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OUR /CDB /USAID-CARCEP/High Commission of Canada
EMERGING REGULATORY ISSUES WORKSHOP
2018 February 6 -7

The evolution of Solar PV technology and its impact on residential and industrial consumption, and possible future technical and economic impacts on utility grid operations.

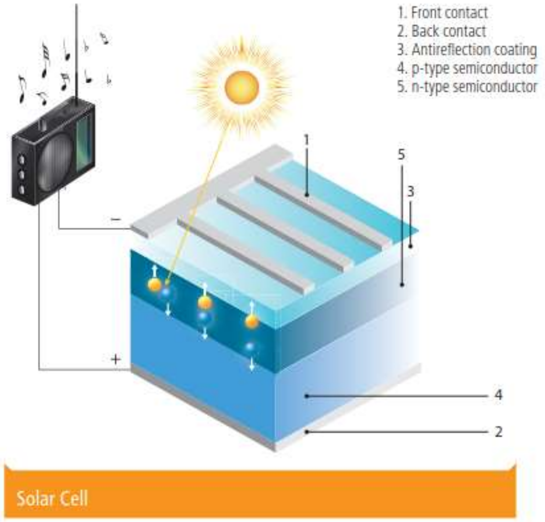
Impact of Solar PV technology on residential and industrial consumption

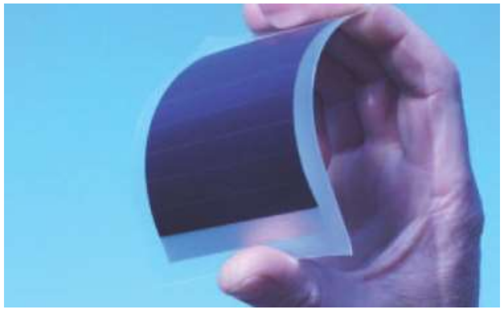
Solar Photovoltaic Technology has over the last 10 years evolved in a number of ways;

- Efficiency moving from 10% to today in some cases 25%
- Capability, initially 150W for a typical panel today 300W
- The pricing has come down as the technology has matured and the suppliers have in some cases increased amid some consolidation.
- Associated infrastructure has also developed adding appeal;
  - Mounting/Racking has developed new and more non intrusive solutions
  - Inverters concepts have moved away from the central inverter to string inverters.
  - Wiring & Combiner Boxes now have arc flash features and are rodent retardant providing a safer work environment.

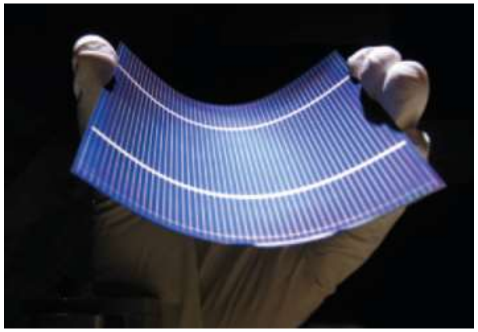
Impact of Solar PV technology on residential and industrial consumption

Solar Photovoltaic Technology has over the last 10 years evolved in a number of ways;





THIN FILM TECHNOLOGIES



WAFER BASED CRYSTALLINE SILICON

Impact of Solar PV technology on residential and industrial consumption

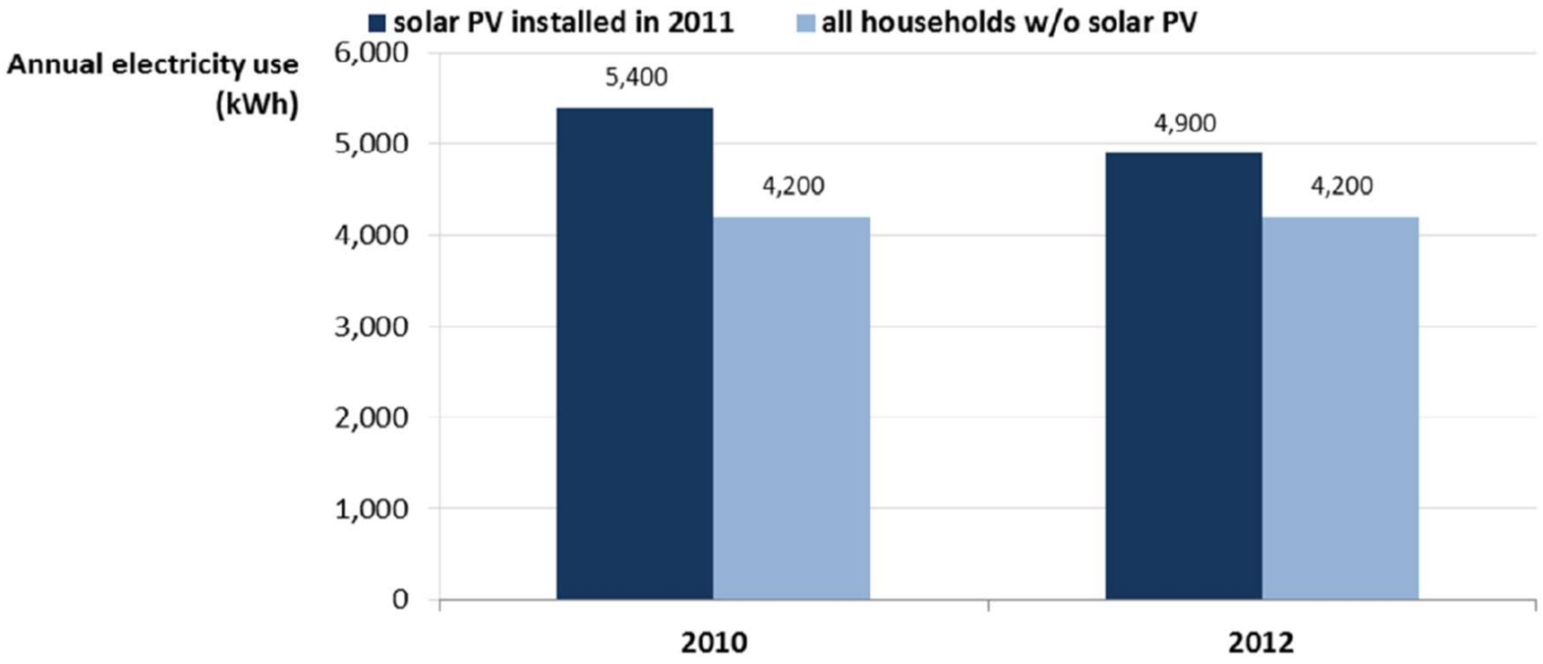
- Study done in the UK between 2005 - 2012, highlighted the immediate impact solar pv had on properties.

