New frontier: engineers and the global energy challenge

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Malcolm Brinded is Executive Director of the Upstream International business.

He joined Shell after graduating in engineering from Cambridge University and has worked for Shell companies in Brunei, the Netherlands, Oman and the United Kingdom. In 1998 he became Managing Director of Shell UK Exploration and Production and from 1999 until 2002 he was Shell Country Chairman in the UK.

Malcolm has been a member of the Royal Dutch Shell plc Board (and its predecessors) since 2002. Prior to his current role, he was Executive Director in charge of Exploration & Production.

Malcolm is a Fellow of the Institutions of Civil and Mechanical Engineers and of the Royal Academy of Engineering. He is a member of the Nigerian President's Honorary International Investor Council and a Trustee of the Emirates Foundation. He was appointed a Business Ambassador by the UK Prime Minister in October 2010.

He is also the Chairman of the Shell Foundation and in 2010 he joined the Network Rail Board as a Non-executive Director. In 2002 he was appointed CBE for services to the UK oil and gas industry. In July 2011, His Majesty the Sultan of Brunei awarded him the title of Dato Seri Laila Jasa in recognition of his services to the state of Brunei.

Hilary Mercer is the Vice President for LNG/Integration at Arrow Energy.

She joined Shell in 1987 and held various roles at the company's Stanlow complex in the UK until 1994 when she transferred to SIPM in The Hague, Netherlands (now Shell Global Solutions). Here she was involved in the development of the Front End Engineering Design for the LNG storage and loading facilities for Nigeria LNG and Oman LNG.

Hilary then became responsible for the feasibility study for Small Scale LNG which led directly to the floating LNG development work which has now culminated in the Prelude Floating LNG project in Australia.

In 1997 Hilary moved onto the Oman LNG project responsible for mechanical construction activities in the field and in 2000 became the Task Force Leader for the Sakhalin LNG project in Russia. Following the project's final investment decision in 2003 she moved to Sakhalin Island as LNG Construction Manager and then as the LNG Project Manager until a successful start-up of Russia's first LNG Plant in 2008.

In 2009 Hilary moved to Dubai to work on creation of a joint venture with the Iraq South Gas Company in Basra province, Iraq. Delays to the project associated with elections in Iraq in 2010 provided an opportunity for Hilary to swap the Gulf for Australia to join Arrow Energy in 2010 as VP LNG/Integration for Shell/PetroChina's coal-seam-gas-to-LNG development in Queensland.

In the first half of this century global energy demand is likely to double, on the back of a rapidly expanding global population and sharp growth in the emerging economies. Over the same period, the world must limit its CO_2 emissions to avoid the worst effects of climate change. Engineers are critical to developing and delivering the energy resources needed to meet this dual challenge.

Within the energy industry, Shell has a proud tradition of engineering innovation and excellence, stretching back more than a century. Today, the company relies on the rigour and flair of its engineers more than ever as they invest some $20 billion in new projects every year. Their expertise spans all manner of disciplines, from the civil engineers who design and build giant offshore oil and gas installations to the chemical engineers overseeing advances in biofuels.

In this lecture, Malcolm Brinded, Fellow of the Royal Academy of Engineering and Executive Director of Upstream International at Shell, and Hilary Mercer, one of the company's most senior project directors, describe how Shell brings to reality some of the energy industry's most demanding projects by pushing the boundaries of what is technically possible and safely achievable.

Introduction

(*Malcolm Brinded*) I should begin by sincerely thanking the Royal Academy of Engineering for their invitation to speak tonight. It's a great honour for both of us, especially after last week's launch of the Queen Elizabeth Prize for engineering, which Shell is delighted to sponsor.

Our company has a proud tradition of engineering excellence. Indeed, an engineering innovation lay behind the early success of the Shell Transport and Trading Company in the 1890s.

The international oil market was then in its infancy. And carrying oil products by ship was problematic and dangerous, because they were carried in barrels, which could leak and took up too much space in the ship's hold.

Safety concerns about this practice meant that the Suez Canal, the main trade artery between Europe and Asia, was closed to oil.

So to meet the canal's safety requirements, Shell commissioned the design and construction of the first bulk oil tankers. And in 1892, the *SS Murex* successfully transported several thousand tonnes of Caspian kerosene to Thailand and Singapore, via the Suez Canal.

This sharply increased the volume of oil products that could be transported, sparking a revolution in the international oil trade and, over time, the global economy.

Today at Shell, we employ some 20,000 engineers, across a wide range of disciplines, from civil, mechanical and control and systems engineers to materials, chemical and petroleum engineers.

