Decarbonize now with LNG-to-power

MAN Energy Solutions
Future in the making

Powering the transition
to clean fuels

List of standard abbreviations

cf.	confer (compare)
e. g.	for example
et al.	et alii (and others)
et seq.	et sequens (and the following)
fig.	figure
p.	page

List of technical abbreviations

ASEAN	Association of Southeast Asian Nations
BCM	Billion cubic meters
CAGR	Compound annual growth rate
CAPEX	Capital expenditure
CC	Carbon capture
CCS	Carbon capture and storage
CCU	Carbon capture and utilization
CHP	Combined heat and power
CO_2	Carbon dioxide
COD	Commercial operation date
DF	Dual fuel (engine type according to the diesel cycle capable of operating on a multifuel strategy)
DRI	Direct reduced iron
DSCR	Debt-service coverage ratio
EPC	Engineering, procurement and construction
FDI	Foreign direct investment
GDP	Gross domestic product
GTCC	Gas turbine combined cycle
H_2	Hydrogen
IDC	Interest during construction
IEA	International Energy Agency Paris
IPP	Independent power producer
IRR	Internal rate of return
ISO	International Organization for Standardization
LCOE	Levelized cost of energy
LNG	Liquefied natural gas
MMBtu	Million British thermal units
MW	Megawatt
MWh	Megawatt hour
NO_x	Nitrogen oxides
NTP	Notice to proceed
O&M	Operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OPEX	Operational expenditure
PEM	Polymer electrolyte membrane
PPA	Power purchase agreement
PV	Photovoltaics
Res & comm	Residential and commercial
SI	Spark-ignition (engine according to the Otto cycle)
sLNG	Synthetic liquefied natural gas
SNG	Synthetic natural gas (often also Bio-SNG)
SO_x	Sulfur oxide
SPV	Special purpose vehicle
TSO	Transmission system operator
WACC	Weighted average cost of capital

Synopsis

Decarbonization of the various sectors, including the energy sector, is the biggest challenge facing the industry. While the hard CO_2 reduction targets are defined from 2030 on, steps can already be taken for future-proof and LCOE-driven investments that will pave the way for the new energy world. Although in the long run, fossil fuels will lose their share of the energy production market, in the mid-term they will still remain the main source for energy production. Natural gas is the cleanest of all fossil fuels and is already able to reduce CO_2 emissions by approximately 50 % compared to coal.

Natural gas, in its liquefied form (LNG), can be used across the globe. With a professional approach and consideration of all possible revenue streams, the investment into an LNG-to-power plant is still bankable and will enhance your business income, and this can even be optimized with a flexible fuel supply strategy and using a convoy concept to reduce initial costs. This paper will provide a detailed use case on a 350 MW gas power plant that is scattered over different locations, providing valuable insights and proving the economic viability of such an investment.

A power plant is a long-term investment and the business case has to cover the entire lifetime of the plant. We are living in dynamic times, and it is clear that in many regions across the world, policies have been or will be implemented with the goal of reaching carbon neutrality by 2050. However the way to achieve this goal is still under discussion. What seems undisputed is the important role hydrogen and hydrogen-based CO_2 neutral fuels will play in the future. Synthetic natural gas is such a fuel and has the advantage that it can use the infrastructure that already exists, including gas networks or expansion projects, LNG infrastructure, LNG-driven vessels, gas-fired CHP plants, etc. Small scale LNG-to-power plants are another possibility and immediately contribute to decarbonization, but will also allow for an easy switch to hydrogen-based fuels at a later time.

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The price of energy

In recent years, the global LNG market has undergone an impressive period of development. 2014 saw large price gaps emerge between the three main markets in Europe, the US and Asia, and peak prices of $20 per MMBtu for the main importers in Asia. In 2020, the three main markets moved closer with prices in the range of $3 to 6 per MMBtu. In Germany, for example, the price level is close to 50 % of that for EU piped gas. Today, with the global COVID-19 pandemic still ongoing, prices went up to levels of between $10 and 12 per MMBtu[1].

(cf. METI 2021)

It's all about price

This market development offers an opportunity for investors and operators to switch from coal- and oil-based power production to LNG and gas-to-power solutions. This trend is already supported by international banks and private equity investors, which are actively supporting renewables and gas projects and have put a ban on new-build coal and oil projects.

Many stakeholders around the globe are now developing greenfield LNG-to-power projects in two main categories:

1. **Large-scale LNG-to-power** projects with LNG import facilities, dealing with cargos from Qatar-Max size vessels, for example, and with more than 10 million tons per annum of LNG, huge regasification capacities and gas-grid connection or large power plants in the Gigawatt range. These projects require long development times and a huge upfront investment, very often with strong involvement from the local government.
2. **Small-scale LNG-to-power** projects with a power output ranging from 50 MW to 300 MW[2]. These projects are characterized by much shorter development times, reduced stakeholder involvement and early cash flows for the investors after notice to proceed (NTP). Beside this, they also offer smaller countries the chance to make the switch from mainly oil-based fuels and coal at much faster rates than when dealing with large infrastructure projects.

These small-scale projects are mainly linked to power plants based on highly efficient and flexible gas and dual-fuel engines in the 10-20 MW range per unit. As they are mainly decentralized solutions for unloading LNG from ships or, most commonly, trucks, storage (vacuum-insulated tanks) and regasification are part of the process.

(cf. IEA/NEA 2015)

Retrofit capability: switching from heavy fuel oil and diesel to clean natural gas

To avoid stranded assets, liquid fuel-fired engine power plants can in some cases be retrofitted for gas operation. This is the case for large bore MAN Energy Solution engines, of the “4x” bore type which can then be equipped with the same LNG infrastructure components as new greenfield projects.

Already installed, this fleet of liquid fuel-fired engines also provides a strong foundation for reducing the environmental footprint by switching to clean natural gas and extending the operational lifetime of the assets under today's state-of-the-art technology.

[1] $12 per MMBtu = $40.96/MWh or €34.4/MWh
[2] As of today, there is no official definition available for defining small- or large-scale LNG-to-power projects

Fig. 1: Logistic concepts will be a strategic pillar within the decarbonization of the power industry

Adaptability to today's market requirements

Paired with a flexible extendable power output, these installations fulfill the most stringent of current environmental regulations. The engine-based power plants are also the perfect solution when it comes to flexible operation, supporting the higher share of non-dispatchable renewables like photovoltaics (PV) or wind power in the grids with ancillary services and active frequency control.

Looking at the future of LNG and synthetic gas

Nevertheless, flexible operation is not the only benchmark of small-scale engine-based solutions. They are also future-proof as they have the capability to switch to hydrogen-based future fuels like synthetic natural gas, once they are available in sufficient volume and price.

