LDC Tomorrow Fund MiGen

Commercialization Plan

- Milestone C -

1 Table of Contents

For consistency and thoroughness, this document is a culmination of requisite reports submitted to the Ontario Smart Grid Fund, a primary MiGen funder.

2 Introduction

The concept of MiGen is an open-source, interoperable solution that attempts to address the missing link between the Home Energy Management System (HEMS), which is behind-the-meter and the grid. The MiGen solution attempts, in real time, to negotiate power needs between customers through Demand Response (DR) commands from the Utility to alleviate grid capacity constraints. The utility can benefit from this link by helping the grid in reducing peak loads on constrained neighbourhood transformers, increasing transformer life and/or preventing costly grid upgrades to meet peak demand. Customers benefit from the technology by having a more dynamic relationship with the local distribution company (LDC) and allowing the LDC to create a partnership with the customer to help manage their utility bills. With the forecasted increase of electric vehicle and renewable energy adoption the team believes MiGen is an important technology to develop. MiGen's main goal is to maintain and modernize the distribution system within Hydro Ottawa Limited (HOL) and the greater Ontario grid so that it becomes more robust and efficient. The enclosed analysis shows that the MiGen system is presently not commercially viable in the context of HOL's Service Area. This is primarily due to:

- HOL's grids are, for the most part, not constrained to the point of overloading existing assets, such that there is no need for Demand Response (DR) at the edge.
- There needs to be a transformational shift in the utility industry to enable a mechanism for Transactional Energy Markets (TEM) at the grid edge to put a valuation on grid constraints and compensate prosumers for their participation in DR events.

The MiGen platform solution will become more viable if the grid becomes significantly constrained due to external factors, such as the electrification of transportation, and the high adoption of renewables and/or there is a transformational shift in the utility industry. Predicting when this will happen is difficult since the above items are heavily influenced by policy, political landscape, market trends and the economy. More specifically, we've seen government incentives play a significant role in adoption rates with PV systems and EVs. That being said, herein we will review the commercial viability of the MiGen system within the HOL Service Area in the near term (1-5yrs) to better understand the viability limitations today.

3 Executive Summary

MiGen 1.0 (Phase 1) was a novel Transactive Demand Response (TDR) platform project. The Phase 1 approach was to build out and deploy a full system (Hardware and Software) with the intention of enabling DR events from the Utility, micro-grids, power negotiations, and real time asset monitoring.

What we learned from this approach is as follows:

- It’s difficult to measure the response from a DR event with the large amounts of load “noise” in the house.
- We would need to develop a method to fairly compensate participants for DR events.
- Having HOL build and develop hardware required significant resources and ended up being a distraction to the primary objective. MiGen needs to review building on existing hardware, since solutions exist today in many different forms.
- The phase 1 (Ph I) solution was hardware heavy, making if very expensive to deploy and encourage adoption.
- Assets at the grid edge are typically underutilized, such that asset monitoring is not required.

MiGen future approach would have to pivot in the following direction to be immediately commercially viable:

- Include and empower the customer to participate in a smart energy future;
- Help the customer manage their bill;
- Ensure that the utility has a role to play in the smart energy future;
- Prepare the grid to be more flexible and adaptable;
- Connect the utility to the edge/customers’ HEMS to enable mutual benefits.

The MiGen Pivot:

- Developing a new rate structure that encourages self-load management behind the meter (at the edge).
    - The new rate structure (for buying and selling) is being proposed to empower the customer with a tool to self-manage their energy consumption for their benefit (bill savings), the utility’s benefit (improved asset utilization), and greener generation (eliminating need for gas peaker plants).
        - The new rate structure will reflect market energy rates and costs associated with local delivery;
        - The rates can be tailored annually, monthly, daily, etc.;
        - The rates can be tailored to different regions (Macro→HOL to Micro → local transformer);
        - Hourly rate can be constant for the 24hr period or change hour-to-hour to respond to grid level and/or generation level constraints;
        - Rates may need to be different for buying and selling;
        - For those who participate, rates will be published in the cloud for the HEMSCs to access and optimize consumption for the purpose of minimizing their bill or GHG footprint.
- Creating a GHG signal to allow customers to make greener energy consumption choices.
    - The GHG signal will give an opportunity for the customer to minimize GHG footprint by optimizing when they consume energy.

- Implementing a direct communication channel to the customer for significant events (rate changes, planned outages, restoration notices, severe weather events).
    - Direct communication channel to the customer for significant events (rate structure changes, planned outages, restoration notices, severe weather events);
    - This direct communication line enables:
        - Customer to prepare for power interruptions (example: cancel dinner plans);
        - HEMS to charge battery in preparation for outage;
        - Customer or utility to stage loads during restoration;
        - Utility to notify customers of severe weather events that may cause service interruptions so they may appropriately prepare.

4 Background

4.1 Demonstrated Innovative Capabilities

MiGen has delivered a real world field deployment of a transformational technology product -- with actual active participants -- that begins to modernise and democratize the grid, specifically how utilities manage and monitor the grid, and how customers become prosumers. Below is a quick capture of the MiGen Team's, with funding support from the Ontario Smart Grid Fund and the LDC Tomorrow Fund, successes:

- Delivered and succeeded in developing technologies that allow for decentralised Energy Transactive Demand Response (TDR) commands at the Grid Edge.
- Designed and demonstrated an Open Source Wi-Fi Mesh Network as a competitive Field Area Network option.
- Demonstrated that negotiated Energy TDR can be decentralized and work at the Grid Edge (TA negotiation with several CA-HEMSCs) considering participant preference between cost savings and comfort.
- Accomplished delivery of a system that abides by the three design principles: interoperability, privacy by design, and cyber-security.

4.2 Migen – Improvement Over Status-quo

MiGen was developed with intention and capabilities to provide improvements over the status-quo, as described herein.

4.2.1 Grid Democratization

The status-quo DR options have been limited to the most recent, now retired, Ontario Peak Saver Program, and the DR program for larger commercial and industrial customers. Presently, the IESO is trialing a DR/Capacity auction over the next five-years. These programs, like past, rely on an aggregator to consolidate and include residential customers, and more significantly do not involve the local distribution utility who will ultimately deal with any local side effects.

The benefits of costly grid modernization solutions can be distributed amongst the stakeholders; however, under present regulation in Ontario, the cost remains one entity's.

4.2.2 Allows for increased electrification & higher renewable generation penetration.

According to the International Energy Agency's "Global EV Outlook 2018," 2017 worldwide EV sales exceeded one million (up 54% from 2016), and topped 3.1million on the road (up 57% from 2016). China and the US had the highest sales volume in 2017; Norway is the world's leader with 39% of 2017 new sales being EVs. Nine countries, including France, the UK and Norway plan to phase out some or all gas-powered vehicles between 2025 and 2050. Canada has seen a significant EV market expansion with Ontario, Quebec and BC accounting for 97% of all plug-in EVs sold in Canada between 2013 and 2018. Between 2017 and Q3-2018, sales increased by ~80%. The national EV market share was 2.2%, compared to 0.9% in 2017. In Q3-2018, Ontario EV sales were 5,808, up 209% over the same period in 2017, i.e 44% of all new EV sales in Canada. MiGen's vision is to allow for a more integrated and cost effective way to manage this market and culture shift.

