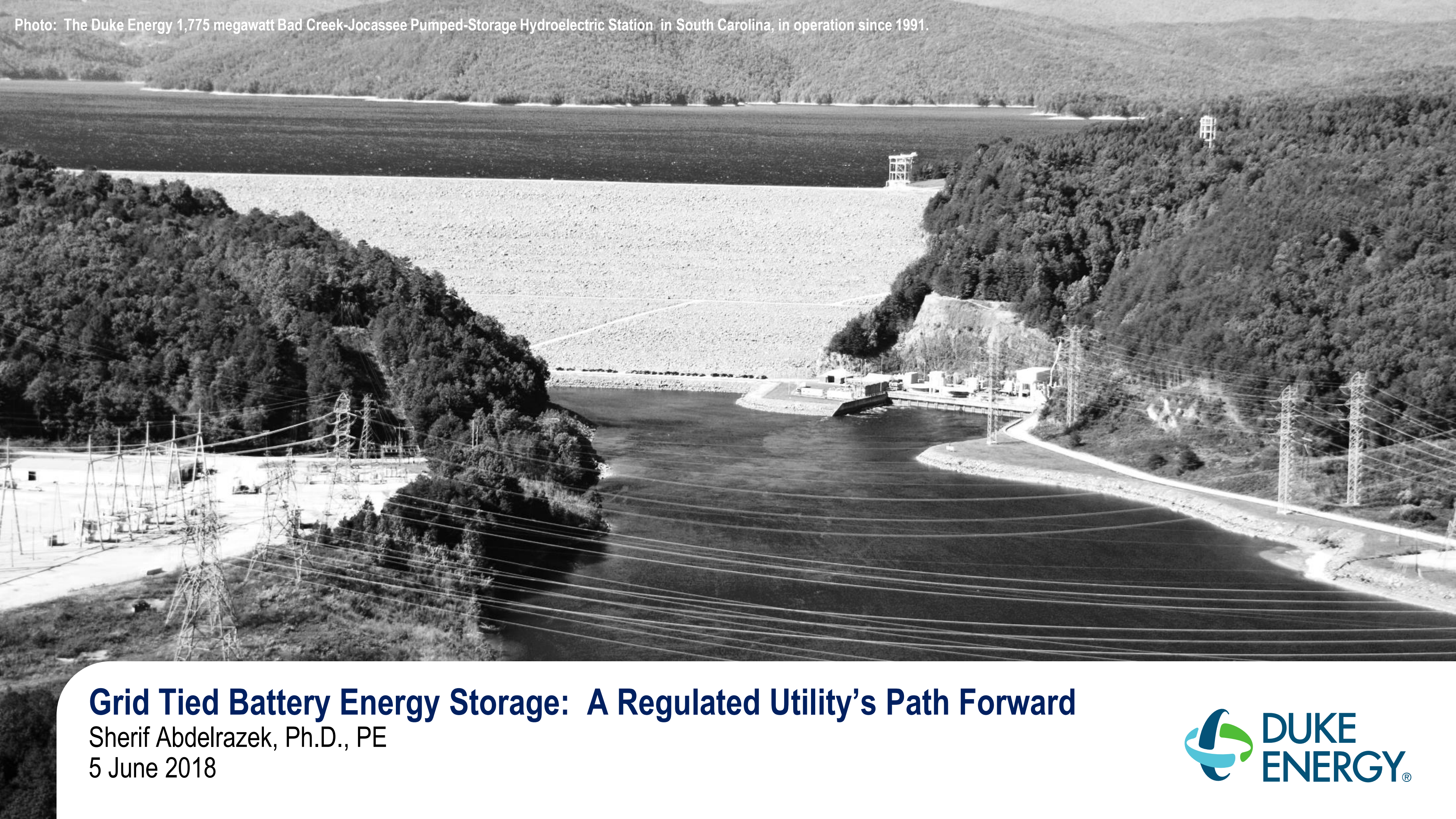
Photo: The Duke Energy 1,775 megawatt Bad Creek-Jocassee Pumped-Storage Hydroelectric Station in South Carolina, in operation since 1991.



Grid Tied Battery Energy Storage: A Regulated Utility's Path Forward

Sherif Abdelrazek, Ph.D., PE

5 June 2018

Outline

- Duke Energy R&D and Early Adoption of Energy Storage
- Energy Storage Project Pipeline within Duke Energy
- Duke Energy's Future Outlook for Energy Storage: Renewables Integration
  - Ancillary Services
  - Renewables Integration

- **Duke Energy R&D and Early Adoption of Energy Storage**
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Duke Energy R&D and Early Adoption of Energy Storage

