Congratulation

Ronnie Sookermany
Building Operator
Northam Realty Advisors Limited

Project:
Energy Management Plan, 250 University Bank of Canada Building

Result:
Over the past 25 months, 250 University achieved a total kWh reduction of 1,100,000 kWh and a monetary benefit of $220,847, including avoided costs and OPSaver Program incentive

James Draper
Maintenance Lead
Magna International (Plastcoat)

Project: focused on monitoring, targeting, implementation and reporting initiative to improve inefficiencies in operations and create energy use reduction at Plastcoat

Result : Identifying and correcting these defective TCUs created an estimated annual savings of approximately 110,000kWh per Thermalator. This issue was identified and corrected in 11 instances with a combined estimated annual saving in excess of 1MWh. And other contribution that resulted in 35 KW of reduction and $13,700 of electricity savings

Energy Storage Technology Review + Flywheel / Solar Hybrid Project Case Study

Association of Energy Engineers – GTA Chapter

March 22 2022

Cody MacNeil, P.Eng, M.Eng – Senior Director of Assets & Engineering

Agenda

- NRStor Company Overview
  - Existing Portfolio
  - Market Potential
- Energy Storage – In a Nutshell
  - Energy Storage Overview
  - Why Storage?
  - Common Technologies
  - Performance Characteristics
  - Types of Li-Ion Batteries
  - DC to AC Power Conversion
  - Grid Services
- 2MW Minto Flywheel + Solar Storage Facility
  - Brief History
  - Renewable Smoothing Application
- Q&A

NRStor – Portfolio

- NRStor’s operating portfolio consists of a diverse mix of utility-scale, commercial, and residential storage technologies including batteries, flywheels and compressed air energy storage projects
  - **Minto Flywheel Facility:** First commercial flywheel facility in Canada (contracted in 2012)
  - **Goderich A-CAES Project**: Largest fuel-free Advanced Compressed Air Energy Storage (“A-CAES”) project in the world (contracted in 2015)
  - **C&I BESS Projects:** Over 100 MW of behind the meter commercial & industrial battery projects in Ontario (pipeline sold to Blackstone in 2020)
  - **Tesla Powerwalls:** Largest deployment of residential Tesla Powerwalls (>1 MW) in Canada (first deployed in 2016)
  - **Strathroy BESS Facility:** First commercial battery facility in Ontario (commercial operations in 2014; acquired by NRStor in 2019)
  - **Arviat Microgrid Facility:** Microgrid for remote community with no road access, including wind, bifacial solar, and battery energy storage

- NRStor is currently in partnership with Indigenous communities across Canada to develop various projects

- NRStor’s current development pipeline includes well over 1,000 MW of projects across Canada

Minto Flywheel Facilities

Project: First commercial flywheel facility in Canada (2 MW)

Goderich CAES Project

Project: Largest fuel-free CAES project in the world (2 MW)

C&I BESS Projects

Project: >100 MW of behind the meter battery projects contracted in Ontario

Tesla Powerwalls

Project: Largest fleet of Tesla Powerwalls in Canada (1 MW)

Strathroy BESS Facility

Project: Ontario’s first utility BESS Project (4 MW)

Arviat Microgrid Facility

Project: Microgrid including a 2 MW BESS, 2 MW of wind and 200 kW of solar in the Hamlet of Arviat, Nunavut

Under Development: Oneida BESS

– **Power Rating.** 250 MW.

– **Duration / Energy**. 4-hour duration battery. 1000 MWh total.

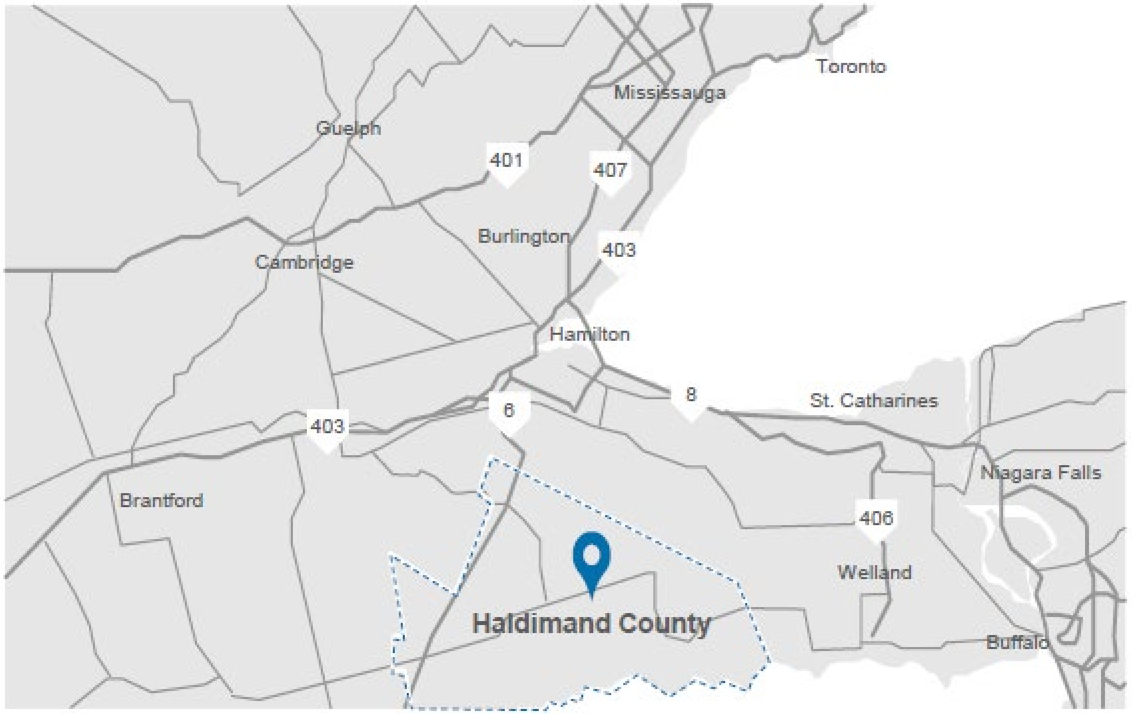
– **Battery Technology**. Lithium-Iron-Phosphate Battery Cells (LFP). Chosen for their superior cycle life and safety characteristics.

– **Operating Life.** 20 – 25 Years

– **Battery Vendor**. To be announced after final negotiations.

– **Location.** Nanticoke, Haldimand County, Ontario.

– **Expected COD.** Late 2023



NRStor – Energy Storage Market Potential

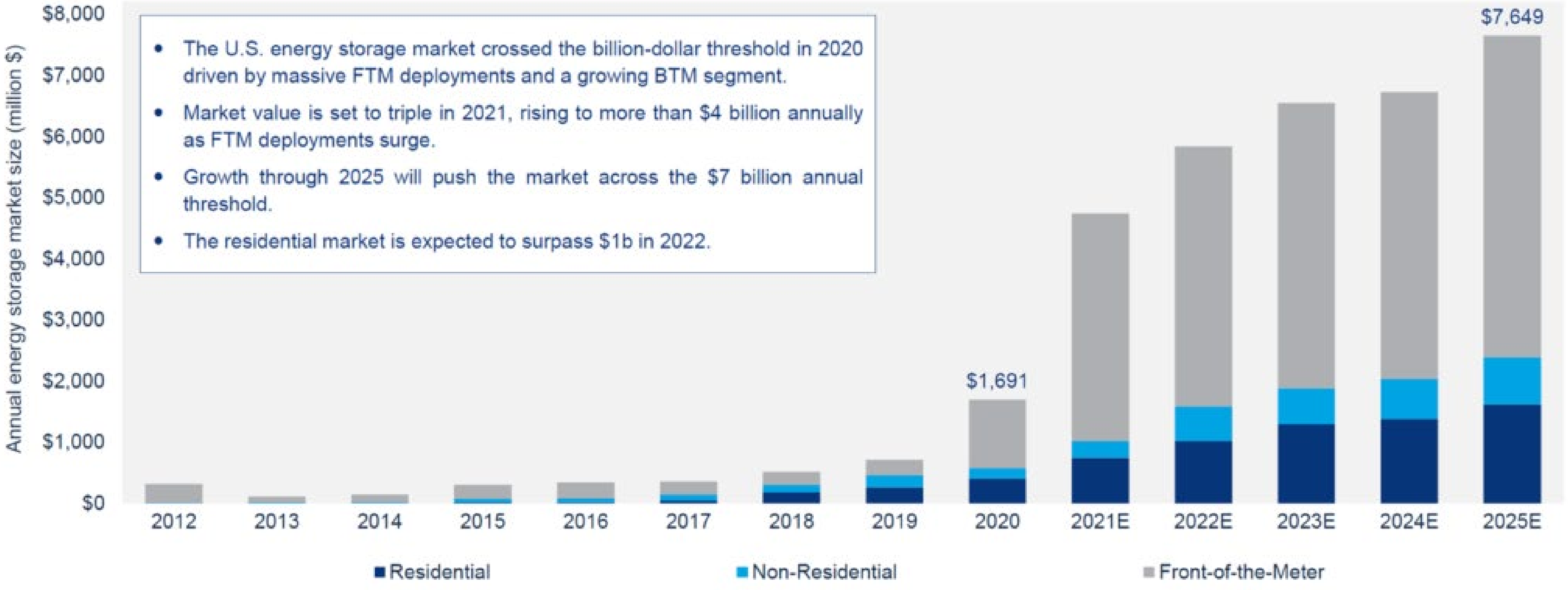
Wood Mackenzie P&R/ESA | U.S. energy storage monitor 2020 year in review

woodmac.com

U.S. energy storage will be a $7.6 billion annual market in 2025

Market crossed $1.5 billion annual threshold in 2020

U.S. annual energy storage market size, 2012-2025E (million $)



Source: Wood Mackenzie Power & Renewables. Note: Market size is reported as energy storage system deployment revenue (product of deployments and installed system prices).

