Energy+Environmental Economics

NSPI Resource Options Study

Nova Scotia Power

July 2019 – Final Draft

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Outline

- **Resource options study approach**
- **Summary of proposed assumptions**
- **Details of resource options considered**
  - Renewables
    - Wind, utility-scale PV, biomass, municipal solid waste, tidal
  - Storage
    - Battery storage, compressed air, pumped storage
  - Fossil
    - Natural gas, coal repowering
  - Nuclear
    - Small modular nuclear

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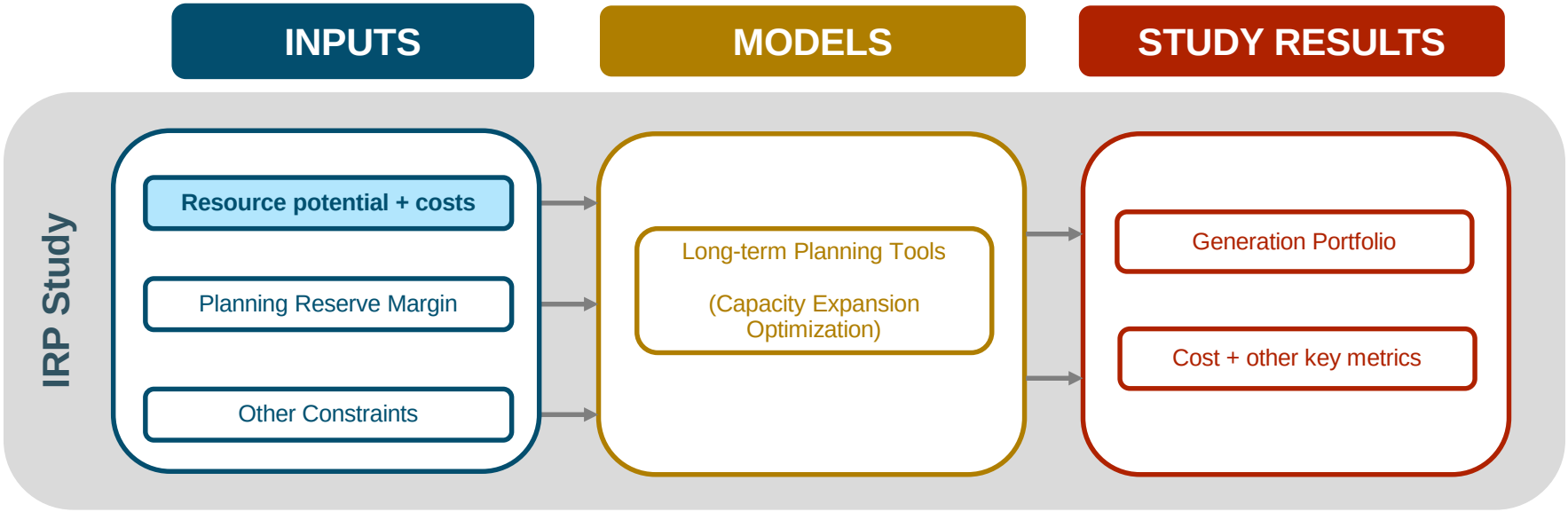
Resource options study approach

Approach

- **In preparation for its upcoming integrated resource plan, NSPI has asked E3 to provide guidance on resource costs and potential**
  - **Cost:** what are the costs (capital, O&M, fuel) associated with developing and operating each new resource? What future changes are expected?
  - **Performance:** what are the operational constraints associated with each resource (e.g. hourly profiles for wind/solar)
  - **Potential:** how much of the resource can be developed within Nova Scotia (or remotely)?



E3's Pro Forma Model

- **Resource costs are typically quoted in either upfront capital costs ($/kW) or levelized costs ($/MWh) that are indicative of likely PPA prices**
- **Levelized cost of energy* (LCOE) include several other cost factors and assumptions beyond the project's upfront capital cost**
  - Financing costs: cost of capital, financing lifetime, tax rates, and incentives
  - Operating costs: fixed and variable O&M of plant operations ("opex"), including fuel
  - Performance assumptions: amount of energy generation over which fixed costs are spread, i.e. average capacity factor, is a major driver of LCOE
- **E3's Pro Forma model produces both LCOE ($/MWh) at an estimated capacity factor as well as the fixed ($/kW-yr) and variable ($/MWh) cost components**
- **E3 analyzed all resources using NSPI's financing assumptions**
  - Independent power producer financing may result in changes to levelized costs

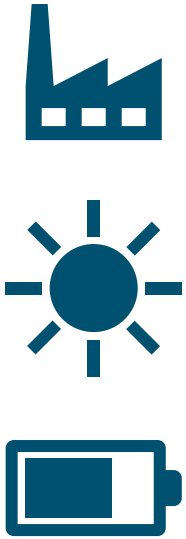
* In this study, LCOE is calculated using a real discount rate assuming that LCOE escalates at an inflation rate of 2%.

Resource Cost Modeling
Fixed vs. Variable Costs for New Resources

- **Fixed costs: expenditures required to install and maintain generating capacity, independent of operations**
  - Capital costs:
    - Overnight capital cost (equipment cost, balance of systems, development costs, etc.)
    - Construction financing
    - Nominal interconnection costs (i.e. a short spur line, not longer lines required for remote renewables)
  - Fixed O&M:
    - Operations and maintenance costs incurred independent of energy production
    - Insurance, taxes, land lease payments and other fixed costs
    - Annualized large component replacement costs over the technical life (aka sustaining capital)
- **Variable costs: marginal costs for each MWh of generation, based on modeled operations**
  - Variable O&M:
    - Operating and maintenance costs (parts, labor, etc.) incurred on a per-unit-energy basis
  - Fuel cost:
    - Commodity costs for fuel ($/MMBtu * heat rate MMBtu/MWh = $/MWh)
- **Capacity factor: annual energy production per kW of plant capacity**
  - Used to estimate variable costs as well as the spread of fixed costs over expected generation

Resource Options Considered

- **Fossil fuels:** coal-to-gas, coal-to-biomass, natural gas (CC, CT, reciprocating engine, CC w/ carbon capture and storage)
- **Renewables:** biomass, municipal solid waste, solar PV, tidal, wind (onshore and offshore)
- **Energy storage:** li-ion batteries, compressed air, pumped hydro
- **Emerging technologies**: modular nuclear



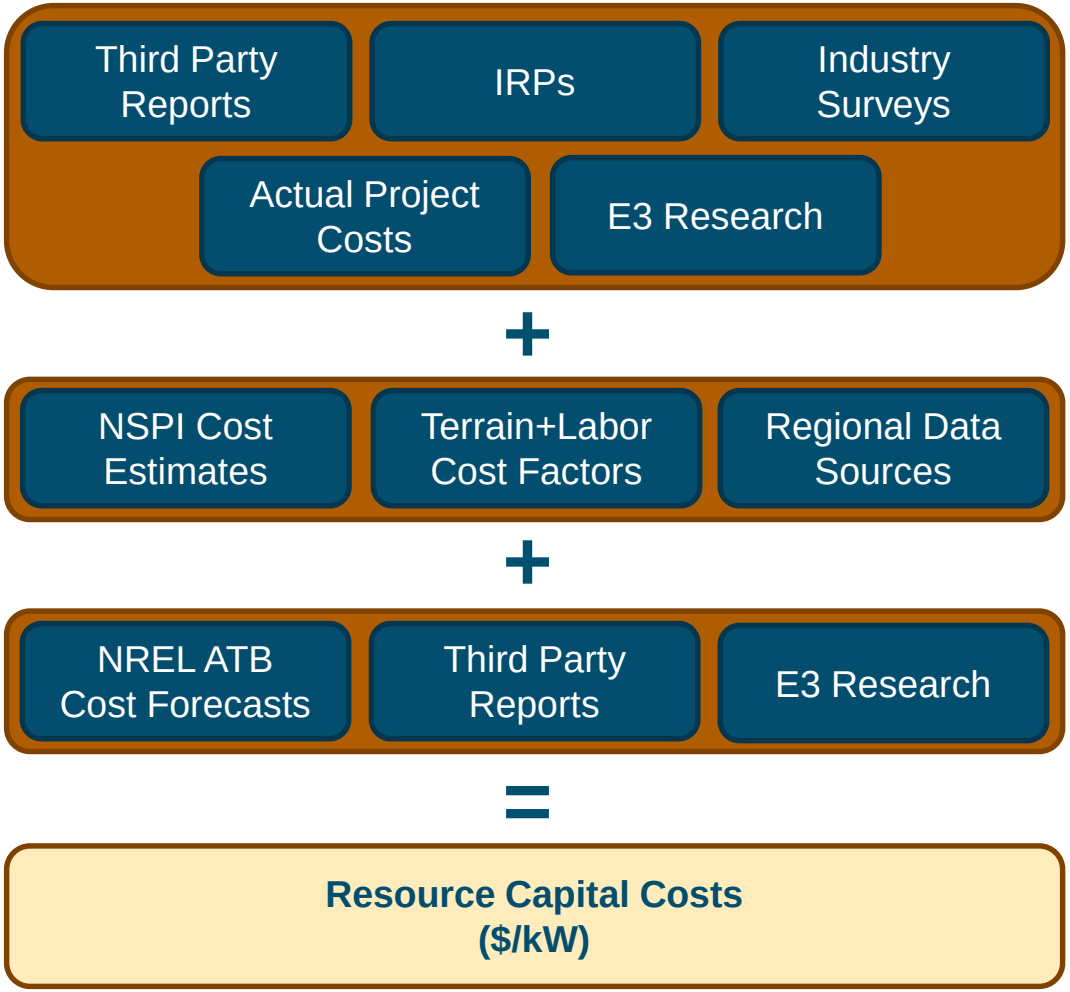
Resource Cost Modeling
Step 1: Capital Cost Assumptions

Generic Capital Costs
US/Global

Local Cost Adjustments
Nova Scotia

Future Cost Forecasts
2020-2050

E3 Recommendations
Nova Scotia, 2019-2050



NOTE: all US cost estimates converted to CAN dollars using a 1.32 exchange rate.