Their technical ingenuity is critical to building the vast energy infrastructure projects the world needs. These are often in extremely challenging conditions, such as the deep waters of the Gulf of Mexico or the Russian sub arctic.

We rely on our engineers' professionalism to ensure our operations are managed safely and with the smallest possible impact on the environment. And our need for highly qualified engineers will only grow, to help meet the surging global demand for energy and to address rapidly rising CO_2 emissions.

I'll begin by describing this changing energy landscape. Hilary and I will then focus on how our engineers are responding – by describing four of our major gas projects in Russia, Qatar and Australia, in which we have both been closely involved.

In each case, we'll describe how our engineers are pushing the boundaries of technical innovation and mega-project execution.

We'll also demonstrate the breadth of challenges our engineers face in the course of careers, where they can find themselves in the frontline of a highly charged geo-political dispute – or looking after the welfare of tens of thousands of workers in the desert.

But let's start by asking why all this matters.

The global energy challenge

At Shell, we think that global energy demand is likely to double in the first half of this century. This will be driven by a rising global population, which has just reached 7 billion on its way to over 9 billion by 2050, and by strong growth in the emerging economies.

In these economies, disposable incomes are rising fast. And with higher living standards comes rising energy use, as people buy their first washing machines, fridges, cars, and computers. Indeed, the human story of this rising energy use is often forgotten. But it is lifting billions of people out of energy poverty, in a world where some 1.3 billion people still lack access to electricity.

Supplying the world's rising energy needs will be extremely tough. The world will need to invest heavily in all energy sources from oil, gas and nuclear to wind, biofuels and solar.

In fact, the International Energy Agency estimates that the world will need to invest some $38 trillion to meet projected energy demand in the period to 2035. That's around $30 billion a week, or $3 million every minute.

Over the same period, the world must clearly tackle its CO_2 emissions. According to the consensus of climate scientists, the atmospheric concentration of CO_2 should be limited to 450ppm to avoid the worst consequences of climate change. Yet it's estimated that we have now passed the 390ppm mark, rising at some 2ppm every year – so just 30 years or less to go.

The reality is that we will probably overshoot the 450ppm target. But we must limit the extent to which we do, whilst preparing for and adapting to the likely consequences of climate change. At Shell, we think that by 2050, renewable energy sources could supply as much as 30% of the world's energy – up from 13% today. And that would represent remarkable progress, given the financial and technical scale-up challenge facing new energy sources.

For example, in the case of wind the world would need another 1 million turbines covering an area nearly the size of France in order to reach just 10% of global electricity generated by 2030, which would still mean under 2% of total primary energy. And that would require expanding the number of turbines manufactured annually by a factor of 6 from today.

This begins to explain why fossil fuels are still likely to supply more than 60% of global energy in 2050, with nuclear accounting for less than 10%. So a more sustainable energy system will not just be composed of renewable energy sources. We must also reduce the carbon intensity of fossil fuels.

> "...the world must clearly tackle its CO2 emissions."

Natural gas revolution

And that's why major new natural gas supply projects are so important.

Displacing coal with natural gas – the cleanest burning fossil fuel – is the fastest way to reduce CO_2 emissions in the global power sector over the next 20-plus years.

Last year, coal was responsible for 44% of energy-related CO_2 emissions. And here is the most worrying fact: this decade, the incremental increase in CO_2 emissions from coal-fired power in India and China alone is expected to be roughly double the increase from the entire global transport sector.

Natural gas is the quickest way to address these emissions because modern gas plants emit half the CO_2 of modern coal plants, and up to 70% less CO_2 than old coal plants, of which there still hundreds in operation today in China, North America and Europe.

Natural gas power plants are also much cheaper to build than other new sources of electricity. They require only half the capital cost of coal per MWh; one-fifth of nuclear, and less than one-tenth the capital cost of offshore wind power. This is key in these economically challenged times.

Gas power plants can also be switched on and off much more swiftly than other sources of power. This makes them the ideal complement to the intermittent power of wind turbines and solar panels; after all, the wind does not always blow – nor the sun shine, especially in the UK.

Many of you will have heard about how the North American energy outlook has been transformed by the opening up of vast, low-cost deposits of tight gas, shale gas and coal bed methane – all gas deposits trapped in very tight or nearly impermeable rock.

Only ten years ago, the industry considered these resources much too difficult and costly to access. But advanced techniques in drilling and fracturing mean we have dramatically increased the rate at which we recover the gas, making it commercially viable.

