Technology and Disruptive Innovation in the Natural Gas Sector

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ENBRIDGE®

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Net-Zero Is A Disruptive Opportunity

The role of Net-Zero Ready construction & Near-Net Zero policy

Today's code built home

- Typically uses ~ 56 gigajoules (GJ) of thermal energy (~15.5 MWh)
- Total home energy consumption is ~ 100 GJ (27.8 MWh)
- Estimated to produce 3.3 tonnes of greenhouse gas (GHG) emissions per year

If we construct to Net-Zero Ready (NZR)

- Significant improvements in construction standards for energy efficiency
- Approximately 2/3rd reduction in GHG emissions for mixed fuel NZR home

- Near-net-zero is a concept that enables a range of technologies and renewable energy supplies to deliver remaining GHG reductions over next several decades
  - From an energy policy perspective, the last 1/3rd GHG emissions can be supported with next-generation disruptive technologies that support diversity and affordability

Evolving Net-Zero – Improved Diversity & Affordability

Leading jurisdictions include both “Site & Source” options

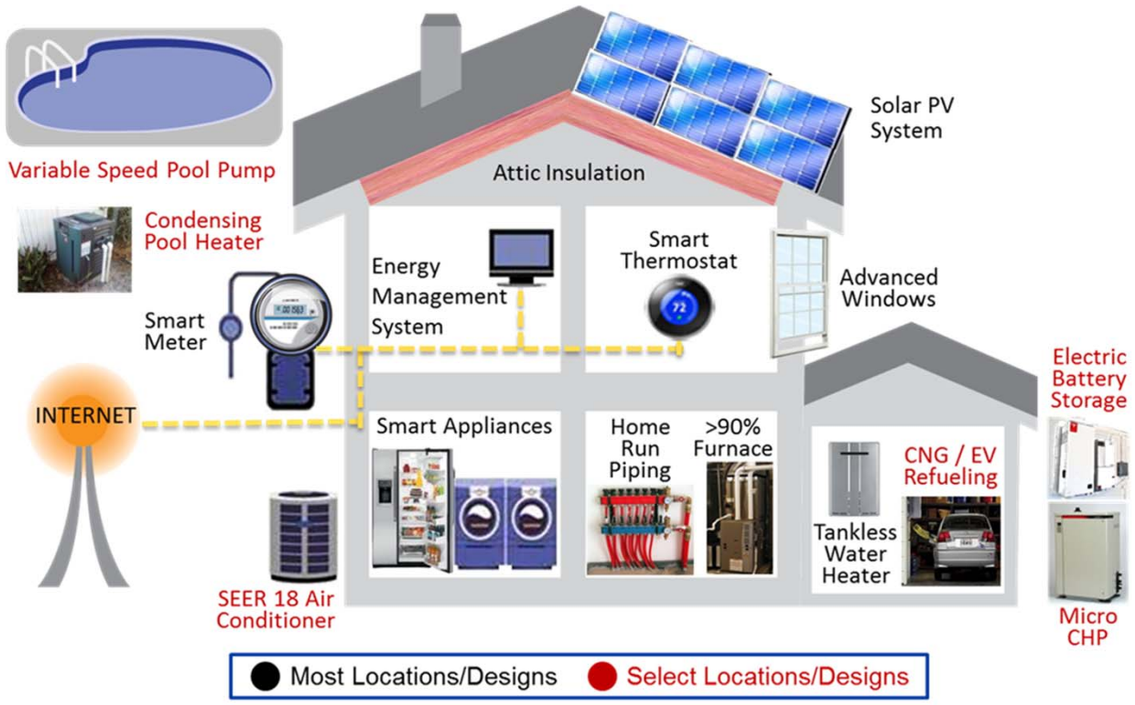
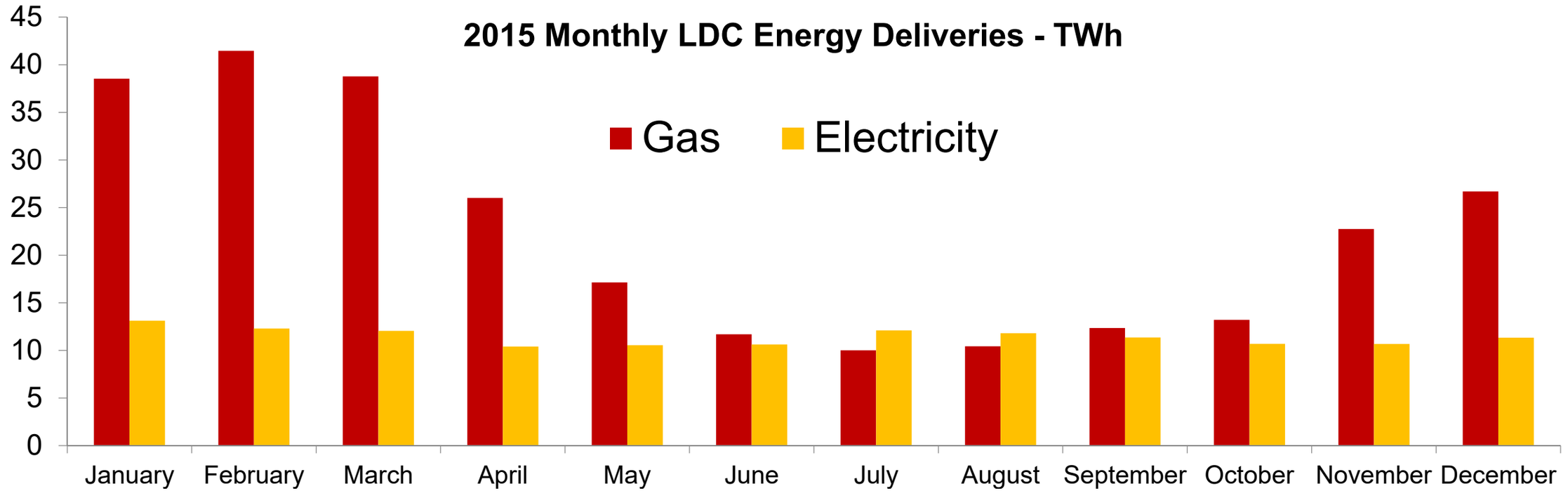


