Helping you harness the energy of opportunity
The use of natural gas is on the rise. Cleaner, cheaper and more abundant than diesel, natural gas offers organizations the opportunity to lower their operating costs and reduce emissions to meet increasingly strict global requirements.

However, large scale liquefied natural gas (LNG) plants are often too complex and costly, tying up capital and requiring several years of development before they’re operational. And they’re often located far from the point of use, adding transport time and cost.

Small scale LNG plants are a powerful alternative for this growing market. But the design and configuration of the plant can make a big difference in how well it meets an organization’s goals.

A developer must ask:
- Are we looking to minimize operating complexity? Or is it more important to have lower operating costs?
- What type of plant construction should we use? How quickly do we need to be operational? What is the optimal liquefaction cycle for our needs?
- How important is ease of use and integration when it comes to the plant’s control system?

This guide outlines several key considerations when designing your small-scale LNG plant to ensure optimal operations and sound project economics.
Consideration 1: Type of Plant Construction

LNG facilities designed with small-scale trains realize improved economics due to the plant’s modularity—process modules built in a factory environment and delivered to the field. Benefits include:

- Cost savings from a reduction in skilled craft labor required at the construction site, as well as the ability to minimize use of heavy equipment on-site
- Improved quality and safety, with fabrication completed using standardized procedures in a factory environment
- Faster project execution, with work being done at the factory and in the field simultaneously

With the acquisition of Salof—the pioneer of modular cryogenic plant construction—GE brings over 40 years of experience in modular and plug-and-play cryogenic plants.

MODULAR VS PLUG-AND-PLAY

Though similar in terms of the benefits that they offer to developers, there are significant differences between modular and plug-and-play-style construction.

MODULAR CONSTRUCTION

Modular skids are constructed in the factory and transported to the site, where they are installed. Interconnecting piping and structures are then fabricated in the field to complete the plant.

PLUG-AND-PLAY CONSTRUCTION

With plug-and-play, the complete plant is assembled at the factory from the modules. All modules, interconnecting piping and cable trays are mechanically fit-tested, and an end-to-end test of the control system is performed. The plant is then disassembled and shipped to the construction site.

Compared to modular construction, benefits include:

- Reduction in commissioning time
- Improved safety and repeatability, with assembly and mechanical testing in a factory environment
- Training on assembly at factory

Whether with modular or plug-and-play, companies can see improved economics and fast-track execution with small-scale LNG plant construction.
Consideration 2: Choosing the Optimal Liquefaction Cycle

The choice of liquefaction cycle will have a significant impact on the efficiency of the plant—namely, its cost in kilowatts per gallon to operate. There are two categories of liquefaction cycles:

**Mixed Refrigerant:** A pre-cooled mixed refrigerant (PCMR) or single-cycle mixed refrigerant (SCMR) cycle uses a custom mix of nitrogen and hydrocarbons that cool the natural gas until it condenses. This offers the highest possible efficiency and the lowest operating costs.

**Expansion Cycle (EXP):** EXP is a single-cycle compression-expansion refrigeration process that uses either self-boil-off gas or nitrogen as a refrigerant. However, because a process utilizing a single refrigerant is unable to optimize the compressor horsepower to the cooling curve of the main heat exchanger, it can be up to 40% less efficient—leading to higher operating expenses.

See below for an example of efficiency loss.

**LNG IN ACTION: THE IMPACT OF LIQUEFACTION CYCLE ON PROJECT ECONOMICS**

<table>
<thead>
<tr>
<th>Specific power</th>
<th>Electricity cost</th>
<th>Total annual power cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Cooled Mixed Refrigerant Cycle</td>
<td>0.80 kWh/gal</td>
<td>$0.06/gal</td>
</tr>
<tr>
<td>Nitrogen Expansion Cycle</td>
<td>1.1 kWh/gal</td>
<td>$0.09/gal</td>
</tr>
</tbody>
</table>

Specific powers above are for illustrative purposes. Actual specific power for a given liquefaction train will vary based on several factors. Assumes 300,000-gallon/day production for 350 days per year with $0.08/kWh electricity cost.

**Additional factors that developers must understand:**
- Location and site conditions
- Permitting requirements
- Gas conditions
- LNG purity requirement
- Storage (pressurized vs. atmospheric)
- Availability of refrigerants
- Availability of utilities
- Operational philosophy
- Production requirements
Consideration 3: Avoiding Pitfalls With Control Systems

Control systems are the brains of small-scale LNG plants. By providing visibility into operations, they empower operators to quickly identify process and equipment parameter deviations, solve problems proactively and avoid system errors—ultimately impacting plant efficiency and performance.

Yet, with plants comprised of equipment from a multitude of different manufacturers—each with their own unique control system—integrating these machines into a single system can be challenging. Often, plant equipment providers and engineering firms accomplish this using external vendors who lack experience with the plant operation and the equipment involved. The resulting control system is, at best, a patchwork solution, which is more vulnerable to programming and communication errors that can disrupt operations and lead to costly downtime.

GE’s holistic approach to controls—one system running all major equipment—can make all the difference, simplifying operations and ensuring prime functionality. A fully integrated system offers total visibility into process conditions, operating parameters and historical logs, giving operators the information they need to optimize performance plant-wide.

