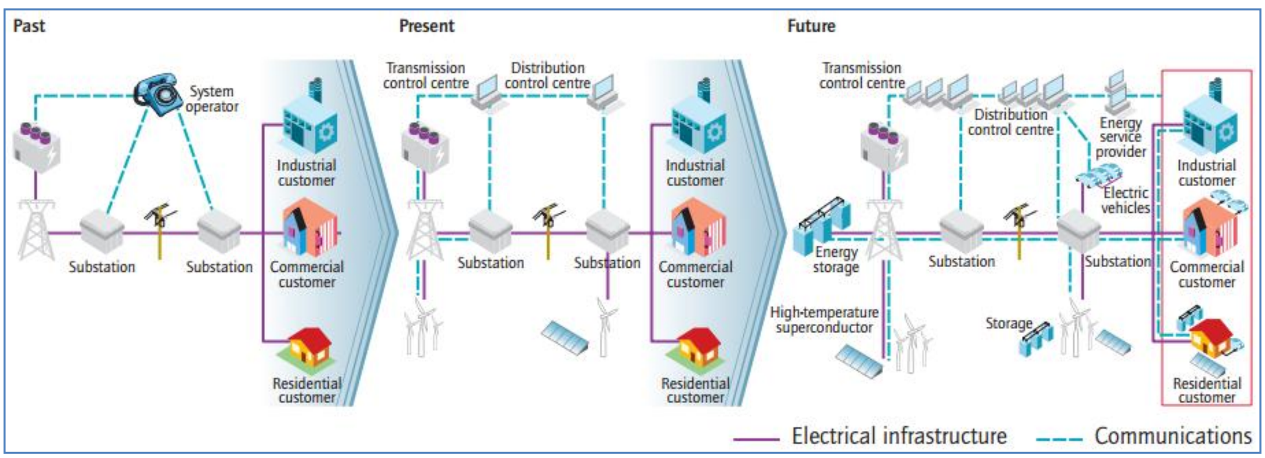
Theory & Practice of ICST Adoption within the Smart Grid Ecosystem

Enabled by Information, Communication, and Security Technologies (ICST)



(IEA, 2011)

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ABSTRACT

The traditional electricity system is based on a single direction energy flow from generation through transmission and distribution to the end user. Today, this system is challenged by the dynamic society requirements, increasing population and industrial growth, variations in demand profiles, increasing distributed generation, mounting concerns about world energy security and environmental degradation, pressure to keep costs down, and an aging infrastructure requiring transformation to cope with the fast-changing landscape.

Through the use of Information, Communication, and Security Technologies (ICST), Smart grids will enable cost-effective, reliable, and efficient power generation, distribution and consumption by building intelligence into the electricity grid. Using wide-scale situational awareness, a smart grid can facilitate large-scale renewable energy integration, multi-direction power sourcing and distribution, enhanced grid resiliency, and market-driven pricing.

ICST adoption within the smart grid industry ecosystem is faced with technical collaboration obstacles and a set of interrelated underlying policy development challenges that must be addressed to accelerate this key smart grid enabler. Using the information captured from the literature analysis and industry interviews, this research provides ICST technical guidelines to assist more utilities with evaluating roadmap options, and also presents key policy levers that can boost ICST adoption for accelerated smart grid development.

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INTRODUCTION

The traditional electricity system (also referred to as grid or network), designed decades ago based on unidirectional power flow and limited communication infrastructure for simple society needs, is now under stress for a major transformation. This stress manifests itself through wide-scale blackouts and is a result of multidimensional challenges including the lack of wide-scale situational awareness and proactive protection, adverse climate change events, non-conservative consumer behavior, and recently the intermittent distributed renewable generation input to the grid (e.g. solar, wind, bio-energy) among other factors (Luiken, 2014). Electricity authorities are constantly looking for ways to increase grid reliability and efficiency. Smart grids enable efficient location-based power sourcing and distribution, large-scale renewable energy integration, market-driven pricing, automated grid self-healing, and other performance and consumer choice features.

Developing a smart grid ICST solution is new territory for the electricity industry where experience can be drawn from the telecommunication and information technology (IT) sectors to benefit from years experience with mature and proven technologies. This field is also new for policy-makers and authorities. In fact, smart grids lead to a total shift of paradigm, enabling the creation of prosumers (combined electricity producers and consumers), new energy services market, and a change of how society interacts with the electric grid, all together creating great technical and policy challenges (IEA, 2011).

The expected reliability and efficiency requires a considerable flow of information from smart meters gathering consumption and status information from the demand side, and from sensors monitoring the status of various components across the smart grid infrastructure. After processing such information, control signals are sent to various components of the smart grid and to end-user devices and appliances to facilitate 2-way interactive automation. This 2-way communication is a key smart grid enabler and is made up of three sub-components, namely, Information, Communication and Security technologies (ICST). This research, applied to Ontario context, is based on two objectives:

a) To presents the technical ICST requirements that can help utilities of different sizes and capabilities to evaluate options towards planning their smart grid roadmap.
b) To identify key policy levers that can be used by the province to boost ICST adoption and accelerate smart grid transformation from an ecosystem perspective.

METHODOLOGY

The research employed a combination of meta-analysis of local and international smart grid literature, and qualitative industry interviews to capture inter-related vectors affecting ICST adoption. The literature review focused on gathering key technical ICST requirements and successful policy tools used in other jurisdictions where smart grid penetration is ahead of Ontario. Meanwhile, the interviews covered the areas of power generation, transmission, distribution, solution providers, and academia for multi-stakeholder perspective. Ontario was chosen for subject context because preliminary research highlighted the province's positive smart grid momentum being faced with ecosystem challenges slowing down adoption, and also for proximity to interview respondents. The information gathered at different levels from domestic to international was applied to Ontario context to address these challenges. Finally, the theory and practice of smart grid implementation were combined to formulate industry priorities and the technical and policy recommendations. The challenges identified are not unique to Ontario, therefore, the final recommendations can also be applicable to other jurisdictions for successful smart grid accelerated deployment.

THEORY: LITERATURE REVIEW & ANALYSIS

What is a Smart Grid, and Why Do We Need It?

Traditionally, the electricity grid was built on the basis of one direction energy flow from generation, through transmission and distribution, to customer premises (Figure 1). As the customer base and consumption patterns grew dramatically due to population increase, industrial and commercial growth, and high penetration of electrical appliances and electronic equipment in our homes and offices, major expansions had to take place on the power grid. The static nature of the traditional grid and the principle requirement to ensure that generation capacity is always higher than peak consumption creates system inefficiencies such as high peak-to-mean difference in installed versus averagely used capacity (Litos Strategic Communication, 2008). In addition, traditional electricity generation technologies accounted for a significant share of total carbon emissions which Ontario has done a great job reducing by phasing out coal-based power plants. However, gas-based plants still contribute to emissions both through fuel extraction and power generation. Also, Ontario's increased dependence on Nuclear power is coupled with a history of excessive operational budgets contributing to increased electricity costs, and nuclear waste facing environmental/safety concerns.

The need to transition to clean renewable energy technologies became evident following international reports correlating anthropogenic contribution to global warming and adverse climate change conditions (IPCC, 2013) (IPCC, 2012) that are now being experienced more frequently in the province. However, renewable technologies like solar, wind, biomass, and hydro have a geographically distributed nature in terms of optimal site location, thereby disrupting the traditionally centralized generation architecture with the need to support distributed generation from geographically dispersed rooftops, rural lands, waterfalls, etc. In addition, the challenging power consumption patterns and variance in generation profile of renewable sources based on time of day, weather, season, etc all added to the complexity required to manage grid efficiency, ultimately calling for the need to build intelligence onto the grid to make optimal real-time power sourcing decisions. In simple terms, the system needs a means to monitor real-time changes on power generation side and make efficient distribution decisions for cost-effective demand-side matching. This intelligence requires a 2-way information exchange and, since the sites sourcing renewable energy can also be customers of the grid, this meant that the infrastructure also had to support 2-way energy flow leading to development of the smart grid concept (NARED, 2009).

Various stakeholders have different definitions for smart grid mainly because the definitions are based on functional, technological, or benefits-oriented perspective. However, based on the reasoning above, the common ground between various definitions is that a smart grid is power grid with the ability to carry energy in different directions, and uses secured 2-way information exchange between various components of the grid to facilitate wide-scale visibility, information processing, and intelligent real-time decisions for reliable and efficient power sourcing, delivery, and system protection (Cisco, IBM, SCE, 2011). The direct objective of this architecture is to increase reliability and efficiency of the electricity grid, whereas the long-term objective is to achieve triple bottom line benefits for the environment, economy, and society (Litos Strategic Communication, 2008).

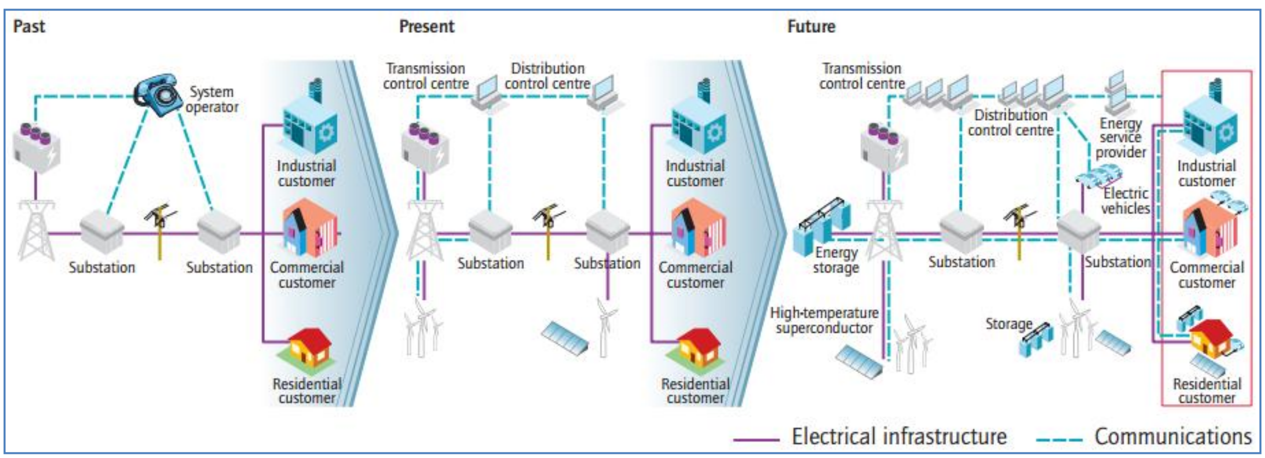


Figure 1: Transformation of the Electricity Grid (IEA, 2011)

Environmental benefits include large-scale renewable generation thereby reducing carbon emissions from fossil fuel sources and radioactive waste from nuclear generation (Ancillotti, Bruno, & Marco, 2013). Meanwhile, the economic angle is addressed by enhanced reliability and operational efficiency creating financial savings. Finally, in addition to reduced electric bills from such cost savings and when consumers become prosumers, the smart grid movement also drives more research and opens new business opportunities, thereby, creating jobs and improving the overall social well-being.

ICST Technical Requirements

Smart grid implementation engages stakeholders, primarily utility companies and policy-makers, on a long journey of establishing the goals and vision, formulating the suitable policy environment, complex testing and development, and eventual solution deployment and iterative improvement. This section sheds lights on technical ICST requirements to help key stakeholders evaluate options towards their contribution and roadmap. The role of ICST stems from the principle that what cannot be measured cannot be improved. As such ICST enables secured wide-scale situational awareness, information processing, and reliable automation. Therefore, the smart grid ICST solution requires three fundamental components, namely, the information being exchanged, the communication medium(s) needed to carry such information between respective end-points, and the security of the whole system (Figure 2).

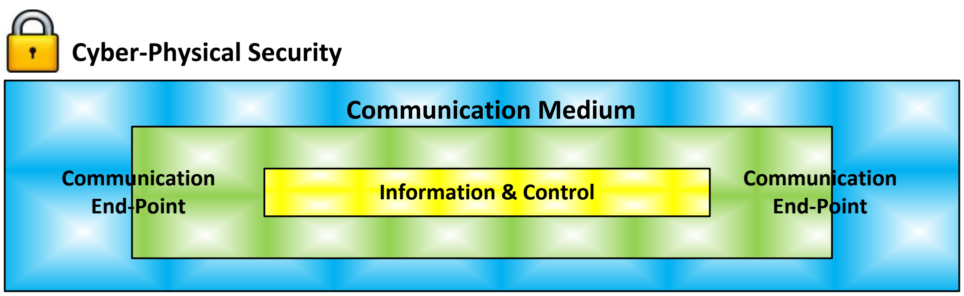


Figure 2: Smart Grid ICST Components

Information

To begin with, it is important to understand the types and amount of information being exchanged and the end points involved (Kuzlu, Pipattanasomporn, & Rahman, Communication network requirements for major smart grid applications in HAN, NAN and WAN, 2014). This flow dimensioning is later used to plan the communication network needed to carry the information across the grid. The amount of information is also directly related to the monitoring frequency (e.g. probing the status of a component every few seconds). Smart grid information flows can be grouped into four broad categories.

Firstly, the power consumption information on the demand side is collected from millions of smart meters at respective customer premises. The Advanced Metering Infrastructure (AMI) component of the smart grid facilitates automated collection of this data compared to previous requirement for field workers to read meters manually across the province. The data is stored in a repository and formatted for billing calculations. This data is currently used to enable time-of-use billing to encourage consumers to shift some of their consumption to time periods where electricity demand is less thereby reducing the overall demand peak-to-mean ratio and the need for higher total generation capacity. However, static time periods may end up shifting peaks to cheaper zones creating another problem. In future, with higher degree of interactive communication, more data collection frequency and granularity of information (e.g. by home appliance type), more frequent price signals can be sent to home energy management systems that in-turn control home appliances in the optimal manner to reduce bills and fine-tune aggregate electricity consumption across neighborhoods. A commercial example of this is the current ability to control thermostats and future application of staggering the charging of electric vehicles to protect neighbourhood transformers through demand side management or demand response (Oviedo, Fan, Gormus, & Kulkarni, 2014). With the advent of smart home technologies and the Internet of Things (IoT), AMI data dimensioning becomes more important for network scalability planning. This requires an understanding of what a smart home will look like (IESO, 2012), and the data fields needed to gather information from, and control home systems behind the meter.

Secondly, the electricity grid operates on a delicate process of supply-demand matching. As the system moves away from traditional centralized generation to distributed renewable generation, it is important to know how much supply capacity is available at any given point in time for each distributed generation site. Also, without wide-scale economically viable energy storage solutions, distributed renewable generation remains naturally intermittent depending on sun intensity, wind speed, water flow, etc. Therefore, the smart grid needs to be highly responsive in its ability to match such variations with demand to maintain grid efficiency and stability (Li, et al., 2010). This requires a 2-way information exchange of market supply and demand data between energy producers on one end, including forecasted commitment of generation time and capacity, and various local, provincial, and cross-border customers on the other end. Hence, information from these sites is used to create a new capacity markets concept where distributed generators can bid to compete for providing supply for currently available demand in a similar fashion to a stock exchange. Depending on the degree of instantaneous demand-supply matching and automation of such transactions, such exchange of information must take place in real-time (seconds rather than hours), and be driven by pre-set business intelligence rules. This includes logging and presenting live supply-demand data to bidders and customer alike.

