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SMART GRID IN CANADA

2018

Authors: Anjali Wadhera, Josef Ayoub and Marylène Roy

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About This Report

This report provides an update on smart grid activities in Canada since the last report published in 2014. Key research, development, demonstration and deployment activities related to smart grid are highlighted as of December 2018. The report is intended to be a useful reference for Canadian and international smart grid practitioners, stakeholders and policymakers.

This report is published by Natural Resources Canada's CanmetENERGY research centre in Varennes, which manages the Canada Smart Grid Action Network (CSGAN) shown in Figure 1. CSGAN members discuss regional activities, share research topics of interest, collect smart grid metrics in Canada, present international knowledge and experience sharing opportunities, track standard development, and explore smart grid outlooks. CSGAN members' updates have contributed significantly to producing this report.

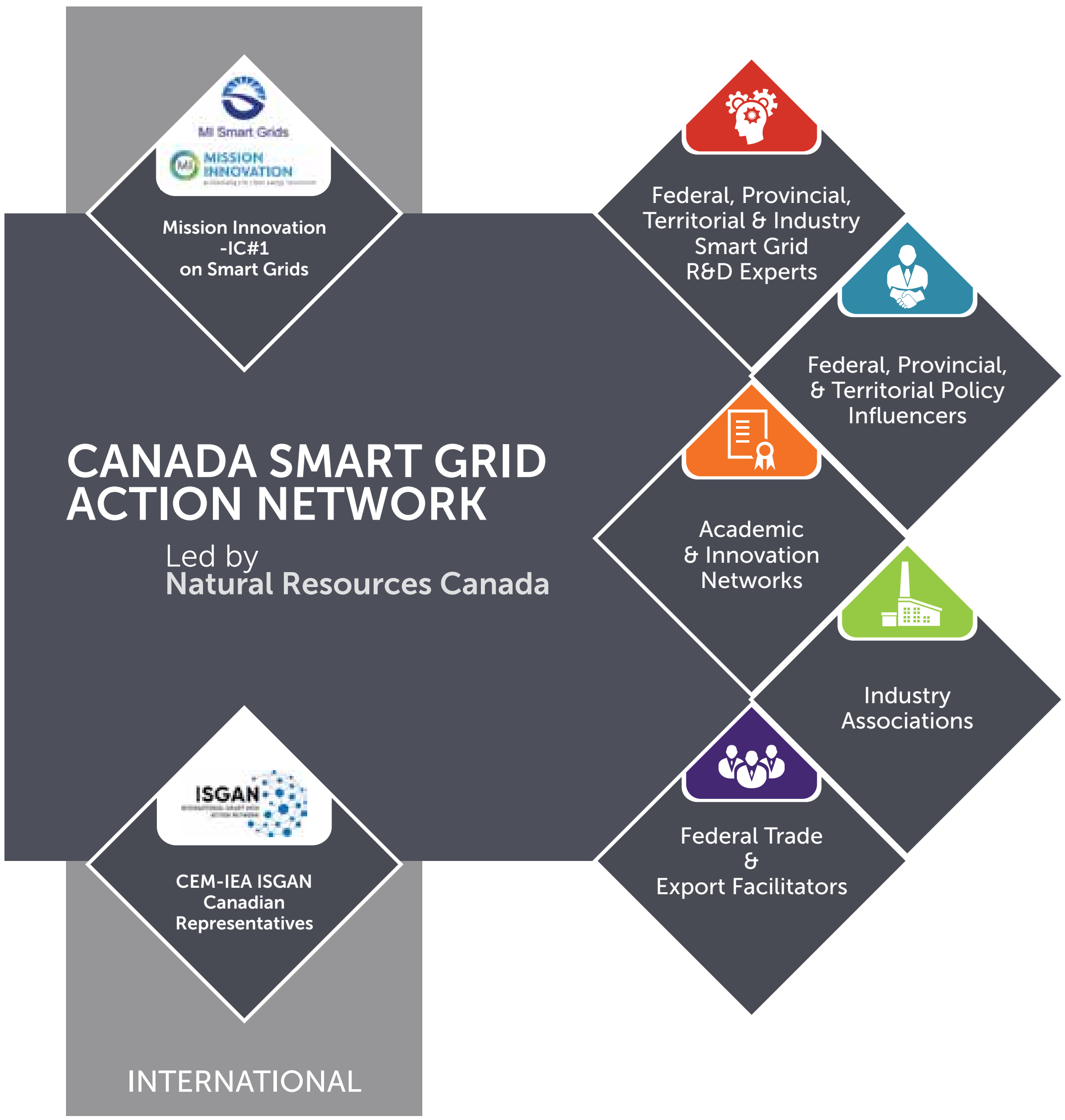

Figure 1: Canada Smart Grid Action Network (CSGAN) members

About CanmetENERGY

Natural Resources Canada's CanmetENERGY is Canada's leading research and technology organization in the field of clean energy. Nearly 175 scientists, engineers and support staff at the CanmetENERGY facility in Varennes, Quebec design and implement clean energy solutions, and expand on research areas that help produce and use energy in ways that are more efficient and sustainable.

CanmetENERGY has been addressing technical, institutional and regulatory barriers for smart grid technologies for over a decade such as limitations to integrating renewable energy on the grid, demand flexibility, smart inverter controls and smart grid related standards. CanmetENERGY also established CSGAN to connect key Canadian smart grid stakeholders and to leverage opportunities under the International Smart Grid Action Network and Mission Innovation—Innovation Challenge #1 on Smart Grids. CSGAN brings together members from provincial and territorial energy ministries, federal departments, academia, innovation networks, and industry associations to exchange their knowledge and experience about smart grid activities.

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Abbreviations

AC	Alternating Current
AEC	Advanced Energy Centre
AESO	Alberta Electric System Operator
AMI	Advanced Metering Infrastructure
BC	British Columbia
BCUC	British Columbia Utilities Commission
BEV	Battery Electric Vehicle
C&I	Commercial and Industrial
CEA	Canadian Electricity Association
CEATI	Centre for Energy Advancement through Technological Innovation
CEM	Clean Energy Ministerial
CEV	Clean Energy Vehicle
CMD	Connect My Data
COP	Conference of the Parties
CSA	Canadian Standards Association
CSGAN	Canada Smart Grid Action Network
DC	Direct Current
DER	Distributed Energy Resource
DERM	Distributed Energy Resource Management
DG	Distributed Generation
DMD	Download My Data
DR	Demand Response
DSO	Distribution System Operator
EDA	Electricity Distributors Association
EDC	Export Development Canada
EV	Electric Vehicle
FIT	Feed-in Tariff
GHG	Greenhouse Gas
GI2	Green Infrastructure Phase 2
HVDC	High Voltage Direct Current
IC	Innovation Challenge
ICE	Innovative Clean Energy
ICT	Information and Communication Technology
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IESO	Independent Electricity System Operator of Ontario
IoT	Internet of Things
ISED	Innovation, Science and Economic Development
ISGAN	International Smart Grid Action Network
IT	Information Technology
LEV	Light Emission Vehicle

LRP	Large Renewable Procurement
MI	Mission Innovation
MI-IC1	Mission Innovation – Innovation Challenge #1
microFIT	Micro Feed-in Tariff
NARIS	North American Renewable Integration Study
NBP	New Brunswick Power
NESTNet	Natural Sciences and Engineering Research Council Energy Storage Technology Network
NRCan	Natural Resources Canada
NSERC	Natural Sciences and Engineering Research Council
OEB	Ontario Energy Board
PCF	Pan-Canadian Framework
PF	Power Factor
PHEV	Plug-in Electric Vehicle
PV	Photovoltaics
QEC	Qulliq Energy Corporation
R&D	Research and Development
RD&D	Research, Development and Demonstration
RDD&D	Research, Development, Demonstration and Deployment
RE	Renewable Energy
RECSI	Regional Electricity Cooperation and Strategic Infrastructure Initiative
REP	Renewable Electricity Program
RES	Renewable Energy System
RPP	Regulated Price Plan
SCADA	Supervisory Control and Data Acquisition
SDTC	Sustainable Development Technology Canada
SGIN	Smart Grid Innovation Network
SIRFN	Smart Grid International Research Facility
TCP	Technology Collaboration Program
TEQ	Transition Énergétique Québec
ToU	Time-of-use
TRL	Technology Readiness Level
TSO	Transmission System Operator
UL	Underwriters Laboratories
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2X	Vehicle-to-Everything
VPP	Virtual Power Plant
VV	Volt-var
ZEV	Zero Emission Vehicle

GENERAL FRAMEWORK

General Framework

The impacts of climate change are becoming more evident not only in Canada but around the world. The Intergovernmental Panel on Climate Change report finalized in October 2018 states that human activities have accelerated global warming, which poses significant risks to human health, security and biodiversity.

Canada has been proactive in addressing global warming by participaring in initiatives like the *Paris Agreement* at the twenty-first Conference of the Parties (COP21) in 2015. This international call for action committed countries to reducing greenhouse gas (GHG) emissions to diminish effects of global warming. The *Paris Agreement* commits countries to reduce (GHG) emissions by 30% below 2005 levels by 2030, and to strengthen efforts in limiting the global average temperature rise to below 2 °C as compared to preindustrial measurements. Following this agreement, the Government of Canada, collaborated with provincial and territorial governments to develop the *Pan-Canadian Framework on Clean Growth and Climate Change* (PCF) in 2017. The PCF identifies the electricity sector as a key sector in Canada's transition to a low-carbon economy as the Government of Canada works with provinces and territories to:

- Invest in non-emitting and renewable energy (RE) sources for access to clean electricity;
- Increase connectivity in transmission lines between provinces and territories to share clean electricity;
- Modernize the power system through demonstration and deployment of smart grid technologies to better integrate RE and energy storage while expanding RE capacity; and
- Reduce reliance on diesel by engaging Indigenous Peoples and northern and remote communities to improve quality of life.

Canada has one of the cleanest electricity systems in the world with 80% of electricity produced by non-emitting sources. However in pursuit of a low-carbon economy, the electricity sector will have to increase grid capacity while replacing emitting generation sources with clean geration like RE. Additional grid capacity will be required for the electrification of sectors like transportation, industrial processes and buildings looking to leverage a clean electricity system to reduce their respective emissions. Furthermore, large centralized generation plants are no longer the only source of supply for the power grid as decentralized RE systems (RES) are also being deployed. The variability of RE sources like solar photovoltaics (PV) and wind requires new technologies which includes grid flexibility options, to ensure grid reliability and resiliency in the transition to a cleaner modernized grid.

By applying technologies pioneered in the digital information and telecommunication sectors, smart grid can connect electricity generation facilities and customers through real-time communication. New approaches involving digitalization will be necessary to effectively operate a modernized grid with bidirectional power flow, advanced protection and control capabilities, and tools that benefit customers. From generation, transmission and distribution, to behind the meter, digital monitoring and controls can provide added value like demand response (DR) programs where customers gain incentives for adjusting their consumption based on grid needs. This technology is key to enable RESs to reduce GHG emissions in the electricity sector, and establish a smarter grid.

SMART GRID DRIVERS AND TECHNOLOGY

Smart Grid Drivers and Technology

The traditional grid is evolving as new technology is adopted to upgrade infrastructure, reduce operation costs, emit less GHG and meet increased demands. To accommodate this new grid technology, research, development, demonstration and deployment (RDD&D) efforts are necessary to ensure grid reliability. Cleaner generation sources like wind or solar are variable by nature and new grid technology must be seamlessly integrated to maintain customer grid service. More distributed generation (DG), variable renewable energy (RE), and other distributed energy resources (DERs) with information communication technology (ICT) are coming online as the resources required to build a smart grid.

Variable RE deployment in Canada is rapidly growing. The total installed wind capacity has surpassed 12.7 GW in 2018 [1], where approximately 1 GW of this capacity is interconnected to the distribution system (assuming that 20 MW projects and less are distribution connected) [2]; and solar PV has surpassed 2.6 GW [3] grid-connected capacity, out of which almost 2.3 GW is distribution connected largely as a result of solar PV installations in Ontario [4].

