

JM

LCH™ Process for the production of blue hydrogen

By Johnson Matthey



Johnson Matthey
Inspiring science, enhancing life



Information contained in this publication or as otherwise supplied to Users is believed to be accurate and correct at time of going to press, and is given in good faith, but it is for the User to satisfy itself of the suitability of the Product for its own particular purpose. Johnson Matthey plc (JM) gives no warranty as the fitness of the Product for any particular purpose and any implied warranty or condition (statutory or otherwise) is excluded except to the extent that exclusion is prevented by law. JM accepts no liability for loss or damage (other than that arising from death or personal injury caused by JM's negligence or by a defective Product, if proved), resulting from reliance on this information. Freedom under Patent, Copyright and Designs cannot be assumed.

© 2022 Johnson Matthey Group

Contents

1.0	Why low carbon hydrogen now?	4
2.0	What is JM's LCH technology?	4
2.1	Sources of hydrogen	4
2.2	The LCH plant	4
2.2.1	Process description	4
2.2.2	Reference technology	5
2.2.3	Introducing GHR technology	5
2.3	Plant performance	6
2.3.1	Energy efficiency	6
2.3.2	CO ₂ emissions and capture	6
2.3.3	System flexibility and operating rates	7
2.3.4	Product purity	7
2.3.5	Plot plan	7
2.3.6	How will uptime be maximised?	7
3.0	At what cost?	7
4.0	To summarise	7
5.0	Glossary	8

1.0 Why low carbon hydrogen now?

There is an urgent need to limit the rise in global temperatures to avoid severe environmental and societal impact. Many countries across the world have committed to zero emission targets being met by 2050, this timeframe is now only one typical syngas plant lifetime away. The provision of decarbonised hydrogen at scale is an essential step to achieve this. Johnson Matthey's (JM's) **LCH™** technology enables decarbonised hydrogen to be produced at scale now, in the most sustainable manner.

The **LCH** process is the most profitable process for the production of low carbon hydrogen because, as a minimum whether compared to SMR or ATR, it:

- Utilises 10% less natural gas feedstock than competitive processes;
- Generates 10% less CO₂ to be sequestered as a result; and
- Has the most intensified plant footprint of available technologies.

In this document JM's **LCH** process is introduced, providing details of its key features. In addition, a comparison to a Steam Methane Reformer (SMR) with equivalent CO₂ capture is provided. This technology was used by the UK Government Department for Business, Energy and Industrial Strategy (BEIS) when reviewing low carbon hydrogen production routes. The comparison reveals that JM's **LCH** technology offers; lower cost, higher CO₂ capture rate, improved scalability and feedstock flexibility.

2.0 What is JM's LCH technology

JM has been a leading developer of catalysts and process design in the production of chemicals from synthesis gas since the 1930s. JM has applied this knowledge to develop the best in class technology to produce high purity hydrogen with a CO₂ capture rate of more than 95%. The **LCH** technology builds upon the expertise and experience of JM, from our Leading Concept Ammonia (LCA) and Leading Concept Methanol (LCM) commercialised flowsheets.

JM is focused upon effective and efficient utilisation of the world's resources while still enabling our customers to operate in a profitable way. This is showcased in our **LCH** technology. When **LCH** technology was compared to a conventional SMR the **LCH** technology demonstrated:

- 10% lower natural gas consumption;
- 10% less CO₂ produced; and
- 75% lower capital cost for the CO₂ capture system.

Use of **LCH** technology will derisk the project by minimising the impact of increasing feedstock costs, increasing costs of CO₂ transmission and storage and any potential governmental scheme for carbon taxation.

2.1 Sources of hydrogen

Low carbon hydrogen can be produced via three primary routes:

1. Electrolytic splitting of water using renewable electricity;
2. Reforming of fossil resources with Carbon Capture Utilisation and Storage (CCUS); or
3. Conversion of renewable biomass with or without CCUS.

