ARUNDO

Value creation from Advanced Analytics in the LNG industry



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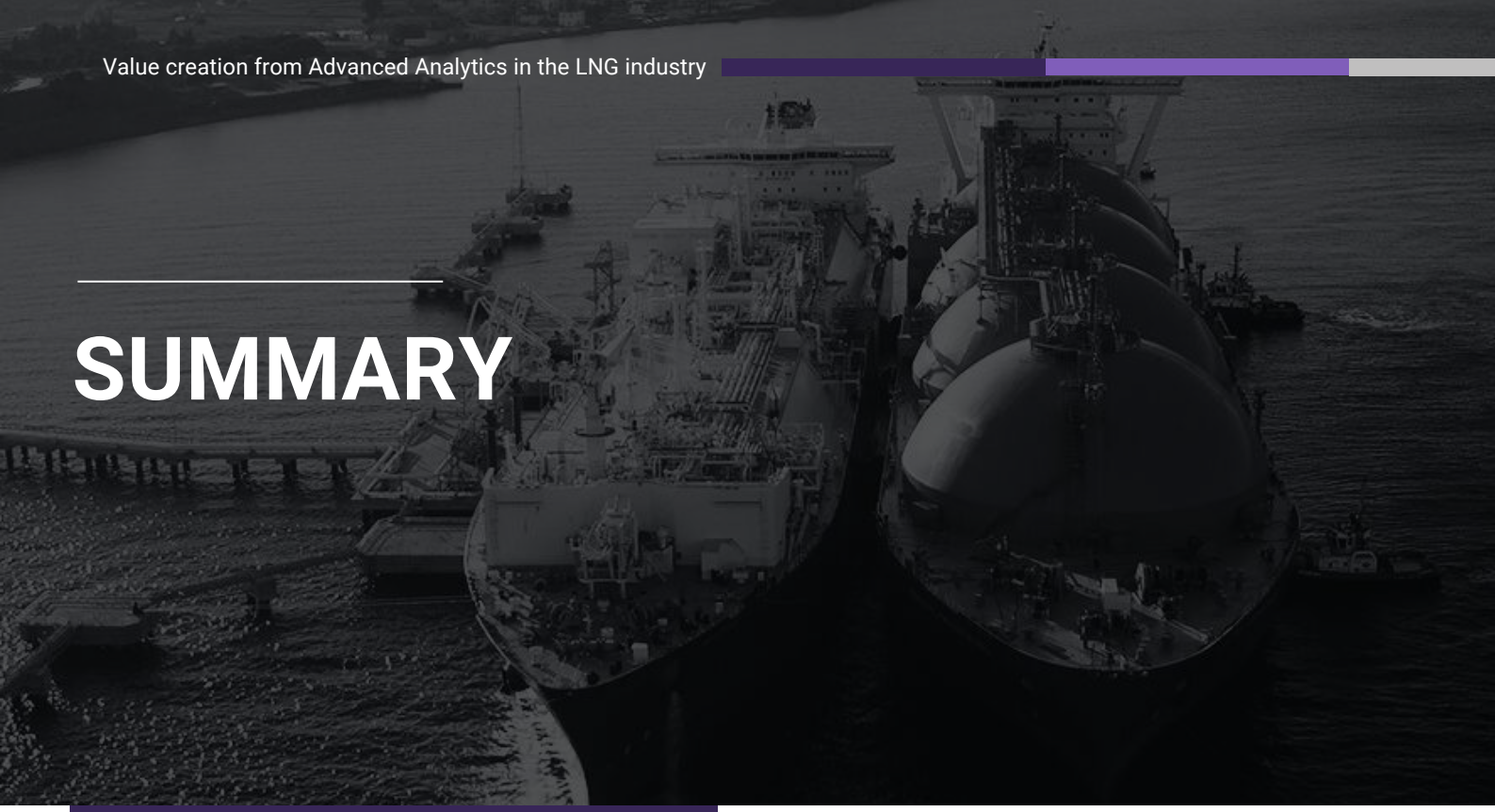
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SUMMARY

The global energy crisis has made LNG more valuable than ever.

