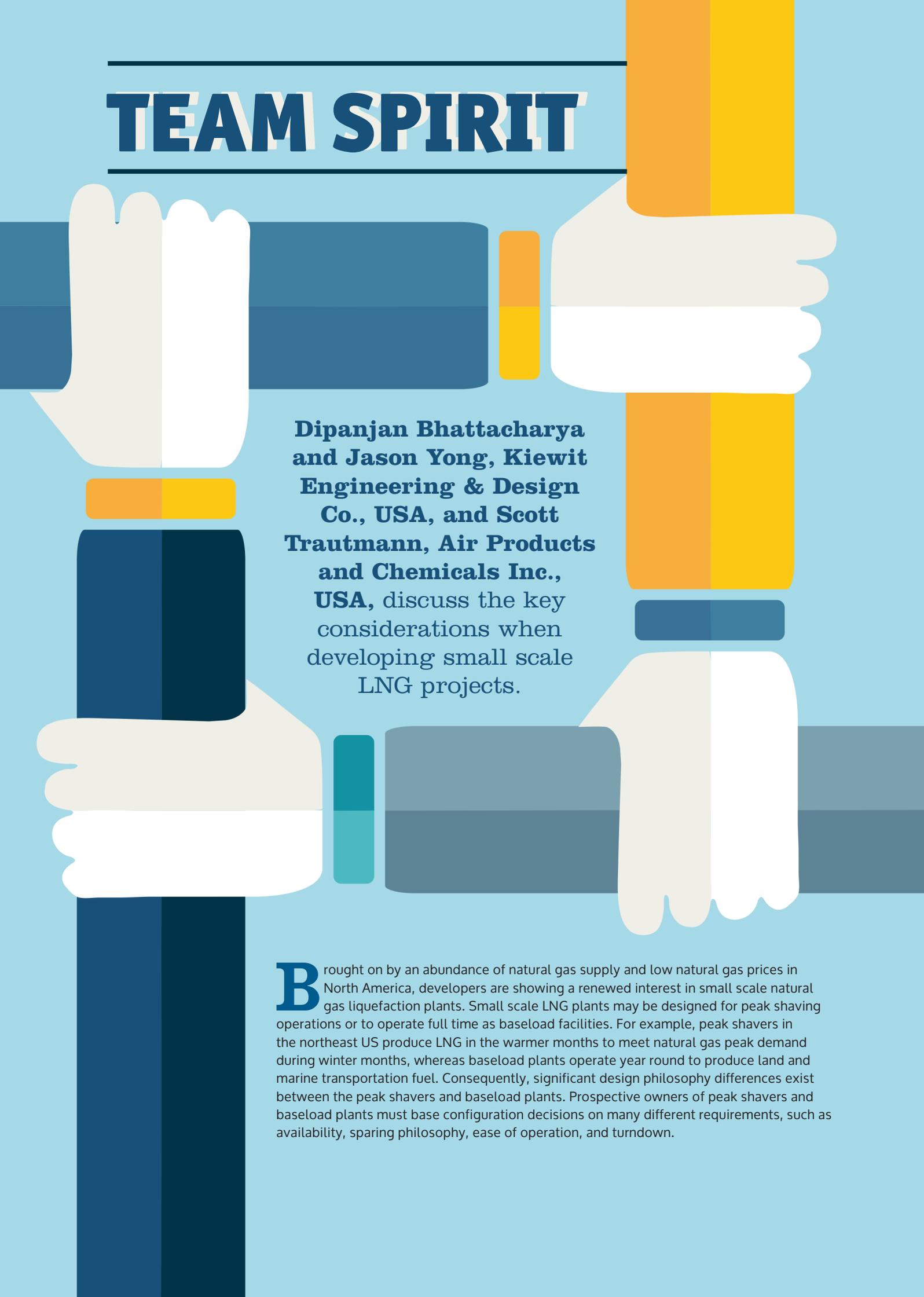


TEAM SPIRIT



Dipanjana Bhattacharya and Jason Yong, Kiewit Engineering & Design Co., USA, and Scott Trautmann, Air Products and Chemicals Inc., USA, discuss the key considerations when developing small scale LNG projects.

Brought on by an abundance of natural gas supply and low natural gas prices in North America, developers are showing a renewed interest in small scale natural gas liquefaction plants. Small scale LNG plants may be designed for peak shaving operations or to operate full time as baseload facilities. For example, peak shavers in the northeast US produce LNG in the warmer months to meet natural gas peak demand during winter months, whereas baseload plants operate year round to produce land and marine transportation fuel. Consequently, significant design philosophy differences exist between the peak shavers and baseload plants. Prospective owners of peak shavers and baseload plants must base configuration decisions on many different requirements, such as availability, sparing philosophy, ease of operation, and turndown.