Resource Cost Modeling

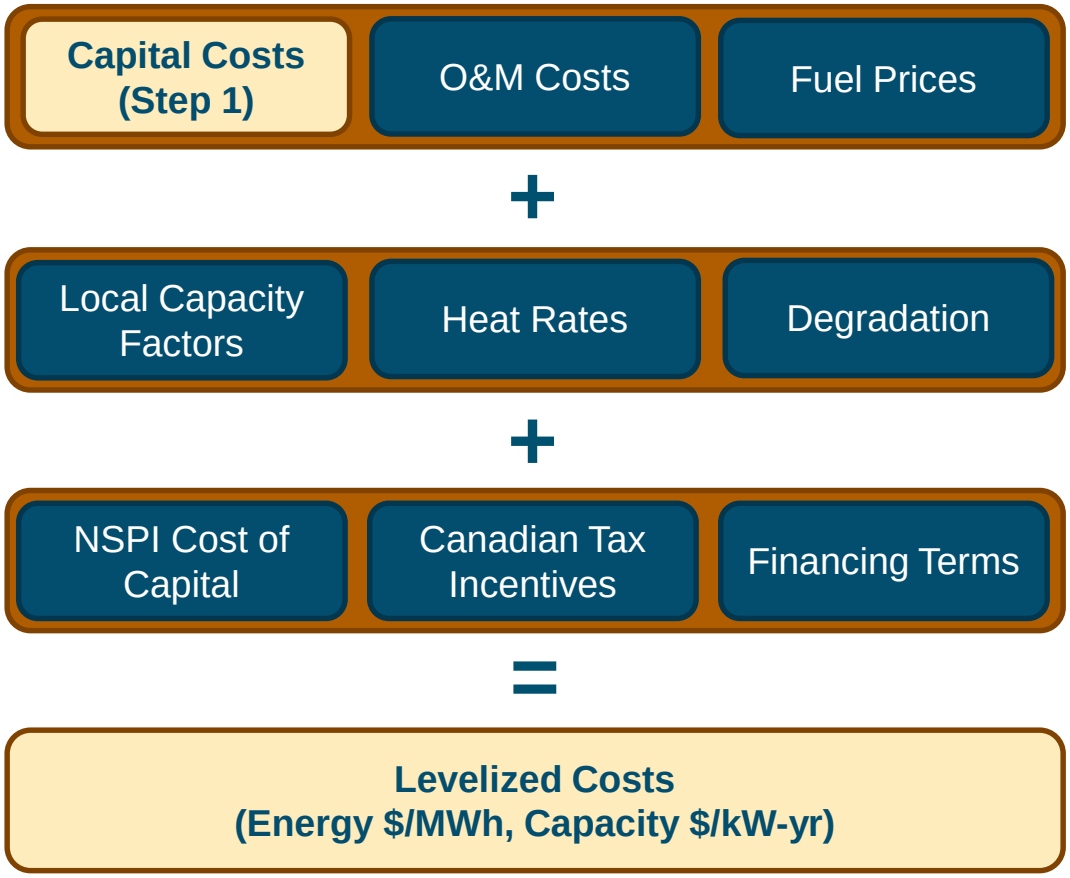
Step 2: Pro-Forma Financial Model

Resource Costs
Nova Scotia, 2019-2050

Resource Performance
Nova Scotia specific

Financing Assumptions
Based on NSPI Financing

Levelized Cost Forecasts
Costs to NSPI, 2019-2050



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Summary of proposed assumptions

Summary of Proposed Assumptions
Capital Costs (1 of 2) – Renewables and Storage

Technology	Subtechnology	Capital Cost (2019 CAD $/kW)		
		2019	2030	% Change
Wind	Onshore	$2,100	$1,959	-7%
	Offshore	$4,726	$3,340	-29%
Solar PV[a]	Tracking	$2,250	$1,803	-20%
Biomass	Grate	$5,300	$5,010	-5%
	Municipal Solid Waste	$8,470	$8,470	0%
Tidal	n/a	$10,000	$10,000	0%
Storage	Li-Ion Battery (1 hr)	$814	$410	-50%
	Li-Ion Battery (4 hr)	$2,325	$1,172	-50%
	Compressed air	$2,200	$2,200	0%
	Pumped Storage	$2,700	$2,700	0%

[a] Solar PV costs reported in $/kW-ac, reflecting an inverter loading ratio of 1.3

Summary of Proposed Assumptions

Capital Costs (2 of 2) – Fossil and Nuclear

Technology	Subtechnology	Capital Cost (2019 CAD $/kW)		
		2019	2030	% Change
Coal	Coal-to-gas conversion (102 – 320 MW)	$127 – 237	$127 – 237	0%
Natural Gas	Combined Cycle (145 MW)	$1,688	$1,609	-5%
	Combined Cycle w/ carbon capture and storage (145 MW)	$3,376	$3,101	-8%
	Combustion Turbine – Frame (50 MW)	$1,080	$1,031	-5%
	Combustion Turbine – Aero (50 MW)	$1,755	$1,676	-5%
	Reciprocating Engine (50 MW)	$1,823	$1,823	0%
Nuclear	Small modular reactor (100 MW)	$8,073	$7,731	-4%

Summary of Proposed Assumptions

Operating Costs – All Technologies

Technology	Subtechnology	Operating Cost	
		Fixed O&M ($/kW-yr)	Variable O&M ($/MWh)
Wind	Onshore	$54	$0
	Offshore	$108	$0
Solar PV	Tracking	$20	$0
Biomass	Grate	$162	$7
	Municipal Solid Waste	$162	$0
Tidal	n/a	$338	$0
Storage	Li-Ion Battery (1 hr)	$8	$0
	Li-Ion Battery (4 hr)	$27	$0
	Compressed air	$20	$0
	Pumped Storage	$32	$0
Coal	Coal-to-gas conversion	$37-$45	$1
	Coal-to-biomass conversion	$152	$7
Natural Gas	Combined Cycle	$14	$3
	Combustion Turbine - Frame	$12	$7
	Combustion Turbine - Aero	$17	$7
	Reciprocating Engine	$27	$9
Nuclear	Small modular reactor	$203	$0

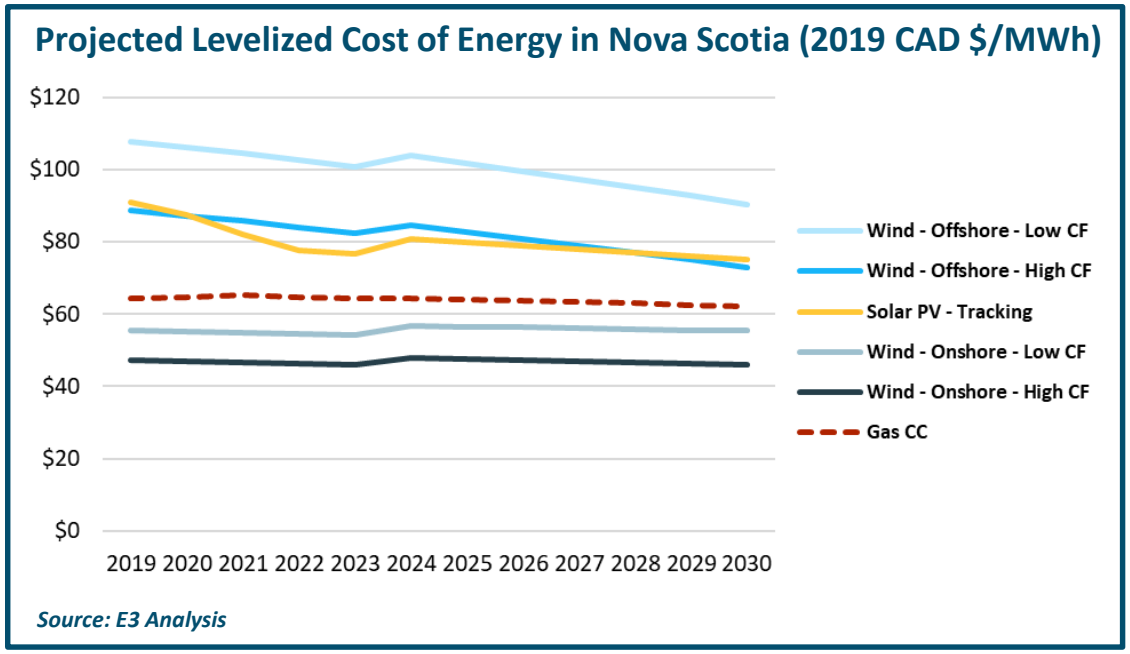
All O&M costs assumed to escalate at 2% per year.

Summary of Proposed Assumptions
Performance Assumptions

- **Capacity factors for wind resources in Nova Scotia are based on CanWEA data**
  - Onshore wind: 35% to 41%, Offshore wind: 37% to 45%
- **Capacity factors for solar resources in Nova Scotia are based on US NREL data**
  - Tracking solar: 15-19%
  - Solar assumed to have 30-degree tilt, fixed or single-axis tracking, and 1.3 inverter loading ratio
- **An 85% capacity factor is assumed for biomass and an 80% capacity factor for municipal solid waste**
- **A 26% capacity factor is assumed for tidal power**
- **Storage round-trip efficiencies**
  - Li-ion: 87%, Compressed air: 70%, Pumped hydro: 80%

Summary of Proposed Assumptions
Future Resource Cost Competitiveness - Energy

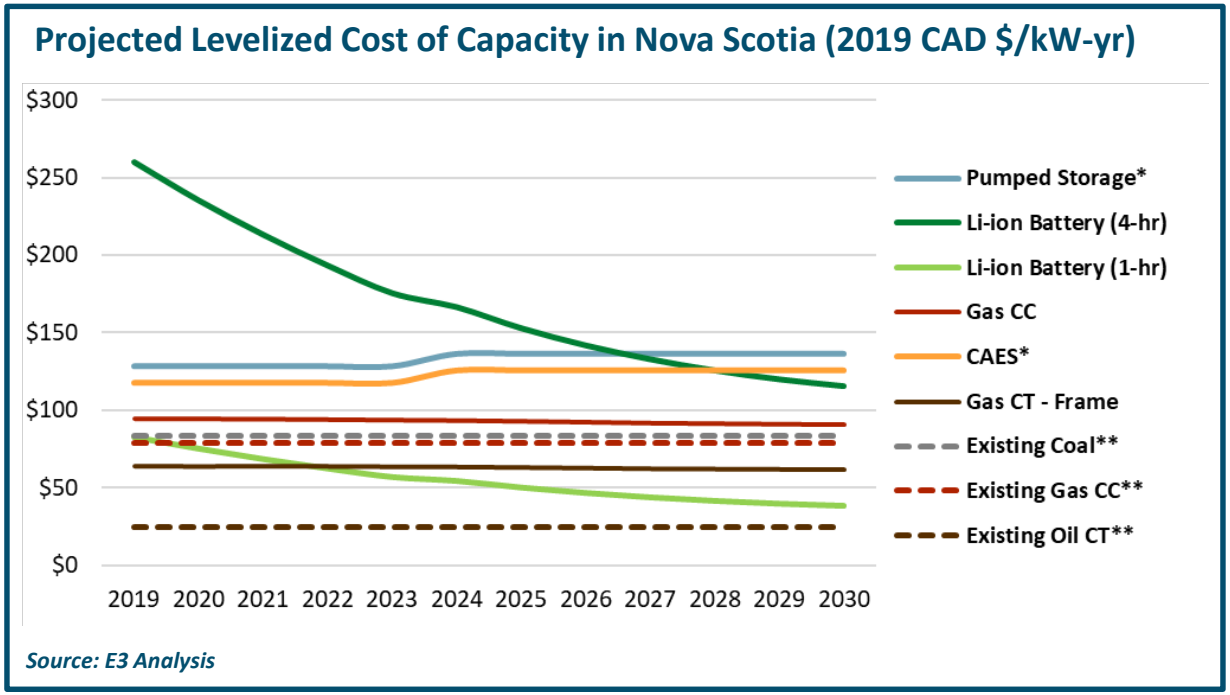
- **Onshore wind is least-cost resource today**
- **Offshore wind remains expensive**
- **Solar is not competitive without further cost decline**



Note: interconnection costs not included.