As in most industries, the equipment to refine and process this valuable commodity has inherent limitations. By applying advanced analytical models to data harvested from key equipment types in the LNG industry, we have enabled our clients to create considerable value by increasing equipment efficiency and moving emergency maintenance to condition-based maintenance.

Having for decades been seen as a cumbersome by-product of the muscular crude oil industry, natural gas is the commodity of the hour. The reasons for this are several, but three eclipse all other in their magnitude of recent impact:

1. The global effort to reduce the industrialized world's greenhouse gas emissions (GHG) benefits LNG in the energy mix. While it's by no means a GHG-neutral fuel, natural gas' environmental footprint is lower than alternative sources such as coal and oil, making it an attractive transitory energy source on the way to full carbon neutrality. This fact was cemented by the European Union's decision in 2022 to classify natural gas as a "green" energy source.

2. The economic sanctions imposed on Russia as a consequence of that country's invasion of Ukraine and the very likely related sabotage of the Nord Stream 1 natural gas pipeline have massively increased the demand for LNG in central Europe.

3. The continued advances made by shale gas adoption (primarily in the US) and increased exploration efforts (e.g., in South America and Africa) have increased the industry's prospects of extracting natural gas from the ground for many decades.

With global demand for natural gas at a historical peak and new projects aimed at increasing supply not yet coming online, the price of natural gas has skyrocketed. The spot rates on the Asian market increased by over 400% in a few months in 2021 and remain at volatile-but-high levels ever since.

Despite the gloomy backdrop, this development has been very advantageous for companies engaged in the Liquid Natural Gas (LNG) value chain. The LNG industry's overall value proposition is to take natural gas at a point of abundant supply, compress and cool it to a state where the gas becomes an energy-dense liquid, move it to a point of demand, and restore it to its gaseous state where it can be fed to plants generating heat and electricity for industries and households. With the steady demand increase and the sudden supply cutoff from the Russian pipeline, LNG producers, transporters, storage providers, and traders found their products and services to be wanted by virtually everyone.



LNG Investments

One example of optimism in the industry is Shell's investment in Prelude - a floating integrated LNG production facility built for a staggering USD 12.5 billion investment. This vessel is the largest ever built, with almost half a kilometer in length. While plagued by technical accidents and worker disputes, this Prelude initiated LNG shipments in 2019.



A YOUNG INDUSTRY STILL EVOLVING

In the context of the global energy system, LNG is a newcomer.

The technology for liquifying methane (the main constituent of natural gas) was developed in the 1960s, but it took until the turn of the century that the technology matured to the point where it can be considered a mature part of the energy system.

Although today's industry exports around 400 million tonnes of LNG, compared to other primary industries like coal, oil, and even nuclear, the technology enabling the LNG industry has not had the same amount of time to undergo the iterative cycles of engineering that perfects the technology.

This is the vantage point from which we should consider the value Advanced Analytics can add to the industry.

From the simplified value chain description provided upstream in this article, we can derive the type of economic activities and companies that are active in the industry.

These include:



LNG producers:
the companies that liquify the natural gas close to the source of extraction



LNG storage providers:
the companies that store the LNG until it's either shipped to a demand-side port or until it's due for regasification



