

1.1 The Hydrogen Generation System

HyGear offers a Hydrogen Generation System based on steam reforming in combination with pressure swing adsorption with an output capacity of 100 Nm³/h H₂. The system HyGear offers is a stand alone system and therefore will be easy to integrate. The system includes water purification, a burner supplied with natural gas and or off gas, a desulphurisation unit and a hydrogen purification unit based on pressure swing adsorption PSA. An internal buffer tank for pure Hydrogen is included as well as all required valves, control and alarm systems and sensors. This all is needed to guarantee safe operation of the unit. A process flow diagram is added which includes all input and output streams. Below you will find a short basic description of the HGS-C system.

1.2 GENERAL DESCRIPTION HGS-C

1.2.1 INTRODUCTION

The HGS-C system is a hydrogen generation system based on small scale fuel processing combined with PSA. It has an output of 100 Nm³/hr of hydrogen with a purity of 99.999%. The HGS-C consists of four sections:

- The reformer section
- The PSA section
- An off-gas vessel section
- A hydrogen storage section



The HGS uses state of the art steam reforming process combined with an advanced PSA process. This means that the design is based on a highly integrated technology in which no external fuel stream, besides the PSA off gas, is required to provide heat for the reforming reactor.

The high level of integration and full utilization of the PSA off gas yields a very high efficiency in hydrogen production. Further, the design for a single pressure stage means that there is no compression between the reformer and PSA which yields high efficiency and safe operation.



A 3-D drawing is depicted here. From left to right the following sections are positioned: reformer section, PSA section, off-gas vessel section, hydrogen storage section. The system control unit is placed in the reformer section (top left side).

1.2.2 Reformer section

The reformer section consists of following subsystems:

- Fuel Preparation Module. In this module the natural gas is pre-cleaned and de-sulphurized to avoid problems in the reforming process due to contamination. The Fuel Preparation Module is designed to prepare natural gas at the right pressure and remove contaminants such as sulphur from the feed stream. In this case, the module, specifically designed for your local natural gas composition will be included. This means that amongst others, a sulphur removal system is included that removes locally used odorants from the feed stream.
- Reformer Module. In the reformer module the natural gas is converted to a hydrogen rich stream, using a precious metal catalyst. The process used is steam reforming; the required steam is generated with an integrated steam generator. The necessary heat is brought into the system using an integrated burner that combusts the off-gas coming from the PSA through the off-gas section. The reforming process operates approximately at 7 bar(a) at temperatures between 650 and 800 °C.
- Control Box. In this section the control box is placed. With the control box the whole system is managed based on a start up and shut down signal. When running the system can run based on a demand signal of the user. Several process and sub-process parameters are monitored and controlled. It also covers all required safety functions. A shut down sequence can be triggered manually. Further it is equipped with a PC interface connection compatible to an Ethernet converter based on the TCP/IP network protocol for data logging.

1.2.3 PSA-section

The PSA-section is based on HyGear's Q-cycle PSA-technology. It is a Pressure Swing Adsorber that operates at the exit pressure of the reformer section. In a continuous cycle, the hydrogen rich stream coming out of the reformer section is fed to the vessels, where all contaminants are adsorbed. Thus, when opening the hydrogen exit valve, a pure hydrogen stream (purity 99.999%) is created which is fed into the hydrogen storage vessel. After that, the vessel is purged to a lower pressure, and all contaminants are fed into an off-gas vessel. At that stage, one of the other vessels has taken over the hydrogen cleaning, thus realizing a continuous high purity hydrogen stream out of the system. The off gas (a mixture of H₂, CO, CO₂ and some other fractions) is all going to the Off Gas Vessel.

1.2.4 Off-gas vessel section

The off-gas vessel section contains a high quality stainless steel storage vessel where the off-gas is collected. This vessel is used to equalize the pulsating off gas stream from the PSA into a continuous stream, which is fed back into the burner of the reformer module, where it is utilized to generate heat in the integrated burner.

1.2.5 Hydrogen storage vessel section

The pure hydrogen stream coming out of the PSA is fed into a high quality stainless steel storage vessel. The hydrogen is stored at a pressure of 6 bar. The rest fraction is in total less than 10 ppm. Therefore all possible pollutants, such as CO are maximized to 10 ppm total, which is in line with state-of-the-art requirements for fuel cell application and fuel cell testing.