Thirdly, the grid monitoring data from thousands of sensors across the smart grid network is needed to probe the status of components and zones (e.g. phasor measurement units, transformer utilization levels, transmission wires thresholds, sub-station KPI's, power outages, physical security alerts, etc). Sensor data transmission can be event-based or periodic, and requires higher collection frequency than AMI given that the electricity system runs at 60Hz cycles (~1 cycle every 17ms). Maintaining wide-scale situational awareness of the grid health helps identify and isolate areas of outages to they do not quickly cascade to disrupt the whole network as the case in many outages. This visibility also helps facilitate efficient energy delivery and ensure no lines become overloaded as a result of rechanneling energy flow during outages or scheduled maintenance. This example also highlights the importance of identifying the communication end-points, the size of each information exchange, how frequently it takes place, and latency thresholds that can all help designers plan other aspects of the communication and security systems needed (Budka & Deshpande, 2011) (Kuzlu, Pipattanasomporn, & Rahman, 2014).

Fourthly, the three types of information flows above will ultimately all feed into a virtually centralized data repository and smart grid intelligence system (i.e. using a physically distributed architecture for geographic redundancy) for processing towards billing, automation, and smart grid optimization (Cisco, IBM, SCE, 2011). The smart grid intelligence system sends out the fourth type of information flow for autonomous control of various grid components. These are standards-based time-sensitive control signals (e.g. via DNP^3/IEC68150, SCADA/GOOSE protocols) to control grid-wide energy flow including sourcing, transmission, distribution, isolation and disconnection (Cisco, IBM, SCE, 2011). Automated control allows for fast response times, reduced outage time, minimized disaster damages, intelligent power sourcing and efficient power distribution and load control, altogether leading to overall optimization of grid operation and efficient society use of electricity. Crafting the optimal business intelligence rules needed to process various inputs to drive such automation is a significant challenge. This is based on the assumption that such intelligence should logically account for every possible operational situation, or at least include a safe default operation mode if unaccounted operational conditions are encountered by the system.

Finally, the information component of ICST requires large reliable and highly secure data centres for storage and processing operational rules with high computational capacity. Dynamic time-of-use billing, grid operation, system modelling and supply & demand forecasting are some basic functions that the solution should support. Solutions for this component make use of cluster-based server systems to increase computational capacity and purpose-built data analytics systems that can perform data-mining, multiple scenario evaluation, and translation of results to actionable information in real-time (Berst, 2012). It is important that such business intelligence and data analytics systems are fully customizable and allow for integration with existing grid management systems to leverage previous investment. Also, distributed control centres managing grid sub-domains can offer additional operational efficiencies through management of smaller networks, but are generally more difficult to setup and coordinate.

Communication

With the understanding of key information flows above, the next step is planning for the communication mediums that form the network which carries such information across the smart grid. The network design exercise is based on planning the logical and physical network architectures. In the logical architecture, the large smart grid network is divided into smaller networks that form a hierarchy (Kuzlu, Pipattanasomporn, & Rahman, Communication network requirements for major smart grid applications in HAN, NAN and WAN, 2014). Starting from the demand side on Figure 3, the customer premises comprise the Home Area Network (HAN) /building (BAN)/Industrial (IAN) electrical loads that connect to the local smart meters. These small networks are combined at the Neighbourhood Area Network (NAN) through aggregation of smart meters, and further combined at the Field Area Network (FAN) which aggregates the NAN Field Routers at FAN sub-stations. Finally, the FAN layer is aggregated at the Wide Area Network (WAN) layer for connectivity to the Core Network where all the back-end systems reside.

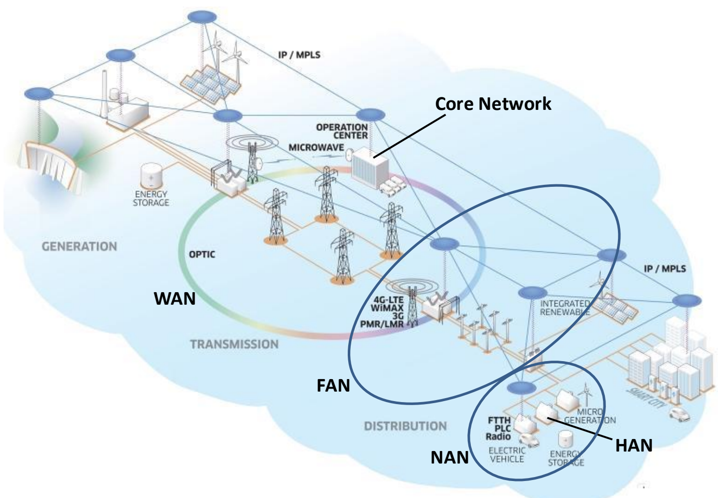


Figure 3: Smart Grid Logical Communication Architecture - Adapted from (Acatel-Lucent, 2012)

Next, the physical network architecture involves selecting the appropriate physical medium for each of the networks above. This selection depends on several factors including, but not limited to, architecture scalability, access layer density and interface flexibility, bandwidth, latency, open-standards support, cost and ownership, in addition to the overall reliability and security of the system (Table 1).

Factor	Explanation & Smart Grid Context
Scalability	The ability to expand the network end points without major changes in the upper layers. This is done using a modular inverted tree architecture to easily add endpoints or functional blocks by increasing tree branches at any level of the hierarchy, e.g. adding a new district with smart meters (Odom, 2013).
Access density, Interface flexibility, for Switches & Routers.	The Access layer of a telecom network facilitates connectivity to the system using network switch ports (wired or wireless). The more ports available with flexibility to connect legacy electrical systems (serial) and various communication mediums (copper, fiber, wireless), the easier the integration process (Garrettcom - Belden Inc., 2012). Multiple switch segments are then aggregated by routers that direct traffic in a hierarchical fashion towards the core network or between other smart grid end-points.
Bandwidth	Speed (direct function of Channel Bandwidth) requirements are set on link basis based on the application. The higher the speed the more data the network can carry and higher-end features like CCTV video feeds, Voice of IP field communication, etc. This metric is key in selecting the appropriate communication network to ensure there is enough capacity to carry the information flow across grid end points.
Latency	Latency is directly related to bandwidth but viewed from an end-to-end perspective (e.g. SCADA control messages to substation automation equipment). Latency is one of the most critical aspects of the communication solution choice given the high degree of time-sensitive applications in the smart grid. Appendix A shows the mapping of IEC 68150 standard classifications for smart grid latency requirements to communication network options.
Open Standards	Ensures that equipment and solutions are standards-based to avoid being locked with one vendor's proprietary solution (Cisco, IBM, SCE, 2011). This is important for future upgrades and supporting new systems for integrated expansions or backward compatibility. Ethernet and the (Internet Protocol) IP technologies enjoy large vendor community, high economies of scale, and seamless mature system integration and interoperability.

Cost	Depends on the number of connections, capacity, type of equipment, installation complexity, scale of deployment (geographic area), and the operation & maintenance needed thereafter. Design engineers can create a balance between funds available, roll out time-frame, and technical capabilities (e.g. wired versus wireless). Optical fiber offers much higher bandwidth, low latency, and security but incurs very high installation costs due to extensive ground excavations needed and tedious multi-stakeholder coordination needed. Wireless solutions also require expensive frequency spectrum with recurring costs to minimize to interference which can severely degrade performance and also introduce security concerns.
Ownership	Some utilities believe in spending an initially high investment to own the infrastructure to achieve higher security and guaranteed bandwidth. Meanwhile others believe that partnership with specialized Telecom/IT companies would yield better overall performance. The business case is more for ownership (CDG 450 SIG, 2013). However, there is no hard and fast answer and the ultimate choice requires a case-by-case feasibility study (Ericsson AB, 2013) based on several factors including design, financial and technical resources available, and the business proposition which can be facilitated by a utility-Telco partnership.

Table 1: Physical network technology selection factors - Adapted from (Garrettcom - Belden Inc., 2012)

The migration from analogue to digital technologies and then to Internet-Protocol (IP)-based packet networks provides enhanced operational efficiency and lower maintenance costs. However, such packet-based networks (large messages are sent in smaller individually multiplexed segments without the need to establish end-to-end dedicated transmission circuits) create another challenge of managing synchronization and latency for time-critical applications. This challenge is not new to the telecom industry and proven mature and commercial technologies are available to tackle it. A great example of this is Multi-Protocol Label Switching (MPLS) which is adopted by many large-scale operators working with high performance resilient heterogeneous requirements (Figure 4).

MPLS offers faster connections, Quality of Service (QoS) prioritization of critical data streams, faster network restoration times, built-in security and proactive monitoring (Kobi, 2011). MPLS is also highly interoperable supporting the integration of multiple protocols and interfacing technologies at end points in a manner transparent to the communicating devices. Many utility companies are still hesitant about using Ethernet technologies to meet the IEC68150 standard requirements for substation automation, which also helps increase flexibility and reduce costs. To their comfort, numerous project demonstrations continue to provide greater confidence with tested solutions using MPLS for low latency and IEEE 1588v2 synchronization over packet networks (Sidhu & Yin, 2007) (SELF & GUGLIELMO, 2013) (Kobi, 2011) (McGhee & Goraj, 2010).

Appendix (A) shows a mapping between message types defined in the IEC68150 standard and physical network technologies that can meet such requirements. It is evident that, although 3GPP's old GSM/GPRS technologies dominated initial smart grid deployment to-date, there isn't one technology which is optimal for the entire smart grid implementation, and hence, a combination of technologies is used. Meanwhile, some technologies are known to have stronger solution development ecosystems resulting in roadmap security for utility companies. For example, the Power-Line Communication (PLC) technology has a great advantage of using the existing electricity wires to carry data, but unfortunately has drawbacks including low capacity (speed), many proprietary solutions, limited vendor community, technical scalability limitations, and does not enjoy the required open standards development momentum compared 3GPP's LTE or IEEE's WiMAX ecosystems. Equally important, PLC technology creates shared points of failure where a failed electric cable also results in loss of visibility.

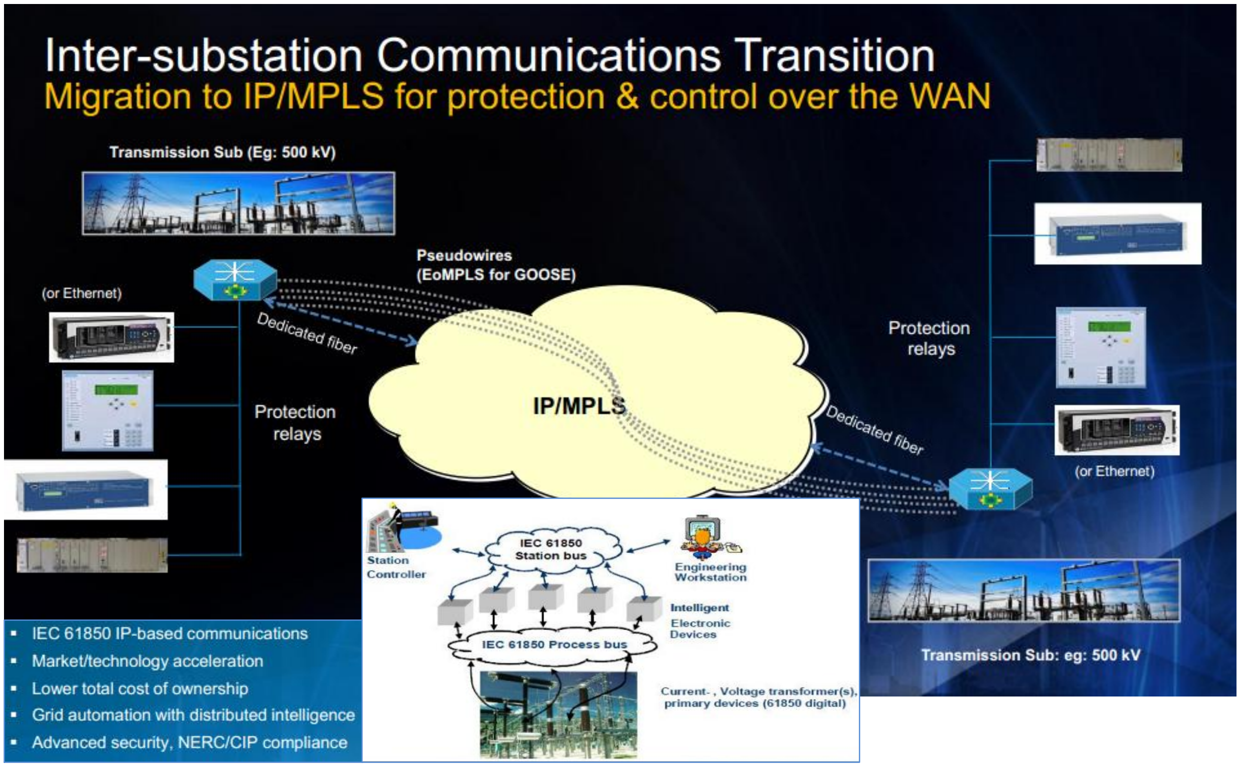


Figure 4: Smart Grid Application of IP/MPLS (Cisco Systems, 2013)

On the other hand, considering the abundant use of 3GPP's old GSM/GPRS technologies for smart grid applications, Appendix A shows the significant 3GPP evolution for reduced latency towards today's LTE technology, thereby, giving further confidence in the 3GPP industry direction for utility roadmap planning. The new LTE-Advanced standards with optimized Machine-to-Machine (M2M) communication provide further enhancements for supporting most communication requirements in the smart grid. LTE-Advanced facilitates quick geographic coverage roll out, provides superior wireless quality, high data capacity, low network latency, enjoys a large vendor community, global acceptance and standards momentum. However, the real challenge is meeting the stringent IEC 61850 requirements for sub-station automation on Type 1,1A messages for 3ms substation automation. In 2013, 3GPP accepted three submissions from the EU's FP7 ICT Objective 1.1 (ICT-LOLA, 2013) working on achieving Low Latency (LOLA) for Wireless M2M Applications. Perhaps a future purpose-built version with simplified core removing mobility and other system overheads will allow for one communication technology to be suitable for all end-to-end smart grid communication, thereby, simplifying the current heterogeneous architecture. Such solution can also be significantly more cost-effective for utilities to implement as a private fully owned network rather than leasing public shared infrastructure.

Cyber Physical Security

A smart grid requires tight coupling between ICST and the electricity grid. Compared to the traditional cyber-security term, the goal of 'cyber-physical' security is to protect the whole cyber-physical system, which includes the reliable and safe operation of the electricity infrastructure (Bruno Sinopoli, 2012).

