# SCALING UP TO SCALE DOWN

**Applying Proven Mid-Scale LNG Technology and Equipment to Large-Scale Facilities**

Gastech 2020 Virtual Summit

Session: LNG Plant Design and Configuration

BLACK & VEATCH

**JUSTIN ELLRICH**
PRINCIPAL PROCESS ENGINEER
LNG SYSTEMS LEADER

# 1.0 Introduction

Many current projects and major players in the LNG industry are shifting focus away from the traditional mega-train installations and instead turning to solutions employing technologies and execution strategy more typically seen in mid-scale developments. This does not mean the economy-of-scale principle is being turned upside-down but rather a different approach to achieving a competitive project is being implemented.

Smaller facilities and smaller trains result in more manageable and de-risked projects but are often seen as disadvantaged due to economy of scale. But technology providers and EPC's have been hard at work to erase this perception and prove there is another way to remain competitive. By using current manufacturing capabilities for machinery and heat exchangers as well as module fabrication to their maximum extent, mid-scale technologies like single mixed refrigerant cycles can realize commensurate $/tonne figures as multi-loop mega-trains for 5, 10, or even 20+ MTPA developments with certainty in performance and schedule.

Multiple mid-scale trains also afford a better opportunity for a phased implementation. Commercial agreements and financing are far more difficult for 11-figure price tags, so smaller chunks of offtake and capital expenditure can be a faster route to market while easily maintaining the ability to expand in the future. Other benefits of multiple mid-scale trains independent of each other are faster time to first LNG, increased overall availability, better turndown flexibility, and simpler startup and operations compared to complex multi-loop technologies.

# 2.0 Train Size Approaches

Scale-up of these typically smaller facilities receives intense scrutiny to ensure the risk is low. There are two varied approaches to constructing a large facility out of smaller mid-scale blocks – increased multiplication of more common small capacity trains, and minimum train counts by maximizing scale-up of mid-scale technology. Both of these strategies are being applied in the industry and not enough data yet exists to single out the better tactic, but this report addresses major considerations for each and methods to mitigate the associated risks and promote competitiveness with traditional baseload facilities.

## 2.1 MULTIPLICATION OF "SWEET SPOT"

One approach that has been put into production at Elba Island and by Venture Global is to keep the size of each individual train to the "sweet spot" for historic mid-scale experience, about 0.2 – 0.6 MTPA, and build them in parallel until desired total LNG capacity is achieved. The unit operations in this size are well-known and well-proven and can open the market to a greater number of contractors, suppliers, and craft that do not necessarily need highly specialized skillsets as would be desired for larger projects. This gives assurance of performance of critical equipment as well as confidence in schedule due to simpler small module construction and standardized designs from many EPC and technology providers which are simply duplicated a number of times over.

While this generally carries lower risk from technology and equipment perspectives, the drawbacks come from the same enabling principle of multiplication. While all vessels, piping, etc. are smaller,

execution risk is heightened by increasing site hookup work and by virtue of the sheer number of instruments, valves, etc. that can cause issues during startup and operations. And while not exclusively applied in this size range, lower efficiency refrigeration cycles are more commonly applied in these concepts to keep the equipment count and control complexity as low as possible to combat the increased train count.

## 2.2 SCALED UP TRAIN

Another approach taken by many current projects is to maximize the train size achievable by single mixed refrigerant technology but still fit onto a single module resulting in 1.0 – 1.5 MTPA per train, a method also applied to floating liquefaction. These projects may have to handle design risk by scaling-up equipment, but it is a more efficient execution strategy in line with the traditional economy of scale mantra – one big train is cheaper than five small ones – but applied to the individual unit and not the total facility. This maintains the phased and duplicate mid-scale philosophy while taking advantage of capabilities proven in the large-scale realm. Current project developments employing this strategy include Annova, Driftwood, Jordan Cove, and Cheniere (CC Stage 3) among others.

