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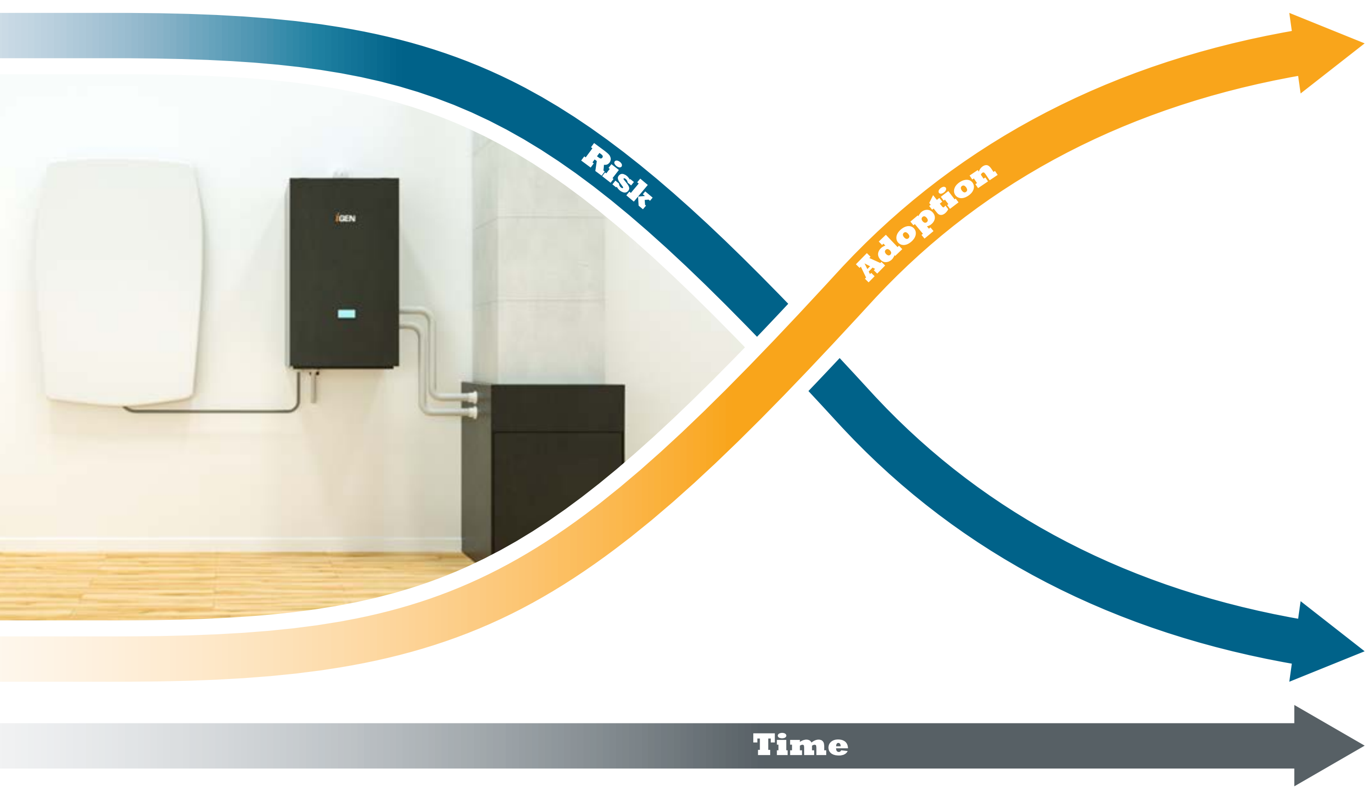
BLOOM CLEAN TECHNOLOGY DEMONSTRATION PROGRAM

CASE STUDY

Demonstrating the Performance of a Blackout Proof Micro CHP Smart Furnace



GREENHOUSE GAS REDUCTION

LOW CARBON ECONOMY

Prepared by:
The Bloom Centre for Sustainability (BLOOM)

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CASE STUDY
Demonstrating the Performance of a Blackout Proof Micro CHP Smart Furnace

Program Overview

The objective of the BLOOM Clean Technology Demonstration Program is to demonstrate the commercial application of cleantech and low carbon solutions with a high potential to achieve major greenhouse gas (GHG) emission reductions in targeted sectors.

The outcomes and results from the demonstration Projects are being used to:

- Illustrate to sector stakeholders that viable cleantech and low carbon solutions are commercially available;
- Reduce the perceived environmental, economic, and business risks of adopting cleantech solutions; and
- Bridge the 'adoption gap' and increase the market demand for cleantech solutions that can reduce GHG emissions and support the transition to a low carbon economy.

Background

For the majority of Ontario households, the conventional natural gas fueled furnace is the common choice for home comfort heating. At its core, the conventional furnace is a box where fuel is combsted to generate heat, which in turn is transferred to air that is blown through ducts by a fan. In addition to the fuel used to support combustion, the furnace also requires electricity from the grid to run on-board fan motors and system controls. Unknown to many, at approximately 500W the fan motor is the major consumer of electrical energy in a furnace.