36 MW / 24 MWh
Advanced Lead Acid / Li Ion - West Texas

**402 kW / 282 kWh
Sodium Nickel Chloride - Mt. Holly, NC

75 kW / 42 kWh
Lithium Titanate - Indianapolis, IN

250 kW / 750 kWh
Lithium Polymer - Charlotte, NC

25 kW / 25 kWh
Lithium Ion - Charlotte, NC

200 kW / 500 kWh
Lithium Iron Phosphate - Charlotte, NC

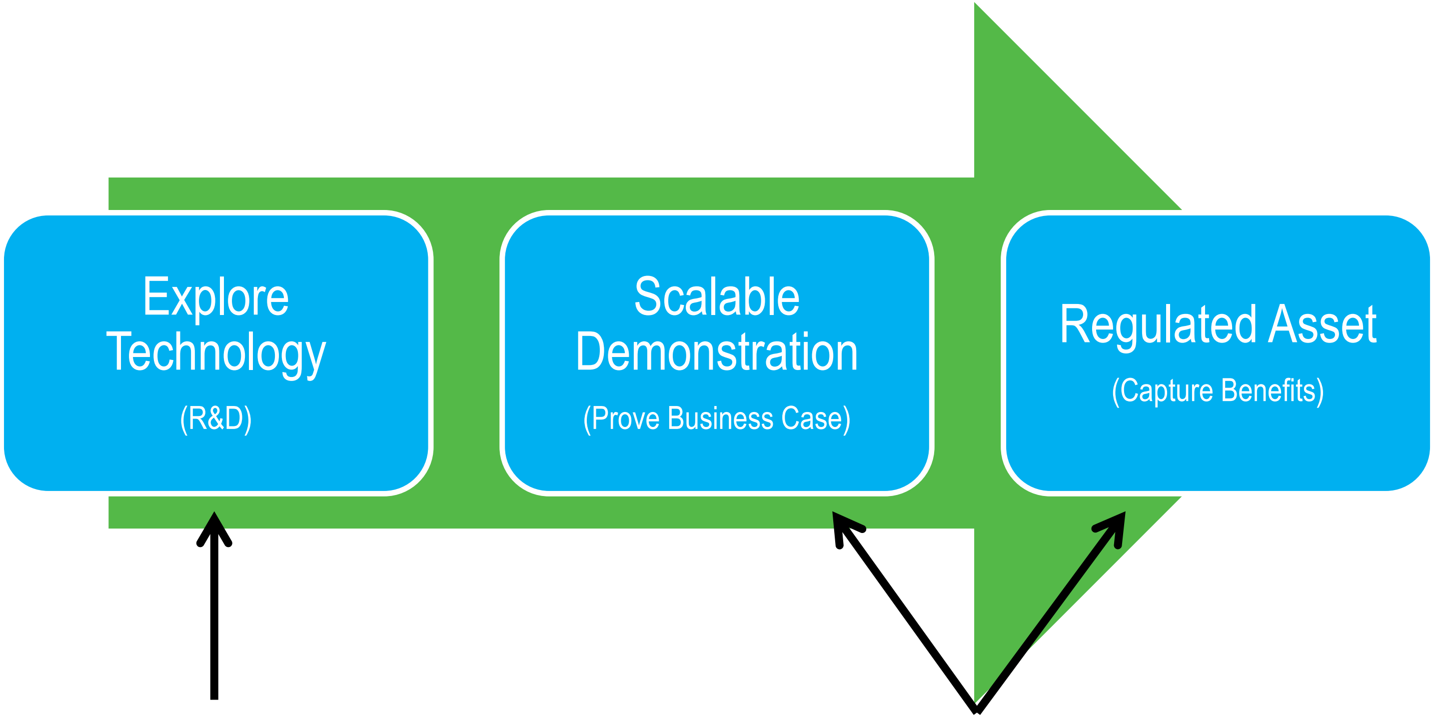
4 MW / 1.5 MWh
Beckjord Station - New Richmond, OH

200 kW / 400kWh
Lithium Ion - St. Petersburg, FL

Residential Product Testing
Misc. - Mt. Holly, NC

Duke Energy tested the most technically attractive lithium battery chemistries with nearly **40MW** of R&D and Commercial Installations

Duke Energy R&D and Early Adoption of Energy Storage



We have been here…

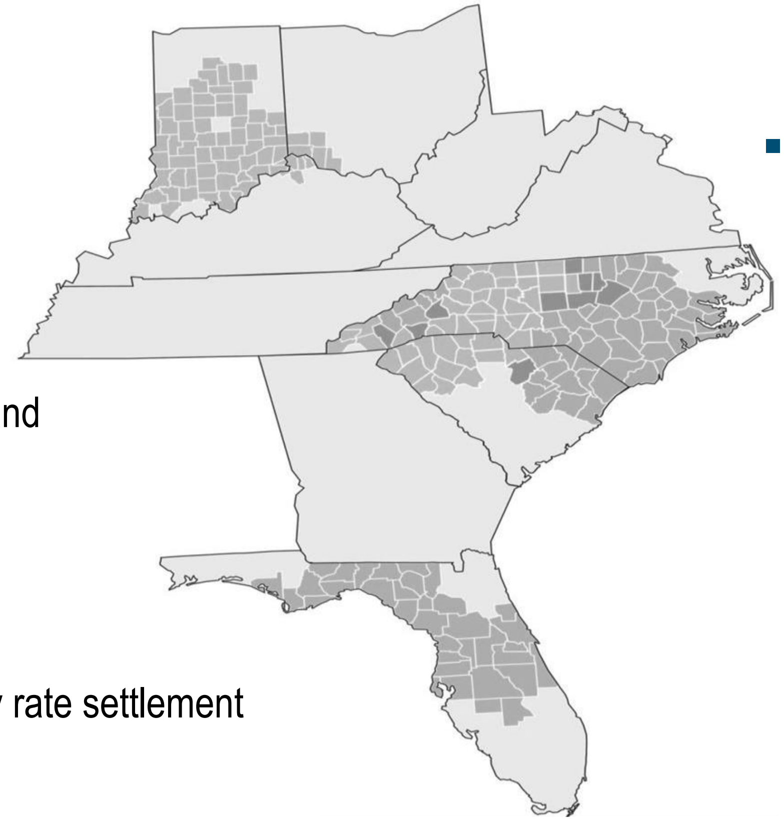
Now we are moving here…

Outline

- Duke Energy R&D and Early Adoption of Energy Storage
- **Energy Storage Project Pipeline within Duke Energy**
- Duke Energy’s Future Outlook for Energy Storage: Renewables Integration
    - Ancillary Services
    - Renewables Integration

