Handout 1: Thermodynamic Resources in the 2016 IRP

This handout consists of a summary table that provides the Black & Veatch technical and financial parameters for resources considered in the 2016 IRP.

The complete Black & Veatch report is available in the 2016 IRP document as Appendix K.

Contact Us:
Portland General Electric
Integrated Resource Planning
121 SW Salmon Street
Portland, OR 97204
(503) 464-7312
irp@pgn.com

Table 2-1 Design Basis for Supply-Side Options

SUPPLY-SIDE OPTION	MAJOR EQUIPMENT	DUTY	NET CAPACITY (MW)	CAPACITY FACTOR (PERCENT)	PRIMARY FUEL
1x0 GE LMS100	Combustion Turbine: GE LMS100 PA Wet Intercooler (IC) Emissions Control: Selective Catalytic Reduction (SCR), Carbon Monoxide (CO) Catalyst, Water Injection for NOx Control Heat Rejection: Wet Cooling Tower	Peaking	100	21	Natural Gas
1x0 GE 7F.05	Combustion Turbine: GE 7F.05 Emissions Control: SCR, CO Catalyst	Peaking	230	21	Natural Gas
6x0 Wartsila 18V50SG	Recip. Engine: Wartsila 18V50SG Heat Rejection: Wet Cooling Tower Emissions Control: SCR, CO Catalyst	Peaking	110	13	Natural Gas
1x1 MHPS M501GAC Fast	Combustion Turbine: MHPS M501GAC Fast Duct Firing: None Emissions Control: SCR, CO Catalyst Heat Rejection: Wet Cooling Tower	Intermediate	365	71	Natural Gas
1x1 GE 7HA.01	Combustion Turbine: GE 7HA.01 Duct Firing: None Emissions Control: SCR, CO Catalyst Heat Rejection: Wet Cooling Tower	Intermediate	400	71	Natural Gas
2x1 GE 7HA.01	Combustion Turbine: GE 7HA.01 Duct Firing: None Emissions Control: SCR, CO Catalyst Heat Rejection: Wet Cooling Tower	Intermediate	810	71	Natural Gas
Biomass Combustion	Boiler: Bubbling Fluidized Bed Emissions Control: Selective Non-Catalytic Reduction (SNCR), Fabric Filter Heat Rejection: Wet Cooling Tower	Baseload	35	85	Wood
Geothermal -- Binary	System: Binary Geothermal System Heat Rejection: Air-Cooled Condenser	Baseload	35	85	n/a
Pumped Storage Hydro	System: Closed Loop Discharge Duration: 8 hours Upper Reservoir: 2,500 ft. Lower Reservoir: 1,000 ft.	Storage	300	n/a	n/a
Battery Storage	Battery: Lithium Ion Discharge Duration: 2 hours	Storage	50	n/a	n/a
Battery Storage	Battery: Redox Flow Discharge Duration: 4 hours	Storage	10	n/a	n/a

