“It’s time for integrative thinking on Energy”

We can’t afford to waste any more.

Daryl Wilson, Hydrogenics
June 2013 Hyrail Conference Toronto
Sept. 2007
Concept
Political buy-in
Moon shot goal
Announcement

Technology?
Political Will?
Money?
Lots to Analyze – but Analysis is the problem

- Logistical Design
- Support Infrastructure
- Incumbent Technology Providers
- Fuel Availability
- Public Acceptance
- Political Will
- Safety
- Land Use Planning
- Propulsion Technology
- Gas Storage Technology
- Cost
- Incumbent Technology Providers
- Public Acceptance
- Political Will
- Safety
- Logistical Design
- Support Infrastructure
- Fuel Availability
- Public Acceptance
- Political Will
Lots to Analyze – but Analysis is the problem

Electrification

Project Status Update
Updated: May 29, 2013

Public Open House: UP Express Electrification Environmental Assessment (EA)

What's New

Updates and Reports
- E-Study Final Report
- Metrolinx Staff Recommendation
Lots to Analyze – but Analysis is the problem

Electrification Performance Specifications: December 2012

1 Electrification Performance Specifications: Executive Summary
2 Traction Power Supply System
3 Traction Power Distribution System
4 Grounding and Bonding
5 Electromagnetic Compatibility
6 Signal System Compatibility
7 Operations and Maintenance
8 Maintenance Facilities: Part 1
9 Maintenance Facilities: Part 2
10 SCADA System
11 Operations Control Centre
12 System Integration
13 System Assurance
14 Safety and Security
15 Sustainability
Shocking Waste – When we can least afford it

Lawrence Livermore Labs USA 2011 Data
Most companies today have innovation envy. They yearn to come up with a game-changing innovation like Apple’s iPod, or create an entirely new category like Facebook.

Many make genuine efforts to be innovative— they spend on R&D, bring in creative designers, hire innovation consultants. But they get disappointing results.

Why? In The Design of Business, Roger Martin offers a compelling and provocative answer: **we rely far too exclusively on analytical thinking, which merely refines current knowledge, producing small improvements to the status quo.**
See **more factors**

to be relevant

Consider **more relationships**

between more things

See the **whole**

and interactions

Creatively **resolve tensions**

in opposing ideas

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Integrative Thinkers see more and do more
The Vision is appealing – what’s stopping us?

What if we had trains that:

- were smaller but ran with higher frequency
- ran on otherwise wasted energy
- eliminated 100% of local emissions
- had fuel efficiency 2.5x the current system
- required no catenary system
- were much quieter
- required less land space
- fueled up as fast as diesel
- cost less and moved more people
Lack of Integrative Thinking is what stops us

- Power to Gas Energy Storage
- High Penetration Renewable Generation
- Transport Electrification Technology
- Integrative Thinking Transport & Energy
A Power-to-Gas Solution brings new economic and technology flexibility between the traditional energy silos of power grids, gas pipelines and transport.

Germany provides a window on the challenges of integrating high penetration of renewables

Falkenhagen Region in Northern Germany

- Increasing excess power
- Huge peak power
- Steep power gradients

Solution: Storage of excess wind power instead of curtailment.

Source: Presentation by Dr. Alexander Vogel, Head of Alternative Energy Systems, E.ON Ruhrgas at Gas to Power Conference, Cologne, Germany – November 2012
They are doing it on purpose!

**Today**

- 80% fossil based power generation
- Power generation “on demand”
- Power generation “on site”
- Base-load operation mode
- Centralized structure
- ...

Technology: ICCS / CPT / ...

**By 2050**

- 80% power generation by RE
- Power generation “by offer”
- Power generation “remote”
- Peak-load operation mode
- De-centralized structure
- ...

Technology: GT / CHP units / ...
Energy Storage – “Surplus Free Energy”

Surplus Power 8 TWhr/year in Ontario

- 12,000 MW Nuclear
- 2,500 MW Must-Run Hydro
- 1,500 MW ‘Average’ Wind

12,000 MW Nuclear
1,500 MW ‘Average’ Wind
2,500 MW Must-Run Hydro

% of Time
Energy Storage – Power-to-Gas

- Enables renewable generation through storage & stabilization
- Introduces “Energy Banking” services to the electrical industry
- Leverages existing natural gas infrastructure
- Delivers Flexibility – electricity, heat, fuel, industrial
Only hydrogen can provide seasonal storage capacity by charging consecutive days or even weeks without needing to discharge.
Only hydrogen offers storage capacity for several days or weeks.
Energy Storage – Germany Leading

