Waukesha – Gas Electric Partnership

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INNIO = Waukesha + Jenbacher

Waukesha VGF
- Output: 240 - 1,065 bhp
- Introduced in 1987

Waukesha VHP
- Output: 515-2500 bhp
- Introduced in 1967

Waukesha 275GL+
- Output: 2813-5000 bhp
- Introduced in 2009 / 1988

Jenbacher Type 3
- Output: 633-1,059kW (60 Hz)
- Introduced in 1988

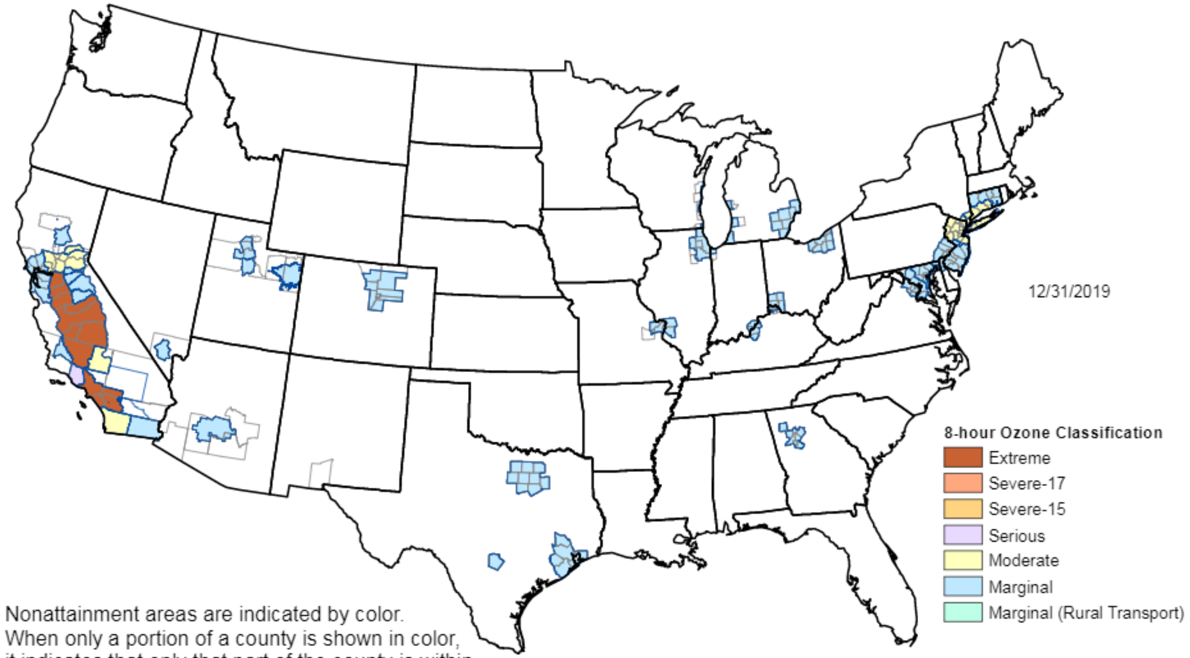
Jenbacher Type 4
- **Output: 852 - 1,421kW (60 Hz)**
- Introduced in 2002