Table 3-4 Technical Parameters for Conventional Generation Options

SUPPLY-SIDE OPTION	NET CAPACITY (MW)[1]	AVERAGE DESIGN LIFE NET CAPACITY, INCLUDING DEGRADATION (MW)	CAPACITY FACTOR (PERCENT)	LAND REQUIRED (ACRES/ MW)[2]	NET PLANT HEAT RATE (BTU/ kWh-HHV)	AVERAGE DESIGN LIFE NET PLANT HEAT RATE, INCLUDING DEGRADATION (BTU/kWh-HHV)	FUEL CONSUMPTION VERSUS OUTPUT (MMBtu-HHV VERSUS KW-NET, NEW AND CLEAN)[3]	MINIMUM TURNDOWN CAPACITY (PERCENT)[4]	RAMP RATE (MW/MIN)	MINIMUM RUN/ DOWN TIMES (HOURS)	START TIME TO FULL LOAD (MINS)[5]	WATER CONSUMPTION (MGD)	SCHEDULED MAINTENANCE (WEEKS/YR)[6]	EQUIVALENT FORCED OUTAGE RATE (PERCENT)	EPC PERIOD (MONTHS)[7]
1x0 GE LMS100	110	105	21	0.06	9,031	9,176	$y = 2.25579E\text{-}13x^3 - 4.60425E\text{-}08x^2 + 1.00877E\text{-}02x + 1.40587E{+}02$	30	50	0.5 / 0.5	10	0.38	0.07	2.1	24
1x0 GE 7F.05	230	224	21	0.04	9,843	9,981	$y = 1.49882E\text{-}14x^3 + 1.36515E\text{-}08x^2 + 1.41949E\text{-}03x + 1.02989E{+}03$	38	40	0.5 / 0.5	11	0	0.10	1.5	24
6x0 Wartsila 18V50SG	110	110	13	0.06	8,371	8,437	$y = -6.69785E\text{-}08x^2 + 9.35009E\text{-}03x + 4.57192E{+}00$	7	31.8	0.5 / 0.5	10	0.36	0.20	3.2	24
1x1 MHPS M501GAC Fast	395	383	71	0.04	6,744	6,926	$y = -1.32139E\text{-}13x^3 + 1.24103E\text{-}07x^2 - 3.20871E\text{-}02x + 4.11935E{+}03$	58	54	1.5 / 1.5	Hot:60 Warm:100 Cold:210	1.84	0.84	2.9	30
1x1 GE 7HA.01	400	387	71	0.04	6,370	6,503	$y = -5.85279E\text{-}15x^3 + 7.52543E\text{-}09x^2 + 2.81340E\text{-}03x + 5.92389E{+}02$	33	50	1.5 / 1.5	Hot:60 Warm:100 Cold:210	1.86	1.23	2.9	30
2x1 GE 7HA.01	810	784	71	0.02	6,351	6,485	$y = -1.26147E\text{-}15x^3 + 3.40328E\text{-}09x^2 + 3.00625E\text{-}03x + 1.14354E{+}03$	16	100	1.5 / 1.5	Hot:60 Warm:100 Cold:210	3.71	1.23	2.9	34

Notes:

1. Performance parameters assume International Organization for Standardization (ISO) conditions (59° F, 60% relative humidity, and sea level elevation). Net capacity is defined as the nameplate (or gross) unit capacity minus any auxiliary losses.
2. Typical value; actual value is specific to project, location, and owner's requirements.
3. For combustion turbines and reciprocating engines, heat rate is a function of output as well as fuel consumption. In Black & Veatch's experience, providing a curve showing fuel consumption as a function of output provides a more accurate result. The curve provided is fuel consumption versus output (MMBtu-HHV versus kW-net, new and clean). Heat rate can be further determined by dividing fuel consumption by output.
4. While maintaining emissions compliance for combustion turbine and reciprocating engine based option.
5. Start times exclude purge time. Combined cycle start time definitions: Hot start is defined as a start after an 8 hour shutdown (generally considered 8 hours or less). Warm start is defined as a start after a 48 hour shutdown (generally considered 8 to 48 hours). Cold start is defined as a start when the steam turbine rotor temperature is at or near atmospheric temperature (generally considered greater than 48 hours).
6. Maintenance values are annual averages based on prime mover (combustion turbine or reciprocating engine) manufacturer recommended maintenance.
7. The project duration period starts with EPC contractor notice to proceed (NTP) and ends at the commercial operation date (COD). Some excluded activities are permitting and EPC specification development.

