INL/MIS-23-71885-Revision-0

Grid Enhancing Technologies in ISO-NE

March 2023

Changing the World's Energy Future

Sean Morash, Andrew Siler, Leonard Kapiloff, Derek Stenclik, Matthew Richwine, Christopher Roger Sticht, Alexander W Abboud, Jake P Gentle

Idaho National Laboratory

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TOGETS Task Force

Grid Enhancing Technologies in ISO-NE

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Idaho National Laboratory

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- TOGETS background and Resources (5ish mins)
- Modeling Methodology Highlights (25ish mins)
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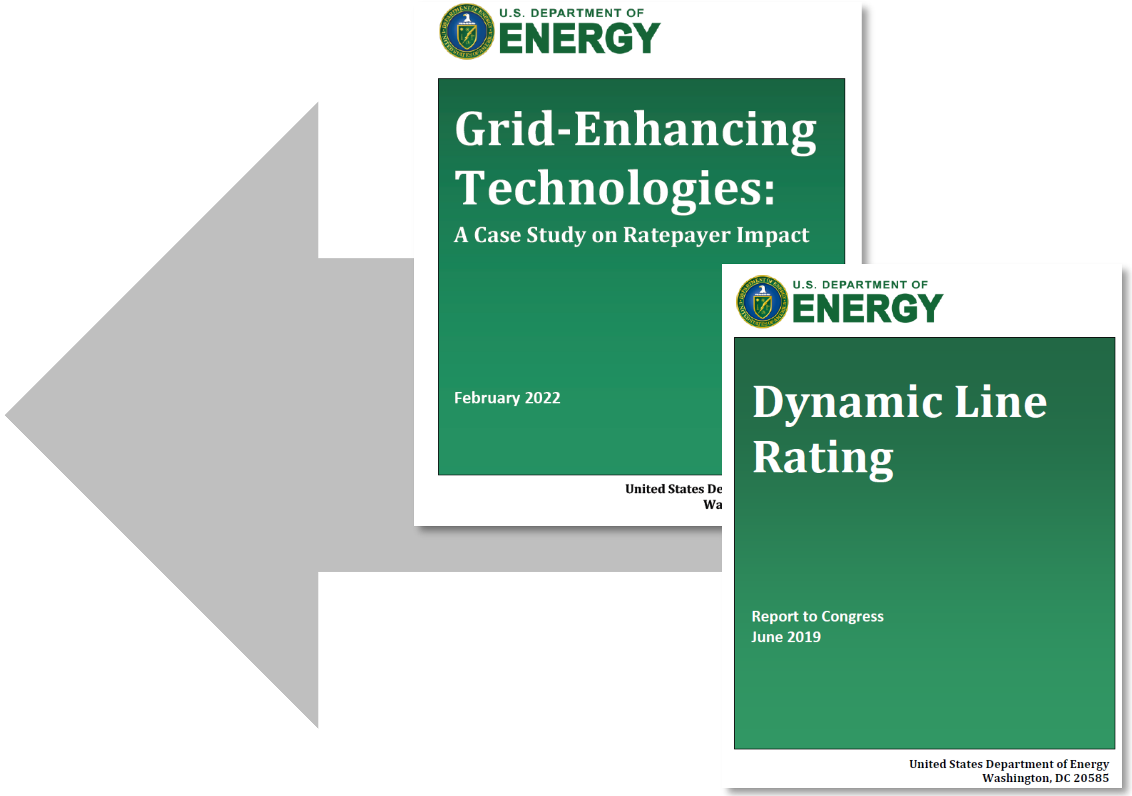
  - Key Lessons Learned and Next Steps
- GETs User Group (ESIG - 10 mins)

TOGETS Background

- One recommendation from the 2022 report is to “Assemble a Task Force to Share GETs Data”
- Over the last 12+ months, INL has assembled an advisory board to direct INL activities in this space. Advisory Board members include:
  - Grid Operators: MISO, National Grid, WAPA, PJM, BPA
  - Researchers: EPRI, POWERS, EnerNex
  - Policy: FERC, NERC, WECC, OMS, DOE
  - Others
- Primary Project = Transmission Optimization and Grid Enhancing Technologies (“TOGETs”)
  - Site Demonstration / Other Resources
  - Modeling = FOCUS of this webinar



Reports to Congress *(2019 and 2022)*

https://www.energy.gov/sites/prod/files/2019/08/f66/Congressional_DLR_Report_June2019_final_508_0.pdf
https://www.energy.gov/oe/articles/doe-study-shows-maximizing-capabilities-existing-transmission-lines-through-grid

TOGETs Publications and Longer Catalogue of Relevant Info

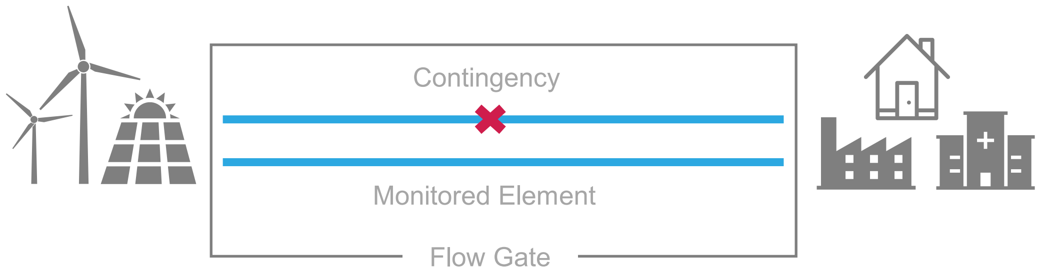
- GETs website - inl.gov/national-security/grid-enhancing-technologies/
  - Background
  - Variety of products
    - Guide to Case Studies for GETs
    - Real-time and Forecasted DLR Use Cases
    - DLR Forecast Time Frames
    - Interoperability Profile
  - Related Information
- DLR website – inl.gov/national-security/dynamic-line-rating/
  - Last 10-15 years of DLR R&D
  - Overview of DLR
  - Technical Articles and Papers

Terminology Review

Grid Enhancing Technologies (GETs) include, but are not limited to:

1. **Power Flow Control (PFC)** and transmission switching equipment
2. Storage technologies
3. Advanced line rating management
   - **Ambient Adjusted Ratings (AAR)**
   - **Dynamic Line Ratings (DLR)**

This effort is primarily focused on the items in **bold** above.



Power Flow Control is a set of technologies that push or shift power away from overloaded lines and onto underutilized lines/corridors within the existing transmission network. Multiple power flow control solutions exist.

Dynamic Line Ratings (and Ambient Adjusted Ratings) adjust thermal line ratings based on actual weather conditions including, ambient air temperature, wind speed/direction, and solar irradiance, in conjunction with real-time monitoring.

Contingency - the loss of a transmission component

Monitored Element - the elements overloaded when a contingency happens

Flowgate – the contingency and monitored element pair that limit power transfer across the transmission system (from wind/solar to load in this example)

GETs definition from FERC Notice to Convene a Workshop on Grid-Enhancing Technologies: https://cms.ferc.gov/media/7198

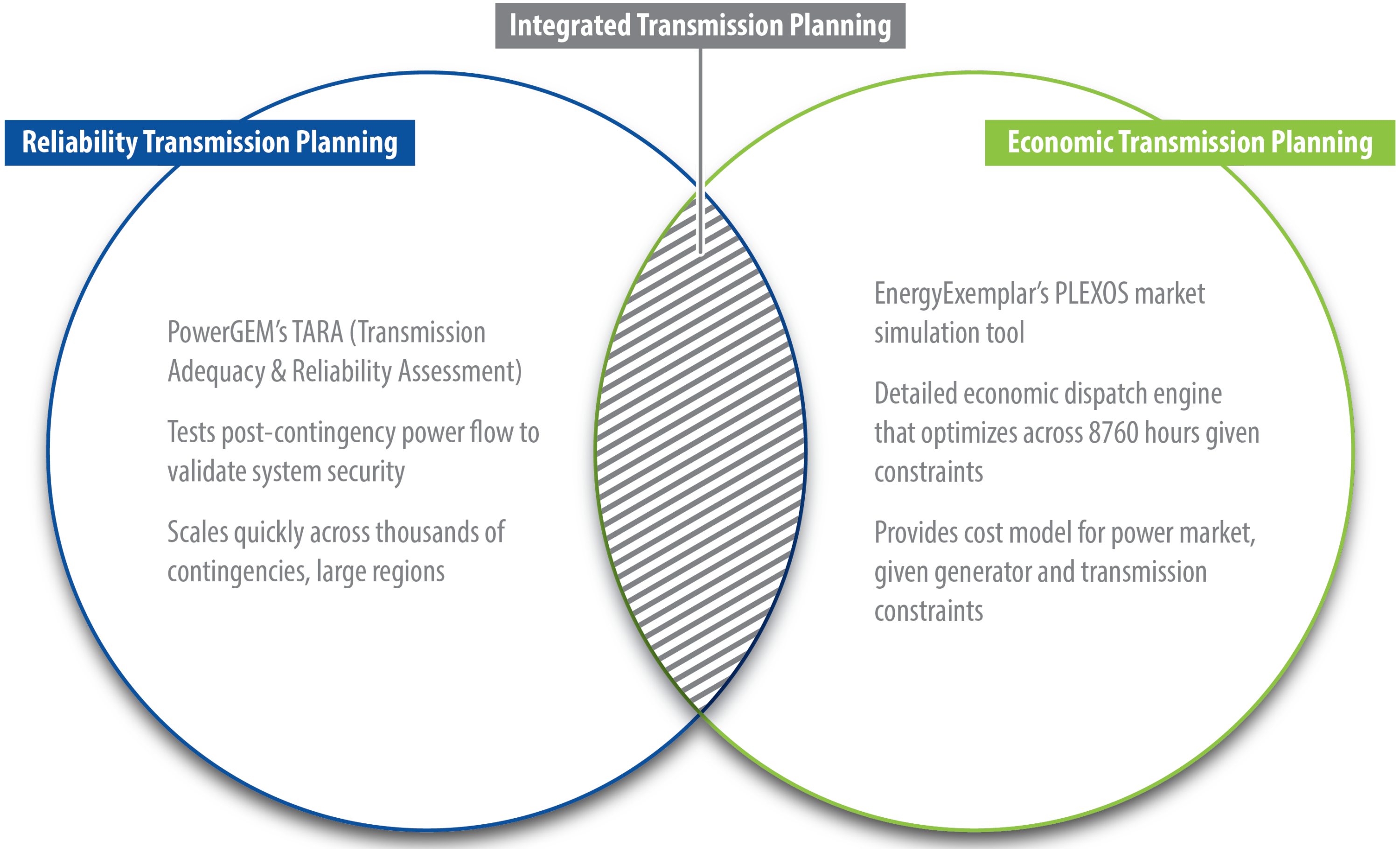
Modeling Objectives

Assess Grid Enhancing Technologies in transmission planning by coupling economic and reliability analysis over an entire time horizon rather than a few dispatch conditions.