- **Percentage of Ontario households with forced-air furnaces: 76 percent**
- **Percentage of Ontario households where natural gas is principal energy source: 62 percent**
- **Percentage of total Ontario household energy use coming from natural gas: 58**

Evolving innovations over the last decade have largely focused on commercial and residential building energy efficiency and related sustainability efforts. The outcomes have been efficiency gains, better operational controls and behavioural learnings that can be linked to the evolution of a house into a 'smart home'. Unfortunately, 'smart' is not a descriptor that to date can be linked with the home furnace. While incremental advances in furnace design have significantly increased combustion efficiency over the past decades, the primary home furnace technology has not substantially changed during this time. This has made the furnace the barrier to doing more with a home heating solution.

The Challenge

The motivation for iGEN to rethink what a furnace can do started with the personal experiences of the founders during the Ontario ice storm in 2013, when they and their families struggled with no heat through a blackout. Recognizing that the status quo approach was no longer a viable option, iGEN identified two key challenges that the traditional furnace could not address:

- **Energy resiliency:** The reliable and constant ability to provide heating service in the face of energy input supply challenges; and
- **Reducing the environmental footprint:** Extracting more output and value from a fixed amount of energy input.

Energy Resiliency

In 2016, there were a total of 421 electrical grid outages across Canada. Ontario led the way with 162 grid outages, affecting over 640,000 people.

In the US, there were a total 3,879 electric grid outages affecting almost 18,000,000 people.

For both countries, extreme weather and faulty equipment were the main causes (source: Eaton Company).

Conventional heating, domestic hot water or ventilation appliances lack energy resiliency. During a grid outage, theses appliances stop working, compromising occupant comfort and safety.

The Opportunity

iGEN recognized an opportunity existed for a furnace to do more with the energy that was being used, and to provide an expanded suite of features beyond just heating a home.

The outcome was the development and commercialization of the i2 furnace, a Micro Combined Heat and Power (mCHP) unit that utilizes the vapour expansion cycle (VEC) (Figure 1) to recover some of the energy in the hot furnace exhaust.

The VEC process utilizes a refrigerant inside a piping loop containing four main components:

- Evaporator Heat Exchanger – changes the refrigerant phase from liquid to vapour
- Expander/Generator – produces power by decreasing the refrigerant pressure
- Condenser Heat Exchanger – changes the refrigerant phase from vapour to liquid
- Pump/Motor – uses power by increasing the refrigerant pressure

In addition to heating the house, the i2 addresses the resiliency challenge by being able to electrically power itself. This ensures blackout-proof energy resiliency and even provide surplus electricity for other loads, while increasing energy efficiency and lowering GHG emissions.

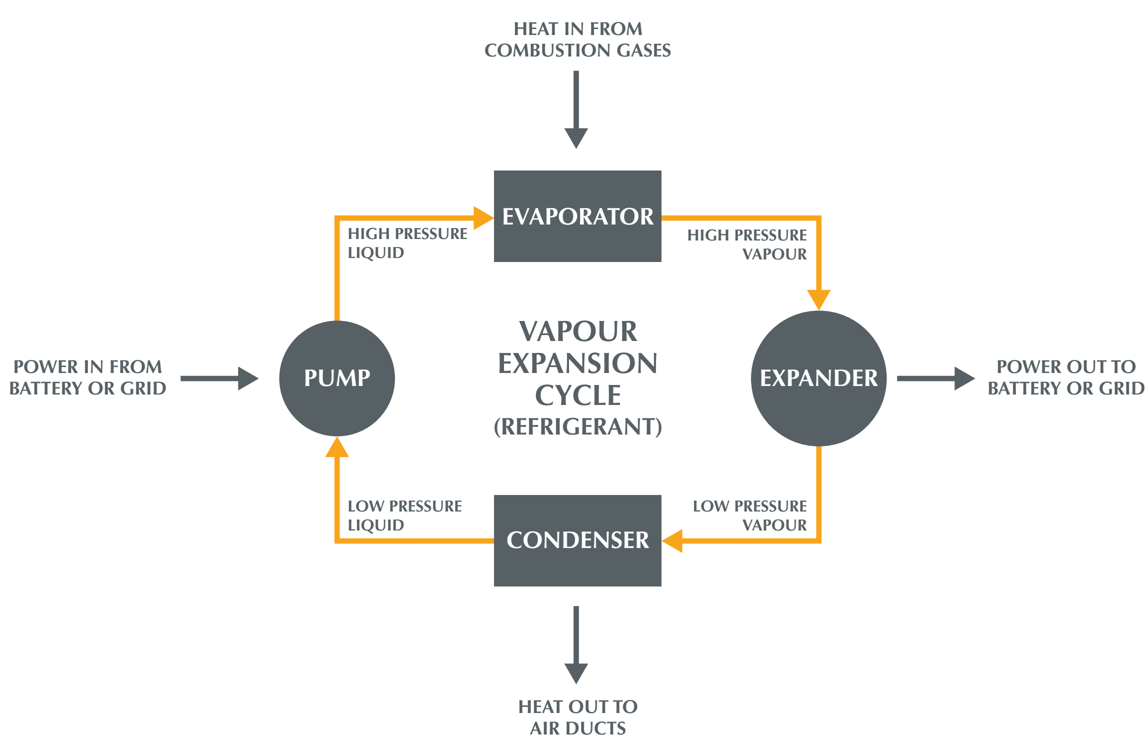
Combined heat and power (CHP) systems for homes or small commercial buildings are often fueled by natural gas to produce electricity and heat.

