MICROGRID TECHNOLOGIES & THEIR IMPACTS

The State of Development of DER and the Factors Affecting their Integration into the Utility Sector

Dan McGillivray, Ph.D., April , 2016

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Outline

1. Introduction: *Drivers of change…*
2. The State of Development of DER Technologies & Microgrids
3. The Costs of DER Technologies
4. Problems DER Solve & the Problems they Pose
5. Conclusion:

Drivers of Change in Ontario's Energy Sector

- **Age** Workforce & Infrastructure
- Supply & Demand
- Negative & Rising Prices
- Culture of Plenty & NIMBY
- Climate Change
- Oil & Gas Abundance
- COP21
- Smart Meters Smart Grid
- Renewables (intermittent)
- Energy Storage & EVs
- Pace of Innovation
- Pace of Regulation
- Innovation Economics & Politics
- DER grid parity & load defection

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Distributed Energy Resources (DER) defined by the NY REV (2014)

DER technologies are defined as “behind-the-meter” power generation and storage resources typically located on an end-use customer’s premises and operated for the purpose of supplying all or a portion of the customer’s electric load. Such resources may also be capable of injecting power into the transmission and/or distribution system, or into a non-utility local network in parallel with the utility grid.

These DERs include such technologies as solar photovoltaic (PV), combined heat and power (CHP) or cogeneration systems, microgrids, wind turbines, micro turbines, back-up generators and energy storage.

Some, including the New York Public Service Commission (PSC), have defined DERs more broadly to include energy efficiency and demand response.

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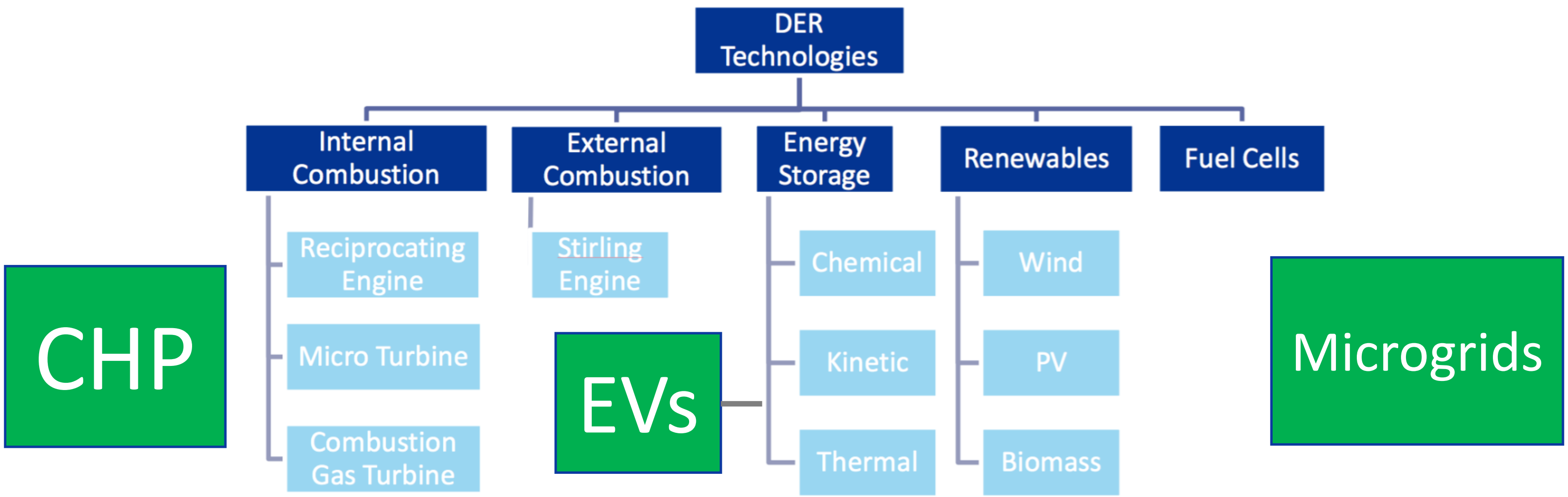
The State of Development of Distributed Energy Resource (DER) Technologies



Microgrids are defined by their function, not their size.

Most microgrids can be described by one of five categories:

1. **Off-grid microgrids** including islands, remote sites, and other microgrid systems not connected to a local utility network.
2. **Campus microgrids** that are fully interconnected with a local utility grid, but can also maintain some level of service in isolation from the grid, such as during a utility outage. Typical examples serve university and corporate campuses, prisons, and military bases.
3. **Community microgrids** that are integrated into utility networks. Such microgrids serve multiple customers or services within a community, generally to provide resilient power for vital community assets.
4. **District Energy microgrids** that provide electricity as well as thermal energy for heating (and cooling) of multiple facilities.
5. **Nanogrids** comprised of the smallest discrete network units with the capability to operate independently. A nanogrid can be defined as a single building or a single energy domain.

http://www.microgridinstitute.org/about-microgrids.html

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Estimating the costs of DER Technologies is complex; it involves:

- **Capital costs ($/kW)** – here we note a trend of declining price points over time, particularly for solar PV and some battery technologies.
- **Installation costs** which is a function of labour and geography (location, existing infrastructure, weather/climate, etc.)
- **Maintenance costs** which is a function of the technology type, maintenance frequency, labour etc.
- **Costs associated with the integration** of the technology and the need for protection systems, breakers, transformers, smart inverters, voltage regulators, etc.
- **Costs associated with the IT** (and communication) components of the connected grid including HAN, NAN, FAN, WAN, PLC, WIFI, WIMAX, Dash 7, 3G/4G, LTE-A, ZigBee[1]… and cyber security systems.