Summary of Proposed Assumptions
Future Resource Cost Competitiveness - Capacity

- **Levelized capacity costs do not account for fuel/charging costs for storage**
- **For long-duration capacity needs, gas CTs cheapest new resource today**
- **Battery costs are forecasted to rapidly fall and be competitive for short duration capacity needs**
  - However, significant uncertainty still exists for current and future battery costs



* Pumped Storage and CAES costs and storage duration depend highly upon site conditions and are subject to significant uncertainty

** Existing units based on sustaining capex + fixed O&M. Sustaining capex in this study is based on the 2019 10 Year System Outlook's assumed sustaining capital forecast. For this study, these cost streams are levelized and fully collected over this horizon (2020-2029). In practice, NSPI's revenue recovery mechanism for long-lived assets depreciates the costs over longer time periods.

Summary of Proposed Assumptions
Resource Potential

- **Wind and solar**
  - Wind resource technical potential informed by CanWEA Wind Integration Study
  - Solar resource technical potential informed by US NREL estimates
  - Wind and solar resources subject to existing transmission limits
    - Renewables Stability Study (in-process) to inform IRP on costs of integrating more variable renewable energy
- **Other renewables**
  - Biomass 30 MW
  - MSW: 50 MW
  - Tidal: 300 MW
- **Natural gas**
  - Gas pipeline capacity may present a constraint to the number or type of gas plants that can be built
- **Coal repowering**
  - Only 3 units with existing pipeline supply considered for coal-to-gas

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Details of resource options considered

Wind

Industry Trends: Historical Cost
Wind

- **Wind project installation cost has declined since reaching a peak in 2010**
  - Average cost of projects installed in 2017 in US: **$1,610 USD/kW ($2,131 CAD/kW)**

Installed Wind Power Project Costs Over Time

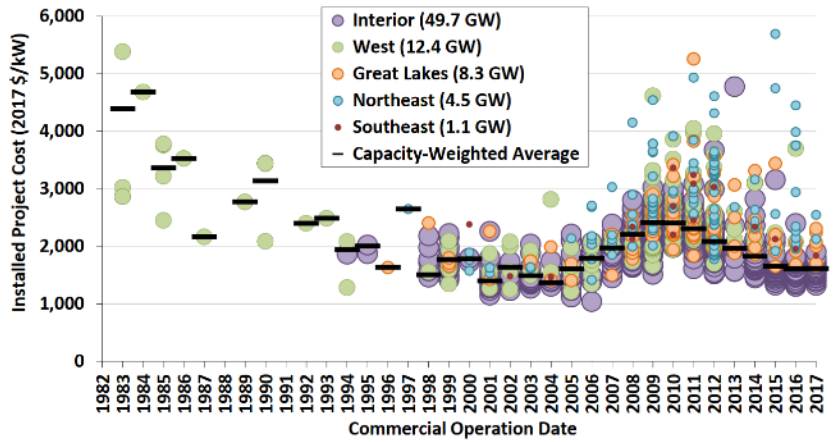


Figure source: 2017 Wind Technologies Market Report (LBNL)

Levelized Wind PPA Prices by PPA Execution Date

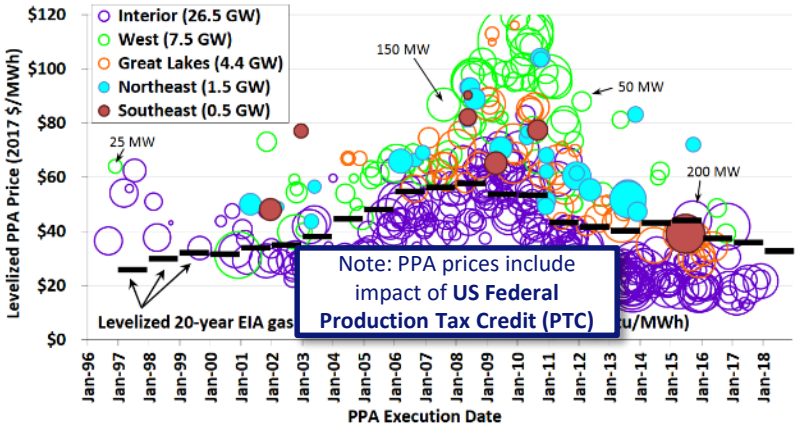


Figure source: 2017 Wind Technologies Market Report (LBNL)

Capital Cost Recommendations
Onshore Wind

- **Wind costs vary significantly by region and terrain**
- **Regions with higher capacity factors show slightly lower capital costs**
  - Captured in NREL's 10 techno-resource groups (TRG)
  - Nova Scotia wind costs estimated based on NREL TRG 5 (~40% CF for onshore wind)

	2019 Capital Cost		
Source	**US $/kW**	**CAN $/kW**	**Notes**
E3 WECC Survey (***link***)	$1,640	$2,179	Based on survey of Western US
New Brunswick IRP (***link***)	—	$2,456	2017 IRP used as regional index
NREL 2018 ATB (***link***)	$1,641	$2,180	Based on NREL TRG5 (40.7% CF)
E3 Recommendation	**—**	**$2,100**	**Lowers US estimates informed by NSPI engineering estimates**

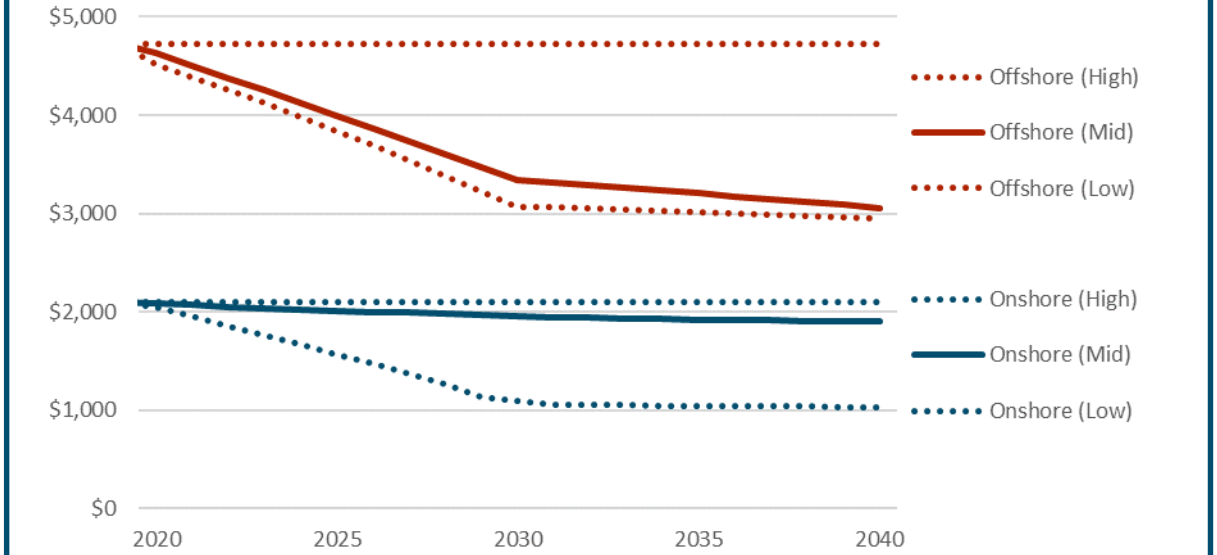
Capital Cost Recommendations
Offshore Wind

- **Offshore wind is considerably less mature than onshore wind and subject to greater cost uncertainty and development risk**
- **Assumes fixed-bottom turbines for Nova Scotia**
  - Floating turbines significantly more expensive, only needed for water depths >50-60 meters
- **NREL's offshore wind costs do not reflect recent market trends**

	2019 Capital Cost		
Source	**US $/kW**	**CAN $/kW**	**Notes**
E3 WECC Survey (***link***)	$3,570	$4,726	Based on survey of Western US
New Brunswick IRP (***link***)	—	—	2017 IRP used as regional index
NREL 2018 ATB (***link***)	$4,568	$6,047	Based on NREL TRG4 (41% CF)
E3 Recommendation	**—**	**$4,726**	**Use WECC survey**

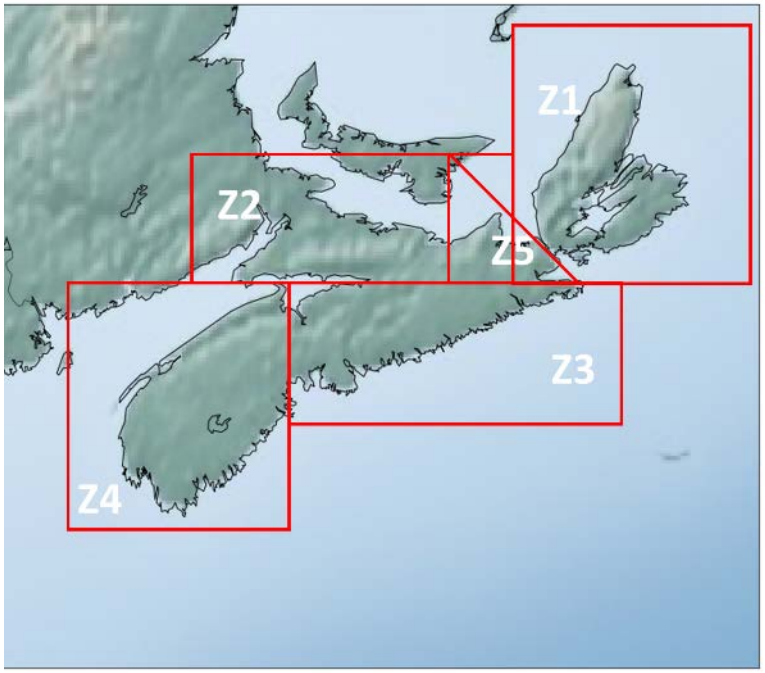
Future Cost Reductions
Wind

- **Wind costs will continue to decline in future**
  - Further improvements in physical scale (hub height, blade length) will increase efficiency
  - Offshore capital cost declines very likely, onshore cost declines less likely
  - NREL ATB mid case (onshore TRG 5, offshore TRG 4) used for capital cost reduction trajectory
    - High and low scenarios available for sensitivities
    - NOTE: WECC cost survey also uses NREL cost trajectories



Performance Assumptions and Resource Potential
Wind

- **To estimate capacity factors, E3 used the CanWEA pan-Canada wind integration study**
  - Modeled current and possible future wind plants in Nova Scotia (171 wind sites in province)
- **5 development zones align with solar development zones (based on NREL's NSRDB)**
- **Little variation in CF across Nova Scotia**
- **1,000 MW of potential assumed per zone (500 onshore / 500 offshore)**
  - Potential will be updated based on Renewables Stability Study that will inform grid constraints and investments required to integrate larger amounts of new renewables



