# Energy Storage

## Helping islands meet energy targets


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FLUENCE

A Siemens and AES Company

# 30 MW of energy storage for San Diego Gas & Electric, California, United States


Largest energy storage project in the world
Contract to online in 6 months
Sited on 1 acre, where a power plant could not be permitted

# About Fluence – A Siemens and AES Company

## EXPERIENCE

10+ years of experience in energy storage from two proven industry pioneers

- World’s leading storage provider
- Deployed or been awarded 56 projects, in 15 countries, 486 MW

## SCALE

Complete technology and service offerings delivered worldwide

- Proven technology platforms that address full spectrum of applications
- Delivery & integration in 160 countries
- Comprehensive services including financing

## THE RIGHT PARTNER

Deep understanding of modern power markets, customer needs, and local market challenges

- Collaborate with customers to solve their energy challenges
- Avoid pitfalls of inexperienced packagers and integrators
- Strong financial backing and industry staying power

**Created and backed by two industry powerhouses**

SIEMENS Ingenuity for life + AES we are the energy

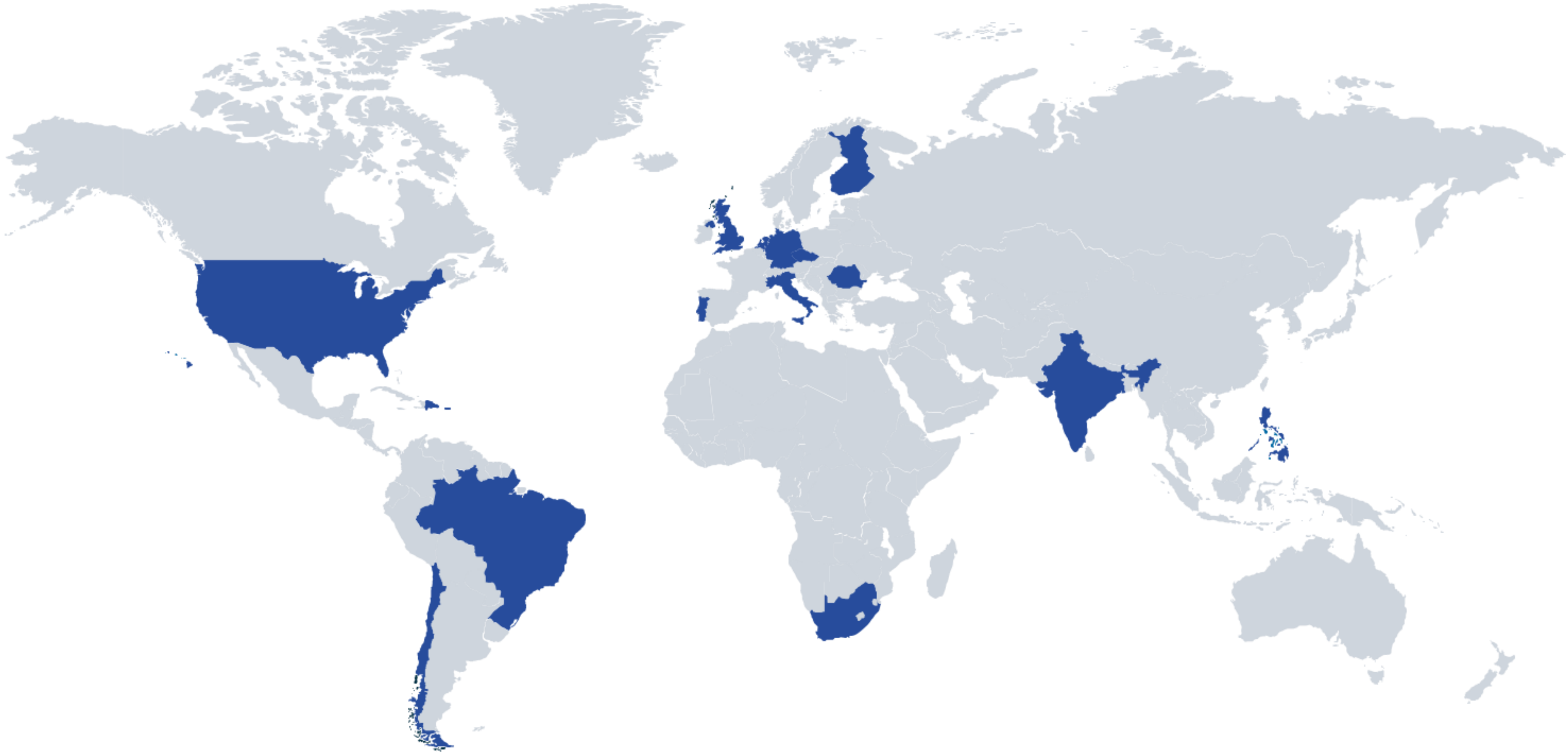
# Energy storage is being deployed at scale around the globe

**485**
TOTAL MW

**15**
COUNTRIES

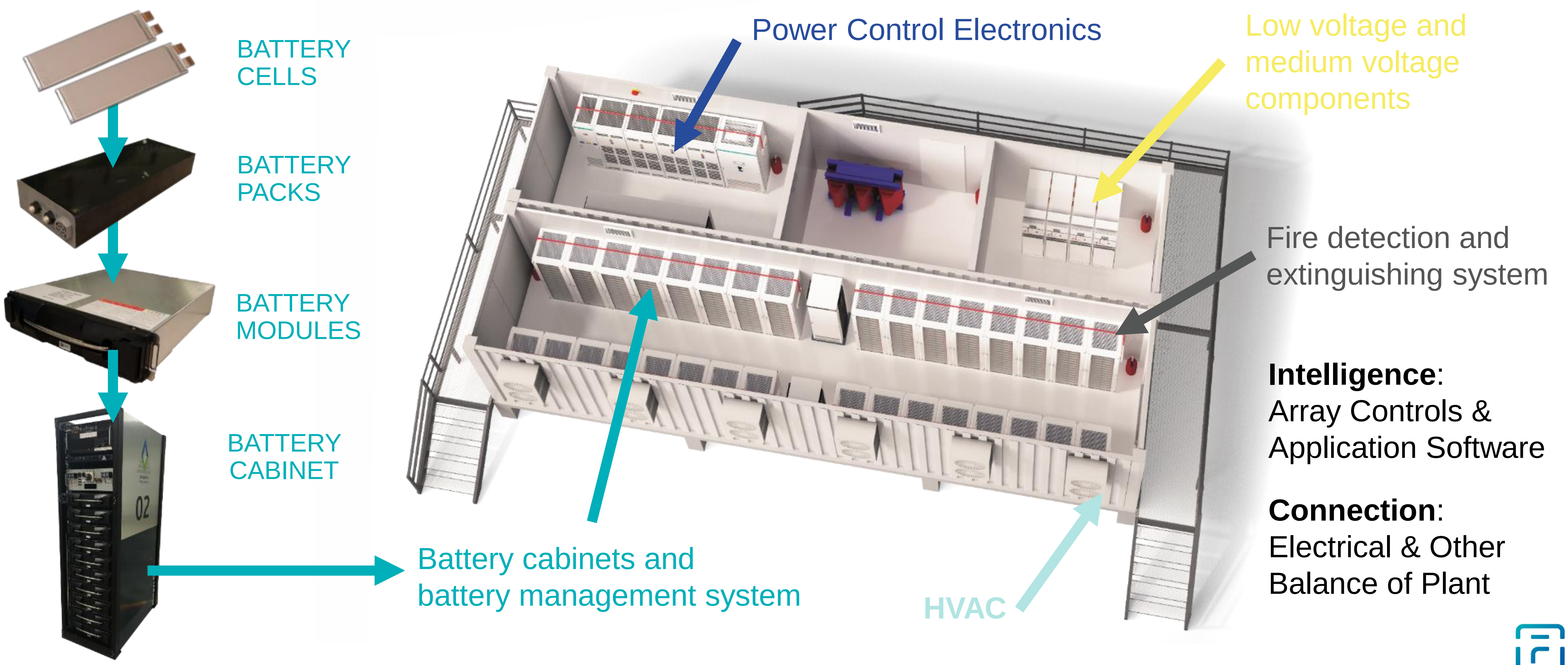
**56**
PROJECTS*

*Deployed or Awarded



# What is energy storage? Large-scale batteries for industrial applications.

Modular, scalable arrays of proven technologies integrated at utility and industrial scale.

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Energy Storage
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AES
Safety First
Dependable
02


# Storage Value Proposition in Islands

# Island markets have certain unique characteristics

## Sparse transmission and limited power generation options make islands unique

| Market Attribute | Island Grids | Mainland |
|---|---|---|
| Fuel prices | Typically tend to be high (imported fuel in many cases) | Tends to be low due to lower transportation costs and available supply |
| Power supply stack | Fewer generation units leading to significant gradation in cost | Wide variation of units and interconnected nature brings diversity in supply stack. |
| Transmission | Usually pretty sparse and not very networked | Highly networked with several redundancies available to meet contingencies |
| Loss of generation or transmission failure | High system impact due to generation loss or transmission failure | Generally options may be available due to highly networked transmission grid |

- Spinning reserves, frequency regulation and transmission system reliability have very high value in island markets.
- Few generation units have to provide these critical ancillary services leading to inefficient operation; in non-island markets, many units take equal responsibility for these services.

# THE RATE OF CHANGE OF FREQUENCY (ROCOF) MUST BE ADDRESSED TO KEEP OUR POWER SYSTEM STABLE – VARIOUS STRATEGIES CAN BE DEPLOYED.

## THE CHALLENGE
## MATCHING SUPPLY AND DEMAND, IN THE BLINK OF AN EYE

Keeping the grid stable means matching supply of and demand for energy, at all times. When the system is balanced the frequency is stable at around 50Hz. However when a power plant drops off the system, due to a sudden and unexpected fault, there is an immediate short-fall in energy. This causes the frequency of the system to start dropping. This drop must be arrested and reversed to avoid a system failure.

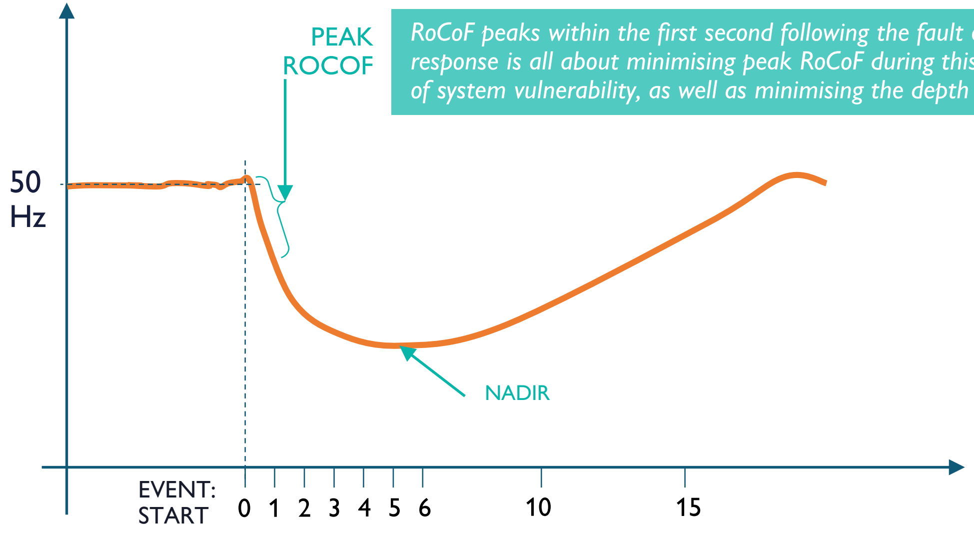
There are two metrics of concern after a fault:

1. **RoCoF**, the Rate of Change of Frequency, is how fast the frequency changes. If RoCoF exceeds 1Hz/s, additional power stations could be tripped offline and / or damaged.
2. **The nadir**, the minimum level the grid frequency reaches during an event. Below 50Hz, the potential for power stations to be tripped offline increases.