This capacity range for a single train is not as common as the smaller ones described previously, mainly due to the historical delineation of projects – peaking and transportation fuel use small-to-midscale trains and export facilities use large scale trains. In a risk-averse industry, this need to scale-up has been a barrier to applying mid-scale for large export volumes. However, by recognizing the experience of major equipment in the same service for large trains, each component can be analyzed to instill confidence in performance with proven references in operation which will be discussed in Section 3.

Another gap between the mid-scale and large-scale technologies is efficiency. Multiple refrigerant loops and higher complexity no doubt give an edge over traditional single refrigerant loops in terms of energy consumption per tonne. That extra equipment and complexity is not economically justified for small facilities; but by using the approach of larger parallel trains, items like liquid expanders and modified refrigeration loops discussed in Section 4 are justified and mid-scale technologies can close the efficiency gap to be more competitive with large-scale facilities in that regard.

## 2.3 MODULARIZATION

The inherently unitized nature of the mid-scale technology makes it well suited to modularization, be it via “truckable” skids or mega modules. The use of modules allows for rapid and straightforward installation using pre-fabricated hookup spools that could be fit tested prior to shipment. This allows a significant reduction in the required field works as compared to standard stick-built construction - by modularizing and pre-assembling most of the project, the peak manpower at the job site is substantially reduced to less than half of a stick-built plant. Moving this work to the manufacturing setting of a fabrication yard will typically improve productivity and safety metrics as well.

For applications with logistics constraints, an approach of maximum modularization can be applied within the limits of the truckable transport envelope. Apart from very large equipment items, all equipment, instruments, piping, valves, steel, E&I, etc. will be included in pre-assembled units. These

modules are designed to be transported by widely available commercial cargo vessels, transported to site via truck trailer and set or stacked via crane at site.

When direct marine offloading is available, a standardized design for a single module per LNG train can be installed – "One Train, One Module" – in the range of 3000 to 5000 tonnes depending on train size ultimately selected. The Refrigerant Compressor and driver are set to the side of the module on a single base frame already significantly modularized by the manufacturer. As the Refrigerant Compressor and driver are separate from the module, their selection is flexible which allows for easy optimization. A major advantage of a single module per train is that it minimizes the connections in the field and limits hook-up work primarily to the compressor piping and rack connections. This also facilitates more extensive pre-commissioning work in the fabrication yard as much of the electrical and instrumentation are already wired in.

Gas pretreatment will follow the same approach, whether truckable or mega-modules, by placing all equipment save for the towers and fired heaters onto skids or a single module to minimize field hook-up work. All items needing to be maintained or have filters/adsorbents replaced will be accessible internal to the module by monorail or on the edges of the module with a crane to facilitate proper and safe maintenance. The use of modularized piperacks independent from process modules for multi-train facilities allows parallel modules to be identical, which reduces engineering time and simplifies fabrication. The extent of modularization of these ancillary components will be different from project-to-project but evaluation protocols are in place to quickly determine the best approach based on specific sites and labor situations, sometimes even concluding that stick-building some pieces provides a more levelized craft presence that increases productivity.

# 3.0 Equipment Applicability

The proposed equipment for 1+ MTPA mid-scale trains can be systematically analyzed at a component level to confirm there is an equivalent application currently in-service to confirm the scale-up risk is mitigated. The Refrigerant Compressor and Main Cryogenic Heat Exchanger are the heart of the liquefaction plant and imperative to be provided with low risk and certain performance.

Balance of plant equipment will not be discussed in detail in this report as sizes required for separators, pumps, valves, exchangers, etc. are well-known throughout the industry and pose no scale-up issue in comparison to the main equipment. Large air cooler fields can be considered a new aspect of mid-scale designs when multiplied out to hit large capacities, but issues with air distribution and hot air recirculation are well-known from large-scale facilities and learnings are directly applied to mid-scale trains paralleled together.

