Preliminary Assumptions for Natural Gas Peaking Technologies

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GRAC

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Today's Discussion

- Overview of peaking technologies
  - Key attributes, applications, and characteristics
- Discussion of overnight capital cost assumptions and estimations
- Preliminary draft reference plants and capital cost estimates for peaking technologies
  - Frame, Aeroderivative, Intercooled, Reciprocating Engines
- Next steps

Definitions

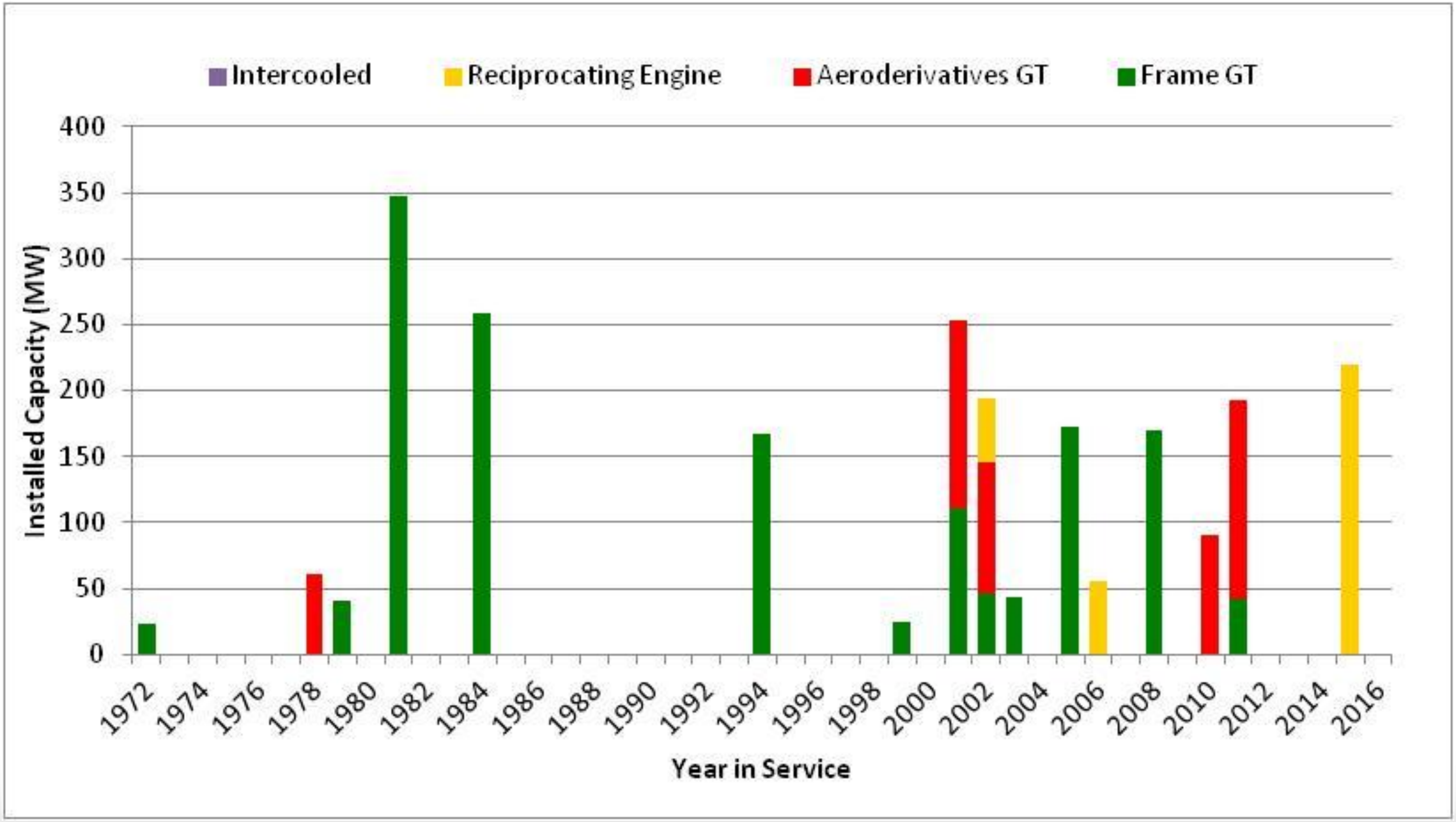
- <u>Baseload Energy</u>: power generated (or conserved) across a period of time to serve system demands for electricity
- <u>Peaking Capacity</u>: capability of power generating and demand-management resources to satisfy maximum system demands for electricity at a specific point in time (~daily occurrence)
- <u>Hydro firming</u>: extended operation during poor water years and may be inactive for years at a time
- <u>Flexibility</u>: ability to continuously and reliably match generating and demand-side resources to system demands for electricity (ramp rate, etc.)