Table 3-5 Financial Parameters for Conventional Generation Options

SUPPLY-SIDE OPTION	DESIGN LIFE (YEARS)	EXPENDITURE PATTERN (BY MONTH)	OVERNIGHT EPC CAPITAL COST ($000, 2015$)	OWNER'S COST ALLOWANCE (PERCENT)[8]	OVERNIGHT TOTAL CAPITAL COST ($000, 2015$)	OVERNIGHT TOTAL CAPITAL COST STANDARD DEVIATION, 1σ ($000, 2015$)	FIXED O&M COSTS ($/MW-MONTH)[9]	NONFUEL VARIABLE O&M COST (2015$/MWh)[9]	NONFUEL VARIABLE WEAR AND TEAR COSTS (2015$/MWh)[10]	CAPITAL ADDITIONS/ MAINTENANCE ACCRUAL (2015$/YEAR)	NONFUEL STARTUP VARIABLE O&M COSTS (2015$/ START)[11]	FUEL STARTUP VARIABLE O&M COSTS (MMBTU-HHV/ START)[12]	DECOMMISSIONING COST ($000, 2015$)[13]
1x0 GE LMS100	30	Refer to Appendix B	99,000	25	123,800	9,300	267	5.22	3.88	Refer to Note 14	10	66	6,800
1x0 GE 7F.05	30	Refer to Appendix B	112,000	25	140,000	10,500	261	9.29	9.03	Refer to Note 14	4	294	7,700
6x0 Wartsila 18V50SG	30	Refer to Appendix B	128,000	25	160,000	12,000	280	8.93	5.43	Refer to Note 14	11	72	8,000
1x1 MHPS M501GAC Fast	30	Refer to Appendix B	342,000	25	427,500	42,800	744	3.00	1.94	Refer to Note 14	361	850	42,800
1x1 GE 7HA.01	30	Refer to Appendix B	349,000	25	436,300	43,600	688	2.60	1.60	Refer to Note 14	369	950	43,600
2x1 GE 7HA.01	30	Refer to Appendix B	623,000	25	778,800	77,900	502	2.29	1.55	Refer to Note 14	557	1,900	77,900

Notes (continued from Table 3-4):

8. Owner's cost allowance includes costs associated with project development, operating spare parts and plant equipment, owner's contingencies and project management, utility interconnections, taxes, and legal fees. The owner's cost allowance can vary widely.
9. Estimates expressed in terms of new and clean condition.
10. Estimated wear and tear costs include annualized estimated variable maintenance costs on the turbines, generators, HRSG, and SCR catalysts, as applicable.
11. Assumes average start. Includes makeup water and chemicals. Does not include fuel or electricity.
12. Startup fuel consumption for achieving CTG/RICE full load operation.
13. Decommissioning costs are typically accrued annually over the design life of the asset to decommission the facility. Total project decommissioning costs, net of salvage, are provided in 2015 USD. Assumes the site would be returned to a brownfield condition at the end of its design life.
14. Operation of certain SSOs requires periodic replacement of specific systems or equipment (either dependent upon number of years in service or hours of operation). In instances where these periodic costs are necessary, these costs have been included in the relevant O&M costs associated with specific technology options.

Table 5-1 Representative Performance Parameters for Lithium Ion and Redox Flow Energy Storage Systems

PARAMETER	LI-ION	REDOX FLOW
Commercial Availability	Commercial	Commercial
Facility Power Rating, MW	0.005 to 32	0.05 to 5
Module Power Rating, MW	0.005 to 4	0.005 to 0.25
Facility Energy Capacity, MWh	0.005 to 32	0.2 to 10
Module Energy Capacity, MWh	0.1 to 2	0.03 to 0.5
Ramp Rate, MW/min	Note[1]	Note[1]
Response Time[2]	< 100 ms	< 100 ms
Round-Trip Efficiency, percent	75 to 90	65 to 75
Discharge Duration, hours	0.25 to 4	3 to 8
Charge/Discharge Rate, C[3]	C/4 to 4C	C/8 to C/3

Notes:

1. Li-ion and Redox Flow systems are able to ramp up from an idle status to full rated capacity in less than 1 second.
2. Amount of time system takes to reach rated power.
3. Charge/discharge rate is conventionally expressed in terms of "C-rate". Under this convention, a system with a charge/discharge rate of 2C could be fully charged or discharged in 30 minutes (1/2 hour), while a system with a charge/discharge rate of 6C could be fully charged or discharged in 10 minutes (1/6 hour).