Energy Storage Project Pipeline within Duke Energy

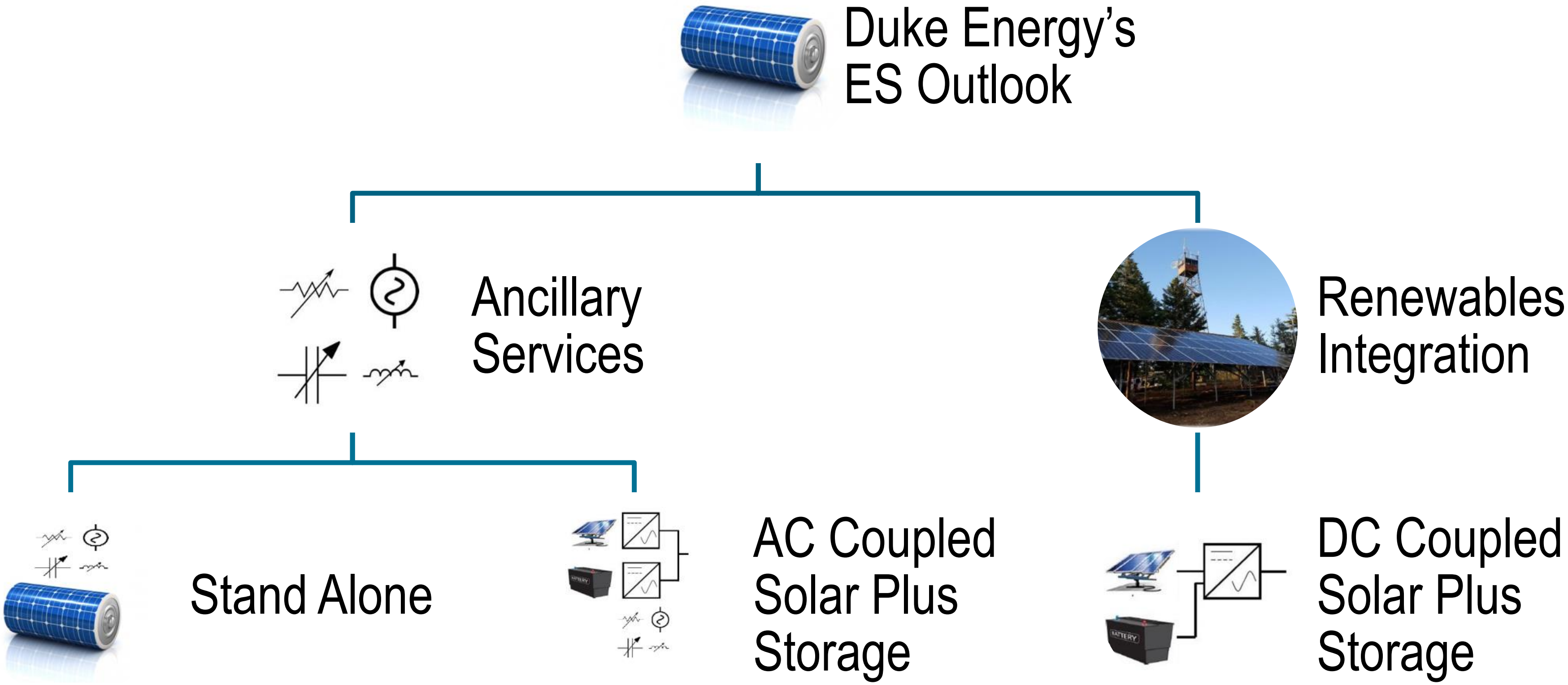
- **DEO**
  - ➢ 10 MW pilot program included in ESP
- **DEI**
  - ➢ 5 MW Camp Atterbury and 5 MW Nabb
  - ➢ Approved by IURC
- **DEF**
  - ➢ 50 MW included in utility rate settlement
  - ➢ Approved by FPSC



- **DEP/DEC**
  - ➢ 95 kWh Mt. Sterling Microgrid (Commissioned)
  - ➢ 75MW placeholder in the Carolinas IRP
    - ➢ 4 MW Hot Springs and 9 MW AVL Rock Hill (Announced)

- Duke Energy R&D and Early Adoption of Energy Storage
- Energy Storage Project Pipeline within Duke Energy
- **Duke Energy's Future Outlook for Energy Storage: Renewables Integration**
    - Ancillary Services
    - Renewables Integration

Duke Energy's Future Outlook for Energy Storage



How does the utility grid perceive energy storage?

How does the utility grid perceive energy storage?

Well, as seen by the grid,

Energy Storage =

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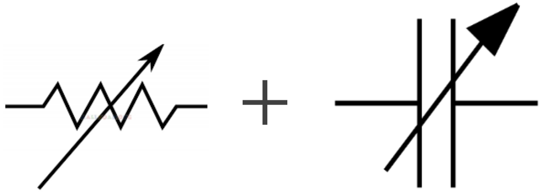

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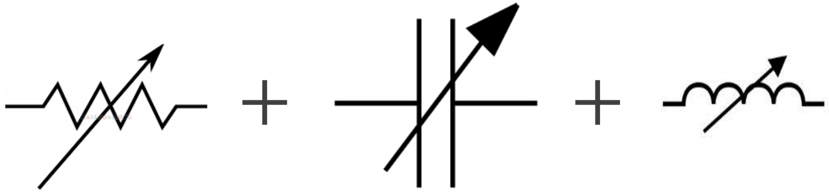

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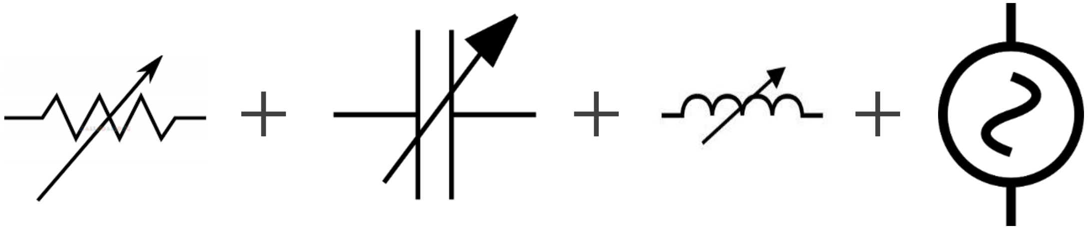