A micro-CHP system usually contains a small fuel cell or a heat engine as a prime mover used to rotate a generator which provides electric power, while simultaneously utilizing the waste heat from the prime mover for an individual building's heating, ventilation, and air conditioning.

A micro-CHP generator may primarily follow heat demand, delivering electricity as the by-product, or may follow electrical demand to generate electricity and use heat as the by-product.

When used primarily for heating, micro-CHP systems may generate more electricity than is instantaneously being demanded in circumstances of fluctuating electrical demand.

FIGURE 1: VAPOUR EXPANSION CYCLE SCHEMATIC OF THE IGEN I2 SMART FURNACE



The Technology

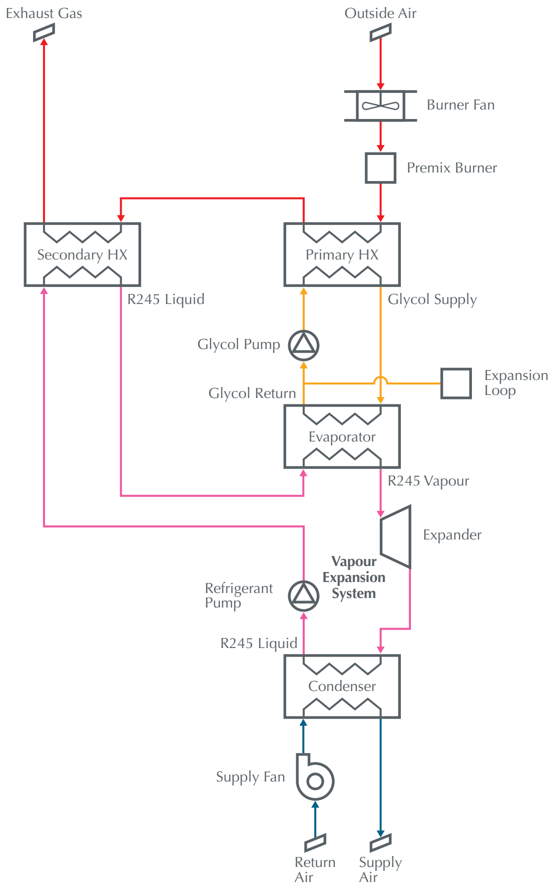
Within the VEC, up to 1,000 W of power is generated by the expander to run the i2 furnace unit. The i2 unit itself utilizes up to 500W of the generated power, with any excess power available for critical loads in the home or to recharge the onboard 1kWh battery.

Compared to a conventional furnace, the i2 furnace occupies a similar footprint and uses the same type of service connections. The same contractors that maintain a conventional furnace can also maintain the i2 furnace.

Self-powered blackout proof appliances not only save property owners the electrical cost of heating, it also removes the appliance from the electric grid, delivering energy resiliency and sustainability. In addition, it has the capability to switch between fuels, specifically natural gas or propane, and electricity with the benefits of reduced greenhouse gas emissions.

IMAGE 1: iGEN i2 FURNACE WITH COVER REMOVED

FIGURE 2: SCHEMATIC OF IGEN SYSTEM



Colour Key:

- Combustion Exhaust Gas Stream
- Intermediate Glycol Loop
- VEC Refrigerant Loop
- Building Air Stream

The Demonstration

A frequent challenge in conducting demonstrations in a real-world setting is to ensure that the project can address the potentially large number of variables that can impact the performance of the system being tested. In this case, the demonstration project had to be structured to ensure that the impact of variables such as occupant behaviour, variation between houses, and weather would all be mitigated. This was critical to ensuring that any benefits and/or impacts captured were real and attributable to the i2 furnace, and not one of these variables.

To achieve this goal, the i2 furnace was installed and its performance demonstrated at the Canadian Centre for Housing Technologies (CCHT) Twin Homes facility in Ottawa. This facility replicates the actual operation of a typical home setting, supported by extensive in-facility monitoring (see sidebar). The i2 furnace was installed in one of the Twin Homes, with a conventional furnace installed in the adjacent identical home.

This allowed a side-by-side comparison of the i2 furnace and a traditional furnace under a variety of structured and identical operating scenarios designed to eliminate the potential impact of uncontrolled variables.

This demonstration allowed iGEN to achieve a critical stage in their development: product viability in real world application.

Canadian Centre for Housing Technology – Twin House

The Canadian Centre for Housing Technology features twin research houses to evaluate the whole-house performance of new technologies in side-by-side testing. The twin houses offer an intensively monitored real-world environment with simulated occupancy to assess the performance of the residential energy technologies in secure premises.

The houses are extensively wired with computerized monitoring equipment designed to track every aspect of performance.

Researchers plan to maintain one house exactly the same over time as a baseline [reference house], while testing advanced technologies by making changes on its twin [test house].

The Canadian Centre for Housing Technology has solved these problems in assessing energy efficient equipment and components. The two identical test and reference houses are 'occupied' by electronic controllers that turn on and off appliances, lighting and equipment the way people do. This system of device control is referred to a 'simulated occupancy'.