Applications of Gas Units

	Peaking	Hydro Firming	System Balancing/ Flexibility	Base load/Intermediate Load
CCCT				X
Advanced CCCT			X	X
Recip	X	Y	X	
Aeroderivative	X	Y	X	
Intercooled	X	Y	X	
Frame	Y+	X	Y+	

X – primary use
Y – alternative use, but wouldn't build as primary purpose

Historical Peaking Plant Additions in the Region (MW)



Note: There are currently no intercooled/aero hybrid plants in the PNW

Overnight Capital Cost Assumptions and Normalizations

Capital Cost Assumptions and Normalizations

1. Reference sources – reported plant data, generic reports
2. Objective - normalize to draft Seventh Plan reference plant design
   - Overnight capital costs in $2012
   - ISO capacity and heat rate
   - Typical configuration for PNW
3. Look for outliers, trends; forecast future 20 year trend line

Reference Sources

- Project-specific publically available reported info
- Technical data from manufacturer
- Regional utility IRPs
- Gas Turbine World (2013 Handbook)
- Black & Veatch analysis for Black Hills (2011)
- NERA analysis for NYISO (2010)
- EIA Capital Cost (2013), EIA AEO (2014)
- National Energy Technology Laboratory (2013)
- National Renewable Energy Laboratory (2012; prepared by Black & Veatch)
- California Energy Commission (May 2014)

Some assumptions may have a significant effect on the final estimate of capital cost

- **Unit scaling factor** – The more units in a project, the greater the economies of scale
  - Currently assuming single unit plants cost 15% more per kw than multi-unit plants (6th Plan – 30%)
- **Owner's Cost** – 25% of EPC (6th Plan – 12%)
- Acknowledgements – limited information to make adjustments
  - Brownfield vs. Greenfield
  - Location and local air quality regulations

Draft Seventh Plan Reference Plants and Capital Cost

Proposed Configuration for 7th Plan Reference Plants

Technology	Proposed Configuration	Capacity
Frame GT	(1) 215.8 MW GE 7F 5-series	~ 216 MW
Aeroderivative GT	(4) 47.3 MW GE LM 6000PF Sprint	~ 190MW
Intercooled/Aero Hybrid GT	(2) 100 MW GE LMS100 PB	200 MW
Reciprocating Engine	(12) 18 MW Wärtsilä	220 MW

Proposing reference plants that resemble capacity of Port Westward II (220MW) – most recent peaking plant to be constructed in the PNW

Properties of Frame Technologies

Frame (80MW – 250 MW units)

- Stationary device, weight not an issue
- Strengths - longevity and durability
- Weaknesses – slower response time; higher heat rate; higher exhaust temperatures/more expensive air quality control
- Typical use – on for several days, then shut down; newer models tout flexibility
- PNW – several frame units built in 1970's – 1990's for hydro back-up (firming)

Proposed Frame Reference Plant (1)

