CB&I Lummus and partners to turn LNG FPSO concept into a reality

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The notion of shipboard liquefaction plants has drifted around the industry for more than 30 years. This revolutionary concept now floats on the brink of reality.

Designs abound and several companies, including CB&I, are in the race to claim title to the "world's first LNG FPSO" (Floating Production, Storage and Offloading) vessel.

CB&I has worked on more than 20 floating LNG (FLNG) designs offering a variety of liquefaction processes and power-system options tailored for diverse locations, ranging from arctic to tropical.

In recent years, the concurrence of three phenomena - volatility of oil prices, insecurity surrounding the energy supply, and the growing global demand for natural gas - has made FLNG an attractive option for producers looking to commercialize stranded gas in offshore fields.

FLNG enables natural gas to be produced and liquefied on a floating vessel and offloaded directly onto a tanker without touching onshore facilities.

Advantages

This approach may be less capital intensive and in some cases more politically palatable than constructing an onshore liquefaction plant, thereby eliminating the need to site an onshore facility and develop major infrastructure and massive facilities.

Furthermore, it has double environmental benefits: it increases the supply of a clean fuel (natural gas), while at the same time providing an economically preferable option to flaring.

Fuel of choice

Natural gas has become the fuel of choice because it has the lowest carbon dioxide emissions of any fossil fuel and because it has a larger reserve-to-production ratio than oil.

Electric power generation has been the primary driver for the increased use of gas, especially in the United States.

A recent expansion of the natural gas supply, due in part to increased availability of gas from unconventional sources, has produced a pricing environment where natural gas is currently cheaper than oil per unit of energy produced [1], as shown in Figure 1.

These factors are prompting gas developers to consider FLNG as a way to monetize associated or stranded gas reserves.

Transporting natural gas over long distances is more economical as LNG than through pipelines. In addition, transporting LNG consumes less energy than converting the gas to liquid fuels such as GTL fuels, dimethyl ether (DME) and methanol.

Furthermore, LNG does not tie consumers to suppliers, as is the case with pipeline infrastructure, and FLNG production will enable more countries to export gas and will improve diversity of supply in the long run.

Design

FPSO vessels have been used to produce oil from deep-water production fields since the 1970s. Using the FPSO model, FLNG vessels are custom-tailored to meet the field's unique characteristics, including:

- size of the gas field
- composition of the gas
- local metocean conditions (waves, wind, etc.)

Safety is the prime consideration for the layout of any LNG FPSO. The living accommodation is generally at the opposite end of the vessel to the flare.

There is more than one approach to FPSO layout. However, one proposed layout using a generic sequence from bow to stern, assuming an internal turret, is shown in Figure 2. The red line indicates the flow of hydrocarbons.

As the FPSO weathervanes around the turret, the prevailing wind will blow from bow to stern. The following layout shows one way safety is built into an FLNG design:

1. Living quarters (LQ) with helideck, the central control room (CCR) and air intakes are at the bow, upwind of any possible gas release. The aft side of the LQ will be a blast and fire wall.
2. Power generation with air intakes and exhaust, which have potential ignition sources, are located away from the NGL separation and LNG liquefaction units.
3. The internal turret should ideally sit forward to provide natural weathervaning capability, but not too far forward in order to limit the thruster power required for heading control during offloading.
4. The utilities without hydrocarbons (instrument air and nitrogen storage, cooling water, heating medium) are located just beyond the turret, which helps to maximize the distance between combustibles and the living quarters.
5. Gas processes, which follow, consist of inlet facilities, gas treating (CO_2, H_2O and Hg removal), and LNG liquefaction.
6. Locating the NGL separation equipment (LPG distillation, refrigeration and tanks) at the stern provides maximum distance between the living quarters and the heavier-than-air hydrocarbons.

When the FPSO has only electric motor drives, this ensures there are no air intakes or ignition sources downwind of any gas containing equipment.