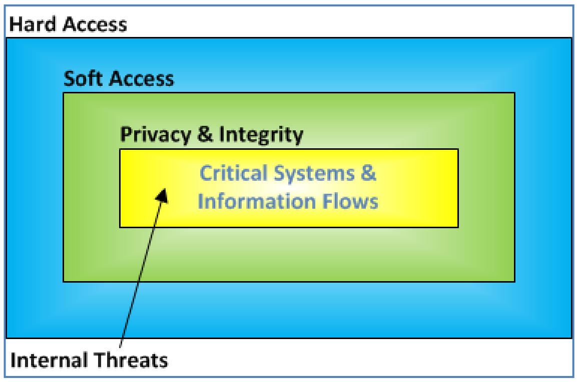


Figure 5: Cyber-Physical Security Perimeters

Based on the holistic view shown on Figure 5, Cyber-physical security starts with addressing the physical tampering of any telecommunication or electricity system component using hard access and soft access protection, and then employs other layers of protection if attacks go beyond those levels Table 2.

Security Principle	Smart Grid Context	Technologies
Physical devices and platform integrity	Any infrastructure devices that are subject to direct physical access e.g. smart meters, pole routers, sensor systems, etc, should be temper-resistant with status probing and alert mechanisms. Physical access restriction in the form of site access control, cages, and special equipment enclosures can be used.	Tamper-proof design (e.g. locked enclosure) & encrypted components (e.g. memory), physical characteristics (extended temperature operation, vibration & Interference resistance), Secure unique device identifier (802.1AR), Digital Signatures for Operating System & Configuration, with Syslog/SNMP alters.
Soft Access control	Every user connecting to the grid must be authenticated into the network before being allowed to transmit or receive smart-grid data. User-based (usernames & passwords) and chip-based (unattended devices like smart meters) authentication and logging can be used.	X.509 Certificates, Role-based Access Control, IEEE802.1x, Enterprise Authentication, Authorization and Accounting (AAA).
Internal Threat (Data Privacy & Integrity)	If hard and soft access perimeters are broken, the next protection for the various data flows traversing the smart grid employs advanced encryption algorithms operating at layers 2, 3, 4 and 7 of the OSI model to ensure that even if access is compromised the data is not readily legible. Meanwhile, cryptographic has functions guarantee data integrity between sending and receiving devices making it harder to inject fraud information that can change the autonomous behavior of the smart grid (man-in-the-middle attacks).	AES Encryption for Layer 2 (Switching) e.g. NAN-Smart Meter Network over RF/PLC Mesh, and IP-Sec for Layer 3 (Routing) at FAN and WAN networks. Upper layer technologies allow for verifying message integrity and origin using ANSI C12.22 or DLMS/COSEM. Other technologies and best practices in ISO/IEC 27000 series standards.
Internal Threat (Cyber-physical threat detection, prevention and mitigation)	The last layer of cyber-physical security protects against evident unauthorized network and physical access or service disruption. Intrusion prevention & detection systems can be triggered by abnormal traffic patterns, business rules or alters from sensors (e.g. a hacker controlling a large number of thermostats). Prevention and Mitigation also requires eliminating single points of	Modular design using virtual LANs and tunnels, real-time Syslog & SNMP alters to NMS, Active Firewalls and IDS/IPS. Use of the "implicit deny-all" approach for unknown traffic. Anti-jamming solutions for wireless networks (e.g. future cognitive radios).

	failure, and isolating traffic flows that are not meant to communicate directly (e.g. AMI with Substation Automation).	
Failsafe Mode	In addition to the principles above, other problems can occur beyond normal control of system planners (e.g. Hardware or software failure, natural disaster, etc). A default fail-safe operation of the grid should be planned to address such situations.	Given the highly connected nature of the electricity grid resulting in cascaded failures, physical isolation of affected areas is a key protection mechanism requiring proactive real-time (sub-second) monitoring and visibility with high speed reaction-times to facilitate isolation.

Table 2: Smart Grid Cyber-Physical Security - Formulated from (Cisco Systems, 2012)

These principles cover the security of the areas of information flows discussed and the cyber-physical infrastructure itself. In terms of standards and best practices, NERC-CIP represents the primary reference for the electricity industry with Version 5 coming into effect April 1, 2016. Meanwhile, the ISO/IEC 27000 series also provide detailed guidelines for information security guidelines and best practices. The cyber-physical security solution should protect the customer network side of the meter, utility network side of the meter, physical infrastructure, and the control/data centre(s), in addition to protecting the system from extreme events (Cisco, IBM, SCE, 2011) (Li, et al., 2010).

Last, but not least, choosing the right technology partners can make a significant difference in the quality of ICST implementation. In addition to making use of reports highlighting the top market-dominant solution providers (INFONETICS RESEARCH, 2013), utilities also need to evaluate the partners' true engagement in the smart grid ecosystem development process. In addition to technically sound and standards-based solutions, flexible partners whose corporate structure conveys valuation for the potential of smart grids, and who demonstrate in-depth understand of the underlying business, policy, and other external vectors influencing success, are more likely to be the partners of choice through the smart grid transformation journey.

Policy Levers

The smart grid triple bottom line benefits highlighted come handy during a period of rising political, economic, and environmental pressures. The United States recently released a game changing climate change report (Melillo, Richmond, & Yohe, 2014) followed by immediate proposal for policy ramp up. China also initiated a new direction through the Department of Climate Change National Development and Reform Commission through collaborative work via the US-China Climate Change Working Group, with current priorities highlighting smart grid implementation (IIP Digital, 2014). Together, these two initiatives create political pressure especially based on previous government skepticism manifested by the media that without official efforts from US and China additional Canadian efforts would not be viable. Meanwhile, energy security is gaining priority on the international agenda given the increasing political instability in key energy supply regions of the world like the Middle East, Eastern Europe, and South America (World Economic Forum, 2006).

Combining the pressure points above with the three angles of increasing population, finite fossil-fuel reserves, and concerns of environmental degradation, major countries around the world have embarked on increasing the contribution of renewable energy technologies within their energy mix. As explained above, a smart grid is necessary to facilitate high-scale renewable energy penetration needed to reduce emissions and enhance energy security. Ontario's experience from the Green Industry Strategy 1994 highlights the effective role of policy in creating the environment needed to boost an industry including its drivers and market potential (GIMAC, 1994). Therefore, the question becomes; what policy levers can be used to accelerate smart grid adoption in Ontario to realize the associated triple bottom line benefits? Crucially, given the notable efforts to-date, this is about identifying the areas that are creating barriers to accelerated adoption. Note that the focus is still on ICST adoption as a key enabler of grid transformation, however, policy development needs to address this objective directly and also through inter-related set of problems.

A look at smart grid innovation policy in US and China is of particular relevance given their high CO2 emissions and global influence having the largest smart grid implementations (Briones & Blase, 2012). First, smart grid policies must recognize the importance of ICST in the success equation. According to the United States Department of Energy`s modern grid initiative, a smart grid is an intelligent grid which integrates advanced sensing and measurement technologies, 'interactive communication' and automated control methods into the current electricity grid (Litos Strategic Communication, 2008). Meanwhile, the State Grid Corporation of China defines the architecture of a "Strong Smart Grid" as an ultra-high-voltage (UHV) backbone grid (to span a large geographic area) and coordinated development of subordinate grids that are IT-based, automated and 'interactive' (Chen-Chun, Chia-Han, & Joseph, 2013). While each country has its own flavor for the definition, the keywords of sensing, measuring, interactive communication, and automation are common. These key functions all require a highly efficient, reliable and secure communication infrastructure which, in turn, enables all the benefits-oriented definitions of the smart grid. Moreover, the interpretation of each country's definition, detailed implementation strategies, and roll out priority timeline of various components differ between the two nations. Given this variance, this paper highlights three areas of the policy development process where smart grid adoption challenges exist, namely, stakeholder engagement, policy formulation, and policy implementation.

Stakeholder Engagement

A fundamental requirement for sound policy development requires 360 degree stakeholder engagement to incorporate different perspectives, and generate higher consensus and momentum towards achieving shared goals (REVIT, 2006). This starts with identifying the most influential and most affected (benefit or loss) stakeholders, to those least, and those in between (Figure 6). The nature and degree of engagement or involvement depends on the degree of influence and benefit/loss related to the subject policy. Similarly, the use of tools such as dialogue, consultation, information giving and gathering depend on the role each stakeholder plays. It is imperative for policies that have an international influence that the process of stakeholder identification and engagement crosses political and jurisdictional boundaries while maintaining local confidentiality as needed through the creation of local, national, and international forums, committees, and task forces. Using a practical tiered approach, the general public can contribute through interest groups and industry association (e.g. Ontario Centres of Excellence, CanSIA, CanWEA, etc) who in turn join provincial and federal consultation exercises or event join designated forums and working groups/committees engaged in policy development.

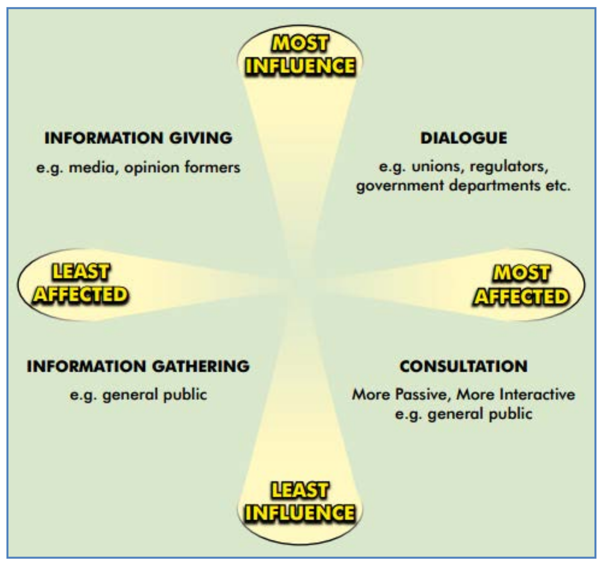


Figure 6: 360 degree Stakeholder Engagement
(REVIT, 2006)

In Ontario, the creation of Ontario Smart Grid Forum, Cyber Security Forum, Smart Grid Working Group, and Smart Grid Advisory Committee to OEB, were all meant to help to bring various stakeholders together to contribute to the policy development process. However, given that ICST is a key enabler for smart grid development, ICST solution vendors and operators inclusion is minimal to none within these stakeholder venues. Some reasons gathered from industry interviews include the difference in degree of regulation between these industries, the fact that telecommunication is federally governed whereas electricity is provincial, and that these industries always existed in isolation. Acknowledgement of the change in paradigm calling for cross-discipline collaboration and integration is critical for sound ICST solution and policy development towards realizing Ontario's smart grid vision.

Policy Formulation

Using an efficient stakeholder engagement process, the next task is to establish a unified definition of the problem, respective goals, and formulate a policy framework which guides the ecosystem to the realization of such goals. Based on the understanding that public policy helps address a given issue and the inter-related set of problems (Pal, 2013), developing a policy framework for the ICST component of the smart grid also requires addressing the non-technical vectors affecting accelerated adoption. This is a more holistic approach compared to using strictly engineering functional block method of representing the system as a black box and dealing only with inputs and outputs to the subject component. It is also important to state here that given the practical constraints of time, finance, technology, and politics, stakeholders must strive to strike a balance regarding how much of the black box system's internal details should be catered for in the subject policy at a given point in time, leaving further incremental improvements for future iterations of policy review and with adequate provisions in the framework to allow them to do so.

Realizing the smart grid vision requires a high degree of innovation given the great shift of paradigm (Farhangi, 2014). Enjoying the largest smart grid implementations, the US and China represent two contrasting policy environments which adds to the value of evaluating of their smart grid innovation policies to find useful success ingredients and apply to Ontario's context. Figure 7 examines three areas of the policy framework, supply (drivers - push policies), demand (market - pull policies), and the environment (government guidance & control), representing a rotating conveyor belt to guide smart grid development from concept to reality. Benchmarking the innovation policies of US and China using this model (Figure 7) manifests the following key findings (Chen-Chun, Chia-Han, & Joseph, 2013):

(a) "Scientific and technical development" is the most significant policy tool for smart grids in both countries in spite of their different smart grid ecosystems.
(b) China relies highly on 'public enterprise' to drive its smart grid vision. Smart grid development is mainly controlled by the Chinese government using a unified vision, centralized planning, and direct government support for R&D and proof-of-concept (PoC) demonstration projects.
(c) The US relies heavily on 'environmental-side' policy using 'private enterprise' to drive its vision but assisting the private sector with strong 'financial' and 'political' support (e.g. the US government's $3.6 billion smart grid investment matching (US DoE, 2013), and the formation of the FERC/NARUC Smart Grid Collaborative with focus to create State and Federal policy consistency, dialogue, and cooperation.
(d) Limited "demand-side" policies in both nations indicate the current focus on upstream investment for economy drivers (R&D, PoC's, Financial Support, and Education.
(e) The major purpose of the "legal regulatory" policy is to set industry standards. This is another area where China, perhaps concluding the global standards development is taking too long,

went ahead aggressively to develop the "Smart Grid Technical Standards System" as the roadmap for the nation's smart grid standardization covering 92 standards series (Gianinoni, Losa, & Nigris, 2014). Appendix B explains the factors in each of the three policy areas.

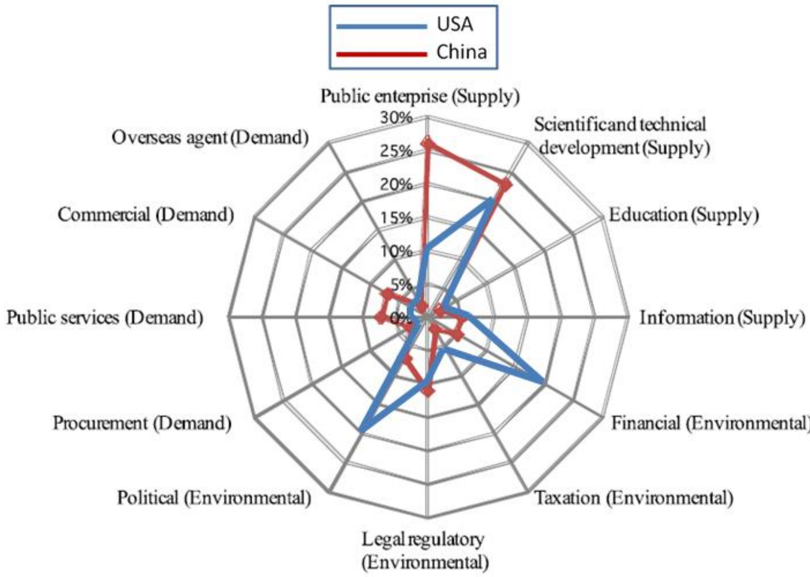


Figure 7: Compare smart grid innovation policies (Chen-Chun, Chia-Han, & Joseph, 2013)

Meanwhile, a scan of the smart grid policy landscape in Ontario highlights the government's notable efforts to be one of the leading jurisdictions in the field (SGF, 2011) (SGF, 2013) (Briones & Blase, 2012). The smart grid movement in Ontario is primarily driven by four key government initiatives; the February 2005 Smart Meters Directive to Ontario Energy Board (OEB), the Green Energy and Green Economy Act (GEA) 2009 - legislative definition for smart grid), the November 2010 Smart Grid Directive to OEB (outlining smart grid policy objectives), the Renewed Regulatory Framework for Electricity (RRFE) 2012 - regulation. Ten policy objectives are highlighted by The Smart Grid Directive for the power grid including efficiency, customer value, co-ordination, interoperability, security, privacy, safety, economic development, environmental benefits and reliability, each with its general definition.