1. Develop novel methods to link economic and reliability transmission planning tools.
2. Consider the flexible nature of GETs across wide ranges of system conditions.
3. Evaluate how GETs can be used to defer, reduce, and potentially eliminate the need for new transmission upgrades.

This webinar focuses on the modeling ***results and benefits analysis*** for possible transmission upgrades as applied to the New England (ISO-NE) power system. As part of the overall project, the modeling approach was also applied to a test system with those results ultimately informing the approach executed in studying the ISO-NE system.

Modeling and Simulation: *Why?*



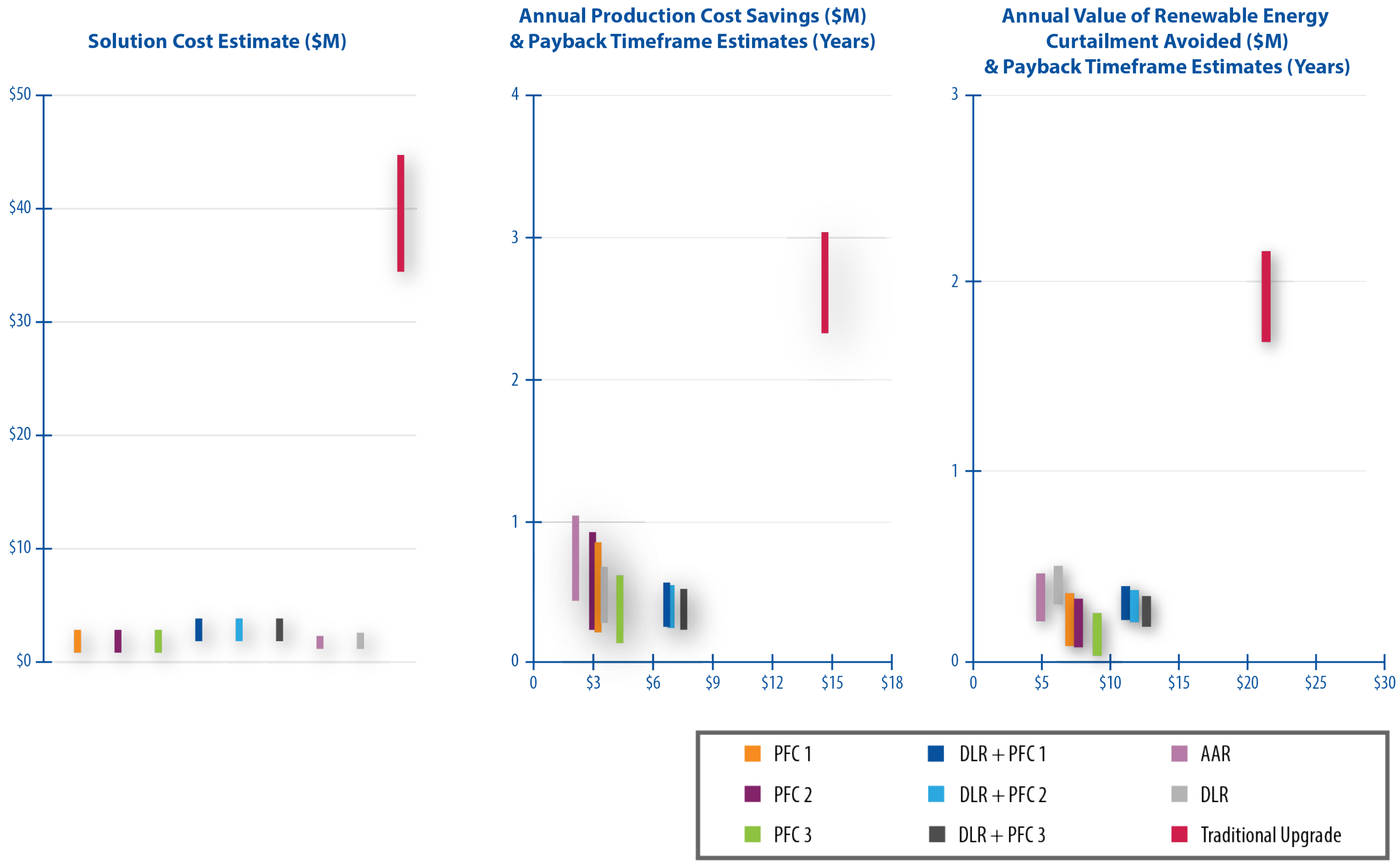
Integrated Reliability & Economic Planning

- Combined reliability analysis with economic planning will highlight full benefits of GETs and other transmission upgrades.
- Reliability analysis in TARA informs PLEXOS contingency modeling and dispatch.
- Reliability analysis in TARA paired with PLEXOS congestion costs informs PFC placement.

Results Up Front

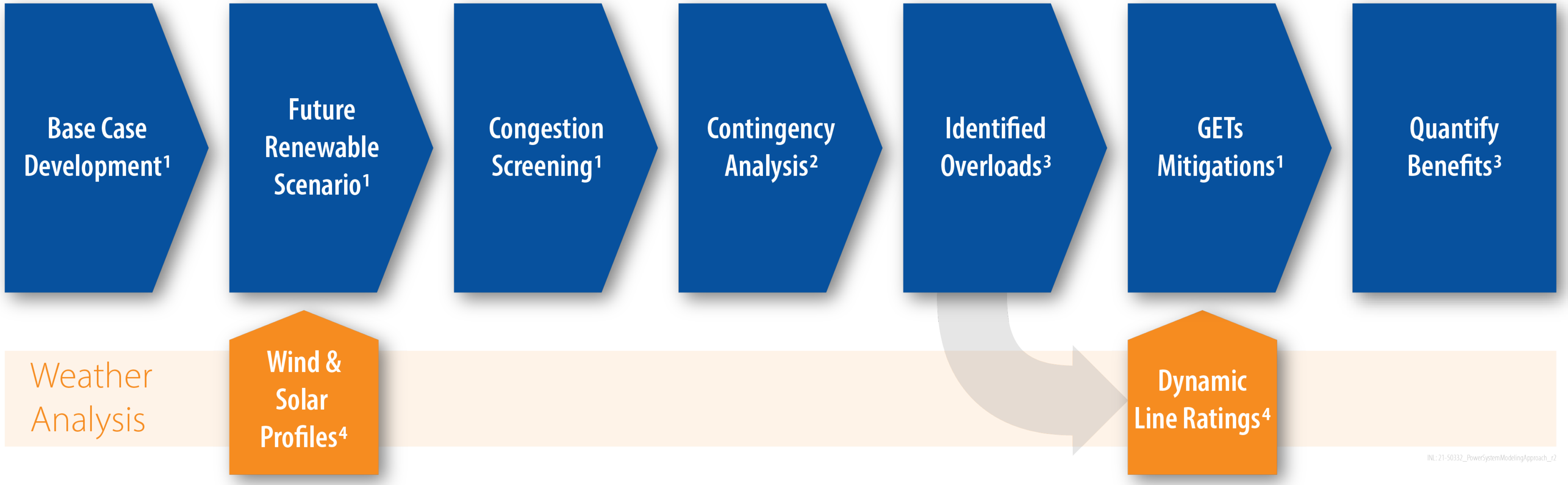
The figures to the right show the costs and benefits associated with each of the technology strategies. The uncertainty in costs for various strategies is represented by the length of the boxes along the y-axis. More accurate costs would have an impact on the ultimate solution selected. Because the ability of existing pole infrastructure to support a new circuit in the traditional upgrade case is unknown, the uncertainty band on the traditional upgrade is large.

- Each of the GETs options has a payback period in months (not years) regardless of the metric used to assess.
  - This could allow for rapid deployment while the traditional upgrade is scheduled and built.
- While the traditional upgrade integrates more renewable generation, it also costs more than the GETs.