Hydrogen produced from renewable resources is commonly referred to as 'green hydrogen', from fossil resources with CCUS as 'blue hydrogen' and from fossil resources without CCUS as 'grey hydrogen'.

Conversion of natural gas to grey hydrogen is a mature technology today. With the addition of known CCUS technology it offers the potential for bulk low carbon hydrogen production considerably more cost effectively than electrolytic hydrogen or bio-hydrogen. Therefore, whilst it is expected that there will be a mixture of hydrogen sources in the future, blue hydrogen is expected to be the major source in the medium term, as assessed by the UK Committee on Climate Change.

Steam methane reforming and advanced gas reforming are the two principle technologies used for blue hydrogen production. Advanced gas reforming consists of either an Autothermal Reformer (ATR) or an ATR coupled with a Gas Heated Reformer (GHR). Where there is a requirement to capture CO₂, it is recognised that advanced gas reforming is a more appropriate technology for generation of blue hydrogen due to its provision of a more suitable stream for CO₂ capture.

2.2 A plant using LCH technology

2.2.1 Process description

At a basic level, a flowsheet showing hydrogen production using **LCH** technology is shown in Figure 1.

Purified natural gas is pre-heated and reformed in the GHR before entering the ATR. In the GHR, 30% of the total hydrocarbon is reformed by reaction with steam to form syngas. In the second stage, the ATR, oxygen is added allowing some of the partially reformed gas to combust to raise the process gas temperature. The resultant gas

