Overview of Distributed Generation Technologies and Applications

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Energy and Environmental Analysis, Inc.
www.eea-inc.com
Energy and Environmental Analysis

- Professional services company focusing on energy markets and technologies
- Distributed generation and CHP
- Analysis of energy technologies and markets
- Environmental policy analysis
- Energy supply and demand modeling and forecasting
Overview

• Why DG?
• What are the applications?
• What are the technologies?
• What are the environmental issues?
Distributed Generation

• Strategic use of small (<25 MW) generation units

• Energy generated at or near the point of use for:
  – Energy: provide kWh and Btu
  – Capacity: meet peak load requirements
  – Reliability: provide service with minimal interruptions
  – Backup/Standby: provide all or partial power needs when called in certain circumstances

• Now driven by new technology, restructuring, changing consumer needs.
DG Applications

- **Emergency generation** - historical application. Concern over changing profile.

- **Combined Heat and Power** - common practice by large industrials; large untapped potential in small industrial and commercial establishments

- **Peaking** - potential growth market for customer peak shaving (500 to 2000 hours/year) by light industrial and commercial

- **Premium Power** - emerging market to provide quality power to sensitive customers

- **Niche Applications** - providing power in remote or isolated applications, stranded gas wells, and landfill and municipal waste gas
Emergency Generation

- On-site power generation for periods when grid power is interrupted - 100s of hours.
- Critical loads have been served by back-up generators for many years.
- Reciprocating engine technology is the only quick-start option available. Low-cost diesels have been the technology of choice.
- Increased use for other uses is a major regulatory concern.
Peak/Load Shaving

- On-site generation during periods of high electric system demand to:
  - Reduce peak electricity costs
  - Avoid grid reliability/power quality problems
  - Generate electricity for sale to grid
  - Also includes utility use to address T&D constraints.

- Typically up to 1,000s of hours per year.
- Use of emergency diesels for peaking is a regulatory concern.
Peak/Load Shaving

• Turbines or reciprocating engines applicable.
• Efficiency not critical.
• Low capital cost and low fixed O&M costs are important.
• Availability/reliability are key
Premium Power

• High quality power for mission critical applications.

• Reliability, reliability, reliability.

• Tight specs on voltage and frequency.

• Cost and efficiency are secondary.
## The Value of Reliability

<table>
<thead>
<tr>
<th>Industry</th>
<th>Cost of Downtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular communications</td>
<td>$41,000/hr</td>
</tr>
<tr>
<td>Telephone ticket sales</td>
<td>$72,000/hr</td>
</tr>
<tr>
<td>Credit card operations</td>
<td>$2,580,000/hr</td>
</tr>
<tr>
<td>Brokerage operations</td>
<td>$6,480,000/hr</td>
</tr>
</tbody>
</table>
Alternative Fuels

- Oil and gas wells, land fills.
- Efficiency not critical, fuel is “free”.
- Fuel flexibility is important.
- Availability / reliability are key.
- Unattended operation and predictable maintenance required.
Combined Heat and Power

• CHP systems sequentially produce electricity, thermal or mechanical energy.
  – Coincident electric and thermal loads
  – Moderate to high operating hours

• CHP boasts energy utilization efficiencies up to 80%.

• CHP is very attractive from an energy efficiency as well as economic perspective.
Providers of DG

- ESCO’s
- Utility Unregulated Affiliates
- Equipment Manufacturers and Licensed Distributors
- System Packagers
- New “Integrators”
- Utilities for T&D issues
DG Value Chain

- **Customers**
  - Reduced costs
  - Increased revenues
  - Price risk mitigation
  - Enhanced reliability
  - Productivity enhancements
  - Competitive advantage in core offerings

- **Public Interests**
  - Energy Efficiency
  - Supply
  - Environment
  - Customer Choice

- **Providers**
  - Energy sales
  - Equipment sales
  - Engineering and Installation
  - Financing
  - Maintenance services
  - Fuel commodity
  - Fuel transportation
  - Energy services
# Commercial and Institutional Market Segments

