Global energy demand is surging. Gas is likely to make up a significant proportion of the world’s energy supply for decades to come, but the LNG industry is facing a number of significant challenges. New LNG projects are located in harsh or remote locations, which make them more challenging and expensive to develop and operate. LNG projects have to become more cost competitive in the future while enabling the energy transition. Additionally, companies are facing the prospect of staff shortages with experts retiring from the industry and new generations preferring to live in the cities.

Traditional project, engineering and operations in the LNG value chain may not be adequate to cut enough costs and reach the required levels of performance. The (r) evolution in the world of digital technology provides an opportunity to make the necessary step changes.

This paper reviews areas where Shell is introducing new technologies that are expected to make a substantial contribution to the development of new LNG projects and the success of future operations – digitalisation, robotics, sensing and process control.

Recent advances will enable the industry to further digitalise project planning and development tools reducing capital costs and schedule. New robotics and sensing minimises risks to personnel in harsh, frontier locations, enhance and accelerate decision making to minimise deferment and reduce facility turnaround times, achieve and maintain performance excellence in process operations. They will help to increase productivity and efficiency and boost asset integrity.
Introduction

Global population is expected to increase from around 7 billion today to over 9 billion by 2050, with 66% living in cities and the demand for energy will continue to increase rapidly. As societal awareness and consensus on the impact on the environment and on human health of greenhouse gas emissions increases, the energy landscape is set to undergo a strong shift over the coming decades. Natural gas as the cleanest burning hydrocarbon and in its abundance will be a significant part of the future energy mix. Between now and 2035, natural gas demand is expected to grow at an average of 2% per year\(^1\); twice the rate of total global energy.

Shell is one of the world's leading suppliers of natural gas and liquefied natural gas (LNG) and has been a pioneer in LNG for more than 50 years (see Figure 1). With LNG, gas which is unevenly distributed in the world is made widely available meeting the energy demand across the globe.

Shell forecasts that the demand for LNG is set to increase at an average of 4% per year and in its LNG outlook 2018\(^1\) noted that new supply investment (see Figure 2) is needed to meet this long-term demand growth.
However, LNG project developments are facing significant challenges with costs of base load LNG plants having increased significantly since early 2000. LNG projects have to become more cost competitive whilst enabling a cleaner future through its low CO2 emissions.

Over time, LNG plants have increased in size and complexity. Shell has successfully applied economy of scale to build LNG projects right from the early designs in Brunei LNG to the most recent one of Canada LNG. However, it is recognized that economy of scale (driven by equipment cost) has reached its limits and will not be sufficient to achieve further lower costs for future developments. In parallel, LNG plants have also increased in complexity by embedding operational feedback into the designs to allow for maintenance on the run, to support the reliability and availability performance.

Over the last few years, Shell has developed simplified concepts by significantly reducing scope, making the plant design more compact, reducing labour cost and leveraging technological developments to reduce cost while improving the environmental performance. Operations and maintenance philosophy including opportunities such as reduced sparing or enabling remote operations were also critically investigated to further reduce capital investment and the lifecycle cost.

While significant CAPEX reductions have been achieved by these simplified concepts, more can be done. Also, new LNG projects are located in harsh or remote locations, which make them more challenging and expensive to develop and operate. Locally accessible talent is also a challenge for such projects and they can benefit from opportunities to access global talent and expertise. The evolution in the world of digital technology provides an opportunity to address these challenges and make a step change in the way we execute and operate LNG projects and plants.

Organisations have been digitising for decades, but the digital revolution in general and specifically in the Oil and Gas industry is only just beginning. There is mounting evidence that we are approaching a tipping point in the exponential advancement of digital technology [2]. Digital technologies have 'come of age' - maturing to the extent that significantly more is possible than even a few years ago [3]. Sensors, data storage and processing costs are dropping dramatically, processing power continues to increase rapidly, artificial intelligence and machine learning are no longer science fiction, and access to high speed, reliable internet is available almost worldwide.

The World Economic Forum Digital Transformation Initiative [4] for Oil and Gas Industry estimates that we can achieve 20-25% cost reduction across multiple segments including IMR (inspection, maintenance, repair), drilling, completion, employee costs and autonomous operations [3]. Building on the digital technology trends, Shell is continuing to adopt digital technologies to achieve significant benefits in the way projects are executed and plants are operated. Robotics, Artificial Intelligence (AI), Big Data, Internet of things (IoT), advanced analytics, smarter project planning tools are some of the key digital technologies that are being used in Shell’s LNG projects and plants across the project lifecycle to increase efficiency, reduce cost and to keep people from harm’s way. This paper describes Shell’s current view of digitalised future LNG projects and plants and how it is leveraging today’s digital technologies in the journey to the future.