This report focuses on the former: RoCoF.

Managing RoCoF is a growing challenge. As the maximum amount of non-synchronous generation – notably wind – allowed on the grid increases, inertial response is eroded – increasing the threat to system security which RoCoF poses.

*RoCoF peaks within the first second following the fault event. Inertial response is all about minimising peak RoCoF during this short period of system vulnerability, as well as minimising the depth of the nadir.*




## THE SOLUTION
## LEARNING HOW TO ROCK THE ROCOF

In the face of increasing RoCoF, System Operators have two strategies for RoCoF management. These strategies can be deployed separately or together.

### STRATEGY 1: ADAPT

**Increase generator tolerance to high RoCoF.** The grid code has already been amended to incorporate an increased RoCoF withstand level from 0.5 to 1.0 Hz/s, increasing system resilience to frequency events. However, additional solutions are needed to achieve 75% SNSP and beyond.

### STRATEGY 2: MANAGE

**Proactively manage RoCoF.**

This can be provided through analogue or digital inertia.

### ANALOGUE INERTIA

**Passively provide instantaneous kinetic energy from rotating synchronous plant**

*Sample technologies: coal plant, CCGT, biomass plant, synchronous compensators, rotational stabilisers, compressed air energy storage, pumped hydro storage…*

This is how RoCoF is currently managed, representing the status quo option; however, as coal and gas plants come offline, it can no longer be taken for granted. The nature of the response is not controllable, and instead is managed by physics.

### DIGITAL INERTIA

**Actively inject/remove power from asynchronous plant on inertia timeframes**

*Sample technologies: batteries, demand-side response, interconnectors, wind energy…*

Digital inertia can take different forms:

1. Frequency response: providing an enhanced governor response (slow)
2. RoCoF response: emulating the real inertial response (fast but unstable)
3. Step response: effectively a combination of frequency and RoCoF response (fast but needs an engineering consensus).

Batteries can provide all forms.

Note: Although batteries do not provide spinning mass, what we are calling digital inertia response provides a service which provides the same benefits - or greater - as inertia.

# QUB RESEARCH AND BATTERY OPERATIONAL EXPERIENCE SHOWS THE ABILITY OF BATTERIES TO SATISFY SYSTEM OPERATOR INERTIA REQUIREMENTS



In 2016, the System Operators (SOs) in the Island of Ireland (Eirgrid and SONI) undertook a major study reviewing the ability of synthetic inertia to help keep RoCoF within manageable levels at 75% SNSP level.

Their report outlined key requirements for synthetic (or digital) inertia providers. QUB's research and international operational battery experience demonstrates that batteries can meet all requirements.

## ON THE CUSP
### THE ABILITY OF BATTERIES TO MEET SYSTEM OPERATOR REQUIREMENTS

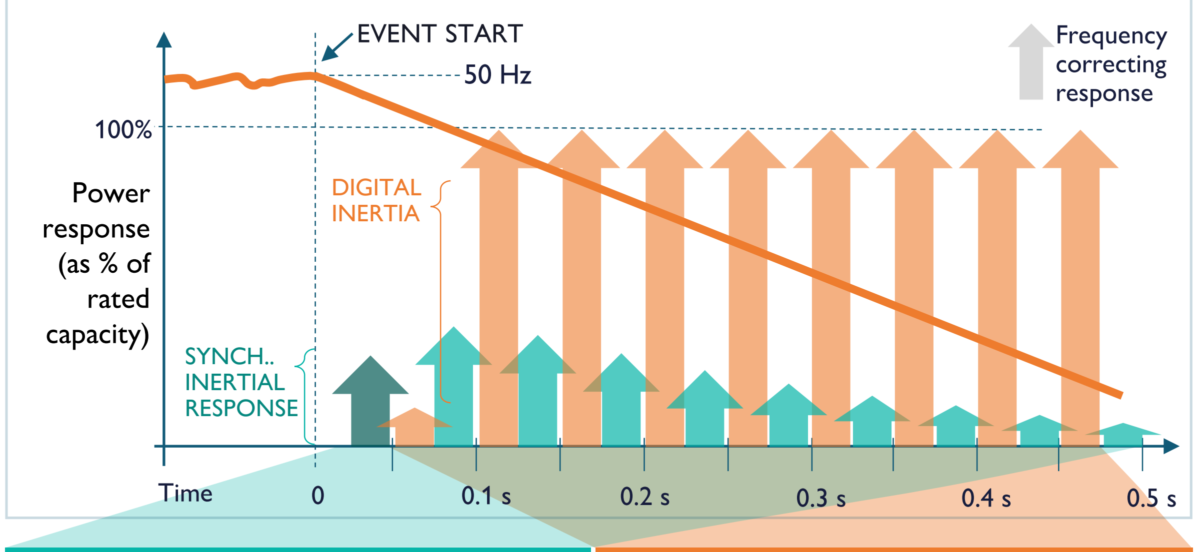
| CHECKLIST | PERFORMANCE |
|---|---|
| ***1. Fast response*** *"to begin responding from 100 milliseconds from the start of the event"* | QUB research shows that on recent frequency transients (July-Sept '17) the Kilroot array responded in timescales **approaching 0.1 secs**. This could be reduced through implementing an 'emergency signal' triggered from transient detection, either through voltage or synchronous machine power measurements; this could be generated locally or as part of a wide-area control network. |
| ***2. Fast ramp-up*** *"the active power injection must be fully achieved 200 milliseconds [0.2 s] after the device begins to respond"* | At present the Kilroot array is set up to provide the slower ramp rate required for current services, with a ramp time of ~0.5 seconds. With the right control system in place, the battery at Kilroot could ramp to full power **in 0.05 secs**. |
| ***3. Smooth recovery*** *"to present unintended adverse system issues during the frequency recovery"* | Battery can respond dynamically. The output can be sustained for a period determined by the MWh capacity of the battery; at Kilroot a full response can be provided for up to **30 minutes**. |

*Eirgrid/SONI (March 2016), RoCoF alternative & complementary solutions project: Phase 2 Study Report*

Moreover, in the faults studied by QUB, 360MW of batteries could have provided the same amount of power after 0.1 secs as the inertial response of 3000MW of synchronous generators. This exceeds the stability requirements set by EirGrid and SONI for system operation at an SNSP of 75% or higher.

**3,000MW** SYNCH. GENERATORS = **360MW** BATTERIES

**POLES APART:** DIFFERING RESPONSE CHARACTERISTICS IN THE FIRST HALF SECOND




## SYNCH. GENERATORS

When frequency drops suddenly, synchronous generators respond **automatically and immediately** by slowing down, releasing energy stored by the large rotating masses contained in these plants. This is **inertial response,** with each unit providing a **power increase of 7-14%** of their rated total capacity within 0.05 seconds for a typical large event. The inertial response tails off after a few seconds and then might be replaced by a governor response that tries to push the frequency back up.

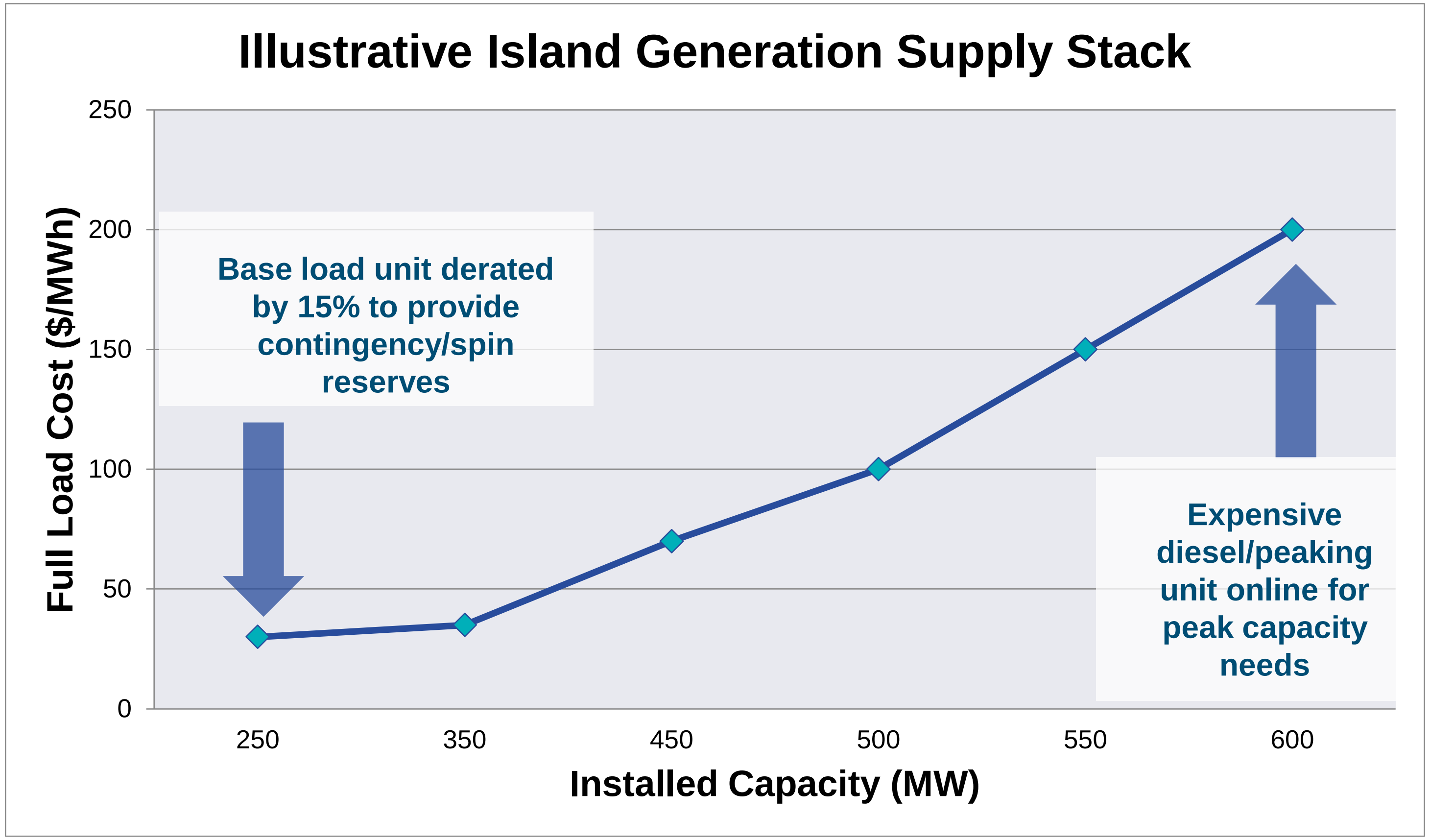
To respond, synchronous generators must be running. Each unit can only increase output by a small proportion. This means a large number of units have to be running on the system, in case there is a fault, displacing variable renewables.

## BATTERIES

Batteries have no moving parts. They begin to **respond as quickly as the fault can be measured**, with reaction times approaching 0.1 seconds being seen. This provides a slightly slower initial response than that of synch. generators. But once the fault is detected, batteries can **respond dynamically with high ramp rates**. This means that with the right control procedures, batteries can deliver **full output in less than 0.2 seconds**. This output can be sustained for minutes to hours depending on the size of the battery.

Batteries are 'turned up' when needed. By responding more aggressively to faults, and at full power output, batteries reduce curtailment – allowing renewable generation to replace more conventional generation.