Jenbacher Type 6
- Output: 1,800 - 4,335kW (60 Hz)
- Introduced in 1989

GE sold Waukesha and Jenbacher to Advent International (PE) in Nov., 2018

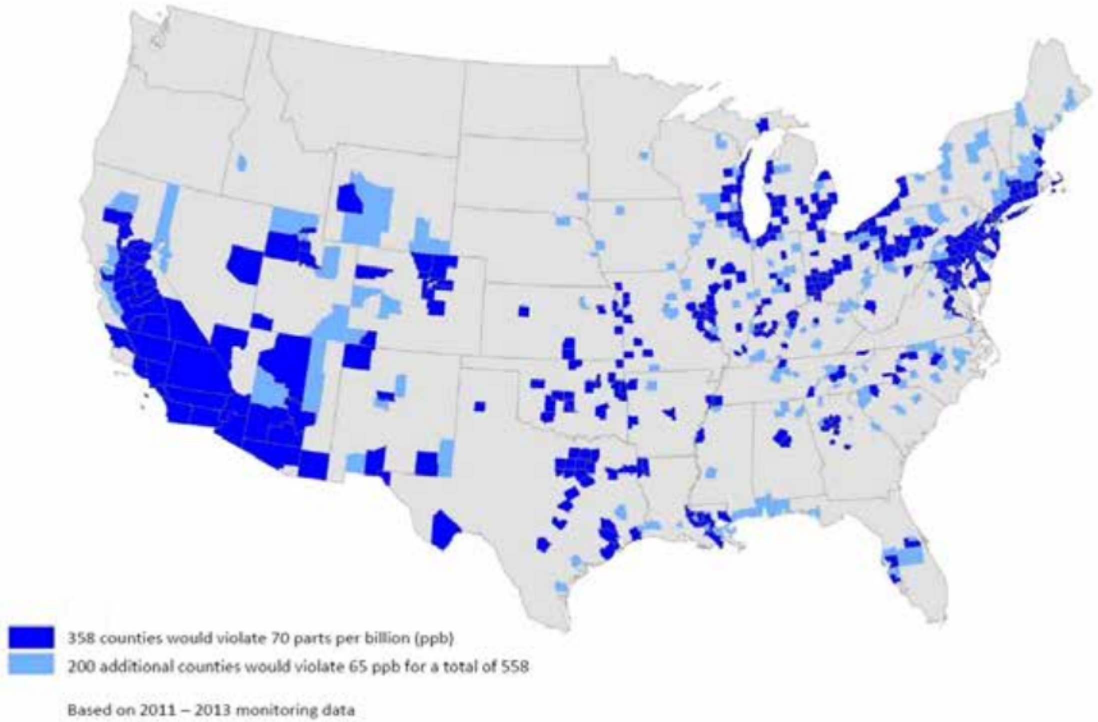
Emissions Landscape - NAAQS

8-Hour Ozone Nonattainment Areas (2015 Standard)



Nonattainment areas are indicated by color. When only a portion of a county is shown in color, it indicates that only that part of the county is within a nonattainment area boundary.

Counties Where Measured Ozone is Above Proposed Range of Standards (65 – 70 parts per billion)



The 2015 change from 75 to 70 ppb ozone limits not as drastic as expected, but a future drop to 65 could happen.

State Response (Colorado Example)

Permitting Strategies to Consider

- Operator Strategies
  - Existing facilities
    - Reduce actual emissions and obtain permits limiting emissions to minor source levels < 50 tpy VOC and NOx
    - This will involve rethinking operational practices
      - Electrify compression
      - Add vapor recovery towers (VRT) or HLP separators to lower storage tank emissions profiles
      - Convert to zero emissions dehydration units
    - Reduce existing permit emissions and process limits where excess buffers exist
      - Don't permit at the design Potential to Emit (PTE) when not needed
      - Develop site specific emissions factors (E.F.) where gene

4/17/2019 RMEHSPG April 2019 Meeting

- Colorado shifted from moderate to serious nonattainment in their front range area, where oil and gas activity is concentrated.
- Recommendations made by air boards to use electric drive compression.
- Regulations proposed to target lower emissions from grandfathered engines.

Proposed Emission Standards & Testing

- All affected engines conduct initial performance test by May 1, 2021
- All affected engines comply with annual adjustments, quarterly portable analyzer monitoring, biannual performance tests, and other applicable monitoring and recordkeeping.
- There will be a new section in Regulation 7 (**XVII.E.4.**) considering the following ranges of applicable emission standards for engines greater than or equal to 1000 hp[1]:

Beginning	Engine hp	Emission Standards (g/hp-hr)		
		NO_x	CO	VOC
May 1, 2022	≥ 1,000 hp	0.5-1.0	2.0-4.0	0.7-1.0

CO has shifted from moderate to serious nonattainment in the front range.

