Gas vs. Diesel Generator Sets—Performance Cost & Application Differences
Agenda

• Introduction
• Distributed Energy Products
  – Diesel, Gas and Turbine generator sets
• How Engines Accept Loads
• Gas Product Markets
• What to look for in project economics
• Conclusions
## Installation Differences Between Diesel and Gas Engines

<table>
<thead>
<tr>
<th>System</th>
<th>Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical</td>
<td>None</td>
</tr>
<tr>
<td>Mechanical</td>
<td></td>
</tr>
<tr>
<td>- 4 stroke cycle</td>
<td>Similar components</td>
</tr>
<tr>
<td>- Air intake systems</td>
<td>None</td>
</tr>
<tr>
<td>- Exhaust systems</td>
<td>None</td>
</tr>
<tr>
<td>- Cooling systems</td>
<td>Similar 2 circuit systems</td>
</tr>
<tr>
<td>Ignition system</td>
<td>Compression ignition vs. spark ignition</td>
</tr>
<tr>
<td>Fuel system</td>
<td>Direct injection vs. carbureted</td>
</tr>
</tbody>
</table>
Gas Engine Fuels

Fuel is THE critical success factor when applying gas engines

- Rating
- Attachments
- Engine Arrangement
- Operation & Maintenance
Fuel Fundamentals
Common Diesel Fuel Types

• Diesel #1
• Diesel #2
• Winter #1 and #2 blend
• Other blended fuels
  – Jet A
  – Kerosene

Most common diesel fuel used worldwide
Fuel Fundamentals
Common Fuel Types

• Natural Gas
  • Methane
  • Ethane
  • Propane
  • Butane
  • Pentane

• Propane
  • > 95% propane

• Field Gas
  • Mixture of gases

• Landfill & Digester Gas
  (Anaerobic Digestion)
  • Methane (30-65%)
  • Carbon dioxide
  • Nitrogen

• Pyrolysis Gas
  (Biomass Gasification)
  • Carbon monoxide
  • Carbon dioxide
  • Hydrogen
  • Methane
  • Nitrogen
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Which Prime mover fits best my application?

- Diesel Engines
- Gas Engines
- Gas Turbines
Diesel Engine / Gas Engine Similarities

• Can achieve low emissions levels

• Excellent for continuous, high load applications
  • High reliability
  • High availability

• Good for heavy start/stop applications

• Tolerant to high ambient conditions and high elevations

• Low installed first cost

• Quick delivery and ‘on-line’ capabilities

• Proven technology used in many applications
Diesel Engine Advantages vs. Gas Engine

- Higher Power Density
  - Low initial install costs
  - Lower weight / kW
- On line in less than 10 seconds (meets NFPA requirements)
- Very simple design
- High level of parts and service available
- Best where local fuel sourcing is required
- Excellent transient capability
- Higher ambient temperature and altitude capabilities
Altitude Derate Comparison

Diesel vs. Gas Generator Set Engine

Standard emission settings at 100 deg F
Gas Engine Advantages vs. Diesel Engine

• Best fuel efficiency
• Lowest owning and operating costs (Especially in high hour applications)
• Well suited for CHP operation
• Lower emissions capabilities
• Better suited for variable load applications
• No local fuel storage requirement
• Accepts a wide range of gaseous fuels
  • High BTU fuels
  • Low BTU fuels
Gas Engine / Turbine Similarities

• Low emissions levels / Beneficial use of natural gas
• High reliability
• High availability
• Excellent for continuous, high load applications
• Low life cycle costs
• Quick delivery and ‘on-line’ capabilities
• Proven technology in many applications
Gas Engine Advantages vs. Turbine

• Higher fuel efficiency

• Lower initial costs for small schemes (<10 MWe)

• Better suited for variable load applications

• More tolerant to high ambient conditions and high elevations

• Lower fuel pressure requirement

• Accept low BTU fuels

• On line in less than 30 sec
Gas Turbine Advantages vs. Gas Engine

- Well suited for CHP w/large heat to ekW ratio
- Higher exhaust temperature: 480 C / 900 F
- Low weight & minimal space requirement
- Very simple design
- Lower emissions capabilities
- Less down time per machine
  - Replacement at overhaul
- Ideal for 24/7 operation
  - Turbines do not like starts & stops
- Accept high BTU fuels
  - No detonation – low sensibility to MN
  - Can burn low energy fuels as well
STEAM/POWER RATIO
Ranges by Cycle Type

Gas Turbine Cycle
Spark Engine
Gas Turbine Combined Cycle
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How Gas Engines Accept Load

