# Pathway to 100% Renewable

Presentation to the Jamaica Institution of Engineers (JIE)

Engineers' Week

September 18th, 2023

By

Presenter: Aston Stephens

# Climate Change and the Power Grid Contribution

## What is Climate Change

- The long-term shift in global temperature and weather pattern

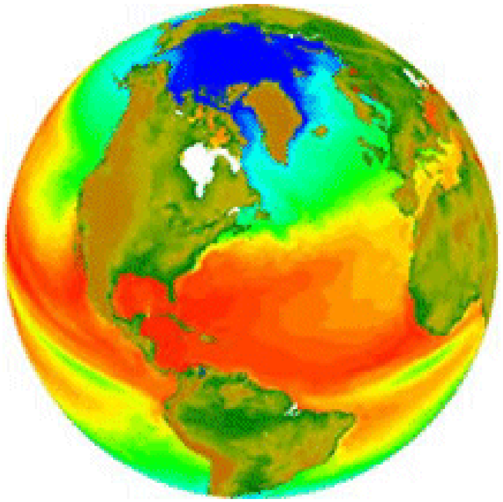
## Causes of Climate Change

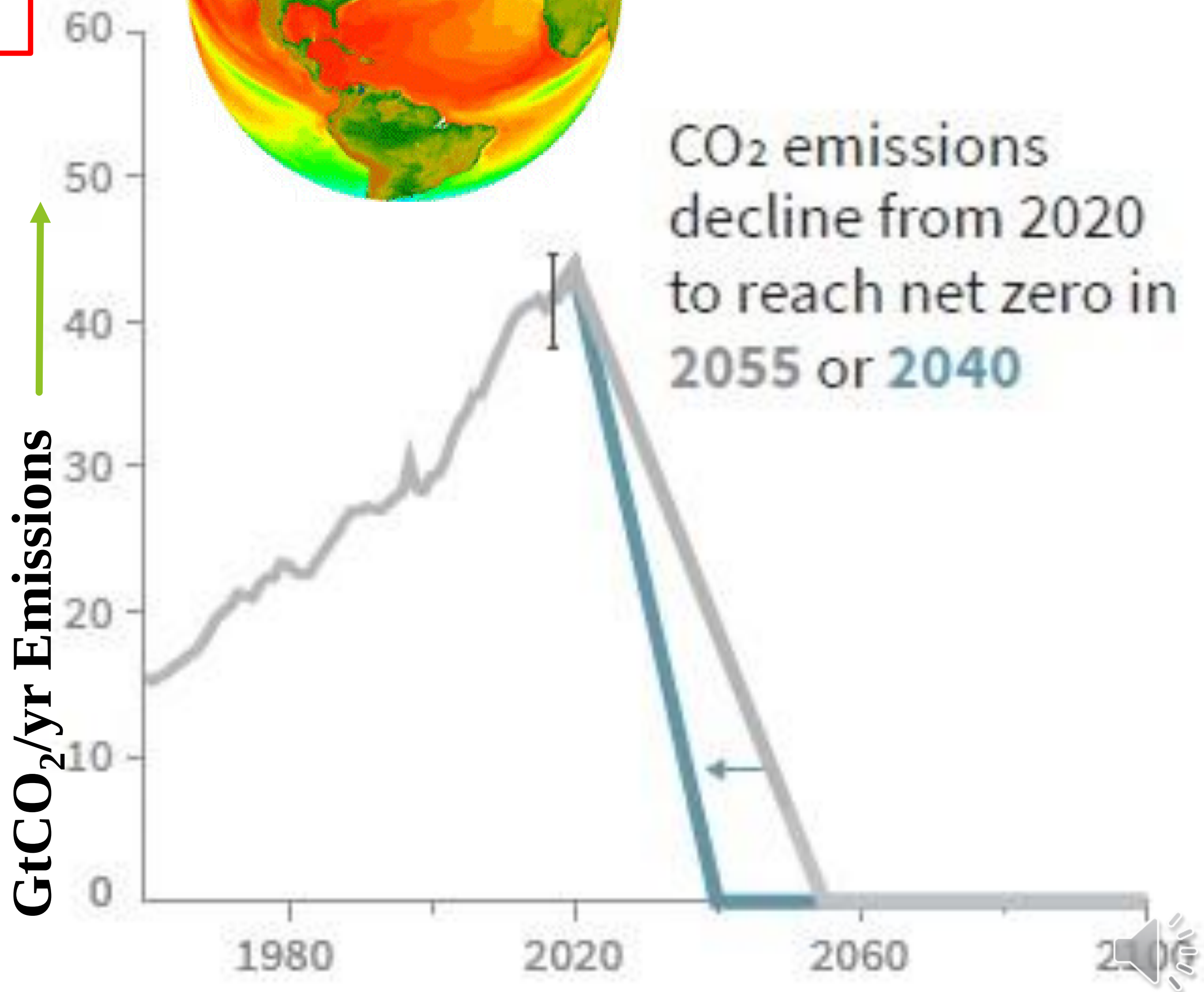
- Variations in the solar activities of the sun
- Large volcanic eruptions
  - Causing the emission of GHG such as $SO_2$ & $CO_2$, with $CO_2$ being the main contributor to GHG
- Human elements

  - main contributor to climate change since the industrialization started in the 1800s

**How can the net global $CO_2$ emission be reduced to limit temperature rise to $1.5^0C$?**

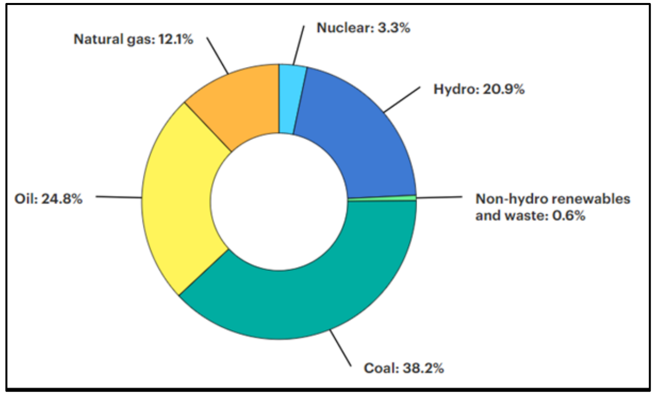
***Transition to 100% Non- Fossil Fuel using Renewables***

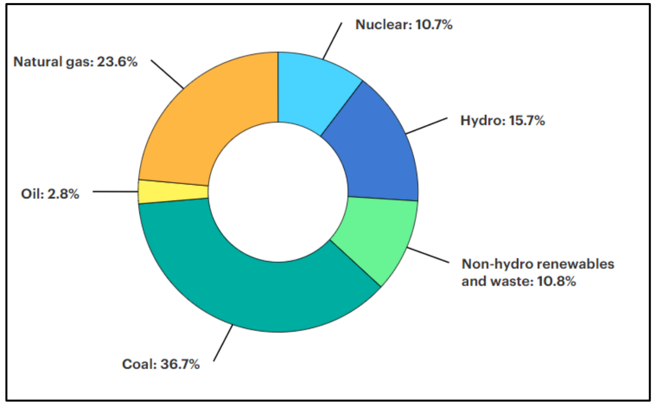




# Global Share of Electricity Generation

## 1973 & 2019 % generation by technology

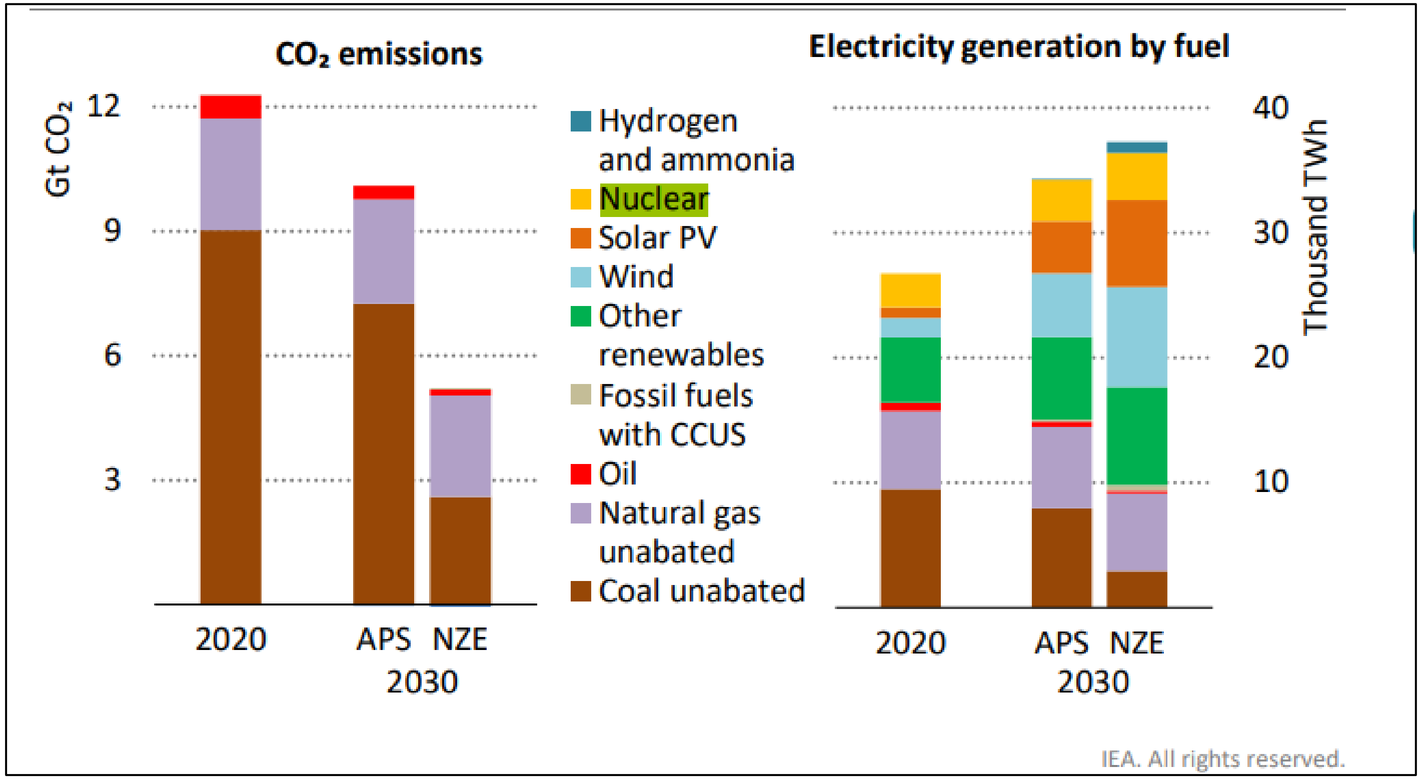



## 1973 & 2019 energy production (TWh)

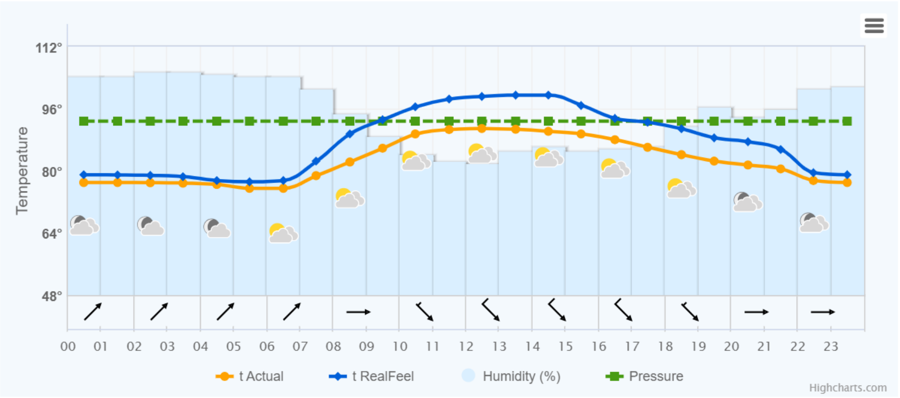
| Technology | 1973 | 2019 |
|---|---|---|
| ADO, HFO | 1,520 | 752 |
| Coal | 2,348 | 9,856 |
| Natural Gas | 742 | 6,357 |
| Nuclear | 202 | 2,874 |
| Hydro | 1,281 | 4,216 |
| Other RES | 37 | 2,881 |
| Total | 6,131 | 26,936 |

