It has been said that turbomachinery is at the heart of every LNG plant whether small, mid or large scale. When it comes to selecting the right turbomachinery for an LNG project, there are a number of factors to consider, such as space, weight, reliability, maintainability, and safety.

No matter what equipment is chosen, the ultimate goal is to optimise the economic return. Total expected lifecycle costs, including both OPEX and CAPEX, play a critical role when choosing turbomachinery for an LNG facility.

Choosing the design and selecting rotating and electrical equipment to achieve the highest reliability, efficiency and safety for LNG applications of any size, while also reducing CAPEX, is not an easy task.

Figure 1: Two workers looking at the northernmost LNG plant near Hammerfest (photo: Florian Sander; source: Siemens).
The site specific gas reserves available, the size of the production plant and the project objectives are key drivers for selecting the most appropriate liquefaction process. There are LNG liquefaction processes that use pure gas as refrigerants, or a composition of different gases, called mixed refrigerants (MR).

Depending on gas properties and the amount of refrigerant to be compressed, the compressor-inclusive drive system comprising the compression string must be developed. As these compression strings are key components in the LNG production chain, it is essential to carefully evaluate the available alternatives as early as possible.

Another important decision is the type of power to integrate into the plant. A lot of energy is required to liquefy natural gas. In most cases, the feed gas is used for the gas turbine, which operates as either a mechanical drive or generator drive. Electrical drivers in combination with the power from a combined cycle power plant could also be considered for the main liquefaction compressors.

For energy transfer from the gas source to refrigerant compression, the Dresser-Rand business offers highly efficient products and solutions for such a ‘power-to-compression’ system.

Siemens’ recent acquisitions of Dresser-Rand and the aeroderivative gas turbine product portfolio from Rolls-Royce Energy has resulted in a wider selection of both drivers and compressors for all plant sizes. Equipment options include the main liquefaction unit, amine unit, booster machine, controls, and water treatment facility, etc.

When selecting the primary energy source for an LNG production process, the goal is always to select the source that offers the most efficient solution, regardless of what liquefaction process is being considered by the owner.

In the past, the LNG industry primarily used steam turbine drivers, but the steam process efficiency is often low at approximately 26%. Project owners are increasingly turning to electrical motor and gas turbine drives.

Unless the owner can secure a low price for power (US$/kWh) and the level of power to meet peak facility demand early in the project, the aeroderivative gas turbine solution typically is the most attractive option. Electrical motors do not necessarily reduce greenhouse gas (GHG) emissions if powered by a combined cycle gas plant. However, emissions would be lower if powered by a combined heat and power (CHP) or a renewable/hydro-electric facility. While there are pros and cons to each option, having access to alternative solutions can provide peace of mind when planning a new LNG plant.

**Melkøya LNG plant**

In many cases, the electrical variable speed drive system (VSDS) offers the highest degree of flexibility in order to fulfill all of the process duty requirements of an LNG plant. Such systems are available up to 90 MW. VSDS design concepts are usually evaluated early in the project stage with a goal to optimise the overall LNG plant solution and to avoid interharmonics in operating speed range.

In principle, generated harmonic torque oscillations may have an essential impact on the torsional vibration behaviour of the entire train. Dynamic and accurate speed control via electronic variable speed controllers is possible.

The VSDS allows for a soft start of the unit. It also provides a torque that allows the compressor to restart from settle-out pressure, regardless of process volume flow. Consequently, the driver and compressor manufacturers must carry out a detailed analysis to examine the expected operating condition of the rotating equipment. Close collaboration of the driver and compressor manufacturers in designing and engineering a VSDS driven train is essential.

One example comes from the state-owned Norwegian oil and gas company, Statoil, which developed the huge Snøhvit natural gas field in the Barents Sea, approximately 140 km off the North Norwegian coast. Due to the remoteness of the field, Statoil decided to move large volumes of natural gas via pipelines to Melkøya Island near Hammerfest, Norway, where the gas is liquefied for export.

Reliable turbomachinery with minimal downtime was a key requirement for the Melkøya LNG plant. For this project, several refrigerant compressors are used at various stages of the gas liquefaction process for CO₂ re-injection and driven by massive 65 MW VSDS electric motors.

