Power.House Hybrid

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Project Collaborators

alectra Discover the possibilities | ENBRIDGE Life Takes Energy | MARKHAM | Natural Resources Canada / Ressources naturelles Canada | Toronto Metropolitan University Centre for Urban Energy, Faculty of Engineering & Architectural Science

Section 1

- Introduction
- Partnerships
- Project overview
- Timeline and location

Power.House Hybrid (PHH)

Reducing GHGs through integration and optimization

Project at-a-glance:

- Technology integration demonstration
- Multiple partners & vendors
- Advanced control logic
- All in solar + storage + EV charging + hybrid heating, micro combined heat and power
- Minimize GHGs via equipment + controls

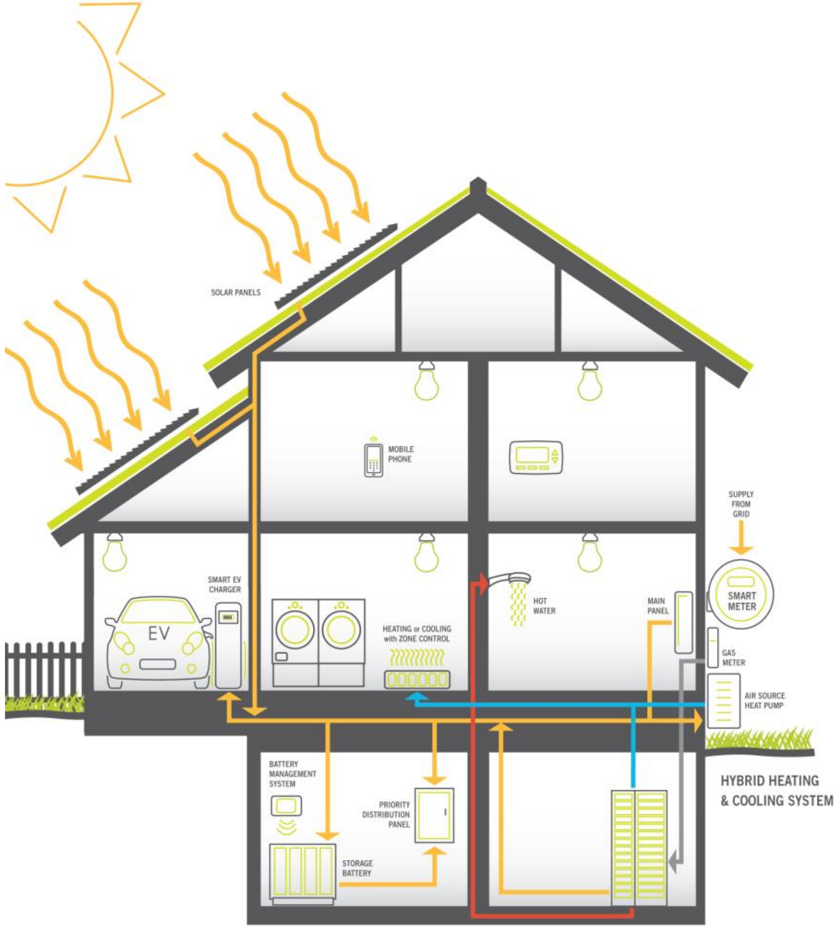


Illustration of a Power.House Hybrid Home showing all thermal and electrical equipment

From Smart Homes to Net-Zero Communities

- PHH aims to achieve reduction of Greenhouse Gases (GHGs) in single family retrofits, a **hard-to-reach customer segment.**
- Gas/electric **hybrid** heating offers resilience, reduces GHG emissions and with the newly tested smart controls can reduce operational costs
- Homeowners are **empowered** with generation & storage to address grid constraints through demand response, empowers communities to embrace new technologies to drive down carbon emissions.
- The project demonstrates an **end-to-end integrated household solution**, with advanced controls to maximize GHG benefits.

Project Objectives

- The primary objective of this project is to reduce GHG emissions using a variety of residential distributed energy resources (DERs), such as solar photovoltaics (PVs) coupled with battery storage, electric vehicles (EVs), and hybrid heating systems that can use either electricity or natural gas to optimize the use of energy in a typical Canadian single-family detached home and community.

- The Project will contribute to the Canadian economy and environment by supporting the development of Canadian technological innovation and will act as a model for municipalities, utilities and other stakeholders across the country to emulate and gain key insights towards reducing GHG emissions and transforming to a more sustainable energy sector.

Measuring Success

- GHGs were assessed during a baseline period by assigning an emission factor to each kWh of electricity, m^3 of natural gas, and litre of gasoline consumed by each participating household
- Each of the utility partners had a role in ongoing measurement during the project via sensors installed throughout the participating homes
- Alectra was particularly interested in the performance of the solar PV, battery and EV charger, and Enbridge was focused on monitoring performance, emissions, and operational costs of the hybrid heating system and micro combined heat and power
- All partners closely monitored the control system and engaged in a process of continuous improvement throughout the project to reduce GHGs

Partnership: Utilizing the Strength of Diverse Allies

- All partners have an imperative to achieve cost-effective GHG reductions for retrofit applications
- Strong interest in testing different technologies and how they come together in a reliable package
- Demonstrating possibilities - future homeowners can “pick and choose” the equipment to meet their needs

- **Alectra** is committed to building a sustainable future, moving from traditional one-way flow to a two-way loop, to alleviate grid constraints, minimize GHG emissions, and empower households with clean energy choices.
- **Enbridge** is working together with our stakeholders to meet our future energy needs sustainably. We’re collaborating to advance new low carbon technologies, renewable natural gas, hydrogen and carbon capture to heat buildings, power industry and fuel transportation
- **The City of Markham** is committed to reducing GHG emissions and energy consumption Citywide, with the objective of Net-zero emissions by 2050

PHH: Project Overview

System and Controls Strategy

Alectra and Enbridge jointly shared the responsibility for developing a controls strategy. Clear responsibilities were defined for each partner as follows:

- **Alectra** - scoping and sourcing the electrical equipment, including battery, solar PV, and EV charger
- **Enbridge** - scoping and sourcing the thermal equipment, including hybrid heating system and micro combined heat and power

Participant Recruitment and Communications

- **City of Markham** - engaging and recruiting participants and developing communications materials