# Global electricity sector $CO_2$ emission and generation source in the APS & NZE emission by 2050 Scenarios



# The Jamaican Effect: Comparing July 2022 and 2023 (July 12, 2023, the hottest day ever)  weather forecast

Hourly forecast for 12.07.2022

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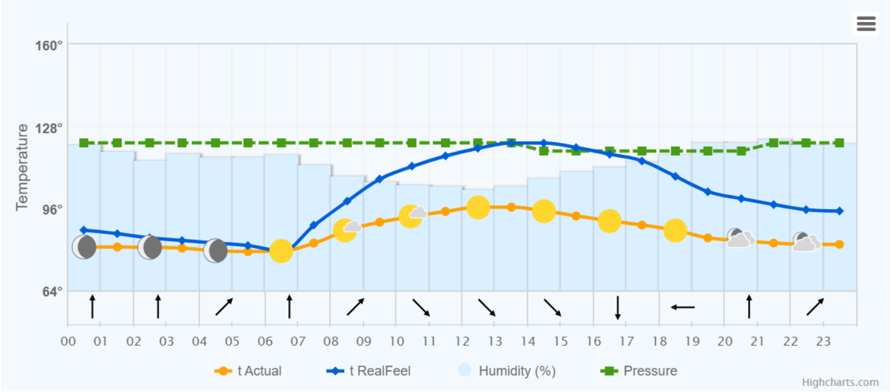
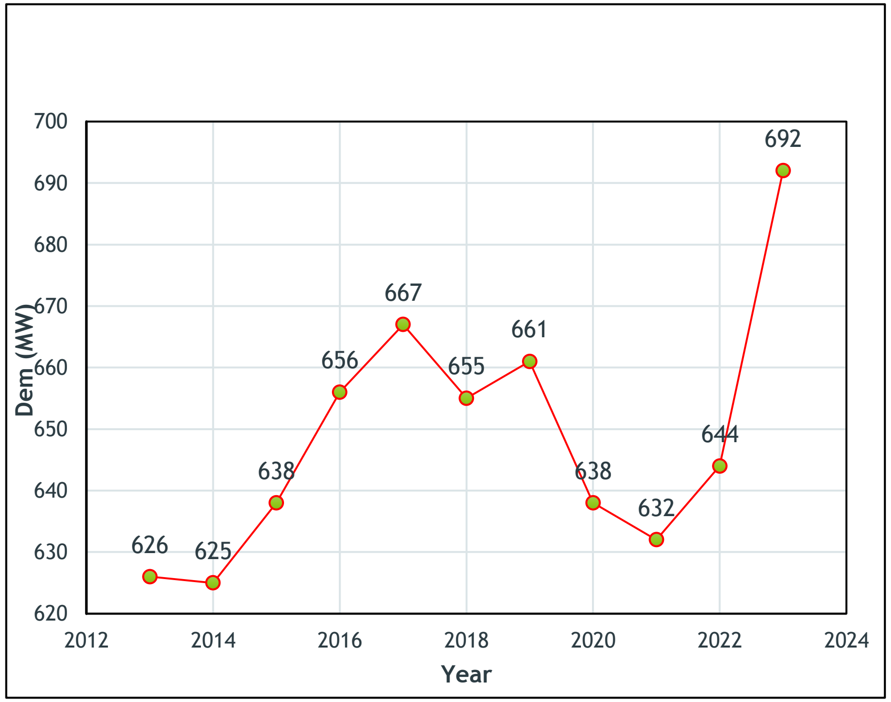
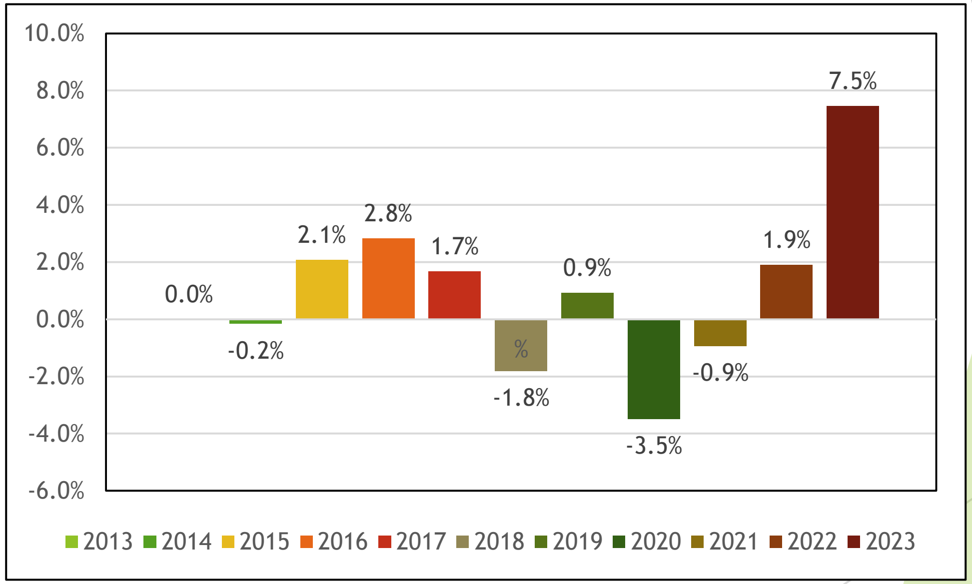


# Power grid impact (July 12th, 2023 was the hottest day ever)

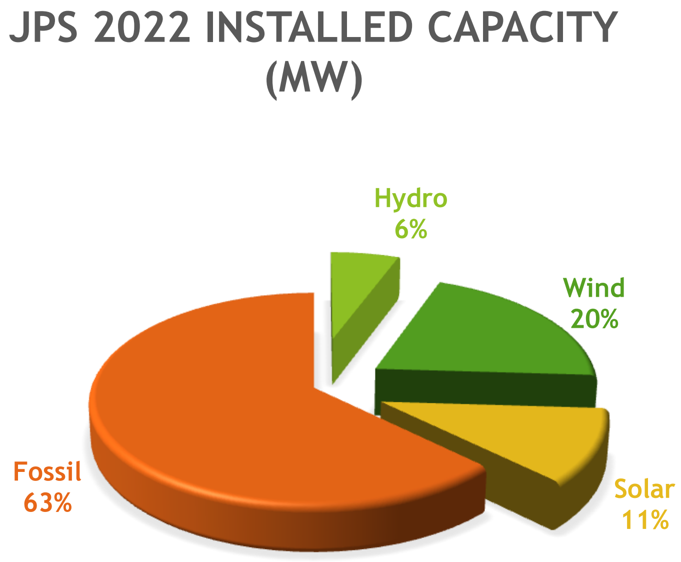
## JPS Historical peak Demand (MW)