An LNG FPSO has more equipment

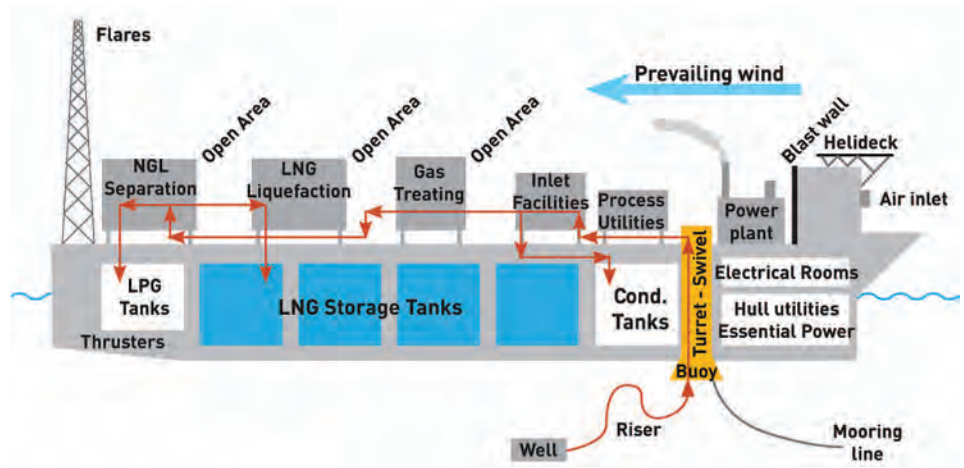

Figure 2: Typical layout of an LNG Floating Production Storage and Offloading vessel to be used for monetizing any gas reserves

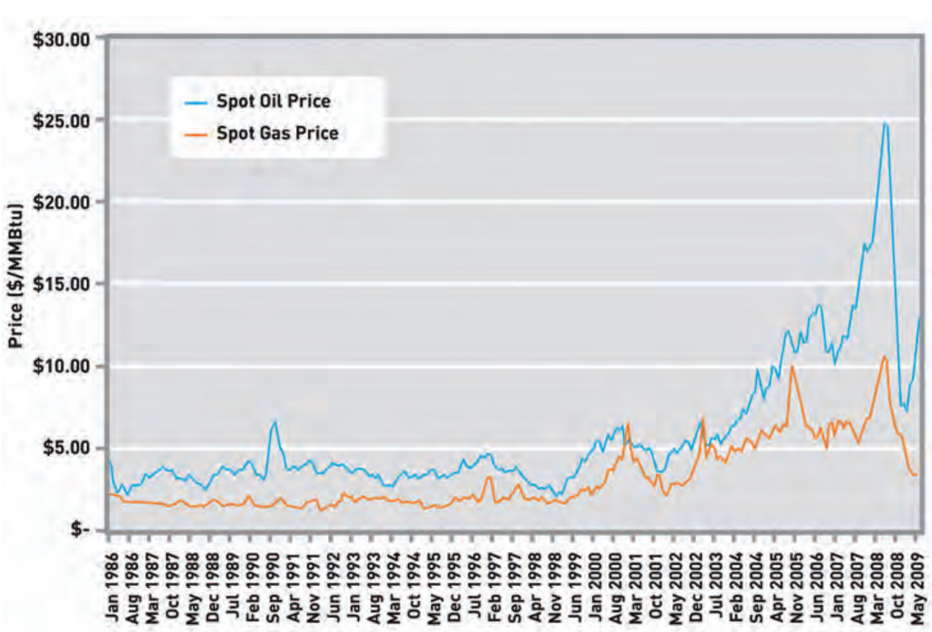

Figure 1: Historic movement of oil & gas prices per million British thermal units

and more high-pressure gas piping than oil FPSOs. For safety it should be assured by blast pressure calculations that explosions do not escalte to adjacent areas.

This escalation can be prevented either by leaving open areas between modules or by inserting blast walls. As blast walls will hamper natural ventilation, and increase the explosion pressures and topside weight, open areas are the preferred solution.

An LNG FPSO will require all of the safety systems normally found on onshore facilities, such as a fire water deluge system, gas and fire detection, and cryogenic spill protection. Particular attention needs to be given to escape routes and minimizing leak sources.

In a typical LNG FPSO, the gas pre-treatment system can be more complicated and often uses considerably more space than the actual liquefaction process.

The inlet facilities consist of a slug catcher, water/condensate separation, hydrocarbon condensate stabilizer, and a glycol inhibitor system if the wet incoming gas is below hydrate temperature.

The acid-gas removal system is normally an amine absorption system. Dehydration uses a molecular sieve process because of the extremely low residual water content required to prevent freeze out in the LNG liquefaction process.

