100 Percent Study Update Meeting

February 18, 2022

Fred Kelley

Power Plant Research Program

Kevin Porter
Katherine Fisher
Matthew Hoyt

Exeter Associates, Inc.

Chris Clack
Aditya Choukulkar
Sarah McKee
Brianna Cote

Vibrant Clean Energy

EXETER
ASSOCIATES, INC.

Today's Presentations

Study Scope and Status

Discussion Topics

Amended Project Schedule

Photo Credit: Peter Haas via Wikimedia Commons
http://commons.wikimedia.org/wiki/File%3APower_Lines_DSC1993w.jpg

Study Scope

Scope based on requirements in the Clean Energy Jobs Act (CEJA) of 2019 and correspondence with State Senator Brian Feldman in February 2021.

- Redo selected portions of the Maryland RPS Study that PPRP submitted to the Maryland General Assembly in December 2019
- Assess the costs and benefits of a 100% RPS and a 100% clean energy standard by 2040
- Determine which industries and communities could be positively and negatively impacted
- Design mechanisms to alleviate any negative impacts for affected workers and communities
- Provide recommendations for changes to the Maryland RPS or make recommendations for incorporation into future proposals for a Maryland clean energy standard

Status

- Planning to do three model runs initially
  - Base case (economic run with current Maryland RPS)
  - 100% RPS
  - 100% clean energy (modeled after proposed, but not enacted, Clean and Renewable Energy Standard)
- We've made several changes to inputs and assumptions since we last met, and we thought it would be helpful to have input from the working group

Today's Presentations

Study Scope and Status

Discussion Topics

Amended Project Schedule

Photo Credit: Peter Haas via Wikimedia Commons
http://commons.wikimedia.org/wiki/File%3APower_Lines_DSC1993w.jpg

Discussion Topics

- Transmission in PJM
- Maryland Greenhouse Gas Emissions Reduction Act
- Illinois Clean Energy Jobs Act
- Geothermal Heating and Cooling
- Combined Heat and Power

Discussion Topics (cont.)

- Carbon Capture and Storage (CCS) (including biomass)
- Biomass and Hybrid Resources
- Small Modular Reactor (SMR) Costs
- Discount Rate
- Offshore Wind Build-Out

Approximations and Model Run Time

- There's a tradeoff between precisely modeling every aspect of the electric power industry and the amount of time needed to run VCE's model
- Some approximations are necessary to adequately capture what we are trying to model while also maintaining a manageable model processing time
- Much of what we will talk about today involves those approximations

Transmission

Transmission Modeling Overview

- In the VCE model, transmission buildout and flows can be modeled from state-level resolution down to nodal resolution
- For the current modeling, transmission buildout is modeled down to county level resolution over the whole domain
- Transmission flow are aggregated in the model to state-level resolution over the modeled domain, expect for Maryland, where flows are aggregated to county-level resolution

Transmission in PJM

- VCE's model originally assumed:
  - All transmission expansion as new builds with double-circuited lines, with substations every 100 miles
  - Retired plants opened new transmission capacity on existing lines at the retired generation node
- For the current modeling, VCE added ability to upgrade existing lines
  - Upgrade potential of all lines within the model domain is evaluated assuming that lines can be upgraded only one voltage class (e.g. from 138 kV to 230 kV)
  - Cost numbers from PJM Offshore Wind report, rebuild option (see next slide) for the voltage class being upgraded to used.