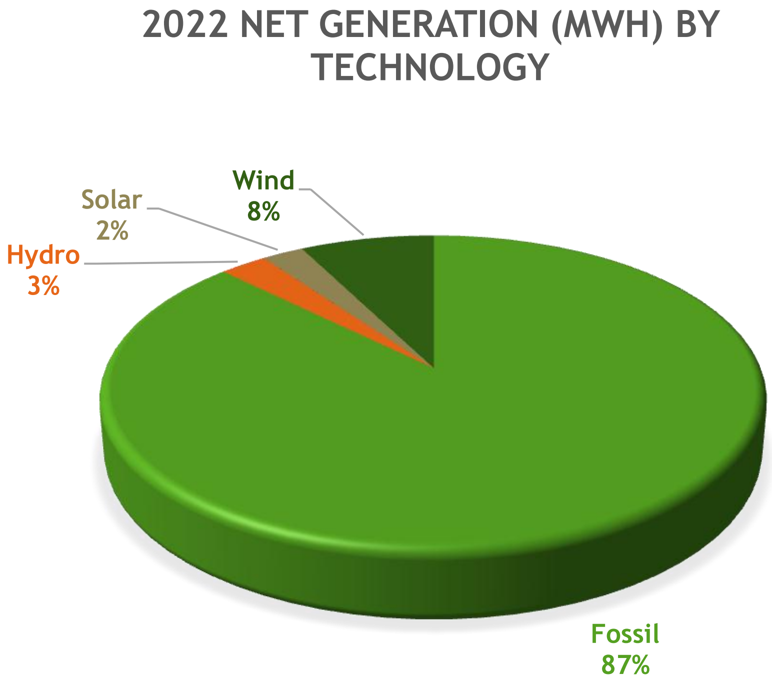



## % Variation in demand profile

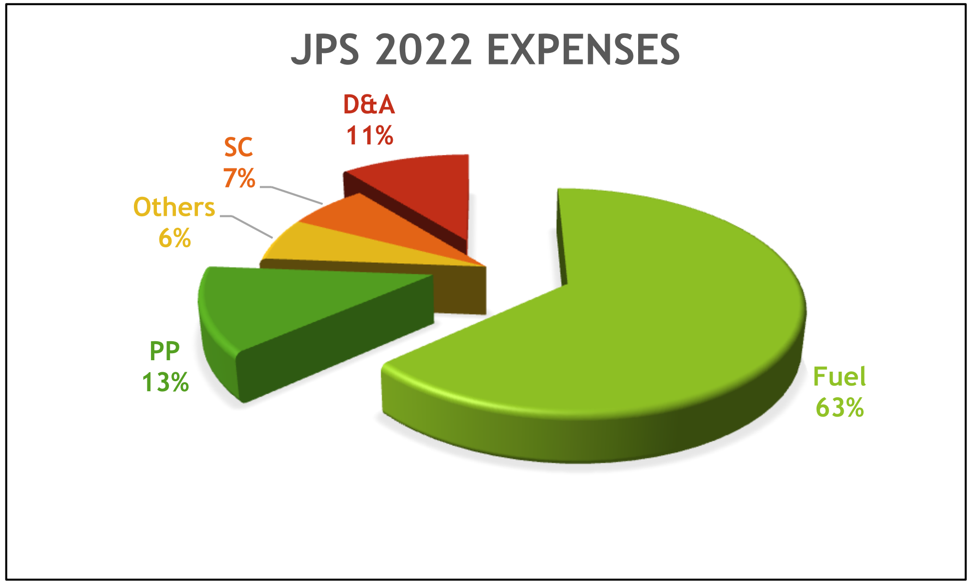


# JPS generation mix



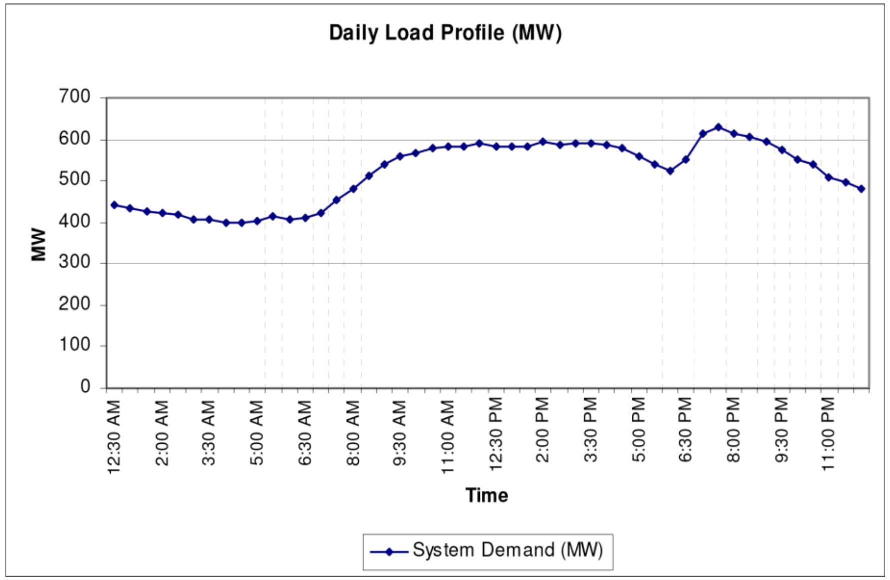
# JPS’ 2022 Expenses




| | |
|---|---|
| Fuel | - Fossil fuel including ADO, HFO & LNG |
| PP | - Purchase power, including RE |
| SC | Staff cost |
| D&A | -Depreciation & Amortization |
| Others | |

# Typical demand profile and spinning reserve

## Typical weekday JPS demand profile




## Convention plant & spinning reserve

| No. | Date | Units Tripped | Condition Prior to Outage (MW) | | | | UFLS Stages |
|---|---|---|---|---|---|---|---|
| | | | Unit (MW) | Dispatch | System | Spinning Reserve | |
| **1** | **14/04/2018 4:38** | **RF2** | **20** | **19.4** | **448.2** | **60.0** | **0, 1** |
| 3 | 04/05/2018 1:48 | B6 | 68.5 | 59.44 | 464.76 | 53.5 | 0, 1 |
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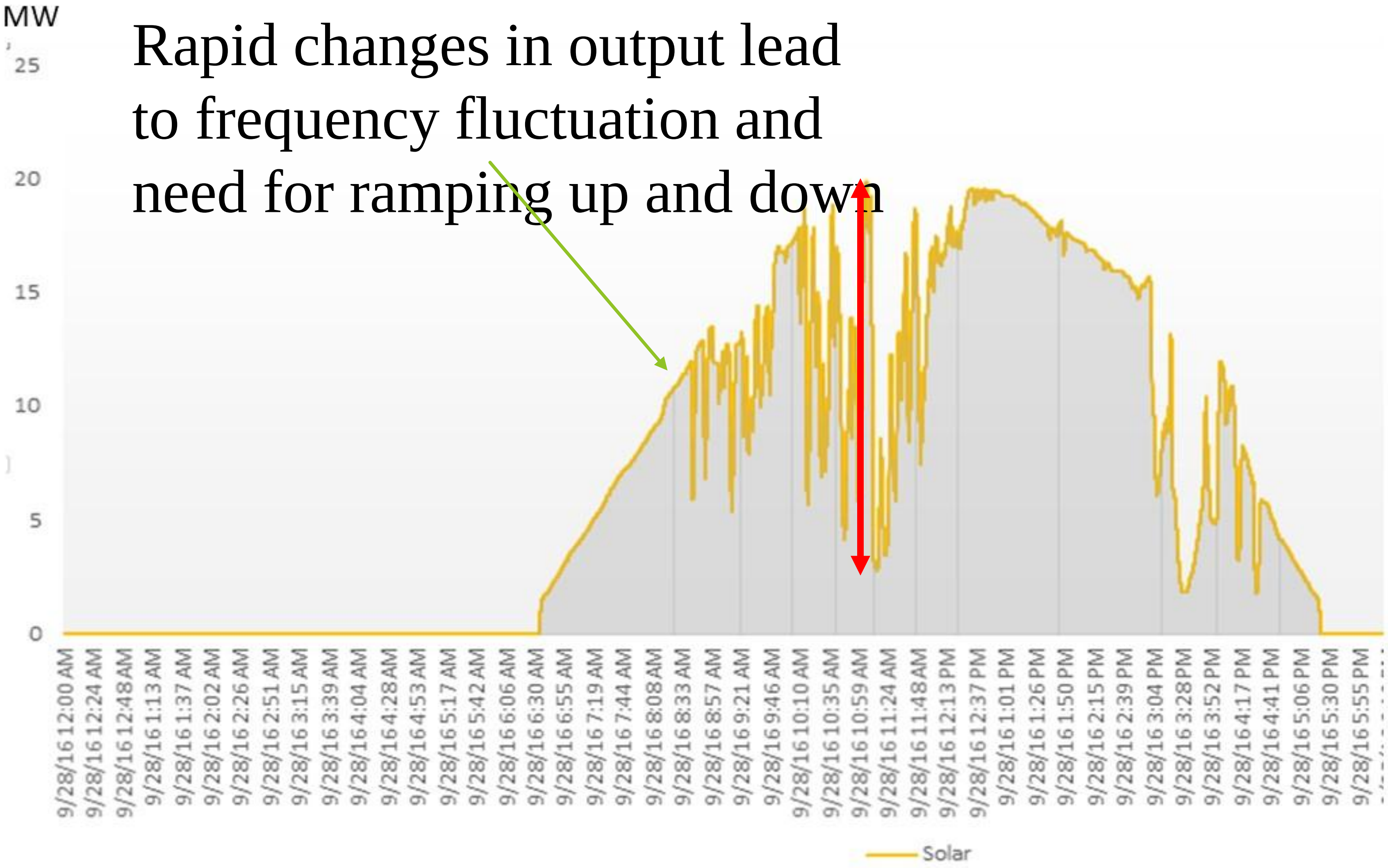
# Mitigating Technologies

- Renewable resources: Economically competitive with fossil fuel and applicable in many places, but intermittent, Can be large part of solution
  - SOLAR
  - WIND
  - Hydro
  - Others

Site specific, sometimes seasonal and environmental concerns if water is dammed

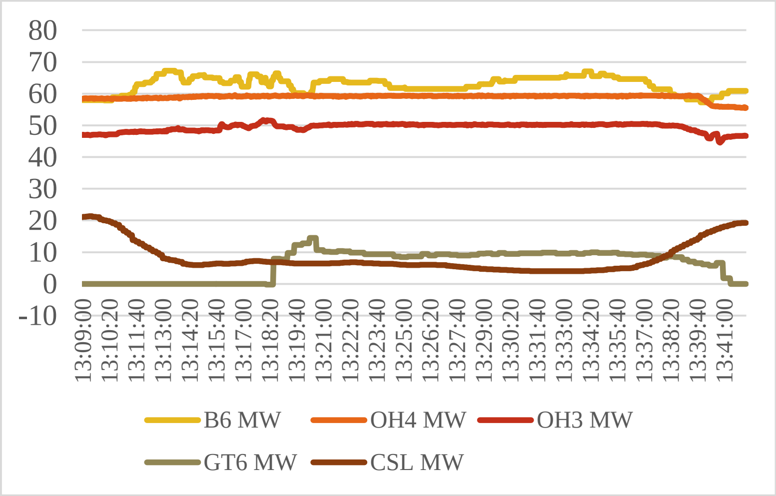
# *Cloud induced transient over the PV plant*

Rapid changes in output lead to frequency fluctuation and need for ramping up and down

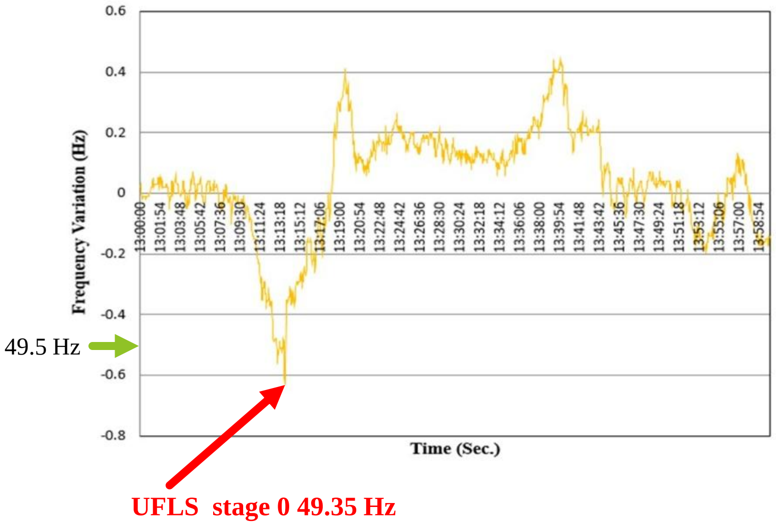


# *Cloud induced transient over the PV plant*

## PV output decreased




## System frequency plot



# Plants ramp up and Ramp down rate

## PV decreased by 7 MW and wind 7.3 MW

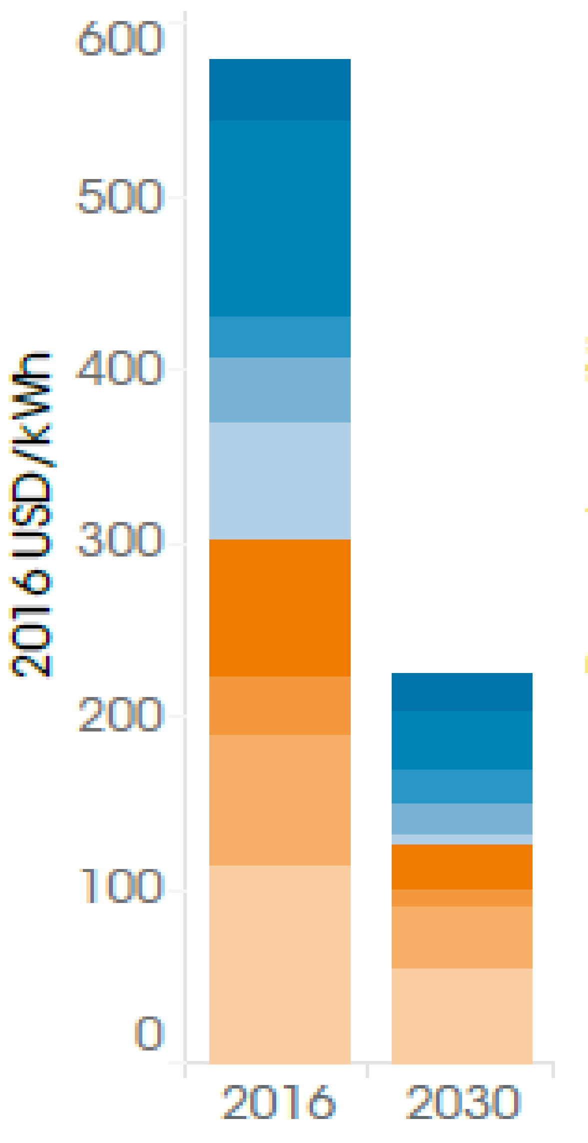
| Plant Name | Generation (MW) | | Duration (min) | Ramp Rate (MW/min) |
|---|---|---|---|---|
| Renewables | | | | |
| Agg Wind | 31.06 | 24.11 | 2 | -3.48 |
| Solar | 20.01 | 12.67 | 2 | -3.67 |
| Total ramp down rate | | | | -7.15 |
| Conventional Generator | | | | |
| OH3 | 47.02 | 48.05 | 2 | 0.51 |
| OH4 | 58.45 | 58.62 | 2 | 0.08 |
| B6 | 57.92 | 63.02 | 2 | 2.55 |
| Total ramp up rate | | | | 3.15 |
| Net ramp rate (MW/min) | | | | -4.00 |