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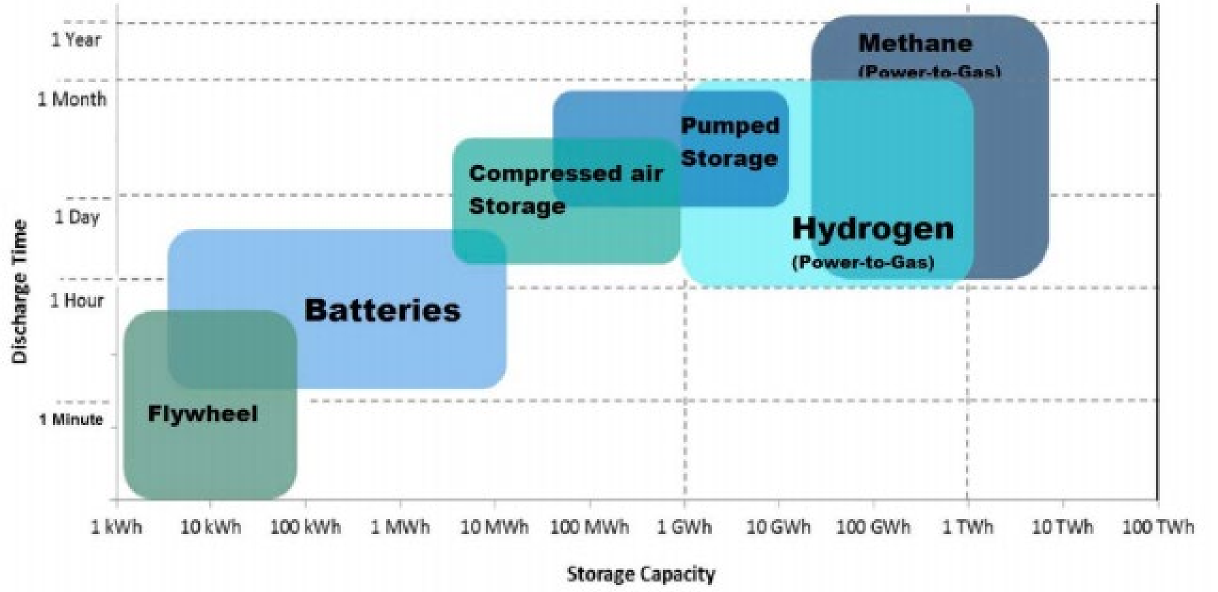
Energy Storage – Overview

– Grid-Scale Energy Storage assets store electrical energy from the grid by acting as a **load**, and give the energy back to the grid by acting as a **generator**.

– Energy Storage facilities store energy in a limited capacity medium. As a result, facilities have a nameplate **power rating**, as well as an **energy capacity**. Sometimes, the asset will be specified by its **duration**, which is typically defined as the amount of time the facility can provide its rated power during charging or discharging.

– Energy storage technologies can range from having a duration on the order of **seconds** (i.e. capacitors), **minutes** (i.e. flywheels), **hours** (i.e. batteries), and even **days** (i.e. pumped hydro, compressed air energy storage).



Source: School of Engineering, RMIT University (2015)

Figure 3. Available storage technologies, their capacity and discharge time.

Grid-Scale Energy Storage – Why Storage?

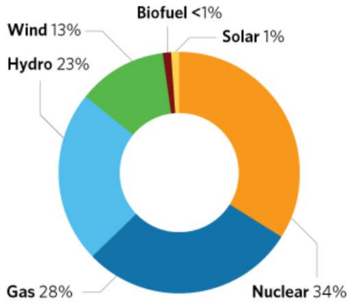
– Storage relies on available power from the grid to charge. As such, there are typically no direct GHG emissions from operating an energy storage plant.

– In Ontario, the primary source of carbon emitting generation comes from natural gas which is used as a peaking resource. Storage can displace this generation by charging at night using primarily hydro and wind, reducing the overall GHG emissions from operating the electricity grid.

– The price of electricity in Ontario drops significantly at night due to excess wind generation and lack of demand. Storage can reduce the cost to rate payers by buying electricity at night and reselling it during peak periods in the day.

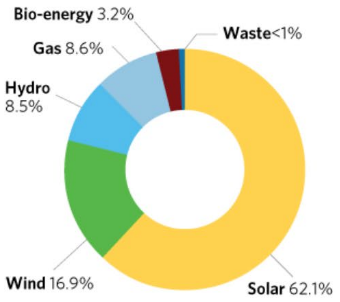
– Energy storage often leverages other power technologies such as AC inverters which can provide energy to the grid extremely quickly (<100ms) and reliably.

Transmission Connected Gen.



Nuclear	13,089 MW or 34%
Gas/Oil	10,515 MW or 28%
Hydro	8,918 MW or 23%
Wind	4,783 MW or 13%
Biofuel	296 MW or <1%
Solar	478 MW or 1%

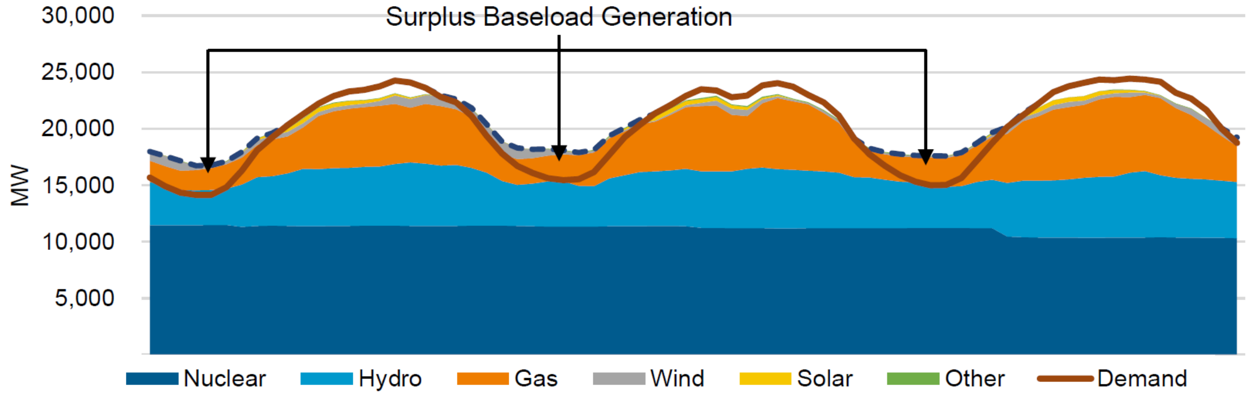
Distribution Connected Gen.



Solar	2,166 MW or 62.1%
Wind	590 MW or 16.9%
Hydro	297 MW or 8.5%
Gas	299 MW or 8.6%
Bio-energy	110 MW or 3.2%
Waste	24 MW or <1%

Source: https://www.ieso.ca/en/Learn/Ontario-Supply-Mix/Ontario-Energy-Capacity

Surplus Baseload Generation



Typical operation of Ontario power system over 72 hours in the Summer (actual data from July 7-9, 2020)

Grid-Scale Energy Storage – Technologies

NRSTOR INC

Mechanical	Electrical	Electro-Chemical	Chemical / Fuels
Energy stored as kinetic or potential energy. **Flywheels** – Rotational kinetic energy **Compressed Air Energy Storage** – Potential energy in compressed air + thermal storage from compression process **Pumped Hydro** – Gravitational potential energy **Thermal** • Phase Change • Delta T	Energy stored in electric or magnetic fields. **Supercapacitors** – Electric fields from voltage across terminals **Superconducting Coils** – Magnetic fields from current flowing through zero resistance inductors	Energy stored in an electro-chemical cell (battery). **Lead Acid Battery** • Flooded • Sealed **Lithium-Ion** • Lithium Cobalt Oxide (LCO) • Nickel Manganese Cobalt (NMC) • Lithium Iron Phosphate (LFP) **Flow Battery** – Scalable dissolved liquid battery **Zinc / Iron Air** – Metal-Air oxidation reaction, mechanically reversable	Energy stored in the chemical potential energy released during controlled reactions. **Hydrogen** – Released through fuel cells or combustion • Compressed • Liquified

Grid-Scale Energy Storage – Performance Characteristics

There are several technology specific performance parameters which also impact the efficacy of the energy storage plant to support the grid.