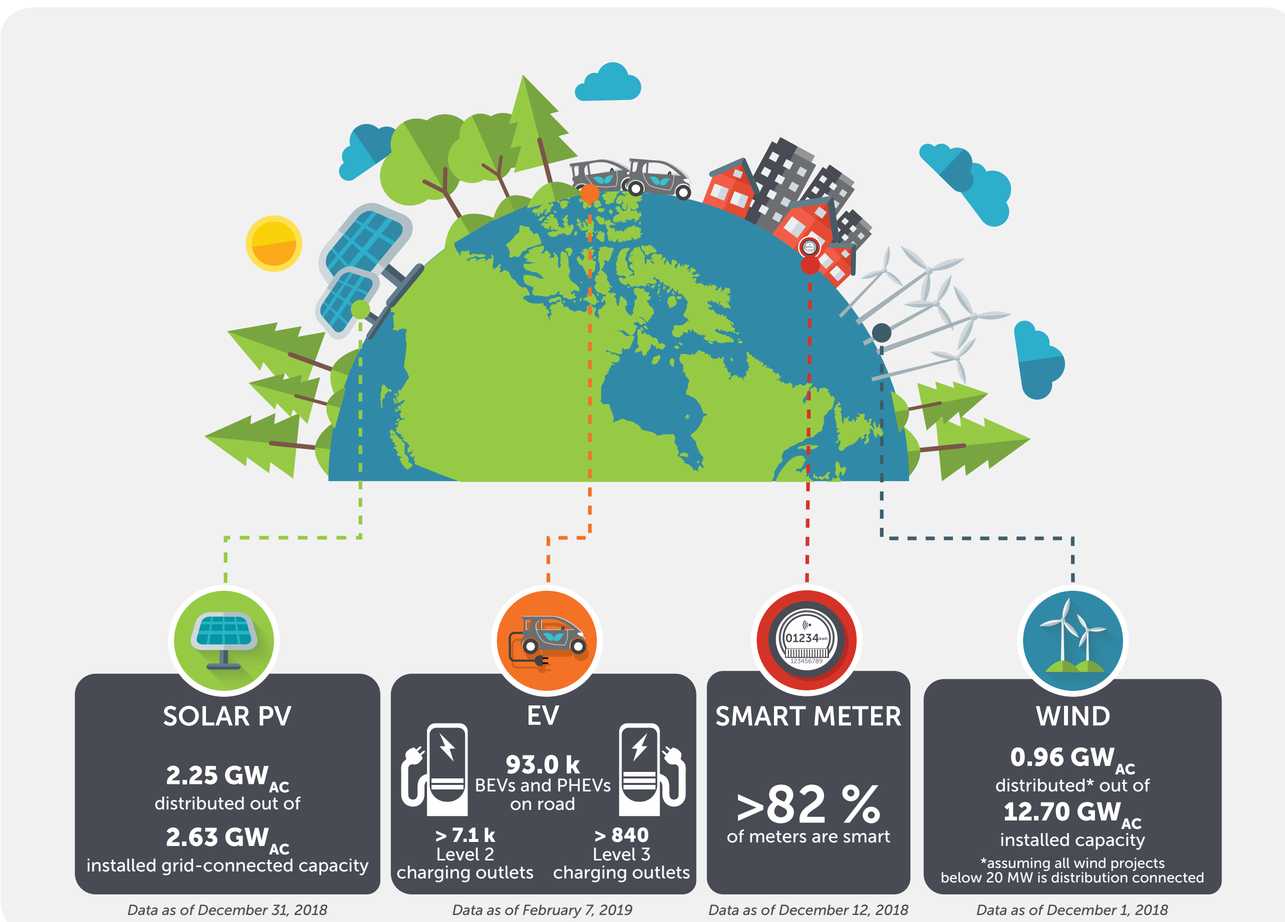


Figure 2: Select smart grid deployment metrics for Canada in 2018

DERs are a way to effectively use RE generation and support grid services like peak-shaving, voltage control and congestion management. In addition to traditional energy storage technologies like pumped hydro plants and batteries, DERs are also comprised of DG and controllable loads. Controllable loads include systems managing space heating loads (e.g. HVAC, smart thermostats) or water heating loads (e.g. electric water heaters), have the potential to provide the grid with added flexibility. The flexibility potential in residential space and water is estimated to be 39 GW/85 GWh in Canada, and is only a fraction of the controllable load potential across various sectors [5]. Additional controllable load potential exists in other sectors like industrial processes, commercial buildings and electrified transportation.

Electric vehicles (EVs) are seen as a potential mobile grid resource with controllable load characteristics. With access to a clean grid, EVs can be the transportation sector's means of reducing GHG emissions.

More Canadians have been purchasing EVs in the last few years [6] with over 87,000 Battery and Plug-in Hybrid EVs (BEV and PHEV respectively) that require fuel from the power grid. There are more than 850 Level-3 public EV chargers and over 5,800 Level-2 public EV chargers [7] which can draw a maximum of 150 kW [8] and 19.2 kW per charger respectively [9].

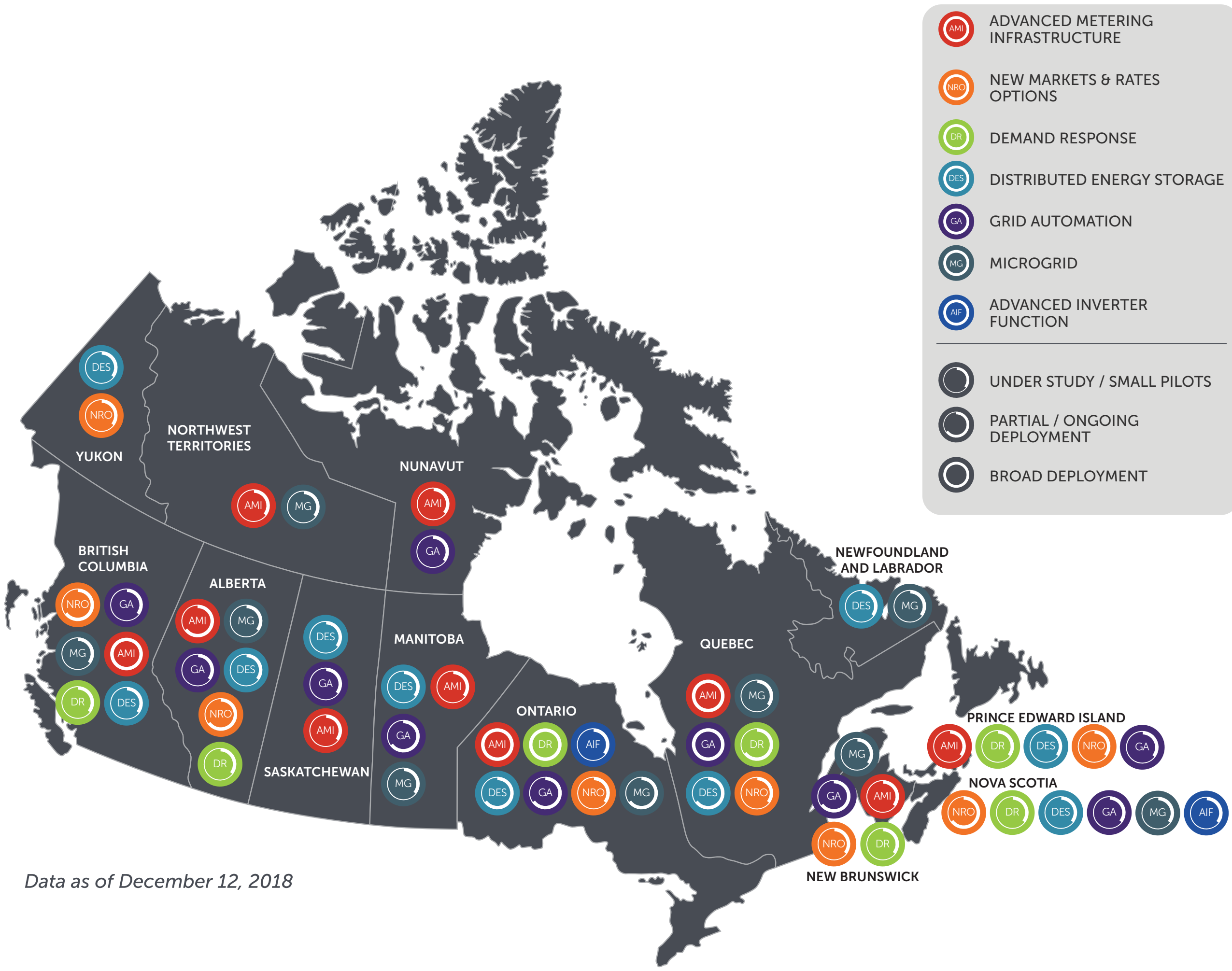


Figure 3: Deployment levels of different smart grid applications across Canada

Given that over 82% of meters in Canada are classified as smart meters, there is an opportunity for utilities to more actively interact with customers to better assess and manage potential load flexibility on the grid. Smart meters can be used as a gateway for information exchange with the customer to support customer tools and utility operations, such as establishing incentives to support their grid operation strategies.

Figure 3 shows the levels of various smart grid applications deployed across Canada. The level of deployment of each application is indicated by the inner circle: a 1/3 circle indicates under study or small pilots, a 2/3 circle indicates partial or ongoing deployments and a full circle indicates broad deployment. Provinces and territories are assessed based on publicly available information and input from provincial and territorial government representatives on CSGAN. Note that for Ontario, a deregulated market and time-of-use (ToU) rate structure has been deployed for many years hence the infographic is tracking new pilots testing different price structures. For definitions on the seven highlighted smart grid applications, see Appendix: Smart Grid Applications operations, such as establishing incentives to support their grid operation strategies.

PUBLIC SECTOR ACTIVITIES

Public Sector Activities

The public sector supports RD&D to better understand technical and non-technical barriers for broader smart grid deployments. Transitioning from technical demonstrations to market pilots allows for real-world experiences to address concerns like commercialization, system operation, and scalability. The public sector is also supporting deployment of mature technologies to catalyze the transition to a cleaner low-carbon economy.

Figure 4 summarizes public investments announced in smart grid RDD&D projects across Canada. Each icon indicates the type of smart grid activities at least one project in the province or territory received funding. Canada has invested $261 million public dollars to fund $758 million in total project value since 2003 over 135 projects. Funding for academic networks and projects are not included, nor are the significant contributions made through the Smart Grid Fund under the Ministry of Ontario Energy, Northern Development and Mines. The vast majority of funding, about $231 million of the total publicly investments are from federal funds, whereas $30 million was invested through provincial or territorial funds.