Image Source: Navigant Study on Net-Zero Conducted for Southern California Gas Company

- “NEZ-Source” was defined by the California Energy Commission in May of 2016
  - California will save $1.9 billion over 9 years and achieve GHG reductions
- A portfolio of efficiency, renewable energy generation and external renewable supply with the lowest life-cycle costs
- “Right-Sizing” on-site PV with energy storage & mCHP to optimize seasonal performance

Ontario's Energy Profile

Monthly natural gas and electricity use

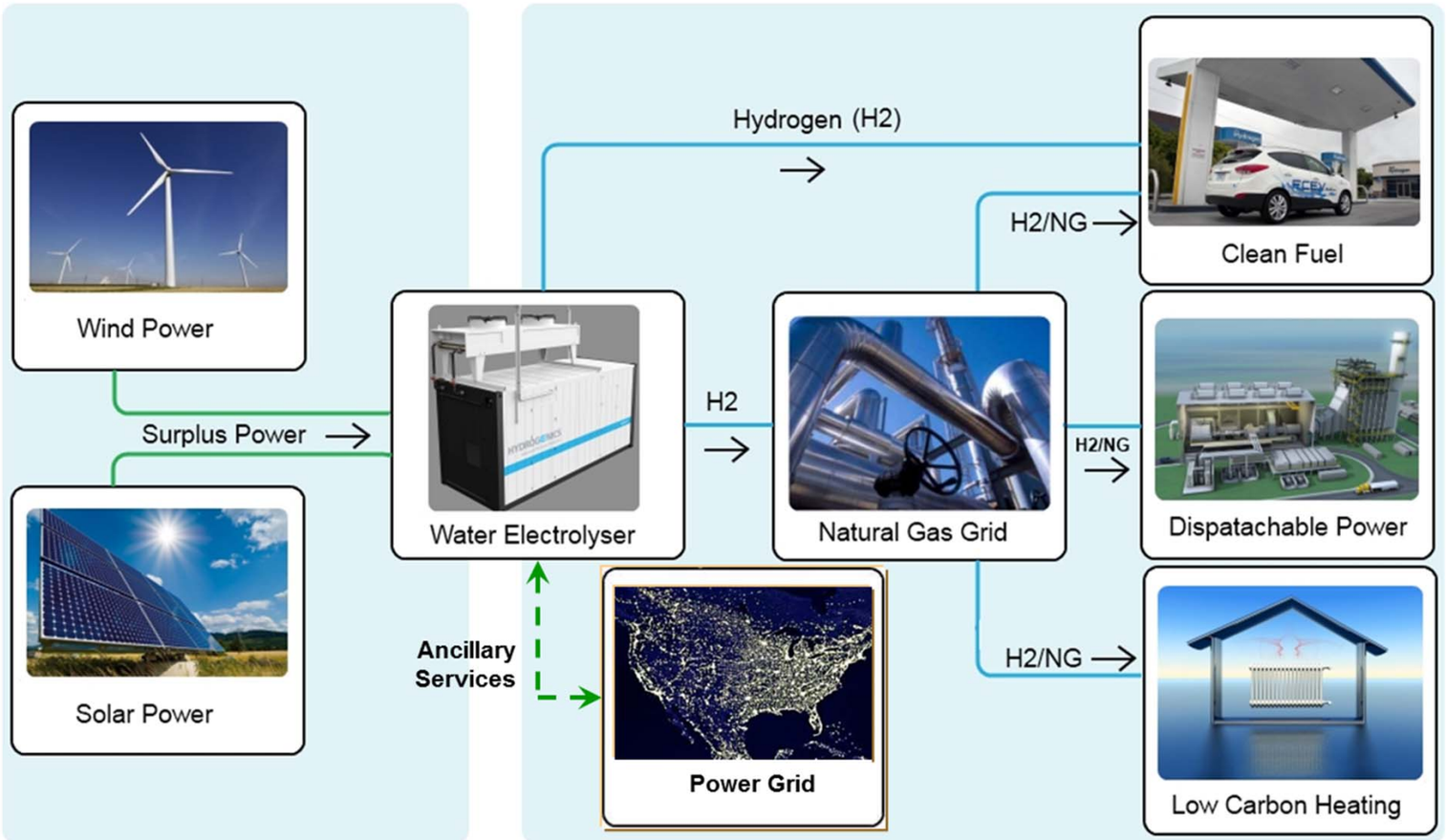


- Gas supplied 3.6 million customers with 270 TWh
- Electricity supplies 5.0 million customer with 137 TWh

Notes: 1. IESO Data for Ontario Demand, 2. Enbridge and Union – Internal, OEB Filings

Expanding Renewable Gas: Power- to- Gas

2 MW Energy Storage project schedule for operation in early 2017



- Power-to-Gas energy storage converts off-peak & surplus electricity to green hydrogen
- Can provide grid reliability service and bulk power mgmt. to the Independent Electricity System Operator (IESO)
- Support increased renewable power generation on the electricity grid while supplying green hydrogen for pipelines, power generation and vehicles