For more information: http://www.ccht-cctr.gc.ca/eng/facilities/twin_houses.html

Installation and Monitoring:

A prototype of the i2 furnace (V3b) was installed and commissioned in early January 2018 at the Twin House Test Facility at the CCHT (Image2).

It was operated in the Test House for three consecutive weeks to compare its total space heating energy use against that of the Reference House system and to assess its net energy performance in a whole house situation.

See Table 1 for the demonstration comparison details.

IMAGE 2: i2 (V3b) FURNACE

TABLE 1: REFERENCE AND TEST HOUSE SETUP DETAILS

	Reference House Standard Furnace System	Test House iGEN i2 Furnace System
Heating and air distribution	High efficiency two-stage condensing gas furnace with electronically commutated (EC) motor; circulation fan "on" at standby. Forced-air distribution through standard ducting.	iGEN i2 Hybrid Smart Furnace prototype Forced-air distribution through standard ducting.
Ventilation	HRV continuous operation (~90 cfm)	Same as reference
Windows & Shading	Windows closed and locked Venetian blinds down with slats horizontal (open)	Same as reference
Thermostat	Single central thermostat set to maintain minimum between 22°C and 22.5°C on the main floor (thermostat set point = 22.5°C)	Same as reference
Water Heater	Natural Gas Water Heater with power vent. (Energy Factor, EF = 0.62)	Same as reference
Water Draws	~200 L/day hot water Water heater outlet temperature maintained between 60°C and 70 °C during draws	Same as reference
Doors	All interior doors open	Same as reference
Simulated Occupancy	Standard schedule (Appendix C)	Same as reference

The list below summarizes the variables within the overall data collection package.

Weather data - From weather station on M-24A

- Outdoor ambient temperature
- Outdoor relative humidity
- Solar radiation

House Conditions – Test and Reference houses

- Air temperatures by floor and at centre of rooms
- Relative humidity by floor
- Simulated occupancy hot water consumption
- Energy recovery ventilator flows and their relative humidity and temperature

Energy Consumption and Generation (iGEN) – Test and Reference houses

- Meter (electrical, gas and water) data for each test day
- Summary of total daily gas and electrical energy use for space and water heating in test house operating the i2 system and reference house operating the benchmark equipment.

Other data, including blower air speed and venting in-take and exhaust temperatures, was collected on the Campbell Scientific data acquisition units in each house and monitored by Natural Resources Canada.

Demonstration Results

A detailed data intensive experimental report was prepared by the CanmetENERGY Research Centre. The key performance findings from the report are summarized below.

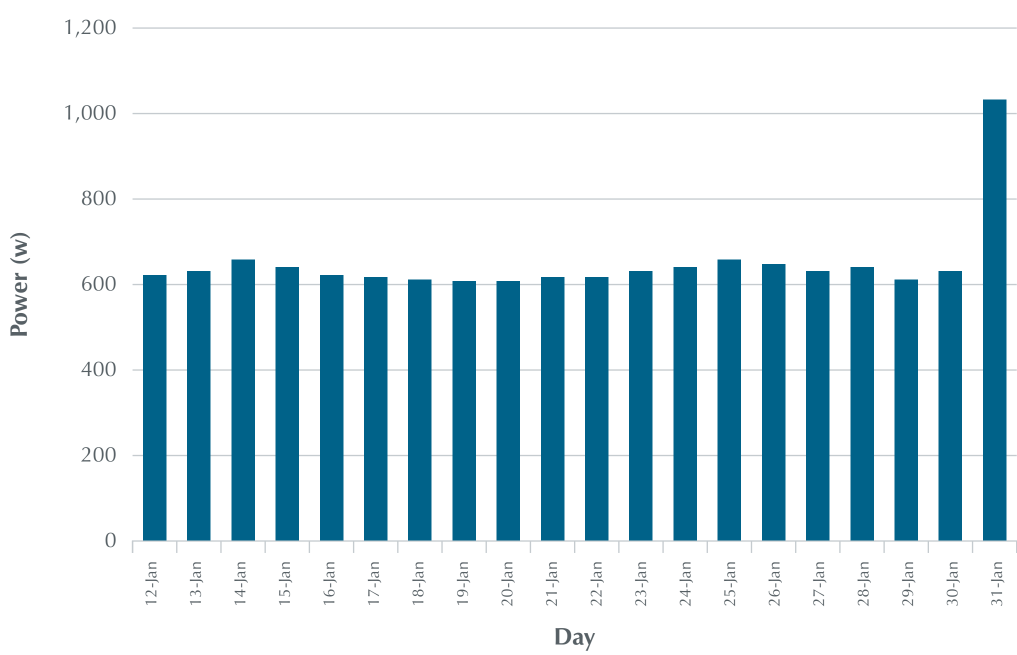
- With an average heat input of 8.8 kW (30,000 Btu/h), the iGEN i2 furnace was capable of generating about 600 Watts of power, which was more than enough to power the i2 smart furnace consumption. Power generation of just over 1,000 Watts was seen at the end of the test period (see Figure 3).

- From the combustion measurements made at CCHT, the i2 smart furnace appeared to be operating with a steady state combustion efficiency above 95 percent.

- As with many demonstration projects, opportunities for improvement were identified. General observations of the combustion data indicate that minor improvements to the air/fuel ratio could be made to help prevent the formation of excess carbon monoxide, sooting, or burner overheating.