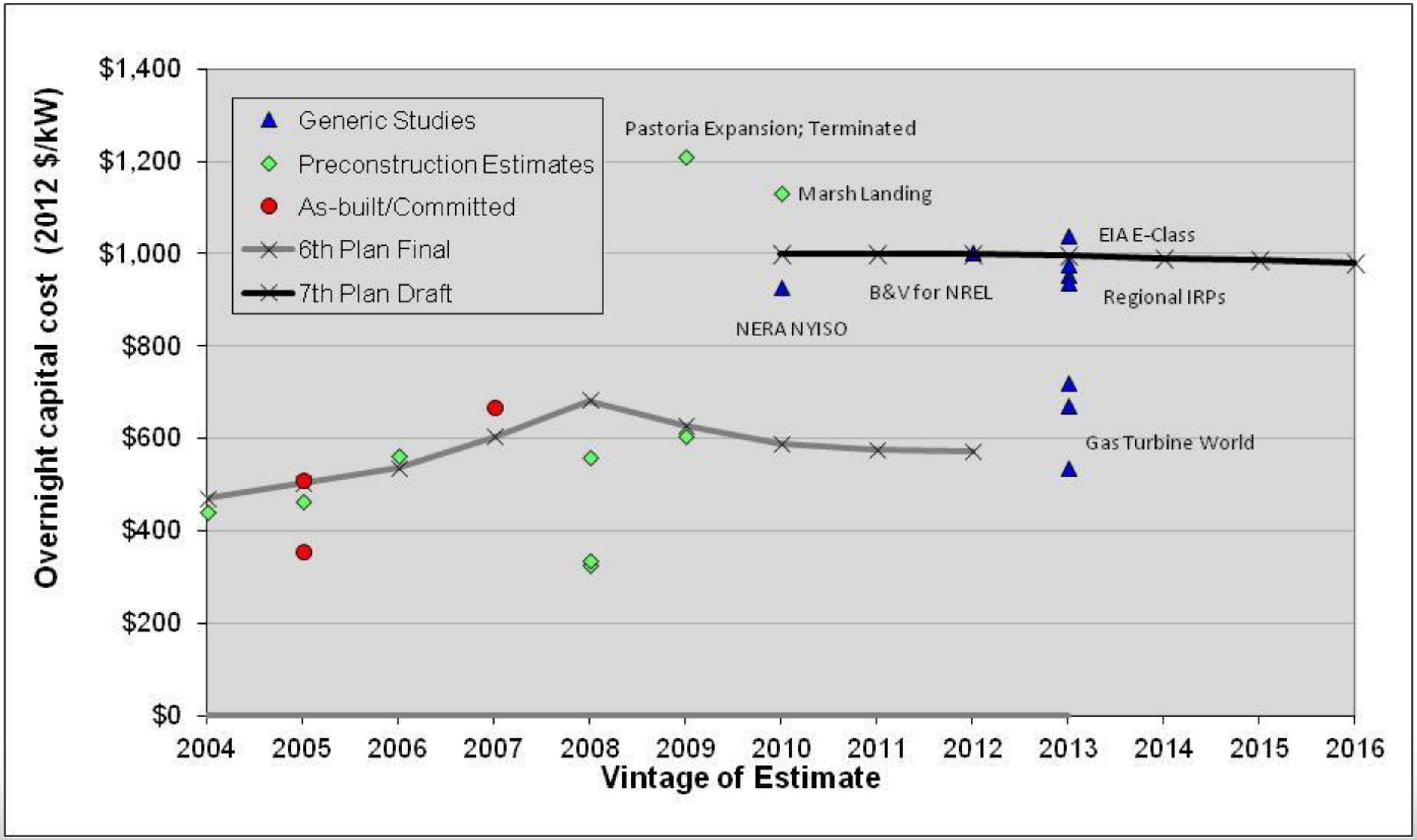
- **GE 7F 5 Series**
  - 216 MW nominal output
  - Available starting in 2009
  - 7E and 7F are popular among new installations in WECC
  - Start time – 11 minutes to base load
  - Ramp rate – 40 MW/minute per turbine
  - Turndown to minimum load – 36% baseload
  - We selected GE's 7F 5-series over 3-series
    - 5-series builds on advancements to inlet, compressor, combustion and power turbine systems
    - 5-series touts enhanced flexibility

Proposed Frame Reference Plant (2)

Technology & Configuration base	(1) GE 7F 5-Series
Output per unit (MW)	216 (nominal, ISO)
Output Total (MW)	216 nominal / 202 lifecycle avg
Fuel	Natural Gas
Heat Rate (btu/kWh)	9801 HHV
Capital Cost (mm$ 2012)	$216 MM
Capital Cost ($/kW 2012)	$1,000/kw
Fixed O&M	TBD
Variable O&M	TBD
Economic Life (Years)	30
Construction Time (Months)	18 mos development 9 mos early construction 6 mos committed construction

* All SCCT reference plants to match Port Westward II – 220 MW

Preliminary Capital Cost Estimates for Frame Technology



Properties of Aeroderivative Technologies

Aeroderivative (15 – 60 MW units)

