Reducing the cost of LNG or gas at its final destination requires optimising an often complex LNG logistic chain with lots of variables. Wärtsilä’s LNG value chain optimisation tool takes into account key parameters, like LNG purchase price, terminal EPC cost and charter rates, to work out the optimal solution that gives the lowest cost of LNG at the final destination.

Introduction to value chain optimisation

The liquefied natural gas (LNG) value chain, from gas well to consumer, is complicated and investment intensive. This adds a considerable amount of cost to the end user, if one does not understand how it can be optimised. Therefore, the most economical solution can often be overlooked if one focuses only on infrastructure investment costs.

Economy of scale plays a big role in LNG logistics. Larger liquefaction plants, larger LNG carriers and larger terminals all contribute to a lower unit cost. However, to be able to deliver LNG to smaller consumers that are unable to utilise the large terminals or receive a large LNG carrier in their small harbour, there needs to be a medium- and small-scale logistic chain in place before they can get their gas.

The cost of delivering LNG to its final destination largely depends on the length of the logistic chain, with the following main parameters:

- Source cost of LNG
- Location of the LNG liquefaction plant in relation to the final destination
- Size and route of the LNG carrier
- Size and location of receiving terminal(s)
- Utilisation of boil-off gas (BOG) in the process and the end customer’s requirements for gas availability.
Large-scale LNG operations

Liquefaction plant: A large-scale LNG operation typically includes production trains with single capacities between 1 and 6 MTPA (million metric tonnes per annum), and they can include multiple trains. For example, in Qatar, the world’s biggest supplier of LNG, Qatargas and Rasgas have a total production capacity of 77 MTPA from their production sites. Cheniere’s newly opened Sabine Pass liquefaction plant will have a nameplate capacity of 27 MTPA, once it opens all 6 trains of about 4.5 MTPA each. Large liquefaction sites are always located in coastal areas since the only practical method of large-scale transportation is using LNG carriers, with capacities ranging from approximately 100,000 m³ (44,000 tonnes) for older vessels to up to as much as 261,000 m³ (120,000 tonnes) for the largest Q-max vessels. As an example, this means that Cheniere’s Sabine Pass plant could deliver more than a Q-max vessel of LNG every second day.

Receiving terminals: Conventional receiving terminals (LNG hubs) in the large-scale LNG chain are also located by the coast so that LNG carriers can arrive and unload the cargo. Main hubs include LNG storage facilities, typically in the range of 100,000 m³ or larger, designed to receive at least the full capacity of the allocated LNG carrier. The LNG is re-gasified at the hub, and the main distribution channel for the consumers is normally a national, high-pressure, natural gas pipeline.

Medium-scale LNG operations

A medium-size LNG logistics chain includes terminals up to 100,000 m³ in size, which are supplied by small-scale LNG carriers, starting from sizes of 1000 m³ up to around 40,000 m³. Here again, the vessel size and loading frequency play an important role in determining storage capacity.

Medium-scale liquefaction is not as common today, due to the challenge with high, specific production costs. In any case, these will probably play a larger role in the future for decentralised solutions, to which extending the large-scale logistic chain would not be feasible.

Small-scale LNG operations

A small-scale LNG logistics chain is comprised of LNG distribution terminals up to 50,000 m³ in size which are supplied by small-scale LNG carriers, starting from sizes of 200 m³ to up to a few thousand cubic metres.

Small-scale liquefaction is becoming popular due to the liquefaction of biogas and other smaller pockets of stranded gas. Small-scale liquefaction can be modularised and, to some extent, standardised. The systems are similar to the re-liquefaction process used in large terminals to handle the BOG (boil-off gas).