## PV increase by 8.5 MW and wind 7.2 MW

| Plant Name | Generation (MW) | | Duration (min) | Ramp Rate (MW/min ) |
|---|---|---|---|---|
| Renewables | | | | |
| Agg Wind | 23.68 | 32.20 | 2 | 4.26 |
| Solar | 8.7 | 15.85 | 2 | 3.58 |
| Total ramp up rate | | | | 7.84 |
| Conventional Generator | | | | |
| OH3 | 49.89 | 47.49 | 2 | -1.20 |
| OH4 | 59.35 | 57.75 | 2 | -0.80 |
| B6 | 61.37 | 57.23 | 2 | -2.07 |
| Total ramp down rate | | | | -4.07 |
| Net ramp rate (MW/min) | | | | 3.77 |

# *Battery Storage Solution*

Li-ion batteries of 4 hr. duration already economical and falling in price



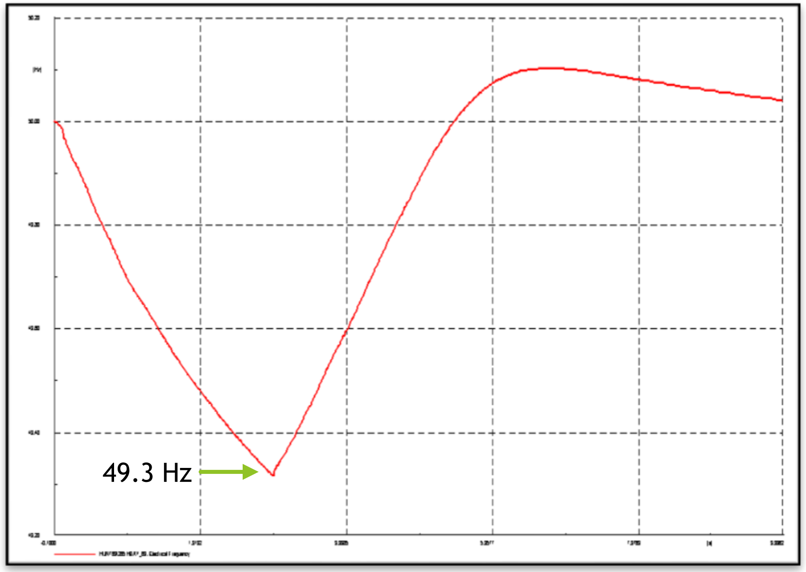

Expected Cost Reduction

# Case Study – Frequency regulation

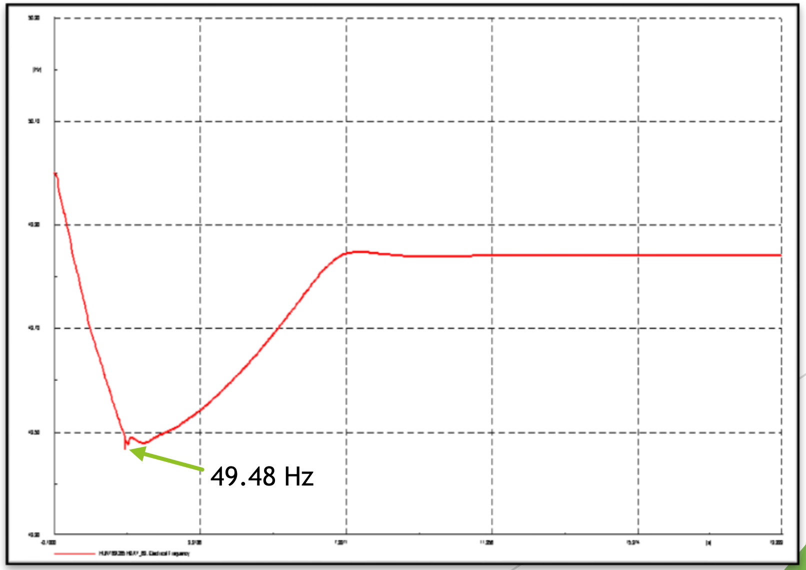
- Unnecessary operation of UFLS schem

- Battery Energy Storage System (BESS) best for frequency regulation and avoiding load shedding:
  - Balances difference between generation and demand immediately