	Total Capacity (GW)	# Total Sites	# Offshore Sites	Avg. CF: Offshore	Avg. CF: Onshore	Avg. CF: Overall
Zone 1	16.4	89	7	41%	38%	38%
Zone 2	1.0	17	3	39%	37%	37%
Zone 3	3.6	23	19	45%	39%	43%
Zone 4	1.0	10	7	42%	41%	41%
Zone 5	5.0	32	6	40%	38%	38%

Financing and Operating Assumptions
Wind

+ Financing:

- Financing lifetime: 25 years
- Cost of equity: 9.00%
- Cost of debt: 5.54%
- Debt ratio: 62.5%
- Pre-tax WACC: 6.84%
- Tax rate: 31%
- Depreciation:
  - Class 43.2 Advanced CCA (50%) to 2019
  - Class 43.1 CCA (30%) thereafter
  - Implemented tax measures from 2018 federal government economic update

+ Operating costs

- Onshore fixed O&M: $54/kW-yr
  - 2% annual escalation
- Offshore fixed O&M: $108/kW-yr
  - 2% annual escalation
- Variable O&M: $0/MWh

Levelized Cost of Energy Results
Wind

- **Onshore wind LCOE relatively stable**
- **Significant decline in offshore wind LCOE by 2030**

Year	LCOE (2019 CAD $/MWh)			
	Onshore		Offshore	
	Low CF 37%	High CF 41%	Low CF 39%	High CF 45%
2020	$55	$47	$106	$87
2030	$55	$46	$90	$73
2040	$54	$44	$83	$67

Note: Low and High CFs represent range from zone-based Nova Scotia sites in CanWEA testing database

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Utility Scale Solar PV

Industry Trends: Historical Cost
Utility-Scale Solar PV

- **Continued declines in module pricing and balance of system costs have led to installed system costs approaching USD $1/W-dc in 2018**
  - Premium associated with tracking technology has nearly disappeared
- **With impact of US ITC, recent PPA prices for higher quality solar resources have ranged between USD $20-$40/MWh**

NREL Utility-Scale PV System Cost Benchmark Summary (Inflation Adjusted), 2010-2018

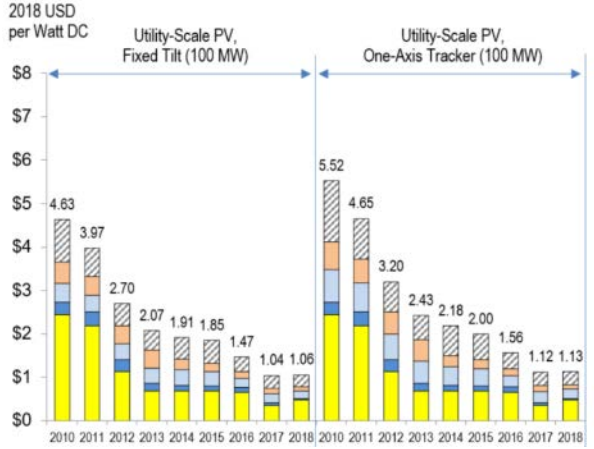


Figure source: US Solar Photovoltaic Cost Benchmark: Q1 2018 (NREL)

Levelized PPA Prices by Region, Contract size, and PPA Execution Date: 2014-2018

Note: PPA prices include impact of **US Federal Investment Tax Credit (ITC)**

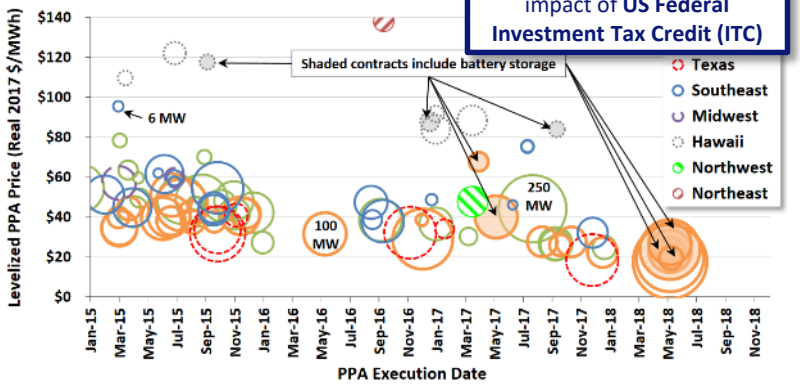


Figure source: Utility-Scale Solar 2018 (LBNL)

Industry Trends: System Design

Utility-Scale Solar PV

- **The inverter loading ratio (ILR) reflects the ratio between the DC rating of modules and the AC rating of the system's inverters**
  - Design choice is a tradeoff between increased system cost and improved performance (i.e. higher capacity factor)
  - With reductions in module costs, increasing ILRs (i.e. oversizing module arrays) to improve capacity factor has become industry standard
  - Median ILR for new systems is **1.3**

Trends in Inverter Loading Ratio by Mounting Type and Installation Year

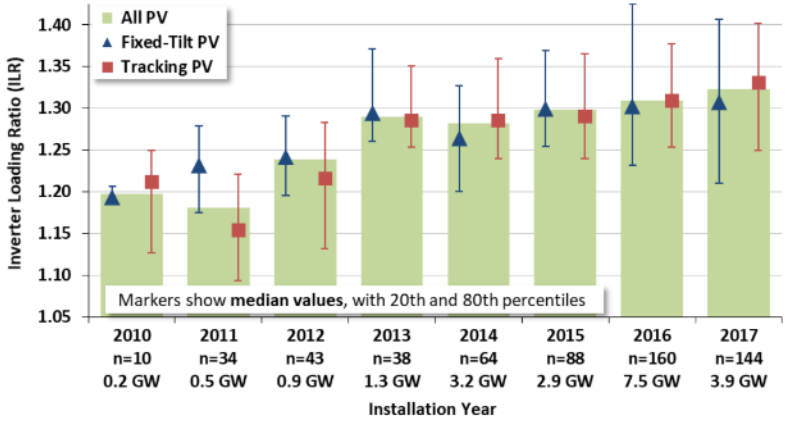


Figure source: Utility-Scale Solar 2018 (LBNL)

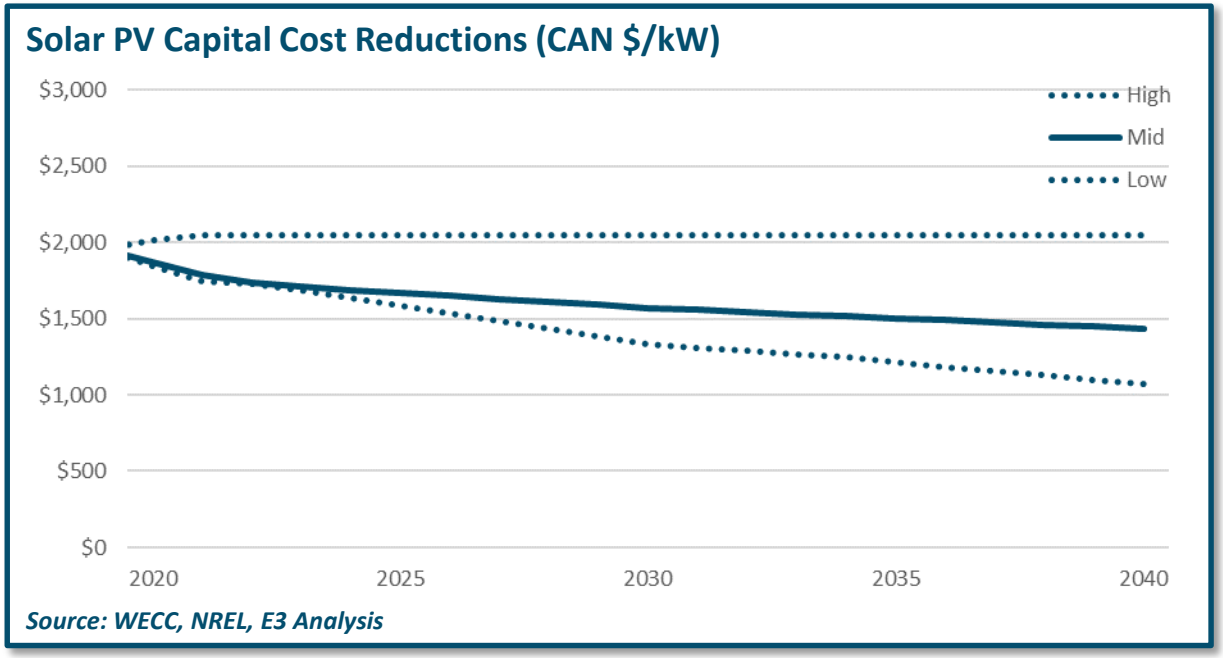
Capital Cost Recommendations
Utility-Scale Solar PV

- **Utility-scale PV projects now almost exclusively single-axis tracking**
  - Tracking solar provides increased capacity factor for little to no premium in capital costs
  - Only tracking solar considered
- **WECC costs adjusted per local labor costs, terrain, and other factors, informed by NSPI internal estimates**

	2019 Capital Cost		
Source	**US $/kW-ac**	**CAN $/kW-ac**	**Notes**
E3 WECC Survey (***link***)	$1,479	$1,958	Based on survey of Western US
New Brunswick IRP (***link***)	—	$2,620	2017 IRP used as regional index
NREL 2018 ATB (***link***)	$1,449	$1,917	NREL annual technology baseline
E3 Recommendation	**—**	**$2,250**	**WECC, 2019 + local cost adjustment**

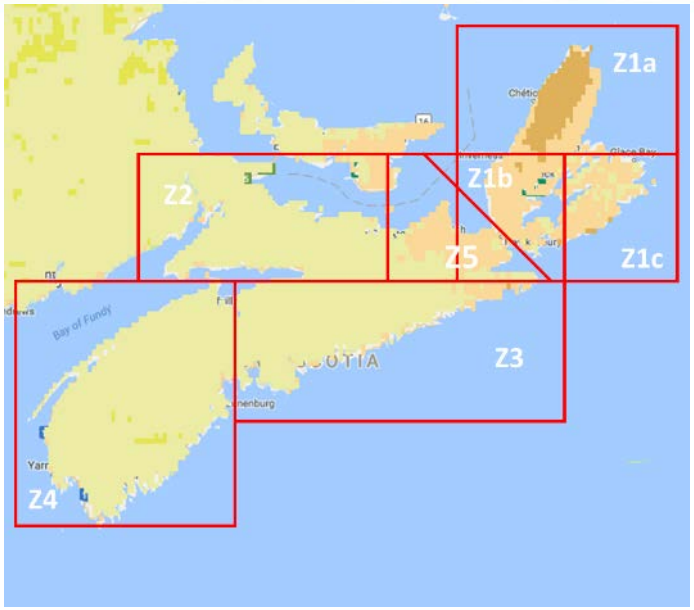
Future Cost Reductions
Solar PV

- **Solar PV costs will continue to decline in future, driven by technology development, soft cost declines, and learning effects**
  - NREL 2018 ATB (mid case) used for capital cost reduction trajectory
    - High and low scenarios available for sensitivities
    - NOTE: WECC cost survey also uses NREL cost trajectories