Mercury removal is standard to safeguard the aluminum heat exchangers in the liquefaction system.

Gas composition

The Higher Heating Value (HHV) or Wobbe Index specification of the envisaged LNG market will determine the degree of treatment and the amount of Natural Gas Liquids (NGLs) extraction for a given feed-gas composition.

The complexity of the gas pre-treatment system is highly dependent on the contaminants found in the gas stream such as CO_2, H_2S, mercaptans, Hg and BTX, which can vary significantly from field to field.

When NGLs must be removed, the number of products to be made, stored and offloaded from the LNG FPSO could result in sizable NGL separation facilities.

As an example, Figure 3 shows two modules from a recent Front-End Engineering Design for Höegh LNG.

The module on the right separates LPG and condensate; the module on the left cools the LPG for storage.

The gas composition and the LNG specifications determine whether these two large modules, and the related LPG storage and offloading facilities, are required. This would certainly be a factor for associated gas fields which typically contain more NGLs.

Hull and carriers

Local metocean conditions guide the marine design. One issue is the selection of the type of LNG tank. Unlike LNG carriers, which generally operate in either a full or empty state, an LNG FPSO requires a tank that can operate at any liquid level. As a result, sloshing becomes more of an issue on an LNG FPSO compared with an LNG carrier.

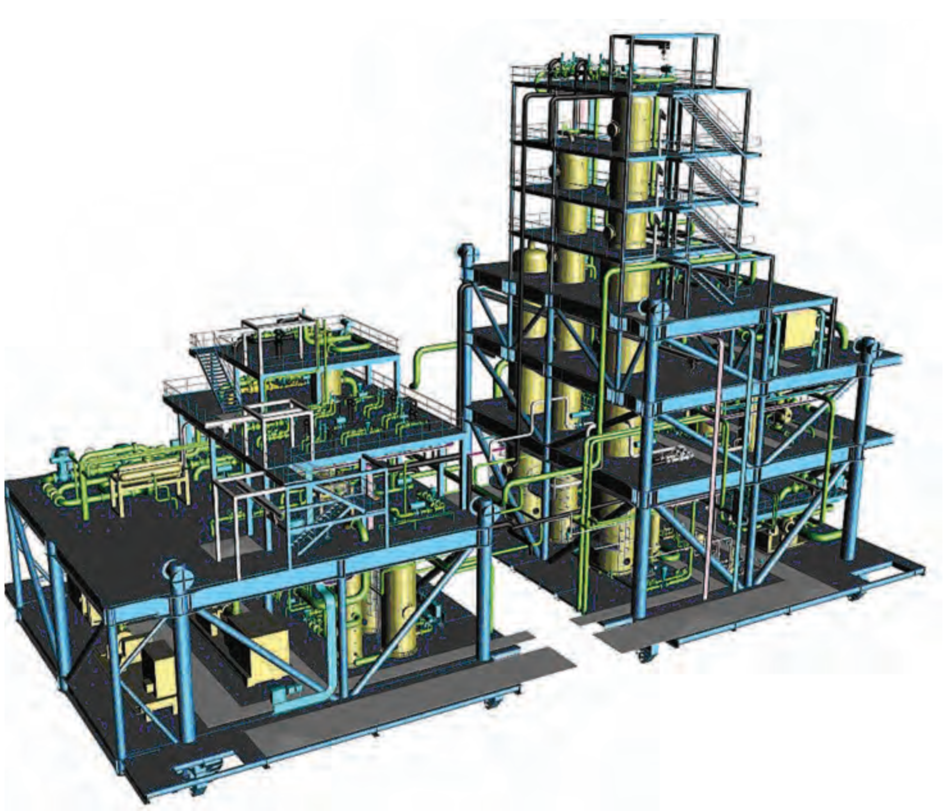

Figure 3: NGL Removal in Two Modules of 2.2 Mt/a FLNG for Höegh LNG

Three types of LNG storage tanks are common in LNG carrier service: spherical or Moss type, membrane, and the Self-supporting Prismatic Type B (SPB). There are differences of opinion as to which type of tank is best suited to an FLNG application. Each type will impact the design of an LNG FPSO based on a number of factors:

- Availability of deck space
- Resistance to sloshing
- Cost and weight
- The fabrication and project execution sequence of the hull and tank construction
- Availability of suppliers
- Material selection, which is dependent on the type of tank and the supplier that builds it
- Support structure for the topsides

Not all combinations of tank type and materials are available from every supplier. While SPB tanks are generally considered more tolerant relative to sloshing, developments have been made to reduce the impact of sloshing using membrane design as well.