This paper deals with business cases and a financial model for today's LNG-to-power solutions and a later use of green hydrogen-based synthetic natural gas (SNG/sLNG) for a CO_2 neutral plant operation in the main prime mover system up to a level of 100 %.

The aim is to show how today, small-scale LNG-to-power investment, logistics and infrastructure already open the door to a future, green hydrogen-linked power business.

International energy policy needed to support the transition

Today, the basis for production of green hydrogen-based fuels, like sufficient low cost renewable energy, is not available, resulting in the prices for synthetic fuels being too high. It is therefore important that private investment, financing models and, most importantly, long-term supply agreements are available to build up this industry and thereby reduce the price gap between fossil-based fuels and green hydrogen-based fuels. Governments need to support green fuels over fossil fuels by using the levers available to them, such as adjusting the carbon tax.

Success factors for LNG

According to the Shell LNG Outlook 2021, global demand for natural gas will grow from 3,800 billion m³ last year to 5,000 billion m³ annually by 2040.

Although Europe shows the smallest growth rate, we shall nevertheless use Europe as an example of an installed small LNG-to-power solution.

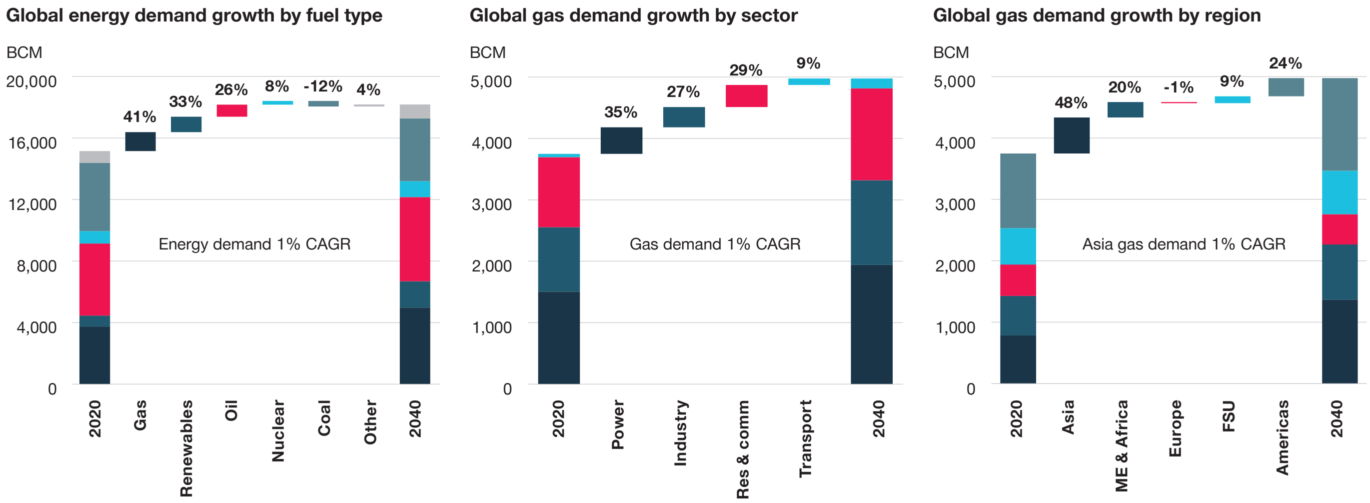


Fig. 2: Gas demand projected to grow and play a key role

Fig. 3: 80 MW LNG-to-power solution in Gibraltar. Powered by highly efficient MAN gas- and dual-fuel engines, viewed from the sea

Fig. 4: 80 MW MAN Power Plant Project Gibraltar from land

The use of LNG in Europe – Just one aspect of the politically driven strategic supply strategy

Europe is another importer of LNG, and also offers a good example of a mix of gas infrastructure.

Today, Europe has the most advanced pipeline system in the world, with gas import pipelines from neighboring countries but also large LNG import facilities in the North Sea, Baltic Sea and coastal areas of the Mediterranean Sea. Europe's own resources are becoming increasingly depleted and a diversified supply strategy is the target of the current EU energy policy.

LNG is currently used where a gas pipeline is not available or where the policy requires more flexibility and independence in its supply. Countries in the Mediterranean area are still experiencing a demand to switch from oil-based fuels to natural gas. Here, LNG is an important step in the decarbonization of areas without an existing pipeline network.

An impressive example is the 80 MW power plant in Gibraltar, commissioned midway through 2019. In baseload operation, the power plant makes use of imported liquefied natural gas via its own small-scale LNG terminal. Details and features about the new power plant are listed in the table below.

(cf. MAN Energy Solutions 2019a, 2019b)

Project Details

Installed electrical power	80 MW
Project investment	Approx. €90 million
Operation mode	Base load
Grid connection	Island grid – Gibraltar is not connected to the Spain/EU electrical network
Prime mover technology	Highly efficient dual-fuel (DF) and spark-ignition (SI) internal combustion engines from MAN Energy Solutions – 3x 14V51/60G and – 3x 14V51/60DF
LNG storage tanks	Vacuum-insulated, double wall, stainless steel, submerged pumps, vaporizer skids and heat delivery system.
LNG storage volume	5,000 m³ (5x 1,000 m³)
Regasification	The regasification system uses water/glycol equipment and waste heat from the engine cooling circuit
LNG supply cycle	14 days/LNG supply vessel
Emission regulation	Fulfilling high EU environmental regulations by using a selective catalytic reduction system (SCR)
Emission reduction from former status quo based on oil-based liquid fuel	– NO_X: Minus 90 % – SO_X: Minus 90 % – CO_2: Minus 40 % – Particulates: Close to Minus 100 %

Tab. 1: 80 MW LNG-to-power Project Gibraltar

Asia, the future LNG powerhouse

As much as 75 percent of the growth in demand for natural gas will come from one regional market: Asia. China plays an important role in Asia's LNG demand, which is expected to peak in around 2040, however the fast growing nations in South and South-east Asia will take over as key drivers of demand. This results from the pace of industrial development and double-digit GDP growth.

Asia will also become the largest future offtaker when it comes to volumes and distribution of LNG within its energy intensive industry and the power sector.

(cf. MOFA 2018)
(cf. Berteaud 2020)
(cf. JEPIC 2019)

Logistics will be a strategic pillar for business success. With more than 80,000 km of coastline in total, Asia has a strong advantage when it comes to logistics and the supply of natural gas and other commodities via seagoing vessels. Asia has also a strategic position alongside the international sea routes as well the supply routes of all multinationals in the LNG business.