Transmission Costs

Cost Estimates for New Transformers ($M per unit)	**138 kV** High Side	$4
	230 kV High Side	$6
	345 kV High Side	$9
	500 kV High Side	$25
	765 kV High Side	$45

Cost Estimates for Transmission Line Upgrades ($M per mile)	Upgrades	Reconductor	Loadings	Rebuild	Loadings
	115 kV & 138 kV	$0.8	≤ 400 MVA	$1.2	> 400 MVA
	230 kV	$1.2	≤ 1,200 MVA	$1.8	> 1200 MVA
	345 kV	$2.0	≤ 1,800 MVA	$3.0	> 1,800 MVA
	500 kV	$5.5	≤ 4,000 MVA	$8.0	> 4,000 MVA
	765 kV	$8.0	≤ 6,000 MVA	$12.0	> 6,000 MVA
	230 kV Cable	$15 ($M per mile)			

Source: PJM Interconnection. *Offshore Wind Transmission Study: Phase 1 Results*, October 19, 2021.

Maryland Greenhouse Gas Emissions Reduction Act

Maryland Greenhouse Gas Emissions Reduction Act

- The Maryland Greenhouse Gas Emissions Reduction Act (GGRA) sets a target for the state to meet a 40% reduction in statewide greenhouse gas (GHG) emissions from 2006 levels by 2030
- The Maryland Department of Environment's GGRA plan issued last year calls for a 48.7% reduction in statewide GHG emissions
- We view this as a goal, not a requirement, and are not including it in our initial three scenario runs. A similar standard applies to goals in other states
- Remember that we are only looking at the electricity sector in this study, not the entire economy
- It is also quite possible that either or both of the 100% RPS and 100% clean energy scenarios will meet the GGRA goal
- We almost certainly will have a sensitivity case on climate change and we will want the working group's input as to what that sensitivity case should be. Some possibilities:
  - 50% reduction by 2030
  - Net zero by 2050
  - Legislation pending before the Maryland General Assembly

Illinois Clean Energy Jobs Act

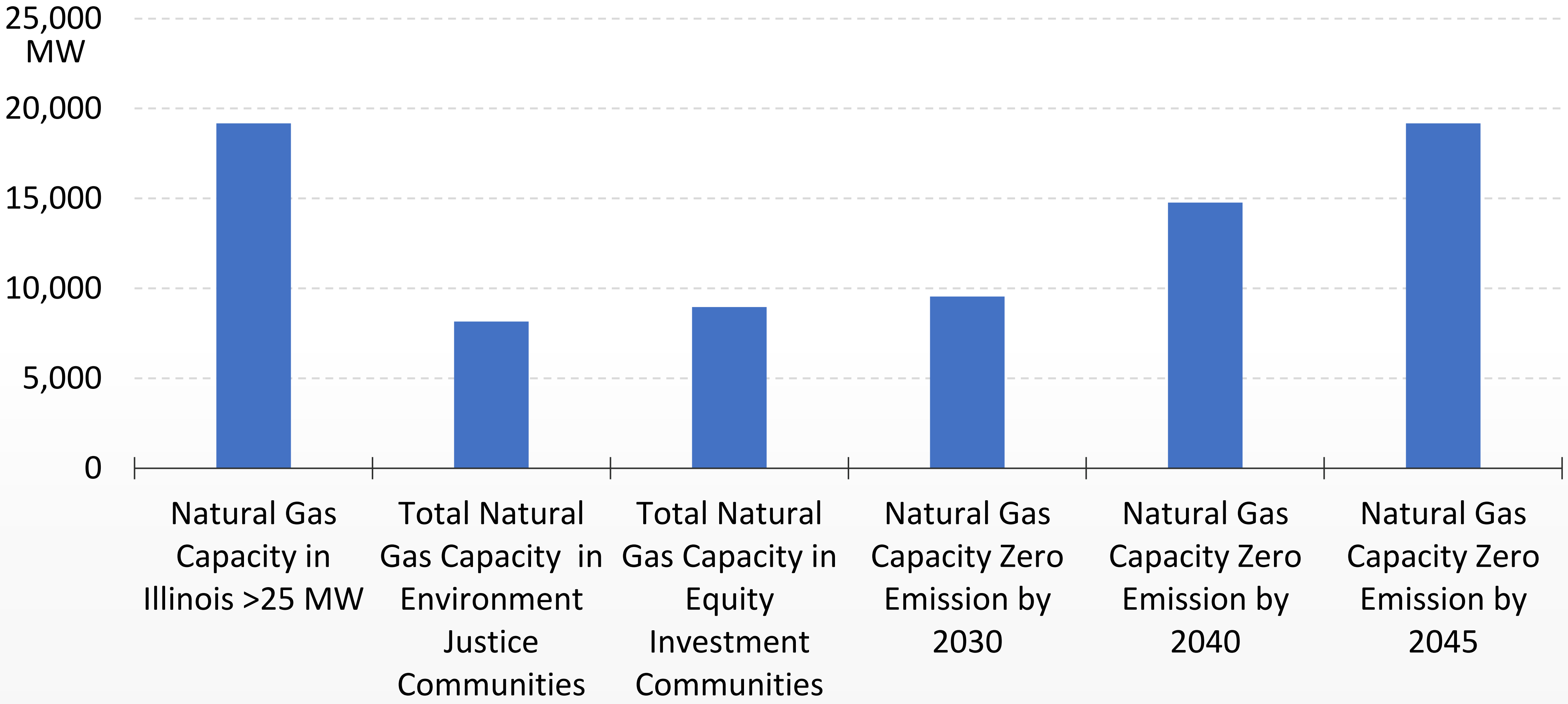
Many Changes to Model Inputs and Assumptions from Enactment of the Illinois Clean Energy Jobs Act