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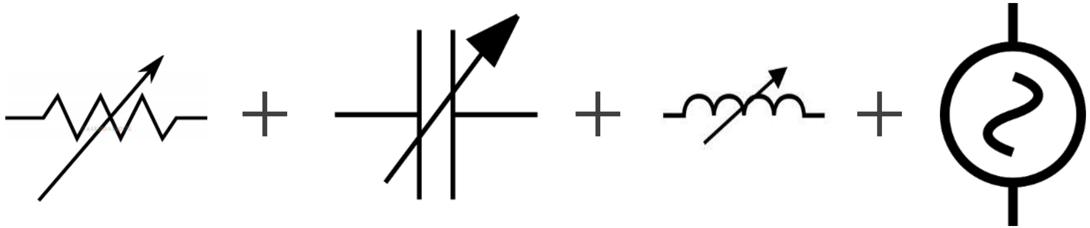
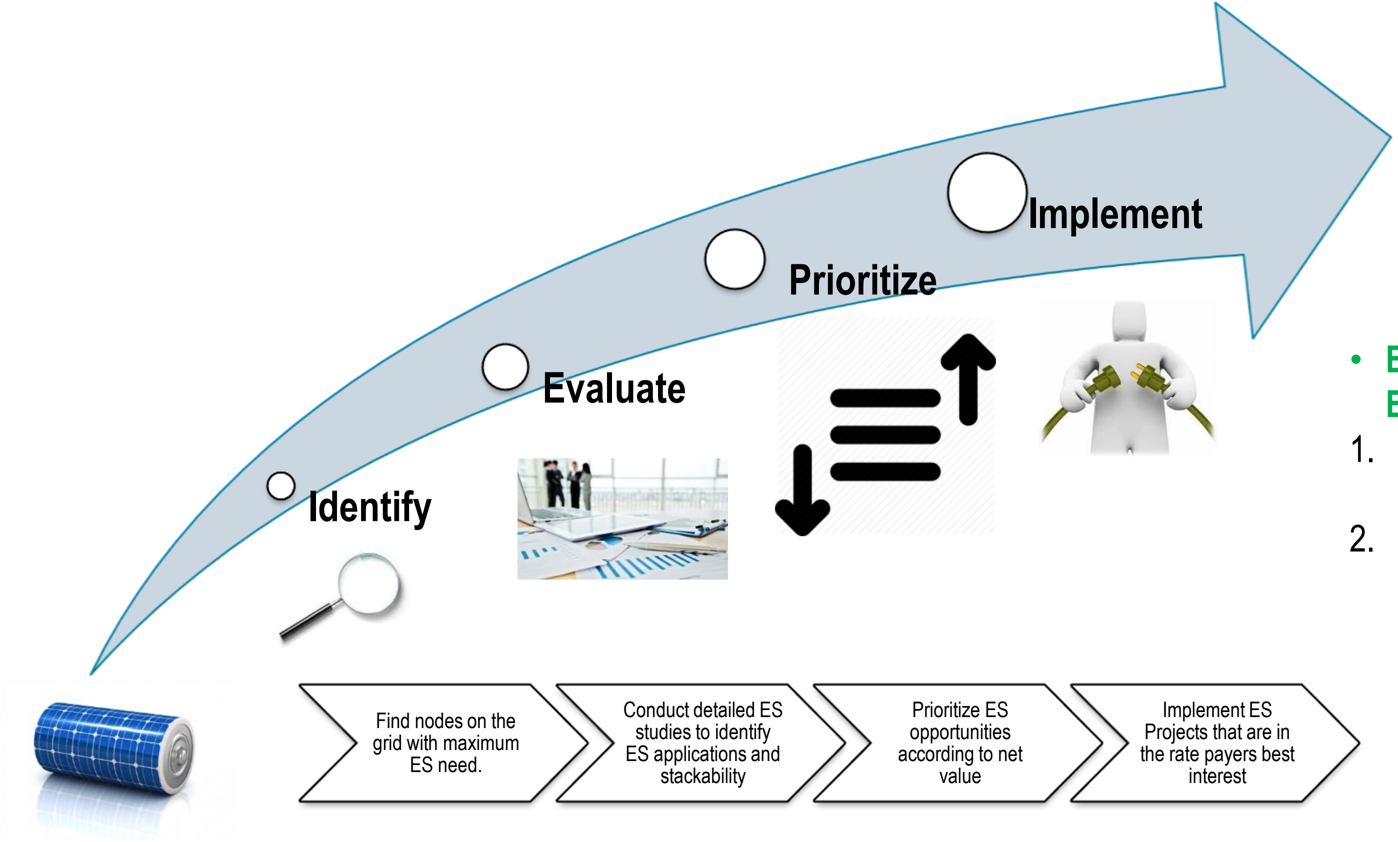
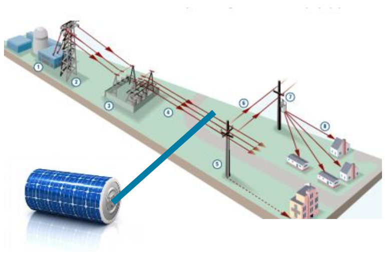


Energy Storage = All Basic Physical Electrical Elements in One!

Energy Storage Opportunities Identification & Implementation in a Regulated Environment