# Storage Provides Contingency Response, Frequency Regulation and Other Ancillary Services Freeing Up Traditional Units to Operate Efficiently




## Key Assumptions

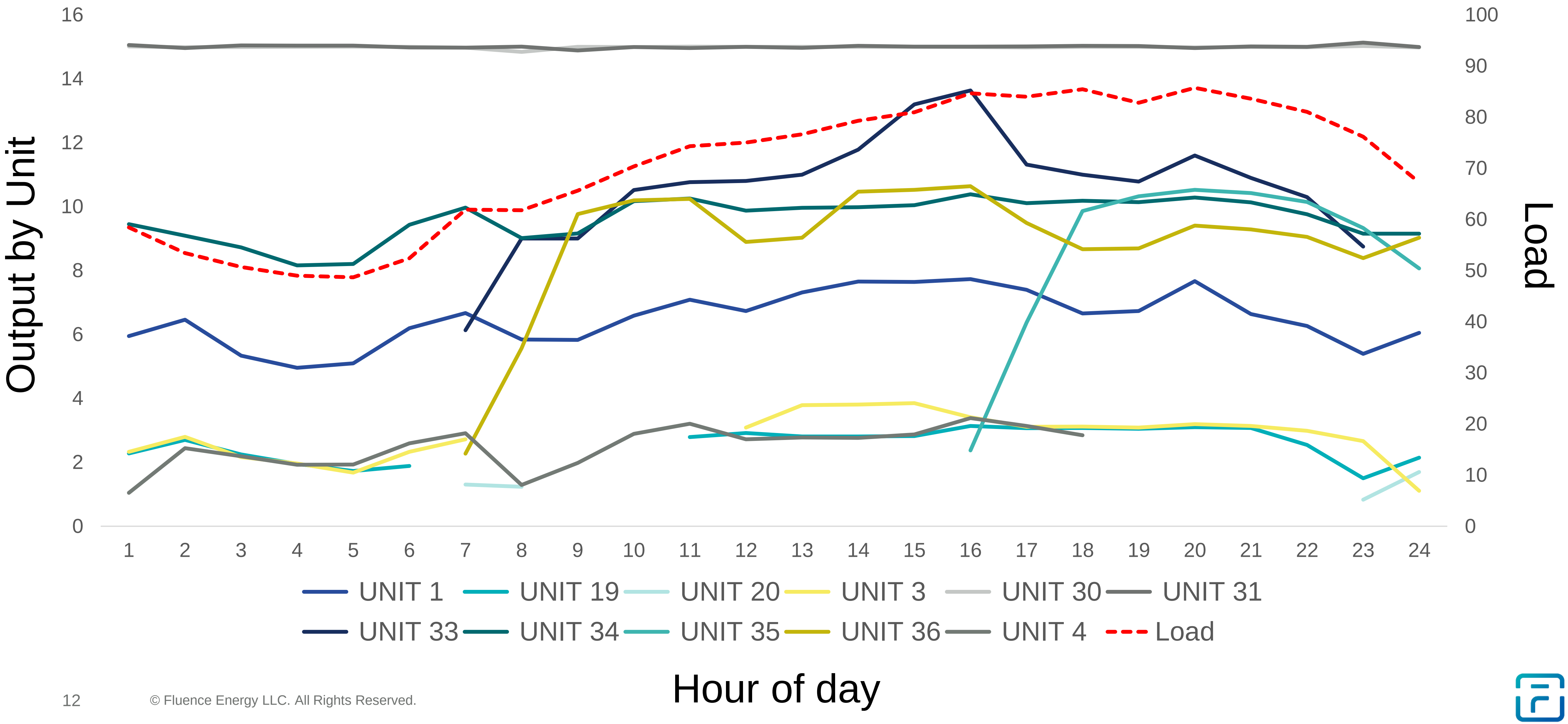
- 600 MW Installed capacity in island. Cheapest unit = $30/MWh, Most expensive unit = $200/MWh
- Base load unit holds back 15% capacity (37.5 MW) for contingency/spin reserves.
- 37.5 MW increase in base load unit avoids dispatch of $200/MWh most expensive unit .

## Storage Value

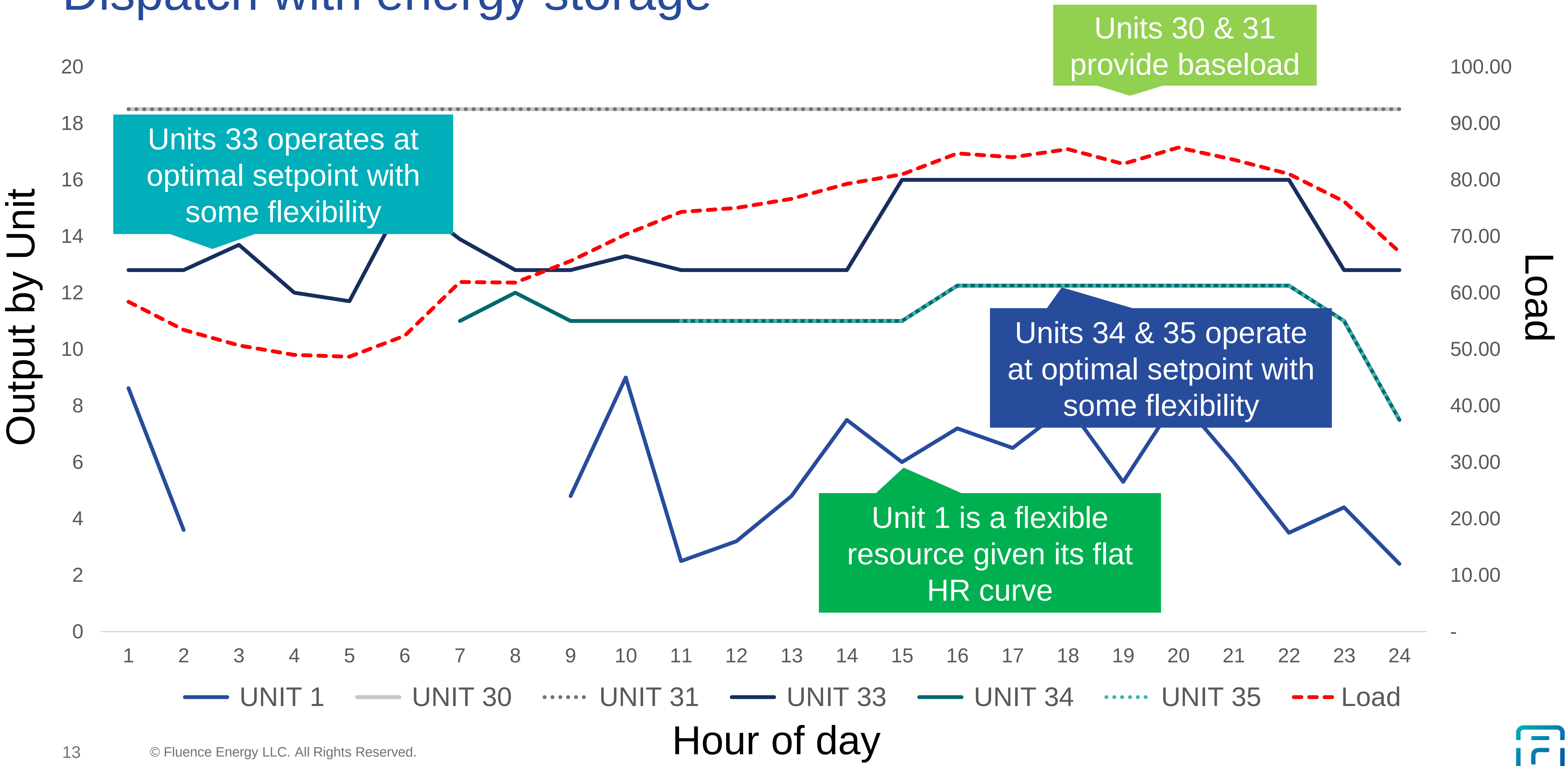
- **Storage benefit** = 37.5 MW * $200/MWh * 2,000 hours (typical capacity factor for simple cycle gas turbines) = $15 MM/Year
- **Storage cost** (assuming 1-hour system) = 37.5 MW *$1000/kW = $37.5 MM
- **Simple payback** = less than 3 years

Key questions on storage capacity and duration required for this application have to be addressed in each island market; existing supply stack and resources that currently provide ancillary services are usually enough to develop first-cut storage value proposition.

# Illustrative example of island grid dispatch



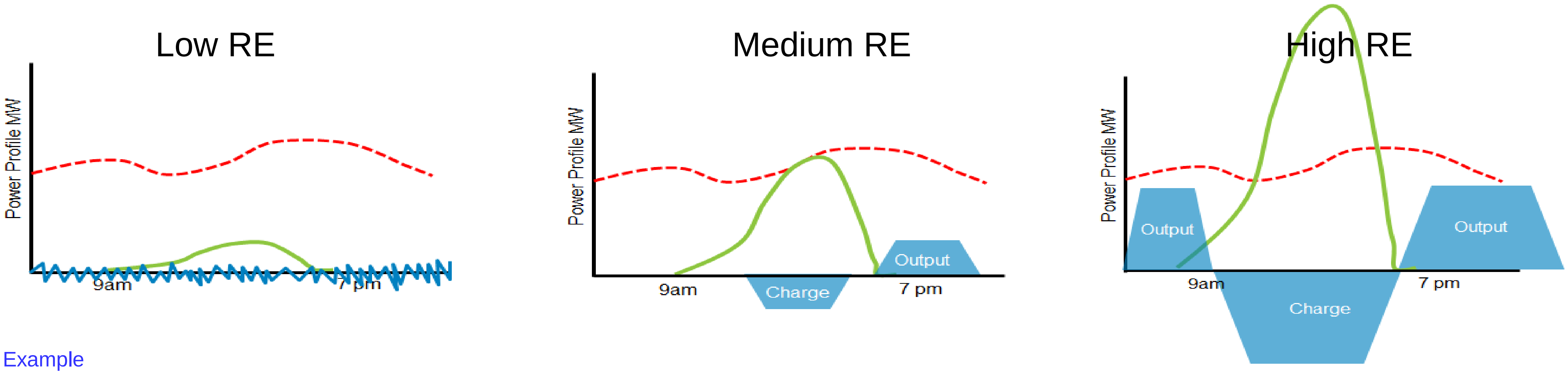
# Dispatch with energy storage



# But wait, there's more…

## What percentage of small islanded grid peak load can energy storage capture?

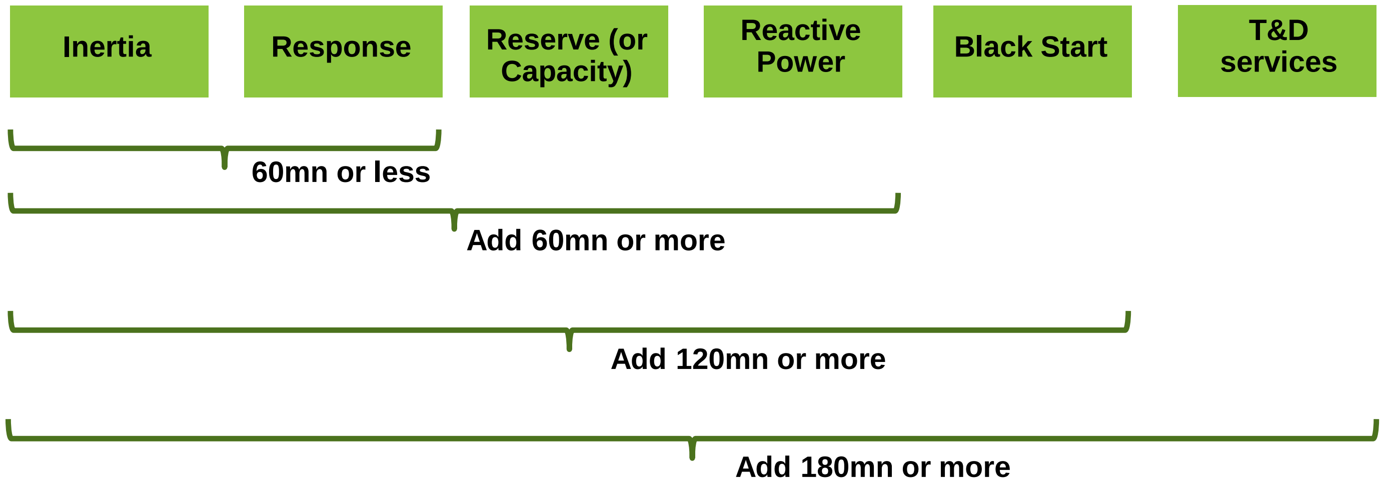
| RE Penetration | Battery Application | Annual Average RE Generation | Duration |
|---|---|---|---|
| Low | Grid Stability | <20% | 30 minutes to 1 hour |
| Medium | Peak Shifting | 20-50% | 1 hour to 4 hours |
| High | Bulk Energy Storage | 50-100% | 4 hours to 7.6 hours |




