INTRODUCTION

With the Big Thing in the rear view mirror and our minds clearly looking towards the future, we are all eagerly looking forward to revolutionize how we use the way energy is used, stored and managed.

During the hands on workshop, we demonstrated how to build a microgrid – with the added twist of adding a more robust, long-lasting, energy-dense energy storage solution compared to conventional batteries. Hydrogen's versatility makes it the battery we need for seasonal storage, the fuel we use in our cars and heaters and, which due to its unique properties, has near endless applications in industrial uses.

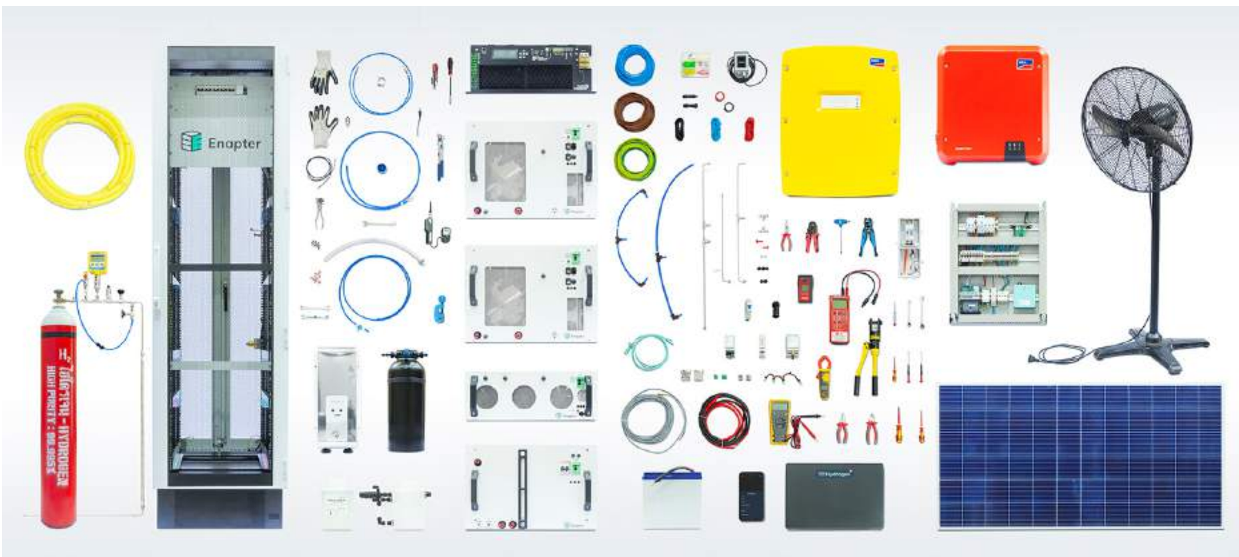

Figure 1: The Big Thing: The assembly of a hydrogen microgrid

In this quick start guide we will recap how to assemble and integrate various systems for a microgrid and how to integrate a hydrogen system into these established ecosystems. Following this guide will (hopefully) enable the reader to establish a hydrogen microgrid of their own.

Danger due to improper use!
Improper use of the products described in this guide can result in serious injuries.

- Comply with all safety instructions and warnings with each component integrated into microgrids.
- Please ensure to follow and comply with all local regulations. It is the responsibility of the system installer/end user to ensure all local regulations and directives regarding the system are followed and implemented.

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THE BIG THING MICROGRID

The demonstration microgrid which was established during the hands on workshop combined all common components usually found in an off grid installation. We made an effort to only select modular system components, so if more loads are connected or higher storage capacity is needed, you could simply achieve this by adding more of the components to each of the areas.

While the included grid and load in the microgrid were not very large scale, larger installations typically use complicated and expensive PLC control systems, which are not needed with a success

ful implantation of Enapter's EMS.

Figure 2: The fully assembled microgrid at the Big Thing

With the EMS (Enapter Monitoring System) integration of the various components, the setup, control and monitoring on the microgrid systems becomes easier than it ever was before. In the following section every component included in the demonstration microgrid will be described and their function inside the microgrid explained with a little more detail.

THE ENERGY SOURCE: THE SOLAR PANELS AND THEIR INVERTER

At the Big Thing, 20 solar panels were installed to provide the microgrid with power, totaling 6.4 kWp.

Figure 3: Solar Panels installed at Nong Nooch Gardens for the Big Thing

In this microgrid we used the SMA Sunny Boy 5.0 to invert the DC from the solar PV to AC and supply it to our AC distribution panel.

Figure 4: The solar inverter used in the Big Thing: Sunny Boy 5.0

Datasheet

The datasheet for the Sunny boy 5.0 can be found here.

THE BUFFER: THE BATTERIES AND THEIR INVERTER

In this microgrid we used the SMA Sunny island 6.0H to charge and discharge the battery and to build the AC microgrid.