Hydrogenics has been selected for largest share of German projects

- Lübeck - USV aus Windenergie, Wind Electrolysis
- Rostock - NEMO-Initiative, Wind Electrolysis
- H₂ Feed
- Methanization and Feed
- Use as Fuel
- Hydrogen Fueling Station and Power with Biogas (enriched)
- P2G Hamburg - E.ON Hanse AG
  - In Planung, H₂ Feed
- P2G Werlte - Audi AG
  - Leistung: 6,3 MW, 4,000 m³/Tag CH₄
  - In Bearbeitung (Betrieb Anfang 2013)
  - Methanization and Feed; later direct H₂ Injection
- DEW21
  - In Planung
  - H₂ Feed / Industry Application
- P2G Herten - Evonik AG
  - Mitte 2012 vollständiger Betrieb
  - Wind Electrolysis
- P2G Karlsruhe – DVGW-EBI
  - Machbarkeitsstudie bis 30.06.2012
  - Methanization
- P2G Stuttgart - SolarFuel GmbH
  - Leistung: 25 kW (ohne Optimierung)
  - In Betrieb (11/2009)
  - Methanization
- P2G Stuttgart - SolarFuel GmbH
  - Leistung: 250 kW, < 10 m³/h CH₄
  - In Bearbeitung (Betrieb 2012)
  - Methanization
- Projekt Clean Energy Partnership
  - Wasserstoff für den Straßenverkehr
  - Orte: Berlin, Hamburg, Herten, Bottrop, Karlsruhe, Stuttgart
  - (Support NOW)
- P2G Stuttgart - EnBW AG
  - Forschung (2012)
  - Hydrogen Fueling Station
- P2G Werder/Kessin/Altentreptow - WIND-projekt GmbH
  - Leistung: 1 MW Elektrolyseur
  - In Bearbeitung (Betrieb 2014)
  - Electricity and H₂ Feed Later
- P2G Prenzlau - ENERTRAG AG
  - Leistung: 120 m³/h H₂
  - In Betrieb (11/2011)
  - Hydrogen Fueling Station and Power with Biogas (enriched)
- P2G Berlin Flughafen – Total
  - Wasserstoffherstellung aus WEA
  - Use as Fuel
- P2G Falkenhausen - E.ON AG
  - Leistung: 360 m³/h H₂
  - In Bearbeitung (Betrieb Ende 2013)
  - H₂ Feed
- P2G Graben - Erdgas Schwaben GmbH
  - Machbarkeitsstudie 1 MW Anlage
  - Methanization and Feed
- Thüga AG
  - Demoanlage 2013
  - Machbarkeitsstudie zur
  - Wind Power Electrolysis / Feed
- P2G – Greenpeace Energy
  - Windstromelektrolyse
  - Projektstart 2012
  - H₂ Feed – Wind Power Cooperative
Energy Storage – Credible Partners

- Innovative Energy Leader
- Largest utility in the world
- Integrated Energy interest
- Won confidence as leader
- Won order for 2MW – May 2012
- Delivered in just 7 months
- Just announced F/O order

- NA Innovative Energy Leader
- One of the largest NG Distr in Cdn
- Integrated Energy interest
- Invested in 15% share of HYG
- Projects under development
2 MW Plant Delivered December 2012
# Economics of Power to Gas

**Doubling the Effective Renewable Energy**

**3:1 Ratio of Wind and Power-to-Gas**

<table>
<thead>
<tr>
<th>100 MW Wind Farm at $210 million capital cost</th>
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<tbody>
<tr>
<td>▪ Approximately 58,000 MWh of potential 245,000 MWh annual production at high-value times$^1$</td>
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<tr>
<td>▪ $17.8 million annual cost premium for power outside of the high-value times ($115/MWh FIT less $20/MWh average wholesale price)</td>
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<tr>
<th>32 MW Power-to-Gas plant at $35 million capital cost$^2$</th>
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<tr>
<td>▪ Generates power only at high-value times (58,000 MWh annually) using existing gas generation fleet</td>
</tr>
<tr>
<td>▪ Energy storage service contract at $5.3 million per year to operate storage assets based on utility rate of return</td>
</tr>
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Annual Ratepayer Savings of $12.5 million/year; $250 million over 20 year period

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Footnotes:  
1) High-value defined as the 24% of the annual hours with highest demand  
2) Estimated installed cost for 32 MW of Hydrogenics electrolyzer based on mature production volumes
Power-to-Gas converts renewable generation when it is not needed into renewable power, fuel or heat where and when it is needed.