Equipment Ownership and Management

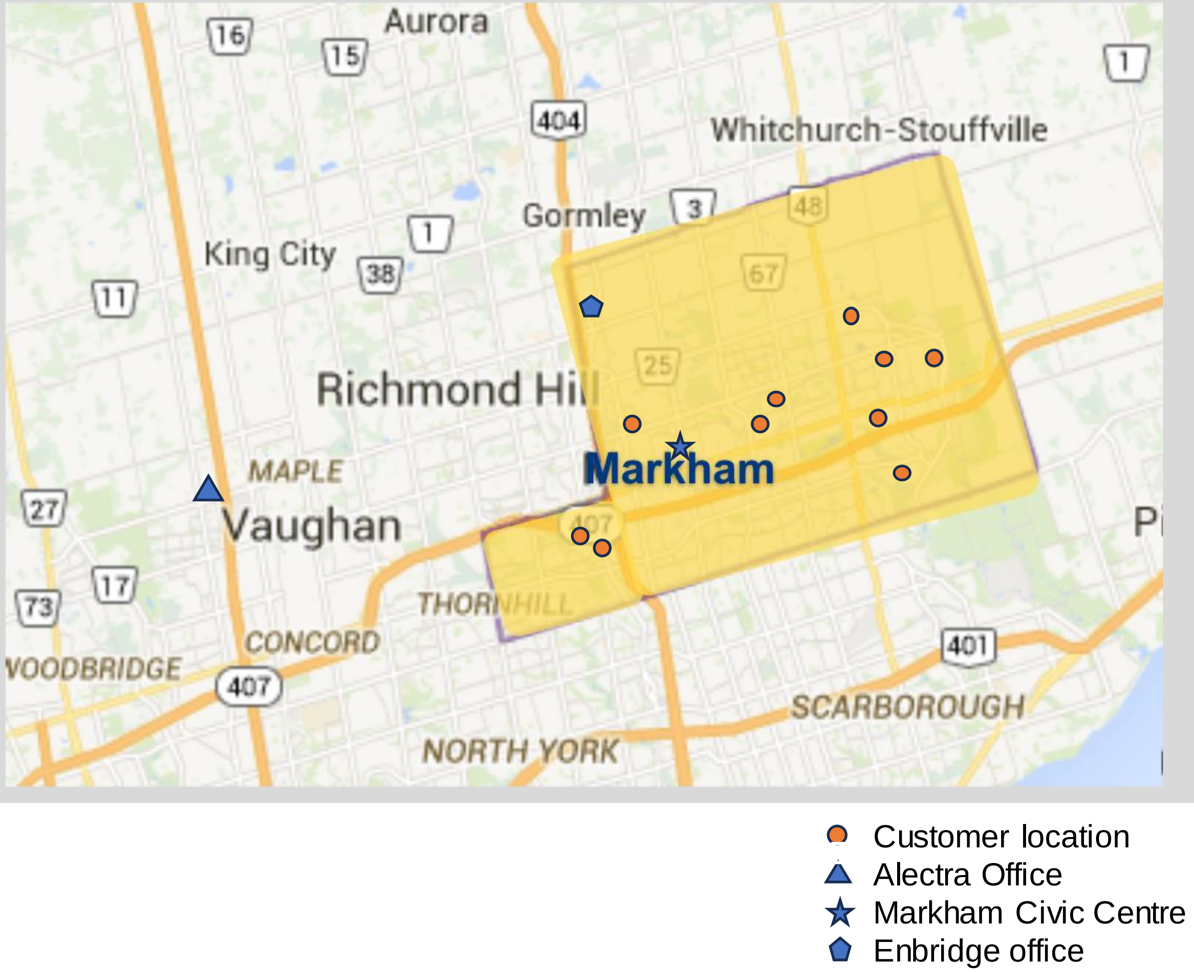
- **Alectra and Enbridge** - purchased and installed the equipment and operated it during the pilot. Post-pilot, customers will retain ownership of equipment, where feasible, at no cost to the homeowner

Equipment was controlled by the project team, with the potential for customers to opt-out of certain elements to avoid significant disruption to their daily schedules

PHH: Timeline and Location

- **2018-19**: Project development, detailed workplan and partner agreement
- **2019-20**: Participant screening and selection, equipment selection
- **2020-21**: Equipment and measurement sensor installation
- **2021-22**: Refining the control strategy, implementation of complete system
- **2022-23**: Final collection of data, analysis and communications efforts

All participating homes were located in **Markham, Ontario.**



Section 2

- Participant onboarding
- Participant engagement
- Participant acceptance

Customer Onboarding

- Customers were screened based on several criteria, including EV ownership, rooftop solar exposure and-orientation, utility room size, and energy use
- Customers were selected based on their preference during interviews, for example willingness to accommodate site visits
- Emphasis was placed on this being an innovative project – not everything worked perfectly at the start, and participants need to understand that troubleshooting and patience are part of the experience

> “I was **aware of some of these technologies, I was interested in implementing them** myself. We purchased an EV and when the opportunity came-up I thought what a nice way to complete the picture and **accelerate where I wanted to go** with our household.

Participant Engagement

Voice of the Participants

Reliability

"If I were to put a **home elevator** and the power went down and someone was in the elevator than that becomes an issue. PHH features battery back-up, solar PV and micro combined heat and power generation, ensuring reliability - a very important perspective from an aging individual.

Home Comfort

"The furnace doesn't heat the air, the tankless water heater heats the water. As a result, the heat is not as drying as it used to be. It's **a much healthier heat,** it makes a massive comfort difference.

Lower Bills

"**I don't need to freeze to save a few dollars anymore.** We used to turn down the temperature at night, we now keep it at a consistent temperature through-out the day and night, and it doesn't cost us.*

Reduced GHG Emissions

"When you see all the stuff happening all over the world, you really feel the **importance of trying to do your little bit.**

* Note that homeowners benefited through reduced operating costs but did not bear any of the equipment/installation costs