Without BESS 30 MW shed

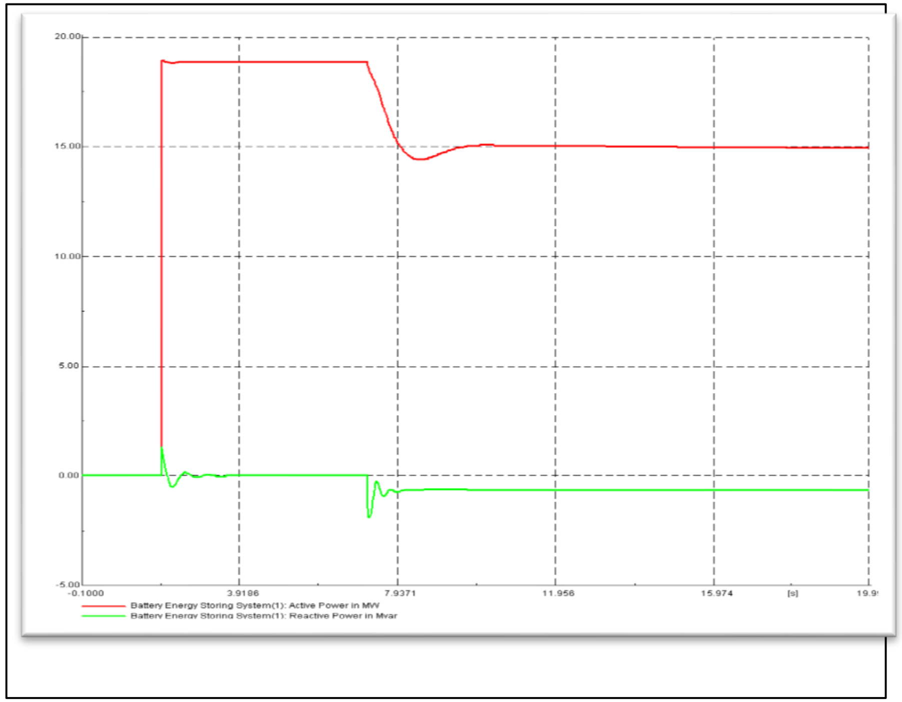



With BESS 30 MW shed

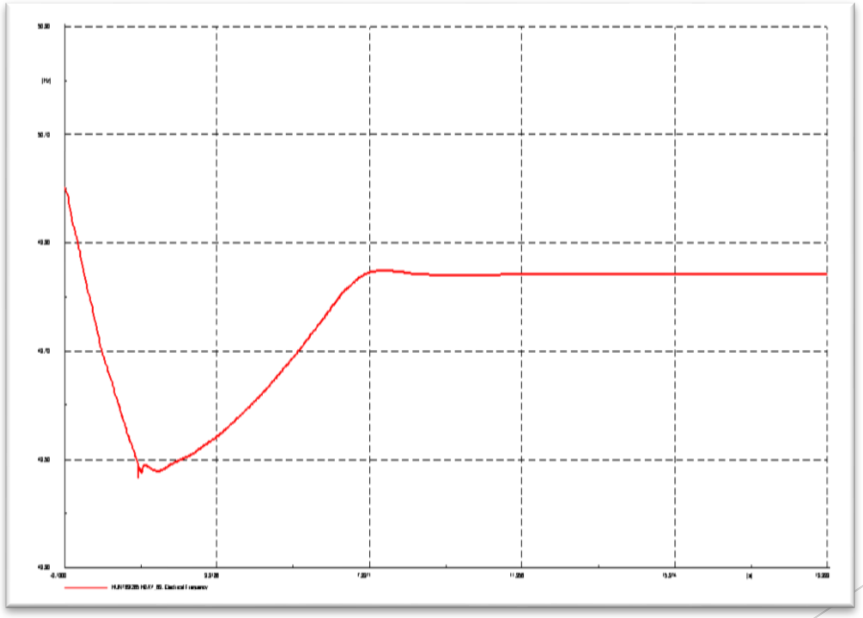


# Case Study – Frequency regulation

**BESS output**



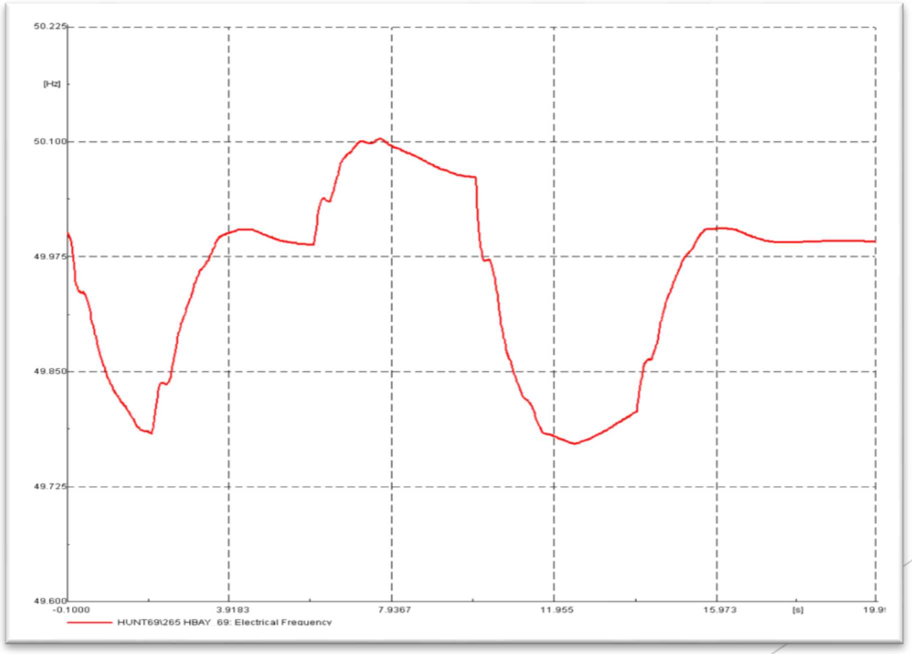

**30 MW Load shed**



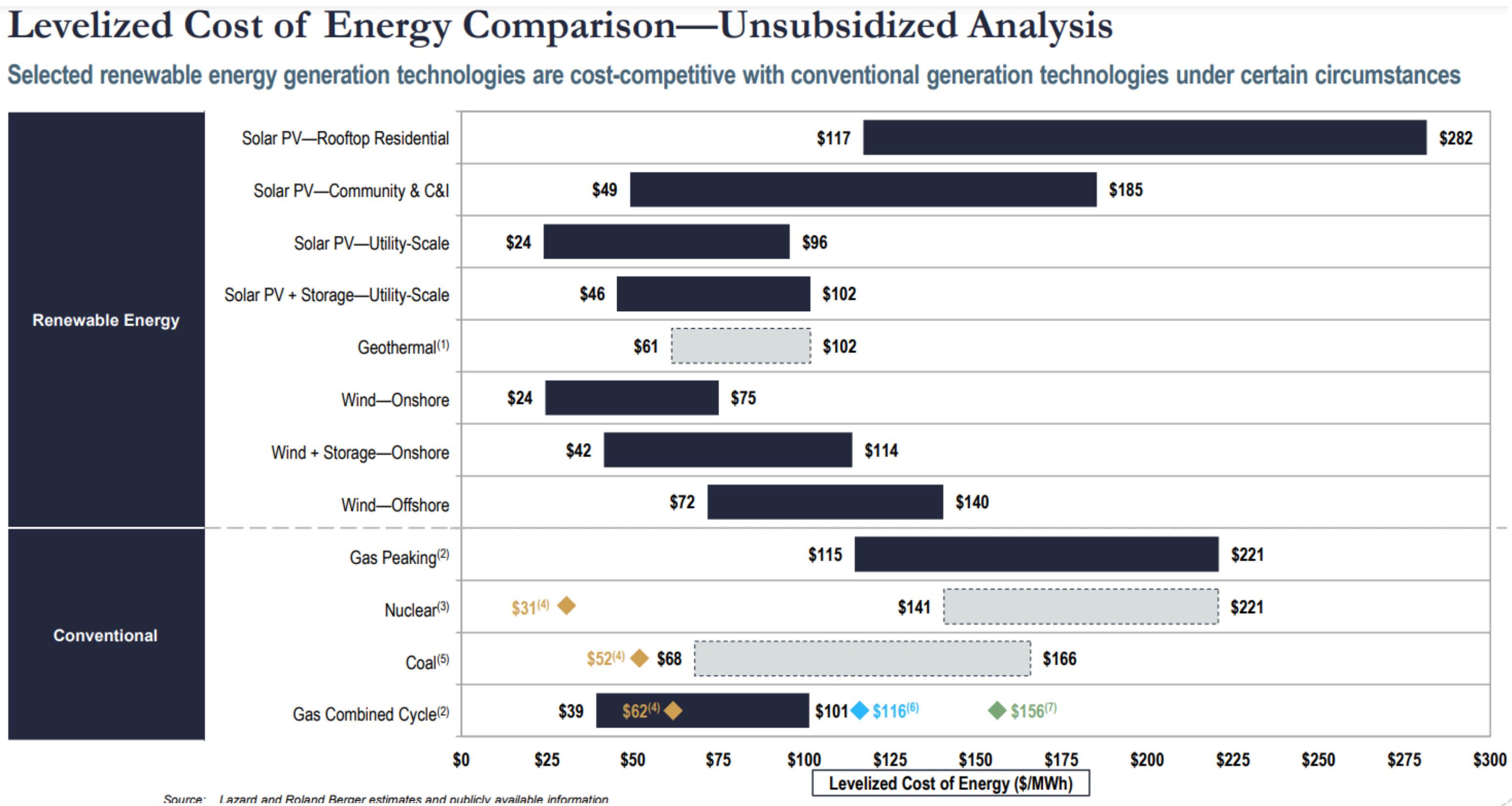
# Frequency Regulation

**BESS output**


**Freq maintained within +/- 0. 2 Hz**



# Cost comparison of RES and conventional plants



# *Savings using batteries for frequency control and ramping up Based on BESS Analysis*

| Year | Demand (MW) | Battery & O&M Costs Present Worth (US$) | Conventional Spinning Reserve Present Worth (Cost of spinning reserve, UFLS,Out of Merit) (US$) | Net Benefit Present Worth (US$) | Cumulative Present Worth (US$) |
|---|---|---|---|---|---|
| 1 | 655 | $76,752,000 | $19,848,789 | -$56,903,211 | -$56,903,211 |
| 2 | 675 | $10,663,393 | $27,520,818 | $16,857,426 | -$40,045,786 |
| 3 | 695 | $9,520,886 | $24,572,159 | $15,051,273 | -$24,994,513 |
| 4 | 716 | $8,500,791 | $21,939,428 | $13,438,636 | -$11,555,877 |
| 5 | 737 | $7,589,992 | $19,588,775 | $11,998,783 | $442,906 |
| 6 | 759 | $6,776,779 | $17,489,978 | $10,713,199 | $11,156,104 |
| 7 | 782 | $6,050,695 | $15,616,051 | $9,565,356 | $20,721,460 |
| 8 | 806 | $5,402,407 | $13,942,903 | $8,540,496 | $29,261,957 |
| 9 | 830 | $4,823,577 | $12,449,021 | $7,625,443 | $36,887,400 |
| 10 | 855 | $4,306,766 | $11,115,197 | $6,808,431 | $43,695,831 |

More analysis needed

# Research topics

- Frequency regulation
  - Technical – BESS simulation
  - Economics – cost of solar+ battery storage vs cost of unserved energy + cost of spinning reserve
    - What is presently available
    - What is projected for the future
  - Technical - controls
- Capacity Storage for longer storage times
  - Economics
    - What is presently available and What is projected for the future
  - Technical - Battery Chemistry
- DC electricity
  - Distributive network, Appliances without AC to DC converters, Scenarios of DC future

Utility DIVE

**Updated: Tucson Electric signs solar + storage PPA for 'less than 4.5¢/kWh'**

**New solar will be cheaper than old coal by 2032**

CleanTechnica

# *Economic benefits*

Besides Climate Change Mitigation, Economic benefits to be gained:

- UP-side cost benefits
  - Better frequency regulation with PV + Battery – JPS problem
  - Wind and Solar save on cost of fuel, Solar saves O&M costs
    - US$1.42 Billion for mineral fuels in 2017
  - Energy security and energy independence
  - New job opportunities
  - LCOE for renewable plants are or will be less than fossil fuel
    - $1.74M/MW Gas vs $1+ M Photovoltaic – Capital & Installation costs
- Down-side - What if we discover oil?
- Have to plan to make it happen – Our Project

# *Summary of Problem & Solution*

| Problem | Solution |
| --- | --- |
| • Frequency Control and Ramping Up and Down Power.<br>• Conventional governors and spinning reserve plants do not respond quickly enough. | • Problem can be rectified by using PV & batteries.<br>• Based on Li-Ion Battery Energy Storage System (BESS) simulations done by AS.<br>• BESS also has economic advantage.<br>• JPS has now installed 25MW of storage, however, more is needed. |

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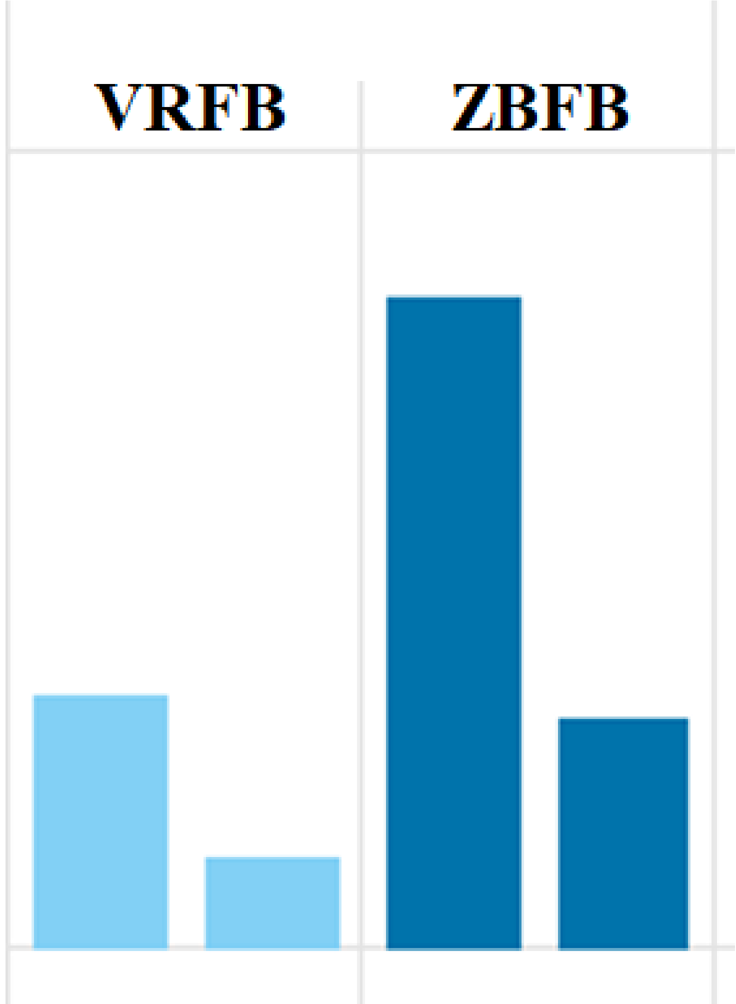
# *Flow batteries of 8 hr. duration to become economical in near future*