- When analyzing the test data it was determined that there were unexpected performance discrepancies between the Reference House furnace and the iGEN i2. In the case of the Reference House furnace, the electrical consumption necessary to operate the furnace (i.e., fan, blower, controls) was well below what is normal for a similar high efficiency two-stage condensing gas furnace within the market. This was taken into consideration during the GHG Impact Quantification that follows this section.

FIGURE 3: POWER GENERATION OVER TEST PERIOD



GHG Impact Quantification

The BLOOM 'Impact Quantification' methodology, known as BLOOM IQ, was used to provide a third party quantification of GHG emissions reductions and other environmental, economic and social benefits that can be realized over the entire life-cycle of the i2 furnace system.

The scope of the project for GHG quantification is determined by the approach being one that only looks at the "net" difference between the current or "baseline" approach and the new approach which in this case is the conventional furnace. Elements that are included in the GHG quantification must be relevant, different from the baseline, and have available quantification methodologies for the GHG emission reductions and removal enhancements. Further details are provided in Appendix A.

Considering the iGEN i2 furnace relative to the Test House furnace, as well as similar High efficiency two-stage condensing gas furnace within the market, it was decided that the scope of the quantification would be limited to the measured capacity of the iGEN i2 furnace to recover energy from the exhaust in the form of electrical energy, and the subsequent displaced need for energy from the grid. This is based on the assessment that it is only the VEC that is the major difference between the two units. Variations in energy use between the two furnaces are due to differences in internal component sourcing which can easily be addressed by iGEN and is therefore not relevant to the impact quantification.

The GHG impact quantification was carried out for two scenarios: one limited to adoption in Ontario; and a second expanded to include adoption across Canada. The primary difference between the two scenarios other than market potential is the different emission factors for the Ontario electrical grid versus a blended national electrical grid.

The Market

iGEN has identified the North American gas-fired furnace market as its first target for disruption. This market includes retrofit and new construction installations and is worth an estimated $5 billion in revenue to the HVAC (heating, ventilation and air conditioning) industry. The total addressable market (TAM) in North America for conventional furnaces is stable at around three million units sold per year. In general, the average life-span of a conventional furnace is between 10 and 15 years.

Out of the TAM, iGEN has an initial serviceable market of 1.7 million on-grid and 96,000 off-grid conventional furnaces each year. The provinces of Ontario, Alberta and Saskatchewan, as well as the Northeastern USA and Midwestern USA regions will be the initial serviceable market area. This serviceable market is comprised of single-family homes with duct distribution systems located in cold climate regions with significant utility rate price differences.

Table2 lists the historical annual unit sales of conventional furnaces by select regions. These formed the basis for developing potential GHG emission reductions based on various future market adoption rates.

TABLE 2: HISTORICAL ANNUAL UNIT SALES OF CONVENTIONAL FURNANCES

Year	Ontario	Canada	USA
2014	196,873	319,807	2,734,713
2015	210,013	341,151	2,814,203
2016	199,440	323,977	2,942,545
2017	206,456	335,373	not available

GHG Emission Reductions

Tables 3 and 4 show the calculated net emission impacts relative to a single furnace for the Ontario and national electrical grids respectively. Taking this approach makes it simple to prorate the emissions based on potential percent market adoption.

When calculating the potential GHG reduction impacts, the capacity of the iGEN i2 furnace to generate a range of power had to be considered and taken into account. From the demonstration project, the data shows that the power recovery ranged from approximately 600 to 1000W output. These two data points were used to calculate potential low and high GHG and other emission reductions.

These results were used to calculate the cumulative GHG reductions per year, using potential annual market adoption percentages of: 10 percent, 25 percent and 50 percent.

The definitions of the various emission parameters are:

CO_2e – Carbon dioxide equivalent is a standard unit for measuring carbon footprints. The idea is to express the impact of each different greenhouse gas in terms of the amount of CO_2 that would create the same amount of warming.

SOx – Sulphur oxides, the generic terms for a group of emissions mainly due to the presence and burning of sulphur compound in the fuel.

NOx – Nitrous oxides, the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts.

PM – Particulate matter, is a complex mixture of extremely small particles and liquid droplets that get into the air.

CO – Carbon monoxide is a colorless, odorless, tasteless, and toxic air pollutant that is produced from the incomplete combustion of carbon-containing fuels.

VOC – Volatile organic compounds means any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which are involved in atmospheric photochemical reactions.

TABLE 3: SUMMARY OF PROJECT IMPACTS WITH POTENTIAL ADDITIONAL ELECTRICITY USES – ONTARIO GRID

Element Name	Based on 600 W Output/ Heat Input of 8.8 kW	Based on 1,000 W Output/ Heat Input of 8.8 kW
Annual Energy Recovery (generation is per single iGEN i2 furnace)		
Energy Generation – kWh/year	1,764.00	2,940.00
Annual Emission Reductions due to Energy Recovery (emissions are per single iGEN i2 furnace)		
CO2e – $kgCO_2e$	75.85	126.42
Sox – kgSOx	0.0103	0.0172
Nox – kgNOx	0.1265	0.2109
PM – kgPM	0.0055	0.0092
CO – kgCO	0.0856	0.1426
VOC – kgVOC	0.0043	0.0071