Power System Modeling Approach

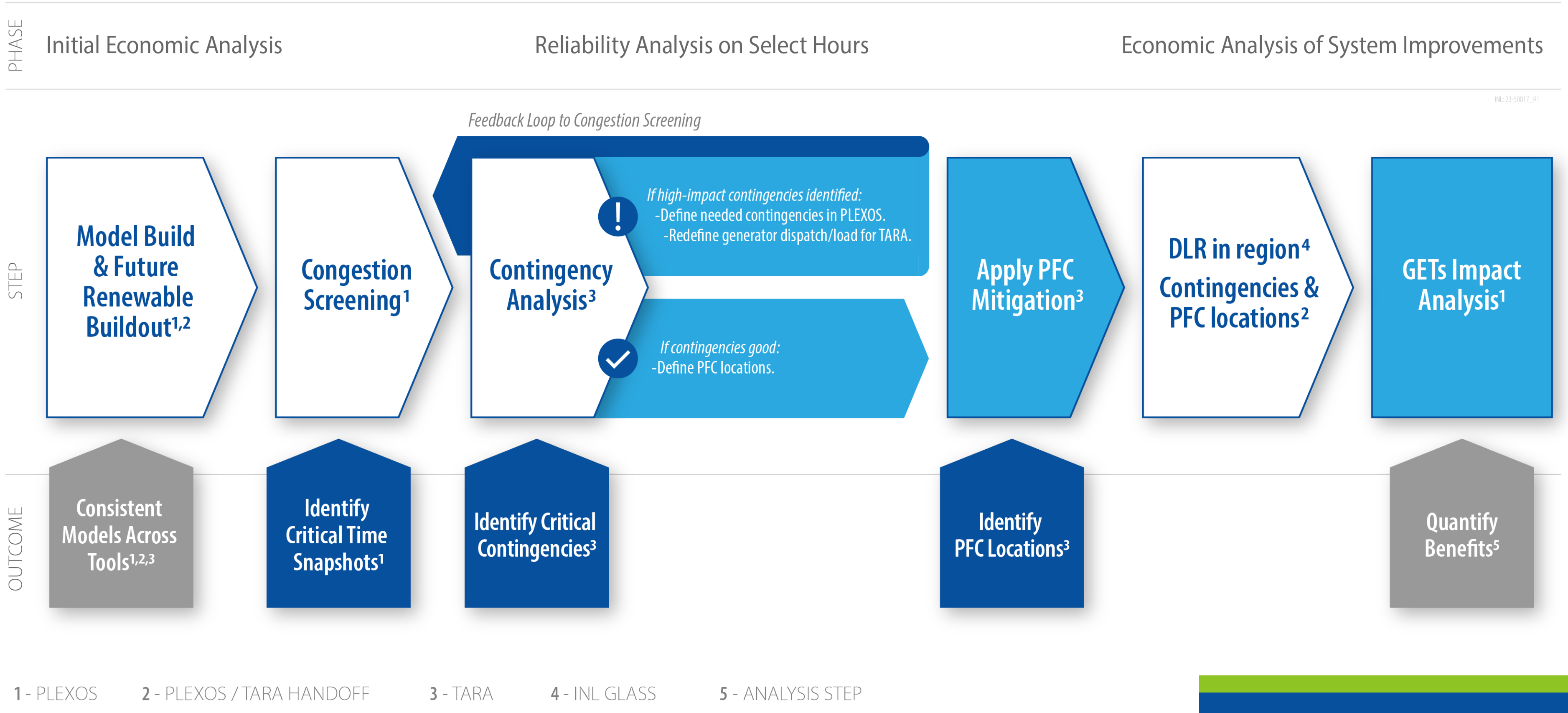
Power System Analysis



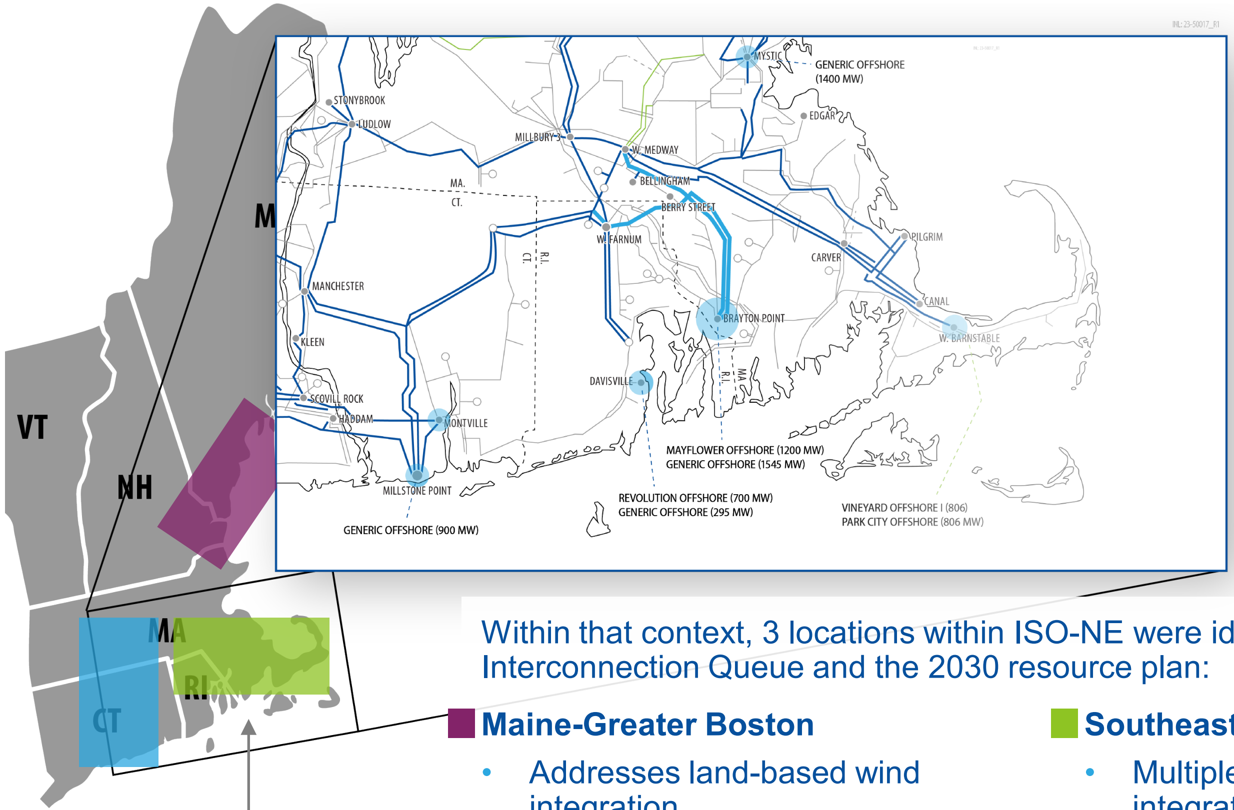
1- PLEXOS 2 - PSS/E 3 - EXCEL 4 - GLASS

Process Design Pairing Economic and Reliability Analyses

In order to combine these tools, the project team developed a detailed methodology to link the tools before ultimately assessing different GETs scenarios. The process begins with an initial economic analysis, then moves into a reliability analysis on select hours, and ultimately moves back to a (more accurate) security-constrained economic analysis of multiple potential system improvements.



Model Build: *Pick a Region and Examine Factors*



Selected Southeast Massachusetts (SEMA) for detailed modeling region

The 2022 Report to Congress[1] identified six key indicators for GETs value:

1. Wind and Solar Share
2. Renewable Curtailment
3. Transmission Congestion
4. Price Differentials
5. Proposed Transmission
6. Proposed Renewables

Within that context, 3 locations within ISO-NE were identified as potentially well-suited for GETs based on the Interconnection Queue and the 2030 resource plan:

Maine-Greater Boston

- Addresses land-based wind integration
- Challenges today expected to worsen with electrification
- Minimal paths for PFC optimization (Mostly NE/SW)

Southeast Massachusetts (SEMA)

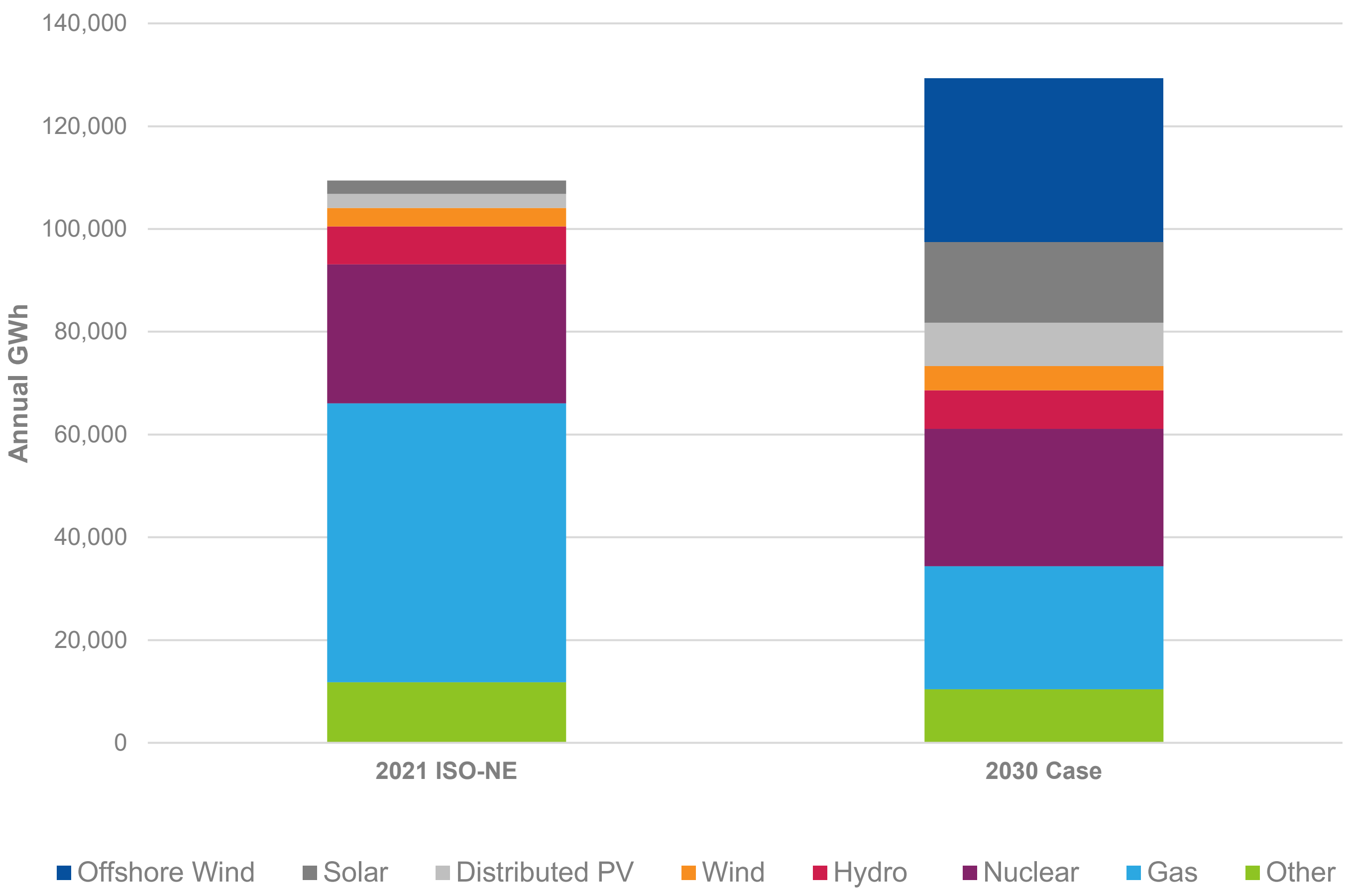
- Multiple Offshore Wind (OSW) integration points
- Multiple paths, voltages (345 & 115kV), orientations (N/S, E/W)
- Impacts both New England and New York power systems

Eastern Connecticut (ECT)

- Single OSW landing spot
- Multiple 345kV paths
- Impacts both New England and New York power systems

[1] https://www.energy.gov/sites/default/files/2022-04/Grid%20Enhancing%20Technologies%20-%20A%20Case%20Study%20on%20Ratepayer%20Impact%20-%20February%202022%20CLEAN%20as%20of%20032322.pdf