Solar Methodology

- **Data from NREL's National Solar Radiation Database (NSRDB)**
- **Assumptions:**
  - Invertor loading ratio = 1.3
  - Tilt = 30 degrees
  - Single-Axis Tracking
- **CF developed by resource zone**
  - Range from 15-19%
- **500 MW of potential assumed per zone**
  - Potential will be updated based on Renewables Stability Study that will inform grid constraints and investments required to integrate larger amounts of new renewables



Zone	Tracking: Avg. CF
1a	15%
1b	16%
1c	18%
2	18%
3	18%
4	19%
5	17%

Financing and Operating Assumptions
Utility-Scale Solar PV

+ **Financing:**
  - Financing lifetime: 25 years
  - Cost of equity: 9.00%
  - Cost of debt: 5.54%
  - Debt ratio: 62.5%
  - Pre-tax WACC: 6.84%
  - Tax rate: 31%
  - Depreciation:
    - Class 43.2 Advanced CCA (50%) to 2019
    - Class 43.1 CCA (30%) thereafter
    - Implemented tax measures from 2018 federal government economic update

+ **Operating costs**
  - Fixed O&M: $20/kW-yr
    - 2% annual escalation
  - Variable O&M: $0/MWh

Levelized Cost of Energy Results
Utility-Scale Solar PV

- **Solar relatively expensive given Nova Scotia's limited resource**
  - However, costs will continue to decline

Year	LCOE (2019 CAD $/MWh)	
	Low CF (15%)	High CF (19%)
2020	$111	$87
2030	$95	$75
2040	$87	$68

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Other renewables

Capital Cost Recommendations
Biomass

- **NSPI understands biomass regulations limit the amount of forest biomass available to attain any renewable electricity standard to 350,000 dry tonnes/annum**
- **Biomass project capital costs are typically location specific**

	2019 Capital Cost		
Source	**US $/kW**	**CAN $/kW**	**Notes**
E3 WECC Survey (***link***)	$4,488	$5,941	Based on survey of Western US
New Brunswick IRP (***link***)	—	$5,713	2017 IRP used as regional index
NREL 2018 ATB (***link***)	$4,019	$5,321	NREL annual technology baseline
E3 Recommendation	**—**	**$5,300**	**Informed by NSPI engineering estimates**

Financing, Operating, and Performance Assumptions
Biomass

+ Financing:

- Financing lifetime: 35 years
- Cost of equity: 9.00%
- Cost of debt: 5.54%
- Debt ratio: 62.5%
- Pre-tax WACC: 6.84%
- Tax rate: 31%
- Depreciation:
  - Class 43.2 Advanced CCA (50%) to 2019
  - Class 43.1 CCA (30%) thereafter
  - Implemented tax measures from 2018 federal government economic update

+ Performance:

- 85% capacity factor assumed
- 13,500 Btu/kWh heat rate

+ Operating costs

- Fixed O&M: $162/kW-yr
  - 2% annual escalation
- Variable O&M: $7/MWh
  - 2% annual escalation

+ Fuel

- Based on existing biomass fuel costs
- Approx. $60/MWh

Levelized Cost of Energy Results
Biomass

- **LCOE of biomass almost does not change from 2020 to 2040 due to slow reduction in capital costs**

Year	LCOE (2019 CAD $/MWh) Biomass
2020	$140
2030	$141
2040	$140

Capital Cost Recommendations
Municipal Solid Waste

+ **Municipal solid waste capital costs are typically location specific**

	2019 Capital Cost		
Source	**US $/kW**	**CAN $/kW**	**Notes**
E3 WECC Survey (***link***)	—	—	Based on survey of Western US
New Brunswick IRP (***link***)	—	$11,427	2017 IRP used as regional index
E3 Recommendation	**—**	**$8,470**	**Informed by NSPI engineering estimates**

Financing, Operating, and Performance Assumptions

Municipal Solid Waste

+ Financing

- Financing lifetime: 35 years
- Cost of equity: 9.00%
- Cost of debt: 5.54%
- Debt ratio: 62.5%
- Pre-tax WACC: 6.84%
- Tax rate: 31%
- Depreciation:
  - Class 43.2 Advanced CCA (50%) to 2019
  - Class 43.1 CCA (30%) thereafter
  - Implemented tax measures from 2018 federal government economic update

+ Performance

- 80% capacity factor assumed
- 18,000 Btu/kWh heat rate

+ Operating costs

- Fixed O&M: $162/kW-yr
  - 2% annual escalation
- Variable O&M: $0/MWh

+ Fuel

- $5/MMBtu assumed

Levelized Cost of Energy Results
Municipal Solid Waste

- **Slight capital cost increases due to changes in depreciation schedule**

Year	LCOE (2019 CAD $/MWh) Municipal Solid Waste
2020	$167
2030	$171
2040	$171

Capital Cost Recommendations
Tidal

- **NSPI has been a global leader in developing tidal power**
  - Annapolis Tidal Power Plant was the first tidal plant in North America
  - E3 recommends using NSPI capital cost estimate
- **However, tidal power is still an expensive technology with limited commercial deployment**
  - Recent failure of OpenHydro highlights the challenge of the tidal power industry

	2019 Capital Cost		
Source	**US $/kW**	**CAN $/kW**	**Notes**
New Brunswick IRP (***link***)	—	$8,643	2017 IRP used as regional index
E3 Recommendation	**—**	**$10,000**	**Informed by NSPI engineering estimates**

Financing, Operating, and Performance Assumptions

Tidal

+ Financing:

- Financing lifetime: 35 years
- Cost of equity: 9.00%
- Cost of debt: 5.54%
- Debt ratio: 62.5%
- Pre-tax WACC: 6.84%
- Tax rate: 31%
- Depreciation:
  - Class 43.2 Advanced CCA (50%) to 2019
  - Class 43.1 CCA (30%) thereafter
  - Implemented tax measures from 2018 federal government economic update

+ Operating costs

- Fixed O&M: $338/kW-yr
  - 2% annual escalation
- Variable O&M: $0/MWh

+ Performance:

- 26% capacity factor assumed

Levelized Cost of Energy Results
Tidal

- **Tidal power is a relatively expensive resource option**
  - Driven by very high capital and O&M costs

Year	LCOE (2019 CAD $/MWh) Tidal
2020	$344
2030	$359
2040	$359

Energy+Environmental Economics

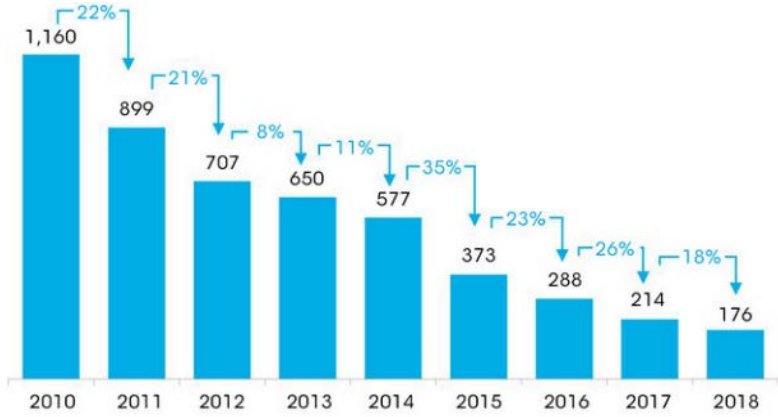
Battery Storage

Industry Trends: Historical Cost
Battery Storage

+ **Innovation in battery technology, driven mainly by transportation applications, has led to recent dramatic declines in costs to produce lithium-ion batteries**
  - Since 2010, year-on-year declines of 8-35% have been observed

+ **Future stationary applications of battery technology will benefit from cost reductions driven by transport applications**

BNEF Lithium-Ion Battery Price Survey, 2010-18 (2018$/kWh)



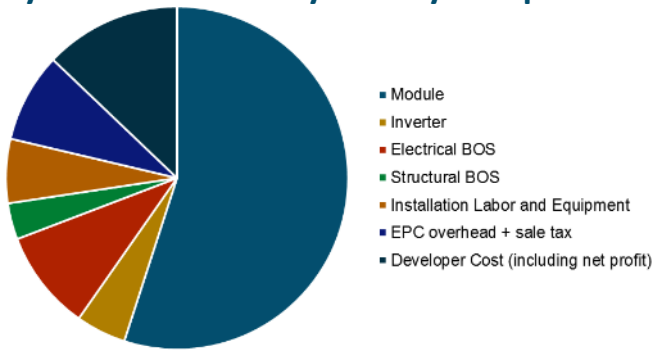
Note: reported prices reflect cell & pack costs for transportation applications

Figure source: Lithium-ion Battery Prices (BNEF)

Lithium-ion battery cost breakdown by power capacity and duration

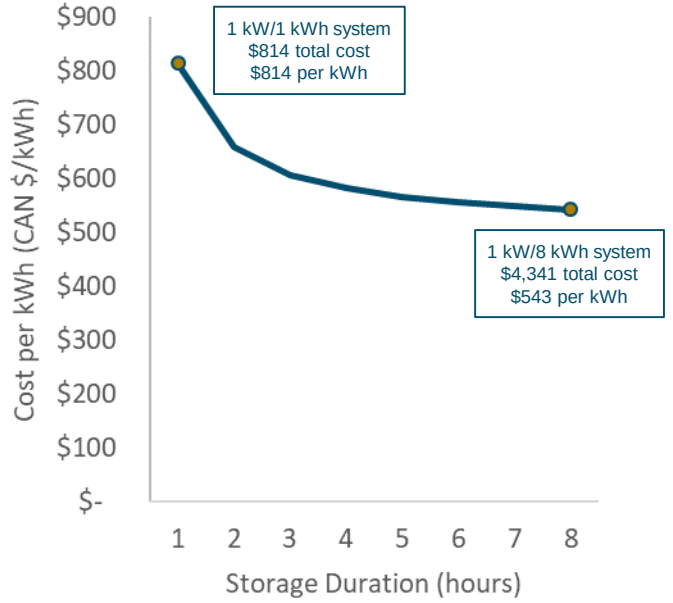
- **Battery costs vary significantly by system specifications**
- **For modeling purposes, costs are commonly broken into two categories**
  - Costs that scale with *power* ("capacity"), quoted in $/kW
  - Costs that scale with *energy* ("duration"), quoted in $/kWh
- **Battery modules are the largest and best understood component of system cost and the one that scales most linearly with duration**
- **Fixed capacity cost including inverter and interconnection vary significantly by project**
- **Longer duration batteries cheaper per MWh of storage due to spreading of fixed costs**

