Markham Energy Storage Facility

Anna Murray, P.Eng.
Senior Program Manager

Growing the Hydrogen Ecosystem in Ontario
Mississauga – June 13, 2018
Hydrogenics is based in Mississauga with operations around the world

Hydrogenics Corporation
- Headquarters
  - Mississauga, Ontario
  - Incorporated in 1996 [NASDAQ: HYGS; TSX: HYG]
  - 175 employees worldwide
  - Fuel Cells, PEM electrolyser stacks, Power-to-Gas, H₂ refueling and mobility products / projects

Hydrogenics Europe
- Oevel, Belgium
- Since 1987
- Power-to-Gas, industrial onsite hydrogen production, and H₂ refueling station projects

Hydrogenics USA
- Carlsbad, California
- Fuel Cell power module integration and sales office

Hydrogenics
- Gladbeck, Germany
- Since 2002
- Fuel Cells, mobility projects

Production Facility
Sales Office
Hydrogenics designs and builds Fuel Cell Power Modules and Electrolyser systems

Fuel Cells

- Fuel Cell Bus Integrators, China
- Alstom Coradia iLint, Germany
- UPS Delivery Van, US

Electrolysers

- Uniper 2MW P2G, Germany
- P2G H₂ Fueling, California
- 5MW Power-to-Gas, Ontario
Electrolysers and Fuel Cells are electrochemical energy conversion devices

**Electrolysers**

HyLYZER PEMWE Stack
- Power Input: 1.25 MW
- Hydrogen Output: 22.5 kg/h
- Output Pressure: 35 bar

**Fuel Cells**

HyPM HD30 Fuel Cell Power Module
- Power Output: 30kW
- Integrated Balance of Plant
- Low Pressure Design
- Cold Temperature Operation

**Chemical Reactions**

Electrolyser: \( \text{WATER (H}_2\text{O)} + \text{POWER} \rightarrow \text{HYDROGEN (H}_2\text{)} + \text{OXYGEN (O}_2\text{)} \)

Fuel Cell: \( \text{HYDROGEN (H}_2\text{)} + \text{OXYGEN (O}_2\text{)} \rightarrow \text{WATER (H}_2\text{O)} + \text{POWER} \)

Exhibit Sources: US Department of Energy and The Fuel Cell and Hydrogen Energy Association
Power-to-Gas

Ancillary Service(s)
- Frequency Response
- Secondary Frequency Control (AGC)
- Non-Spinning Reserve
- Other Services

H₂O (water)
O₂ (oxygen)

Renewable Hydrogen Applications
- FCEV H2 Fueling
- Renewable Natural Gas
- Green Chemicals

H₂ (hydrogen)

Renewable Natural Gas
CO₂

Green Chemicals
Methanol
Ammonia

Off Grid Wind Farm
Transmission Network
Low Carbon Generation

System Operator
Over 35 Power-to-Gas projects operating in Europe

- Hydrogen Applications
  - FCEV H2 Fueling
  - Renewable Natural Gas
    - Direct Injection into NG Grid
    - Biogas Methanation
    - Catalytic Methanation
  - Industrial H2 Feed

- Projects range in size from 500kW to 6MW

- Commercial Scale projects will be 20MW to 50MW scale

Source: DNV KEMA. “Systems analyses Power to Gas: A technology review”. June 20, 2013
Power-to-Gas is classified as Type 3 Energy Storage by the Independent Electricity System Operator in Ontario

<table>
<thead>
<tr>
<th>IESO Classes of Energy Storage</th>
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<tbody>
<tr>
<td><strong>Type 1</strong></td>
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<tr>
<td>Energy storage technologies</td>
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<tr>
<td>that are capable of</td>
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<tr>
<td>withdrawing electrical energy</td>
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<tr>
<td>(electricity) from the grid,</td>
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<td>storing such energy for a</td>
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<td>period of time and then re-</td>
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<td>injecting this energy back</td>
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<td>into the grid (minus</td>
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<td>reasonable losses). Examples</td>
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<tr>
<td>include, but are not limited</td>
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<td>to, flywheels, batteries,</td>
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<td>compressed air and pumped</td>
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<td>hydroelectric.</td>
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Enbridge and Hydrogenics’ Markham Energy Storage Facility is under contract to provide regulation services to the IESO
Hydrogenics’ 1.25MW PEM electrolyser stack has the highest power density and smallest footprint in the world

Twin 1.25MW Electrolyser Stacks at Markham Energy Storage Facility
Markham Energy Storage highlights

- Plant has been designed for 5MW or 1,000 Nm³/hr or 2,160 kg/day capacity
  - Currently installed 2.5MW or 500 Nm³/hr or 1,080 kg/day capacity
- High purity H₂ is produced by the PEMWE stacks at 30 bar
- Plant provides +/- 1.05 MW of regulation service for the IESO
  - 2 second response time, 2 MW/sec ramp rate
- There is a small fuel cell which works with the electrolyser
  - 8MWh of onsite storage to power the fuel cell
- 100% emissions free
- Meets the highest standards of safety and quality
  - Installed on Enbridge property, residential neighbourhood across the street
- Fully approved for operation by multiple certification bodies having jurisdiction:
  - IESO, Technical Standards and Safety Authority (TSSA) Fuels, TSSA Boiler and Pressure Vessels (BPV), Electrical Safety Authority (ESA), Canadian Standards Association (CSA), City of Markham, Ministry of Environment and Climate Change (MOECC)
Power-to-Gas can provide the full range of regulation services for the System Operator

Adapted from EE Publishers article http://www.ee.co.za/article/synthetic-inertia-grids-high-renewable-energy-content.html
P2G Ancillary Services: Secondary Frequency Control

Secondary Frequency Control (AGC)

- This service acts to match total system generation to total system load (including transmission losses) and helps correct variations in power system frequency by correcting for short-term changes in electricity use that might affect the stability of the power system. Regulation service can be provided by generation facilities with automatic generation control (AGC) capability or energy storage plants which can vary their output in response to signals sent by the System Operator.

How an Electrolyser Provides this Service

- An electrolyser is fast-responding dynamic load whose power consumption can be changed every 2 seconds over its entire operating range in response to an Operator signal
- It does not have any operating restrictions and can be “set” at full load or minimum load or any point within its operating range as long as is required
- It is possible to dynamically allocate a portion of operating capacity of an electrolyser plant for frequency regulation and other ancillary services
P2G Ancillary Services: Secondary Frequency Control
We’re ready to help Ontario move to a cleaner energy future

- Serving customers in over 100 countries
- Over 2000 fuel cell and 500 electrolyser installations
- Supplied equipment for over 50 $H_2$ Fueling Stations
- Supplied fuel cell power modules for zero emission bus, train and truck OEMs and integrators