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Probabilistic Integrated Resource Planning Tool (pIRP)

Presented at: DOE Peer Review Analytics Session

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Introductions

- **Dr. Hisham Othman**
  - *Vice President, Transmission & Regulatory*
  - Areas of expertise include power system dynamics and control, hybrid microgrids, grid integration of renewables and storage, economic analysis
  - PhD, Electrical Engineering, University of Illinois, Urbana
  - Over 30 years of technical and managerial experience in the electric power industry

- **Dr. Salman Nazir**
  - *Senior Engineer, Advisory Services*
  - PhD from the University of Michigan, Ann Arbor
  - Areas of interest include DERs, demand response, electricity markets, and advanced analytics and algorithms for integrating DERs into power systems.

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Motivation

- A robust response from utilities and corporations to climate change culminated in NetZero carbon reduction goals to reach 100% between 2030 and 2050.
- Integrated resource planning (IRP) processes and tools have served the industry well over the past 30 years. However, they are increasingly challenged:
  - Increased uncertainties in load development, electrification, technology, and grid development.
  - Reliability concerns of high penetration of inverter-based resources (IBRs) not modeled.
  - Dependance of resource development on availability of T&D hosting capacities, not co-optimized.
  - Resilience requirements associated with intermittent resources and grid vulnerabilities not modeled.
  - Energy storage capacity (i.e., hours) are pre-selected and not optimized.
  - Energy storage value is often restricted energy balancing, and the full stack of benefits not exploited.
- Probabilistic IRP (pIRP) project between Quanta Technology and Sandia has a goal of addressing these challenges and creating a tool that can be accessed by researchers and practitioners through Sandia's QuEST platform.

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Carbon Reduction Plans (NetZero)

	Dominion	Duke	Southern Co	Xcel	SDGE	WEC	EverSource	PSEG	ConEd	DTE	Entergy	Ameren	SCE	PG&E	CMS	Avangrid	FirstEnergy	AES Corp	Vistra Corp	Pinnacle West	NRG	NationalGrid	Nextera	AEP	Exelon	PPL	Alliant Energy	Atmos Energy	Evergy, Inc.	Center Point	NiSource	PREPA
2025						55										35		50			50		67		15							40
2030		50		80		70	100			50	50	50	40	40			30	70	60	65		20		70			50				90	
2035																100												30		70		
2040									100	80	85	85			100											70						60
2045					100			80					100	100																		
2050	100	100	100	100		100		100		100		100					100	100	100	100	100	100		80		80	100		80			100

- NetZero decarbonization goals set at most major utilities and corporations over next 10-30 years
- This is prompting a profound change in the energy resource mix towards inverter-based resources (IBRs) in the form of solar, wind, and energy storage, in addition to clean dispatchable sources (e.g., hydrogen).

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Traditional Probabilistic IRP - Study Process

Policy Drivers ✖ Resource Strategy ❯ Study Scenarios ❯ Resource Optimization ❯ Uncertainties & Sensitivities ❯ Metrics (costs, Benefits, Risks) ❯ Pathways

- GHG Targets
- Electrification
- Coal Retirement
- Price Stability
- Reliability
- …

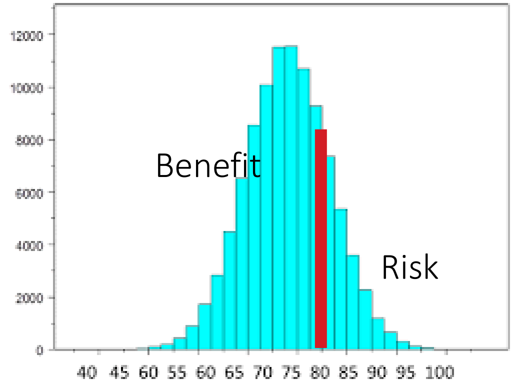
- Biz As Usual
- In-State Supply/Demand
- DG
- Mini/Micro Grids
- Regional Integration
- …

pIRP

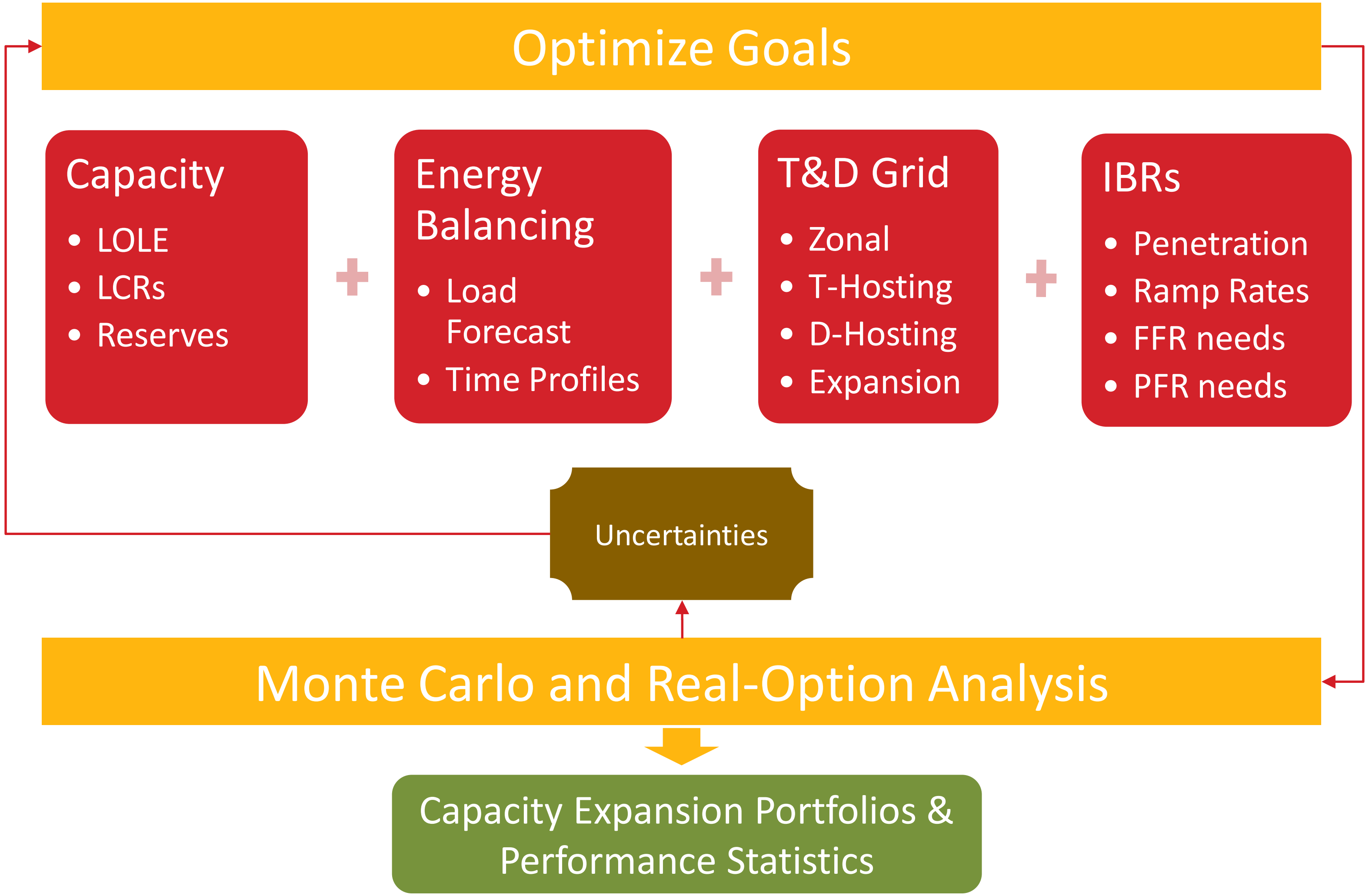
- Technology Cost
- Import Prices
- Fuel Prices
- Fuel Security
- DSM Level
- Load Growth
- RPS Increase
- …

- 25 yr Cost NPV
- 10 yr Rev Req NPV
- Resilience Risk
- GHG Risk
- Investment Timing Flexibility
- …

	Scenarios	A	B	C	D	E	F	G	H
Financial	Capital (Resources, Grid) LCOE LCOE Risk Price Stability Curtailment Risk								
Reliability	Resilience Risk Res. Adequacy Risk Grid Integration Risk								
Environmental	Emission Level GHG Reduction Risk								