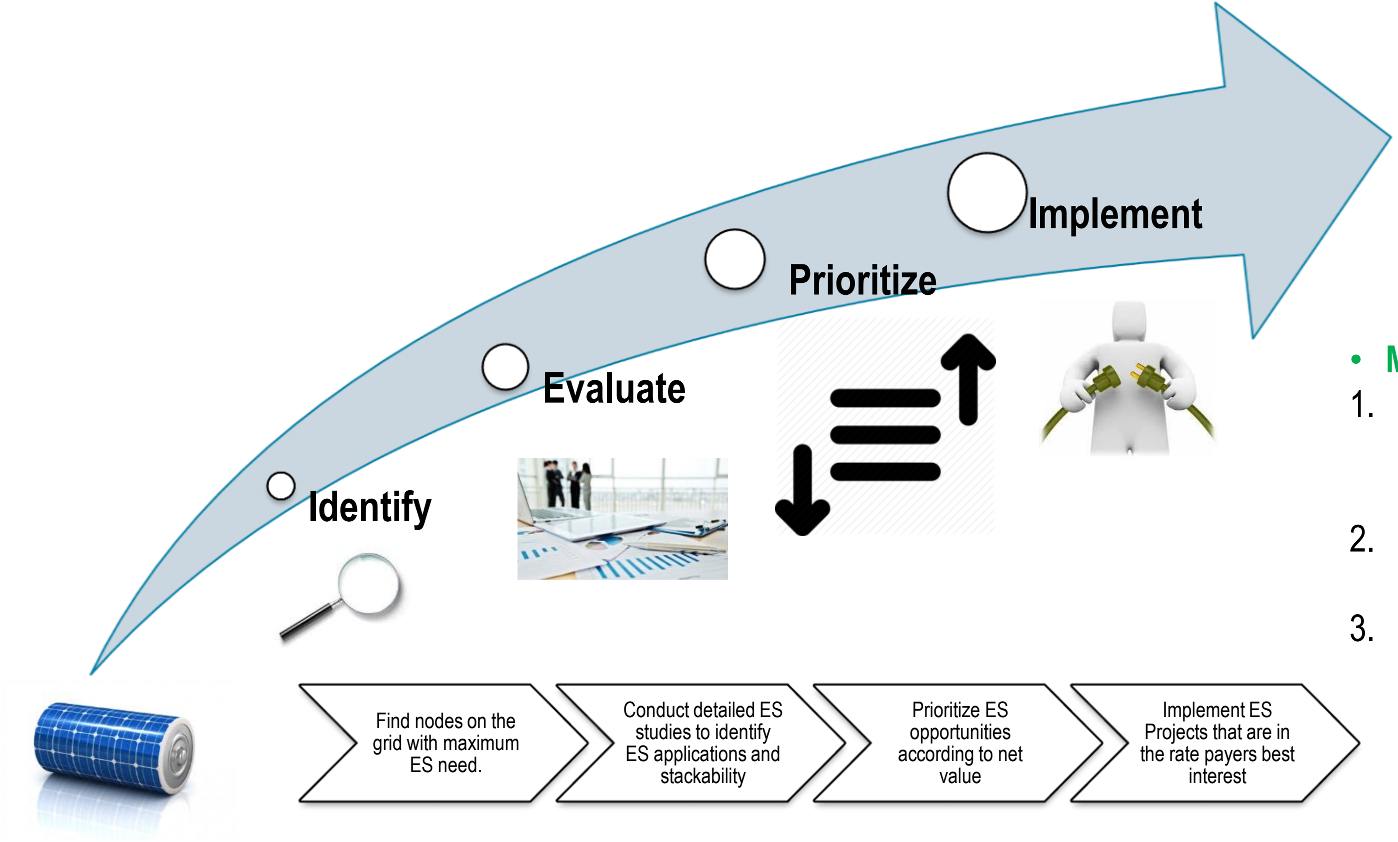


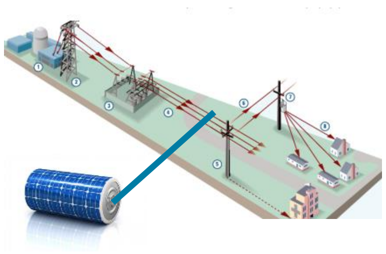


- **ES Can Become Cost Effective Through:**

1. Multi-Application Systems
2. Multi-Avoided Cost Stream Systems

Energy Storage Opportunities Identification & Implementation in a Regulated Environment

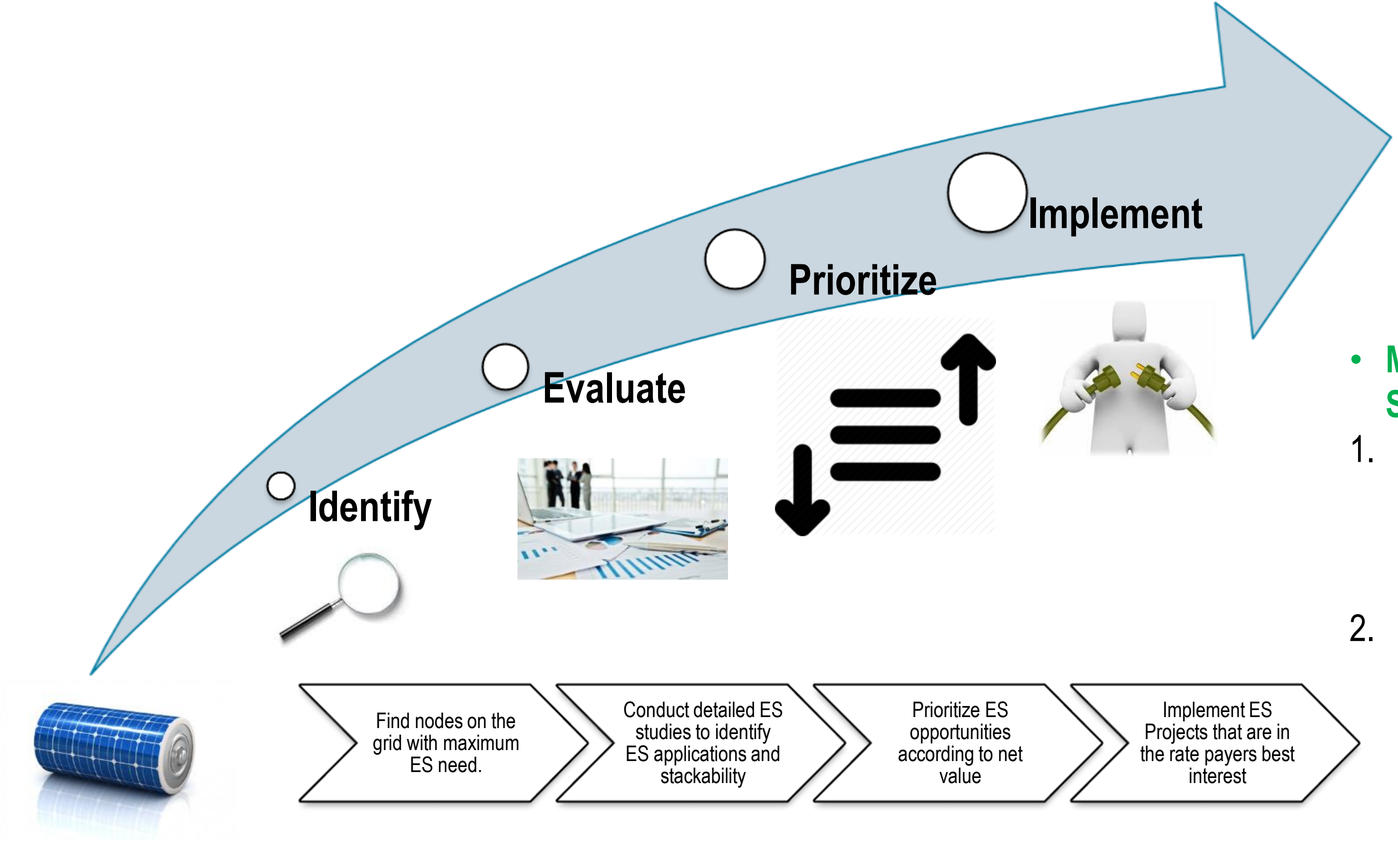


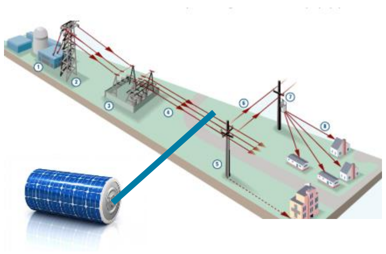


- **Multi-Application Systems:**
1. The current cost of ESSs rarely allow single use case ESSs
2. ES applications can stack in simultaneous manners
3. Utility ES resiliency functions can be easily added to support customer power quality improvement at minimal additional cost