Participant Acceptance

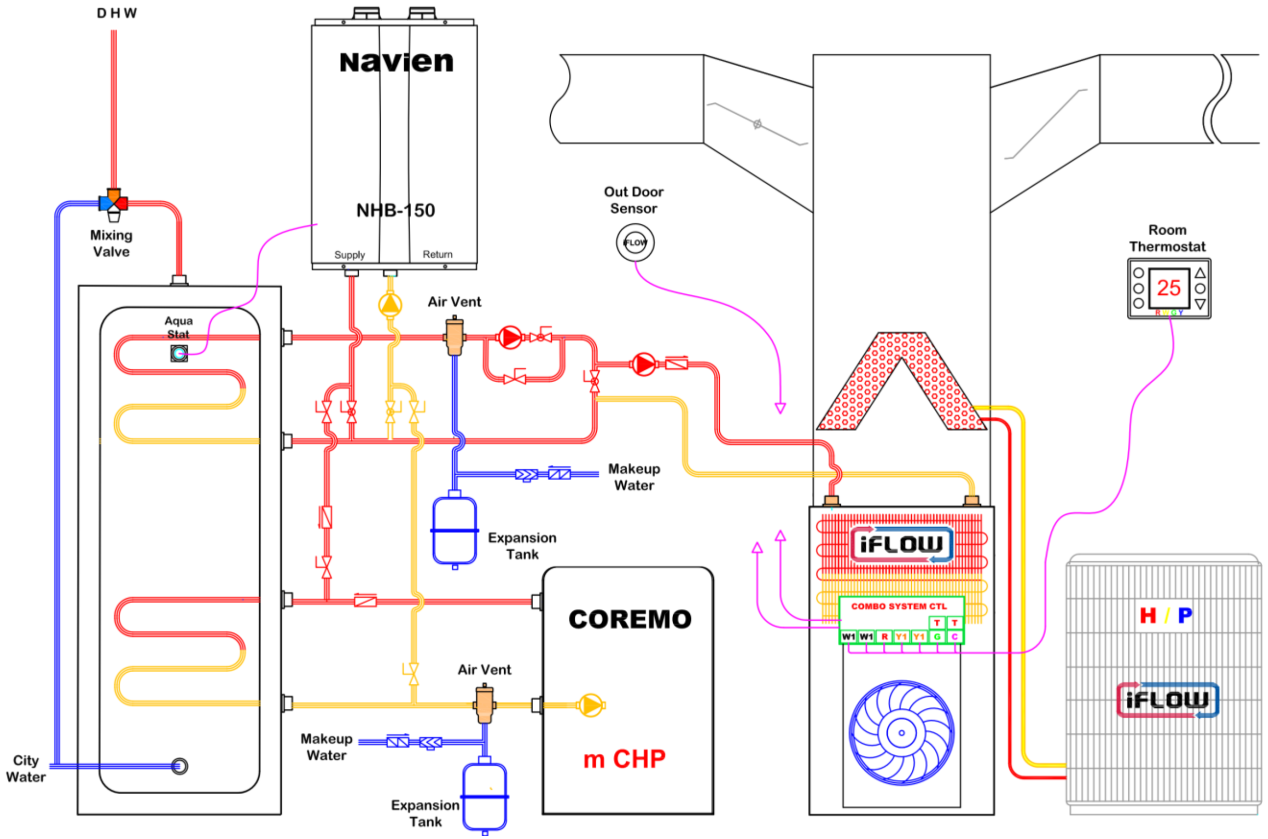
- Promote clean technology in the community where people care about sustainability in addition to resilient, dependable energy solutions for today and in the future
- Enable the move towards Net-Zero energy emission homes - enhance community livability and health
- Promote the adoption of EVs, battery storage, Solar PV and advanced controls, allowing the communities to be a part of clean technology adoption

> "We were thrilled to participate in this technology demonstration pilot, working alongside project partners and the government. The **learnings** from this experience in **our homes** will greatly contribute to helping **the next generation of homes** tackle climate change.

Section 3

- Technology
- Objectives
- M&V

All technologies were optimized to reduce GHG Emissions using a control algorithm

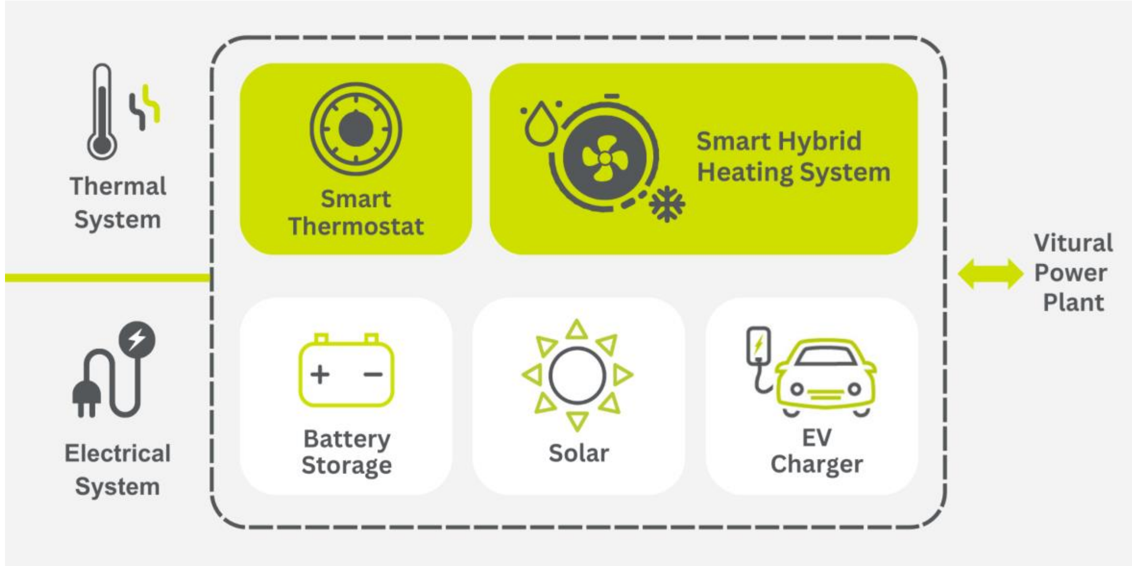


Full energy solutions were installed in 10 Markham homes:

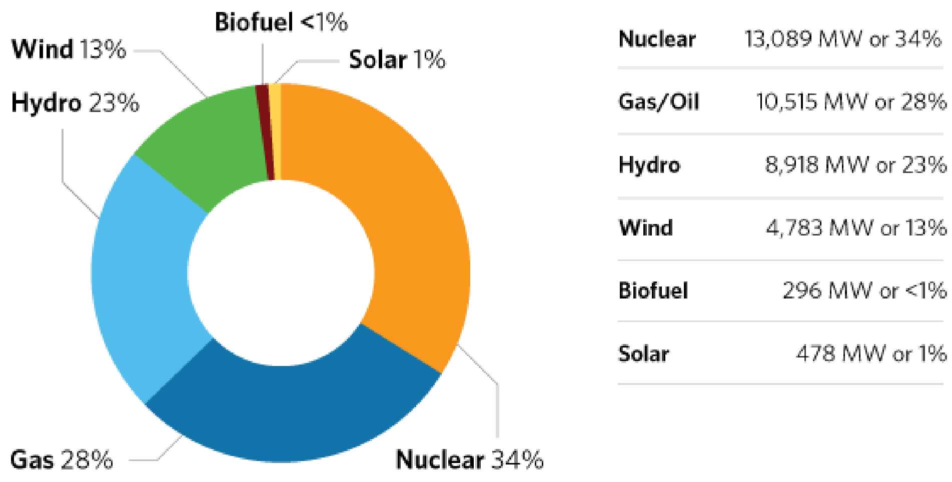
- **Air source heat pump** 34 kBTU output, 10.5 kW max power draw, w/ air handler
- **Tankless water heater** 95% AFUE
- **Electric vehicle charger** Level 2 – 7.2kW
- **Solar PV** 3.3kW AC
- **Battery storage** 6kW / 11.6 kWh
- **Micro combined heat and power** 1.5 kW (4 homes)

Controls & Optimizing for GHG Reductions

- **Maximize solar** for load displacement, battery storage
- Use **air-source heat pumps** during low grid GHG hours
- **Curtail** electric vehicle charging during peak GHG hours (when gas is on the margin)
- **High efficiency** tankless water heater used for space and water heating during peak GHG hours
- **High efficiency** micro combined heat and power for space and water heating as well as electricity generation during peak GHG hours and during power outage.



Power.House Hybrid Schematic: Thermal, Electrical and Virtual Power Plant



Ontario System-Wide Electricity Supply Mix 2021
Source: IESO Year-End Data

Controls & Optimizing for GHG Reductions (Cont'd)

- **Controls were designed to reduce GHGs**, using a schedule to switch between different customer equipment depending on outside temperature and grid GHG emissions.
- **Solar power** was always used as the lowest GHG source of electricity generation, either directly to supply home loads, stored in the battery, or for customers with net metering, exported to the grid.
- **Battery storage** maintained a reserve portion for resiliency purposes, but otherwise was discharged during high grid GHG hours to displace the need for grid supplied electricity, especially during summer morning peaks so that it could absorb surplus solar power during the day.
- **Air-source heat pumps** were used to supply space heating when outside temperatures were greater than 0°C and low grid GHG hours.
- **Electric vehicle** charging was curtailed during high grid GHG hours, as defined by a pre-determined schedule.
- **Gas tankless water heater** used when temperatures were below 0°C or during peak GHG hours.
- **Micro combined heat and power** was used to supply space and water heating as well as power for the home when solar was unavailable, temperatures were below 0°C and at high grid GHG hours.

Participant Equipment Upgrades and Financial Impact

- Many customers in Markham have forced air gas heating and electric cooling systems in their home – the market potential in Canada is very large
- All participants had their gas furnaces and air conditioners replaced with higher efficiency air source heat pumps, tankless water heaters and air handlers: A modest incremental cost above conventional equipment
- Level 2 EV chargers were installed for participants with EVs – the cost of the vehicle is the largest single outlay: Incremental cost vary depending on the type of vehicle and driving patterns
- Solar and battery storage were installed for all participants : This represented a large incremental cost, but was a critical element to help provide clean generation and resiliency

The combination of technologies allows the customer to benefit from reduced bills while helping utilities support the grid – at scale, helping move communities to net zero, improving resiliency and affordability via controls

Equipment Benefits

- **Solar PV** generates electricity with no GHGs, typically during peak hours. Business case varies considerably with solar exposure and installation details, with typical payback around 10 years.
- **Air-source heat pumps** provide high efficiency heating and cooling and can be less expensive to run with controls that avoid on-peak electricity use.
- **EV charging** curtailment during peak hours saves customers on costs, while also benefiting the grid by reducing peak demand, lowering grid GHG emissions.
- **Tankless water heaters** provide high efficiency hot water and space heating, even at extremely cold temperatures, reducing emissions compared to furnace and hot water tanks,
- **Micro combined heat and power units** also providing high efficiency hot water and space heating at cold temperatures and generating reliable and affordable electricity.
- **Battery storage** provides backup and resilient power for homeowners, while also allowing for load shifting to charge off-peak and then discharge at peak rates, reducing peak demand and lowering grid GHG emissions.

PowerHouse Hybrid vs. Conventional Home Scenario

Conventional Home Scenario

- Most homeowners that have forced air systems with conventional natural gas furnaces and air conditioners are used to operating their programmable/smart thermostats to set heating and cooling set points and scheduling.
- When the thermostat hits the desired set point, signals are sent to the furnace or air conditioner to provide heating or cooling, keeping the house temperature within the desired range.

Power.House Hybrid Scenario

- The Power.House Hybrid system replaces the conventional natural gas furnace and hot water tank with an air handler and tankless water heater, and the air conditioner with air source heat pump.
- Additional controls in the cloud server and in the air handler improve on thermostat operation, reducing emissions while improving resilience and affordability by instructing the heat pump, gas tankless water heater, and micro combined heat and power units to run based on outside temperature, equipment performance and based on the GHG intensity of the grid.
- Solar PV, battery storage, micro combined heat and power and EV charging are controlled via the cloud server to reduce GHGs and adding resilient backup to the high efficiency heating and cooling system.