Expected Cost Reduction from 2016 to 2030

# Maturity & level of maturity of various energy storage devices

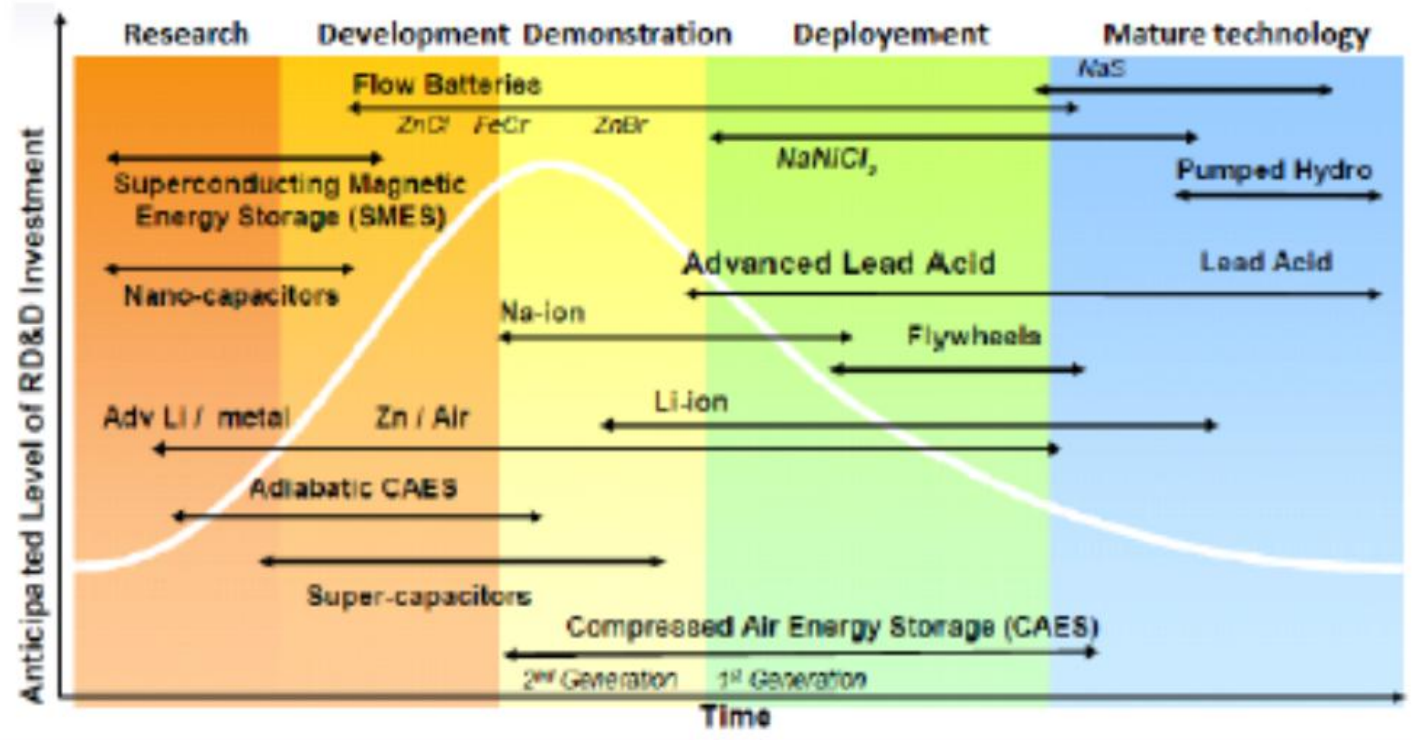
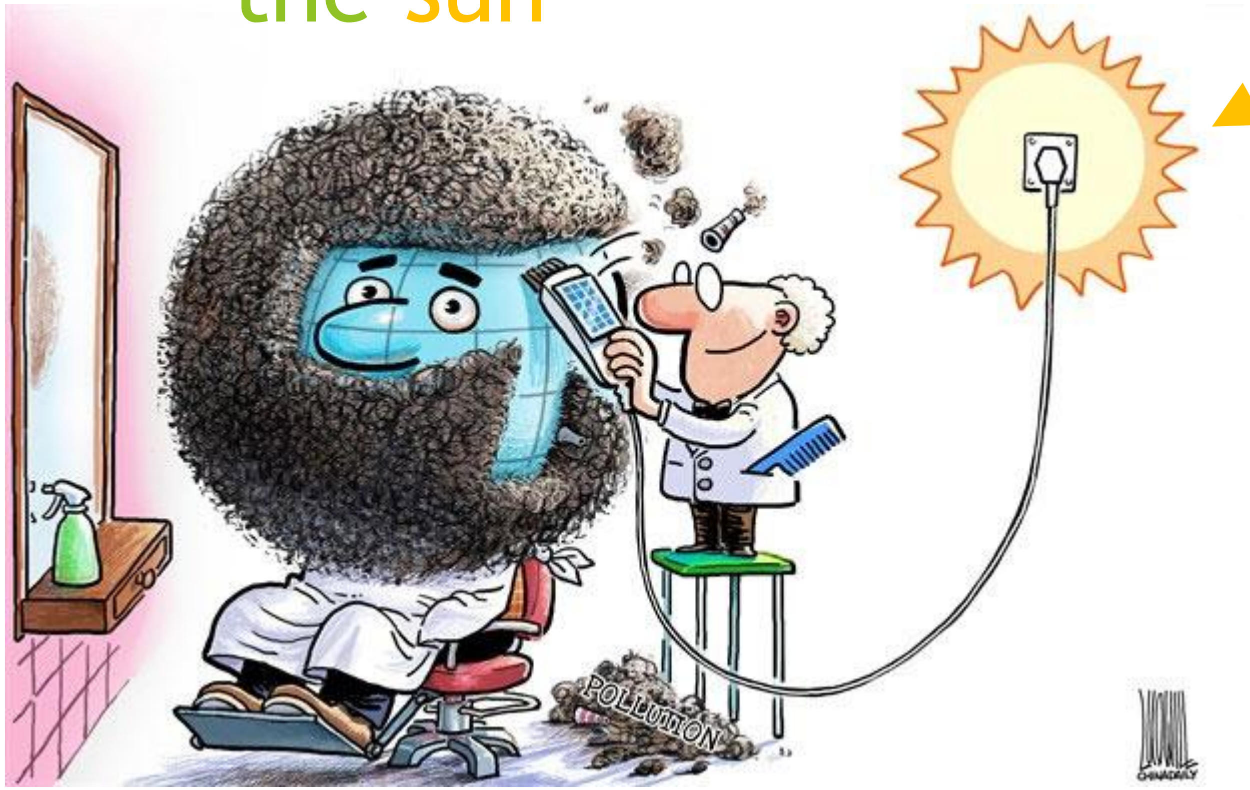



Figure 3-14: Energy storage maturity vs R&D investments

# We need a quick hair cut powered by the sun

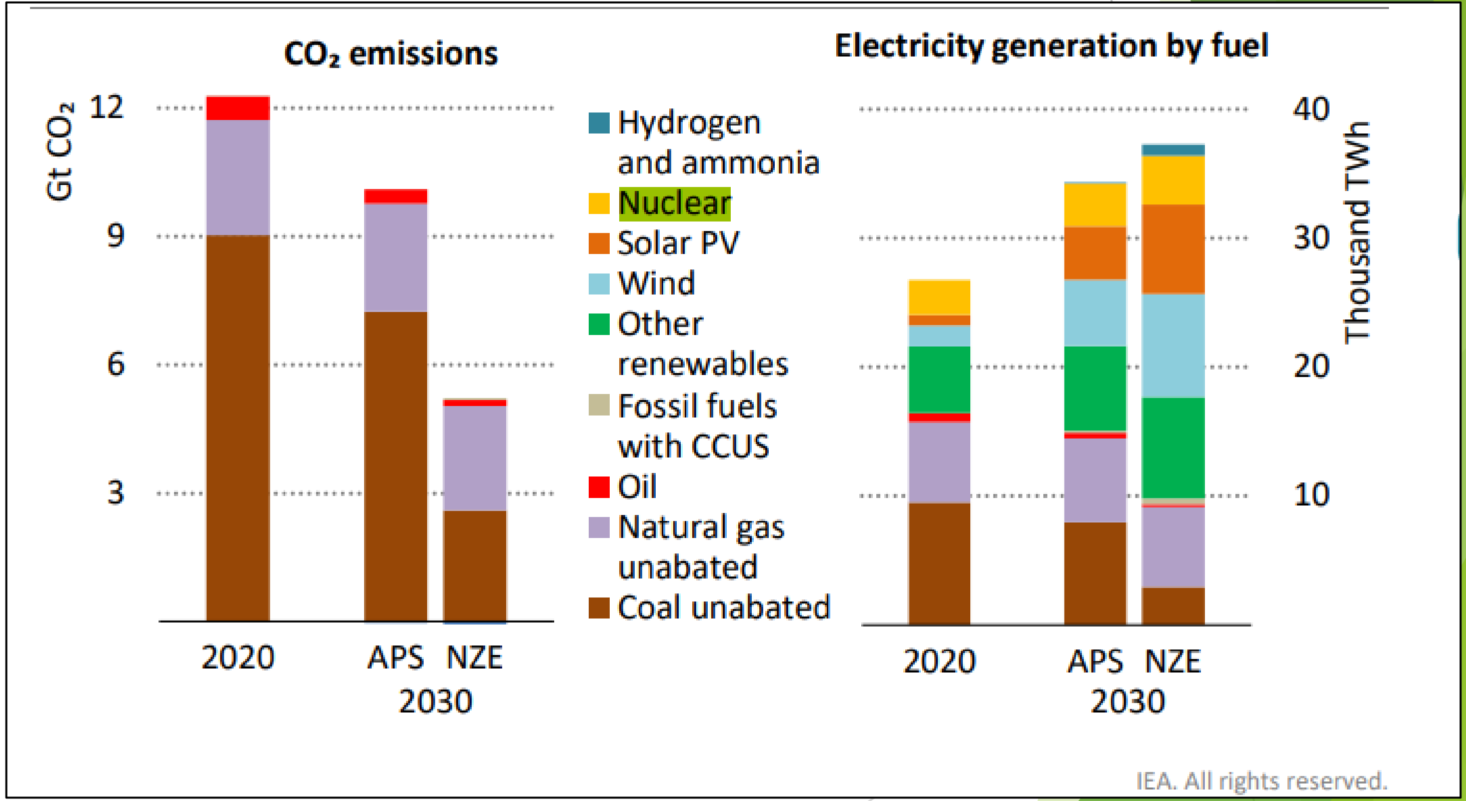


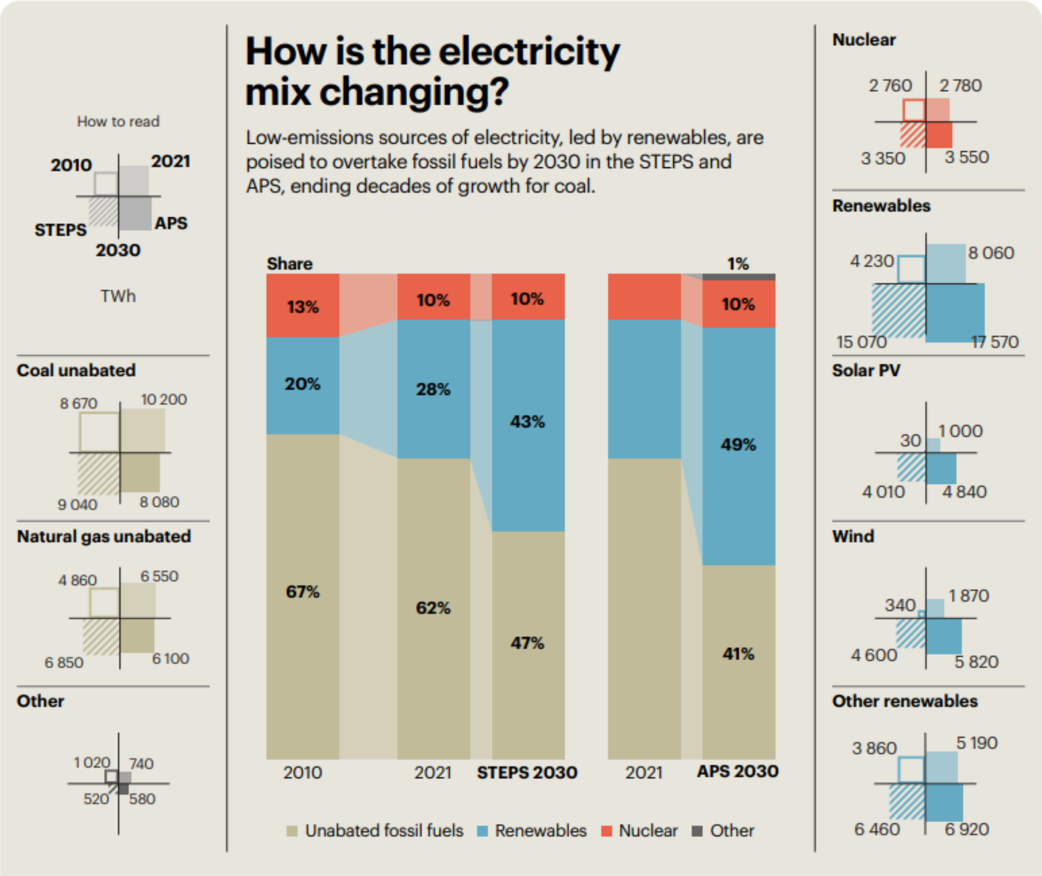

FINIS

# MANY THANKS

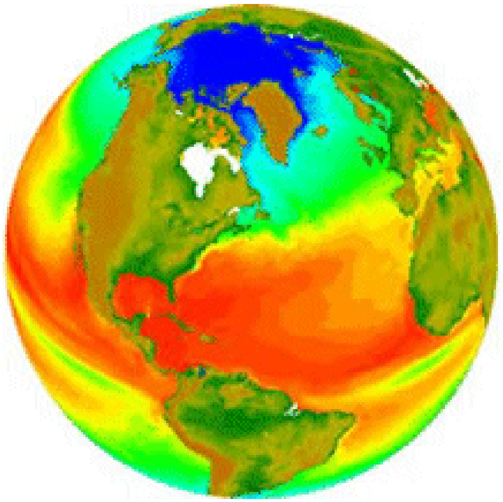
# Global electricity sector $CO_2$ emission and generation source in the Announced Pledges and Net Zero emission by 2050 Scenarios