- Designed from aircraft engine; lighter, more delicate than frame
- Strengths – rapid response; lower heat rate; easy maintenance; smaller unit size; can use SCR and OxyCat
- Weaknesses - ???
- Typical use – meeting short-term peak loads
- PNW – several Pratt and Whitney and a few LM6000 plants

Proposed Aeroderivative Reference Plant (1)

- **LM6000-PF gas turbine**
  - 42 – 47MW output (w/ SPRINT)
  - Available starting in 2007
  - Popular choice among new installs in WECC
  - More available information on cost and performance
  - Second of three LM6000 generations
    - Same gen as LM6000PD used in Sixth Plan, but with improved NOx emissions reductions
  - 5-minute fast start, 10-minute full power
  - Advanced emissions technology
    - Reduced NOx emissions to 15 ppm

Proposed Aeroderivative Ref Plant (2)

Technology & Configuration base	(4) GE LM6000 PF SPRINT
Output per unit (MW)	48 MW (nominal, ISO)
Output Total (MW)	192 MW nominal; 180 MW lifecycle avg
Fuel	Natural Gas
Heat Rate (btu/kWh)	9048 HHV
Capital Cost (mm$ 2012)	$228.6 (lifecycle)
Capital Cost ($/kW 2012)	$1,270 (lifecycle)
Fixed O&M	TBD
Variable O&M	TBD
Economic Life (Years)	30
Construction Time (Months)	18 mos development 9 mos early construction 6 mos committed construction

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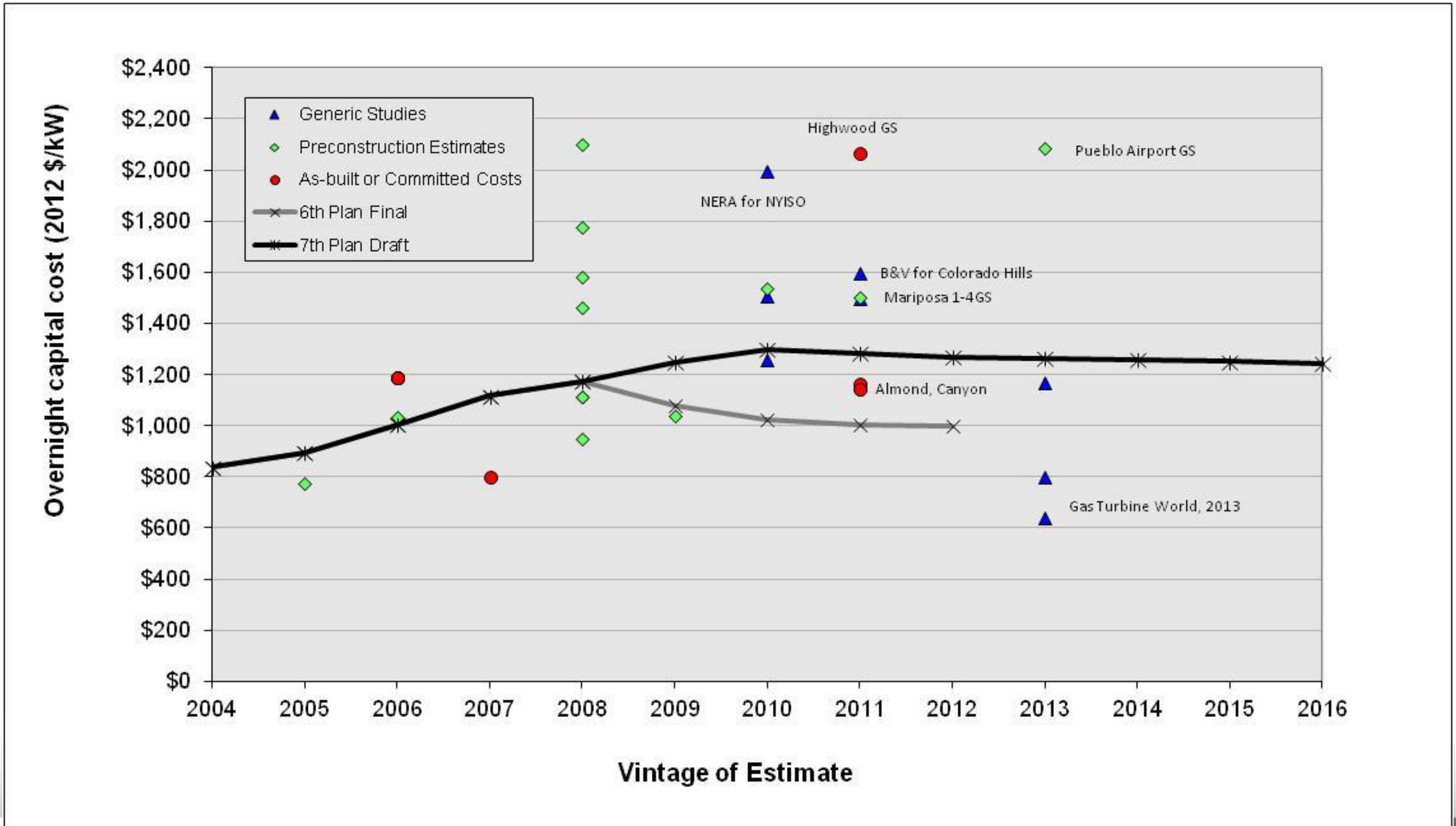
Preliminary Capital Cost Estimates for Aeroderivative