Broadly, digitalisation refers to the use of digital technologies to create more value in core businesses, to change a business model and to provide new value producing opportunities while building the appropriate organisational capability and mindset [5,6].
Digitalisation in Shell

Shell has been at the forefront of digital technologies for decades, from the advent of underwater robots in the 1970s to today’s high-performance computers helping to detect new energy resources deep beneath the earth’s surface. Digitalisation is not new in Shell’s LNG plants, which have had sensors gathering data in thousands of pieces of equipment for a long time. The difference today is that these sensors are being used more and to generate insights real-time giving a greater understanding of how substantial value can be created from it at scale.

Shell’s vision is to build intelligent LNG plants of the future that are fully digital, agile and optimised, enabling more nimble, real-time, flawless operations. There are 3 key functionalities of these intelligent plants of the future which are enabled by digital technologies – real time production optimisation, smarter operations and proactive & predictive monitoring. It continues to deploy several tools and technological advancements that are available today to enable these functionalities. Shell is rapidly creating digitalised versions of its assets, a digital twin, which goes beyond the 3D model, but integrates engineering and operating data and will enable the recreation of the plant in a virtual and digitalised world. By simulating real conditions and applying the outcomes, this will enable a range of efficiency and production improvements whilst reducing safety exposure.

At the core of achieving this is the availability and effective use of data – historic, real time or project/engineering data; data that is created during the project development that should be preserved and handed over to the assets. The data centric approach has already started changing the way engineering is done enabling an integrated design across the globe moving away from the past where project designs were based on 2D paper drawings. When developing the recent simplified concept design for future LNG projects, significant benefits were observed by working with a 3D model of the LNG plant instead of 2D Process drawings right from the beginning. This helped to work through the complex designs, identify opportunities for reducing scope, remove non-value adding redundancies and get a systemic view of the impact from the scope reduction. With technologies and tools available today that give engineers the freedom to optimise and visualise concepts in 3D, digital engineering is expected to bring significant benefits in the efforts needed in front-end development.

When implemented in scale, an integrated data centric environment can influence the more direct flow of engineering from the evaluation of concepts, to front end engineering, through to construction, commissioning and handover to the asset.

With data flowing directly from engineering, advanced work packaging (AWP) can be used to optimize workface planning to drive construction productivity. AWP is a construction-driven process that adopts the philosophy of “beginning with the end in mind”[^1][^2] and is a Construction Industry Institute (CII) industry standard best practice. AWP and 4D construction technology help define and visualize the path of construction. These technologies are available today as market solutions and Shell has been using them in its recent projects.

And finally, the data flow through to handover will enable the creation of the virtual data twin (3D model + other engineering data) of the physical asset thus enabling the creation of digitalised intelligent assets of the future. As mentioned earlier, there are 3 key functionalities of these intelligent assets of the future enabled by digital technologies – real time production optimisation, smarter operations and proactive & predictive monitoring. In this

[^1]: [CII Industry Standard](https://www.cii.org)
[^2]: [AWP Philosophy](https://www.awp.com)
paper, we will look at some examples where Shell is seeing benefits from the successful deployment of digital technologies to realise these functionalities.

**Real time production optimization (RTPO) of Mixed Refrigerant (MR) loop by Data Analytics**

By deploying real time production optimization (RTPO) of the Mixed refrigerant (MR) loop, the setpoint for Advanced Process Control (APC) schemes for refrigerant inventory and composition can be controlled and adjusted, to improve efficiency and throughput of LNG plants. Enabled by data analytics, this technology allows the plant to run for longer at maximum capacity potential of the facility.

A C3/MR (propane precooled mixed refrigerant) plant is one of the widely used refrigeration processes for onshore LNG plants. From an energy intensity and value perspective, the MR loop has the largest opportunity for optimization and drives the core of the LNG plant, the main cryogenic heat exchanger (MCHE) for liquefying natural gas.

There is an established practice to push the throughput of the MCHE / MR loop using APC technology. However, efforts to fully model the process from first principles for RTPO have proven difficult due to the complexities associated with phase changes of the natural gas and mixed refrigerant in the MCHE. With the use of data analytics techniques, however new insights were gathered to build predictive models for RTPO for the MCHE/MR process. By using data analytics on operational data, key optimisation handles in a MR loop were identified/re-affirmed and empirical models for LNG production and MR compressor power were developed as a function of key independent variables. Figure 3 illustrates the implementation process for RTPO for the MR loop. The models thus developed were incorporated in the design of the MCHE APC, to further operate the plant more efficiently resulting in ~1-2% additional LNG production.

![Figure 3 RTPO Implementation Process](image)

**Smart Operations**

There are several digital advancements that are helping Shell in making its operations smarter. From the use of robotics and drones for surveillance to leveraging wearables to bring in virtual expertise, the possibilities are endless. Digital technologies not only help improve productivity but can significantly reduce exposure to safety risks.