Contrasting the US and China smart grid policies with Ontario draws attention to the observation that US and China are most focused on the supply-policy side whereas Ontario is more focused demand-policy side with consumers being the central piece of attention. This is evident from the elaborated consumer satisfaction metrics in RRFE, the conservation focus of the Long-Term Energy Plan (LTEP) (MoE, 2013), and also the programs focused on empowering the customers such as FIT and microFIT, Green Button, Net Metering, etc (MoE, 2013). Generally, consumer focus can be explained by the need to win public consensus where budget is limited and highly driven by tax payers' and rate payers' (electricity consumers) contribution. This demand-side policy focus, compared with more globally dominant drivers

(Figure 8), creates an economic sustainability issue discussed in detail in the following sections. On the environment-policy side, both USA and China enjoy high political and financial ecosystem support whereas Ontario's Smart Grid Fund of $50 million over the last three years is no linear match considering the relative infrastructure size by annual generation (Gianinoni, Losa, & Nigris, 2014). However, more research is required to build an accurate policy comparison using all the factors in the model above.

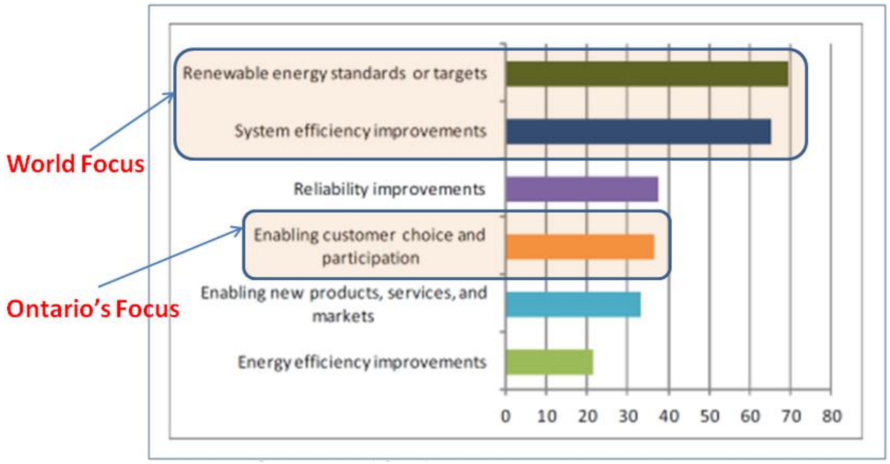


Figure 8: ISGAN Survey of world smart grid drivers (Gianinoni, Losa, & Nigris, 2014)

Policy Implementation

Referring to the initial definition of the policy statement, policy implementation is the process of converting carefully crafted policies to action using the appropriate tools and instruments (levers) to ultimately achieve the initially set goals. These goals include maximizing grid reliability and efficiency, renewable energy integration, and enabling consumer engagement. Solid and efficient implementation requires synchronized political support in the form of horizontal integration (central-central and local-local between Federal and Provincial Ministries, respectively, working together towards shared smart grid goals), and vertical integration (central-local and local-local from policy enactment and down through the implementation chain). This is achieved through efficient communication, synchronization of shared objectives, and balanced delegation of authority downwards on the policy implementation chain (Exworthy & Powell, 2004). This study found Mintrom's 7-step implementation process (Table 3) most suitable for smart grid success because it addresses key areas of policy consistency, institutional inertia, and resource allocation in a holistic manner (Mintrom, 2012).

Implementation Factor	Mapping to Smart Grid Implementation Context
1. Overall policy purpose, where it will be implemented, how is success defined?	Unified smart grid vision including its architecture, components, where they will be installed, their interactions, the players involved, and the respective triple bottom line benefits from the system.
2. Institutional, organizational, and procedural changes required?	"Environment" output from policy formulation exercise detailing smart grid legislative & regulatory revisions needed, formal & informal institutions, horizontal & vertical integration, and appropriate policy instruments. More focus needed on Supply-side policies supporting R&D and PoCs.
3. Institutional inertia and how to overcome?	

	An efficient 360 degree stakeholder engagement process including Telecom and IT stakeholders can help build greater consensus and momentum, formulate more effective policies and interoperability.
4. Policy implementers, and behavioral changes?	'Supply" & "Demand" outputs from policy formulation exercise to be used to detail smart grid prioritized roll out actions for the various players, their roles, and interactions. This prioritization should first focus on enabling smart grid applications that support economic sustainability (e.g. operational efficiency) as the benefits will eventually be extended to the consumers. Public-Private partnerships, in the form of loan guarantees or direct investment, are needed on both Push & Pull sides to boost industry confidence and capabilities.
5. Project management: ideas to tasks, responsibility, time, resources.	Translation of the smart grid prioritized actions above to individual tasks with associated resources, lines of accountability, and implementation timeline. Designating responsibility, time-frame, and adequate resources (financial and cross-discipline skills) publically and in a transparent manner creates a true drive for success when the reputation of various stakeholders becomes at stake.
6. Risk analysis	Identifying possible threats to implementation success and timeline delays and addressing them through mitigation and contingency planning is important to avoid unexpected pitfalls. For example, consumer concerns on privacy, utility concerns about security on customer side of the meter, economic viability for local distribution companies, etc).
7. Provisions for monitoring & evaluation.	Finally, based on the principle (what cannot be measured cannot be improved) it is important to embed meaningful provisions for evaluating achievement including clearly defining success metrics and proactively monitoring key performance indicators in-line with the goals and objectives above.

Table 3: Successful Policy Implementation Process (Mintrom, 2012)

It is imperative to note that the steps above are not 100% chronological, for example, Mintrom states that the process of creating evaluative measures should not be an afterthought but rather an integral part of the policy design process itself.

As mentioned earlier, China made use of public enterprise to ensure synchronized goals, and implementation consistency. Such setup is not foreign to Canada because the industry has witnessed efficient planning examples such as Hydro Quebec running as a single organization successfully achieving near 100% renewable energy generation (Hydro-Québec, 2012). Evidence also shows that consolidating Ontario's once 307 utilities to today's 89 has resulted in significant cost savings and efficiencies, with further room to arrive at fewer than 12 utilities (Elston, Laughren, & McFadden, 2012). The costs per customer in a small utility (fewer than 12,500) are 70% higher than those of a large utility (100,000 customers and above), with the recommended size being 400,000 customers and above for any utility to enjoy true economies of scale and operational efficiency. Ontario's multi-player smart grid ecosystem (Figure 9) requires considerable effort to ensure various players achieve policy consistency and unified implementation. This becomes especially challenging when trying to synchronize the over eighty (high degree of fragmentation) local distribution companies (LDCs) that are not on levelled-ground neither from smart grid knowledge maturity level nor from resource capabilities and economies of scale.

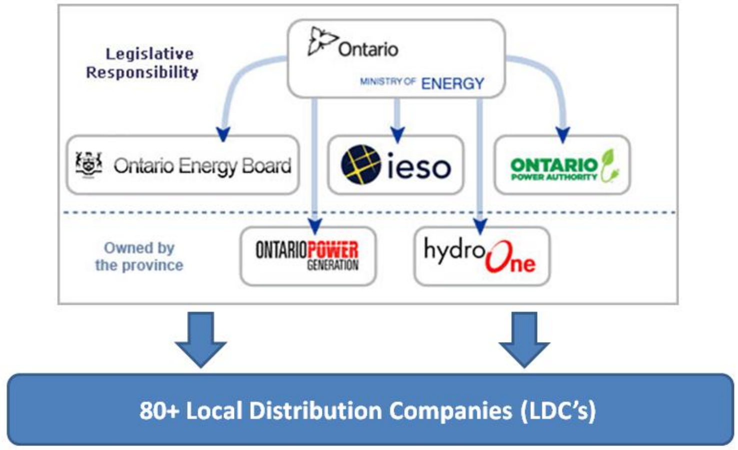


Figure 9: Ontario's Electricity Ecosystem

On the positive side, there were several implementation programs introduced in Ontario. These including the Feed-in-Tariffs (FIT and microFIT) programs by Ontario Power Authority (OPA), which replaced the 2006 Renewable Energy Standard Offer Program providing incentives for renewable energy; the Green Button initiative in cooperation with the Information and Privacy Commissioner of Ontario (IPC) for customers to access their power consumption data; Net Metering to encourage self-sustained distributed generation trading; emPowerMe by MoE to educate customers on the electricity system, and various other home and business programs listed in (MoE, 2014). Therefore, the questions are raised regarding how the performance has been on implementation, whether the targets are set at politically easy local or globally competitive levels, and the areas that policy development still need to be addressed.

Once again, these programs are focused on the demand-side of the equation and create a barrier for adoption for LDCs who currently face economic viability challenges towards smart grid transformation. Utility engagement in smart grid projects is increasing slowly in Ontario, however, a review of the projects also suggests varying degrees of maturity (Briones & Blase, 2012). In addition to stakeholder engagement, policy formulation, and ecosystem alignment aspects discussed, Figures 10 and 11 manifest the need for stronger focused ICST funding and ICST KPI's and metrics to support implementation.

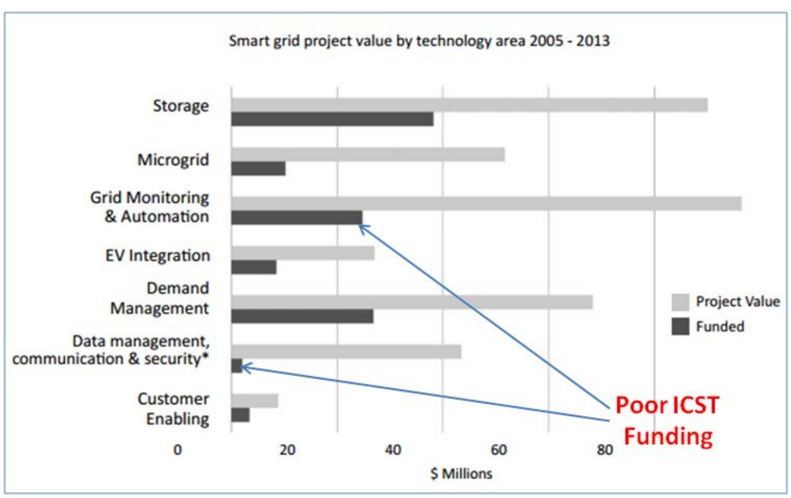
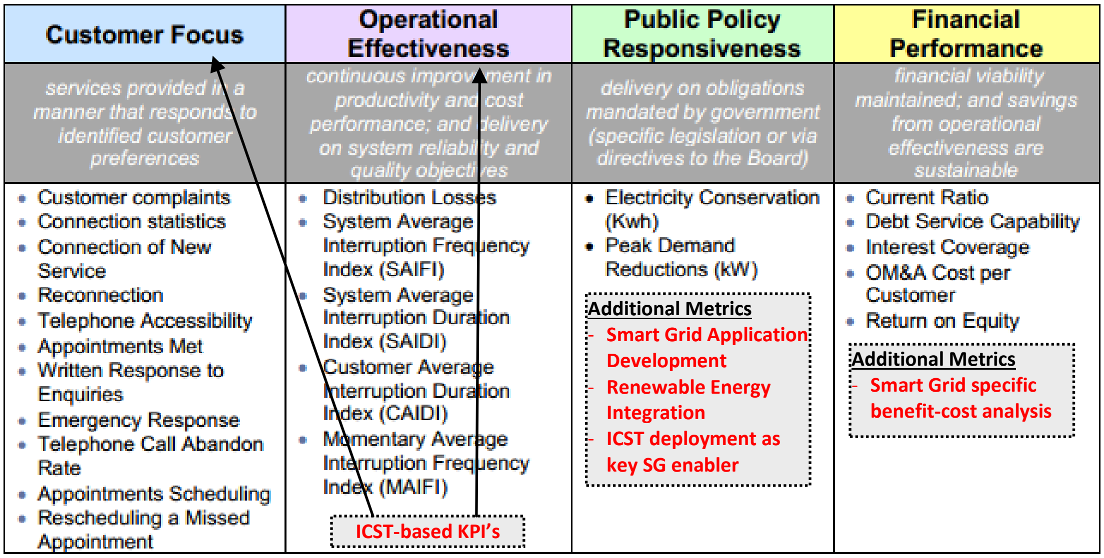


Figure 10: Smart grid funding in Canada (Hiscock & Beauvais, 2013)



Customer Focus	Operational Effectiveness	Public Policy Responsiveness	Financial Performance
services provided in a manner that responds to identified customer preferences	continuous improvement in productivity and cost performance; and delivery on system reliability and quality objectives	delivery on obligations mandated by government (specific legislation or via directives to the Board)	financial viability maintained; and savings from operational effectiveness are sustainable
• Customer complaints • Connection statistics • Connection of New Service • Reconnection • Telephone Accessibility • Appointments Met • Written Response to Enquiries • Emergency Response • Telephone Call Abandon Rate • Appointments Scheduling • Rescheduling a Missed Appointment	• Distribution Losses • System Average Interruption Frequency Index (SAIFI) • System Average Interruption Duration Index (SAIDI) • Customer Average Interruption Duration Index (CAIDI) • Momentary Average Interruption Frequency Index (MAIFI) ICST-based KPI's	• Electricity Conservation (Kwh) • Peak Demand Reductions (kW) **Additional Metrics** - Smart Grid Application Development - Renewable Energy Integration - ICST deployment as key SG enabler	• Current Ratio • Debt Service Capability • Interest Coverage • OM&A Cost per Customer • Return on Equity **Additional Metrics** - Smart Grid specific benefit-cost analysis

Figure 11: RRFE Performance Scorecard (OEB, 2012)

INDUSTRY PERSPECTIVE & ANALYSIS: ONTARIO

Planning an effective ICST solution requires building a good understanding of the practical interrelated set of challenges facing the underlying industry including the associated political, social and economic vectors. Industry interviews were conducted with various stakeholders in an attempt to capture the perspectives of power generation, transmission, distribution, solution providers, academic institutions, and policy developers. This section provides a summary of the feedback from these interviews based on Ontario's smart grid vision, policy challenges, and technical concerns, as detailed in Tables C1, C2, and C3 of Appendix C, respectively.