- Between 2010 -2012,after the installation of solar PV,;
  - **the gap in electricity consumption between properties with and without solar PV narrowed considerably, to 16 per cent.**
  - **Between these two years, electricity consumption in FIT households decreased substantially, by an average of 9.5 per cent (median: 13.2 per cent).**

- **Households with higher initial energy consumption achieved a higher reduction in kWh terms,** but not as a percentage of initial consumption.
  - **property size has an impact on the rate of reduction in consumption: e.g. larger properties had a smaller percentage reduction in consumption between 2005 and 2012 than smaller properties**

UK Study 2005 - 2012

Impact of Solar PV technology on residential and industrial consumption



UK Study 2005 - 2012

Impact of Solar PV technology on residential and industrial consumption

- ***The results suggest that the installation of solar PV panels contributes to a substantial reduction in electricity usage from the grid, in excess of the slight but consistent decreases in year-on- year electricity usage figures that appear in all households***

UK Study 2005 - 2012

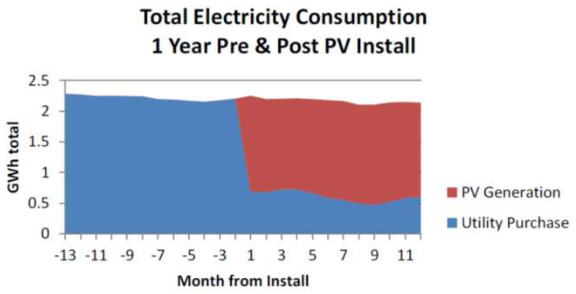
Impact of Solar PV technology on residential and industrial consumption

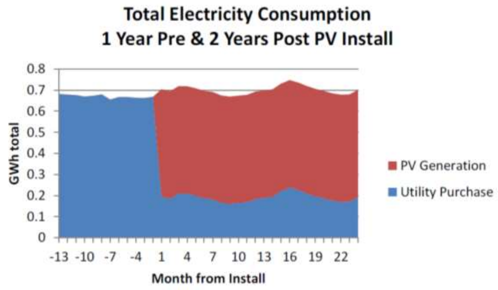
Examples of installations in Toronto

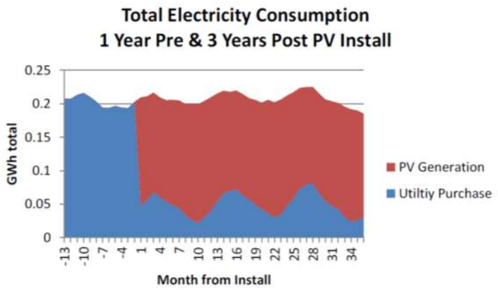
Impact of Solar PV technology on residential and industrial consumption

The three graphs show pre- and post-installation aggregate consumption and PV generation for the adopter groups for which one, two and three years, respectively, of post-installation utility consumption information was available.

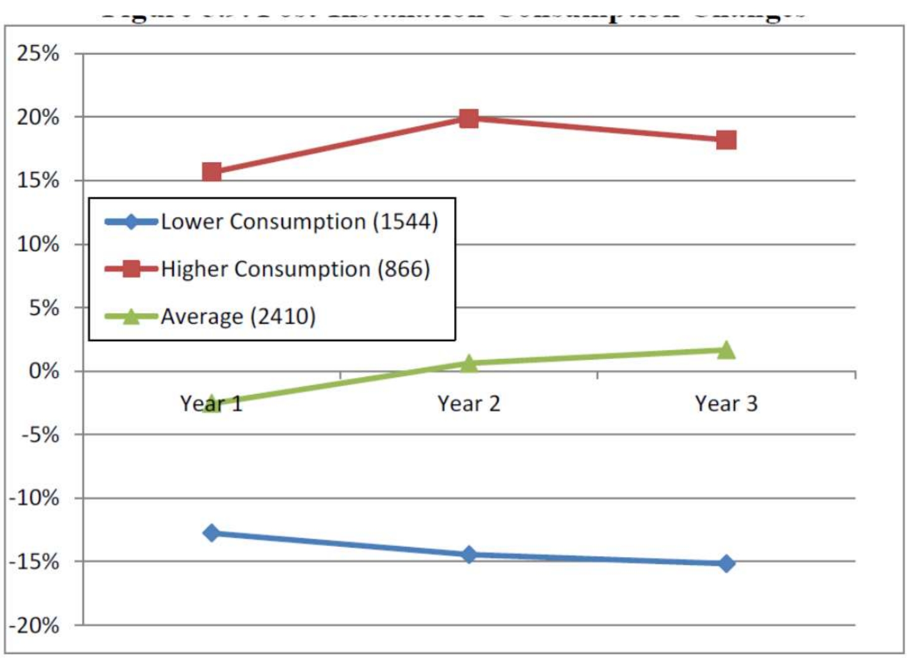
Focus on 12 months, 2410 systems.







Impact of Solar PV technology on residential and industrial consumption



Solar Adoption and Energy Consumption in the Residential Sector

Is there a relationship between system sizing and post-installation consumption?

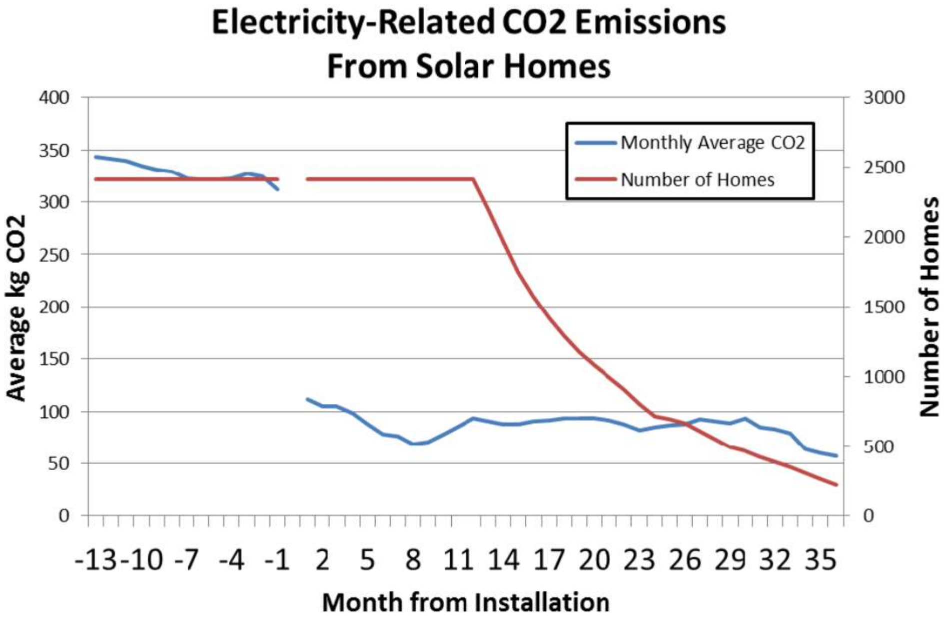
- we see that adopters of smaller systems—meaning ones sized to offset less of the customer’s utility consumption—have a greater tendency to decrease consumption after installation;
- Those installing larger systems tend to increase consumption.
  - Homeowners planning efficiency measures along with their solar installation would likely account for this when purchasing the PV system.
  - Those more interested in covering most or all of their consumption may not be interested in reducing consumption, or may also be involved in home expansion or other energy intensive activities, for which they also may be planning.