<table>
<thead>
<tr>
<th>Application</th>
<th>Electric Demand</th>
<th>Thermal Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hotels/Motels</td>
<td>100 kW – 1+ MW</td>
<td>Domestic hot water, space heating, pools</td>
</tr>
<tr>
<td>Nursing Homes</td>
<td>100 - 500 kW</td>
<td>Domestic hot water, space heating, laundry</td>
</tr>
<tr>
<td>Hospitals</td>
<td>300 kW – 5+ MW</td>
<td>Domestic hot water, space heating, laundry</td>
</tr>
<tr>
<td>Schools</td>
<td>50 – 500 kW</td>
<td>Domestic hot water, space heating, pools</td>
</tr>
<tr>
<td>Colleges/Universities</td>
<td>300 kW – 30 MW</td>
<td>Centralized space heating, domestic hot water</td>
</tr>
<tr>
<td>Commercial Laundries</td>
<td>100 – 800 kW</td>
<td>Hot water</td>
</tr>
<tr>
<td>Car Washes</td>
<td>100 – 500 kW</td>
<td>Hot water</td>
</tr>
<tr>
<td>Health Clubs/Spas</td>
<td>50 – 500 kW</td>
<td>Domestic hot water, space heating, pools</td>
</tr>
<tr>
<td>Country/Golf Clubs</td>
<td>100 kW – 1 MW</td>
<td>Domestic hot water, space heating, pools</td>
</tr>
<tr>
<td>Museums</td>
<td>100 kW – 1+ MW</td>
<td>Space heating, domestic hot water</td>
</tr>
<tr>
<td>Correctional Facilities</td>
<td>300 kW – 5 MW</td>
<td>Domestic hot water, space heating</td>
</tr>
<tr>
<td>Water Treatment/Sanitary</td>
<td>100 kW – 1 MW</td>
<td>Process heating</td>
</tr>
<tr>
<td>Large Office Buildings</td>
<td>100 kW – 1+ MW</td>
<td>Domestic hot water, space heating</td>
</tr>
<tr>
<td>Extended Service Restaurants</td>
<td>50 – 300 kW</td>
<td>Domestic hot water, absorption cooling, desiccants</td>
</tr>
<tr>
<td>Supermarkets</td>
<td>100 – 500 kW</td>
<td>Desiccants, domestic hot water, space heating</td>
</tr>
<tr>
<td>Refrigerated Warehouses</td>
<td>300 kW – 5 MW</td>
<td>Desiccants, domestic hot water</td>
</tr>
<tr>
<td>Medium Office Buildings</td>
<td>100 – 500 kW</td>
<td>Absorption cooling, space heating, desiccants</td>
</tr>
</tbody>
</table>
DG Market Barriers

• Electric Utility Resistance and Rate issues
  – Standby rates, exit fees, deferral Rates

• Permitting and Siting Process
  – Multiple agency approvals may be needed
  – Lack of technology information and universally accepted standards

• Grid Interconnection Process

• Fuel Price Volatility

• Technology Costs & Performance

• Expectations of Emerging Technologies

• Customer Perceptions
DG Technology Options

- Reciprocating Engine
- Gas Turbine
- Photovoltaic
- Fuel Cell
- Microturbine
What Affects Technology Choice?

• Energy costs and fuel availability
• Electrical load size/factor/shape
• Load criticality
• Thermal load size/shape
• Special load considerations
• Regulatory requirements
What Differentiates Technologies?

- Size
- Fuels
- Efficiency
- Capital costs
- O&M costs
- Amount and quality of thermal energy
- Emissions
- Risk
Technology vs Size Coverage

- Gas Turbines
- Lean Burn Engines
- Rich Burn Engines
- Fuel Cells
- MicroTurbines

Applicable Size Range, kW

- Strong Market Position
- Market Position
- Emerging Position

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## How do the Technologies Compare?

<table>
<thead>
<tr>
<th>Technology</th>
<th>Status</th>
<th>Size</th>
<th>Efficiency (%)</th>
<th>Installed Costs ($/kW)</th>
<th>O&amp;M Costs ($/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reciprocating Engine</td>
<td>Commercial</td>
<td>30 kW - 6 MW</td>
<td>28 - 38</td>
<td>500 - 1400</td>
<td>0.007-0.02</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td>Industrial Gas Turbine</td>
<td>Commercial</td>
<td>500 kW - 20 MW</td>
<td>22 - 40</td>
<td>600 - 1500</td>
<td>0.003-0.008</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microturbines</td>
<td>Early Entry</td>
<td>25 kW - 300 kW</td>
<td>20 - 28</td>
<td>800 - 1400</td>
<td>0.003-0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Cells</td>
<td>1996 - 2010</td>
<td>3kW - 3MW</td>
<td>36 - 60+</td>
<td>2000 - 8000</td>
<td>0.005-0.010</td>
</tr>
</tbody>
</table>
Reciprocating Engines

- Size Range: 30 - 6,000 kW
- Electric efficiency: 28 - 38%
- Fast startup (10 secs) capability allows for use as standby
- Thermal energy in the form of hot water or low pressure steam
- High maintenance requirements (lots of moving parts)
- Emissions can be an issue
Reciprocating Engines

- Dominant technology for current applications of small distributed generation
- Mature commercial business with established sales and service networks
- Gas-fired spark ignition engines appropriate for CHP, peak shaving and direct drive
- Diesel engines most common for standby, emergency and remote applications
Reciprocating Engine Emission Controls

