



# Reciprocating Engines in Support of Grid Modernization

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**Imagination at work.**

# Natural Gas Reciprocating Engines

GE (Waukesha, Jenbacher), Caterpillar, Cummins, Cooper, Superior, ....

Eff ~38%, NOx <1g/hp-hr , CHP compatible

[www.eren.doe.gov/deer.html](http://www.eren.doe.gov/deer.html)

0.3 MW

4.4 MW

Power Generation

Lean Burn



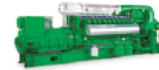
**Jenbacher Type 2**

Output 335 kW (60 Hz)  
Introduced in 1988



**Jenbacher TYPE 3**

Output 633 – 1,059 kW (60 Hz)  
Introduced in 1988



**Jenbacher TYPE 4**

Output 852 – 1,421 kW (60 Hz)  
Introduced in 2002



**Jenbacher TYPE 6**

Output 1,800 – 4,335 kW (60 Hz)  
Introduced in 1989

Power Generation



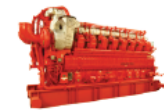
**Waukesha VGF\***

Output 280 – 830 kW (60 Hz)  
Introduced in 1987



**Waukesha VHP\***

Output 300 – 1,600 kW (60 Hz)  
Introduced in 1967



**Waukesha 275GL+\***

Output 2,330 – 3,215 kW (60 Hz)  
Introduced in 2009

Rich Burn

\*Trademark of General Electric Company

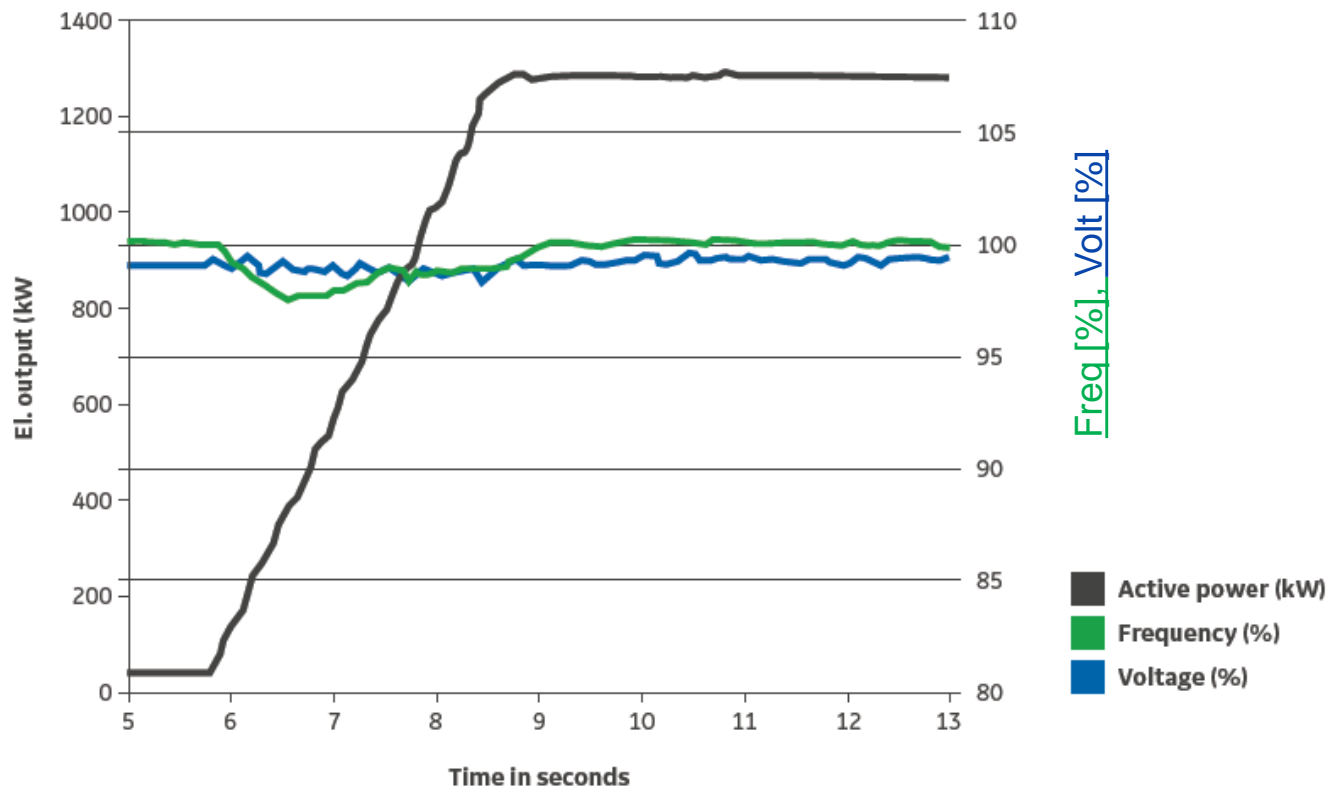


Navigant - 27 GW of NG-Generators installed by 2024

# NG Recip – Rich Burn - Performance

Meets CA, TX standards w/ 3-way catalyst

Grid Independent Mode (Islanded), load ramp-up response



# Grid Services - CAISO

Grid Service	Description	NG Recips
Frequency Regulation	>500kW, <b>max &lt;10 min</b> , 30~60 min commitment, <b>&gt;25% accuracy</b> , ramp	Yes
Spinning Reserves	>500kW, AGC w/ droop, 1 sec response, if F<59.92 Hz, then 10% power in 8 sec, unit at idle for long periods	Yes, <b>provisions for long idle ops</b>
Non-Spin Reserves	>500kW, 10 min to ramp, 30 min commitment	Yes
Ramping Reserves	Award based on 5-min ramp capability	Yes
Demand Response	>500kW, full capacity in 40 min, duration 1~4 hours	Yes
Black Start	Start and support local load w/o grid, Volt/VAr control May start from "cold"	Yes, <b>heaters for cold start</b>
Voltage Reg	0.9 lag to 0.95 lead	Yes



*What will Grid Services look like in 2020? Or 2025?*

# Areas for Improvement - technical

Faster response from lean-burn engines

fuel injection (>5 psi NG feed)

electrified turbo chargers

air impingement techniques

variable valve timing

More efficiency from NG Generators

advanced lean burn technology (→ 50% eff?)

better “bottoming” cycle CHP technology (→ 65% eff?)

Grid Operator needs

models for smaller DER's

aggregation/disaggregation functions to 100's of DER's