Vehicle OEMs' have largely adhered to their declaration that between 2022 and 2025, EV will cost as much as combustion engine cars, and that they'll increase the model offerings by then too. In the IESO's Jan. 31, 2019, report on "Enhancing Long Term Planning Processes and Products and Preliminary 2019 Long-Term Demand Forecast" by 2040, EVs on the road may increase to 1million. Regardless, it's not the increase in EVs that's necessarily worrisome to utilities, rather where in the grid they will charge and when they will charge. As for electric heating, air-source heat pump efficiency has significantly improved and become competitive with any other non-passive heating so may increase in penetration. Several studies by academia, industry and governments clearly identify that managing the electrification within existing grid capacity is the best solution; one of the biggest risks to utilities is how.

Also, renewable embedded generation without utility management was theoretically limited to 30% of a feeder's capacity, and in some areas as low as 7% in rural areas. Requests that breach that limit were rejected. With management, penetration levels can reach 75% or more for micro-grid cases. However, the expense in managing greater numbers of these systems becomes highly costly for the generator (tens to hundreds of thousands of dollars), and the utility with added equipment and system operations costs that raise delivery charges.

4.2.3 Enables the IESO and distribution utility to efficiently play its role.

The IESO, on their website states "The Independent Electricity System Operator (IESO) works at the heart of Ontario's power system ensuring there is enough power to keep the lights on, today and into the future."

The vision of MiGen aims at helping the IESO continue to achieve its goals at best value with increased visibility into the entire Ontario grid. MiGen can become a tool for the IESO in trying to procure supply at least cost of service.

At a micro level the LDC can gain by having increased visibility and collectively sharing this information with the IESO. The distribution utility can consider MiGen as a non-wires solution.

Also, the LDC or even IESO directly can use DR to help manage the integrity of its grid; for the LDC it is by having sovereignty and exercising its accountability for the distribution system, and for the IESO, achieving the demand-supply balance and ancillary services for grid stability.

4.3 MiGen Equipment and Technologies

The MiGen platform consists of the following elements: DR Command Interface, Transformer/Transactive Agent (TA), Customer Agent (CA), and Home Energy Management System Controller (HEMSC). The platform depends on interfacing with the Home Energy Management Systems (HEMS) that control such devices as: solar PV system, storage, thermostats and load control modules. The system deployment vision is to have the DR Command Interface be part of the utility's system control and monitoring environment; the CA and TA be owned by the utility, while the HEMSC and the HEMS, being behind the meter (BtM), would be owned and maintained by the customer.

4.3.1 DR Command Interface

This is intended to be utility owned, controlled and maintained. During the trial, the DR Command Interface was cloud based, and cellular communication was used to pass DR commands/events to the TA and receive information from the TA for analysis and monitoring. The interface with the TA is IEEE2030.5-2013 compliant. In the future, the DR Command Interface may be built into an enterprise system like SCADA, OMS, DMS, ADMS, or DERMS.

4.3.2 Transformer/Transactive Agent (TA)

The TA is intended to be a utility owned, controlled and maintained hardware device located in close proximity to the neighbourhood distribution transformer. The TA was designed to allow for a variety of external installations and ease of access and maintenance. For development, small form factor embedded computer was used with added modules for cellular and Wi-Fi communications. The TA is in a utility grade locked enclosure for physical protection from damage, theft, harsh weather, and tampering. The TA is equipped with Wi-Fi antenna for establishing communication with different CAs. In addition the TA is equipped with an LTE radio and antenna to enable communication with the DR Command Interface. The TA is an IEEE2030.5-2013 compliant device. Future TAs can also be virtualized.

4.3.3 Customer Agent (CA) - with an integrated Home Energy Management System Controller (HEMSC)

The CA is intended to be a utility owned, controlled and maintained hardware device. The HEMSC is intended to be a participant owned, utility controlled and participant maintained hardware device that does the intelligent interfacing with the HEMS. For the trial only and for cost/logistical reasons, the HEMSC was included in the same enclosure and shared the metrology and UPS, though the CA and HEMSC had their own embedded computers and communications modules. The CA provided the gateway to the behind-the-meter (BtM) devices, firewall and a privacy barrier between the utility and customer. It also had the metrology for reporting per minute the loading at the service entrance. The CA communicated with the HEMSC using an Ethernet cable and is equipped with a Wi-Fi antenna for establishing a wireless mesh communication with the TA. The specifications in the requirements document were sufficient for the trial. These are IEEE2030.5-2013 compliant devices.

4.3.4 Wi-Fi Mesh

The mesh resided in the 2.4GHz band and provided the bi-directional multi-path communications between the CA and TA. The deployed Mesh networks allows for data to be sent from a CA to the TA and vice versa via the help other CAs (relay nodes). While the Wi-Fi Mesh offers a low-cost and scalable solution, it is affected by the fluctuations of the signal quality and the interference from neighboring networks. To address these variations, the selection of the least interfered channel for communication and the option of messages' retransmissions have been implemented among other improvements.

4.3.5 Home Energy Management Systems (HEMS)

The HEMS consists of the BtM consumer devices or appliances deemed as Distributed Energy Resources, in general, these are flexible loads and energy sources including storage. For MiGen Ph I, the HEMS deployed were as follows:

a) Solar PV Array & Smart Inverter:

- 6.6kW DC, 5.5kW AC capacity rating
- Roof mounted
- Smart DC Coupled SunSpec compliant - this provided great benefit in managing one device of battery and monitoring output for solar PV and battery. Also provided for an off-grid emergency back-up panel. Round-trip efficiency was also higher. It is larger in footprint than a standard central inverter, though the portrait wall mount shape helped.
- Smart inverter came with pre-programmed routines for peak shaving, internal load displacement only, maximizing arbitrage, or supporting during higher cost periods. The setting was overridden by MiGen for DR events.
- The direct communication connection to the HEMSC provided more consistent and resilient management and performance.

b) Battery storage system:

- 10kWh, 7.4kWh useable Lithium-Ion battery
- Battery dimensions (W x H x D) 580 mm x 600 mm x 551.5 mm (22.8 x 23.6 x 21.7 in)
- Battery weight 110kg (243 lbs) per battery.
- Mounted on 4x swivel casters for maneuverability.
- Location was indoors to provide best environmental conditions for longer life.

c) Load Management Devices

- Smart thermostats replaced each of the existing baseboard thermostats
- Load Control Module was added to manage the electric water heater.

However, the MiGen platform is to work with any BtM device or appliance that is a flexible load, or energy source.