Figure 5:The battery inverter used in the Big Thing: Sunny Island 6.0H

For the batteries, a simple array of locally sourced sealed lead acid batteries were used, with a total capacity of 48V, 20Ah.

Datasheet

The datasheet for the Sunny Island 6.0H can be found here.

THE EMS EXTENSIONS

Without the EMS (Enapter's software defined **E**nergy **M**anagement **S**ystem) integrated into the microgrid and constantly monitoring and controlling the system components, the system could not be considered "smart". With Enapter's EMS, whose high level architecture shown below, the system is able to translate many different communication protocols into a universal one, in order to integrate many different suppliers system components. Enapter supports all relevant industry protocols.

The EMS is based on several modular components, which are combined based on system architecture and desired logic:

- Universal Communication Modules
- Enapter Gateway
- Enapter Cloud and Dashboards
- Mobile Application

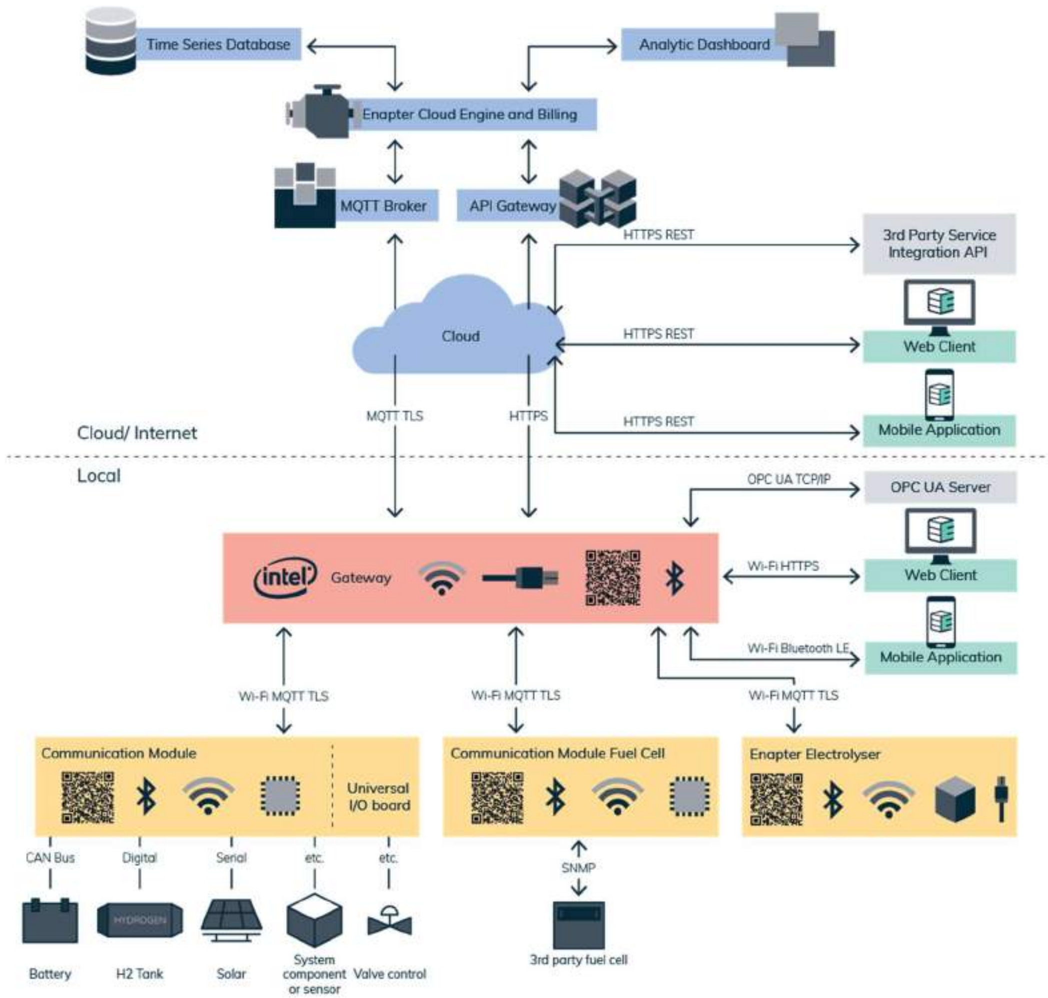


Figure 6: Enapter's software defined Energy Management System

For the Big Thing microgrid, several universal communication modules were installed.

- Modbus extensions were installed and used to communicate and read data via Modbus from the Sunny Island and Sunny Boy inverters, the irradiance sensor [Igenieurburo Irradiance Sensor (SI-RS485TC-T-MB)] and the power meter [Mercury 206 RN (RS-485 Power Meter)].
- A hydrogen tank extension was used to read pressure and temperature data from the hydrogen storage tank and allowed us to calculate the total amount of hydrogen stored at any time.
- An ethernet extension was installed to communicate, read data and control the fuel cell.