Utility-scale 4-hr Battery Cost by Component



Source: E3 Analysis

Utility-scale Battery Cost per kWh by Duration



Source: E3 Analysis

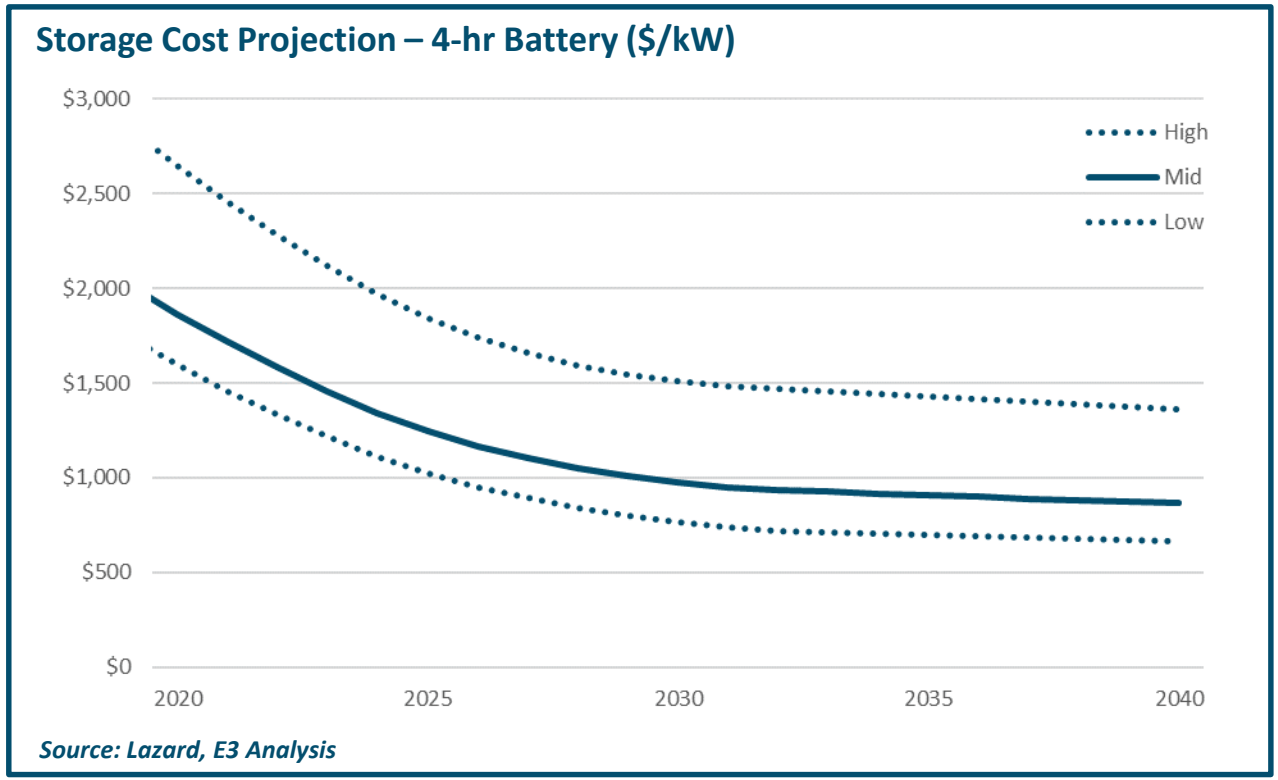
Capital Cost Recommendations
Battery Storage

- **Costs estimates vary widely due to early stage of technology and differences in scale and arrangement**
  - Speed of price decline makes estimates quickly outdated
- **Costs per kWh also depend on duration of battery system**
- **High end of Lazard range utilized per local labor costs, terrain, and other factors, informed by NSPI internal estimates**

	2019 Capital Cost		
Source	**US $/kW-ac**	**CAN $/kW-ac**	**Notes**
E3 WECC Survey (***link***)	$536	$709	Cost estimate for 1-hr battery
E3 WECC Survey (***link***)	$1,530	$2,025	Cost estimate for 4-hr battery
Lazard LCOS 3.0 (***link***)	$1,338 - $1,700	$1,771 - $2,250	Cost range for 4-hr battery (2017)
Lazard LCOS 4.0 (***link***)	$1,163 - $1,850	$1,540 - $2,450	Cost range for 4-hr battery (2018)
E3 Recommendation	**—**	**$814**	**Recommended cost for 1-hr battery**
	—	**$2,325**	**Recommended cost for 4-hr battery**
Costs that scale with power ("capacity")		**$310**	**Recommended capacity $/kW**
Costs that scale with energy ("duration")		**$504**	**Recommended energy $/kWh**

Future Cost Reductions
Battery Storage

- **Future battery cost projections are modeled based on Lazard's Levelized Cost of Storage v.4.0**
  - Forecast is highly uncertain due to emerging status of industry
  - There is variation in current costs, but industry sources predict continued cost declines (driven by expanding electric vehicle market)



Financing, Operating, and Performance Assumptions
Battery Storage

+ **Financing:**
  - Financing/depreciation lifetime: 20 years
  - Cost of equity: 9.00%
  - Cost of debt: 5.54%
  - Debt ratio: 62.5%
  - Pre-tax WACC: 6.84%
  - Tax rate: 31%
  - Depreciation:
    - Class 17 – 8% DB in 2017
    - Step up to Class 43.2 Advanced CCA (50%) in 2018-2019
    - Class 43.1 CCA (30%) thereafter
    - Implemented tax measures from 2018 federal government economic update

+ **Round trip efficiency: 87% (based on Lazard LCOS 4.0, *link*)**

+ **Operating costs (4-hr battery)**
  - Fixed O&M: $27/kW-yr
    - 2% annual escalation
  - Variable O&M: $0/MWh

+ **Li-ion cost adders**
  - Extended warranty: 1.5% of total capital cost, annually starting in Year 3
  - Augmentation charge: 3.3% of energy (kWh) cost component, annually

Levelized Fixed Cost Results
Battery Storage

- **Short duration battery is competitive with NG plants on a capacity basis**
- **Larger decrease in cost by 2030 as technology matures**

	Levelized Fixed Cost (2019 CAD $/kW-yr)	
Year	1-hr Battery	4-hr Battery
2020	$75	$236
2030	$38	$116
2040	$33	$101

Energy+Environmental Economics

Compressed Air

Capital Cost Recommendations
Compressed Air

- **Compressed air costs are highly site-specific and can vary considerably based on the characteristics of the site (geology, etc.)**
- **Few recent commercial projects adds to cost uncertainty**
- **E3 recommendation informed by NSPI engineering estimates**

	2019 Capital Cost		
Source	**US $/kW**	**CAN $/kW**	**Notes**
E3 WECC Survey (***link***)	$2,142	$2,836	Based on survey of Western US
New Brunswick IRP (***link***)	—	$2,073	2017 IRP used as regional index
Pacificorp IRP (***link***)	$1,658	$2,194	Broad range of size and duration
E3 Recommendation	**—**	**$2,200**	**Reflects lower regional estimates vs. WECC survey**

Financing, Operating, and Performance Assumptions
Compressed air

+ **Financing:**
  - Financing lifetime: 35
  - Cost of equity: 9.00%
  - Cost of debt: 5.54%
  - Debt ratio: 62.5%
  - Pre-tax WACC: 6.84%
  - Tax rate: 31%
  - Depreciation: Class 17 – 8% DB
  - Implemented tax measures from 2018 federal government economic update

+ **Operating costs**
  - Fixed O&M: $20/kW-yr
    - 2% annual escalation
  - Variable O&M: $0/MWh
    - 2% annual escalation

+ **Round trip efficiency: 70%**

+ **Emissions:**
  - CAES utilizes gas turbine during operations
  - E3 recommends a 4000 Btu/kWh heat rate for CAES output

Levelized Fixed Cost Results
Compressed air

- **Slight capital cost increases due to changes in depreciation schedule**
- **Fuel cost of natural gas is an additional cost for CAES**
- **More competitive for longer duration storage**

Year	Levelized Fixed Cost (2019 CAD $/kW-yr) Compressed air
2020	$118
2030	$125
2040	$125

Energy+Environmental Economics

Pumped Storage

Capital Cost Recommendations
Pumped Storage

- **Pumped storage costs are highly site-specific and can vary considerably based on the characteristics of the site**
- **For a generic facility cost estimate, E3's recommended Nova Scotia cost estimate is generally lower than other generic point estimates**
  - Informed by NSPI engineering estimates

	2019 Capital Cost		
Source	**US $/kW**	**CAN $/kW**	**Notes**
E3 WECC Survey (***link***)	$2,397	$3,173	Based on survey of Western US
New Brunswick IRP (***link***)	—	$7,369	2017 IRP used as regional index
Pacificorp IRP (***link***)	$2,734 - $3,320	$3,619 - $4,395	Broad range of size and duration
E3 Recommendation	**—**	**$2,700**	**Informed by NSPI engineering estimates**

Financing, Operating, and Performance Assumptions
Pumped Storage

+ Financing

- Financing lifetime: 50
- Cost of equity: 9.00%
- Cost of debt: 5.54%
- Debt ratio: 62.5%
- Pre-tax WACC: 6.84%
- Tax rate: 31%
- Depreciation*:
  - Class 43.2 Advanced CCA (50%) to 2019
  - Class 43.1 CCA (30%) thereafter
  - Implemented tax measures from 2018 federal government economic update

+ Round trip efficiency: 80%

+ Operating costs

- Fixed O&M: $32/kW-yr
  - 2% annual escalation
- Variable O&M: $0/MWh

* Depreciation rate is dependent upon size of installation.

Levelized Fixed Cost Results
Pumped Storage

- **Pumped storage may be competitive for longer duration storage**
  - Cost estimates depend on long financing lifetime (50 years) for high initial capital cost

Year	Levelized Fixed Cost (2019 CAD $/kW-yr) Pumped Storage
2020	$128
2030	$136
2040	$136

Energy+Environmental Economics

Coal Repowering

Repowering Options
Coal Repowering

+ Coal-to-gas

- Only 3 coal units with firm natural gas supply assumed for coal-to-gas
- Costs informed by NSPI engineering estimates

Coal Unit	Capacity	Capital Cost (2019 CAN $)	Capital Cost (2019 CAN $/kW)	Notes
Point Tupper Unit 2	102	$24.2 M	$237/kW	150 MW today, however natural gas pipeline capacity constraints are believed to limit output to 102 MW
Trenton Unit 5	155	$24.4 M	$157/kW	If only unit 5 repowered
Trenton Unit 6	165	$24.4 M	$148/kW	If only unit 6 repowered
Trenton Unit 5+6	320	$35.5 M	$127/kW	If units 5+6 both repowered

+ Impact of federal regulations

- Federal regulations limiting carbon dioxide emissions from natural gas-fired generation of electricity specify performance standards, which limit the allowable operating life of any repowered coal unit

Financing and Operating Assumptions
Coal Repowering

+ Financing:

- Financing lifetime: 8
  - Estimate for illustrative purposes
- Cost of equity: 9.00%
- Cost of debt: 5.54%
- Debt ratio: 62.5%
- Pre-tax WACC: 6.84%
- Tax rate: 31%
- Depreciation: Class 17 – 8% DB

+ Operating costs

Technology	Fixed O&M ($/kW-yr)	Escalation	Variable O&M ($/MWh)	Escalation
Coal-to-Gas: Point Tupper Unit 2	$45	2%	$1.32	2%
Coal-to-Gas: Trenton Unit 5	$37	2%	$1.48	2%
Coal-to-Gas: Trenton Unit 5	$37	2%	$1.48	2%

Repowering Options
Coal Repowering

+ Coal-to-biomass

- Costs informed by NSPI engineering estimates for cost of retrofitting Trenton Unit 5 to co-fire woody biomass at 20% of plant capacity
  - Retrofitted plant would operate as 120 MW coal / 30 MW biomass
- NSPI understands biomass regulations limit the amount of forest biomass available to attain any renewable electricity standard to 350,000 dry tonnes/annum.
  - Given this constraint, and NS Power's Port Hawkesbury biomass power generation plant, it is assumed that a repowered coal/biomass co-fire facility (80%/20%) could meet current regulations, subject to conditions in the Renewable Electricity Regulations.