Logistic chain optimisation

There is a huge difference to consumers if the cost of fuel is USD/mmBtu versus 11.5 USD/mmBtu. It is in the end user’s interest that this value chain be as cost-efficient as possible. There are several things that can be done to optimise the LNG logistic chain in order to reduce the cost of LNG or gas at its final destination. A logistic chain that incorporates the large-, medium- and small-scale chains can be very complex. To be able to optimise this complex chain with lots of variables, Wärtsilä has developed an LNG value chain optimisation tool. This tool estimates, through an iterative process, the cost of LNG at the final destination(s). The tool needs various inputs such as the following:

- Consumer characteristics (location(s), consumption profile, cost vs. feasibility)
- Supply (location(s), suitability, cost)
- Receiving terminals (need for break-bulk, location, type, sizes, investment cost)
- Shipping (vessels available, charter rate, fuel consumption)
- Bolting-off gas (BOG) handling
- Financing (ownership arrangements, cost of capital, payback time)

The tool works so that you start by defining the consumers, the locations and the anticipated consumption profile. Based on this, you analyse the logistic, deciding where to get LNG and where the receiving location(s) are. Depending on the exporting terminal compliance with smaller LNG carriers, you also decide if a breakbulk terminal is needed in between. Based on the number of terminals and their sizes, you can finally propose the size of LNG carriers and the route.

With all basic parameters and the setup in place, the optimisation/iteration takes into account the parameters like LNG purchase price, terminal EPC cost and charter rates to work out the optimal solution that gives the lowest cost of LNG at the final destination, dependent on various scenarios.

LNG consumption & load profiles

When optimising the logistic chain, we need to start from the consumers. It makes sense to cluster together as many consumers as possible to improve the economy of scale in the LNG logistic chain. By clustering together several consumers and increasing the volumes, we can potentially buy LNG at a better price than utilise larger LNG carriers with a lower specific shipping cost. But at the same time, with several consumers in the loop, you add complexity to the logistics and need a plan for how to break up the distribution of the larger amount of LNG into many smaller consumers. This might call for some additional infrastructure to be built. Additional cost of this infrastructure has to be balanced versus the lower cost of the source LNG.

Consumers will, unless forced by legislation, normally decide whether it is worthwhile to change fuel based on the estimated cost of LNG.

When it comes to LNG supply, it is important to understand that it is only a few of the existing export terminals that are able to take small size (<40,000 m³) LNG carriers. There are some technical issues to overcome with the jetties planned for large LNG carriers in order to handle the smaller LNG carriers, but the main reason why the large terminals do not take small size carriers is the risk of disturbing or taking time away from the profitable large-scale operations.
LNG shipping
Large-scale shipping is well established, and today there is an overcapacity of large-scale carriers. For the older, less efficient steam turbine-driven LNG carriers, we have seen a drastic reduction in charter rates during the last 15 years. But when it comes to small-scale LNG, there are only a few small-scale LNG carriers available today. In many cases, the charter rate for them might be the same as for an older, larger LNG carrier.

LNG shipping between the free on board (FOB) sales hub and a new terminal can be arranged in three ways:

1) Operating your own LNG carrier
2) Chartering a carrier from the market place
3) Arranging transport through an LNG provider (DES Contract)

For the first two options, freight volumes should be significant in order to establish in-house organisations to manage this. The third option is the norm when volumes are small or moderate. In this case, the entire supply chain and associated risks can be subcontracted as an entire package to the LNG provider.

Case Aruba
The customer in this case study is the island nation of Aruba, located just north of Venezuela. It is a Caribbean country, with slightly more than 100,000 inhabitants in an area of 179 km², which means it is densely populated, especially on the more sheltered western and southern coasts of the island. Aruba has one of the highest standards of living in the Caribbean region. The island’s economy is built on three main industries: tourism, aloe export, and petroleum refining.

Unlike many other islands in the region, it has a dry climate appreciated by visitors looking for warm, sunny weather.

Aruba does not yet have an LNG terminal.

For this exercise, we will envision the optimisation options that the developers of such a project would face. The island produces its electricity largely using power plants that today are operating on heavy fuel oil (HFO), but could be converted to gas. There are ambitious plans to increase the share of renewable energy, mainly from wind power, to harness the constant trade winds, but also some solar. In the future, cruise ships might switch over to LNG for environmental reasons, and increased demand for district cooling at hotels is expected to drive up electricity consumption.

We have assumed that the annual gas consumption could be approximately 81.1 million Nm³ of gas or 84,400 tonnes per annum (TPA) of LNG. To give an idea of this amount, it corresponds roughly to the consumption of a 45 MW power plant running baseload at 8000 h/year.