Duke Energy's Future Outlook for Energy Storage: Ancillary Services

Energy Storage Opportunities Identification & Implementation in a Regulated Environment

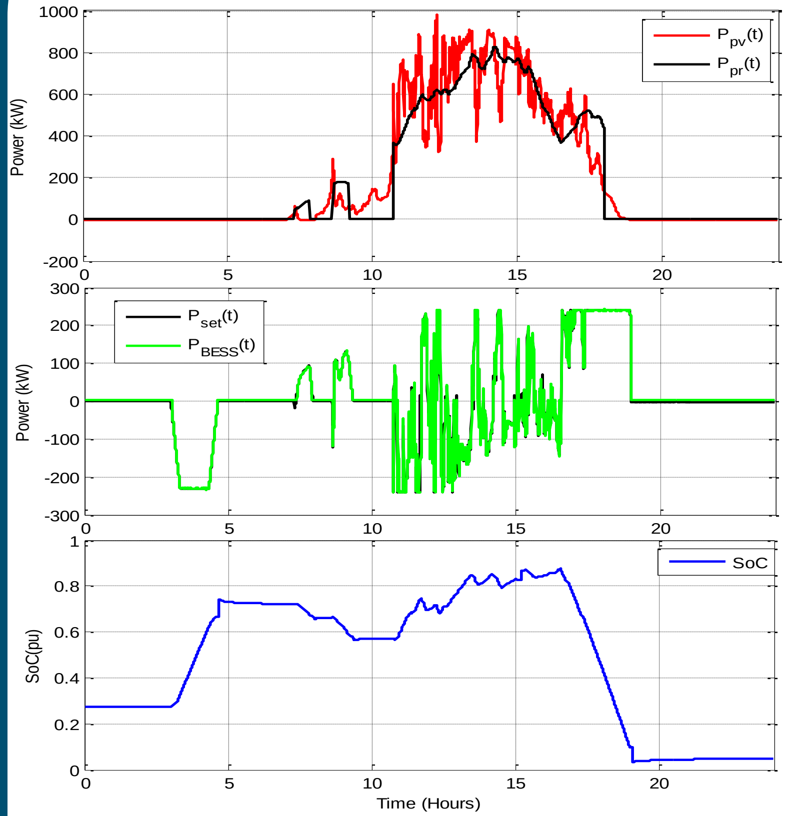


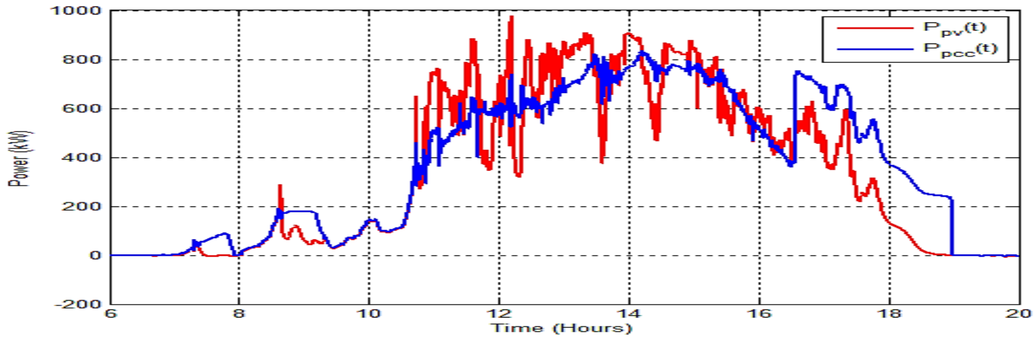


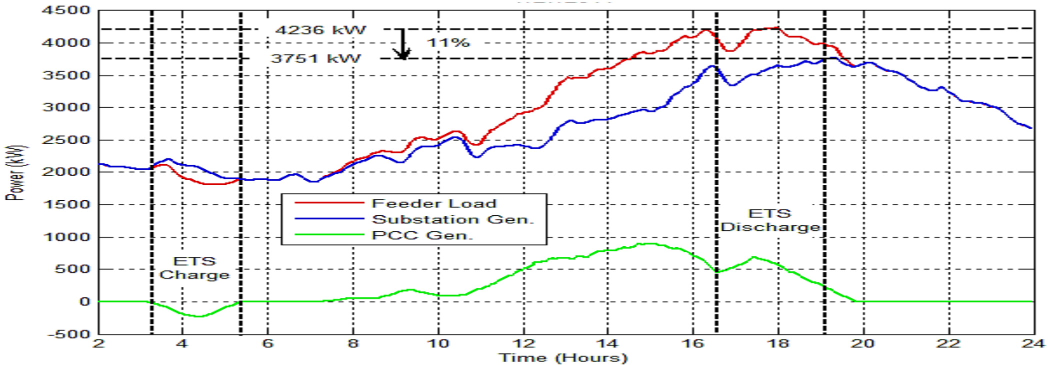
- **Multi-Avoided Cost Stream Systems:**

1. Multi-avoided cost value stream projects can counter act high ES cost in regulated environments.
2. Stacking of multiple functions may not be necessary here.