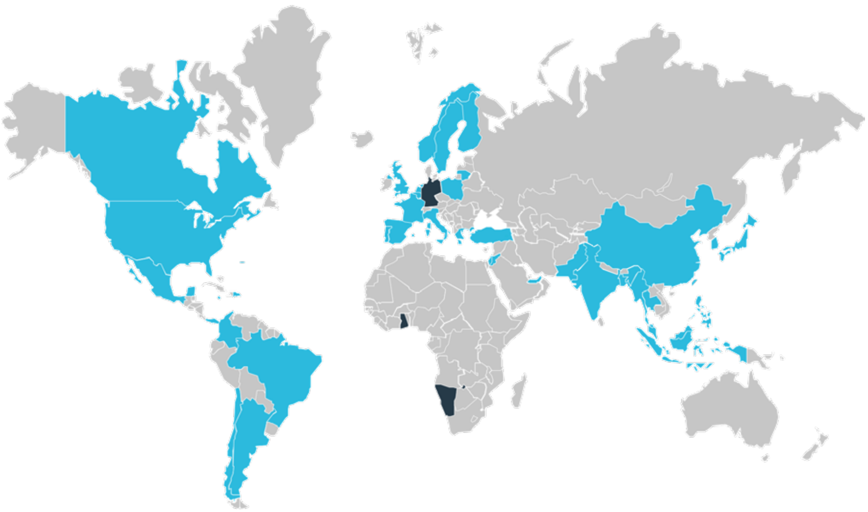
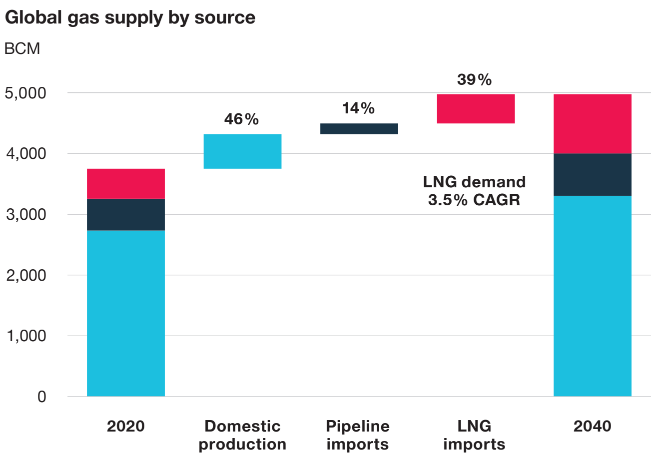
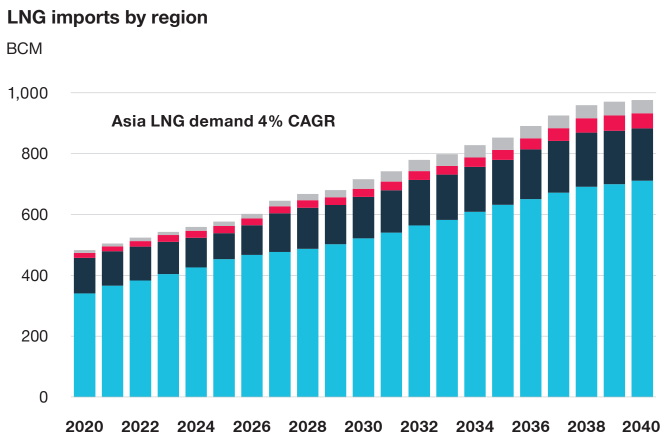


Fig. 5: LNG importing countries 2020





Asia ■ Europe ■ Americas ■ Rest of the world

Fig. 6: LNG to play a pivotal role in meeting gas demand growth

Five reasons to switch to LNG

- **Reducing the environmental footprint** by using the cleanest fossil fuel currently available to support strong economic growth
- **Making use of the bargaining power** in LNG sourcing from a market that is currently more flexible, without being trapped in long-term contracts
- **Decreasing dependency on former single sources** of supply like coal and/or oil
- **Reducing electricity costs** by using a cheaper fuel and switching to highly efficient and flexible gas prime-mover technology
- **Attracting foreign direct investment** (FDI) provided by private equity and international development banks who are supporting the energy transition beyond coal and oil.

Production price and local market models determine the success of LNG

Low production cost per MWh, fast start-up time and a low environmental footprint are only three of the main criteria for successful access to global electricity markets.

Liquefied natural gas, the fuel for change

For many years, natural gas was only available for specific countries, but thanks to the liquefaction, transport, storage and regasification infrastructure, natural gas is now available as LNG everywhere in the world. This applies particularly to Asian countries which, with their long coastlines and booming economies, have become the world's largest consumers of liquefied natural gas.

A diversified LNG sourcing strategy offers a new and interesting lever for reducing the production costs of electricity. Fuel costs currently account for approx. 70 % to 80 % of the operational expenditure (OPEX) of a fossil-based generating asset. In that context, LNG offers a smart and cost competitive option and is also the cleanest fossil fuel currently available. With a carbon content of only 202 g/kWh, LNG can pave the way to decarbonized fuels once they are available in sufficient quantity.

(cf. Agosta et al. 2021)

Supporting the new base-load power – From winners to losers

Without any doubt, renewable energy sources with zero emissions will be the future base load on global electricity markets.

Fossil base-load assets are the big losers from this trend, from smaller coal-fired installations up to 100 MW to the larger supercritical coal-fired power plants with an installed capacity up to 1,000 MW per unit.

These power plants, which were the work horses for decades, are not able to support this new operating regime, as they are not able to run as peakers with multiple daily starts and stops and wide load following capacities. Other than reciprocating engines, they are simply not able to support a grid when a (cold-start-up) secondary reserve is needed to stabilize the frequency within a 15 – 30-minute request.

The new merit order

With a larger integration of CO_2 free renewables as the new base load in the grid, fossil-fired base-load assets with a high specific CO_2 price per MWh will be disregarded in any future merit order system.

All the developments mentioned here mainly promote three trends for a sustainable future:

1. Renewables like PV, wind, hydro and biogas will supply the new base load and will deliver whenever they are available and the grid can integrate and balance the power.
2. Dispatchable power like fast-start gas engines or storage solutions will fill the gap and open new revenue streams, e.g. in ancillary and capacity markets to support a path towards 100 % renewables and a decarbonized power industry.
3. Depending on the available electrical grid capacity, decentralized smaller and much more agile installations with less capital expenditure (CAPEX) and a balanced CO_2 footprint will have an advantage over large coal-fired base-load power plants which need maximum annual full-load hours as their economic foundation.

(cf. IEA/NEA 2015)

The table below gives a good indication of which regions and, more specifically, which countries are currently developing LNG-to-power projects and are supporting a new strategy towards decarbonization with this change.