- Nuclear Energy
  - Usually large capacity
    (> 1000 MW)
  - Modular nuclear plants (10MW) suitable for small scale use are just coming on stream and not fully evaluated.
  - Concerns about safety, sourcing uranium and storage of waste
  - Is a part of the solution

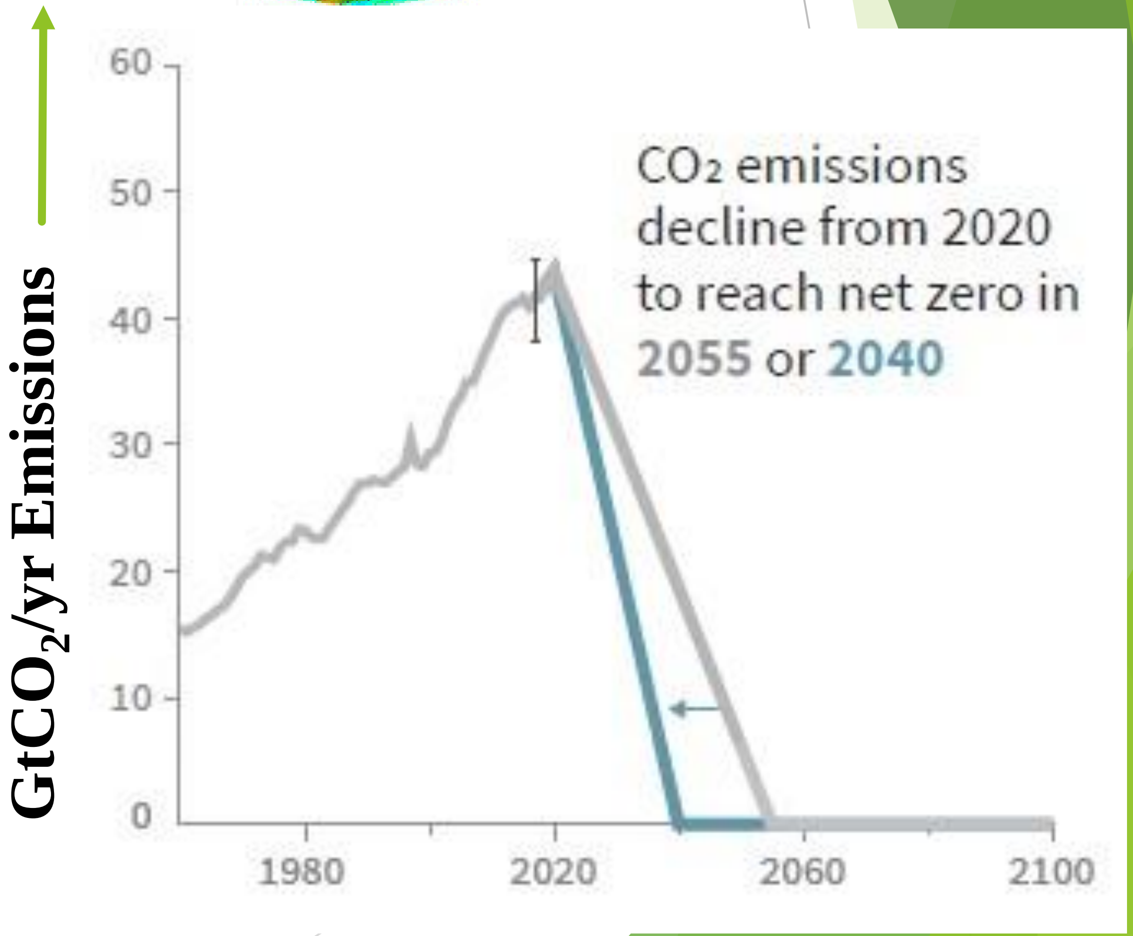



How is the electricity mix changing?
Low-emissions sources of electricity, led by renewables, are poised to overtake fossil fuels by 2030 in the STEPS and APS, ending decades of growth for coal.
How to read
2010
2021
STEPS
APS
2030
TWh
Coal unabated
8 670
10 200
9 040
8 080
Natural gas unabated
4 860
6 550
6 850
6 100
Other
1 020
740
520
580
Share
13%
20%
67%
10%
28%
62%
10%
43%
47%
1%
10%
49%
41%
2010
2021
STEPS 2030
2021
APS 2030
Unabated fossil fuels
Renewables
Nuclear
Other
Nuclear
2 760
2 780
3 350
3 550
Renewables
4 230
8 060
15 070
17 570
Solar PV
30
1 000
4 010
4 840
Wind
340
1 870
4 600
5 820
Other renewables
3 860
5 190
6 460
6 920

**How can the net global $CO_2$ emission to limit temperature rise to $1.5^0C$ be achieved?**



***To achieve a Net-Zero $CO_2$ emission target***



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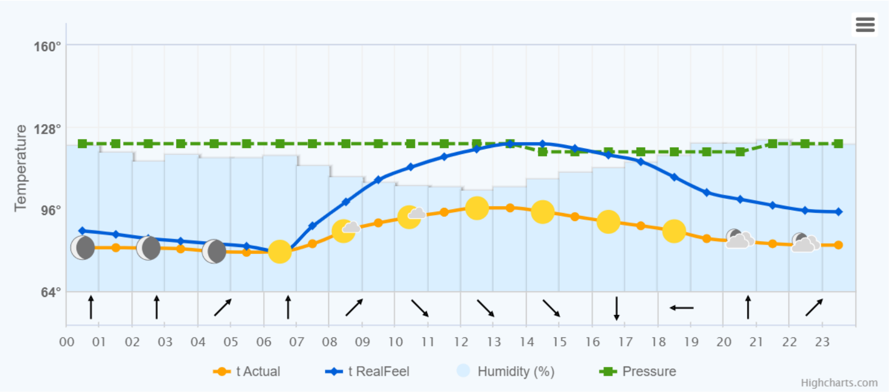


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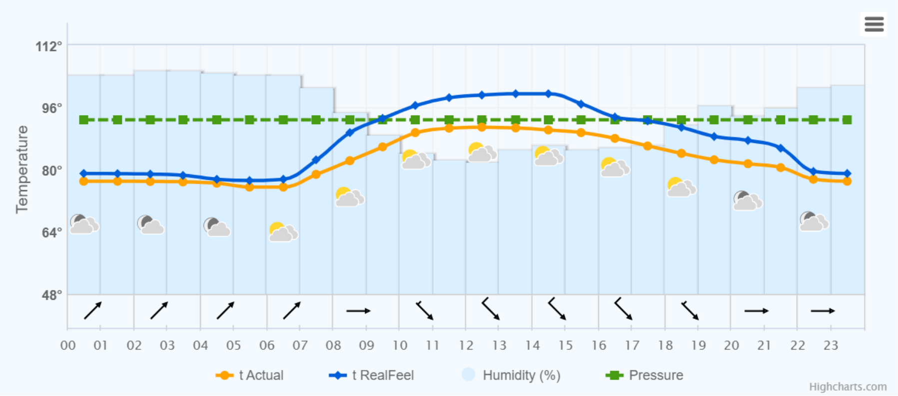
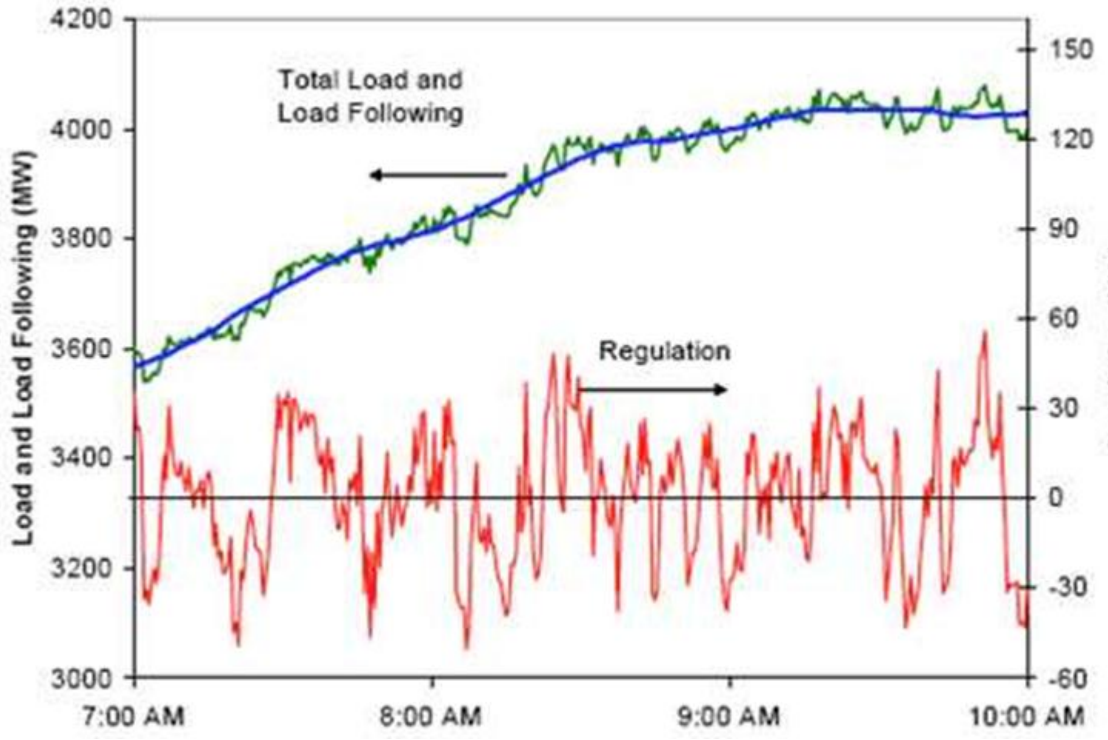



- In June and July 2023, JPS system demand rises 675 MW and 692 MW respectively. The highest ever recorded.
- Similar situation occur in other Caribbean island

# Special Case of a Small Island

- Being isolated from other countries it has to provide its own back up power (Spinning Reserve) to take care of variations in load
  - Spinning reserve usually provided by conventional fossil plants such as: Gas turbines, combined cycle gas (CCG), steam turbine and diesel generating plants.
- Even when island pledges to introduce Renewable Energy to cut emission of CO2 from fossil fuel, it has to have spinning reserve to back up renewables
  - Usually powered by fossil fuel, so there is little reduction in $CO_2$ emission
- To provide 100% power without GHG emissions by Renewable Energy back up must be provided by non-fossil storage, such as batteries or pumped storage), and synthetic reserves (inertia), provided by & fast frequency response.
- Batteries are the future of storage

# Need for Frequency Regulation




Generating ramp up from 3,600 MW to 4,000 MW over a three-hour period from 7 to 10 a.m.

