Energy+Environmental Economics

CLCPA Integration Analysis: Inputs and Assumptions

Climate Action Council

2021/11/18

Contents

Overview of Inputs & Assumptions Materials

+ **This presentation is accompanied by an input assumptions workbook which includes more detailed data**

Climate Leadership and Community Protection Act (CLCPA) Integration Analysis
Input Assumptions Workbook

Prepared by:

Energy+Environmental Economics

44 Montgomery Street, Suite 1500
San Francisco, CA 94104
(415) 391-5100

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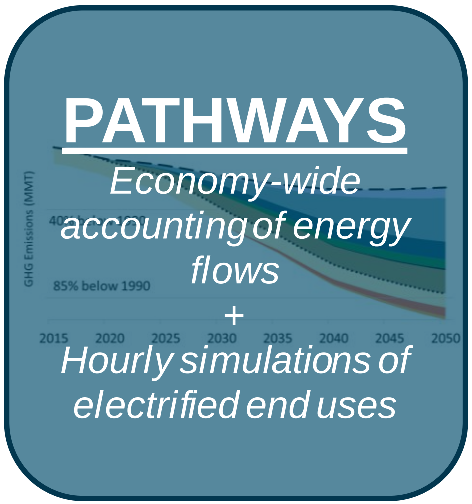
Tab Name	Contents
Sectoral Coverage	Mapping of emissions categories represented
Regions	Mapping of counties to NYISO zones and PATHWAYS regions
Activity Drivers	Demand-side drivers (population, housing units, square footage, VMT)
Bldg_Housing Unit Summary	2018 estimated distribution of various housing unit statistics (type of unit by region)
Building Sector Coverage	Summary of building subsectors, stock, energy demand
Bldg_Res Stock	Initial year stock by subsector, device lifetimes, and 2020 sales efficiency
Bldg_Res Efficiency	Summary of forecast device efficiencies for residential technologies
Bldg_Res Device Cost	Summary of device costs for residential devices
Bldg_Comm Stock	Initial year stock by subsector, device lifetimes, and 2020 sales efficiency
Bldg_Comm Efficiency	Summary of forecast device efficiencies for commercial technologies
Bldg_Comm Device Cost	Summary of device costs for commercial devices
Industry Sector Coverage	Summary of industrial subsectors, energy demand
Trans_Sector Coverage	Summary of transportation subsectors, stock, energy demand
Trans_Stock	Summary of stock data for transportation technologies
Trans_Fuel Economy	Summary of forecast fuel economy data for transportation technologies
Trans_Device Cost	Summary of forecast vehicle prices

Economy-wide Analysis Accounts for Integrated Energy Supply, Energy Demand, and Non-Energy

E3's integrated analytical framework combines a detailed accounting model of energy supplies and demands across the entire economy with an optimized capacity expansion model in the electric sector. Energy sector modeling combined with non-energy emissions accounting (e.g. agriculture, forestry, waste, industrial process).

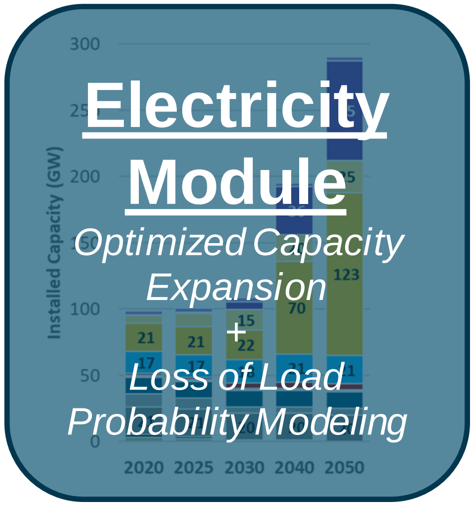
1 Use detailed energy accounting model to examine pathways to reaching long-term economy-wide goals and implications for electric loads

2 Use capacity expansion to optimize future portfolios to meet electric sector policy goals while maintaining reliability



Future System Load Shapes →

← *Electric Sector Emissions*



4 Integration of renewable and zero-carbon fuel production, negative emissions technologies, and non-energy measures as defined by scenarios

3 Iterate between different levels of electrification-driven load growth and resulting electric sector impacts

CLCPA Integration Analysis

+ E3 Pathways framework provides *integration analysis* for Scoping Plan, incorporating insights and recommendations from Advisory Panels and complementary studies

Energy Intensive & Trade Exposed Industries AP

Agriculture & Forestry AP

Waste AP

Power Generation AP

Power Grid Study

CES Cost Study

Land Use & Local Gov't AP
Climate Justice WG
Just Transition Working Group (Jobs Study)

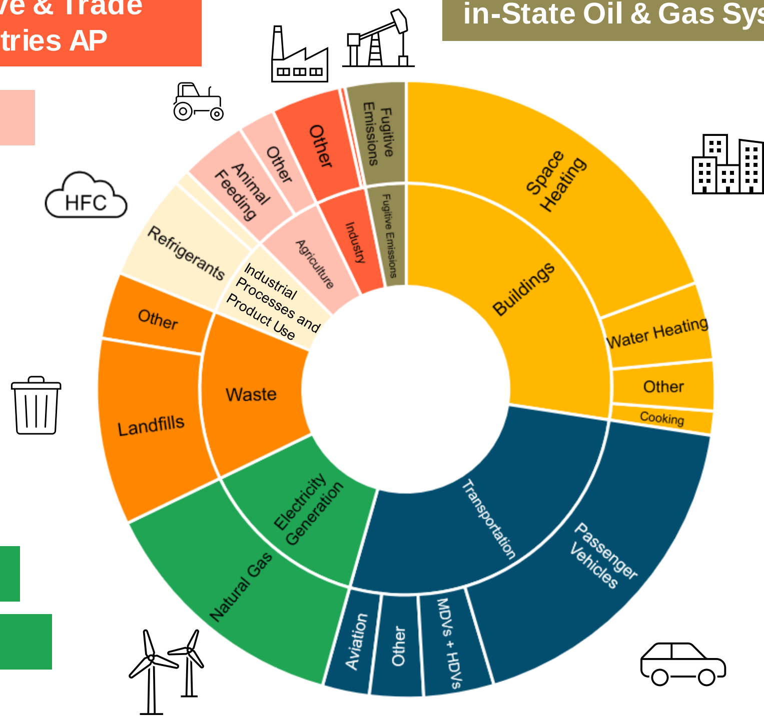
Methane Mitigation Potential from in-State Oil & Gas Systems Study

Energy Efficiency & Housing AP

Carbon Neutral Buildings & Buildings Electrification Roadmap

Transportation AP

Transportation Roadmap



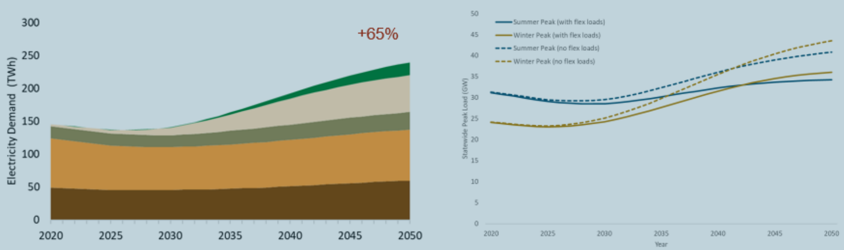
*Draft 2020 results in line with DEC CLCPA accounting including upstream emission factors, 20-year GWP, and estimates from NY PATHWAYS

Linkages to Parallel Workstreams

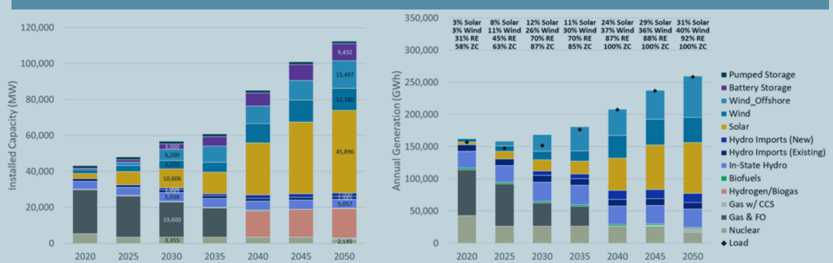
- **CLCPA electric sector analysis draws on insights from other workstreams to more fully understand the impacts and costs of electrification of the buildings and transportation sectors**
- **Impacts of electrification depend on technology shares, customer behavior, and complementary policies and strategies**