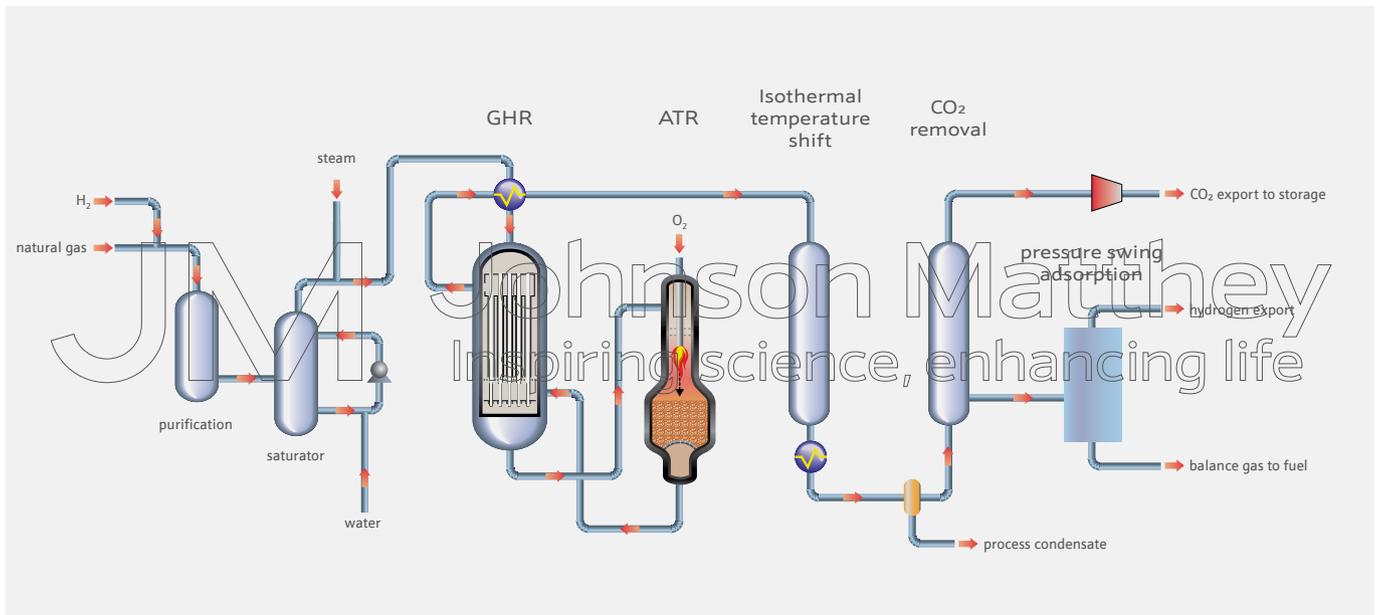


Figure 1 - LCH flowsheet

passes through a bed of reforming catalyst inside the same vessel for further reforming. Since the reaction is limited by equilibrium, operation at high temperature and steam flows minimises the methane content of the product gas exit the reformer. Any methane present at this point will increase CO₂ emissions of the overall process. The hot gas exiting the ATR passes back to the GHR, providing the heat necessary to drive the reforming reaction in the GHR tubside.

Therefore, the main difference between the LCH and SMR flowsheets is that the energy to drive the reaction is provided by introducing oxygen to the ATR as opposed to burning natural gas in the SMR. The oxygen for the ATR can be provided by an Air Separation Unit (ASU). Use of combustion with oxygen within the process provides the heat required for reforming, it is important to note that in regard to methane slip (& hence CO₂ capture capability), the ATR can operate at temperatures in excess of 1000 °C and this drives up the conversion of hydrocarbon to levels that SMR flowsheets cannot achieve.

2.2.2 Reference technology

The LCH process is a combination of mature, well proven unit operations which are already utilised in other JM technologies:

- The JM GHR is used in three LCA (ammonia) plants and one LCM (methanol) plant;
- The JM ATR is used in the above LCA and LCM plants and in over 20 other plants;

- The Isothermal Shift (ITS) converter has been used in the three LCA plants; and
- The saturator circuit has been used in 18 plants, including the LCA and LCM plants in addition to Low Pressure Methanol (LPM) plants.

The LCA, LCM and LPM plants are very large plants, demonstrating that the technology can produce hydrogen at large scale.

2.2.3 Introducing GHR technology

The inherent efficiency of a flowsheet is tied to its ability to manage the energy within it, and by that specifically the exergy within the flowsheet. Exergy is a quantitative measure of energy's ability to do work (physical or chemical) and the quality of that energy is best managed by two main levers:

- (i) Minimising combustion within the flowsheet; and
- (ii) Minimising the size of thermal gradients over which heat is transferred.

JM's LCH process adheres to these two principles by deploying a GHR which reduces the amount of combustion needed to achieve conversion of the hydrocarbons to carbon oxides and also minimise the size of the thermal gradients in the flowsheet by transferring heat back into endothermic reforming reactions in the GHR rather than eroding that high grade energy by sinking it into steam production. By so doing, the fundamental energy efficiency of the flowsheet is maximised. This is

particularly important for a technology that is tied to the need to sustainably generate energy in the guise of product hydrogen. JM has chosen to combine a GHR with an ATR in the **LCH** flowsheet to provide increased energy efficiency.

A GHR is a heat exchange reformer with chemical reactions occurring in its tubes. As stated above, its deployment in the **LCH** process immediately reduces combustion requirements when compared to an ATR-based flowsheet. This consequently not only maximises the exergy within the process but obviously also (due to reduced combustion requirements) **LCH** technology requires less oxygen and hence smaller ASUs. In addition, due to the fundamental efficiency benefits of this configuration, per unit of product hydrogen gas there is a 10% reduction in both natural gas consumption and capture duty of CO₂ leading to smaller sized, intensified unit operations. This improved utilisation of feedstock with regards to carbon efficiency provides a process with a higher thermal efficiency. These operational improvements provided by the **LCH** process also give an economic advantage through less expenditure on natural gas and a lower cost of CO₂ disposal since the CAPEX for ATR-based and **LCH** processes (when evaluated as a whole including ASU, CO₂ removal and product and CO₂ compression) are roughly equal. It is therefore important to evaluate the OSBL impact of the ISBL offering in terms of total capital expenditure for the complex.