Impact of Solar PV technology on residential and industrial consumption

Net Energy Example

	Morning	Mid-Day	Early Evening	Night	Total Net energy consumed for one day
Solar Energy Generated (kwh)	2	3	4	0	
Energy Consumed(kwh)	4	3	4	5	
Net Energy Consumed (kwh)	2	0	0	5	7

Impact of Solar PV technology on residential and industrial consumption



Solar Adoption and Energy Consumption in the Residential Sector

The carbon reduction impact of solar adoption for individual users is dramatic.

- Figure shows the monthly average CO2 emissions for the 2,410 homes for which at least one year of pre- and post-installation consumption data were available.
- Emissions were reduced by 72%, from over 300 kg CO2 per month per home to under 100.

Impact of Solar PV technology on residential and industrial consumption

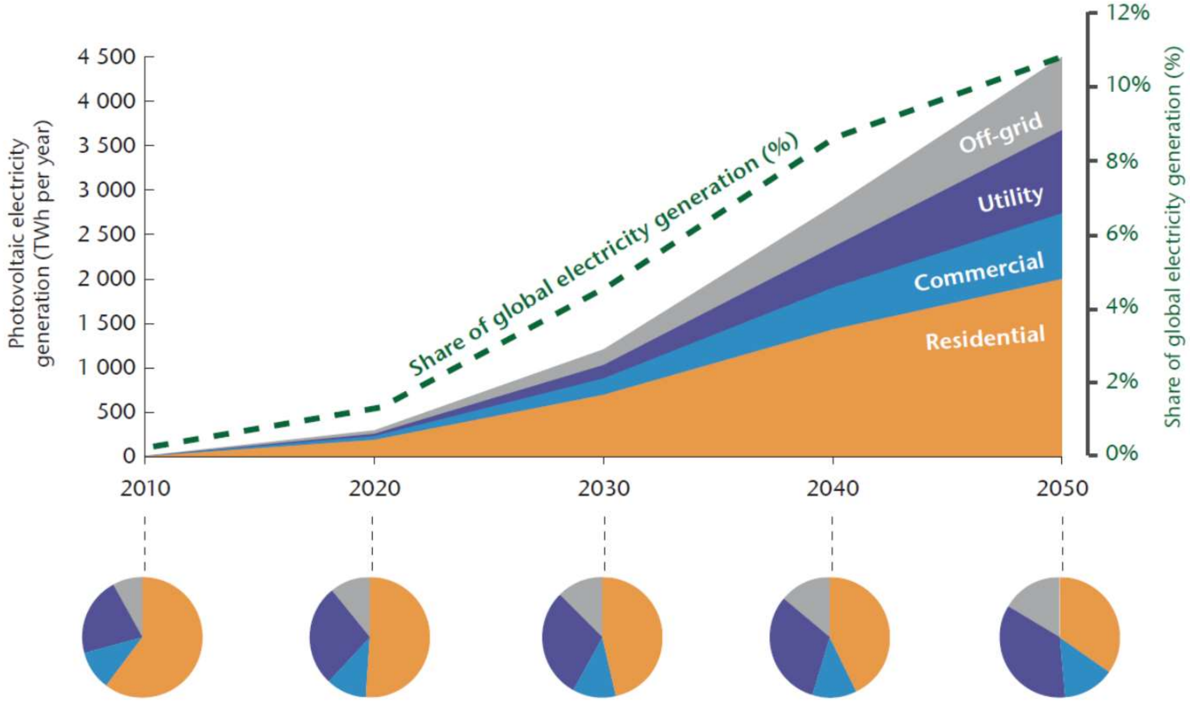
Examples of installations in Toronto

Technological and Economic Impact of Solar PV on Grid Operations

- Solar energy is the most abundant energy resource on earth.
- The solar energy that hits the earth's surface in one hour is about the same as the amount consumed by all human activities in a year.
- Three main solar active technologies are;
  - Direct conversion of sunlight into electricity in PV cells
  - Concentrating solar power (CSP)
  - Solar thermal collectors for heating and cooling (SHC).
- PV provides;
  - 0.1% of total global electricity generation today
  - 5% of global electricity consumption in 2030
  - 11% in 2050

Technological and Economic Impact of Solar PV on Grid Operations

Evolution of photovoltaic electricity generation by end-use sector



Source: IEA analysis based on survey reports of selected countries between 1992 and 2008, IEA PVPS, and IEA 2008 (ETP).

Technological and Economic Impact of Solar PV on Grid Operations

PV capacity (GW)	2010	2020	2030	2040	2050
Residential	17	118	447	957	1380
Commercial	3	22	99	243	404
Utility	5	49	223	551	908
Off-grid	2	21	103	267	463
Total	***27***	***210***	***872***	***2019***	***3155***

Cumulative installed PV capacity (GW) by end-use sector

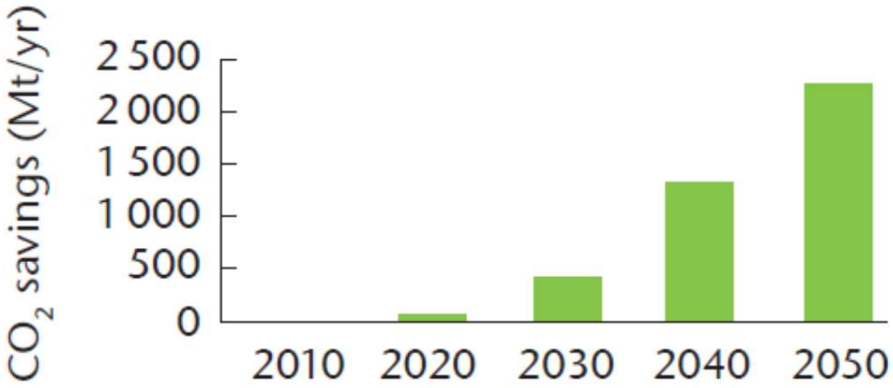
Technological and Economic Impact of Solar PV on Grid Operations

- Homeowners that install solar PV are, in most places, shifting the cost of this infrastructure to ratepayers that have not installed solar panels. There is thus the potential to create a type of “_Death Spiral.”
  - The more homeowners that install rooftop solar, the more expensive the grid maintenance costs become for everyone else, which in turn encourages more homeowners to install solar panels to avoid higher utility costs.

- In the near term, states with high penetration of rooftop solar may need to restructure how the grid is paid for.
  - This technology will eventually force a conversation about the fundamental role of the electric utility and who should have ultimate responsibility for providing reliable electricity, if anyone.
  - Going off the grid has a certain appeal to an increasing segment of the population, but it is far from clear that such a distributed system can deliver the same level of reliability at such a low cost.
  - The utility must be kept financially whole to be allowed to play its role.