4.4 Competitive Advantage and Intellectual Property

There are many competitive advantages to MiGen versus what others have been trying to do, namely:

- MiGen is fundamentally based on true interoperability principles and that is not proprietary. Thus does not lock the buyer into a vendor's technology.
- MiGen guarantees privacy of its users. The system was designed with privacy and cybersecurity as focal points. This actually provides an advantage as countries impose rules like "General Data Protection Regulation" (GDPR) in Europe, and data becomes costly in energy to handle. MiGen is fundamentally based on privacy-by-design for load use, and the data governance ensures that traceability moving up the hierarchical structure is reduced. Consumer products, especially Internet of Things devices (IoT), lowest cost and fastest release is important to a company's bottom line, so if cybersecurity features exist, it is likely up to the user to set-up the firewall. MiGen relies on the IEEE2030.5 Interoperability standard and that inherently establishes the best practices as a minimum right from design so human issues are eliminated at the start. Also, IEEE has developed a conformity and assessment program for certifying compliance to IEEE2030.5 and is interested in doing the same for MiGen.
- MiGen is decentralized for resiliency and can be implemented modularly for the application. The decentralized, modular, interoperability and open source nature of MiGen allows scalability and application to serve any purpose for demand response.

MiGen documentation has been published to an Open Source Repository: https://github.com/MigenTransactiveGrid/MiGen-1.0 Those wishing to leverage the open source code must sign/agree to a license agreement that includes requirements to comply with the interoperability principles (IEEE 2030.5). The intent with this approach is to build the MiGen ecosystem faster because supporters worldwide would pitch in.

5 Value Propositions

As discussed above, the commercial viability of the MiGen system is dependent on its value propositions, which presently is directly related to the savings the utility could achieve through the adoption of the MiGen solution. The primary value proposition of the MiGen solution for a utility is to reduce peak loads at the edge with the intent that doing so would improve local distribution transformer asset utilization and increase the assets' life, and mitigate upstream capacity or supply-demand balance constraints too. There is also the added benefit of improving asset utilization and life upstream (i.e. at the feeder and substation level, and generation level). This was not evaluated, and didn't fall within the scope of MiGen Phase 1. However, in the present regulatory environment, the local distribution utility would likely be the payee for the system deployment and for payback only reap the narrow benefit applicable to itself.

The value propositions are divided here between intrinsic benefits and present savings.

5.1 Intrinsic Benefits

The primary intrinsic benefits of MiGen across the stakeholders can be summarized as follows:

a) i. For Local distribution companies

- Reduced technical and economic risk, because of reduced technology lock-in risk. The MiGen platform is based on an interoperability standard and provided as open source, worldwide royalty free.
- A step closer to improved visibility and prediction at the grid edge for better management of DERs and improved grid management (planning, operating and maintaining).
- Increased grid operating flexibility by using DR as a tool to manage asset loading and thus provide more grid management options.
- Improved ability for the utility to uphold their sovereignty in managing the integrity of the grid. Non-utility DRs is detrimental to grid integrity without coordination with the distribution utility. MiGen's vision is to bring all electrical utility players together with the goal of increasing holistic grid visibility, flexibility and adaptability.

ii. For Hydro Ottawa, the benefits manifested as:

- Captured data & lessons learned will serve as a guide to other utilities in the process of grid modernization.
- Engaged and involved world leading vendors and manufacturers to better understand DR capabilities in their products for the best transactive DR value from compliance with MiGen and the IEEE2030.5 Interoperability standard.
- Garnered industry, government, and electricity customer interest in the solution.
- Built a strong relationship with the Ottawa Community Housing Corporation. This relationship has already flourished and has impacted the organization and City in a positive manner. OCHC has now dedicated a new department to oversee and manage Sustainability and Green initiatives for all of their properties across Ottawa.
- MiGen was deployed at Ottawa Community Housing with a group of tenants who would otherwise not have the opportunity to benefit from this type of green technology.
- MiGen has witnessed an increase in companies shifting toward the DER industry. MiGen has been a key contributor to these efforts.
- MiGen has influenced Hydro Ottawa to discuss across the organization on the importance of modifying and adapting to the future of the utility business. Policies and options for the customers and how Hydro Ottawa interacts with the local population have improved significantly solely because of what the Team has learned and shared about the MiGen Project.
- Externally, HOL has reached out to other organizations and others have reached into Hydro Ottawa regarding MiGen, such as the IESO, NRCan-Varennes, electric utilities in Ontario and elsewhere in North America and Europe, plus vendors and service providers. In addition to the bi-lateral exchanges, we've made presentations on MiGen at international industry events and published on the project in reputable publications.

b) Electricity consumers

- Potentially lower generation integration cost and processing time.
- Should the next release of ESA code allow the use of energy management systems in sizing calculations MiGen can potentially help avoid service entrance upgrade costs by using DR to limit overall loading as electrification increases, like adding an EVSE. Change in the electrical safety code would be required.
- Potentially lower electricity, or energy, costs especially if deriving a monetary or point credit value from DR participation. Confidence in MiGen compatible HEMS being grid ready. Participants were happy that they were trialing HEMS that also worked for the grid

Immediate value will come from the first two benefits.

c) Transmitters

- Reduced transmission congestion and better asset utilization. DRs can be issued, through the independent market operator, to alleviate transmission constraints. The benefit of alleviating constraints and optimizing asset utilization can be shared with other stakeholders. Trialing MiGen for DR was successful and this will work regardless of who or why the DR event was initiated.
- Improved visibility and prediction of loading.

d) Other stakeholders

Other beneficiaries not listed above, and their attributed benefits, are:

i. The Independent Market Operator / Independent Electricity System Operator

- Improved visibility and prediction to the edge.
- Improved ability to achieve least cost of service targets. Management of Flexible loads provide immediate benefit and potentially at a much lower cost to alternative solutions.
- Improved engagement with utilities in planning.

ii. HEMS OEMs

- Defined requirement for HEMS to integrate into the grid and thus, once MiGen is widely adopted, understanding of what utilities would need. This could help them improve sales.

5.2 Saving for utility by improving asset utilization at the edge

MiGen system is to reduce loads on local distribution transformers to prevent unnecessary/ premature upgrades to meet demand and effectively improve asset utilization. In Phase 1, MiGen attempts to achieve this with a power negotiation between the utility and the customer, in real time. This negotiation takes into consideration the customer's comfort profile plus the utility's DR commands. To determine if MiGen's value proposition solves the premature upgrade scenario we evaluated the installation of a MiGen solution and compare it to how HOL would replace a transformer today. This approach is typical and common amongst Ontario Utilities.

Transformer Premature Upgrade Assumptions

1. 10:1 Customer to transformer ratio (typical for HOL).
2. Transformer replacement cost $7.5K (typical for HOL residential; Transformer pricing and labour is based on HOL asset data).
3. MiGen is a fully functioning system and can prevent unnecessary transformer upgrades by reducing peak loads.
4. TAs and CAs are priced assuming mass production, but still standalone (i.e., TA is not incorporated in a transformer or CA not in a revenue meter).
5. Transformer financial life is 35yrs (taken from HOL asset management plan (AMP)).
6. MiGen TA and CA financial life is 10yrs (idealistic assumption since they contain sensitive electronics).
7. HOL will pay for power consumption of the CAs and TAs (ultimately, these costs are passed to the end customer through delivery losses).
8. Transformer count was pulled from 2018-2019 AMP for underground, overhead and vault styles.
9. This analysis just includes depreciation, power, and data costs (it does not include regular maintenance for MiGen or the transformers).
10. Transformer life is 16yrs old (in the worst case for HOL, transformers: ≤15yrs, are repurposed and replaced with a new one, and, otherwise, they are written off and replaced with a new one. See Figure 1 below).
11. MiGen CA deployed to each residential customer (so 100% deployment).