5.3 TECHNICAL AND FINANCIAL PARAMETERS FOR ENERGY STORAGE OPTIONS

Technical parameters for energy storage options considered for PGE are summarized in Table 5-2, while cost and financial parameters for energy storage options considered for PGE are summarized in Table 5-3. Additional parameters specific to energy storage options are shown in Table 5-4.

Table 5-2 Technical Parameters for Energy Storage Options

SUPPLY-SIDE OPTION	NET CAPACITY (MW)[1]	AVERAGE DESIGN LIFE NET CAPACITY, INCLUDING DEGRADATION (MW)	CAPACITY FACTOR (PERCENT)	LAND REQUIRED (ACRES/MW)[2]	NET PLANT HEAT RATE (BTU/ kWh-HHV)	AVERAGE DESIGN LIFE NET PLANT HEAT RATE, INCLUDING DEGRADATION (BTU/kWh-HHV)	HEAT RATE VERSUS OUTPUT (BTU/KWh-HHV VERSUS KW-NET, NEW AND CLEAN)	MINIMUM TURNDOWN CAPACITY (PERCENT)	RAMP RATE (MW/MIN)	MINIMUM RUN/ DOWN TIME (HOURS)	START TIME TO FULL LOAD (MINS)	WATER CONSUMPTION (MGD)	SCHEDULED MAINTENANCE (WEEKS/YR)	EQUIVALENT FORCED OUTAGE RATE (PERCENT)	EPC PERIOD (MONTHS)[3]
Pumped Storage Hydro	300	n/a	n/a	2.0	n/a	n/a	n/a	20	100	n/a	2	n/a	2	1.7	60
Battery Storage – Lithium Ion	50	n/a	n/a	0.04[(4)]	n/a	n/a	n/a	0	Refer to Note 5	n/a	n/a	n/a	2	n/a	12 to 15
Battery Storage – Redox Flow	10	n/a	n/a	0.10[(4)]	n/a	n/a	n/a	0	Refer to Note 5	n/a	n/a	n/a	2	n/a	12 to 15

Notes:

1. Performance parameters assume ISO conditions (59° F, 60% relative humidity, and sea level elevation). Net capacity is defined as the nameplate (or gross) unit capacity minus any auxiliary losses.
2. Typical value; actual value is specific to project, location, and owner's requirements.
3. The project duration period starts with EPC contractor NTP and ends at the COD. Some excluded activities are permitting and EPC specification development.
4. For battery energy storage systems (BESS), 1 acre can accommodate approximately 40 to 60 MWh of energy storage capacity. Therefore, a 50 MW|100 MWh system would require approximately 2 acres and a 10 MW|40 MWh system would require approximately 1 acre.
5. BESS are able to ramp up from an idle status to full rated capacity in less than 1 second.

Table 5-3 Financial Parameters for Energy Storage Options

SUPPLY-SIDE OPTION	DESIGN LIFE (YEARS)	EXPENDITURE PATTERN (BY QUARTER)	OVERNIGHT EPC CAPITAL COST ($000, 2015$)	OWNER'S COST ALLOWANCE (PERCENT)[6]	OVERNIGHT TOTAL CAPITAL COST ($000, 2015$)	OVERNIGHT TOTAL CAPITAL COST STANDARD DEVIATION, 1σ ($000, 2015$)	FIXED O&M COSTS ($/MW-MONTH)[7]	NONFUEL VARIABLE O&M COST (2015$/MWh)[7]	NONFUEL VARIABLE WEAR AND TEAR COSTS (2015$/MWh)[8]	CAPITAL ADDITIONS/ MAINTENANCE ACCRUAL (2015$/YEAR)	NONFUEL STARTUP VARIABLE O&M COSTS (2015$/ START)	FUEL STARTUP VARIABLE O&M COSTS (MMBTU-HHV/ START)	DECOMMISSIONING COST ($000, 2015$)[9]
Pumped Storage Hydro	30	Refer to Appendix B	700,000	25	875,000	218,800	1,000	0.40	n/a	Refer to Note 10	n/a	n/a	8,800
Battery Storage	20	Refer to Appendix B	80,000	12	89,600	11,200	1,250	n/a	n/a	821,250[(11)]	n/a	n/a	2,200
Battery Storage	20	Refer to Appendix B	38,000	12	42,560	5,300	2,500	n/a	n/a	204,400[(11)]	n/a	n/a	2,300