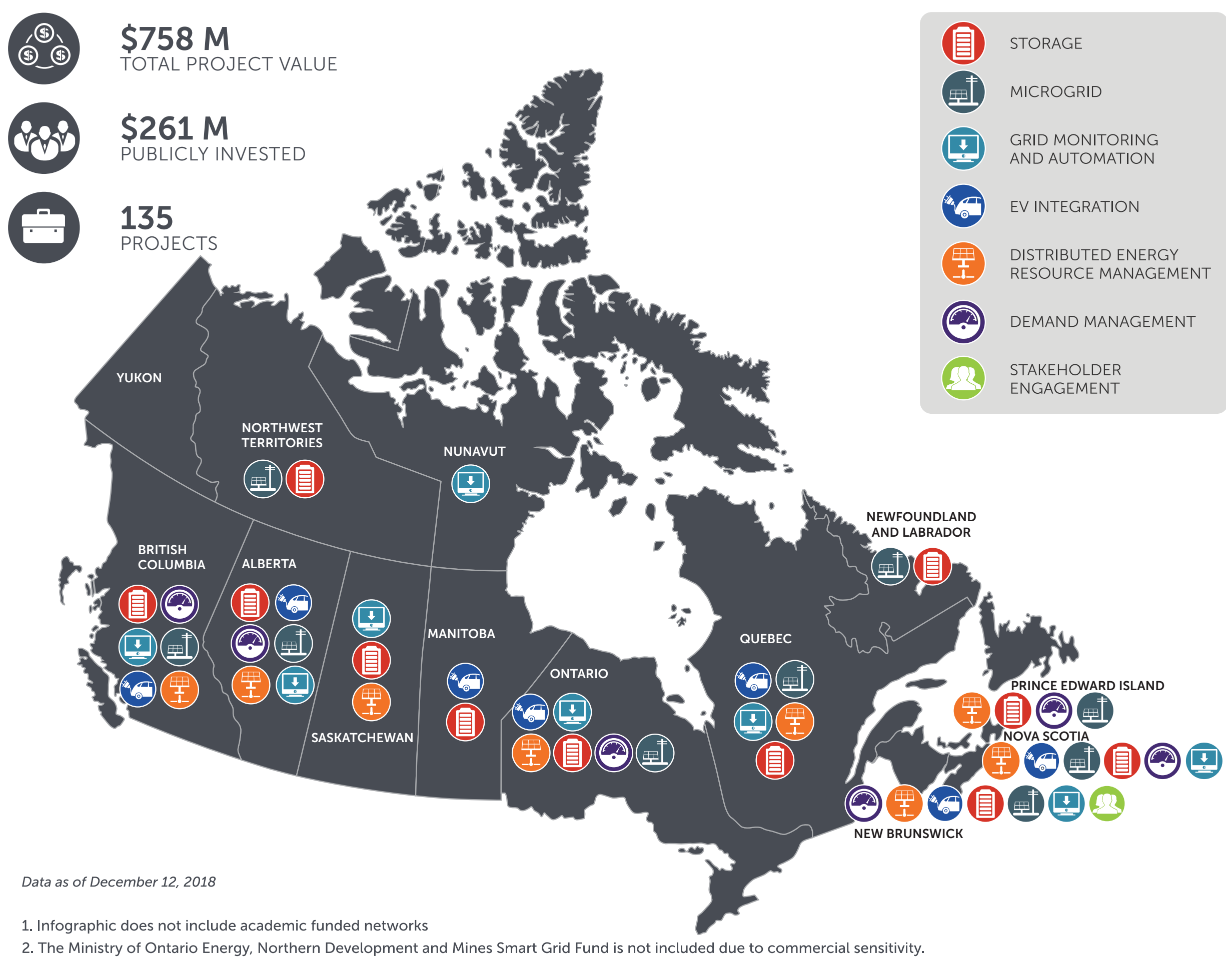


Figure 4: Public investments in smart grid RDD&D since 2003

As shown in Figure 5, a significant amount of funding has been invested related to distributed energy resource management (DERM), storage and EV integration. Stakeholder engagement received most of its total project value from public funding followed by demand management, grid monitoring and automation, and storage. Projects related to EV integration has increased almost entirely due to a federal funding envelope dedicated to EV infrastructure deployment, with Canadian companies and utilities leading these projects. Canadian companies also dominate as the lead proponent on storage projects, whereas utilities are dominating projects related to DERM and grid monitoring and automation given utility investments in grid assets. The largest investments have been made in DERM closely followed by projects related to storage. The different types of lead proponents being funded for various smart grid projects are described in Figure 6. Canadian companies are the lead proponents on the majority of publicly funded demonstration and deployment projects, closely followed by utilities. Note, utilities are classified as any organization responsible for generating, transmitting or distributing power or energy.

The smart grid is supported by various public programs as a catalyst to work towards climate change solutions. Federal, provincial and territorial governments collaborate to expand the smart grid knowledge base and support innovation by policy and diverse funding programs.

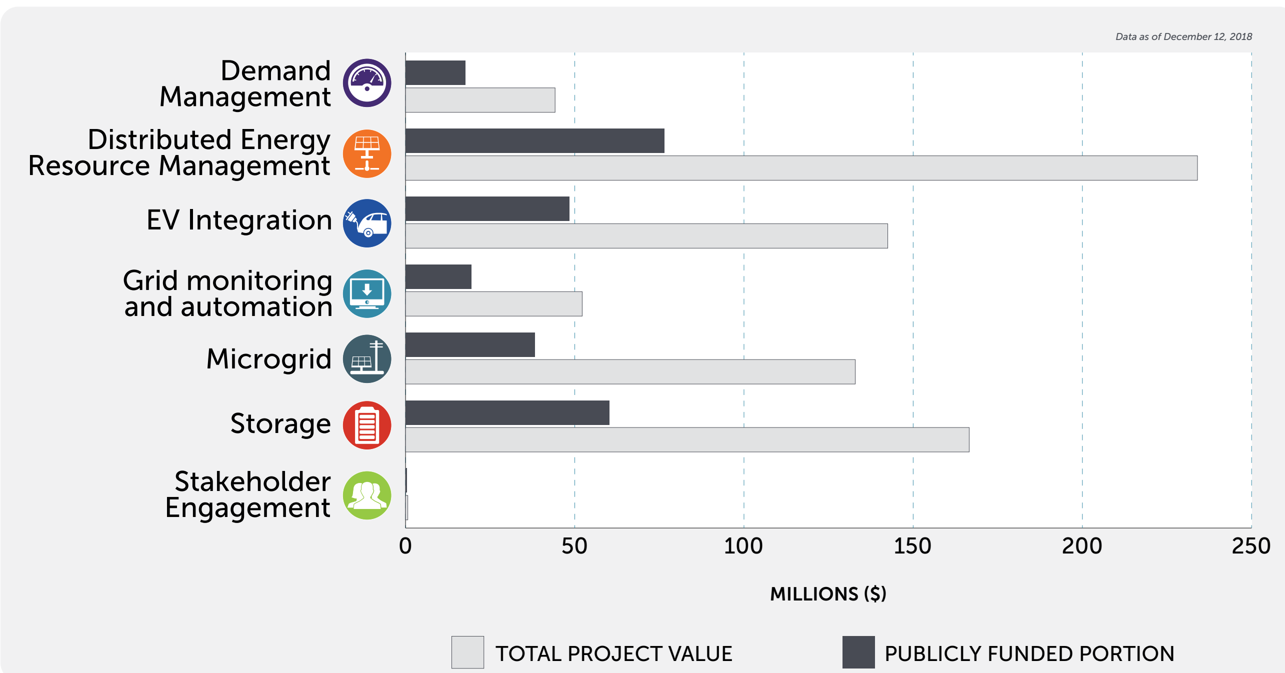


Figure 5: Publicly funded projects funding compared to total project value

Data as of December 12, 2018

1. Infographic does not include academic funded networks.
2. The Ministry of Ontario Energy, Northern Development and Mines Smart Grid Fund is not included due to commercial sensitivity.

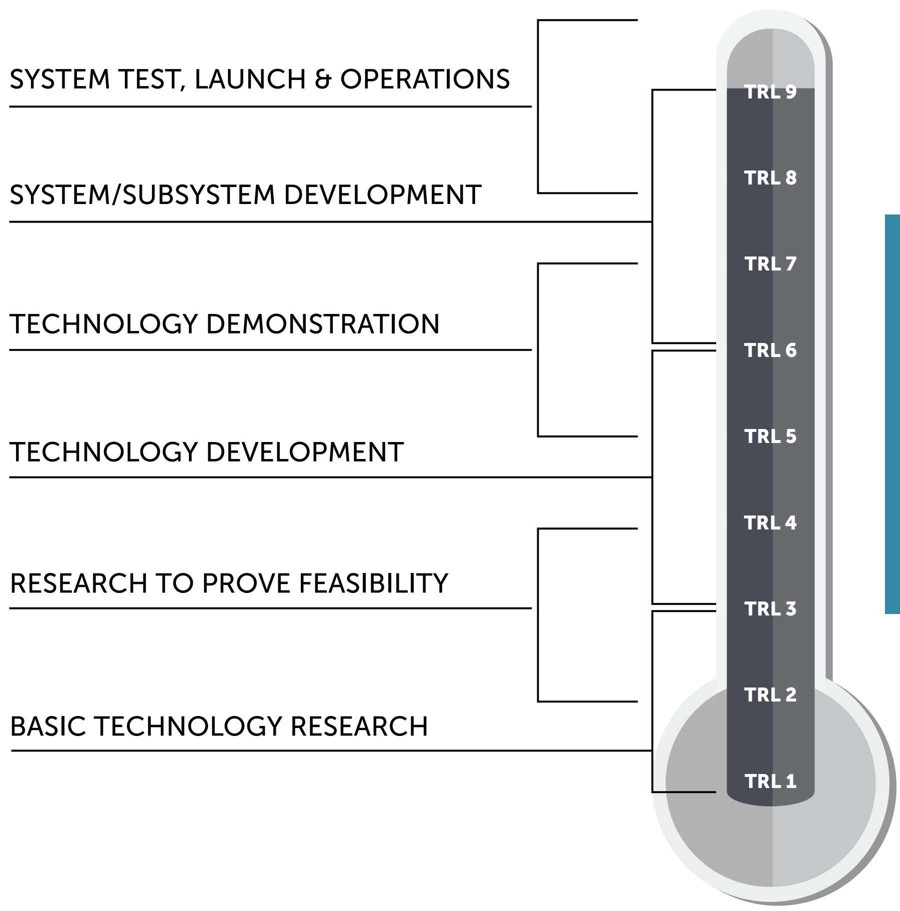
Figure 6: Lead proponents for publicly funded smart grid demonstration and deployment projects

Federal Leadership

In Budget 2017, the federal government announced more than $2.3 billion to support clean technology, Canadian firms and exports. Several programs were created that relate to smart grid directly or indirectly as a result of this announcement.

Federal Funding Programs

Figure 7 is a summary of recent and ongoing federal funding programs that are related to smart grid technology RDD&D in Canada, at least in part. Funding streams are open to government organizations and legal entities incorporated or registered in Canada unless otherwise indicated; internal funding indicates programs only open to government departments whereas external funding is available only to non-federal government entities. This summary does not include funding support from the Natural Sciences and Engineering Research Council (NSERC), an agency supporting academic innovative research, including smart grid related topics. Some federal programs limit the type of projects funded according to technology readiness level (TRL), as explained in Figure 7. If a program uses TRL as a metric to determine which projects are funded, this will be included in the program summary.

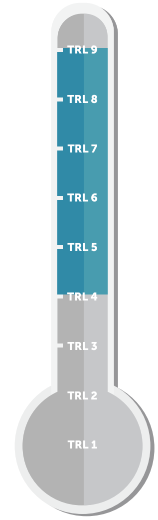


TRL is an indicator for technology maturity. This indicator is used by certain funds to target specific development stages. This report covers all TRL levels, since smart grid activities span all TRLs.

Figure 7: Technology readiness level scale

FUND — ENERGY INNOVATION PROGRAM

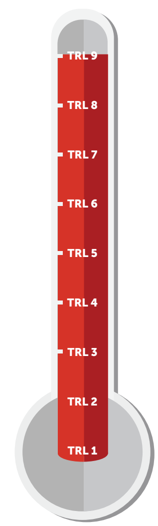
DEPT.	YEAR	AMOUNT (millions)	FUND STATUS
NRCAN	ONGOING	$52.9/YEAR	CONTINUOUS INTAKE



The *Energy Innovation Program* accelerates clean energy technology research and development (R&D) related to investigating renewable, smart grid and storage systems; decreasing diesel usage by industrial operators in northern and remote communities; reducing methane and volatile organic compound emissions; lowering GHG emissions in the building sector; advancing carbon capture, use and storage; and improving industrial efficiency. This program provides internal government and external funding.

FUND — PROGRAM OF ENERGY RESEARCH AND DEVELOPMENT

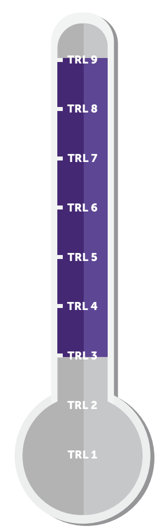
DEPT.	YEAR	AMOUNT (millions)	FUND STATUS
NRCAN	ONGOING	$35/YEAR	CONTINUOUS INTAKE



The *Program of Energy Research and Development* funds internal energy R&D projects focused on building a sustainable energy future for Canada's economy and environment. This fund only supports federal departments and agencies, or outside organizations working directly with a federal department or agency.

FUND — CLEAN GROWTH PROGRAM

DEPT.	YEAR	AMOUNT (millions)	FUND STATUS
NRCAN	2017-2021	$155	CLOSED

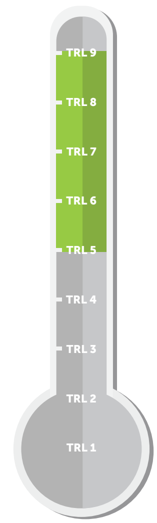


The *Clean Growth Program* supports clean technology RD&D projects in energy, mining and forestry to help Canada meet its climate change goals and create clean jobs.

FUND	DEPT.	YEAR	AMOUNT (millions)	FUND STATUS
GREEN INFRASTRUCTURE PHASE II	NRCAN	N/A	$812	N/A

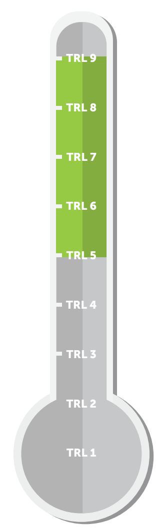
The *Green Infrastructure Phase II* (GI2) fund accelerates the deployment and market entry of next-generation clean energy infrastructure through various programs. GI2 consists of multiple programs that focus on dedicated infrastructure streams as described below. This fund is for external funding only.

FUND	DEPT.	YEAR	AMOUNT (millions)	FUND STATUS
SMART GRIDS	NRCAN	2018-2022	$100	CLOSED



The *Smart Grid Program* under the GI2 supports the demonstration and deployment of smart grid technologies from utility-led projects to reduce GHG emissions, better utilize existing electricity assets, and foster innovation and clean jobs.

