



# PSE 2019 IRP

## Supply-Side Technology Characterizations



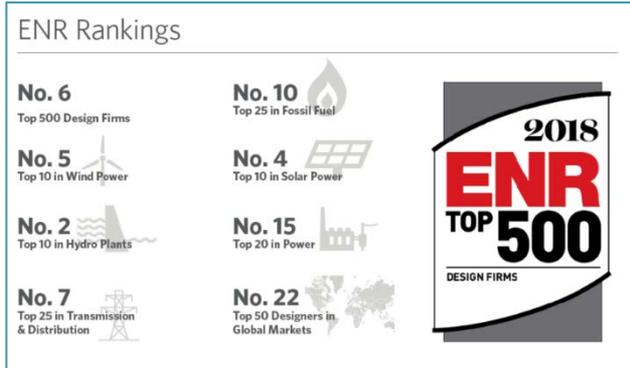
# OVERVIEW

- 2019 IRP supply-side analysis
- HDR characterizing technology alternatives
- Discussion topics:
  - HDR overview
  - Approach/methodology
  - Technologies considered
  - Technology attributes
  - Summary and follow-up



# HDR OVERVIEW

- 10,000+ employee owners, 225+ offices
- Founded in 1917 – domestic + international
- 1,000+ staff dedicated to energy
- Engineering Company Ratings



# HDR ENERGY PROGRAM

- Generation
  - 73+ GW natural gas and coal
  - 35+ GW renewables and storage
  - 11+ GW hydroelectric and pumped storage
- Transmission & Distribution (T&D)
  - Planning and execution
- Regulatory & Permitting
  - Supply-side (thermal, hydro, renewables, and storage) and wires



# HDR ENERGY PROGRAM

- Planning and development
- Owner's engineering
- Conceptual and detailed design
- Support IRP across the US



# METHODOLOGY

- Approach
  - Actual project developments
  - Executed projects
  - RFP/procurement resume
  - Other IRPs, publications
- Generic resource characterizations
  - Manufacturer and project agnostic
- Consideration of PSE and regional specific issues
- Market-based



# PERFORMANCE BASIS

- Performance
  - Estimating software
  - Manufacturer data – normalized
  - Representative & regional site locations
  - Dispatch & auxiliary load estimates
  - Emission Profiles – thermal assets
- Operating Characteristics
  - Start times, ramping capability, etc.



# COST BASIS

- Site and technology generic
- Resource size normalized
- Construction costs and allocations for:
  - Electrical interconnection
  - Fuel supply
- Construction + owner's costs
- Representative operating & dispatch profiles



# SUPPLY-SIDE RESOURCES

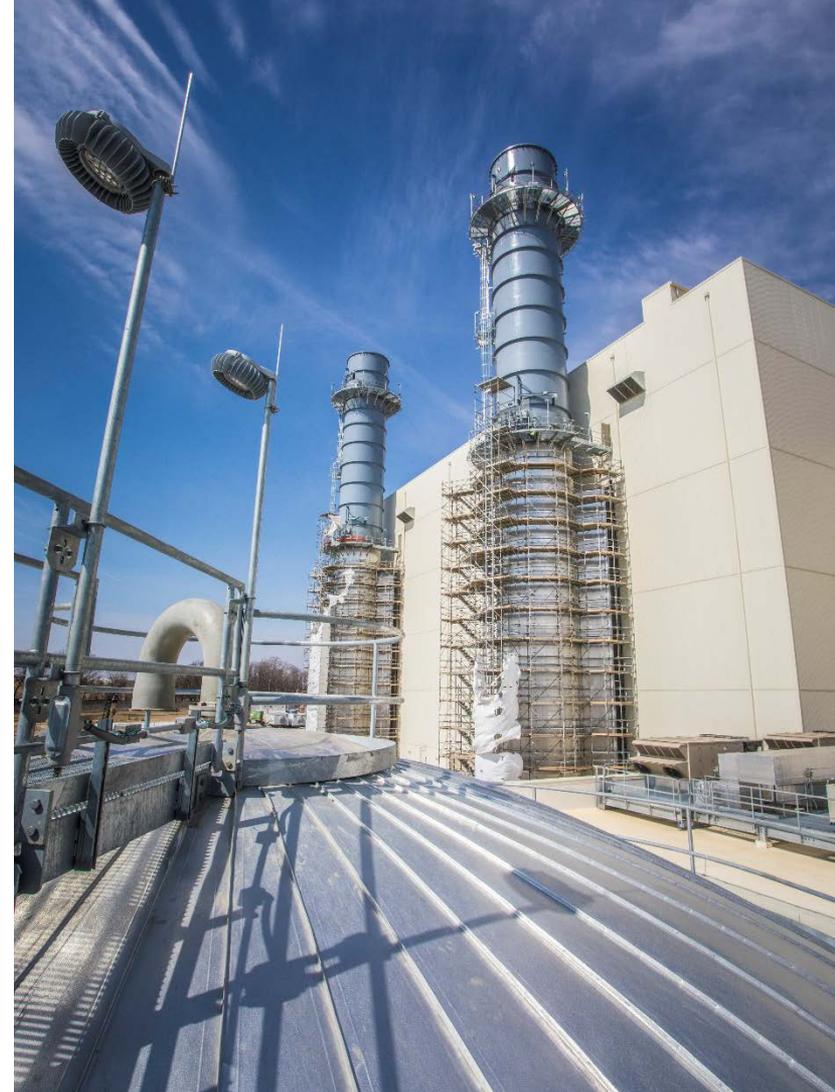
- Thermal – Single and Dual Fuel
  - Simple and combined cycle CT
  - Simple cycle RICE
- Renewable
  - Wind – Montana and Washington
  - Solar – Washington
  - Biomass
- Energy Storage
  - Pumped hydro
  - Battery
    - Li-Ion
    - Vanadium Flow