Pathways Framework

Annual and Peak Electricity Demand



Electric Sector Resource Portfolio



Starting Point Pathways →

← *Impacts of Electrification*

Parallel Workstreams

Transportation Roadmap
NYSERDA, Cadmus, Nexant

Carbon Neutral Buildings Roadmap
NYSERDA, RMI, NBI

Building Electrification Roadmap
NYSERDA, Cadmus, IEc

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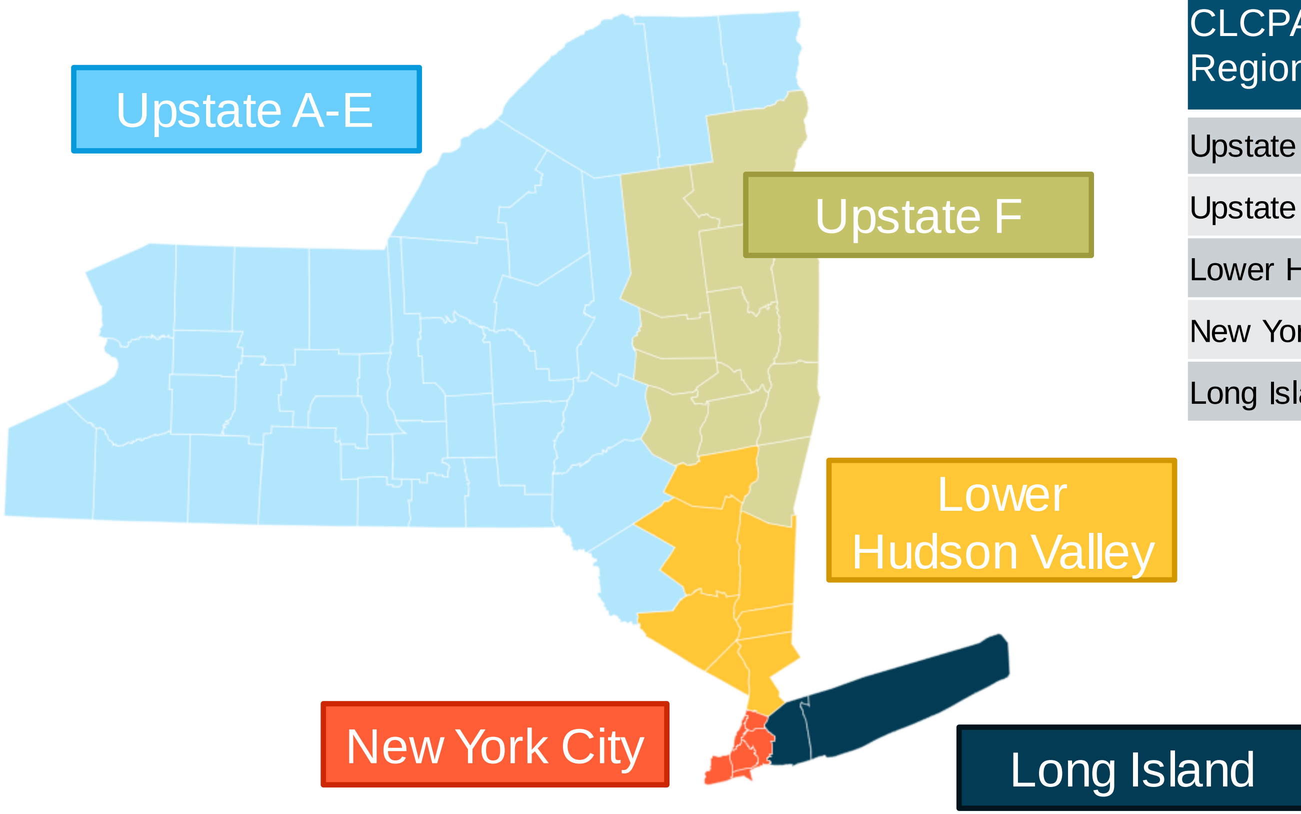
Cross-Cutting Assumptions

Region Mapping

+ **New York State is modeled as five sub-regions, with each sub-region corresponding to a set of NYISO load zones**



CLCPA PATHWAYS Region	NYISO Zone Mapping
Upstate A-E	A, B, C, D, E
Upstate F	F
Lower Hudson Valley	G, H, I
New York City	J
Long Island	K

Map © GeoNames, Microsoft

Cost Accounting Philosophy

- **The Pathways framework produces economy-wide resource costs for the various mitigation scenarios relative to a reference scenario**
  - The framework is focused on annual societal costs and benefits and does not track internal transfers (e.g., incentives)
- **Outputs are produced on an annual time scale for the state of New York, with granularity by sector**
  - Annualized capital, operations, and maintenance cost for infrastructure (e.g., devices, equipment, generation assets, T&D)
  - Annual fuel expenses by sector and fuel (conventional or low-carbon fuels, depending on scenario definitions)
  - Does not natively produce detailed locational or customer class analysis
- **Locational and customer class impact analyses would be developed through subsequent implementation processes**
- **Value of avoided GHG emissions calculated based on guidance developed by DEC**

Sectoral Coverage For Cost

Cost Category	Description
Electricity System	Includes incremental capital and operating costs for electricity generation, transmission (including embedded system costs), distribution systems, and in-state hydrogen production costs.
Transportation Investment	Includes incremental capital and operating expenses in transportation (e.g. BEVs and EV chargers)
Building Investment	Includes incremental capital and operating expenses in buildings (e.g. HPs and building upgrades)
Non-Energy	Includes incremental mitigation costs for all non-energy categories, including agriculture, waste, and forestry
Renewable Gas	Includes incremental fuel costs for renewable natural gas and imported green hydrogen
Renewable Liquids	Includes incremental fuel costs for renewable diesel and renewable jet kerosene
Negative Emission Technologies (NETs)	Includes incremental costs for direct air capture of CO2 as a proxy for NETs
Other	Includes other incremental direct costs including industry sector costs, oil & gas system costs, HFC alternatives, and hydrogen storage
Fossil Gas	Includes incremental costs spent on fossil natural gas (shown as a negative for cases when Gas expenditures are avoided compared with the Reference Case)
Fossil Liquids	Includes incremental costs spent on liquid petroleum products (shown as a negative for cases when liquids expenditures are avoided compared with the Reference Case)
Other Fuel	Includes incremental costs spent on all other fossil fuels

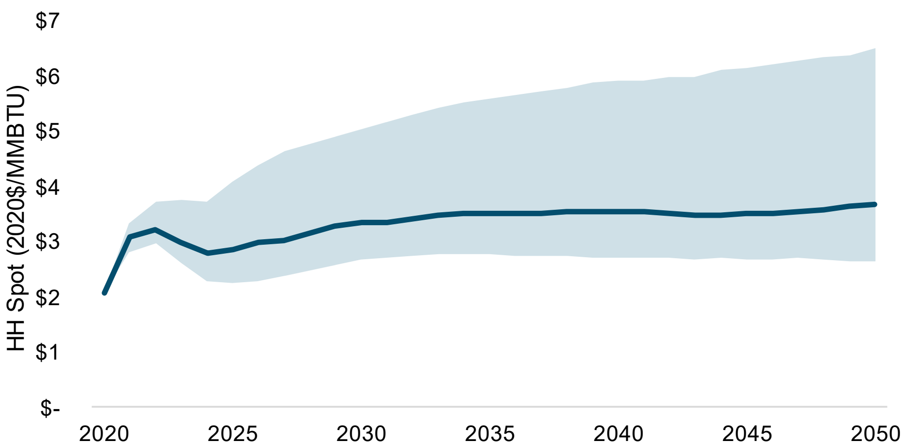
Treatment of Future Costs and Damages

- **The benefit-cost assessment treats costs accrued in future years in three important ways:**
- **Annualization:** Upfront investment costs, e.g., the costs of building a new power plant or of buying a new vehicle, are converted into *annualized* cost streams rather than lump sum investments
  - Technology-specific assumptions targeting financing for different customers/utilities
- **Calculation of future climate damages:** The social cost of climate mitigation is determined by calculating the cumulative effect of future climate damages in the year in which a greenhouse gas was emitted, e.g., the social cost of climate mitigation in 2030 represents the net present value of future climate damages
  - Current assumption is to use DEC recommendations and run sensitivities to test impacts on climate damages
- **Discounting of future cost and benefit streams:** Total system costs are presented on a net present value basis, which requires discounting annual future costs and benefit streams. The discount rate is calculated based on guidance from New York state agencies, such as DPS and NYSERDA
  - Analysis uses DPS-recommended 3.6% discount rate for NPV calculations

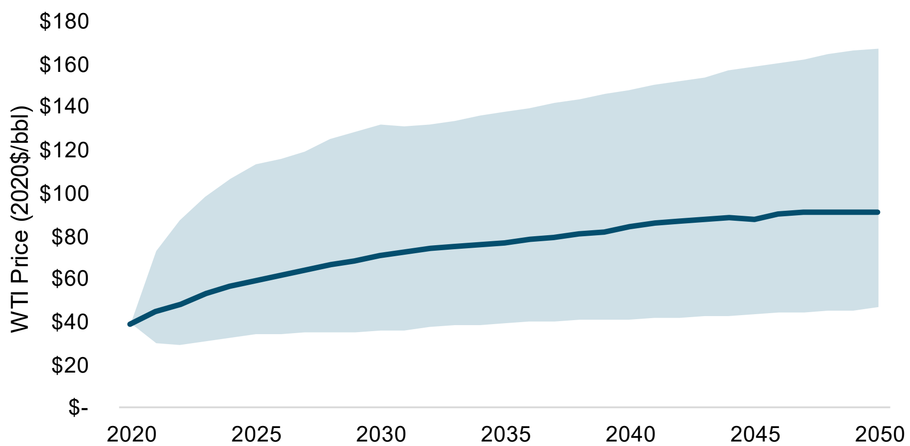
Fuel Prices

- Range of commodity fuel prices sourced from EIA Annual Energy Outlook
- Cost of electricity consumption is treated within the RESOLVE modeling framework
- Prices for renewable fuels and zero carbon fuels (such as hydrogen) were updated based on feedback from parallel analysis, advisory panels, and sub-panels

Henry Hub Commodity Price Range in AEO 2021



WTI Commodity Price Range in AEO 2021



Buildings

Key Data Sources

+ **To characterize energy consumption and greenhouse gas emissions from the buildings sector in New York, E3 relied on a variety of state and national data sources**

- NYSERDA Residential Baseline Study
- NYSERDA Commercial Baseline Study
- NYSERDA New Efficiency New York Study: Analysis of Residential Heat Pump Potential and Economics
- NYSERDA Residential Building Stock Assessment

- EIA Residential Energy Consumption Survey
- EIA Commercial Building Energy Consumption Survey
- DOE LED Adoption Report
- EIA National Energy Modeling System
- American Community Survey
- EIA State Energy Data System
- EIA Building Sector Appliance and Equipment Costs and Efficiency