FUND	DEPT.	YEAR	AMOUNT (millions)	FUND STATUS
ELECTRIC VEHICLE INFRASTRUCTURE DEMONSTRATIONS	NRCAN	2018-2022	$30	CLOSED



The *EV Infrastructure Demonstrations Program* under GI2 supports the demonstration of next-generation and innovative EV charging infrastructure projects.

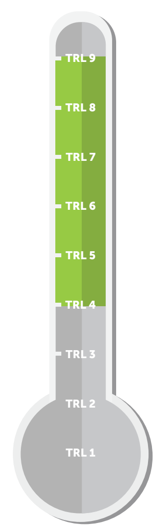
FUND	DEPT.	YEAR	AMOUNT (millions)	FUND STATUS
ELECTRIC VEHICLE AND ALTERNATIVE FUEL INFRASTRUCTURE DEPLOYMENT INITIATIVE - PHASE 2	NRCAN	2018-2022	$80	CLOSED

The *EV and Alternative Fuel Infrastructure Deployment Initiative Program* under GI2 supports the deployment of EV Fast Chargers (Level-3) as well as Natural Gas and Hydrogen Fueling Stations.

FUND	DEPT.	YEAR	AMOUNT (millions)	FUND STATUS
EMERGING RENEWABLE POWER	NRCAN	2018-2023	$200	CLOSED

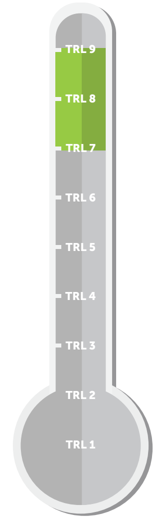
The *Emerging Renewable Power Program* under GI2 supports the deployment of offshore wind, instream tidal, geothermal, concentrated PV, and other emerging RE technologies.

FUND	DEPT.	YEAR	AMOUNT (millions)	FUND STATUS
ENERGY EFFICIENT BUILDINGS RD&D	NRCAN	2018-2026	$182	CLOSED



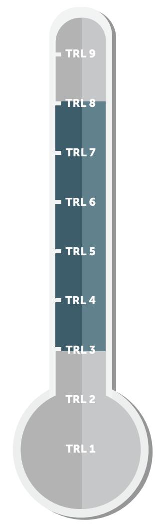
The *Energy Efficient Buildings RD&D Program* under GI2 supports the development and implementation of building codes for existing buildings and new net-zero energy-ready building initiatives.

FUND	CLEAN ENERGY FOR RURAL AND REMOTE COMMUNITIES
DEPT.	NRCAN
YEAR	2018-2024
AMOUNT (millions)	$220
FUND STATUS	VARIABLE



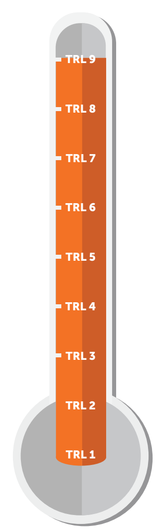
The *Clean Energy for Rural and Remote Communities Program* under GI2 aims to reduce reliance on diesel fuel in Canada's rural and remote communities and industrial sites by supporting a transition to more sustainable energy solutions.

FUND	SD TECH FUND
DEPT.	Sustainable Development Technology Canada (SDTC)
YEAR	ONGOING
AMOUNT (millions)	$400
FUND STATUS	CONTINUOUS INTAKE



The *SD Tech Fund* supports Canadian companies with the potential to become world leaders in their efforts to develop and demonstrate new environmental technologies related to climate change, clean air, clean water and clean soil.

FUND	STRATEGIC INNOVATION FUND
DEPT.	Innovation, Science and Economic Development (ISED)
YEAR	2017-2022
AMOUNT (millions)	$1,260
FUND STATUS	VARIABLE



The *Strategic Innovation Fund* supports various types of innovation projects through four different streams across all of Canada's industrial and technology sectors.

Clean Growth Hub

The Clean Growth Hub is a federal government resource supporting companies and projects, coordinating programs and tracking results in the cleantech sector. This team of experts helps firms of all sizes and stages of development to better understand government programs and services.

Export Development Canada

Export Development Canada (EDC) helps Canadian cleantech companies expand to global markets by providing financing, risk protection, and market knowledge. EDC's global clients value Canada's experiences leveraging smart grid technologies including smart meter deployment, robust grids, and off-grid and grid-tied microgrids. EDC is committed to supporting commercialization and trade of Canadian solutions that enable clean energy, resource efficiency and clean water.

Generation Energy

In 2017, the Government of Canada launched *Generation Energy,* a nationwide open and inclusive dialogue lasting 6 months, to exchange ideas on what a low-carbon energy future would look like for the next generation of Canadians. This initiative convened more than 380,000 Canadians including subject experts, Indigenous and community leaders. A report was released in June 2018 outlining the energy future Canadians envisioned. Despite diverse stakeholders, there was consensus on access to affordable, reliable and clean energy. The report's findings included four complimentary pathways to transition to the depicted future: energy efficiency, clean power, renewable fuels and cleaner oil and gas.

Between 2012 and 2017, EDC worked with 190 cleantech companies to facilitate $5 billion in export sales.

Regional Electricity Cooperation and Strategic Infrastructure

As part of Green Infrastructure Phase I, Budget 2016 allocated $2.5 million for Natural Resources Canada to advance regional electricity cooperation. The *Regional Electricity Cooperation and Strategic Infrastructure Initiative* (RECSI) funded studies and dialogues to identify critical electricity infrastructure projects with the potential to achieve significant GHG reductions.

Two regional dialogues and studies were conducted in Western and Atlantic Canada—Western Canada; included Alberta, British Columbia, Manitoba, Northwest Territories and Saskatchewan; Atlantic Canada's included New Brunswick, Newfoundland and Labrador, Nova Scotia and Prince Edward Island. While recognizing that electricity infrastructure and market structures are different across provinces and territories, both studies came to the same conclusion that coordinated regional investment can provide a more affordable and cleaner energy mix for Canadians.

Provincial and Territorial Initiatives

Given that the provinces and territories each manage their respective electricity systems, each's approach to smart grid differs according to its assets and needs; economic development considerations and energy and environmental policy drivers. Smart grid activities by provincial and territorial governments are highlighted in this section.

Alberta

Alberta's *Climate Leadership Plan* adds 5,000 MW of RE to replace fossil fuels to meet the 30% RE generation by 2030 target [10]. The Alberta Electric System Operator (AESO) has been tasked with managing a competitive and transparent process for RE project bids under the Renewable Electricity Program. The first round set a record for the lowest renewable electricity pricing in Canada, with a weighted average price of ₵3.7/kWh. 600 MW was procured in the first round at the end of 2017 and is planned to be operational by the end of 2019. The projects selected in Round 1 are summarized in Table 1.

The second and third rounds of the *Renewable Electricity Program* (REP) were running concurrently with successful proponents announced in December 2018 as listed in Table 2 and Table 3 respectively. The second round of the REP displayed the Government of Alberta's commitment to encourage greater participation by Indigenous communities in the electricity sector and the development of renewable electricity by requiring a minimum 25% Indigenous equity ownership. The AESO was also tasked with designing and implementing the transition to a capacity market by 2021 [11]. Various stakeholder engagement activities are being carried out until 2019 when the first procurement begins in an effort to foster a market structure that will encourage innovation and present economic opportunities for a modernized grid [12].

The Alberta Smart Grid Consortium was established in July 2017 to accelerate smart grid demonstration and deployment initiatives in Alberta with key collaborators: Alberta Innovates; Alberta Energy; Alberta Distribution Facility Owners, consisting of ATCO, ENMAX, EPCOR, FortisAlberta, Alberta Federation of Rural Electrification Associations, and EQUS; and the cities of Lethbridge, Medicine Hat and Red Deer.

Table 1: AESO RE Procurement Round 1 Results [13].

PROPONENT	RE SOURCE	CAPACITY (MW)
EDP Renewables Canada Ltd.	Wind	248
Enel Green Power Canada, Inc.	Wind	115
Enel Green Power Canada, Inc.	Wind	30
Capital Power Corporation	Wind	202

Table 2: AESO RE Procurement Round 2 Results [14].

PROPONENT	RE SOURCE	CAPACITY (MW)
Sawridge First Nation	Wind	48
Blood-Kainai First Nation	Wind	202
Paul First Nation	Wind	113

Table 3: AESO RE Procurement Round 3 Results [14].

PROPONENT	RE SOURCE	CAPACITY (MW)
Transalta Corp.	Wind	207
Potentia Renewables Inc.	Wind	71
Potentia Renewables Inc.	Wind	122

British Columbia

The Ministry of Energy, Mines and Petroleum Resources released its *2018/19–2020/21 Service Plan* in February 2018 outlining goals, objectives, strategies and performance measures for British Columbia (BC) [15]. BC's goals include a clean, reliable and affordable energy portfolio that meets current and future needs. BC has dedicated programs to meet energy efficiency and conservation goals through BC Hydro's PowerSmart and FortisBC's rebates and programs. Additionally, its *Innovative Clean Energy (ICE) Fund* is funded through a levy on certain energy sales and is designed to support the province's clean energy and economic priorities.

Since 2008, the ICE Fund has committed more than $100M to support pre-commercial clean energy technology projects, clean EV, R&D, and energy efficiency programs.

BC is committed to reducing GHG emissions in the transportation sector. The *BC Renewable & Low Carbon Fuel Requirements Regulation* requires the average carbon intensity of transportation fuels to be reduced 10% by 2020 relative to 2010 measurements [16]. The Clean Energy Vehicle (CEV) Program launched in 2011 has provided $82 million in funding to promote the uptake of zero emission vehicles (ZEVs) [17]; this has resulted in BC having one of the highest per capita adoptions of ZEVs and one of the largest charging and hydrogen fueling networks in Canada. Further, in 2018 the BC Utility Commission (BCUC) launched an inquiry exploring the regulatory issues, cost burden and safety concerns impacting stakeholders regarding EV charging stations levying a usage fee [18].

Manitoba

Manitoba released its *Climate and Green Plan* in 2017, a strategic framework to address approaches to sustainable development in a comprehensive way [19]. With over 99% of electricity generated from clean, renewable sources, the framework on clean energy under the climate pillar puts an emphasis on:

- demand-side management through Efficiency Manitoba, an agency with the mandate to reduce energy consumption and save money on electricity bills;
- Investigation into a clean heating program given the large heating loads;
- Electrification of public transit;
- Community Energy Plans, a tool for municipalities to help their communities achieve deeper efficiency improvements across all sectors;
- Replacing diesel generation in off-grid communities;
- Energy-efficient home and buildings;
- Supporting investments in cleantech; and
- Low Carbon Government, that consider exploring electric vehicle charging infrastructure at government-owned buildings and increasing zero-emission vehicles in the government fleet.

The Energy Opportunities Office created a $30 million Manitoba Energy Jobs Fund to develop innovative local energy companies and appeal to international companies to establish operations in the province [20].

Manitoba Hydro has a *Grid Modernization Program* with projects focused on:

- Increasing network visibility and access to system data with the necessary communication infrastructure along lines and at substations;
- Building a resilient system by installing smart devices to improve distribution infrastructure utilization, and support customer and utility innovation;
- Developing business intelligence and related systems to leverage big data for improved financial and operational decisions, in addition to further interactions with customers during outages; and
- Designing and implementing a distribution control centre to enable a modernized grid.

New Brunswick

The Government of New Brunswick released the New Brunswick *Climate Change Action Plan* in 2016 with commitments to reduce GHG emissions [21]. The plan expands on energy efficiency and clean energy programs, investing in new technologies and making the government carbon-neutral by 2030.

New Brunswick Power (NBP) submitted a plan in 2017 to deploy smart meters for all residential and commercial customers which was subsequently rejected by the regulator in summer 2018 due to its view that it lacked a positive business case [22]. Given that advanced metering is essential to achieving the goals of the Energy Smart program, NB Power intends to resubmit its application to deploy smart meters with a more nuanced and complete business case which shows a positive return for rate payers.

Energy Smart NB evolved from a project where NBP engaged Siemens Canada to modernize New Brunswick's energy infrastructure for capital and fuel cost savings in addition to lowering GHG emissions. Energy Smart NB has a goal of saving New Brunswick approximately 600 MW and 2 TWh by 2038 using their three pronged approach:

- Smart grid investments in digitization of the power system;
- Smart habits including energy efficiency and DR programs; and
- Smart products to improve the lives of customers.