# THERMAL RESOURCES

- Simple cycle combustion turbine
- Combined cycle combustion turbine
- Reciprocating internal combustion engine
- Representative site conditions
- Estimated air emissions

Estimated Emissions	Heat Input	Net Output	NOx	PM	SO2	CO	VOC	CO2
	mmbtu/hr	MW	lb/mmbtu	lb/mmbtu	lb/mmbtu	lb/mmbtu	lb/mmbtu	lb/mmbtu
1x0 F-Class CT (NG)	2,316	237	0.0081	0.0057	0.0014	0.0049	0.0014	118
1x0 F-Class CT (FO)	2,266	229	0.0136	0.0057	0.0082	0.0049	0.0014	160
1x1 F-Class CC (Fired)	2,480	367	0.0081	0.0057	0.0014	0.0049	0.0014	118
1x1 F-Class CC (Unfired)	2,315	348	0.0081	0.0057	0.0014	0.0049	0.0014	118
12x0 18 MW RICE SC (NG Only)	1,846	219	0.0292	0.0057	0.0014	0.0049	0.0014	118
12x0 18 MW Dual Fuel RICE (NG)	1,726	201	0.0373	0.0057	0.0019	0.0049	0.0057	122
12x0 18 MW Dual Fuel RICE (FO)	1,520	173	0.1297	0.0057	0.0082	0.0049	0.0082	160
15 MW Biomass	216	14	0.0290	0.0540	0.0320	0.3000	0.0014	213





# RENEWABLE RESOURCES

- On-shore wind
  - Montana
  - Washington
- Off-shore wind
  - Washington
- Solar
  - Washington
- Biomass



# RENEWABLE RESOURCES

Puget Sound Energy 2019 IRP	Fuel	Winter Peak Net Output	Winter Peak Net Heat Rate (HHV)	EPC Cost	Owner's Cost	Total Cost	Capacity Factor	First Year Fixed O&M	First Year Variable O&M	Gas + Electric interconnect	Total with Interconnect
Unit Type	Type	MW	Btu/kWh	\$/kW	\$/kW	\$/kW	%	\$/kW-yr	\$/MWh	\$/kW	\$/kW
<b>On-Shore Wind</b>											
100 MW Wind Farm - Central Montana (Site #1)	-	100	-	\$1,633	\$280	\$1,913	36%	\$37.00	-	\$103	\$2,016
100 MW Wind Farm - Central Montana (Site #2)	-	100	-	\$1,633	\$280	\$1,913	42%	\$37.00	-	\$831	\$2,744
100 MW Wind Farm - Southeastern Washington	-	100	-	\$1,656	\$283	\$1,939	32%	\$37.00	-	\$103	\$2,042
<b>Off-Shore Wind</b>											
300 MW Wind Farm - Washington Coast	-	300	-	\$5,000	\$1,480	\$6,480	31-35%	\$120.00	-	\$67	\$6,547
<b>Solar Photovoltaic (PV)</b>											
25 MW Solar PV (Washington) - Single Axis Tracking	-	25	-	\$1,352	\$191	\$1,543	19%	\$27.19	-	\$380	\$1,922
<b>Biomass</b>											
15 MW Biomass	Wood	15	14,154	\$7,036	\$2,031	\$9,067	85%	\$345.20	\$6.60	\$628	\$9,695

