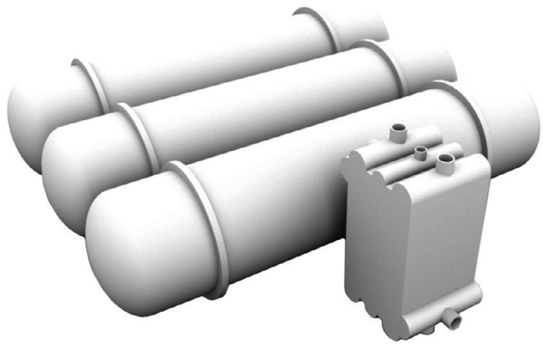

Figure 2. BAHX footprint comparison vs shell and tube technology.

Heat exchange is key to liquefaction

Brazed aluminium heat exchangers are highly efficient, custom designed compact heat exchange devices that offer advantages over alternative heat exchange methods. They are manufactured as an all brazed and welded pressure vessel with no mechanical joints and are designed in accordance with major pressure vessel codes throughout the world. BAHXs are applied in a variety of cryogenic and non-cryogenic heat

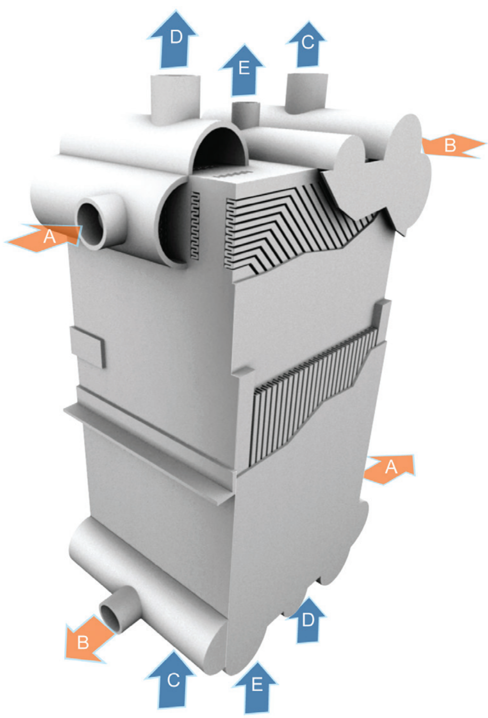

Figure 3. Multi-stream BAHX showing flow path example.

transfer applications, ranging from LNG production, industrial gas production, petrochemical and hydrocarbon processing, and hydrogen and helium liquefaction. Given their high surface area, compactness and the superior heat transfer capability inherent to aluminium, they are a cost-effective solution for processing non-corrosive liquids and gases when compared to alternative heat transfer technologies.

To illustrate the compactness of BAHX, the design provides a heat transfer area density of approximately 1000 to 1500 m^2/m^3, which is six to ten times greater than a coil wound heat exchanger and at least 20 times greater than conventional shell-and-tube technology. This characteristic advantage of a BAHX, coupled with the enhanced heat transfer performance of aluminium plate-fin construction and optimised heat transfer fin designs, results in significantly lower cost (25 – 50% less) and substantially lower weight (95% less) than is provided by a stainless steel shell-and-tube exchanger (Figure 2).

When process UA requirements exceed what can be delivered in a single core block, several BAHXs can be piped or manifolded together in parallel or series to accommodate nearly unlimited flow or duty requirements. The manifolded assembly can be field insulated or installed in a cold box for ease of insulation, support, and installation.

The flexibility of a BAHX allows multiple heat exchange services (10 or more streams in a single block) to be combined into a single compact application. BAHX technology enables pinch analysis, along with all the energy minimising benefits. This feature significantly reduces installation and operation costs, engineering, insulation, support systems, testing, documentation, transportation and site arrangements (Figure 3).

Aluminium plate-fin exchangers have a number of advantages in most LNG processes. Minimising power consumption is a key design criterion for liquefaction processes, creating an inherent requirement for highly efficient heat exchange. Process efficiency is gained by minimising temperature approach between the hot and cold streams. As the temperature approach decreases, the required surface area increases. With that in mind, the heat exchanger of choice must offer high surface area economically. A BAHX is an excellent choice for liquefaction processes.