Example

# Longer durations systems provide flexibility, efficiency, and productivity

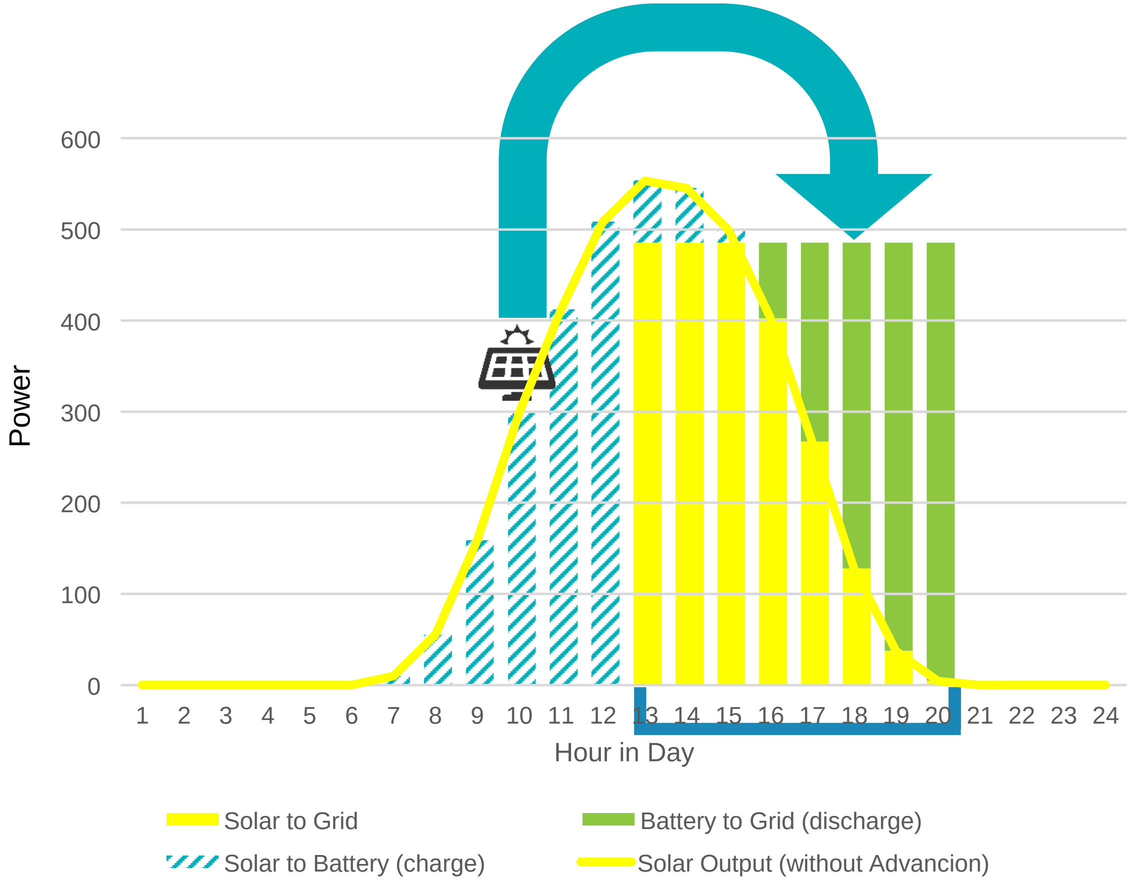
- **Flexibility** in terms of breath of services the asset can provide and how it can adapt to changing system needs
- **Efficiency** as the longer the duration, the lower the operating costs
- **Productivity** as multiple outputs (services) are provided by the same input (MW interconnected to infrastructure)




- Inertia and frequency control services can be delivered by short duration batteries, but more reliably with 60 minute BESS than 30 minute or less
- Reserve and T&D services (constraint management) require longer duration
- Black Start services also require long duration

# Renewable Flexible Capacity

- Energy storage can use excess renewable energy to provide peak capacity
- Reliable delivery of peaking energy with zero associated emissions
- Mitigates renewable over-production during off-peak hours



# Energy Storage Applications for Island Grids

## Critical Spinning Reserve

**Los Andes, Atacama, Chile**

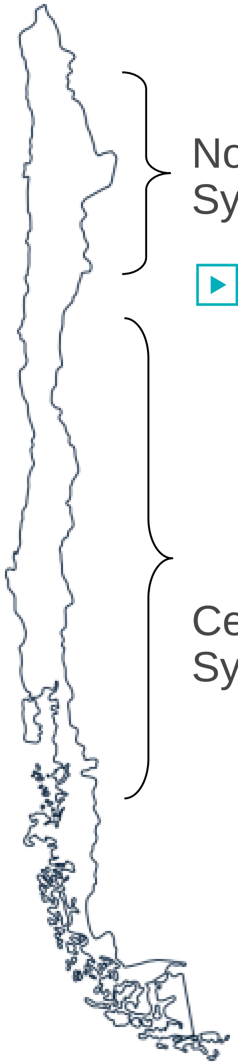
**12MW / 3MWh**

**Replacing oil and standby**

**IMPACT:**

- Avoided load shedding
- Increased energy & reduced costs
- Inertia-like performance

# Northern Chile (Not an Island, But Similar Characteristics)



Northern Interconnected Electrical System (SING)

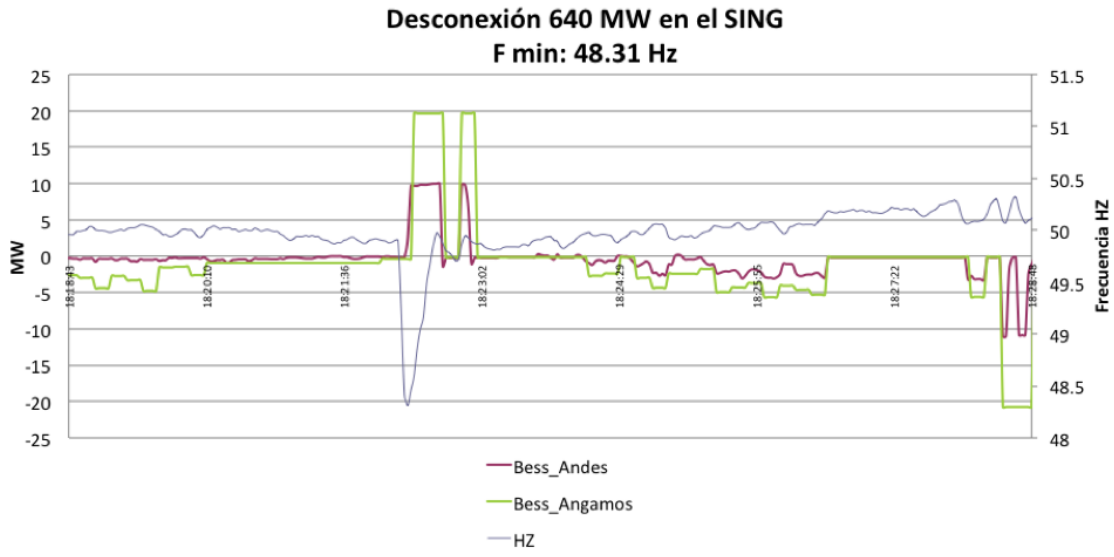
- ~2 GW of Peak Demand, areas of Atacama desert, large mining loads, limited traditional generator supply options, sparse transmission grid.

Central Interconnected Electrical System (SIC)

**AES Energy Storage Projects in SING**

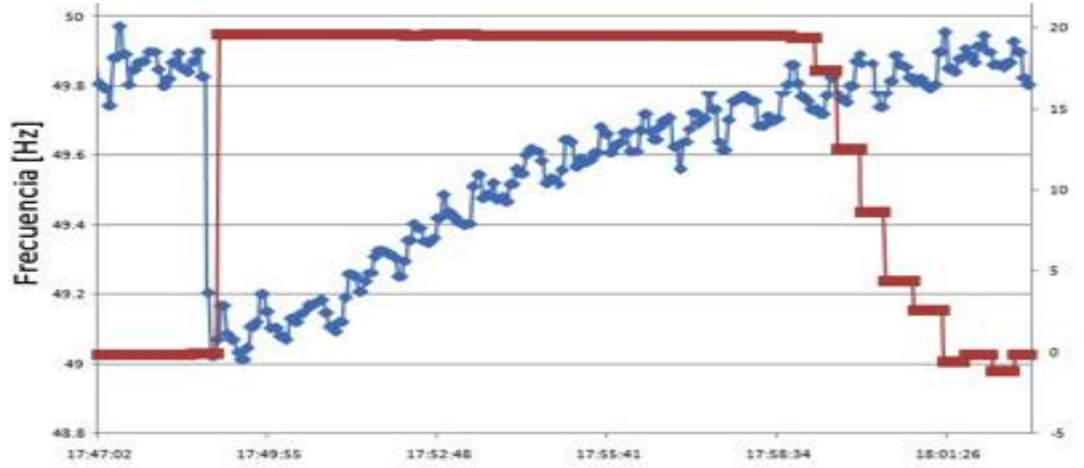
Los Andes, Angamos and Cochrane (52 MW Total)

**Actual Performance: Event from May 2013, when AES Storage Units Autonomously Responded to Frequency Deviation**



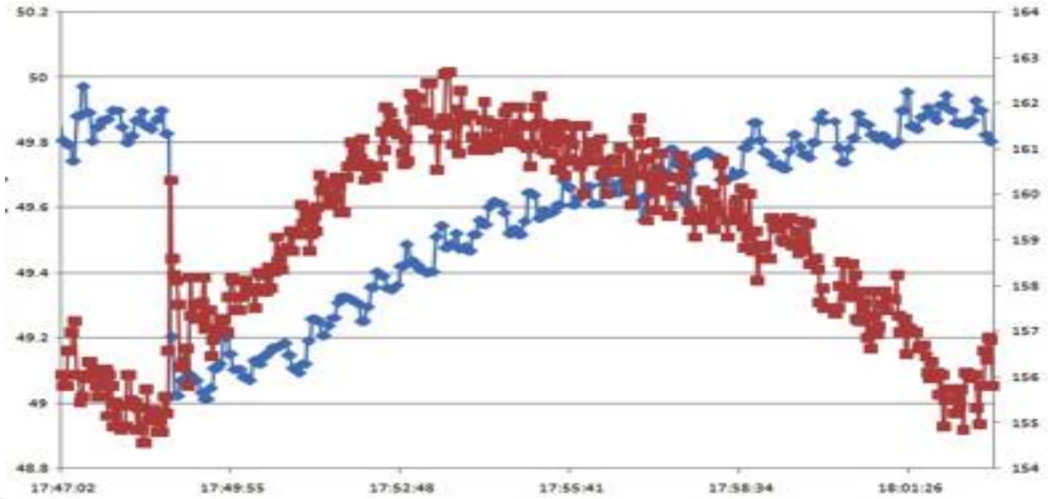
# Superior contingency response, inertia-like impact