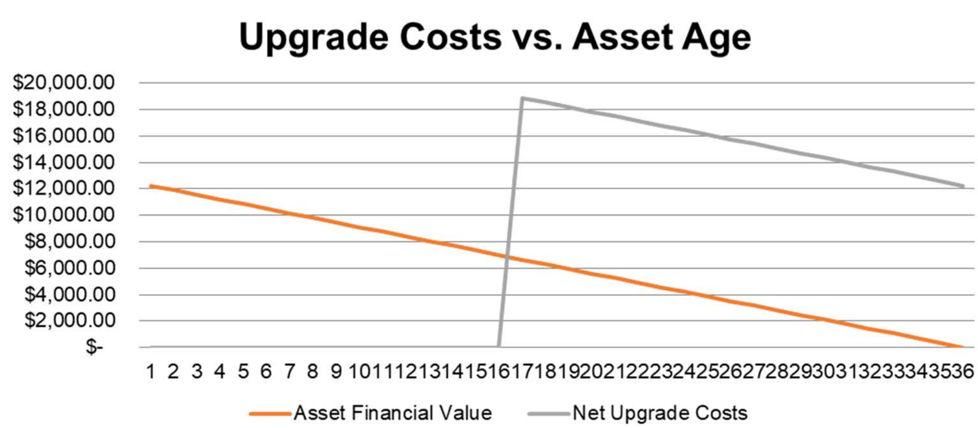

Figure 1: Transformer upgrade costs vs. age

Table 1: Transformer premature upgrade scenario variables

Residential	HOL Res Customers		307,053	
	Transformer Count		30,000	estimate
	MiGen Adoption rate		100%	Percent
	TA Count		1	
	CA Count		10	
	Power Costs	$	0.0239	Average IESO HOEI
	LTE	$	5.00	$/month
TSFMR	Hardware	$	6,000.00	
	Install Labour	$	1,500.00	
	Transformer Life		16	
	Financial Life		35	yrs
TA	Hardware	$	1,410.00	After cost reductio
	Labour	$	600.00	
	Power Consumption		0.02	kW
	Financial Life		10	yrs
CA	Hardware	$	585.00	After cost reductio
	Labour	$	500.00	
	Power Consumption		0.02	kW
	Financial Life		10	yrs
OUTPUTS	TSFMR NET Book Value	$	7,500.00	
	TSFMR Depreciation Rate	$	214.29	$/yr
	MiGen NET Book Value	$	12,860.00	
	MiGen Depreciation Rate	$	1,286.00	$/yr
	MiGen Data Costs	$	60.00	$/yr
	MiGen Power Costs	$	46.08	$/yr for power
	MiGen Annual Operating Cost	$	1,392.08	$/yr
	TSFR Annual Operating Cost	$	214.29	$/yr

Table 2: Results for transformer premature upgrade scenario

Residential 75kVa (1/10 Ratio)					
Asset Type	NET Book Value if all new	Annual Depreciation Rate	Data Costs	Annual Power Costs	Annual Operating Costs
TSFMR	$ 7,500	$ 214			$ 214
MiGen	$ 12,860	$ 1,286	$ 60	$ 46	$ 1,392
Total	**$ 20,360**	**$ 1,500**	**$ 60**	**$ 46**	**$ 1,606**

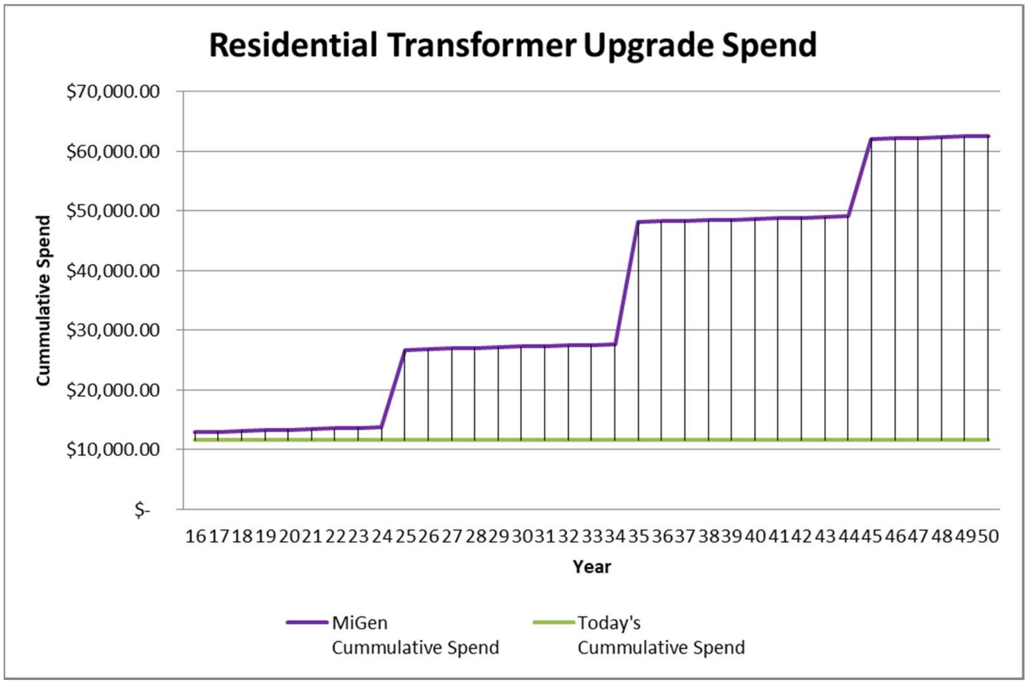

Figure 2: Results for transformer premature upgrade scenario

The above financial model compares the costs associated with prematurely replacing a transformer vs. installing a MiGen solution. The results in figure 2 show, based on cumulative spend, that it's more expensive, from day one, to install a MiGen solution when compared to disposing a 16yr old transformer and replacing it with a new one. Furthermore, we can see that our operating costs jump from $214/yr. to $1,392/yr., in table 2. For the MiGen solution to be commercially viable in this setting there would have to be a significant increase in costs associated with upgrading the transformer, or a reduction in MiGen hardware costs. This is possible, for instance, in a downtown setting, were the assets are in difficult locations, or if the primary residential loop can't support the transformer upgrade, and needs to also be upgraded. However, these are edge cases and don't represent the majority of cases within HOL. In addition there is an opportunity to revisit the system architecture to minimize the costs of the CA by integrating it into, for example, the Smart Meter, and the TA into the transformer. There's also an opportunity to eliminate the TA hardware by simulating its performance virtually using the aggregated CA/Smart Meter data. These are further improvements to the MiGen architecture that would need to be evaluated should future development be an option.

5.3 Savings for utility by increasing asset life

Typically, HOL expects to have 182 of 45,000 distribution transformers prematurely replaced every year. These failures are due to corrosion, oil leaks, bad joints, and bad primary elbows. Since HOL takes a conservative approach to sizing transformer installations, typical Utility company approach, transformer failures due to thermal overloading are not realized. For example, the MiGen site has a 75kVA distribution transformer (nameplate rating) and the maximum load, shown in Figure 3 when the load ratio peaks, was only 53kVA between 2016 and 2017. These maximum loads are only seen for short durations of time in very specific seasons in the year.