Gas or Electric Compression Drive?

Driver	Advantages	Disadvantages
Reciprocating Engine	• Reduced Fuel Costs • Field Familiarity • Robust and Forgiving	• Increased PM Downtime • Increased O&M Costs
Electric Motor	• No Site Specific Emissions • Low Package CAPEX	• Costly Infrastructure • High Power Costs vs. NG • Failure downtime extensive

Decision often comes down to grid and labor availability, emissions landscape, and who pays fuel costs.

Who foots the fuel bill?

- The "spark spread" of natural gas engine drive vs. electric can often drive high fuel bills.
- Midstream companies often pass their fuel bill to the producers and don't care about fuel cost.
- Integrated midstream / E&P companies ultimately pay the bill and should care more.

- Calculation Assumptions:
  - Engine Efficiency = 6500 Btu/bhp-hr
  - Electric Motor Efficiency = 95%
  - Power requirement = 20,000 hp
  - Runtime = 8760 hours/year

Fuel savings of using natural gas vs. electricity

		Natural Gas Cost ($/mmBtu)		
		1	3	5
Electricity Cost ($/kw-hr)	0.05	5,070,000	2,790,000	510,000
	0.10	11,280,000	9,000,000	6,720,000
	0.15	17,490,000	15,210,000	12,930,000

Factoring in fuel costs will drive many to favor engine drive over electric.

Best of both worlds – Rich burn engine drives

- What if you could combine the emissions permitting ease of an electric motor with the installation speed and fuel costs of an engine drive?
- Waukesha rich burn engines have class-leading NOx, VOC, and CO2e emissions that allow for large horsepower installations even in tough permitting environments.
- Such installations enable midstream companies to move quickly to win contracts to move producer gas.

Factoring in fuel costs will drive many to favor engine drive over electric.

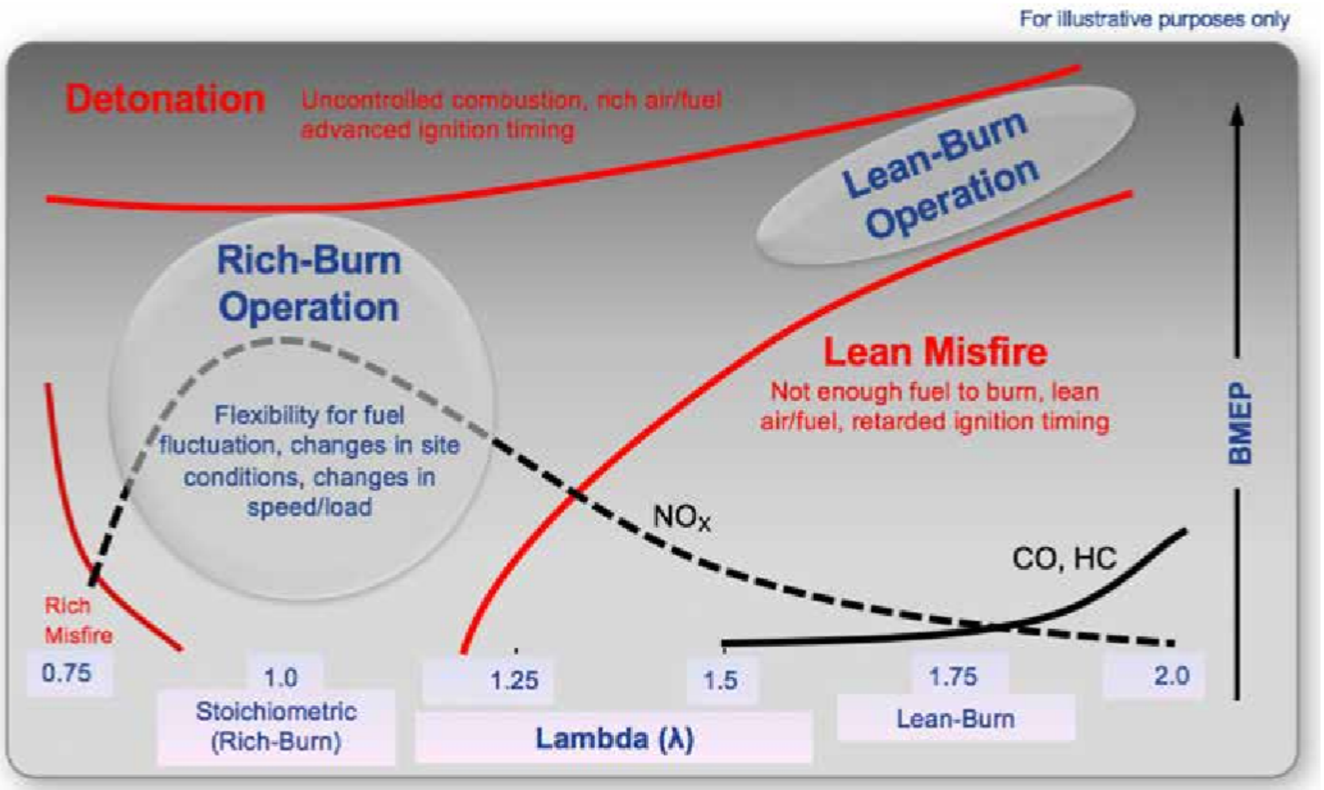
Air / Fuel Terminology and Rich-burn vs. Lean-burn combustion