TABLE 4: SUMMARY OF PROJECT IMPACTS WITH POTENTIAL ADDITIONAL ELECTRICITY USES – CANADIAN NATIONAL BLENDED GRID

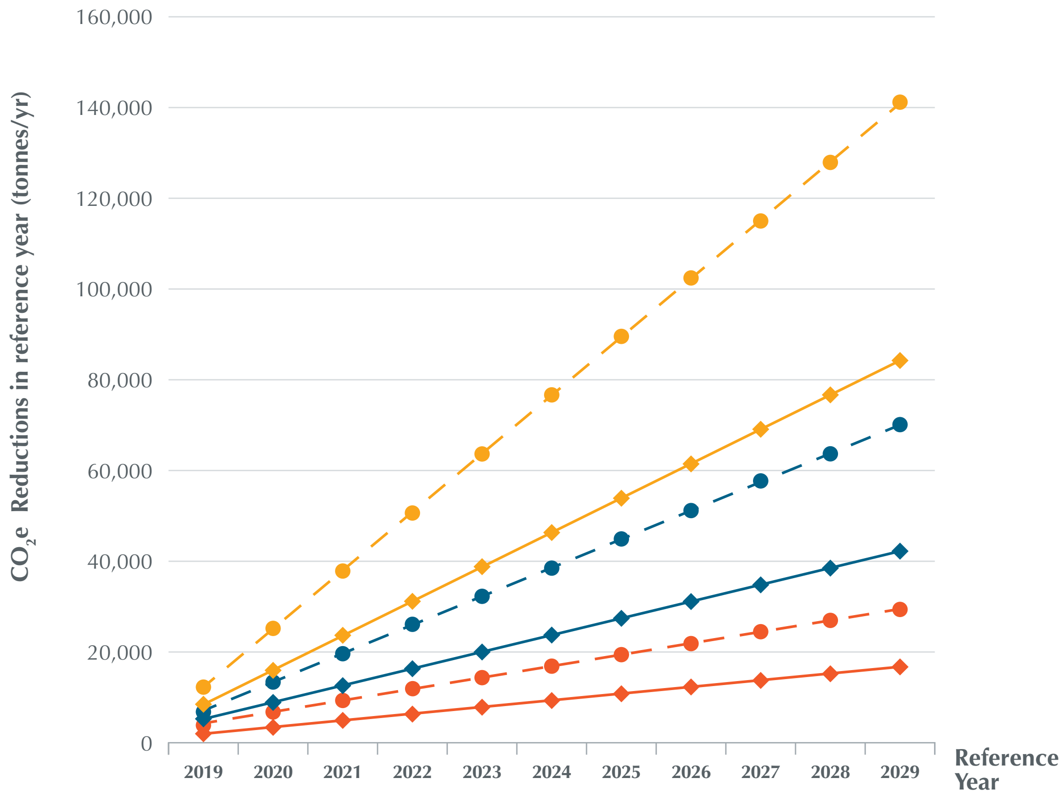
Element Name	Based on 600 W Output/ Heat Input of 8.8 kW	Based on 1,000 W Output/ Heat Input of 8.8 kW
Annual Energy Recovery (generation is per single iGEN i2 furnace)		
Energy Generation – kWh/year	1,764.00	2,940.00
Annual Emission Reductions due to Energy Recovery (emissions are per single iGEN i2 furnace)		
CO2e – $kgCO_2e$	268.128	446.88
Sox – kgSOx	0.8053	1.3422
Nox – kgNOx	0.4864	0.8107
PM – kgPM	0.0603	0.1004
CO – kgCO	0.1250	0.2083
VOC – kgVOC	0.0050	0.0084

Figures 4 and 5 illustrate the potential cumulative reduction in GHG emissions by a given reference year for various adoption rates of the iGEN i2 furnace within Ontario (Figure 4) and across Canada (Figure 5). The various projection lines indicate the potential GHG reductions based on:

- Percent market adoption (red 10 percent, blue 25 percent, and orange 50 percent), and;
- The energy generation range of the VEC from a low of 600W to 1000W