The Caribbean is an interesting area to use for a case study about small-scale LNG since there are many stranded markets there that are not feasible to reach by building pipelines. The main reason why there is not already LNG on these islands is that there has not been a supplier willing and able to supply LNG in suitable quantities. One would have to import LNG either in ISO containers, which is expensive due to the logistics involved, or in large-scale LNG carriers that carry much more LNG than would be demanded. All this changed as of October 2016, when the AES Andres LNG terminal in the Dominican Republic started offering reboots to small-scale LNG carriers. Furthermore, in August, the 185,500 m³ Golar Arctic arrived at its new position as a floating storage unit (FSU) outside Jamaica and will most likely be made available as a supply point for other small-scale LNG projects in the area.

To make this case study more interesting, we have chosen to include four additional suppliers that could become available in the future:

1. Eagle LNG in Jacksonville, Florida, USA.
2. Atlantic LNG in Trinidad & Tobago.
3. Almaco terminal importing LNG to Mexico. If improved pipeline connections to the US are built, Mexico will need less LNG, and this terminal could be reconfigured to offer small-scale reloading.
4. Costa Norte LNG terminal in Panama is under construction and, according to the initial time plan, it should be ready in 2019. There have been plans to offer LNG bunkering near the Panama Canal, and its service could also extend to small-scale reloading.

The Altamira terminal is today a large-scale terminal importing LNG to Mexico. If improved pipeline connections to the US are built, Mexico will need less LNG, and this terminal could be reconfigured to offer small-scale reloading.

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There are many things influencing which solution will be best, but this case study examines the factors in isolation to see the impact of each one on the delivered LNG price. First, we will look at how much the distance between supplier and customer influences the costs. The second element is the time horizon, i.e. how many days of storage, we should select to optimise the project.

About the simulations
As we described in the beginning, when optimising a solution, one has to weigh in the Free On Board (FOB) LNG price, logistical costs and the investment costs of building a terminal. Logistical costs are affected by the choice of LNG carrier, charter rates, port costs, distance, loading/unloading time and time spent inactive. Terminal investment costs depend on the choice of technology, local labour costs, size of storage needed, civil and marine infrastructure needed and risk mitigation measures.

There are many things influencing which solution will be best, but this case study examines the factors in isolation to see the impact of each one on the delivered LNG price. First, we will look at how much the distance between supplier and customer influences the costs. The second element is the time horizon, i.e. how many days of storage, we should select to optimise the project.

There are few small-scale LNG carriers available in the world today, but for this case, we assume that there is a shipping company willing to build a carrier and charter it to us. We also assume that there is no other project to share it with, so we also need to pay for the days when it is idle. The LNG carrier sizes available for this simulation are the following:

- 40,000 m³
- 30,000 m³
- 15,000 m³
- 10,000 m³
- 40,000 m³
- 60,000 m³

Charter rates, port costs, ship speed, fuel consumption and time spent in port loading/unloading have been estimated according to available data about today’s situation. An FOB LNG price of $5 USD/MMBtu has been used for the simulation. This figure was chosen because it is an even number expected to be quite close to the actual price of LNG in small quantities today. LNG consumption is assumed to be constant over the year.
The simulation shows that AES Andres, the nearest LNG supplier, is unsurprisingly the least expensive alternative. But just how much lower must the FOB prices from the other locations be before they cancel out the logistical advantage of AES Andres? And what is the LNG carrier selection that gives the best delivered price? In this example, we will look at two options: 28 days of LNG stored at site and 14 days of LNG stored at site.

Table 1 shows that the FOB price advantage of AES over Altamira is 0.49 USD/mmBtu for 28 days of storage and 0.96 USD/mmBtu for 14 days of storage. AES Andres has less of an advantage over Jamaica FSU, Costa Norte LNG and Atlantic LNG who are all within 0.12 USD/mmBtu of AES Andres’ FOB price. It is also interesting to see, that AES Andres has less of an advantage over Jamaica FSU, Costa Norte LNG and Atlantic LNG who are all within 0.12 USD/mmBtu of AES Andres’ FOB price. It is also interesting to see, that Altamira to Eagle LNG options require a larger LNG carrier that allows for fewer trips, but less travel does not cancel out the other costs.