- System calls for **more power**
- **Throttle opens** up to let more air/fuel in
- “**Transient richening**” makes air/fuel mixture richer
- Air/fuel makes its way through turbo, aftercooler, throttle, intake manifold, cylinder head into cylinder for combustion
- **Spark starts combustion**, mixture burns
- **Heated exhaust** goes through the exhaust manifold to turbo turbine
- **Turbo spins faster**, increasing air flow in engine
- *Fuel control valve increases the amount of fuel* to match increased air flow
- **Process begins again**, this time with larger charge to make more power
How Gas Engines Accept Load

G3500C/E Low Pressure Gas Fuel System

System loses speed, calls for more power.
How Gas Engines Accept Load

Throttle opens up to let more air/fuel in

G3500C/E Low Pressure Gas Fuel System
How Gas Engines Accept Load

...through the aftercooler...

Intake air through the turbo

...through the throttle...

...through the intake manifold, into the cylinder

G3500C/E Low Pressure Gas Fuel System
How Gas Engines Accept Load

G3500C/E Low Pressure Gas Fuel System

Heated exhaust air turn turbo faster…
How Gas Engines Accept Load

Which drives more air...

...to mix with more fuel...

G3500C/E Low Pressure Gas Fuel System
How Diesel Engines Accept Load

• System calls for more power
• The fuel rack on the injector opens up to let more fuel in
• Excess air is already in the cylinder to mix with the fuel for combustion
• Heated exhaust goes through the exhaust manifold to turbo turbine
• Turbo spins faster, increasing air flow in engine
• Process begins again, this time with larger air charge to make more power
How Diesel Engines Accept Load

System loses speed, calls for more power

Diesel Fuel System Diagram
How Diesel Engines Accept Load

Diesel Fuel System Diagram

Unit injector atomizes fuel into hot air
How Diesel Engines Accept Load

Diesel Fuel System Diagram

Which drives more air to the cylinder

Heated exhaust air turn turbo faster…
Comparison of Gas & Diesel

• Natural gas engines will have **less load pickup (transient) capability** than a diesel generator set.

• The steady state (no load change) **frequency deviation (stability) will be larger (worse)** than with a diesel engine generator set.

• **Start up times will be longer** for the natural gas generator set compared to a diesel generator set
  – Exhaust purge cycle
  – Air/fuel mixture to the cylinder

• As **fuel efficiency increases** the gas engine’s capability to accept transients is decreased.
Island Mode Class Requirements

• Island Mode requirements are most likely ISO 8528-5 Class 4 (G4)
• Understand user’s requirements for load and unload steps, and steady state stability
• A UPS system may be necessary to protect critical customer equipment
Understanding Load Acceptance Criteria

• Most critical user requirements effecting load acceptance are:
  – Required % load accept
  – Required % load rejected
  – Allowable frequency dip
    • For both load acceptance and load rejection
  – Allowable voltage dip
    • For both load acceptance and rejection
  – Allowable recovery time
Factors Effecting Load Acceptance

• Most critical application issues effecting load acceptance are:
  – Fuel pressure
  – Fuel “quality”
  – Systems backpressure and restrictions
  – Emission level required
  – Ambient conditions
Factors Effecting Load Acceptance

G3500C/E Low Pressure Gas Fuel System

- Fuel line restriction
- Air restriction
- Exhaust restriction
- Emissions level effects the a/f ratio, volume required

Factors affecting load acceptance include:

- Fuel pressure
- Fuel line restriction
- Plugged or size restricting fuel filter
- Exhaust restriction
- Air restriction
- Emissions level effects the a/f ratio, volume required

Factors such as fuel pressure and emissions level can affect the load acceptance of the G3500C/E Low Pressure Gas Fuel System.
Emissions vs. Transients

• Low emission gas engines can not meet ISO 8528-5 Class 1 transient loads
  – Manufacturers substitute different loads steps and meet the rest of the criteria

• Cat uses transient richening to improve load pickup capability

• The leaner the engine, the harder it is to pick up a load
  – Many very low emission units will be restricted to “parallel with grid” operation only

• Most transient information is available at 1 gm NO\textsubscript{x}
  Lower emissions levels will have reduced transient capability
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Distributed Generation Market

- Central Plant
- Step-Up Transformer
- Transmission Substation
- Distribution Substation
- Commercial User
- Industrial User
- DG User
**Broad Application Experience In DG**