Section 4

- Results
- Challenges
- Learnings

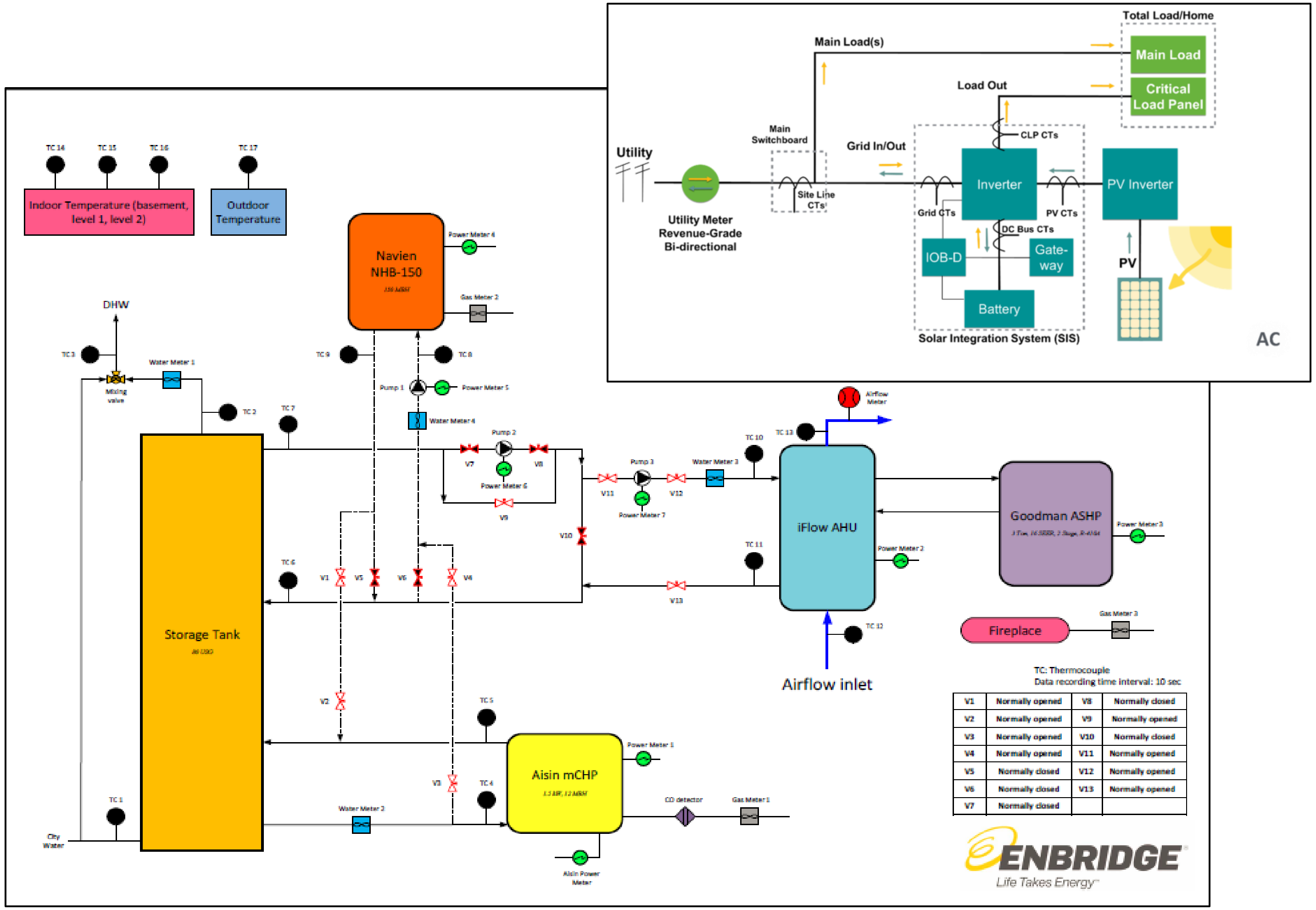
Measurement & Verification

Objective

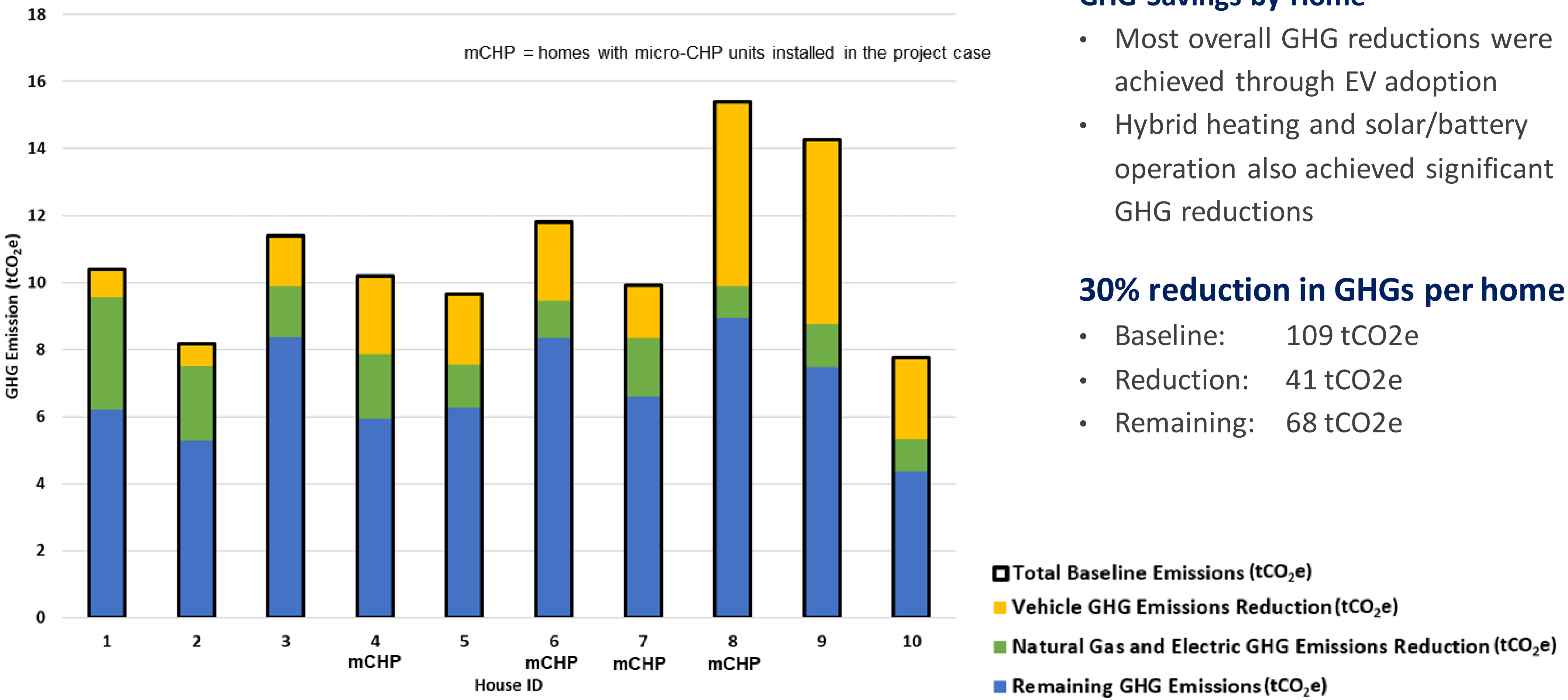
- Calculate power, thermal and GHGs for all equipment to determine the cost effectiveness of GHG reductions
- Estimate homeowner bill impacts and benefits of demand management to the grid

Methodology

- Monitor related flows/temperatures of water, gas and air, as well as power/thermal energy usage and generation for the equipment.