## 3.1 REFRIGERANT COMPRESSOR

Large compressor casings and rotors have been proven for decades by multi-loop technologies which apply directly to scaling-up mid-scale equipment – after all, it is still light hydrocarbon refrigerant service at similar pressure. Multi-loop processes using Frame 7 and 9 gas turbines show dozens of mixed refrigerant compression services in the range of 75 to 100 MW, far larger than mid-scale trains would employ. But power doesn't tell the whole story, so further investigation into the components is needed.

Due to a difference in suction temperature between mixed refrigerant that is a second loop compared to single mixed refrigerant, volumetric flow for the same power will be larger for SMR. But because mid-scale is staying under that 75-100 MW range, the casing needed for the service is the same size and no issues with their manufacture should occur as it is not a new casting. Other major pieces that make up the complex machinery like impellers, seals, and auxiliary systems can go through the same review process - impeller scatter plots will show that each individual stage will perform like many other applications; seal and lube oil systems remain the same or smaller for mid-scale compared to 75-100 MW mixed refrigerant.

If there is a situation where any component would be outside the proven references for the desired mid-scale train size, parallel compression just like multi-loop technology has shown for some time can double the train capacity even above 2 MTPA.

## 3.2 MAIN CRYOGENIC HEAT EXCHANGER

Main cryogenic heat exchangers also scale quite well with little-to-no risk. Larger coil-wounds are known from mega-trains and proven sizes of brazed aluminum cores are just placed in parallel to achieve desired capacity. Coil-wounds are applicable to this size, but brazed aluminum technology offers a simplification and footprint reduction that is more advantageous for mid-scale trains sizes.

Brazed aluminum exchanger fabrication techniques have significantly improved to allow for manufacture of larger units with greater heat transfer characteristics than those used in early designs. As an example, three trains at Sonatrach in Algeria in the mid-1970's using Black & Veatch's PRICO® technology contained eight coldboxes with five cores each, for a total of 40 cores per 1.3 MTPA train. That train size today would fall into a single coldbox with 6 to 8 cores.

Due to the unitized nature of brazed aluminum cores, there is no risk in scale-up of each individual core - the performance of each core is known because it is the same size and construction that is running in smaller-scale facilities. Size per core is limited by the brazing furnace size of the manufacturer so the thermal and mechanical performance is known many times over in previous facilities as cores are just churned out at the same size and placed in parallel. A one core design at a peak shaver can have the same size as those at a 10 MTPA multi-train project, but obviously the number in parallel is different. But to ensure success, the control philosophy across each and every core remains the same from the 1970's until today - if it was successful for 1 core at a peak shaver or 40 cores in parallel before advanced control systems, it is easily scalable to any number of cores with assurance of success.

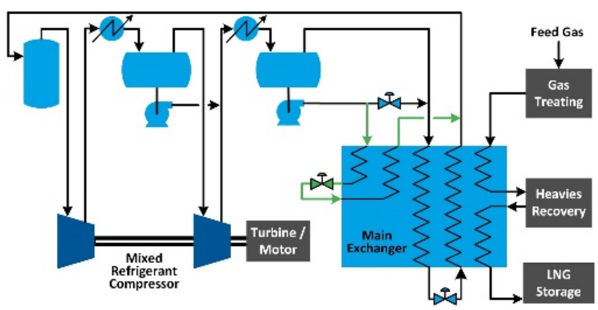
Flow distribution across multiple cores is a straight forward engineering issue; the PRICO design incorporates the same process control philosophy on each individual core regardless of the total number, mitigating any scale-up risk. Every core has an individual control valve on the liquid (high pressure refrigerant) and two-phase streams (J-T valve) to force proper distribution and minimize upsets and potential excursions that have led to cracking of the cores in other applications. Eight cores equate to eight liquid refrigerant control valves and eight J-T valves, all of them outside the coldbox for easy maintenance. Within each core header, Black & Veatch and the manufacturers have developed proprietary design guidelines to ensure proper distribution that has been proven over 200 times at the core level.