To ensure the robustness of the BAHX for LNG applications, state-of-the-art software is coupled with in-house engineering expertise and experience to perform advanced transient thermal analyses. Exchangers are studied three-dimensionally from available operating data or dynamic simulation process software to determine the internal fluid and metal heat exchanger temperatures and the associated thermal stresses imparted on the exchanger. These analyses can be carried forward to predict potential fatigue damage and life expectancy of the equipment. Dynamic simulation is used to simulate operation of the BAHX and plant upset conditions to ensure process technologies are designed with proper controls to mitigate situations that introduce thermal stresses.

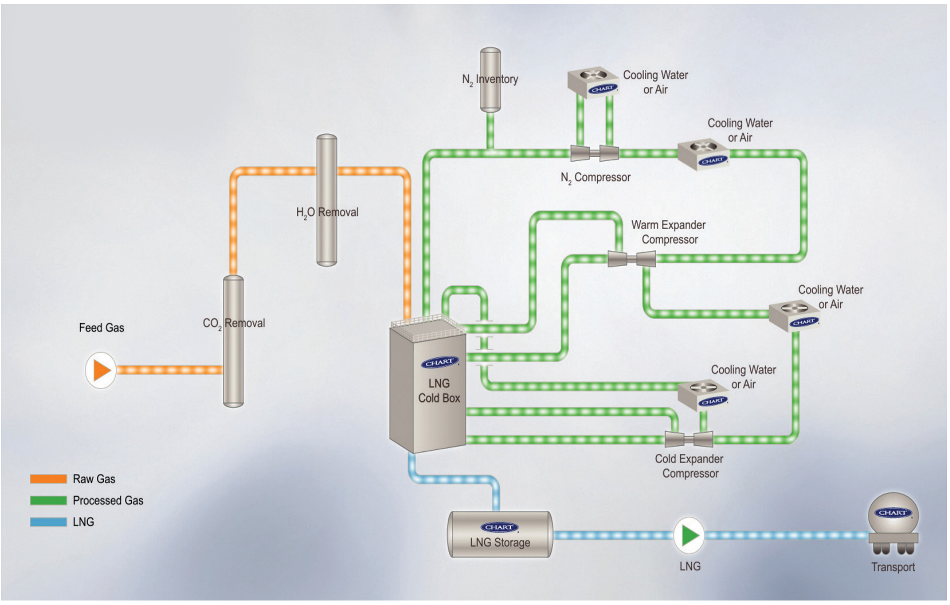

Figure 4. Chart's proprietary nitrogen cycle process technology.

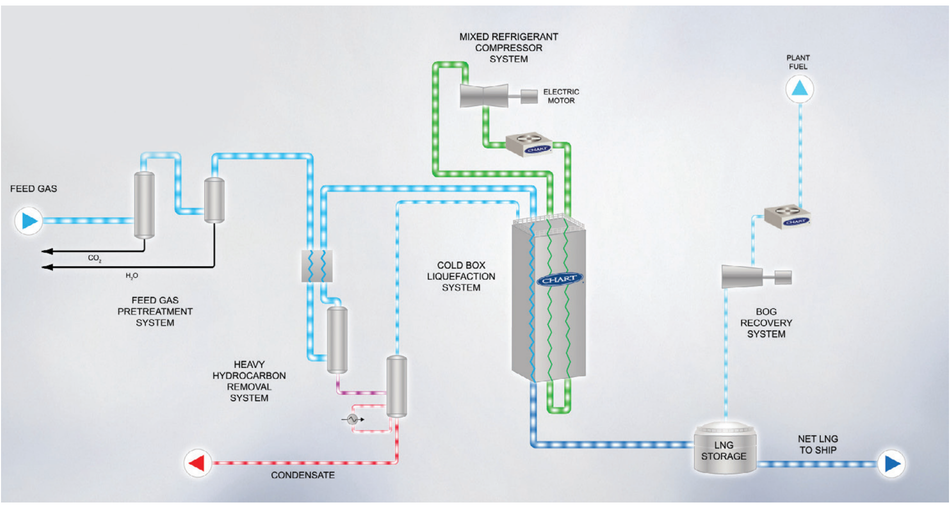

Figure 5. Chart's proprietary IPSMR® process technology (with optional HHC removal system).