Air/fuel ratio: mass flow rate of air/mass flow rate of fuel

Stoichiometry: chemically correct air/fuel ratio, 100% of fuel & oxygen consumed during combustion

Lean-burn: More air in the mixture than required for complete combustion

Rich-burn: More fuel in the mixture than required for complete combustion



Rich-Burn Engines exhibit an Inherently Wider Operating Window

Rich Burns Use Three Way Catalyst Aftertreatment

- Inexpensive, reliable, effective, and low maintenance
- Do not require working fluid and other auxiliary equipment like selective catalytic reduction (SCR) systems
- Highly effective in reducing NOx, CO, and VOCs (see table below)

Emissions (g/bhp-hr)	Lean Burn	Rich Burn
VOC	0.405	0.05
Formaldehyde	0.081	0.001
NOx	0.3	0.15
CO	0.1778	0.3
Methane*	4.01	0.35
PM2.5	?	0.01

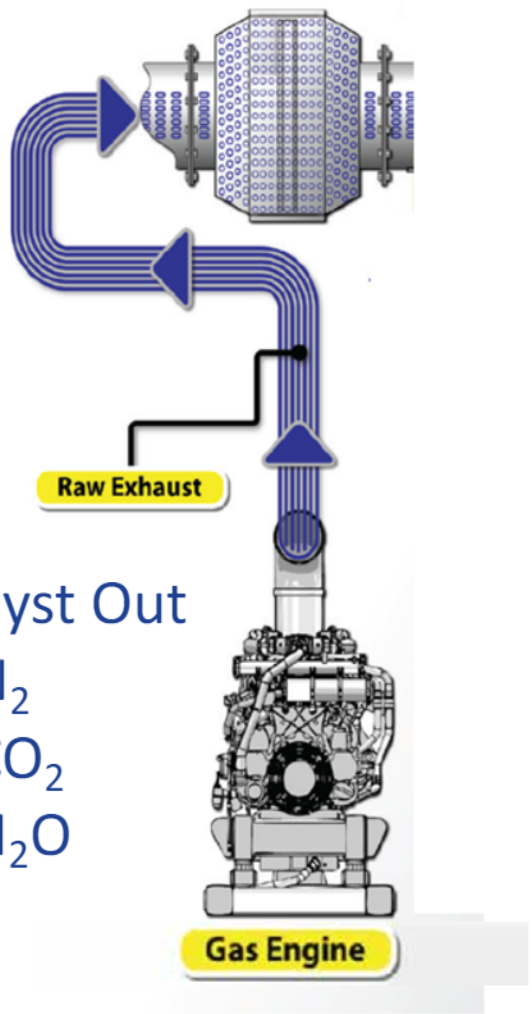
*Engine out emissions. Rich burn catalyst out emissions are 0.25. Lean burn data not available.