As a result, North America may now have more than 100 years' worth of natural gas supplies, just a few years after it was feared long-term production decline had set in. Just look at the change in outlook since 2005.

That is why the gas price in the US today is around \$3 per Million BTU, whilst in the UK we are paying around \$10 and in Asia over \$15: an unprecedented global difference in basic energy prices with major industrial and economic ramifications.

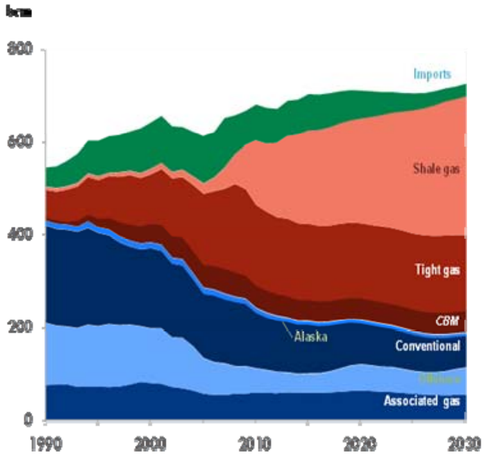

Figure 1 – US tight gas revolution: dramatic impact on US gas production

"...the world is now estimated to have 250 years' worth of gas supplies".

China, Australia, Latin America, South Africa, and Eastern Europe all have significant deposits of these tight gas resources.

And as a result the world is now estimated to have 250 years' worth of gas supplies. Many of you will know that there are certain operational and environmental challenges associated with tight gas production. We think that these are manageable, with the right operating procedures and with strong regulations, rigorously applied. I'll happily address these issues during the question and answer session afterwards. Alongside this tight gas revolution, the world is also seeing a rapid expansion of the liquefied natural gas – or LNG – market.

This is natural gas that has been cooled until it condenses into liquid form for export by ship to distant markets. As you can see, global LNG production capacity will double by 2020 in little more than a decade helping gas supplies to match demand as it fluctuates around the world.

All of which is giving more governments the confidence to back natural gas, paving the way to surging demand growth. According to the IEA, between 2008 and 2035 primary natural gas demand is expected to:

- increase by 60% globally;
- by nearly eight times in China;
- by five times in India.

So a prime task for Shell's engineers is to satisfy this demand, by developing new sources of gas supply.

Exploration and production at Shell

That's why we continue to explore all over the world. In the past three years, we have spent around $3 billion a year on exploration. And we are conducting seismic surveys and drilling exploration wells in the nearly 40 countries in this map.

These days, many such opportunities come through partnership with national oil companies, where our key calling card is to bring new technology.

And that's the reason we invest so heavily in research and development: in fact, in excess of $5 billion between 2006 and 2010 – more than any of our competitors.

Engineers at Shell

(Hilary Mercer) And that's what makes life as an engineer at Shell so fascinating. We spend our lives opening up and delivering resources that other companies lack the technology or capital to access.

That's not all: each project forms part of a web of political, commercial and environmental factors. Shell's engineers must navigate these challenges just as deftly as they deploy their technical skills – and all in a remarkably varied range of locations.

I started off at the Stanlow refinery in Cheshire, where I gained hands-on operational experience as a rotating equipment engineer, and through work in maintenance and turnaround management.

I then moved to corporate headquarters in The Hague, where I obtained experience at the opposite end of the engineering spectrum: working on the development of the front end engineering design for LNG storage and loading facilities for projects in Nigeria and Oman.

My time at head office gave me an overview of Shell's global operations – one that has certainly proved useful: my career has subsequently taken me to Oman, Russia, Dubai, Qatar and now Australia.

So let's now focus on some of these projects.

Sakhalin-2

And let's start with one of the most challenging operating environments of all: the Russian sub arctic.

Sakhalin is an island off Russia's east coast – a lot closer to Anchorage, Alaska, than to Moscow. Despite its remoteness and harsh climate, Shell saw in Sakhalin an opportunity to tap massive natural gas and crude oil deposits.

To reach markets overseas, however, the gas would have to be liquefied first. And to make that possible, we proposed one of the largest integrated oil and gas projects in the world – the Sakhalin-2 project.

This was the first time that Russian oil and gas would be produced offshore. It would also involve building Russia's first LNG plant.The project consisted of three offshore platforms whose oil and gas production would be delivered by subsea pipelines to a landfall on the northern part of the island.

A much longer set of oil and gas pipelines would then need to traverse the island from north to south, where the gas would be liquefied and both the oil and the LNG would be exported from a mostly ice-free port.