Probabilistic IRP Formulation



Objectives:

- Affordable
- Clean
- Resilient

Constraints:

- Demand by Zone
- Resources: Capacity, Asset Life, Buildout Rates, Total Buildout
- Power dispatch:
  - Resources
  - Tie-lines between Zones
  - Energy Storage
  - Renewable Production Profiles
  - Curtailments
- Renewable targets
- Emissions
- Local Capacity Requirements (LCR)
- T&D hosting capacities
- Reserves
- Ramping Flexibility:1-min and 10-min
- Intermittent power penetration limits
- Resilience – Supply Interruption

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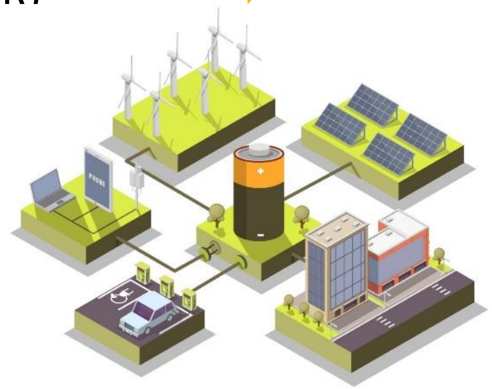
Role of Energy Storage within an IRP

- Gen Resource:
  - Capacity and Reserves
  - Daily energy balance
  - Firm and shape solar and wind profiles
  - Fast ramping
  - Fast Frequency Response (FFR) and Primary Frequency Response (PFR)
  - Multi-day resilience

- T&D Grid Resource
  - Non-Wire T&D Solution (NWS)



- Model Reliability and Resilience Attributes/Metrics of Resources:
  - Dispatchability
  - Predictability
  - Dependability (e.g., Supply Resilience, firmness)
  - Performance Duration Limits
  - Flexibility (e.g., ramping speed, operating range)
  - Intermittency (e.g., intra-hr and multi-hr ramping)
  - Regulating Power
  - VAR support
  - Energy Profile (e.g., capacity credit / ELCC)
  - Inertial Response
  - Primary Frequency Response
  - Minimum Short Circuit Ratio
  - Locational Characteristics (e.g., deliverability, resilience to grid outages)
  - Black start and system restoration support

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How deep should the storage reservoir be?

Sub-hour (Gen)

- Fast and Flexible Response to control Frequency
- Intermittency of VERs (e.g., Solar/Wind)

4-10 hours (Gen)

- Integrated Resource Planning (Capacity, Reserves, Energy)
- Peaker Plants Combined Storage+Renewable

2-8 hours (T&D)

- Address Grid Security Constraints (e.g., NERC TPL Standards)
- NWA solutions

hours to Days (Gen)

- High Renewable Targets (50%+) using low-capacity factor resources
- Balance Supply and Demand
- Mitigate Interruption Supply Risks

VER: Variable Energy Resources
NWA: Non-Wire Alternative Solutions
RE: Renewables

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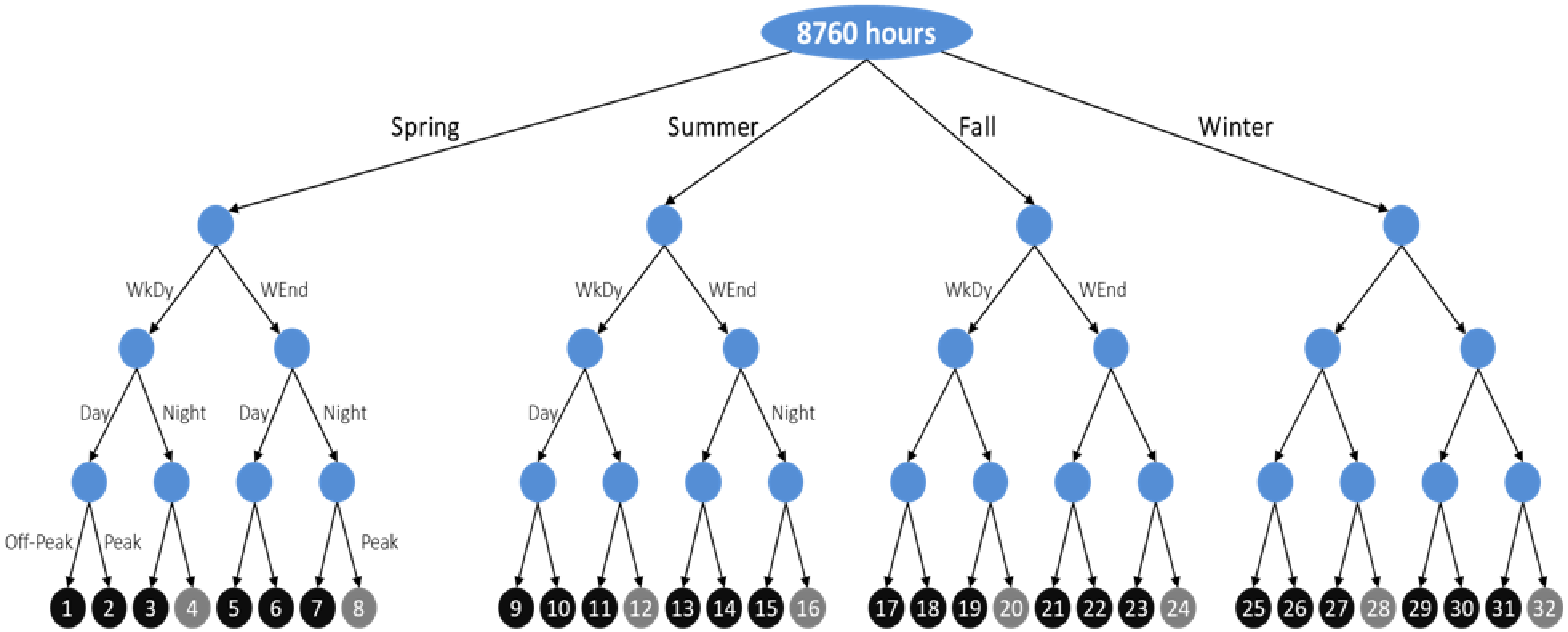
Modeling Time Buckets

TimeBucket	Label	AnnualHrs
1	WD-SpringOffPeakDay	737
2	WD-SpringPeak	402
3	WD-SpringOffPeakNight	469
5	WE-SpringOffPeakDay	286
6	WE-SpringPeak	156
7	WE-SpringOffPeakNight	182
9	WD-SummerOffPeakDay	726
10	WD-SummerPeak	396
11	WD-SummerOffPeakNight	462
13	WE-SummerOffPeakDay	297
14	WE-SummerPeak	162
15	WE-SummerOffPeakNight	189
17	WD-FallOffPeakDay	715
18	WD-FallPeak	390
19	WD-FallOffPeakNight	455
21	WE-FallOffPeakDay	275
22	WE-FallPeak	150
23	WE-FallOffPeakNight	175
25	WD-WinterOffPeakDay	693
26	WD-WinterPeak	378
27	WD-WinterOffPeakNight	441
29	WE-WinterOffPeakDay	286
30	WE-WinterPeak	156
31	WE-WinterOffPeakNight	182



Default values for seasons:
- Spring: 03/20 to 06/20
- Summer: 06/21 to 09/21
- Fall: 09/22 to 12/20
- Winter: 12/21 to 31/12; 01/01 to 03/19

Default values for peak and off-peak hours:
- Day off-peak: 5 to 15
- Day peak: 16 to 21
- Night off-peak: 0-4 and 22-23.
- Night peak: none