## Immediate, controlled response improves security & flexibility




### Energy Storage Response

- ✓ Energy storage responds with rapid increase of output from 0MW to 20MW
- ✓ Autonomous response according to programmed profile
- ✓ Output sustained until stability restored




### Thermal Units

- ❖ Thermal unit responds with  burst, then output drops off
- ❖ Gradually ramps up in oscillating manner to 7MW output increase over 4 minutes

# Critical Grid Stabilization

**Santo Domingo, DR**

**10MW / 5MWh**

**Improving grid efficiency**

**SERVICES:**

- Capacity release for generation facility
- Ancillary services

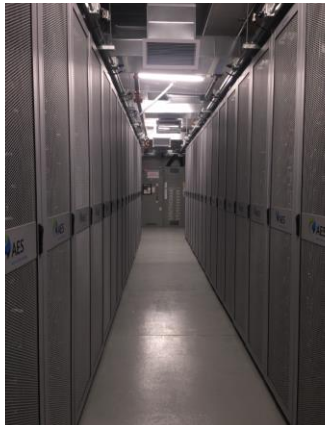

AES Energy Storage

# Los Mina DPP Advancion Energy Storage Array

- **Capacity:** 10 MW interconnected, equivalent to a 20 MW resource (10 MW charge/10 MW discharge)
- **Duration:** 30 minutes
- **Installed MWh:** 5 MWh
- **COD:** June 2017
- **Key Application Provided:** Frequency Regulation
- **Enclosure:** Containers


DPP, Exterior

DPP, Exterior

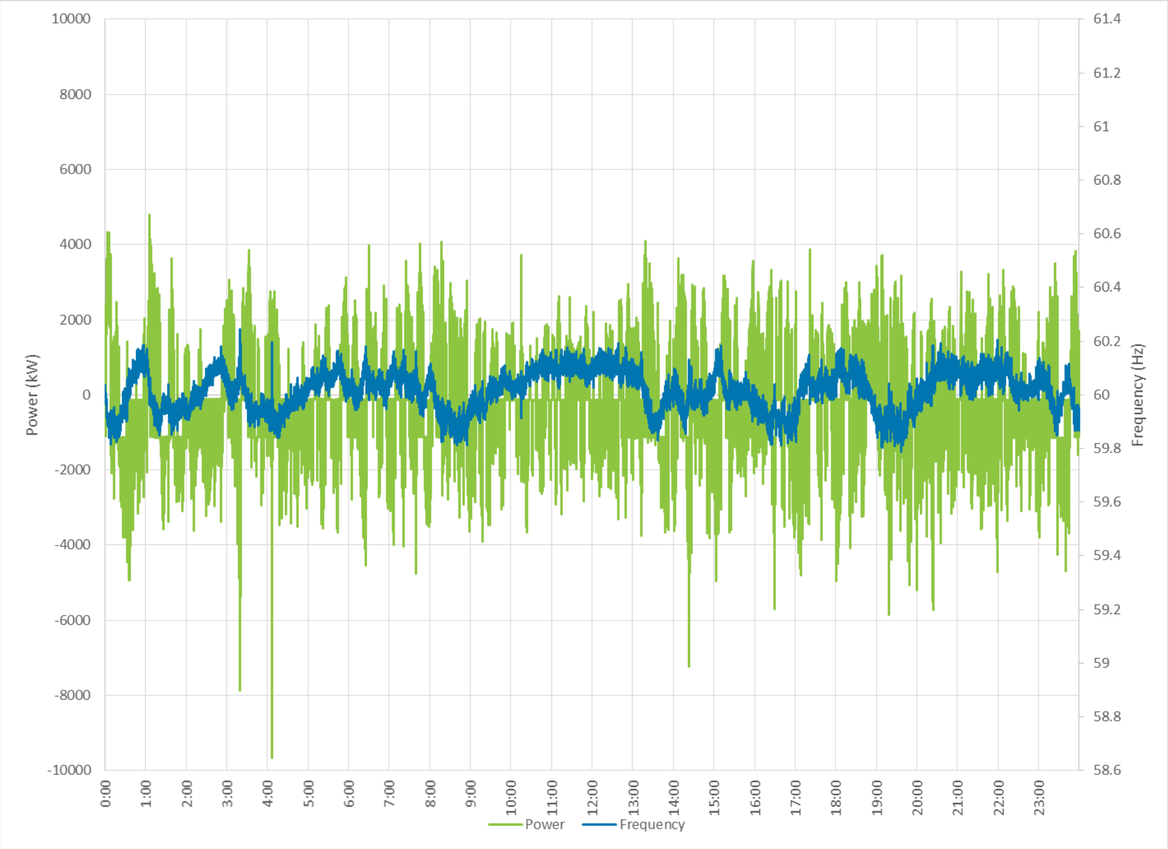


DPP, Battery Enclosure Interior

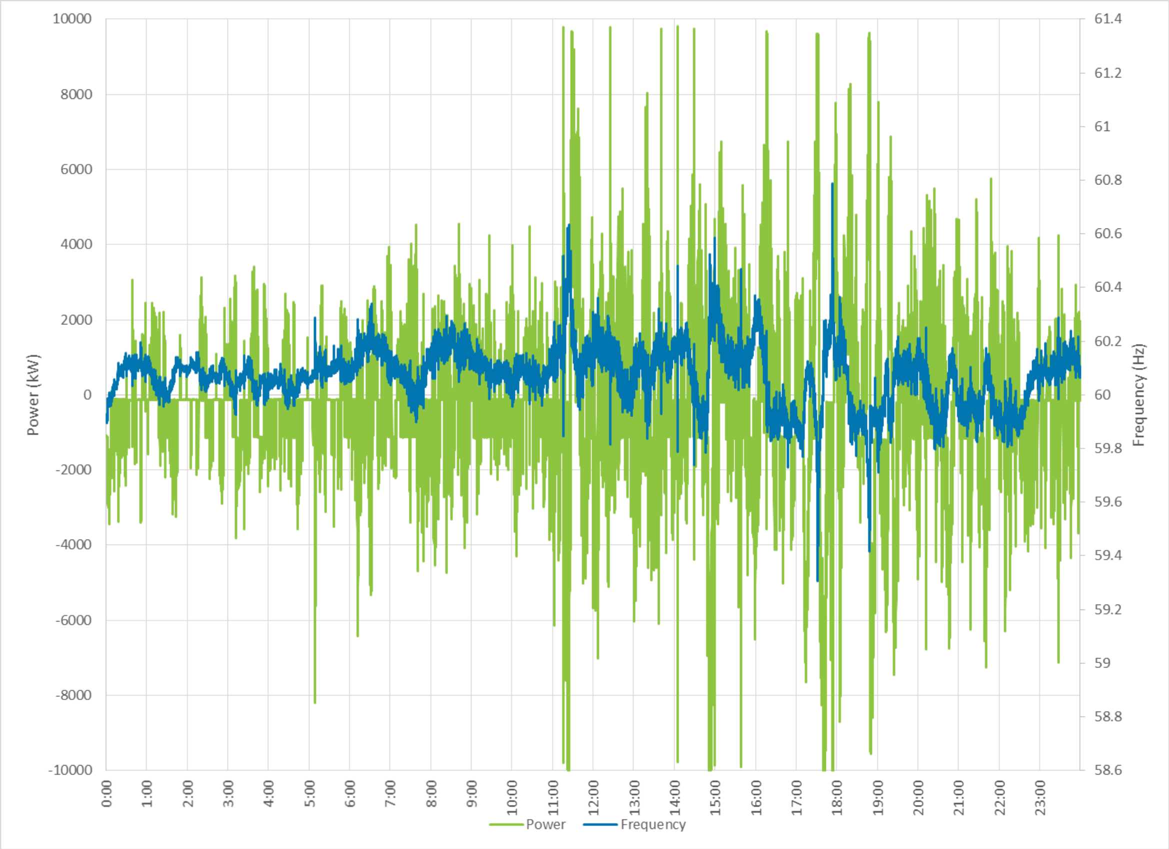

DPP, Control Room

# Andres Power and Frequency – Hurricane Irma

- System charged and discharged at maximum capacity (10MW) during the storm




August 31, 2017
(One week prior to Hurricane Irma)




September 7, 2017
(during Hurricane Irma)

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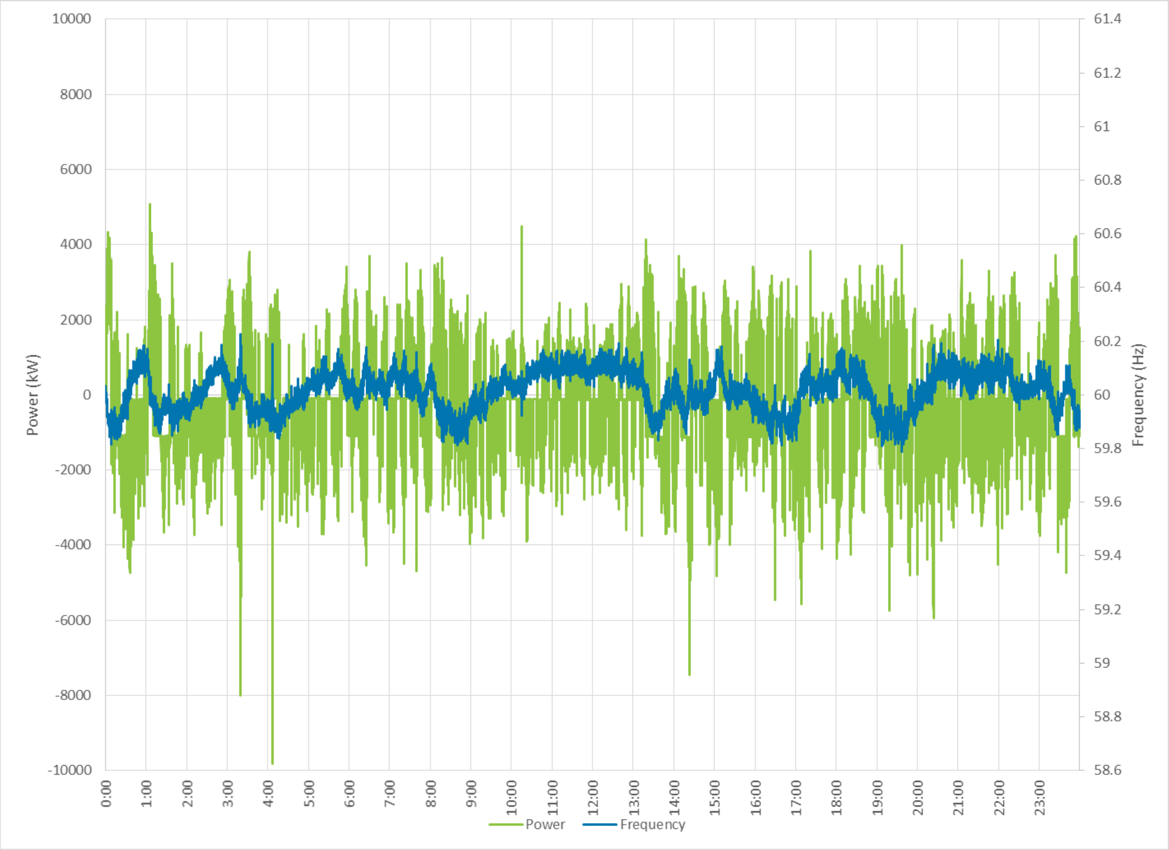