(Malcolm Brinded) As well as skilful engineering, this was a project that required feats of multilateral diplomacy.

Relations between the original shareholders in the project and the Russian government were severely tested. And at one stage we feared that we might even have to stop the project. So how did it come to this?

"We spend our lives opening up and delivering resources that other companies lack the technology or capital to access."

For the Russian government, the terms of our original agreement for Sakhalin-2, signed in 1994, had long been a sensitive issue.

For one thing, the Sakhalin Energy consortium was comprised solely of overseas companies and lacked a Russian partner. For another, Sakhalin-2 was the first Russian oil and gas project to be the subject of a Production Sharing Agreement, or PSA.

These agreements tend to be used by countries perceived to be higher risk by investors and which want to attract foreign oil companies.

Almost all of Russia's other oil and gas projects brought in government revenue under a royalty tax system, as in the US and Europe.

So why had both sides entered into a production sharing agreement in the first place?

For a project requiring an enormous sum of preliminary investment, stabilised PSA terms were thought to be appropriate.

Another factor was the timing. In 1994, Russia was still recovering from the collapse of communism and the 1991 revolution, so it was open to such an agreement. But by the early-mid 2000s, it had regained much of its confidence, amid strong economic growth. And Sakhalin-2 and other PSAs became a source of resentment.

That was the backdrop when, in 2005, we announced that the cost of the project would be more than double our original budget of $9 billion.

This was partly the result of rampant inflation across the industry. The global economy was booming, generating intense competition for the expertise and equipment needed to build major energy projects. There was also very little experience in oil and gas projects of this scale in such a subarctic environment. So it had been difficult to predict the complexity involved.

The spiralling costs raised the suspicion among the Russians that they were being exploited. In the summer of 2006, the dispute escalated. And the Russian government rejected our offer for Gazprom to take a 25% stake in the project.

But ultimately, the dispute was defined by its uncertainty: Gazprom were unsure what percentage of the project they should push for, just as we didn't know what they would find acceptable.

So we made a decisive move: we offered Gazprom a 51% share. That changed the dynamics of the dispute, triggering a swift resolution. And in December 2006, we signed an agreement that made Gazprom the project's 51% majority shareholder.

51% may sound like a large concession. But it brought immediate stability to the project. And Sakhalin-2 is a huge and growing commercial and technical success for all the partners. And we have recently entered into a strategic alliance agreement with Gazprom to expand our co-operation.

"…Sakhalin 2 is a huge and growing commercial and technical success for all the partners."

Grappling with geography

(Hilary Mercer) The political climate for Sakhalin-2 may have improved after 2006, but not the meteorological. Located 15 degrees under the Arctic Circle, it's bitterly cold in winter.

The sea is frozen for six months of the year, and air temperatures may reach as low as minus 40 degrees Celsius. Engineers had to adapt working practices to accommodate the freezing temperatures and moving sea ice.

Sakhalin also sits in the middle of an active seismic zone – the same one that spawned the appalling earthquake in Japan earlier this year. So we also had to safeguard the three platforms in the Sea of Okhotsk from this danger.

One of the platforms is based on a sand-filled caisson that anchors it to the seabed. Bearing pads between the caisson and the platform's deck structure allow the deck to move somewhat with respect to the caisson, protecting it from the jolts of earthquakes.

The other two platforms are built on massive concrete legs – each wider than 20 metres. These concrete structures were both constructed in Russia, near Vladivostok. They are extra thick to help withstand not only the pressure of ice but also the shaking of earthquakes. They also feature an earthquake-protection mechanism that had never before been used offshore: friction pendulum bearings.

A friction pendulum bearing is basically a bearing pad with a smooth, concave surface.

They are designed to withstand earthquakes measuring 8.0 on the Richter scale – greater than the strongest earthquake expected to occur around the platforms, which itself may occur on Sakhalin Island once in 3,000 years.

During an earthquake, the supported structure is free to slide on the concave surface – both horizontally and vertically. The force needed to move the structure upwards limits the horizontal forces that would otherwise cause deformations.

At Sakhalin the friction pendulum bearings sit atop each of the four legs of the two concrete-based platforms. They support topside steel decks. And they are the largest load-carrying seismic isolation bearings ever manufactured.

Crossed lines

Eight friction pendulum bearings provide sufficient earthquake protection for the two concrete-base platforms. But how do engineers earthquake-proof objects that are 800 kilometres long – particularly if they straddle an active seismic fault line at 19 different places?