- Illinois was the largest source of renewable energy credits (RECs) for Maryland RPS compliance in 2020 (24%)
- Because of the many changes from the Illinois CEJA, we'll model all of Illinois rather than just the portion of Illinois that is in PJM. This will avoid a non-optimal buildout of variable renewables in Commonwealth Edison (ComEd) by including solar and wind resources in other parts of Illinois
  - Illinois RPS increased to 40% by 2030 and 50% by 2040
  - Illinois state policy to transition to 100% clean energy by 2050, but we are not modeling it because it's beyond our 2040 target year
  - We assume that the Braidwood, Byron, and Dresden nuclear power plants do not retire while receiving financial support
  - We assume actual energy efficiency requirement is net of "deemed annual savings" and "annual energy efficiency" targets (annual minus deemed)

Thermal Plant Provisions in Illinois CEJA

- The Illinois CEJA has several provisions for fossil-fueled plants to be either retired or at zero emissions by certain dates, with the actual dates dependent on ownership, level of air emissions, and location to environmental justice (EJ) communities (more in Appendix)
- Plant exemptions from these deadlines are available if an RTO states the plant is essential to maintain reliability. We are not applying any exemptions at this point

Natural Gas Capacity in Illinois Affected by the Illinois CEJA



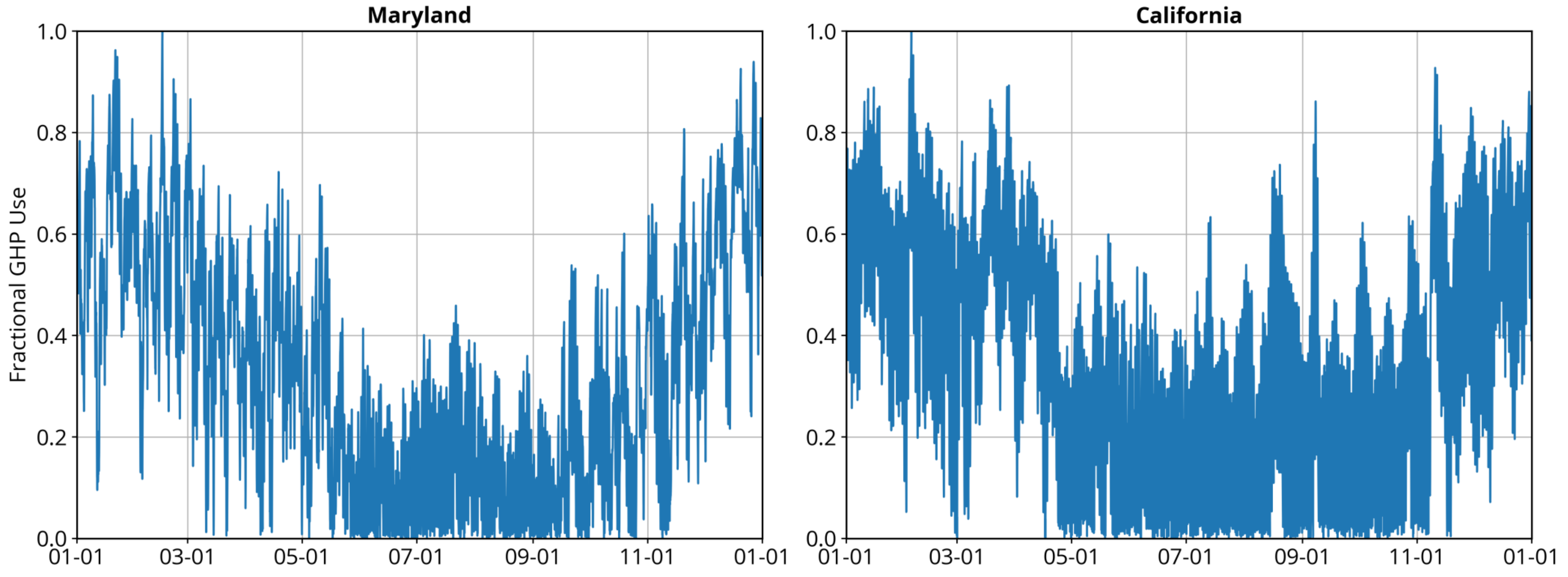
EXETER
ASSOCIATES, INC.

Geothermal Heating and Cooling

Geothermal Fuel Switching

- A geothermal heat pump (GHP) will replace some electric heaters and A/C units in a dwelling. This technology has a carve-out in the Maryland RPS