# ENERGY STORAGE

- Pumped hydro energy storage
  - Slice of PNW project
- Battery energy storage systems
  - Lithium ion
  - Vanadium flow
  - 25 MW capability and 2 daily cycles
  - 2, 4, and 6 hour

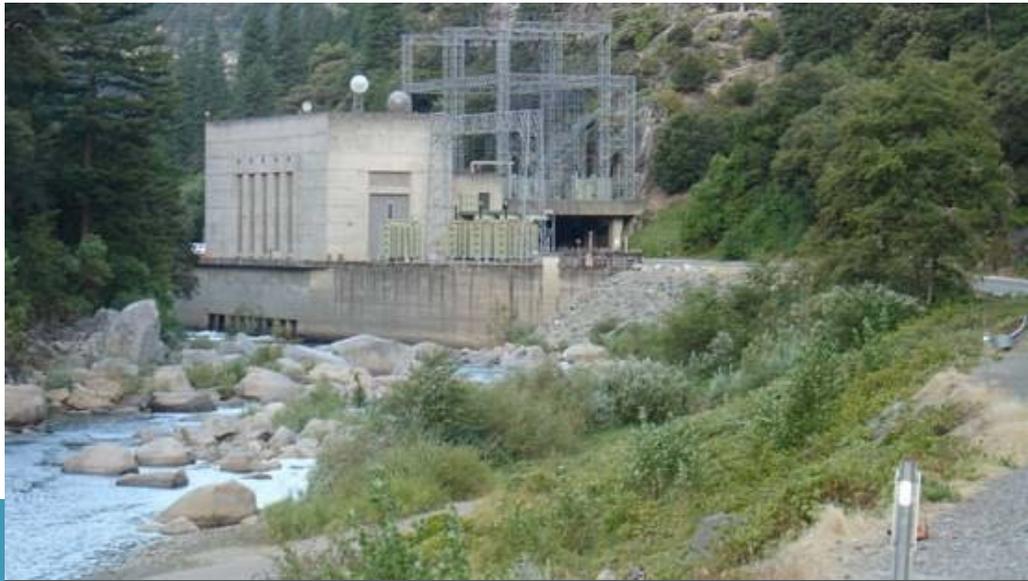


# ENERGY STORAGE

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Unit Type	Type	MW	\$/kW	\$/kW	\$/kW	%	\$/kW-yr	\$/MWh	\$/kW	\$/kW
<b>Pumped Hydro Energy Storage (PHES)</b>										
PHES - 500 MW Closed Loop (8 Hour)	Elec. Grid	500	\$1,800	\$812	\$2,612	-	\$14.55	\$0.90	\$49	\$2,661
PHES - 300 MW Closed Loop (8 Hour)	Elec. Grid	300	\$1,800	\$812	\$2,612	-	\$17.40	\$1.50	\$67	\$2,679
<b>Battery Energy Storage System (BESS)</b>										
BESS - 25 MW Lithium Ion (2 Hour / 2 Cycles Daily)	Elec. Grid	25	\$1,331	\$219	\$1,550	-	\$20.54	-	\$380	\$1,930
BESS - 25 MW Lithium Ion (4 Hour / 2 Cycles Daily)	Elec. Grid	25	\$2,346	\$334	\$2,680	-	\$32.16	-	\$380	\$3,059
BESS - 25 MW Vanadium Flow (4 Hour / 2 Cycles Daily)	Elec. Grid	25	\$1,493	\$239	\$1,732	-	\$30.80	-	\$380	\$2,111
BESS - 25 MW Vanadium Flow (6 Hour / 2 Cycles Daily)	Elec. Grid	25	\$2,050	\$328	\$2,378	-	\$40.27	-	\$380	\$2,758

# SUMMARY

- HDR focus was on supply-side evaluation
- Generic characterization and representation of generation and storage resources
- Thermal, renewable, storage – 13 total
- Representative of current market and forecast trends