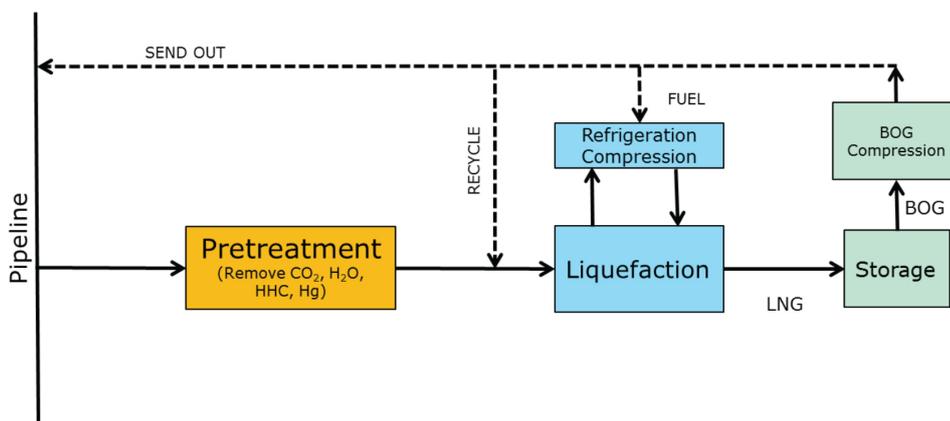


Figure 1. Typical small scale liquefaction plant configuration.

Kiewit Corp. and Air Products and Chemicals Inc. are jointly offering technology solutions for small scale (less than 500 000 gal./d) liquefaction plants for peak shavers, bunkering fuel, as well as for plants built for truck loading facilities in North America. Such a collaboration between process licensor, equipment supplier and engineering, procurement and construction (EPC) contractor can offer the full scope of plant technology selection, design, project management, and construction.

Technology selection

Liquefaction

The nitrogen recycle expander process and the single mixed refrigerant (SMR) closed loop refrigeration process are two liquefaction technologies that are ideal for small scale LNG projects. The nitrogen recycle process uses one or more turboexpanders to provide process refrigeration, while the SMR cycle uses a circulating, boiling refrigerant composed of nitrogen and light hydrocarbons (typically methane through isopentane).

A variety of factors must be considered for process cycle selection.

Liquefaction efficiency

The SMR process offers higher liquefaction efficiency than the nitrogen recycle process as it delivers refrigeration in a manner that more closely matches the natural gas cooling curve. Cost benefits of increased efficiency are best realised at plants with higher capacities and greater on-stream times. Additionally, high cost of power can influence the selection of SMR over nitrogen recycle.

Siting considerations

For plants located in a congested area, nitrogen recycle allows the elimination of hydrocarbon refrigerant inventory on site. Additionally, nitrogen, being the major component of air, can be safely vented, with zero environmental impacts to the surrounding area.

Ease of operations

The nitrogen recycle process is highly flexible in terms of start-up and capacity adjustments, including turndown. Adjustments to the plant's production rate are a simple

matter of adjusting nitrogen refrigerant loop flows and inventory while the SMR process involves managing the hydrocarbon refrigerant inventory. For larger plants, SMR processes using coil wound heat exchangers can operate at deep turndown.¹ However, for smaller plants using brazed aluminium heat exchangers (BAHX), SMR processes are limited in turndown due to flow stability issues. In the

nitrogen cycle, the refrigerant remains in a vapour state throughout the refrigeration loop, enabling deep turndown if the plant needs to quickly adjust operations due to changing market conditions or pipeline demands.

Refrigerant availability and ease of handling

High purity nitrogen is readily available and relatively low in cost, and may be generated on site. Either process cycle will require a liquid nitrogen storage and vaporisation system. The SMR process requires additional storage of other hydrocarbon components, such as ethane, propane, isobutane, etc., which increases capital costs and plot space requirements.

Additionally, since nitrogen is environmentally friendly, any gas leakage or venting from the refrigeration loop does not have to be contained in a flare system (unlike hydrocarbon refrigerant leakage in the SMR process). This can reduce the size of, or potentially eliminate, the need for a flare system. Nitrogen's main hazard is asphyxiation. This hazard in enclosed spaces, such as the refrigerant compressor building, can be handled with oxygen monitors and adequate ventilation. Similar precautions are required for the flammable refrigerant in the SMR cycle.