In addition to this an Enapter gateway was installed, whose software is based on the Open Source Linux and Yocto project. It is run on standard Intel-based hardware. The Gateway aggregates all data on-site from all communication modules and drives IF-THEN-ELSE logic using a Rule-based Engine (RbE). This logic allows to send action commands to devices based on conditions driven by sensors or other devices integrated in the energy system.

Figure 7: The Enapter gateway being provisioned using the mobile application

The Hydrogen System Components

EL2.0

The EL2.0 (Electrolyser 2.0) is the heart of the hydrogen energy storage system. It creates up to 500 NL/hr of H_2 and can be freely stacked together to create larger systems.

Figure 8: An EL2.0 - the modular hydrogen generator produced by Enapter

The key to the modular EL2.0 is the patented anion exchange membrane (AEM) electrolyser stack. The hydrogen is produced on the dry cathodic side from water permeating the membrane from the anodic side, which is where the electrolyte is circulated and the oxygen is vented from.

Our hydrogen is produced under pressure (typically 35 bar) and already extremely dry and pure (99.95%). The only required maintenance is to exchange the electrolytic fluid once a year. Furthermore, due to being integrated seamlessly with the EMS other types of needed maintenance can be analysed, predicted and rectified by our team before any issues occur.

Datasheet

	EL 2.0
Max hydrogen flow rate @ 0°C/1bar:	500 NL/h
Max produced outlet pressure:	35 bar
Purity of hydrogen:	99.95% @ 35bar
Operative power consumption:	2.4 kW
Max power consumption:	3 kW
Power supply:	AC 110-240 VAC/50-60Hz
Ambient conditions: - Temperature: - Relative humidity: - Storage temperature:	5°C – 45°C 20-95% non-condensing Min. 2°C
Demineralized water: - Max conductivity at 25°C:	< 20 µS/cm (at 25° C)
Conditioning solution:	KOH = 40 g (in 4L of demineralized water) (1% by weight)
Max water consumption:	0.40 l/h
Water input pressure:	0.75-4 bar
Net Weight: EL 2.0 Module (empty)	53 kg
EL 2.0 module dimensions (WxDxH):	483x490x354 mm (8U)
Index of protection:	IP22

DR2.0

The DR2.0 (Dryer 2.0) is an inhouse developed, space saving (4 RU), dryer – boosting the hydrogen purity of the Enapter systems from 99.95% to 99.999% required for most FC applications, at a flow rate of up to 2 Nm^3/hr (4 EL2.0 per DR2.0). It is possible to further increase the hydrogen purity to obtain lab quality "6.0" Hydrogen by attaching special particle filters on the outlet line.

Figure 9: A DR2.0 - the space saving, 4U dryer produced by Enapter

As in the EL2.0, all connections on the DR2.0 are located on the front panel. When a dryer is integrated in the same cabinet as the EL2.0s, the dryer should be mounted below all hydrogen generators.

When using a dryer inside a cabinet, all **H1.1** ports coming from the electrolysers should be combined and connected to the port H1.1 of the dryer (module 1). The dry hydrogen (**hydrogen outlet**) and purge hydrogen (**H1.2**) outlets then only need to be connected to the bulkheads which are pre-mounted in the cabinet.

Datasheet

	DRYER 2.0
Max hydrogen flow rate @ 0°C/1bar:	2000 Nl/h
Purity of hydrogen:	99,999% @ 30bar
Operative power consumption:	375 W
Power supply:	110-24VAC/50-60Hz
Ambient conditions: - **Temperature:** - **Relative humidity:**	 5°C – 45°C 20-95% non-condensing Min. 2°C
Dryer Module Weight:	20 kg
Dimensions Dryer Module (WXDXH):	483x500x178 mm
Index of protection:	IP22

WTM

The WTM (Water Tank Module) is an auxiliary system, which is not required for all installations. It provides the ability to continue operations even with intermittent supply of water, as the 35 L tank provides around 80 hours of autonomy for a single EL2.0, while constantly supplying the required water input pressure to the hydrogen generators.

It is recommended to mount the water tank module in the bottom of the cabinet. Simply connect the corresponding ports with the electrolyser system using the appropriate John Guest tubing. The WTM does not require a separate breaker on the power distribution panel as it has its own.

Datasheet

	Water Tank Module 2.0
Dimensions:	Width: 483mm Depth: 640mm Height: 310mm
Weight:	Empty: 25 kg Full: 65 kg
Max outlet water flow rate:	3.8 liters per minute
Max outlet pressure:	4.8 bar
Operative Power Consumption:	50 W
Max power consumption	70 W
Power Supply	AC 85-264 VAC/47-63Hz
Ambient conditions - **Temperature:** - **Relative humidity:**	 5°C – 45°C 20-95% non-condensing
Demineralized water input - **Max conductivity at 25°C:**	 < 20 µS/cm (at 25° C)

Enapter Indoor Cabinet

The Enapter indoor cabinet is a standard 19" IT server rack from Rittal with vented front and back doors. The cabinet is slightly modified to include all the bulkheads needed for standard system integrations.