Examples of CO_2 as a Feedstock for Fuels

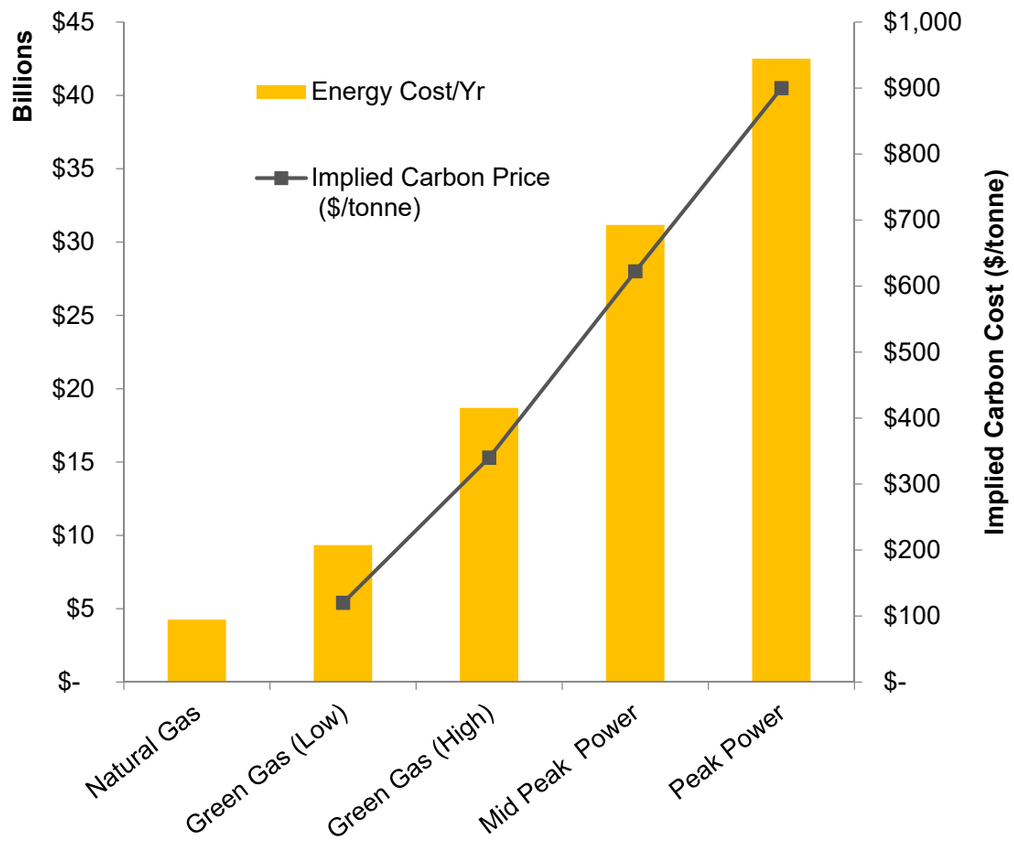
- Wastewater plants in Denmark are upgrading biogas to RNG
- Biological CO_2, normally stripped out of the biogas, is methanized with green hydrogen, from power-to-gas
- Power-to-Gas integrated with RNG plants
  - improves yield on renewable gas volumes
  - helps minimize renewable power surpluses

Source: BioCat Project, Electrochaea, Denmark - First green gas from methanation produced from project in April 2016

Comparison of Green Energy Prices

Pricing energy in similar units provides better understanding of costs

Fuel	$/GJ	Cents/kWh
Natural Gas	5.00	1.8
Renewable Natural Gas (Low cost)	11.00	4.0
Renewable Natural Gas (High cost)	22.00	7.9
Off-Peak Electricity	24.17	8.7
Mid-Peak Electricity	36.67	13.2
Biogas mFIT	46.64	16.8
On-Peak Electricity	51.94	18.7