Coal Unit	Capacity	Capital Cost (2019 CAN $)	Capital Cost (2019 CAN $/kW)	Notes
Trenton Unit 5	30 MW (20% of total net MW)	$39.3 M	$1,313/kW	Informed by NSPI engineering estimate

Levelized Fixed Cost Results
Coal Repowering

- **Coal-to-gas shows average of three units considered**

Technology	Levelized Fixed Cost (2020 CAD $/kW-yr)
Coal-to-Gas	$67
Coal-to-Biomass (20% co-firing)	$360

Energy+Environmental Economics

Natural Gas

Capital Cost Recommendations
Natural Gas Generation (1 of 2)

+ **E3 generally recommends using the WECC Cost Survey for gas plant cost**

Technology	Source	Capital Cost (2019 CAN $/kW)	Notes
Combined Cycle (145 MW)	E3 WECC Survey (***link***)	$1,688	Based on survey of Western US
	New Brunswick IRP (***link***)	$1,974	2017 IRP used as regional index
	NREL 2018 ATB (***link***)	$1,441	NREL annual technology baseline
	E3 Recommendation	$1,688	
Combined Cycle w/ carbon capture and storage (145 MW)	E3 WECC Survey (***link***)	$3,376	Based on survey of Western US
	NREL 2018 ATB (***link***)	$2,979	NREL annual technology baseline
	E3 Recommendation	$3,376	

Capital Cost Recommendations
Natural Gas Generation (2 of 2)

+ **E3 generally recommends using the WECC Cost Survey for gas plant cost**

Technology	Source	Capital Cost (2019 CAN $/kW)	Notes
Combustion Turbine – Frame (50 MW)	E3 WECC Survey (***link***)	$1,080	Based on survey of Western US
	New Brunswick IRP (***link***)	$1,252	2017 IRP used as regional index
	NREL 2018 ATB (***link***)	$1,226	NREL annual technology baseline
	E3 Recommendation	$1,080	Based on WECC Survey
Combustion Turbine – Aero (50 MW)	E3 WECC Survey (***link***)	$1,755	Based on survey of Western US
	New Brunswick IRP (***link***)	$1,693	2017 IRP used as regional index
	E3 Recommendation	$1,755	Based on WECC Survey
Reciprocating Engine (50 MW)	E3 WECC Survey (***link***)	$1,823	Based on survey of Western US
	E3 Recommendation	$1,823	

Cost Components
Natural Gas Generation

- **E3's proposed capital costs include the following cost components for new natural gas plants:**
  - Overnight capital cost
  - Construction financing
  - Nominal interconnection costs (i.e. a short gen-tie line)
- **O&M costs include:**
  - Insurance, taxes, land lease payments, and other fixed costs
  - Annualized large component replacement costs over the technical life
  - Scheduled and unscheduled maintenance
- **CCS capital costs include the cost of capturing and compressing the CO2, but not delivery and storage to a storage reservoir or industrial site for use**
  - $4.76/MWh added to VOM to account for transport and storage costs
    - Assumes CAN $13/ton CO2 transported (Rubin et al, 2015) and 0.36 tons/MWh captured (90% capture rate at 7.53 Btu/MWh heat rate)

Financing and Operating Assumptions
Natural Gas Generation

+ Financing:

- Financing lifetime: 20
- Cost of equity: 9.00%
- Cost of debt: 5.54%
- Debt ratio: 62.5%
- Pre-tax WACC: 6.84%
- Tax rate: 31%
- Depreciation: Class 17 – 8% DB

+ Operating costs

Technology	Fixed O&M ($/kW-yr)	Escalation	Variable O&M ($/MWh)	Escalation
Combined Cycle	$14	2%	$3	2%
Combined Cycle w/ carbon capture and storage	$45	2%	$3	2%
Combustion Turbine – Frame	$12	2%	$7	2%
Combustion Turbine – Aero	$17	2%	$7	2%
Reciprocating Engine	$27	2%	$9	2%

Levelized Fixed Cost Results
Natural Gas Generation

+ **Combustion turbine is least-cost source of capacity in each year of forecast**

Year	Levelized Fixed Cost (2019 CAD $/kW-yr)				
	Combined Cycle	Combined Cycle w/ CCS	Combustion Turbine – Frame	Combustion Turbine – Aero	Reciprocating Engine
2020	$94	$206	$64	$101	$114
2030	$91	$193	$62	$97	$114
2040	$88	$183	$60	$94	$114

Energy+Environmental Economics

Small Modular Nuclear

Industry Trends: State of the Market
Small Modular Nuclear

- **Small modular reactors (SMR) have been proposed as an alternative to large-scale nuclear facilities**
  - Concept = replace economies of scale in size with economies of scale in manufacturing (i.e. cost savings from producing many small modular reactors)
  - Size per reactor ranges from 50-300 MW
- **Various technologies in R&D phase**
- **No technology has been commercialized**

Sample SMR Design (Hitachi's 300 MW BWRX-300)

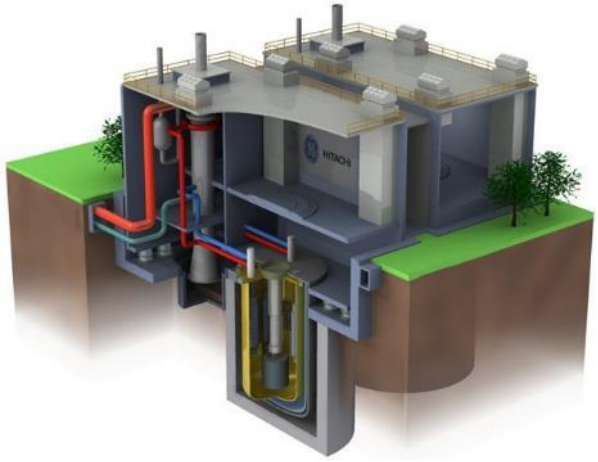


Figure source: Power Engineering Magazine

Capital Cost Recommendations
Small Modular Nuclear

- **High uncertainty of costs given nascent technology**
  - Capital cost estimates vary by 2-3x
  - Low cost estimates unlikely until SMR industry scales up manufacturing capacity
  - Recent US nuclear projects have been over-budget and delayed (~$11,000+/kW)
- **E3 recommends reliance on a broadly used public data source (such as NREL ATB)**
- **High/low cost sensitivities can be explored using other data sources (if desired)**

	2019 Capital Cost		
Source	**US $/kW**	**CAN $/kW**	**Notes**
New Brunswick IRP (***link***)	—	$11,691	2017 IRP, SMR specific estimate
Pacificorp IRP (***link***)	$6,149	$8,140	12 SMRs (570 MW net capacity)
Energy Innovation Reform Project, Adv. Nuclear Cost Analysis, 2018 (***link***)	$4,013	$5,313	Survey of industry-provided cost estimates for advanced nuclear, including SMRs (avg. shown, range was ~CAN $2,900-8,200)
NREL 2018 ATB (***link***)	$6,099	$8,073	Advanced nuclear
E3 Recommendation	**—**	**$8,073**	

Financing and Performance Assumptions
Small Modular Nuclear

+ **Financing:**
  - Financing lifetime: 30 years
  - Cost of equity: 9.00%
  - Cost of debt: 5.54%
  - Debt ratio: 62.5%
  - Pre-tax WACC: 6.84%
  - Tax rate: 31%
  - Depreciation: Class 17 – 8% DB

+ **Capacity factor: 90%**

+ **Operating costs**
  - Fixed O&M: $203/kW-yr
    - 2% annual escalation
  - Variable O&M: $0/MWh
    - 2% annual escalation

+ **Fuel costs**
  - Uranium: $0.86 / MMBtu
    - From NREL ATB

Levelized Cost of Energy Results
Small Modular Nuclear

- **Small Modular Nuclear is very expensive compared to other resources**

Year	LCOE (2019 CAD $/MWh) Small Modular Nuclear
2020	$589
2030	$573
2040	$553

Energy+Environmental Economics

Thank You

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ADDENDUM TO SUPPLY OPTIONS STUDY:
DRAFT COSTS FOR EXISTING ASSETS

JULY 31, 2019

Nova Scotia POWER
An Emera Company

OVERVIEW

- The following provides preliminary high level cost projections for the existing supply side assets on the NS Power system.
- NS Power anticipates the Modeling Plan and Assumptions will include scenarios and/or sensitivities around these assumptions.
- Further detailed unit cost and operating assumptions will be provided in the Assumptions Development phase prior to modeling.
- The team will provide current updates to these parameters during the Assumptions Development phase of the IRP.