Manufactured for the specific conditions that prevail in the Arctic region, the compressors were designed for ambient temperatures as low as -22°C and include a variety of features, such as:
- Glass reinforced plastic water lines.
- High quality stainless steel materials.
- Winterisation with heat tracing and weather protection.

**Figure 2.** An example of a typical LNG process set-up (source: Air Products and Chemicals Inc.).

**Figure 3.** In order to liquefy natural gas, it has to be cooled to approximately -160°C. Siemens constructs the large liquefaction compressors required for this process (source: Siemens).
Coatings systems that include thermally sprayed aluminium.

Dry gas seals.

CO₂ – one of the main components of the natural gas from the wells – is separated at the LNG plant and compressed from 1 bar to 61 bar with a capacity of approximately 100 tph of CO₂ at a rating of 10 MW. The CO₂ is then cooled to approximately 15°C, at which point it condenses to liquid. The liquid CO₂ is then pumped back to the field for permanent storage beneath the seabed, thus minimising CO₂ emissions tax.

Lake Charles LNG project
The Dresser-Rand business offers the SGT-750 and Industrial Trent 60 aeroderivative gas turbines. Each has been selected by several operators and developers for their LNG projects, both onshore and floating, due to their high efficiency, light weight and speed range variation available from the free power turbine.

These two turbines offer ISO efficiencies of 42%. When considering that the fuel burned is LNG not sold, each percentage of turbine efficiency will cost the operator approximately US$24 million net present value (NPV) at 10 years. The NPV is based on a 10% discount rate for a 10 million tpy plant size and fuel gas evaluated as LNG at US$6/million Btu.

Additionally, the Dresser-Rand business packaged an aeroderivative gas turbine in a lightweight concept using a torque tube base plate. This torque tube mini-module design concept can be offered for all industrial gas turbines and can reduce the weight of the total package by approximately 20 t.

A torque tube base plate offers torsional stiffness that is superior to a box beam and provides easier access to the fuel gas system, hydraulic starter, synthetic oil system, and other controls. This design has been used for offshore applications for more than 30 years, but could also be used for onshore plants to minimise site erection cost and cycle time. For a 2 million tpy floating LNG (FLNG) unit, for example, this torque tube concept has demonstrated reduction in hull steel costs of approximately US$2.8 million.

BG Group, which was acquired by Royal Dutch Shell in February 2016, is developing a project to construct and operate a 15 million tpy LNG facility in Lake Charles, Louisiana, US. This mega-plant design is meant to be efficient, environmentally friendly and cost-effective.

During a rigorous evaluation process to find the right main refrigeration compressor driver for its plant, one of the key project goals was to minimise adverse effects of the facility’s operations on the environment.

Siemens was involved early in the process and recommended its Industrial Trent 60 aeroderivative gas turbine for the project, since the higher aeroderivative thermal efficiencies provide low CO₂, CO and NOₓ emissions tonnage per year.

The aeroderivative gas turbine met the initial design criteria as a compressor driver for the facility and was included in a detailed driver selection study, which was based on lifecycle costs for an assumed facility life of 25 years.

The following were the main criteria used during the selection process:
- Cost.
- Footprint.

While BG Group standards mandated aeroderivative gas turbines because of its ‘green’ requirements, a high level comparison of industrial frames vs aeroderivative gas turbines was conducted to obtain a general, rough evaluation of the two types of engines. Heavy duty gas turbines (HDGT) required large (~22 MW) starter/helper motors to meet the nominal production rate of 5 million tpy of LNG per train.

The following main configurations were compared:
- 2 x industrial frame gas turbines with ~22 MW starter/helper motors and inlet air chilling (IAC).
- 4 x large aeroderivative gas turbines + GT IAC on the mixed refrigeration gas turbine only.
- 5 x smaller aeroderivative gas turbines + GT IAC.