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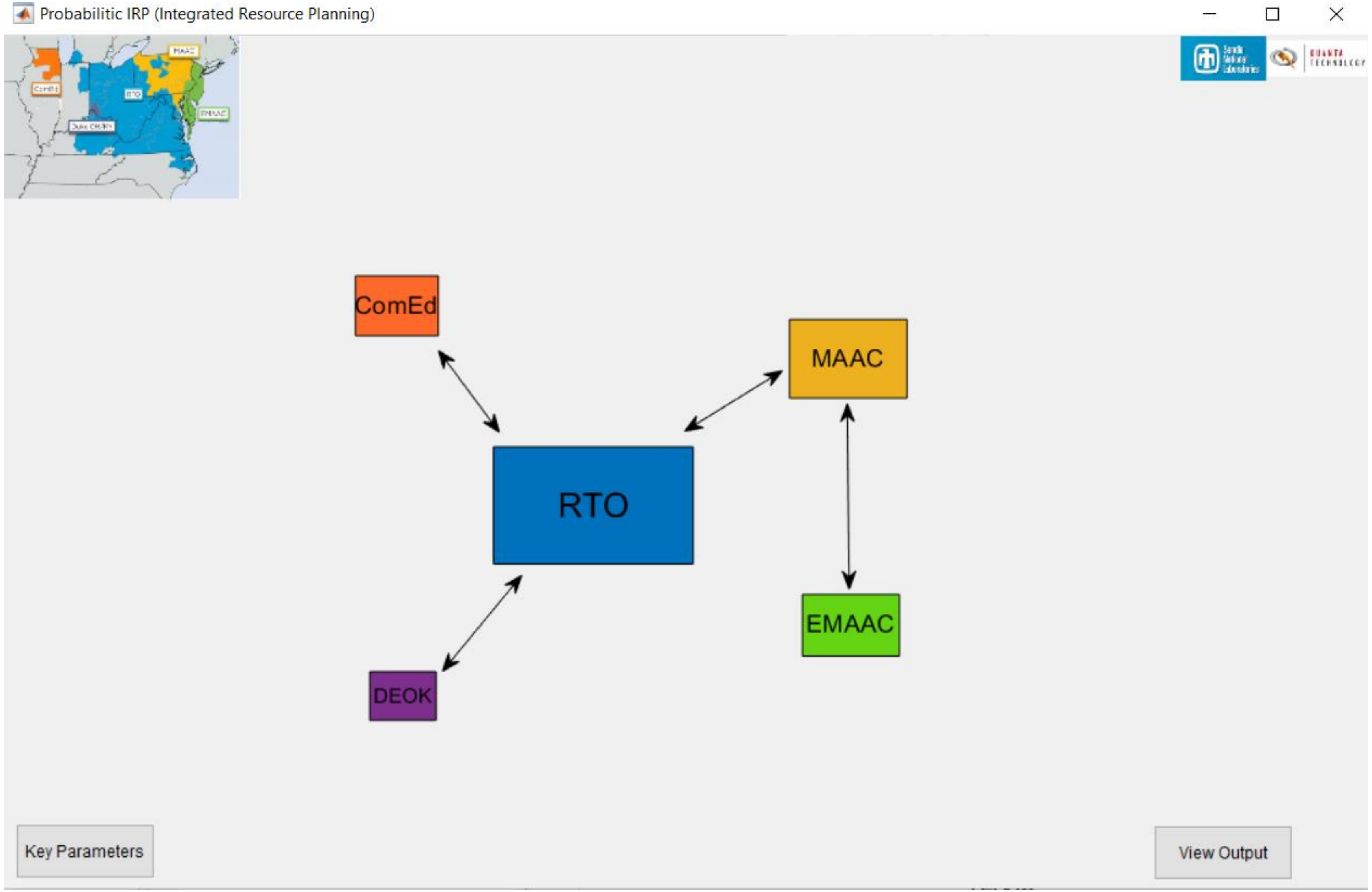
Modeling T&D Hosting Capacity and Grid Expansion - Zonal Model



Tie-Lines (Import/Export)
T- Hosting
D- Hosting Capacity

Available MW
Upgrade MW
Upgrade Cost/MW

Zonal Constraints:
- LCR
- Resilience
- Load
- Uncertainty

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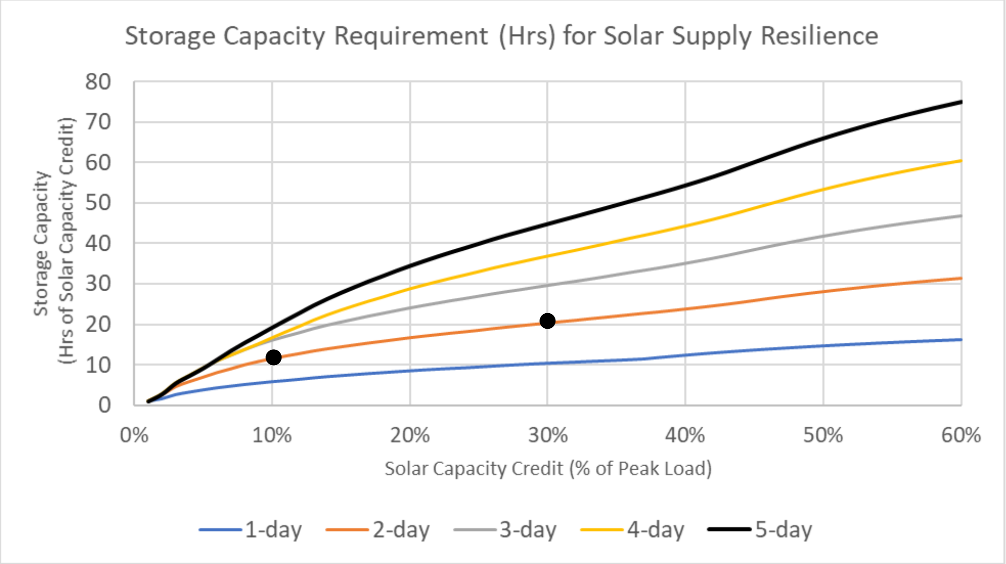
Modeling Supply Resilience

- Objective : Provide backup to resources that can be interrupted under extreme conditions (e.g., hurricane).
- How much backup duration is required? depends …
  - Interruption season and number of consecutive days
  - Capacity credit of all affected resources (e.g., solar/wind)
  - Load Profile
- Backup size increases with affected resource size, capacity credit, and number of consecutive interruption days:
  - Peak load of 1000MW.
  - 500MW solar PV with a capacity credit of 100MW (20%), or 10% of peak load.
  - 2 consecutive rainy days
  - Backup size is 1200MWh (or 12 hours of 100MW capacity). This can be energy storage or a 100MW generator running on renewable fuel.
  - However, if the solar capacity credit is 60% (30% of peak load), the backup size will increase to 6000MWh (or 20 hours of 300MW capacity).



ID	Zone	Resource 1	Resource 2	Resource 3	Resource 4	Interruption Days
1	ComEd	USolar	Wind			3
2	ComEd	Hydro			DSolar	5
3	RTO	USolar	DSolar			2
4						
5						
6						
7						
8						
9						
10						

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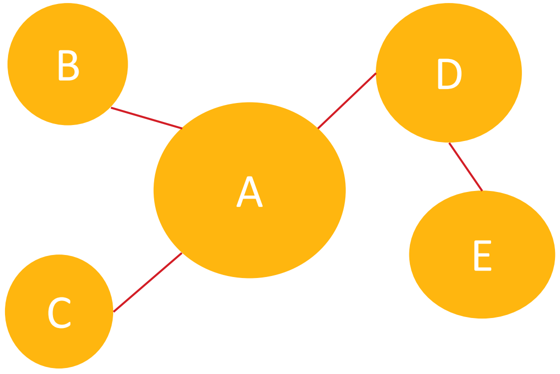
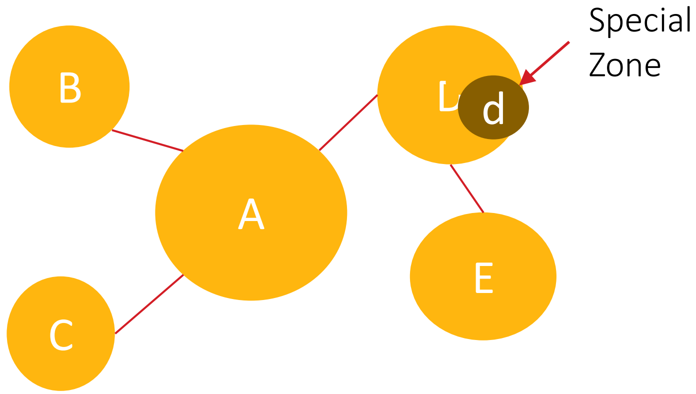
Modeling Grid Resilience

- Protect Critical Load and/or Vulnerable Communities
  - Create special zones for critical loads within the T&D grid
  - Determine capacity credit curves of renewable resources relative to the hourly profile of critical load
  - For resources within special zones:
    - Impose a minimum local capacity requirement constraint to ensure closeness of resources to critical load
    - Impose energy adequacy constraints
    - Impose supply resilience constraints
    - Select if resources should be connected to T or D or both





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Modeling Energy Storage

- Within each zone, optimize multiple storage systems, with different energy capacities:
  - (e.g., 1h, 2h, 4h, 6h, 12h).