The structural support of the topsides weight is an important consideration in the design of the hull and the provision of a central bulkhead along the axis of the ship both simplifies support of the deck and reduces the size of the tanks. This is one enhancement that has been proposed to make membrane tanks more slosh-tolerant.

The primary determining factor for the LNG storage capacity is the size of the largest envisaged carrier to be loaded, plus an operational margin for bad weather and delays in offloading.

Offloading design for LNG FPSOs is being approached from two perspectives, each of which has a considerable body of experience: cryogenic LNG carriers and ambient temperature oil FPSOs.

For LNG carriers, offloading generally employs conventional unloading arms from a static loading platform to a midships manifold. For oil FPSOs, offloading generally employs a flexible hose transfer method in a tandem arrangement.

The use of conventional loading arms in a side-by-side arrangement is limited to more benign sea states than a tandem arrangement using hoses.

At present, several vendors have certified hoses for LNG service [4]. Both types of offshore offloading typically will require a turret moored FPSO; in areas with hurricane risk, a disconnectable turret might be used.

Tandem offloading will require purpose-built LNG carriers with a bow manifold. Floating LNG hoses that could reach a midships manifold are still under development.

Power and driver

Power generation choices are generally independent of the local conditions. There are several driver systems for liquefaction, including steam turbines and gas turbines in a number of different configurations.

All liquefaction technologies use vapor compression requiring a significant amount of driver power.

This driver power can be applied directly to drive the compressors or can be applied indirectly by generating power and then using electric motors. All the drives that can be used for direct mechanical drives can also be used to generate electricity.

Generating electricity can provide redundancy in the power supply more easily than direct drive approaches; however, converting the power into electricity and then back into shaft power causes a loss of efficiency and an increase in cost. This additional cost may be justified by higher availability.

Waste heat recovery to enable a combined heat and power or combined cycle can be applied to either direct drive or electric motor designs. The process is simpler in an electric motor design because all waste heat is centralized in the power plant.

The choice between direct drive versus electric motors is dependent on customer experience and preference. In the electric motor option, it may be possible to avoid any sources of ignition within the process facilities, which can enhance safety.

Liquefaction

When selecting the liquefaction process, the choice is primarily between liquid refrigerants or expander processes.

Expander processes use sensible cooling rather than evaporative cooling, thereby eliminating the need for two-phase flow and distribution.

Taking advantage of large latent heat of evaporation in liquid reduces the amount of refrigerant circulation (power) when compared with sensible

COMPARISON OF LIQUFACTION PROCESSES		
	Liquid Refrigerants	Expander Processes
Quoted efficiency (kW/t/d) [2]	12.2 to 14.5	15.6 to 20
Refrigerants	N_2, C_1, C_2, C_3, C_4, ehtylene	Nitrogen, methane
Production, Storage of Refrigerants	Yes	No
Target Train Capacity	Medium - Large	Small - Medium

Table 1 – Comparison of Liquefaction Processes

cooling in the expander process.

However, achieving low temperatures with evaporative cooling requires operation at low pressures which leads to large diameter suction piping and compressor suction volumes.

By comparison, expander processes achieve their cooling by pressure differences, which can be achieved at higher pressures, resulting in smaller diameter piping.

Due to their high-pressure, single-phase operation, the expander processes are more easily adaptable to an FPSO application. By containing only gas, expander processes are less sensitive to shipboard motion and generally require much less equipment and less space.

As shown in Figure 4, a modern nitrogen expander process has two nitrogen expanders, one warm and one cold, to match the cooling curve of the treated gas.

The main cryogenic exchanger here is a Brazed Aluminum Heat Exchanger (BAHX), also called Plate Fin Heat Exchanger. The nitrogen loop that provides the cooling is a closed loop.

CB&I's NicheLNGsm process [3], shown in Figure 5, has the same equipment count as the nitrogen expander process in Figure 4, but one expander is moved to the methane side where it forms an open cooling loop with the treated gas.