Notes (continued from Table 5-2):

6. Owner's cost allowance includes costs associated with project development, operating spare parts and plant equipment, owner's contingencies and project management, utility interconnections, taxes, and legal fees. The owner's cost allowance can vary widely.
7. Estimates expressed in terms of new and clean condition.
8. Estimated wear and tear costs include annualized estimated variable maintenance costs on the turbines, generators, and batteries.
9. Decommissioning costs are typically accrued annually over the design life of the asset to decommission the facility. Total project decommissioning costs, net of salvage, are provided in 2015 USD. For all SSOs except Pumped Storage Hydro, the site would be returned to a brownfield condition at the end of its design life. For Pumped Storage Hydro, it is assumed that powerhouse equipment would be decommissioned and salvaged, and the facility/reservoirs would be retired in place, with the site secured as appropriate (e.g., reservoirs drained, additional security fencing installed, and signs posted).
10. Operation of certain SSOs requires periodic replacement of specific systems or equipment (either dependent upon number of years in service or hours of operation). In instances where these periodic costs are necessary, these costs have been included in the relevant O&M costs associated with specific technology options.
11. The cost per year presented here assumes 365 cycles per year at 80% depth of discharge (DoD) for both technologies. For lithium ion, the degradation per year is approximately 1.8%. For vanadium redox, the degradation is less than 1% per year.

Table 5-4 Additional Parameters for Energy Storage Options

SUPPLY-SIDE OPTION	NET CAPACITY (MW)[12]	ENERGY CAPACITY (MWh)	ROUND TRIP EFFICIENCY (PERCENT)
Pumped Storage Hydro	300	2,400[(13)]	77
Battery Storage – Lithium Ion	50	100	85
Battery Storage – Redox Flow	10	40	75

Notes (continued from Table 5-3):

12. Performance parameters assume ISO conditions (59° F, 60% relative humidity, and sea level elevation). Net capacity is defined as the nameplate (or gross) unit capacity minus any auxiliary losses.
13. Daily storage based on the 8 hours of discharge per day.

Appendix A. Supply-Side Option Parameters (Full Table)