Source: after B.L. Capehart, 2014: https://www.wbdg.org/resources/der.php
[1]Elyengui et al., 2013: http://arxiv.org/pdf/1403.0530.pdf

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DER CHARACTERISTICS & COSTS (US$)

Characteristic	Internal Combustion Technologies			Fuel Cell Technologies				Storage Technologies		Solar
	Reciprocating Engine	Microturbine	Combustion Gas Turbine	Proton Exchange Membrane (PEMFC)	Phosphoric Acid (PAFC)	Molten Carbonate (MCFC)	Solid Oxide (SOFC)	High Power e.g., li-ion	High Energy e.g., NaS	PV
Size	30kW-6+MW	30-400kW	0.5-30+MW	<1kW-500kW	50kW-1MW (250kW module typical)	<1kW-5MW (250kW module typical)	<1kW - 5MW	kWs to MWs	kWs to MWs	0.2 kW per module, could be 000s of MW
Power Density (mW/cm^2)	2,900 - 3,850	3,075 - 7,175	1,750 - 53,800	350-800	140 - 320	100 - 120	150 - 700	N/A	N/A	up to 175
Operating Temperature	450°C (850°F)	980°C (1,800°F)	1,930°C (3,500°F)	50-100°C (122-212°F)	150-200°C (302-392°F)	600-700°C (1,112-1,292°F)	600-1,000°C (1,202-1,832°F)	ambient	290-360°C	Ambient + ~20 C
Start-up Time	10s to 15 mins	Up to 120s	2 - 10 min	15 - 30 min	3-4 hrs	8 - 24 hrs	8 - 24 hrs	ms	ms	ms
Elec. Efficiency (LHV) %	30-42%	14-30%	21-40%	36-50%	37-42%	45 - 50%	40-60%	93-97%	85-90%	15%
Electric+Thermal (CHP) Efficiency %	80-85%	80-85%	80-90%	50-75%	<85%	<80%	<90%	90-94% AC	78-80% AC	n/a
Installed Cost ($/kW)	$700-1,200/kW	$1,200-1,700/kW	$400-900/kW	$3,500/kW	$4,500 - 9,000/kW	$4,200 - 7,200/kW	$3,500 - 8,000/kW	$1,200-1,800/kW	$3,500-4,000/kW	$2,000-5,000/kWp
Fixed O&M Cost	$600-1,000/kW	$700-1100/kW	$600/kW	$1000/kW	$400/kW	$360/kW	$175/kW	$8-30/kW	$15-40/kW	$10-30/kWp
Variable O&M Cost	$0.007 - 0.02/kWh	$0.005 - 0.016/kWh	$0.004 - 0.01/kWh	$0.003/kWh	$0.002/kWh	$0.004/kWh	$0.0045-0.0056/kWh	$0.002-0.004/kWh	$0.03 0.09/kWh	$10-30/kWp
Maintenance Interval/Fuel Cell Module Durability	750 - 1,000 hrs: change oil and oil fiter 8,000 hrs: rebuild engine head 16,000 hrs: rebuild engine block	5000 - 8000 hrs	4000 - 8000 hrs	20,000 + hrs	40,000 - 80,000 hrs	40,000+ hrs	25,000 - 70,000 hrs	2 yr interval, 10 yr life	2 hr interval, 10 year life	8,000 hrs (annual maintenance for central inverters)

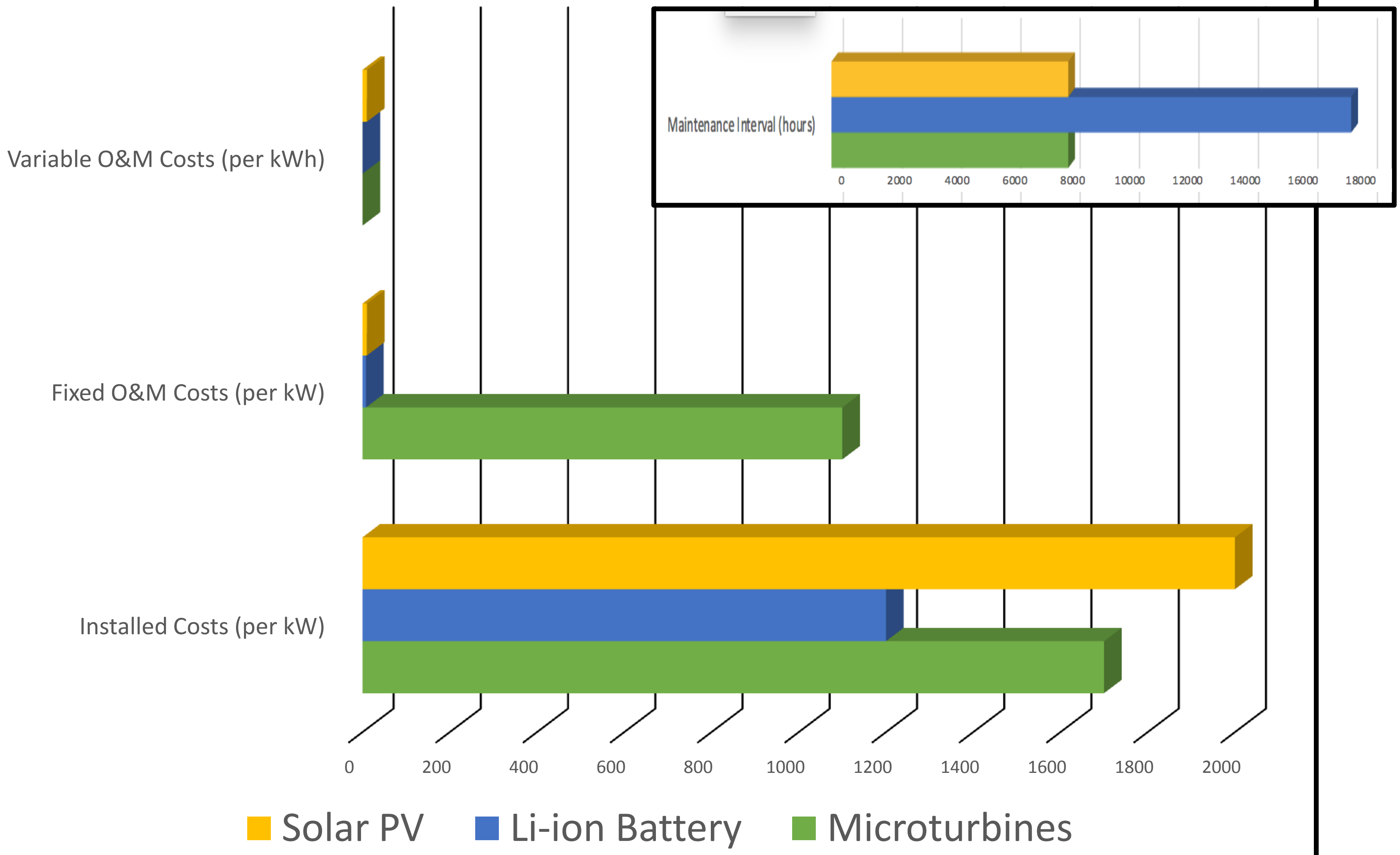
DNV GL ENERGY, 2014: Review of DER, Report Submitted to the NYISO, p 45.
http://www.nyiso.com/public/webdocs/media_room/publications_presentations/Other_Reports/Other_Reports/A_Review_of_Distributed_Energy_Resources_September_2014.pdf