Pretreatment

Pipeline natural gas can be problematic as feed to the liquefaction system. Its tariffs allow a broad range of values for components that are acceptable for household heating and cooking, but can freeze at the cryogenic temperatures associated with LNG production.² Pipeline feed gas is always treated in the pretreatment unit to remove contaminants, such as CO₂ and water, to allowable limits to avoid freezing in the liquefaction unit, and to meet the LNG product specifications. Heavy hydrocarbons (HHCs), such as hexane, heptane and octane, and aromatics, such as benzene, toluene and xylene, must also be removed to prevent freezing.

How and where to remove the HHCs is a complex decision. Multiple methods are suitable for small scale LNG plants and their appropriateness and efficacy depend on a variety of factors, including the quantity of each hydrocarbon, relative amounts of other hydrocarbons in the feed and the range of expected values in future feed

gas. Techniques such as partial condensation, distillation and adsorption – or hybrids of these – are all practical technologies to remove these contaminants to acceptable levels.

An experienced process design team will examine the relative merits of the adsorption process as a means to remove HHCs in an integrated manner with CO₂ and water removal. An option that minimises CAPEX for the pretreatment unit in a small scale LNG plant is a temperature swing adsorption (TSA) system.³ A proprietary TSA system removes the contaminants in one single adsorbent step, instead of the more complex, conventional baseload LNG plant design (amine-based acid gas removal unit (AGRU), followed by a dehydration unit and heavy removal column). TSA technology is specially designed to treat lean US pipeline gas with a significant heavy tail. It has several benefits, including the following:

Sharper HHC (C₆₊) cut

TSA technology removes virtually all C₆₊ HHCs from the feed gas without requiring a refrigeration system.

Minimal system pressure drop at pretreatment (high liquefaction efficiency)

As TSA technology can operate above critical pressure conditions, minimal pressure drops occur through the TSA bed. Thus, high pressure gas is sent to the liquefaction unit, which improves liquefaction efficiency. On the other hand, a typical heavy removal scrub column (or partial condensation drum) requires an operating pressure below the critical pressure to achieve good separation. Depending on the critical pressure, a lower scrub column or separator operating pressure can reduce the plant's liquefaction efficiency.

Regenerative system with less equipment

The TSA bed is a regenerative system, using an adsorbent that lasts up to three to four years. The spent regeneration gas will remove HHCs, water and CO₂ at the same time, requiring significantly less equipment than a conventional baseload pretreatment unit. The spent regeneration gas can be compressed and sent back to a nearby pipeline (if available) or used as plant fuel gas.

Ability to cope with varying feed composition

The TSA bed cycle time can be adjusted to provide efficient treatment of a wide variety of feed compositions and HHC content. This is easily

accomplished by changing the adsorption time in the TSA unit control interface.

Modular design

Many TSA licensors offer a cost-effective and compact modular design for this system, which reduces plot space and field labour costs.

Reliability

The TSA system is designed to be robust and to operate with high on-stream time. The system automatically cycles between adsorption and regeneration with no adjustments to operating parameters needed.

If the pipeline feed gas contains significantly higher CO₂ content, a TSA bed may not be the most cost-effective method to remove CO₂. A conventional amine-based AGRU is instead recommended. A TSA system can still be used for HHC removal with similar benefits, as listed earlier.

Equipment design

Liquefaction equipment integration and process optimisation

An important part of any liquefaction cycle design is integration of the process cycle with the plant's machinery and heat exchangers.

For the SMR process, this involves selecting a refrigerant mixture and compressor operating conditions that maximise liquefaction efficiency.

For the nitrogen recycle process, this involves choosing flowrates, as well as operating pressures and temperatures of the nitrogen loop to maximise process efficiency.

For the rotating equipment, the usual method is to assume machinery efficiencies, choose operating conditions and flows, and then provide this information to machinery vendors who then give feedback to the process licensor for required adjustments.

For the heat exchanger, the process is simulated with performance assumptions. This information is sent to the heat exchanger vendor to confirm the design. The vendor can suggest or request changes to fit their equipment's characteristics and limitations. With a less experienced design team, this convergence loop of simulation, vendor evaluation and feedback can be time consuming and inefficient, possibly resulting in a sub-optimal system.

There are innovations that can simplify this process. For example, as the supplier of the refrigeration compressors used for its nitrogen recycle process, Air Products can integrate the characteristics of its expanders and

compressors into its process simulations.

Additionally, through its air separation business, Air Products has developed close relationships with machinery vendors, which can reduce iterations.