Properties of Intercooled Technologies

Intercooled (100 MW units)

- Hybrid of frame and aeroderivative → compressor intercooler
- Strengths – rapid response; lowest GT heat rate; good turndown characteristics; can use SCR and OxyCat
- Weaknesses - requires continuous source of cooling water
- Typical use –short-term peak loads and variable resource integration
- PNW – none currently planned or in operation; numerous in WECC

Proposed Intercooled Reference Plant (1)

GE LMS100 PB

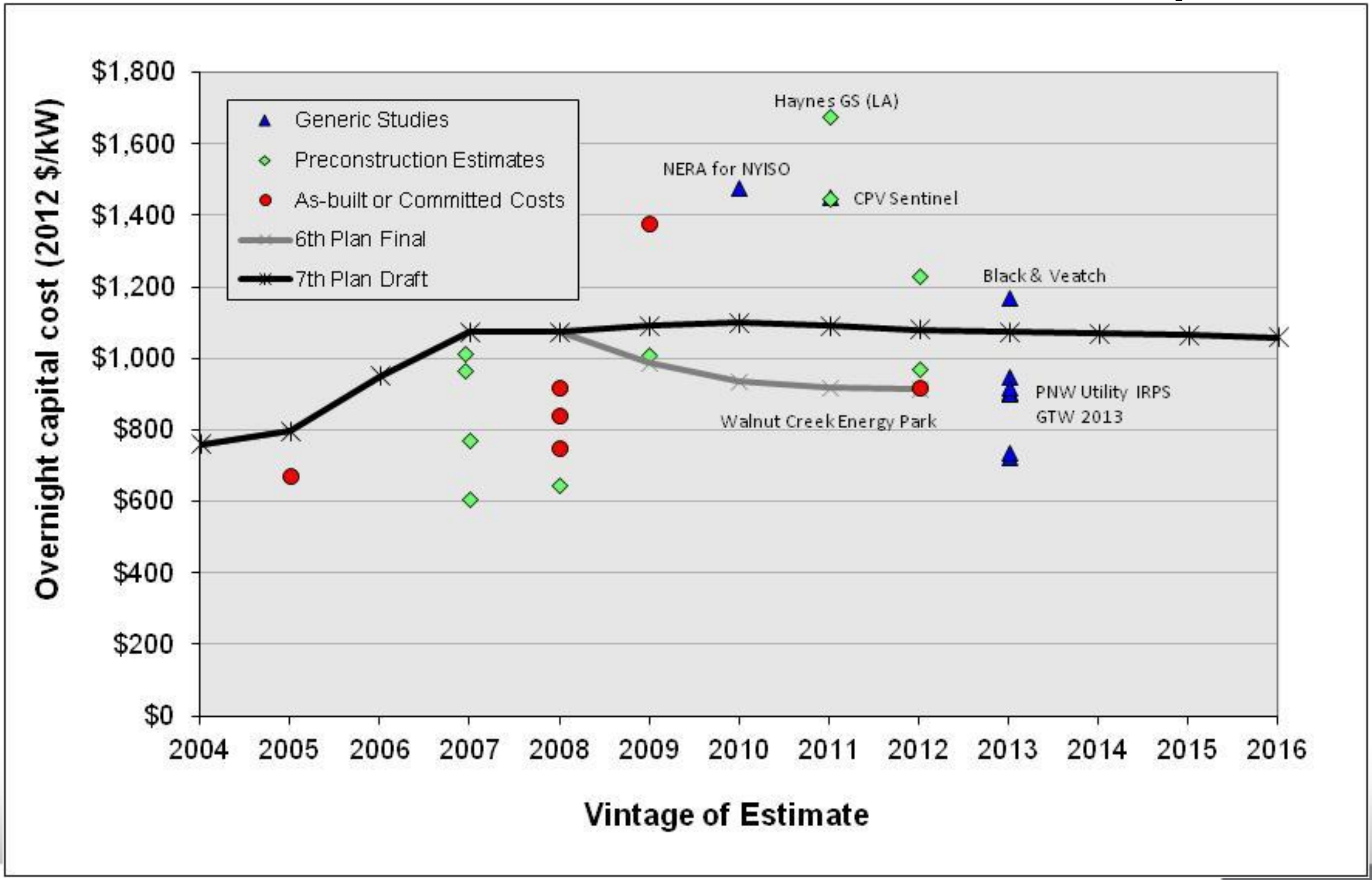
- 99.4 MW output (103.5 MW PA)
- Available starting in 2010
- Similar to PA, but with DLE instead of water injection for NOx emission control
- Based on frame 6FA and Boeing 747 technologies
- Fast start capability, 10 minutes full power