DER CHARACTERISTICS & COSTS (US$)

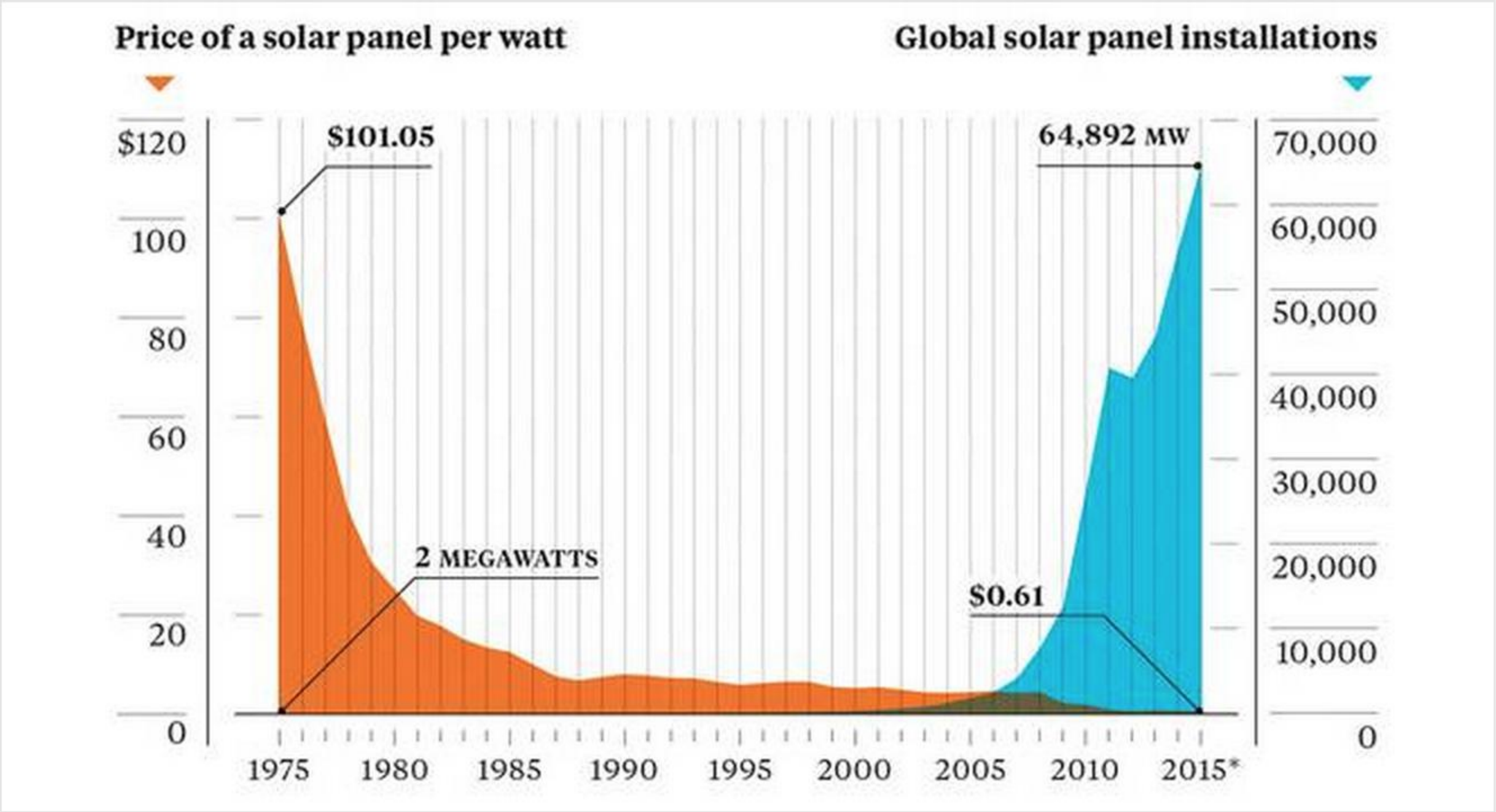
Characteristic	Microturbine	High Power e.g., li-ion	PV
Size	30-400kW	kWs to MWs	0.2 kW per module, could be 000s of MW
Power Density (mW/cm^2)	3,075 - 7,175	N/A	up to 175
Operating Temperature	980ºC (1,800ºF)	ambient	Ambient + ~20 C
Start-up Time	Up to 120s	ms	ms
Elec. Efficiency (LHV) %	14-30%	93-97%	15%
Electric+Thermal (CHP) Efficiency %	80-85%	90-94% AC	n/a
Installed Cost ($/kW)	$1,200-1,700/kW	$1,200-1,800/kW	$2,000-5,000/kWp
Fixed O&M Cost	$700-1100/kW	$8-30/kW	$10-30/kWp
Variable O&M Cost	$0.005 - 0.016/kWh	$0.002-0.004/kWh	$10-30/kWp
Maintenance Interval/Fuel Cell Module Durability	5000 - 8000 hrs	2 yr interval, 10 yr life	8,000 hrs (annual maintenance for central inverters)

DNV GL ENERGY, 2014: Review of DER, Report Submitted to the NYISO, p 45.