MiGen as a solution attempts to increase the life of a local distribution transformer by preventing overloading, which is believed to reduce the rate of aging. A transformer's rate of aging and its overall lifespan are a function of the hot-spot temperature. The hot-spot temperature is the maximum temperature within the windings of the transformer that directly impacts the dielectric properties of the insulation material. If the hot spot temperature increases above 110ºC, then the insulation material breaks down at a higher rate. The temperature of the winding hot spot depends on factors such as ambient temperature and the load the transformer is carrying. Therefore, if the Hot spot temperature is approaching 110ºC, a load reduction could contribute to prolonging the transformer’s service.

After applying the transformer aging method outlined in IEEE C57.91-2011, and using transformer manufacturer data, we can see that the Transformer runs rather cool and the site transformer has lots of un-utilized thermal capacity. This is primarily due to the conservative approach HOL takes with transformer sizing and also because the peak loads happen in the winter months when we have extra thermal headroom.

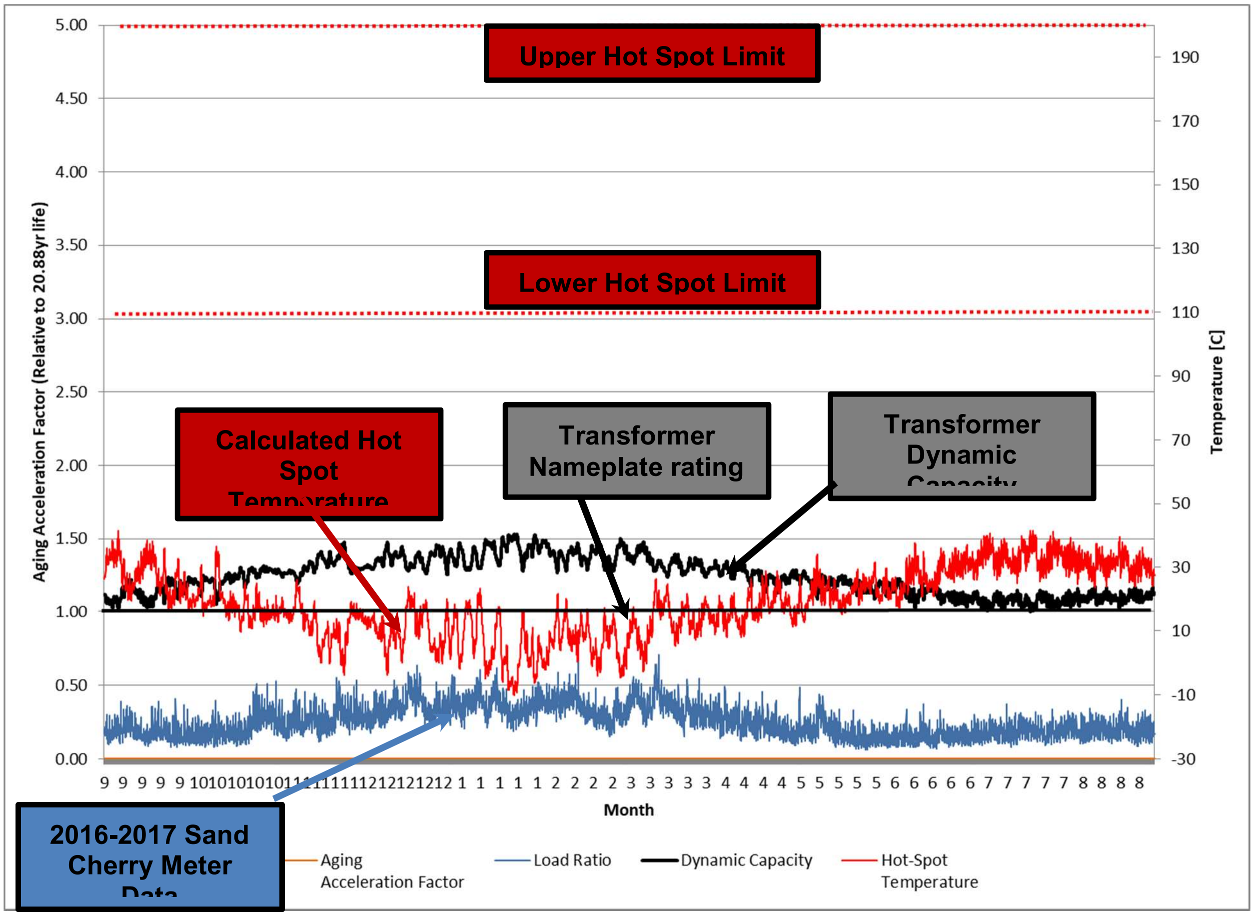

Figure 3: Sand Cherry Transformer Hot Spot Temperature

We can see from the above graph that a MiGen solution is not required on this specific transformer. In fact, we would need to see ~3.8X the loads to reduce the expected age to <=35yrs. See Figure 4 for the simulation.

