Power.House Hybrid

Helping Single Family Homes Transition to Net Zero

Project whitepaper presented by:

MARKHAM

alectra
GRE&T Centre

ENBRIDGE
Life Takes Energy

Natural Resources Canada | Ressources naturelles Canada
Canada

Toronto Metropolitan University
Centre for Urban Energy
Faculty of Engineering & Architectural Science

1 INTRODUCTION

In March 2022, Canada released its first 2030 Emissions Reduction Plan[1], issued under the Canadian Net-Zero Emissions Accountability Act which is described as "a comprehensive roadmap that reflects the levels of ambition that guide emissions reduction efforts in each sector". The 2030 Emissions Reduction Plan describes the many actions that will help reduce emissions across the key sectors of the Canadian economy to reach reduction targets of 40 to 45% below 2005 levels by 2030 and put Canada on a path to achieve net-zero emissions by 2050.

The Plan provides a sector-by-sector path to achieve low emission targets. Within buildings, the Plan highlights that action is required, given that buildings represent 12% of emissions in Canada and emissions have been trending upwards since 2005 as more buildings are constructed.

Specifically, within residential homes, the use of clean distributed energy resources (DERs) such as solar panels, air-source heat pumps and other clean energy technologies are individually insufficient to meet community GHG reduction targets.

Primary challenges for GHG reduction targets include:

1) Optimizing household energy usage to lower carbon footprint of homes while still meeting all energy needs
2) Improving the sustainability, and resilience of the power grid using home-based renewable DERs.

The Power.House Hybrid (PHH) pilot enables the movement towards net-zero energy emission homes by integrating a hybrid set of electrical and thermal equipment into a virtual power plant platform. This mix of technologies demonstrates that homes can transition to net zero today and achieve national goals.

Power.House Hybrid is a collaboration project between Alectra Utilities Corporation, Enbridge Gas Inc, City of Markham, Toronto Metropolitan University and is funded by the Natural Resources Canada (NRCan). The project objective is to demonstrate how integration and control of electrical and thermal technology in existing single-family homes in Markham, Ontario can successfully lower greenhouse gas (GHG) emissions, without compromising on occupant comfort.

2 THE PROJECT VISION

Spurred by consumer appetite favoring sustainability, increasingly affordable solar technology and updated building codes, there is an increasing demand for housing solutions to address climate concerns. Although residential decarbonization technology is rapidly becoming more affordable and common, many homeowners remain hesitant to commit due to unfamiliarity and uncertainty!

What if existing single-family homes were fitted with proven technologies that enable households to generate clean energy and lower their carbon footprint without sacrificing their level of comfort?

What if this was done in a way that also helps decarbonize the local grid?

This is the where the Power.House Hybrid pilot has excelled. The pilot was designed to explore how homes with deep energy retrofits can help lead the transition away from the current large, centralized power generation sources to decentralized, home-based, clean power generation. Data from the pilot will help optimize system configuration design for future installations, and the learnings can be used to further educate Markham residents, as well as residents broadly across Canada in considering energy retrofits.

The Power.House Hybrid pilot shifts energy generation from large, centralized, and possibly GHG emission-intensive sources to decentralized, cleaner generation using solar panels, battery storage, hybrid heating (gas and electric), and in some homes, micro combined heat and power (mCHP). Operation of these electrical and thermal technologies is optimized using advanced control algorithms and grid emission factors. Homes without mCHP units were net metered, meaning any electricity generated by solar in excess of the home's consumption were fed into the local grid to power neighboring communities with clean energy. The grid supplies power when household demand exceeds generation.