- **Round-Trip-Efficiency (RTE)**. The ratio of the energy provided generating to the energy consumed as a load. Typically measured during a full depth-of-discharge (DoD) cycle at rated power.
- **Response Time**. The amount of time required for the asset change its output. Typically measured from 0% to 100% output.
- **Cycle Life**. How many times the storage asset is able to be cycled over its intended operating life. Cycle Life is typically inversely proportional to duration.
- **Parasitic / Standby Losses**. Passive loss of energy / state-of-charge.
- **Scalability.** The ability for the storage asset to be scaled to increase the energy and power capacity.
- **Maturity.** Relative commercial adoption of technology.

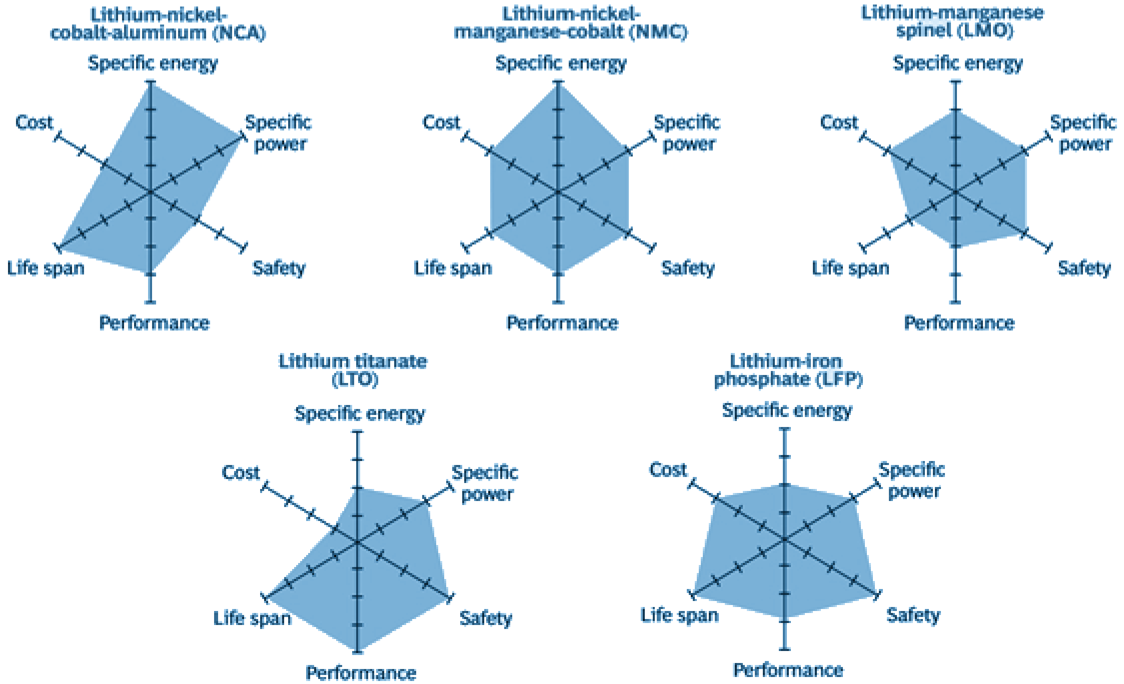
Note: this chart provides a general overview of the main differences between these technologies. OEMs employ different strategies to minimize technology drawbacks, especially with respect to cost parameters

Technology	Duration	$/kW	$/kWh	RTE	Resp. Time	Cycle Life	Parasitics	Scalability	Maturity
Super Capacitors	0 - 5 min	5	1	5	5	3	1	4	2
Flywheels	5 - 30 min	4	2	4	5	5	2	2	3
Li-Ion Batteries	0.5 - 4 hours	4	4	5	5	3	4	4	5
Flow Batteries	6 - 12 hours	3	4	3	5	5	3	5	2
Lead Acid Batteries	4 - 20 hours	1	3	3	4	2	4	2	5
Thermal	0.25 - 2 days	3	3	2	1	5	3	4	3
Compressed Air	0.25 - 2 days	4	5	2	3	5	3	1	3
Pumped Hydro	0.5 - 7 days	4	5	3	3	5	5	1	5
Hydrogen	Months - Years	3	5	1	2	5	4	4	4

1 = Worst | 5 = Best

Li-Ion Energy Storage Technology – Battery Selection

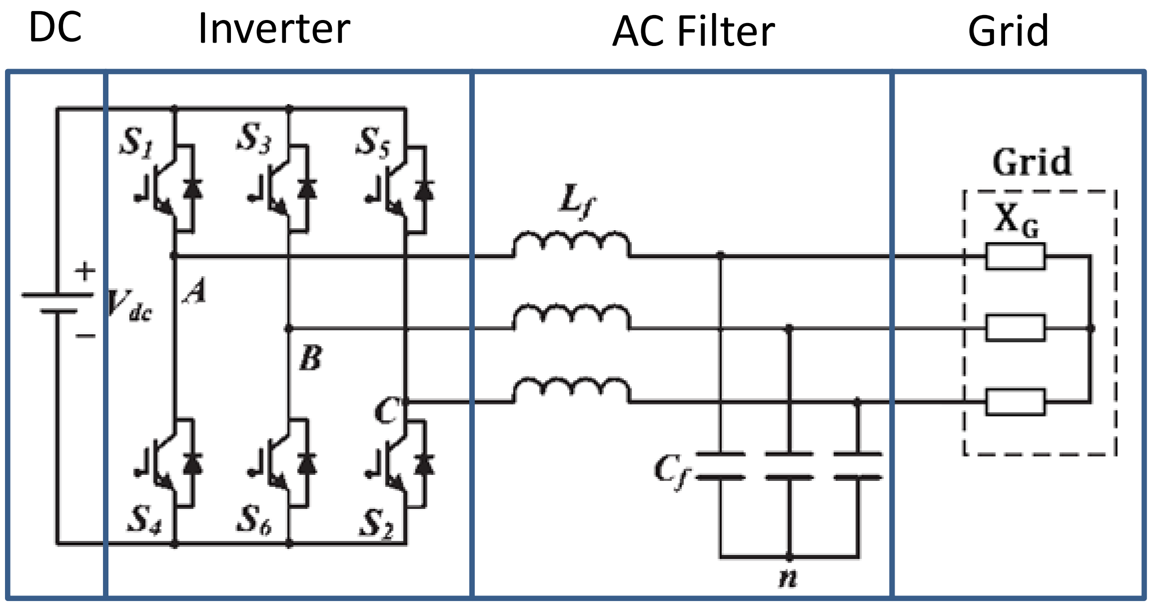
- Lithium-Ion batteries can be purchased in a variety of packages and sub-chemistries.
- NMC batteries are an industry leader as their high specific energy and power coupled with relatively low cost found them located in many electronic devices such as laptops and EVs.
- Stationary energy storage suppliers now offer LFP batteries due to the longer life of the cells as well as the enhanced safety characteristics.
- The long life of the LFP cells reduces ongoing maintenance costs of the equipment. LFP is expected to be the dominant form of new large-scale stationary in the coming years.



Source: BCG research.
Note: The farther the colored shape extends along a given axis, the better the performance along that dimension.

Li-Ion Energy Storage Technology – Power Conversion

- **AC / Grid Side.** Low voltage side of facility connected to power conversion system. Typically, 480V in North America.
- **AC Filters.** Electrical filters used to clean up high-frequency noise which come from power electronics. Required to meet grid power quality standards.
- **AC / DC Inverter.** High power switches used to control current flow between AC and DC side. Switches operate at very high frequency (3kHz – 20kHz) using Pulse-Width Modulation (PWM).
- **DC Bus.** Batteries can be directly connected to DC side or further connected through DC/DC converters for voltage connection flexibility.