DER - High Estimated Costs US$ 2014



Why solar power will take over the world.



© *Earth Policy Institute/Bloomberg*

http://www.treehugger.com/renewable-energy/striking-chart-showing-solar-power-will-take-over-world.html

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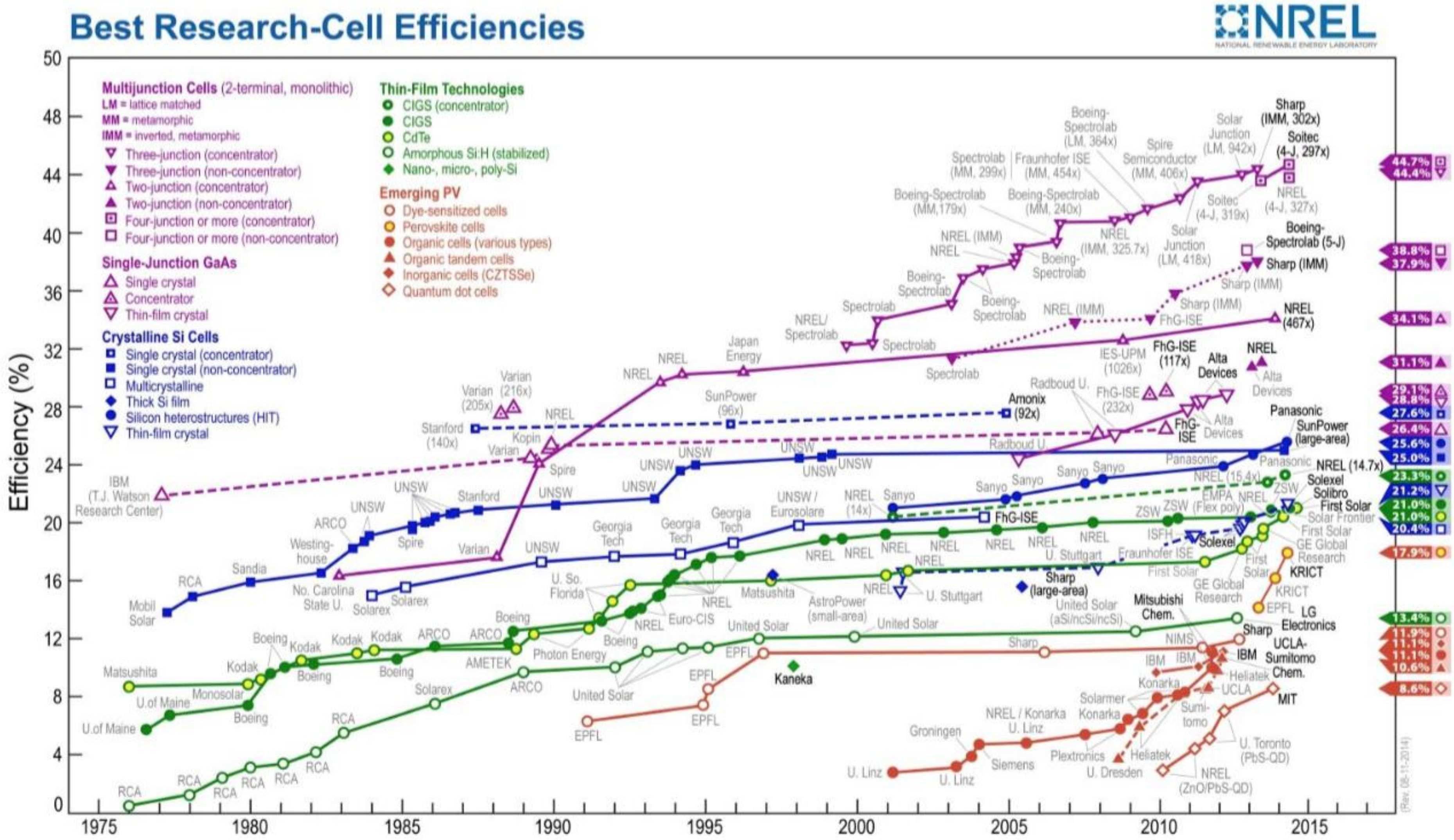