- Model operational constraints:
  - daily energy balance constraints: daily charging = daily discharging plus losses
  - Energy reservoir constraints

- Model storage value stack:
  - capacity benefit curve
  - Fast Frequency Response capability
  - Ramp Rate capability (1min, 10min)

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Roadmap

2019

Conceptual Dev.

MATLAB Prototype

2020

More Features:

Resilience

Uncertainty

Scalability

2021

Python Porting

QuEST integration

Usability/Dashboard

Additional Capability

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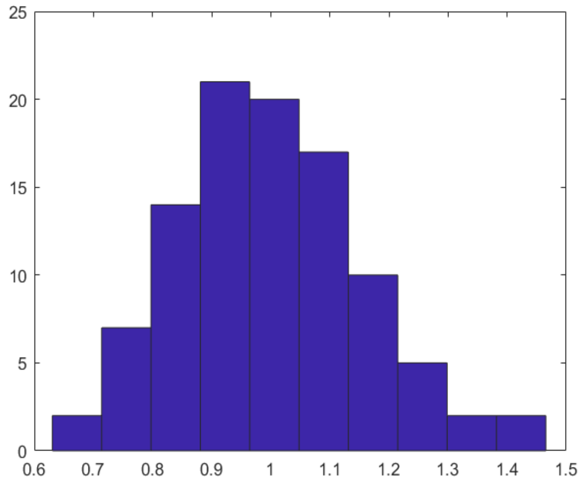
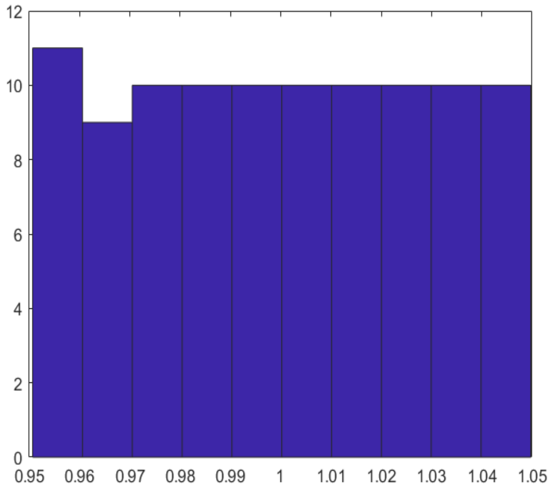
Sample Outputs

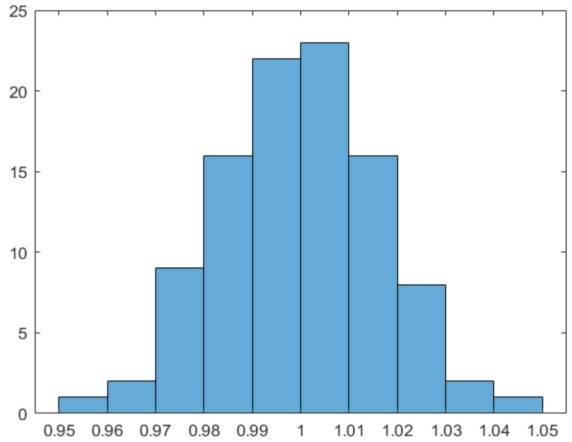
Uncertainty Sampling - Latin Hypercube



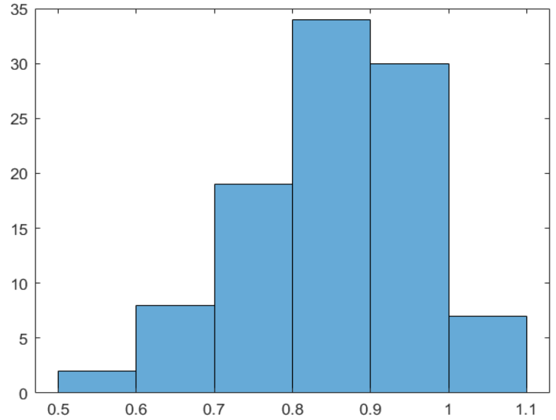
LogNormal distribution - fuel cost



Uniform distribution - zonal load



Normal distribution - Cap Credit



Weibull distribution – Profile (W+BESS-E10)

ID	Category	RandomVariables	NominalValue	StartYear	UncertaintyModel
1	Peak Load	ComEd	22,497.0000	3	Normal
2	Peak Load	DEOK	5,289.0000	1	Uniform
3	Profile	DR	1.0000	1	Normal
4	Fuel Cost	Coal	1.3500	1	LogNormal
5	Fuel Cost Escalator	HFO	0.0300	1	Uniform
6	CapacityCredit	USolar	0.3800	1	Normal
7	Load Growth Rate	DEOK	0.0050	1	Normal
8	Load Growth Rate	MAAC	0.0050	1	Uniform
9	Profile	Wind+BESS-E10	1.0000	1	Weibull
10	Fuel Cost	Nuclear	5.5000	1	LogNormal

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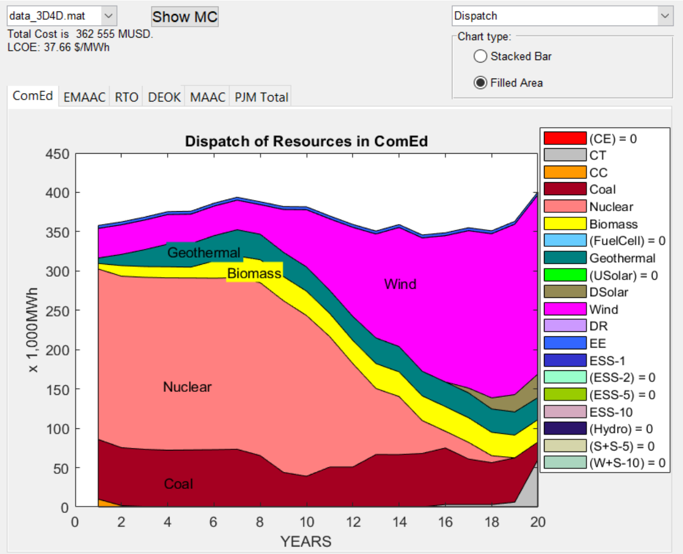
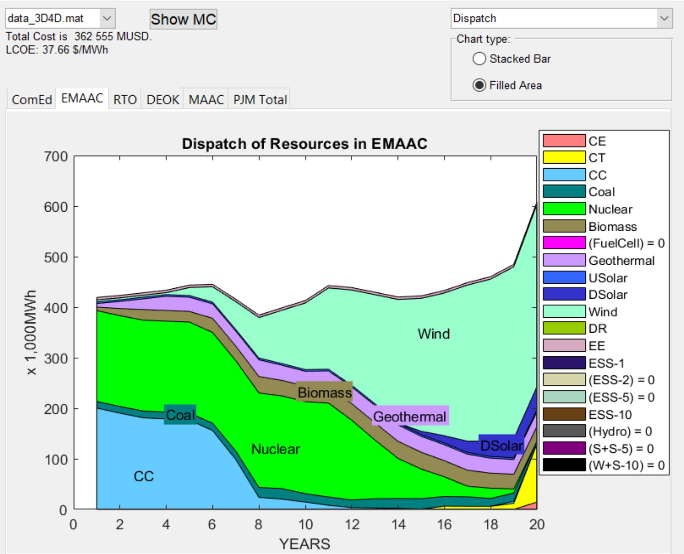
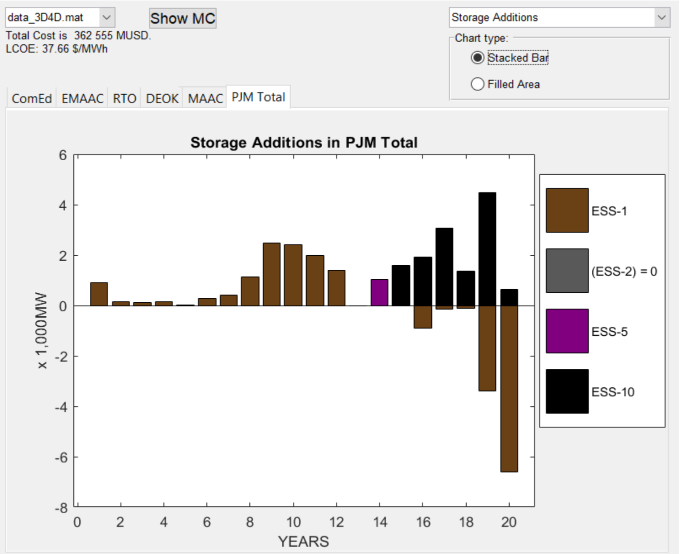
Sample Outputs