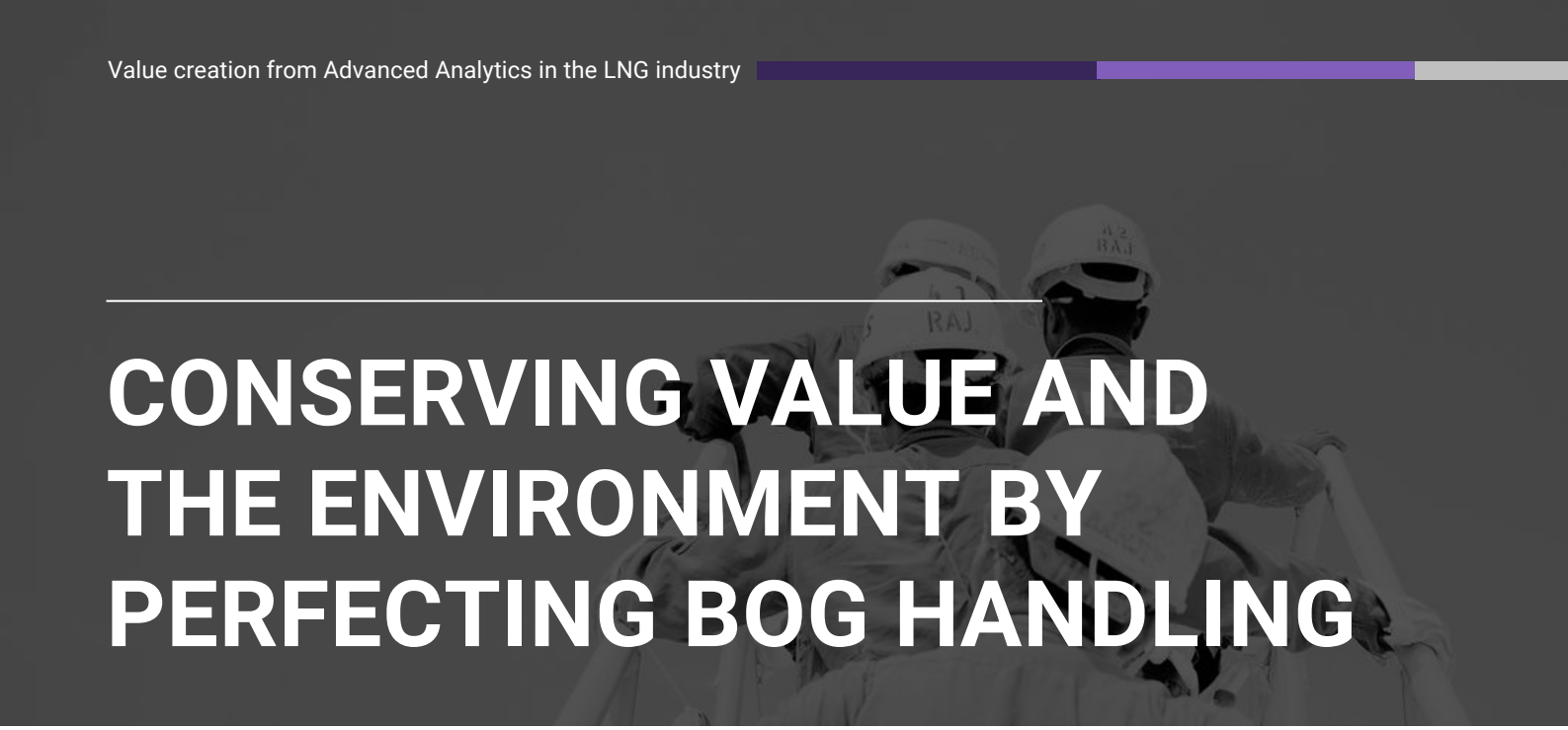
LNG freighters:
due to the bulkiness of LNG, moving the stuff around centers of supply and centers of demand is mainly done on specialized ships



Regasifiers:
the companies that transform the LNG back into its original form as natural gas

These actors all fight against a fundamental industry problem - that LNG does not want to exist at all in what we consider a "normal environment". For LNG to stay liquid at atmospheric pressure, it must be kept at a temperature below -163°C. Since those temperature levels do not exist naturally near the Earth's surface, companies in the LNG industry constantly battle against nature to prevent the LNG from boiling, i.e., returning to its gaseous form.

The boil-off gas (BOG) resulting from boiling LNG increases pressure in an LNG container and is both a powerful GHG that cannot be released into the atmosphere and a flammable substance capable of creating devastating explosions. Hence, in the absence of the perfect LNG tank temperature isolation, anyone handling LNG must manage the constant formation of BOG and the resulting tank pressure.



CONSERVING VALUE AND THE ENVIRONMENT BY PERFECTING BOG HANDLING

Boil-off gas is unwanted for three reasons:

1. **It's inherently less valuable than LNG due to its gaseous form.**
2. **Its formation increases the pressure in the LNG containers, ultimately increasing the risk of tank breach and leakage.**
3. **It's a powerful GHG that cannot be safely released into the atmosphere (in fact, doing so is illegal in most regulatory frameworks).**

As a handler of LNG, there are four principal options for managing care of BOG, presented here in descending order of economic attractiveness:

- **Reconvert the BOG back into LNG.** This can be done using various forms of "reliquefaction equipment", but requires adding energy. Provided sufficient energy can be supplied to the gas (typically through a combination of compression and heat transfer), this is the most desirable alternative since the high value of LNG is conserved over time.