The advantage of keeping the Enapter system indoors is that the cabinet will not consume any power as no forced airflow is needed for Enapter modules if they have the airflow (front to back) is unrestricted.

Figure 10: Airflow through an indoor Enapter cabinet

PlugPower – GenSure E-1100

In the Big Thing cabinet a PlugPower Gensure E-1100 was integrated. According to the manufacturer, the E-1100 is a fully integrated fuel cell system optimized for backup power applications and produces up to 1,100 Watts of power. Due to its small form factor it is easily integrated into a wide range of applications.

Figure 11: PlugPower GenSure E-1100, the FC used in the Big Thing micogrid

Please refer to the system manuals of the fuel cell to determine system operation requirements in terms of operating temperatures, required airflows and fuel input pressure requirements. The DC power input should be separated from the AC electrolyser systems.

Datasheet

The datasheet for the E-1100 can be found [here].

Hydrogen Cabinet Integration

The Big Thing Cabinet

While the cabinet used at the hands on workshop is a standard product Enapter carries a few key modifications were made to the cabinet in order to house the whole hydrogen system part of the microgrid (except for the tank).

In this section we will go step by step through each system component and important things to consider when integrating your hydrogen system.

P&ID

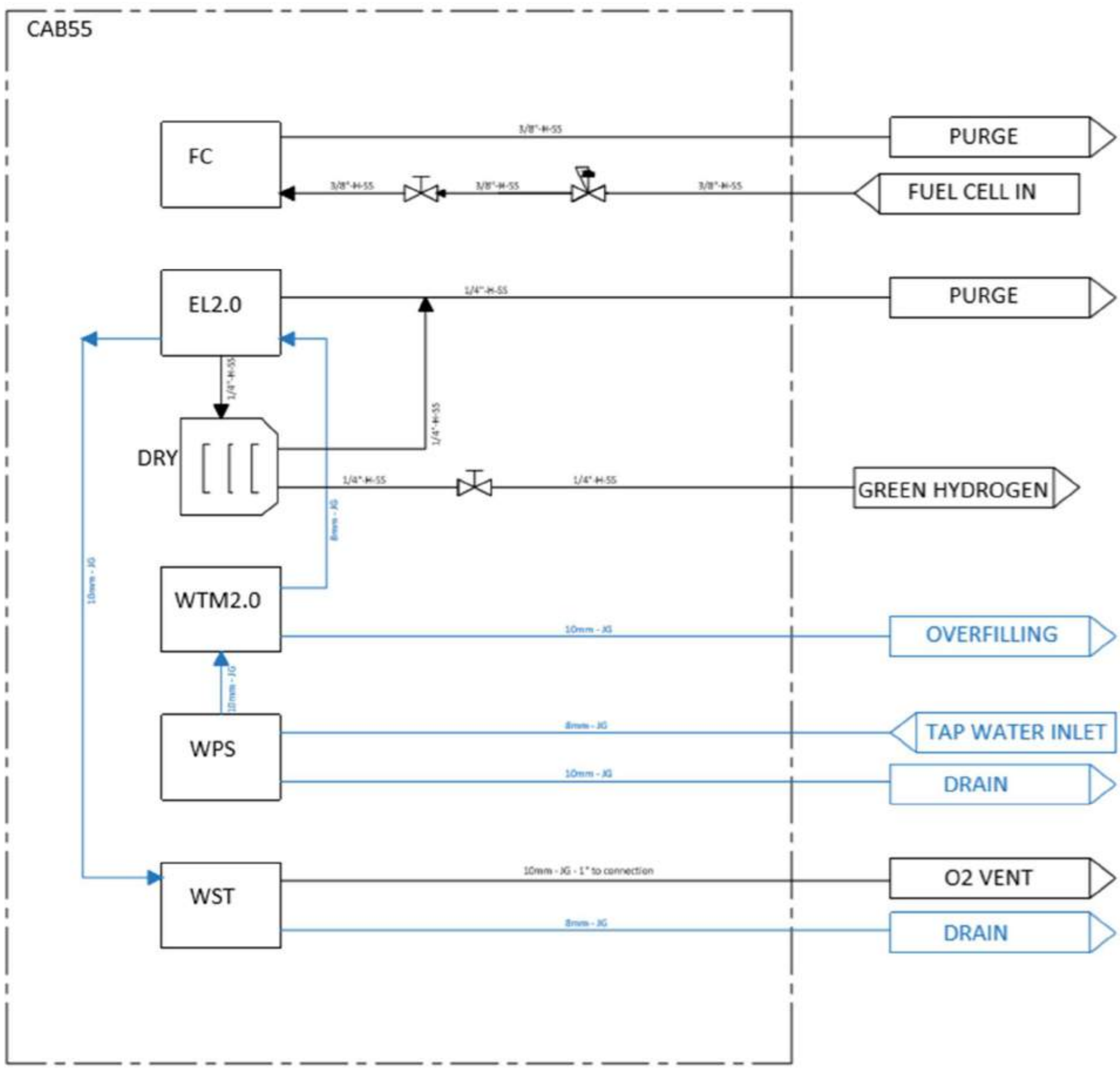


Figure 12: P&ID of the Big Thing cabinet

Hydrogen/Water Piping and Bulkheads

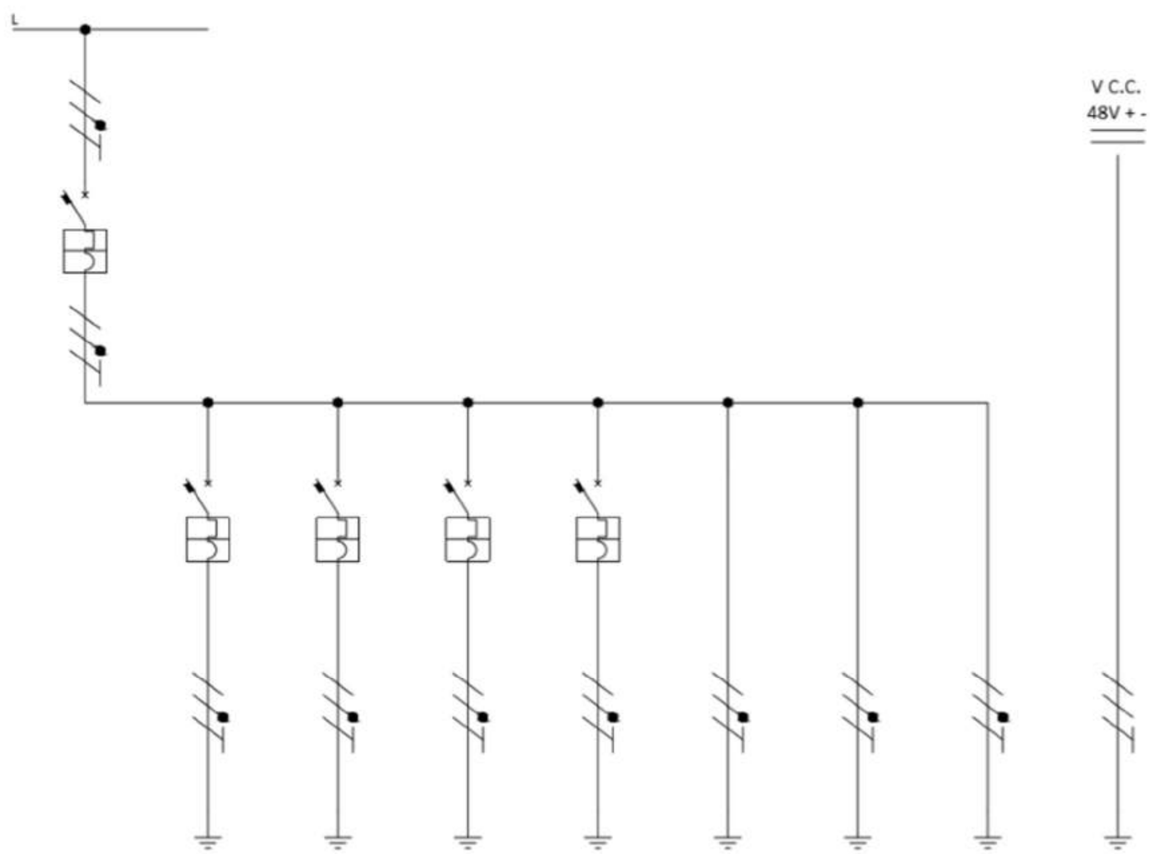
The hydrogen piping within the cabinet is quite simple to install – the piping is moved into the plinth only for aesthetic reasons.

First, high purity hydrogen is released from the electrolyser and fed into the dryer where it is further dried for use in the fuel cell. While in the cabinet for the Big Thing the hydrogen outlet pipe from the dryer is directly connected to the fuel cell's pressure regulator on the inlet in this system for simplicity, it is recommended to separate the hydrogen output and input into two different pipes coming and going from the tank, as shown in the P&ID above.

The water piping used in all Enapter products are easy to use, John Guest pipes that have push-fit connectors. Simply connect the water inlets and outlets together as shown in the P&ID above using the respective ports – please refer to the system manuals to ensure correct assembly.

SLD – Cabinet Wiring

Below is the single line diagram of the wiring installed in The Big Thing cabinet. It is important to keep distribution boxes with AC and DC power separate. Follow any applicable rules and regulations.