I'm talking about the pair of pipelines that run the length of Sakhalin Island, over steep mountains, under rivers and through swamps and forests. One pipeline carries as much as two billion cubic feet of gas per day, the other as much as 180 thousand barrels of oil per day.

About half a million tonnes of steel went into building these pipelines. The type of steel used at the fault crossings was chosen to withstand the higher loads that could occur at those locations during a seismic event.

The pipelines were deliberately laid in trenches in such a way that they had room to move – as much as 5.5 metres in some cases. The trenches were dug out with very shallow sides and refilled with lightweight porous clay pellets – like the type that many gardeners use for their potted plants. The pipeline could then move laterally with minimal resistance.

The trenches were also lined on all sides with waterproof material to prevent water from collecting inside. But should water nonetheless find its way into the trenches, they were also outfitted with drainage systems. And they were covered with thick insulating slabs. This was to prevent ice from building up around a pipeline and gripping it like a vice.

But the key to giving the pipelines the capability to survive severe earthquakes is to design them so they remain in tension even if the ground breaks. Like a piece of string, pipelines are strong under tension but weak under compression. So we picked a route through the faults that would hold the pipe in tension even if the faults were to open.

Some fault crossings were configured in a dog-leg shape of approximately 1 kilometre length. The pipeline could then traverse the fault at a specific angle so as to minimise the compressive stress on the pipe.

And just in case all of these measures fail to prevent earthquake-induced damage, we installed extra remotely controlled block valves on either side of most fault crossings. They can be activated by pipeline operators to isolate any pipeline segment near any serious seismic event.

"About half a million tonnes of steel went into building these pipelines."

Shell's partnership with CNPC

(Malcolm Brinded) Let's now switch focus to Australia and another mega-project where our engineers are opening up the world's gas resources.

Last year Shell and Petrochina – the listed arm of the China National Petroleum Corporation (or CNPC) – completed the joint $3.1 billion purchase of Arrow Energy, an Australian gas company based in Queensland.

Drawing on Queensland's abundant coalbed methane resources, Arrow supplies around one-fifth of Queensland's electricity. This is easing the state's dependence on coal-fired power. We also plan to convert coalbed methane into LNG for export to China.

The project reflects a powerful trend in the modern energy industry. Increasingly the success of companies like Shell depends on our ability to forge new kinds of strategic partnerships with what are called NOCs or the National Oil Companies – oil companies that are government owned or controlled.

We've had partnerships with these companies for decades, gaining access to resources in return for technology, capital, or access to big consumer markets.

But in recent years, the NOCs have collectively been building their technical capabilities and their financial muscle. NOCs now control around 80% of the world's commercial oil and gas reserves but even so they have moved well beyond their borders to access resources around the globe. And China's national oil companies are in the vanguard.

It's against this backdrop that Shell is building a strategic partnership with CNPC, with major joint activities in four countries – with more in the pipeline – and a particular focus on natural gas.

As I said, China's gas demand could rise by eight times between 2008 and 2035. To feed this demand, CNPC and Shell are working together to develop potentially enormous tight gas deposits within China.

Following the Arrow

(Hilary Mercer) And, following the purchase of Arrow Energy, we're now tapping coalbed methane in Australia.

For Shell and CNPC, this is an ambitious step forward in our partnership. It was the first purchase of a public company in a western economy by a Chinese oil company. And many staff from CNPC and Shell – including me – are now working for Arrow together on secondment.

When built, two LNG processing trains will be located on Curtis Island, off the coast of Queensland. Together, they will produce 8 million tonnes per annum of LNG.

So where will all the gas come from? It will be drawn, via two 500-kilometre pipelines, from reserves of coalbed methane in the Surat Basin in the south-east of Queensland and from the Bowen Basin in the centre of the state.

Our licence to explore for and develop gas covers a vast area – some 65,000 square kilometres. That's half the size of England. And we estimate that as many as 10,000 wells could be needed to develop fully the two basins. That will involve drilling up to 700 wells per year.

Mass production

So to make the project economically viable, Arrow will require a system for mass producing wells from standard interchangeable parts.

Fortunately, a solution may come from *another* joint venture that Shell has recently set up with CNPC.

We intend to develop a system for quickly drilling and completing low-cost wells, using advanced automation and standardisation techniques. The details are still being worked out, but we can say a few things about the system.

Like airlines, we've come to the conclusion that operations over large expanses are best organised around regional hubs. Equipment and supplies would be stored at these hubs. Waste would also be treated there prior to its

> "...to make the project economically viable, Arrow will require a system for mass producing wells from standard interchangeabe parts."

disposal. They would also serve as a depot for the rigs.