Figure 4-2. Solar Cell Efficiencies over Time

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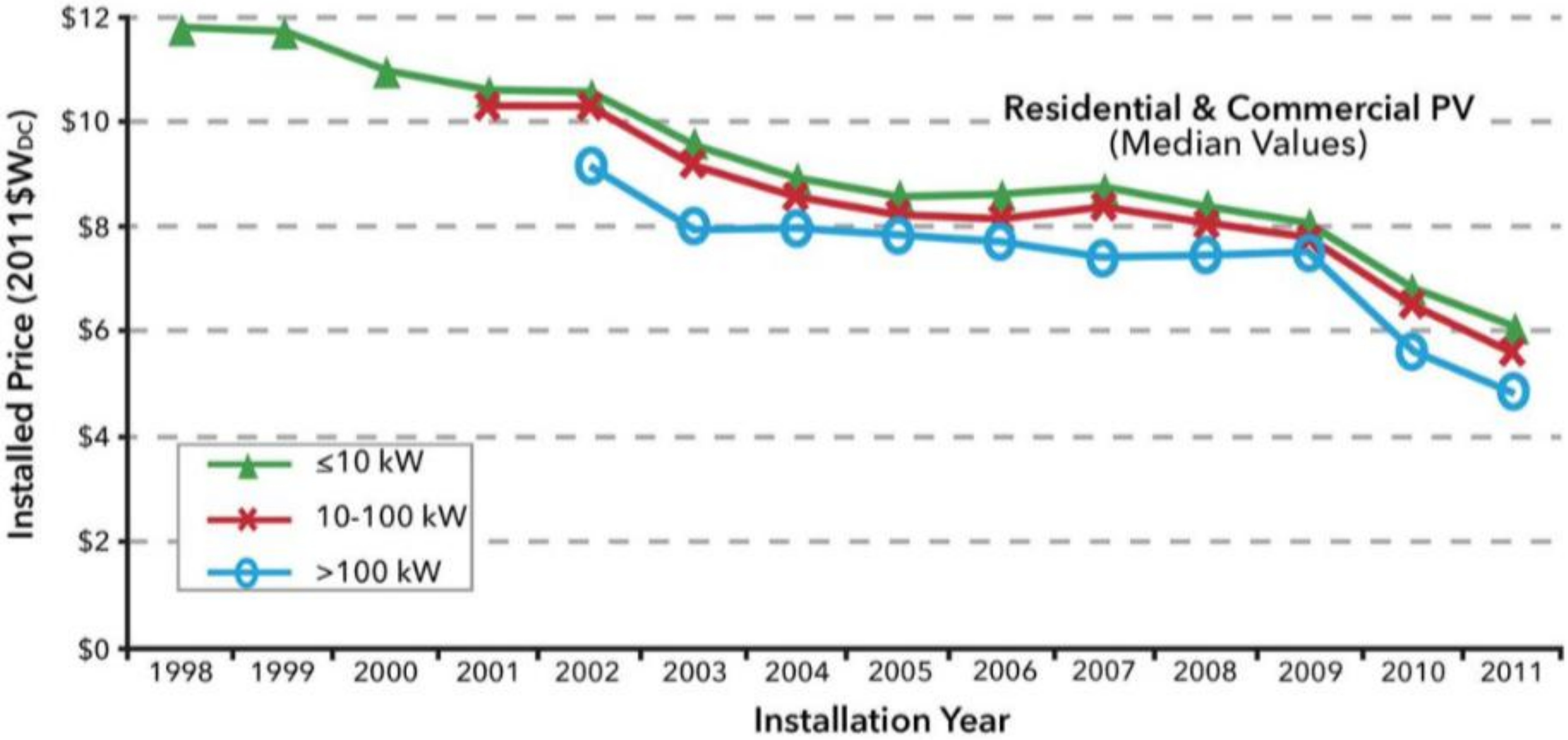

Figure 4-3. Installed Price of Residential & Commercial PV over Time

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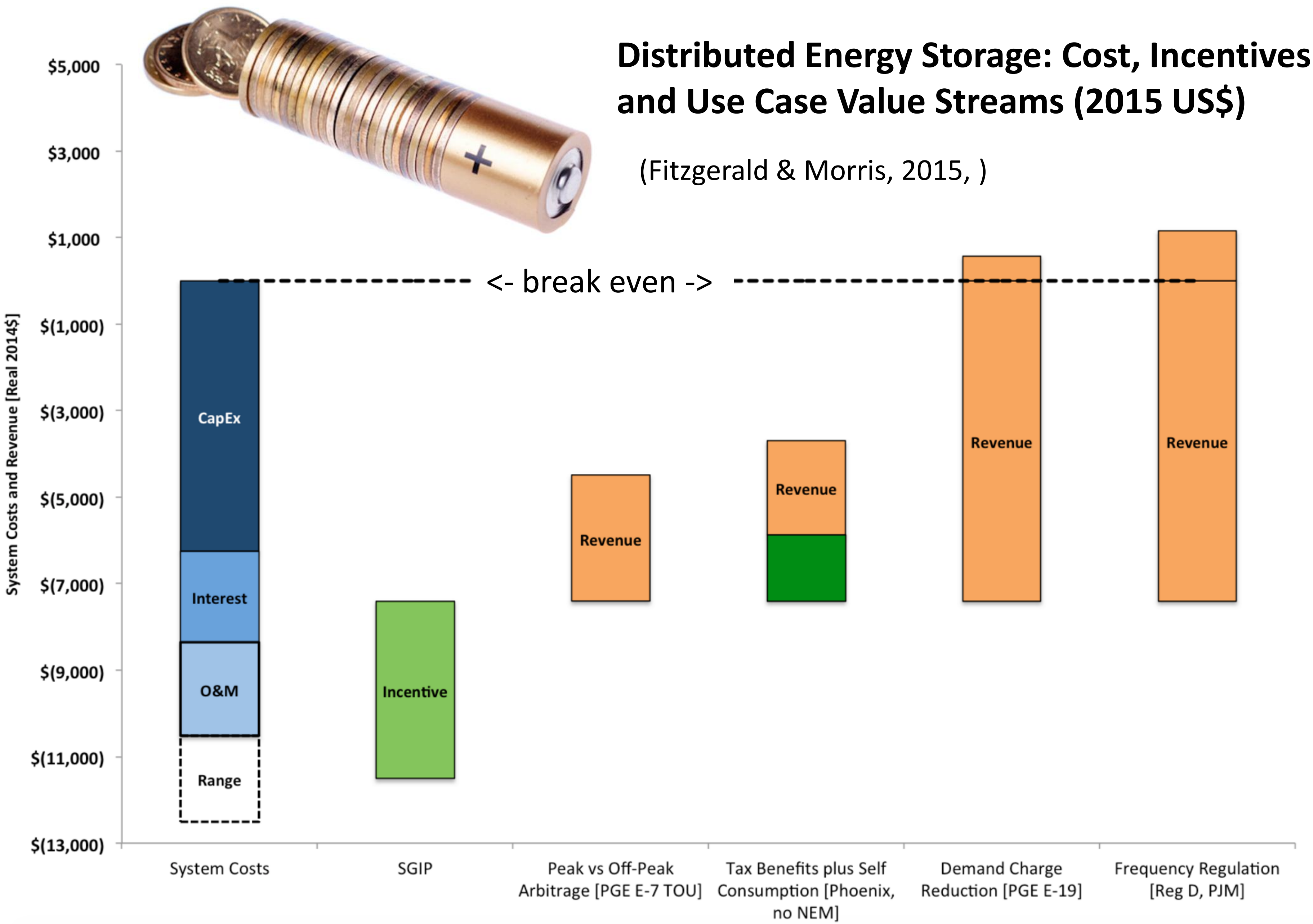
Figure 4-10. Battery Energy Storage Price Projections