Pilot Results: 30% Reduction in GHG Emissions per Home



GHG Savings by Home

- Most overall GHG reductions were achieved through EV adoption
- Hybrid heating and solar/battery operation also achieved significant GHG reductions

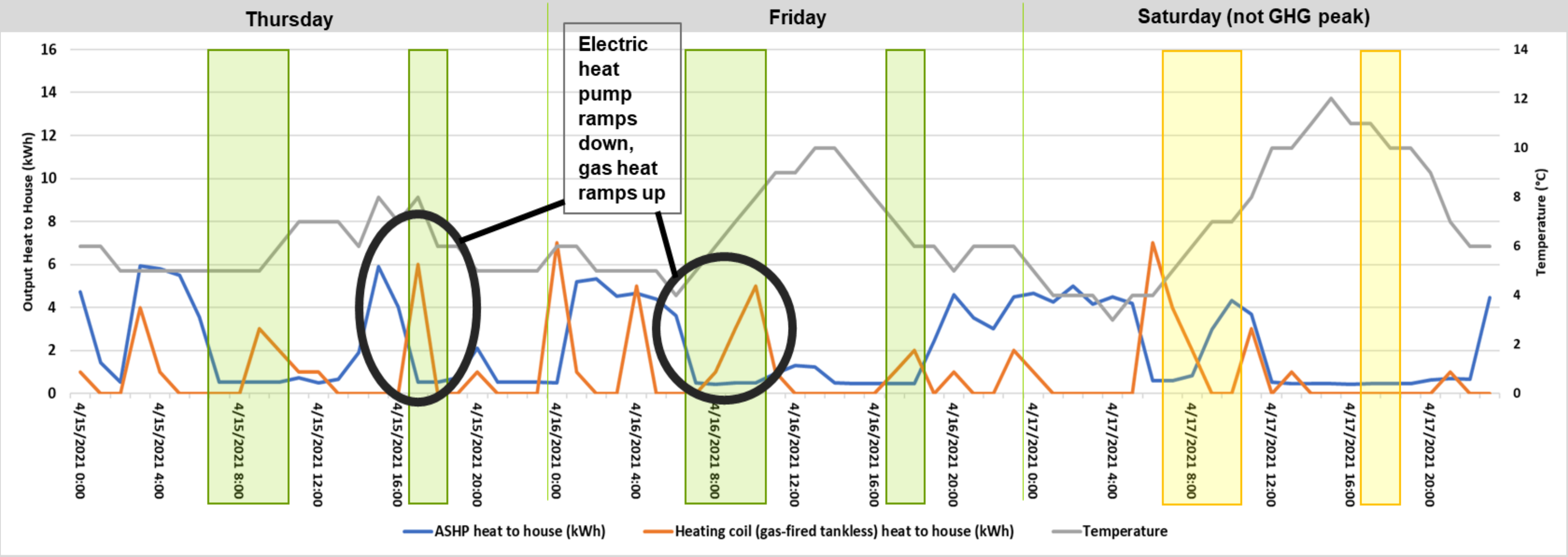
30% reduction in GHGs per home

- Baseline: 109 tCO2e
- Reduction: 41 tCO2e
- Remaining: 68 tCO2e

Energy and Bill Savings

- Total annual energy (electricity and natural gas) consumption decreased by 85 MWh/year.
- The pilot reduced total energy consumption per home for non-EV uses, including electric and natural gas energy, in the range of 10% to 40% across homes.
- Each pilot home was upgraded to equipment with a large incremental cost over conventional equipment (see slide 18 for more details)
- Total homeowners’ annual savings were about $15,000 in annual operating costs, which is approximately $1,500 savings per house.
- The savings represent roughly ¼ to ½ of total energy expenditures per household, although this varies considerably depending on a number of factors, for example savings were mostly a result of avoided gasoline costs for EV drivers, with houses with longer driving distances showing the highest cost savings.

Pilot Results: Hybrid Heating Snapshot



GHG Peak Hours: weekdays 7-11 AM and 5-7 PM

7-11 AM and 5-7 PM hours on Saturday are not GHG peak hours, therefore the grid-optimization algorithm was not active, and the electric heat pump (blue line) turned on during those hours

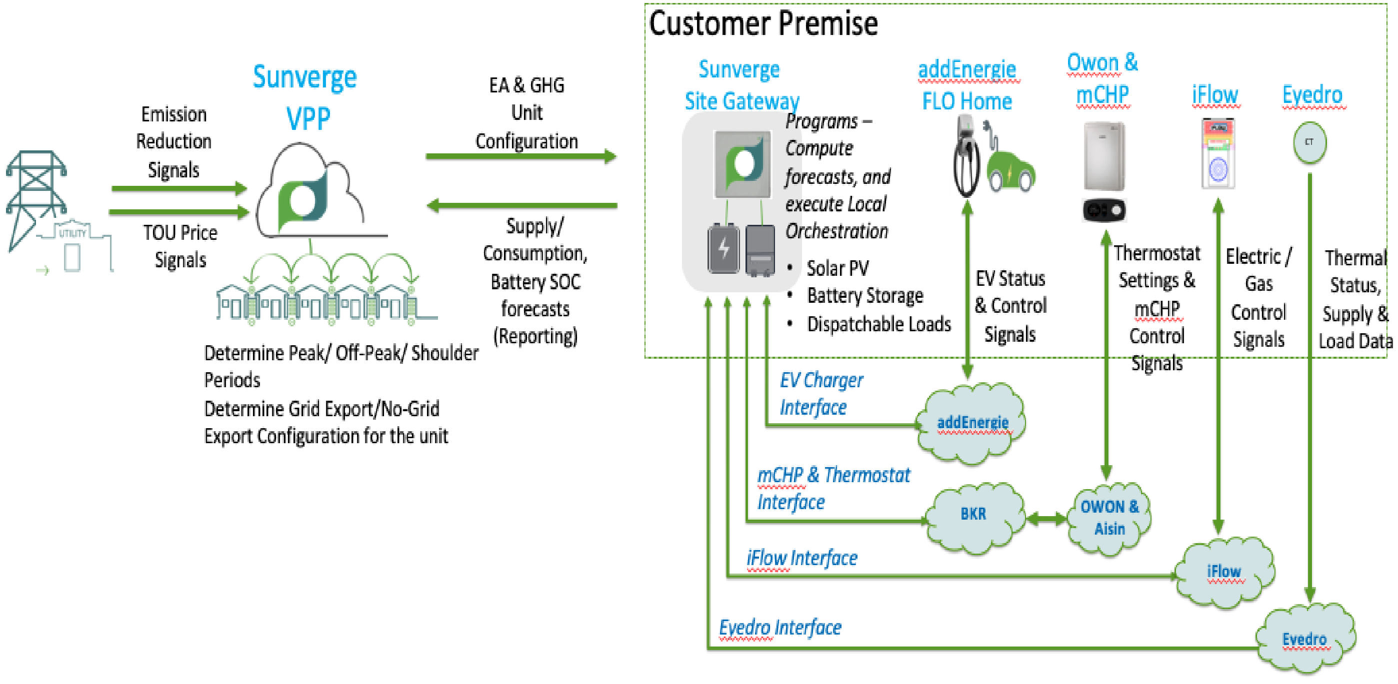
- The blue line shows output of the heat pump and the orange line shows output of the gas-fired water heater varying by outdoor temperature
- Peaks circled show gas-fired heating ramping up to reduce GHGs during on-peak times
- Peaks not circled show gas-fired heater operation to satisfy hot water demand