LNG-to-power projects

Region	Country	Installed Power in MW	Technology	Commercial operating date/ Status as of 08-2021
Africa	Senegal	400	GTCC	Under Development
Africa	South Africa	1,000	gas/dual-fuel engines	2022
Africa	Morocco	6,300	GTCC	2024
Americas	El Salvador	378	gas engines	2021
Americas	Chile	2,000	GTCC/gas engines	Under Development
East Asia	Japan	2,200	gas engines	Under Development
Europe	Gibraltar	80	gas/dual-fuel engines	2019
Europe	Malta (Marsaxlokk)	349	GTCC and dual-fuel engines	2016
South Asia	Bangladesh (Meghnaghat)	3,000	GTCC	Under Development
South Asia	Sri Lanka	200	gas engines or GTCC	Under Development
Southeast Asia	Philippines	3,200	GTCC using LNG will replace a gas pipeline from the depleting Malampaya gas field	2023
Southeast Asia	Vietnam (various sites)	Tbd.	GTCC and engines	2024
Southeast Asia	Myanmar (Thanlyin)	430	gas engines	2019
Southeast Asia	Indonesia	1,500	engines and turbines: 32 locations to supply with LNG and substitute liquid fuel operation	Under Development

Tab. 2: Currently under development or already under commercial operation

How to win in small-scale LNG-to-power projects

Framing a winning business concept – In-depth market expertise and risk assessment are key to success

Developing an LNG-to-power project from the initial idea to an operational business with secure profitable revenue streams over at least 15 to 20 years is complex and requires the expertise of many stakeholders.

MAN Energy Solutions is delivering this support from the initial concept through to the operation and maintenance of an LNG-to-power project using their own in-house resources and in cooperation with strong global partners.

Main steps in the comprehensive development of an LNG-to-power project (simplified):

- **An in-depth country assessment** and related risk assessment covering the macroeconomics, legal system, currencies, local regulations, required (environmental) permits, market design, potential offtakers, competitive landscape and logistics for fuel and consumables.
- **Market assessment** covering a first business calculation with potential project development costs, site costs, upfront investment costs for the EPC (CAPEX), OPEX, revenue expectation.
- **Project finance structure** credit/loan requirements for various phases of the project. Power purchase agreement (PPA) structure to make the project bankable. Equity/loan share and costs, local taxes/incentives and local support programs e.g. tax holiday, weighted average cost of capital (WACC), commercial operation date (COD) scenarios, expected cash flow, first and annual level. Debt-service coverage ratio (DSCR). Shareholder- and sponsor structure.
- **Technology assessment** covering the prime mover technology and operating regime. LNG logistics, storage and regasification design, emission control, grid requirements, local transport conditions, etc.
- **Main partner structure** for the EPC of the power plant plus the LNG infrastructure. Here we would recommend always taking a one-stop solution provider who takes over the responsibility for the small-scale LNG infrastructure plus the power plant. This will ensure a well-integrated design and that responsibilities will be covered under one main contract.
- **Operating structure** is of key importance when it comes to the contract obligations. Here, a company that is able to operate and maintain the power plant over the entire project life cycle is an advantage. The availability of the LNG-to-power facility is the most critical part when it comes to secure revenue streams and debt repayment obligations.
- **Fuel supply strategy for LNG** and, for a dual-fuel power plant, for the liquid fuel too. For a pure gas engine power plant, a secure supply of available natural gas/LNG is also required for the commissioning and start-up phase prior to COD. If the main plant will supply LNG to so-called satellite power plants as well, make sure that the right truck loading capacity is calculated and available (redundancy aspect covered).
- **Active search for additional revenue streams** like selling LNG to other offtakers in the surrounding area or delivery e.g. via trucks. In the early design phase, analyze whether heating or cooling can also be supplied to an industrial complex and other offtakers. Get in touch with the transmission system operator (TSO) and grid operator for delivering additional grid services such as the spinning reserve, ancillary services or capacity obligation on a contract basis.

(cf. Biscardini et al. 2017)

Reference business case for a 350 MW decentralized LNG-to-power solution

Convoy concept

The business concept approach is based on a "one-stop solution", containing an aligned project development concept, a full EPC solution for the land-based LNG infrastructure and the power plants as well as the safe and reliable operation and maintenance of all the assets.

Sites

A multiple site approach with the same approval process to receive the operation license will allow a standardized concept to be used to optimize the approval process to gain time and cost savings.

A standardized convoy concept[3] containing a MAN Energy Solutions power plant plus the tailor-made, matched LNG storage and regasification infrastructure.

For the various sites from 44 MW to 74 MW and 88 MW, MAN would propose a flexible setup to keep the thermal efficiency as high as possible and the environmental footprint as low as possible.

State-of-the-art large-bore medium speed gas engines, with two-stage turbocharging, provide the perfect output for power plants up to 100 MW.

The convoy concept allows standardization for the design, tender and approval process.

The reference market will be an OECD/ASEAN market with stable political and macroeconomic conditions, where the power plant will supply base-load power to the grid.

(cf. Suehiro 2019)

Proof of concept and robustness of the business case – life cycle cost analysis and financial modeling for the reference plant

Based on various input parameters and current overall available energy market characteristics, the following chapters will analyze the robustness of an LNG-to-power business model. Covering the main criteria for success:

- The EPC pricing
- Capital invested including equity cost
- Operational cost
- Generating cost per MWh
- Cash flows
- Internal rate of return (IRR)

Strategic approach and business mapping of a 350 MW decentralized power project

Profitable base-load power

The strategic objective is to deliver imported LNG to various power plant sites using a "hub and spoke" convoy approach.

The project makes use of the entire LNG value chain from LNG purchasing and logistics to offshore handling, onshore storage and regasification.[4]

The LNG stored at the site will be used as regasified natural gas in the highly efficient gas engine generating sets to produce base-load electricity.

The offtaker of the electricity will be the local transmission system operator.

In addition to the financial sponsors, the key partners are:

- **An international LNG supply company** and a logistics company
- **MAN Energy Solutions and a local EPC partner** delivering the entire land-based LNG-to-power infrastructure plus the related operation and management (O&M) of the sites
- **A lead bank** acting within the framework of this project as project finance/credit arranger for the loan agreement and equity arrangement and taking responsibility for the project due diligence and communication with shareholders

[3] The aim of the convoy concept is to simplify the approval process submitted to authorities by means of a standard power plant and LNG infrastructure design. This reduces both the project development time and, as a result, the interest during construction (IDC). A standardized power plant design and LNG equipment should also lower the entire EPC price.

[4] Within this concept study, MAN's remit covered all aspects of onshore LNG handling, regasification and power generation.