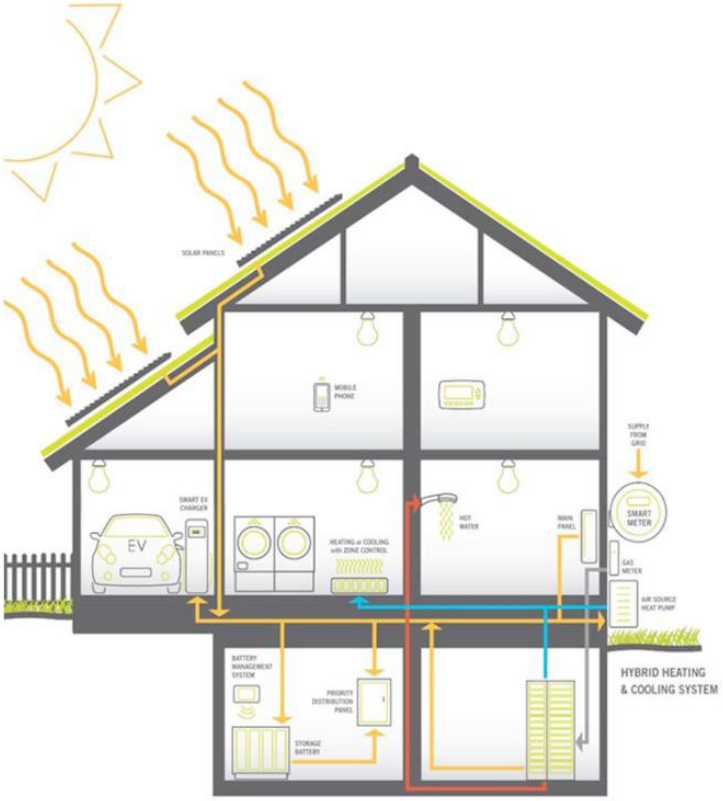


Illustration of a Power.House Hybrid Home showing all thermal and electrical equipment

Homes with mCHP units were run in "load displacement" mode, meaning electricity generation from solar and the mCHP were balanced by the battery to meet the home's consumption, minimizing the need to use electricity from the grid, without exporting any power.

As part of the PHH pilot, ten homes in Markham, Ontario were retrofitted with advanced electrical and thermal technologies and control systems to reduce pressure on the grid during periods of peak demand, when emissions due to electricity generation typically peak due to natural gas peaker plants.

Together these homes act as a localized virtual power plant (VPP), helping the transition from large, centralized power generation to distributed generation. Smart electric vehicle (EV) chargers were installed to shift EV charging load to off-peak times.

3 PROJECT DESIGN

Having multiple, independent electrical and thermal energy solutions in one house requires an energy management system to aggregate and dispatch these resources throughout the house.

The electrical equipment of participating homes was designed to generate, store, and deliver electricity and included:

- 3.3 kW roof-mounted solar photovoltaic cells
- 11.4 kWh battery storage system
- Level 2 electric vehicle charger

The hybrid heating system components varied depending on the home and were designed to:

- Provide dual fuel (natural gas and electricity) capabilities for home heating using a high efficiency tankless water heater and an air-source heat pump and smart thermostat to enable hybrid heating capabilities.
- Provide domestic hot water (DHW) using the same high efficiency tankless water heater to generate hot water

This equipment replaces the home's conventional water heater and furnace for space and water heating. The thermal equipment used varied by home and included one of the following two packages based on the layout:

Package One	**Package Two**
Tankless gas water heater Air handling unit Air-source heat pump (ASHP)	Tankless gas water heater Air handling unit Air-source heat pump (ASHP) Micro combined heat and power (mCHP) Thermal storage tank

The second package was designed to test the equipment with a micro combined heat and power (mCHP) system.

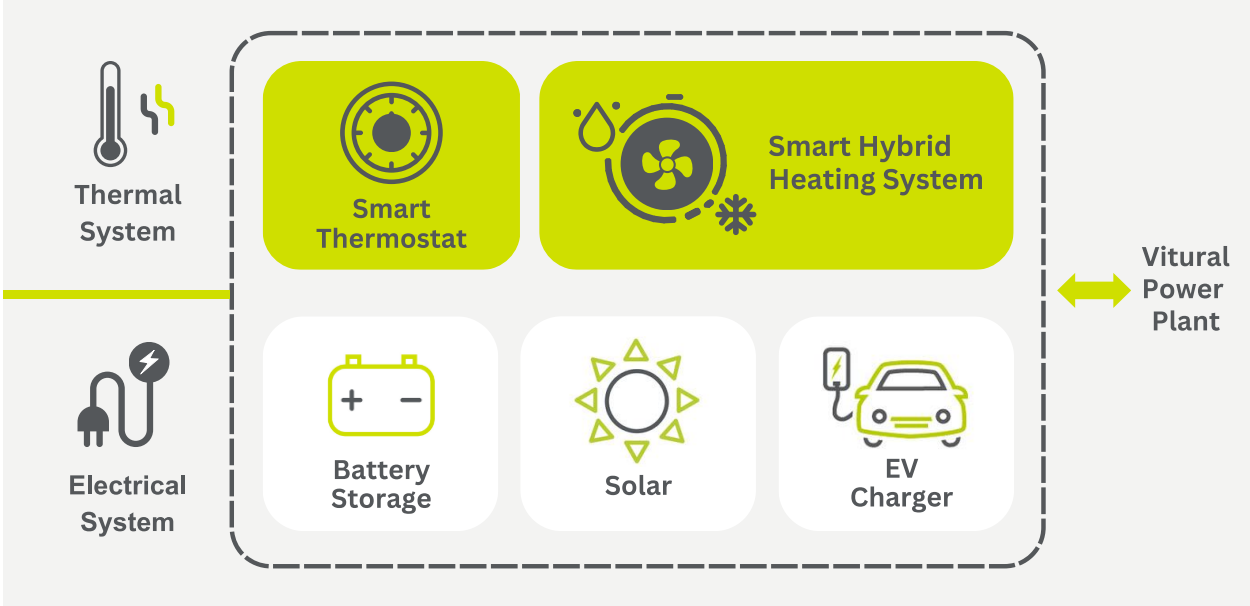
Homeowners were selected based on several criteria including:

- Requirement to own an electric vehicle
- Size of their home
- Suitability of roof for solar panels
- Type of home heating and cooling system
- Electricity and natural gas usage profile of their homes and,
- Willingness to share data and allow occasional site visits for monitoring and servicing the equipment

4 HOW POWER.HOUSE HYBRID WORKS

The PHH heating system includes an air-source heat pump (ASHP), tankless gas water heater, micro combined heat and power (mCHP), thermal energy storage, PV solar panels, and battery storage. Using a combination of technologies offers resiliency during electricity outages, as well as affordable comfort in the coldest months of the year. The smart controls increased cost effectiveness and reduced GHG emissions by switching between the ASHP and gas heating based on utility costs, the outdoor temperature, equipment efficiency, and marginal emission factor of the electric grid.

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



Ontario's baseload electricity demand is met primarily by hydro and nuclear power, with natural gas generation providing flexibility to meet peak demand that ramps up and down to balance variable renewable energy sources. As a result, GHG emissions that are due to electricity generation vary throughout the day, typically peaking in the morning and late afternoon.

Seasonal variation due to changes in weather, daylight, and demand also cause variation in GHG emissions throughout the year. Significant new load from electrification of transportation and heating could intensify these patterns without additional clean generation and intelligent dispatching.

The Power.House Hybrid control scheme is designed to minimize the power a participating home draws from the grid during periods of higher grid emissions. During these periods, the participating homes reduce EV charging and electric heating loads and prioritizes gas and storage sources. The control algorithm charges the battery in anticipation of forecasted demand during peak emission times to limit power consumed from the grid.

Demonstrating Value: Efficiency, Decarbonized Heating, and Resilient Grid

Energy Efficiency: Battery usage and EV charging behaviour are managed to ensure efficient use of clean energy

Decarbonized Heating: Smart hybrid heating system dynamically switches to lowest emissions source to provide heating, hot water, and cooling

Resilient Grid: Advanced control system aggregates storage and generation capacity of individual homes into a localized Virtual Power Plant

5 PILOT IMPACT

The pilot project began in 2018 with site selection and recruitment. Installation of pilot equipment and controls began in 2020. PHH pilot homes were retrofitted with a suite of electrical and hybrid heating equipment, including an energy management system designed to optimally dispatch resources in each house to balance GHG emissions reduction and energy costs to the homeowner.

The pilot was designed to provide direct impacts which includes:

1. Cost savings from energy efficiency using the implemented technologies
2. Reduction in GHG emissions
3. Enhanced protection from power outages
4. 1980s-era homes are empowered to contribute to grid services
5. Scaling up the development of net-zero energy emissions communities

Pictures from the participating houses:

Rooftop Solar PV Panels

Air-Source Heat Pump

Tankless Water Heater and Piping

Battery System with Integrated Solar Inverter

Micro Combined Heat and Power System with Hot Water Storage

Micro Combined Heat and Power Controller

Level II Electric Vehicle Charger

Smart Air Handler for Switching Between Gas and Electric Heating

Guidehouse, a consultant firm that specializes in energy efficiency and GHG emissions reductions in the commercial and public sectors, was tasked with evaluating the impact on GHG emissions and cost savings by leveraging the NRCan GHG emissions reporting template, in addition to gas and electricity utility meter data and EV charging data from the 10 pilot homes. Data from sensors installed in each home was collected over a 12-month period, from July 1, 2021 to June 30, 2022.

The evaluation found that in addition to avoiding 29.7 tCO2e of GHG emissions annually; (tonnes per house per year, on average,) by the PHH Pilot:

- Increased net annual electricity consumption by 9.5 MWh
- Decreased annual gas consumption by 9,140 m^3 (96 MWh)
- Decreased total annual energy consumption by 85 MWh and,
- Saved homeowners about **$15,000 in annual operational costs**, approximately $1,500 savings per house.