LOAD	DESCRIPTION	GENERAL	DRYER	ELE20	ELE20	WATER TANK	NUC	POWER SUPPLY FC COM MODULE	FUEL CELL
	POWER (KW)	3,6 kW	0,6 kW	2,4 kW	2,4 kW	0,1 kW	0,065 kW	0,202 kW	1,1 kW
	Operating Current(A) TENSION (V)	16,38 A - 230 V	2,6 A - 230 V	10,4 A - 230 V	10,4 A - 230 V	0,43 A - 230 V	0,3 A - 230 V	0,88 A - 230 V	22,9 A - 48 V
	Max Current(A)	31,74 A	4,6 A	23,9 A	23,9 A	0,65 A	0,3 A	0,8 A	

Figure 13: SLD - The Big Thing Cabinet

PURGE MANAGEMENT

The purge lines from the electrolyser and fuel cell require specific attention to implement. The purge exit is often called a blowout pipe.

At the end of operation and also after 24 hours of continuous operation, the electrolyser depressurizes and releases a total of all the hydrogen contained inside the system at the operational pressure. The hydrogen is released via the purge outlet port labelled **H1.2**, this is also the case for the dryer (DR2.0). The released hydrogen bears the risk of explosion – therefore, it has to be led into a safe area, which is defined by the absence of any source of ignition. This area should be located at a height of 3 meters above ground or higher.

The extent of this zone depends on different parameters (Length/diameter of piping leading to the safe area, use/no use of an orifice plate, use/no use of a blowout pipe at the end, etc.).

Generally, there are two options:

1. The customer may either calculate the measurements of the zone based on the provided data from above and based on his layout of the purge line up to the safety area, or

2. The customer may follow the recommendations of Enapter. This comprises the use of a standardized blowout pipe. The resulting explosive area, created by the released hydrogen, is cylindrical and has a height of 8,8 meters and a radius of 1,3 meters. Note that this area also extends in direction of the ground for a value of 10 times the diameter of the used blowout pipe (see the figure below).

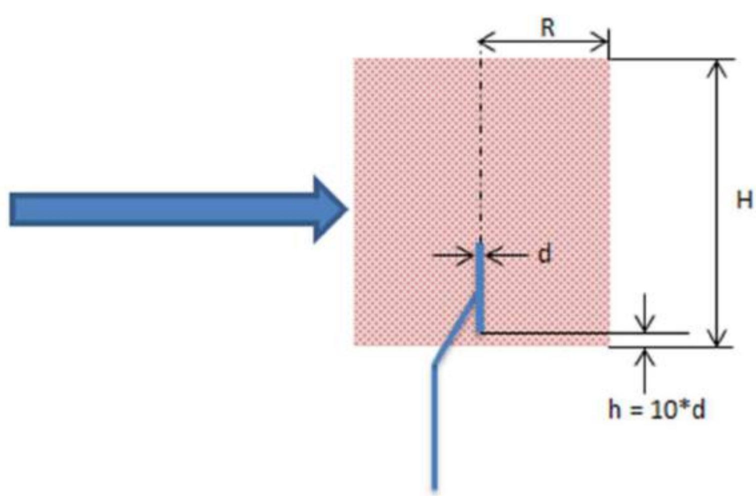


Figure 14: Safety area around vertical blowout pipe

All the purge outlets from Enapter systems can be combined together and piped away to a safety area. It is recommended that the pipe diameter is increased in order to reduce the volume (dB) of the purge.

It is vital that the purge pipe remains unobstructed from debris, ice or other things. Additionally, the pipe should be led straight out, and not be combined to other blowout pipes/pressure release systems. The use of check valves inline of the purge pipe is strictly prohibited.

Quick guide

1. Combine all purge outlets of Enapter systems. Ensure to size your safe area according to the total amount of gas being possible to be released at any one time.
2. Lead the purge outlet away from any sources of ignition to safe area where hydrogen gas can be safely purged.
3. Ensure there are no obstructions in the purge line.

VENT MANAGEMENT

The vent output of the electrolysers contains a non-flammable mix of mostly oxygen, hydrogen and water vapor. In order to run the system well it is very important to manage this output appropriately and to avoid any potential obstructions in the vent line. The vent line should be designed to reduce the amount of overpressure caused in the internal system as much as possible.

A common way to manage the vent line is to create a simple water trap at the bottom of the electrolyser cabinet, this ensure no gas escapes out of the drain pipe. This is especially useful in environments where the potentially hazardous vent output needs to be managed carefully.

Below, the prototype water trap which was integrated into the Big Thing cabinet is shown (denoted as WST in the P&ID above). By allowing the water condensing in the vent pipe to drain back into the tank, while at the same time only draining the vent water at a certain fill level, the system effectively separates the liquid and gaseous outputs and therefore makes drain management easy and safe.