Multi-Application Energy Storage Systems Operation Example: PVS+PLS







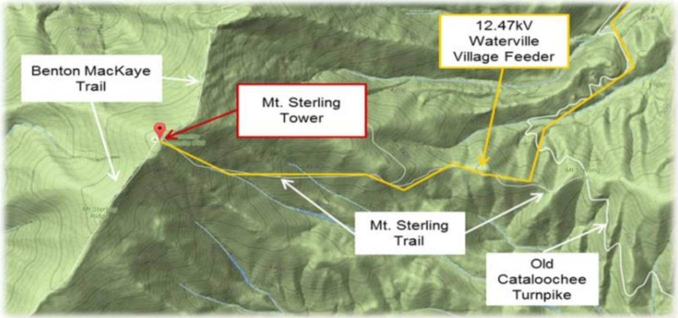
[S.Abdelrazek & S.Kamalasadan. (2016). Integrated PV Capacity Firming and Energy Time Shift. IEEE Transactions on Industry Applications. 52. 1-1. 10.1109/TIA.2016.2531639.]

Multi-Avoided Cost Streams Energy Storage Systems Example: Mt. Sterling Microgrid

- 12.47kV Waterville Village Distribution Feeder
  - Installed in 1960s
  - 5 Miles from nearest disconnection point
  - 48 poles
  - 1 customer **(Mt. Sterling Fire Tower)**
- Planned Upgrades
  - 22 poles to be replaced through 2026
  - High cost due to helicopter operation
- O&M Challenges
  - Inaccessible Terrain
  - High cost vegetation management and restoration
  - **Averages 3+ major outage events per year**
    - **Roughly 1 week per outage**

Multi-Avoided Cost Streams Energy Storage Systems Example

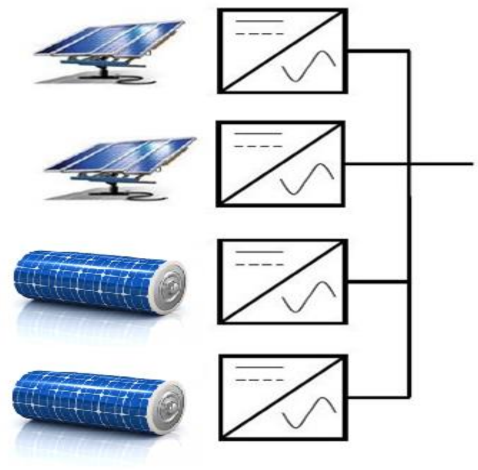
Overview: Utility-owned and -operated Microgrid that serves a remote customer off-grid through 100% renewable energy
Problem: Inaccessible line installed in 1960s to support 1 customer load requires high-cost upgrades and long-term outages
Timeline: 11/2016– Filed for regulatory approval; 04/2017– Received regulatory approval; 05/2017– Construction complete



	Base Case	Microgrid Case
Technology	12.47 kV Distribution Feeder	10 kW Solar PV & 95 kWh Battery
Employee Safety	↓	↑
Footprint	↑	↓
Reliability	↓	↑
Emissions	↑	↓
Revenue Requirement	↑	↓

Topologies:-

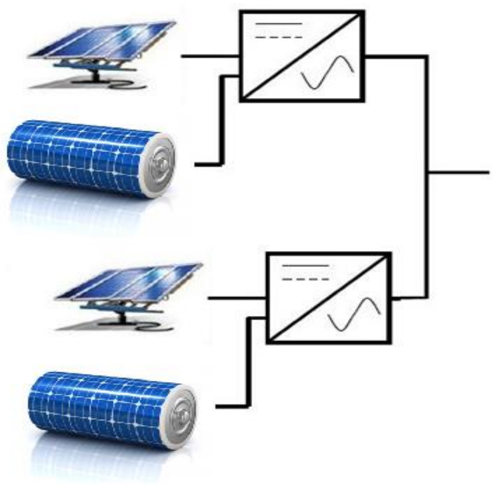
AC coupled



Mature

Camp Atterbury/Hot Springs Projects

DC coupled

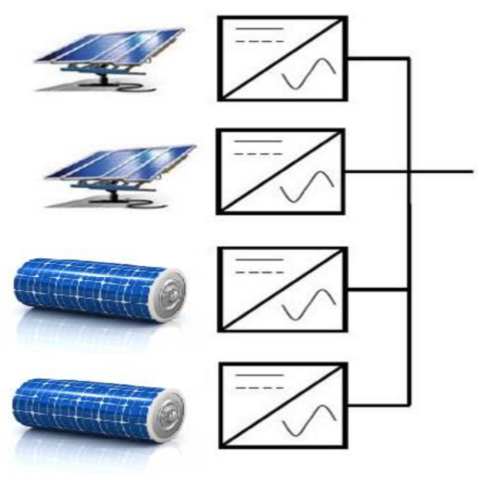


Recently Mature

Technical & Financial Analysis Phase

Topologies:-

AC coupled

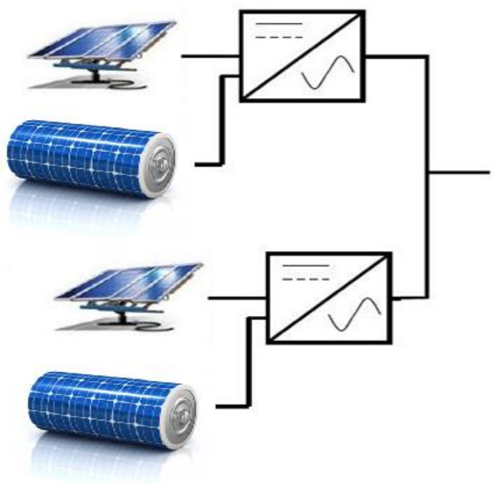


Mature

Camp Atterbury/Hot Springs Projects

- Advantage: Better for ancillary services functions for ESSs

DC coupled



Recently Mature

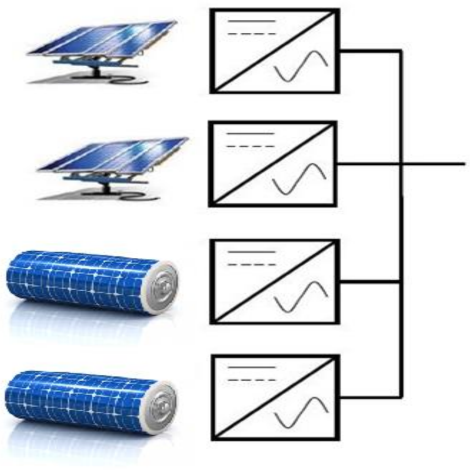
Technical & Financial Analysis Phase

- Advantage: More efficient for renewables Integration. Provides a semi-dispatchable trait to solar facilities, reduces power intermittency