2.3 Plant performance

Table 1 presents plant performance data associated with both **LCH** technology and an SMR for a hydrogen production rate of 100 kNm³/h.

Parameters	Units	SMR	LCH
Natural gas energy (LHV)	MW	432	373
Hydrogen production	kNm ³ /hr	100	100
Hydrogen energy (LHV)	MW	300	300
Energy efficiency (LHV)	%	69.4	80.5
Power import	MW	-0.4	18.7
CO ₂ emitted	kmt/year	77.7	19
CO ₂ captured	kmt/year	700	603
CO ₂ captured	%	90	97
CAPEX	M £	243	148

Table 1 - Plant performance. LHV = Lower Heating Value. SMR data source: IEAGHG Technical Report 2017-02. LCH CAPEX includes ASU. 18.7 MW excludes the CO₂ removal unit power as this depends on CO₂ technology selected.

2.3.1 Energy efficiency

Due to the high temperatures present at the exit of the ATR, the methane slip within the **LCH** technology is significantly lower than the 4.35 mol% dry in the SMR example. This results directly from the higher reforming equilibrium temperature that an oxygen-fired ATR can achieve. As discussed in section 2.2.3, the use of a GHR allows for heat to be recovered at significantly higher temperatures than the raising of steam at 250-300°C in an SMR. As a result, the **LCH** technology uses 10 % less natural gas for every unit of hydrogen produced and therefore produces less overall CO₂.

As with an SMR, the **LCH** technology requires a significant amount of steam to be added to the feed natural gas. In the **LCH** process, around 60% of the steam is raised through the use of the saturator circuit, an additional 20% from the ITS converter and the remainder from the steam boiler. Steam generation using the Saturator circuit and the ITS is more efficient, in terms of quality, when compared to an SMR which uses the 860°C steam at the exit of the reformer to raise medium pressure steam thereby degrading the quality of the heat.

Therefore, **LCH** technology is more efficient than an SMR with an energy efficiency of 80.5% compared to 73.3% (LHV basis), shown in Table 1.

2.3.2 CO₂ emissions and capture

The **LCH** technology produces less than half of the CO₂ emissions compared to an SMR, as demonstrated in Table 1. This is due to:

- Operation of the ATR at high temperatures to minimise the methane slip and hence the CO₂ emissions when the Pressure Swing Adsorber (PSA) tail gas is combusted; and
- Utilisation of a highly efficient shift converter to maximise the reaction conversion, which consequently minimises the CO slip and CO₂ emissions when the PSA tail gas is combusted.

CO₂ can be also removed at lower cost and with a higher capture rate in the **LCH** technology than in an SMR. For the **LCH** process, all of the CO₂ is within the product stream and is therefore at high pressure and high concentration. It can subsequently be easily removed using standard industry CO₂ removal technologies. For an SMR coupled with CCUS, the fluegas CO₂ stream is at low pressure and diluted with nitrogen from combustion so consequently requires a large, and hence expensive, CO₂ capture system. The partial pressure of the CO₂, which is a key parameter in the sizing of the CO₂ removal system, is 30 times higher in the **LCH** technology than with SMR. This permits significant

intensification of the CO₂ removal system and with it reduced CAPEX and associated plot plan, meaning a higher H₂ production intensity per m² of land.

2.3.3 System flexibility and operating rates

If hydrogen is to play a role decarbonising domestic heating in countries such as the UK, the issue of demand fluctuation should be considered. Storage will be important but is expensive, so if the production technology can also provide a flexible output then further cost savings will be experienced.

The **LCH** technology is flexible to meet the varying demand of the end-users quickly. A review of the LCA and LCM plants operation shows that a **LCH** plant can be started up above dewpoint in 6 to 8 hours to reach 40% and ramped up from 40% to 100% in 30 to 60 minutes. The process can be also ramped down from 100% to 40% in 10 minutes. Discussions with ASU vendors have found that they are working on units that can track renewable energy generation and provide buffer storage of O₂ during times of reduced electricity generation.