Source: https://www.researchgate.net/figure/Circuit-diagram-of-a-three-phase-inverter-with-an-LC-output-filter-for-stand-alone-DGSs_fig2_260541922

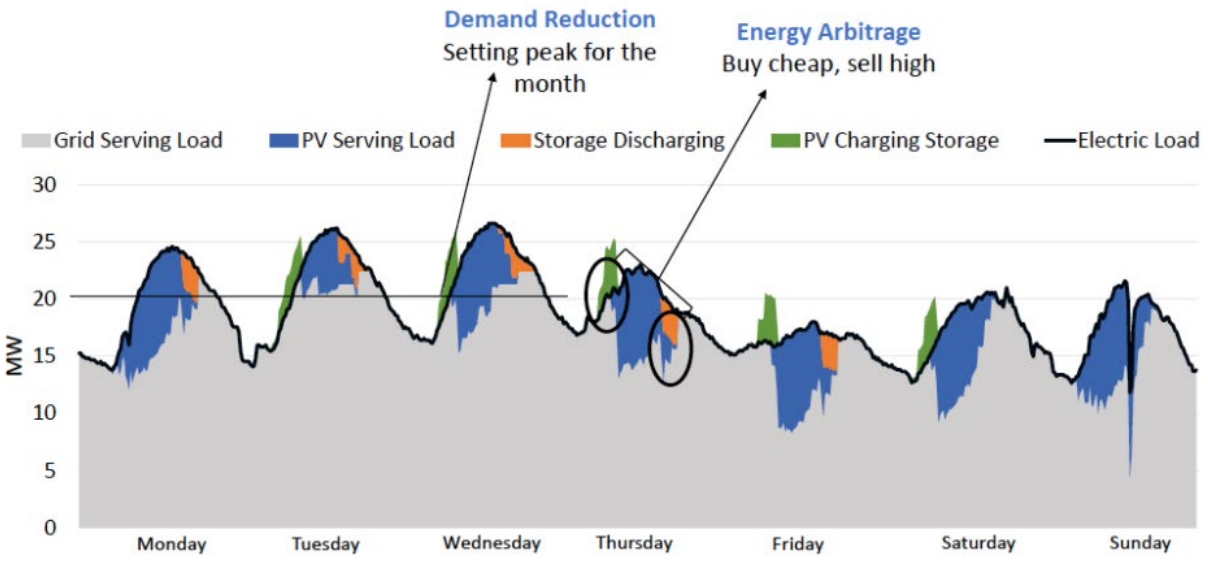
Grid Services – Energy Arbitrage

- Long duration battery storage plants can strategically purchase energy when the price is lowest, typically at night or on weekends. The low price is reflective of the abundance of inexpensive generation sources coupled with low load.

- Facilities generate the energy back onto grid during periods of high prices.

- Rate payers benefit from this activity as the grid can be more efficiently operated with less curtailment at low demand periods along with a reduction in expensive peaker plants needing to operate during high demand periods.

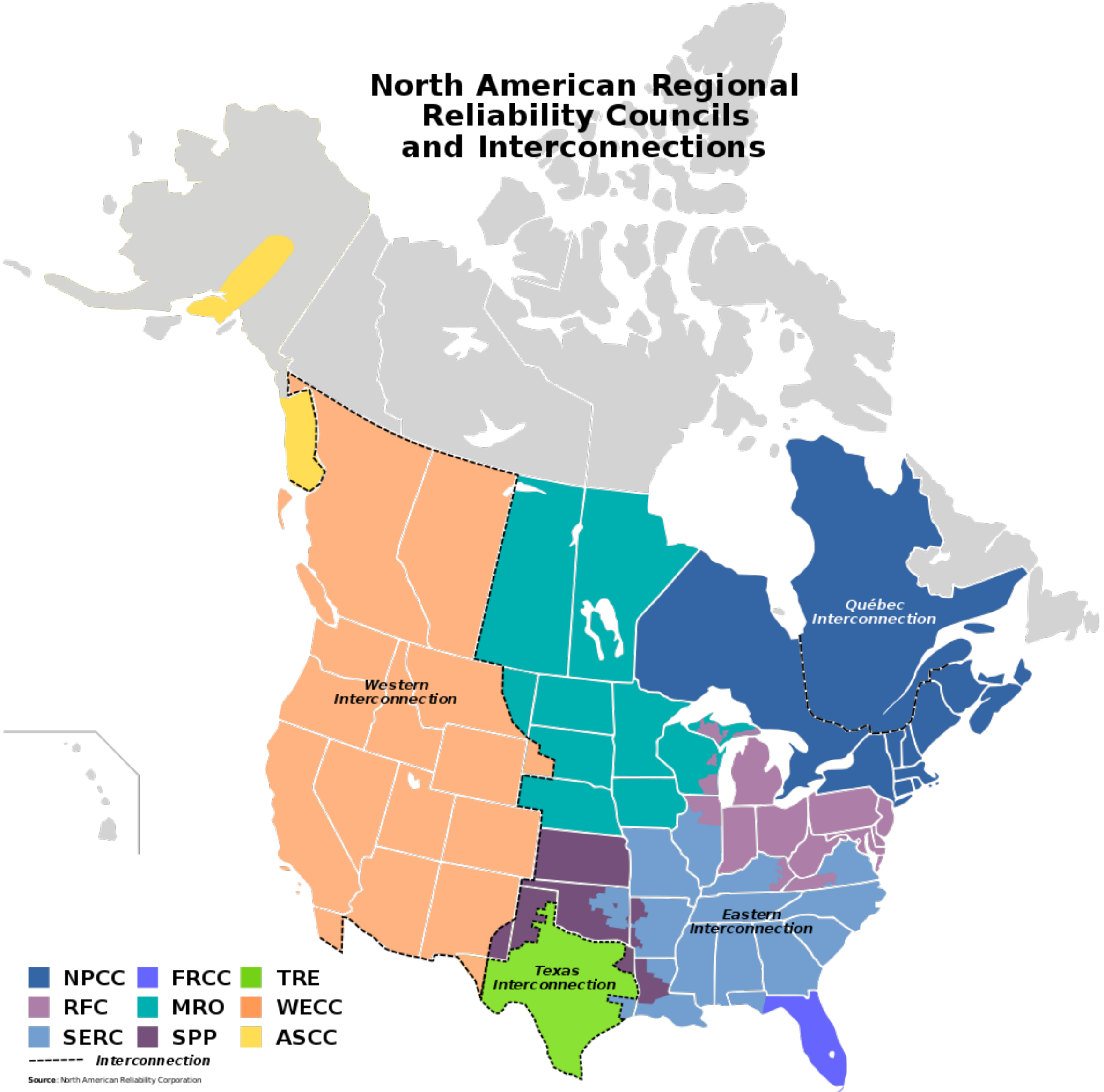
- Additionally, excess energy served by the storage facilities will displace some of the need to call upon gas-fired peaker plants. This will reduce the CO_2 emitted from grid operation over the operating life of the facility.



Source: https://www.dynapower.com/energy-storage-applications/

Grid Services – Operating Reserve

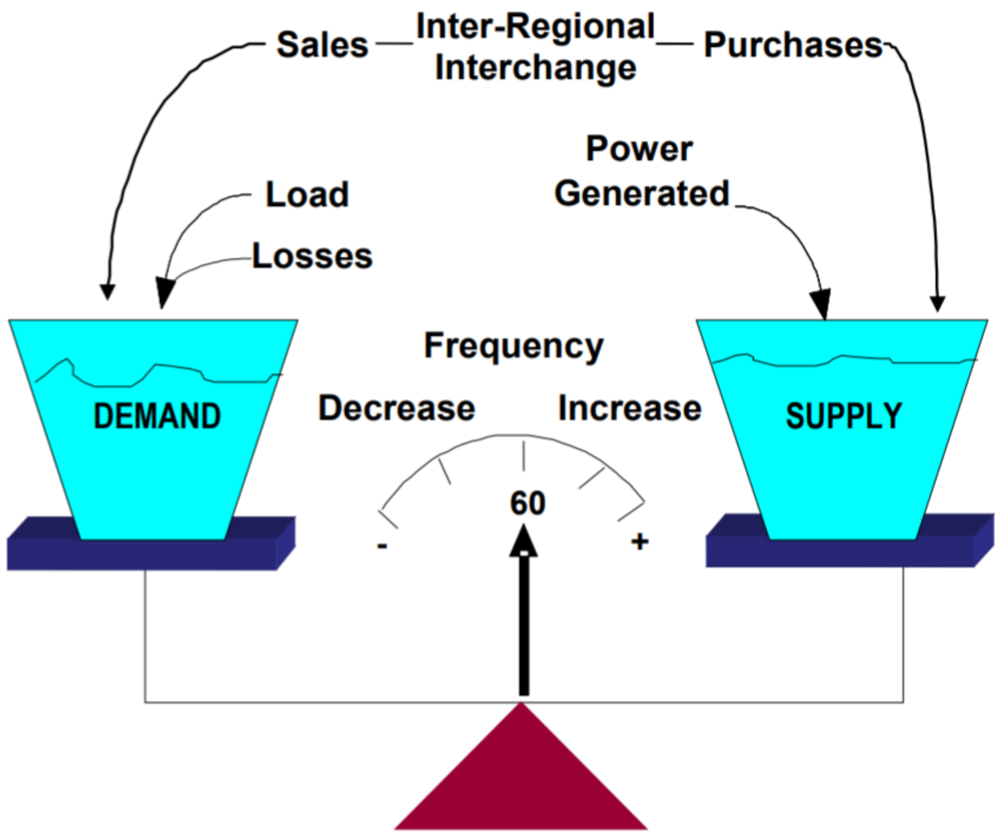
- The IESO is required to provide Operating Reserve (OR) for system reliability. OR is stand-by power that can be called upon with short notice to deal with an unexpected mismatch between generation and load.
- The North American Electricity Reliability Corporation (NERC) and North East Power Coordinating Council (NPCC) set the requirements based on reliability and performance standards.
- OR is categorized in three classes:
  - 10-min Spinning
  - 10-min Non-Spinning
  - 30-min Non-Spinning
- Battery storage can provide OR greatly exceeding the 10-min requirement.