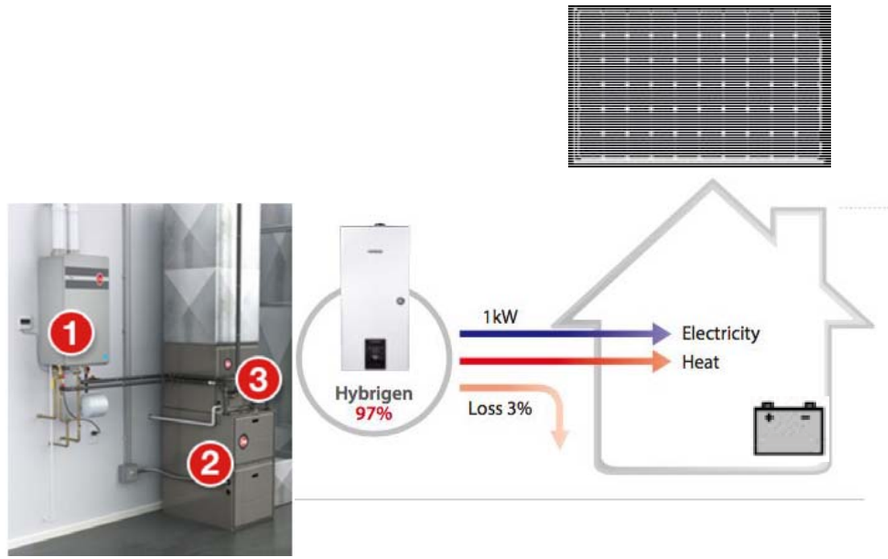


Cost Impacts; Replacing Ontario's Natural Gas Energy with Low-Carbon Alternatives

Home of the Future - Flexibility for Net Zero

Incorporates Micro-Grid planning (electrical and thermal)

Description:	**Home Of The Future**
Partner(s):	Electric Utility, Enbridge, Home Builder & others
Technology Use:	Thermal micro grids, force air fan coil (replaces furnace), solar PV, battery storage, mCHP, etc.
Location:	GTA
Status:	Home builder engagement underway - testing interest with builders community & city planners
In-Service:	2017-2018 winter
Objective:	Demonstrate improved affordability for home designs that achieve deep GHG reductions
Repeatability	Potential model for community redevelopment



Source Images: Sumaran Inc. (Mark Riley, consultant to NRCan)

Key Objectives:

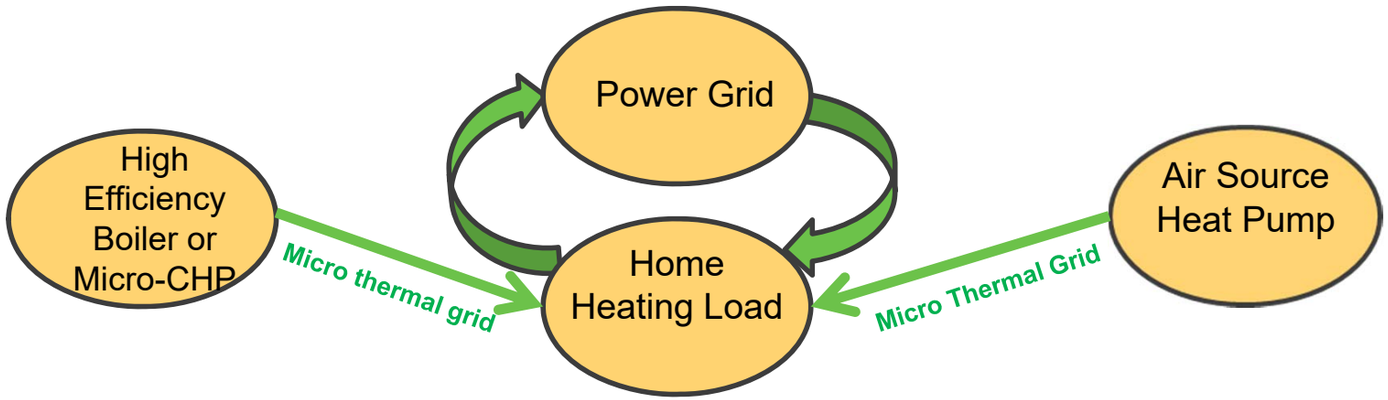
- Develop a low-carbon home design strategy that enables smart energy micro-grid design principles (electricity and thermal)
- Demonstrate how a microCHP ready home helps right-size energy equipment and costs, for solar PV, battery storage, etc.

Virtual Power Plant with Hybrid Heating (Electric Heat Pump and Advanced Gas Heating)

Hybrid Heating and Thermal Micro-Grids

With hybrid heating homes benefit by shifting to hot water micro-grids

Potential to integrate gas and electric thermal solutions into a hot water micro grid as new demand response services for LDC/IESO



Disruptive technologies are emerging – today's natural gas furnace and water heater could be replaced with hot water air handlers, mCHP, natural gas heat pumps, indirect water heaters, etc.