# APPENDIX

Puget Sound Energy 2019 IRP	Fuel	Winter Peak Net Output	Winter Peak Net Heat Rate (HHV)	EPC Cost	Owner's Cost	Total Cost	Capacity Factor	First Year Fixed O&M	First Year Variable O&M	EPC Schedule	Gas + Electric Interconnect	Total with Interconnect
Unit Type	Type	MW	Btu/kWh	\$/kW	\$/kW	\$/kW	%	\$/kW-yr	\$/MWh	Months	\$/kW	\$/kW
<b>Simple Cycle (SC) Combustion Turbine (CT)</b>												
1x0 F-Class Dual Fuel CT (NG / FO)	NG	237	9,774	\$554	\$131	\$686	4%	\$3.93	\$6.56	20 - 22	\$139	\$825
1x0 F-Class Dual Fuel CT (NG / FO)	FO	229	9,900									
<b>Combined Cycle (CC) CT - Wet Cooling</b>												
1x1 F-Class CC (Unfired)	NG	348	6,649	\$898	\$232	\$1,131	85%	\$14.16	\$2.52	30 - 32	\$99	\$1,229
1x1 F-Class CC (Fired)	NG	367	6,761	\$853	\$221	\$1,073	85%	\$13.44	\$2.45	30 - 32	\$94	\$1,167
<b>Reciprocating Internal Combustion Engine (RICE)</b>												
12x0 18 MW Class RICE (NG Only)	NG	219	8,428	\$842	\$201	\$1,043	15%	\$3.74	\$5.30	26 - 28	\$148	\$1,192
12x0 18 MW Class Dual Fuel RICE (NG / FO)	NG	201	8,565									
12x0 18 MW Class Dual Fuel RICE (NG / FO)	FO	173	8,763									
<b>On-Shore Wind</b>												
100 MW Wind Farm - Central Montana (Site #1)	-	100	-	\$1,633	\$280	\$1,913	36%	\$37.00	-	20 - 24	\$103	\$2,016
100 MW Wind Farm - Central Montana (Site #2)	-	100	-	\$1,633	\$280	\$1,913	42%	\$37.00	-	20 - 24	\$831	\$2,744
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25 MW Solar PV (Washington) - Single Axis Tracking	-	25	-	\$1,352	\$191	\$1,543	19%	\$27.19	-	10 - 12	\$380	\$1,922
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15 MW Biomass	Wood	15	14,154	\$7,036	\$2,031	\$9,067	85%	\$345.20	\$6.60	38 - 40	\$628	\$9,695
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## 2019 IRP Electric Supply-Side Resources - Thermal

2018 \$	Units	1x0 F-Class Dual Fuel CT (NG)	1x0 F-Class Dual Fuel CT (FO)	1x1 F-Class CC (NG Only)	12x0 18 MW Class RICE (NG Only)	12x0 18 MW Dual Fuel RICE (NG)	12x0 18 MW Dual Fuel RICE (FO)
ISO Capacity Primary	MW	225	217	336	219	201	173
Winter Capacity Primary (23 degrees F)	MW	237	229	348	219	201	173
Capacity DF (At ISO)	MW			355			
Capital Cost + Duct Fire*	\$/KW	\$686		\$1,073	\$1,043	\$1,196	
O&M Fixed	\$/KW-yr	\$3.93		\$13.44	\$3.74	\$4.12	
Flexibility	\$/KW-yr						
O&M Variable	\$/MWh	\$0.69		\$1.97	\$5.30	\$5.80	
Start Up Costs	\$/Start	\$6,502		\$6,566	\$0.46	\$0.48	
Capacity Credit	%						
Operating Reserves	%						
Forced Outage Rate		2.38%	2.38%	3.88%	3.30%	3.30%	3.30%
ISO Heat Rate – Baseload (HHV)	Btu/KWh	9,904	10,985	6,624	8,445	8,582	8,780
ISO Heat Rate – Turndown (HHV)	Btu/KWh	15,794	12,856	7,988	11,288	11,471	11,736
Heat Rate – DF	Btu/KWh			6,724			
Min Capacity	%	30%	50%	38%	30%	30%	30%
Start Time (hot)	minutes	21	21	45	5	5	5
Start Time (warm)	minutes	21	21	60	5	5	5
Start Time (cold)	minutes	21	21	150	5	5	5
Start up fuel (hot)	mmBtu	366	338	839	69	69	57
Start up fuel (warm)	mmBtu	366	338	1,119	69	69	57
Start up fuel (cold)	mmBtu	366	338	2,797	69	69	57
Location							
Fixed Gas Transport	\$/Dth/Day						
Fixed Gas Transport	\$/KW-yr						
Variable Gas Transport	\$/MMBtu						
Fixed Transmission	\$/KW-yr						
Variable Transmission	\$/MWh						
Emissions:							
CO <sub>2</sub> - Natural Gas	lbs/MMBtu	118		118	118	122	
CO <sub>2</sub> - Distillate Fuel Oil	lbs/MMBtu		160				160
NO <sub>x</sub> - Natural Gas	lbs/MMBtu	0.004		0.008	0.029	0.037	
NO <sub>x</sub> - Distillate Fuel Oil	lbs/MMBtu		0.014				0.130
First Year Available							
Economic Life	Years	30	30	30	30	30	30
Greenfield Dev. & Const. Lead-time	years	1.8	1.8	2.7	2.3	2.3	2.3

