Lines of Business

Onsite Generation
Water Electrolyzers

Power Systems
Power Modules

Industrial hydrogen
Hydrogen Fueling
Stationary power
Mobility power

Energy Storage
Load Control, Smart Grid and Power to Gas
Fuel Cell Value Chain “2.0”:

- **PEM Single Cell**
  - Single cell
    - Proton Exchange Membrane
    - MEA - Membrane Electrolyte Assembly
    - Bipolar plates
    - Gas Diffusion layer
    - Gaskets

- **Fuel Cell Power Module 2.0**
  - Stack with integrated Balance of Plant
    - Multiple cells layered into a stack, including:
      - End plates
      - Tie rods
      - Spring washers
      - Bus bar interfaces
      - Fuel cell voltage monitor
    - Stack and Balance Of Plant, includes:
      - Fuel management
      - Air management
      - Water management
      - Coolant pump and Control
      - Control hardware and software

- **The Hybrid System**
  - Integrators, OEMs
  - OEMs, Fleet Owners
  - Stack and Balance Of Plant, includes:
    - Fuel management
    - Air management
    - Water management
    - Coolant pump and Control
    - Control hardware and software
  - Power Module with:
    - Power conditioning
    - Hybrid energy storage
    - Hybrid control hardware and software
    - Cooling rad or heat exchanger (or CHP)
    - H₂ storage

Hydrogenics Marketed Products

Hydrogenics Core Competence

Hydrogenics Core Competence
Hydrogenics HyPM™ Fuel Cell Power Modules

- Advanced onboard controls and diagnostics
- Integral Balance of Plant
- Rapid start-up and dynamic response
- Liquid-cooled advanced-MEA PEM stack
- Complete with Cathode Air delivery unit
- -46°C sub-zero shutdown capability
- No water for humidification required
- Unlimited start-stop cycling
- No nitrogen required for shutdown

HyPM™ HD
Heavy Duty – High Durability
HyPM™ - The Next Generation

Hydrogenics redefines the benchmark for system power density
HyPM™ HD 90 and HD 180

HyPM™ HD 90
- 99 kW
- 502 L
- 327 kg

HyPM™ HD 180
- 198 kW
- 1002 L
- 654 kg

Simplicity of integration for Heavy Duty Mobility

Fully Integrated Units
Breakthrough in compactness
HyPM™ HD 300

Simplicity of integration for Heavy Duty Mobility

300 kW
1440 L
870 kg
HyPM™ HD 300 Dimensions
HyPM™-R1000  (1000 kVA net)

(10) HyPM™ FC Power Racks, 100 kW\textsubscript{net} each

Inverter/Transformer Racks

Cooling Unit

40 foot sea container
1000 kVA Fuel Cell Plant

- Using the building block of our G2 Fuel Cell Power Modules, greater density, scalability and flexibility is achieved.

- **Features**
  - Modular rack system
  - High efficiency fuel cells
  - Thermal control system
  - Controls from low to full power

- **Benefits**
  - Scalable and flexible
  - High durability
  - Built in redundancy
  - Improved availability
HyPM™-R120

Controller

Fuel Cells
4x 30 kW

Cooling
HEX
HyPM™-R120 Layout

Design

Execution
HyPM™ HD60…300 layout

HD90 “Engine”- with (3) HyPM™ HD30 FCPMs
HyPM™ HD 90 Interface

- Ventilation Inlet
- Hydrogen Supply
- Coolant Return
- Air Supply
- Comm. Interface
- Power Output Connections
- Coolant Supply
- Exhaust
- Water Drain
<table>
<thead>
<tr>
<th><strong>Type:</strong> PEM (Proton Exchange Membrane) Fuel Cell Power Generator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance:</strong></td>
</tr>
<tr>
<td>Electrical Output Continuous</td>
</tr>
<tr>
<td>Electrical Efficiency</td>
</tr>
<tr>
<td>System Output Voltage</td>
</tr>
<tr>
<td>System Output Frequency</td>
</tr>
<tr>
<td>Package Design Life</td>
</tr>
<tr>
<td><strong>Physical Characteristics:</strong></td>
</tr>
<tr>
<td>Dimensions (H x W x L)</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Hydrogen</td>
</tr>
<tr>
<td>Fuel Consumption</td>
</tr>
<tr>
<td>Aux Electrical Input Power</td>
</tr>
<tr>
<td><strong>Available Heat:</strong></td>
</tr>
<tr>
<td>Output Heat Load</td>
</tr>
<tr>
<td>Stack Temperature</td>
</tr>
<tr>
<td>Exhaust Gas Temperature</td>
</tr>
<tr>
<td><strong>Emissions:</strong></td>
</tr>
<tr>
<td>Noise level at 1m</td>
</tr>
<tr>
<td>Pollutants</td>
</tr>
</tbody>
</table>
The 2014 HyPM™ Portfolio