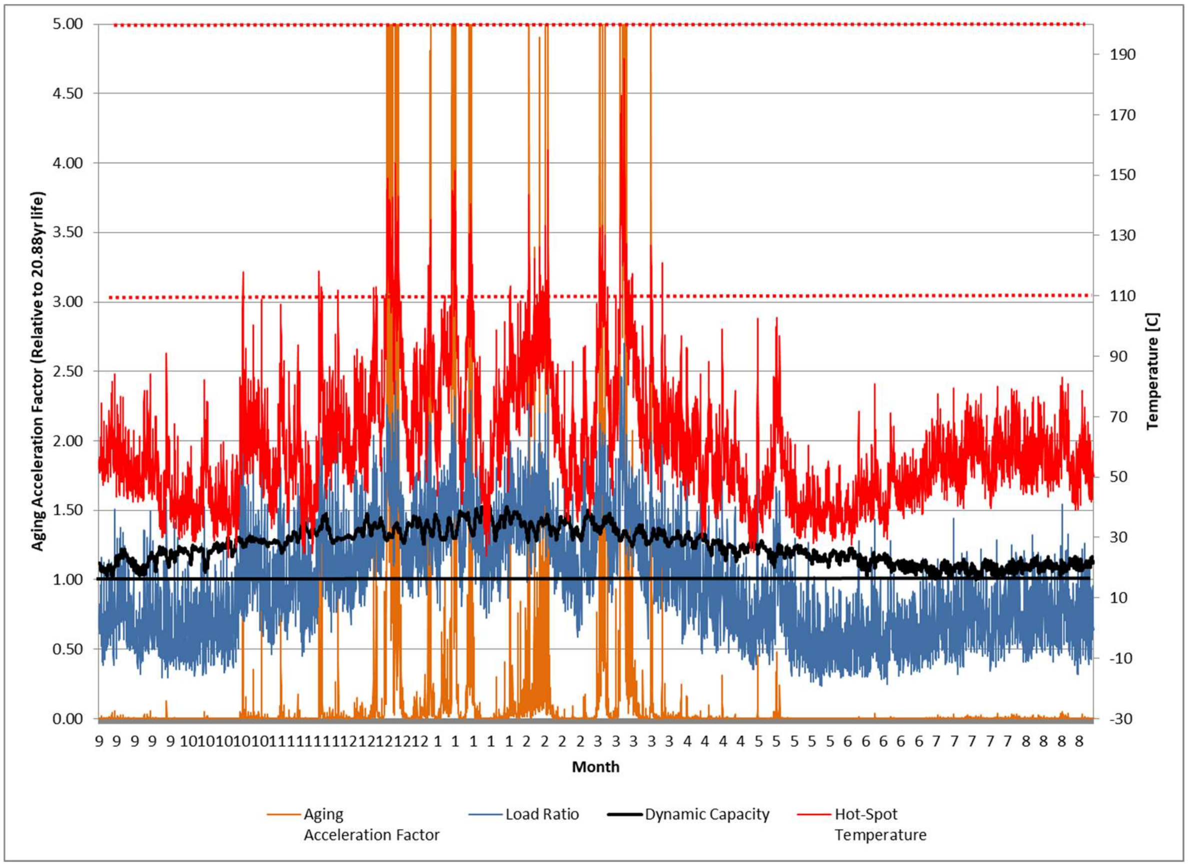

Figure 4: Sand Cherry Transformer with Simulated Overload to Optimize a 35yr Life

If our load profiles starts to look like that shown in Figure 4, then we need to consider MiGen as a solution to prevent the premature failures of our transformers due to thermal overloading.

Currently HOL chooses to not actively monitor and optimize its distribution transformers. Instead HOL spends the relatively low incremental costs of oversizing these assets and runs them to failure and forgoes the need to monitor and optimize. Furthermore, in most cases, it takes significant overloading of the transformer above nameplate to get the hot-spot temperature to reach and exceed 110°C. Therefore, the MiGen solution does not apply in this scenario. HOL would need to see significant increases in load demand to be concerned with overloading the local distribution transformer.

6 Typical Operational Use Cases

The MiGen Team has identified the following typical operational use cases beyond the ones tested and provided in a separate Technical Report. These additional use cases are:

(1) prosumer onboarding of DERs

(2) prosumer GHG setting preference

(3) Utility addressing HEMSC when TA switched to another feeder

(4) Utility use of HEMSCs to support grid restoration

(5) Utility using MiGen to dynamically set IEEE1547-2008 set-points to allow higher DER penetration and enhance support of grid integrity as a NWA solution -- a focused support for DERMS and replacement for most DER monitoring and control or transfer trip solutions

(6) Prosumer using MiGen to support micro-grid/off-grid environment

(7) Utility managing EVSE clusters to grid capacity, cost of use limits, and GHG tolerance

(8) Utility, developer, resident / prosumer, or building operator using MiGen to support maintaining Net-Zero Carbon communities (i.e., electrifying loads, managing DERs and encouraging behaviour)

7 Customer Feedback

A customer satisfaction survey was conducted after installation of the MiGen system. The purpose of the survey was to get an overview of how the participants viewed the project thus far. The system was installed in four units at the site but at the time of the survey we were only able to contact 3 participants. One of the three participants surveyed was a new tenant that had just moved in post installation. The table below summarizes the questions asked and overall response from the participants.

Questions	**Response**
How would you rate your level of understanding of the MiGen project?	Good
How would you rate the MiGen **installation**? The MiGen **installation** in my home was:	Neutral
The **operation** of the MiGen system in my home is:	Neutral
The MiGen project is about to run some experiments over the next few weeks (called "Demand-Response" (DR) events). My understanding of what these DR events might adjust in my home is:	Good
During the DR experiment, I feel that I will have _______ control on the comfort level of my home.	Complete control
I understand how to control my comfort levels during the experiment period.	Yes

The communication with Hydro Ottawa on the MiGen project has been:	Good
I understand how to contact Hydro Ottawa if I have a question or concern.	Yes
How would you rate the interaction with the MiGen personnel?	Good
I understand what feedback Hydro Ottawa is looking for from me during and after the MiGen Demand-Response experiment period.	Yes
The reason for my participation in the MiGen Project is:	It will modernize the grid It will save me electricity It is good for the environment

8 Market Opportunity

MiGen is a smart grid platform solution that presently is only viable if there is significant strain on the grid or there is a transformation shift in the utility business to allow for a TEM. The benefit from allowing higher levels of electrification and integration of DERs is presently not of additional benefit to Ontario utilities. The major barriers to commercialization are:

- Utility ability to effectively bring all its resources together to implement new technologies.
- The initial cost of this new technology.
- Difficulty in recovering the operating costs (communications, IT, software, "low" cost hardware) through rate base (versus capital).
- Regulatory "red tape" within the electricity sector.
- Risk of technological obsolescence in consumer components.
- Limited RD&D budgets within Ontario utilities.
- Need for rate options and utility model options.

Thus, presently, MiGen is not commercially viable in Ontario.

However, the MiGen CA-HEMSC elements can replace, at a lower cost and with more functionality, the Monitoring and Control Box (MCB) Hydro Ottawa had developed for Energy Resource Facilities (ERFs i.e., generators and electricity storage facilities) between 10kW and 500kW in size. Thus, the MiGen elements in this case can be standalone; however, the greater value is in eventually working as part of the whole platform. The answer is also "no," because Hydro Ottawa Limited is not in a position to commercialize the platform as its intent was to publish for others to grow the market.

MiGen proved it could be useful in providing these grid services especially as the barriers indicated were systematically removed: capacity, demand response, load following, asset deferral, grid command and control, support intermittent energy sources, cybersecurity, grid protection, and home energy management. MiGen has also proven Support Smart Grid Technologies directly are: load management, grid automation, micro-grid, storage, and other DER; indirectly it supports EV integration, and grid building interfaces. Based on progress made in phase one, MiGen is ideally located at the transformers, the meter and behind the meter. With further development, it may exist along major feeders or stations, and totally or partially exist in the cloud.

Publishing of the MiGen platform as open source and worldwide royalty free is intended to encourage companies to build HEMS compatible with the platform, and also MiGen elements that adhere to the platform. Our vendor partners already have the HEMSC-HEMS interface and other Original Equipment Manufacturers (OEMs) had expressed interest in MiGen. The compelling argument is that by having an interoperable interface to the grid, utilities would offer support for compatible products, buyers would have confidence in the value the compatible products can give them, and OEMs would then have a compelling feature for buyers and sell more product.