Study C: 50-75% Renewables by 2040

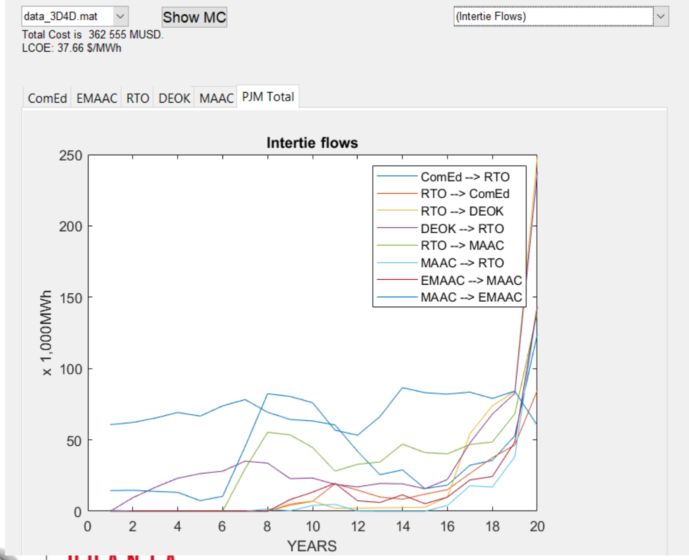


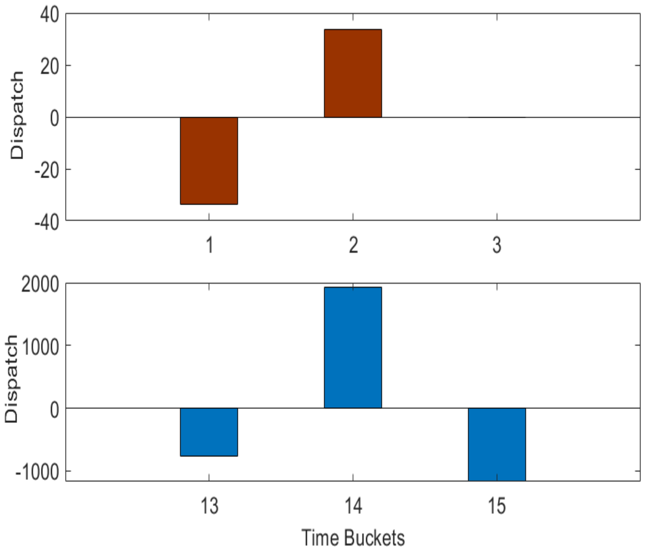


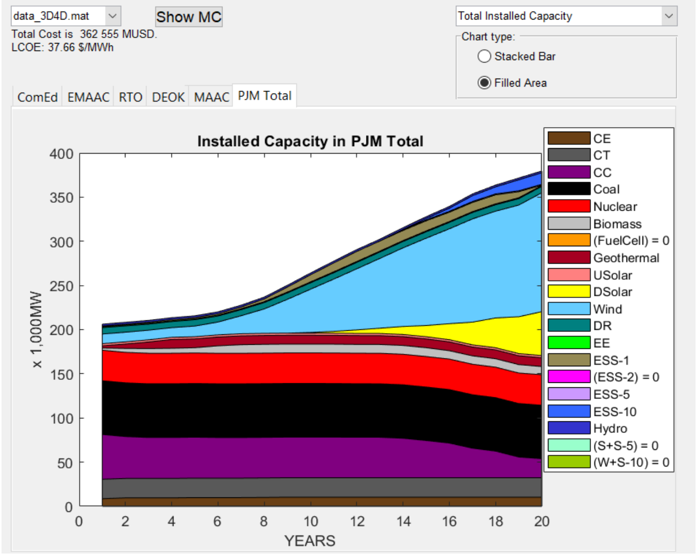


Resilience Impact:

- Storage capacity requirement increased by 17.5%







- LCOE increased from 45.7 $/MWh to approximately 48.9 $/MWh

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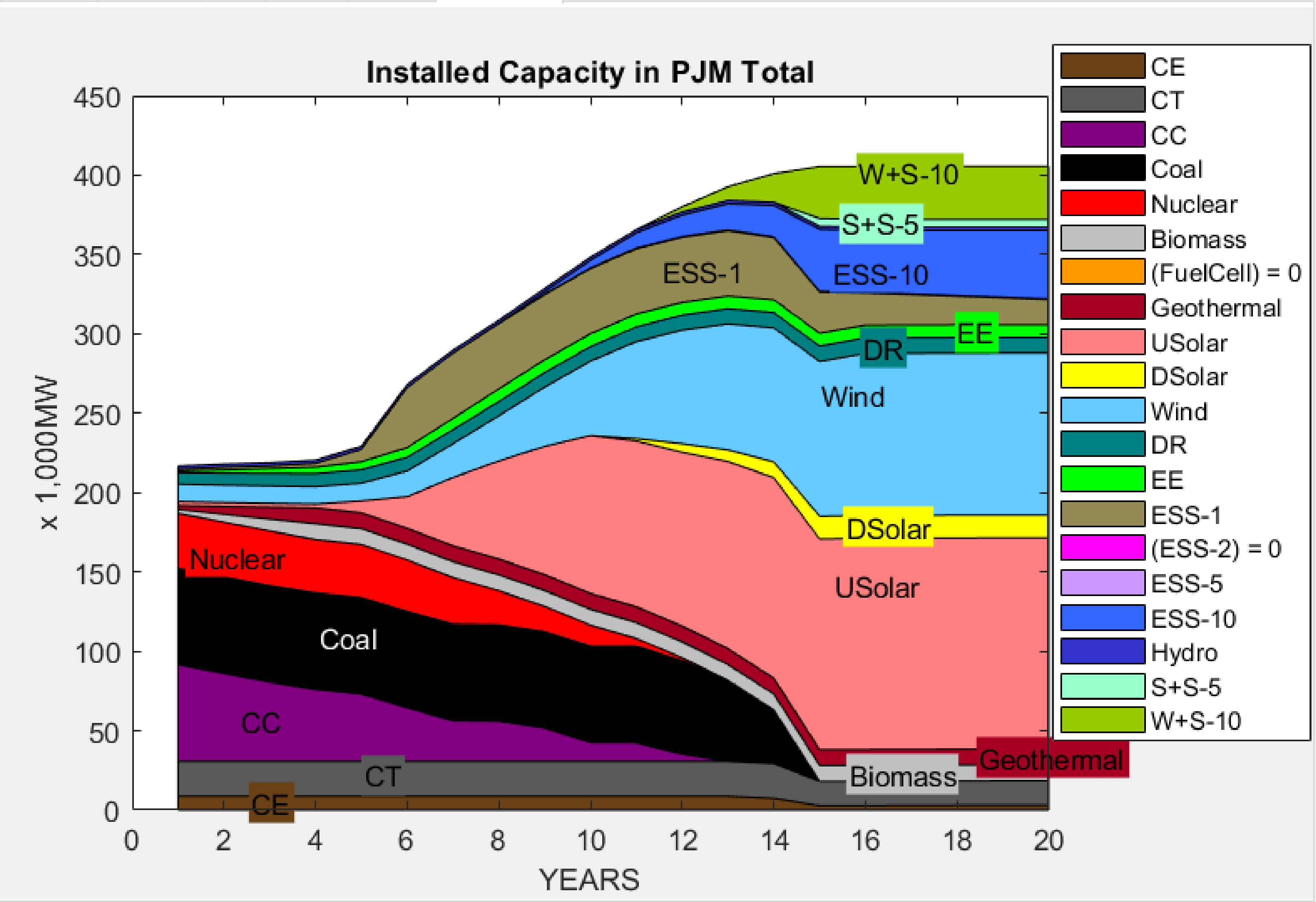
100% Renewable IRP: Example