OTHER FACTORS TO CONSIDER WHEN CHOOSING A CONTROL SYSTEM:

- **Ease of use**—a well-designed, intuitive interface saves time and effort, making training and ongoing use easier
- **Accessibility**—control panels should be easy to access
- **Remote access**—the ability to troubleshoot issues and work with technology partners remotely, anywhere, anytime

GE’s proven control system runs on a single software platform, offering simplicity and complete visibility for more efficient operations and optimal performance.
Get on the fast track to LNG power with GE

With speed and simplicity—and the experience and expertise that only GE can provide—we help small-scale LNG plant developers get up and running with modular or plug-and-play solutions that deliver the best economics for their needs.

From choosing the right liquefaction cycle to minimizing installation costs to configuring the optimal control system, we work with our clients to design and fabricate a modular plant solution, enabling them to ramp up production quickly, to the size and scale that makes sense for the market and their business.

Why GE?

The power of GE

- Unmatched technology, resources and expertise
- Unwavering commitment to partner success
- Ongoing LNG research and development, backed by GE’s Global Centers of Excellence

Responsive partner

- Guidance throughout commissioning, installation and beyond
- Analysis, troubleshooting and expert consultation
- Optimization of assets and operations for greater profitability

Proven experience

- Over 130 small-scale cryogenic plants in operation, with a variety of different liquefaction solutions
- 17 small-scale LNG trains in production
- 40 years of cryogenic process design and manufacture

DIVERSE OFFERINGS OF SMALL-SCALE LNG TRAIN CAPACITIES:

<table>
<thead>
<tr>
<th>Capacity</th>
<th>LNG25 (mm TPA)</th>
<th>LNG50 (mm TPA)</th>
<th>LNG100 (mm TPA)</th>
<th>LNG300 (mm TPA)</th>
<th>LNG450 (mm TPA)</th>
<th>LNG600 (mm TPA)</th>
<th>LNG1200 (mm TPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(k) gal/day</td>
<td>25</td>
<td>50</td>
<td>100</td>
<td>300</td>
<td>450</td>
<td>600</td>
<td>1,200</td>
</tr>
<tr>
<td>(k) Nm3/day of gas</td>
<td>59</td>
<td>117</td>
<td>234</td>
<td>702</td>
<td>1,053</td>
<td>1,410</td>
<td>2,778</td>
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</table>
Bringing GE’s large-scale LNG experience to small-scale LNG

In 1989, GE’s Frame 5 gas turbine driver first surpassed 2 MT/year. In the decades since, our solutions have played a critical role in the development of every major large-scale LNG plant in the world, contributing much needed power, efficiency and reliability to companies and countries around the globe.

Today, GE continues to be a leader in LNG production, both big and small scale. Together with our partners, we help generate 70% of the world’s liquefied natural gas—over 181 MT/year.

### GE SMALL-SCALE LNG PLANTS

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Cycle</th>
<th>(mm) SCFD</th>
<th>(k) gal/day</th>
<th>(mm) TPA</th>
<th>Nm3/day of gas</th>
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<tbody>
<tr>
<td>2004</td>
<td>China</td>
<td>EXP C₁</td>
<td>5.6</td>
<td>69</td>
<td>0.04</td>
<td>150,000</td>
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<tr>
<td>2005</td>
<td>Australia</td>
<td>PCMR</td>
<td>10.0</td>
<td>124</td>
<td>0.07</td>
<td>268,300</td>
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<tr>
<td>2009</td>
<td>China</td>
<td>SCMR</td>
<td>11.2</td>
<td>139</td>
<td>0.08</td>
<td>300,000</td>
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<tr>
<td>2010</td>
<td>China</td>
<td>PCMR</td>
<td>1.9</td>
<td>23</td>
<td>0.013</td>
<td>50,000</td>
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<td>2010</td>
<td>China</td>
<td>PCMR</td>
<td>3.8</td>
<td>46</td>
<td>0.026</td>
<td>100,000</td>
</tr>
<tr>
<td>2010</td>
<td>China</td>
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<td>2010</td>
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<td>PCMR</td>
<td>3.8</td>
<td>46</td>
<td>0.026</td>
<td>100,000</td>
</tr>
<tr>
<td>2010</td>
<td>China</td>
<td>PCMR</td>
<td>19.0</td>
<td>231</td>
<td>0.13</td>
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<tr>
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<td>China</td>
<td>SCMR</td>
<td>38.0</td>
<td>462</td>
<td>0.26</td>
<td>1,000,000</td>
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<tr>
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<td>Canada</td>
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<td>36.5</td>
<td>450</td>
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<tr>
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<td>U.S.</td>
<td>SCMR</td>
<td>365.0</td>
<td>4,500</td>
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<td>U.S.</td>
<td>PCMR</td>
<td>24.3</td>
<td>300</td>
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<td>694,100</td>
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<tr>
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<td>Russia</td>
<td>EXP N₂</td>
<td>8.1</td>
<td>100</td>
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<td>213,696</td>
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<tr>
<td>2014</td>
<td>Nigeria</td>
<td>SCMR</td>
<td>73.0</td>
<td>900</td>
<td>0.50</td>
<td>1,947,330</td>
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<tr>
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<td>Canada</td>
<td>EXP N₂</td>
<td>8.1</td>
<td>100</td>
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In development