Actual demand during the same time period.

Scaled up representation of the minute-to-minute differences between the blue supply line and the green demand line.
~ ± 2% of power

Source: https://seekingalpha.com/article/107832-alternative-energy-storage-why-frequency-regulation-is-important

A gap between power generation and demand causes frequency variation:
When demand momentarily exceeds generation, the generator slows down.
When generation momentarily exceeds demand, the generator speeds up.
Automatic regulation must be put in place that respond in immediately to avoid tripping out.

| No. | Date | Units Tripped | Condition Prior to Outage (MW) | | | | UFLS Stages |
|---|---|---|---|---|---|---|---|
| | | | Unit (MW) | Dispatch | System | Spinning Reserve | |
| 1 | 14/04/2018 4:38 | RF2 | 20 | 19.4 | 448.2 | 60.0 | 0, 1 |
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# What we wish to discuss

- $CO_2$ Pathway to 100% Renewable to limit temperature rise to $1.5^0C/2^0C$
- Economic benefits of following pathway using renewables plus storage of energy
  - Problems and Solution using JPS example
- Supplying base load and power grid support when required.
- Other benefits
  - Energy security
  - Clean air – Reducing air pollution

$$$$
Cost is our primary concern

# Influence Policy: New regulation creating new opportunity Battery Energy Storage for Frequency regulation

**Puerto Rico Mandates Energy Storage in Green Power Mix**

The long, convoluted path to making batteries an integral part of island solar and wind projects

by Jeff St. John
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"Under the new MTRs, all new green power projects must include some minimum energy storage capabilities aimed at helping to stabilize the island's grid."

***What does it mean in Practical terms?***

No new fossil fuel plants after 2020.

Any replacement or additional plants to be non-fossil fuel.

All fossil fuel plants replaced with non-fossil fuel plants by 2055.

| | |
|---|---|
| ~ 30 years to get rid of fossil fuel plants. | No fossil fuel plant with useful life will have to be discarded, not throwing away money. |

Complements the proposed development of the National Natural Disaster Risk Financing Policy

# What can Commonwealth Scientists do?

Study and Disseminate Results in order to drive the market and policy:

- Potential Value of Market for PV + Battery Storage in individual countries
  - Highlight favourable economics and practical advantage of Frequency Regulation using Batteries
    - This can be the driver of the battery market
  - Encourage Large scale substitution of fossil fuel (3 to 8 hrs storage)
- Collaborate on Miniature Stern like report ?– Commonwealth Review: Economics of Climate Change Mitigation
- Let Government know you upport the Global Apollo Programme
- Engage in research on DC Electricity

# *Pathway to 100% Renewable (Conservative)*

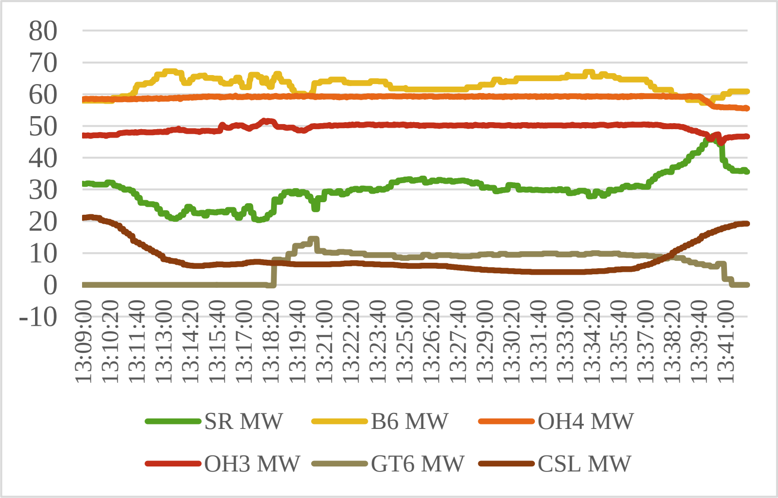
- Now to 2030: Add PV + Li Ion Battery up to 30% renewable to replace old fossil fuel plants or for expansion
  - Inline with government policy
  - Fossil fuel to provide firm energy
- 2030 to 2055: Add PV + Batteries up to 100% renewable
  - Gradually reducing fossil fuel and Increasing Renewables Plus Battery
  - Mix of Fossil and RE + storage to provide grid stability until 100% RE
    - Flow batteries (8 hours duration) or double up on Li Ion Batteries (4 hour duration)

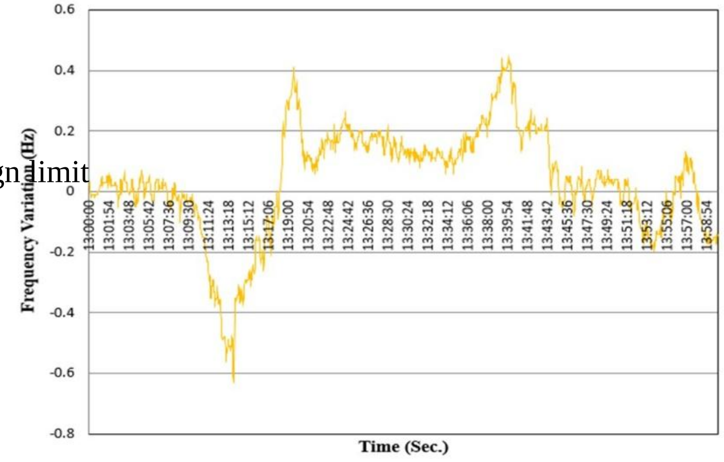
# *Project on Pathway to 100% Renewable*

- Project aims* & components**
- Possible Project Funding
  - Direct Government Funding
    - Some of J$200 M for R&D
  - Government applying for International Funding
    - Green Climate Fund, GEF Trust Fund
    - European Union, Bi-Lateral Donor Agents
    - World Bank, IDB (?????) etc.
  - Private Sector Participation
  - Pilot projects with Private Investors

# *Problem at JPS - Cloud induced transient Output of over the PV plant*

## PV output decreased



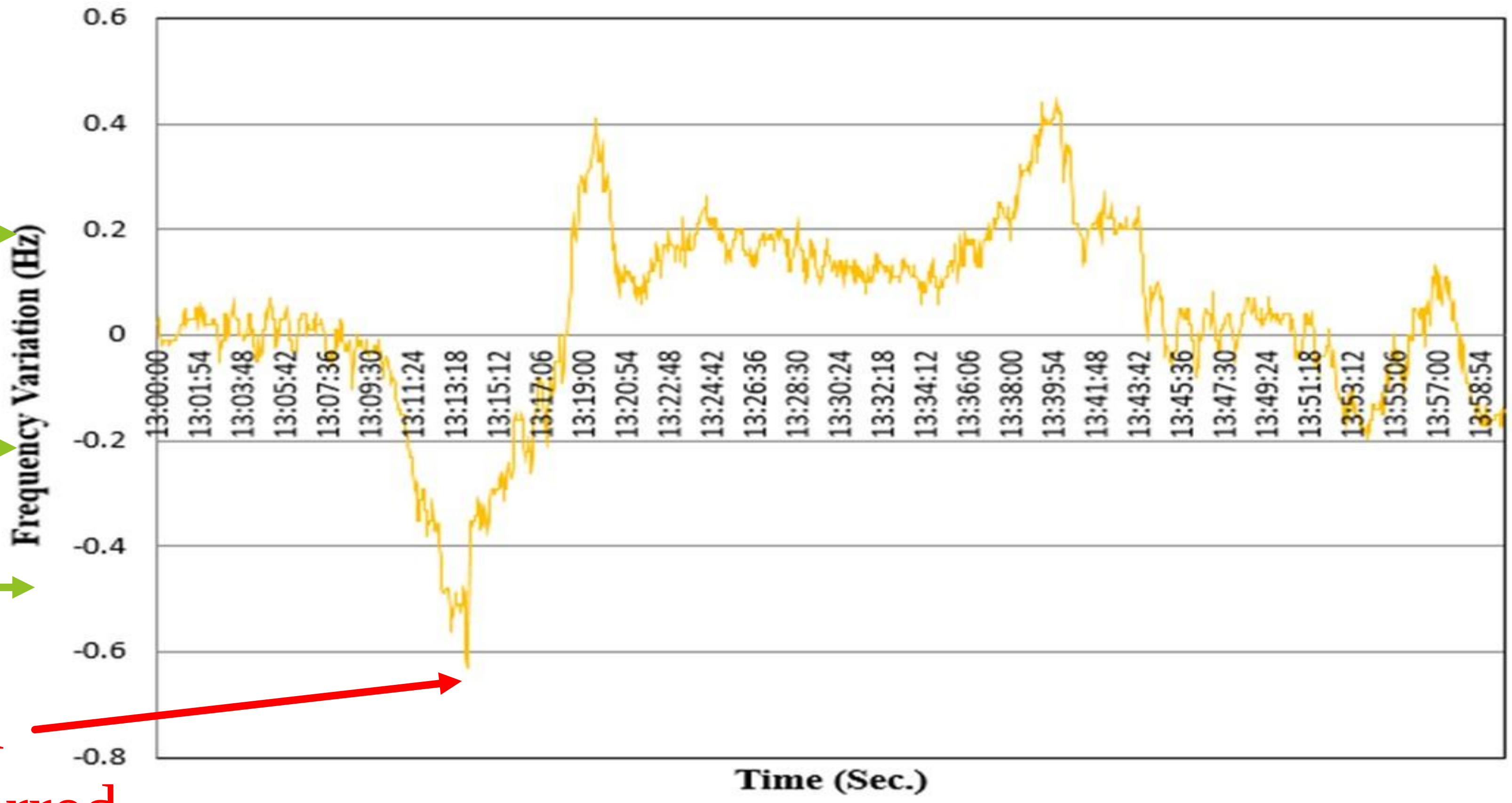



# *JPS Problem - Frequency Excursions*

Steady state operating limit ($\pm 0.2\ Hz$)

Design limit

Under Frequency Load Shedding (UFLS) occurred



# Pathway to 100% Renewable & Mitigating Climate change

- Why Low Carbon
- Timeline for Low Carbon
- How Low Carbon can be achieved
  - Wind and Solar Competitive and Ubiquitous
- Problems with Wind and Solar
  - Intermittent

# Part II: Solving the Problem

# Introduction

## Part I: Mitigating Climate Change by Renewable Energy and the Electric grid Impact

- Why Low Carbon
- Timeline for Low Carbon
- How Low Carbon can be achieved
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## Part II: Solving the Problem

# Market potential for Battery Storage for Frequency Regulation in the Commonwealth and worldwide

Commonwealth as an example:

- Generates 9658.219 GWh of electricity daily
- Assume frequency regulation for 1% of that amount of energy
- Assume LCOE of US$0.19 per kWh and battery life of 10 years
- Cost of storage component is approx. US$60 Billion
  - Very Nice incentive for encouraging investors

For the world the cost of storage component ~ US$400 Billion