Nova Scotia POWER An Emera Company

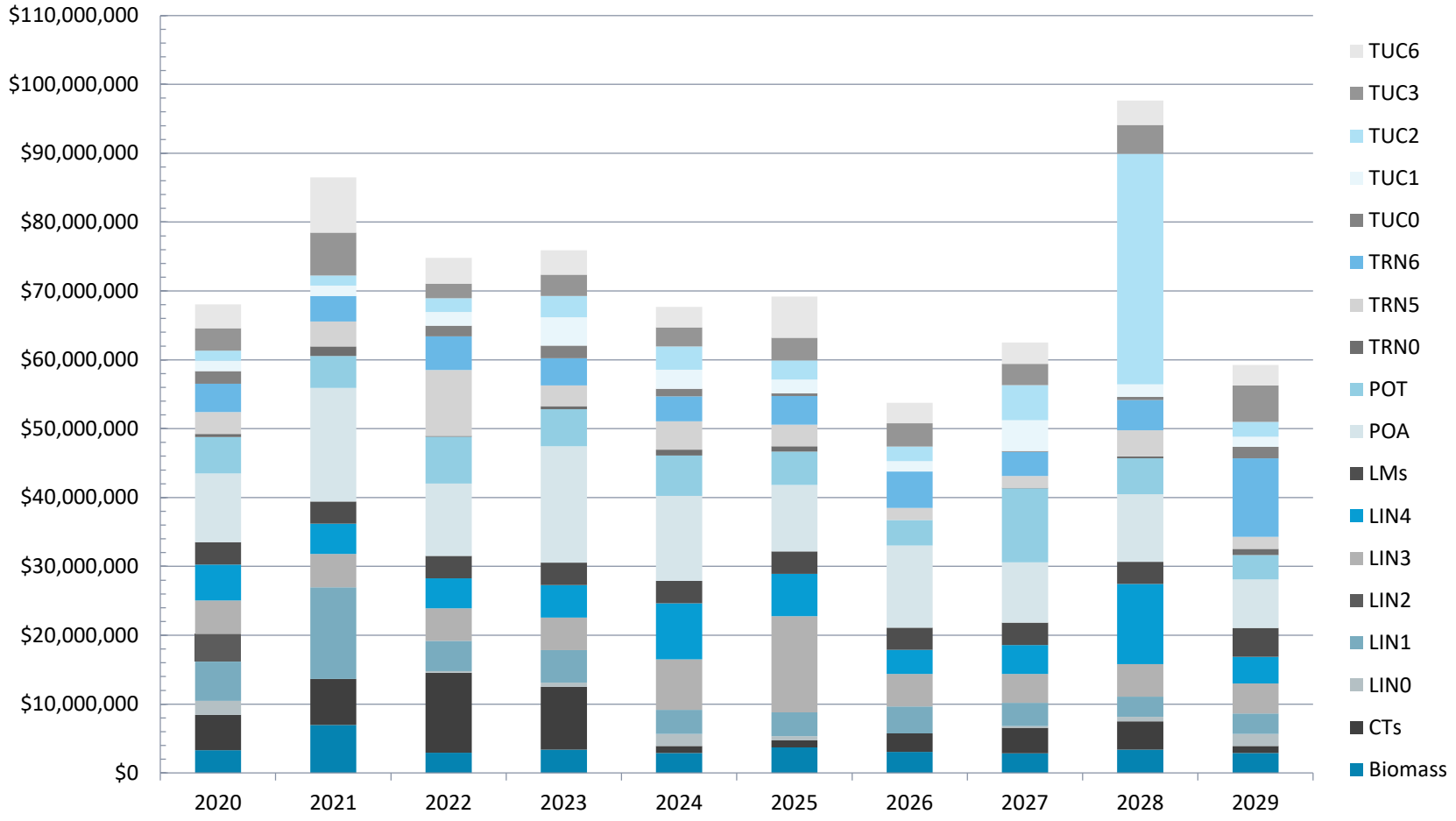
SUSTAINING CAPITAL FORECAST: BACKGROUND

- The sustaining capital forecast is developed based upon the expected utilization of the assets. The most recent cost forecast is from the 2019 10 Year System Outlook Report.

- During the 2019 ACE Proceeding, NS Power conducted a Hydro Asset Study to estimate the costs of sustaining and decommissioning small hydro assets on the NS system. These costs, with updates as applicable, will be used as the cost assumptions for existing small hydro.

- Scenarios for sustaining capital (for example, different utilization factors driving different investment profiles) around sustaining capital, particularly in the longer term where uncertainty is increased, will be developed in collaboration with stakeholders through the Modeling Plan and Assumptions Development phases.

SUSTAINING CAPITAL FORECAST: THERMAL & CTS



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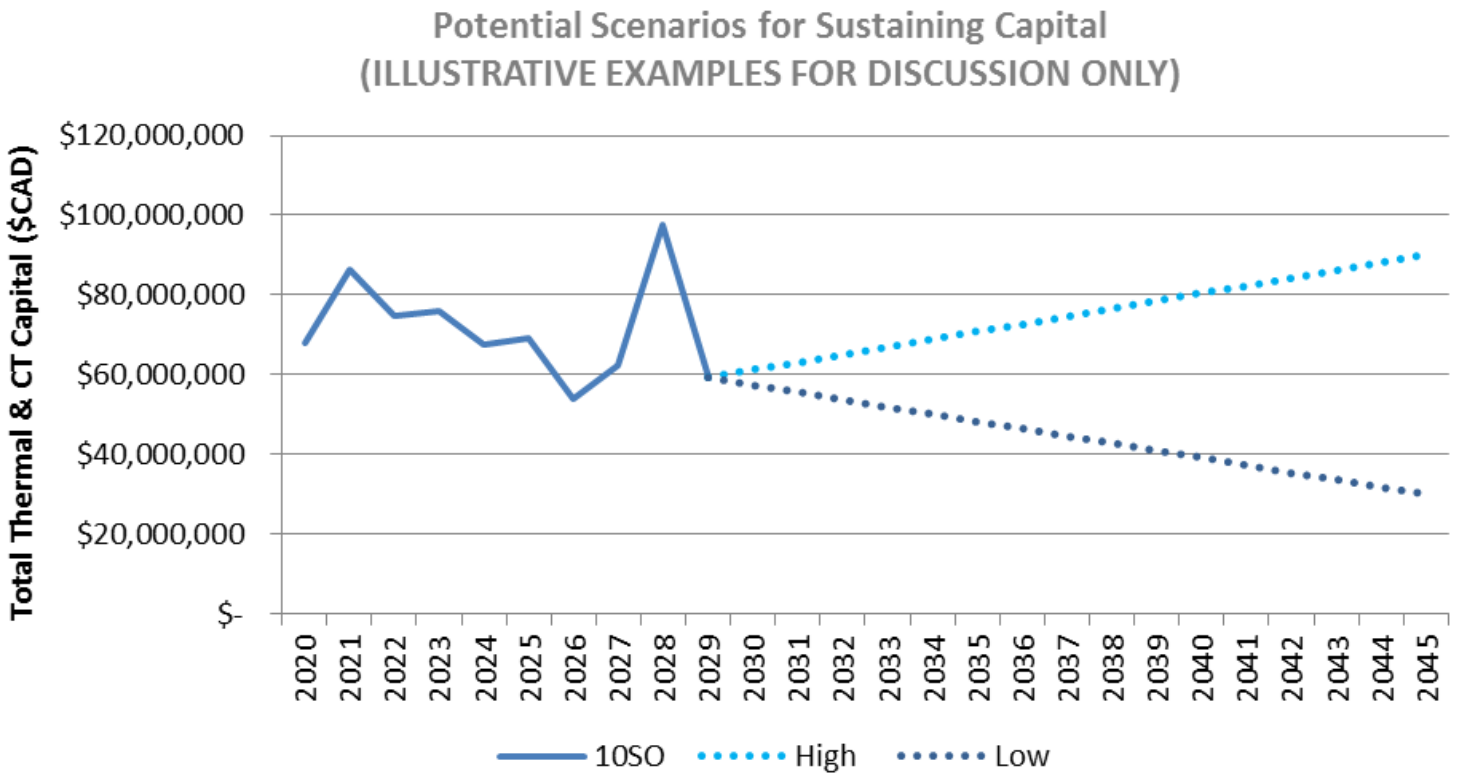
SUSTAINING CAPITAL FORECAST: THERMAL & CTS



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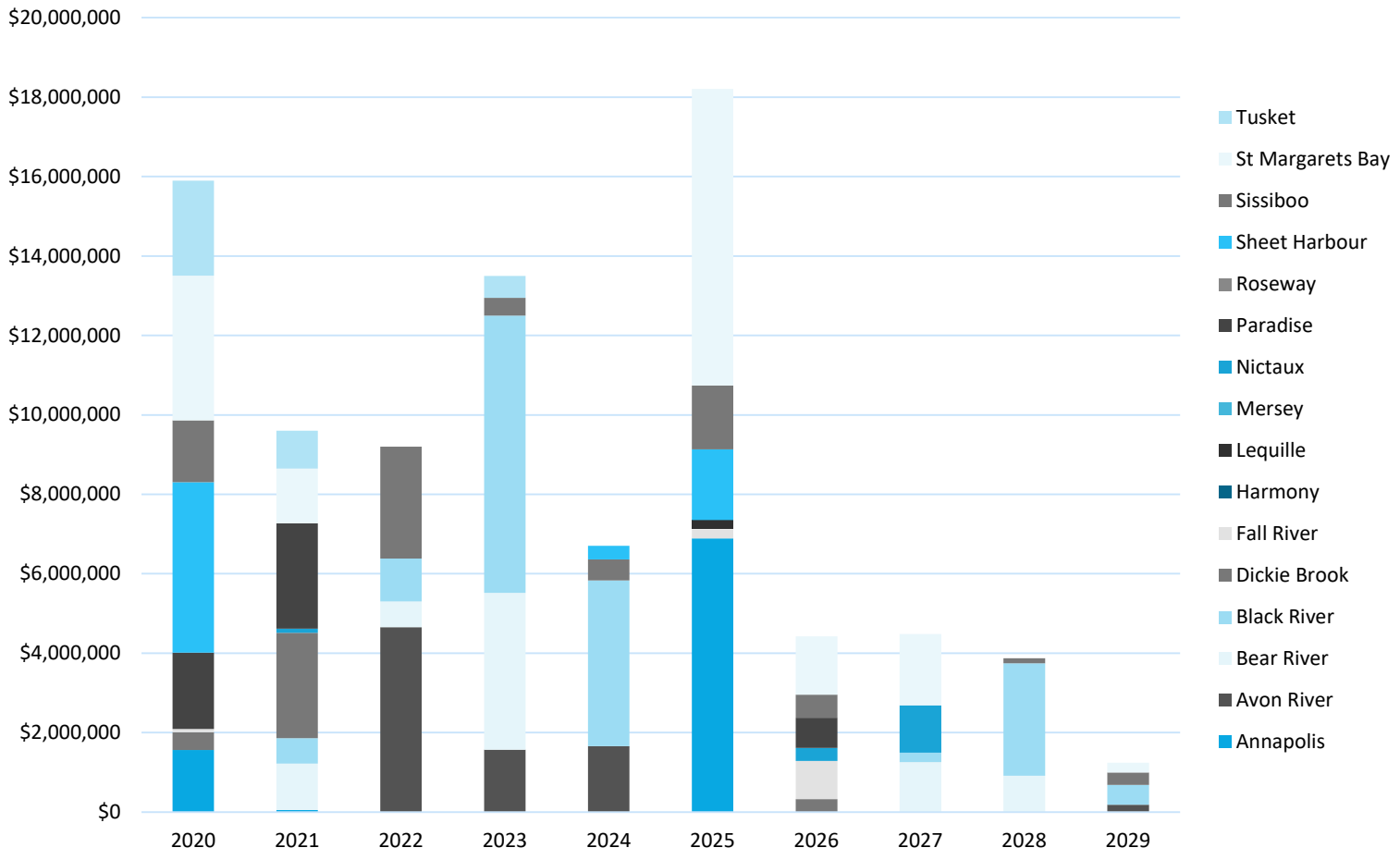
SUSTAINING CAPITAL FORECAST: HYDRO ASSET STUDY



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