• Lean burn gas with electronic air/fuel ratio control - 0.5 - 2 gm NO\textsubscript{x}/bhp-hr (1.5 - 6 lb/MWh)
• Rich burn gas with three-way catalyst - 0.15 gm NO\textsubscript{x}/bhp-hr (0.47 lb/MWh)
• Diesel engine - 4.5 to 7 gm/bhp-hr (14 - 21 lb/MWh)
Industrial Gas Turbines

- Size range: 500 kW - 50 MW
- Electric efficiency (22-40%)
- Start-up time: 10min - 1hr
- Established technology for many power and direct drive applications
- Multi-fuel capable, but economics and emissions favor natural gas
- High pressure steam or high temperature direct heat
Gas Turbine Emission Controls

- Water/steam injection (42 ppm NO\textsubscript{x} - 1.8 lb/MWh)
- Lean-premix, dry low NO\textsubscript{x} (15 - 25 ppm NO\textsubscript{x} - 0.6 - 1 lb/MWh)
- Selective catalytic reduction (3 - 9 ppm NO\textsubscript{x} - 0.1 - 0.4 lb/MWh)
- Control technologies can be used in series (3 ppm NO\textsubscript{x} - 0.1 lb/MWh)
- Emerging technologies: catalytic combustion - 3 ppm; SCONO\textsubscript{x}\textsuperscript{TM} -2 ppm; lean pre-mix <15 ppm
Microturbines

- Size range: 25 - 300 kW
- Electric efficiency: 20 - 30%
- Start-up time: >1 min.
- Fuel compressor usually required
- Alternative to small reciprocating engines
- Commercial introduction underway
Why the Interest in microturbines?

- High reliability expected due to few moving parts
- Potential for low maintenance requirements
  - No Oil Changes
  - No Spark Plug Changes
  - No Valve Adjustment or Machining
- Low NO\textsubscript{x} (9 ppm ~ 0.5 lb/MWh), CO, CO\textsubscript{2}, and UHC emissions
- Competitive efficiency (24 - 26%) when recuperated
Fuel Cells

- Size range: 3 - 3,000 kW
- Start-up time: 3 hrs +
- Electric efficiency: 36-65%
- Very low emissions - exempt in some areas
- Only PAFC is commercially available
Combined Heat and Power

- CHP sequentially produces electricity, thermal or mechanical energy
- Traditionally the most effective DG option
- High system efficiency is key to economics
- High operating hours covers high capital costs
- CHP is attractive from an energy and environmental policy perspective
Typical CHP Systems

Steam Boiler/Steam Turbine:

Gas Turbine or Engine/Heat Recovery Unit:
Efficiency Benefits of CHP

Conventional Generation:
Power Plant

Efficiency: 30%

Power Station Fuel
(103)

168
(65)
Boiler Fuel

Combined Heat & Power:
5 MW Natural Gas Combustion Turbine

Combined Heat And Power
— CHP —

Heat

Heat

Losses (72)

Losses (13)

Losses (17)

52

31

49%...TOTAL EFFICIENCY...83%
Environmental Benefits of CHP ($\text{NO}_x$)

**Conventional Generation:**
- Power Station Fuel
  - Power Plant
    - Efficiency: 30%
    - Emissions: 26 Tons
  - Boiler
    - Boiler Fuel
    - Efficiency: 80%
    - Emissions: 15 Tons

**Combined Heat & Power:**
- 5 MW Natural Gas Combustion Turbine
  - Combined Heat And Power
    - CHP Fuel
    - Emissions: 17 Tons

**Total Emissions:**
- 41 Tons/yr
- 17 Tons/yr
Central Power vs On-Site CHP Emissions

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Grid = 1.5 lb NOx/MWh
Boiler = 0.10 lb NOx/MBtu