Model Build: *Capturing a future Resource Mix*

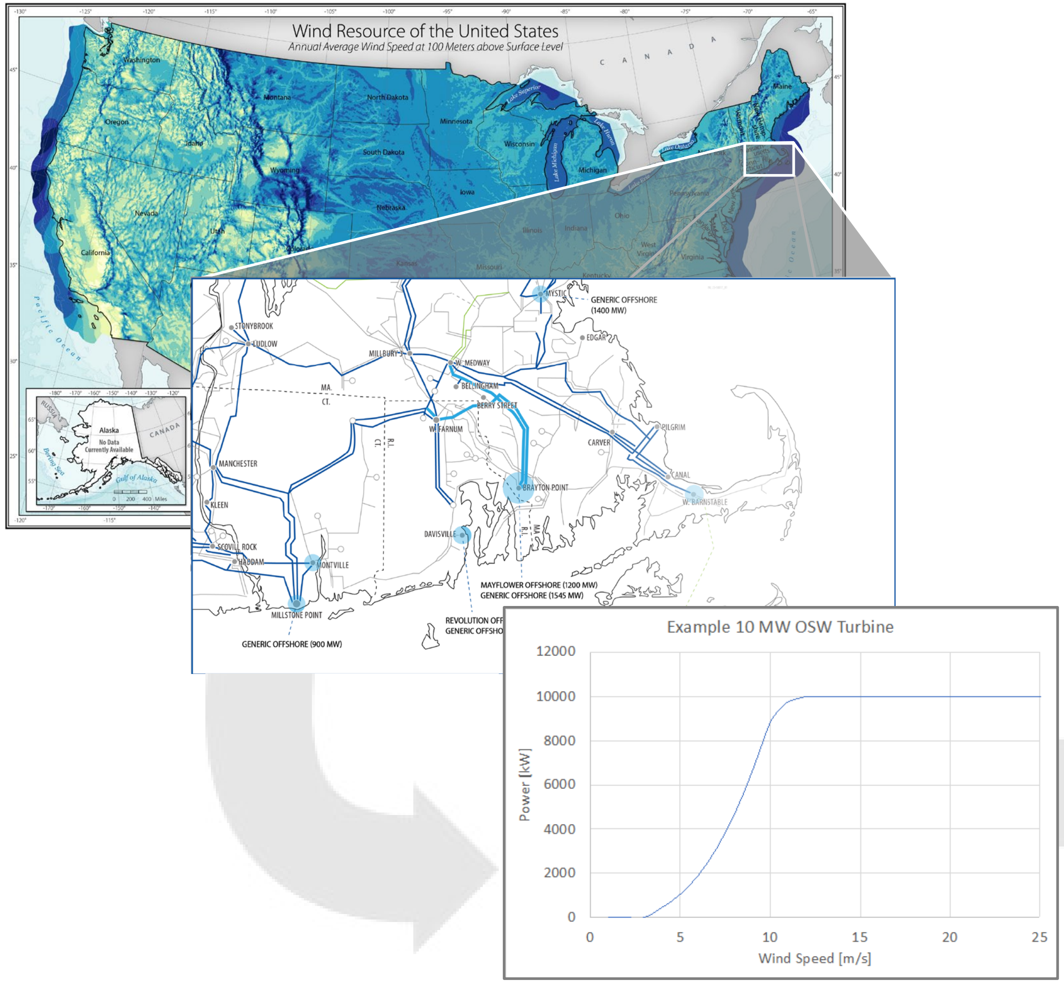


The study team built a representation of the 2030 ISO-NE system based on a variety of resources including [1-2].

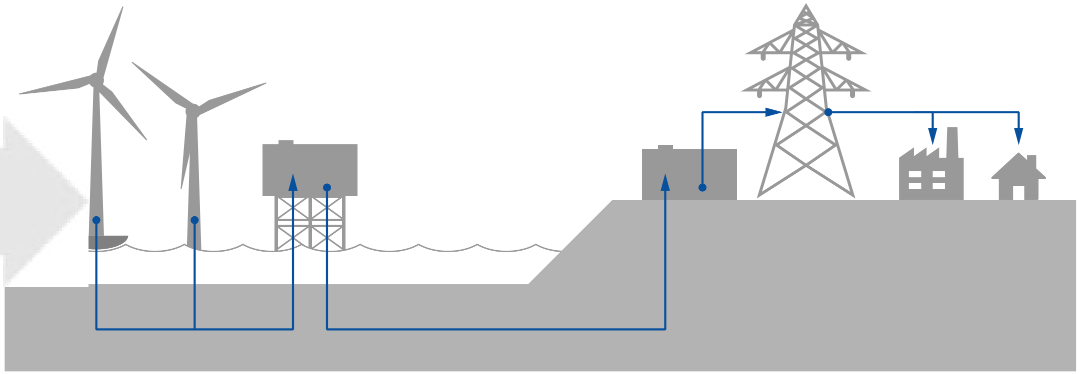
From here, we are going to ask different tools different questions:

- TARA (A/C Contingency Analysis Tool):
  1. Have we accurately captured important system security constraints in our dispatch?
  2. Where should we put power flow controllers for the greatest reliability impact?
- PLEXOS (Production Simulation):
  3. What is the market value of the grid enhancing technologies given system constraints?

OSW Power Generation



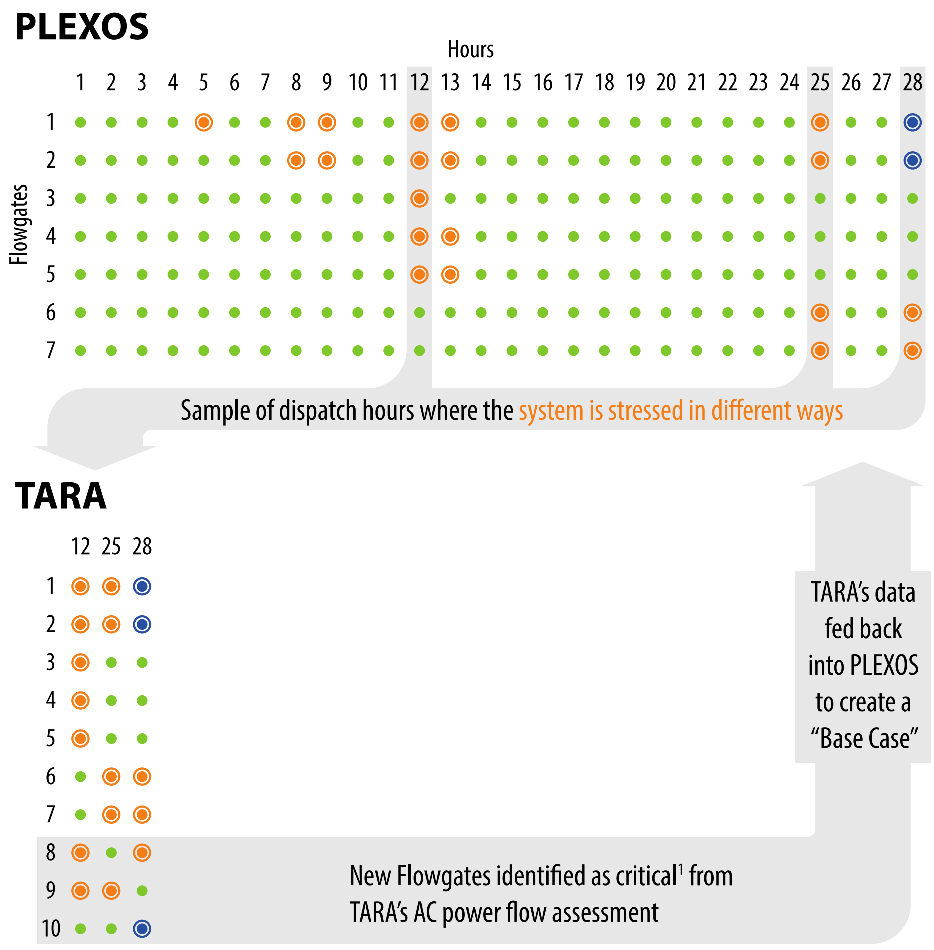
- Utilize NREL wind database (2007-2013) for power production
- Take wind history at OSW locations in regional
- Feed wind profiles through turbine power curve for estimates
- Use similar process for 10-meter wind profiles for DLR



Identify Critical Snapshots: *Pick hours for TARA to perform reliability analysis?*

TARA scales to assess a few dispatch hours, PLEXOS has 8760 hours. Because TARA only analyzes a few hours for system reliability analysis, selecting hours representative of a range of dispatch conditions for security assessment is vital.

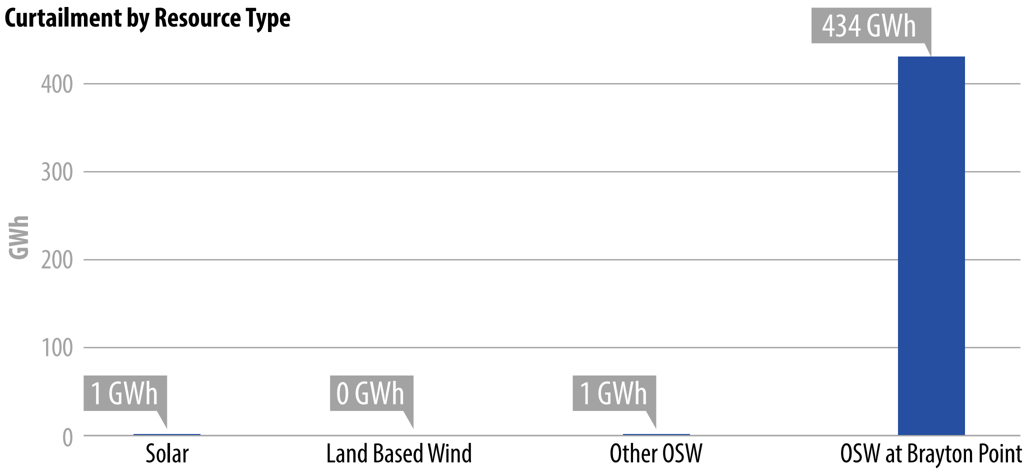
- There are options for how to identify the critical snapshots. The method used herein is fairly manual but could be automated and programmed. Critical snapshots are passed from PLEXOS to TARA based on:
  - Flowgate performance (see below)
  - Peak and minimum load
  - High and low offshore wind generation
  - Imports/Exports, particularly the DC ties
- There are times when TARA may not see PLEXOS's initially defined flowgates as critical, but those high voltage flowgates remain in the base model because of the impact of high voltage system security and the possibility that the Critical snapshot selection missed the hours when those flowgates are most important.



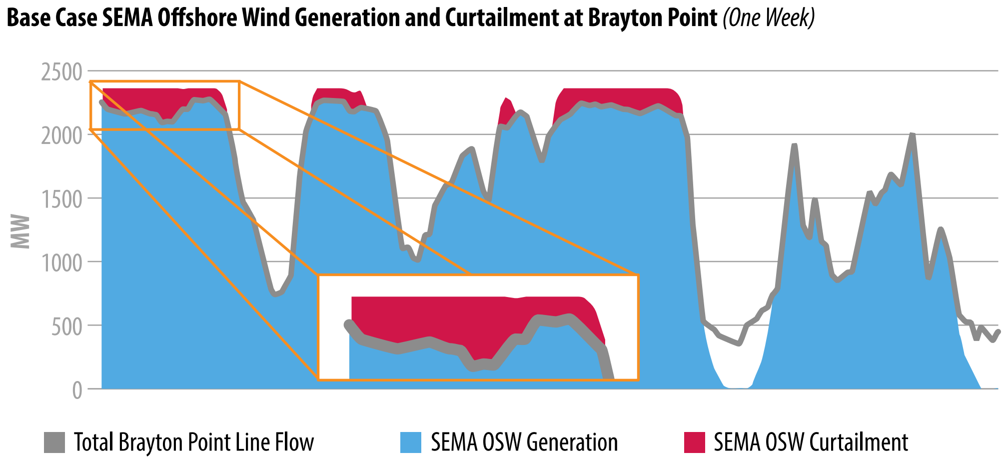
Understand Base Case Renewable Curtailment

With the base case established, the renewable curtailment is assessed for potential mitigation strategies. In this case, the curtailment is at a single interconnection point (substation) for offshore wind integration.

