# SMR HYDROGEN YIELD IMPROVEMENT AND $CO_2$ EMISSIONS REDUCTION USING CRYOGENICS

*Refinery at Port Jerome sur Seine, France*

**Much has been said about CCS – carbon capture and storage. The need to decarbonise is clear. Renewable power generation and green hydrogen may do much of the heavy lifting when they scale up in coming decades, but there are many steam methane reformers (SMRs) existing on refineries that must also be decarbonised.**

Steam methane reforming of natural gas, refinery gas or naphtha feedstocks is the most common process to produce hydrogen is. When these fossil fuels are used to generate hydrogen without capturing the $CO_2$ emissions, it is called 'grey' hydrogen. If most of the $CO_2$ from the SMR is captured, the hydrogen is referred to as 'blue'.

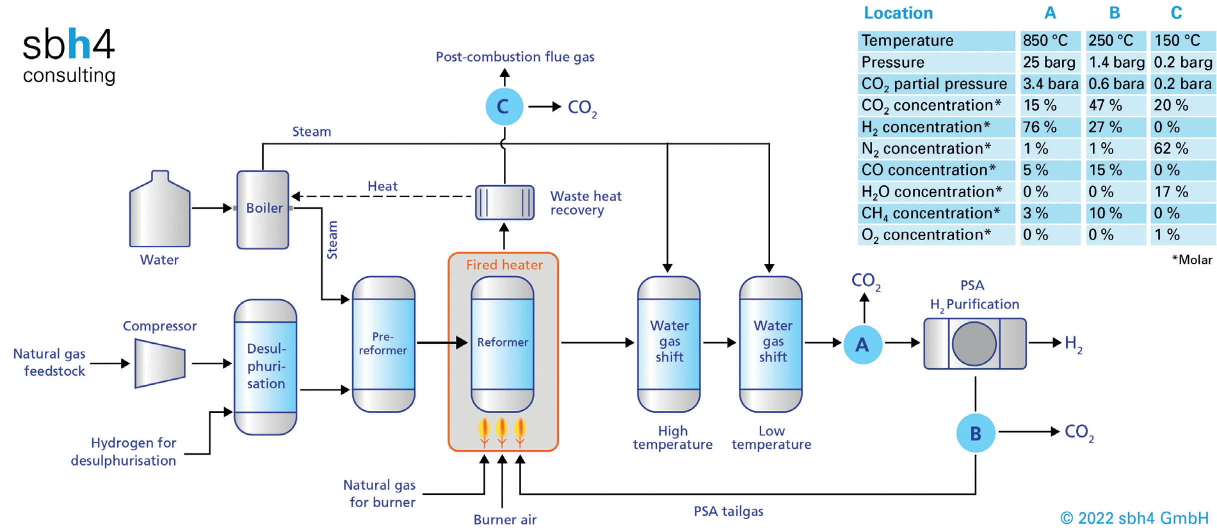
$CO_2$ is released from the SMR in two locations, firstly as the feedstock is transformed to hydrogen, $CO_2$ is produced within the process as a by-product. This is an unavoidable consequence of this chemical pathway. The second source of $CO_2$ emissions are from the combustion of fossil fuels, generally the same natural gas feedstock, to create the heat that is required to drive the reforming chemical reactions that convert the feedstock to hydrogen.

*SMR at Port Arthur, Image courtesy of Air Products and Chemicals Inc*

## Potential Locations for $CO_2$ Capture from Steam Methane Reforming

| Location | A | B | C |
|---|---|---|---|
| Temperature | 850 °C | 250 °C | 150 °C |
| Pressure | 25 barg | 1.4 barg | 0.2 barg |
| $CO_2$ partial pressure | 3.4 bara | 0.6 bara | 0.2 bara |
| $CO_2$ concentration* | 15 % | 47 % | 20 % |
| $H_2$ concentration* | 76 % | 27 % | 0 % |
| $N_2$ concentration* | 1 % | 1 % | 62 % |
| CO concentration* | 5 % | 15 % | 0 % |
| $H_2O$ concentration* | 0 % | 0 % | 17 % |
| $CH_4$ concentration* | 3 % | 10 % | 0 % |
| $O_2$ concentration* | 0 % | 0 % | 1 % |

*Molar




| | Location A | Location B | Location C |
|---|---|---|---|
| Process stage | Pre-PSA | Post-PSA | Post-combustion |
| Advantages | High pressure, high $CO_2$ concentration, highest $CO_2$ partial pressure, lowest unit cost of $CO_2$ capture from Amine Solvent or VSA processes | Low flowrate ($H_2$ removed), highest $CO_2$ concentration | More than 90 % capture rate possible (captures process $CO_2$ and burner $CO_2$ emissions), low pressure location can be suitable for emerging $CO_2$ capture technologies such as TSA and mineralisation |
| Disadvantages | Max 70 % $CO_2$ capture rate possible (burner $CO_2$ emissions not captured), high flowrate ($H_2$ included) | Max 70 % $CO_2$ capture rate possible (burner $CO_2$ emissions not captured), low pressure | Low pressure, lowest $CO_2$ concentration, high flowrate due to combustion air, highest unit cost of $CO_2$ capture from Amine Solvent or VSA processes |