1.2.6 Specifications

1.2.6.1 Size

The HGS-C is a fully packaged system, with following dimensions:

Height:	2.60 mtr
Length:	6.00 mtr
Width:	2.50 mtr
Weight:	12.500 kg

1.2.6.2 Connections

The HGS-C is adapted to reform high caloric natural gas, with its specific odorant locally used. We assume that at the facilities natural gas is available at 8 bar pressure from a 15 mm connection pipe. If the natural gas is not available at that pressure, an additional natural gas compressor unit is required and can be offered (option). The hydrogen out connection is standard delivered as 12 mm stainless steel pipe. A 15 mm tap water inlet connection is foreseen in the design.

The unit is designed to operate at 230 VAC 50 HZ. The exhaust of the burner is a standard central heating boiler connection of 80 mm.

1.2.7 Capacity

The HGS-C has a nominal capacity of 100 Nm³/hr of hydrogen with a purity of 99,999% (5.0 quality). The outlet pressure is 6 bar(a). There is no intermediate compression of hydrogen mixtures between the reformer and the PSA.

1.2.8 Modulation

Because of its specific design, the HGS-C can be modulated in a range of 25 to 100% of the capacity. This means the system can produce between 25 and 100 Nm³/hr.

1.2.9 Conversion rate and overall efficiency

The HGS-C has a conversion rate of between 50% and 75%, depending on the operation mode (full load versus partial load). Full utilization of the PSA off-gas and optimized steam generators and efficient heat management lead to these high conversion rates. The total efficiency of the installation at full load is about 70%.

1.2.10 Testing

After construction the system will be completely tested in our facilities. After completing the tests a formal Factory Acceptance Test will be performed together with your representative. A Factory Acceptance Form will be drawn up and signed by our and your representative. It will be filed in the product binder.

1.2.11 Installation



HyGear performs the on site installation for which a date has to be agreed in mutual understanding. Together with your representative a first start up will be performed. A Commissioning Report will be made and signed by our and your representative. It will be filed in the product binder.

1.2.12 Documentation

The system will be delivered with following documentation:

- Installation manual
- Operation manual (including instructions of measurement equipment and controlling devices)
- Maintenance manual
- Product binder for filing Maintenance Reports and Service Reports

All documentation and forms are in English language.

1.2.13 Training

A training of your representatives is included in the installation and first start up activities (see above). Training will be carried out to ensure that the required knowledge for operating the HGS-C is more widely spread and absorbed and thus safe and reliable operation is ensured. Upon completion of the training a Certificate of Training will be granted to the persons that successfully completed the training. A copy of these certificates will be kept in the product binder. In order to maintain the guarantee on the HGS-C it should be operated only by staff trained and certified by the supplier or by appointed maintenance personnel of the supplier.

1.2.14 Maintenance

A maintenance manual will be handed over upon delivery. Of each maintenance visit a Maintenance Report will be filled in and filed in the product binder. We recommend to also include maintenance carried out by yourselves in this binder as well as changes and/or adaptations to the system.

1.2 Feed stock and utilities spec.

The feedstock for the HGS-C is high caloric natural gas.

The HGS-C with a capacity of 100 Nm³/h of Hydrogen has a natural gas consumption of less than 60 Nm³/h natural gas at the inlet. In the HGS-C a desulphurisation unit has been build in as part of the total system, therefore a separate sulphur trap is not necessary.

The water supply to the system is normal tap water as a water purification subsystem is included in the HGS-C. This subsystem is operating fully automatically and will be maintenances according to the existing maintenance procedure every year. The maximum amount of water consumption is 280 litre/h, this leads to a steam/carbon ration between 3 and 4.

The connections to the reformer unit HGS-C are:

- natural gas: round 15 mm copper
- water: round 12 mm stainless steel



The HGS-C unit needs a connection for electricity with the following specifications: 230 VAC 50 Hz with a maximum load of 10 kWe. A separate cooling water connection or system is not necessary, there is also no utilities necessary for inert gas for purging and air for pressure valves. The special requirement that the HGS-C system needs is hydrogen for a short period during the start up procedure. For maintenance and repair HyGear could request that the installation needs to be flushed with inert gas like nitrogen before start of the maintenance.

The HGS-C has an integrated heating unit that keeps the installation frost free. If the unit will be placed outside with possible sub-zero operation an additional electrical connection should be available (3 phase 400 VAC max 10 kWe).

1.3 Hydrogen production and purification

The HGS-C unit will deliver 100 Nm³/h hydrogen with a purity of 99.999 % H₂ (5.0). The required measuring equipment to prove this is not included. HyGear guarantees that in the outlet stream of pure hydrogen will be less than 5 ppm O₂, less than 5 ppm of H₂O and less than 10 ppm CO.