- **Make productive use of the BOG.** The energy content in the BOG can be put to productive use (after all, this is the gas we pay top-dollar for when we get through a pipeline). Examples of this are gas-fuelled generators that can be deployed to supply either a steam-producing boiler or for direct generation of electricity to equipment surrounding the LNG-handling systems. For LNG freighters, even the main propulsion engines can today be fully run using compressed BOG - supplanting the need to use standard marine diesel oil (MDO) as propellant fuel.

- **Burn the BOG.** While it's akin to burning greenbacks, sometimes you have no other means left to control the LNG tank pressure than putting the BOG on fire. While any LNG operator would consider this a next-to-last resort, the gas combustion units (GCUs) containing this intensive fire are mandatory equipment in large parts of the LNG value chain and their functionality is critical for the safety of humans and the environment.

- **Release the BOG.** Releasing BOG into the atmosphere has detrimental effects on financials and the environment and is only done in extreme circumstances to save human lives.

Each option forms its own segment in the LNG equipment industry, with engineering powerhouses like Siemens, Honeywell, and Alfa Laval each having broad portfolios of LNG-specific equipment. Over time, these and other OEMs have added sensors and increased the sophistication of the control systems. Today, this equipment is mostly connected to integrated control panels or distributed control systems (DCS), where predefined algorithms perform detailed process control based on sensor-emitted data.



THE LIMITATIONS OF EMBEDDED CONTROL SYSTEMS AND THE ROLE OF COMPLEMENTARY ANALYTICS

Although equipment OEMs steadily improve the performance of LNG equipment, four inherent factors delimit what an owner or operator of these assets can do:

1. **Processing power scarcity** - Adding the raw compute power that would enable this equipment to perform advanced analysis would increase the price point and risk robustness of the control algorithms.

2. **Absence of data contextualization** - A single piece of equipment will not have full awareness of the environment it's operating in. To avoid triggering nonsense alarms and alerts in edge-case circumstances, equipment OEMs must delimit the scope of their embedded control systems.

3. **Long hardware lifetime** - The economic lifetime of a compressor, scrubber, or other physical equipment far outlasts the economic lifetime of a computing processor. As such, the compute power in the equipment will be a few generations behind the state-of-the-art algorithms used by data scientists harnessing cloud-hosted compute power.