Storage energy capacity requirements increase with time:

- Freq Response:
  - ESS-1hr
- Capacity & Energy Balance:
  - ESS-5hr
  - ESS-10hr
- Capacity & Energy:
  - S+S-5hr
  - W+S-10hr



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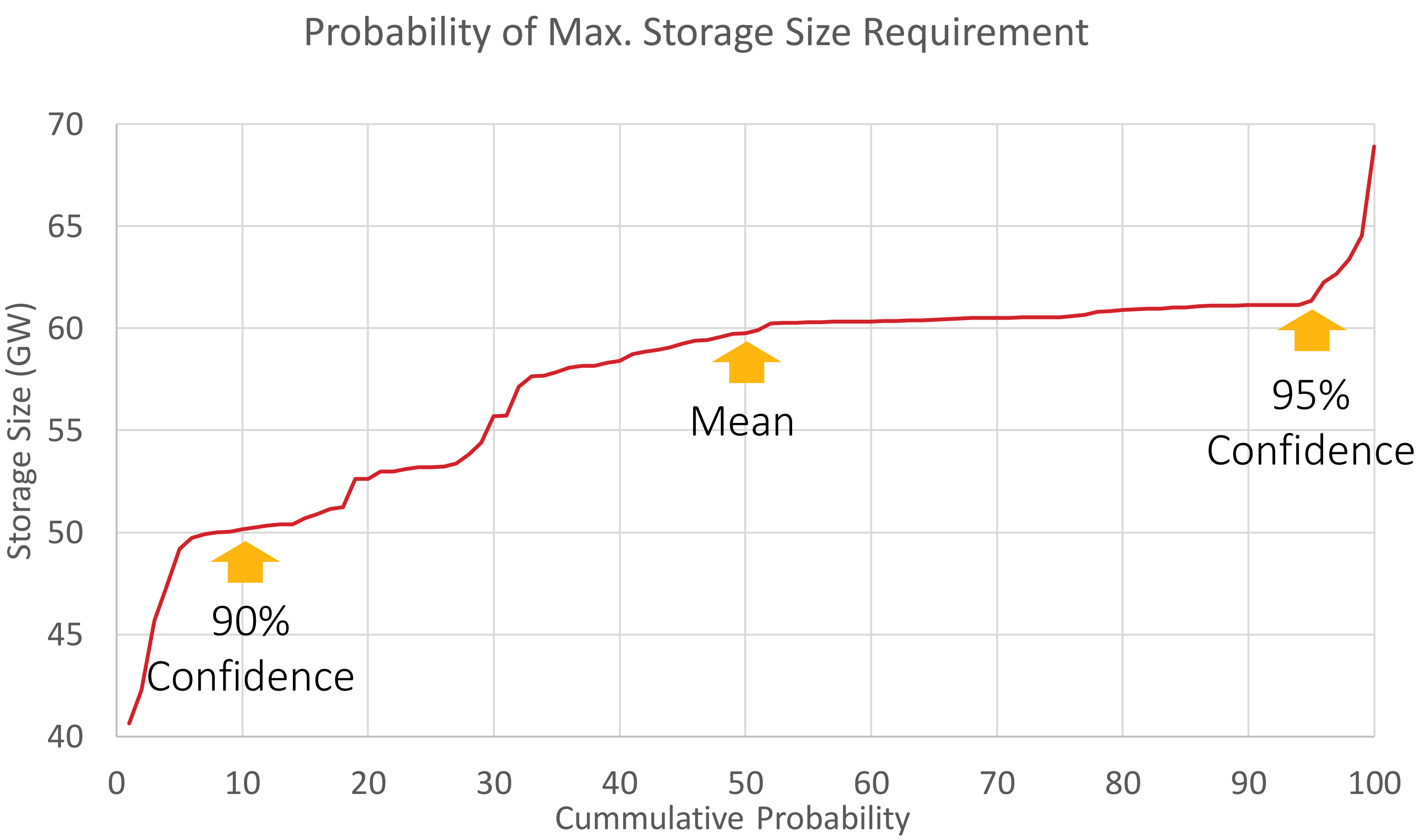
Energy Storage Requirements at Year 20 (Probabilistic IRP)



- Storage Requirements range between 41-69GW, with a mean of 60GW.
- 90% probability the storage requirements will exceed 50GW; 95% probability will not exceed 62GW.

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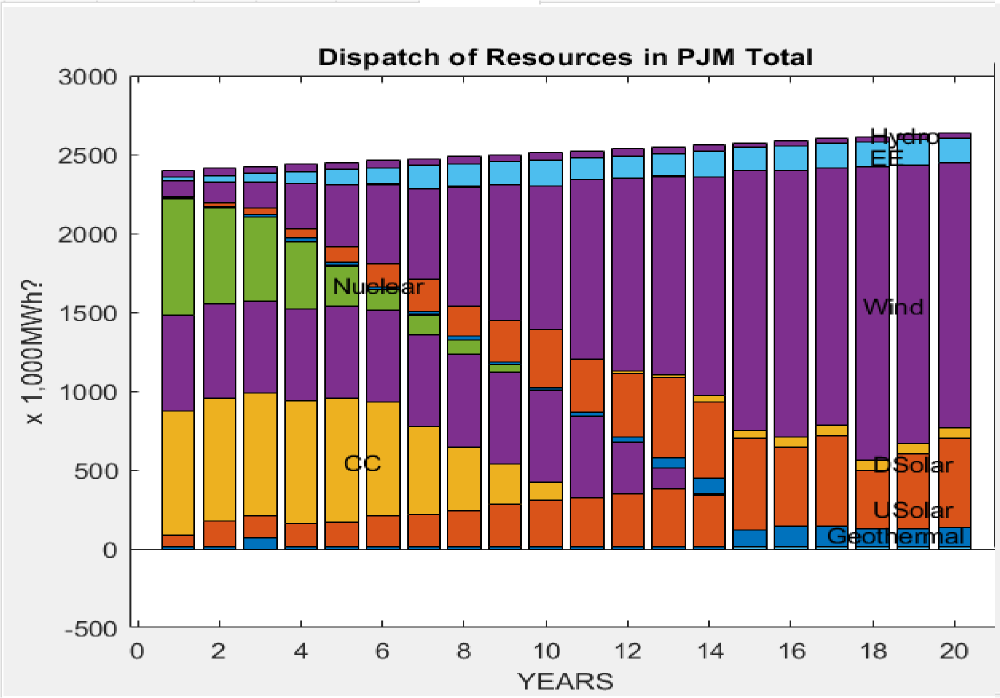
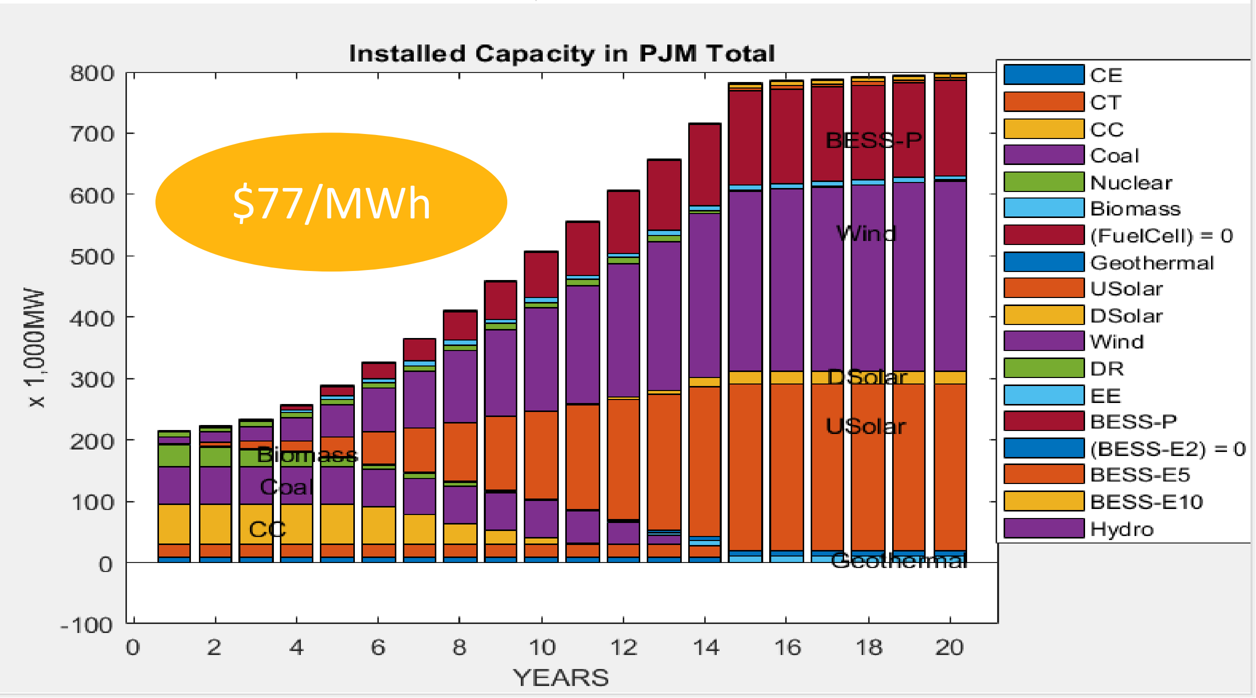
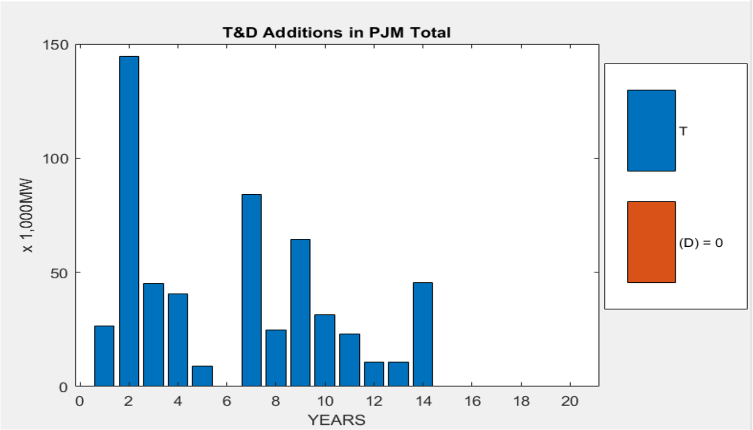
Case Study for a Carbon-Neutral Future – Solar, Wind, Storage