Proposed Intercooled Ref Plant (2)

Technology & Configuration base	(2) GE LMS100 PB
Output per unit (MW)	99.4 MW (nominal, ISO)
Output Total (MW)	199 MW nominal; 187 MW lifecycle avg
Fuel	Natural Gas
Heat Rate (btu/kWh)	8541 HHV
Capital Cost (mm$ 2012)	$214.9 (lifecycle)
Capital Cost ($/kW 2012)	$1,080 (lifecycle)
Fixed O&M	TBD
Variable O&M	TBD
Economic Life (Years)	30
Construction Time (Months)	18 mos development 9 mos early construction 6 mos committed construction

* All SCCT reference plants to match Port Westward II – 220 MW

Preliminary Capital Cost Estimates for Intercooled Hybrid



Northwest **Power** and **Conservation** Council

nwcouncil.org

Reciprocating Engines

Steven Simmons
Northwest Power & Conservation Council
May 28, 2014

Engine Hall at Goodman Energy Center Kansas

Reciprocating Engines for Electric Power Generation

Recips are internal combustion engines – an air/fuel(Ntrl Gas) mixture is compressed by a piston and ignited within a cylinder to drive a piston and turn the shaft.

These engines can burn a variety of fuels including natural gas, fuel oil and biofuels.

Often individual engines are grouped into blocks called generating sets.

Strengths

1. Start quickly
2. Follow load well
3. Have good part-load efficiencies and due to modularity can operate a subset at full load
4. Maintain output at increasing elevation
5. Good reliability
6. Minimal water usage