Traditional drilling rigs usually serve multiple purposes and require a lot of manual tasks to operate. But the rigs we're thinking of would be mobile, specialised and computer controlled.

They would move easily from location to location. And their specialisation means that we can have one type of rig for preparing the top part of a well, another rig to extend the well to the target depth, a third type of rig for drilling directional wells and a fourth type for completing wells. By connecting a computer to virtually all of a rig's controls, we would be able to manage the individual machines on the rig and monitor all aspects of the drilling process.

The computer automation will make it possible to perform activities that most current rigs would be incapable of executing. The drill bit, for example, can steer itself through the ground on the basis of real-time data measured by sensors near the bit. No intervention from an experienced driller is needed at the rig site.

Such rigs would allow two wells to be drilled at a slant so as to intercept the bottom of a vertical gas well. The slanted wells would be used to drain water out of the coal seam, initiating the gas production through the vertical well.

And when the drilling is finished, only the well head in a small clearing would remain.

I should say that in some situations it may be preferable to drill as many wells as possible from one surface location. Around 30 of them could be drilled in different directions without compromising our safety or environmental performance. Such well clustering also helps to reduce our operational footprint.

A revolutionary idea

(*Malcolm Brinded*) For our next project, we will stay in Australia but move offshore, approximately 200 kilometres off the coast of Western Australia.

To meet the growing demand for gas, we are also going after gas that has hitherto been rejected as uneconomic to develop, including offshore gas fields far removed from land or existing infrastructure.

For such fields, the need to lay a pipeline to shore and build a port can make conventional LNG prohibitively expensive. And subsea pipelines and coastal LNG ports can sometimes exact a high toll on marine and coastal environments.

But a floating liquefied natural gas facility – or FLNG – changes the rules of the game. Production, processing and liquefaction of the gas – as well as the storage and offloading of the products – can all take place at sea. And with such a facility, a country can develop small, remote gas fields in its waters – and earn revenue by exporting the LNG.

The engineering

(*Hilary Mercer*) FLNG has long captured the imagination of the industry's engineers. Our original idea was to scale down a liquefaction plant so that it could be put on a barge – a mini-LNG plant moored near the coast.

But then at Shell we began to think about a floating facility not only for liquefaction but also for production and storage: one that would enable "stranded" offshore gas fields to be developed.

We started a serious FLNG work programme in the mid nineties and progressed to safety studies, conceptual design, feasibility studies, and detailed engineering to validate and optimise the concept.

All in all, we spent several hundred million dollars on developing the FLNG technology before deciding to debut it at the Prelude gas field, approximately 200 kilometres off the coast of Western Australia.

"…we are also going after gas that has hitherto been rejected as uneconomic to develop…"

The final investment decision – a commitment to put money on the line – was made earlier this year. Shell is the first company to take such a decision.

Shrink to fit

Conventional LNG plants require about 350,000 engineering hours for front end design. Shell's FLNG facility for the Prelude gas field has taken 1.4 million hours – the equivalent of 729 man-years. More than 600 engineers in the Netherlands, France, and South Korea were involved.

Why was so much effort needed? One of the main challenges is how to make all the necessary components fit together in a limited space; the FLNG facility's layout has to be much more compact than an onshore facility of comparable capacity.

The FLNG facility would also have to include gas-production facilities, which normally are located some distance away from liquefaction plants.

The FLNG designers have managed to fit everything onto an area a fraction the size of the site of a conventional onshore LNG plant. Even so, the Shell FLNG facility will be a colossus.

From bow to stern, it will be almost half a kilometre. When fully equipped and its storage tanks full, it will weigh around 600,000 tonnes – roughly six times as much as the largest aircraft carrier. In fact, it will be the largest floating offshore facility in the world.

Fortunately, the sheer size of the Shell FLNG facility gives it stability in the open seas – even when buffeted by 280-kilometre-per-hour winds of a Category 5 cyclone.

To keep the FLNG facility as safe and as reliable as possible, the designers opted for tried-and-tested processes and equipment – but the demands of space and seaworthiness required the designers to assemble them in novel combinations. Many components had to be stacked on top of each other to fit in the limited floor space. For example, the operating plant was placed above the LNG storage tanks.

But the paramount focus has been on safety: making sure that we leave enough space, and have all the necessary protection equipment, to minimise risks. Prelude FLNG will be as safe as any other modern offshore oil and gas facility.

"…the Shell FLNG facility will be a colossus".