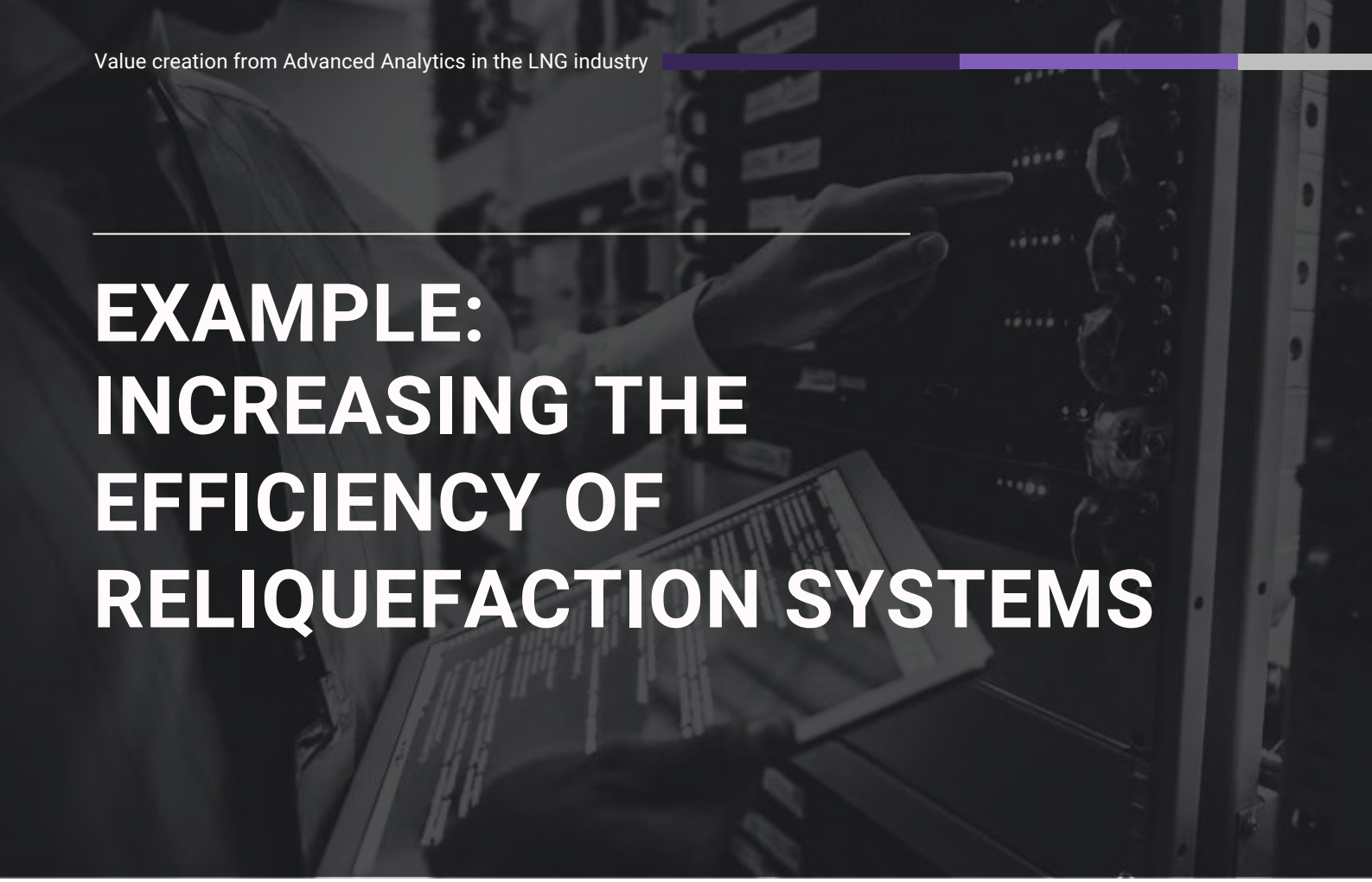
4. **Unknown owner-specific needs** - It's virtually impossible for an OEM to cater to every customer's specific needs and wants while maintaining a consistent product line.

At Arundo, we recognize these limitations from other asset-heavy industries like upstream oil & gas, chemical processing, and material handling and develop and deploy software accordingly.

Asset owners all want to minimize downtime, maximize lifetime, and reduce maintenance efforts. Our answer to these wishes is to harvest the data emitted from the equipment as it is produced and apply analytical models to it in parallel with the algorithms embedded in the equipment.

With this approach, we can target specific pain points for an individual asset owner, add the necessary context to the data, and make use of the latest know-how from the data science arena to provide a level of control and stability that the embedded systems cannot offer.





EXAMPLE: INCREASING THE EFFICIENCY OF RELIQUEFACTION SYSTEMS

Reliquifying boil-off gas is usually the most desired way to take care of the boil-off gas that inevitably forms as LNG is slowly warmed up to the ambient temperature at constant pressure. Reliquefaction systems come in several variants, but they all combine removing heat, modifying pressure, and forcing fluid dynamics processes that condensate the gas back to liquid form.

At one of our clients experiencing problems with the effectiveness of their reliquefaction system, we analyzed six months of raw data from 28 sensors mounted on a reliquification system. By joining this data with the asset context (on/off states, servicing events, physical movement, etc.), we could isolate a few points where the output in the form of LNG did not match what one would expect, given the input of BOG.

After a closer analysis of this data, we could together with the asset operators, form a hypothesis that the level-off in reliquefaction effectiveness was caused by a build-up of lube oil deposits in the inline heat exchanger, causing gradually less efficient heat removal from the compressed gas, eventually reaching the point where it could no longer be condensated by the fluid dynamics process used in the equipment. We could also identify a combination of measurements that allowed us to observe this gradually decreasing efficiency and construct a "virtual sensor" from these.