<table>
<thead>
<tr>
<th>Power Range</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 kW to 2000 kW</td>
<td>Open Gen Sets</td>
</tr>
<tr>
<td>5 MW to 50 MW</td>
<td>Sustainable Solutions</td>
</tr>
<tr>
<td>100 MW or More</td>
<td>Power Barges</td>
</tr>
</tbody>
</table>

- **Mobile Units**
- **Modular Power Plants**
- **Turnkey Power Plants**
Electric Power Quality and Availability
Hourly Load (kW) Projection

3D Yearly Load Analysis

KW Use

Hour of the Day
Day of the year
Electric Utility Demand For Electric Power

Utility Demand Curve

Peaking with Diesel Resource

24 Hour Cycle

Load

Distributed Generation With Diesel Resources
Reduces Peak Operating Cost/kW·hr
Operates 100 – 500 hours/yr
Electric Power Quality and Availability
Improved Gas Product Utilization

Distributed Generation With Gas Resource Improves Operating Cost/kW-hr
Allow Increased Time Online
100 – 500 hrs/yr  ➔  100 – 3000 hrs/yr
Electric Power Resource Efficiency
Improved Gas Product Effect

24 Hour Cycle

Load

Utility Demand Curve

Peaking with Diesel Resource
Peaking with Gas Resource
Peaking with Gas CHP Resource

Distributed Generation With Gas Resource
Improves Operating Cost/kW-hr
Allow Increased Time Online
100 – 500 hrs/yr  →  100 – 4000 hrs/yr
Electric Power Resource Efficiency

Power Generation Efficiency
- Waste: 30-35%
- Line Losses: 23-27%
- Heat Recovery: 90% Overall System Efficiency
CHP Definition

Combined Heat and Power (CHP) also known as cogeneration, is broadly defined as…

“The simultaneous and sequential use of power and heat from the same fuel source.”
Combined Heat & Power (CHP) /Distributed Generation Basics

Heat Recovery Options

- Steam-Low Pressure & High Pressure
  - Typically from exhaust
  - Sometimes low pressure from special IC Jacket Water

- Hot Water
  - Typically from IC Jacket Water and aftercooler circuits

- Chilled Water
  - Typically from steam or hot water fired absorption chillers
  - Sometimes steam turbine driven centrifugal chillers
  - Sometimes direct fired chillers
Combined Heat & Power (CHP) / Distributed Generation Basics

Exhaust Heat Recovery Steam Generator

- 5 kW to 7 MW in a single unit
- 450°F to 1,600°F
- Gas Engines, Gas Turbines
- Hot water and Steam
Combined Heat & Power (CHP) /Distributed Generation Basics

Single Effect:
• Low Temperature Activation, 200 F
• Low Cost
• Simple system
• Good Efficiency…
  – 0.7 COP

Double Effect:
• High Temperature Activation, 350 F
• Moderate Cost
• More complex system
• Higher Efficiency…
  – 1.2 COP

Wide range of models from <100 tons to >1,000 tons
Activated by Hot Water, Steam (15 psi - 125 psi) or Exhaust
Waste Heat Desalinization
Input: 7MW thermal
Output: 12,000 ft³ of fresh water /day
Industries using CHP

- Refinery / Oil
- Industrial
- Hospitals
- Universities
- Utilities
CHP System with Supplemental Firing
Provides for significant steam supply variability
Municipal District Heating

2 MWe
Over 89% Total Efficiency
800MW District Heating Cogeneration
Gas Engine Combined Heat and Power

Jacket Water
Heat Recovery Module
One powerful future.

Gas Engine Combined Heat and Power

Exhaust Heat Recovery Module And Silencer
Heat Recovery Package From Caterpillar

Natural Gas CHP system
2 MW electrical
2.2 MW heat
870 kg/h CO₂
Up to 96% Total Efficiency
Heat Recovery In Series

Using natural gas for heating and lighting
6MW CHP Power plant with CHP + boiler in industrial green houses
Commercial CHP: Snowbird Ski Resort - Utah

2MW of Power Generation, Facility Heating

200,000 Hours of Service
LEED Platinum Hospital using CHP
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Target Market Attributes

• Geographically
  – High electric costs
  – Relatively low fuel costs
  – Adequate grant/funding levels
  – RPS-compliant & voluntary

• Site specific
  – High electric costs
  – Solid load factor
  – Coincident thermal and electric load profile
  – Available opportunity fuel, ADG, LFG etc.
  – Site power quality, high reliability requirement
2011 Gas Prices - US Overview

2011 Brief: Henry Hub natural gas spot prices fell about 9% in 2011

Spot natural gas prices at major trading locations, 2011

Legend
Trading point
2011 average spot natural gas price
% change 2010 - 2011
2011 Electric Prices- US Overview

U.S. Total Average Price per kilowatthour is 9.74 Cents

Average Price
(Cents per kilowatthour)

- 5.61 to 7.09
- 7.14 to 8.00
- 8.18 to 9.11
- 9.26 to 13.00
- 13.10 to 29.20
One powerful future.