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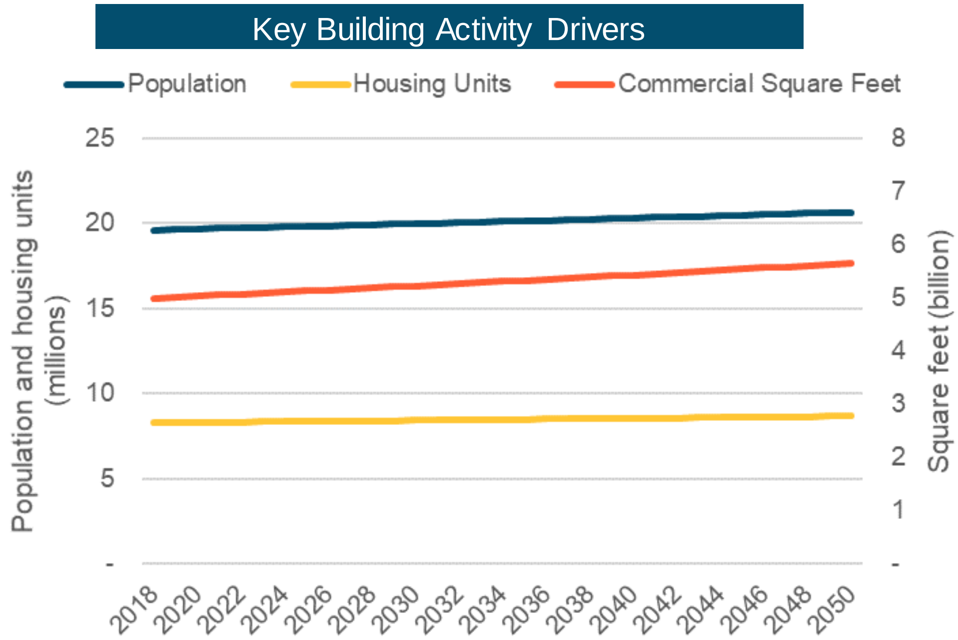
Key Activity Drivers

+ **Key drivers of energy use in buildings are population growth, housing unit growth, and commercial square footage growth rate**
  - Population and Housing Unit: We use data from Cornell Program on Applied Demographics to estimate population and housing unit growth over time
  - Commercial Square Feet: We use a relationship between population growth and commercial square feet growth, derived from AEO data, to forecast growth rate for New York State commercial square feet
  - Additional detail can be found in the Inputs and Assumptions Workbook



Transportation

Key Data Sources

- To characterize energy consumption and greenhouse gas emissions from the transportation sector in New York, E3 relied on a variety of state and federal data sources
- Further state-specific data as identified by parallel analyses, advisory panels, and sub-panels included

- NYSDEC MOVES Modeling
- Transportation Roadmap Modeling

- EIA Annual Energy Outlook
- EIA State Energy Data System
- US Federal Highway Administration Highway Statistics

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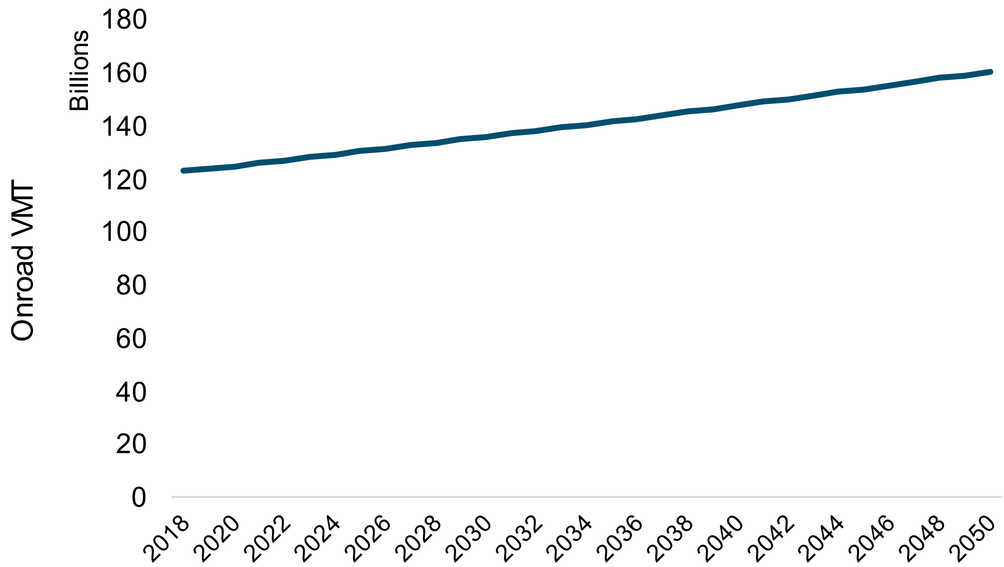
Key Activity Drivers

+ VMT growth is a key driver for the transportation sector

- VMT assumptions were informed by the Transportation Roadmap analysis
- Additional information can be found in the Inputs and Assumptions Workbook



Industry

Key Data Sources

+ **To characterize energy consumption and greenhouse gas emissions from the industrial sector in New York, E3 relied on a variety of state and federal data sources**
+ **Further state-specific data as identified by parallel analyses, advisory panels, and sub-panels included**

- NYSERDA Energy Efficiency & Renewable Energy Potential Study
- NY Department of Labor Employment

- EIA Annual Energy Outlook
- EIA State Energy Data System
- American Society of Manufacturers Survey
- NREL Industry Energy Tool

Maps © GeoNames, Microsoft

Key Activity Drivers

- **Key drivers for industry emissions include growth in energy consumption in key industrial subsectors**
  - Growth rates from AEO 2021
  - Additional information can be found in the Inputs and Assumptions Workbook

Industry Subsector	Energy Consumption Average Annual Growth Rate (2018-2050)
Agriculture	1.6%
Construction	1.4%
Aluminum	0.3%
Bulk Chemicals	1.2%
Cement and Lime	-1.9%
Food	1.2%
Glass	-0.1%
Iron and Steel	-0.7%
Metal Based Durables	0.8%
Mining	0.7%
Other Manufacturing	1.4%
Paper	0.0%
Plastics	1.2%
Wood Products	1.0%

Power Generation

Key Data Sources

+ **To characterize electricity generation, fuel costs, and technology costs, E3 relied on a variety of state and federal data sources**

- NYISO Gold Book
- NYISO CARIS Study
- NYISO Demand Curve Study
- NYISO Reliability Needs Assessment
- NYSERDA Storage Roadmap
- NY DPS and NYSERDA Clean Energy Standard White Paper

- EIA Annual Energy Outlook
- NREL Annual Technology Baseline
- NREL Technical Potential Study
- Lazard Levelized Cost of Storage

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Generation Resources

+ **Electric sector modeling can consider a broad range of candidate technologies**
  - Decisions on technology inclusion were made as part of scenario definition
+ **Analysis relies on the following key inputs:**
  - **Existing and Planned Capacity**
    - NYISO Gold Book and CARIS Report, NYSERDA CES procurements
  - **Costs of Candidate Resources:**
    - **Thermal Generators:** NYISO Demand Curve Study
    - **Renewable Generators:** Clean Energy Standard Whitepaper and NREL Annual Technology Baseline
    - **Storage:** Lazard Levelized Cost of Storage, NYSERDA Storage Roadmap, NREL Annual Technology Baseline
  - **Fuel Prices**
    - NYISO CARIS Report, EIA Annual Energy Outlook
  - **Peak Load Impacts and Load Flexibility**
    - Parallel Workstreams

Resource Type	Examples	Considerations
Thermal Generation (Fossil Fuels)	• Simple cycle combustion turbines (CTs) or combined cycle gas turbines (CCGTs)	• Balancing near-term reliability needs with long-term phaseout
Thermal Generation (low-carbon / zero-emission)	• Nuclear • Combustion turbines utilizing zero-emission fuels (RNG, H2) • Hydrogen fuel cells	• Techno-economic feasibility • Crossover with long-duration storage
Renewable Generation	• In-state hydro • Hydro imports • Solar PV (utility-scale and distributed) • Wind (onshore & offshore)	• Execute on processes for planning, siting, and integration
Energy Storage	• Short-duration storage (>1hr) • Long-duration storage (>12hr)	• Continue progress • Long-duration storage a priority for innovation
Customer Technologies	• Flexible loads	• Need for temporal and locational price signals • Optimize across the meter

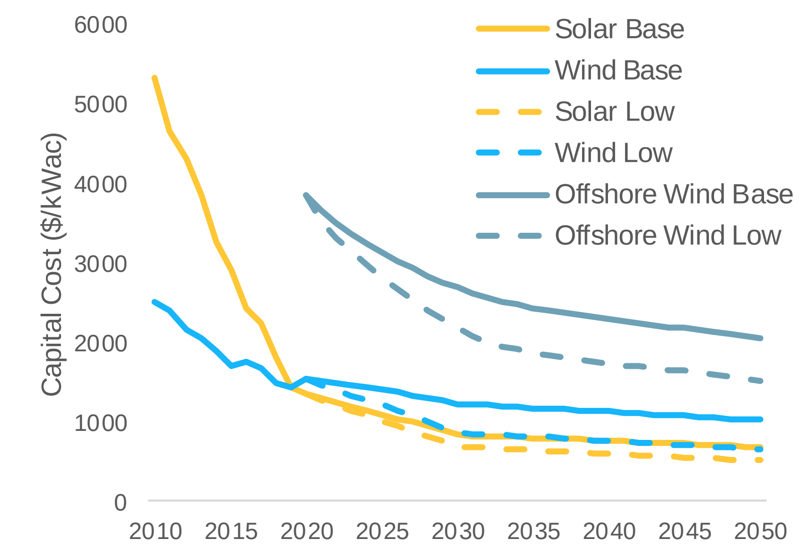
Existing and Planned Resources

+ **RESOLVE modeling relies on the NYISO Gold Book to estimate existing generation resources in New York State**
+ **Planned thermal resources are incorporated using the NYISO CARIS Base Case**
  - Modeling assumes that existing thermal resources retire at end-of-life (60 years)
+ **Planned renewable resources incorporated based on recent NYSERDA CES awards**

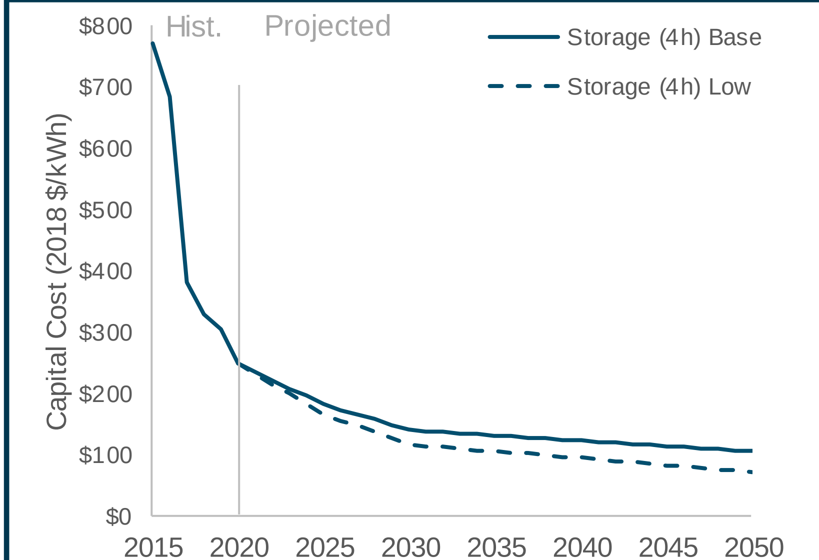
Key Technology Costs

- Wind and solar capital costs have declined by 43% and 73% respectively over the past decade
- Costs of Li-ion battery storage have declined by 68% since 2015
- Our analysis incorporates future cost declines for each technology as projected by NREL's Annual Technology Baseline