1. **Segment Resource Curtailment by type and location to isolate acute challenges**



Nearly all Renewable Curtailment is due to Offshore Wind Interconnected at Brayton Point



Offshore Wind seems to be curtailed at high output levels, but there is not a single level at which curtailment begins

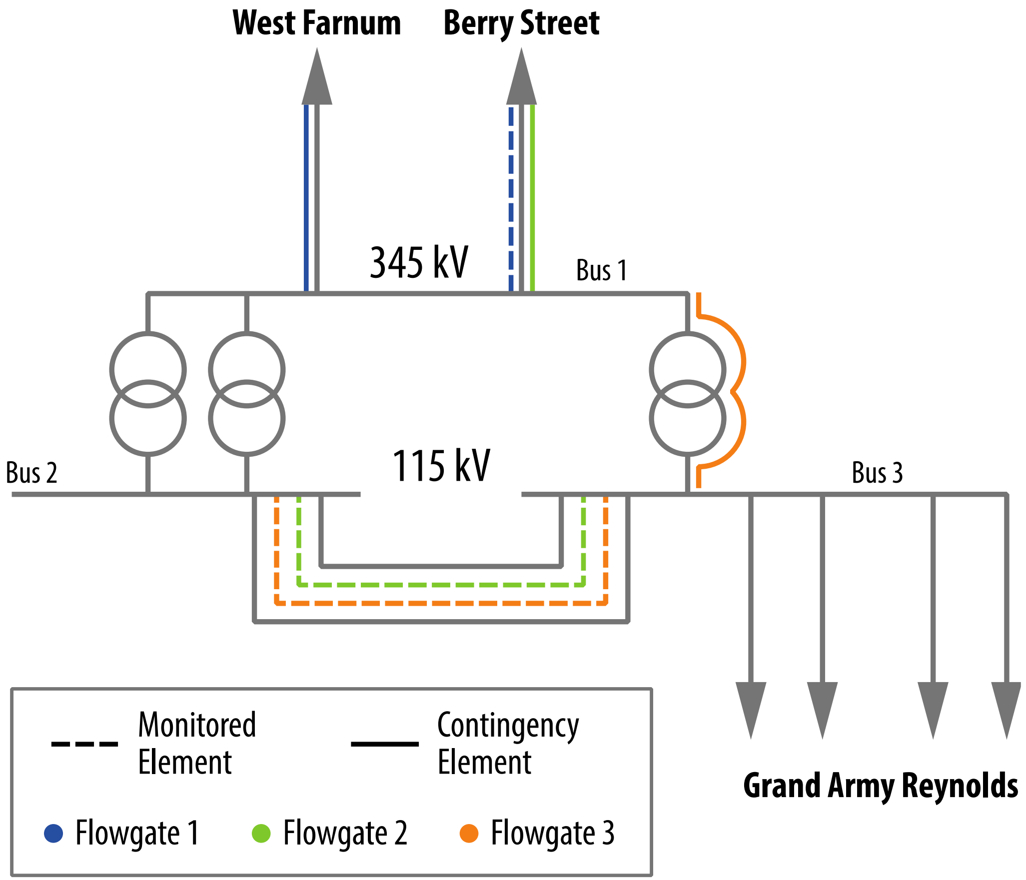
Understand Base Case Renewable Curtailment

The curtailment that occurs at Brayton Point is due to high offshore wind generation in the region leading to system security curtailments that ensure the system remains stable should any single element be lost. These constraints are thermal capacity limitations that would occur if a single element is lost. In particular, this system is concerned with three primary flowgates.

2. Determine curtailment cause (flowgates)

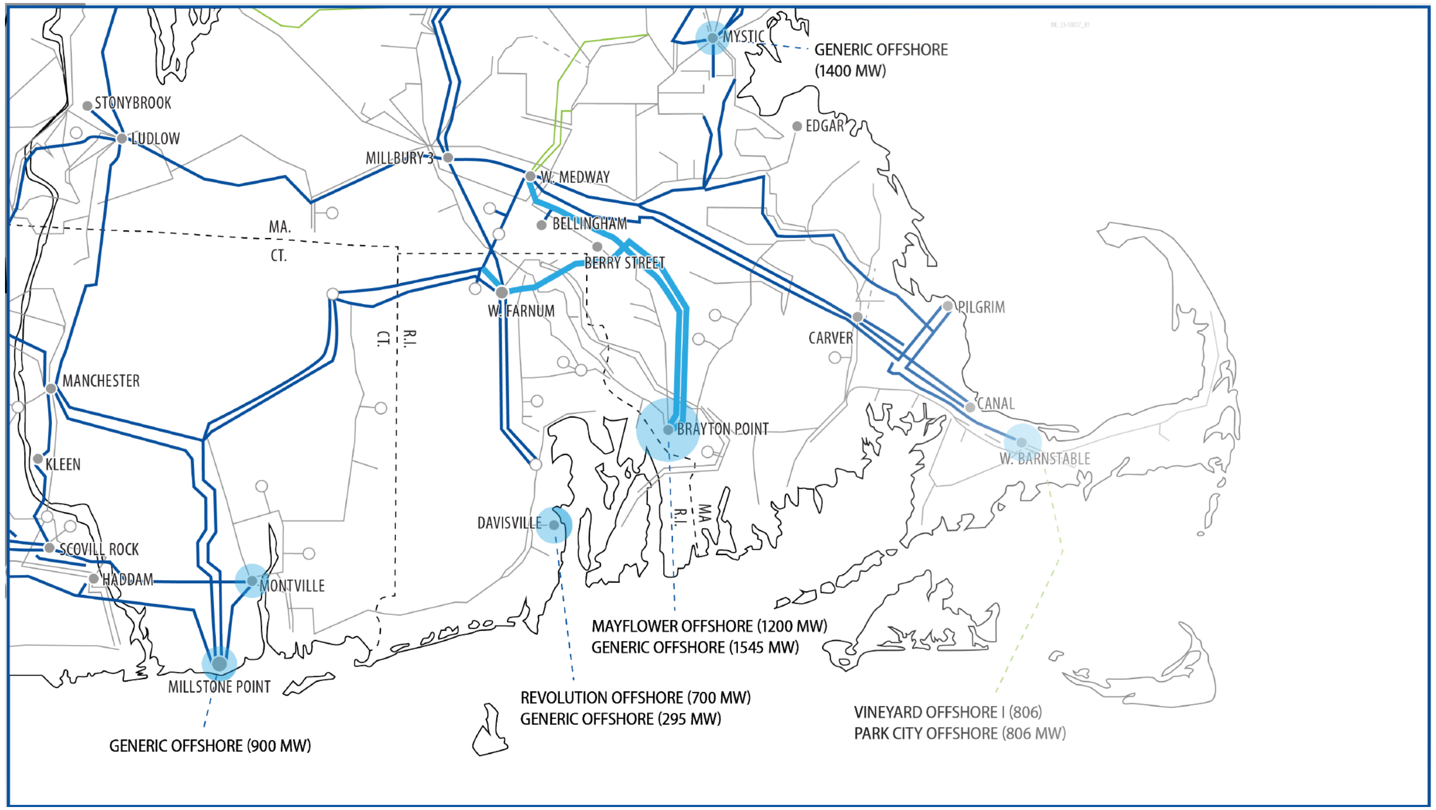
Three primary flowgates are around Brayton Point

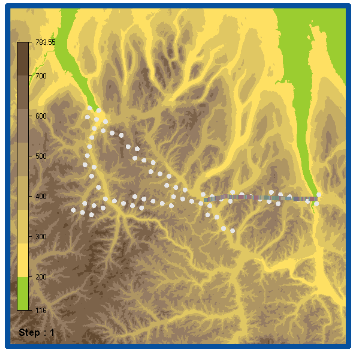
- The first flowgate relates the loss of one of the 345kV lines overloading the other.
- The second flowgate overloads the jumper from Bus2 to Bus3 if the Berry Street 345kV line is lost.
- The third flowgate overloads the jumper if one of the 345/115kV transformers is lost.



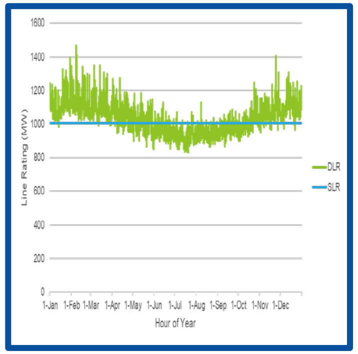
Picking Lines for DLR/AAR in the Region

AAR and DLR's were developed specifically for this region using established weather-based methods by INL

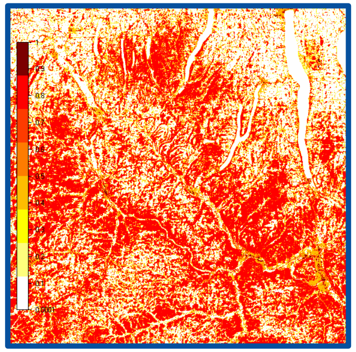




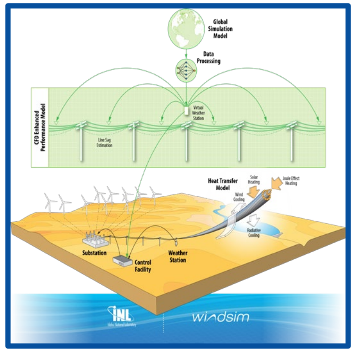
Topology



DLR and AAR



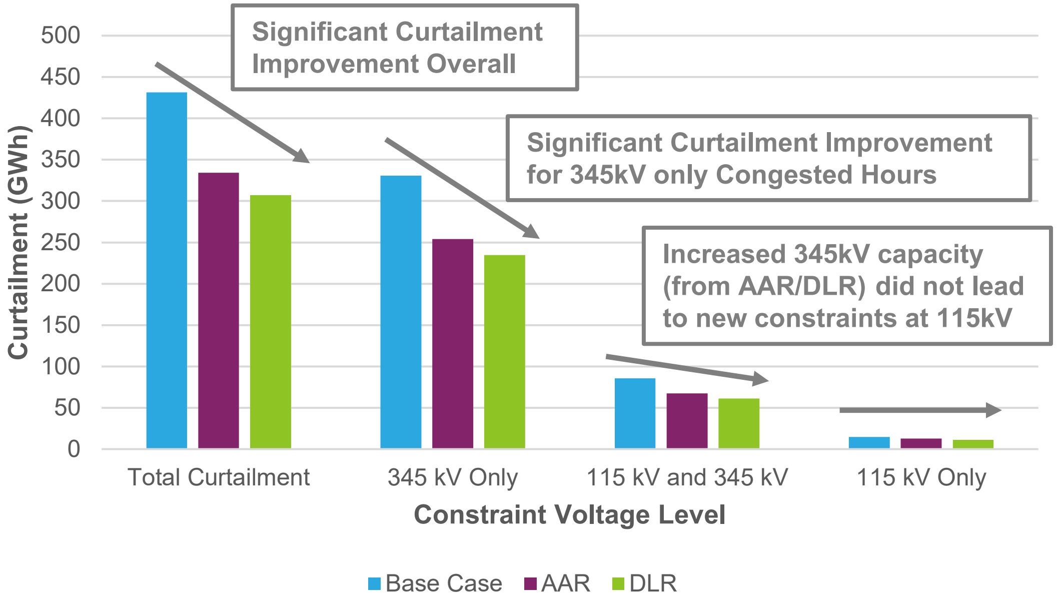
Roughness



Weather Forecast Mapping

AAR and DLR Decrease Congestion and OSW Curtailment

DLR and AAR save on production costs and increase offshore wind generation across the year. It's important to note these savings are seen when the congestion is primarily on the 345kV lines that received AAR/DLR. When there is congestion across both the 115kV and 345kV systems, AAR/DLR applied to only the 345kV lines did not relieve the widespread congestion.