Source: North American Reliability Corporation

Grid Services – Frequency Regulation

- Frequency Control is a critical operation conducted by the IESO in Ontario to help keep the grid stable and reliable. The control of the system frequency must be delicately balanced, typically between 59.98 Hz and 60.2 Hz. The IESO relies on the following to maintain the frequency.
- **Inertial Response:** Spinning rotors from large generators connected to the grid prevent the frequency from changing too quickly.
- **Primary Control:** Generators are configured to automatically provide extra power if their frequency drops. This is known as governor control. This arrests the changing frequency.
- **Secondary Control:** A signal (AGC) is sent to assets to perform frequency regulation which is used to prop the frequency back to its intended location.
- **Tertiary Control:** New assets are brought online to relax efforts required by the Secondary Control equipment. This is done using Operating Reserves.



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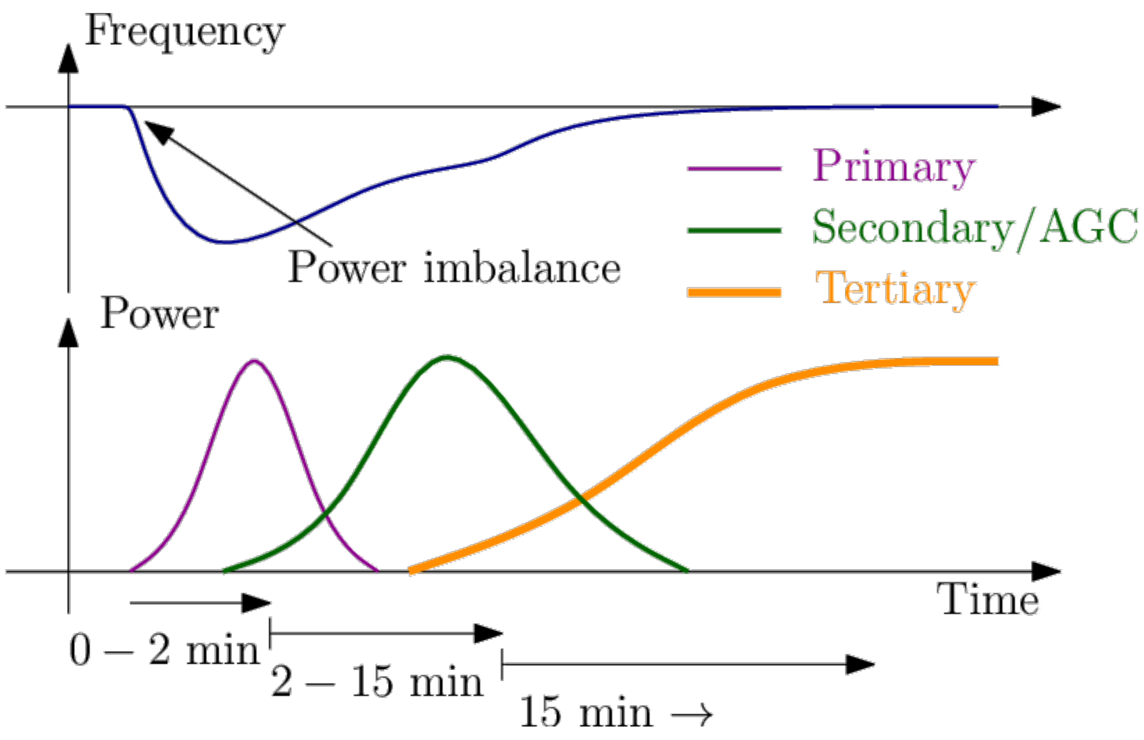
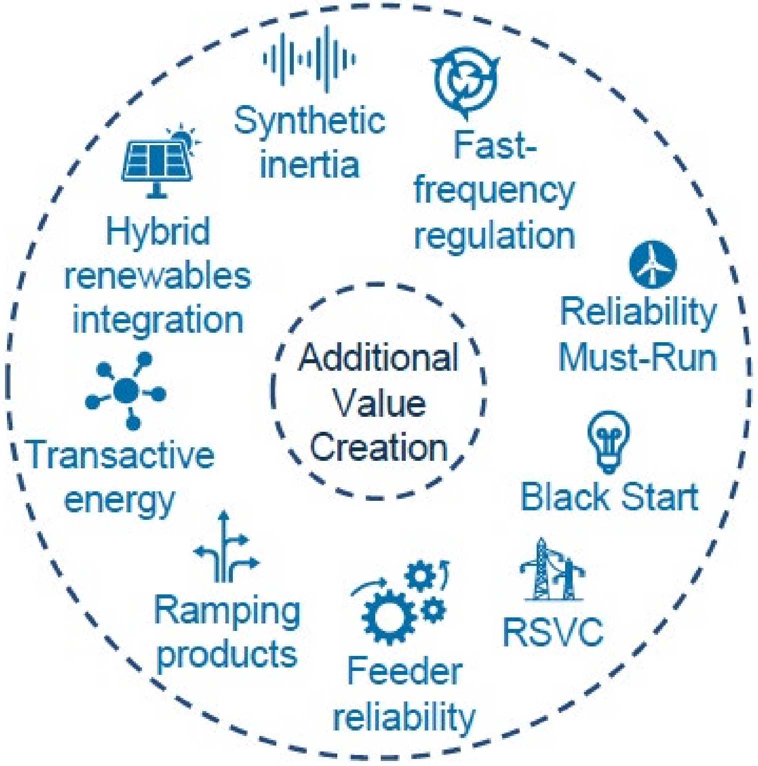


Grid Services – Other Services

- **Synthetic Inertia.** High speed controllers can mimic or even enhance grid inertia, providing the grid operator valuable time to respond to major outages.
- **Primary Frequency Control.** Facilities can be configured to automatically respond to frequency deviations.
- **Fast (Secondary) Frequency Response.** The highspeed performance of the battery-inverter system provides top-of-class response to AGC. This minimizes the total AGC needed to regulate system frequency.
- **Reactive Power and Voltage Control.** Facilities can automatically provide or consume reactive power to support the local grid voltage.
- **Black Start.** The technology is capable of being configured to assist with re-energizing the grid in the event of a total loss of grid frequency and power.



Minto 2MW Flywheel + Solar Energy Storage Facility

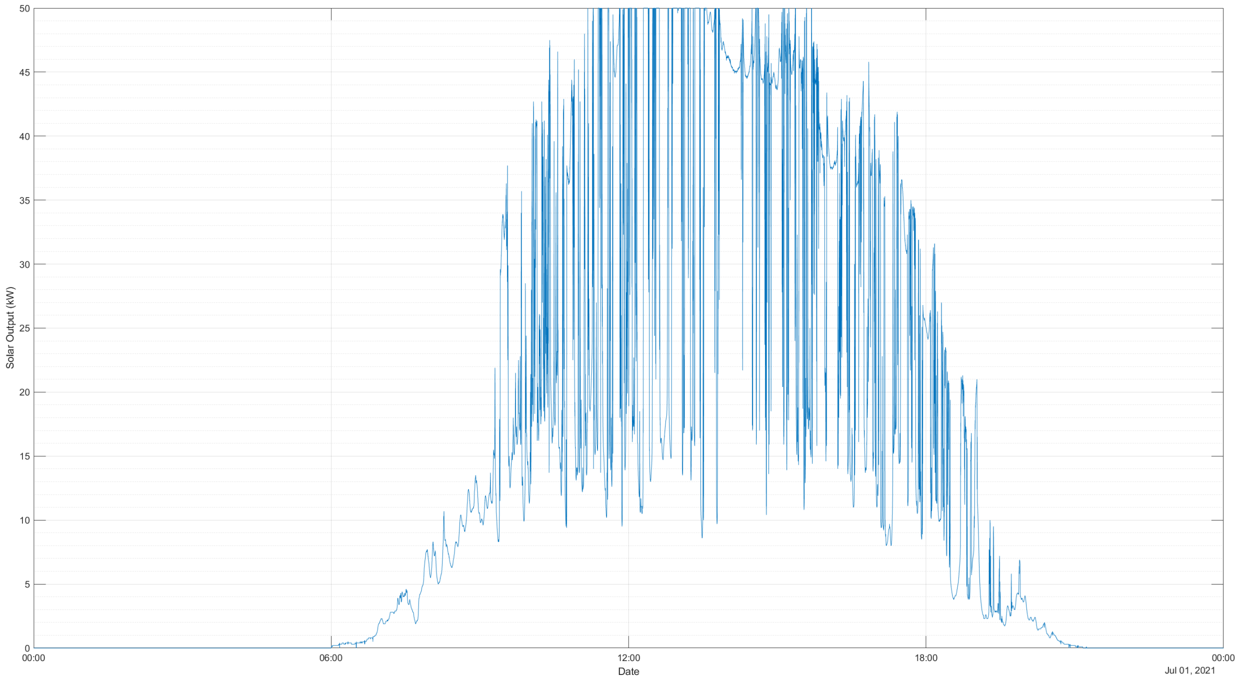
A Brief History:

- (10) 250 kW | 50 kWh flywheels built by Temporal Power. Flywheel rated speed at 11,500 rpm. Solid steel rotors weighing over 9000 lbs.
- Built in Harriston, Ont. Operations began in July 2014 under the IESO Alternative Technology Review (ATR) program.
- Facility followed the IESO AGC signal until 2018.
- The facility assisted the IESO in pioneering a new fast-frequency regulation signal better suited for energy storage.
- In 2021, a solar array was installed. The facility now tests various storage/solar configurations for the IESO.

Minto 2MW Flywheel + Solar Energy Storage Facility

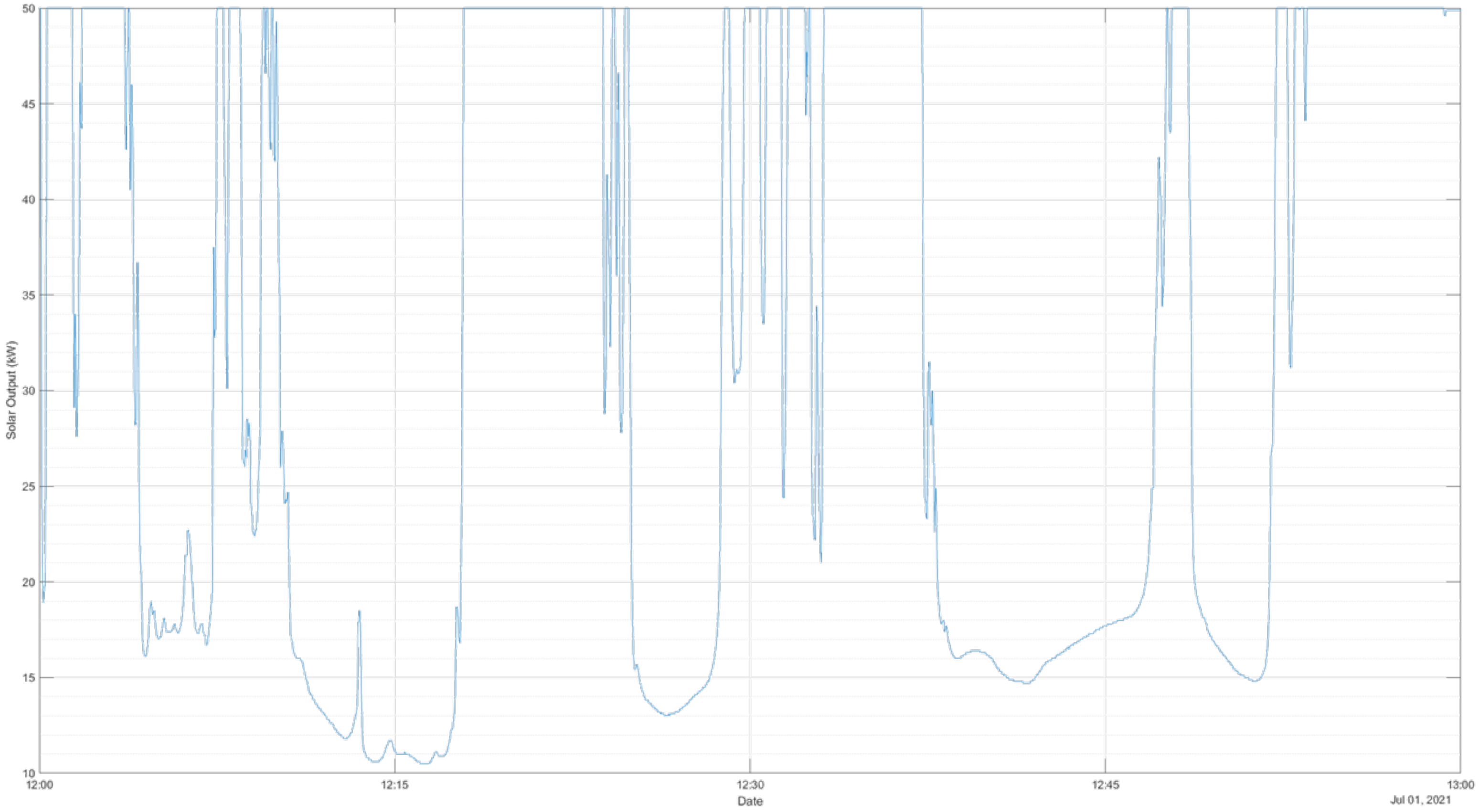
Renewable Smoothing

- Levels of solar output can vary rapidly due to cloud cover.
- Variations in solar output can be unpredictable between days making it difficult to predict in utility day ahead markets
- Large, sudden swings in output due to passing clouds, up to ~80% of max output
- Storage can be used buffer the output of a solar facility, making the power delivery more predictable and manageable for the utility.



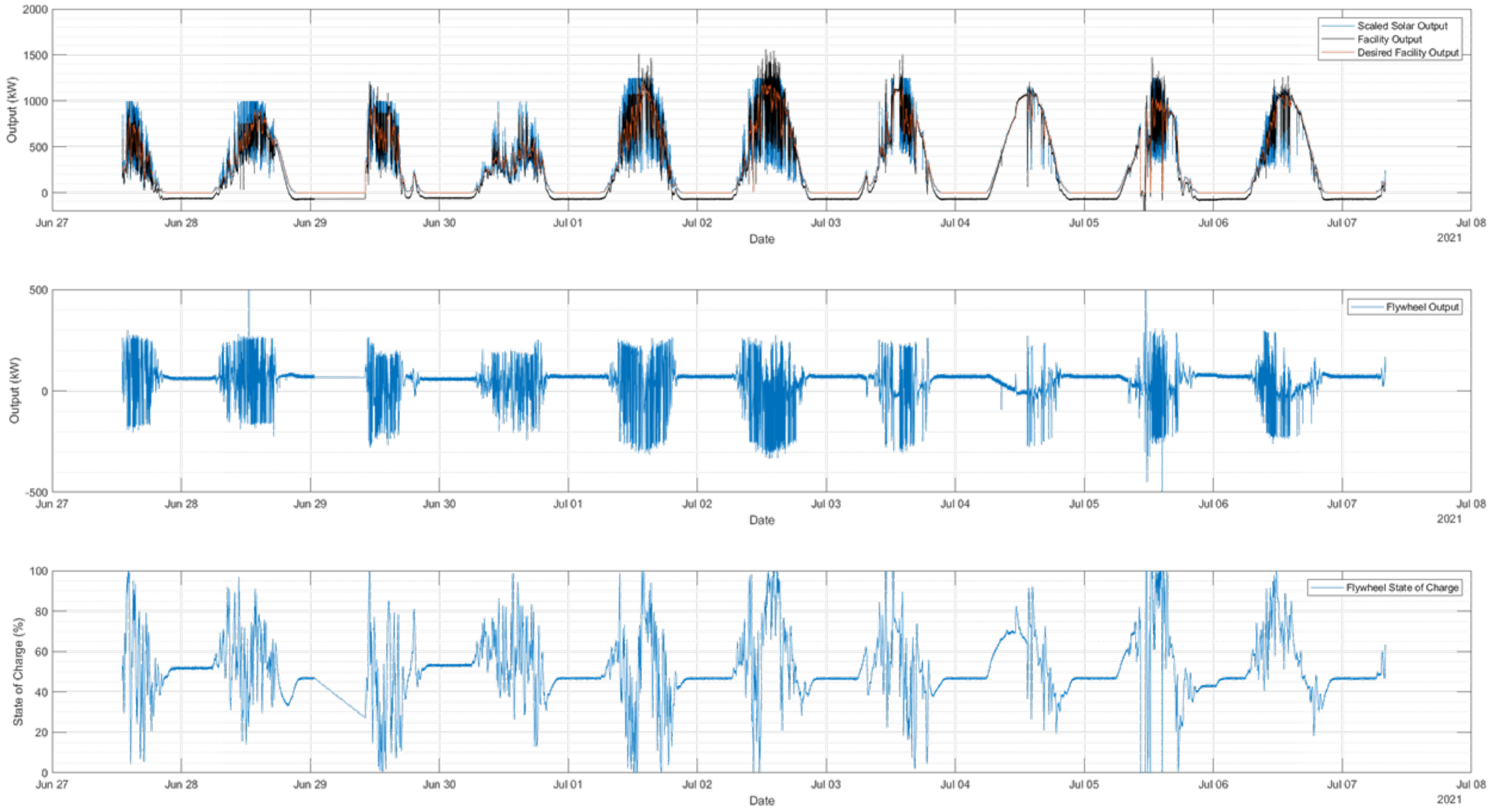
Minto 2MW Flywheel + Solar Energy Storage Facility