## 2019 IRP Electric Supply-Side Resources - Renewables

2018 \$	Units	On-Shore Wind - MT (Site #1)	On-Shore Wind - MT (Site #2)	On-Shore Wind - SE Wash.	Offshore Wind - WA Coast	Solar PV - WA	Biomass	
ISO Capacity Primary	MW	100	100	100	300	25	15	
Winter Capacity Primary	MW	100	100	100	300	25	15	
Capacity Credit	%							
Operating Reserves	%							
Capacity Factor	%	35.5%	42.4%	31.9%	29.3%	24.2%	85%	
Capital Cost	\$/KW	\$1,913	\$1,913	\$1,939	\$6,480	\$1,543	\$9,067	
O&M Fixed	\$/KW-yr	\$37.00	\$37.00	\$37.00	\$120.00	\$27.19	\$345.20	
O&M Variable	\$/MWh	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$6.60	
Land Area	acres/MW	48.2	48.2	48.2		5 - 7	6 - 8	
Degradation	%/year	0	0	0	0	0.50%	N/A	
Location	-							
Fixed Transmission	\$/KW-yr							
Variable Transmission	\$/MWh							
Loss Factor to PSE	%							
Heat Rate – Baseload (HHV)	Btu/KWh							14,972
Emissions:								
NO <sub>x</sub>	lbs/MMBtu							0.03
SO <sub>2</sub>	lbs/MMBtu							0.03
CO <sub>2</sub>	lbs/MMBtu							0.30
First Year Available								
Economic Life	Years	25	25	25	25	20	30	
Greenfield Dev. & Const. Leadtime	years	2.0	2.0	2.0	3.2	1.0	3.3	

## 2019 IRP Electric Supply-Side Resources - Energy Storage

2018 \$	Units	PHES - Closed Loop (8 Hour)	PHES Closed Loop (8 Hour)	BESS - 25 MW Li-Ion (2 Hour / 2 Cycles Daily)	BESS - 25 MW Li-Ion (4 Hour / 2 Cycles Daily)	BESS - 25 MW Flow (4 Hours / 2 Cycles Daily)	BESS - 25 MW Flow (6 Hours / 2 Cycles Daily)
Nameplate Capacity	MW	500	300	25	25	25	25
Winter Capacity	MW	500	300	25	25	25	25
Capacity Credit	%						
Operating Reserves	%						
Capital Cost	\$/KW	\$2,612	\$2,612	\$1,550	\$2,680	\$1,732	\$2,378
O&M Fixed	\$/KW-yr	\$14.55	\$17.40	\$20.54	\$32.16	\$30.80	\$40.27
O&M Variable	\$/MWh	\$0.90	\$1.50	\$0.00	\$0.00	\$0.00	\$0.00
Forced Outage Rate	%	1%	1%	<2%	<2%	<5%	<5%
Degradation	%/year	(a)	(a)	(d)	(d)	(d)	(d)
Operating Range (e)	%	147-500 MW (b)	112.5-300 MW (c)	2.0%	2.0%	2.0%	2.0%
R/T Efficiency	%	80%	80%	82%	87%	73%	73%
Discharge at Nominal Power	Hours	8	8	2	4	4	6
Location							
Fixed Transmission	\$/KW-yr						
Variable Transmission	\$/MWh						
Flexibility Benefit	\$/KW-yr						
First Year Available							
Economic Life	Years	30+	30+	20	20	20	20
Greenfield Dev. & Const. Leadtime	years	5 - 8	5 - 8	1	1	1	1

### Notes

PHES (assumed to represent a slice of a larger project).

a - PHES degradation close to zero

b - The operating range minimum is the average of the minimum at max (111 MW) and min head (183 MW).

c - The operating range minimum is the average of the minimum at max (86 MW) and min head (139 MW).

Li-ion BESS: Additional capacity prepurchased included in capital to ensure 20 yr operating life

d - Fixed O&M costs include augmentation by OEM ensuring MW and MWh rating for project life.

e - Battery can discharge upto the indicated percent of nameplate

HDR