Renewables



Storage

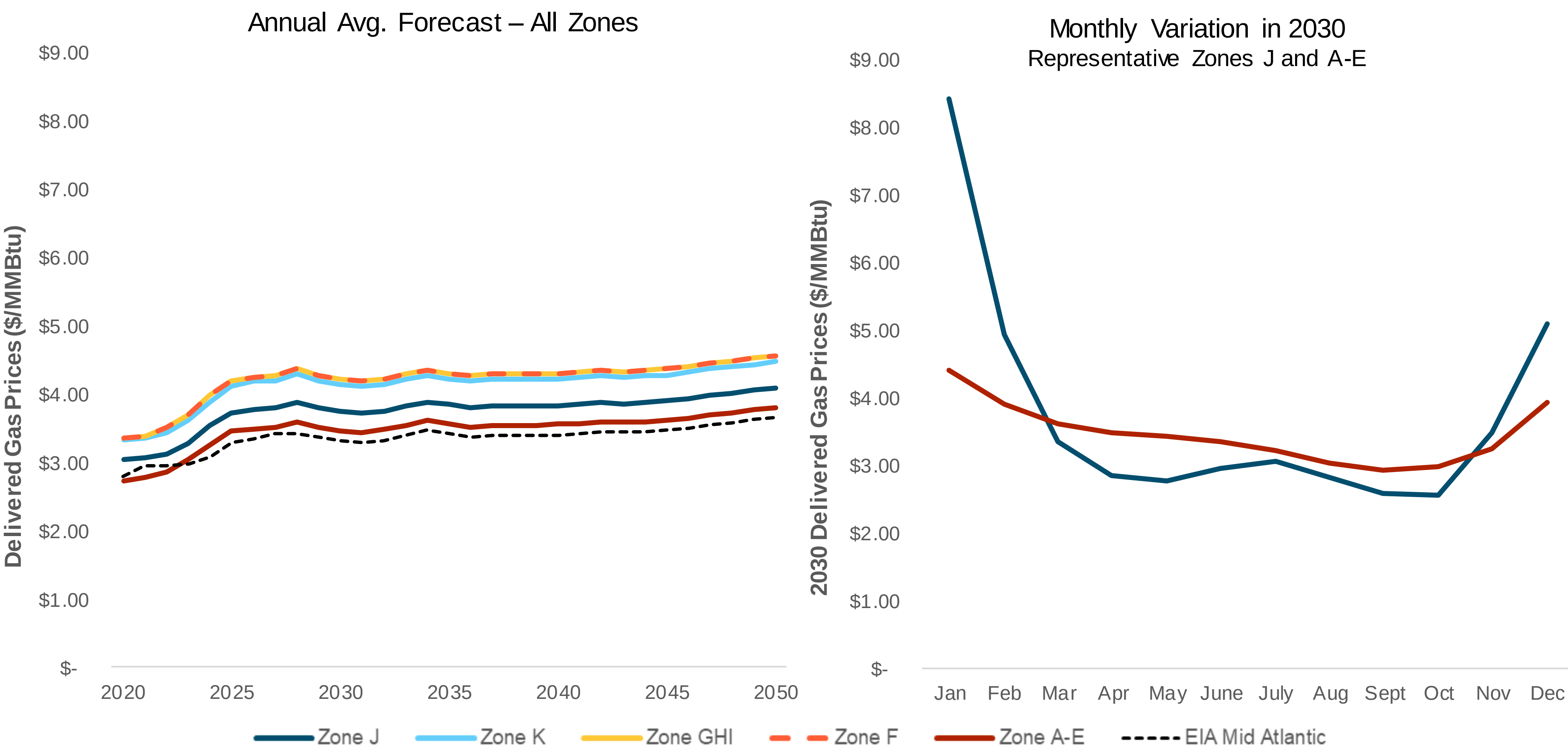


Sources: LBNL, NREL, Lazard. Charts reflect historical and projected national average costs.
The Integration Analysis will incorporate NY-specific and zone-specific resource costs and availability.

Fuel Costs

+ **Fuel cost projections are developed using NYISO CARIS prices by zone, with long-term escalation from EIA Annual Energy Outlook**
  - Monthly shaping also derived from NYISO CARIS projections

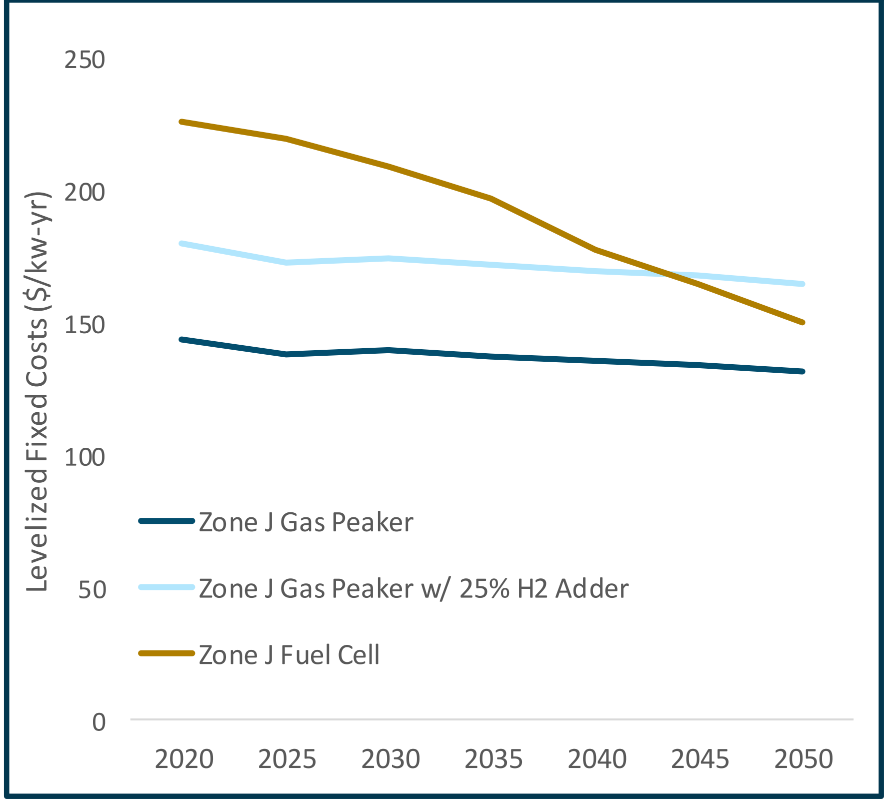
Delivered Natural Gas Price Forecast by Zone



Accelerated Transition away from Combustion: Electric Sector Considerations

- **Integration Analysis includes exploration of transition away from combustion-based resources**
- **A generic firm resource is included to help meet reliability needs, modeled with the following characteristics:**
  - No GHG emissions
  - No local air pollution
  - Firm dispatchable capacity over period of days to weeks
  - Cost projections are based on hydrogen fuel cell with learning curve similar to electrolyzers

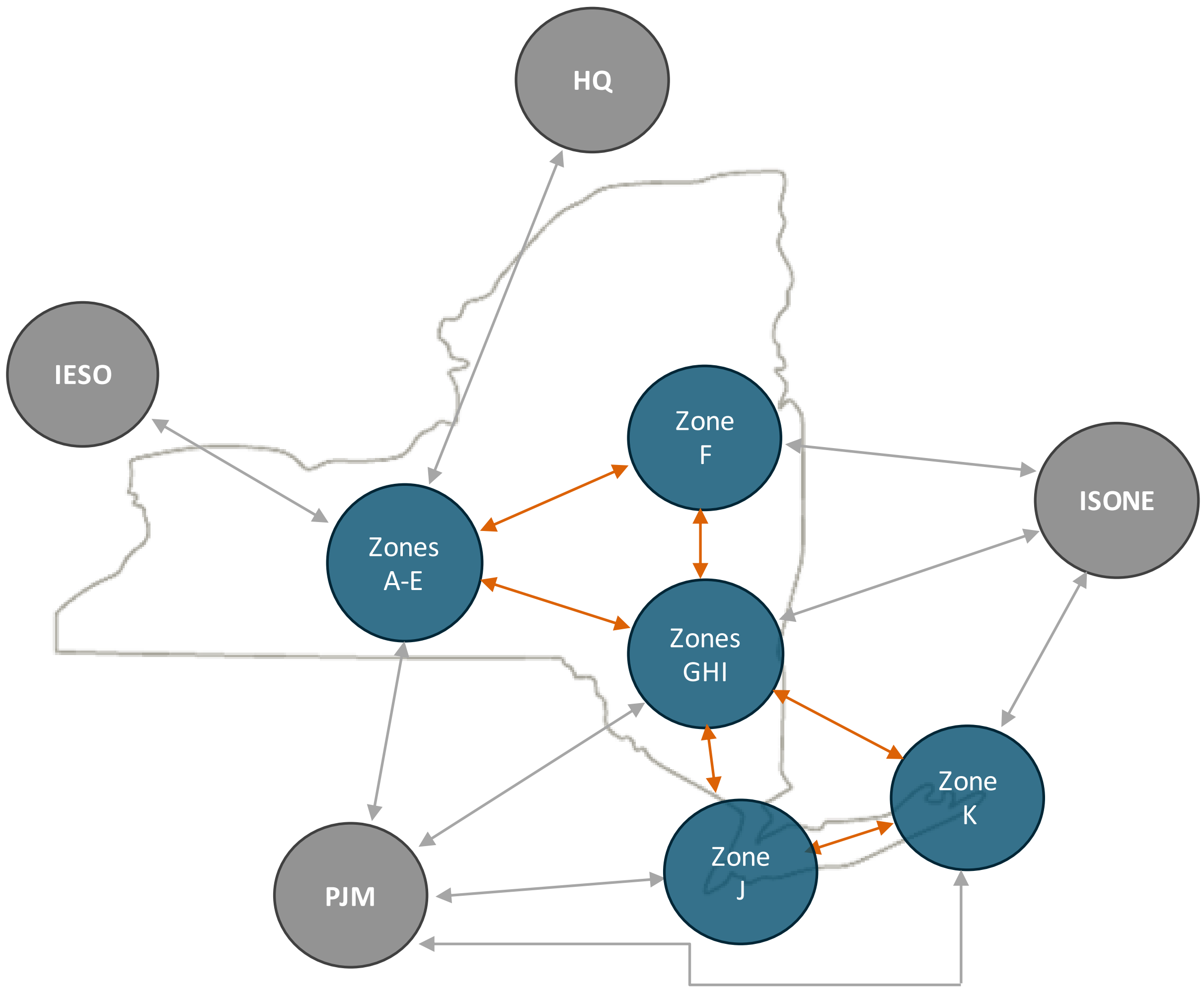
Hydrogen Resources



Source: Fuel cell 2020 costs and operating characteristics sourced from DOE Fuel Cell Technologies Office Targets; cost declines mirror electrolysis learning curves.