From a methodology perspective, and while effort was made to capture feedback from various areas of the industry, there are two limitations to note. First, the respondent size was restricted based on time available. A larger respondent size would help generate useful statistical representation for various responses. Second, respondents were asked to provide crude scoring regarding smart grid progress. More accurate quantitative feedback would require an extensive consultation exercise involving a larger respondent sample of the industry, and scoring criteria based on clearly detailed progress objectives and metrics. Finally, other details regarding the respondents are kept confidential in accordance with McMaster research ethics guidelines and procedures.

Analysis of Interviews

Assessing the smart grid vision during interviews manifested evident differences in expectations by stakeholders. The responses indicated that this is primarily attributed to a shortage of knowledge-sharing opportunities and also different stakeholders focusing on direct effects within their sphere rather than the collective ecosystem objectives to be realized by smart grid adoption. Government leadership to establish common goals with stakeholder consensus can facilitate synchronized policy implementation and technical innovation momentum e.g. US FARC/NURAC Smart Grid Collaborative and Clearinghouse (Litos Strategic Communication, 2009).

The policy analysis demonstrated key strengths in Ontario in terms of government effort to generate positive momentum, but this is heavily challenged by several issues summarized in Table C2. The most prominent factor reiterated was that of lacking business case for LDCs who represent the key stakeholders needed for accelerated smart grid adoption. The LDC sector, which operates on tight electricity pricing regulations with little room for profits, are expected to make key infrastructure upgrades to the existing electricity systems, and also on the ICST components, while the whole investment seemingly results in more conservation and load reduction on the customer end, thereby, reducing LDC revenue. This is a conflicting proposition which needs to be addressed at all levels. LDCs do not make profits from electricity sale, and the distribution component represents 20-25% of the electricity bill (OEB, 2012) which is expected to diminish with smart grid adoption. This is because enabling distributed generation translates to prosumers using less electricity from the grid and more self generated at their premises. Charging the customers a flat rate for distribution would help the LDC business case but works against conservation since customers will not have the same cost-saving incentive to change consumption behavior. Meanwhile, a new energy services market will be enabled by smart grids for installing and maintaining more distributed generation projects, load aggregation across customers and neighborhoods, and brokering electricity sales, all of which can create new revenue streams. Perhaps changing the role of LDCs to participate in such markets may help justify smart grid infrastructure investments. Also noted is the need to consolidate the highly fragmented ecosystem from number of LDCs to the number of 'referees' controlling implementation.

Finally, the current regulatory control is deemed too restrictive, as conveyed by interview feedback, and needs to be revised to employ more market flexibility (as in USA) enabled by healthy smart grid interactions where competition between many decentralized sources, renewable technology innovations, and increased operational efficiency and reliability will drive prices down for the benefit of the prosumers and the environment. This makes use of the key vector that smart grids enable multi-directional power flows, and also requires leveling the ground between LDCs in Ontario either through consolidation or pooling of ICST investment for shared infrastructure to benefit from economies of scale. Equally important, several processes need to be simplified, streamlined, and further synchronized with smart grid goals including smart grid funding approvals and complex rate filing processes. Based on the current LDC regulation structure, initial smart grid adoption may need to be disconnected from the rate filing processes altogether.

On the technical side, industry feedback from interviews highlighted the need for more R&D and PoCs to boost industry confidence. Two key areas of interest are storage solutions, that are critical for high-scale renewable energy integration and grid stability, and ICST solutions for meeting the IEC68150 substation automation latency requirements. In addition, more detailed metrics and KPI's need to be defined for ICST solutions within the objectives of Figure 11 through more multidisciplinary collaboration including ICST stakeholders.

Lastly, respondents were also asked to provide generic scores on the degree of adoption progress in Ontario benchmarked against where they hoped the industry would be within the journey of smart grid transformation. The average scores obtained for the Supply, Environment, and Demand domains were 4, 4, and 6 out of 10, respectively, with general consistency in relative scoring. This reflects a greater focus on the customer end, while highlighting the need for more upstream support for drivers (Funding, R&D, PoCs) and the environment (unified vision, multidisciplinary collaboration, and economic viability of the distribution/service regulations). On a country scale, China, which officially commenced its journey after Canada, now enjoys almost 300 demonstration projects versus fewer than 50 in Canada (Appendix D).

RECOMMENDATIONS

While the preceding discussion provided section-specific feedback (i.e. smart grid vision, technical and policy areas), it is also useful to understand and view the smart grid development journey from an overall system point of view. The Smart Grid Maturity Model (Figure 12) was developed by IBM and seven utilities from four continents. It is adopted by US Department of Energy (Litos Strategic Communication, 2009) and also used by utilities in Ontario (Briones & Blase, 2012). This research concludes that Ontario between stages 2 and 3 based on the fact that some operational linkages between two or more functional areas are still emerging (e.g. AMI and Demand-side management) but this is evidently a result of adherence to regulation and ministerial directives rather than driven by a sustainable business case (Bettencourt & Malenfant, 2013). However, the model's literature emphasises that the smart grid journey is unique to every utility company, and that this model also serves as a strategic framework for regulators, vendors, and consumers who have or desire a role in Smart Grid transformation, to set their priorities and benchmark progress.

Using this model, the technical and policy review, and the feedback from interviews, this section outlines the respective recommended priorities (Tables 4a and 4b) for Ontario along with customized reference models (Figures 13 and 14) to visualize the same. Note that progress already exists in some of these priority areas and that the order does not imply fully dependency to complete one before commencing with the next. These recommendations are complimentary rather than a replacement of efforts to-date.

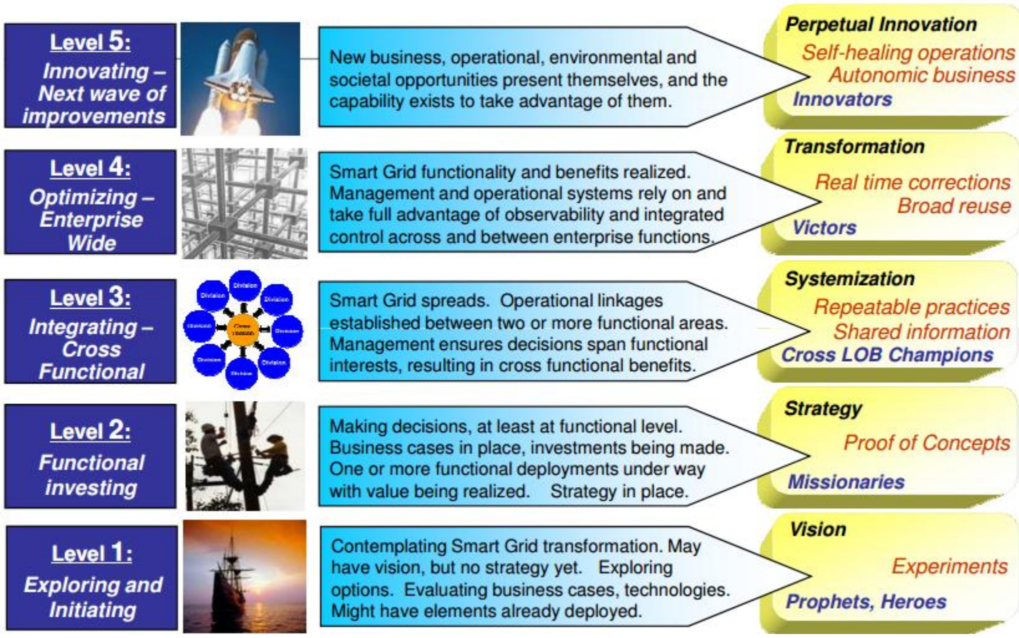


Figure 12: The Smart Grid Maturity Model (Software Engineering Institute, 2009)

Technical
1) **Smart Meters** security
2) ICST phase-1 for **wide situational awareness**
3) Utility-grade **energy storage** for efficiency
4) **Distributed generation**
5) ICST phase-2 for **control, and 2-way transactions**
6) **Distribution automation** & operational efficiency
7) **Capacity markets** transactions
8) **Smart Home** transactions
9) Energy **Conservation**
10) Wide-scale **demand response**
11) **Energy services** (brokering, load aggregation)
12) **Self-healing** network

Policy
1) 360 **stakeholder engagement** and **skills training**
2) Unified & prioritized smart grid **implementation plan**
3) **ICST metrics & KPI's** in-line with policy objectives
4) Policies to create **economic viability**
5) Revise **LDC regulatory framework**
6) Consolidate Federal/Provincial support for **R&D, PoCs**
7) **Public-Private Partnerships** to lead implementation

Table 4a & 4b: Recommended Technical and Policy priorities

On the technical side, the key focus is stagerring smart grid applications to support sustained growth first, then expand the demand side for long-term consumer benefits. Also, ICST adoption is split into two main phases by first employ large-scale monitoring-only capabilities to build knowledge maturity at reduced cyber-phyical risk, and then enable 2-way interaction and reliable automation for full benefits. Meanwhile, the policy side is focused on further aligning Ontario's smart grid vision and success metrics, addressing the business case and viability for LDCs, and driving the supply side of the ecosystem.

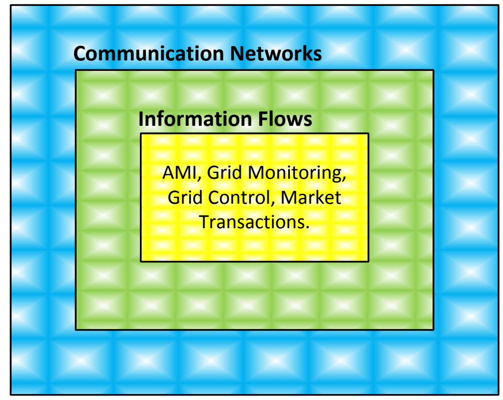
Technical Guideline

Figure 13 integrates the key points to be considered for smart grid ICST planning and design, along with lessons learnt from industry experiences (Garrettcom - Belden Inc., 2012).

Information Area	Recommendation
End-points	Setup cyber-physical security to protect access, data privacy, and physical tampering. This also includes isolating traffic streams that do not need to communicate with each other.
Traffic Type (AMI, Monitoring, Control, 2-Way Data Transactions)	Plan the data fields needed to collect information based on future requirements (e.g. Smart Home), data/file formats, and auditing processes.
Traffic Dimensioning	The information above, together with planning of how much data will be sent and how frequently helps plan the appropriate communication technology, network architecture, and link bandwidth, etc.
Business Intelligence	Solution must be fully customizable and supports integration with GIS, Data Analytics, Decision Support Systems, and other management systems.

Network Layer	Recommendation
HAN	WiFi: being the most abundant wireless local area network technology available, already benefits from very cheap production and easy integration into any appliance or electronic device. Zigbee satisfies current requirements but not as abundant on end-user devices and provides lower bandwidth.
NAN	M2M over Cellular LTE with migration path to LTE-Advanced: Suitable for large-scale smart meter aggregation, enjoys global dominance, security, spectral efficiency, and scalable capacity for future Smart Home and IoT applications. RF Mesh and PLC are not scalable. RF Mesh is also more susceptible to interference and jamming issues.
FAN	High Capacity Point-to-multipoint Microwave with purpose-built air-interface: Operates at higher cheaper frequency spectrum, roll out to cover whole cities is much faster than fiber and cheaper, offers lowest wireless latency with no mobility overhead, scales better than current Point-to-point architecture. Commercial solutions support multiple end-interfaces and latency below 10msec. Substation automation testing proven in China using IEEE 1588v2 timing over packet networks with IP/MPLS. (ref)
WAN	Fiber from Core Network to where possible, and P2MP Microwave for extended reach to FAN Layer.
Routing, Switching, and Traffic Engineering	Even in a well designed communication infrastructure, traffic patterns can degrade network performance. The choice of routing protocol, switching efficiency, and use traffic prioritization (e.g. control messages over all others) will ensure the system operates as planned. IP/MPLS technology is a must for smart grid communication.

Cyber-Physical Security



Industry Experience

- Scalability Architecture
- BigData Bandwidth
- Flexible Connectivity
- Precision Timing Control
- Industry Grade Equipment
- IP-Serial Integration
- Wired & Wireless
- Embedded Security
- Partner with Corporate IT
- **Standards Based**
- **Iterative Work-In-Progress**

Security Area	Recommendation
Customer Side of Meter	IEEE 802.1x enterprise security for all smart grid certified products to minimize security risks on customer end of meter.
Utility Side of Meter	All standard communication industry best practices discussed herein (e.g. ISO 27002) NERC-CIP cyber physical security standards for smart grids
Core Network	All standard communication industry best practices discussed herein (e.g. ISO 27002) NERC-CIP cyber physical security standards for smart grids. Intrusion prevention and detection systems are critical to identify malicious traffic patterns that pass the firewalls or originate internally. Customer data, grid monitoring, and SCADA control must be given extreme protection.
General	ICST Phase-1: implement all solutions for monitoring purposes only (minimized risk) and use the experience to bring ICST to maturity. ICST Phase-2: enable two-way communication wide-scale demand side management, distribution control and market transactions.

Figure 13: Technical Guidelines

Policy Framework

Figure 14 integrates the lessons learnt from policy review (stakeholder engagement, policy formulation using Supply, Environment, and Demand levers, and policy implementation using Mintrom's 7-step process), and the ICST technical requirements and planning.