Engine Out → Catalyst Out

- NOx
- HC
- CO

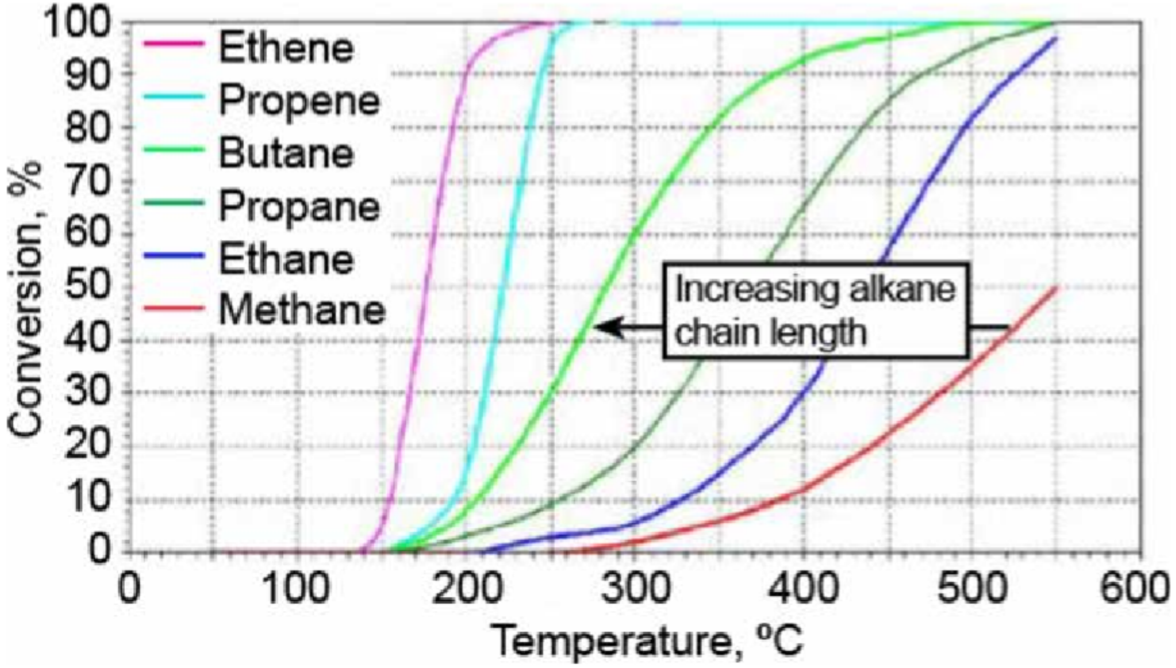
→

- N_2
- CO_2
- H_2O



Ultra Lean Burn Emission Challenges with High Btu Fuel

- Leaner operation better for NOx, but reduces exhaust temperature, lowering oxidation catalyst effectiveness
- Shorter carbon chains are harder to catalyze, but methane and ethane are excluded from VOC calculations
- Propane is the challenge -> ~50% conversion at typical lean burn exhaust temps