		Design Basis Parameters						Technical/Performance Parameters												
No.	Supply-Side Option	Option Design Basis	Duty	Net Capacity (MW)[1]	Average Design Life Net Capacity, Including Degradation (MW)	Capacity Factor (%)	Primary Fuel	Land Required (acres/MW)[2]	Net Plant Heat Rate (Btu/kWh-HHV)	Average Design Life Net Plant Heat Rate, Including Degradation (Btu/kWh-HHV)	Heat Rate vs Output (Btu/kWh versus kW-net, New and Clean)	Fuel Consumption versus Output (MMBtu-HHV versus kW-net, New and Clean)[3]	Minimum Turndown Capacity (%)[4]	Ramp Rate (MW/min)	Minimum Run/Down Times (hours)	Start Time to Full Load (mins)[5]	Water Consumption (MGD)	Scheduled Maintenance (weeks/yr)[6]	Equivalent Forced Outage Rate (%)	EPC Period[7] (months)
1	1x0 GE LMS100	Combustion Turbine: GE LMS100 PA Wet IC Emissions Control: SCR, CO catalyst, water injection for NOx control Heat Rejection: Wet Cooling Tower	Peaking	110	105	21%	Natural Gas	0.06	9,031	9,176	See Next Column	$y = 2.25579E-13x^3 - 4.60425E-08x^2 + 1.00877E-02x + 1.40587E+02$	30%	50	0.5 / 0.5	10	0.38	0.07	2.1%	24
2	1x0 GE 7F.05	Combustion Turbine: GE 7F.05 Emissions Control: SCR, CO catalyst	Peaking	230	224	21%	Natural Gas	0.04	9,843	9,981	See Next Column	$y = 1.49882E-14x^3 + 1.36515E-08x^2 + 1.41949E-03x + 1.02989E+03$	38%	40	0.5 / 0.5	11	0	0.10	1.5%	24
3	6x0 Wartsila 18V50SG	Recip. Engine: Wartsila 18V50SG Heat Rejection: Wet Cooling Tower Emissions Control: SCR, CO catalyst	Peaking	110	110	13%	Natural Gas	0.06	8,371	8,437	See Next Column	$y = -6.69785E-08x^2 + 9.35009E-03x + 4.57192E+00$	7%	31.8	0.5 / 0.5	10	0.36	0.20	3.2%	24
4	1x1 MHPS M501GAC Fast	Combustion Turbine: MHPS M501GAC Fast Duct Firing: None Emissions Control: SCR, CO catalyst Heat Rejection: Wet Cooling Tower	Intermediate	395	383	71%	Natural Gas	0.04	6,744	6,926	See Next Column	$y = -1.32139E-13x^3 + 1.24103E-07x^2 - 3.20871E-02x + +4.11935E+03$	58%	54	1.5 / 1.5	Hot: 60 Warm: 100 Cold: 210	1.84	0.84	2.9%	30
5	1x1 GE 7HA.01	Combustion Turbine: GE 7HA.01 Duct Firing: None Emissions Control: SCR, CO catalyst Heat Rejection: Wet Cooling Tower	Intermediate	400	387	71%	Natural Gas	0.04	6,370	6,503	See Next Column	$y = -5.85279E-15x^3 + 7.52543E-09x^2 + 2.81340E-03x + 5.92389E+02$	33%	50	1.5 / 1.5	Hot: 60 Warm: 100 Cold: 210	1.86	1.23	2.9%	30
6	2x1 GE 7HA.01	Combustion Turbine: GE 7HA.01 Duct Firing: None Emissions Control: SCR, CO catalyst Heat Rejection: Wet Cooling Tower	Intermediate	810	784	71%	Natural Gas	0.02	6,351	6,485	See Next Column	$y = -1.26147E-15x^3 + 3.40328E-09x^2 + 3.00625E-03x + 1.14354E+03$	16%	100	1.5 / 1.5	Hot: 60 Warm: 100 Cold: 210	3.71	1.23	2.9%	34
7	Biomass Combustion	Boiler: Bubbling Fluidized Bed Emissions Control: SNCR, Fabric Filter Heat Rejection: Wet Cooling Tower	Baseload	35	35	85%	Wood	1.0	13,000	13,350	$y = 4,800x^2 - 10,800x + 18,999$	n/a	25%	1.75	8.0 / 8.0	180	1.0	3.83	7.5%	36
8	Geothermal -- Binary	System: Binary Geothermal System Heat Rejection: Air-Cooled Condenser	Baseload	35	n/a	85%	n/a	1.0	n/a	n/a	n/a	n/a	50%	4.5	0.5 / 0.5	10	0.00	3.83	6.0%	24[16]
9	Pumped Storage Hydro	System: Closed Loop Discharge Duration: 8 hours Upper Reservoir: 2,500 ft. Lower Reservoir: 1,000 ft.	Storage	300	n/a	n/a	n/a	2.0	n/a	n/a	n/a	n/a	20%	100	n/a	2	n/a	2	1.7%	60
10	Battery Storage -- Lithium Ion	Battery: Lithium Ion Discharge Duration: 2 hrs	Storage	50	n/a	n/a	n/a	0.04[14]	n/a	n/a	n/a	n/a	0%	Refer to Note 15	n/a	n/a	n/a	2	n/a	12 to 15
11	Battery Storage -- Redux Flow	Battery: Redux Flow Discharge Duration: 4 hrs	Storage	10	n/a	n/a	n/a	0.10[14]	n/a	n/a	n/a	n/a	0%	Refer to Note 15	n/a	n/a	n/a	2	n/a	12 to 15

NOTES:

(1) Performance parameters assume ISO conditions (59° F, 60% relative humidity, and sea level elevation). Net capacity is defined as the nameplate (or gross) unit capacity, minus any auxiliary losses.