Shutting down and restarting an SMR, either cold or hot, can result in a reduction in the useful life of the SMR tubes and can lead to catalyst damage. SMRs are also prone to both minor and catastrophic failure during transient operations such as start-up or changes in plant rate. The **LCH** technology eliminates these as potential causes of poor reliability due to its inherent design. Shutdowns and start-ups can also lead to some refractory damage, especially when the shutdown is not executed in a well-controlled manner. The **LCH** technology has less refractory than an SMR and therefore such damage will be limited.

As all unit operations have been operated at scale, we have assumed an onstream factor of 95%. The LCA and LCM plants have demonstrable onstream factors in excess of 95%.

2.3.4 Product purity

LCH technology can provide hydrogen with a minimum purity of 99.9 mol% and carbon dioxide at 99.7 mol% purity. These purity levels will support deployment across a range of industrial and domestic uses. However, there is flexibility within the flowsheet to produce hydrogen to the purity required by the end user.

2.3.5 Plot plan

The **LCH** technology offers a smaller plot area than an SMR. The work carried out indicates an ISBL plot plan of 65 m x 110 m for the plant using **LCH** technology compared to an estimated plot area of 110 m x 150 m for the SMR, using a plant capacity of 100 kNm³/h hydrogen as detailed in Table 1.

2.3.6 How will uptime be maximised?

A plant utilising the **LCH** process is designed for continuous operation with maximum uptime, and therefore availability, in order to generate the best economic return on investment. The demonstrated cycle times have been four (4) years with an expectation of five (5) years where legislation permits. Planned outages for significant maintenance will be organised at set durations through the plant life and will be campaigned to reduce the downtime, and consequently the impact on the economics of the plant. The outage duration for **LCH** technology is no longer than would be anticipated for SMR.

3.0 At what cost?

Based on CAPEX and OPEX figures¹ and performance data, a levelised cost assessment has been undertaken. The results are displayed in Table 2 and are lower than the equivalent cost of natural gas based on data from BEIS, accounting for the cost of carbon in 2035.

Levelised Cost of Hydrogen (HHV basis) £/MWh

Total	43.46
Capital	10.66
Feedstock	21.63
Operational	11.16

Table 2: Levelised cost of hydrogen

Feedstock costs and capital costs account for the majority of the LCOH. With its reduced Natural Gas consumption, and lower capital cost the **LCH** technology results in a lower LCOH than SMR.

4.0 Summary of key benefits

JM's **LCH** technology is a market leading solution for the production of low carbon hydrogen and it can be delivered at a range of capacities.

LCH technology is the most profitable process for the production of low carbon hydrogen because it:

- Utilises 10% less natural gas feedstock than competitive processes;
- Generates 10% less CO₂ to be sequestered as a result; and
- Has the most intensified plant footprint of available technologies.

1. For the purposes of this assessment, the operational costs have been annualised to an average figure

5.0 Glossary

ASU	Air Separation Unit
ATR	Autothermal Reformer
BEIS	Business, Energy and Industrial Strategy
CAPEX	Capital Expenditure
CCUS	Carbon Capture Utilisation and Storage
CO ₂	Carbon Dioxide
GHR	Gas Heated Reformer
ISBL	Inside Battery Limit (LCH core technology)
ITS	Isothermal Shift
JM	Johnson Matthey plc
LCA	Leading Concept Ammonia
LCM	Leading Concept Methanol
LHV	Lower Heating Value
LPM	Low Pressure Methanol
OPEX	Operational Expenditure
PSA	Pressure Swing Adsorption
SMR	Steam Methane Reformer

Designed and produced by www.houseoftype.co.uk

For further information on Johnson Matthey, please contact your local sales representative or visit dedicated hydrogen home page at matthey.com/hydrogen. LCH is a trademark of the Johnson Matthey group of companies.

Billingham, UK
Tel +44 (0) 1642 553601
www.matthey.com