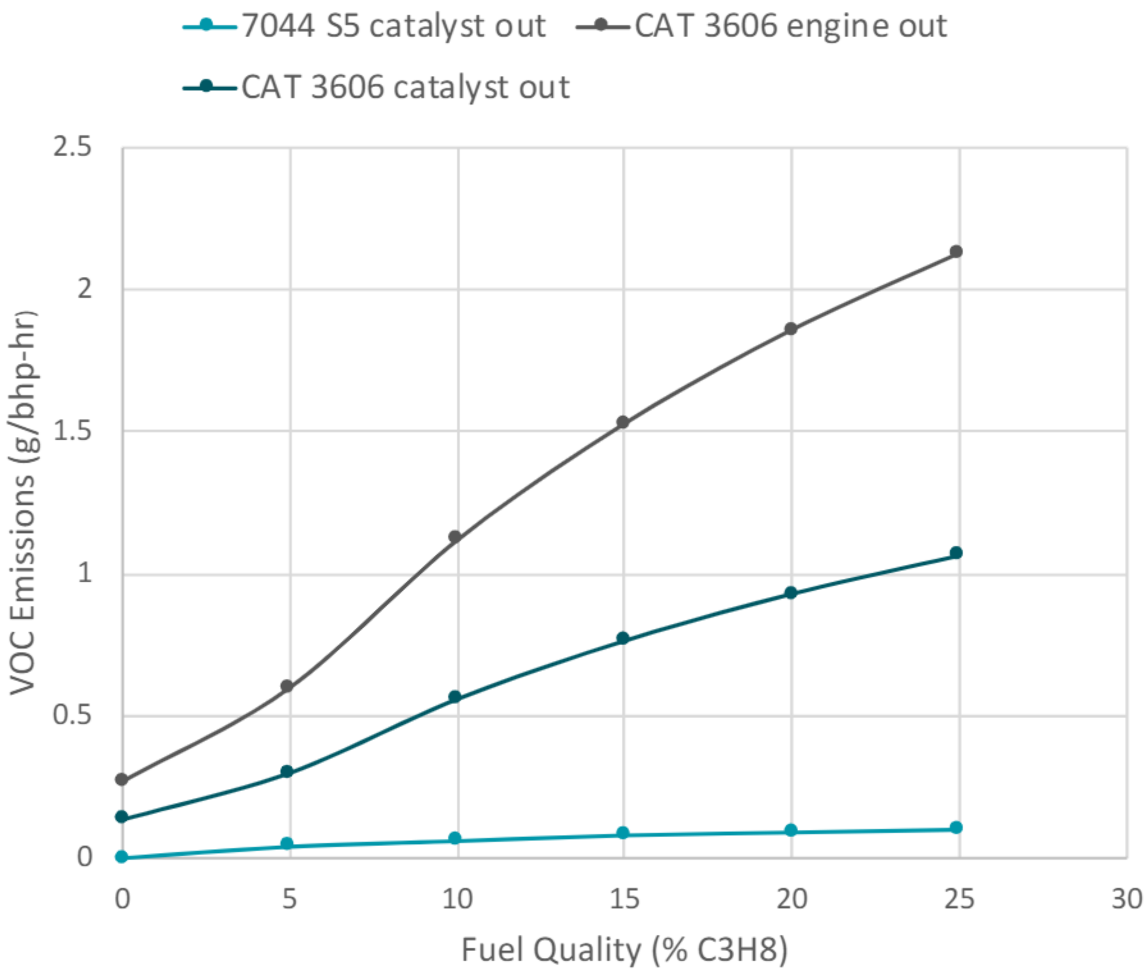


https://www.technology.matthey.com/article/60/4/228-235/

Conventional oxidation catalysts not effective with high propane / low exhaust temperatures

Rich Burn vs. Lean Burn VOC Emissions

- As fuel propane content increases, VOC emissions from lean burn engines increase much faster than from rich burns
- More complete combustion / higher exhaust temperatures of VHP Series Five
- Assume 50% catalyst reduction for 3606 catalyst out.



VHP Series Five produces low VOC emissions (~10% of lean burns)

Faster permits + more HP per site with rich burn

- Standard permitting typically takes a year between submission & when construction can start
- General Permits (GP) & Permits By Rule (PBR) can take as little as 30 days
- Avoids tasks that slow permitting such as dispersion modeling, public notice, and negotiated emission limits (e.g., “Best Available Technology” (BAT) review in PA)

Go to the head of the line with rich burn Waukesha!

e.g. GP, PBR states –

- Texas
- New Mexico
- Colorado
- Pennsylvania
- Oklahoma
- Ohio

Use general permit and permit by rule to put more HP per site and faster with ultra low emission rich burn VHP‘s