The framework agreement

(*Malcolm Brinded*) We don't intend the Prelude FLNG facility to be a one-off. We see it as the first of several FLNGs specified in a "master" agreement that Shell signed with Paris-based engineering contractor Technip and Korean shipbuilder Samsung Heavy Industries.

The agreement fits a "design one – build many" philosophy – where multiple Shell FLNGs can be built over a 15 year period to a standardised design that can be tailored to fit individual gas fields.

The facility's default LNG production capacity is about 3.5 million tonnes per year. That's equivalent to around 5% of the UK's total gas consumption last year. We estimate that the Prelude FLNG will generate tens of billions of dollars in revenue over a 25-year lifetime.

FLNG's design flexibility and longevity also keeps open the option of redeployment at the end of the original field's productive life.

By building multiple FLNG facilities based on one multi-functional design, we have the opportunity to climb the learning curve, reducing costs and shortening schedules with each project.

I'm really excited about FLNG both as an engineer and as a businessman.

Pearl: background

(Malcolm Brinded) We'll finish with another Shell project which is reshaping the global gas market. That's gas-to-liquids: the large-scale conversion of natural gas into premium liquid fuels, lubricants and chemical feed stocks.

I was at Pearl GTL this week for the inauguration of our vast new $18.5 billion plant in Qatar, which we started up this summer. It is the first ever world-scale GTL plant – that is, on a scale equivalent to a very large oil refinery. When fully up and running in 2012, it will produce enough GTL diesel to fill over 160,000 cars a day and enough synthetic base oil each year to make lubricants for more than 225 million cars. That's around seven times the number of cars currently on Great Britain's roads.

But only ten years ago, Qatar was an unlikely location for the largest single investment in Shell's history. We had no employees in the country, having left in tricky circumstances in the 1990s.

Shell had first entered Qatar in the 1930s, and spent more than fifty years there. My first job in Shell was designing offshore platforms for Qatar in 1974. But the most significant milestone was our discovery in the early 1970s of the giant North Field, offshore in the Gulf, today containing gas estimated to be roughly 90 times the UK's remaining proven gas reserves.

The largest gas field in the world, it now supplies the gas for Pearl GTL, and Qatar's thriving LNG export industry. Ironically, it was left untapped in the 1970s and 1980s because, with LNG still in its infancy, Qatar was seen as too remote from gas markets for the field to be viable.

Shell had then left Qatar in 1991 after a series of commercial disputes.

And that was how things stood for more than a decade, with competitors entering the country and taking strong positions.

So what changed? By the early 2000s, the Qataris were thinking about how to derive greater and more robust value from their gas resources, overall the third largest in the world.

Exporting it by physical conversion into LNG was one option. But quite another was the chemical conversion of Qatar's gas into high value liquid fuels, such as diesel, and other products, including lubricants.

"At Shell, we had been researching gas-to-liquid fuels since the 1970s".

Pearl: technical process

(Hilary Mercer) As a technical process, the first step is to convert natural gas into synthesis gas, a mixture of hydrogen and carbon monoxide.

Then catalysts are used to convert the synthesis gas into long chain hydrocarbon molecules. To the chemists among you, this will be familiar as the Fischer-Tropsch process. And it is not an easy thing to do, at least not on a commercial scale.

We then use standard refinery processes to convert the long molecules into chemical feedstocks and cleaner liquid fuels.For example, a GTL kerosene blend can be used in jet engines without any modifications to existing aircraft. Because it is a cleaner burning aviation fuel we expect improved air quality around airports. In 2009, Qatar Airways flew the first commercial international passenger flight using GTL Jet Fuel flying between London and Doha. In fact, this is only the fourth new fuel in aviation history.

At Shell, we had been researching gas-to-liquid fuels since the 1970s. In our laboratories and pilot plant in Amsterdam, we developed and fine-tuned our cobalt catalysts until they could support a commercial-scale operation. That led on to the opening of the world's first commercial GTL plant of its type, at Bintulu in Malaysia in 1993, where we gained invaluable operational experience. In fact, between 2001 and 2010 the plant achieved an average reliability of 98%.

By the early 2000s, we were ready to build a much bigger GTL operation (Pearl's output will be ten times that of Bintulu).

Pearl: clinching the deal

(Malcolm Brinded) So we were evaluating possible locations just at the

time Qatar was developing an interest in GTL.

Even so, Qatar still seemed an unlikely location for our project. Several other companies were negotiating to build a GTL plant there. And memories of past discord lingered.

But then the tide began to turn in our favour.

That was partly because Shell was running a GTL plant on the scale of Bintulu. We also benefitted from a strengthening of relations between the UK and Qatar governments in the early 2000s.