Bulk Transmission

- Updated framework contains more detailed representation of Downstate NY
- Captures important local dynamics including CES Tier 4, impacts of offshore wind on zonal capacity requirements
- Costs of Bulk Transmission upgrades are based on recent NY transmission project costs
- Incorporates learnings from Power Grid Study



Local Transmission Upgrades

- Multiple studies have found that local transmission congestion will need to be alleviated to integrate large quantities of renewables in New York State (e.g. NYISO CARIS)
- NY Utilities developed reports of the costs of local transmission upgrades in their service territories
- Studies indicate a very wide range ($18-96/kW-yr) without geographic correlation
  - e.g. ConEd Phase 1 and Phase 2 projects fall on high and middle end of range, respectively
- Approach uses central average of $63/kW-yr for local transmission upgrades across all zones
- Assumes new renewables capacity incur transmission costs for 60% of nameplate (i.e. $38/kW-yr per MW installed)

Phase 1 Projects

	Cost ($M)	Benefit (MW)	Levelized Cost ($/kW-yr)
Central Hudson	$ 152	433	$ 35
ConEd	$ 860	900	$ 96
LIPA	$ 402	615	$ 65
National Grid	$ 773	1130	$ 68
NYSEG/RGE	$ 1,560	3041	$ 51
O&R	$ 417	500	$ 83

Phase 2 Projects

	Cost ($M)	Benefit (MW)	Levelized Cost ($/kW-yr)
Central Hudson	$ 138	766	$ 18
ConEd	$ 4,050	7686	$ 53
LIPA	$ 1,281	1830	$ 70
National Grid	$ 1,371	1500	$ 91
NYSEG/RGE	$ 780	943	$ 83

Source: Utility Transmission and Distribution Working Group Study, App. C to Initial Report on Power Grid Study, November 2020. E3 calculations used to convert to levelized costs.

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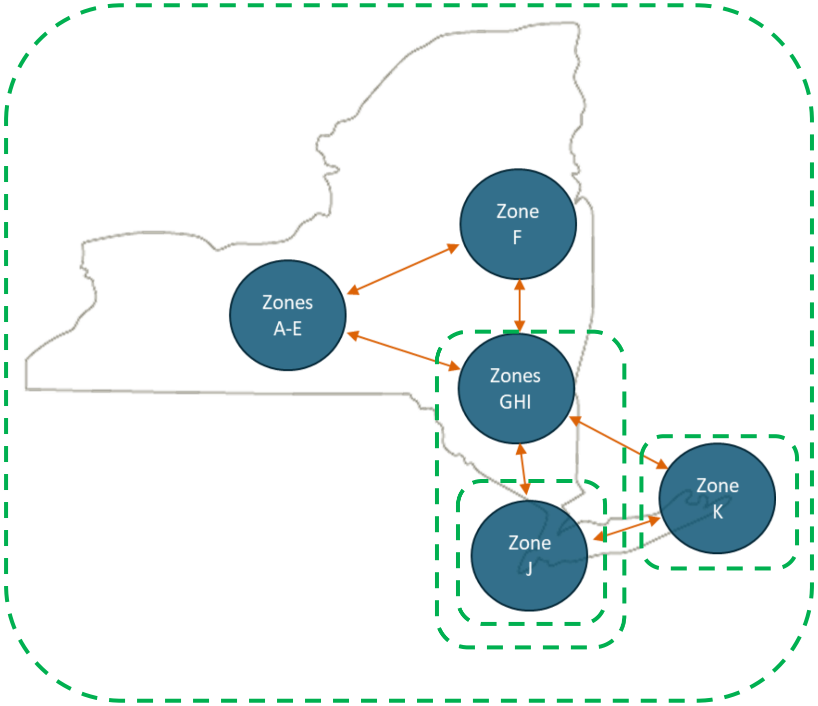
Reliability Analysis

Reliability Model

- ELCC surfaces/curves are developed for each PRM constraint, e.g. there is a separate storage ELCC curve for Zone J than for NYCA
- ELCC analysis is performed for both the Reference and Mitigation scenarios

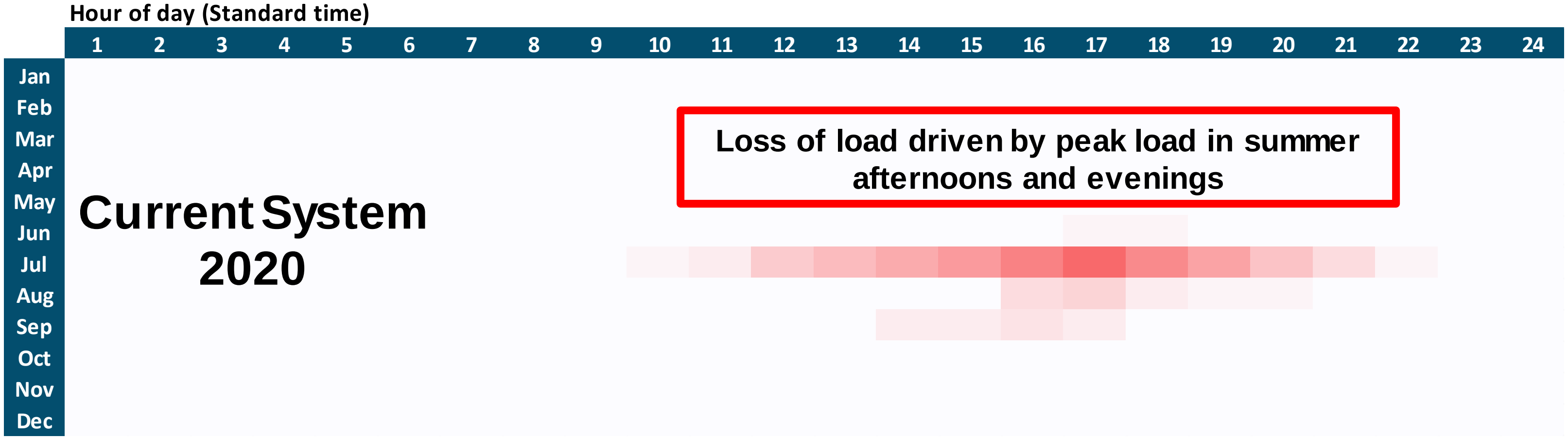
Zonal Grouping for PRMs	ELCC Surface(s) and Curve(s) built in order
NYCA	Ons - Ofs Wind, Solar – 4-hr Storage
G-J	Ofs Wind, Solar – 4-hr Storage
J	Ofs Wind, Solar – 4-hr Storage
K	Ofs Wind, Solar – 4-hr Storage