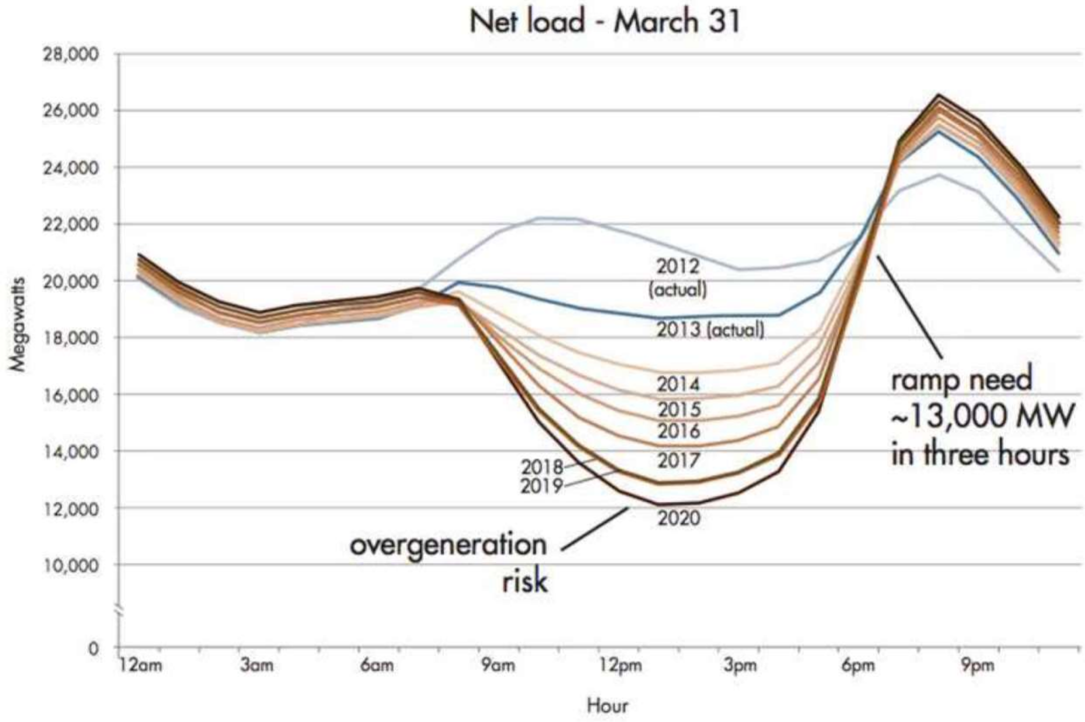
Technological and Economic Impact of Solar PV on Grid Operations

- The deployment of PV will contribute significantly to the reduced carbon intensity of electricity generation.
- The 4 500 TWh generated by PV in 2050 is expected to save 2.3 Gt of CO2 emissions on an annual basis.



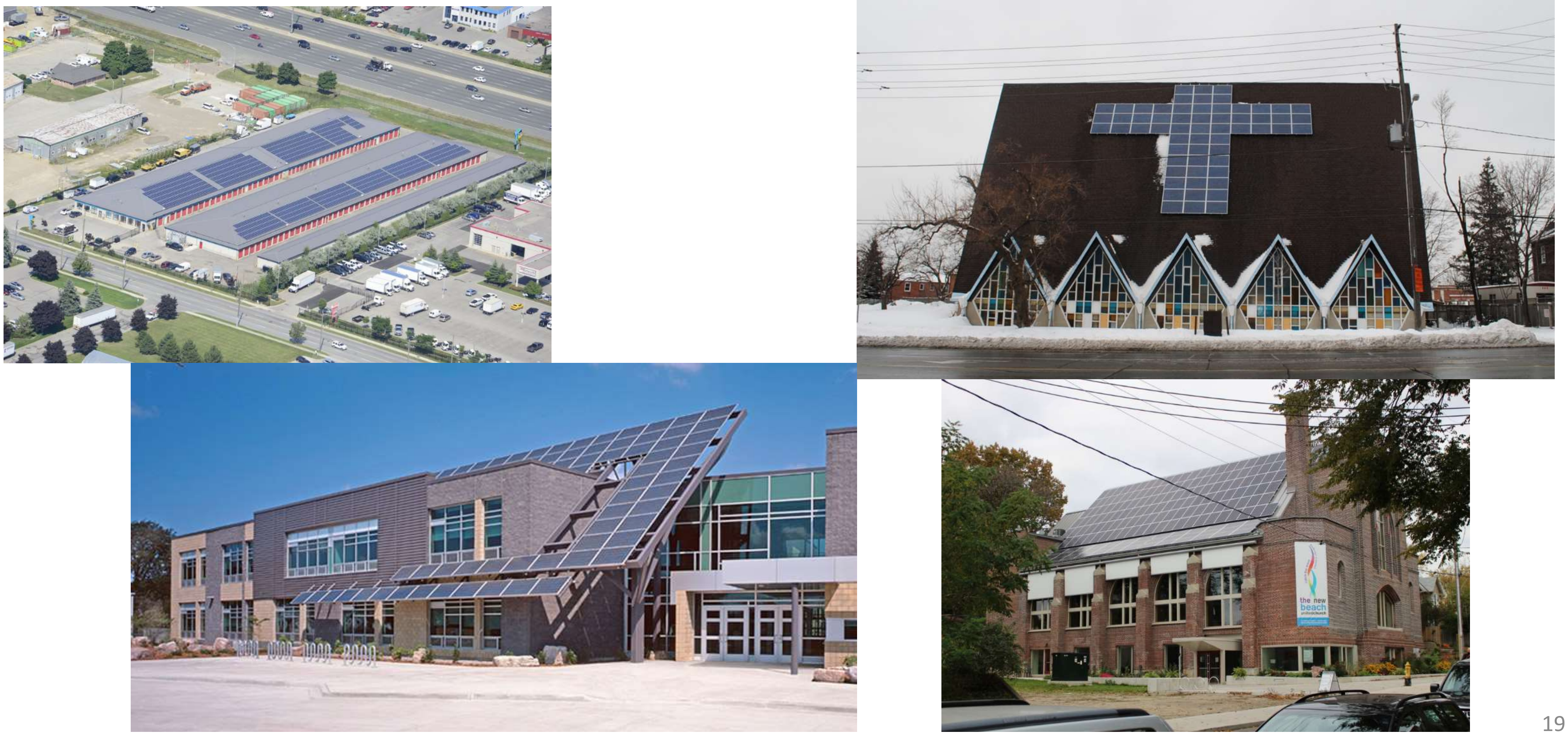
Annual CO2 emissions avoided through PV

Technological and Economic Impact of Solar PV on Grid Operations



This famous graph, called the duck curve, shows how rooftop solar panels are supplying so much power during the day that the demand on central power generators is falling dramatically. California ISO

Impact of Solar PV technology on residential and industrial consumption



Examples of installations in Toronto

Technological and Economic Impact of Solar PV on Grid Operations

Grid Resiliency

- Distributed solar photovoltaic (PV) systems have the potential to supply electricity during grid outages resulting from extreme weather or other emergency situations.
  - Distributed PV can significantly increase the resiliency of the electricity system.