### Time Horizon

The time horizon indicates the number of days of consumption for which the LNG storage tank is designed. If you have a time horizon of 14 days, it means that after you have consumed the theoretical daily demand for 14 days, there is still enough LNG in the tank to keep it from heating up. This so-called “heel” is often designed to be 10% of the tank’s total demand in bullet tanks and less in flat-bottom tanks. When choosing a time horizon, one has to weigh in factors such as distance to the supplier, reliability of deliveries, e.g., due to weather, storage tank investment costs and the size of LNG carriers available. By using a larger LNG carrier, one can lower the shipping cost per mmBtu, but that affects the length of your time horizon and investment costs.

A simplified case is presented on how the system costs (TotRoutingCost = ShippingCost + InvCost) can be minimised for deliveries from AES Andres and Altamira respectively. Figure 5 shows that 10 days’ time horizon gives the minimum total cost (TotRoutingCost = ShippingCost + InvCost) for deliveries from AES Andres to Aruba. The blue line (ShippingCost, includes e.g. charter fees, fuel consumption, port costs) illustrates the cost impact of LNG carrier types and the number of trips. The selection of these is made by the algorithm on the basis of what combination, capable of delivering the necessary quantities of LNG, produces the lowest costs. With a time horizon of 13 days or less, one can use a 5000 m³ LNG carrier that makes one trip during that period. From 14 to 26 days, the same 5000 m³ LNG carrier needs to travel twice, from 27 to 59 days requires three trips, etc. Here, the same ship is optimal throughout, so the local minima in the Shipping Cost curve correspond to multiples of the optimal 10 days horizon.

In Figure 6 a 14-day time horizon gives the minimum total cost (TotRoutingCost = ShippingCost + InvCost) for deliveries from Altamira to Aruba. In this example, the blue line shows some interesting features with peaks for certain days. It is not feasible to make the deliveries in less than 12 days with this setup, and for 12–13 days, a fairly large LNG carrier is needed in order to complete the deliveries in such a short time. Therefore, we start from 14 to 19 days, showing more feasible configurations where a 7900 m³ LNG carrier travels once, from 20 to 26 days a 10,000 m³ LNG carrier travels once and for 27 days twice, hence the peak. This is because there is not enough time to complete the trip with a smaller and slower LNG carrier. From all to 24 days, there is enough time for a 7900 m³ LNG carrier to make the deliveries by travelling twice. For 40 days, a 10,000 m³ LNG carrier travelling twice is needed, as for 27 days and, therefore, we again see a peak. Above 41 days, a 7500 m³ LNG carrier needs to travel three times.

An interesting observation when comparing the graphs for AES Andres and Altamira is that if AES Andres is chosen as the supplier, one can safely firm up a contract for a 5000 m³ LNG carrier before the final configuration of the terminal size. On the other hand, the Altamira case illustrates the inherent complexity of identifying the configuration corresponding to the minimum costs, as the fleet changes with the time horizon. Optimisation becomes increasingly difficult when more factors are considered. In upcoming issues of In Detail, we will present a case where the terminal size is simultaneously optimised with the time horizon and the fleet configuration.

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**Table 1 - FOB price differences and LNG carrier selection.**

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<th>28 days storage</th>
<th>54 days storage</th>
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<td>FOB Price</td>
<td>Logistics</td>
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<td>Altamira LNG</td>
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<td>2 trips with 7500 m³ LNGC</td>
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<td>Eagle LNG</td>
<td>8.59</td>
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<td>Jamaica FSU</td>
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<td>3 trips with 5000 m³ LNGC</td>
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<td>Atlantic LNG</td>
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<tr>
<td>AES Andres</td>
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<td></td>
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**Fig. 5** - Optimised system cost for deliveries from AES Andres for a fixed annual consumption of 62,400 TPA LNG.

**Fig. 6** - Optimised system cost for deliveries from Altamira for a fixed annual consumption of 62,400 TPA LNG.