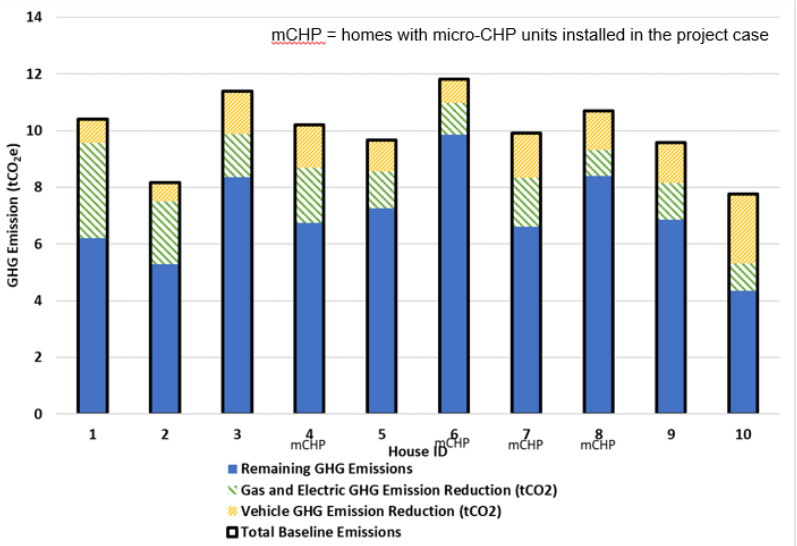
GHG Emissions Reductions for the 10 Pilot Homes

Baseline Case Pilot GHG Emissions:
99.6 tCO_2e

Pilot GHG Emissions Reduction:
29.7 tCO_2e

Pilot GHG Emissions Reduction (percent):
30%

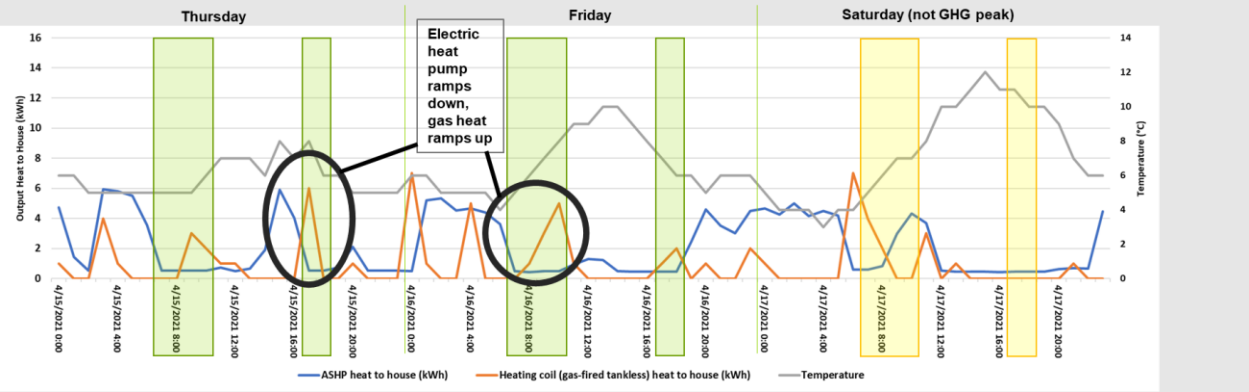
Remaining Project Case Pilot GHG Emissions:
70.0 tCO_2e



The evaluation of the pilot also examined the heating, ventilation, and air conditioning (HVAC) and EV control systems to assess their ability to minimize grid emissions during peak hours. Specifically, for HVAC systems with smart controls, the evaluation found that:

- Improved fuel efficiency of HVAC systems played a role in reducing electric and natural gas energy consumption resulting in cost savings to homeowners, as well as lower GHG emissions
- Control sequences designed to minimize GHG emissions during specific time of day and time of week periods, such as during GHG peak hours, are capable of automatically reducing GHG emissions in response to real time hourly emissions factor signals.

Hybrid Heating Snapshot for a Power.House Hybrid Home



* **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.

The evaluation found that inclusion of EV and hybrid vehicles in the PHH pilot further reduced GHG emissions. This reduction resulted through avoided gasoline emissions and avoided electric grid emissions due to curtailment of EV charging system demand during GHG peak hours.

Additionally, the EV portion of homeowner cost savings was substantial, demonstrating about 89% of total pilot operational cost savings. The project team has plans to continue to analyze the data and exploring further opportunities to decrease GHG emissions with pilot equipment and setup.