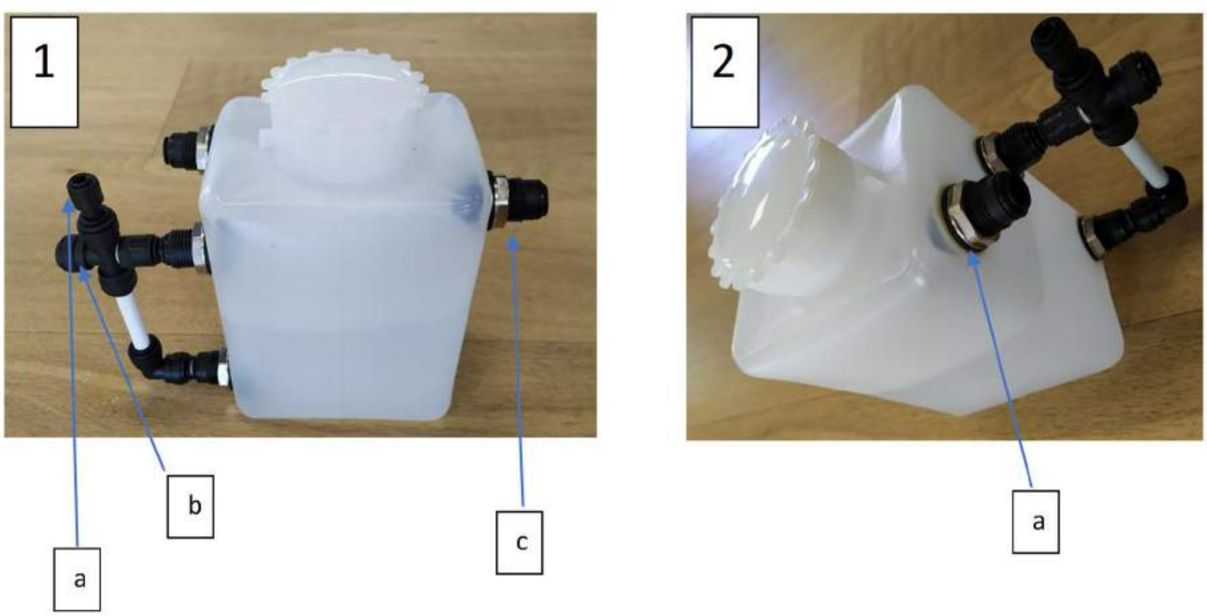


Figure 15: The vent management system (WST) installed in the Big Thing cabinet

Port 1.a serves for the entry of air, allowing the pressure to stabilize inside the tank and allows the correct draining of the condensed water through port 1.b.

The vent line attached at 2.a, should always have a positive inclination, in this way any water which is condensed inside the vent line is allowed to flow back into the container, where it is allowed to drain freely from the port labelled 1.b. It should be connected to a drain system without any increase in elevation to allow water to drain easily.

Port 1.c is the "Vent" inlet coming from the electrolysers:

From port 2.a, on top of the oxygen, a minimum percentage (up to 2%) of hydrogen gas is be expelled, therefore it must be connected with a plastic pipe and vented to a safety area.

The gaseous output from the vent and purge lines must be clearly separated in the safe area, so no mixing of high concentration of hydrogen and oxygen gas can occur.

Quick guide

1. Attach all vent outputs from the electrolyser systems together.
2. Pipe the gas/vapor mixture into a water trap or equivalent (steam traps can also work if properly sized according to your system size) to separate the outputs.
3. Ensure the backpressure in front of the electrolysers never exceeds 0.5 barg.
4. Vent the oxygen output to a safe area, ensure condensed water inside the vent pipe can flow back freely into the WST.
5. Keep the gaseous purge and vent outputs as far apart as possible.

DRAIN MANAGEMENT

With the vent properly managed the WST, there are a total of 3 drain outputs from the system at the Big Thing. These can be simply led down a negative gradient away from the system and do not need to be led to a safe area as the output will be simply water and air.

The output from the reverse osmosis system should be separated from the other 2 drains (one from the WTM, one from the WST), which can be combined to make the system and attached piping simpler.

Quick guide

1. Using the appropriate John Guest pipe, or similar piping system, connect all drain and overfilling connections together.
2. Make sure the water can flow freely out of the pipe and cannot freeze.

POWER IN/OUT

In the case of the Big Thing cabinet, all piping and electrical connections are connected at the rear plinth of the cabinet. Two IP-rated distribution boxes inside the plinth connected the AC and DC to the cabinet power distribution panel and the fuel cell respectivley.

Figure 16: The connections at the back of the Big Thing cabinet

Quick guide

1. Remember to separate AC and DC distribution boxes.
2. Size your input/output cables carefully. For larger installations it is recommended to distribute the load across multiple phases.

Fuel Cell Purge Management

When integrating a fuel cell with the cabinet which houses Enapter modules, please refer to the FC's manuals and guidelines for a successful implementation.

Normally fuel cells work on a low pressure H2 supply and the FC purge carries away a lot of produced water. It is important to allow the FC purge to carry the water out and away without obstructing the purge line.

It is generally recommended to keep the purge lines separate as their outputs and pressure profiles will be vastly different to Enapter electrolyser systems and if both systems happen to purge at the same time there is a high risk of damaging the fuel cell.