The use case project

350 MW LNG-to-power EPC with a convoy concept

Project KPIs/request

- Highest electrical base-load efficiency
- Using imported LNG to optimize the life cycle costs and cost of electricity
- Low environmental footprint

LNG Hub

2x 60 m³/h Truck loading

42,000 m³ tank

5x 1,000 m³ storage tanks

Power Plant

2x 60 m³/h Truck loading

Plant I Power Plant

2x 60 m³/h Truck loading

10x 1,000 m³ storage tanks

Plant II Power Plant

2x 60 m³/h Truck loading

6x 1,000 m³ storage tanks

Plant III Power Plant

2x 60 m³/h Truck loading

3x 1,000 m³ storage tanks

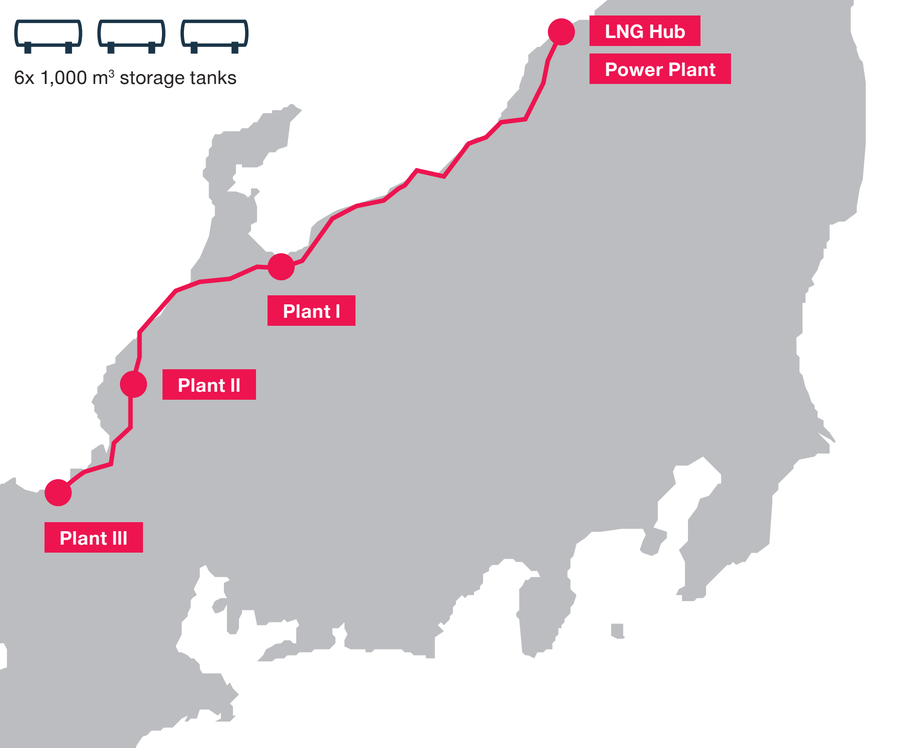


Fig. 7: 350 MW LNG-to-power EPC - Project structure

Project key data for the various sites	Unit	LNG Hub and Power Plant	Plant I	Plant II	Plant III
Gas engine type		**18V51/60GTS**		**18V51/60G TS**	**20V35/44G TS**
Planned electrical output	MW_{el}	74	2x 74	88	44
Total rated plant electrical output	MW_{el}	75.71	151.4	91.16	47.34
Full load operational hours per year	h/a	8,000	8,000	8,000	8,000
Electricity generated per year	MWh/a	605,714	1,211,428	729,312	378,751
LNG consumption & storage for the sites					
LNG consumption per year (Hi)	MWh/a	1,263,192	2,526,384	1,544,213	802,677
LNG consumption per year (Hi)	m³/a	202,376	404,752	247,399	128,597
Truck supply					
Truck delivery per day (14 t per truck; 6 days per week)	Trucks/day	23	2x 23	28	14
Truck unloading units	units	2	2	2	2
Truck unloading time	h/unit	6	2x 6	7	4
Storage capacity at site					
Onshore storage capacity	m³/w	5,000	10,000	6,000	3,000
Onshore bullet storage tank (1000 m³ LNG)	pieces	5	2x 5	6	3
Onshore storage capacity	days	7	7	7	7

Tab. 3: Liquefied natural gas receiving concept

Liquefied natural gas receiving concept

To run a profitable LNG-to-power business, it is essential to lower the fuel cost. This might require the termination of existing supply contracts if they cannot flexibly mirror the global market price. Provided that your location can be serviced by suppliers that offer global spot market prices, you can lower the fuel cost of your operation considerably. Having access to low-priced gas is key for a profitable business.

For that reason, the IPP has decided to be as flexible as possible and make use of its own LNG import facility – the Hub – which has the capability to store and distribute imported LNG to other satellite power plant sites nearby.

Analysis of key performance indicators

On wholesale and competitive electricity markets, the production cost of electricity per MWh is the leading way to measure the profitability of a power-generating asset.

Available generating technologies are categorized on wholesale markets according to a merit-order system. This is a way of ranking available sources of electricity-generating assets, based on an ascending order of price. It reflects the order of their short-run marginal/variable cost of production – the so-called clearing price – together with the amount of energy generated.

An electricity production price below the clearing price of an electricity market is the most important measure for every investor. The gap between the sales price of electricity and the production costs needs to meet the financial expectations of an investor and cover the debt service as part of an upfront operational investment.

In detail, the main key performance indicators for a power plant solution like the LNG-to-power setup in this case are as follows:

Technology
- Net efficiency, net heat rate under ISO and under site conditions covering derating aspects
- Emissions, preliminary CO_2 and NO_X linked to the efficiency and fuel type

Project finance
- EPC price
- Cost to owners including infrastructure work, project development work and permitting process
- Construction time for the asset from NTP to COD determines the IDC cost
- Capital and investment structure/ equity vs. loan structure
- Local tax rate
- WACC
- Annuities

Operational
- Expected full load hours under PPA
- Dispatchable or non-dispatchable technology (“additional grid services for an additional revenue”)
- Operational expenses including insurance (e.g. breakdown insurance)

(cf. Yescombe 2014)