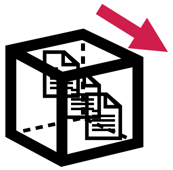
	AAR	DLR
Offshore Wind Curtailment / Curtailment Decrease (GWh)	338.4 / 96.5	310.8 / 124.1
Production Cost Improvement (Million $)	2.1	3.5
Brayton Point – Berry St Line Congested Hours / Congested Hours Improvement	2,382 / 204	2,069 / 517

Identify PFC Placement

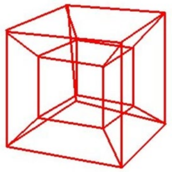
Once a base case model is developed that includes the important flowgates in the economic dispatch optimization, the grid enhancing technology strategy options for the region should be defined. This includes identification of where to locate power flow controllers. With respect to PFC placement, there is a Dimensionality Problem. In this planning context, PFC's should be placed in a manner that addresses the (1) overloaded elements during (2) different contingencies at (3) different hours of the year that (4) have the highest impact on costs and (5) consider other GETs.

Elements
associated w/ congestion

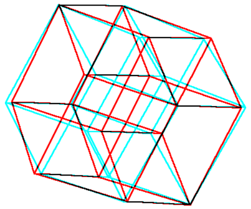
Contingencies
Inform Overloading Situations



Snapshots
Different Hours' Dispatch capture the likelihood of certain conditions



Economic Dispatch
Refine PFC placement based on economic impact.



GETs Co-Optimization
Adjust PFC placement based on DLR and storage.

Engineering Optimization
PFC placed based on highest impact in addressing N-1 planning criteria at different times of the year

Economic Validation
PFC placement modeled to confirm impact on the security constrained economic dispatch

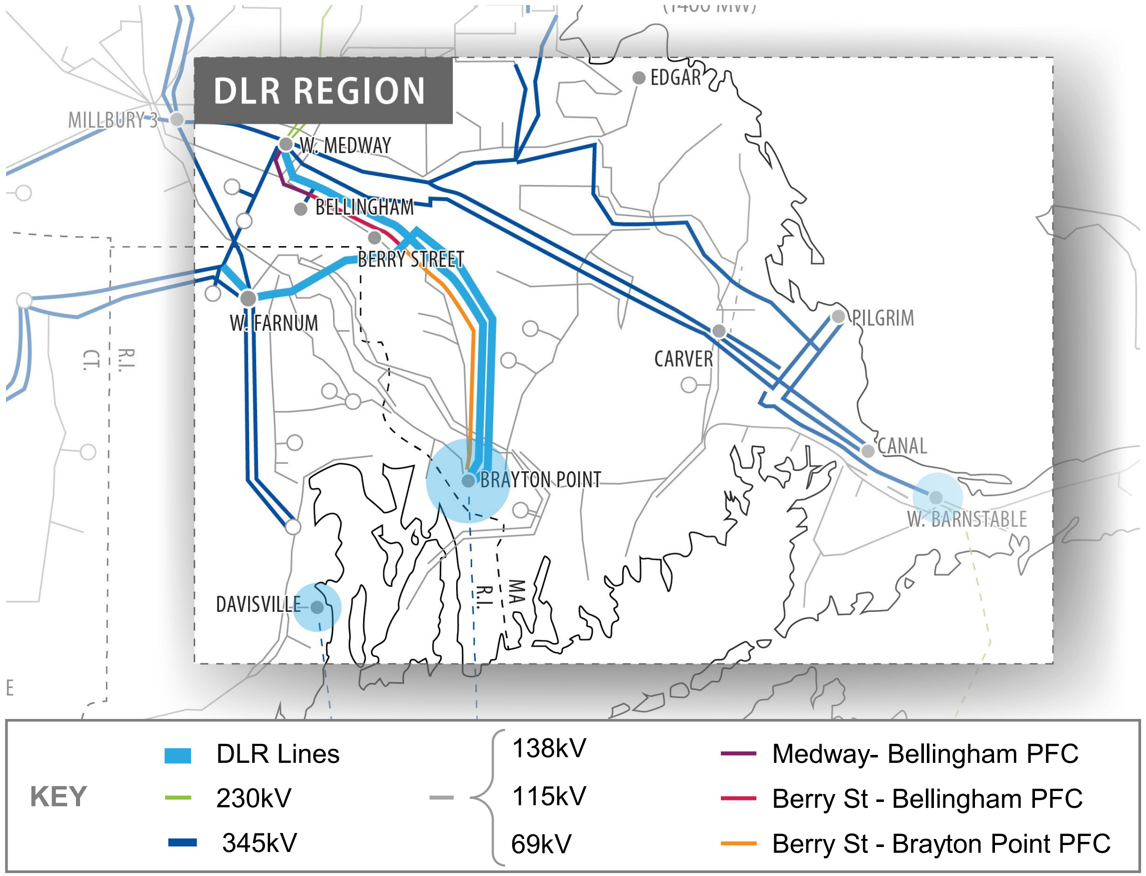
GETs Planned Together
PFC placement modeled based on unaddressed congestion after DLR implementation

Picking PFC Location (in TARA)

PFC Locations were chosen according to a PFC siting optimization script using TARA. Additional information is available in the Modeling Methodology report.

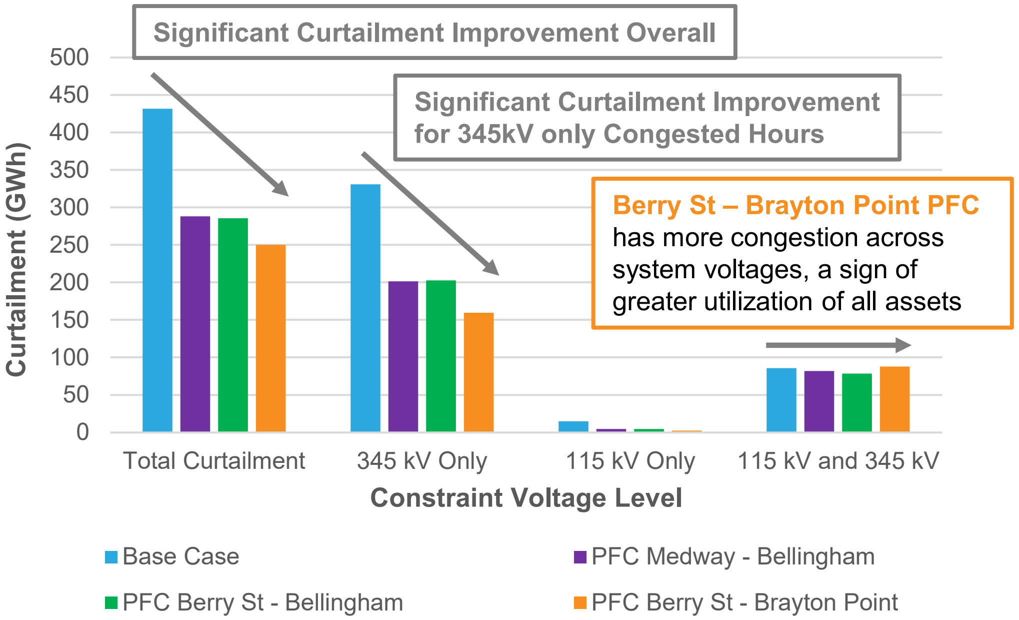
The three PFC locations identified in the map and table were identified by TARA as the most suitable to mitigate congestion in the Brayton Point area.

PFC Location	Ranking
Berry St - Brayton Point	1
Medway - Bellingham	2
Berry St - Bellingham	3



This analysis modeled a single PFC device capable of shifting the angle on a 345kV system by 1.5° at each of the locations independently.

PFC Benefits Summary



	PFC Berry St – Bellingham	PFC Berry St – Brayton Point	PFC Medway – Bellingham
Offshore Wind Curtailment / Curtailment Decrease (GWh)	288.7 / 146.2	253.1 / 181.8	291.4 / 143.5
Production Cost Improvement (Million $)	3.1	4.3	3.1

The PFCs save on production costs and increase offshore wind generation across the year.