$CO_2$ capture from steam methane reformers (SMRs) is often regarded as a 'quick-win' in the decarbonisation of industrial processes. The $CO_2$ concentration, pressure, and partial pressure in the SMR process gas is high. This leads to cost-effective $CO_2$ capture. Furthermore, $CO_2$ has been captured from SMRs for decades so that the $CO_2$ can be used to make urea fertilizer, when reacted with ammonia that is produced from hydrogen made on the SMR. There is therefore a wealth of experience to leverage.

The use of cryogenics to capture and purify $CO_2$ from SMRs is likely to be the next milestone in the development of $CO_2$ capture from these units. The Cryocap™ H2 process from Air Liquide combines cryogenic separation of $CO_2$ from the SMR process gas stream with membrane separation of hydrogen.

A demonstration project at an SMR in Port Jérôme, on the river Seine in France, showed that an additional 12% hydrogen yield from the SMR is achievable using the Cryocap™ H2 process. This can have a tremendous positive impact on operational economics and can help to fund the investment in the Cryocap™ H2 equipment.

With Cryocap™ H2 directing more hydrogen to the product stream, there is less hydrogen available for the SMR fired heater, so additional natural gas is required to compensate for the reduced heat energy available. However, the additional hydrogen production can more than offset the cost of the additional natural gas.

If liquid $CO_2$ is required for food and beverage applications, additional $CO_2$ purification is required. In the Cryocap™ H2 process, oxygen is added to react with hydrogen in the $CO_2$

## Steam Methane Reforming Chemistry

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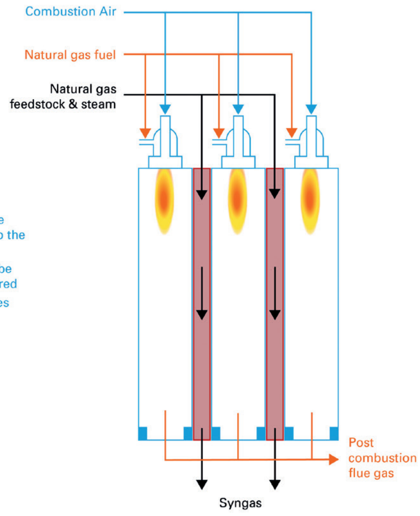


**Notes:**
- In the SMR the air/fuel combustion reaction takes place in a separate part of the equipment to the reforming reaction
- SMR may alternatively be side-fired or upwards-fired
- Red shaded area denotes catalyst bed



| | Steam Methane Reforming – SMR |
|---|---|
| Carbon feedstock | Natural gas, refinery gas or naphtha |
| Oxygen input | Air for fuel combustion to heat the reforming process |
| Steam feedstock | From waste heat recovery boiler |
| Catalyst | Nickel |
| Target chemical reactions | $CH_4 + H_2O \rightarrow CO + 3H_2$ |
| Additional side reactions | $CO + H_2O \rightarrow CO_2 + H_2$ |
| Energy required/released | Endothermic, requires heat input |
| Hydrogen content in syngas | ~70% $H_2$, balance CO, $CO_2$ and $CH_4$ |
| Syngas pressure | 15 to 40 bar, 25 bar is typical |
| Syngas temperature | 850 °C |
| Downstream process | Water-gas shift: $H_2O + CO \rightarrow H_2 + CO_2$ |

## Steam Methane Reforming Decarbonisation

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**Notes:**
- $CO_2$ is released from the reforming process chemistry
- $CO_2$ emissions are also associated with heat energy required to drive the reforming reactions
- The heating process can potentially be decarbonised with renewable power and electrical heating or microwaves
- CCS to capture $CO_2$ from the process and / or the associated heat energy production is possible

Steam Methane Reformer

| | Steam Methane Reformer SMR |
|---|---|
| Combustion reaction forming post-combustion $CO_2$ | $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ |
| Chemical reaction producing $CO_2$ in process | $CH_4 + H_2O \rightarrow CO + 3H_2$<br>$CO + H_2O \rightarrow CO_2 + H_2$ |
| Decarbonisation approach for $CO_2$ generated by the process | Feed the reformer with biomethane instead of natural gas or $CO_2$ capture |
| Industries with SMR applications | Ammonia, Methanol, Gas-to-Liquids, Refining |

stream to produce water using catalytic oxidation. The water is then removed on regenerative dryer adsorption beds. Excess oxygen is separated from the liquid $CO_2$ using cryogenic distillation. Mercury removal is a final polishing stage which is achieved on an activated carbon filter bed.