6 CUSTOMER INSIGHTS

Interviews held with participating households at the end of the pilot confirmed that there is a strong desire among consumers to do their part to mitigate climate change, but they are not ready to take this on alone. All participating households had considered or researched many of the PHH technologies prior to the pilot but never fulfilled that aspiration as they had been skeptical of the net benefits, not knowing how or where to get started, or who to trust given the premature market.

Having participated in the PHH pilot, these early adopters have been able to experience the benefit of reliable power, improved home comfort, and lower bills – often exceeding expectations. Participants were also very excited to tell their friends, families, and neighbours about the technologies which increased interest and education.

1) PHH helped accelerate customer sustainability journey

The environmental benefits were the main driver of consumer participation. PHH gave participants the confidence and guidance they needed to start their journey towards lowering the carbon footprint of their homes through experience with new technologies and access to experts. Consumers also recognized and appreciated the involvement of Federal and Municipal governments, along with local utility partnerships, to accelerate their vision beyond just their personal homes, to inform policies ahead, and lead the path towards net-zero communities.

> *Having this completely integrated technology to meet all our energy needs, where we can charge our electric car, heat our water, heat our home, and do it* ***efficiently, in an environmentally friendly way is such a bonus.***
>
> *When you see all the stuff happening all over the world, you really feel the* ***importance of trying to do your little bit.***
>
> *I was already intending to put in an electric heat pump and solar. I have gotten various quotes over the years****; I just never pulled the trigger.***
>
> ***The financial saving was not the primary motivation for me****, but the fact that you could help make the grid greener. And more importantly this notion that it's a pilot, with all the partners and government taking the learnings from the experience in our homes to help the next generation of homes,* ***to help with global warming.***

2) Customers appreciated the reliability of power PHH provided Customers appreciated having a backup battery to run their homes 'as usual' despite grid outages from extreme weather or grid constraints. This added reliability brought peace of mind during outages and a daily safety assurance, especially for homes depended on key equipment or those with an aging population.

> *We had a couple of outages, and because* ***our fridge, our modem, and key appliances*** *are on the battery back-up, so that was great.*
>
> *If I were to put in a* ***home elevator*** *and the power went down, elevator with battery backup would give me peace of mind. And that's my perspective as an aging individual.*
>
> ***That was particularly important to me****. Our house is a* ***very old house*** *- we have sewage ejection pumped-up all the time, we also have a weeping system on a pump to prevent water intrusion. We had a 2-day outage and our house was fine.*

3) Having PHH setup added to the comfort of the house

Participants felt that the setup provided better air flow, healthier air, more consistent heat and cooling temperature, and responsive hot water. They also appreciated the seamless and effortless customer experience. Most participants still don't fully understand how the hybrid system works and they don't have to –the system controls do all the thinking & switching for them.

> *The heat is not as drying as it used to be. I don't need the humidifier. It's **a much healthier heat**, that adds to the comfort.*
>
> ***It's amazing how much our bills have gone down.** On late spring and early fall days I generate as much as I use.*
>
> *The air-source pump runs most of the day, and we **like the air flow in the house*** from the new smart air handler.

4) PHH lowered energy bills for participating households

The integrated system of technologies and controls resulted in significant savings for most participants, varying by season and household composition.

> *The Hybrid system manages our heat costs and sustainability goals **effortlessly**.*
>
> ***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* because the smart hybrid heating controller does this for us.
>
> *The heat pump is also doing a **good job in cooling the house**.*
>
> *We actually had a brand new furnace system put in just before this pilot came along. The hybrid heating system has been **cheaper to operate** than our new furnace.*

Despite some challenges, the message from participants was clear – the benefits were well worth it, they would do it again, and encourage others to follow suit if given the opportunity.

7 WHAT'S NEXT?

Climate change and the transition to net zero is a compelling challenge of our time. To be successful in the transition we will need to leverage multiple solutions and integrate them into a pathway that supports traditional utility mandates of safety, reliability, and affordability. Power.House Hybrid showcases that enabling consumers' access to a fully optimized solution and an effortless customer experience is essential to accelerating the path towards a net-zero community.

The PHH Pilot is a small-scale demonstration of what will be required to be successful in the transition to net-zero. It demonstrates the value of collaboration among multiple entities and the value of combining multiple solutions to benefit both customers and the grid. The PHH pilot was successful in reducing GHG emissions while also reducing costs to customers. When scaled, the PHH pilot concept can also be used to benefit the grid by providing reductions in demand at times when it is most beneficial to the grid.

For more information on the project, email: GREAT@AlectraUtilities.com

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Project Collaborators