Illustration of Virtual Power Plant Potential

Micro-grids and hybrid heating a viable alternative to new-build power plants and transmission

Virtual Power Plant Opportunity per 10,000 Homes

kW	Low-Carbon Solution	Avg Dispatchable MW per 10,000 homes	Peak Dispatchable MW per 10,000 homes
3	Solar Array *	4.5	4.5
4.5	Storage Inverter **	45	45
1.5	mCHP	15	15
5.5	Hybrid Heating (Avg)	55	-
11	Hybrid Heating (Peak)	-	110
		119.5	174.5

Footnotes:

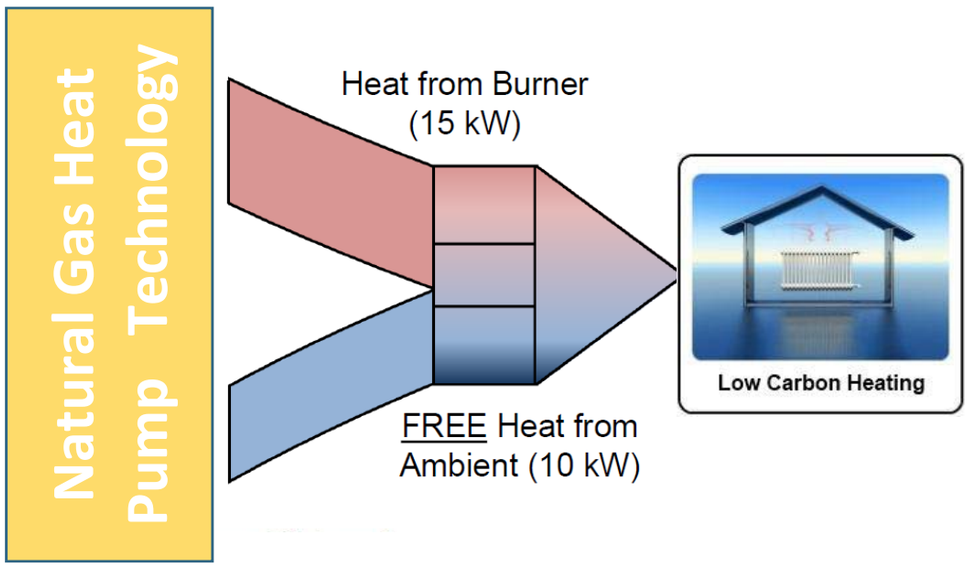
* 10% of Variable Solar assumed as Dispatch Capacity

** 100% of Storage inverter dispatchable - duration dependency on battery size

Hybrid Heating integrates heat pump system with full gas alternative

Emerging Gas Technology Focus

Role of Advanced gas technologies, like natural gas heat pumps, in both new construction and retrofit



- Conservation: building envelope improvements (e.g. Net Zero Ready)
  - 40% to 60% reduction in energy and GHG emissions
- ***Transformative natural gas end-use technology development***
  - ***30% to 50% reduction in fuel & GHGs***
- Greening of the Gas Grid (deep renewable penetration 2030-2050)
  - 40% to 50% reduction in GHGs

Meets 80% GHG reduction by 2050

Opportunity for Industry & Academic Collaboration

Supply-side technology developments - like solar fuels - represent a growth vector for renewable energy and cost-effective storage

- Long-term, potential exists for technology development to synthesize CO_2 into easily stored fuels
- Important to incubate research and include green gas planning into planned 2030-2050 GHG reductions
- Solar fuels leverage existing pipeline and storage infrastructure; Diversifies a deep GHG reduction strategy
- Potential to derive lower cost/tonne GHG reductions (CO_2 becomes a value add feedstock – not pollutant)

Summary

- Greening the Natural Gas Grid complements our low-carbon power supplies as a balanced approach to meeting cost-effective GHG reductions
- Power-to-gas energy storage offers a unique way to integrate our low-carbon power grid with the larger wholesale energy market in Ontario
  - Surplus low-carbon power can be leveraged for our competitive advantage – not exported
- Diversity in energy infrastructure enhances energy resiliency, affordability of renewable energy and improved flexibility for energy planning
- Significant opportunities exist for the development of next-generation end-use appliances (electricity and gas) to establish robust hybrid heating solutions
- Lowest $/tonne should be a priority under cap-and-trade and net-zero planning (lower-cost GHG reductions today / research breakthroughs in long-term)