Source: RMI 2014[71]

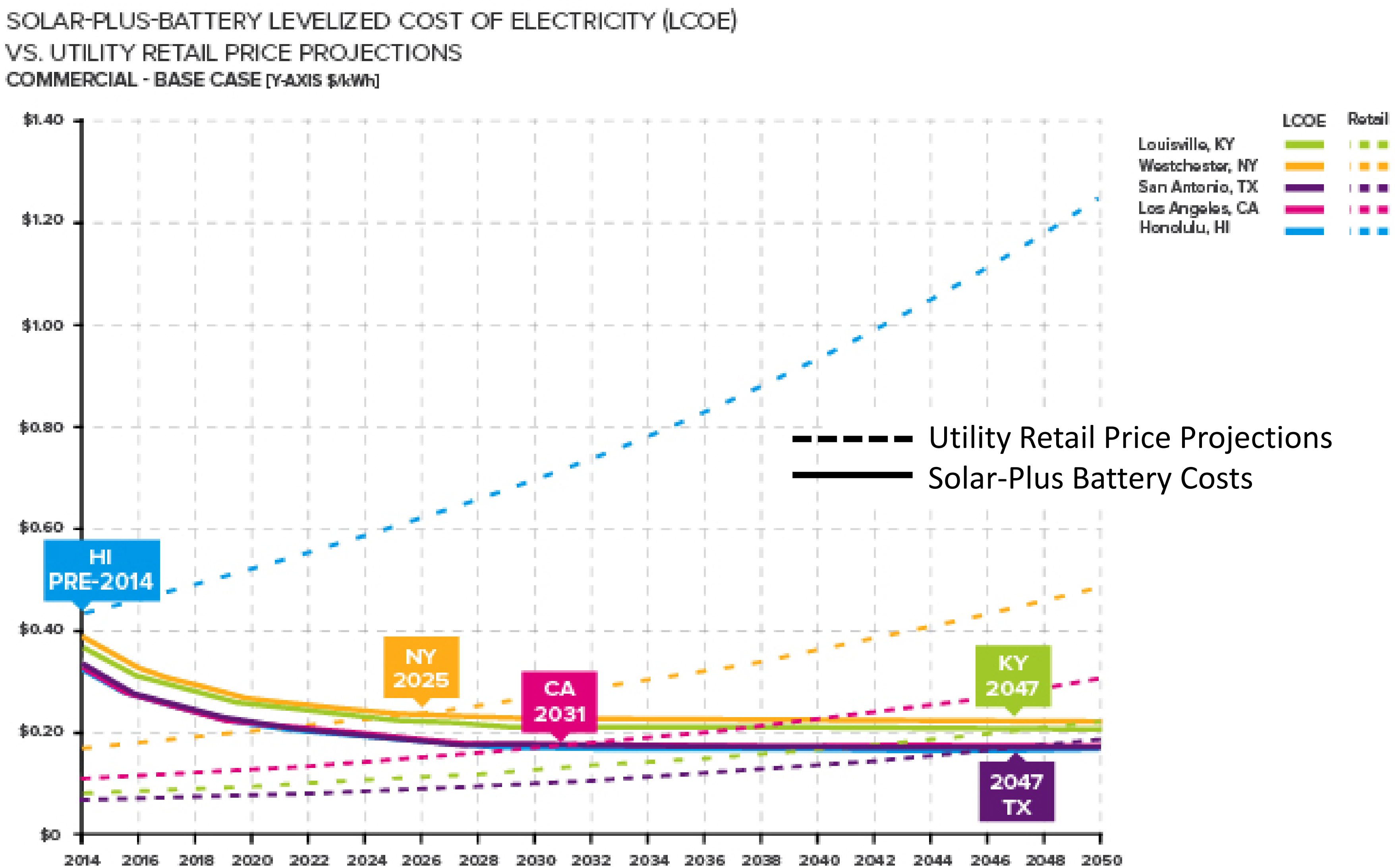
Distributed Energy Storage: Cost, Incentives and Use Case Value Streams (2015 US$)

(Fitzgerald & Morris, 2015,)



http://blog.rmi.org/blog_2015_02_04_the_distributed_energy_storage_industry_in_one_chart

Rocky Mountain Institute, February 2014:



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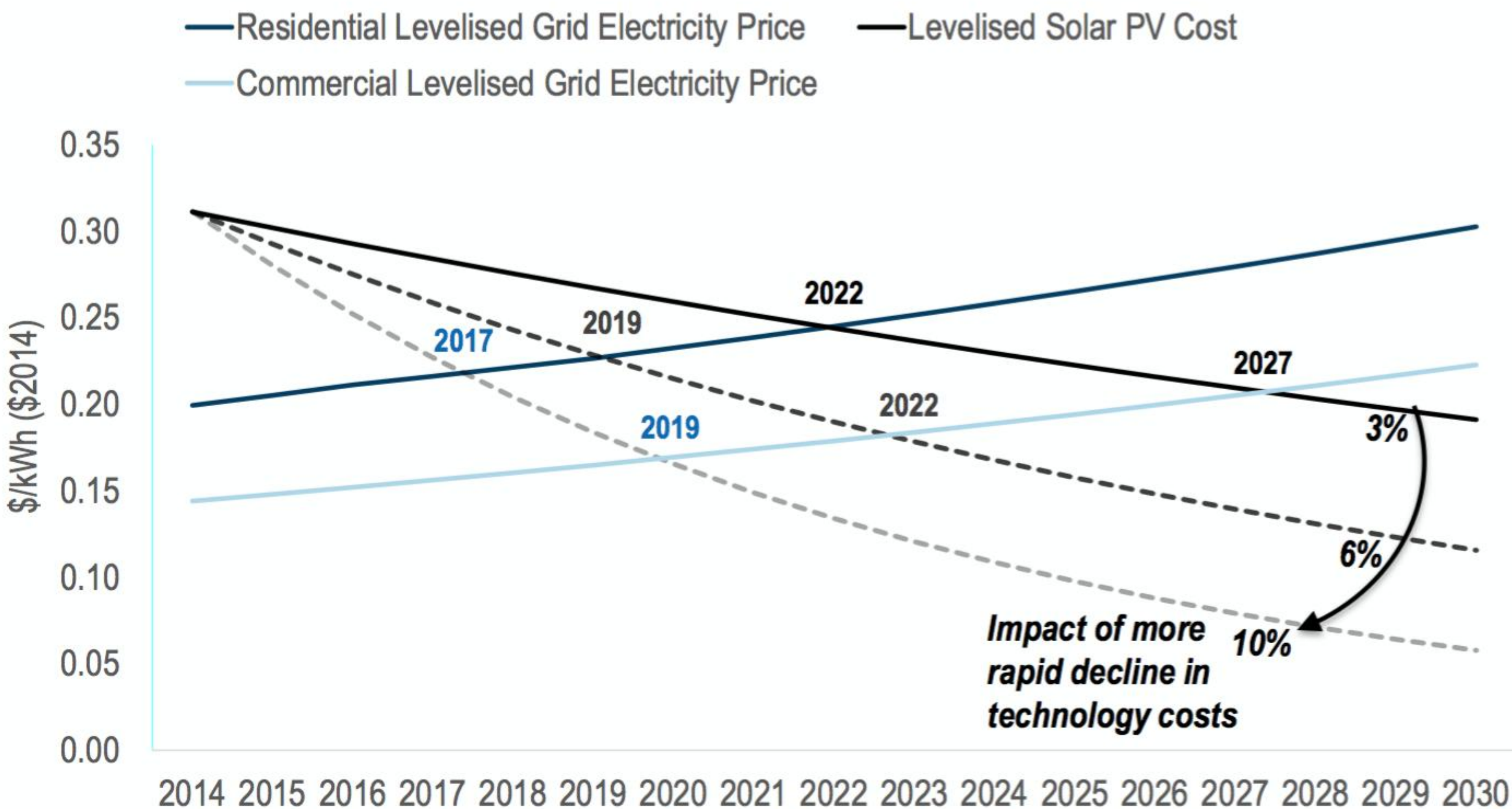
○ GRID PARITY FOR RESIDENTIAL OR COMMERCIAL SOLAR INSTALLATIONS COULD OCCUR IN THE NEXT 5 TO10 YEARS IN ONTARIO



Source: Navigant

Problems Solved Problems Posed by DER

Drivers for Microgrid Development:

- Need for **electrification** in remote locations and developing countries
- Customer need for more **reliable, resilient, and sustainable** service
- Grid **security and survivability**
- Utility needs for **grid optimization**, investment deferral, **congestion relief**, and **ancillary services**
- Demand for **lower-cost energy** supplies than are locally available (especially at remote sites, such as islands, military or mineral/resource installations, and isolated communities relying on expensive, high-polluting fuels)
- **Environmental, efficiency, and renewable** energy benefits

Source: http://www.microgridinstitute.org/about-microgrids.html

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Problems Solved Problems Posed by DER

Customer Benefits attributed to DERs include:

- **avoided costs** - energy and demand bill management;
- **resiliency** - power outage mitigation or critical power support during power outages;
- **reliability** - power quality improvement;
- **revenue** - direct compensation by grid operators or providers for services; and
- **financial incentives** as defined by local, state/provincial or federal policymakers (avoided costs or revenue).

Source: DNV GL ENERGY, 2014: Review of DER, Report Submitted to the NYISO, p 45.

Problems Solved Problems Posed by DER

Grid benefits of DER:

(which vary greatly by location and are dependent on the grid characteristics):

- reduced grid losses achieved by providing power closer to the customer and by reducing peak loads;
- development of virtual power plants
- volt/var support achieved either indirectly or directly through the use of inverters and reactive power controls;
- deferred need for generation, transmission or distribution capacity by reducing peak load;
- grid ancillary services, such as selling reserves and capacity services in wholesale markets;
- avoided emissions;
- improved grid resiliency by directly serving customers during outage or power quality events or potentially supporting restoration processes;
- improved energy security from increased fuel diversity; and
- avoided energy production or purchases.

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Problems Solved Problems Posed by DER

While certain DER technologies can provide grid benefits, they also potentially create problems under current operating paradigms. For example:

- intermittent or variable power production can affect local voltages, creating new requirements for grid voltage management.
- excess production from DG can result in reverse power flows where aggregate DG is greater than aggregate demand; solutions are costly involving re-conductoring power lines, adding breakers and capacitors, and upgrading transformers and tap changers.

Source: SWECO, 2015

Schneider Electric Smart Grid Laboratory

Built to serve as a "sandbox" for Ontario institutions to develop, demonstrate and discover new smart grid products, solutions and ideas… and to provide a platform for training of the next generation of smart grid engineers, scientists and planners.