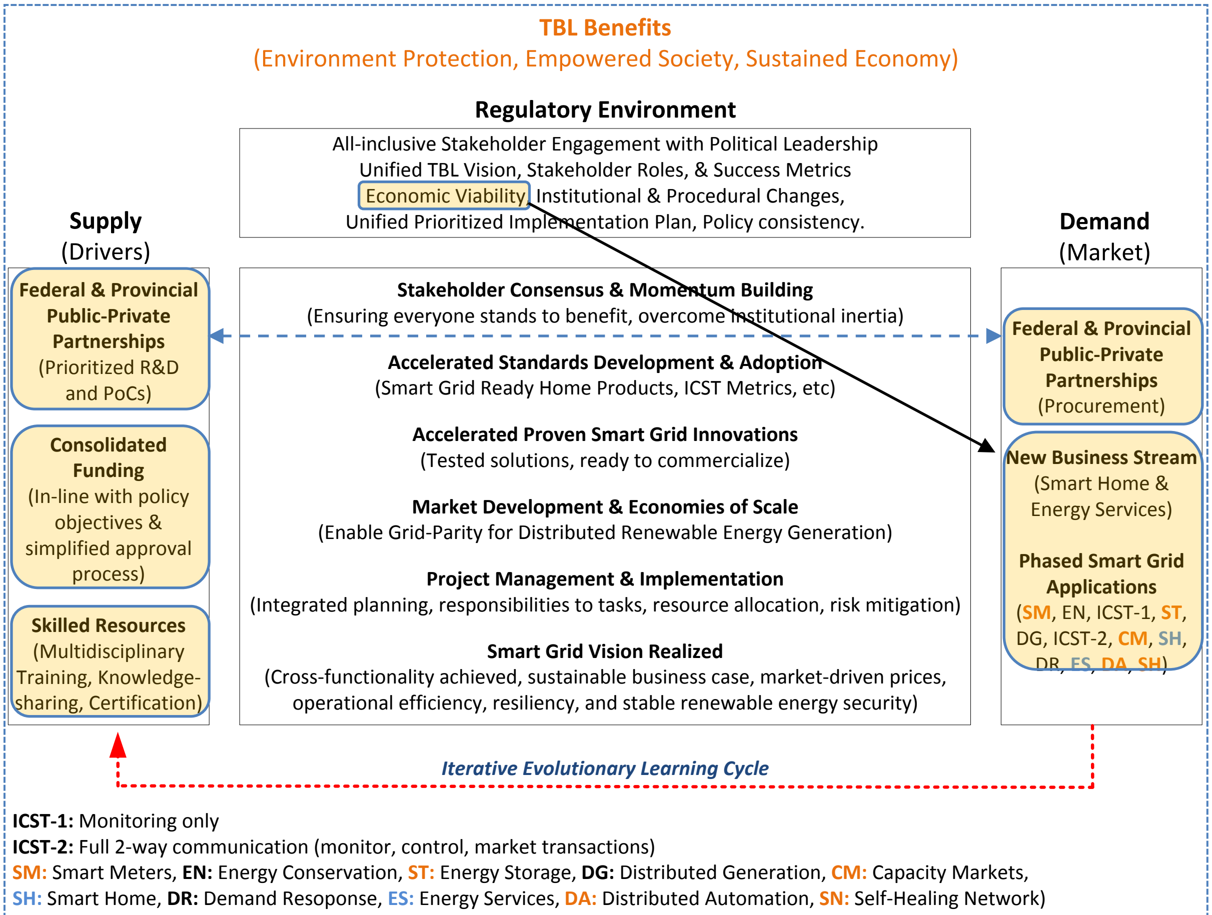


Figure 14: Policy Framework

Key actionable items highlighted in the framework include:

1. 360 degree stakeholder engagement to build greater consensus and momentum. This includes public awareness to address concerns and highlight smart grid societal benefits (Wolsink, 2012).
2. Federal & provincial public-private partnerships on both supply and demand sides for prioritized R&D and PoCs, and new project procurement (both locally and technology export), respectively. These partnerships should foster Utility/Telco/IT convergence for overarching benefits.
3. Consolidated federal & provincial funding with streamlined approval process, in-line with policy objectives and with ICST implementation priority as a key smart grid enabler.
4. Development of skilled resources through multidisciplinary training at educational institutions, increasing knowledge-sharing venues at all levels of the ecosystem, and professional certifications.
5. Creating economic viability and establishing the business case for key stakeholders (including LDCs and consumers through:
    a. Identifying new business streams (e.g. Smart Home & Energy Services markets, bundled Utility/Telco services, and revising the role of LDCs).
    b. Phasing the smart grid applications to first help utilities recuperate smart grid investments through operational savings, and then enable large-scale customer side applications for conservation and demand-side management with energy services.

CONCLUSION

The aging electricity infrastructure was built decades ago based on simple society needs compared to the dynamic and energy-pervasive demands of today. Together with energy security and climate change pressure, these challenges require a transformational change towards a smart grid architecture. Using ICST for wide situational awareness, information processing, and reliable & efficient grid automation, smart grids enable efficient energy sourcing and distribution, multi-directional power flows, and higher resiliency to failure. The shift of paradigm introduces new capacity markets allowing for large-scale distributed renewable generation, new energy services, and customer empowerment and choice, thereby achieving triple bottom line benefits.

This research used a combination of literature review and qualitative industry interviews to present the theory and practice of ICST adoption within the smart grid ecosystem. The technical sections established ICST guidelines to help level the knowledge grounds between utilities and assist in evaluating options within their roadmap. Meanwhile, the policy sections highlighted stakeholder engagement, innovation policy formulation areas used in US and China, and the application of Mintrom's 7-step policy implementation process, all as key levers that can be used to accelerate smart grid development. Finally, the practical feedback from interviews confirmed theoretical principles and findings, and helped shed light on key non-technical vectors affecting ICST adoption and smart grid development.

The recommendations made included prioritized lists of policy and technical roadmap actions along with visual representation to assist various stakeholders in their existing or new smart grid transformation journeys. The most prominent technical priorities included stagerring smart grid applications to first support sustained growth through more R&D and PoCs, priority for deploying ICST operational efficiency applications, and utility-grade energy storage solutions for renewable energy integration. Meanwhile, the key policy priorities included government leadership through public-private partnerships and streamlined ICST funding, revising the role of LDCs, and establishing the business case for key stakeholders.

In all respects, Ontario's notable effort to-date was highlighted in working towards timely smart grid development. The findings in this research serve to highlight key areas for complimentary improvements to realize the overarching vision. Further collaboration between the industry and academic institutions for continuous research along the areas addressed, using iterative transparent industry feedback, can go great lengths in optimizing and accelerating smart grid adoption and associated triple bottom line benefits for Ontario.

ACRONYMS

3GPP	: 3^{rd} Generation Partnership Project
ANSI	: American National Standards Institute
CanSIA	: Canadian Solar Industry Association
CanWEA	: Canadian Wind Energy Association
DLMS/COSEM	: Device Language Message Specification / Companion Specification for Energy Metering
FERC	: Federal Energy Regulatory Commission
FIT	: Feed-In Tariffs
IEC	: International Electrotechnical Commission
IED	: Intelligent Electronic Devices
IEEE	: Institute of Electrical and Electronic Engineers
ISO	: International Organization for Standardization
NARUC	: National Association of Regulatory Utility Commissioners
NERC-CIP	: North American Electric Reliability Corporation – Critical Infrastructure Protection
NIST	: National Institute of Standards and Technology
NMS	: Network Management/Monitoring System
OSI	: Open Systems Interconnect
PoE	: Power over Ethernet
SFP	: Small Form-factor Pluggable transceiver
SNMP	: Simple Network Management Protocol
WiMAX	: Worldwide Interoperability for Microwave Access

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APPENDIX A: Communication Technologies & Smart Grid Requirements

Parameter	GSM at 900 MHz	LTE at 800 MHz	CDMA at 450 MHz	Fiber optics	DSL	Power line
Scalability	Competition on resources	Competition on resources	No competition on resources	No competition on resources	No competition on resources	No competition on resources
Low latency	No	Yes	Yes	Yes	Yes	Narrowband no
Data rates are sufficient	Problematic	Yes	Yes	Yes	Yes	Narrowband no
Enhanced Resilience	Not available	Not available	Available	Available	Only limited SLAs	Not available
Indoor penetration/ availability	Fair	Fair	Good	Good	Good	Good
System availability	Constrained	Constrained	Yes	Yes	Yes	Constrained
Network and system optimization for M2M applications	No	No	Yes	No	No	No
Interference with other services (e.g. broadcasting)	No	No	No	No	No	Expected
Cost effective nationwide coverage available/possible	Yes	Yes	Yes	Very limited	Partially limited	Limited
Installation / rollout	Simple	Simple	Simple	Difficult	Difficult	Simple
Security	Public Grid	Public Grid	Closed Network	Public grid	Public grid	Closed network
Long-term system availability	No	Yes	Yes	Yes	Yes	Yes
Exposure to customer behavior	No	No	No	Yes	Yes	No
Exposure to developments in the broadband market	no	Yes	No	No	Yes	No

Table A1: Comparison of Communication Network Technologies (Sörries, 2013)

Type/Application	Latency Requirements	Network Technology
Type 1A "trip" (fault isolation & protection)	3ms - 10ms (P1/P2)	Fiber, Metro-Ethernet, High Performance Microwave
Type 1B "Other IED automation"	20ms - 100ms (P2/P3)	Fiber, Metro-Ethernet, High Performance Microwave, Future LTE-Advanced (Ericsson, 2013) with purpose-built customization.
Type 2 - Medium speed Control	100ms (P4)	LTE, WiMAX, and above.
Type 3 - Low speed control	500ms (P5)	PLC, RF-Mesh, 3G, LTE, WiMAX, and above.
Type 4 - Continuous Raw IED data messages	10ms (P1/P2)	Fiber, Metro-Ethernet, High Performance Microwave, Future LTE-Advanced with purpose-built customization.
Type 5 - File transfer functions	>= 1000ms (P6)	PLC, RF-Mesh, 3G, LTE, WiMAX, and above.
Type 6 - Time synchronization	Accuracy $\pm$1ms or $\pm$0.1ms	Stratum 2 clock signal via GPS, over a dedicated TDM connection, or over the network (3G, LTE, or above)

Table A2: Mapping Latency Requirements

Adapted from (Agba, Riendeau, Shirazipour, Krishnan, Aranibar, & Monette, 2014)

Performance class	Requirement description	Transfer time Class	Transfer time ms	Application
P1	The total transmission time shall be below the order of a quarter of a cycle (5ms for 50Hz, 4ms for 60Hz).	TT6	≤ 3	Trips, blockings
P2	The total transmission time shall be in the order of half a cycle (10ms for 50Hz, 8ms for 60Hz).	TT5	≤ 10	Releases, status changes
P3	The total transmission time shall be of the order of one cycle (20ms for 50Hz, 17ms for 60Hz).	TT4	≤ 20	Fast automatic interactions
P4	The transfer time for automation functions is less demanding than protection type messages (trip, block, release, critical status change) but more demanding than operator actions	TT3	≤ 100	Slow automatic interactions
P5	The total transmission time shall be half the operator response time of ≥ 1s regarding event and response (bidirectional)	TT2	≤ 500	Operator commands
P6	The total transmission time shall be in line with the operator response time of ≥ 1s regarding unidirectional events	TT1	≤ 1000	Events, alarms

Table A3: IEC68150 Performance classes and requirements (Ericsson AB, 2013)

Network	Application	Data rate	Latency	Relia-bility	Security	Coverage range	Communication technologies: Wired: Fiber Optic	Wired: DSL	Wired: Coaxial Cable	Wired: PLC	Wireless: ZigBee	Wireless: WLAN	Wireless: Z-Wave	Wireless: Wireless Mesh	Wireless: WiMAX	Wireless: Cellular	Wireless: Satellite
HAN/BAN/ IAN	Home/building automation	< 100 kbps	< minutes	High	High	Up to 100m				X	X	X	X				
NAN/ FAN	On-demand meter reading	>100 kbps	< 5 sec	High	High	Up to 10km		X	X	X				X	X	X	
	Multi-interval meter reading	>100 kbps	< several hours					X	X	X				X	X	X	
	Load management	>50 kbps	< 5 sec					X	X					X	X	X	
	Distribution automation	>18 kbps	< 1 sec					X	X					X	X	X	
WAN	Synchrophasor	> 2 Mbps	< 20 ms	Very High	Very High	100 km or more	X								X	X	
	Backhaul/core/metro networks	>10 Mbps	< 50 ms				X								X	X	X

Table A4: Smart grid applications & network technologies (Kuzlu, Pipattanasomporn, & VirginiaTech, 2013)

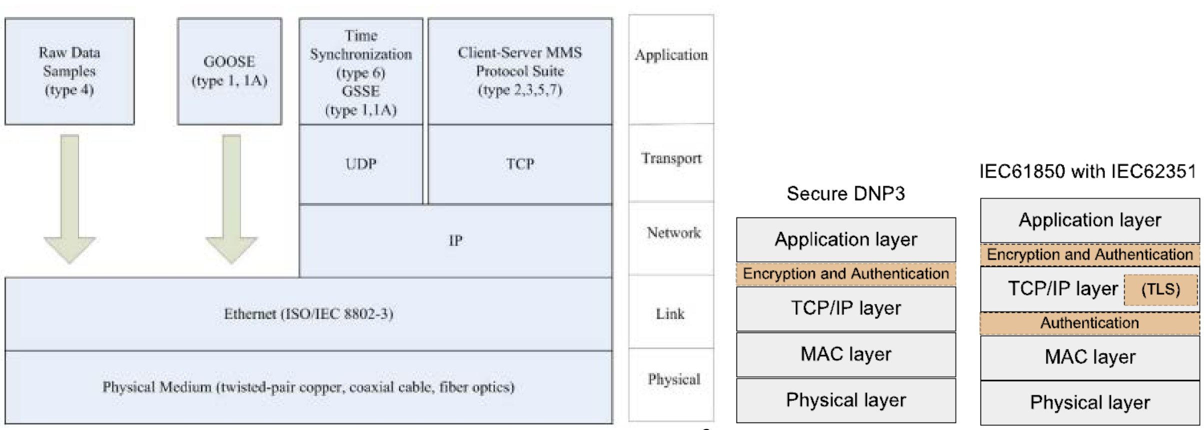


Figure A1: IEC68150 added flexibility & security over DNP[3] (Sidhu & Yin, 2007) (Wang & Lu, 2013)

3GPP Technology Dominance

Communication Technologies	Generation		Transmission			Distribution			Consumer			
	Conventional Generation	Distributed Renewable Energy based Generation	Transmission Line Monitoring and Protection	Insulator Monitoring	FACTs Monitoring and Control	Substation Automation and Protection	Distribution Line Monitoring and Protection	Equipment Monitoring and Protection	Home Automation and Control	Industrial Automation and Control	Automatic Metering Reading	PHEVs
Power Line Communication (PLC)	∞	∞	√	√	√	√	√	√	√	√	√	Δ
ZigBee	Δ	Δ	∞	∞	∞	Δ	Δ	Δ	√	√	√	Δ
WiFi	Δ	∞	Δ	∞	Δ	√	∞	√	√	√	√	Δ
WiMAX	Δ	Δ	Δ	∞	∞	Δ	∞	∞	∞	∞	Δ	∞
GSM and GPRS	√	√	√	Δ	√	√	√	√	√	√	√	√
DASH 7	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ

√ = In use, some mature solutions available
∞ = Not in currently in use, solutions can be developed
Δ = On-going Research, some solution available but under testing

Figure A2: Dominance of old 3GPP Technologies [GSM/GPRS] (Usman & Shami, 2013)

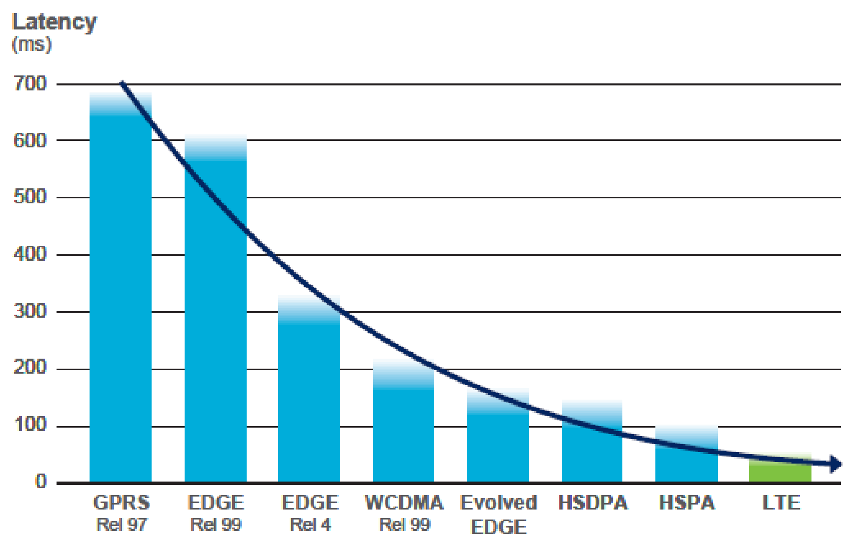


Figure A3: Evolution of Network Latency (Ericsson AB, 2013)