* **Note:** the ASHP (blue line) shown here was always enabled (always available). The plot therefore demonstrates that the electric ASHP was ramped off, and the gas-fired heat was ramped on, based solely on GHG peak hours.

PHH: Challenges Faced during the Project

- **Integration:** This illustration shows the integration across 5 different vendors, managed by multiple partners. Ensuring interoperability among various vendors posed a notable challenge, including tasks such as navigating firmware updates and pinpointing points of failure within the intricate layers of vendor operation and control.

- **Installations:** Participants were chosen with an aim to minimize installation challenges



- **Customer:** Working with participants required a consistent level of effort, coordination around troubleshooting

- **Regulatory:** Net metering limits on gas-fired mCHP leading to control issues with reverse power flow

- **Administration:** Multiple partners increases the complexity of legal, approvals, procurement, insurance

Learnings from the Project

- **GHG reductions** can be **achieved in a number of ways** and there are often tradeoffs between capital and operating costs and bill impacts when it comes to optimizing equipment and operation
- **Thermal comfort is non-negotiable**, especially in a cold climate country where heating is essential, and increasingly cooling is required in summers – there is a customer value proposition in providing backup power
- **Innovation requires flexibility** – participants and contractors need to understand that there will be technical and logistical challenges and troubleshooting will be required
- **Overcommunicate** the complexity to participants so they are prepared when multiple site visits are required to get the equipment working as intended, & ensure partners are aligned on objectives and detailed design
- **Dedicated contractors** are needed to implement complex projects, as the time and level of effort can be higher than with more conventional, business as usual projects
- **Post-pilot thinking pre-pilot,** develop a proper plan for project sunset early in the project scoping and build that into the workplan from the onset to ensure adequate resources are allocated

Section 5

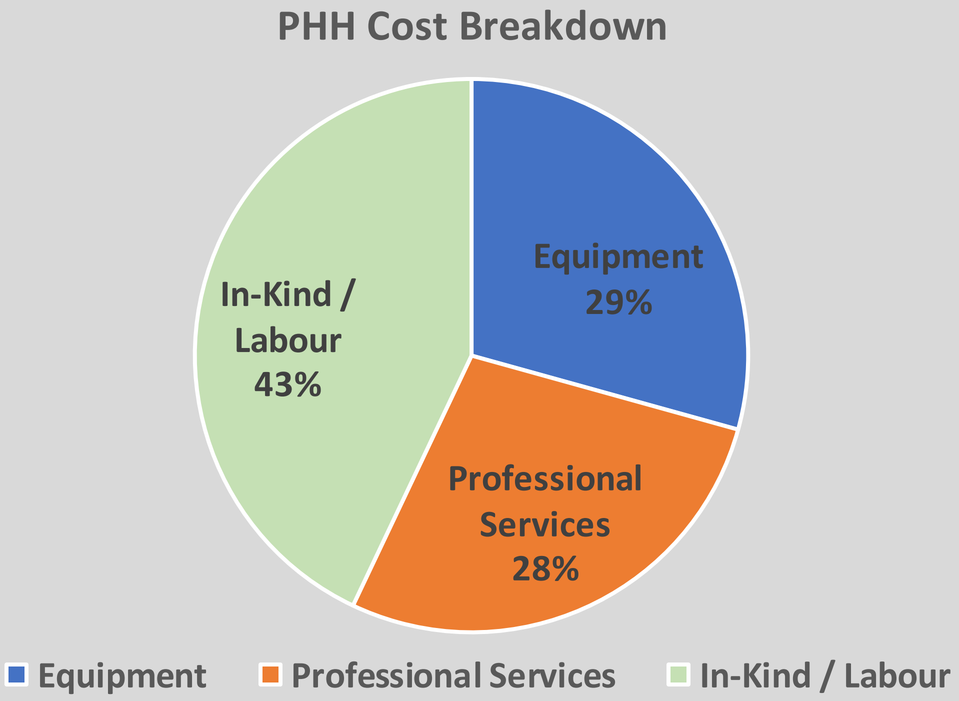
- Project financials
- Next steps

Project Financials

Total Project Costs for the span of over 5 years was $3.38 million, with NRCan contributing $1.669 million.