Newfoundland and Labrador

Newfoundland and Labrador is developing a new *Climate Change Action Plan* and a *RE plan* focused on further positioning the province as an energy hub and creating RE employment opportunities [23]. Newfoundland and Labrador is also working towards diverse distributed energy distribution, prioritizing communities isolated from the primary power grid [24]. In addition to energy efficiency and reduced electricity bills, Newfoundland and Labrador Hydro and Newfoundland Power have offered a net metering program since July 2017 in an effort to support a clean environment [25]. The net metering program allows RE projects up to a maximum of 100 kW and sized smaller than a customer's load to be connected to the grid. This program is accepting up to 5 MW of generation across the province.

Nova Scotia

Nova Scotia released its *Electricity Plan 2015–2040* summarizing public and stakeholder consultations on the transformation of the power grid for short and long-term plans [26]. The report highlights the following 4 themes:

- Stable electricity prices;
- Importance of innovation, as demonstrated by the Department of Energy and Mines has demonstrated by collaborating with Innovacorp, an early-stage venture capital organization, to create the Smart Energy Innovation program to award $700 k as part of the province's *Electricity Plan*;
- Accountability from the vertically integrated regulated utility Nova Scotia Power; and
- Competitive market like the renewables to retail market created where independent RE producers are able to sell to retail customers [27].

Nova Scotia Power has received approval from the Nova Scotia Utility and Review Board for a $133 million smart meter roll out in June 2018 with deployments starting in early 2019 and expected to be completed by late 2020 [28].

Smart grid solutions are explored through several pilots in the province related to storage and microgrids to ensure a goal of 40% RE generation by 2020 is achieved. Additional pilot programs being developed include the *SolarHomes* program and the *Solar Electricity for Community Buildings Pilot Program* to encourage solar in Nova Scotia Communities [29].

Northwest Territories

The Northwest Territories released its *2030 Energy Strategy* to outline a long-term approach for secure, affordable and sustainable energy [30]. Extensive public consultations with communities, businesses, Indigenous governments and other stakeholders identified the need to address climate change, energy affordability and develop the energy potential in Northwest Territories. The *2030 Energy Strategy* highlights 6 strategic objectives which will be re-evaluated every 5 years:

- Find solutions through community engagement, participation and empowerment;
- Reduce GHG emissions from electricity generation in diesel-powered communities by an average of 25%;
- Reduce GHG emissions from road vehicles by 10% per capita;
- Increase the share of RE used for space heating to 40%;
- Increase residential, commercial and government building energy efficiency by 15%; and
- Develop energy potential, address industrial emissions, and strive to meet national climate change objectives.

The *2018–2021 Action Plan* details all the actions and initiatives planned in the short-term to achieve each strategic objective [31]. Annual reports will be released publicly to track progress in achieving the outlined objectives.

Nunavut

Nunavut's only electrical power provider, Qulliq Energy Corporation (QEC), uses imported fossil fuel to meet demand. QEC launched a net metering program in April 2018 to allow customers to install up to 10 kW of generating capacity with any surplus sent back to the grid for bill credits. Solar panels supplied RE to the Iqaluit Grid for the first time in March 2016 as part of a pilot project; this demonstration project with a capacity of 2.86 kW seems promising from a performance point of view [32].

A feasibility study was completed in 2016 by QEC to assess the wind potential in 25 different communities. The report concluded that certain communities have potential for wind power generation that could displace or reduce fossil fuel requirements for power generation [33].

QEC also installed Advance Metering Infrastructure (AMI) in Iqaluit and replaced all conventional customer meters with smart meters. Through implementing AMI, QEC has the capability to pull consumption data for automated billing. QEC is looking for more opportunities to roll out AMI in other communities.

Ontario

Ontario released *A Made-in-Ontario Environment Plan* in 2018 to ensure a healthy environment and economy for future generations [34]. The guiding principles of this plan are centred on clear rules and strong enforcement, trust and transparency, as well as resilient communities and local solutions. One of the calls of action to address climate change is to increase access to clean and affordable energy through efforts like:

- Connecting Indigenous communities in Northern Ontario to clean electricity;

- Increasing the renewable content requirements in gasoline through the Greener Gasoline regulation;
- Encouraging community-based systems like district energy where appropriate, and heat pumps for space and water heating;
- Requiring a voluntary renewable natural gas option for customers;
- Investigating tax policies that could make it cost effective for homeowners to invest in energy efficiency measures;
- Integrating smart grid technologies and DERs; and
- Accelerating adoption of low-carbon vehicles by removing regulatory barriers.

Ontario and its partners have invested approximately $200 million through the *Smart Grid Fund* into 45 grid modernization projects to develop innovative solutions empowering the customers and further increasing the reliability of the system. Projects were funded in various categories including proactive customers, data analytics, EV integration, energy storage, grid automation, microgrids and building local capacity.

The wholesale competitive electricity market structure in Ontario is largely unchanged since it opened in 2002 [35]. The Independent Electricity System Operator (IESO) has undertaken the *Market Renewal* project in 2016 to restructure the electricity market to meet future system needs while reducing cost. Four initiatives are supported through this project to efficiently meet Ontario's current and future needs:

- Single Schedule Market: align market price with dispatch schedules to ensure economic benefits align with grid benefits and simplify dispatching necessary resources to maintain grid stability [36].
- Enhanced Real-Time Unit Commitment: optimize generator commitments based on larger time duration rather than on a per hour basis and account for all implicated resource costs to make a commitment decision [37].
- Day-Ahead Market: enable certainty for market participants committing dispatchable resources in terms of price and production commitments, real-time operation conditions, and cost-effective decisions for the overall system [38].
- Incremental Capacity Auction: gain access to increments of capacity in a competitive market that will ensure system reliability at low-cost with the added benefit of having the ability to adjust for dynamic supply and demand conditions [39].

The IESO historically procured new supply, including energy storage and other clean energy generation, to meet Ontario's energy needs through various programs. The *Feed-in Tariff (FIT) Program* (for projects 10 kW to 500 kW inclusively) and the *microFIT Program* (for projects less than 10 kW) allowed Ontario to grow RE capacity with the majority of contracts awarded to solar PV projects. Before the final *FIT* 5 call, the *Large Renewable Procurement (LRP) Program* was launched to procure RE projects greater than 500 kW in a competitive bidding process. The *LRP1* process ended in April 2016 resulting in 16 contracts being awarded for 454.9 MWAC RE capacity [40]. Table 4 summarizes the contracts awarded for *FIT* programs 1–5, *microFIT* and *LRP*. The *FIT*, *microFIT* and *LRP* programs have all been completed; the final *FIT* application period was in 2016, *microFIT* reached its procurement target by the end of 2017, and the second round of *LRP* (*LRP2*) was suspended during the Request for Qualifications stage in 2016.

Energy storage capabilities were evaluated through the *Grid Energy Storage Procurement*

Phase 1 contracts with approximately 34 MW procured, and *Phase 2* awarded 10-year contracts in November 2015 for an additional 16.8 MW of energy storage [41]. The facilities under the *Grid Energy Storage Procurement Phase 1* in service as of November 2018 are summarized in Table 5, and contracts awarded under Phase 2 are summarized in Table 6.

Table 4: Summary of IESO RE Project Contracts by Program Stream as of September 2018 [42].

			SOLAR PV		WIND	
PROGRAM	NUMBER OF FIT CONTRACTS	TOTAL CAPACITY CONTRACTED [MW]	NUMBER OF CONTRACTS	TOTAL RATED POWER [MW]	NUMBER OF CONTRACTS	TOTAL RATED POWER [MW]
FIT 1 to FIT 5	4070	4792	3906	1797	55	2831
microFIT	29,669	257	29,665	257	4	0.02
LRP	16	455	7	140	5	300

Table 5: IESO Energy Storage Procurement Phase 1 Facilities in service as of November 2018 [43].

ANCILLARY SERVICE PROVIDER	TECHNOLOGY	POWER CAPACITY (MW)	ANCILLARY SERVICE TYPE
Guelph Energy Storage Lp	Flywheel	5	Regulation Service
Sault Ste Marie Energy Storage Lp	Battery—Solid	7	Reactive Support and Voltage Control
Hydrogenics Corporation	Hydrogen (Power-to-Gas)	2.5	Regulation Service
Powin Energy Ontario Storage Ii Lp	Battery—Solid	2	Reactive Support and Voltage Control
Powin Energy Ontario Storage Ii Lp	Battery—Solid	2.4	Reactive Support and Voltage Control
Powin Energy Ontario Storage Ii Lp	Battery—Solid	2	Reactive Support and Voltage Control
Powin Energy Ontario Storage Ii Lp	Battery—Solid	2.4	Reactive Support and Voltage Control
Hecate Energy Ontario Storage Vii Lp	Battery—Solid	2	Reactive Support and Voltage Control

Table 6: IESO Energy Storage Procurement Phase 2 Contracts as of January 2019 [43].

PROPONENT	TECHNOLOGY	CAPACITY (MW)
Ameresco Canada Inc.	Battery—Solid	2.0
Ameresco Canada Inc.	Battery—Solid	2.0
SunEdison Canada Origination LP	Battery—Flow	2.0
SunEdison Canada Origination LP	Battery—Flow	1.0
SunEdison Canada Origination LP	Battery—Flow	2.0
NextEra Canada Development & Acquisitions, Inc.	Battery—Solid	2.0
NextEra Canada Development & Acquisitions, Inc.	Battery—Solid	2.0
NRStor Inc.	Compressed Air	1.75
Baseload Power Corp.	Battery—Flow	2.0

The Ontario Energy Board (OEB) established the R*egulated Price Plan* (RPP) in 2005 to provide low-volume electricity customers stable predictable electricity prices [44]. Today, almost all RPP-eligible customers have smart meters and over 96% pay under the ToU electricity rate structure [45]. In 2015, the OEB released their *RPP Roadmap* which lays out a plan for a comprehensive review of the *RPP*, including working with electricity utilities across the province to pilot different ToU rate structures. The pilots are targeting approximately 18,000 customers to test the impact of both price and non-price mechanisms on customer behaviour, including additional tools for customers to better understand and manage their electricity consumption. These pilots will help inform future OEB decisions on offering customers a choice between different electricity rate structures with a view to improve system efficiency [46].

The Electricity Distributors Association (EDA) is the voice of Ontario's local electricity distribution companies—the municipally and privately owned utilities that deliver safe, reliable power to more than five million homes, businesses and institutions across the province. *The Power to Connect* series of EDA policy papers outlines a bold vision for the transformation of Ontario's electricity grid. The papers identify challenges and provide high-level solutions to ensure a resilient, reliable electricity system that meets evolving customer demands now and well into the future.

Prince Edward Island

The Government of Prince Edward Island released its *Energy Strategy 2016/2017* with stakeholder and public input. The *Energy Strategy* assesses the province's current energy usage and streamlines a vision for the future highlighting three guiding principles [47]:

- Lowering greenhouse gases;
- Implementing cost effective actions and decisions; and
- Increasing local economic development.

A grid modernization study was completed by Power Advisory LLC to find methods that would reduce system peak, shift energy consumption with cost savings or emission reductions, increase distributed generation and further increase wind integration. This document will be used to guide Government policies on electricity rate structures and related infrastructure which can enable the future smart grid.

The first *Demand Side Management Plan* was filed with the Island Regulatory and Appeals Commission in June 2018 [48]. PEI Energy Corporation in partnership with efficiency PEI put forth a plan that addresses efficiency and conservation as a preliminary stage before using advanced metering infrastructure for programs like DR.

Quebec

Quebec released its *Energy Plan 2030* in 2016 with a particular focus on economic and environmental benefits for all customers [49]. One of the plan's targets is to increase RE generation by 25%.

The key policy directions highlighted are:

- Ensure integrated governance of the energy transition;
- Promote transition to a low-carbon economy;
- Offer a renewed, diversified energy supply to customers; and
- Define a new approach to fossil energies.

Transition Énergétique Québec (TEQ) was created as an initiative outlined by the Energy Policy 2030 for a public corporation to ensure a smooth transition to meet energy targets set by the Government of Quebec. Plans are created every 5 years with input from partners to ensure measures are in place to meet government targets. The first plan, *2018–2023 Master Plan,* was released as a short-term plan for energy transition, innovation and efficiency to meet 2030 targets.

TEQ and SDTC collaborated on the TechnoClimat Program to support energy innovation and GHG emission reduction for technology in pre-commercial phases in Quebec.

Hydro-Québec submitted a request to regulators to gradually introduce dynamic pricing options on a voluntary basis for summer 2019 [50]. Increased pricing during morning and evening peak hours would provide an incentive for customers to reduce or shift consumption to off-peak hours when the system is less constrained.