As a potential consumer product or service, it is inherently secure, open architecture, and interoperable. Identified were the following potential markets for MiGen:

Type of Target Client	**Location of Target Client (please list target clients for each jurisdiction, if applicable)**			
	Ontario	Rest of Canada	USA	Rest of World
Short Term (2 years)				
Electric Utilities				
System Operators (ISOs / RTOs)	IESO			
Residential Customers and Small Businesses	We had over 250 interested in MiGen during the recruitment phase, and a steady flow averaging one call a day simply from the static unpublicized HOL MiGen website			
Large Customers (e.g. Commercial / Industrial / Institutional / Multiunit Residential)	JL Richards			
Generators				
DER Aggregators				
Other (list):	GetSmart Analytics,	eMcREY	Google, Amazon	

	Thorium Technologies, Maple Microsystems, BluWave-ai, Opus One, Vocalize, PESC, Tantalus, CIMA+	Systems, Stash Energy, IdEnergie		
Medium Term (5 years)				
Electric Utilities	Alectra Utilities, Utilities Kingston, Toronto Hydro, Lakeland Power Distribution,	BC Hydro, ATCO, Hydro Quebec (IREQ)	National Rural Electric Cooperative Association (NRECA), Hawaii Electric	Scottish and Southern Electricity Networks,
System Operators (ISOs / RTOs)		Alberta Electric System Operator		
Residential Customers and Small Businesses				
Large Customers (e.g. Commercial / Industrial / Institutional / Multiunit Residential)	s2eTech	University of Ottawa, Carleton University, Algonquin College		
Generators				
DER Aggregators				
Other (list):	Mattamy Homes, Ottawa Community Housing Corporation, Centertown Citizens Community Housing		IEEE-SA, Quality Logic, Sunspec Alliance	Intracom S.A. Telecom Solutions (Greece), Universitat de Girona-Spain
Long Term (10 years)				
Electric Utilities				Electricity Authority of Cyprus, Estabanell Energia
System Operators (ISOs / RTOs)				Helenic Energy Exchange
Residential Customers and Small Businesses				

Large Customers (e.g. Commercial / Industrial / Institutional / Multiunit Residential)				
Generators				
DER Aggregators				
Other (list):				

The concept of MiGen is an open-source, interoperable solution to address the missing link between the Home Energy Management System (HEMS), which is behind-the-meter, and the grid. The MiGen solution will, in real time, negotiate power needs between each customer's and the capacity constraints of the grid. The grid benefits from this link by reducing peak loads on constrained neighbourhood transformers, increasing transformer life and/or preventing costly grid upgrades to meet demand. Customers benefit from the technology by having a more dynamic relationship with the local utility company (LDC) and allowing the LDC help the customer manage their bill. With the increase of electric vehicle and renewable energy adoption the MiGen team believes this is an important technology to develop to maintain a robust and efficient distribution system within Hydro Ottawa Limited (HOL) and the greater Ontario grid.

9 Forward Looking

In addition to the benefits and value propositions above, MiGen as smart grid platform, has the ability to foster the following stacked benefits with further development:

1) Gain partnerships, experience, knowledge and credibility at standards, regulatory and policy tables to better manage utility modernization;

2) Support electrification, including higher renewable generation penetration, that helps the environment and optimized use of grid assets with confidence;

3) Allow customers to have a greater sense of involvement in the grid and thus control over their bill by democratizing the grid;

4) Provide better grid management with visibility for planning and operating;

5) Support efforts towards non-wires solutions;

6) Support efforts of Smart City concepts so customer engagement strengthens and new business opportunities arise;

7) Play in the IESO capacity auction (formerly demand response auction);

8) Play a role in the management of large energy resource facilities more economically and applying similar technology at the residential level. For example, replacing the metering control box (MCB) that HOL uses today, to control PV systems 50kW-500kW, and integrating PV systems below 50kW, which isn't practical today;

9) Gives the OEB more options with billing rate structures, which may include real time representative price signals;

10) Enables DERMS functions through connecting DERs, which allows monitoring and control at the grid edge

11) Ability - should regulatory and billing rates change, could in the future - to reduce GHGs for residents. This could be realized by charging the battery from the grid during cleaner times of the day (between 12:00am and 7am - typical for Ontario's grid), when peaker plants are off-line and then injecting that power locally or to the grid during high demand periods. However, running MiGen in this mode is currently not economical because when switching to a bi-directional meter the billing rate structure switches from time-of-use (TOU) to tiered. This will have a negative financial impact on the customer because they will be purchasing power at 11.9cents/kWh and then selling back to the grid at 11.9cents/kWh, meanwhile losing ~10% due to battery full trip losses. However, if the OEB changes its rate structure this could be both economically and environmentally beneficial for the residents.

10 IESO's Vision for the Electricity System

The electricity industry in Ontario has continuously been in flux with changing messaging to align customers to campaigns and industry restructuring such as: go electric, conserve energy, reduce demand, deregulation, seasonal rates, time of use rates, global adjustment, and more recently thoughts on restructuring the Ontario electricity system. In June 2019, the Electricity Network of Ontario (ETNO) published a report on "Structural Options for Ontario's Electricity System in a High-DER Future: Potential implications for reliability, affordability, competition and consumer choice." ETNO is an IESO led think tank of top Ontario electric and natural gas utilities, NGOs and industry representatives who regularly meet to identify industry impacting issues and then derive strategies suited to Ontario and the electricity consumers for contemplation or trial by policy makers and others. This report directly addresses different options for restructuring utilities for best provision of connection services, distribution system management and provision of electricity options and services while protective of customer interests. Similar restructuring activities are underway in other electricity markets such as in the UK and the US.

MiGen, as a secure, open source and interoperable platform, can help democratize the grid and facilitate many of the models contemplated. The platform, if implemented end-to-end, meaning by the IESO through to the consumers, then the benefits can be both socialized and also be directed to the participants. Theoretically, if 1/3rd of HOL 320,000 residential customers reduced 2kW ea. at the same time, they would easily satisfy 236MW of Ontario's spinning reserve capacity.

Really, the 236MW can be achieved in many ways, such as by having all HOL customers contributing on average 2kW for 20-minutes every hour in groups of 1/3rd, or all contributing just under 1kW for one hour with 2/3rds overlapping at any time, and so on. Practically though, the transmission grid is a limitation; nonetheless, the math shows how managing a few customer flexible loads or energy sources can have a greater offset in load serving infrastructure or energy. Figure 5 below is from the referenced ETNO report and illustrates the benefit of DERs to the customer and the electricity system. However, the best benefit is when these DERs are managed and the management system is based on interoperability principles and other standardized requirements of the managers.