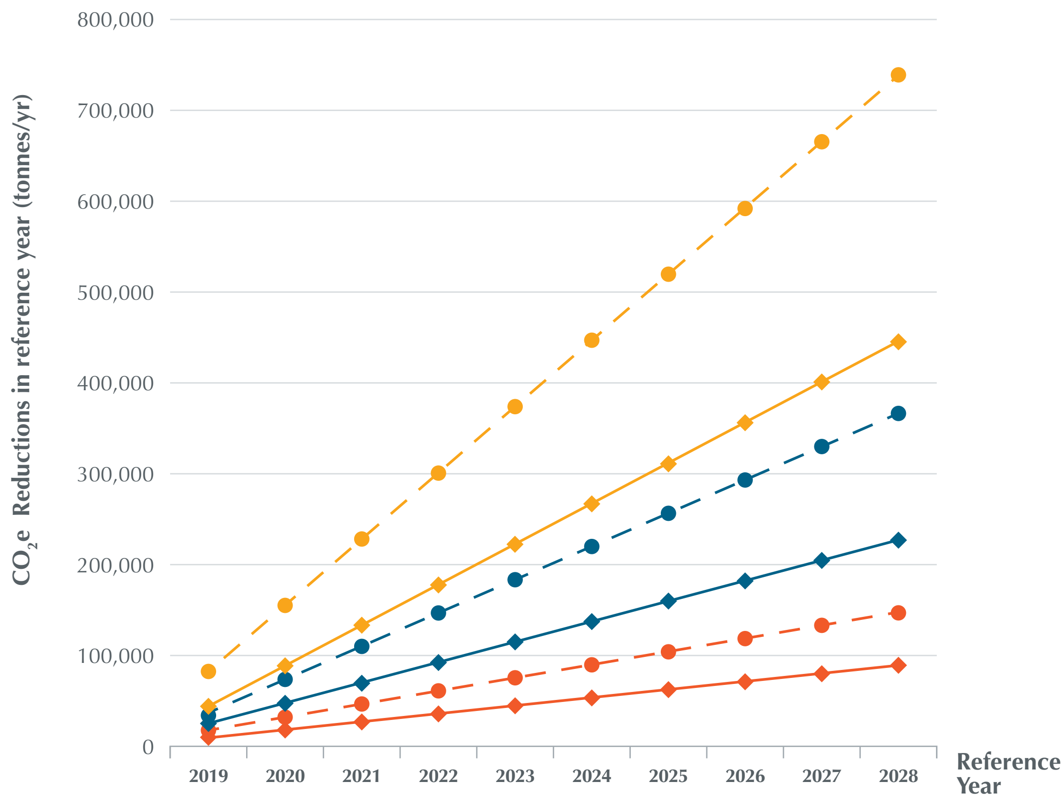
As shown in Figures 4 and 5, increasing the rate of adoption of the i2 furnace can result in significant cumulative reductions in GHG emissions in Ontario and across Canada. For example, an adoption rate of 50 percent per year over a 10 year period, could achieve a cumulative national GHG reduction of over 730,000 tonnes.

FIGURE 4: ONTARIO – CUMULATIVE GHG REDUCTIONS PER YEAR BASED ON PERCENT MARKET ADOPTION



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
10% – low range	1,541	3,083	4,624	6,165	7,706	9,248	10,789	12,330	13,872	15,413	16,954
10% – high range	2,569	5,138	7,706	10,275	12,844	15,413	17,982	20,550	23,119	25,688	28,257
25% – low range	3,853	7,706	11,560	15,413	19,266	23,119	26,972	30,826	34,679	38,532	42,385
25% – high range	6,422	12,844	19,266	25,688	32,110	38,532	44,954	51,376	57,798	64,220	70,642
50% – low range	7,706	15,413	23,119	30,826	38,532	46,238	53,945	61,651	69,358	77,064	84,770
50% – high range	12,844	25,688	38,532	51,376	64,220	77,064	89,908	102,752	115,596	128,440	141,284

FIGURE 5: CANADA –- CUMULATIVE GHG REDUCTIONS PER YEAR BASED ON PERCENT MARKET ADOPTION



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
10% – low range	8,850	17,701	26,551	35,401	44,251	53,102	61,952	70,802	79,653	88,503
10% – high range	14,750	29,501	44,251	59,002	73,752	88,503	103,253	118,004	132,754	147,505
25% – low range	22,126	44,251	66,377	88,503	110,629	132,754	154,880	177,006	199,131	221,257
25% – high range	36,876	73,752	110,629	147,505	184,381	221,257	258,133	295,010	331,886	368,762
50% – low range	44,251	88,503	132,754	177,006	221,257	265,509	309,760	354,012	398,263	442,514
50% – high range	73,752	147,505	221,257	295,010	368,762	442,514	516,267	590,019	663,772	737,524

Sector-wide Adoption – Positioning for the Future

The primary home heating system currently used in Ontario now, and likely for the foreseeable future, is the natural gas forced air furnace. However, due to government climate change regulations, policies to transition to a low carbon economy and tightening energy efficiency standards, new home builders are moving towards cost-effective low-energy home design and construction.

There is a similar mindset for retrofit opportunities where energy resiliency, return on investment and a lower carbon footprint are all potential adoption drivers for solutions such as the iGEN i2 furnace.

The Power of the Cumulative Potential GHG Emission Reductions

ONTARIO:

Cumulative GHG Reductions by 2028: Approximately 16,900 to 141,000 tonnes CO2e

Equivalent to annual emissions of 3,619 to 30,193 cars

CANADA:

Cumulative GHG Reductions by 2028: Approximately 88,000 to 737,000 tonnes CO2e

Equivalent to annual emissions of 18,844 to 157,816 cars

Market Trends

With the traditional furnace innovation lagging behind other home efficiency improvements, iGEN plans to use the outcomes of this demonstration project to engage new home builders that are embracing resiliency, sustainability and the net-zero home energy concept.

Through better siting, design and construction, the vision for future homes is to produce as much energy as they consume. Net-zero homes are not widespread yet due to economic or operational constraints, and lack of progressive building code standards.

By working with new home builders to adopt the i2 furnace in conjunction with other clean energy technologies (heat pumps, solar photovoltaics), the goal of reaching net-zero will be one step closer.