- Using data from PJM-GATS, VCE incorporated the current installed capacity of distributed GHP for Maryland
- VCE's model will optimize the size of the GHP systems needed
- VCE incorporates the GHP into the overall cost equation of the model to be optimized. GHP also reduces the load on the grid due to its higher efficiency as compared to the combination of air-conditioning and resistance heating
- Model won't allow utility-scale geothermal to be built going forward

GHP Capacity Factors



EXETER
ASSOCIATES, INC.

Combined Heat and Power

Modeling of CHP in 100% Clean Energy Case

- Under a proposed Maryland Clean and Renewable Energy Standard, Combined Heat and Power (CHP) plants must meet certain efficiency requirements
  - For a full "clean energy resource credit", CHP must have an efficiency level of 90% or more
  - ¾ clean energy resource credit for efficiency levels between 75% and 90%
  - ½ clean energy resource credit for efficiency levels between 60% and 75%
- VCE incorporated this technology as an average between reciprocating engines and gas turbine technologies
  - Reciprocating engine – currently the most installed by unit count
  - Gas turbine – currently the most installed by capacity
- Because other CHP technologies saw only a small efficiency increase at high cost, we plan to only model an average of gas turbines and reciprocating engines as CHP units, even though they will not be eligible for a full clean energy resource credit

Data on Combined Heat and Power

	Gas Turbine	Reciprocating Engine	Gas/Reciprocating Average	Fuel Cell
Capital Cost ($/kw)	2323	2301	2312	6193
Fixed Cost ($/kw-yr)	54	15	35	N/A
Variable Cost ($/MWh)	8	10	9	42
Terms (years)	25	25	25	25
Heat Rate (MMBtu/MWh)	4.81	4.40	4.61	4.98
Sources: CEJA, MEA, Mondre				