In order to take advantage of this capability, however, the PV systems must be designed with resiliency in mind and combined with other technologies, such as energy storage and auxiliary generation.

- Electricity System Resiliency Focuses on:
  - **Prevention** of power disruption
  - **Protection** of life and property dependent on electricity service
  - **Mitigation** to limit the consequences of a power disruption
  - **Response** to minimize the time needed to restore service
  - **Recovery** of electricity supply.

Technological and Economic Impact of Solar PV on Grid Operations

Grid Resiliency

- For safety reasons, current operating standards require that grid-connected solar PV systems automatically disconnect from the grid during a power outage. (Anti Islanding)

- Systems not designed to function as both a grid-connected and a standalone system.
  - Most PV systems in place today are not coupled with batteries or an auxiliary power source (such as a diesel generator) to allow them to provide continuous power to a load.

Designing a PV system for standalone operation and adding batteries and/or an additional generating resource allows it to produce power even when the grid is down, offering resiliency during an emergency.

Technological and Economic Impact of Solar PV on Grid Operations

Solar PV with Energy Storage

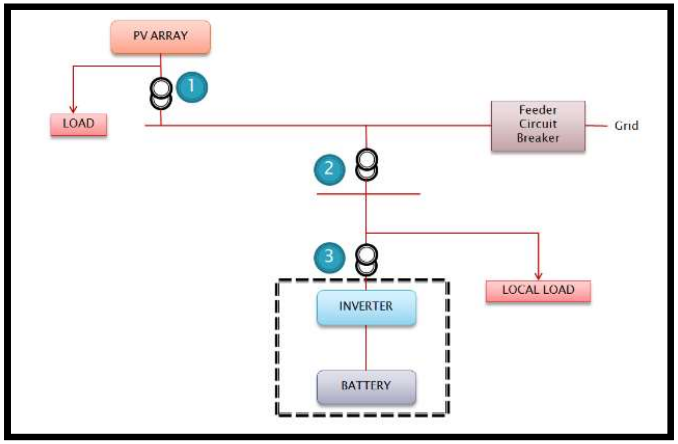
- As interconnection policies and incentives for energy storage gain attention, it has become apparent ;
  - *that it is important to be able to distinguish whether an energy storage unit is being charged with electricity generated by a distributed solar system or with grid power.*
- Energy arbitrage refers to the practice of storing electricity during periods with low energy prices and discharging it at periods with high energy prices.
  - Customers with solar systems can install battery units with the intent of saving excess electricity from their solar system. But the same batteries could also be charged using electricity from the grid.

  - This means that, in the absence of controls, electricity could be purchased from the grid, stored, and sold back to the grid for a higher price than it was purchased.
  - Without metering controls, it is impossible to confirm whether the electricity being discharged from the battery originated from the grid or from the customer's solar panels.
  - Specific bi-directional micro processor based metering is what is required.

Technological and Economic Impact of Solar PV on Grid Operations

Solar PV with Energy Storage

-Project Size: 75kWac / 90kWdc
-Project Production: ~100MWh annually



Supervisory Predictive Grid Control

Active Power Control
- Power curtailment
- Frequency response
- Ramp rate control
- Start/stop

Optimization
Forecasting
Modeling

Automatic Voltage Regulation
- Voltage control
- Power factor control
- Reactive power control
- OLTC control
- Capacitor/inductor control

IEC 61850, Modbus RTU & TCP, DNP3, IEEE C37.118
WiFi, PLC, Radio, GSM, T1/56k

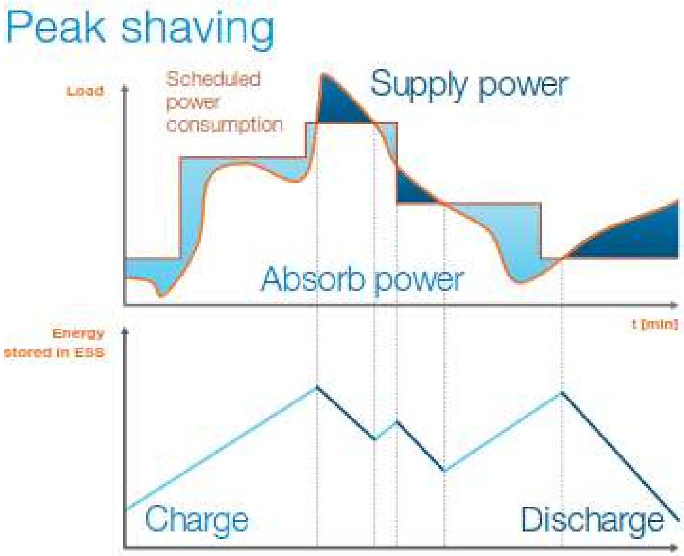
- Li-Ion Battery Energy Storage System
  - Outdoor Pad Mounted
  - 500 kW/250 kWh
  - 600/347 V, 3-phase
- Eaton AC/DC inverter
  - Outdoor Pad Mount
  - 500 kW
  - Voltage Range 432-605 VDC

Technological and Economic Impact of Solar PV on Grid Operations

- Given its variable, non-dispatchable nature in distributed applications, PV presents new challenges for grid integration
- with an increasing number of PV systems in place, interconnection and load management will become important issues
- Grid planning and management also bring opportunities.
    - For instance, PV can reduce critical summer load peaks in some regions, reducing the need for high-cost peak generation capacity and new transmission and distribution investments.

Technological and Economic Impact of Solar PV on Grid Operations

- Energy Storage can be implemented in conjunction with the solar pv
- Benefits:
  - Emergency backup, electrify your home if it doesn't have a grid connection
  - Save by offsetting peak electricity prices



Technological and Economic Impact of Solar PV on Grid Operations

- In order to accommodate an increasing share of variable PV, a higher degree of system flexibility is required. This will require new ways of thinking about;
  - how electricity is generated and distributed
  - development of new technologies that make it simple, safe, and reliable for solar electricity to feed into the grid.
    - *For example, Smarter inverters, monitoring and control devices*
  - Flexibility can be increased both through market and transmission

Flexibility refers to the amount of quickly dispatchable capacity – generation, interconnection and storage – that is available to respond to fluctuations in supply and demand.

Source: Empowering Renewable Energies – Options for Flexible Electricity Systems, IEA 2008. optimisation measures.

Technological and Economic Impact of Solar PV on Grid Operations

- Market measures include expanding markets to smooth overall variability and implementing demand response measures that better match demand with supply.
  - *For example tools that have enhanced predictability algoritms that allow for predicting solar production and load development*
- Transmission optimisation measures include improved interconnection and adoption of advanced transmission and management technologies, including;
  - smart grids
  - metering
  - enhanced energy storage.

Source: Empowering Renewable Energies – Options for Flexible Electricity Systems, IEA 2008. optimisation measures.