**Stationary**

<table>
<thead>
<tr>
<th>HyPM™</th>
<th>XR 3-200</th>
<th>XR 5</th>
<th>XR 8</th>
<th>XRL 12</th>
<th>XRL 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Power [kW]</td>
<td>3</td>
<td>5.5</td>
<td>8.5</td>
<td>12.5</td>
<td>33</td>
</tr>
</tbody>
</table>

**Mobility**

<table>
<thead>
<tr>
<th>HyPM™</th>
<th>HD 4-200</th>
<th>HD 5-200</th>
<th>HD 8-200</th>
<th>HD 10-200</th>
<th>HD 15</th>
<th>HD 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Power [kW]</td>
<td>4.5</td>
<td>5.5</td>
<td>10</td>
<td>10</td>
<td>15.5</td>
<td>33</td>
</tr>
</tbody>
</table>

**Packages**

<table>
<thead>
<tr>
<th>HyPM™</th>
<th>HD 60</th>
<th>HD 90</th>
<th>HD 120</th>
<th>HD 150</th>
<th>HD 180</th>
<th>Vehicle Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Power [kW]</td>
<td>66</td>
<td>99</td>
<td>132</td>
<td>165</td>
<td>198</td>
<td>3…300</td>
</tr>
</tbody>
</table>
Gen 2.0 Power Module Components

- GDL (Gas Diffusion Layer)
- MEA (Membrane Electrolyte Assembly)
- Flowfield Plate
- End Plate
- Controls
- Coolant Pump
- H2 Recirc pump
- Fuel delivery assembly
- Air Filter
- Blower
- Air Flow Meter

FC Power Module Subsystems
### FC Development History – Hydrogenics Gen2.0 HyPM™ Power Module

#### Gen2.0

<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2009</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stack Pressure</strong></td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>25 kW</td>
<td>25 kW</td>
<td>20 kW</td>
<td>16.5 kW</td>
<td>33 kW</td>
</tr>
<tr>
<td><strong>System Mass</strong></td>
<td>290 kg</td>
<td>200 kg</td>
<td>170 kg</td>
<td>92 kg</td>
<td>75 kg</td>
</tr>
<tr>
<td><strong>Power Density</strong></td>
<td>86 W/kg</td>
<td>125 W/kg</td>
<td>117 W/kg</td>
<td>180 W/kg</td>
<td>440 W/kg</td>
</tr>
<tr>
<td><strong>System Volume</strong></td>
<td>365 L</td>
<td>340 L</td>
<td>180 L</td>
<td>133 L</td>
<td>125 L</td>
</tr>
<tr>
<td><strong>Power Density</strong></td>
<td>68 W/L</td>
<td>73 W/L</td>
<td>111 W/L</td>
<td>124 W/L</td>
<td>264 W/L</td>
</tr>
<tr>
<td><strong>System Efficiency</strong></td>
<td>45…38%</td>
<td>45…38%</td>
<td>54…40%</td>
<td>54…48%</td>
<td>55…48%</td>
</tr>
<tr>
<td><strong>Major Components</strong></td>
<td>25</td>
<td>19</td>
<td>8</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td><strong>Onboard water</strong></td>
<td>Required</td>
<td>Required</td>
<td>Not required. With Ca and An saturators.</td>
<td>Not required</td>
<td>No saturators</td>
</tr>
</tbody>
</table>

Hydrogenics HyPM Power Modules (mobility)
HyPM™ HD30 (33 kW)

Product Number: 1038478
Refer to Spec Sheet PN: 1038480

<table>
<thead>
<tr>
<th>Technical Data</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated (Max Continuous) Power kW</td>
<td>kW</td>
<td>30 (33)</td>
</tr>
<tr>
<td>Dimensions (L x W x H) mm</td>
<td>mm</td>
<td>950 x 1630 x 265</td>
</tr>
<tr>
<td>Mass kg</td>
<td>kg</td>
<td>≤ 70</td>
</tr>
<tr>
<td>Gravimetric Power Density kW/kg</td>
<td>kW/kg</td>
<td>0.5</td>
</tr>
<tr>
<td>Operating Current A\text{dc}</td>
<td>\text{A}_{\text{dc}}</td>
<td>0 to 500</td>
</tr>
<tr>
<td>Operating Voltage V\text{dc}</td>
<td>\text{V}_{\text{dc}}</td>
<td>60 to 120</td>
</tr>
<tr>
<td>Peak Efficiency %_{LHV}</td>
<td>\text{%}_{\text{LHV}}</td>
<td>55</td>
</tr>
<tr>
<td>Stack Operating Pressure kPa</td>
<td>kPa</td>
<td>&lt; 120</td>
</tr>
</tbody>
</table>