Note: Variable cost for fuel cells includes both fixed and variable costs

Carbon Capture and Storage

Carbon Capture and Storage – Natural Gas

- Added data from the National Energy Technology Laboratory (NETL) to the model on retrofitting existing natural gas plants with CCS
- This is in addition to what is in the model for new fossil plants with CCS, which is drawn from the National Renewable Energy Laboratory's (NREL's) Annual Technology Baseline report
- Assume 95% efficiency for new natural gas + CCS and 90% for a CCS retrofit. We assume that will meet the requirements of CARES

	New Natural Gas Unit	Natural Gas CCS Retrofit Alone	New NG with CCS
Capital Cost ($/kw)	970	1407	2378
Fixed Cost ($/kw-yr)	28	38	66
Variable Cost ($/MWh)	2	4	6
Heat Rate (MMBtu/MWh)	6.36	N/A	7.64

Note: 2020 costs.

Carbon Capture and Storage – Biomass

- Cost data provided from Massachusetts Institute of Technology (MIT) for a new biomass unit with CCS. From this, VCE estimates costs of retrofit by subtracting the cost of a new biomass unit without CCS
- This technology is allowed double-credit for CARES
- Assume 90% efficiency for new biomass + CCS and 90% for a CCS retrofit. We assume that will meet the requirements of CARES

	New Biomass Unit	Biomass CCS Retrofit Alone	New Biomass with CCS (BECCS)
Capital Cost ($/kw)	4557	5108	9665
Fixed Cost ($/kw-yr)	119	65	184
Variable Cost ($/MWh)	5.9	3.6	9.5

Note: converted to 2020 $ from 2015 $.

Biomass and Hybrid Resources

Biomass and Hybrid Resources

- To minimize run time of the model, all biomass technologies are modeled as a block (e.g., waste-to-energy, landfill methane, wood waste, etc.)
  - Percentage of biomass generation that qualified for RECs fixed to 2020 values
  - RECs change in proportion to the generation of biomass in subsequent years which incorporates any changes in biomass capacity or usage
  - Black liquor will not be eligible for RECs after 2020
- Similarly, hybrid resources (e.g., solar and storage) are not modeled explicitly. The model does co-locate the resources on any given node and optimizes them with each other

Small Modular Reactor Costs

SMRs

- The SMR technology is going to be available as an option only for the Clean Energy scenario run
- Capital Cost Source:

Black, G.A., Aydogan, F., & Koerner, C.L. (2019). Economic viability of light water small modular nuclear reactors: General methodology and vendor data. *Renewable and Sustainable Energy Reviews.* Vol. 103, 248-258. https://www.sciencedirect.com/science/article/abs/pii/S1364032118308372?via%3Dihub

- Other Source: VCE Industry Partner

Capital ($/kw)	3569
Fixed ($/kw-yr)	85
Heat Rate (MMBtu/MWh)	10.45
Fuel Costs ($/MMBtu)	0.90
Ramp Rate (%)	0.75
Power Min (%)	0.00
Power Max (%)	0.95

Discount Rate

Discount Rate

- Previous plan was to use the NREL ATB rate of ~2-4% depending on technology
- Given inflationary pressures, we're proposing to raise that to 5.87%
  - From industry sources and partners (VCE)

Offshore Wind Build-Out in Maryland

Offshore Wind Build-Out in Maryland

- In December 2021, the Maryland PSC approved the issuance of Offshore RECs (ORECs) to US Wind and Skipjack for two offshore wind projects totaling 1,654 MW. Both projects are slated to come online by the end of 2026
- These projects are in addition to two other offshore wind projects, also by US Wind and Skipjack, representing 368 MW
- We previously had 1,200 MW of additional offshore wind as authorized by the Maryland CEJA
- Based on our understanding of expected online dates, we are assuming the following:
  - The first US Wind project (248 MW) comes online by 2025
  - The three remaining projects (1,774 MW) come online by 2027
- We are assuming interconnection into Sussex County, Delaware