- To reach carbon-neutral, 165GW peak load (LF 60%) will require a resource mix that grows from 200GW to 800GW in 20 years at a high total cost of $667B (LCOE=$77/MWh), and significant grid investments.

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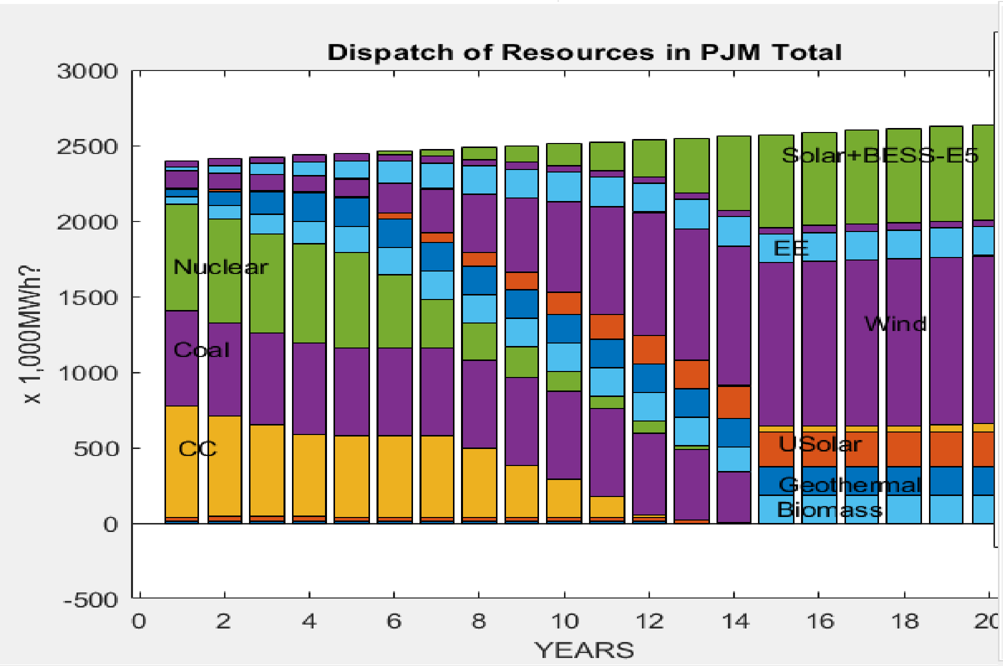
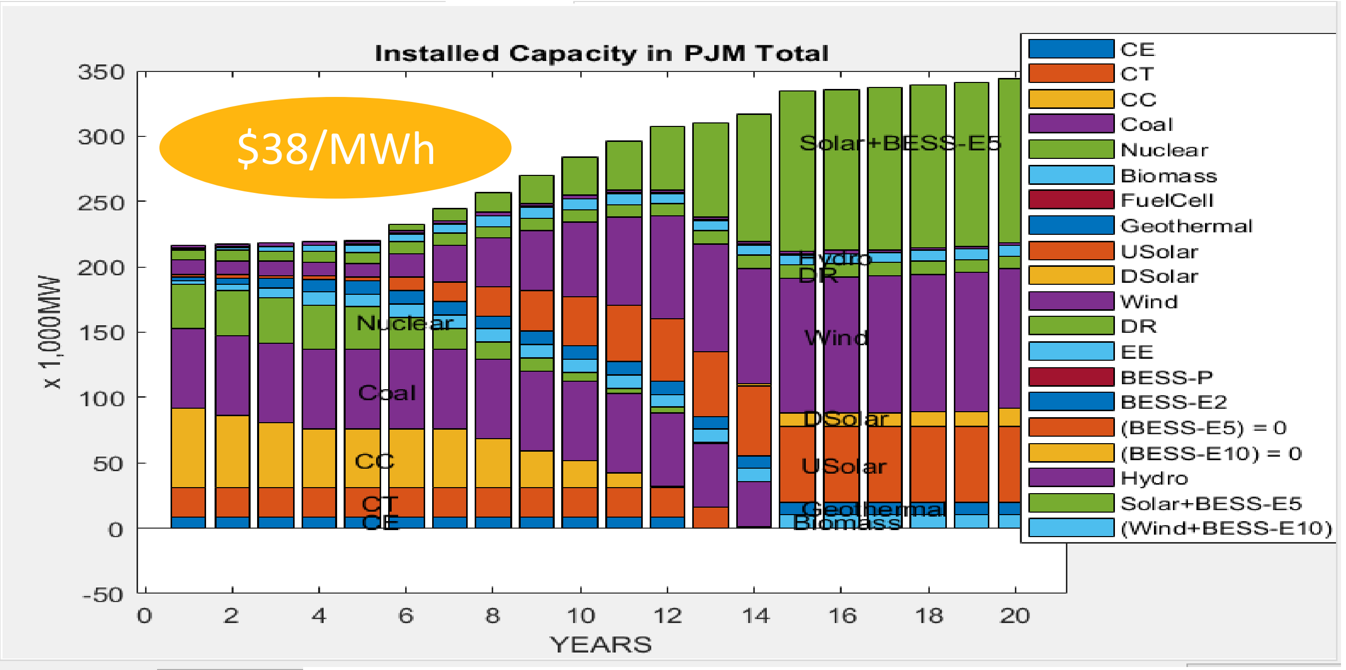
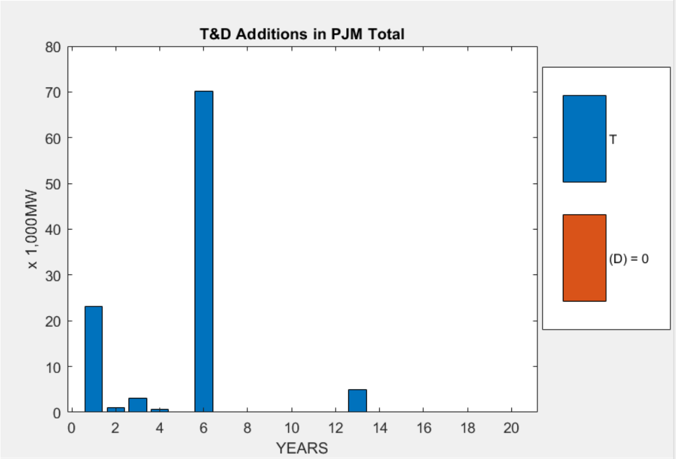
Adding Solar+Storage to the Resource Mix







- To reach carbon-neutral 165GW peak load (LF 60%) will require a resource mix that grows from 200GW to 350GW in 20 years at a moderate total cost of $331B (LCOE = $38/MWh) and small grid investments.