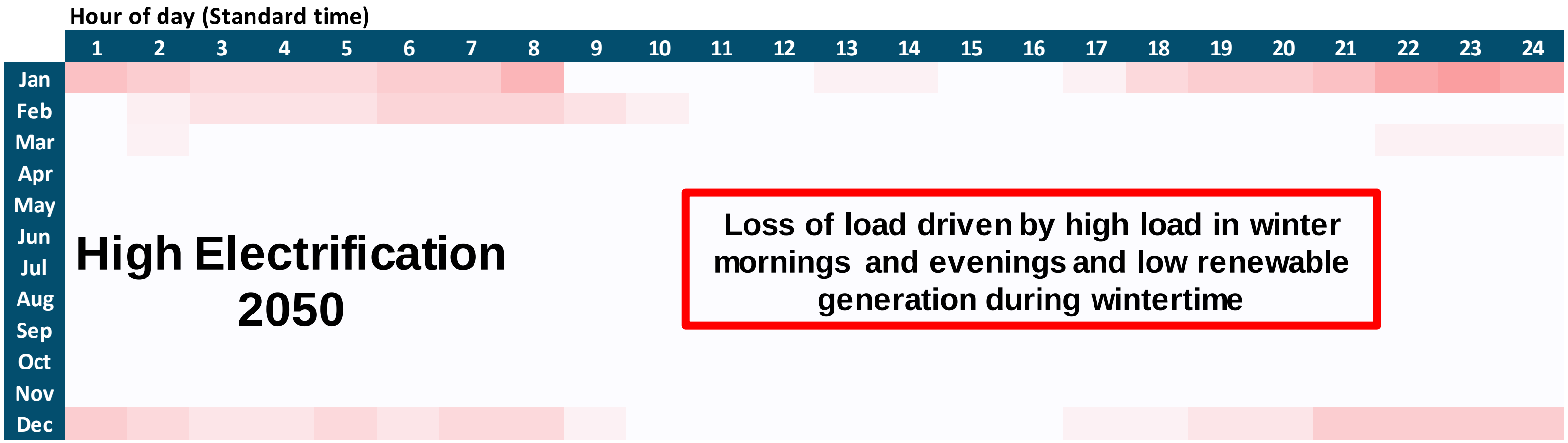


4 capacity requirements
5 zonal groupings for operational modeling

Impacts of Electrification on Reliability Challenges

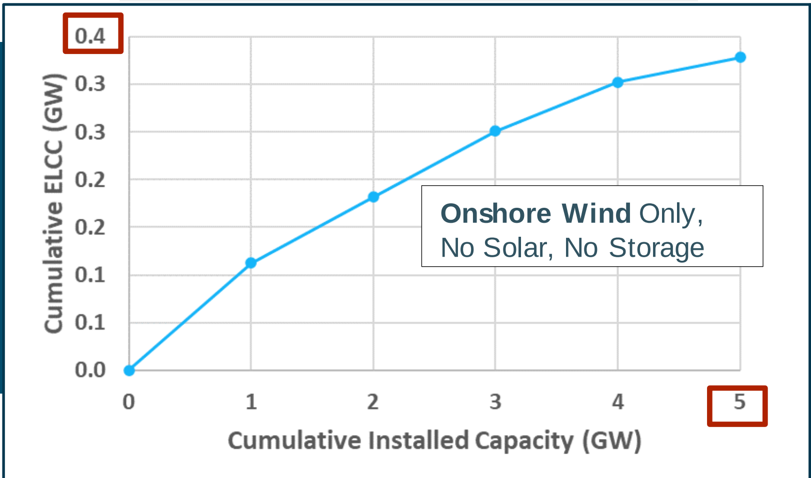
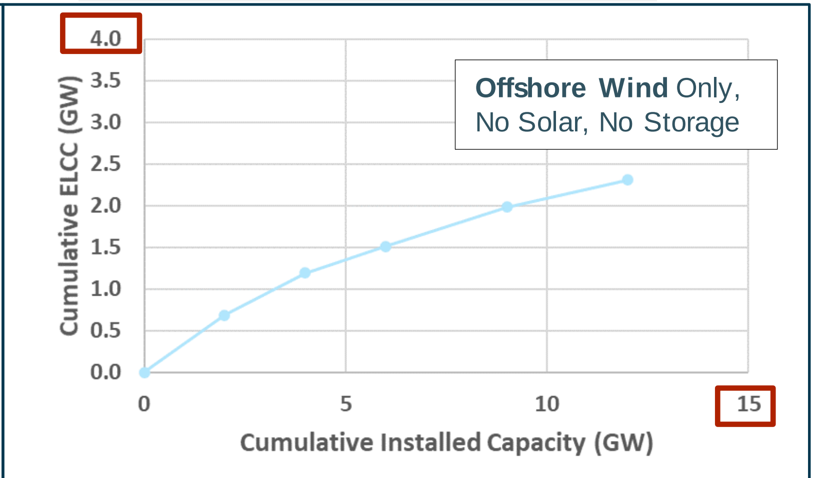
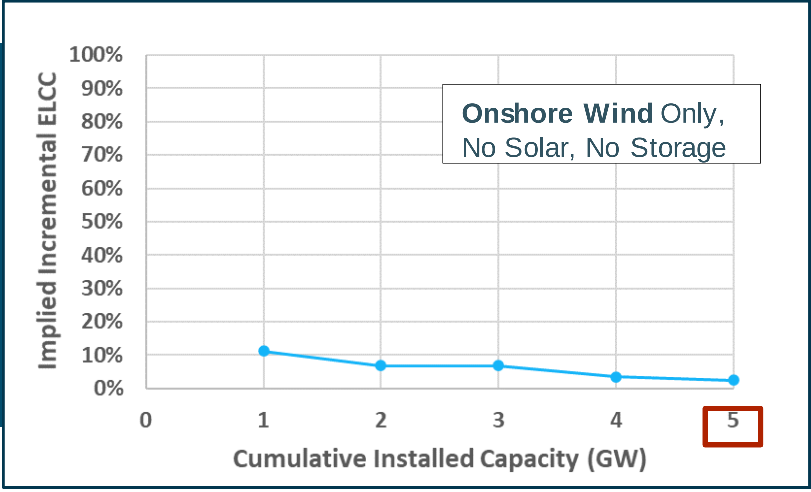
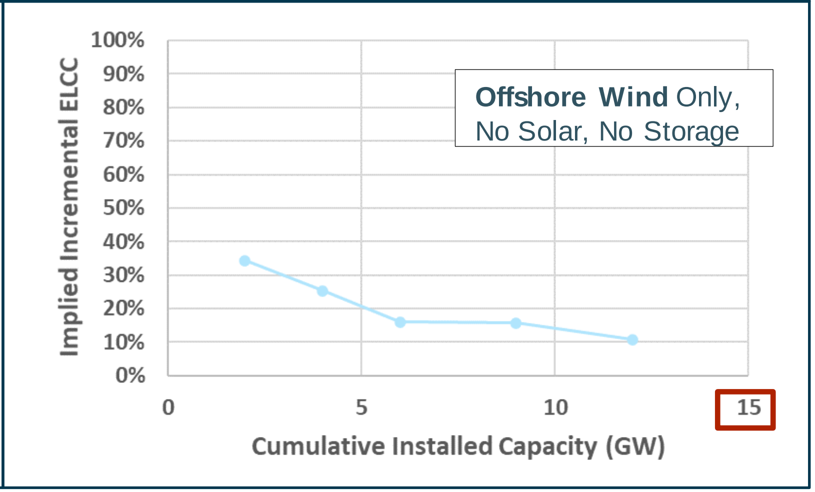
Loss of Load Probability Distribution by Month and Hour of the Day





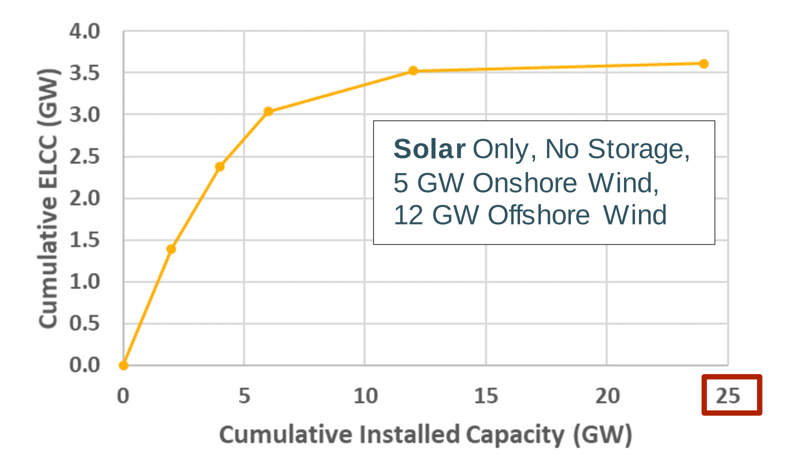
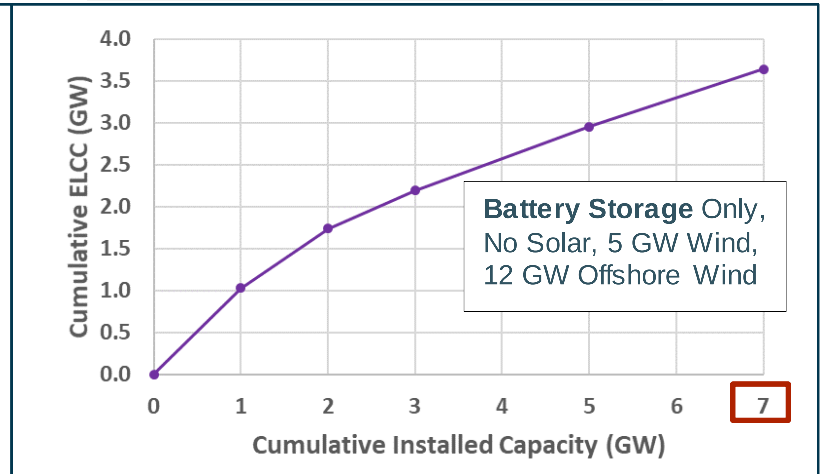
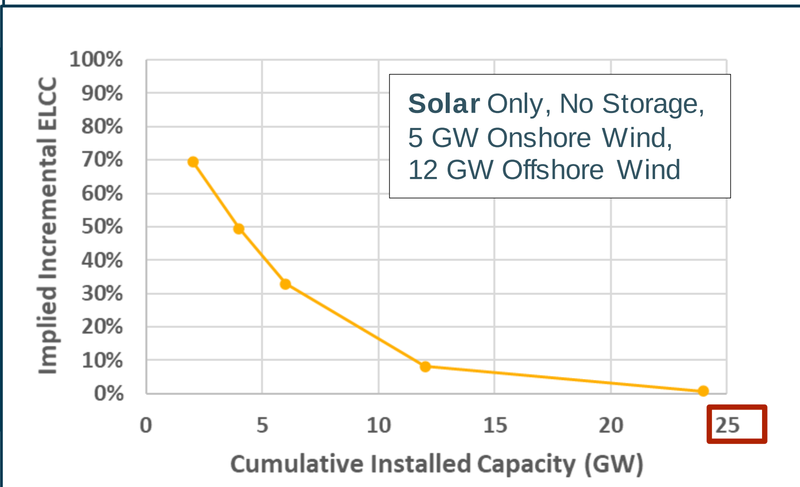
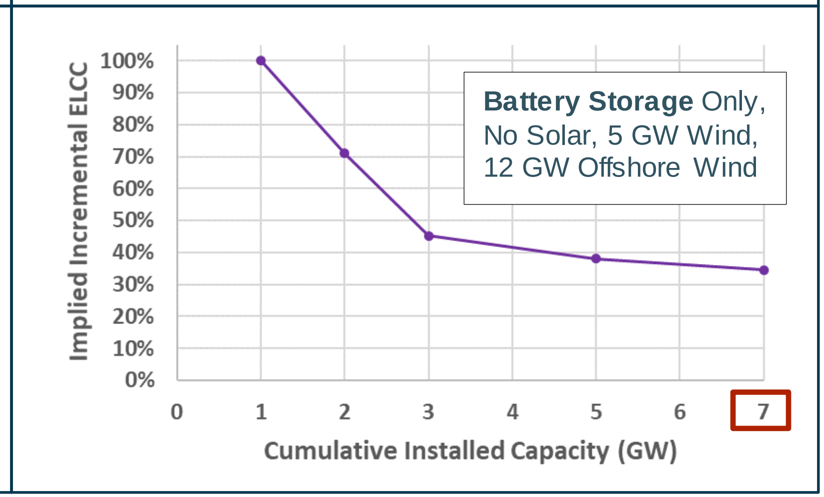
System likely starts running short earlier in the day; loss of load occurs once storage is exhausted