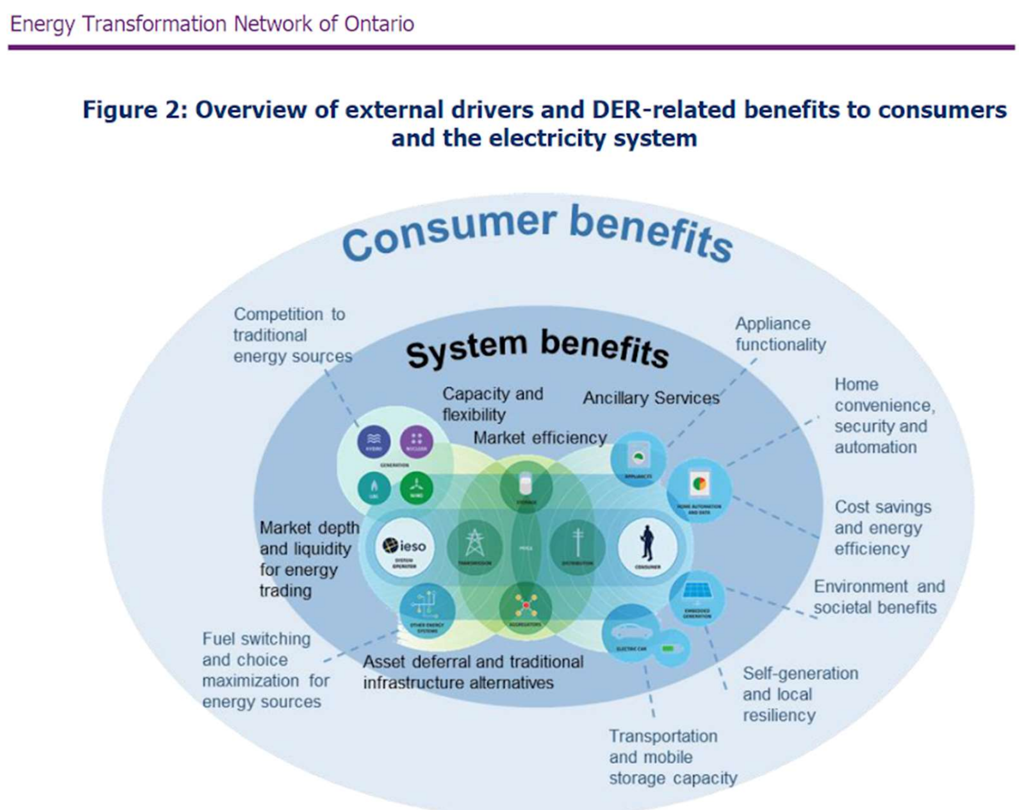

Figure 5: Benefits of DERs

11 Lessons Learned

Within this section, summarized are issues that arose during this project and how we addressed them or would do so, the remaining barriers to future success, the unexpected project outcomes and generally other lessons learned.

1. **Recruitment:** reported many times was the difficulty in signing on interested prospects and the reasons why. It came to a point whereby the project needed to be completed in the best way. Thus, we ensured that we covered 50% or more of the customer base load profiles in the field trial, and that allowed extrapolation of DR impact across the customer base. In commercial application participation in MiGen would not require a full HEMS outfitting, the participant can use MiGen with any number, type or mix of HEMS.

2. **Wi-Fi Mesh:** reported many times was the difficulty in implementing the CA to TA communications given the linear topology of the CAs creating a bottleneck at the first CA closest to the TA, the RaspberryPi3B shared controller not being dedicated to the communications shield, and so on. This is a lingering concern for the future release and consideration needs to be given to the computing board, the routing protocol, and the consideration for using, if needed, Ethernet power for relays. Other FAN solutions are available, however, just like for the Wi-Fi Mesh, would have needed set-up and would have had usage and other costs too. MiGen is does not mandate on the communications technology used between the TA and CAs.

3. **HEMS capability:** throughout the trial, we recognized improvements to HEMS that would help Transactive DR and customer use of the products. These were noted to the collaborating OEMs as a benefit for their participation in the project. Some of this information is provided in Schedule D3; for example, the battery responds to DR events and provides more power than requested. These issues did not limit the success of the Project, and resolution would be HEMS enhancements for the prosumer's benefit.

4. **Residential GUI:** or a better term would be Prosumer GUI. This was not intended to be part of the MiGen project and did not affect the success of the Project. It did, however, allow us to understand what features a useful GUI should have, namely: mobile app platform; one dashboard consolidating all vendor HEMS interfaces.

5. **Asset Sizing:** interestingly, prior to the MiGen System being installed at Sand Cherry, the 50kVA transformer was replaced because of rusting. In its place, per HOLs sizing standard a 75kVA unit was installed though a 50kVA unit would have sufficed based on historical loading of the transformer. Importantly, the ability to manage the loading may have provided the comfort to keep to a 50kVA.

6. **Data:** MiGen would benefit from a study for defining the residential demand baseline that when combined with other signal-triggers, like monetary incentives, can provide for a more effective load reduction by means of load shaving and/or valley-filling. Without

the battery contribution to the DR effect, it was difficult to ascertain the DR effect when other uncontrolled loads were fluctuating. There is a discussion on this issue elsewhere in the submission.

7. Should **regulatory and billing rates** change, MiGen could, in the future have the ability to reduce GHGs for residents. This could be realized simply by charging the battery from the grid during cleaner times of the day (between 12:00am and 7am - typical for Ontario's grid), when peaker plants are off-line and then injecting that power locally or to the grid during high demand periods. However, running MiGen in this mode is currently not economical because when switching to a bi-directional meter the billing rate structure switches from time-of-use (TOU) to tiered. This will have a negative financial impact on the customer because they will be purchasing power at 11.9₵/kWh and then selling back to the grid at 11.9₵/kWh, meanwhile losing ~10% due to battery full trip losses. However, if the OEB changes its rate structure this could be both economically and environmentally beneficial for the residents.

8. **Unexpected Project outcomes:** the platform delivered on its technical objective. This was the first time anyone had tried what we did and risks were many. The participants ultimately behaved as we would expect once one has used MiGen for a while. For the most part, they "set it and forget it" because other things in life were important to them; however, they were aware of the opt-out options and only one invoked it once. In the meantime, MiGen was issuing and reacting to Transactive DR requests. Since the participants were not actually concerned with the management of their devices if their comfort wasn't overly compromised, then the customers are likely to rely fully on their HEMSC to run their devices optimally. It may also mean that customers are likely to lend their devices to the utilities for helping the grid.

12 Conclusions

The analysis above shows that the MiGen system is presently not commercially viable in the context of HOLs Service Area. As discussed, this is primarily due to:

- HOL's grid is, for the most part, not constrained to the point of overloading existing assets, such that there would be a need for DRs at the edge. However, as discussed above, government incentives play a huge role in technology adoption, such as PV systems and EVs, so we need a technology platform to be able to handle high adoption rates on the grid without having to rebuild it.

- There needs to be a transformational shift in the utility industry to enable a mechanism for transactional energy markets (TEM) at the grid edge to put a valuation on grid constraints and compensate prosumers for their participation in DR events.

The MiGen solution will become more viable if the grid becomes significantly constrained due to external factors, such as the electrification of transportation, and the high adoption of renewables and/or there is a transformational shift in the utility industry. Predicting when this will happen is difficult since the above items are heavily influenced by policy, political landscape, and the economy.

Having said that, the MiGen project Phase 1 accomplished the platform field trial in multiple premises electrically connected to the same neighbourhood transformer. MiGen demonstrated the Wi-Fi Mesh Network, the three design principles for MiGen design: privacy-by-design, interoperability and best cyber-security practices. The MiGen Team, through MiGen, has demonstrated that negotiated Transactive Demand Response can be decentralized and work at the grid edge while upholding these three design principles. Also, the TA negotiation -- with several Home Energy Management System Controllers (HEMSCs) through their respective Customer Agents (CAs) – was validated. The MiGen contributors and sponsors walk away with a copious amount of data and lessons learned that will help Hydro Ottawa, its partners, the Ontario Ministry of Energy Northern Development and Mines, and the LDC Tomorrow Fund to strategically plan next phases or related projects.