Quebec plans to create a DC fast charging network where revenue generated will be used to further expand the network which is seen as a critical element to facilitate the rapid EV uptake [51]. Workplaces are also incentivized through the charging station at work program (i.e. *Roulez vert-volet branché au travail*) that provides funds to procure and install EV charging infrastructure at Level-1 and/or Level-2 [52].

As of January 2018, Quebec became the first province in Canada to adopt a ZEV standard [53]. Credits are accumulated by each automaker dependent on the number of ZEVs and Light Emission Vehicle (LEVs) sold or leased, and their respective range in electric mode. A percentage is calculated based on the number of credits and the total number of new cars sold or leased in the province.

Manufacturers are required to sell or lease an increasing percentage of ZEV and LEV motor vehicles in the Quebec market per year. Bonus credits will also be given for sales and leases from 2014 until 2017 to give automakers some flexibility to meet future targets.

Saskatchewan

SaskPower, the principal electric utility in Saskatchewan, is expanding their commercial and industrial (C&I) AMI through the second phase of the smart meter pilot project [54]. The second phase adds 7500 smart meters, resulting in about 15% of C&I customers in Saskatchewan with smart meters by the end of 2018, and further C&I deployment proposed for upcoming years. Deployed smart meters will support better customer insights into their consumption, eliminate billing estimates, as well as extend operational visibility into the grid.

SaskPower is preparing for a 2019 launch of their outage management system and distribution supervisory control and data acquisition (SCADA) system, which are part of their integrated advanced distribution management system. SaskPower has been deploying intelligent switching and metering at substations, with the objective of integrating 200 substations and all C&I meters into the advance distribution management system by 2020.

SaskPower has announced a new *Power Generation Partner Program* which supports the development of new small renewable ranging from 100 kW to 1 MW and new carbon neutral non-RE projects throughout Saskatchewan. An existing net metering program also allows for up to 100 kW installations to offset customer consumption. The first of two 10 MW utility-scale solar projects is expected to be in service as early as 2019 with a total commitment of 60 MW of solar power by 2021 [55].

In early 2016, Manitoba Hydro and SaskPower signed a 20-year 100 MW power sales agreement which could lead to annual reductions of approximately 0.2 to 0.4 Mtonnes of carbon dioxide displaced from Saskatchewan's electricity emissions [56].

Yukon

Yukon is developing an integrated strategy on climate change, energy and economy through various stakeholder collaborations and engagements [57]. Current policies in place include the *Independent Power Production Policy Implementation* supporting the uptake of RE generation. The Micro-generation Program also enables RESs to be connected to the grid and provides customers with incentives to diversify Yukon's energy supply. The *Innovative Renewable Energy Initiative* is a $1.5 million fund to support commercial-scale electrical or heat generation from RE sources like wind, solar PV and run-of-river hydro.

RESEARCH AND INNOVATION NETWORKS

Research and Innovation Networks

Research and innovation networks are exploring emerging ideas and trends. Smart grid activities backed by research and innovation networks are highlighted in this section.

Advanced Energy Centre at MaRS Discovery District

The Advanced Energy Centre (AEC) was founded in 2014 as a public-private partnership with founders from MaRS Discovery District, Ontario Ministry of Energy, and Siemens Canada. While supporting the adoption of innovative energy technologies in Canada and sharing expertise in international markets, the AEC offers a range of programming related to:

- building energy efficiency,
- utility transformation,
- community energy,
- energy data access, and
- going global services.

The AEC leverages their strong partnerships to facilitate necessary consultations contributing to the evolution of the energy industry. In March 2018, *The Future of Energy: Taking the Digital Leap* workshop gathered a diverse audience and presented a 2030 scenario where various digital technologies were integrated into society. Topics related to human behaviour, big data, AI and blockchain implementation in the energy sector were described by industry leaders and then further explored through collaborative discussions.

The Energy Innovation Snapshot was created by AEC as a platform to highlight Canadian commercially demonstrated projects and innovative companies. The intent of this online platform is to help discover and connect Canada's energy innovators.

Of 220 cleantech companies supported by MaRS Discovery District, 27 are related to smart grid.

NSERC Energy Storage Technology Network

NSERC supports and promotes post secondary research projects for the benefit of Canadians. Through various programs, NSERC has invested over $6.1 million since 2015 towards smart grid-related topics [58]. A significant part of this investment went to support the NSERC Energy Storage Technology Network (NESTNet).

Led by the Centre for Urban Energy at Ryerson University, NESTNet consists of 27 Canadian researchers from 15 universities working alongside partners and collaborators from 26 technology companies, utilities and government agencies. Since 2015, NESTNet has been developing, testing, demonstrating and commercializing next-generation energy storage technologies, products, processes and services.

NESTNet will receive a total of $5.2 million in NSERC funding and $3.5 million from partner organizations over its five-year term.

NESTNet projects are divided into four themes:

- Energy storage technologies, which focuses on batteries, flywheels, compressed air energy storage, thermal storage and hybrid energy storage models.
- Power electronics converters, which includes modular converters, digital controllers, SCADA systems, and power electronics for repurposed EV batteries.
- Power systems integration, which enables seamless integration of energy storage into power systems by developing tools, solutions and reliability benchmarks.
- Economics and policy, which investigates the techno-economic challenges of integrating of energy storage into power systems, including from policy, regulation and social acceptance issues.

Smart Grid Innovation Network

The Smart Grid Innovation Network (SGIN) is a partnership between NBP, the University of New Brunswick and Siemens Canada to enable the successful deployment of smart grid initiatives in New Brunswick and to drive and support a smart grid ecosystem for innovation, technology advancement and R&D. SGIN helps prepare products and solutions at various maturity levels for market. To date, 39 companies have received help and mentorship through the network.

INDUSTRY SUPPORT

Industry Support

Industry associations are key for gathering private companies to mutually benefit from lessons learned, future-proofing, market entry and success, and technology development required to profit from smart grid uptake. Smart grid activities backed by some key industry leaders are highlighted in this section.

Canadian Electricity Association

The Canadian Electricity Association (CEA) represents members that generate, transmit, and distribute electrical energy to customers across Canada. CEA works with its members to ensure an affordable and reliable electricity grid to all Canadians.

To address Canada's energy transition to clean renewable electricity, CEA supports development in integrated clean energy solutions including smart grid solutions. Improvements to existing technology while encouraging new innovation is critical to achieving grid modernization.

CEA has been advocating five key recommendations to continue this vision:

- Design and implement a national energy strategy;
- Implement the financial and policy instruments that enable further carbon reduction;
- Incentivize the electrification of vehicles, industry and commercial buildings;
- Build, support and invest in a deeply embedded culture of innovation; and
- Enhance Canadian businesses competitiveness in the face of increasing nationalistic policies.
- Centre for Energy Advancement through Technological Innovation

According to CEA experts, approximately 20% of the $350 billion required for electricity infrastructure investments between 2011 and 2030 will be invested in smart grid technologies [59].

Centre for Energy Advancement through Technological Innovation

The Centre for Energy Advancement through Technological Innovation (CEATI) gathers utility companies, government agencies, and technical experts across the world to collaborate on power system programs related to generation, transmission, distribution, and utilization. Within each of its 22 distinct Interest Groups, CEATI facilitates knowledge exchange through various programmatic activities, most notably technical projects, in-person meetings, workshops and conferences, including the annual *Smart Grid Conference*. CEATI's Smart Grid portfolio comprises 7 Interest Groups that cover different components of a smart grid:

- Distribution automation, and network components and architecture;
- Emerging technologies and DER integration;
- Distribution planning, reliability and asset lifecycle management;
- Power quality and advanced technologies;
- Protection and control technologies and solutions;
- Cyber and physical security related to people, property, and processes; and
- Demand-side energy management programs and technologies.

SmartGrid Canada

SmartGrid Canada is an industry association dedicated to advancing smart grid for the benefit of Canadians. The association brings together electric utilities along with other smart grid stakeholders to discuss lessons learned, shared experiences, and current trends on grid modernization technology and utility transformation.

Annual conferences are hosted to bring together industry leaders to discuss the business implications of integrating energy storage, distributed energy resources, electric vehicles and other modernization initiatives into the grid. As the smart grid has matured, the conference has broadened to discuss topics of utility-city collaboration and the cyber security implications of a more connected grid.

SmartGrid Canada has conducted broad research on Canadians' attitude towards smart grid since 2012. Two thousand Canadians were surveyed about their opinion of their electric utility provider, thoughts on different pricing structures, intentions about solar energy and electric vehicles investments, and incentives necessary to leverage their behind-the-meter resources for grid flexibility. The survey provides a useful reference for monitoring the evolution of customer perceptions of the smart grid in Canada.

INTERNATIONAL COLLABORATIONS

International Collaborations

Canada is well positioned through various international engagements to exchange technical and policy insights related to RE integration efforts leveraging smart grid technologies. As the host of the 10th Clean Energy Ministerial (CEM) meeting in May 2019, ministers and high-level government delegates will be welcomed from over 25 countries to advance towards a clean energy future. Canada will be taking the time during this event to highlight the leadership of women, Indigenous peoples and youth efforts.

IEA International Smart Grid Action Network TCP

ISGAN is the common name for the International Energy Agency (IEA) Technology Collaboration Programme (TCP), a cooperative program on smart grids. ISGAN is an international strategic platform for the development and exchange of knowledge and expertise to support high-level government attention and action for the accelerated development and deployment of smarter, cleaner, flexible and resilient power grids around the world. It provides a valuable channel for communication of experience, lessons learned and visions on key aspects of smart grid policy, technology and investment.

Currently, 25 executive committee members report on progress and projects to the CEM, in addition to satisfying all IEA Implementing Agreement reporting requirements. As a founding member, Canada continues to actively participate in the network's activities. The work within ISGAN is organized into eight standing working annexes which consist of national experts from participating Contracting Parties, and Canada is an active member on Annex 2, 4, 5 and 6.

- Annex 1 on *Inventory* is completed and gathered information on various smart grid activities of member countries to better delineate and transition the work program of ISGAN.
- Annex 2 on *Case Studies* has currently two priority work streams: an assessment of current case studies on smart grid deployments and in-depth peer-to-peer knowledge sharing through workshops held in conjunction with Annex 4.
- Annex 3 on *Cost-Benefits* analyzes the benefits and costs of smart grid technologies, practices and systems in order to inform policymakers at global, regional, national and sub-national levels.
- Annex 4 on *Policy Insights* collects data, identifies key issues, distills important themes and provides insightful analysis for use by policymakers; and, consolidates and disseminates efforts of other ISGAN Annexes at times beyond ISGAN when appropriate, in support of greater reach and impact.
- Annex 5 on *Testing Labs*, also known as the Smart Grid International Research Facility (SIRFN), gives participating countries access to research facilities to test technology and share the data from these tests among SIRFN participants in pursuit of accelerating the development of smart grid technologies and systems and enabling policies.

- Annex 6 on *Power Systems* contributes to the development of smarter and stronger transmission and distribution systems, by undertaking efforts to improve understanding of smart grid technologies, accelerate their development and deployment, and promote adoption of related enabling regulatory and government policies.

- Annex 7 on *Transitions* investigates institutional changes associated with smart grid deployment. The aim is to support policymakers by focusing on non-technical aspects such as the direction, efficacy and efficiency of the energy system transition.

- Annex 8 on *ISGAN Academy* offers the ISGAN community, particularly high-level engineers and decision makers, a means of continuous professional development in the field of smart grid through a set of e-learning modules and webinars ranging on power system fundamentals to more specialized courses on breakthrough smart grid solutions.

Research laboratories from SIRFN are working to create a common testing platform to quickly and accurately assess the communications and electrical performance of DER devices for different grid codes.

Recent Canadian contributions to ISGAN include deliverables for Annex 5 and Annex 6. Under Annex 5, the paper on *International Development of a Distributed Energy Resource Test Platform for Electrical and Interoperability Certification* was presented at the *World Conference on Photovoltaic Energy Conversion* in June 2018. This paper describes the common certification platform to evaluate DER for interoperability and grid-support functionality using open-source test logic and automated test procedures. To demonstrate the use of the platform, the same testing logic from Underwriters Laboratories (UL) 1741 Supplement A were used at multiple laboratories to generate test results for specified power factor (PF) and volt-var (VV) functions. The paper presents the results from the combined efforts of 11 international labs that demonstrated the portability of the scripts and platform to function in multiple laboratory environments. Thus, the findings of this paper prove DERs are capable to support grid services in a test environment before being deployed and integrated to the power grid. Under Annex 6, Canada contributed to the paper on *Flexibility Needs in the Future Power System* discussed the flexibility potential in residential loads within a Canadian context. The paper explains how advanced load management techniques can leverage smart flexible residential loads as an inexpensive means to provide grid services, support the integration of RE and meet future load growth.