# 4.0 Process Enhancements

There are several flowsheet optimizations to single mixed refrigerant loops that are not justifiable at smaller capacities but easily payoff for larger trains to close the efficiency gap compared to multi-loop processes. Liquid expanders used commonly for large-scale trains (in place of J-T valves on LNG and refrigerant streams) enhance LNG production by over 6% from the same driver power compared to a conventional offering. Other improvements to PRICO, which have been patented and published with 2.5-6% production or efficiency increase, may be applied if a fit for the specific project conditions.

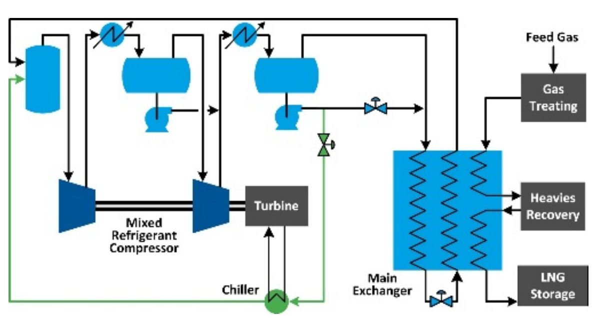
The largest gap in single mixed refrigerant efficiency is absence of a separate pre-cooling step. This area of the cooling curve traditionally has the widest approach for SMR and efficiency can increase if that is reduced. PRICO-PLUS® (shown in Figure 1 below) achieves this reduction by creating a pseudo-second loop, using a single compressor but splitting passes in the MCHE tailored to the specific project cooling curve and saving up to 2.5% power. Other SMR technologies have developed similar schemes as well.

*Figure 1. PRICO-PLUS Modification*




Black& Veatch has also developed a modification to the single mixed refrigerant loop to integrate turbine inlet air chilling (TIAC) to increase capacity from a set gas turbine driver. TIAC is well known in the power industry and is being applied more commonly for LNG facilities as well, but usually with a separate packaged refrigeration unit that adds to cost and footprint. By utilizing a slip-stream of refrigerant already being processed for liquefaction, a significant simplification and space savings can be achieved. PRICO-Boost™ in Figure 2 below is not an efficiency upgrade but allows approximately 3-6% greater LNG production for nearly the same cost and footprint thus enabling a better economy of scale.

*Figure 2. PRICO-Boost Modification*



# 5.0 Carbon Footprint

Smaller compressor power requirements, generally in the range of 30 to 50 MW for mid-scale trains, accesses more options for compressor drivers. The gamut of aeroderivative turbines fit mid-scale train sizes quite well, and they consume significantly less fuel per kilowatt than traditional industrial turbines used throughout mega-train facilities. And while there are 65-75 MW motors now proven in a couple LNG facilities, smaller proven motor sizes de-risk the selection.

Similar to the refrigeration process enhancements becoming economically viable at larger sizes, so to does waste heat recovery from turbines. It is another well-known technology employed at large scale facilities to provide process heat or even steam for power generation in a combined cycle fashion that is not widely applied to smaller scales as the economic and emissions incentives are muted. But increasing train and facility size and employing waste heat recovery is another step to making mid-scale facility efficiency and emissions competitive with other world-scale developments.

Smaller power requirements can be particularly attractive if power is sourced from renewables which results in significant reduction of the facility's carbon footprint. Either a phased approach or overall smaller facility may better fit the available renewable generation in the area. And even if not fully renewable, the electrical infrastructure required for mid-scale versus mega facilities better enables full or partial grid connection instead of necessitating onsite power generation which increases both costs and emissions.

# 6.0 Summary

The scale-up risks associated with applying mid-scale LNG technology to large-scale facilities is now well known, as are the mitigations. Multiple current and newly proposed projects are proving there is a competitive approach in the global LNG export market in scaling down from mega-trains by scaling up other proven technologies.

Mid-scale technology with a single train per module and proven equipment can de-risk project execution. Multiplying numerous duplicate modules in parallel moves vast labor hours to controlled offsite yards thus increasing productivity and minimizing onsite resources to remain competitive with the traditional mega-project approach. Pushing the technology and equipment to the upper end of proven operations and applying viable enhancements to efficiency furthers the competitiveness achievable by mid-scale applications.