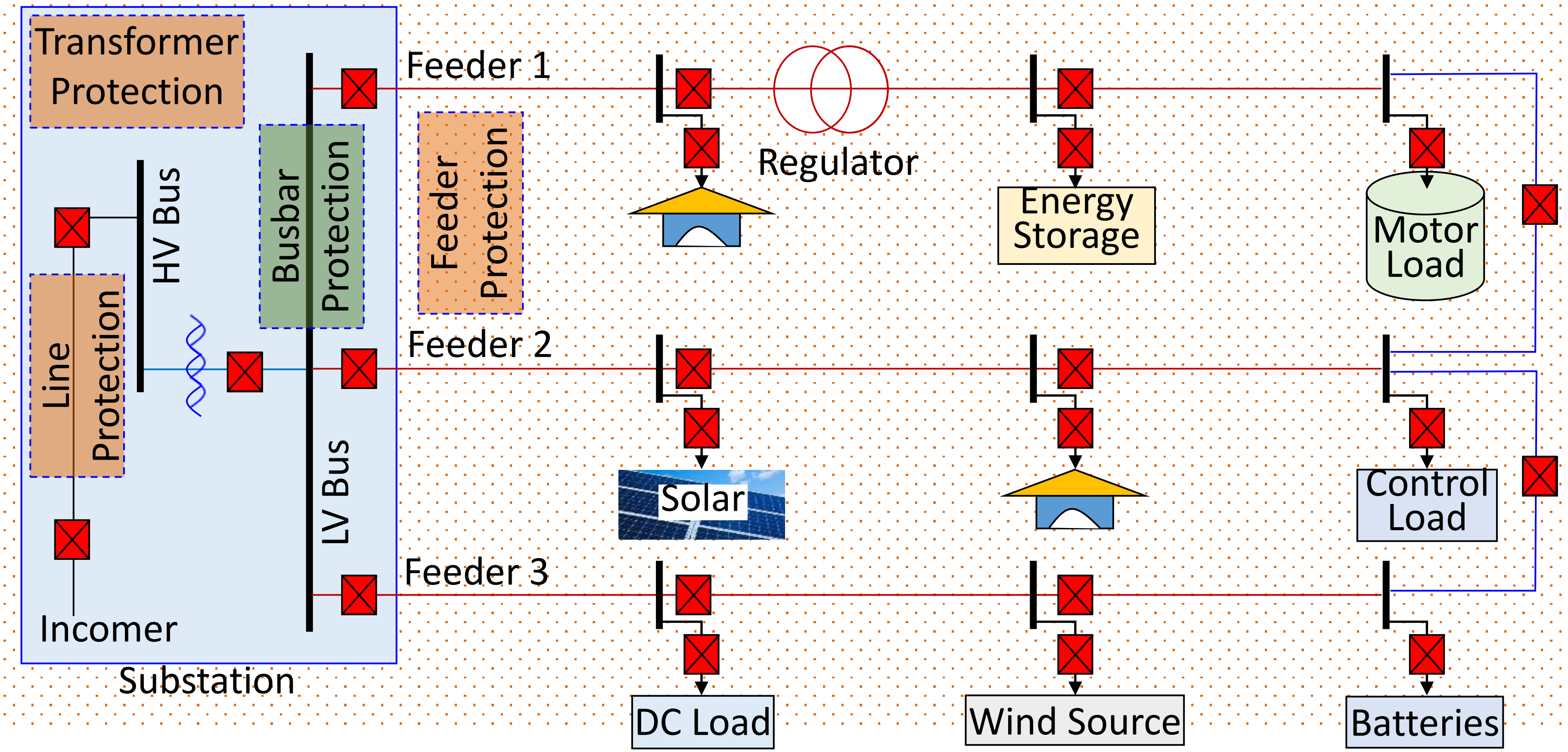
SUBSTATION FEEDER 1 FEEDER 2 FEEDER 3

Schneider Electric Smart Grid Laboratory

AMI (Advanced Metering Infrastructure)

SCADA (Supervisory Control &Data Acquisition)

ADMS (Advance Distribution Management System)



One of a Kind In Canada

APPLIED RESEARCH

Solar panels and transformers

Name of Project:
The impact of solar panels on transformer station components

Timeline:
January 2011 – January 2014

Research Focus:
Renewables

Principal Investigator:
Dr. Bala Venkatesh

Research Team:
Dr. Travis Xu, Dr. Mohamed Awadallah, Pauline Dongrazi

Increasing the operational life of distribution transformers…

*Awadallah et al., 2015: On the Effects of Solar Panels on Distribution Transformers, IEEE Transaction on Power Delivery, 10 p.

hydro one

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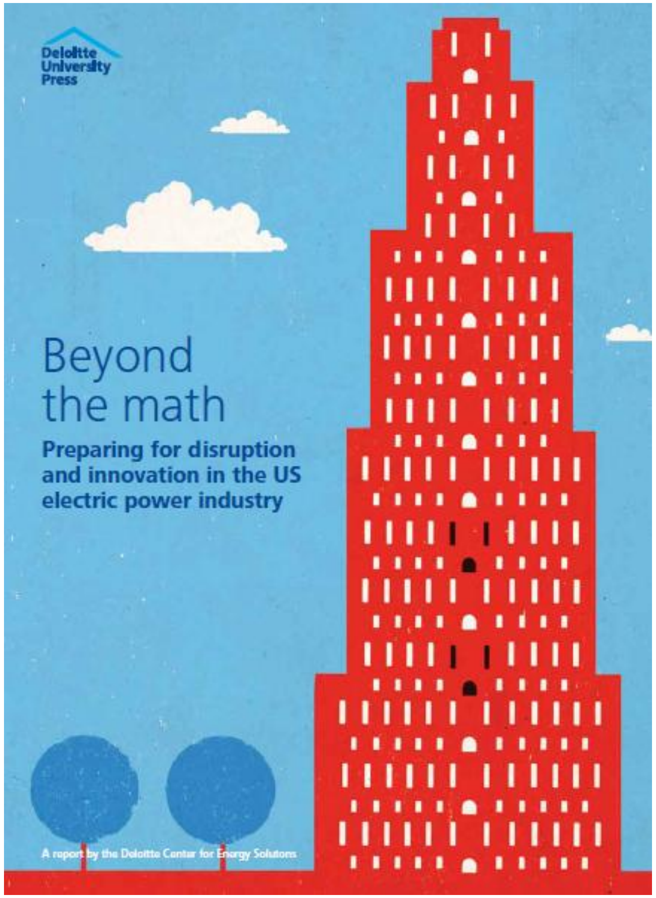
Conclusion: *Six forces controlling change to the electricity Grid?*



Customer Demand

DER Technologies & Microgrids

Regulations

Alternatives to the Grid

Unexpected Competition

Costs & Benefits of the Grid

Source: after Gregory Aliff, 2013: Energy & Resources, Deloitte LLP
http://dupress.com/articles/beyond-the-math-preparing-for-disruption-and-innovation-in-the-us-electric-power-industry/

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