Technological and Economic Impact of Solar PV on Grid Operations

Distributed Generation
Energy Storage

ecamion

Finding Resilience

Revitalizing the Caribbean energy system with energy storage

Who We Are

Founded in **Ontario, Canada** in 2009

Over 20 MWh in energy storage solutions installed

$70+ Million projects delivered or in development

ecamion

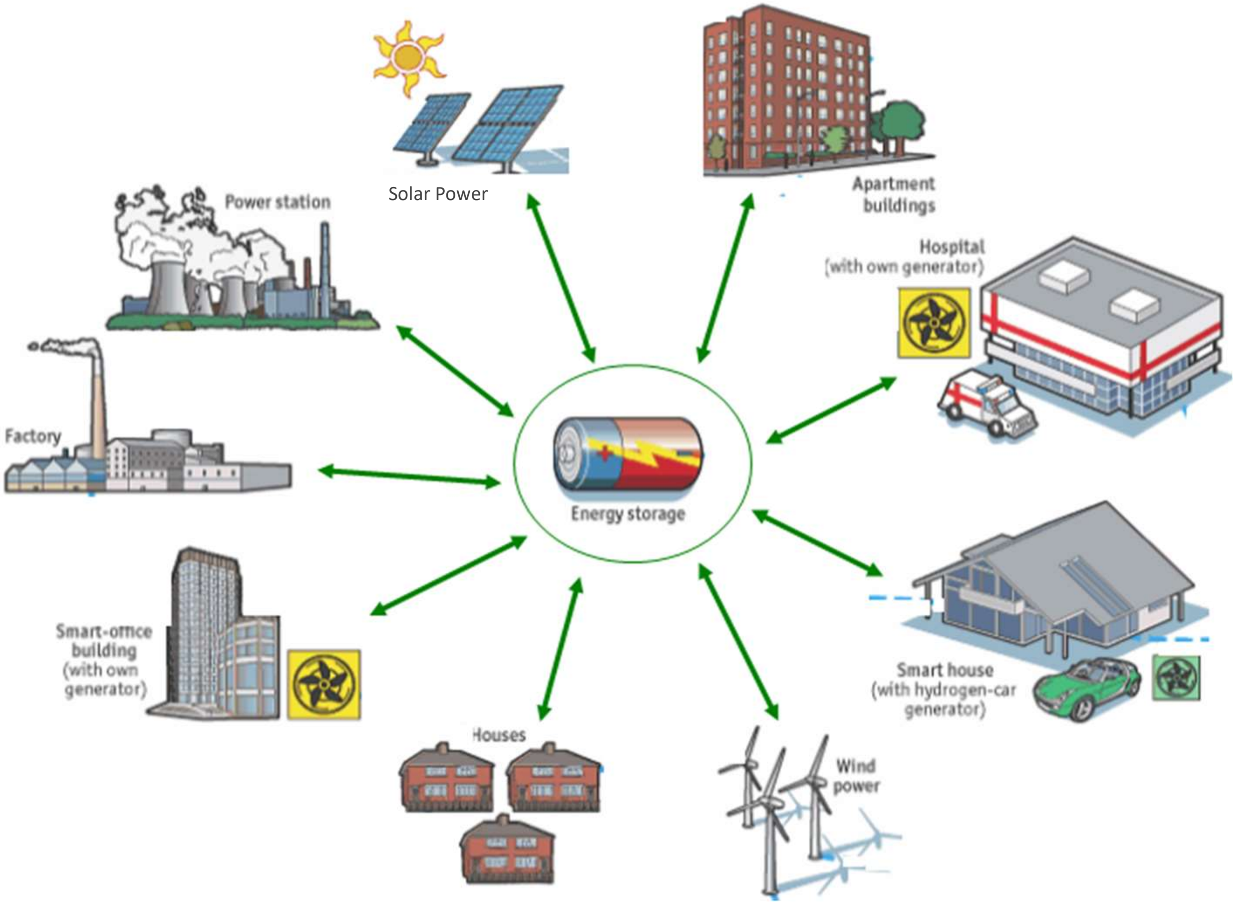
POWER OVER ENERGY

Privately owned, partially held by the **Government of Canada**

30 **energy storage projects** currently in deployment across **North America**

70 more projects **in progress**

Energy Storage: Applications



Our Solutions

eCAMION's energy storage solutions

Community Energy Storage

Stabilizes demand on the electricity grid and ensures quality of power

Pole-Mounted Energy Storage

A first-of-its-kind initiative to provide stable power support from hydro poles

Anti-Idling Solutions

Reduce greenhouse gas emissions from fleet vehicles.

Electric Vehicle Charging

Enable fast and versatile charging services.

Renewables Integration

A Puerto Rican solar company discovered that, in the wake of the 2017 Hurricane Maria, only **10-15% of their solar installations** were affected compared to **80% of transmission lines** that were taken down.

However, since these renewable systems were **connected to the grid**, they could not be operated due to grid damage.

Renewable Integration Challenges

Cost of large-scale installations

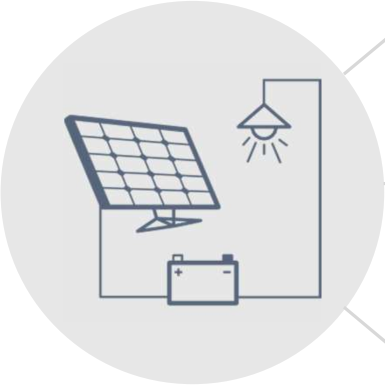
Inconsistent generation ability

Difficulty integrating to grid

Renewables Integration

eCAMION's energy storage stations can be used as grid support to **reduce the volatility placed on existing solar infrastructure**, by capturing excess energy generated in the day and making them available to be used at night.

How energy storage enables efficient renewable energy generation



- **Increases the efficiency** of each solar installation, reducing the total system capacity needed
- Allows Caribbean nations to take advantage of their abundant sun and wind resources **without large-scale infrastructure investment**
- Provides a reliable, **grid-independent source of energy**

Electric Vehicle Adoption

Canada’s EV Adoption Problem

The Canadian government has supported electric vehicle use by granting subsidies and attempting to install more stations. However, EV adoption has remained stagnant for various reasons:

Inaccessible Public Charging

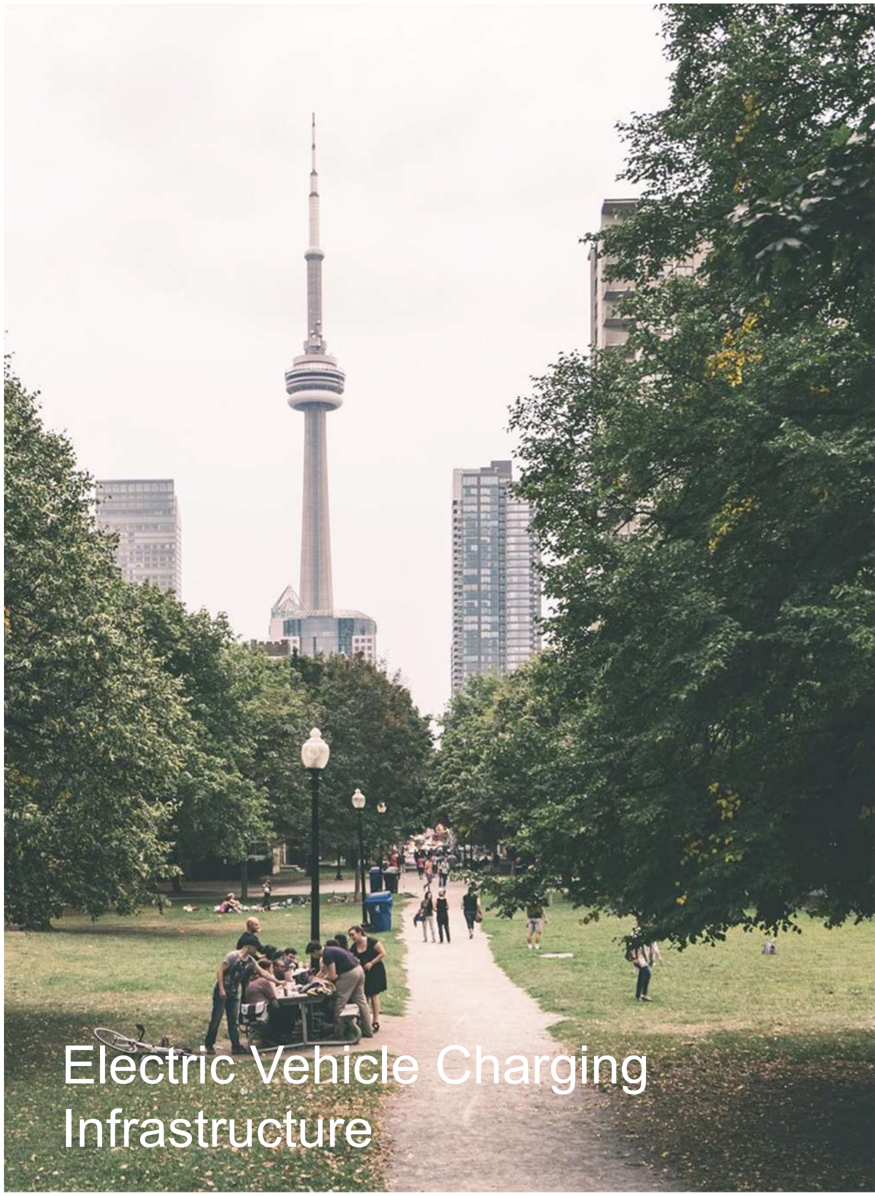
Currently, the most common charging type in Canada is Level 2, which takes 3-8 hours for a full charge. This is inconvenient while on-the-go and discourages drivers from switching to electric

High Charger Power Demands

Due to the high, sporadic power requirements of electric vehicle charging, it is difficult to install stations in high-density areas such as urban centres. In addition, it is difficult to install fast-charging stations as they require even more power.

Costly Grid Upgrades

In order to update the grid to accommodate the demand placed by electric vehicle charging, utility companies must undergo large-scale infrastructure upgrades, which are time-consuming and expensive.



Electric Vehicle Charging Infrastructure

Electric Vehicle Adoption

The eCAMION Solution

eCAMION's charging stations circumvent key grid restrictions because of their battery component, which allows stations to provide high-speed charging without straining the utility grid.

✓ Enables High-speed Charging

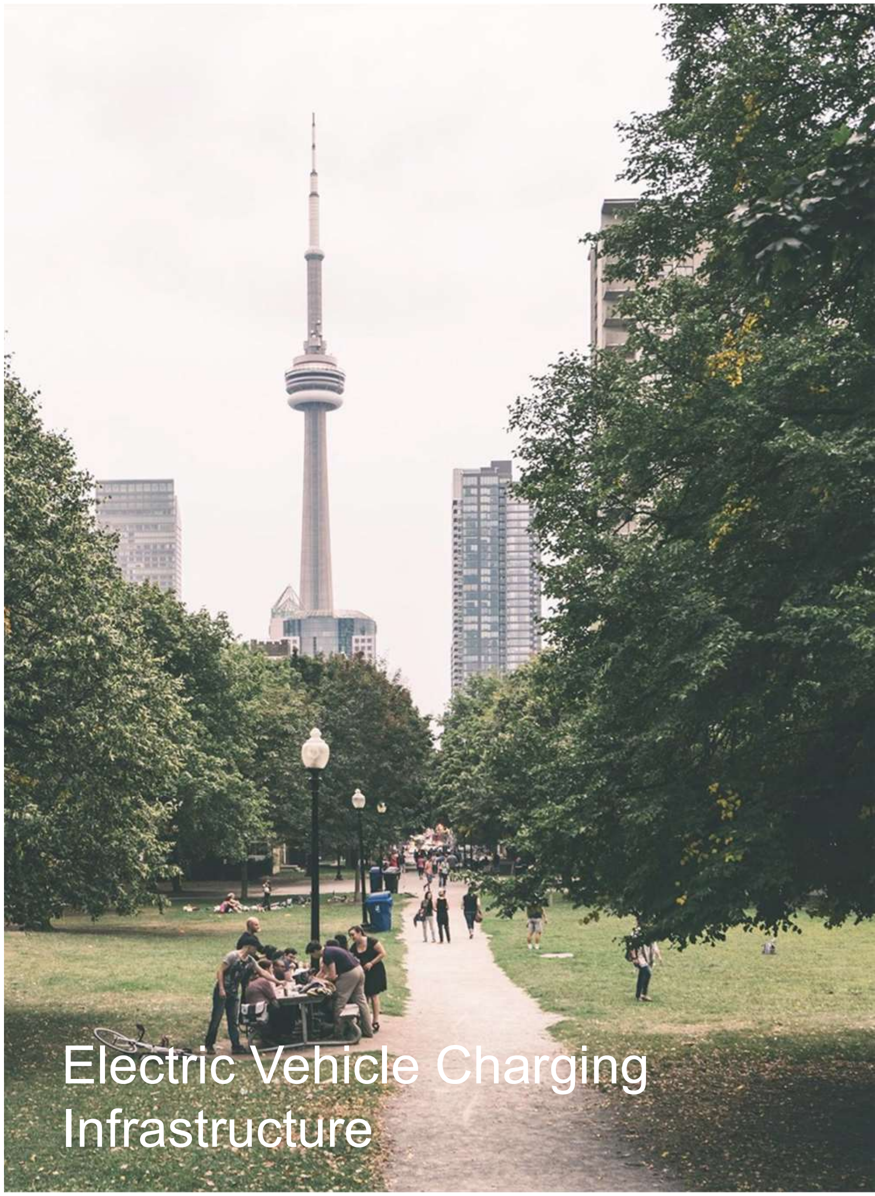
eCAMION's energy storage-supported stations can provide fast, "Level 3" (25 minutes to full charge) discharge without placing high demands on the grid. Thus, these stations can be installed in high concentrations all across the country.