$CO_2$ liquefaction is achieved using a heat exchanger to condense $CO_2$ gas. The cold side of the heat exchanger is generally fed with a refrigerant gas from a typical mechanical refrigeration circuit. Electrical power is required to operate the refrigeration equipment, so the process can be decarbonised using renewable electricity.

The $CO_2$ side of the liquefaction circuit is operated at a pressure of 15 to 25 bar. At elevated pressure, common refrigerant gases such as $CO_2$, ammonia or F-Gases can be used to achieve the temperature required to liquefy the $CO_2$.

As an alternative to mechanical refrigeration, ammonia absorption refrigeration can be used. This process avoids the mechanical compression of a refrigerant gas and derives the cold energy instead from the absorption and desorption of ammonia in water. To drive the ammonia out of the water, heat energy is required. If waste heat is available, this process can be more efficient than mechanical refrigeration.

After liquefaction, $CO_2$ is stored and transported in tanks which are insulated to minimise boil off. Typically, liquid $CO_2$ storage tanks are constructed of carbon steel and insulated with polyurethane foam. Often, a refrigeration unit is used to re-liquefy boiled off $CO_2$. This avoids $CO_2$ losses and over-pressurisation of the $CO_2$ storage tank.

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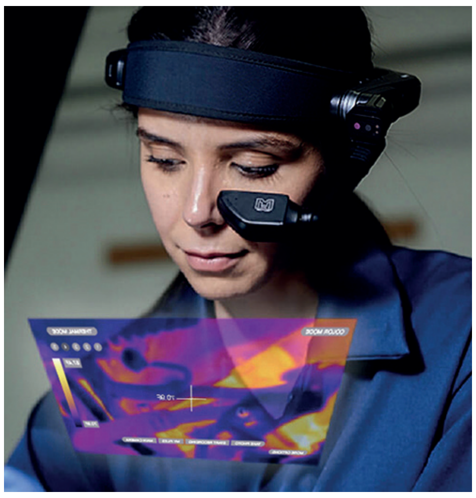
# World's first hands-free, voice-controlled thermal camera



RealWear's innovative Thermal Camera module connects seamlessly with RealWear NavigatorTM Series headsets, includes radiometric FLIRLepton® and is the only device that supports MSX® technology to enable frontline industrial professionals to conduct inspections, enhance remote support sessions and avoid equipment downtime using simple voice commands

"RealWear Navigator head-mounted devices, with its revolutionary modular design, continues to gain support with Global 1000 companies as the new gold standard in assisted reality. The compelling option to add thermal image capture without occupying your hands in hazardous environments gives frontline professionals more real-time information to do their jobs safely and productively," said Rama Oruganti, Chief Product Officer at RealWear. "By combining **Teledyne FLIR's** thermal expertise with RealWear's best-in-class voice-driven wearables through its Thermal by FLIR program, we're creating a digital tool with extended capabilities for the modern frontline worker."

"As a XR wearable evangelist for Honda, the idea of leveraging the modular design of RealWear Navigator 500 is a no-brainer," said Greg Cooper, Innovation Engineer, Manufacturing, American Honda Motor Company. "A fully hands-free thermal camera will give our technicians another superpower to get the job done fast. For example, a hands-free fully voice-controlled thermal enables us to immediately show what we're doing to address airlocks and ventilation leaks to the reliability team to give them the confidence that our engines and systems are reliable and meet our high-quality standards."

Imagery is viewable in real time and will in the future have the ability to be shared via Microsoft Teams, Zoom, Webex Expert on Demand, among others. Compatible with Teledyne FLIR's ecosystem, the special radiometric JPEG format images can be stored, transmitted, and downloaded for use within the FLIR Thermal Studio post-processing software for greater analysis and reporting options.

"Thermal imaging is critical to assembly, effective condition monitoring and predictive maintenance programs," said Dan Jarvis, Sr. Director Business Development Teledyne FLIR. "RealWear Navigator 500 is the only hands-free system to currently incorporate the FLIR Lepton and patented MSX technology, which overlays the live edge detail from the visible camera on the thermal image to provide critical information."

Key use cases of RealWear Navigator with thermal include electrical, mechanical, plumbing, HVAC inspections along with initial installation readiness, process monitoring or line monitoring where a connected hands-free device adds flexibility, safety, and overall efficiency for optimum plant production such as automotive assembly line processes.

"Our long-term vision of assisted intelligence takes shape when you start connecting new captured data like thermal imaging into the cloud and beyond," continued Oruganti. "Industrial wearables have a huge role to play going forward in industry 4.0, and we're proud to be a part of the global movement."

For More Info, email: 59171pr@reply-direct.com