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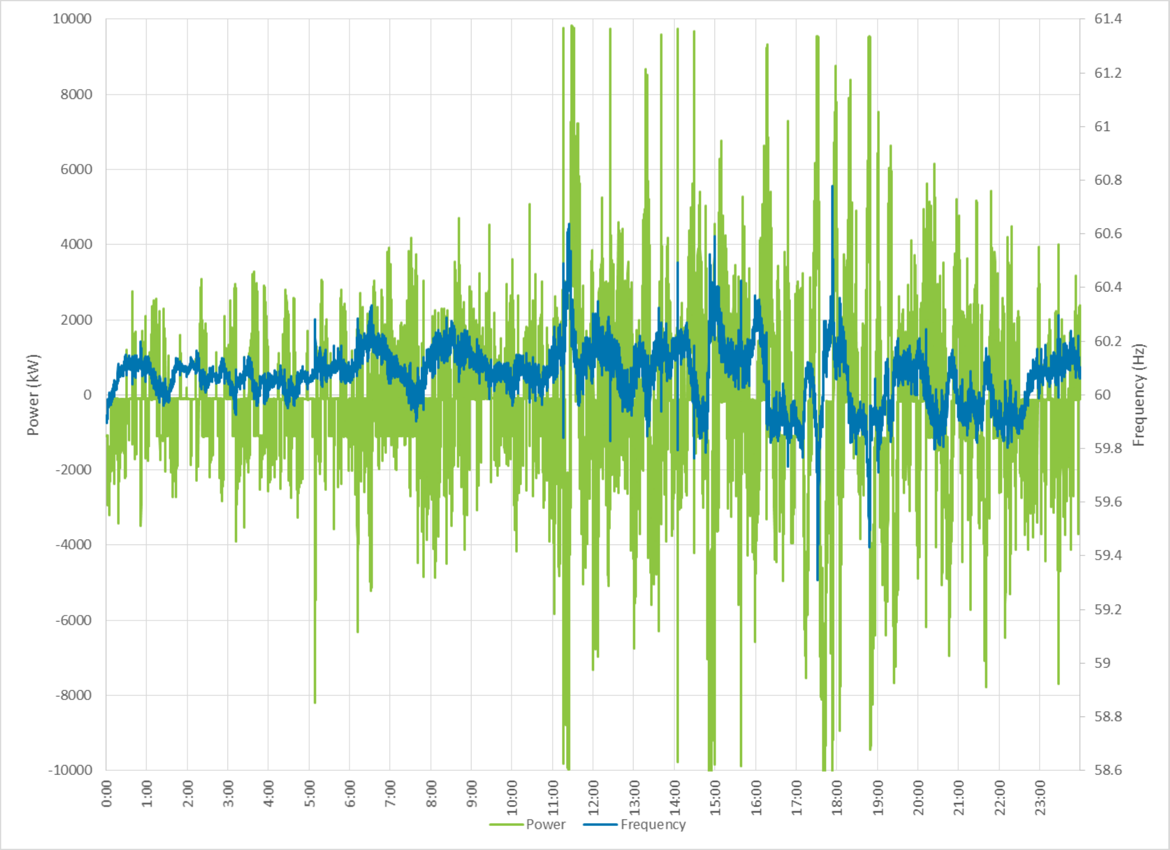


September 7, 2017
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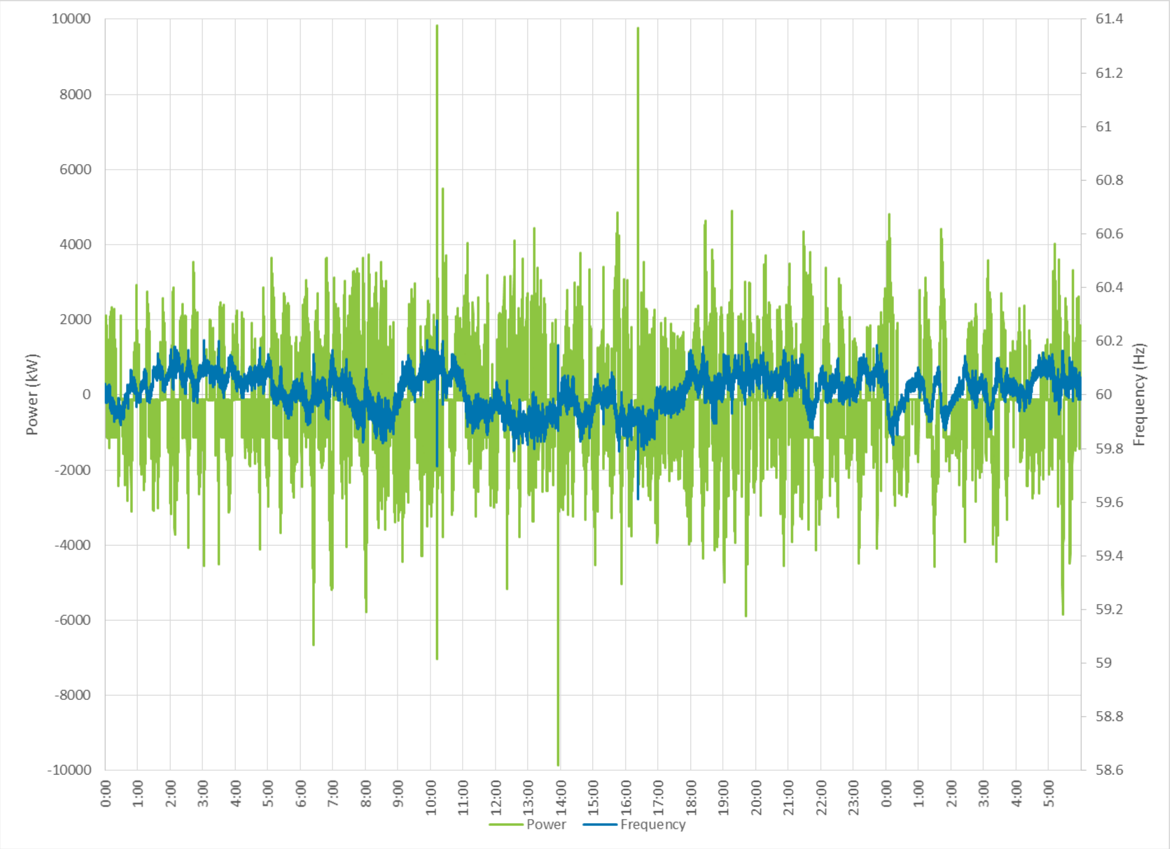
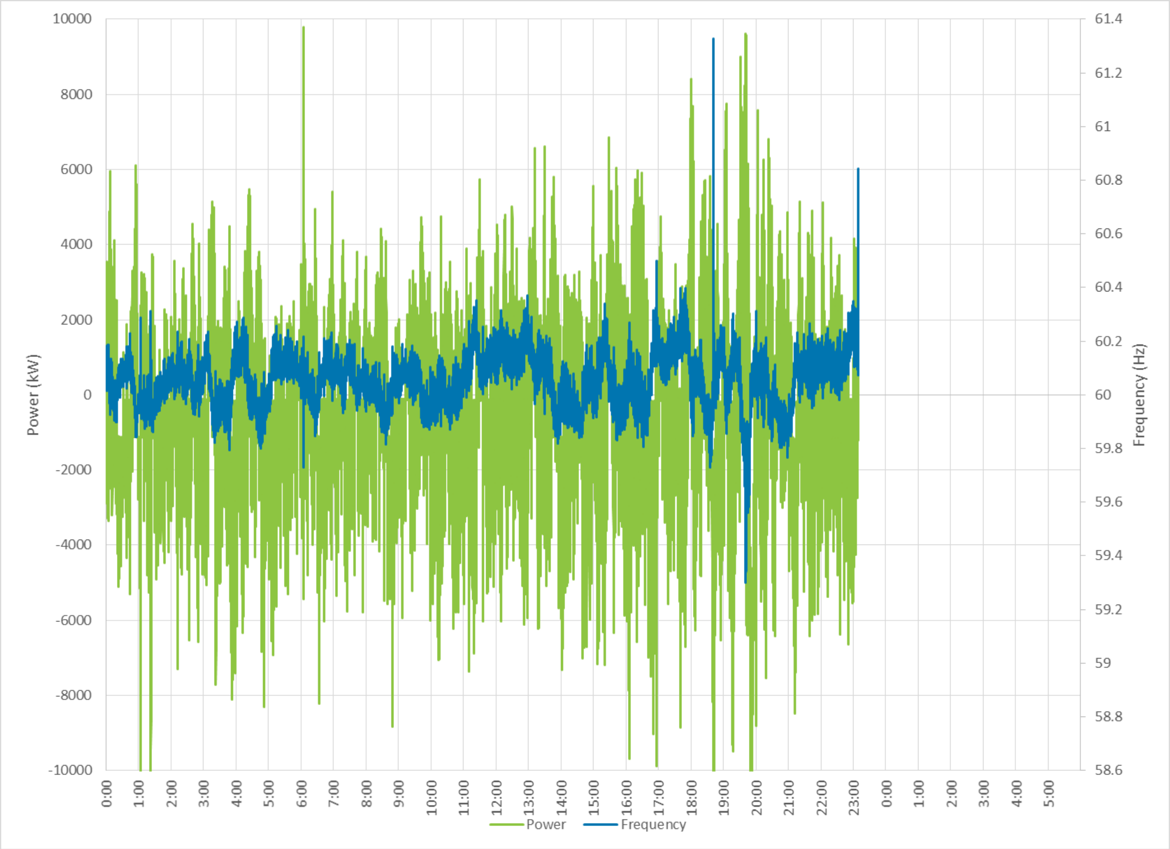
# Andres Power and Frequency – Hurricane Maria