Renewable ELCC Curves
Reference Case Loads

	Onshore Wind	Offshore Wind
Slices of ELCC Surface		
Implied Incremental ELCCs		

Note the difference in X and Y axes

Renewable and Storage ELCC Curves
Reference Case Loads

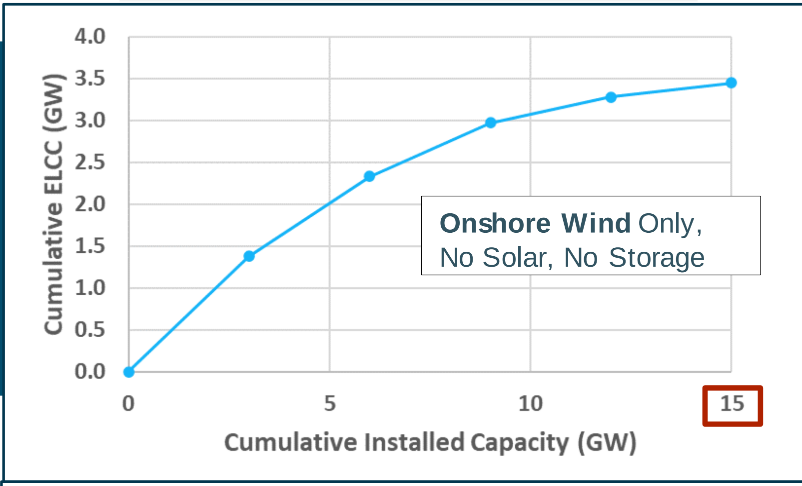
	Solar	4-hour Battery Storage
Slices of ELCC Surface		
Implied Incremental ELCCs		

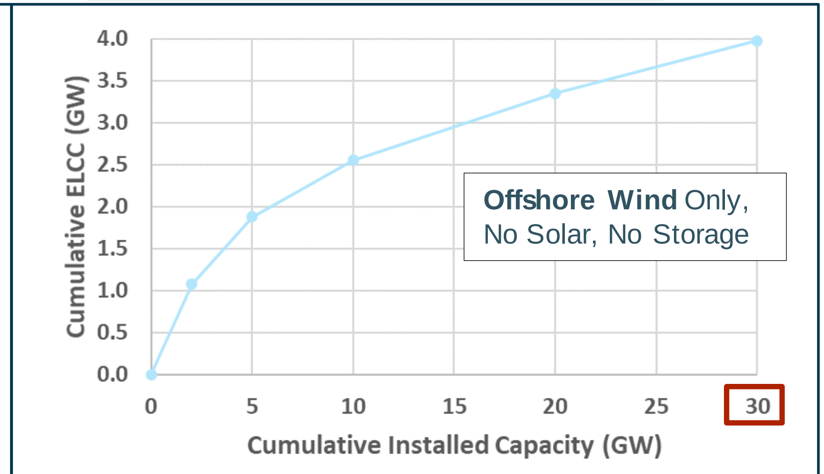
Note the difference in X and Y axes

Renewable ELCC Curves
High Electrification

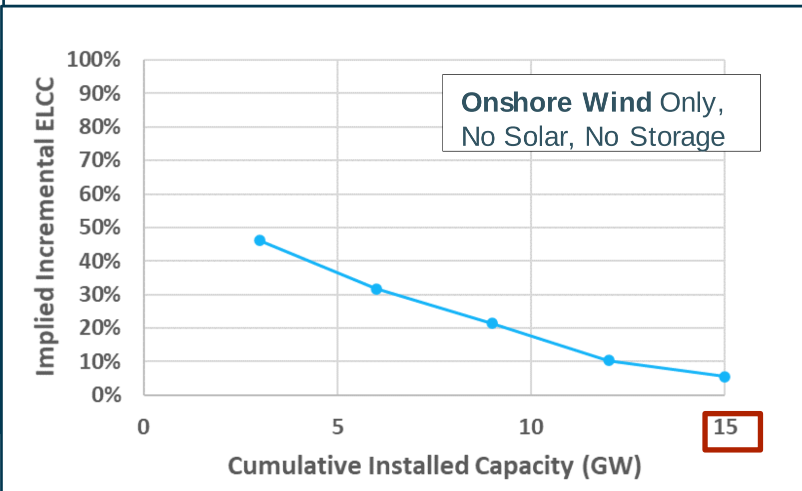
Onshore Wind | **Offshore Wind**

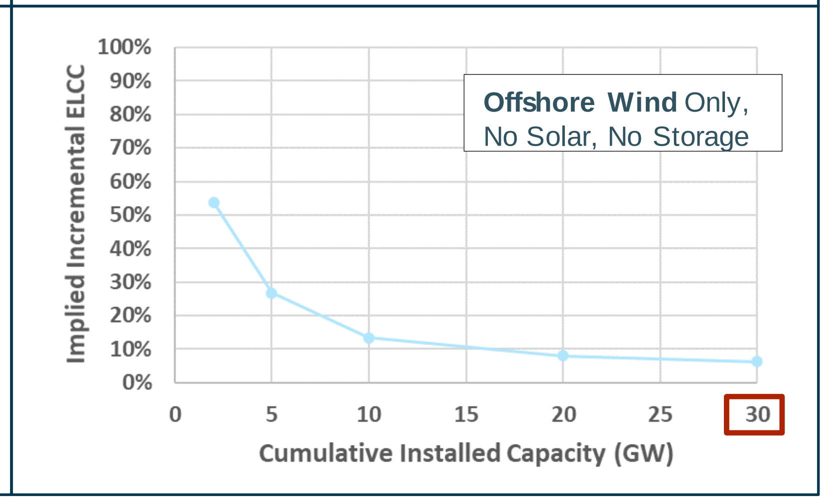
Slices of ELCC Surface





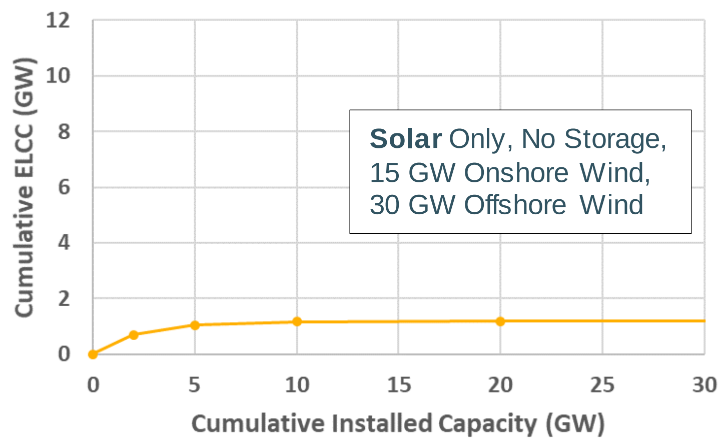
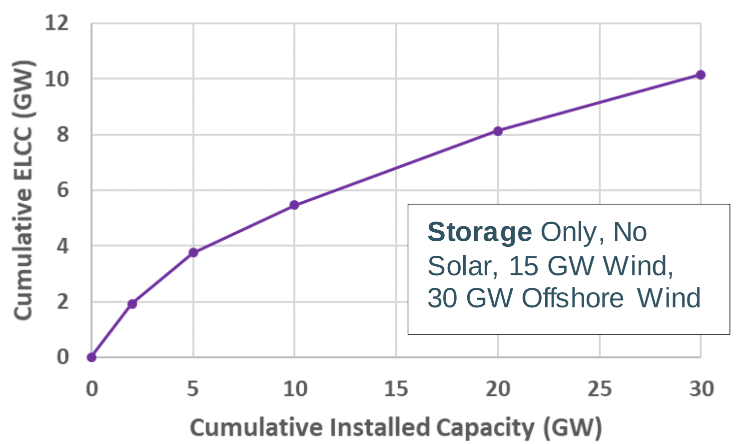
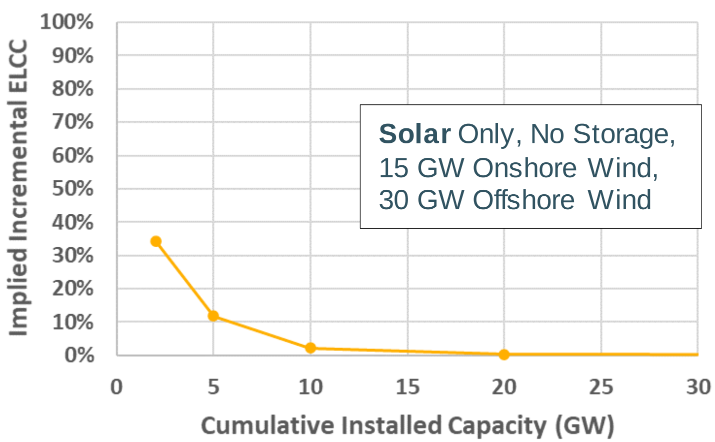
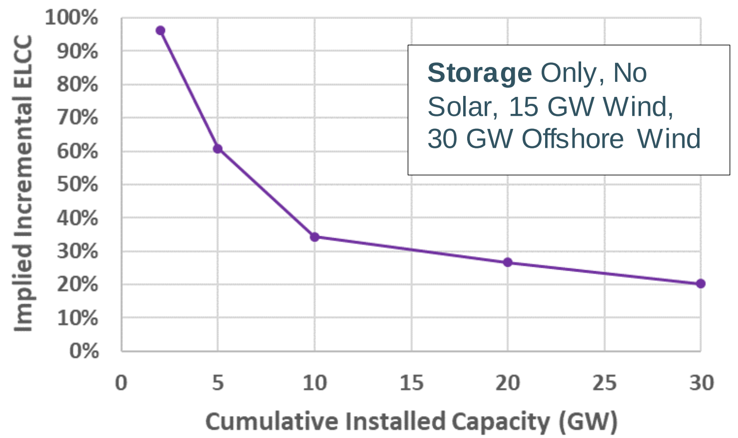
Implied Incremental ELCCs