Input parameters for the Life Cycle Cost Calculation

Parameters	Comment	Installation/site		
		44 MW "Plant III" 4x 20V35/44G TS	74 MW "Plant I" 4x 18V51/60G TS	88 MW "Plant II" 5x 18V51/60G TS
Plant net output (60 Hz)	Net electrical power available for delivering electricity under the PPA.	47.3 MW_{el}	75.7 MW_{el}	91 MW_{el}
Plant net heat rate/ electrical efficiency	Covering own consumption of the power plant and the efficiency of the high voltage step-up transformer. 5 % tolerance for project specific adjustments.	not displayed for this publication	not displayed for this publication	not displayed for this publication
EPC investment costs for the power plant and LNG related installation. Without site costs	Power plant investment based on MAN experiences. LNG infrastructure due to international projects. LNG covers under an EPC: Related 1,000 m^3 vacuum-insulated tanks plus regasification system and truck unloading. Suitable for seven days' storage.	not displayed for this publication	not displayed for this publication	not displayed for this publication
IDC	IDCs are used – typically construction time from NTP to COD is between 12 and 18 months depending on the complexity. Site preparation works and for example costs for HV connection are not implemented within this concept study.	€ 1.9 million	€ 3.1 million	€ 3.8 million
Capital costs/Annuities based on 8.3 %	Included for a 25-year lifetime of the asset	€ 4.0 million	€ 6.5 million	€ 7.9 million
WACC	Included based on 30 % equity (12 % equity costs) and 70 % debt financed with 5 % loan costs	6.6 %	6.6 %	6.6 %
Tax rate	We assume no tax holiday/income taxes due to the local market mechanism. Income tax for an SPV/ Power Plant operation, estimated	15 %	15 %	15 %
Fixed operation and maintenance costs[5]	Included: The personnel who operate the power plant in a three-shift model	15 people	17 people	17 people
Insurance and other services	Not included	-	-	-
Variable maintenance costs	Included: Costs per periodic maintenance service with spare parts and supervisor assistance	€ 4.5/MWh	€ 4.5/MWh	€ 4.7/MWh
Lube oil	Included: As consumable for the power plant	€ 1.2/MWh	€ 1.2/MWh	€ 1.2/MWh
Fuel price in €/MWh	Under a fuel supply agreement $ 5.78/MMBtu.	€ 17.9/MWh (plus higher price scenario € 25/kW)	€ 17.9/MWh (plus higher price scenario € 25/kW)	€ 17.9/MWh (plus higher price scenario € 25/kW)
Emission regulation	According to EU standards	-	-	-
COD	COD starting after 1.25 years; 15 months after NTP	2023	2023	2023
Annual operating hours	Base-load operation – basis for financial model	8,000	8,000	8,000
Operating years	From COD to decommissioning	25 years	25 years	25 years

Tab. 4: Input parameters for the Life Cycle Cost Calculation

[5] Escalation rate for costs 2.5 %/a

Financial modeling for the LNG-to-power solution

Discounted cash flow – Time value of money

The model for the profitability is based on the discounted cash flow method using a project-specific WACC including a 15 % corporate tax rate.

All project cash flows are linked to an energy market scenario with sales prices for electricity[6] as well as expenses for fuel and other consumables and services.

The inputs are:

- **Variable operation and maintenance costs** including periodic maintenance, lube oil and start-up costs. Full O&M management has not been considered due to the early stage of the project.
- **Fixed operation and maintenance costs** for running the power plant, including costs for operating staff and local tax rate.
- **Financing parameters** covering the construction time with the important allocation of the IDC, equity ratio, costs and **WACC.**
- **Capital costs** that reflect the annuities linked to the operational lifetime of the power plant.

The results for the decision makers are:

- Cash flows
- The discounted and net operating profit available for shareholders and investors
- The project IRR for the capital invested as a benchmark for the profitability of the project
- The payback time in years linked to the first positive discounted cash flow
- DSCR

Success criteria and indication of the financial profitability

In this concept study, the leading financial indicators were calculated under two scenarios.

Scenario one is the “expected scenario” with the given input data. The second scenario includes a sensitivity linked to a price increase for the LNG/natural gas of up to €25/MWh under a so-called “higher gas price scenario”- as we adopt a “ceteris paribus” approach.

[6] Based on €90/MWh

	Scenario 1: "Expected scenario"	Scenario 2: "Higher gas price"
LNG price at COD	**€17.9/MWh/$5.8/MMBtu**	**€25/MWh**
Sales price of electricity under PPA	€90/MWh	€90/MWh
Power plant load	8,000 annual operating hours with 100 % load	8,000 annual operating hours under 100 % load
Years of commercial operation (project lifetime)	25	25
WACC	6 %	6.6 %
Tax rate (corporate tax rate for SPV)	15 %	15 %

Tab. 5: Leading financial indicators calculated under two scenarios

Results for scenario 1: "Expected scenario"

Parameters	44 MW site	74 MW site	88 MW site
Operation profit (accumulated)	€478 million	€795 million	€924 million
Cash flow out of operation (accumulated)	€429 million	€715 million	€829 million
Discounted cash flow (accumulated)	€214 million	€358 million	€414 million
Project IRR – Return of the investment over the project lifetime	29.4 %	29.7 %	29.3 %
DSCR on average over 25 years	1.3	2.0	2.6
Payback time[7]	6 years	6 years	6 years

Tab. 6: Results for the "Expected scenario"

Results for scenario 2: "Higher gas price scenario"

Parameters	44 MW site	74 MW site	88 MW site
Operation profit (accumulated)	€293 million	€510 million	€567.8 million
Cash flow out of operation (accumulated)	€244 million	€430 million	€473 million
Discounted cash flow (accumulated)	€111 million	€199 million	€215 million
Project IRR – Return of the investment over the project lifetime	8.9 %	20 %	18.9 %
DSCR on average over 25 years	0.8	1.4	1.6
Payback time[7]	9 years	9 years	9 years

Tab. 7: Results for the "Higher gas price scenario"

[7] First cumulative positive cash flow

2021 SWOT analysis for small-scale LNG-to-power solutions

Strengths

- The LNG market has become a buyer's market with good price conditions, even for smaller projects
- The long-term projection for LNG prices is stable
- Momentum from banks to support efficient gas instead of oil- and coal-based power
- Availability of technology such as highly efficient reciprocating engine technology and modularized small-scale LNG infrastructure
- Fast decarbonization effect by switching from oil and coal to cleaner natural gas
- Supply strategy via virtual pipeline (e.g. via trucks) to remote locations

Weaknesses

- Stronger policy support needed with dedicated PPAs, tax and loan incentives for low carbon power generation
- Lack of local governmental policy support for promoting as well as cross-selling of natural gas and LNG from a terminal for sector coupling and other downstream use

Opportunities

- Retrofit capability to switch from oil-based fuels to clean natural gas operation
- Huge cost-saving potential for the entire life cycle and electricity generating cost
- Reduction of sector subsidies especially under private IPP projects
- Opportunity to use the LNG-to-power infrastructure for 100 % carbon-neutral synthetic natural gas
- Grid stabilization while supporting the increased share of renewables in the local energy mix

Threats

- Not taking the chance to invest gradually in decarbonization, starting right away. Adopting a conservative approach and failing to accept that the new base-load power will be supplied by non-dispatchable sources like wind and PV and therefore needs new approaches to energy infrastructure
- Uncertainty as to which hydrogen-based fuel will be available in sufficient quantity, and the economic situation in 2040

Tab. 8: SWOT for small-scale LNG-to-power solutions 2021

Evaluating the results

Financial performance

The overall financial performance of the business case is very attractive:

- **Project IRR** ranging from 17 % to 29 % for both scenarios. Strong operational performance of the power plants in the base-load market.
- **Short construction time** of between 15 and 18 months from notice to proceed to commercial operation date to secure an early commercial start-up and first positive cash flow.
- **Operational cash flows** linked to the size of the power plants are strong and, especially in the expected scenario, deliver good overall debt-service cover ratios of up to 2.4 (Bond rating e.g. according to S&P (cf. S&P Global Ratings 2014)).
- **Stable financial and macroeconomic conditions** support the entire business for the proposed life time of the assets.