Texas

- Texas PBR (permit by rule) – 30 TAC Chapter 106 if annual emission (tpy) below thresholds listed below (and not in nonattainment area)
- VOC emissions threshold (lower than NOx, CO) defines HP capacity
- Low VHP Series Five VOC emissions combined with near zero formaldehyde emissions allow installation of >50,000 bhp, w/o other site VOC emissions
- Typically 30 day timeline to construct

Pollutant	PBR Limit (tpy)	VHP 7044 S5 (tpy)	Typical LB (tpy)
VOC	25	0.92 (51,780 bhp limit)	7.33 (6,393 bhp limit)
Formaldehyde	25	0.018	0.18
NOx	250	2.75	5.43
CO	250	5.50	3.22
PM2.5	10	0.18	?

Large Compressor Stations can be built around Rich Burn VHPs using Permit by Rule (51k vs. 6k hp)

Example: ETC's Rebel Gas Plant in the Permian Basin

Equipment	NOx (tpy)	CO (tpy)	VOC (tpy)	HCOH (tpy)
CAT 3616	22.86	18.86	15.55	1.42
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CAT 3616	22.86	18.86	15.55	1.42
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Engine Total	91.44	75.44	62.2	5.68
Balance of Plant	34.67	35.83	29.18	-0.01
CAT Powered Site Total	126.11	111.27	91.38	5.67

Equipment	NOx (tpy)	CO (tpy)	VOC (tpy)	HCOH (tpy)
Waukesha 9394GSI S5	3.67	7.33	1.23	0.024
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Engine Total	29.33	58.67	9.81	0.192
Balance of Plant	34.67	35.83	29.18	-0.01
9394 Powered Site Total	64.00	94.50	38.99	0.182
% emissions drop	49%	15%	57%	97%

CAT Powered Site is a Major Source and Waukesha is not (but needs twice the compression packages).

Pennsylvania

- Pennsylvania GP-05
- Both engine out & site tonnage limits
- Strict limit for VOC emissions
- Low VHP Series Five VOC & NOx emissions allow installation of 34,500 bhp, even with other site VOC emissions
- VHP Series Five meets all GP-05 engine out limits (g/bhp-hr)
- Typically 130 day timeline to construct

Pollutant	GP Limit (tpy)	VHP 7044 S5 (tpy)	Typical LB (tpy)
VOC	50	0.92	7.33 (12,785 bhp)
Formaldehyde	10	0.018	1.47
NOx	100	2.75	5.43
CO	100	5.50 (34,500 bhp)	3.22

Waukesha VHP engines can site 34.5k hp vs. 12.8k for the lean burn offering, assuming 6% propane in fuel.

Colorado Dispersion Modeling Guidance

- Colorado Draft Modeling Guideline for Air Quality Permits, dated May 2018
- Both Long Term & Short Term trip points
- Low VHP Series Five NOx & PM2.5 emissions allow permitting w/o modeling
- Currently a minimum of 6 months to begin review of modeling projects
- To use a general permit and avoid modeling, the table below applies.

Draft New Rule

Pollutant	Long Term(tpy)	Short Term (lbm/hr)
CO	23 lbm/hr	
NOx	40	0.46
SO2	40	0.46
PM2.5	5	11 lbm/day

Emissions limit | **Engine emissions**

Engine	NOx limit [tons/year]	CO limit [tons/year]	CO2e limit [tons/year]	HAP limit [tons/year]	NOx [g/bhp-hr]	CO [g/bhp-hr]	CO2e [g/bhp-hr]	HAP [g/bhp-hr]	PM2.5 [g/bhp-hr]	Max site HP
CAT G3500 ULB	40	90	90,000	8	**0.5**	0.1	500	0.14	0.033	8,285
CAT G3600 A4	40	90	90,000	8	**0.3**	0.1	460	0.14	0.033	13,808
VHP GSI Series 5	40	90	90,000	8	0.15	0.3	**450**	0.05	0.01	**20,720**

Avoid dispersion modeling and site more hp faster with Waukesha VHP

Waukesha

INNIO