Mission Innovation—Innovation Challenge #1

Launched in 2015 on the margins of the United Nations Climate Conference in Paris (COP21), MI is a global partnership of 23 countries and the European Union aimed at doubling government investment in clean energy R&D over five years, while encouraging greater levels of private sector investment in transformative clean energy technologies. These additional efforts aim to dramatically accelerate the availability of the advanced technologies that will define a future global energy mix that is clean, affordable, and reliable.

MI member countries identified eight Innovation Challenges (ICs) designed to accelerate the global transition to low-carbon economies; MI-IC1 is on smart grid. Co-led by Italy, India and China, Canada along with 16 other participating countries in addition to the European Union are facilitating the uptake of cost effective RE by advancing the development and demonstration of smart grid technologies [60].

Four main sub-challenges have been identified by participating countries: regional grid innovation, distribution grid innovation, micro grid innovation, and cross innovation. From these sub-challenges, six relevant RD&D topics have been selected and constitute the basis for the future work. Canada is co-leading Task 4, and participating in Task 1, Task 3 and Task 5. Results from these tasks will help build a shared understanding of R&D gaps and opportunities in smart grid fields internationally.

- Task 1: Improve storage integration at all-time scales (in operation for system services but also when performing planning studies as an additional degree of freedom) as a source of flexibility.
- Task 2: Use of DR for system services with well-defined interactions between with the market players and the network operators (and TSO-DSO exchange of information).
- Task 3: Develop regional electricity highways with both AC and DC technologies (e.g. long transmission systems, HVDC).
- Task 4: Identify and support improvements of suitable flexibility options (RES generation, flexible thermal power generation, load, network, storage, integration with other energy networks) to ensure adequacy and security.
- Task 5: Study and demonstrate new grid architectures both at transmission and distribution level as a source of flexibility.
- Task 6: Novel/advanced power electronics technology for improving efficiency and controllability of smart grids.

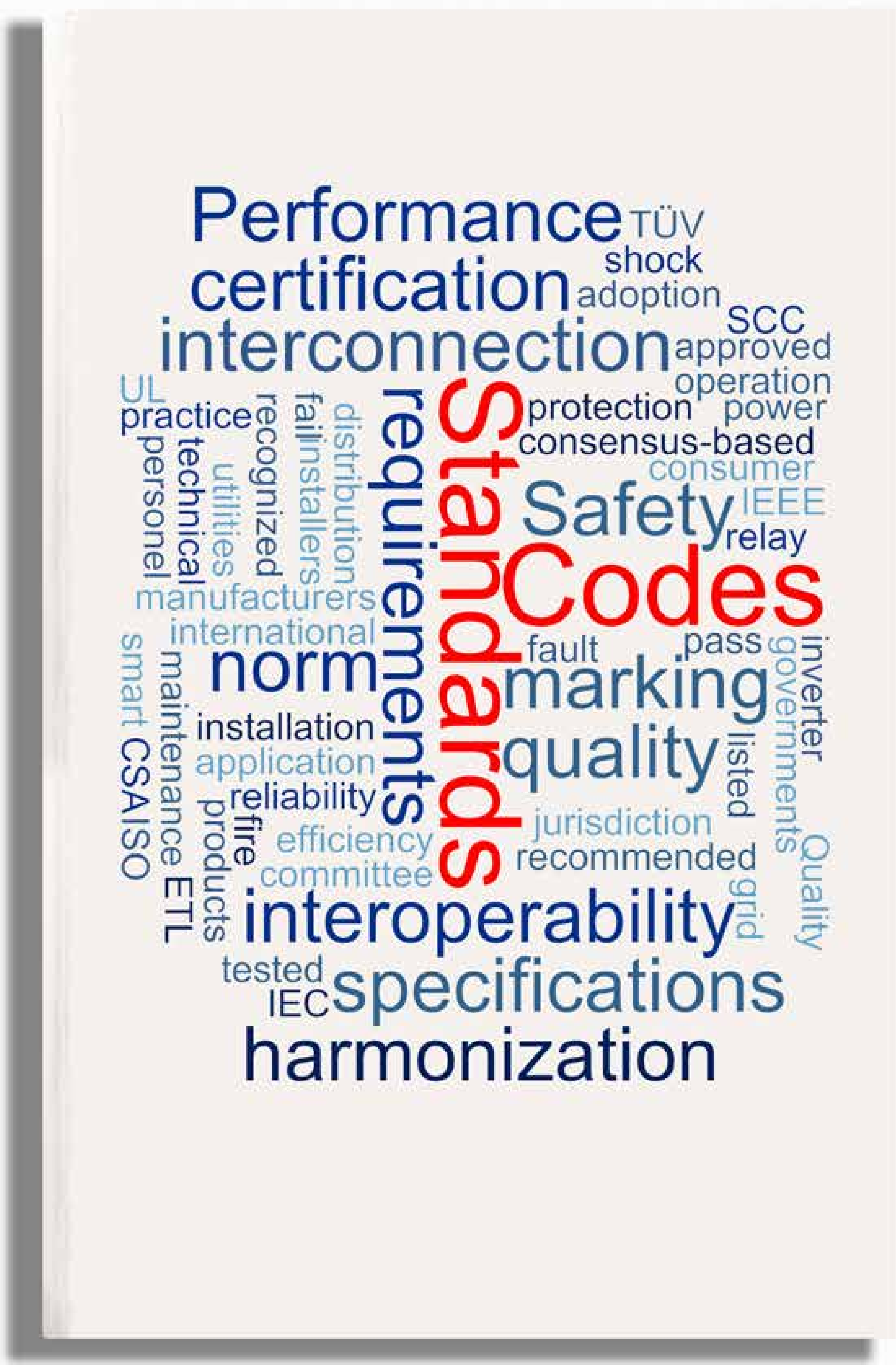
Since the MI-IC1 launch in 2016, four deep-dive workshops have taken place on different key aspects of the Challenge to discuss its ongoing strategy and shared achievements. Fourteen members contributed to the first publication of the *Smart Grids Innovation Challenge Country Report 2017* as an initial effort for annual updates about smart grid-related activities for each country.

North American Renewable Integration Study

Launched in 2016, the *North American Renewable Integration Study (NARIS)* is a collaborative effort between Natural Resources Canada, the Secretaría de Energía and the U.S. Department of Energy. It aims to inform decision makers about the opportunities of adding more RE on the North American power grid. Final results are expected for 2019. *NARIS* is expected to develop state-of-the-art methods, scenarios, and datasets that will help with investigating coordinated grid planning and operations, cross-border transmission, grid flexibility, and other strategies and technologies to enable high penetration of renewables.

Power Forward Challenge

The *Power Forward Challenge* seeks to increase collaboration between innovators from Canada and the United Kingdom to develop end-to-end solutions integrating DERs. Led by NRCan as an Impact Canada Initiative and the Department for Business, Energy and Industrial Strategy, the initiative aims to demonstrate how to integrate disruptive, modular, scalable and interoperable energy resources in a smart grid that adds value for customers and/or service providers. The challenge was launched in fall 2018 with semi-finalists to be announced in mid 2019 and the final award winning team to be announced in March 2021.



STANDARDS DEVELOPMENT

Standards Development

Standards are bringing together proven technical specifications tests, and procedures to ensure safety and performance of products and systems. Some smart grid-related standards are highlighted in this section.

Advanced Inverter Functions and Interconnection Standard

With the rapid uptake of inverter-interfaced storage and RESs, inverters can not only contribute to a balanced grid, but also provide ancillary services like grid protection in response to system disturbances and voltage and frequency support. These capabilities are outlined in the Canadian Standards Association (CSA) C22.3 No. 9 on *Interconnection of Distributed Resources and Electricity Supply Systems* which was updated and released for public comments in fall 2018. This revision also considered alignment with the Institute of Electrical and Electronics Engineers (IEEE) 1547 on *Interconnection and Interoperability of DERs with Associated Electric Power Systems Interfaces* for utility interconnections and advanced inverter functions. The adoption of the standard would allow a smart grid to maximize capabilities from grid resources that are uniformly integrated, in order for utilities to maintain a safe and reliable system.

London Hydro is the first utility to be tested and Certified CMD-compliant by UL Verification Services under the Green Button CMD Certification Program [61].

Green Button

Green Button is a data standard owned by the North American Energy Standards Board formally named the *Energy Services Provider Interface* standard, that includes a common format for energy data, *Download My Data (DMD)*, and a sharing protocol for that data, *Connect My Data (CMD)*. Ontario electricity utilities were early adopters of Green Button—London Hydro being one of the first to adopt the standard in 2012.

Since then, several Ontario electricity utilities, representing about 60% of the province's electricity customers, have implemented *DMD* for their residential and small business customers. These customers can download their energy usage data from their utility's website. London Hydro's Green Button platform was leveraged in a shared services business model with Festival Hydro and Whitby Hydro to deploy *CMD* for their customers. These customers can choose to share their energy usage data with other entities or software tools, which can further analyze their energy use, identify energy efficiency opportunities, and better manage their energy bills. Green Button also presents a new market opportunity for app developers and solution providers to innovate useful customer tools using the standardized energy data format.

OUTLOOK

Outlook

Smart grid is evolving from being an R&D concept to demonstration pilots to deployed commercial solutions. Support from various stakeholders has pushed smart grid deployment forward. Canada continues to be a world leader in supporting clean generation developing solutions and partaking in knowledge sharing activities to accelerate into a future smart grid.

The uptake of smart grid technology enables grid modernization and improvement of current grid operation. Further research and solution demonstrations are necessary to better understand how to use these technologies to build a smarter grid of the future like that shown in Figure 8 where all energy resources are sharing data and communicating. Improved monitoring, control and automation helps to achieve objectives like reduced GHG emissions from various energy resources; improved asset management, safety, resiliency, reliability, customer options, and cost savings.

There has been a drive for campuses, communities and cities to work towards socially responsible goals like net-zero energy or “smart” targets. In 2017, the Government of Canada stated that all federal government operations will be powered by 100% clean electricity by 2025 [62]. Furthermore, 10 Canadian cities have already indicated similar commitments to 100% RE in some part of their future plan, whether it’s for municipal operations or for the entire city [63]. To meet these targets, effective resource management will be key.

In the process of modernizing the power grid, there will be a diverse mix of assets. Utilities have invested heavily to build a reliable, predominantly unidirectional power system. However a bidirectional system is required to effectively integrate a significant amount of DER. In order to maintain the level of service in such circumstances, interconnected DERs will need to be managed as a virtual power plant (VPP) by collectively coordinating resources or, for added resilience against blackouts, a self-sustaining microgrid with seamless transition from grid-connected to islanded mode. Both the VPP and microgrid require visibility and control of connected resources to effectively manage the power between DERs and non-flexible loads. Resources like smart inverters, EVs, and flexible loads can be a means to support this and also provide grid ancillary services. Technology can be used to tap into the potential of existing resources on the grid and/or create tools that will be able to maximize their potential in a cost-effective manner.