Today's Presentations

Study Scope and Status

Discussion Topics

Amended Project Schedule

Photo Credit: Peter Haas via Wikimedia Commons
http://commons.wikimedia.org/wiki/File%3APower_Lines_DSC1993w.jpg

Amended Project Schedule

- March/April/May: Run model/analyze results; vet results with PPRP and working group, re-run model as needed
- June: Recommend sensitivity scenarios and vet with PPRP and working group, begin sensitivity model runs
- September: Finish sensitivity cases, analyze and share results with PPRP and working group
- December 2022/January 2023: Finish modeling, use model output for input-output modeling

Amended Project Schedule (cont.)

- March/April 2023: Finish input-output modeling, begin drafting report
- Fall 2023: Finalize and issue report
- January 1, 2024: Final deadline for providing the report to the governor per CEJA

Appendix

Environmental Provisions for Thermal Plants in Illinois Clean Energy Jobs Act

- All privately owned/investor-owned utility coal/oil plants must become zero emissions by January 1, 2030 or retire. Coal/oil plants owned by public utilities have until January 1, 2035
- All natural gas plants must be zero emissions or convert to green hydrogen by January 1, 2045. Some of these plants may have to have to meet these requirements earlier than 2045, depending on proximity to environmental justice communities and rate of emissions

Environmental Provisions for Thermal Plants in Illinois Clean Energy Jobs Act (cont).

- Non-public gas plants:
  - Reach zero emissions or retire or adopt 100% green hydrogen by:
    - 1/1/2030, if (NOx emissions >0.12 lbs/MWh or SO_2 emissions >0.006 lbs/MWh) and (located within 3 miles of an EJ community or equity investment eligible community)
    - 1/1/2035, if (operating prior to September 2021) and (NOx emissions <=0.12 lbs/MWh) and (SO_2 emissions <=0.006 lbs/MWh) and (located within 3 miles of an EJ community or equity investment eligible community)
    - Reduce existing CO_2 emissions by 50% by 1/1/2030
    - 1/1/2040, if
      - (NOx emissions >0.12 lbs/MWh or SO_2 emissions >0.006 lbs/MWh) and not (located within 3 miles of an EJ community OR equity investment eligible community)
      - Reduce existing CO_2 emissions by 50% by 1/1/2035 and limit operations to <=6 hours per day on average each calendar year except in ISO/RTO designated emergency conditions [when up to 25 consecutive hours is allowed]
      - Not already in compliance or retired and heat rate >=7,000 Btu/kWh
  - 1/1/2045, all remaining large electric generating plants must reach zero emissions or retire or adopt 100% green hydrogen, including cogeneration and combined heat and power

Assumptions in VCE Model – Reference Case (Current RPS)

Year	MD Tier 1 RPS Requirement* (%)	Solar (%)	Offshore Wind (MW)	Geothermal (%)	Tier 2 (%)	Total MD RPS Requirement (%)
2021	30.80	7.50	0	0	2.50	33.30
2022	30.10	5.50	0	0	2.50	32.60
2023	31.90	6.00	0	0.05	2.50	34.40
2024	33.70	6.50	270	0.15	2.50	36.20
2025	35.50	7.00	270	0.25	2.50	38.00
2026	38.00	8.00	2,044	0.50	2.50	40.50
2027	41.50	9.50	2,044	0.75	2.50	44.00
2028	43.00	11.00	2,044	1.00	2.50	45.50
2029	47.50	12.50	2,044	1.00	2.50	50.00
2030	50.00	14.50	2,044	1.00	2.50	52.50

US Wind Phase 1

US Wind Phase 2, Skipjack Phase 1 & 2

* Inclusive of carve-outs

EXETER ASSOCIATES, INC.