Coil-wound heat exchangers (CWHEs) and brazed aluminium heat exchangers (BAHXs) are good options for small scale LNG plants. CWHEs are the preferred choice in all SMR, floating LNG (FLNG) and

Table 1. Summary of process technology selection determinants

	Liquefaction efficiency	Ease of siting	Ease of operations	Refrigerant availability and handling
Advantage SMR	✓			
Advantage nitrogen recycle		✓	✓	✓

larger LNG plants due to their robust design and inherent scalability. For SMR cycles, Air Products manufactures the CWHE, which offers complete control of the exchanger design and its integration with the cycle. For situations where BAHXs are a better fit, such as in small scale nitrogen refrigeration systems, familiarity with the design and limitations of each vendor is essential for an efficient and cost-effective design.

BOG system design

Boil-off gas (BOG) is normally generated from multiple sources depending on the project configuration: LNG rundown flashing at the LNG tank; vapour displacement due to LNG filling into the storage tank; heat leak at LNG storage tank and piping; and BOG generated during loading.

Reduction of BOG

In many cases, small scale LNG plants, especially those with electric motor drives, will have no outlet for excess fuel, BOG or flash gas generated in the process. In order to eliminate flash gas, LNG must be subcooled prior to lowering the product pressure at the storage tank. Both SMR and the nitrogen recycle processes facilitate subcooling the LNG. For small scale liquefaction plants, the nitrogen recycle process can readily subcool the LNG with the addition of a cold expander or with a Joule-Thomson valve at the cold end of the process. For SMR, the nitrogen content of the refrigerant mixture can be increased to deliver the refrigeration necessary to reduce BOG generation. In addition to subcooling, multiple cost-effective methods are available to dispose of BOG, reducing the need for subcooling.

Pipeline availability

The excess BOG can be compressed and sent back to the nearby pipeline, if available.

Gas turbine driver for refrigeration compressor

If a gas turbine is used to drive the refrigeration compressor, BOG can be compressed and used to fuel the gas turbine.

BOG reliquefaction

The BOG can be compressed and sent back to the liquefaction unit or a standalone refrigerant system for condensing. This depends on availability of the main refrigerant compressor power and heat transfer area in the cold box. A small purge from the BOG circuit may be required to avoid N₂ or other inert gas from building up in the BOG circuit.

Flare system design

The flare design is relatively simple for a nitrogen refrigeration system. System overpressure, due to a blocked refrigerant compressor discharge scenario, is not an issue since nitrogen can be safely vented. The simplicity of the flare design will help reduce project cost and minimise plot plan complexity.

In an SMR system, the blocked refrigerant compressor outlet scenario is frequently the controlling case for flare

system sizing. A relatively larger flare system is required to handle this relief load. A high integrity protective system can mitigate the relief load for this compressor blocked outlet case, but it involves advanced dynamic simulation to properly design. The flare system also becomes more complex as the SMR system's refrigerant contains heavier hydrocarbons, with propensity to cause smoking.

Plant design and construction

The most effective EPC project strategy brings a safety-based approach to all aspects of a project, including a strong focus on process safety and safe equipment design and operation. The collaboration between the EPC and liquefaction technology provider ensures that the entire plant is designed with safety in mind.

During the early engineering phase, constructability reviews should be performed to both minimise cost and ensure that safety is designed into the project from a construction, commissioning and operations standpoint. Early construction planning focuses attention on items such as crane selections and office trailer placement. From an operational perspective, access to critical areas is reviewed to ensure that future operators and maintenance personnel have safe, easy access.

Another key constructability focus is to optimise modularisation for cost and schedule advantages. Equipment manufacturers can fabricate and supply the complete compander and BAHX cold box assemblies as prefabricated modules, which are easily placed in the field. Other opportunities for modularisation are explored to minimise costs and field labour.

Early planning applies to start-up and commissioning as well. The commissioning team and end operators are engaged in the early stages to develop a system-based completions plan and fully integrated EPC schedule.

Strategic alliances bring a community-based approach to project execution, with a goal to minimise the impacts of new LNG projects on the surrounding community. This is done through logistical planning. By carefully coordinating material and equipment deliveries, congestion and traffic delays are minimised.

Conclusion

With the increased interest in small scale North American liquefaction plants, strategic alliances offer a cost-effective, safe and reliable solution, based on extensive industry experience, collective expertise and strong construction capabilities. Process design and technology selections must be based on a variety of factors to find the right fit, while meeting owner expectations and applicable codes and regulations. **LNG**

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