(2) Typical value; actual value is specific to project, location, and owner's requirements.

(3) For combustion turbines and reciprocating engines, heat rate is a function of output as well as fuel consumption. In Black & Veatch's experience, providing a curve showing fuel consumption as a function of output provides a more accurate result. The curve provided is Fuel Consumption versus Output (MMBtu-HHV versus kW-net, New and Clean). Heat rate can be further determined by dividing fuel consumption by output.

(4) While maintaining emissions compliance for Options 1 through 7.

(5) Start times exclude purge time. Combined cycle start time definitions: Hot start is defined as a start after an 8 hour shutdown (generally considered 8 hours or less). Warm start is defined as a start after a 48 hour shutdown (generally considered 8 to 48 hours). Cold start is defined as a start when the steam turbine rotor temperature is at or near atmospheric temperature (generally considered greater than 48 hours).

(6) Natural gas fueled option maintenance values are annual averages based on prime mover (combustion turbine or reciprocating engine) manufacturer recommended maintenance. Renewable option maintenance based on industry norms

(7) The project duration period starts with EPC contractor notice to proceed (NTP) and ends at the commercial operation date (COD). Some excluded activities are permitting and EPC specification development

(8) Owner's cost allowance includes costs associated with project development, operating spare parts and plant equipment, owner's contingencies and project management, utility interconnections, taxes, and legal fees. The owner's cost allowance can vary widely

(9) Estimates expressed in terms of new and clean condition.

(10) Estimated wear and tear costs include annualized estimated variable maintenance costs on the turbines, generators,steam generator, batteries, and SCR catalysts, as applicable

(11) Assumes average start. Includes makeup water and chemicals. Does not include fuel or electricity

(12) Startup fuel consumption for achieving CTG/RICE full load operation.

(13) Decommissioning costs are typically accrued annually over the design life of the asset to decommission the facility. Total project decommissioning costs, net of salvage, are provided in 2015 USD. For all SSOs except Pumped Storage Hydro, the site would be returned to a brownfield condition at the end of its design life. For Pumped Storage Hydro, it is assumed that powerhouse equipment would be decommissioned and salvaged, and the facility/reservoirs would be retired in place, with the site secured as appropriate (e.g., reservoirs drained, additional security fencing installed, and signs posted)

(14) For battery energy storage systems (BESS), 1 acre can accommodate approximately 40 to 60 MWh of energy storage capacity. Therefore, a 50 MW|100 MWh system would require approximately 2 acres and a 10 MW|40 MWh system would require approximately 1 acre

(15) BESS are able to ramp up from an idle status to full rated capacity in less than 1 second

(16) EPC period for geothermal projects is considered 24 months for construction of generation systems. Project development, including drilling of test wells and associated well development activities, is assumed to require 24 months, but development is assumed to be conducted prior to the EPC period

(17) Design life for battery energy storage options is consistent with the warranties/guarantees provided by battery OEMs and is consistent with the capacity maintenance costs listed in the Table

(18) Operation of certain SSOs requires periodic replacement of specific systems or equipment (either dependent upon number of years in service or hours of operation). In instances where these periodic costs are necessary (for the SSOs under consideration in this report), these costs have been included in the relevant O&M costs associated with specific technology options

(19) The cost per year presented here assumes 365 cycles per year at 80% depth of discharge (DoD) for both technologies. For lithium ion, the degradation per year is approximately 1.8%. For vanadium redox, the degradation is less than 1% per year.

(20) Daily storage based on the 8 hours of discharge per day.