Questions

Backup Slides

Jump-Starting the RNG Market

Green Gas Supplies Leverage Existing Storage for Lower Consumer Costs Compared to Electrification Options

- Digester – Farm-based / Agricultural Waste
  - Highest market potential for GHG offsets

- Digester – Municipal Source Separated Organics (SSO)
  - Divest organics from waste stream for the creation of renewable biogas

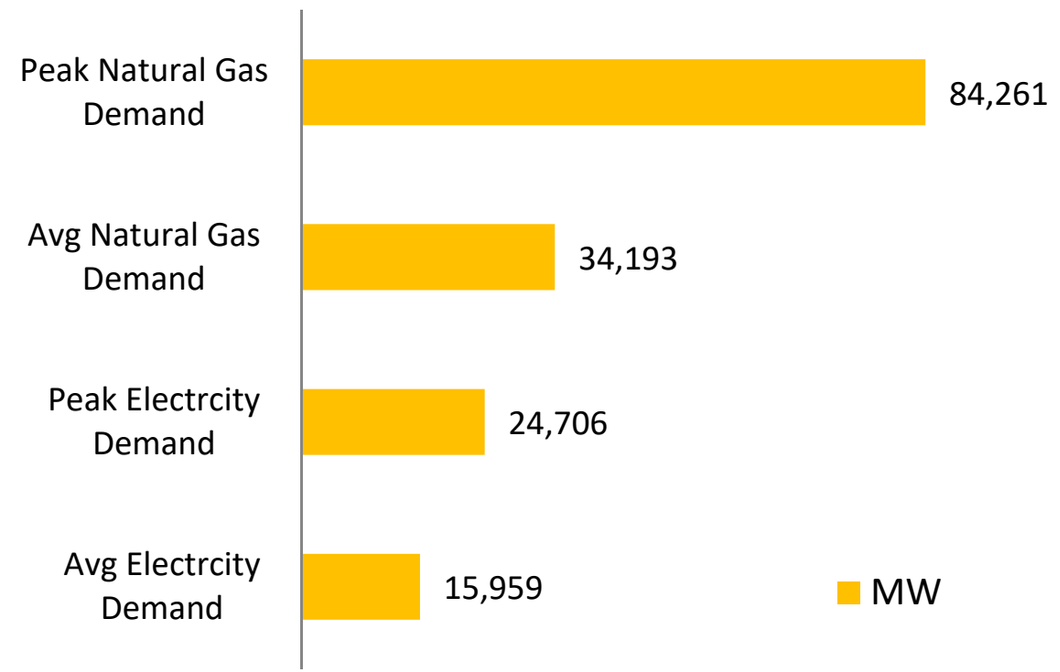
- Wastewater Treatment Facilities
  - Today this biogas is flared or inefficiently used for generating electricity

- Landfill Gas clean up and injection into Pipelines
  - Earliest entry point for lower-cost RNG

Natural Gas provides low cost peak supply

Green fuels & renewable fuel switching is key to affordable peak energy

Ontario Energy by Fuel Type



Notes: 1. Ontario Peak natural gas demand is 6.9 bcf/day
2. Avg. natural gas demand includes refill of storage
3. Peak electricity demand recorded in Summer 2006 (IESO)

- Fuel switching large plug loads with renewable gas supplies:
- Cooking /cloths drying with renewables:
  - Green Power ~ $93.50/year
  - Green Gas ~ $36.50/year
  - Savings ~ 60%
- Lifestyle Benefit - Consumers reduce their exposure to time of use
- Free up electricity infrastructure to accept growth in EV charging

Assumptions: a) Mid-Peak Power $132/MWh + Toronto Hydro Residential Rate; b) Green Gas $17.00/GJ + Enbridge Residential Rate