Assumptions in VCE Model – Reference Case (Current RPS, Coop)

Year	MD Tier 1 RPS Requirement* (%)	Solar (%)	Offshore Wind (MW)	Geothermal (%)	Tier 2 (%)	Total MD RPS Requirement (%)
2021	30.80	2.50	0	0	2.50	33.30
2022	30.10	2.50	0	0	2.50	32.60
2023	31.90	2.50	0	0.05	2.50	34.40
2024	33.70	2.50	270	0.15	2.50	36.20
2025	35.50	2.50	270	0.25	2.50	38.00
2026	38.00	2.50	2,044	0.50	2.50	40.50
2027	41.50	2.50	2,044	0.75	2.50	44.00
2028	43.00	2.50	2,044	1.00	2.50	45.50
2029	47.50	2.50	2,044	1.00	2.50	50.00
2030	50.00	2.50	2,044	1.00	2.50	52.50

* Inclusive of carve-outs

EXETER
ASSOCIATES, INC.

Assumptions in VCE Model – Reference Case (Current RPS, Muni)

Year	MD Tier 1 RPS Requirement* (%)	Solar (%)	Offshore Wind (%)	Geothermal (%)	Tier 2 (%)	Total MD RPS Requirement (%)
2021	18.45	1.95	0	0	2.50	20.95
2022	18.45	1.95	0	0	0.00	18.45
2023	18.45	1.95	0	0	0.00	18.45
2024	18.45	1.95	Max 2.5	0	0.00	18.45
2025	18.45	1.95	Max 2.5	0	0.00	18.45
2026	18.45	1.95	Max 2.5	0	0.00	18.45
2027	18.45	1.95	Max 2.5	0	0.00	18.45
2028	18.45	1.95	Max 2.5	0	0.00	18.45
2029	18.45	1.95	Max 2.5	0	0.00	18.45
2030	18.45	1.95	Max 2.5	0	0.00	18.45

* Inclusive of carve-outs

Assumptions in VCE Model – 100% Renewable Energy Scenario

Year	MD Tier 1 RPS Requirement (%)	Solar (%)	Offshore Wind (MW)	Geothermal (%)	Tier 2 (%)	Total MD RPS Requirement (%)
2031	55.00	14.50	2,044	1.00	2.50	57.50
2032	60.00	14.50	2,044	1.00	2.50	62.50
2033	65.00	14.50	2,044	1.00	2.50	67.50
2034	70.00	14.50	2,044	1.00	2.50	72.50
2035	75.00	14.50	2,044	1.00	2.50	77.50
2036	80.00	14.50	2,044	1.00	2.50	82.50
2037	85.00	14.50	2,044	1.00	2.50	87.50
2038	90.00	14.50	2,044	1.00	2.50	92.50
2039	95.00	14.50	2,044	1.00	2.50	97.50
2040	97.50	14.50	2,044	1.00	2.50	100.00

* Inclusive of carve-outs

Assumptions in VCE Model – 100% Clean Energy Scenario (CARES Act)

Year	Total (%)	Solar (%)	Offshore Wind (MW)	Clean Energy Tier (%)
2022	58.1	8.5	0	3.3
2023	60.4	9.5	0	4.2
2024	62.7	10.5	270	5.0
2025	65.0	11.5	270	5.8
2026	67.5	12.5	2,044	6.7
2027	70.5	13.5	2,044	7.5
2028	72.5	14.5	2,044	8.3
2029	74.5	14.5	2,044	9.2
2030	75.0	14.5	2,044	10.0
2031	77.5	14.5	2,044	12.0
2032	80.0	14.5	2,044	14.0
2033	82.5	14.5	2,044	16.0
2034	85.0	14.5	2,044	18.0
2035	87.5	14.5	2,044	20.0
2036	90.0	14.5	2,044	22.0
2037	92.5	14.5	2,044	24.0
2038	95.0	14.5	2,044	26.0
2039	97.5	14.5	2,044	28.0
2040	100.0	14.5	2,044	30.0

* Inclusive of carve-outs