Shell is developing and deploying robotic technologies in areas where there is scope to reduce risks to personnel while maintaining the highest levels of operational safety. For example, Shell together with National Robotics Engineering Center at Carnegie Mellon University has developed Sensabot, a robot system that can carry out...
autonomously many of the inspection and first responder tasks currently performed by people. The Sensabot\textsuperscript{[10],[11]} (see Figure 4) is a robust, battery-operated system with a wireless command capability. It is designed to meet IECEx Zone 1 standards, which makes it ideal for facilities where the hydrocarbons being produced or processed contain high concentrations of toxic hydrogen sulphide (H2S). It is designed to be durable and reliable, with a 6-month period between human interventions. Its robust design means that it can cope with extremes of temperature from -35°C to +50°C and an IP-67 rating which means it is protected against dust and can operate safely outdoors even in heavy rain. It is packed with sensors and cameras enabling it to gather data about temperature, noise and vibrations, and sniff for any toxic and flammable gases that might be present. An operator sitting in a control centre out of harm’s way can guide Sensabot over WiFi or mobile network. Progress can be monitored via high-definition video as it inspects pipes and valves in complex installations. Parallelly, Shell is working on educating and upskilling its staff to equip them with better tools so that they can seamlessly co-work with robots in the future.

Shell has also pioneered the use of remotely operated aerial vehicles (ROAVs)\textsuperscript{[10],[12]} (see Figure 4) or drones to conduct routine, but potentially difficult or dangerous inspections onshore and offshore, particularly those that involve working at heights. Using ROAVs reduces HSSE exposure while enabling Shell to increase uptime and optimize shutdown timings as a result of gathering better quality data more frequently. ROAV deployments have included visual inspection of gas flares, vents and chimneys at several Shell and Joint Venture refineries and gas plants, including for example the marine flare stack inspection at Brunei LNG.

\textbf{Figure 4 On the left, Sensabot in action; On the right, ROAVs – to examine some of Europe’s biggest energy plants}

It’s not long ago that bringing a mobile phone or a camera into a live plant with hydrocarbon was not possible due to sparks/explosion risks. Today, there are intrinsically safe smart phones and tablets that can be used in operating facilities. Internet of things (IoT) brings in an enormous opportunity to make a step change in the way we operate. Providing field staff with simpler digital tools means using any mobile device to execute mundane tasks while in the field (work orders, asking for assistance). Being able to understand and relate the work they do through real-time asset performance is also key. By simply allowing the operators access to all the data and information they need while mobile, and in the field, an increased productivity by 20% has been observed at a Shell operating facility. With smart glasses, smart helmets and other wearables which allow for over the shoulder coaching through voice and video, staff can now collaborate with experts or vendors from around the world in real time to fix problems,
reducing valuable time wasted in the past on operator spotting an issue, logging it in a complex system, calling in an expert etc., not to mention the cost and time in bringing in such expertise to remote locations.

**Proactive & Predictive monitoring**

Digital technologies are helping Shell to move away from time-based to proactive and predictive ways of doing things thus improving the safety and reliability of critical equipment. Digital sensors installed in operational facilities around the world produce a constant flow of data which are analysed to improve processes and to take better business decisions. It is estimated that engineers spend around 50% of their time looking for the right data and end up making good use of only about 10% of the data that is being gathered. The difference now is that machine learning and advanced analytics are being used to enable the best use of the data.

One example, is in maintenance. Maintenance spend is significant and it is known that gas compressor failure is one of the biggest causes of unscheduled deferment or unplanned downtime in our industry and Shell is not immune to this. In this regard, improvements are being made in Shell’s predictive maintenance capability to help identify ‘weak signals’ and act before an incident or a trip occurs. This is made possible using machine learning and advanced analytics and can prevent significant production losses and reduce maintenance costs.

With Shell’s Smart Connect technology which collects data from sensors installed in operating plants across the Businesses from refineries & chemicals plants to gas facilities to offshore platforms and even sub-sea pumps, performance of plants can be optimised by predicting when maintenance will be needed, and unplanned downtime and lost productivity can be limited. And all of this can be done remotely from the comfort of a control center anywhere in the world and in the future with advances in AI, perhaps without any human interference.

![Compressor Steady State Outliers](image)

**Figure 5 Illustration of Predictive monitoring to identify outliers/weak signals**

**The Future**

Digital technologies are advancing at a much faster pace than we can truly leverage its potential. However, digitalisation is not just about technology and data – they need to fit within the social environment. This requires an organizational culture change both in the internal and external ecosystem and it needs people with the right skillset to make the most of the technology. Engineers would need to become digitally literate, and would need the ability to acquire, process and interact with data in new ways. We will need to ensure continued compliance with regulation and legislation. Increased data collection and storage also brings up potential obstacles in cyber security, data export and data localisation requirements, data security and personal data protection. We will have to work out how to get the right data to the right people while preventing unwanted access and can learn from the mistakes and advancements in the technology industry.
It is indisputable though that the potential for digitalisation to make a difference in our industry is huge – to transform how data is employed to improve efficiencies, reduce costs and improve safety. When embraced across the LNG value chain and with greater collaboration within and outside the industry, a step change can be made in the way LNG projects and plants are developed, executed and operated, thus paving the path towards a fully digital and highly automated future.

![Figure 6 An illustration of what the future holds: From Digital Engineering to Automated Execution to Digital and Intelligent assets](image)

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