Recip. Cost Information

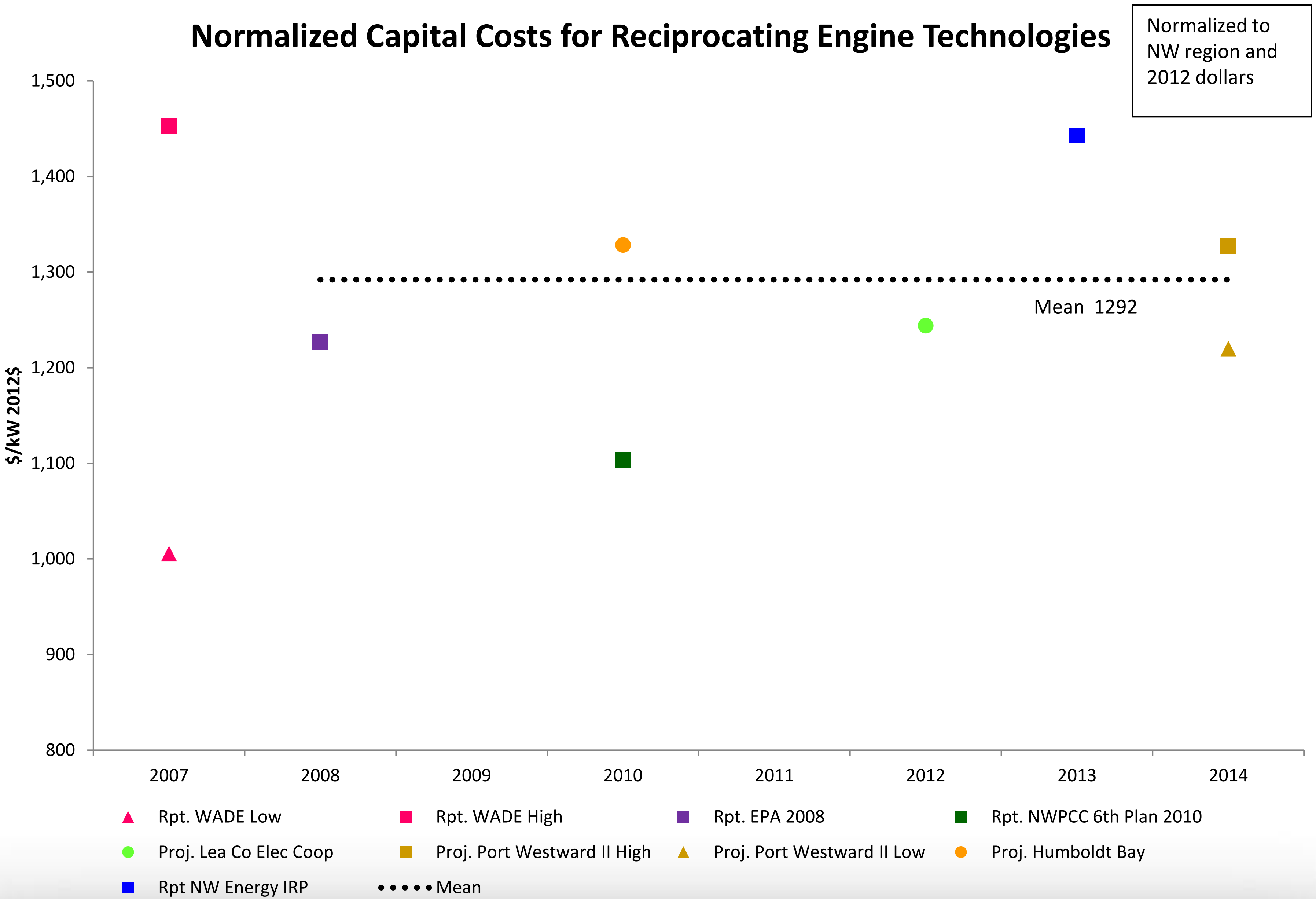
REPORTS

1. Northwest Power & Conservation Council 6th Plan – 2010
2. EPA Tech. Char. Of Recip. Eng. – 2008
3. World Alliance for Decentralized Energy (WADE) 2007

PROJECTS

1. Humboldt Bay (PG&E) 2010
   - Eureka CA
   - 110 MW
   - 6x18V50SG Wartsilia
2. Port Westward II (Portland Gen.) 2015
   - Clatskanie OR
   - 220 MW
   - 12x18V50SG Wartsilia
3. Lea County Electric Coop 2012
   - Lovington New Mexico
   - 46.5 MW
   - 5x20V34SG Wartsilia

Normalized Capital Costs for Reciprocating Engine Technologies



Recip Proposed Reference Plant

Technology & Configuration base	Wartsilia 12x18V50SG
Output per unit (MW)	18.7
Output Total (MW)	224
Fuel	Natural Gas
Heat Rate (btu/kWh)	8,176
Capital Cost (mm$ 2012)	289
Capital Cost ($/kW 2012)	1,292
Fixed O&M	TBD
Variable O&M	TBD
Economic Life (Years)	25
Construction Time (Months)	12

Preliminary Capital Cost Peaking Units

Technology	Capital Cost (2012 $/kW)
Frame (7F 5-Series)	$1,000/kw (lifecycle)
Aeroderivative (LM6000PF Sprint)	$1,272/kw (lifecycle)
Intercooled Hybrid (LMS100 PB)	$1,080/kw (lifecycle)
Reciprocating Engine (Wartsila 18V50SG)	$1,292/kw (new and clean)

Next Steps for Peaking Units

- O&M costs
- Part load heat rate curves
- Availability (planned outage rate, FOR)
- Resource potential in region
- Local air permitting
- Development, early construction, committed construction schedule and cost payout for RPM