Methane has double the specific heat of nitrogen and a stronger Joule-Thomson effect than nitrogen, resulting in a liquefaction process that is more efficient with the same equipment.

Utilities

As with the other processes, there are a number of choices when it comes to utilities. Choices for the heating medium include steam, hot water and hot oil.

The choice of heating medium will be driven by operator preference and process heating requirements. In addition, design considerations will include safety, equipment count, layout, operating pressures, circulation rates and operating costs.

The main cooling medium on an LNG FPSO will be water, not air, because the latter requires significantly more space.

For cooling water, there is the choice between direct seawater cooling or an indirect closed fresh water loop. The trade-offs involved are the minimum process temperature versus capital cost, operating cost, availability and maintenance considerations, along with space requirements and weight.

The quantity and the quality of the fuel gas stream will vary based on the gas composition in any given field. Fuel gas may be a mixture of Boil-Off Gas (BOG), end flash gas (from flashing the LNG to storage pressure), off-gas from the treatment facilities, and raw feed gas.

The ratio between these gases can change during start-up, full and part load operation of the plant and especially during offloading. This can lead to significant or excessively fast changes in the Wobbe Index of the fuel gas mixture, with a resulting impact on gas turbines and other fired equipment. In addition, fields with high nitrogen or high ethane content can also influence fuel-system design.

For every process plant, and especially for an LNG FPSO, it is important to prevent accidental hydrocarbon releases.

All relief valves from hull and topsides are connected to central relief systems that release the gases to the flare at a safe location.

The maximum allowed backpressure requires a low-pressure flare for the storage tanks, separate from the high-pressure process feed gas flare.

Also water-wet (warm) and cryogenic releases should be separated to prevent potential ice blockage. This can result in four separate flare collection systems. The height of the flare is determined by the maximum allowable radiation and gas dispersion in case of relief.

In addition to the process power requirements, an LNG FPSO typically has a separate marine power generating system in the hull. While not addressed here, other utilities commonly required include instrument air, inert gas and water systems.

Figure 6 (Page 46) shows a rendering of an LNG FPSO design for Höegh LNG. This FEED, by CB&I and Daewoo, included a complete suite of safety studies.

The design has a 2.2 million tonne per annum product capacity, gas-turbine power generation, electric drives, two liquefaction trains, side-by-side offloading, heating by steam and hot water, an indirect cooling water system, and centrifugal BOG-compressors.

Future developments

To optimize the FLNG design, a number of challenges must be addressed to improve efficiency and accommodate the unique characteristics of marine environments. New equipment will be developed or existing equipment redesigned to meet some of these challenges.

- It would be advantageous to develop a system that will offload to carriers via a buoy at some distance from the FPSO, using subsea and/or floating hoses. This could considerably increase the weather window for offloading and make it possible to moor two carriers simultaneously.
- New types of storage tanks that can withstand sloshing are especially important for smaller FPSOs or harsh environments. The existing membrane tanks are being further developed to withstand sloshing and new types are being developed like the Aluminium Double Barrier Tank (ADBT) [5], bi-lobe tanks and CDTS (Cubic Doughnut Tank System) [6].
- The development of larger expander-compressors will allow for higher capacity LNG liquefaction trains.
- Electric-driven compressors can be