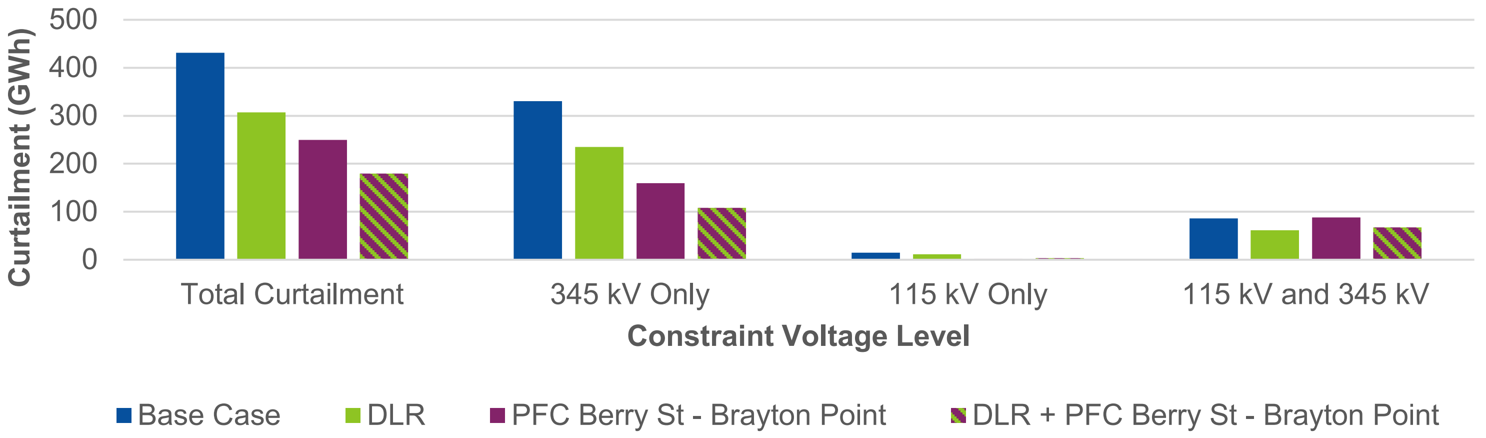
- PFCs significantly reduce wind curtailment when either the 345kV or the 115kV export paths out of Brayton Point substation are congested by shifting power from the constrained export paths to the unconstrained export paths.
- PFCs do not meaningfully reduce wind curtailment when all the export paths out of Brayton Point substation (115kV and 345kV) are congested.
- In the Berry St-Brayton Point case, some of the congestion is shifted from the 345kV bucket into the 115 and 345 bucket, a sign that power is being pushed onto the 115kV system for more complete system utilization.

The GETs Case with PFC and DLR

In addition to cases with just PFC and just DLR, the project analyzed cases with DLR and PFC to identify if any device interactive effects were observed. The table below characterizes the system conditions where each device can help. The table characterizes the challenges into "All Export Paths Congested" or "Some Export Paths Congested." Effectively, this draws a distinction between heavy utilization across the entire system or just on some portions of the system (such as only on the 115kV lines).

Device Type	All Export Paths Congested	Some Export Paths Congested	Devices Interactive Effects
DLR	DLR can add additional transmission capacity to congested export paths.	DLR can increase transmission capacity on average if placed on congested export paths.	N/A
PFC	PFC cannot alter power flow to mitigate congestion.	PFC can alter power flow away from congested export paths.	N/A
PFC+ DLR	DLR can add additional transmission capacity to congested export paths.	PFC can alter power flow away from congested export paths.	Adding a PFC can be helpful when DLR (1) Shifts congested hours from the bucket of "All Export Paths Congested" to "Some Export Paths Congested" (2) Does not fully alleviate congestion, particularly in the "Some Export Paths" case.

The GETs Case with PFC and DLR



DLR and PFC work together to mitigate congestion and improve system costs:

- DLR (on its own) on the 345kV portion of the Brayton Point substation significantly but not fully mitigates the 345kV Brayton Point export path congestion.
- The main value provided by an additional PFC is to shift power flow from the 345kV to the 115kV Brayton Point export paths in cases when DLR cannot fully mitigate the 345 Brayton Point export path congestion.
- There are still some hours where even with DLR, both the 115kV and 345kV export paths out of Brayton Point substation are congested – adding a PFC does not mitigate congestion in these hours.

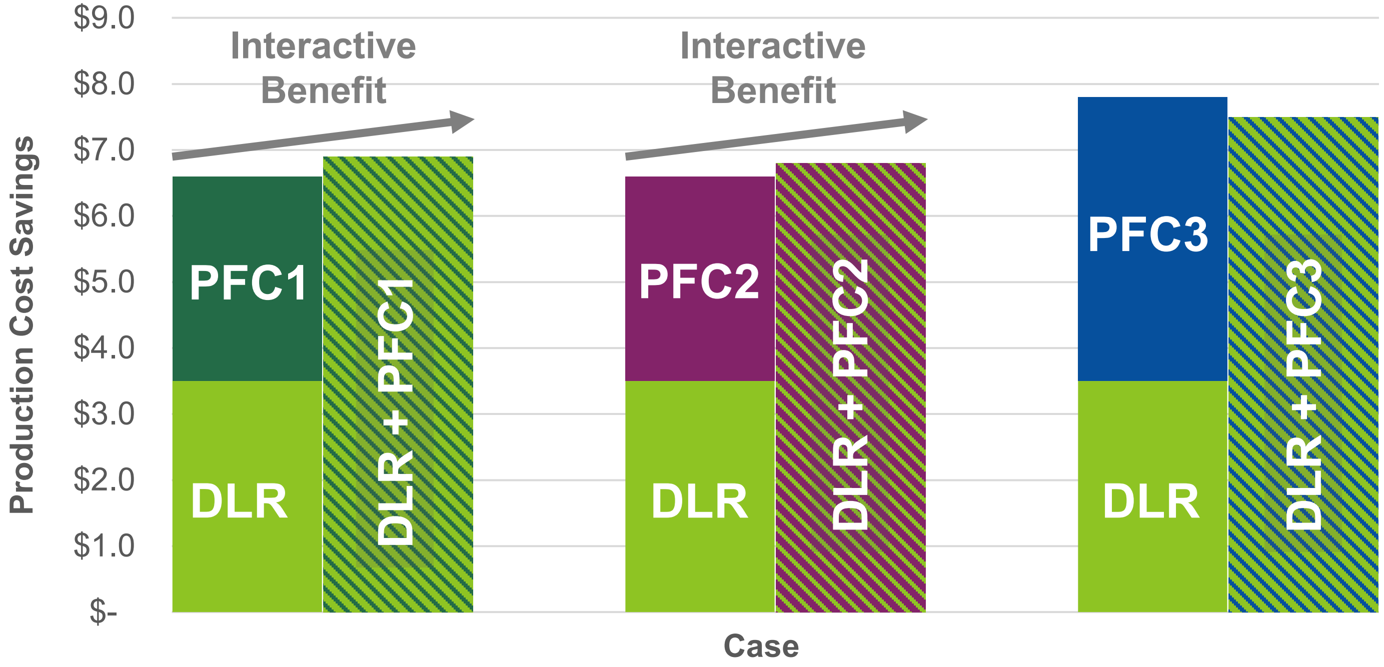
DLR + PFC > DLR or PFC

The PFC siting script was run again given the DLR thermal limits and the same location (Brayton Point-Berry Street) was identified as optimal from a reliability perspective. However, the interactive effects of DLR and PFC are shown to have a greater impact on system curtailments than the DLR or PFC independently across metrics.

The GETs Cases with PFC and DLR

The addition of a PFC in combination with DLR improves utilization of the Brayton Point export paths by about 0.6% for the year compared to 0.2% for DLR and 0.4% for various PFC cases.

- In the case of Production Cost, the benefit of combining PFC + DLR (rows 5-6) is greater than the sum of benefits of placing DLR and PFC individually (rows 1 and 2-3) for 2/3 PFC placements.



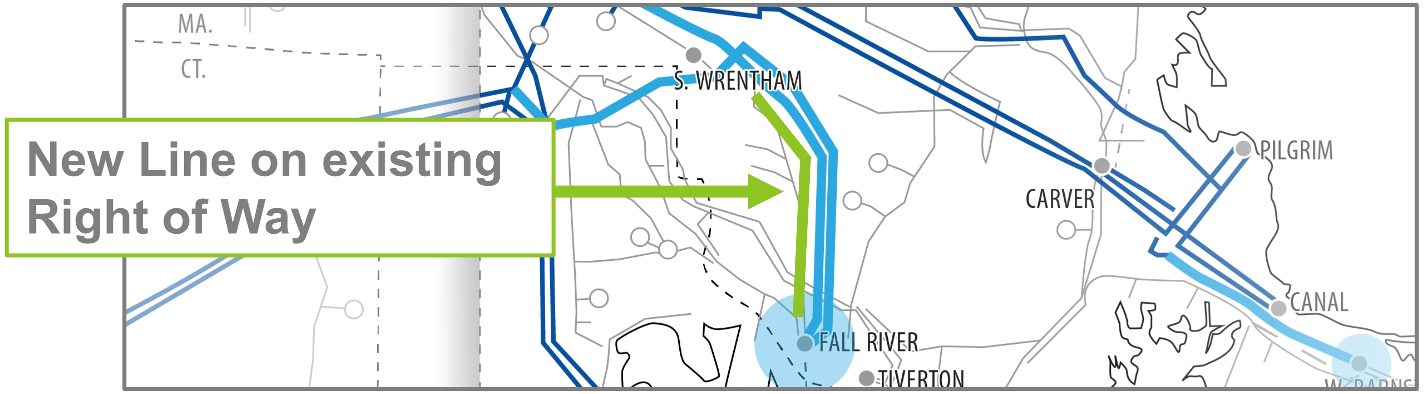
DLR + PFC > DLR and PFC

For congestion rent and production cost, the interactive effects of DLR and PFC are shown to have a greater impact on congestion rent than when the benefits of DLR and PFC evaluated independently are assessed. According to this metric, effectively 1+1=3. This metric is informative in certain conditions, as discussed in the Appendix. However, the focus of this work will remain on curtailment and production cost metrics as those are the optimization parameters for most market constructs.

Traditional Upgrade Option

The GETs upgrades should be compared against traditional system upgrades. While the GETs benefits are enticing, there may be a simple traditional approach to this anticipated problem.

- The traditional upgrade evaluated was to add a second circuit to the existing line from Brayton Point – Berry St
  - This option adds an additional 345kV export path out of Brayton Point with a relatively short line (~30 miles) along an existing right of way (which makes the project relatively feasible).
- With the traditional upgrade, wind curtailment is nearly eliminated and congestion in the Brayton Point area is significantly reduced.