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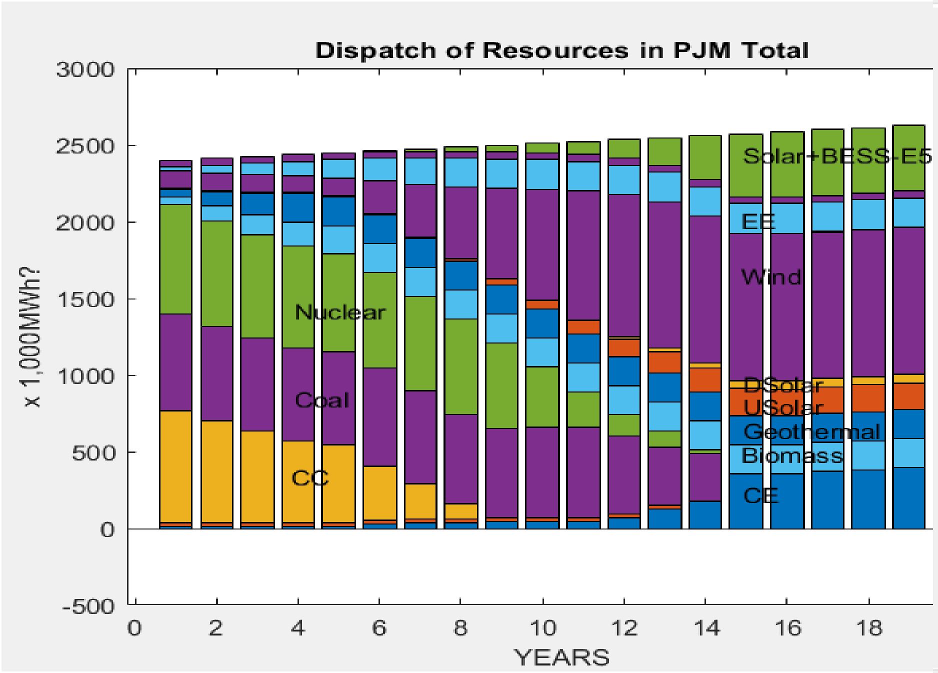
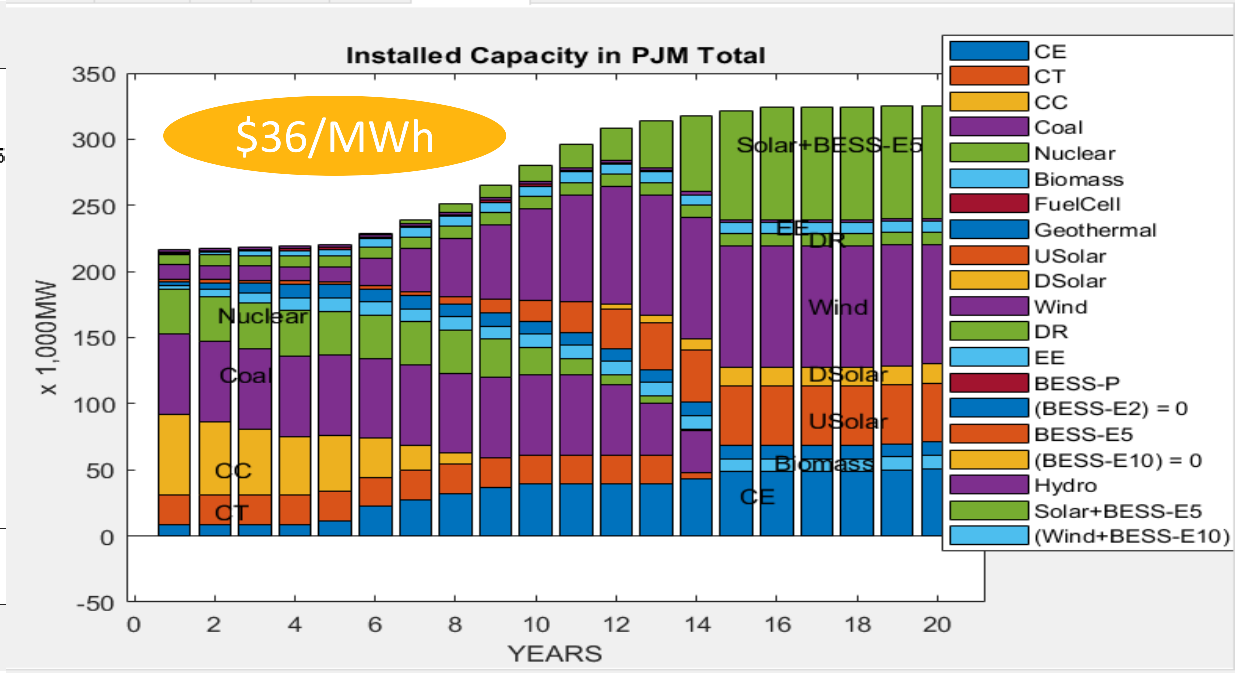
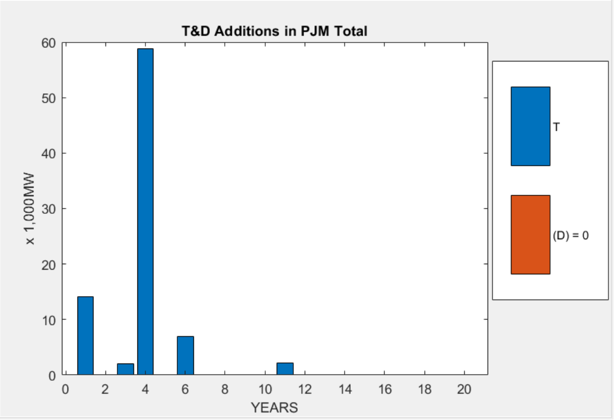
Adding Renewable Fuel (e.g., Hydrogen) to the Resource Mix







- To reach carbon-neutral 165GW peak load (LF 60%) will require a resource mix that grows from 200GW to 320GW in 20 years at a moderate total cost of $313B (LCOE = $36/MWh) and small grid investments.

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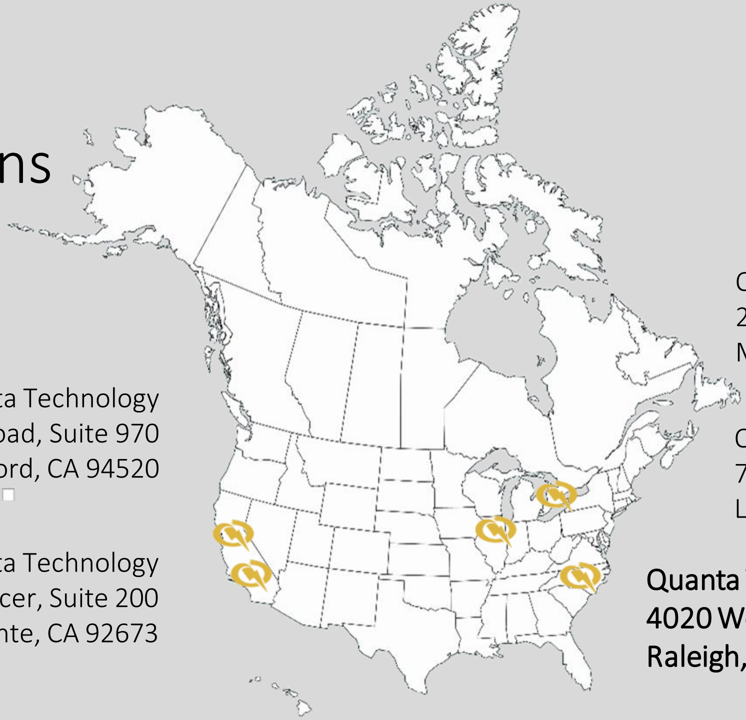
Thank you!

Office Locations



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