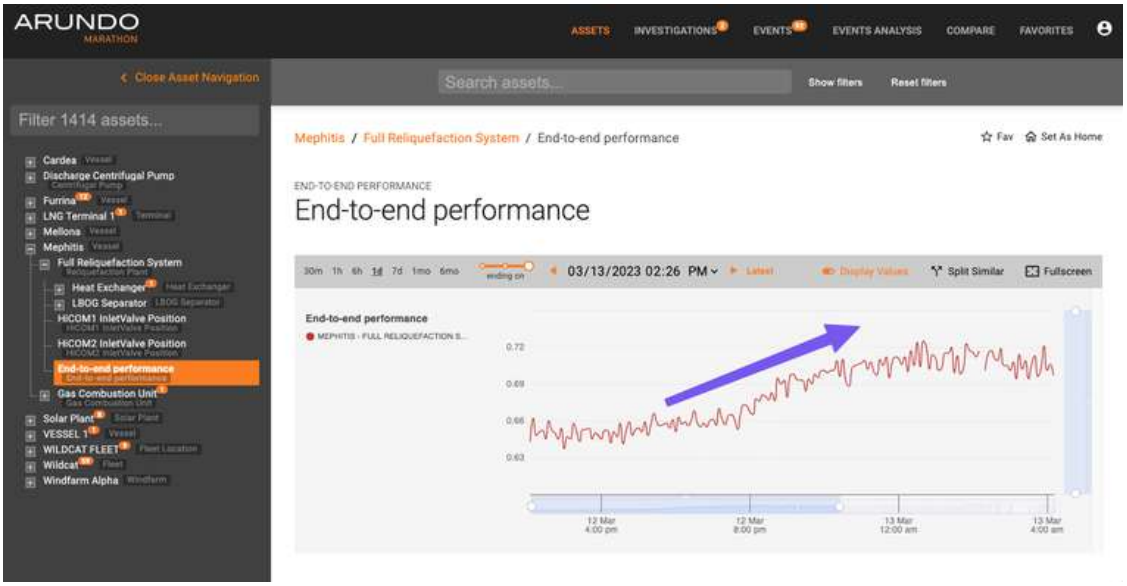


Exhibit 1: Virtual sensor measuring the end-to-end efficiency of converting BOG back to LNG. The overlaid blue arrow shows an increasing efficiency in the time frame selected, providing operators peace of mind that reliquefaction continues as per plan.

By monitoring the output of this virtual sensor, the system operators can get a warning a few days before an upcoming drop-off in system efficiency, allowing them to perform preventative maintenance on the system and keep the reliquefaction levels high. For the asset owner, this implies additional reliquefaction of BOG for a value of several million dollars per year - an effect that increases in value in tandem with the price of LNG.



EXAMPLE: PREVENTING FAILURES OF GAS COMBUSTION UNITS ON LNG CARRIERS

On a vessel transporting LNG, having a functional Gas Combustion Unit (GCU) is mandated by regulators, and is a critical component to be able to maintain tank pressure, especially in the loading/off-loading stages of the transport process.

GCUs are fed with boil-off gas (BOG) from the vessels' cargo tanks. As pure LNG contains no oxygen, air is added to the BOG and the now-flammable mixture is blown on an open flame, creating a combustion reaction that emits mainly carbon dioxide and water vapor. The powers at play when operating a GCU at full capacity are considerable - an unstable air-to-gas mixing process or an inability to keep the incineration temperature under control can cause vibrations and thermal stress, eventually leading to reduced equipment lifetime and in the worst case, cracking of the unit.

One of our clients had experienced exactly this type of cracking of GCUs, but they had not been able to isolate what caused it. After extracting several months of data from two dozen sensors attached to the GCU, we could observe much sharper swings on one of the temperature sensors than what was normally seen. The timing of these temperature swings preceded the discovery of cracks by a few days, leading the joint team to believe it was indeed the culprit of the equipment failure.