Duke Energy's Future Outlook for Energy Storage: Renewables Integration

Topologies:-

AC coupled



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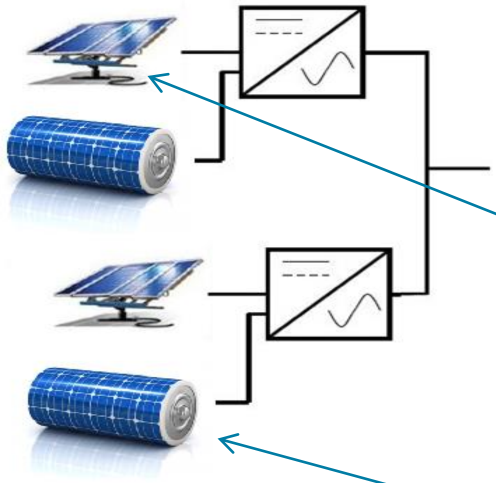

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Technical & Financial Analysis Phase

- Advantage: More efficient for renewables Integration. Provides a semi-dispatchable trait to solar facilities, reduces power intermittency

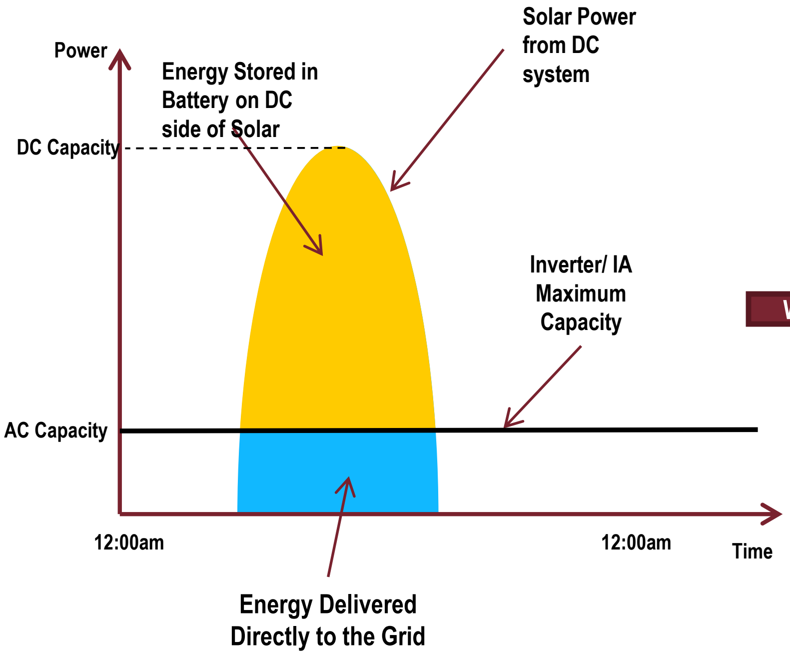
Decline in cost of modules drives towards higher DC/AC ratio designs

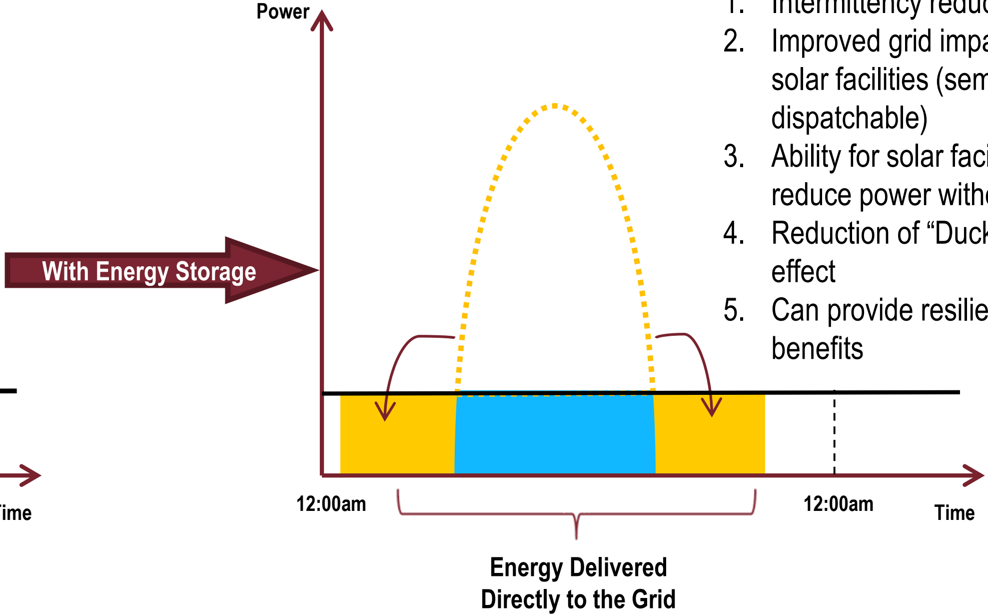
Decline in cost of ES drives better economics for DC coupled Solar Plus Storage Systems. Especially with higher DC AC ratio solar facilities

Duke Energy's Future Outlook for Energy Storage: Renewables Integration

Operation:-

Goal: maximize solar DC capacity relative to inverter capacity such that the additional capacity can be charged during the day and discharged during times when solar production is less than inverter maximum capacity.





- **Advantages:**

1. Intermittency reduction
2. Improved grid impact of solar facilities (semi-dispatchable)
3. Ability for solar facilities to reduce power without loss
4. Reduction of "Duck Curve" effect
5. Can provide resiliency benefits

1. Duke Energy views energy storage as a prime grid ancillary services tool.

2. Energy storage projects pursuing ancillary services benefits are more successful when grid locations are identified properly.

3. Renewables integration applications of energy storage are better suited for some topologies versus others.

4. DC coupled solar plus storage systems can reduce negative impacts of solar facilities on the grid.

Questions ?