Energy Cost Savings

The 'conventional' furnace market is mature and the i2 furnace's integrated power plant will represent an option for customers that are seeking resilience, energy efficiency and related cost-savings. One of the highest kWh consuming pieces of mechanical equipment in the home is the electrically-powered furnace fan. The i2 eliminates this load entirely, as the embedded fan is powered by the combustion of natural gas. The annual savings on this feature alone will range from $300 to $500 on electricity per home.

Future Proofing

Additionally, as a result of the technical capability built into the i2 furnace, it can act in the role of an 'energy hub' suitable to the integration of a variety types of energy inputs. For sites with existing solar PV or batteries, the i2 will support integrated expandable battery storage (1 kWh on-board battery) complete with remote controller and multi-platform dashboard to adequately offset the bulk of kWh consumption for critical loads used on a daily basis by occupants.

Coupling renewable generation via the i2 would support the 'future proofing' of the modern home and allow it to facilitate a fully integrated 'smart grid' type energy security system capable of energy (heat and electrical) generation, storage, and deployment of electrical power, year round.

The Power of (The Cumulative) Multiplication

This technology is representative of an often overlooked approach to achieve GHG emission reductions. This approach takes advantage of a large number of potential installations to multiply the relatively small GHG savings achieved through an individual home installation versus the significant cumulative GHG reduction savings achieved through higher market adoption over a 10-year period.

Considering this from the perspective of Ontario's climate change objectives, the iGEN technology has the potential to make a major impact in reducing GHG emissions in the residential sector while providing an additional suite of benefits to a wide spectrum of stakeholders.

Appendix A: GHG Quantification Scope and Boundaries Approach

Procedures for Identification Elements and Boundaries

The project and baseline boundaries and elements were identified using the following process:

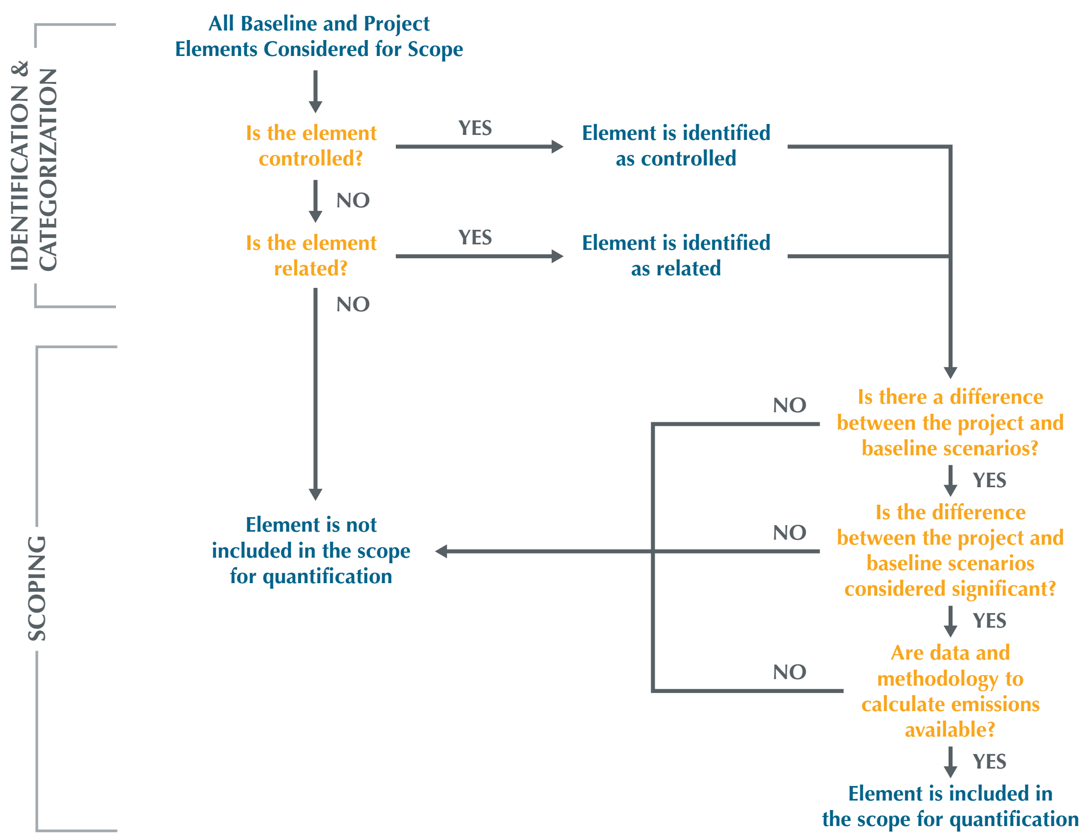
1. Identify the elements for the system (i.e. those directly controlled or owned in the project), including the related (i.e., those elements that are related to the project by energy or material flows) and affected elements (i.e. those elements that cause changes in markets or activity outside the project boundary that are not connected to the project through material or energy flows);

2. Define system boundaries; and

3. Determine if elements are in scope by assessing relevance, significance, and practicality.

All elements identified earlier are either directly or indirectly related to the project or the baseline. In order to determine whether these elements should be included in the scope of the project and would be part of the environmental impacts quantification, the methodology presented in Figure 4 was used.

FIGURE 6: GENERAL METHODOLOGY FOR ELEMENT SELECTION



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