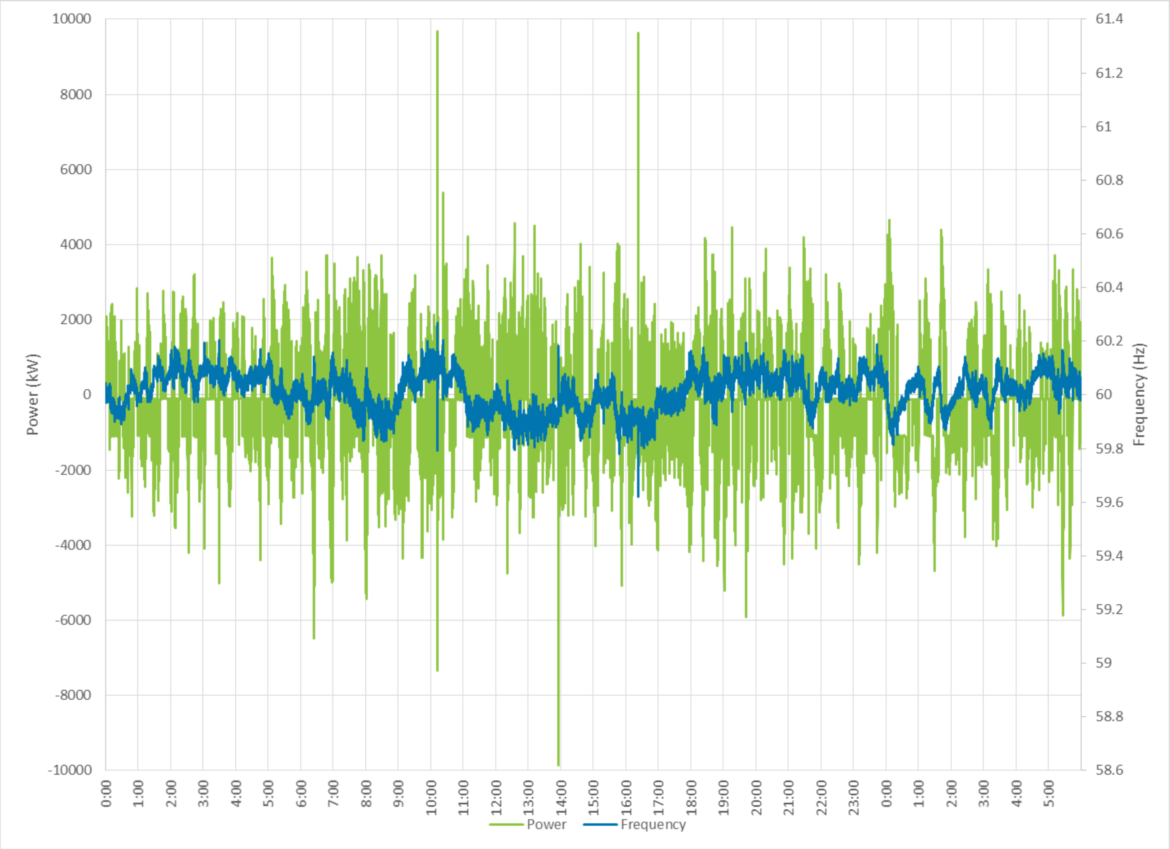

00:00 September 14 – 06:00 September 15, 2017
(one week prior to Hurricane Maria)




00:00 September 21– 06:00 September 22, 2017
(during Hurricane Maria)

Note: Hurricane Maria caused a transmission line to trip at 23:09 on September 21, which forced the Andres battery offline until September 22.

# Los Mina DPP Power and Frequency – Hurricane Maria

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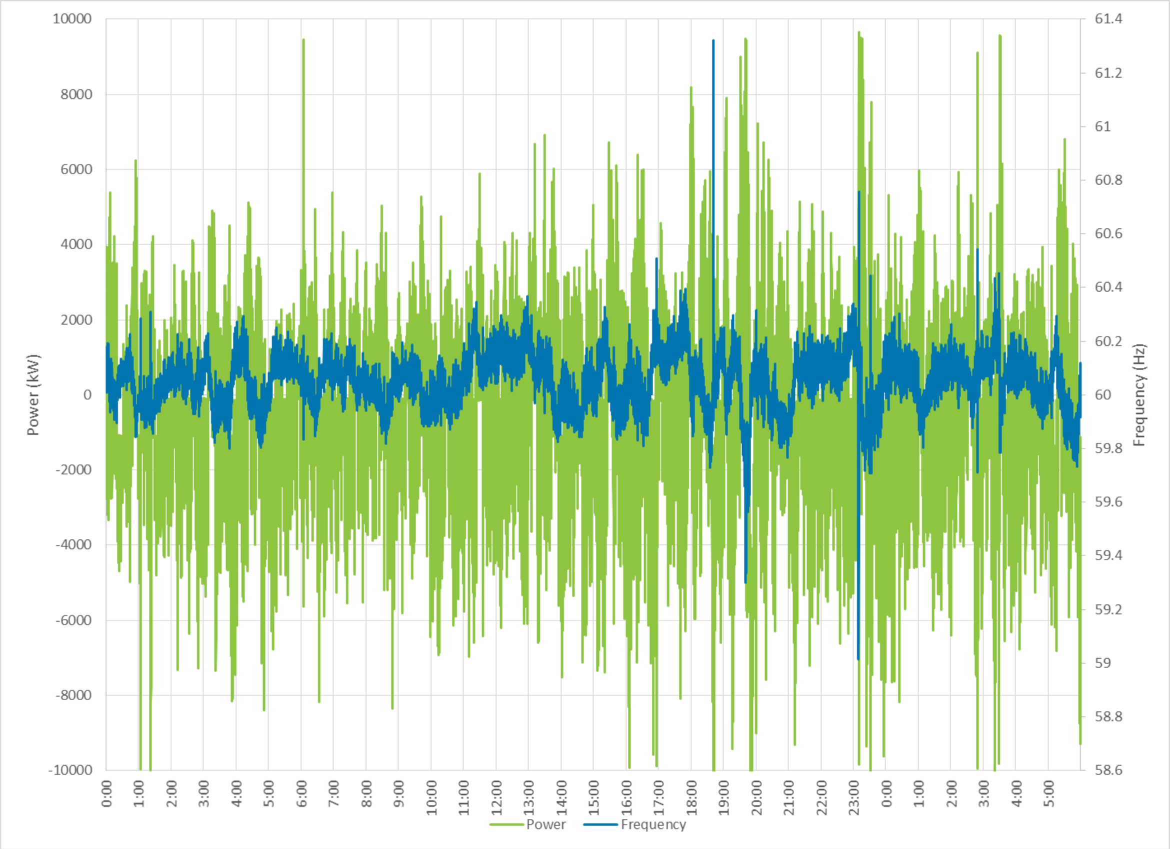



00:00 September 21– 06:00 September 22, 2017
(during Hurricane Maria)

# Generation Enhancement

Long Beach, California, United States
100 MW, 4-hour (400 MWh)
AES Alamitos, COD Jan 1, 2021

## SERVICES

- Capacity, local reliability
- Peak power/off peak mitigation
- Ancillary services

## IMPACT

- Competitive bid vs thermal peaker, cost effective
- Replaces environmental retired units
- Meets flexibility (duck curve)

**World’s largest contracted energy storage project**

# Renewable Integration

Hawaii, United States

28 MW Solar PV

20 MW, 5-hour (100 MWh) energy storage

KIUC

**SERVICES**

- Renewable integration
- Peak power/off peak mitigation

**IMPACT**

- Avoids oil and fossil fuels
- Lowers cost and supports 100% renewable energy

## Solving peak energy demand through solar + storage in Hawaii

## Microgrids & Islands

**Isle of Ventotene, Italy**

**1MW / 1MWh**

**ENEL**

**IMPACT:**

- Complex control developments for stable operation with existing gen sets.
- 15% Fuel savings demonstration on-islanded grids.
- Enable further integration of renewables.

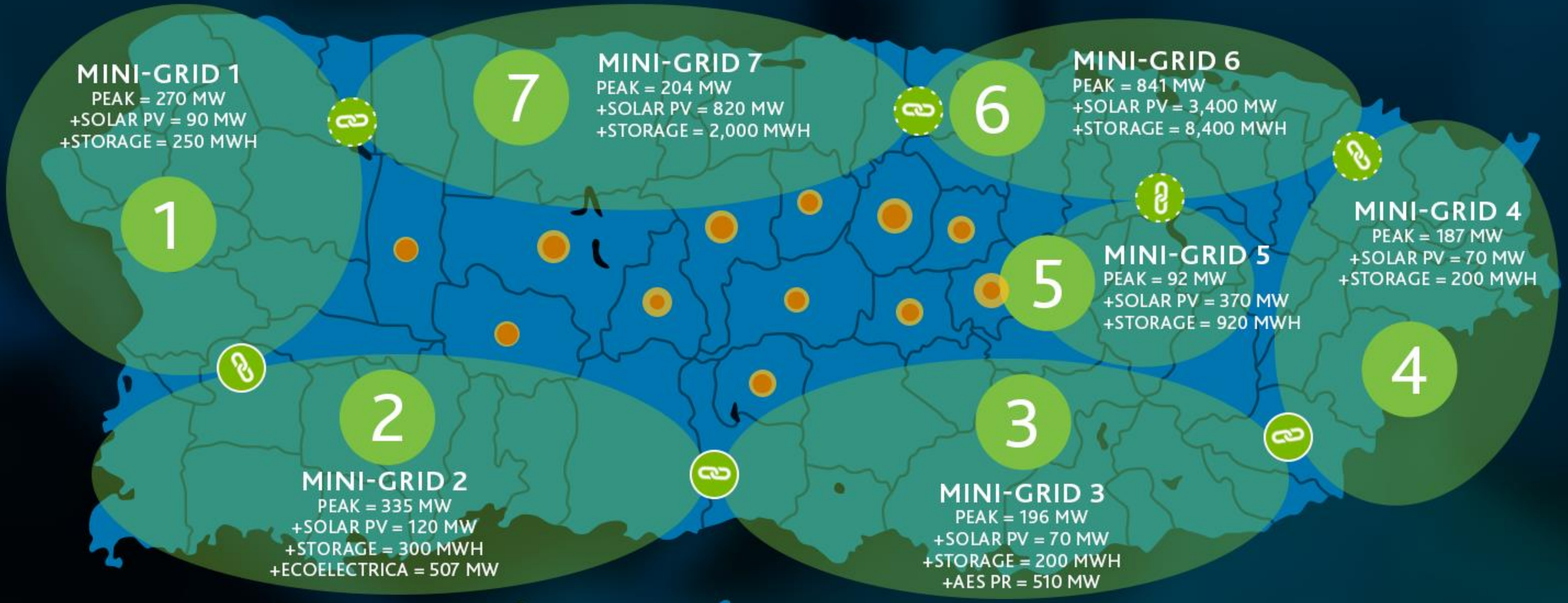
MINI-GRID DESIGN OPTION #1

# Central Lines, Solar + Storage


* Non-aggregated load centers are their own mini-grids. Microgrids

MINI-GRID DESIGN OPTION #2

# Fewer Lines, Solar + Storage




* Non-aggregated load centers are their own mini-grids. Microgrids

# Three Key Benefits of Mini-grid Design with Hardened Critical Tie-Lines

## Most Resilient

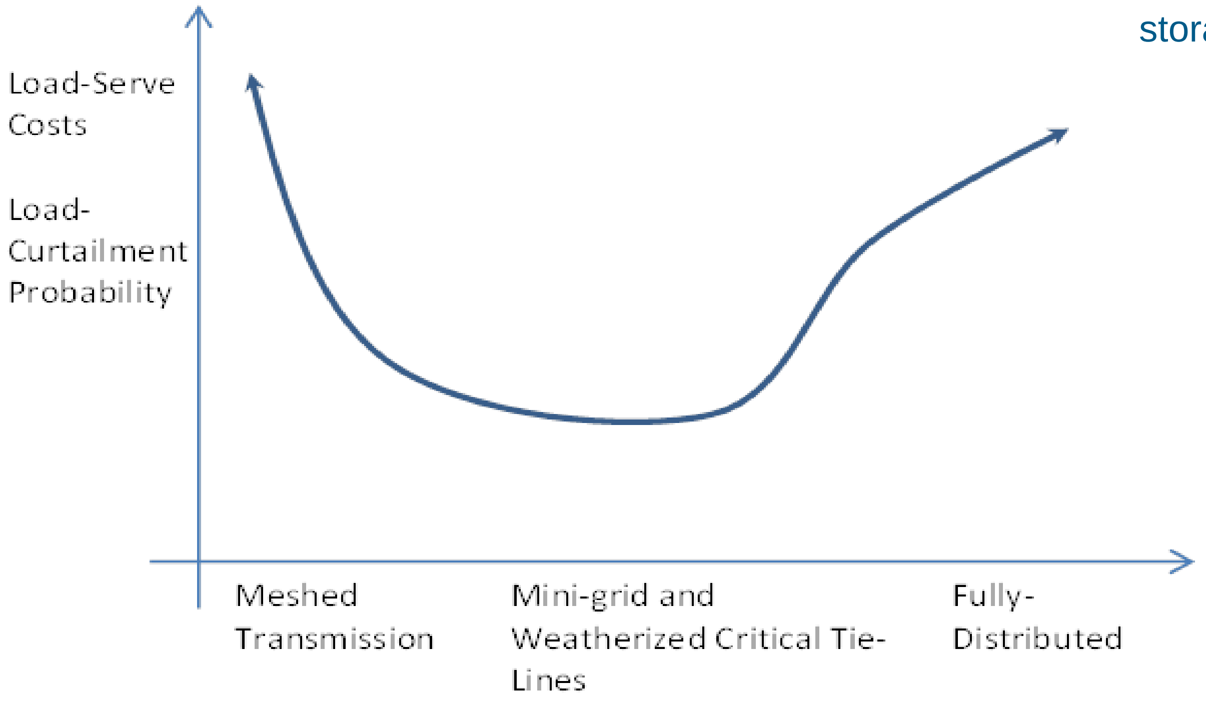
Operation primarily relies on the distribution system, which tends to have a radial nature and proportional relationship between system outage and load shedding capability.