Major cost categories include:

- **Equipment and installation** costs, including battery, solar PV, EV charger, tankless water heater, smart air handler, measurement and verification sensors and all mechanical and electrical installation costs
- **Professional services** include measurement and verification costs, external technical consultants for development of the control strategy, project management, communications and other costs
- **In-kind / labour** costs include partner labour for time spent working on project deliverables



Lasting Impacts of the PHH Project

- The partners gained valuable information from the project in terms of technology, controls, partnerships, and customer engagement – learnings that will inform other projects
- One of the resulting impacts of the project has been to spur the HVAC industry to improve controls to help homeowners and utilities reduce GHGs and utility bills by dispatching heating equipment
- While PHH was a great project to understand how to maximize GHG emissions, simple controls and systems that achieve similar results are needed for scalability and customer acceptance.
- This project demonstrated that leveraging both the gas and electric systems can effectively reduce emissions, while providing other important benefits including greater consumer choice, reliability and resilience.
- The potential for these solutions to impact overall GHGs is significant as the single family retrofit market is one of the biggest and hardest to reach sectors of the economy

Next Steps

NRCAN: Program results analysis across projects, identification of persistent sector innovation barriers and priorities

Alectra: Considering next steps for residential pilots – EV charging, solar/storage, and heat pumps and continuing to work with Enbridge and partners to advance low carbon, hybrid heating solutions

Enbridge: Continue to lead/support advancement of a variety of technologies that serve the various needs of our customer groups through collaboration with stakeholders.

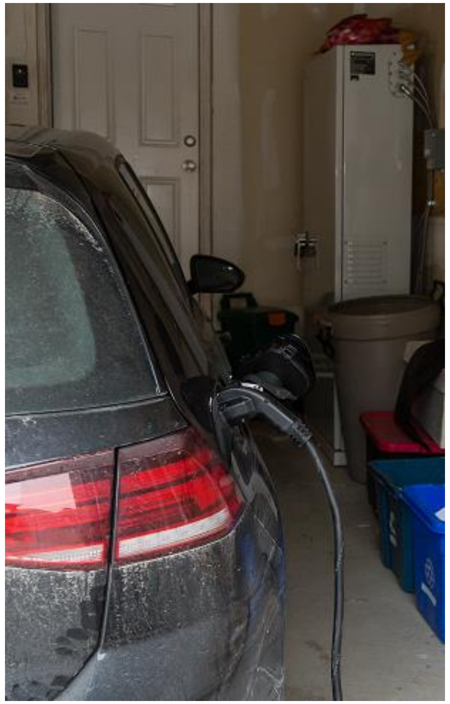
City of Markham: Providing resources, education and expertise to increase residential retrofits and exploring further options to help homeowners towards net-zero emissions by 2050

Appendix

Photos of the equipment used in PHH homes

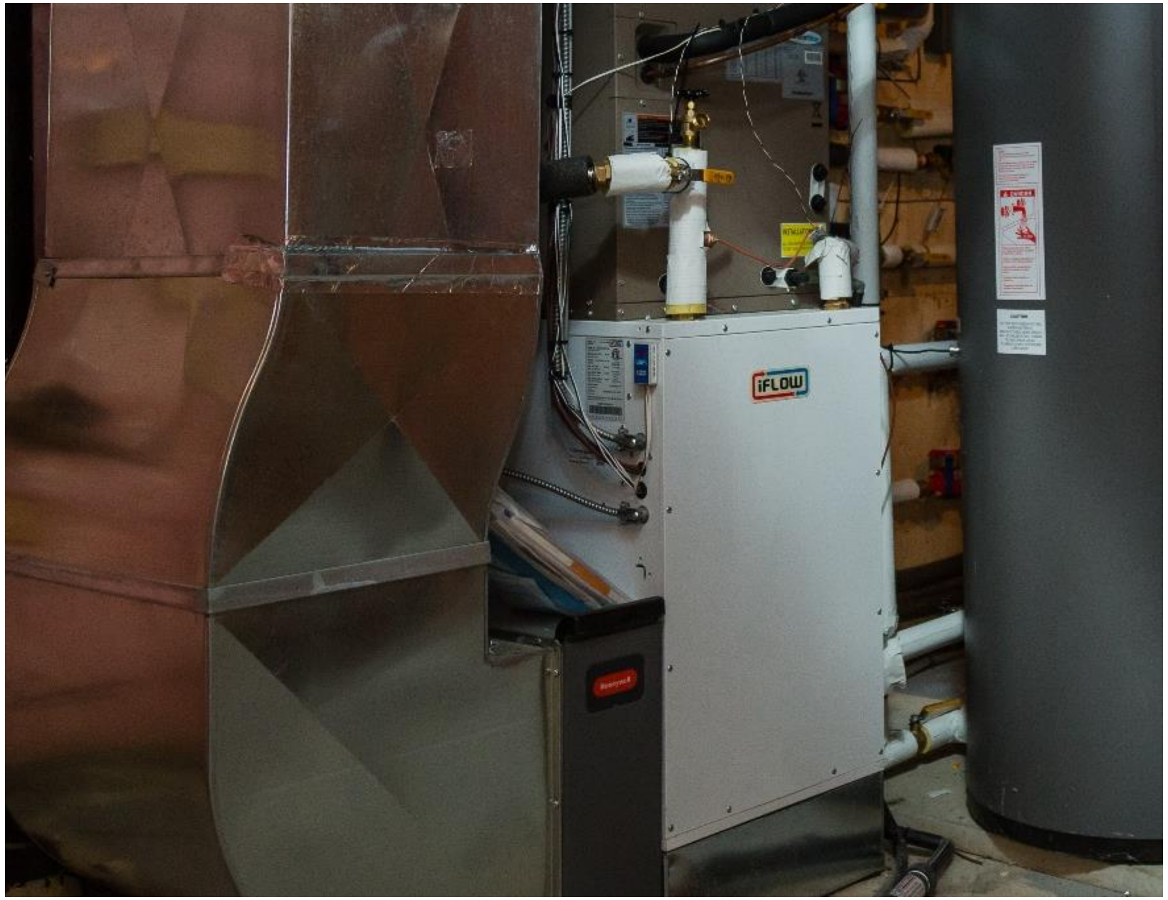
Roof-Mounted Solar Photovoltaic Cells

Battery Storage System



Level 2 Electric Vehicle Charger

Air Handling Unit with Smart Controls



Participant Perspective

"The furnace is certainly **easier to maintain**, its significantly better. Because there is nothing to maintain except for an air filter. It's a lot less work than our old furnace.

Micro Combined Heat and Power & Thermal Storage System

Tankless Water Heater

Participant Perspective

"The tankless water heater is significantly much more responsive than the large tank.

Air Source Heat Pump

Participant Perspective

> The heat pump is certainly doing a **better job in cooling the house.**

> It's **not dry air anymore.** It's a great tech.

For more information on the project, email:

GREAT@AlectraUtilities.com