The relative CAPEX values for aeroderivative vs industrial frame gas turbines were comparable when the costs of the additional power generation required to support the starter/ helpers were considered. However, the OPEX values were significantly different. Fuel gas consumption was considered in the evaluation based on the value of LNG not sold. In this analysis, the substantially lower thermal efficiency of the industrial frame gas turbines translated into higher OPEX. Furthermore, using the Henry Hub (HH) price in the analysis still demonstrated a cost benefit due to the high efficiency of the aeroderivative gas turbine driver.

![Figure 4. The Siemens Industrial SGT-750 aeroderivative gas turbine (source: Siemens).](image)

![Figure 5. The Siemens Industrial Trent 60 aeroderivative gas turbine (source: Siemens).](image)
The higher fuel gas consumption resulted in much higher emissions, which increased the annual CO\textsubscript{2} and NO\textsubscript{X} emission tax costs. In addition, the industrial frame gas turbine availability was lower than that of the aeroderivative engines, mainly due to extensive downtime during major overhauls (50 000 hr between overhauls). As a result, the industrial frame gas turbines were removed from the list of potential driver alternatives because of their much higher overall lifecycle costs.

Electric motors were also considered in the driver selection study, but were found to require a large amount of electrical power (almost 800 MW). This option would have also required an extensive electrical system with multiple, large variable frequency drivers (VFD) and the associated harmonic filters. As such, further consideration was not given to electric motors for the liquefaction compressor drivers because of the high CAPEX associated with this solution.

The final stage of the driver selection study focused on comparing larger aeroderivative gas turbines (Industrial Trent 60) to smaller aeroderivative gas turbines, as outlined below:
- 4 x Industrial Trent 60 gas turbines + GT IAC.
- 5 x smaller aeroderivative gas turbines.

CAPEX costs were similar for the two aeroderivative engine configurations, but when the total installed cost was considered, there was a small benefit resulting from the option with the least amount of equipment.

OPEX, however, was the key differentiator when comparing the two options. With fewer engines installed in the 4 x option, cost savings were realised in NO\textsubscript{X} and CO\textsubscript{2} emission taxes, as well as fuel consumption and maintenance costs.

In summary, the 4 x Industrial Trent 60 DLE (dry low emission) configuration scored favourably in critical evaluation categories and was selected as the preferred driver for the Lake Charles liquefaction plant’s main liquefaction compression service.

### Meeting the needs for small scale distributed LNG
Small scale LNG projects can operate as small fleets of redeployable liquefaction units. These smaller capacity plants require lower total CAPEX and allow end users to deploy a more adaptable LNG programme designed to adjust quickly to fluctuations in market demand and gas availability.

Combining a small scale LNG system with a transportable LNG storage and dispensing solution offers a portable (or redeployable) liquefaction asset that can be located close to natural gas supply and/or fueling demand, depending on logistics and economics.

Elizabethtown Gas, a subsidiary of AGL Resources based in Elizabeth, New Jersey, US, delivers natural gas to approximately 281 000 customers and recently ordered two LNGo™ natural gas liquefaction systems from the Dresser-Rand business.

Sized to produce approximately 13 500 gal./d of LNG, this system is a modularised, portable, natural gas liquefaction plant designed to provide on-site natural gas liquefaction. This point-of-use production plant is a standardised product made up of four packaged skids: a power module, compressor module, process module, and a conditioning module.

LNGo natural gas conversion plants enable the distributed production of LNG on a small scale. The technology eliminates the need for the costly trucking of LNG over long distances from large, centralised plants to LNG fueling depots, as is the practice today.

The peak shaving application will enable Elizabethtown Gas to liquefy natural gas on-site, which can then be stored for future use. By doing so, the company expects to avoid higher prices for the spot purchases of LNG to meet peak demand requirements.

### Conclusion
Meeting the needs of any LNG project, whether large in scope, mid scale in size, or developed for peak shavings, can be done in a way that enhances efficiency and environmental footprint, while at the same time lowering total lifecycle costs. Turning to a supplier with an extensive portfolio of both compressors and drivers and other turbomachinery equipment can play a major role in helping to meet the ‘power-to-compression’ needs of any project, large or small, while at the same time meeting the individual requirements and key objectives of the project operator. LNG