Renewable Smoothing – 1 Hour Snapshot of Solar Output



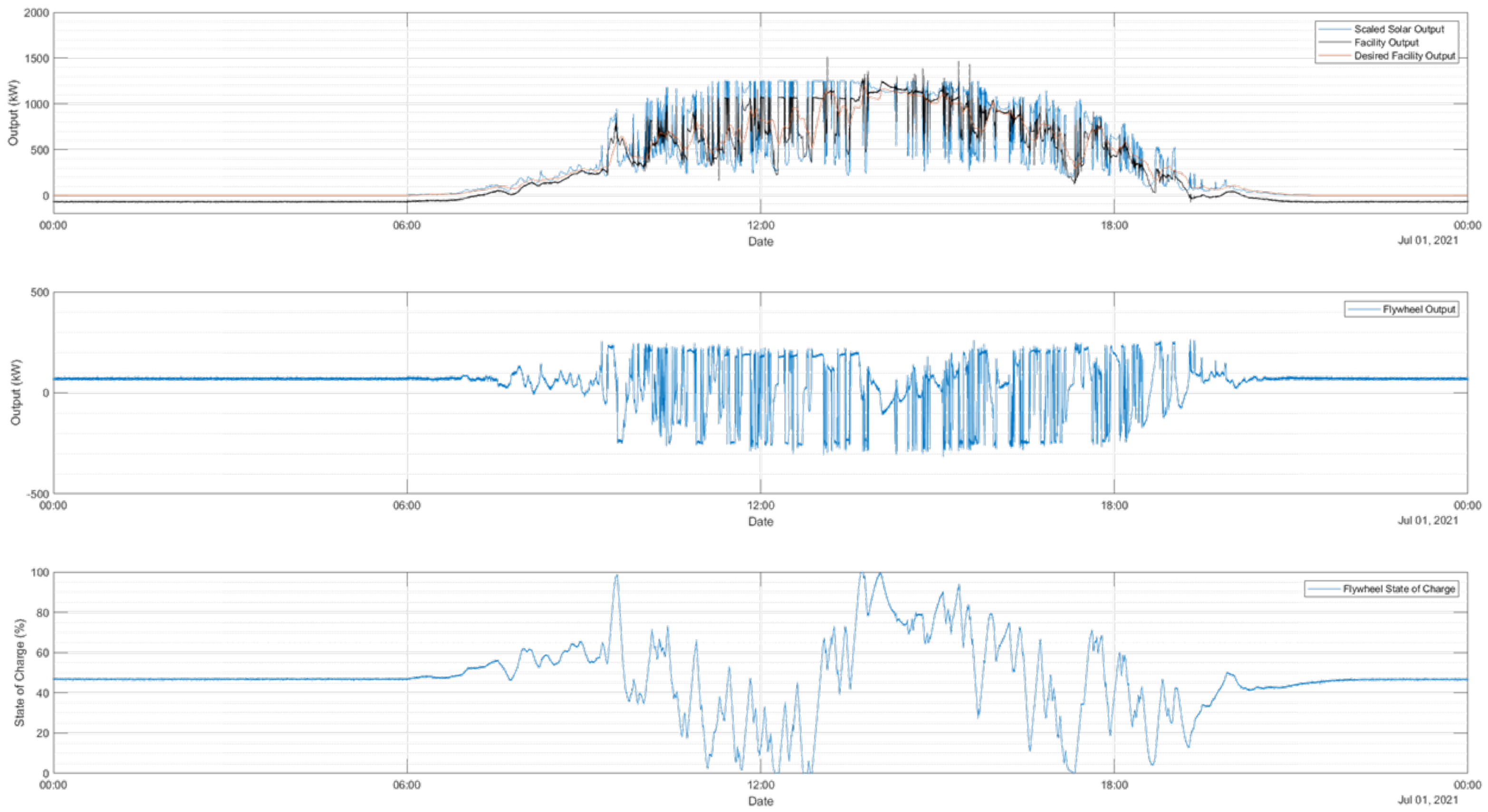
Minto 2MW Flywheel + Solar Energy Storage Facility

Renewable Smoothing – 10 Day Solar Smoothing Summary



Minto 2MW Flywheel + Solar Energy Storage Facility

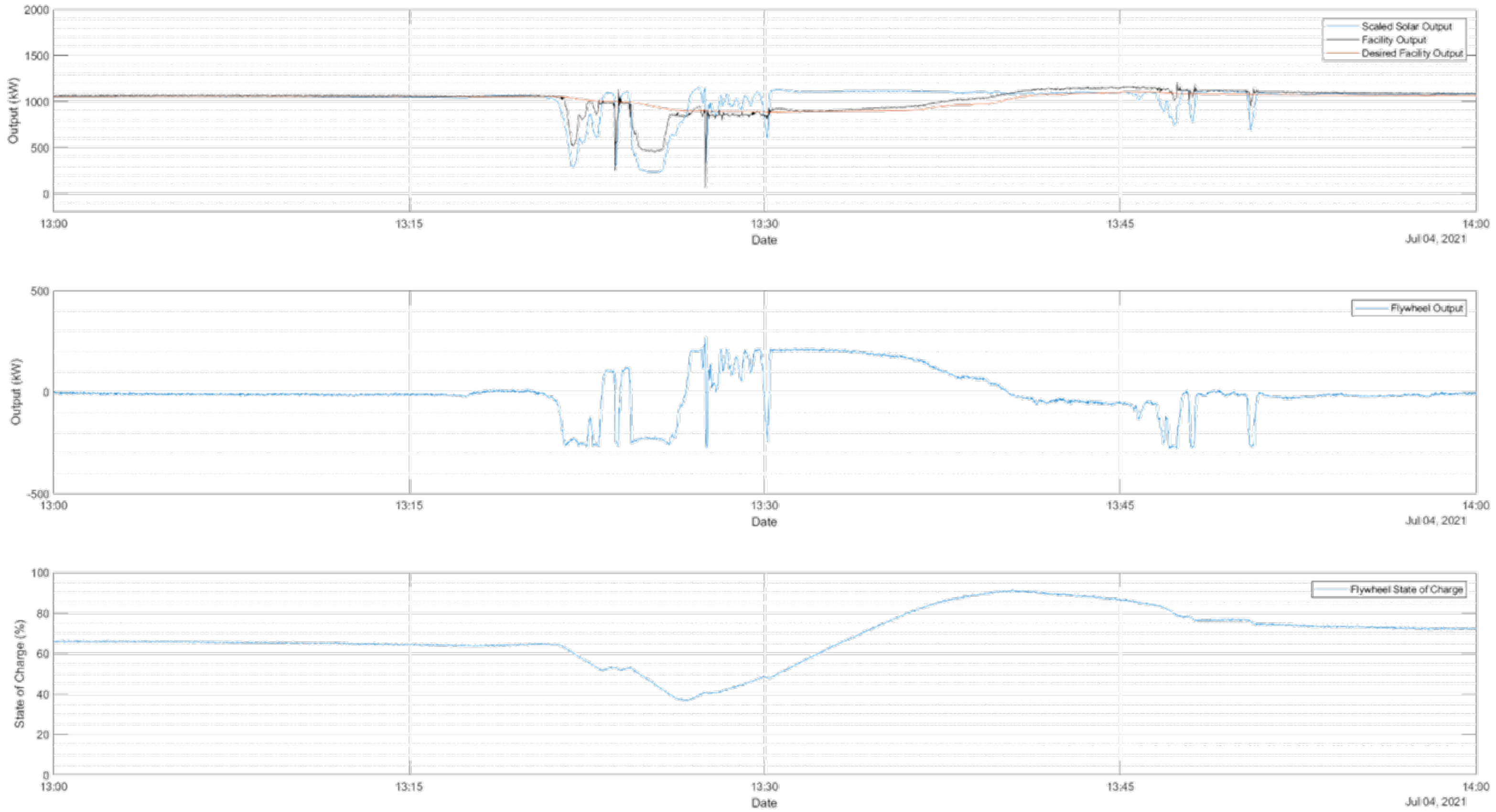
Renewable Smoothing - 1 Day Solar Smoothing