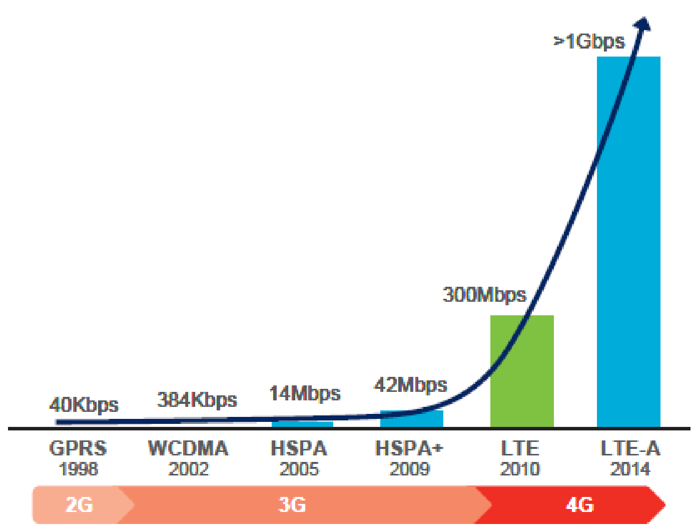
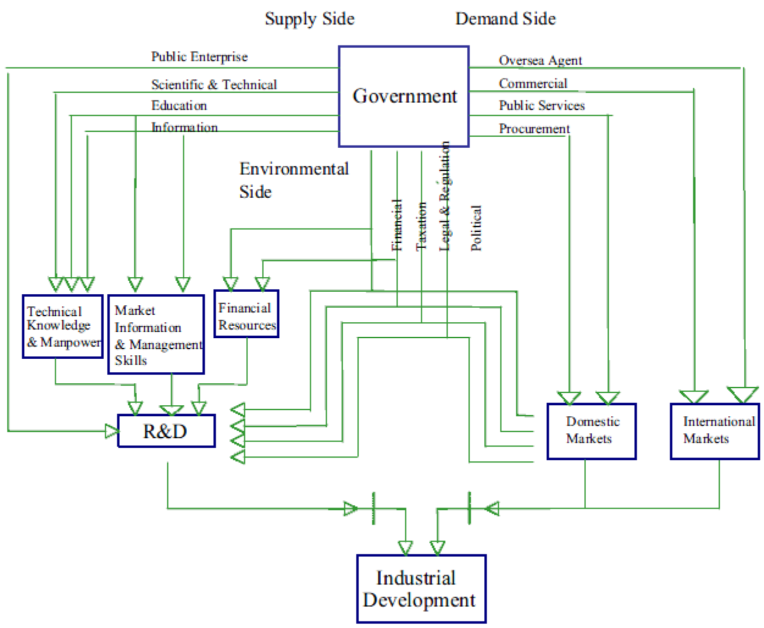


Figure A4: Evolution of Data Rates (Ericsson AB, 2013)

APPENDIX B: Smart Grid Innovation Policies



	Policy tool	Examples
Supply side	Public enterprise	Innovation by publicly owned industries, setting up of new industries, pioneering use of new techniques by public corporations, and participation in private enterprise
	Scientific and technical development	Research laboratories, support for research associations, learned societies, professional associations, and research grants
	Education	General education, universities, technical education, apprenticeship schemes, continuing and further education, and retraining
	Information	Information networks and centers, libraries, advisory and consultancy services, databases, and liaison services
Environmental side	Financial	Grant loans, subsidies, financial sharing arrangements, and the provision of equipment buildings or services, financial loan guarantees and export credits
	Taxation	Company, personal, indirect and payroll taxation, and tax allowances
	Legal regulatory	Patents, environmental and health regulations, inspectorates, and monopoly regulations
	Political	Planning, regional policies, honor or awards for innovation, the encouragement of mergers of joint consortia, and public consultation
Demand side	Procurement	Central or local government purchases and contracts, public corporations, R&D contracts, and prototype purchases
	Public services	Purchases, maintenance, supervision and innovation in health services, public building, construction, transport, and telecommunications
	Commercial	Trade agreements, tariffs, and currency regulations
	Overseas agents	Defense sales organizations

Figure B1: Smart Grid Innovation Policy Framework (Chen-Chun, Chia-Han, & Joseph, 2013)

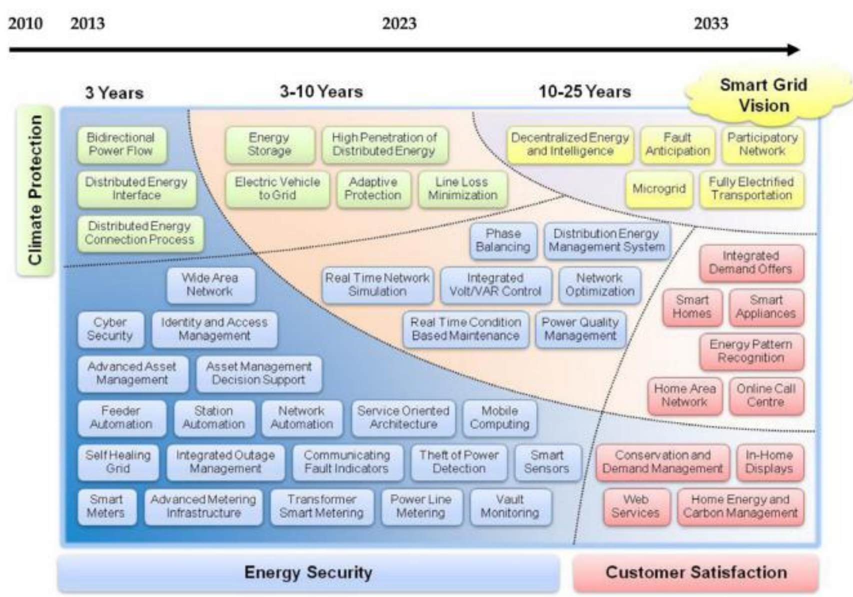


Figure B2: Smart grid vision and applications

Source: Toronto Hydro-Electric System Limited. (2011, August 1). *THESL 2012 GEA Plan*, p. 13.

APPENDIX C: Feedback from Industry Interviews

Concern Area	Environment	Industry	Society
Complex vision must be further simplified, unified, and prioritized with cross-discipline stakeholders	-Reduce total electricity generation needed. -Reduce emissions for needed generation. -Reliable renewable energy enhances energy security, helps reduce fossil fuels extraction, improves environmental conditions, and encourages sustainable development. -Need to work with precautionary principle (reducing adverse climate change impacts, nuclear radiation risks, etc). -Indirect benefits (e.g. more EV adoption saves emissions from transport sector).	-Optimize overall energy use reducing wasteful expansions. -Enable various technology integration, more distributed generation, -Enable a new service sector to install/ maintain/ store/ broker energy, and aggregate loads for utilities. -Better system modeling & forecasting, visibility on distribution, proactive. -Enable DA to boost operational efficiency, QoS, and reduce OpEx through real-time alerts, fault location/isolation, auto-reprovision, self-healing reducing problem resolution from days to hours to minutes to seconds, shift peaks via efficient dispatch control (source/load), and enhance power & service quality. -Flexible Capacity Markets. -Resiliency and redundancy with independent microgrids, large DG & storage. -Smart meters enable IoT.	-New complex society needs addressed (e.g. smart home) Vs old grid built for basic needs decades ago. -Customer awareness on conservation, cost-savings, self-empowerment and control. - Proactive utilities, less/shorter outages, faster resolution times, better customer service.

Table C1: Smart Grid Vision

Smart Grid Development / Policy Area	Supply Drivers	Regulatory Environment	Market Demand
- Stakeholder Involvement - Skills Development	- 360 degree Stakeholder engagement is necessary. E.g. no Telco representation in Smart Grid Forum. - Traditionally isolated industries. - Telcos must spend time to better understand utility requirements. - A cross-discipline collaboration gap exists. Best remain for now unless stronger requirement show otherwise. - Federal/Provincial governments must consolidate efforts. - More field knowledge sharing needed - Cross-disciplinary training only needs to develop the understanding, not experts.	- Unify vision between multiple stakeholders with clear roles and success metrics specifically for ICST as an enabler. - No SILOs in policy development, multi-disciplinary approach needed.	- Business culture changes required (ICST solutions assumed to exist seamlessly) - Telcos can develop the market behind meter e.g. bundled services including remote energy management as a control lever for utility and customers. - Utilities lack the understanding of ICST technologies and how to benefit from them. - Many technology promises, whatever becomes available will guide the smart grid direction.
- Business Case	- What is the business case for Telcos is utilities want to own the infrastructure? O&M? - Utilities challenges by old electricity infrastructure	- Flat Rate option for distribution works against conservation. - What role will LDC’s play? - Need to clarify the LDC business case moving towards smart grid. - More investment on the grid, and less	- For Utilities, ICST is not a core business. - Help utilities understand the potential. - Support for more ICST demonstration projects for

	needing renewal. - Pressure to keep costs down. - The current utility demand for smart grid is not a big business case for Telcos. - Finding the right technology partners who play an active role in the smart grid movement.	customer load with distributed generation and conservation. -Regulation must change the traditional money flow to match smart grid dynamics. - Too many players in the industry. Consider consolidating LDCs for economies of scale. - Tight regulation, no profit, tax payers pay => not sustainable. - Market alone not enough, regulation support needed. - Regulation to provide partnership opportunities. - Regulation to protect Utilities from less regulated Telco industry.	industry confidence. - Public Private Partnerships to create new revenue streams. - Government endorsed implementation timeline for various smart grid enablers and applications.
- ICST R&D, Standards, and PoC Demos	- Approval process for SG Fund is a major obstacle. - Need to put clear priorities on smart grid implementation plan and couple with funding priorities. - Clear focus on ICST and storage as enablers. - 90% should be upstream on R&D and PoC demonstrations	- Consolidate Federal & Provincial support. Smart Grid should be viewed as a nation-wide movement and asset. - The electricity grid is not isolated as experienced in the 2003 blackout. Accessible testbed environment needed. - Policies are made by non-technical people. - Too much bureaucracy. Need a transparent, one-stop project approval process. - All support (e.g. funding) must be out of rate filing. Rate filing system is slow and not flexible. - Regulation does not provide better incentive to use more efficient systems and products Vs cheap non-efficient alternatives. - Renewable penetration must be driven by location-based demand and understanding of the changing FIT portfolio needed by Ontario. - Need more frequent review and steering. - More clarity on who pays for grid connection. - Current policies need more clarity on KPI's expected from Telco/IT partners, and creation of large business opportunities.	- More ICST and storage PoC demonstrations to provide industry confidence. - Solar rooftop potential can boost renewable penetration. - Foster market competition => faster tech adoption. Too much scrutiny is not healthy. - Renewables need economies of scale. More government leadership with solar potential. Put Solar in building code. - Canada needs to step up smart grid acceleration to be a leader not follower - LDCs are under too much regulation with tiny profit margin. Allow for open market, foster competition. - Net Metering program doesn't work. Global Adjustment pushes customers to leave the grid hence less incentive to trade.
- ICST Deployment: *AMI Infrastructure* *Demand Response* Dist. Generation Capacity Markets Dist. Automation	- ICST tech roadmap not clear. - Smart grid initially helped with public awareness on renewable generation, but now too much confusion. - Technology will not lead smart grid movement, customer taste and behavior will. - Smart grid movement not helping to foster innovation because it's not well	- Government endorsed implementation timeline for smart grid enablers and applications. - About 80 LDCs working with competing interests is not efficient - Government direction to replace nuclear generation coming to end of life with more distributed generation. - Telecom sector less regulated. Electric grid is critical infrastructure.	- Market potential not clear, new players? What smart grid will really end up doing? Where to invest? - What will be the real benefit (LDC operational efficiency to reduce costs, or empowering customers to be self-sufficient and depend less on the grid)? - Insurance will change. - Smart grid benefits are not clear to customer. Must

	guided. - Society culture will shape innovation and smart grid just keeps pace.		Engage beyond ToU pricing. - Mismatch between Telco/Utility development cycle (5-10yr Vs 30-40yr). - ICST ownership is better (security). - Telecom/IT is not core business, better to have a strategic partner.
General: (i) Consolidated Federal and Provincial political involvement can go a long way in facilitating support for accelerated smart grid adoption. For example, in US, Federal and state regulatory officials have joined together under DOE sponsorship to form the FERC/NARUC Smart Grid Collaborative. Also, all recipients of DOE's Smart Grid Investment Grants are required to report lessons learnt to develop best practices for iterative maturity (Litos Strategic Communication, 2009). (ii) Public-Private Partnerships for funding and standards development also help boost investor confidence to accelerate smart grid development. The US government's $3.6 billion investment was met with $4.5 billion from private sector (US DoE, 2013). Meanwhile, Whirlpool, the world's largest manufacturer and marketer of major home appliances, plans to make all of its electronically controlled appliances Smart Grid compatible by 2015. The company highlights two key requirements; the development of an open global standard for transmitting signals to and receiving signals from a home appliance, and appropriate policies that reward consumers, manufacturers and utilities for using such systems (Litos Strategic Communication, 2009).			