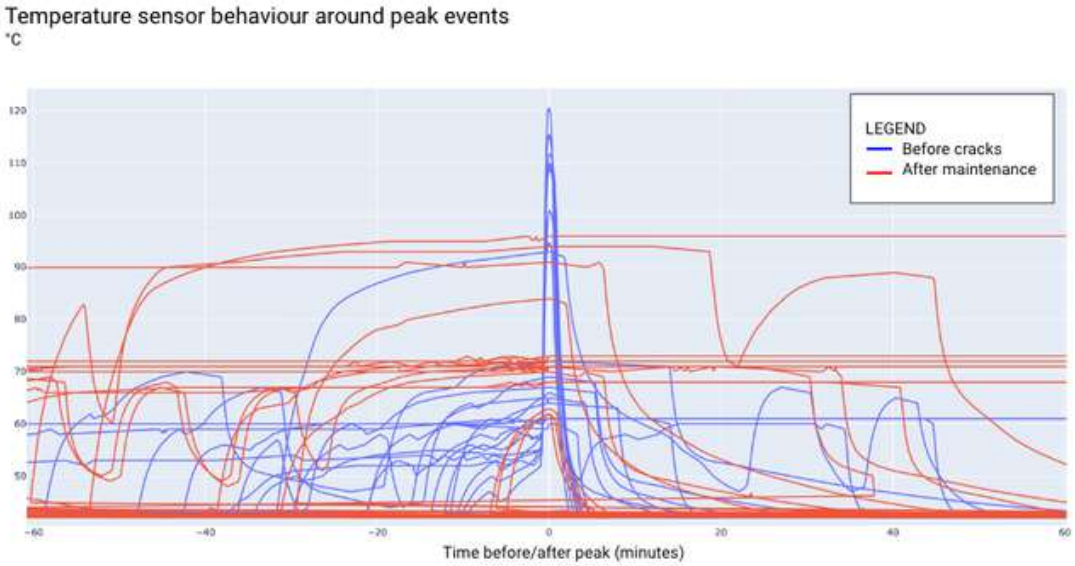


Exhibit 2: Example from the historical data analysis showing that temperature swings before cracks were found in the GCU were distinctly sharper than after the repair and maintenance of the same equipment.

The nozzles and valves in the GCU are sensitive to small disturbances to their designed configuration. While we could never fully determine exactly which component had failed, the crew of the LNG carrier can now continuously monitor if temperature swings start to become more accentuated and perform preventive maintenance before these events become extreme to the point that they may cause cracking events again.

In the shipping industry, performing unplanned maintenance involves flying experts around the world at short notice, possibly disrupting voyage schedules. The ability to shift emergency maintenance to condition-based maintenance was worth several hundred thousand dollars to our client, making the software and analytical development to enable it an investment with a very short payback period.



CONCLUSION - THERE'S MUCH MONEY HIDDEN IN THE DATA

Our experience from applying analytics to the data constantly emitted by the equipment along the LNG value chain tells us that there are plenty of opportunities for asset owners.

Value is obtainable by

1. Reducing LNG losses from boil-off
2. Moving from scheduled to condition-based maintenance of reliquification equipment and tank pressure control equipment
3. Reducing downtime of equipment such as pumps and compressors that are vital to process performance

Asset owners we work with share the challenge of having a lot of data on the equipment handling the LNG but struggling with how to use it to create value. As Arundo, we advocate for a use case-led approach, where we focus on solving operational problems for asset operators using already-existing data. While this may delimit the theoretical solution space, it accelerates the time-to-value, especially when models are built to fit in existing end-user solutions such as Arundo Marathon.

With LNG prices at historical peaks and the energy security of a large part of the world depending on maximum performance of LNG supply chains, we believe there's not been a better time to harvest the value from the data of LNG-handling assets.

ABOUT ARUNDO

Arundo Analytics supports equipment operators to make better decisions and improve efficiency, reliability, and sustainability.

Our products link data science, cloud computing, and big data with industrial IoT, providing prescriptive actions beyond simple alerts. Broad industry experience makes us a powerful partner for digitalization and process optimization.

Maximize your business' capabilities with Arundo products.

Benefit from more than 250.000 development hours for:

- increased production levels,
- minimized downtime, and
- significant cost savings for your operations.

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