Success criteria

- **Worldwide direct sourcing of LNG** to stabilize the fuel costs.
- **Convoy concept** for optimized CAPEX and permitting process.
- **Aligned EPC responsibility** for the power plant and the LNG infrastructure.
- **High technical and commercial availability** of the entire asset secured via a responsible EPC/O&M company.
- **Full control over the entire value chain.**

Risk prevention

- **Secure a flexible power purchase agreement** linked to the gas price on site.
- **LNG supply contract** based on “take-or-pay”.
- **Hedging of LNG supply** should be considered.
- **Optimizing the IDC phase** with a separate credit line to keep main capital costs low.

Suppling more than base-load power to the local market

- **Expand the business model towards more flexibility.**
  The engines are offering a very flexible operating regime from ancillary services to spinning and non-spinning reserve thereby generating an additional revenue stream. In energy markets with a high amount of fluctuating renewable sources, grid operators usually need to maintain a stable grid frequency.
- **Expand the operation time of the power plant by using hydrogen-based fuels.**
  These include synthetic natural gases (sLNG). This applies particularly in Asian markets like Japan which are currently developing their hydrogen strategy for the power and mobility sector.

Future-proof investment and outlook

The calculations prove that investing now in a small-scale LNG-to-power plant based on reciprocating gas engines is profitable. But will the profitability prevail when further measures for decarbonization are taken and the cost side of your business is weighed down by increasing CO_2 costs? Such scenarios will have an impact on the initial business case calculation. In a worst case scenario, plant operation has to be discontinued due to stringent emission regulations. But this case is not expected to take place, due to the initiatives being taken along the entire value chain from well to tank, such as carbon capture (CC) technologies. Hydrogen is regarded as the future fuel for decarbonizing sectors and will play a central role in the plan to decarbonize economies by 2050.

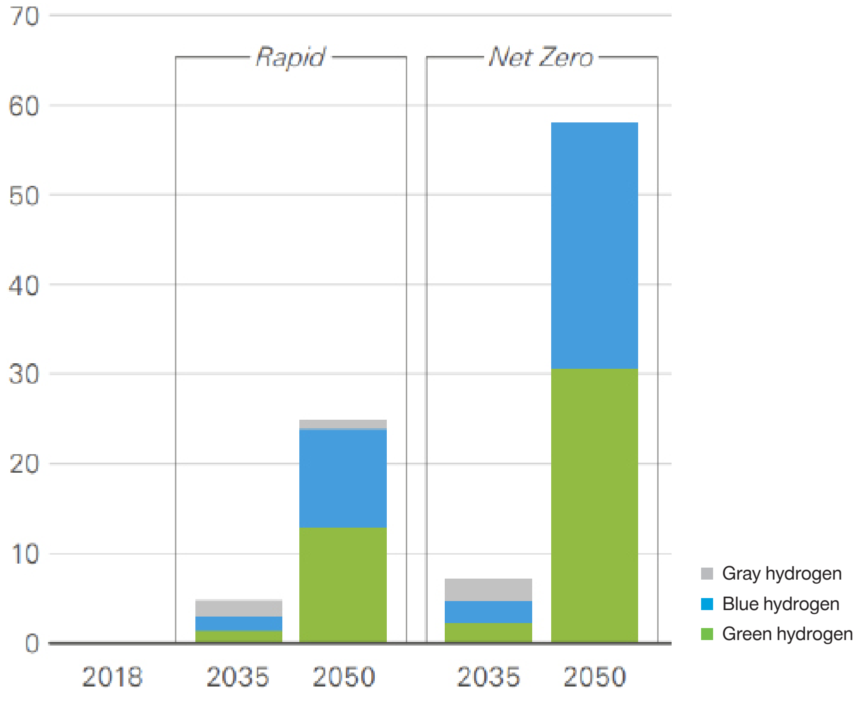


Fig. 8: Hydrogen production per type

Hydrogen-based fuels will have huge potential in future, provided that the CO_2 emissions from production are taken care of. This will be the case for blue hydrogen from natural gas where CC technology is used to separate the CO_2 which is then either further utilized (CCU) or stored (CCS). Green hydrogen of course has the biggest potential as it is produced from renewable energy by splitting water into its components, hydrogen and oxygen. However for large-scale production of green hydrogen, sufficient renewable energy needs to be available and this is expected from 2040 on.

There are various sectors ready and waiting to use hydrogen for their decarbonization targets, and power generation is expected to become a major factor once hydrogen is available in sufficient volume and price.