Case

Traditional Upgrade

Offshore Wind Curtailment / Curtailment Decrease

8.2 / 426.7 GWh

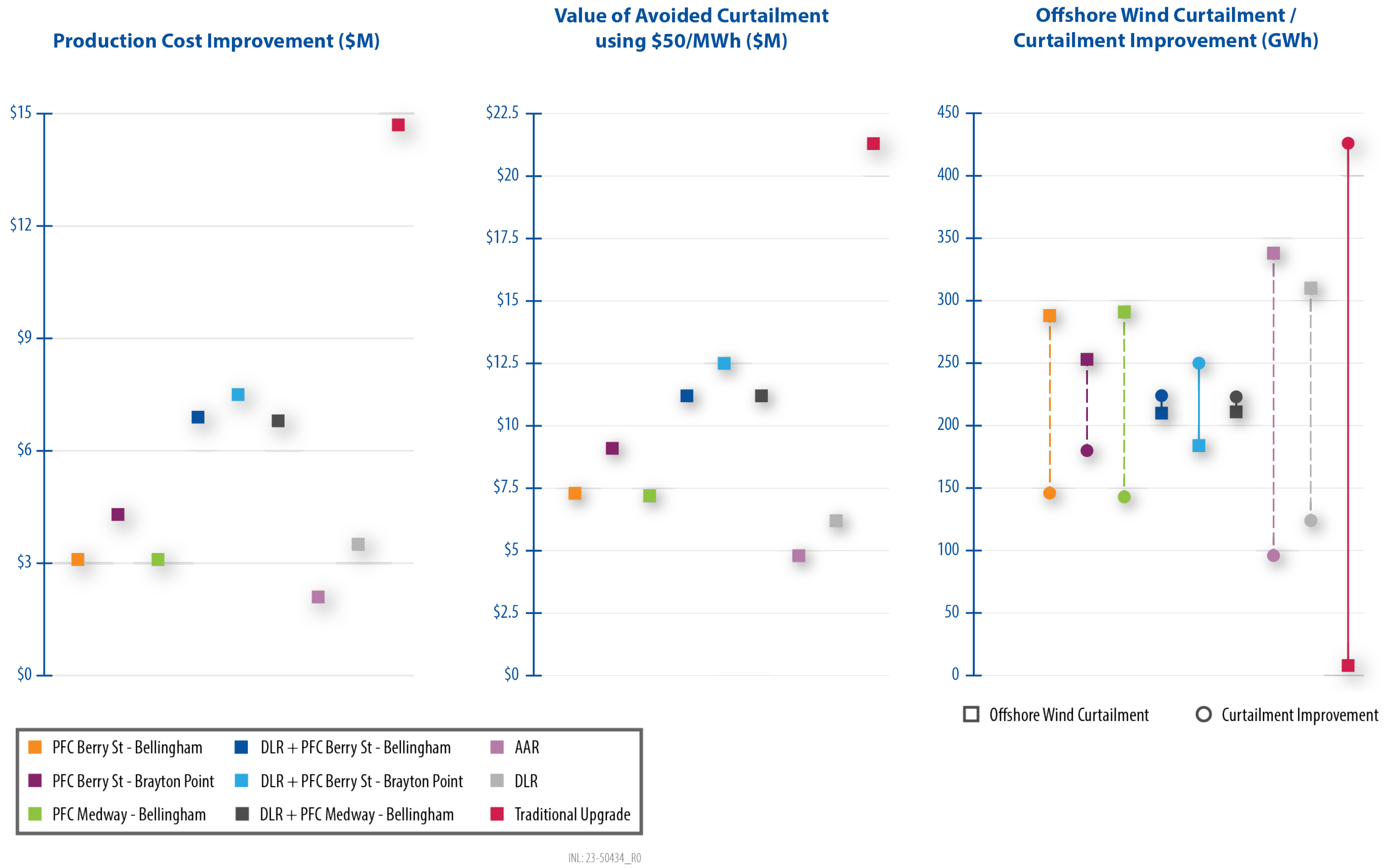
Production Cost Improvement

14.7 M

Congestion Rent Improvement

187.8 M

Comparing the Options



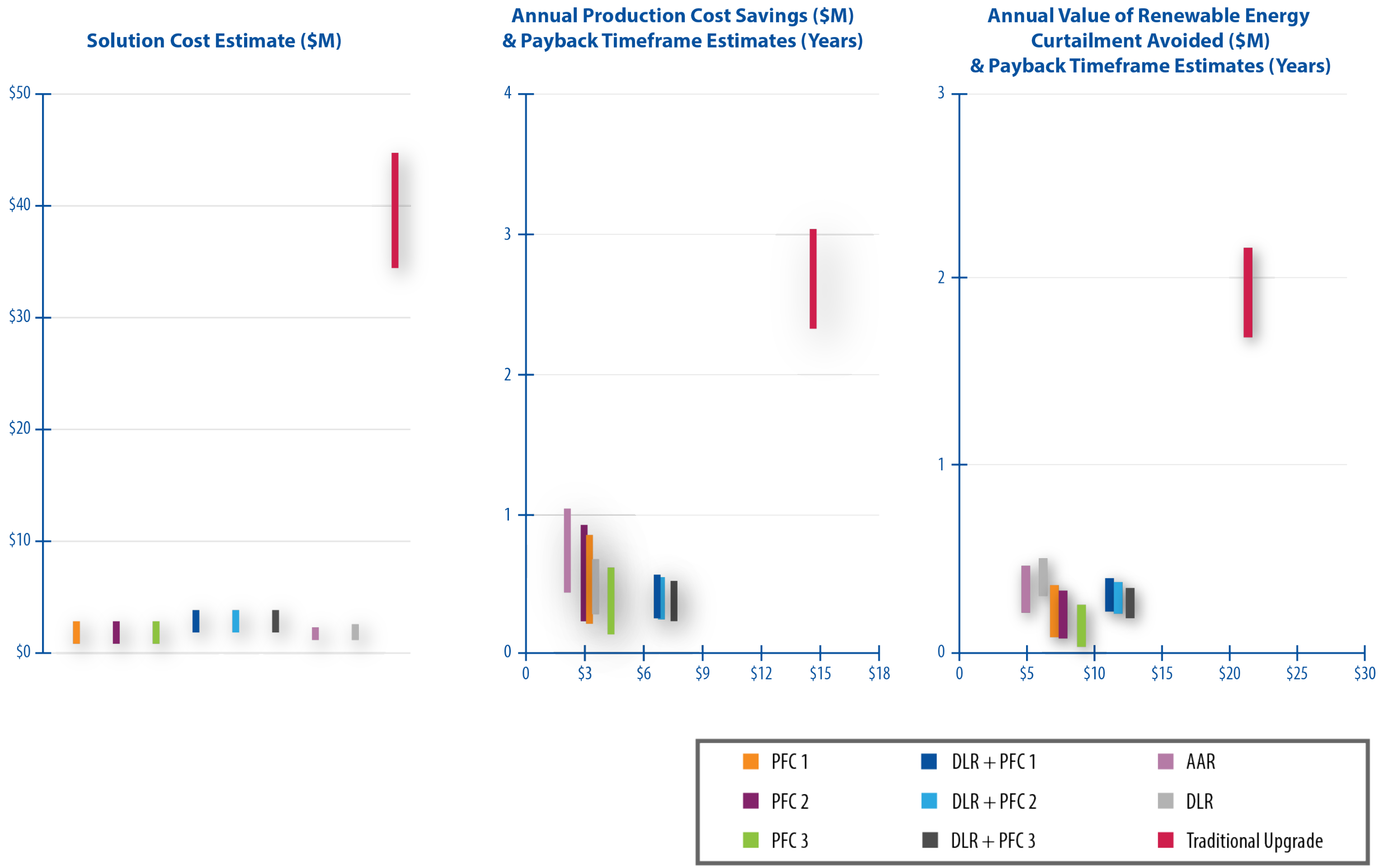
For the case study region where each state has carbon impact goals by 2030, the annual value of the avoided renewable energy curtailment is a valuable metric. Renewable energy is a primary driver for transmission upgrades in this region. Using the 2022 NREL Annual Technology Baseline Data, the generation-weighted LCOE is $50/MWh for the mix of land-based wind, offshore wind, and solar in the interconnection queue [1]. By applying that LCOE to the renewable energy curtailment avoided, the annual value of the renewable energy curtailment avoided is calculated. Again, the curtailment that was avoided in this region represents generation that would have been built elsewhere to meet policy goals.

[1] https://atb.nrel.gov/electricity/2022/data

Comparing the Options: *Payback Period*

The figures to the right show the costs and benefits associated with each of the technology strategies. The uncertainty in costs for various strategies is represented by the length of the boxes along the y-axis. More accurate costs would have an impact on the ultimate solution selected. Because the ability of existing pole infrastructure to support a new circuit in the traditional upgrade case is unknown, the uncertainty band on the traditional upgrade is large.

- Each of the GETs options has a payback period in months (not years) regardless of the metric used to assess.
  - This could allow for rapid deployment while the traditional upgrade is scheduled and built.
- While the traditional upgrade integrates more renewable generation, it also costs more than the GETs.



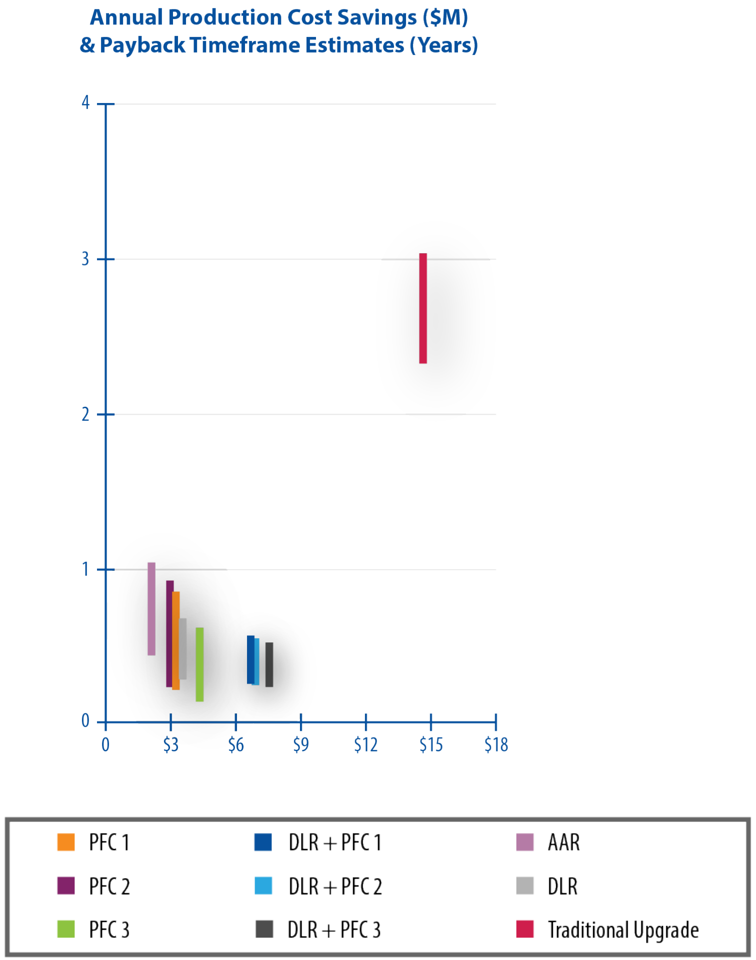
Summary: *Technical*

Key Technical Insights from this project:

1. Individual GETs devices can make an impact on the overall system performance.
2. The value of GETs is highly system-dependent.
3. PFC and DLR together can be better than each individually.
4. The appropriate GETs device is dependent upon the type of congestion.

This analysis is distinct in the following ways:

1. Individual GETs devices were placed in a targeted fashion to assess economic impact.
2. The Security Constrained Economic Dispatch (SCED) model was validated and improved with the use of a reliability screening tool that solves A/C power flow across multiple hours.
3. Offshore wind integration and GETs is a novel overlap analysis.



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