### Power-to-Gas Solution

**Integrate Renewables**

- Surplus Power

**Renewable Gas Options**

- Dispatchable Power
- Fuel
- No Carbon Heat

**Electrolysis**

- H2 or SNG
Power-to-Gas is a new energy storage paradigm which unlocks options for the conversion, transport and storage of energy.

**Power-to-Gas Value Proposition**

- **Integrate Renewables**
  - Fast Load-Following
  - Surplus RE
  - Flexible Deployment
    - P2G plant site is not restricted to geologic formation
    - Scalable solution
  - T&D Capital Deferral

- **Renewable Gas Options**
  - Seasonal Storage
    - Unparalleled TWh storage capacity in natural gas system
    - Transport energy
  - Dispatchable Power
    - H2 Direct Injection
    - Substitute NG by Bio-Methanation
  - Distributed H2 Fueling
Energy Storage Technology Roadmap

Power-to-Gas demonstration plants today will drive commercial scale deployments in the future

**Today…**
Among the most proven and utilized technology

**Needs…**
Tailored for large scale energy storage

**Tomorrow…**
Advanced MW-scale GEN3 technology plant solutions

**2 MW Alkaline**

**1 MW PEM**

**40 MW Plant**
What is NOT stopping us: Technology

50% Cost Reduction in 5 years

World First

Mega Watt PEM Electrolysis
Multi Mega Watt Energy Storage

85% Cost Reduction in 5 years

Standard Fuel Cell Power Modules
Mobility/Propulsion
What is NOT stopping us: Fueling Systems

- Hydrogenics Headquarters: Toronto, Canada
- Hydrogenics Offices
- Hydrogenics Installed Fuelling and Power Systems
- Hydrogenics Installed Industrial Systems

Locations:
- Southfield, MI, USA
- Toronto, ON, CA
- Dunkirk, FR
- Haile, BE
- Amsterdam, NL
- Barcelona, ES
- Dunkirk, FR
- Halle, BE
- Stockholm, SE
- Malmö, SE
- Southfield, MI, USA
- Minot, ND, USA
- Richmond, CA, USA
- Oakland, CA, USA
- Chino, CA, USA
- Santa Monica, CA, USA
- Torrance, CA, USA
- Los Angeles, CA, USA
- São Paulo, BR
- Barcelona, ES
- Brugg, CH
- Istanbul, Turkey

Tags:
- Hydrogenics Headquarters: Toronto, Canada
- Hydrogenics Offices
- Hydrogenics Installed Fuelling and Power Systems
- Hydrogenics Installed Industrial Systems

- Built 45 of 250 hydrogen vehicle fueling stations globally
- Completed the largest station in EU Feb 2012
- Respected partner of Linde & Air Liquide
- Conversion of green electrical energy to fuel in EU
Fuel Cell Systems have the most appropriate signature for rail electrification.
What is NOT stopping us: Technology

under WATER

in the AIR

in SPACE

on LAND
HyPM™ 100 kW continuous power

- Three HD 30 (33 kW) FCPM’s electrically in series
- Single communications interface
- Mechanically in parallel, common manifold for coolant and exhaust
- Three LP cathode air blowers with a common air filter

What is NOT stopping us: Technology
What is NOT stopping us: Integration

Example architecture:

HyPM™
Fuel Cell Power Modules

DC/DC Converter → Battery +/- Ultra-cap bank
DC/DC Converter → DC/AC Inverter
DC/DC Converter → Low Vdc onboard
DC/DC Converter → AC Line Filter
DC/DC Converter → Motor 1
DC/DC Converter → Motor 2

High Voltage Bus
What is NOT stopping us: Integration

Project: TRANVIA DE HIDROGENO

(2) HyPM™ HD 16
What is NOT stopping us: System Design

Typical Commuter Route well suited to Hybrid
What is stopping us: NO Integrative Thinking

Wind, PV, Hydro or Nuclear Electricity

HySTAT™ Electrolyser

H₂Filling Station

GHG-free H₂

HyPM™ Fuel Cell Power Modules
There are many electrified rail systems in the world. Incremental steps have “reliability” and “credibility.” But they don’t necessarily hold total overall “validity.”

What is stopping us?: Lack of Raging Reference Sites
What is stopping us?: Scale takes time

Global production of primary energy sources.

Source: Shell Oil
We’ve Been Here Before

Truck Design; Double Decker Design;
We’ve Been Here Before

1. Leadership (Governments, Industry, Academia)
2. Fresh Thinking
3. Raging Reference Sites
4. International Collaboration
5. OEM Partners with Credibility to drive Validity
6. Technology partners with the know-how & confidence
WE’RE READY