Liquefaction processes

There are several refrigeration cycle configurations that can be utilised to liquefy natural gas, but for small and mid scale LNG, Chart focuses on the nitrogen cycle and the mixed refrigerant (MR) cycle. Each cycle has its advantages and disadvantages when evaluated for use in a specific application. Designers usually study the trade-offs between power consumption and equipment utilisation. This analysis allows them to optimise the liquefier for the total plant cost (capital plus operating costs). Comparison of operating costs should focus on the energy consumption of the refrigeration system, as the balance of plant should be essentially the same for all processes.

Nitrogen cycle

Nitrogen cycles are simple to operate and eliminate the need for the use and storage of hydrocarbons as refrigerants. They offer advantages to operators who do not want to spend the capital and energy to extract their hydrocarbon refrigerants from the treated feed gas and are ideally suited to remote areas that do not have easy access to hydrocarbons for refrigerants. However, simplification comes at the expense of higher specific energy consumption (Figure 4).

MR cycles

MR processes are based on mixtures of light hydrocarbons and nitrogen, usually a single mixture system with or without precooling. In some instances, the processing scheme utilises dual mixture systems. Process optimisation is achieved by varying the mixture of refrigerant components and operating pressures in a manner that essentially allows the heating curve of the refrigerant to mirror the cooling curve of natural gas in a tight temperature approach. The brazed aluminium exchanger accommodates the surface area requirements resulting from the tight approach temperatures and log mean temperature differences (LMTD). Its inherent multi-stream capability also allows the process engineer to add or remove refrigeration along the process thermal gradient, wherever needed, to optimise process efficiency. A single service main liquefaction BAHX has been an integral part of MR base load, mid scale, and peak shaving plants since the early 1970s. Another advantage to the process is the use of a single service compressor to provide the refrigeration pressure boost.

For the smallest small scale LNG plant, Chart offers a nitrogen cycle process but, as capacities within small scale LNG grow, and for all mid scale LNG applications, the company recommends a mixed refrigerant process. Its own proprietary integrated pre-cooled single mixed refrigerant (IPSMR®) process was designed specifically to minimise operating differential temperature in the BAHX, which significantly reduces the possibility of overstress from plant upset conditions and also improves process efficiency (Figure 5).

In cases where the condition of the inlet gas is outside the range supported by the liquefier design, the design can be supplemented with customised 'bolt-on' modules to ensure system functionality. These bolt-on modules can include the following:

- Feed gas compression.
- Heavy hydrocarbons removal.
- Ethane rejection.
- Nitrogen rejection.
- Water and carbon dioxide removal.
- Mercury removal.
- Sulfur removal.

Small scale LNG concept

The market for small scale LNG facilities initially developed in China to support its virtual pipeline and is now gathering pace in the US using shale reserves to supply fuel for high horsepower applications, such as drilling, mining and other civil projects. The transportation demands of trucking, marine and rail are also providing further market expansion. These small scale facilities lend themselves to a highly compact, modular design to reduce overall costs.

Chart's Standard Plant Concept consists of maximising equipment with an essentially fixed mechanical design for a portfolio of capacities. At the specified nominal capacities, this concept applies to the pretreatment, liquefaction, refrigeration, storage, truck loading, and balance of plant utilities. Project specific design conditions are used to check rate the existing design and equipment package to set the expected production and guarantee points.

In addition to developing a set of 'go by' project documents for use as a basis for every project effort, the strategy also includes designing the key pieces of equipment once and replicating those designs on an ongoing basis. Many key components are prefabricated in Chart's facilities to ease the installation complexity and, as the infrastructure demand grows, consideration can be given to building key equipment packages or subcomponents for inventory.