Minto 2MW Flywheel + Solar Energy Storage Facility

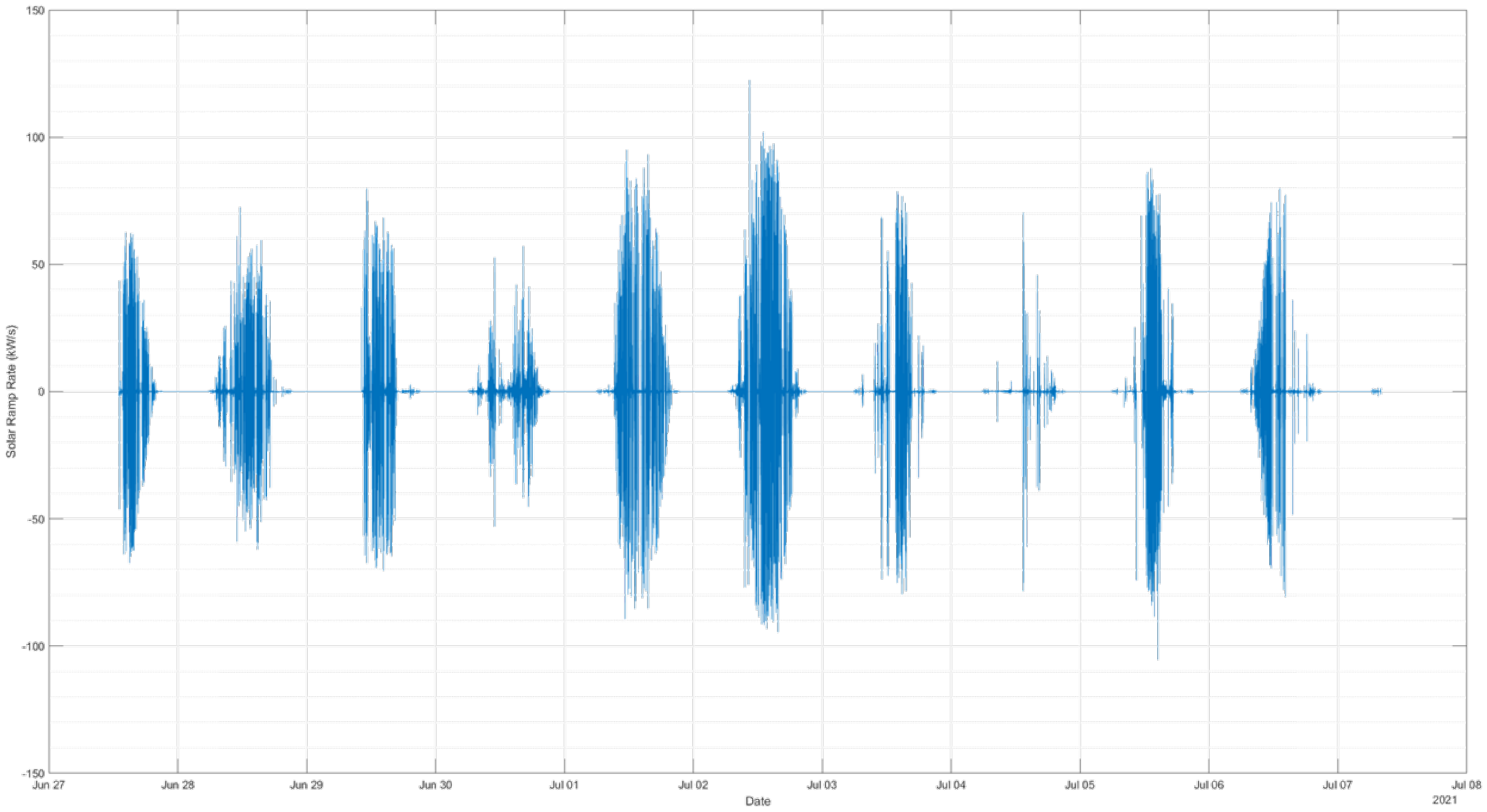
NRSTOR INC

Renewable Smoothing - 1 Hour Solar Smoothing



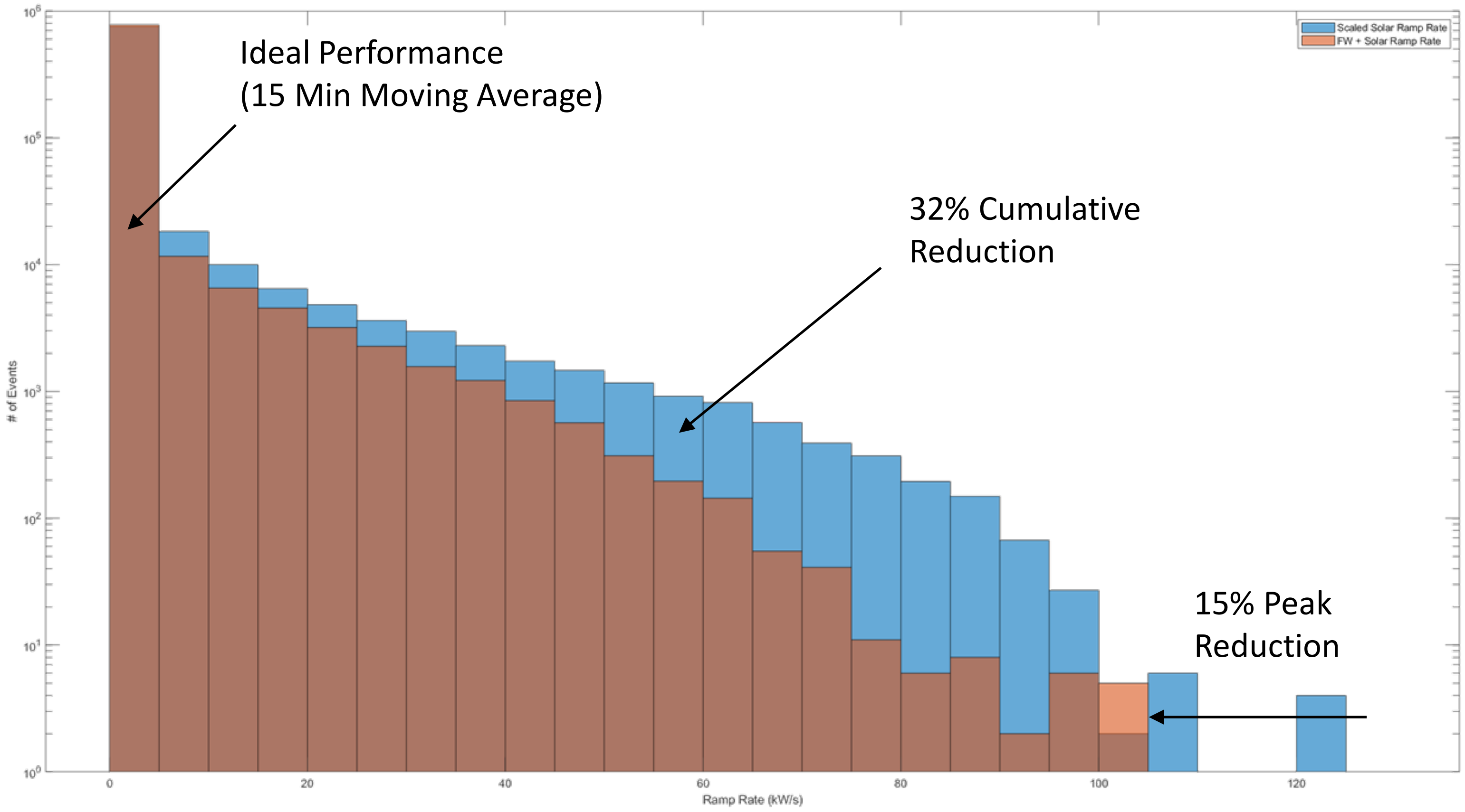
Minto 2MW Flywheel + Solar Energy Storage Facility

Renewable Smoothing – Quantifying the Problem



Minto 2MW Flywheel + Solar Energy Storage Facility

Renewable Smoothing – Quantifying the Problem



Thank You! – Q&A

Cody MacNeil, P.Eng, M.Eng
Senior Director, Assets & Engineering
cmacneil@nrstor.com