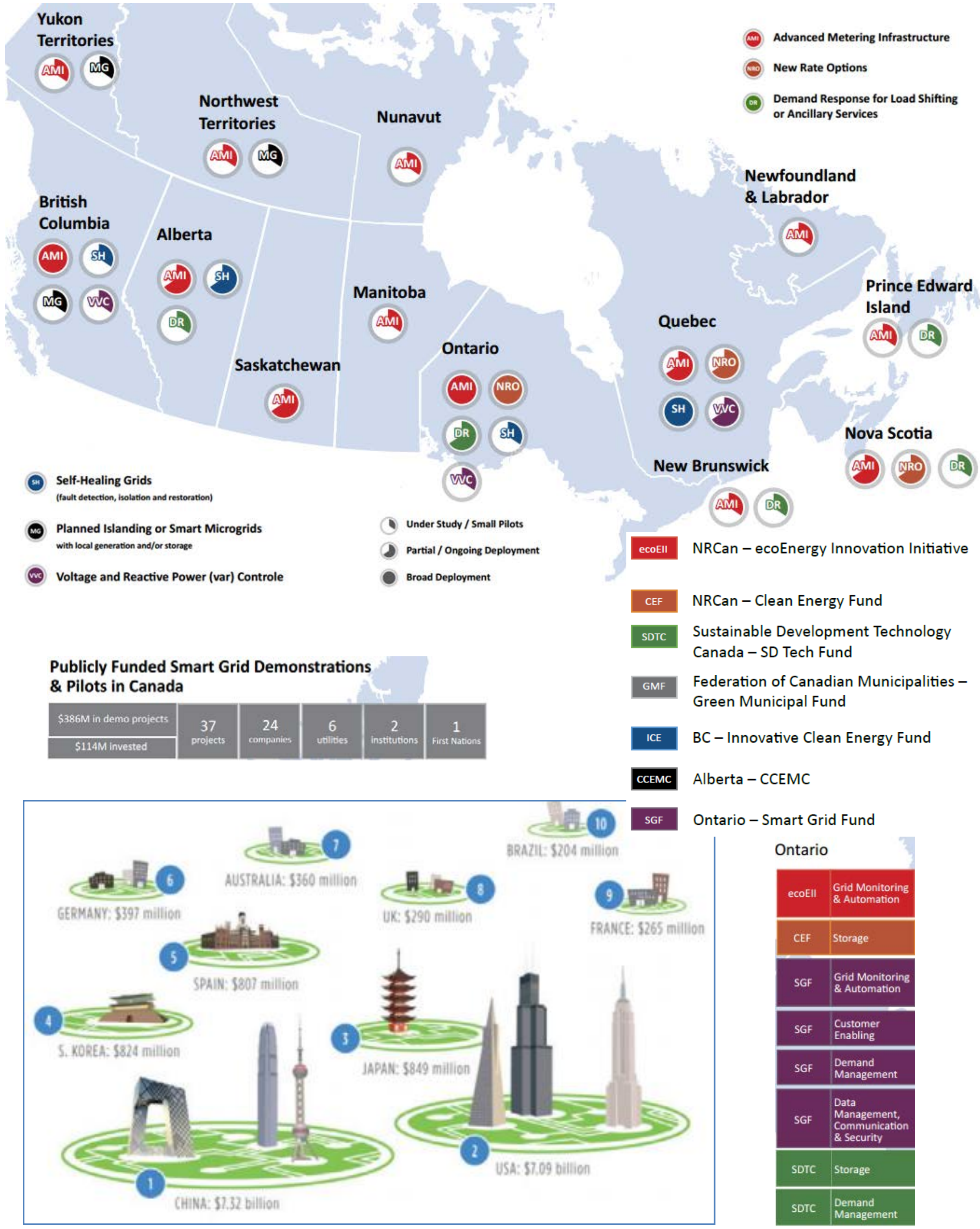
Table C2: Policy Landscape

Technical Area	**Information**	**Communication**	**Security**	**Other**
AMI	Need % utilization trend on current solutions aggregating smart meter traffic.		NERC-CIP addresses utility side. Hard to control behind the meter. Need open standards devices (SG Certified). Privacy by Design	
Demand Response	Survey indicates more customer incentive needed to participate **(ref)**.		Customer resistance to be controlled by utility or other party.	
Distributed Generation	Intermittency creates grid instability, need more modeling and forecasting data analytics.	Dispersed over large geographic area, lack of demand/location coordination.		Needs storage solutions to handle peaks, eliminate variations, and improve power quality.
Capacity Markets	Need real-time analytics and trend analysis to ensure committed demand matching.			
Distribution Automation	Requires efficient communication at NAN, and FAN layers.	Old grid components due for renewal. Need a compatibility path. IEC68150 3ms GOOSE (for teleprotection) difficult to achieve w/o fiber LTE not proven for this yet and evolving. Oversubscribed cells, statistical multiplexing, and mobile overhead create challenges for LTE when scaling to BigData traffic volumes.	No room for error here. Must include reliable security breach or SCADA/GOOSE messaging hack) fall-back procedure.	GIS solutions being used for first step visibility.

Internet of Things	Requires efficient communication at HAN, NAN, and FAN layers.			
Metrics & KPI's	-Need to size data streams and analytical capacity required. -Customer service & awareness. -Optimized energy use.	-Need to size data streams and end-points -Standards compliance. -Operational efficiency improved by alerts and response visibility. -Enable more renewables.	-Need to size data streams and end-points. -NERC-CIP requirements on utility side of meter. -No standards on customer side of meter.	Reliability & Efficiency encompass all objectives.
General		- Utility telecom companies focus on transmission. Not enough expertise. Not regulated by OEB. - Future role of LDC not clear to plan solutions. - Dilemma to Own or Lease / Partner? High CapEx to own, technology changes fast, utilities have no say. Leasing utilizes partner experience, low CapEx, but increase OpEx. Can migrate to Ownership later with good planning.	- Concerned about hacking the core network data and systems than field systems. - New solutions more software intensive (more prone to failure than hardware logic). - Fall-back procedure needed in case of SW failure. Telecom/IT are less regulated (e.g. what if providers are taken over by Chinese giants?)	- SILO planning, design, and operation will not work. - Multidisciplinary Skills are a must.

Table C3: ICST Challenges

APPENDIX D: Smart Grid Funding in Canada



(Hiscock & Beauvais, 2013) and (Briones & Blase, 2012)

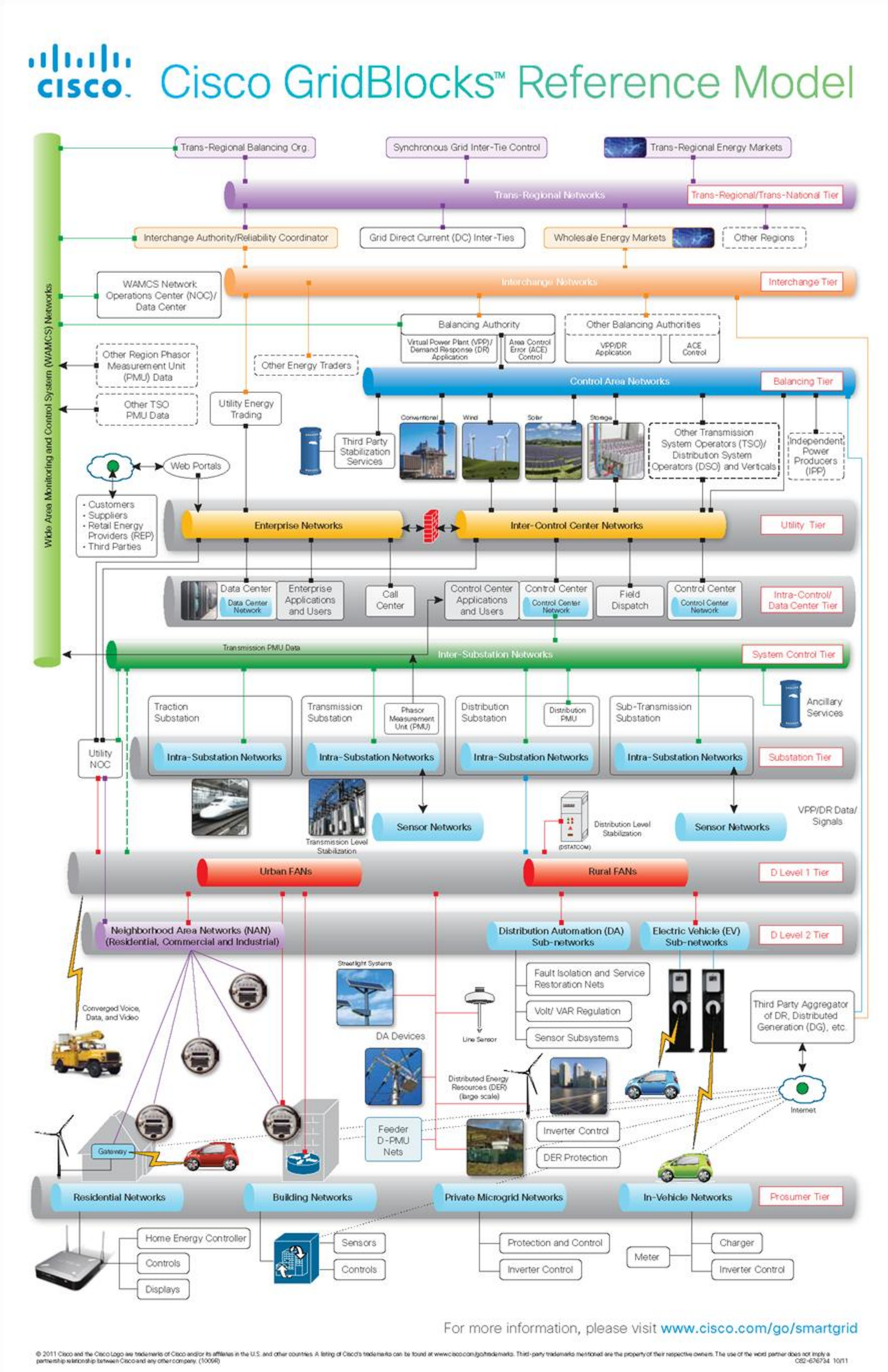
With Government leadership, China has over 287 large-scale demonstration projects at over $9 Billion.

APPENDIX E: Industry Lessons from Smart Grid Implementation

Network Characteristic	Reason
Plan for scalable capacity.	To support the increasing data and information exchange. This can be achieved using a modular and tiered architecture of Access, Distribution, Core, Edge, Remote network segments.
Upgrade to equipment with precision timing, and plan for appropriate network latency.	Critical smart grid components need to be synchronized to a time reference clock to ensure real-time autonomous control is executed safely and efficiently. Appropriate network latency is required to support time-sensitive synchronized data management and system control communication.
Use industry-grade switches and routers	Hardened, robust, vibration resistant, DC/AC power, high processing power, multi-layer redundancy, and multi-open-standard interoperability, as needed in substations, control centres and other areas of the smart grid.
Use switches with flexible port configurations.	To support legacy serial and new IP equipment, along with port density where needed. Support for various Ethernet technologies and interface types (e.g. PoE, SFPs)
Plan to integrate serial equipment with new IP networks.	IP-based networks are the de-facto for any large-scale network given the technology's global dominance, efficiency, vendor support, and cost-effective operation. Using the latest IPv6 addressing system, every device exchanging information or control communication on the smart grid supply and demand side will need an IP address. Some legacy serial equipment need special integration (e.g. serial to Ethernet converters to connect RTUs and Station Control Systems) to be included.
Expect to integrate wireless communication.	Economic viability is a key constraint and wireless solutions e.g. LTE offer fast industry-grade connectivity roll out to millions of customers in a much more cost-effective manner than fiber.
Integrate security (cyber & physical) strategy.	Physical site security avoids direct tampering with equipment using locked cabinets, cages, and data centers with site access protocols. Cyber security prevents access through the network using any connection point to access or inject data, or mimic control signals for malicious intent.
Partner with corporate IT.	Many of the above requirements are mature experiences in the ICST industry. It is imperative that corporate IT becomes a partner in developing the smart grid ICST solutions to avoid reinventing the wheel and learning things the hard way.
Lease or Own Model.	Owning the ICST infrastructure increases security and ensures dedicated capacity, but increases both CapEx and OpEx costs. Ownership also translates to better return on investment (CDG 450 SIG, 2013). Leasing benefits from using specialized ICST partners who can launch projects much faster. This depends on several factors including existing ICST infrastructure, availability of resources (financial and skilled staff), smart grid roll-out time-frame, and the policy environment. Some utilities believe in a transitional model from leasing to ownership, while others are confident the choice dictates a one way path with very high costs incurred for changing later.
Use a work-in-process mindset, not one-time event.	The ICST industry is a high-pace innovative ecosystem where new solutions and modular components continuously emerge. With a carefully planned and prioritized roll out plan, ICST solutions can be built to support the smart grid for a long time and allow for cost-effective incremental expansions when and where needed.

Table E1: Smart Grid ICT Implementation Lessons (Garrettcom - Belden Inc., 2012)

APPENDIX F: Smart Grid Reference Model



APPENDIX G: Key IEA Roadmap Objectives

Expand smart grid collaboration; particularly related to standards and sharing demonstration findings in technology, policy, regulation and business model development.

This roadmap recommends the following actions:	***Milestones***
Governments and industry should evaluate priorities and establish protocols, definitions and standards for equipment, data transport, interoperability and cyber security, and create plan for standards development to 2050.	From 2011 to 2013
Expand collaboration in the development of international standards to reduce costs and accelerate innovation while developing globally accepted standards.	Continue from 2011 to 2050

Smart grid equipment and systems are provided by many industry sectors that historically have not worked together, such as equipment manufacturers, ICT providers, the building industry, consumer products and service suppliers. Control systems operated by utilities whose networks interconnect need to be able to exchange information. Customer-owned smart appliances, energy management systems and electric vehicles need to communicate with the smart grid. Standards, definitions and protocols for transport of data are essential for this complex "system of systems" to operate seamlessly and securely (Figure 14).

This roadmap recommends the following actions:	***Milestones***
Build up commercial-scale demonstrations that operate across system boundaries of generation, transmission, distribution and end-use and that incorporate appropriate business models addressing key issues including cost, security and sustainability.	Concentrated effort from 2011 to 2025

Lead stakeholder	***Action***
Electricity generators	Utilise flexibility and enhancements delivered by smart grids to increase use of variable generation to meet demand growth and decrease emissions.
Transmission and distribution system operators	Develop business models along with government and regulators that ensure all stakeholders share risks, costs and benefits. Lead education in collaboration with other stakeholders on the value of smart grids, especially with respect to system reliability and security benefits. Promote adoption of real-time energy usage information and pricing to allow for optimum planning, design and operation of distribution and transmission systems in a co-ordinated fashion. Demonstrate smart grids technology with business models that share risks, benefits and costs with customers in order to gain regulatory approval and customer support.
Government and regulators	Collaborate with public and private sector stakeholders to determine regulatory and market solutions that can mobilise private sector investment in all electricity system sectors. Recognise that smart grid deployments should reflect regional needs and conditions – a "one-size-fits-all" does not apply to the deployment of smart grids. Plan for evolution in regulation along with technology development – new technologies will both offer and need new regulatory options. Invest in research, development and demonstration (RD&D) that address system-wide and broad-range sectoral issues, and that provide insights into behavioural aspects of electricity use.

Lead stakeholder	***Action***
Consumers and consumer advocates	Develop understanding of electricity system reliability, quality, security and climate change benefits of smart grids. Help develop regulatory and market solutions that share investment risks, costs and benefits with all consumers. Actively engage in developing system demonstrations and deployments in order to ensure consumer contribution to and benefit from future electricity systems and markets, while ensuring consumer protection.
Environmental groups	Support the development of smart grids necessary for a range of clean energy technology deployments such as wind, solar and electric vehicles.
International governmental organisations	Support the RD&D of smart grid solutions for developing countries through targeted analysis, roadmapping exercises and capacity building. Support international collaboration on and dissemination of smart grid RD&D, including business and regulatory experiences.
Technology and solution providers	Deliver full technology solutions to system operators through partnership with others in the value chain to address concerns with technology system integration, long-term post-installation support, and security and reliability. Create a strategy and develop standards in participation with industry and government stakeholders on an international level to ensure interoperability of system components and reduce risk of technology obsolescence.

(IEA, 2011)