Process conditions (flow, temperature, pressure and composition – also including oxygen, NO_x and other impurities) of the outlet gas streams for both the steam reforming unit and hydrogen purification unit are described in Annex 5: Schematically overview of the installation

1.4 Operation of the reformer system

The HGS-C can be operated in a non-continuous manner and with varying production capacity. The system will work according to the following requirements and performance skills:

1. Start-up from cold state to full load in less than 2 hours,
2. Shut-down from full load to zero in less than 1 hour, Hydrogen production will stop immediately, controlled PSA cleaning and internal head waist (within own internal cooling system), will be finished within one hour.
3. Maximum rate/change in production capacity (yielding hydrogen with the specified quality): $\pm 3\%$ /minute.
4. Turn-down ratio is: 1:4 (25-100% capacity of the actual reformer unit, system has buffering system, this means 0-100%)

With the HGS-C unit a maintenance manual is been added and hand over at the actual installation of the unit on site. This manual includes all required documents and working procedures. For replacement of the major components HyGear must be consulted. Concerning the catalyst replacement: Due to the design of the reformer system, the catalyst can easily be replaced by representatives of HyGear. All the other components like PSA vessels, valves, pumps, control unit etc. can also be replaced easily.

1.5 Process control and safety systems

For operating the HGS-C a PLC of Siemens is used. It controls the process and also it checks the safety of the total system. The control unit operates by measuring and monitoring several key variables of the system.

Below you will find the basic information about the reformer control and about the shutdown procedure:

Process: Siemens PLC

Burner: Separate fail-safe burner control unit with ionization flame detection

Reformer controls

Variable:

Natural gas into reformer

DI-water into reformer

Burner input

Gas to air ratio

Reformer/PSA pressure

PSA cycle time

Control based on:

Hydrogen consumption

Temperature sensor of water level control

Reformer catalyst temperature

Oxygen sensor in flue gasses

PSA pressure control system

PSA feed

Shutdown

Manual and automatic safe shutdown are managed by the PLC, and result in a controlled shutdown, preventing too high temperatures and pressures in a controlled manner followed by the cleaning of the PSA-system so the system is ready for restart.

Controlled emergency shutdown (manual or automatic) is identical to manual and automatic safe shutdown.

Hard wired emergency shutdown results in loss of the 24VDC power to the valves and the uncontrolled blow-down of the reformer through the NO safety valve. In such case the PLC keeps logging data.

Power outage results in loss of the 24VDC power to the valves and the uncontrolled blow-down of the reformer through the NO safety valve. No data acquisition.

Hydrogen for startup

At first startup or after an uncontrolled shutdown 20 Nm³ of hydrogen (approximately 2 standard bottles) is required for repressurizing the PSA and reformer. This hydrogen must be delivered at a pressure of at least 8 bar(a).

The used safety control has an interface using PROFIBUS DP.

1.6 Instrumentation and data acquisition

HyGear is aware that the delivered system has a combined research and demonstration function, and it is important that all process data from operation of the reformer system are readily available to a monitoring system. Measurements of flow, temperature and pressure can be made available by HyGear.

The HGS-C is standard equipped with the following measuring points inside:

1. Temperature and pressure before and after the reformer, and temperature in the exhaust gas from the burner
2. Temperature and pressure before and after the purification unit (PSA)
3. Reformer temperature is in principle classified information, indicative will be provided.

All flows in and out of the reformer are not measured by HGS-C this also includes the flows of the purification, including the exhaust gas from the burner. The only flow accurately measured is the inlet flow of the natural gas.

Composition of all flows in and out (including gas feed and exhaust gas from burner) of the reformer and purification units are not measured standard

The HGS-C is standard not equipped with analyzers that can measure the gas composition; several sampling points as described above however are installed.

1.7 Quality, Health, environment, safety (HES) and certification

The reformer system of HyGear HGS-C and auxiliary systems will comply with industrial practise for safe and environmentally friendly operation. This implies that the HGS-C has:

1. No components, or parts of these, that have outer surfaces temperature higher than 60°C
2. The equipment will not, under normal operation, emit hazardous/ poisonous components. The HGS-C has a safety vent pipe, which must be installed correctly by Hytec according to the local legislation.
3. If emissions of hazardous/poisonous components may occur in special occasions systems for detection of such components will be identified and suggested installed, already inside the HGS-C sensors are installed and connected to the safety control of the HGS-C .
4. Sensors for explosive and flammable gases and CO are inside, both cabinets are protected by CO sensors with a high cross senility for hydrogen.
5. Ventilation flow that is required inside the system is working up to maximum of 2000 m³/h based on outside installation.
6. Noise \leq 65 dB(A)

The HGS-C will be delivered with a CE marking.