Quick guide

1. Remember to separate FC purge and Enapter system purge lines. The outputs can be led to a safe area.
2. Follow the fuel cell's manufacturer guidelines on purge management. A secondary drain may need to be installed if the purge line of the FC is too long.

FAQ

Apart from the system components used in the Big Thing, can we use the EMS extensions to integrate inverters/power meters/fuel cells from other suppliers?

Short answer: Yes! The adaptability of the EMS allows it to communicate and read data from every standard of communication normally used in microgrid systems, as well as analogue inputs.
If you would like to integrate a new system into the EMS ecosystem, please contact us for help!

What kind of smart production regulation possibilities are there using the EMS in my system?

The EMS and its system of extension modules can perform a large variety of smart futures. Due to the rule based control, the system can truly be programmed to be as versatile as needed.
For example the system can regulate production rates to keep the output pressure stable at a certain pressure set point (useful for constant flowrate requirements). Another example is the use case for the Big Thing microgrid, using the EMS and the integrated extension modules, the system can regulate which devices are running when, anticipate bad weather and determine how much hydrogen is needed to be stored for continuous autonomy.

What are the installation requirements for your system (location, set off distances from adjacent walls, electrical outlet, ventilation, ambient temperature, siting location, indoor/outdoor, non-hazardous/non-classified area)

The electrolyser is designed for indoor installation, by itself it doesn't have protection from the elements. The installation of the EL2.0 can be done in most standard 19" racks/cabinets by the system integrator so depending on the type of enclosure it can be installed anywhere. If Enapter is tasked with the integration into a cabinet, we currently use IP20 cabinets from Rittal.

What are the maintenance requirements and cost for the dryer?

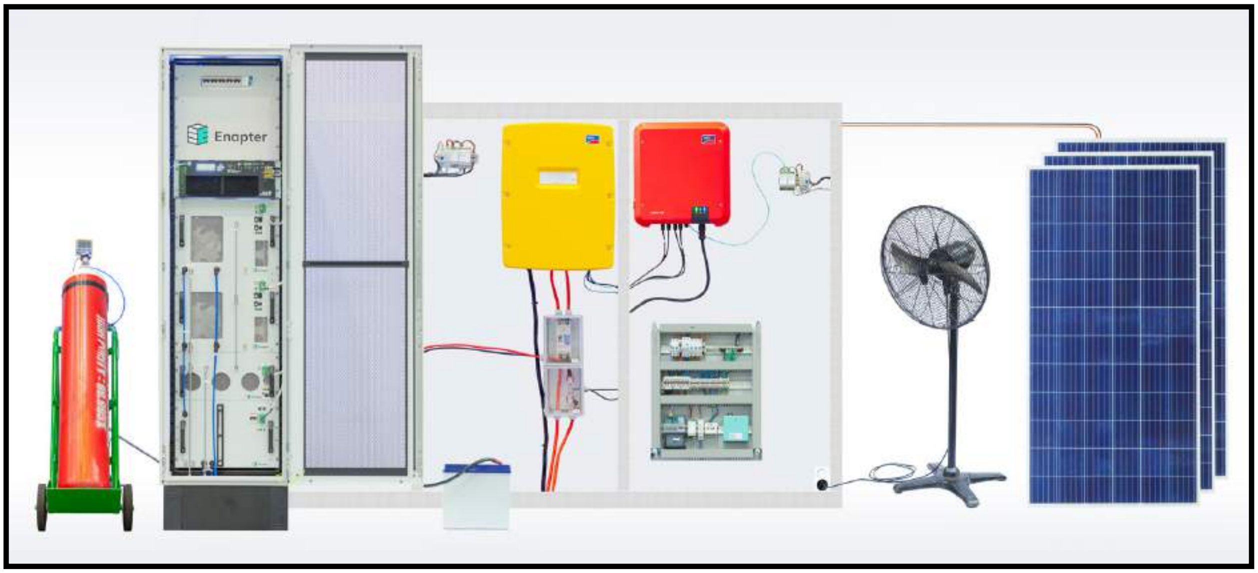
The dryer is maintenance free – while one cartridge is drying the stream of hydrogen, the other is regenerated. There are no consumables to be exchanged or any user intervention needed during normal operation. We expect that the dryer can operate for many years, before the dryer media may degrade.

We need a water purification unit to feed the electrolyser. And what is the maintenance associated with this?

If a water purification unit is needed, we will resell a water purifier using some reverse osmosis filters and resins to clean up tap water and supply it to the electrolyser. The maintenance consists of filter/resin replacements and will depend on the input water quality and the amount of water consumed. As long as the water purity requirements of our electrolysers are met, you can use any water purification system you like.

Do I have to use the Enapter EMS monitoring system or can the system also be controlled via the ethernet port via modbus?

While we believe our EMS is the best way to access, monitor and control the ELs, you don't have to use it. To control the electrolyser our customers can use the Ethernet port with Modbus TCP to integrate it with their system of choice.



Thank you for attending and being part of The Big Thing!