- Boiler+Grid
- Boiler+Non-CHP DG (25 ppm)
- CHP (25 ppm)
- CHP (15 ppm)
<table>
<thead>
<tr>
<th>Technology</th>
<th>Capacity (kW)</th>
<th>Heat Rate HHV (Btu/kWh)</th>
<th>Electrical Efficiency HHV (%)</th>
<th>Total CHP Efficiency HHV (%)</th>
<th>Equipment Process Capital Costs ($/kW)</th>
<th>Installed Costs Power Only ($/kW)</th>
<th>Installed Costs CHP ($/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Turbine</td>
<td>1000</td>
<td>15,580</td>
<td>21.9</td>
<td>68.0</td>
<td>1,136</td>
<td>1,329</td>
<td>1,929</td>
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<tr>
<td>Gas Turbine</td>
<td>5000</td>
<td>12,590</td>
<td>27.1</td>
<td>69.0</td>
<td>663</td>
<td>773</td>
<td>1,063</td>
</tr>
<tr>
<td>Rich-Burn Gas Engine</td>
<td>100</td>
<td>11,780</td>
<td>29.0</td>
<td>77.0</td>
<td>771</td>
<td>1,030</td>
<td>1,491</td>
</tr>
<tr>
<td>Lean-Burn Gas Engine</td>
<td>800</td>
<td>10,246</td>
<td>33.3</td>
<td>76.0</td>
<td>593</td>
<td>724</td>
<td>971</td>
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<tr>
<td>Microturbine</td>
<td>30</td>
<td>15,443</td>
<td>22.1</td>
<td>73.0</td>
<td>1,851</td>
<td>2,201</td>
<td>2,604</td>
</tr>
<tr>
<td>Microturbine</td>
<td>100</td>
<td>13,127</td>
<td>26.0</td>
<td>68.0</td>
<td>1,260</td>
<td>1,485</td>
<td>1,745</td>
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<tr>
<td>PA Fuel Cell</td>
<td>200</td>
<td>9,480</td>
<td>36.0</td>
<td>75.0</td>
<td>4,230</td>
<td>-</td>
<td>4,500</td>
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<tr>
<td>MC Fuel Cell</td>
<td>250</td>
<td>7,930</td>
<td>43.0</td>
<td>65.0</td>
<td>4,730</td>
<td>-</td>
<td>5,000</td>
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<tr>
<td>SO Fuel Cell</td>
<td>100</td>
<td>7,580</td>
<td>45.0</td>
<td>70.0</td>
<td>3,220</td>
<td>-</td>
<td>3,500</td>
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<tr>
<td>PEM Fuel Cell</td>
<td>10</td>
<td>11,370</td>
<td>30.0</td>
<td>68.0</td>
<td>5,050</td>
<td>-</td>
<td>5,500</td>
</tr>
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</table>
NO\textsubscript{x} Emissions Comparison

<table>
<thead>
<tr>
<th>Type</th>
<th>NO\textsubscript{x} (lb/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine: Large Combined Cycle, SCR</td>
<td>0.06</td>
</tr>
<tr>
<td>Turbine: Large, Simple Cycle</td>
<td>0.6</td>
</tr>
<tr>
<td>Turbine: Microturbine</td>
<td>0.4</td>
</tr>
<tr>
<td>Turbine: Small, Simple Cycle</td>
<td>1.1</td>
</tr>
<tr>
<td>Turbine: Medium, Simple Cycle</td>
<td>0.6</td>
</tr>
<tr>
<td>Turbine: ATS Simple Cycle</td>
<td>0.3</td>
</tr>
<tr>
<td>Fuel Cell: Solid Oxide</td>
<td>0.01</td>
</tr>
<tr>
<td>Fuel Cell: Phosphoric Acid</td>
<td>0.04</td>
</tr>
<tr>
<td>Engine: Gas fired, Lean Burn</td>
<td>2.2</td>
</tr>
<tr>
<td>Engine: Gas fired, 3-way catalyst</td>
<td>0.5</td>
</tr>
<tr>
<td>Engine: Diesel</td>
<td></td>
</tr>
<tr>
<td>Engine: Diesel, SCR</td>
<td></td>
</tr>
<tr>
<td>U.S. Average Coal Generation</td>
<td>5.6</td>
</tr>
<tr>
<td>U.S. Average Fossil Generation</td>
<td>5.1</td>
</tr>
<tr>
<td>U.S. Average All Generation</td>
<td>3.4</td>
</tr>
</tbody>
</table>

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CO₂ Emissions Comparison

CO₂ (lb/MWh)

- Turbine: Large Combined Cycle, SCR - 776
- Turbine: Large, Simple Cycle - 1,281
- Turbine: Microturbine - 1,596
- Turbine: Small, Simple Cycle - 1,494
- Turbine: Medium, Simple Cycle - 1,327
- Turbine: ATS Simple Cycle - 1,154
- Fuel Cell: Solid Oxide - 950
- Fuel Cell: Phosphoric Acid - 1,185
- Engine: Gas fired, Lean Burn - 1,108
- Engine: Gas fired, 3-way catalyst - 1,376
- Engine: Diesel - 1,432
- Engine: Diesel, SCR - 1,432
- U.S. Average Coal Generation - 2,115
- U.S. Average Fossil Generation - 2,031
- U.S. Average All Generation - 1,408
Conclusions

- DG can meet a variety of real customer needs.
- The value must be significant to move the market past commercial and institutional barriers.
- Improved technology offers improving efficiency, utility and emissions.
- Environmental regulations should recognize the role, value and limitations of DG technology.