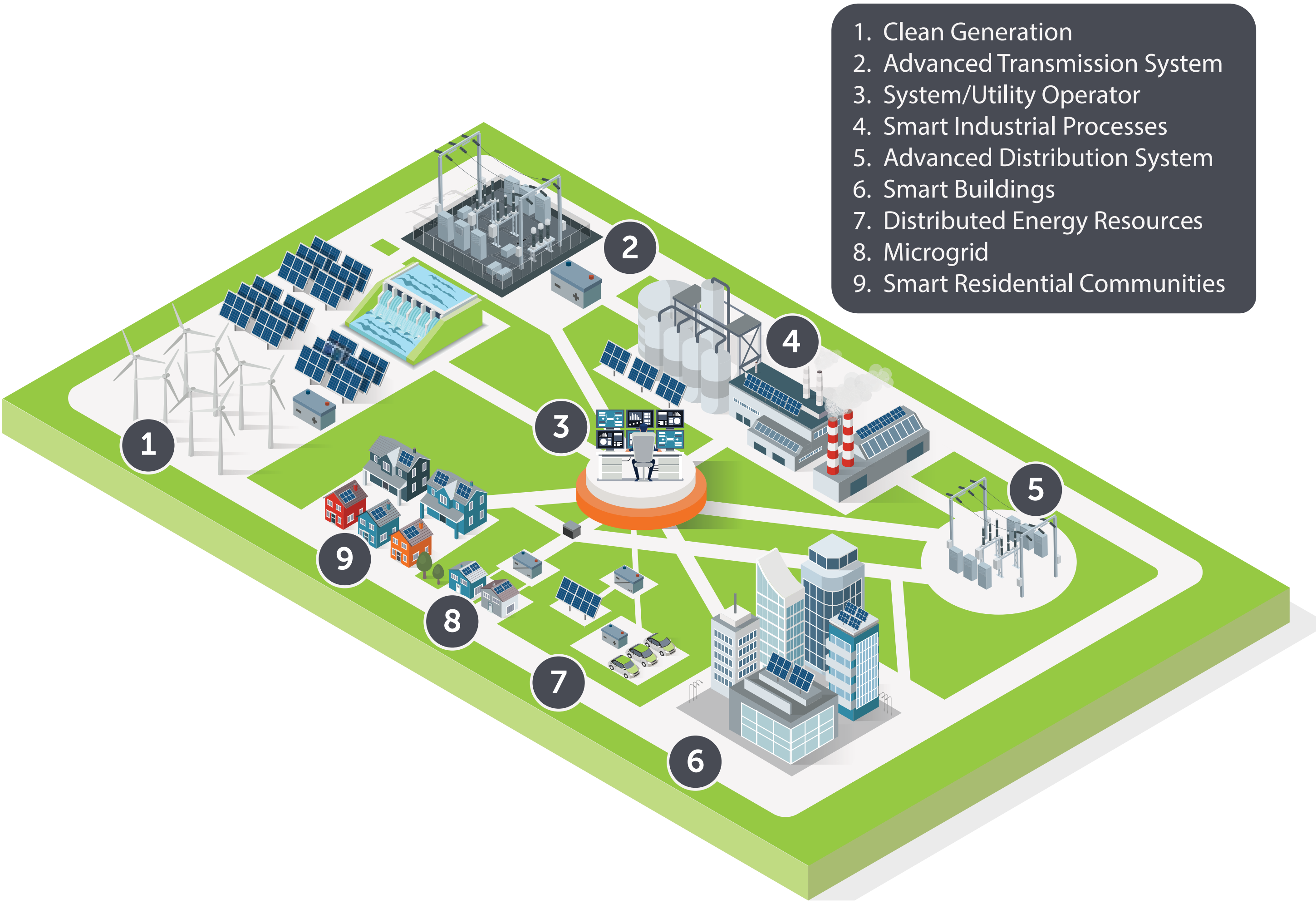


Figure 8: Smart grid of the future

The electrification of various sectors presents challenges and opportunities for the power grid. The impact of the electrification of transport is being studied since EVs using Level-3 and even Level-2 chargers can create huge demand draws if multiple EVs are charging on the same feeder; this can cause great strain on grid assets as feeders can suddenly become overloaded without warning if proper planning precautions are not considered. Tools need to be in place to properly integrate EVs and optimize the potential they offer. Concepts pertaining to vehicle-to-building (V2B), vehicle-to-grid (V2G), and vehicle-to-everything (V2X) are being explored to compliment business operations of the respective building, grid or any other entity where the EV is being integrated.

Beyond EVs and the transportation sector, electrification of other sectors also serves as an opportunity for the smart grid. Resources with flexibility can use technology to become better connected to the grid. Smart buildings and industrial processes can leverage potential in existing equipment to further support system or utility operators, or leverage 3rd party aggregator expertise to gain incentives.

Data is key to better understand how resources can be better managed. Cleaning datasets to improve on current tools, or create new tools with added value for the utility and customers alike can help utilities optimize the use of their assets and modernize their customer relations at the same time. With concepts like big data and data mining being explored across various sectors, the energy sector can also leverage these concepts in grid modernization efforts. Utilities in particular have massive datasets from outage management systems, distribution automation systems, SCADA, asset management, and billing systems that can benefit from an integrated platform where various data is used to improve operations, planning and/or customer relations. Advanced transmission and distribution system infrastructure can collect data relevant for an integrated platform which can include functions like automated DR event negotiations with customers' flexible loads; this serves a cost-effective solution for utilities since flexible load investments have already been made by customers.

With the deployment across Canada of smart meters, there is potential to provide customers with better tools to effectively manage their consumption while providing utilities with a platform to interact with customers. Smart meters can also be a key technology to effectively deploy demand management tactics like ToU or other dynamic rate structures. Net metering also serves as a way for customers to leverage the smart meter deployment to become prosumers consuming and generating their own power. This evolving customer-utility relationship will require further tools with the support of regulations to tap into a mutually beneficial scenario.

Standards can play a key role to ensure interoperability between various grid resources and how they are integrated into a smart grid. If manufacturers of like products are compliant with standards, integrating a variety of resources into systems will be far less complex, and a smart grid will be able to effortlessly communicate with an assortment of resources. ITC is the fundamental communication infrastructure the telecommunication industry has deployed.

Leveraging Internet of Things (IoT) technology over ICT infrastructure allows resources energy resources to communicate and meet their respective objectives. The standardized nature of IoT technology allows for easier integration of additional energy resources coming online, and also to communicate with other smart grids as the networks continue to expand. As smart grids start to communicate and/or connect to other smart grids, having conformity between the grids will allow for straightforward integration. Adequate information technology (IT) services are required to establish and maintain this vast network.

With the proper communication channels in place to gain access to relevant data, intelligence strategies can be used to optimize system operation and planning. Techniques including model predictive control and deep learning can be used to optimize grid operation, planning and maintenance while considering various parameters dependent on the environment, economy, resource health, or human factors. These techniques can also be useful for security measures—cyber and physical alike. Cybersecurity in particular, must include both intentional and non-intentional threats where vulnerabilities are exposed regarding confidentiality, integrity, availability and accountability of digital information. Collaborating with other sectors on cybersecurity can be explored to ensure the smart grid is well equipped to be protected from cyberthreats. The severity of these attacks becomes increasingly critical when transactive energy models are considered.

Transactive energy models like blockchain, a peer-to-peer distributed ledger solution, are becoming increasingly popular as a means to take control of decisions made by utilities, like using more DG to reduce GHG emissions or reduce energy costs. Customers are looking for increasingly interactive and digital solutions that presents more options in service. To deploy these solutions, various aspects need to be carefully considered from managing customer profiles to exchanging data to security concerns to implementing economic framework. These types of solutions challenge the current model of monopolistic electric utility company operations to one that provides customers with more control of their electric service.

Customers are driving the change adopting low cost commercial solutions and becoming prosumers. From DG to EVs, prosumers are investing in various DERs to offset high energy costs or play a part in adopting solutions supporting less GHG emissions. Utilities can leverage prosumer investment in DERs with flexibility potential by creating customer tools and providing customer incentives to leverage these behind-the-meter resources. With more DG and RES installed as a means to reduce GHG emissions, the added grid flexibility will ensure grid operators are able to maintain or improve grid services. Continuous efforts will be necessary to gain knowledge and insights from demonstration projects to better deploy smart grid technology to build a modernized and clean power grid.

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Resources Library

General Framework

Pan-Canadian Framework on Clean Growth and Climate: https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework.html

Conference of the Parties:
http://www.cop21paris.org/

Canada's Paris Agreement Commitment:
https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/progress-towards-canada-greenhouse-gas-emissions-reduction-target.html

Public Sector Activities

NRCan Energy RD&D Investments:
https://www.nrcan.gc.ca/energy/funding/21146

Energy Innovation Program:
https://www.nrcan.gc.ca/energyinnovation

Program of Energy R&D:
https://www.nrcan.gc.ca/energy/funding/perd/4993

Clean Growth Program:
https://www.nrcan.gc.ca/cleangrowth/20254

Green Infrastructure Program:
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Smart Grid Program:
https://www.nrcan.gc.ca/energy/science/programs-funding/19793

EV Infrastructure Demonstration Program:
https://www.nrcan.gc.ca/energy/science/programs-funding/20467

EV and Alternative Fuel Infrastructure Deployment Initiative:
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Clean Growth Hub:
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Ontario Smart Grid Fund:
https://www.ontario.ca/document/projects-funded-smart-grid-fund

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Transition Énergétique Québec 2018-2023 Master Plan:
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ZEV Standard:
http://www.environnement.gouv.qc.ca/changementsclimatiques/vze/index-en.htm

TechnoClimat Program:
https://transitionenergetique.gouv.qc.ca/en/innovation/program/technoclimat/

SaskPower Power Generation Partner Program:
https://www.saskpower.com/-/media/SaskPower/Our-Power-Future/Powering-2030/Sell-your-Power/Infosheet-Power-Generation-Partner-Program-Guidelines.ashx?la=en&hash=F61AA8E60ED3662ABB4B0E131D06F0B24DE9A6CA

Yukon Independent Power Production Policy Implementation:
https://yukon.ca/sites/yukon.ca/files/emr/emr-yukon-independent-power-production-policy.pdf

Yukon Micro-generation Program:
https://yukon.ca/en/micro-generation-program

Research and Innovation Networks

AEC Energy Innovation Snapshot:
http://energyinnovationsnapshot.ca/

NESTNet Outputs:
https://www.ryerson.ca/nestnet/outputs/

SGIN:
http://www.sgin.ca/

Industry Support

CEA :
https://electricity.ca/

CEATI:
https://www.ceati.com/en/

SmartGrid Canada:
http://www.sgcanada.org

International Collaborations

ISGAN Publications:
http://www.iea-isgan.org/publications/

ISGAN Annex 5 International Development of a Distributed Energy Resource Test Platform for Electrical and interoperability

Certification Paper:
https://www.researchgate.net/publication/325976510_International_Development_of_a_Distributed_Energy_Resource_Test_Platform_for_Electrical_and_Interoperability_Certification

ISGAN Annex 6 Flexibility Needs in the Future Power System:
http://www.iea-isgan.org/flexibility-in-future-power-systems/

MI Publications:
http://mission-innovation.net/resources/publications/

MI-IC1 2017 Country Report:
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NARIS:
https://www.nrel.gov/analysis/naris.html

Power Forward Challenge:
https://impact.canada.ca/en/challenges/power-forward

Standards Development

CSA C22.3 No. 9:
https://www.scc.ca/en/standardsdb/standards/25004

IEEE 1547:
https://standards.ieee.org/standard/1547-2018.html

Green Button:
http://www.greenbuttondata.org/

Appendix: Smart Grid Applications

APPLICATION	DESCRIPTION
Advanced Inverter Function (AIF)	Inverter-based generation systems can use advanced functions to effectively respond to maintain (and if used effectively improve) grid operation. AIF capabilities include voltage and frequency support as well as grid protection to respond to disturbances (e.g. voltage and frequency ride through, PF and active power adjustments). The use of these functions directly tackles some variability and DG challenges.
Advanced Metering Infrastructure (AMI)	Smart meters or AMI includes the meter and associated communication communications network. Automatic remote meter reading and interval metering enables new methods of electricity data collection and network planning. Depending on the utility's system integration, AMI could be used to support other systems like outage management, new rate options or billing, DR, and various interactive customer tools.
Demand Response (DR)	DR involves controllable loads shifting their consumption to off-peak hours to relieve the grid during peak hours. In general, DR can be implemented in one of three ways: through a direct load control (instructional signal) sent by the utility, through the SO or controlled by a third party aggregator to a customer; or through an indirect control (price signal) sent to a customer.
Distributed Energy Storage (DES)	Electric storage technologies support grid services such as frequency regulation and peak shaving to further support grid reliability. Any DES supporting microgrids are included. However backup power systems are not included in this category unless the storage technology also provides grid services when it is not providing backup power during an outage, nor does it include large storage connected to the bulk system such as large pumped hydro.
Grid Automation	GA refers to a distribution network that is able to monitor, measure, protect and control using communication to automatically react to service interruptions. This includes fault location, isolation and service restoration (FLISR), or fault detection, isolation and restoration (FDIR), technologies applied to increase the capacity of the distribution grid to reroute power to ensure system reliability. A fully automated grid requires little to no intervention from a grid operator. This category does not differentiate advanced intelligence techniques which can leverage real-time feeder sensing information and control systems (e.g. outage management systems and advanced distribution management systems).
Microgrid (MG)	A MG is a segment of the grid able to control DERs like DG and storage to sustain loads whether connected, or disconnected from the bulk grid to form an isolated network (i.e. islanding mode). This category does not include northern or remote communities.
New Markets & Rate Options (NRO)	NRO looks at how electricity (power and energy) is exchanged. This changes the nature of how the grid operates, and introduces additional players in a smart grid if markets are established. New rates can serve different customer energy needs and help to increase the value proposition of electricity services to customers. Rate options include price signals sent to customers to manage better system peaks, or DR. The most recent developments are tracked so if a province has deployed markets or rate options but new pilots are underway, the new pilots will take precedence.