But most important was Shell's willingness to approach the Qataris in a spirit of humility and openness. In 2002-3, senior executives from Shell visited Doha, emphasising that a new generation of leaders were now in charge. And we hosted visits by Qatar Petroleum to Bintulu, to London and to our R&D centre in Amsterdam.

As we got into commercial negotiations, we focused relentlessly on the needs of the Qataris, accommodating as many of their requirements as possible and negotiating the key commercial terms for this giant deal in just one momentous Saturday afternoon, in London in 2003. Thus the stage was set to deliver this enormous project.

Figure 2: Pearl GTL – largest construction site in the industry

Off the scale

(*Hilary Mercer*) Two million tonnes of prefabricated parts had to be ordered from suppliers all over the world. The project required more steel and pipe than 40 Eiffel towers. At one stage we were erecting an Eiffel Tower's worth of steel every 12 days. And twenty-four GTL reactors – at 1,200 tonnes, each as heavy as eight diesel locomotives – had to be set on a concrete base.

But our biggest challenge was ensuring safe and comfortable working conditions for such a huge workforce – as many as 52,000 people, at the peak of activity.

"Our workforce came from 65 countries and spoke many more languages".

It takes a village

The history of major energy projects suggested that, for a project of this size – requiring 500 million man-hours to build – we could expect to see as many as 20 fatalities. And that was completely unacceptable.

Our workforce came from 65 countries and spoke many more languages, including Tamil, Arabic, Tagalog and Mandarin. And they followed various religions – Hinduism, Islam, Christianity, Buddhism.

So to build the plant, we first had to build a community, and one with a deep-rooted safety culture. We wanted the workers to feel empowered to stop work if they saw a potentially unsafe situation – one of the major goals of Shell's global safety programme.

In the Middle East, managers and workers often come from different countries and socio-economic classes. So that can be a big cultural barrier for the workers to get over.

To encourage a change in behaviour, all personnel received training in identifying unsafe situations and intervening. Incentives also helped focus attention on safety.

To celebrate annual Safety Day, we brought in legendary Indian cricketer Kapil Dev, a dream come true for the site's many south Asian workers.

To keep the workers as healthy and comfortable as possible, Shell organized a temporary town – Pearl Village – where 40,000 of them lived.

The 10 major contractors that worked with Shell on the project were responsible for the housing, but we cared for their fundamental physical and mental welfare.

Food was key to a motivated workforce. And we made sure our workers were fed the food they grew up with. We also tried to make workers feel at home in other ways. For Muslim employees, we held the largest outdoor prayers ever held in Qatar. Other observances were also encouraged, such as holding parades during Onam, the south Indian harvest festival.

The outdoor cinema also catered to different audiences – alternating between Filipino, Bollywood and Hollywood.

In any one month, there would be as many as 300 social events and sports events to choose from. All of which created the very real impression that management genuinely did care for the welfare of its workforce.

Pearl Village was also an excellent hub for training. From a purpose built centre, we delivered some 400,000 individual courses. And we provided more than 6,000 supervisors with seven or more days of leadership training.

The results have been striking. Last year the project achieved 77 million man-hours without an injury leading to lost work time – a record for Shell worldwide.

Conclusion

(*Malcolm Brinded*) Pearl's safety record is a great illustration of the positive impact engineers can make in our industry.

This evening, we've shown just a few of the mega-projects that Shell is tackling around the world which offer engineers young and old tremendous breadth, challenge and excitement. We have lots more examples, from our massive Canadian oil sands mines to the world's deepest water development in the Gulf of Mexico, and from our planned drilling off northern Alaskan shores to one of the world's largest biofuels ventures in Brazil.

You can imagine that Shell's need for highly skilled and professional engineers is only growing.

So we owe a huge debt of gratitude to the Royal Academy of Engineering for its tireless work in promoting careers in engineering among young people.

Now, I hope all the mechanical, materials, chemical and electrical engineers among you might forgive me as I finish by quoting the original Royal Charter of the Institution of Civil Engineers from the mid-19th century. It describes the purpose of engineering as "to harness the great forces in nature for the use and convenience of man."

This is an eloquent description of the work done by engineers in so many industries. But especially in the energy industry. As you have seen – great forces in nature being harnessed for all our convenience - with engineers playing a vital role in supplying the world's need for cleaner, more secure and more affordable energy. *Thank you.*

> "…we owe a huge debt of gratitude to the Royal Academy of Engineering for its tireless work in promoting careers in engineering among young people."

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