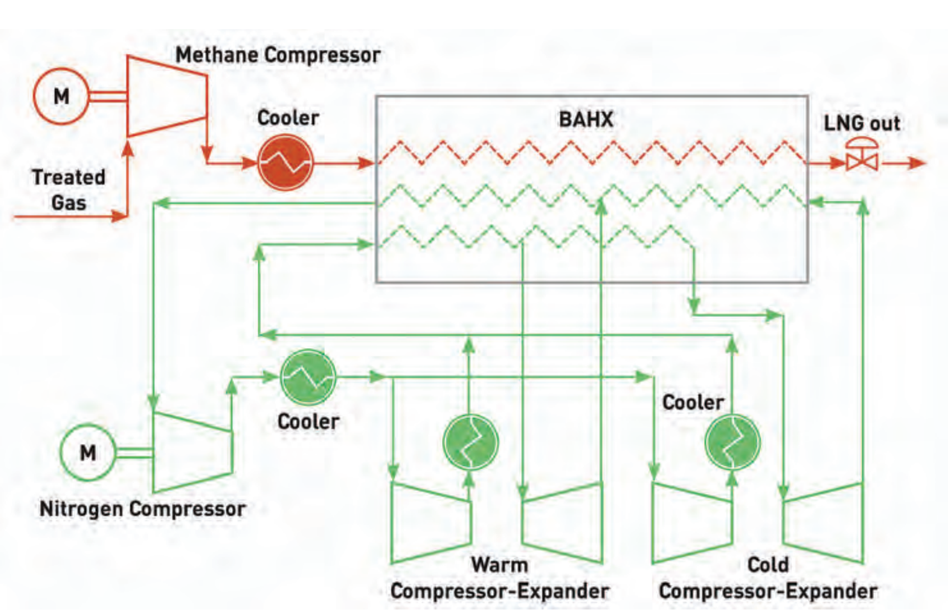

Figure 4 – Twin Nitrogen Expander Process for FLNG liquefaction

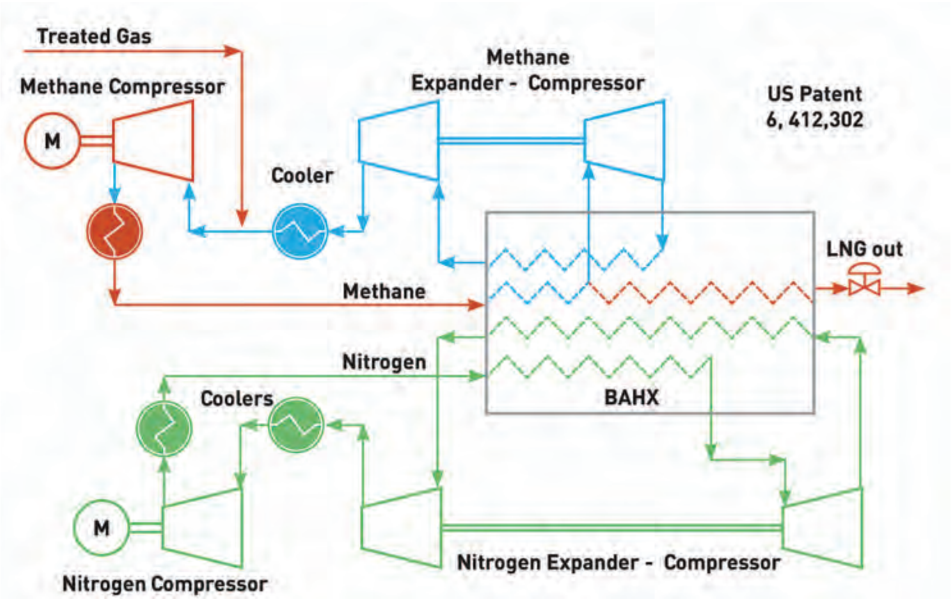

Figure 5 – The NicheLNGsm Expander Process for FLNG liquefaction

Figure 6: Rendering of an LNG FPSO for Höegh LNG

built totally enclosed with magnetic bearings so that the compressor and motor are in one pressure vessel. The motor is cooled here by the process gas. They would be ideal for LNG-service, as the pre-treated gas is very clean. This will obviate the need for gas seals, and, with high speed electric motors, these compressors do not need gear boxes either. Proven designs presently range from 6.2 MW at 12,000 rpm to 12.5 MW at 10,000 rpm.[7] There are already motor designs up to 35 MW at 7,000 rpm.

- There is also development in frequency converters for large electric Variable Speed Drive Systems (VSDS). The dominant Load Commutated Inverter (LCI) technique requires large filters to handle the harmonic distortion. The newer Voltage Source Inverter (VSI) for large motors will cause much less harmonic distortion, so that the filters are not required. It is also less dependent on the grid voltage and gives lower motor torque variations.
- CB&I is presently engaged in the design of an LNG FPSO with a capacity in excess of 2.5 Mt/a of LNG.

Before the world's first floating LNG liquefaction project becomes a reality, design considerations will continue to be evaluated and solutions for the most challenging issues will continue to be sought.

As world demand for energy grows, the value of using clean-burning natural gas as the fuel of choice will add momentum to the quest for a floating liquefaction plant that can be used to monetize stranded and associated gas in various locations around the world. The race is on. ■

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