Note the difference in X and Y axes

Renewable ELCC Curves
High Electrification

	Solar	4-hour Battery Storage
Slices of ELCC Surface		
Implied Incremental ELCCs		

Diversity Impacts on Average ELCCs for NYCA

Solar – 4-hr Storage

Reference

Diversity Impact (% of combined installed capacity)		Solar installed capacity (MW)					
		0	2,000	4,000	6,000	12,000	24,000
4 hr storage installed capacity (MW)	0	0%	0%	0%	0%	0%	0%
	1,000	0%	-6%	-2%	-1%	0%	0%
	2,000	0%	-7%	-4%	-1%	2%	1%
	3,000	0%	-6%	-4%	0%	6%	3%
	5,000	0%	-5%	-4%	-1%	9%	7%
	7,000	0%	-4%	-4%	-2%	7%	12%

High Elec

Diversity Impact (% of combined installed capacity)		Solar installed capacity (MW)					
		0	2,000	5,000	10,000	20,000	50,000
4 hr storage installed capacity (MW)	0	0%	0%	0%	0%	0%	0%
	2,000	0%	-2%	0%	0%	0%	0%
	5,000	0%	0%	2%	4%	4%	2%
	10,000	0%	-1%	1%	5%	6%	5%
	20,000	0%	-1%	0%	3%	5%	5%
	30,000	0%	-1%	0%	2%	4%	5%

Lack of diversity penalizes solar and storage when both are meeting peak in the middle of the day. Benefit is observed once net peak is narrowed and shifted into the evening

Onshore Wind – Offshore Wind

Reference

Diversity Impact (% of combined installed capacity)		Onshore wind installed capacity (MW)					
		0	1,000	2,000	3,000	4,000	5,000
Offshore wind installed capacity (MW)	0	0%	0%	0%	0%	0%	0%
	2,000	0%	1%	3%	2%	2%	2%
	4,000	0%	1%	2%	1%	2%	2%
	6,000	0%	1%	2%	2%	2%	2%
	9,000	0%	1%	2%	2%	2%	2%
	12,000	0%	1%	2%	2%	2%	2%

High Elec

Diversity Impact (% of combined installed capacity)		Onshore wind installed capacity (MW)					
		0	3,000	6,000	9,000	12,000	15,000
Offshore wind installed capacity (MW)	0	0%	0%	0%	0%	0%	0%
	2,000	0%	-1%	-3%	-3%	-2%	-1%
	5,000	0%	-1%	-2%	-2%	-2%	-1%
	10,000	0%	0%	-1%	-1%	-1%	0%
	20,000	0%	0%	0%	-1%	0%	0%
	30,000	0%	0%	0%	-1%	0%	0%

Negligible diversity impact is observed between onshore and offshore wind

Other

Non-Energy Emissions

Waste:

- Magnitude of emissions reductions per scenario were provided by the state team working group
- E3 developed cost assumptions for waste emissions from the EPA's *Global Non-CO2 Greenhouse Gas Emission Projections & Mitigation* report

Agriculture, Forestry and Other Land Use:

- Magnitude of emissions reductions and increase in sequestration per scenario were provided by the state team working group
- E3 developed cost assumptions from the EPA's *Global Non-CO2 Greenhouse Gas Emission Projections & Mitigation* report and WRI's *CarbonShot: Federal Policy Options for Carbon Removal in the United States* report

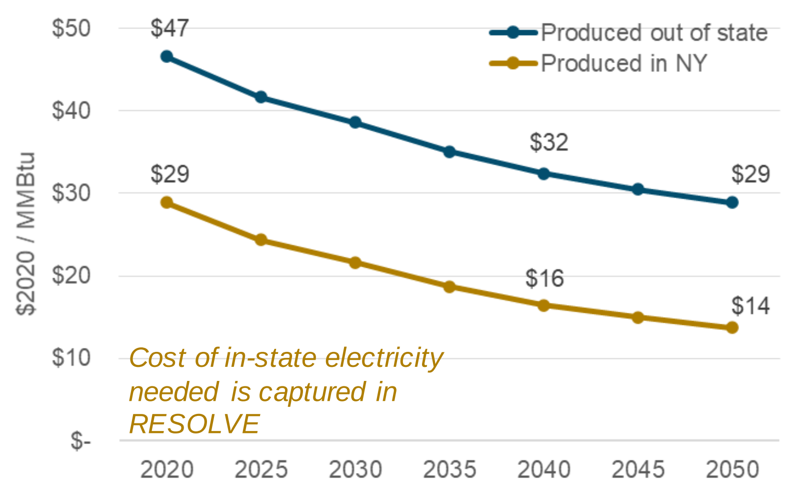
Industrial Processes and Product use:

- HFC emissions data and costs from *HFC Emissions Mitigation Potential Study*
- Other IPPU emissions assumptions were developed from the EPA's *Global Non-CO2 Greenhouse Gas Emission Projections & Mitigation* report

Hydrogen

+ **Hydrogen is a strategic low-carbon fuel in Scenarios 1 and 2, meeting demands in transportation, industry, and electricity generation.**
  - Under CLCPA accounting, hydrogen combustion achieves zero GHG emissions, although there are still local air pollutant implications to combustion (e.g., NOx emissions)
  - Hydrogen can be produced through a variety of pathways, including steam methane reformation (SMR), SMR with carbon capture and sequestration (SMR+CCS), biomass to hydrogen with carbon capture and sequestration (BECCS H2), and electrolysis
+ **In Integration Analysis scenarios, all hydrogen is assumed to be produced through electrolysis powered by electricity. Whether in-state or out-of-state, scenarios assume declining costs of electrolyzers and infrastructure over time**
  - Electrolysis costs
    – Costs of electrolyzer and infrastructure: \$21/mmbtu in 2030 declining to \$14/mmbtu in 2050
    – All-in costs, including dedicated electricity production: \$37/mmbtu in 2030 declining to \$29/mmbtu in 2050
  - Electrolyzer efficiency
    – Efficiency of electrolysis: 70% in 2030 increasing to 75% in 2050
+ **In addition to cost for electrolyzers, infrastructure, and transportation Integration Analysis includes an additional cost to represent the cost for building long-term hydrogen storage systems**
  - Range of costs for hydrogen storage sourced from Sandia National Lab, Economic Analysis of Large-Scale Hydrogen Storage for Renewable Utility Applications (2011)

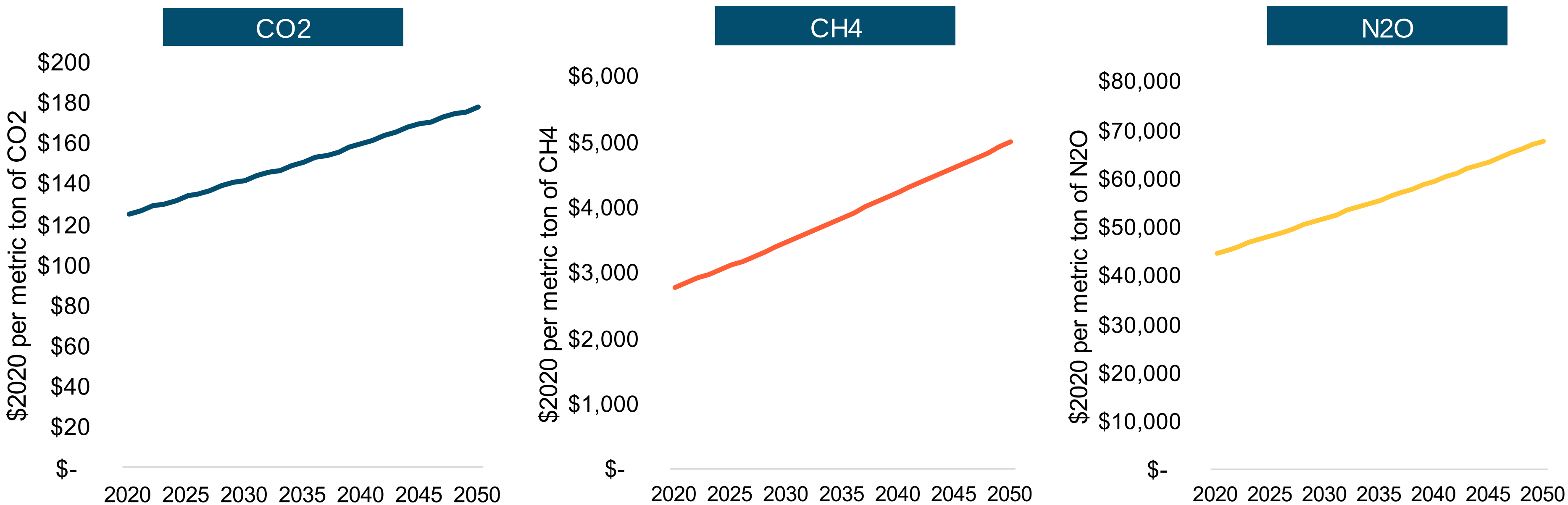
Price of Hydrogen (\$2020/MMBtu)



Fifty percent of the hydrogen is assumed to be produced out of state and transported to New York via dedicated pipeline, while the remaining fifty percent is assumed to be produced within the state as part of grid-connected resource.

Social Cost of GHGs

- **Social cost of GHG mitigation was sourced from DEC Value of Carbon Final Appendix**
  - DEC's central estimate (2%) was used when evaluating avoided emissions benefits
  - https://www.dec.ny.gov/docs/administration_pdf/vocfapp.pdf



Negative Emissions Technologies (NETs): Direct Air Capture

- **Direct Air Capture (DAC) is used as a proxy for negative emissions technologies (NETs) which are used to reduce emissions in Scenarios 2 and 3, to close the gap between the gross emissions limit of 85% by 2050 and the carbon neutral target**
  - Costs for Direct Air Capture are estimated using plant configurations and CAPEX from Keith, et al. 2018: https://www.sciencedirect.com/science/article/pii/S2542435118302253

Key DAC Costs