In all instances, bringing supply to market quickly is a key driver for project success. This goal is achieved by significantly shortening project durations compared to customised designs (Figure 6). The result is lower overall cost and improved project economics. Production is expected to begin within 15 to 18 months of contract execution. The current plan is to deliver equipment to site within 12 to 14 months, with start-up following three to four months afterwards.

Mid scale LNG concept

In the mid scale sector, Chart's clients' interests are centred on the export of low-price US gas, as LNG, to foreign markets. Chart's mid scale modular model challenges the traditional paradigm that a large baseload LNG facility provides the best economy of scale for an export project.

The development and construction of a baseload facility for the export of LNG requires many multiple billions in financing, as well as many years of planning, permitting and construction.

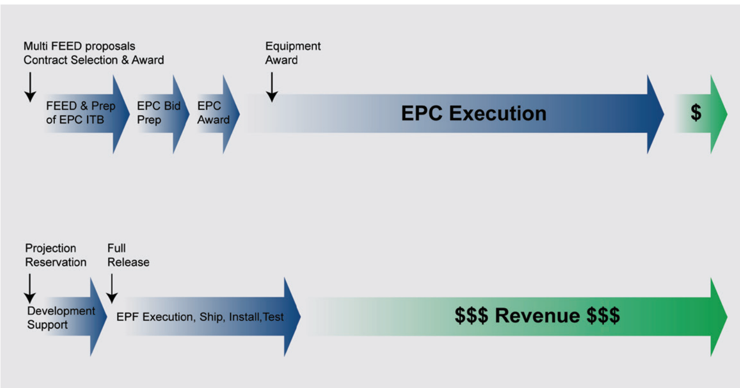

Figure 6. Schedule savings with standardised plant.

Additionally, signing long-term off-take contracts, securing a gas supply and finding sufficient construction labour, all add to the project complexities and overall risks. Recent data has shown baseload LNG project costs are upwards of US$1000/t and, in some instances, well above that mark. When the baseload project is eventually successful and the plant is built, the client faces an operational risk that an upset or failure may cause a complete stoppage of all LNG production. In other words, a plant with a single LNG liquefaction train loses all production when that train is down.

In contrast to the risk profile and upward CAPEX price pressures from traditional baseload projects, Chart, and others, have developed solutions using multiple, smaller, modular LNG trains that allow clients to scale their project, and costs, with market conditions. For example, if feed gas supply resources are not fully developed, clients can start small and proceed with the additional LNG trains as feed gas supply comes online. If sufficient off-takers are not available, or ready to commit, clients can serve the off-takers that are ready and expand plant capacity as LNG demand grows. If multiple billions in financing are not available, clients can start with a smaller facility and expand as they sell out LNG and secure more funding. In all cases, the modular solutions are quicker to market and thus generate revenue faster for stakeholders.

Examples of modular solutions for LNG include, but are not limited to, the following:

- Chart's project with Energy World in Indonesia is a 2 million tpy plant, with four trains producing 0.5 million tpy each. The plant is under construction and Energy World is projecting that the first train will start-up later this year. As demand increases, the Energy World facility has the capability to add six more trains for a total build-out of 5 million tpy.
- Venture Global will export LNG from the US Gulf Coast. Advanced engineering is underway. At final build-out, the site will have 20 Chart 0.5 million tpy IPSMR® trains for a total capacity of 10 million tpy.
- Parallax Energy's Live Oak LNG and Louisiana LNG projects are both planning modularised, multiple train solutions to serve their clients effectively and efficiently.
- The Magnolia LNG project comprises four LNG production trains, each with 2 million tpy capacity. It is scheduled to provide first LNG in late 2018 and achieve full capacity in 2019.

All of these projects are estimating a CAPEX basis well below a traditional baseload facility. With high CAPEX costs for baseload projects at US$1000/t, a modular solution is an attractive alternative for many clients pursuing onshore and floating LNG (FLNG) projects.