## Least cost framework

Critical tie-lines also help connect large and low cost supply to distribution connected load during normal operations

## Leverages Diversity in Supply and Load

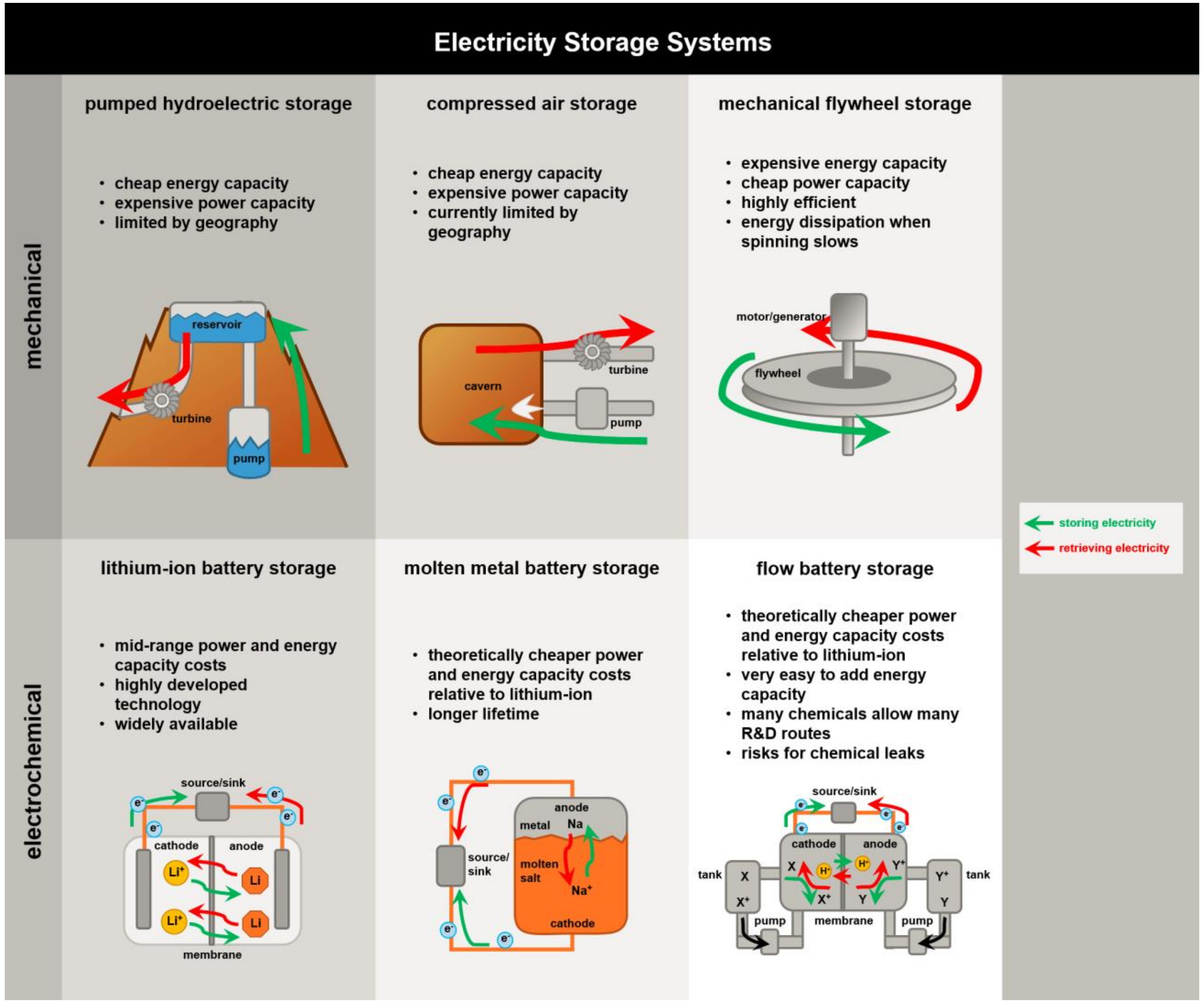
Hardened critical tie-lines help connect/pool separate distribution systems to leverage the effects of diverse distribution connected generation, storage and load.



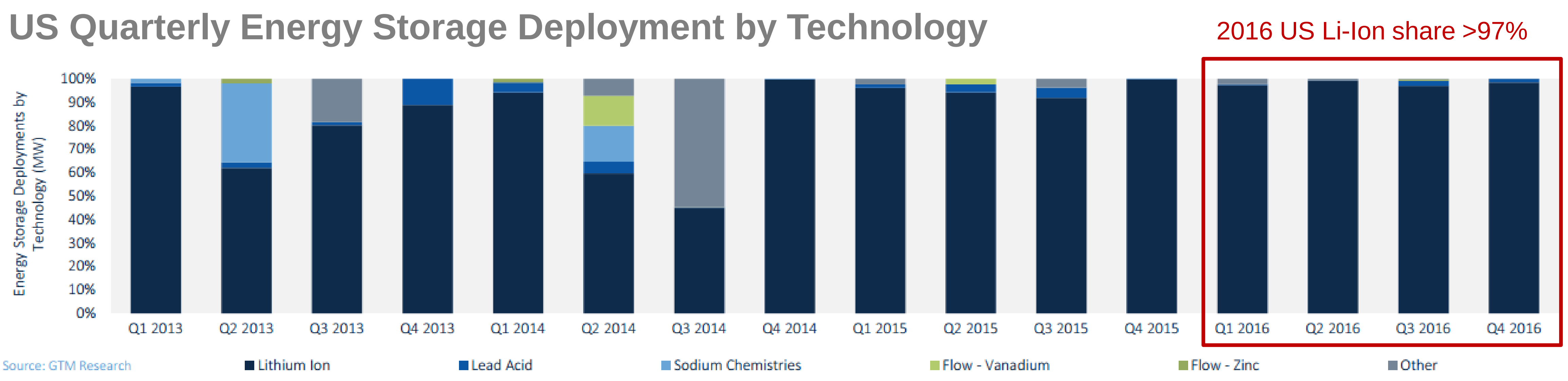

# Energy Storage Options

# What are the best grid scale storage technologies available and what size power system are they compatible with?

## Power, energy and geography are important considerations



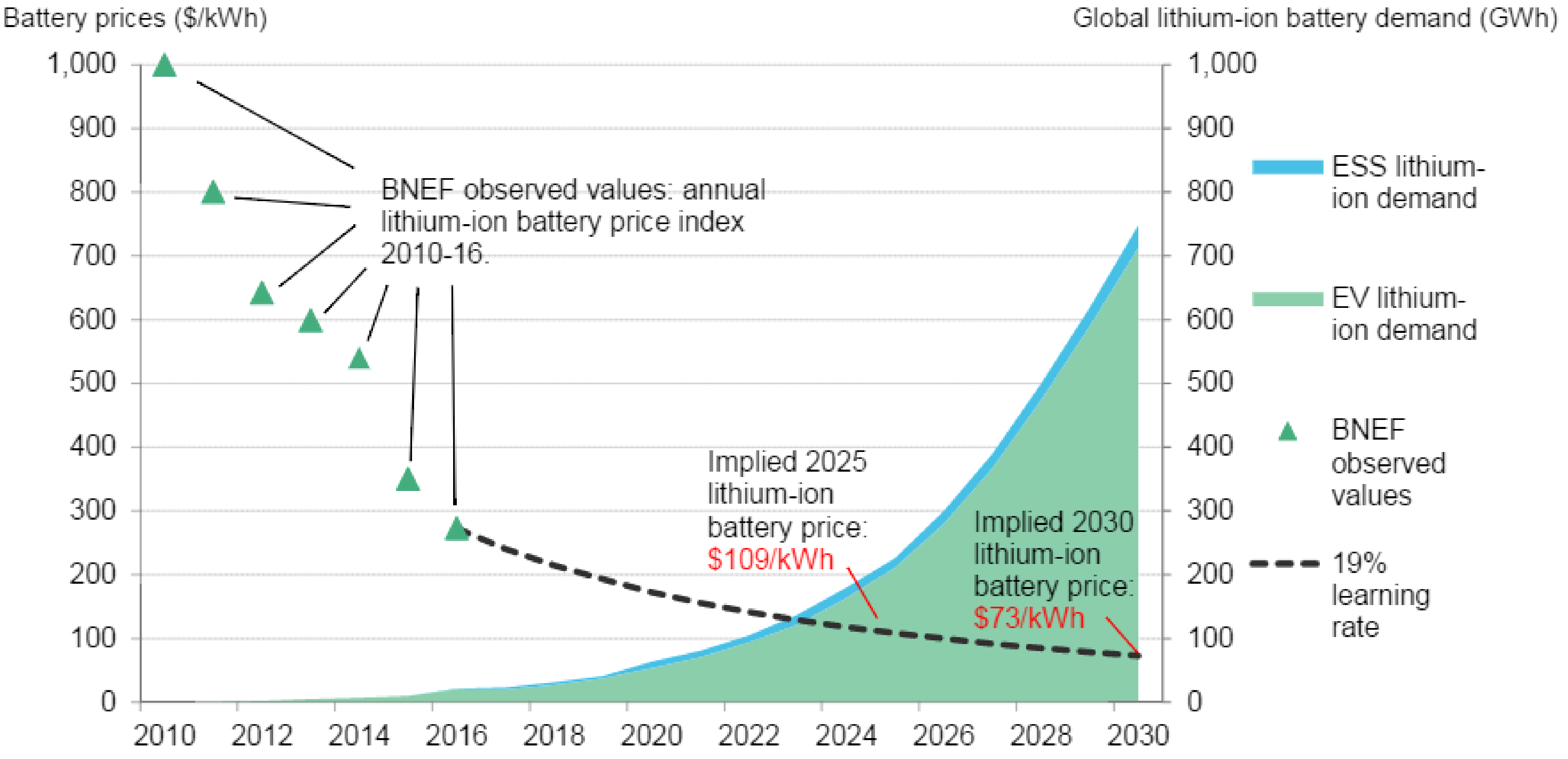
# Lithium Ion batteries are dominating the energy storage market




Source: GTM Research

# Lithium Ion costs benefit from global supply chains and multiple uses

**Figure 9: Lithium-ion battery price forecast, 2010-30e ($/kWh)**




*Source: Bloomberg New Energy Finance. Note: Lithium-ion battery demand is based on EV demand only, taken from our Global EV outlook to 2040 (web|terminal). Prices are an average of BEV and PHEV batteries and include both cell and pack costs. Cell costs alone will be lower. We assumed the ESS capacity here is 75% of our total forecast of ESS, as our original forecast includes other technologies than li-ion.*


# Thank you