US Market Driver

Source = US DOE Energy Information Administration
High Level First Look

Start with the obvious deal killers-Fatal Flaw Analysis

- Air quality permitting
- Waste water discharge permitting
- Adequate space
- Adequate facility utilities
  - Electrical
  - Water
  - Fuel
  - Waste water
High Level First Look

Move to high level feasibility analysis
  - Identify and stack $/kW pricing components (running costs)
    • Fuel
      - Typically biggest cost component
    • Capital recovery
    • O & M
    • Thermal credit
High Level First Look

• Thermal Credit
  – Understand technology and model specific recoverable heat
  – Determine existing boiler efficiency
  – Calculate avoided boiler fuel cost
  – Convert to cents/kWh
High Level First Look

• Roll Up of Stacked Running Costs & Credits (cents/kWh)
  
  \textit{Plus} \quad \text{Fuel}

  \textit{Plus} \quad \text{Capital Recovery}

  \textit{Plus} \quad \text{O & M}

  \textit{Less} \quad \text{Thermal Credits}

  \textit{Total cents/kWh}

• If this beats present retail purchase price, all in, including demand charges, investigate further.

• Potentially pull in engineer or developer.

• Commission a feasibility study.
Key Evaluation Points

Understand the details of the customers utility costs

- Tariff
- Demand Charge $/kW-Month Peak and off Peak
  - Month to Month
  - Ratcheted
- Energy Charge cents/kWh Peak and Off Peak
- Standby Charges & Non availability penalties
- Customer Capacity Load Curves
- Existing or Pending CHP Incentives
Demand Charges

• Utility Charges Customer by Monthly Demand Put On Their System by Customer Facility

  – Typically Highest 20 Minute Demand in kW During Utility Peak Period

  – Some Are Month by Month

  – Others are Ratcheted
    – Pay peak demand for that month and then 80-90 % of that Cost For Following 11 Months – Unless Customer Establishes A new Peak Demand In the Out Months

Can Significantly Impact Plant Cost and Required Redundancy
Utility Energy Charges*

- Utility Charges Customer By Monthly kWh Consumption
  - Typically Utility Peak Rate
  - And Associated Off Peak Rate

Standby Charges*

- For CHP the Utility Will Charge Fee to Have Capacity “Standing By” If the Customer’s Plant Is Off Line – In An Amount Equal to the Customer’s Plant Capacity.

*In Some Areas These Charges Are Going Away
CHP is an Economic Decision based upon:

Electrical power or heat recovery

- Some electric power requirements are sized to meet heat load needs.
- Some system run times are determined by electric load needs.

Bottom Line:
What is the $ value of the heat recovered vs. the cost associated with retrieving and distributing the heat?
CHP Payback vs. Electricity & Fuel Pricing

- **US Industrial Natural Gas Price**
  - $4 / MMBtu
  - $7.5 / MMBtu
  - $10 / MMBtu

- **European Industrial Natural Gas Price**

- **European Subsidized CHP Electricity Rate**

- **Industrial US Electricity Rate**

**Electricity Price ($/kW-h)**

$0.07 to $0.21

**Payback (Years)**

1 to 4.5
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WHO IS THE WINNER?
Diesel Engine, Gas Engine or Turbine…

In fact in 95% of cases there’s no contest…
If the NPV and site requirements evaluation is made correctly the choice is evident

- High power density, low hour usage, on site fuel requirements, lowest initial cost will go diesel engines

- Low temp CHP, low pressure gas, high altitude will go gas engines

- Large Heat / ekW ratio schemes, high pressure steam will go turbines

- Hybrid systems with both gas engines, diesel engines and turbines are possible.
Michael Devine

Electric Power Gas Product/Marketing Manager, Caterpillar Inc.

In the 37 years Mike has worked for Caterpillar, he has been in a variety of roles – manufacturing, service engineering, electric power product and project management, and education and training. Involved in the field of power generation since 1979, Michael has spent the majority of this time working to develop power generation products to serve the load management, distributed power, quality power and low energy markets. During this time he has traveled extensively developing power projects and educating utility companies and users worldwide on the benefits of distributed generation, cogeneration, and the use of renewable fuels in reciprocating engines.