Summary

Through deployment of standard and modular plant designs, which significantly reduce overall time to production and provide lower cost and earlier recognition of revenues, the answer to the original question, 'what shall we do with all this gas?' can be to liquefy it and use it domestically as a fuel substitute to diesel, and valuable export commodity. **LNG**


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Standard liquefaction plants for the transportation and energy industries
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- C250IMR – 250,000 gpd IPSMR®
- C450IMR – 450,000 gpd IPSMR®
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LNG
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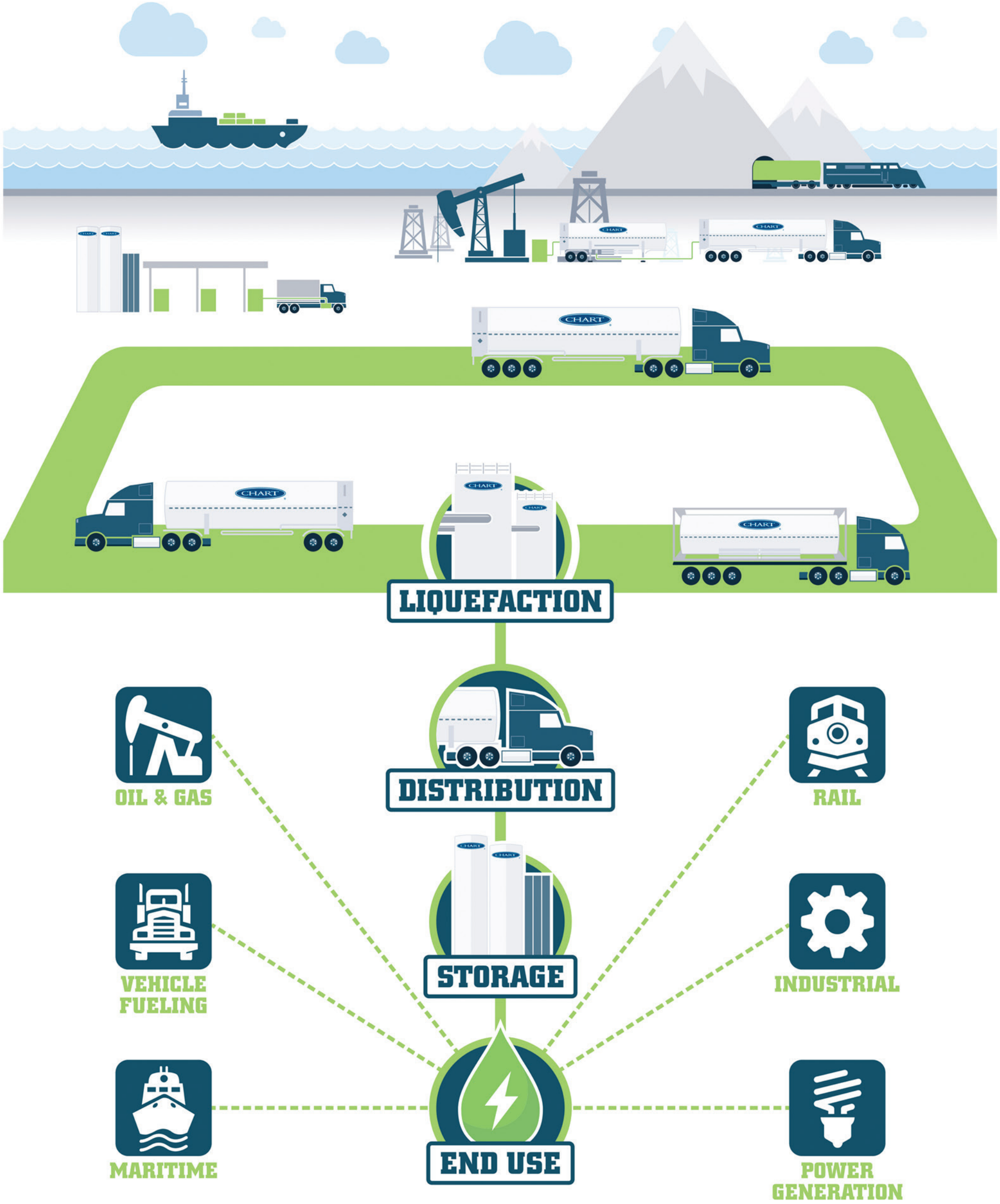
LNG VALUE CHAIN



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