Flexible, Scalable Integration

The storage stations supporting each charging station can be easily relocated depending on where and when there is high demand. In addition, the capacity of these storage systems can be easily increased, which accommodates a future where EVs are used more frequently

$ Targeted & Cost Effective

Storage stations provide support for the grid wherever needed - utilities do not have to make large-scale infrastructure changes. In addition, these stations are easy to install and relocate, allowing for fast setup and operation.


Electric Vehicle Charging Infrastructure

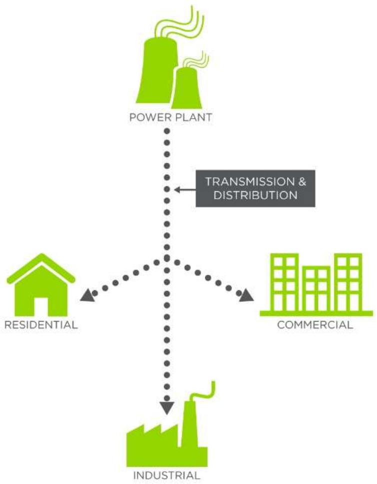
Technological and Economic Impact of Solar PV on Grid Operations

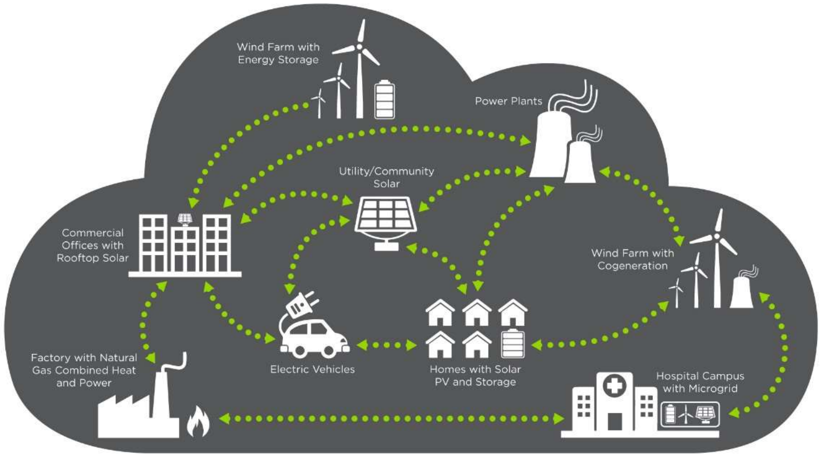
Energy Centre Concept

Source: Autogrid

Technological and Economic Impact of Solar PV on Grid Operations

Future


TODAY: ONE-WAY POWER SYSTEM


EMERGING: THE ENERGY CLOUD

Technological and Economic Impact of Solar PV on Grid Operations

Summary of proposed actions- Governments

- Establish market support mechanisms to achieve grid competitiveness – to be phased out over time.
- Develop regulatory framework preparing large-scale integration of PV into the grid.
- Facilitate internalisation of external costs of energy for a more level playing field.
- Streamline building codes and standards for PV products and interconnection rules.
- Set energy standards that account for solar building regulations and obligations.
- Increase R&D funding to accelerate cost reductions and efficiency gains.
- Improve educational/outreach programmes on environmental advantages of PV.

Technological and Economic Impact of Solar PV on Grid Operations

Summary of proposed actions - Universities

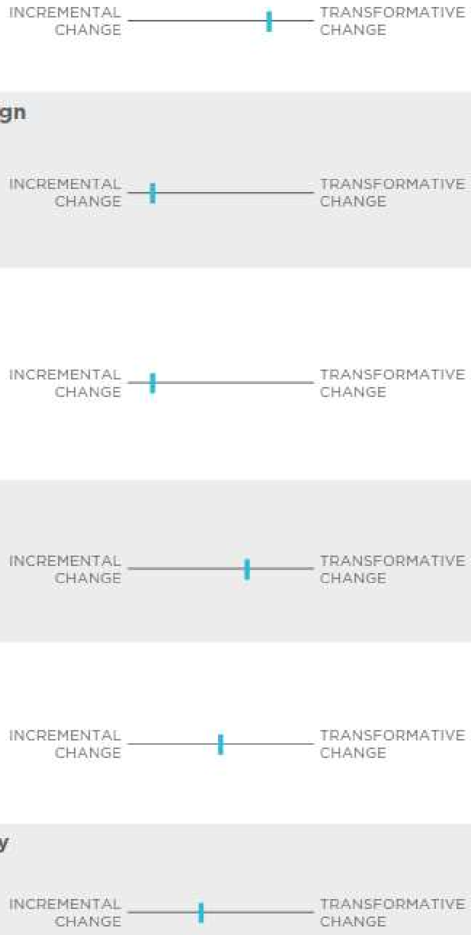
- Identify PV educational development/training needs for important areas like small-scale system installation and grid connection; develop training plans/grants for universities.
- Develop national PV technology RD&D roadmap that identifies pathways to achieve critical longer-term technology breakthroughs.

Technological and Economic Impact of Solar PV on Grid Operations

Summary of proposed actions- Utilities and other market stakeholders

- Develop business models for end-users and rural electrification.
- Streamline building codes and standards for PV products and interconnection rules.
- Support training and education for skilled workforce along the PV value chain; technology outreach to target audiences/stakeholders.
- Deploy smart grid technologies and grid management tools.

Degree of Change Reflected in the Current State



Retail Market Design

- Retail choice provides options, but more is needed
- At >5% NEM, DER customers can get compensated for locational, temporal, and performance-based value to the grid
- AMI enables transformative rate plans (e.g., ComEd PJM hourly energy pricing)

Wholesale Market Design

- Ongoing work in PJM, MISO regarding DER participation
- DER role limited by classifications, especially for storage
- Behind-the-meter resources not yet included

Utility Business Model

- Traditional cost of service dominates
- But performance-based formula rates introduced and ComEd has embraced a "utility as a platform" model
- New approaches tested through smart grid initiatives
- Future DER rebates may be treated as virtual regulatory assets (like energy efficiency), earning a return

Rates and Regulation

- Myriad rate plans—ComEd residential customers, e.g., have 94 rate plan options
- ICC NextGrid initiative: Collaborative process seeking "21st Century Regulatory Model"

Asset Deployment

- Significant upgrades in distribution systems
- Projects include distribution automation, communications infrastructure, substation metering, smart switching on high-voltage distribution lines, and smart grid test beds
- Smart meters across ComEd and Ameren territories by 2018 and 2019, respectively

Information Technology

- Distribution automation, data-sharing programs, and enabling secure communications networks

Sources: SEPA; ScottMadden

Example; Illinois electric utilities developed programs that facilitate current and future integration of DERs and renewables

Technological and Economic Impact of Solar PV on Grid Operations

The four main areas of policy intervention include:

- Creating a policy framework for market deployment, including tailored incentive schemes to accelerate market competitiveness
- Improving products and components, financing models and training and education to foster market facilitation and transformation
- Supporting continuing technology development and sustained R&D efforts to advance the cost and efficiency improvements outlined above
- Improving international collaboration to allow for accelerated learning and knowledge transfer to emerging and developing countries

Technological and Economic Impact of Solar PV on Grid Operations

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