a) Air blower and water pump excluded in dimensions
b) Includes coolant pump and air delivery, peak power of 35 kW where applicable
# Heavy Mobility Packages

<table>
<thead>
<tr>
<th>Technical Data</th>
<th>Unit</th>
<th>HD30</th>
<th>HD90</th>
<th>HD180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated (Max) Power</td>
<td>kW</td>
<td>30 (33)</td>
<td>90 (99)</td>
<td>180 (198)</td>
</tr>
<tr>
<td>Dimensionsa (L x W x H)</td>
<td>mm</td>
<td>605x410x265</td>
<td>950x1630x265</td>
<td>950x1630x530</td>
</tr>
<tr>
<td>Volumea</td>
<td>L</td>
<td>66</td>
<td>410</td>
<td>820</td>
</tr>
<tr>
<td>Massb</td>
<td>kg</td>
<td>≤ 70</td>
<td>≤ 250</td>
<td>≤ 475</td>
</tr>
<tr>
<td>Gravim. Power Densityb</td>
<td>kW/kg</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Operating Current</td>
<td>A&lt;sub&gt;dc&lt;/sub&gt;</td>
<td>0 to 500</td>
<td>0 to 500</td>
<td>0 to 500</td>
</tr>
<tr>
<td>Operating Voltage</td>
<td>V&lt;sub&gt;dc&lt;/sub&gt;</td>
<td>60 to 120</td>
<td>180 to 360</td>
<td>(2x) 180 to 360 or 360 to 720</td>
</tr>
<tr>
<td>Peak Efficiency</td>
<td>%&lt;sub&gt;LHV&lt;/sub&gt;</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Stack Operating Pressure</td>
<td>kPa</td>
<td>&lt; 120</td>
<td>&lt; 120</td>
<td>&lt; 120</td>
</tr>
</tbody>
</table>

a) For the HD30 Air blower and water pump excluded in dimensions
b) Includes coolant pump and air delivery
# HyPM™ HD300 (300 kW)

Product Number: 1046223  
Refer to Spec Sheet PN: 1046225

<table>
<thead>
<tr>
<th>Technical Data</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated (Peak) Power</td>
<td>kW</td>
<td>300 (330)</td>
</tr>
<tr>
<td>Dimensions&lt;sup&gt;a&lt;/sup&gt; (L x W x H)</td>
<td>mm</td>
<td>2000 x 1200 x 600</td>
</tr>
<tr>
<td>Mass&lt;sup&gt;a&lt;/sup&gt;</td>
<td>kg</td>
<td>≤ 870</td>
</tr>
<tr>
<td>Operating Current</td>
<td>A&lt;sub&gt;dc&lt;/sub&gt;</td>
<td>0 to 500</td>
</tr>
<tr>
<td>Operating Voltage</td>
<td>V&lt;sub&gt;dc&lt;/sub&gt;</td>
<td>500 to 800</td>
</tr>
<tr>
<td>Peak Efficiency&lt;sup&gt;b&lt;/sup&gt;</td>
<td>%&lt;sub&gt;LHV&lt;/sub&gt;</td>
<td>55</td>
</tr>
</tbody>
</table>

---

<sup>a</sup> Includes air delivery and coolant pump

<sup>b</sup> Excludes parasitics (air delivery, coolant pump, radiator fans)
HyPM™ HD 300 Performance
HD30 Performance

[Graph showing the relationship between Net Current [A], Voltage [VDC], Net Power [kW], and FCPM Efficiency [% LHV] / Net Power [kW].]
Non-Humidified Stack Advancements in Durability

2005

2007

2008 (on-going testing)
-6.2 µV/hr

End of Test Crossover Threshold
Freeze Capability Advancements
Module performance not sensitive to freeze / thaw cycling

![Graph showing Mean Cell Voltage vs. Current Density for Before Freeze/Thaw and After Freeze/Thaw](image-url)

- Before Freeze/Thaw
- After Freeze/Thaw
Example Vehicle System Overview:

Example architecture:

HyPM™
Fuel Cell
Power Modules

DC/DC Converter
DC/DC Converter
DC/DC Converter
DC/DC Converter

Battery +/- Ultra-cap bank
DC/AC Inverter
DC/DC Converter
DC/AC Inverter

Motor 1
Low Vdc onboard
AC Line Filter

Motor 2

180 VDC to 360 VDC LV Bus

High Voltage Bus (520 VDC to 700 VDC)
Variants, Hybrids, Combinations

All combinations are possible and have been realized with Fuel Cells
Hydrogenics Power Modules in Mobile Applications
HyPM™ in Light Fleet Applications
HyPM™ in Material Handling Applications
HyPM™ in Urban Transit Bus Applications

Cardiff, Wales  
Berlin/Munich, Germany  
Aachen, Germany

Honolulu, Hawaii  
Winnipeg, Canada & Scottsdale, AZ  
San Francisco, CA USA

Barth, Germany  
Los Angeles, CA  
Perugia IT & Gladbeck DE
HyPM™ in Heavy Commercial Fleet Applications

- Basel, Switzerland
- Berlin, Germany
- Salzburg, Austria
- Toronto, Canada
- North Rhine Westphalia, Germany
- Palm Springs, CA, USA
- Spain
- Los Angeles, CA, USA
- Los Angeles, CA USA
HyPM™ in the Military
Project: TRANVIA DE HIDROGENO

(2) HyPM™ HD 16
Hydrogen Infrastructure
Total System Overview:

- **HySTAT™ Electrolyser**
- **HyPM™ Fuel Cell Power Modules**
- **H₂ Filling Station**
- **Wind, PV, Hydro or Nuclear Electricity**
- **GHG-free H₂**
45+ Fueling Stations Worldwide
Fluctuating Wind Energy
Compared to Conventional Pump Storage Capacity

This much could be fed into a large pump storage:
8,000 MWh = 1M Chevy Volt vehicles

Source: General Motors
Store Fluctuating Wind Energy
Storage of Compressed Air in Salt Caverns

This much could be fed into an underground compressed air storage (2 Mio m³ salt cavern):
4,000 MWh

Source: General Motors
Hydrogen
The Energy Storage Solution for Renewable Energy

![Graph showing energy storage capacity for several days]

- **600,000 MWh**
  - This much could be fed into an underground hydrogen reservoir (2 Mio m³ salt cavern)
  - equals 3.6 Mio tank fills

Source: General Motors
The Natural Gas Grid offers both: Storage and Distribution

Electrical Grid

Natural Gas Grid

Power Capacity:
- Single digit GW
- Double digit GW

Storage Capacity:
- 0.04 TWh\textsubscript{el}
- 220 TWh\textsubscript{th} + grid

Source: IWES, 2011
Largest to date P2G Plant

2 MW E.ON’s Falkenhagen Power-to-Gas Plant inaugurated August 2013
1 MW P2G Plant in full operation since Sept 2013
OBJECTIVES
• Produce electricity coming from a 140MW onshore wind farm (some turbines are rated at 7.5MW) using hydrogen as energy storage. Have CO₂ savings of +/- 250,000 t/year.
• Use the H₂ in an internal combustion engine to produce electricity and retrieve the heat from the system for the building. In a further stage, use H₂ for transport and demonstrate the PtG (Power to Gas) solution by injecting the produced H₂ in the nearby pipeline.

SOLUTION
• 1MW HySTAT™ indoor solution with all peripherals to produce 210Nm³/h H₂.
• H₂ compression and storage system (4'500Nm³ H₂ at 310bar) with 90 + 150kW HICE.
Hamburg Reitbrook, Germany (on site startup 2015)

1 MW Power to Gas

OBJECTIVES
• Development of 1 MW PEM Electrolysis Stack and System
• Optimize operational concept (fluctuating power from wind vs. changing gas feed).
• Gain experience in technology and cost.
• Feed H₂ into the natural gas pipeline

SOLUTION
• 1x 1 MW PEM Electrolyser with all peripherals in 40Ft. housings for 200 Nm³/h H₂.
• A 40 Ft container including 2 compressors to compress the hydrogen to 55barg.
• Power: 1 MW
Illustration of a future 40 MW Power-to-Gas plant

Compact Plant Footprint
The Bottom Line

100% Fossil
- Pollution + emissions
- Imported energy
- Limited Resource
- Fuel price dictates cost

100% Renewable
- Zero-emissions
- Fully self-sufficient
- Unlimited Resource
- Capex dictates cost