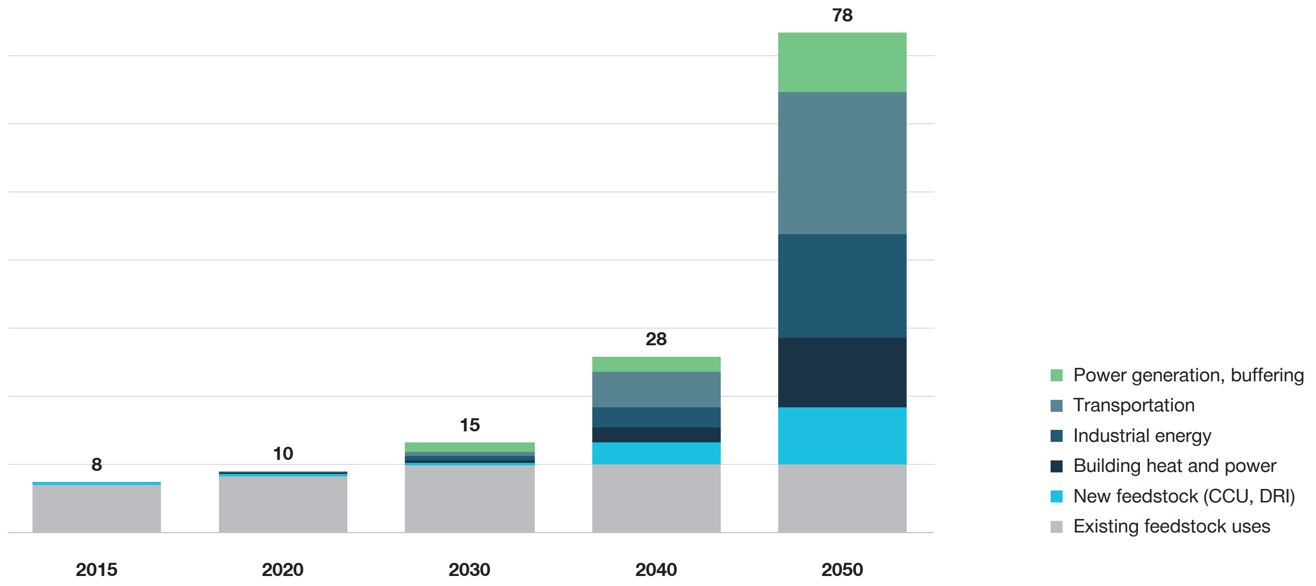


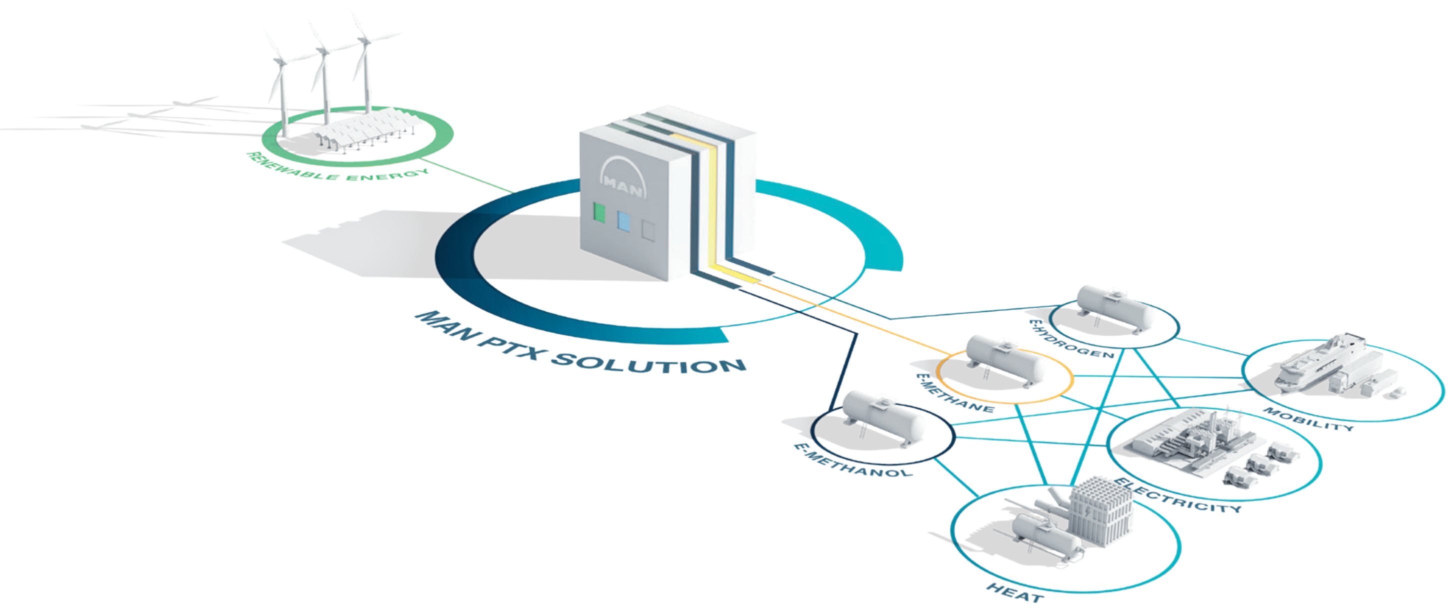
Fig. 9: Global energy demand supplied with hydrogen

So what is the link between investment in small-scale LNG-to-power and the availability of hydrogen-based green fuels? The economical production of green hydrogen is expected to take place in areas with sufficient low cost renewable power, e.g. Chile, Australia, whereas the consumption will take place elsewere. To bridge this future gap, various ways of transporting green hydrogen are under investigation. One of these is via SNG. This is produced from green hydrogen and CO_2 via a CCU process, which makes SNG a carbon neutral fuel.

MAN Energy Solutions is closely following these streams as a supplier of compressors for CCU/CCS, designer and producer of chemical reactors, and supplier of PEM electrolyzers and methanation reactors to produce gases including synthetic natural gas.

SNG and liquefied SNG have the same properties as LNG. That is the reason why existing LNG installations can also be operated with sLNG.

Fig. 10: MAN power-to-x solution



Conclusion

The pressure to decarbonize the energy sector requires quick action. The availability and acceptance of synthetic fuels including hydrogen will take quite some time. However, this does not mean there is time to waste, when a stepwise approach can be adopted.

An investment into a small-scale LNG-to-power plant represents the first and most important step to support decarbonization by using natural gas, the cleanest fossil fuel. At the same time, this investment builds the bridge from natural gas to hydrogen-based fuels.

An LNG-to-power plant will start to generate profit with drastically reduced CO_2 emissions from the outset and is prepared to immediately switch to synthetic natural gas or an SNG mix.

It can therefore be regarded as a fully future-proof investment as, depending on the availability and LCOE, the infrastructure can be switched to renewable fuels.

Falling prices for green hydrogen and rising prices for CO_2 prove that operating the plant with sLNG can be profitable, but this will require the support from governmental bodies in the form of incentives to promote the use of carbon neutral fuels.

As described, the LNG-to-power plant can also be switched to run on sLNG without any modifications. The same applies to gas mixes containing up to 25 % hydrogen.

However, if 100 % hydrogen, ammonia or methanol operation is required, it will be possible to retrofit the reciprocating engine gensets to run with these fuels. MAN is presently testing these fuels in their test engines and planning to provide the respective technology from 2025 on.

This is another initiative to support customers to ensure their investment in the power plant does not become a stranded asset. This will future-proof your power plant over its entire lifetime.

MAN Energy Solutions will be more than pleased to discuss any questions that might arise or provide technical and commercial consultancy for our customers' LNG-to-power projects.

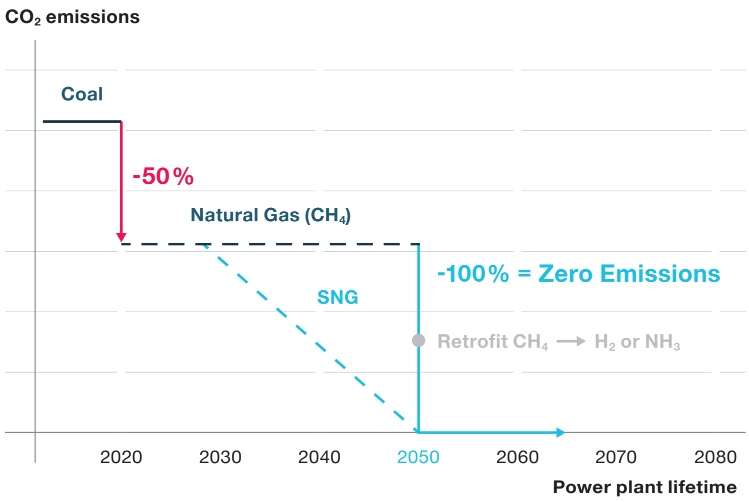


Fig. 11: Future-proof investments in LNG-to-power

Figures

Tables

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