CHP and Bioenergy Systems for Landfills and Wastewater Treatment Plants

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Reciprocating Engines for ADG and LFG

- Reciprocating engines are either Otto (spark ignition) or Diesel (compression ignition) cycle systems
- Natural gas engines, as well as those powered by ADG or LFG, are typically spark ignition systems

- Some dual fuel engines have been developed using ADG/LFG with a portion of diesel as the pilot fuel (compression ignition), but this presentation is focused on spark-ignition engines using 100% ADG/LFG
- Most used for ADG or LFG are under 2 MW

Fuel Pretreatment for ADG/LFG

- In the past, many ADG/LFG projects ignored contaminants such as siloxanes
- Too much contamination can lead to expensive maintenance/ repair, irreversible damage, and can void manufacturer warranties
- Currently, most projects employ a coalescing dryer for moisture, various particulate filters, a carbon filter for siloxane, and an iron filter for H_2S (if necessary)
- While experience has been better with fuel pretreatment, costs can be extremely high (up to $3,000/kW for small engines) – this prevents a number of projects from proceeding
- In general pretreatment adds between $500 and $3,000/kW to a project's capital costs, depending on various factors

Reciprocating Engine Performance

- When running on natural gas, reciprocating engines have an electric efficiency of 30-40%, with overall efficiencies of up to 80% when using CHP
- ADG and LFG engines are slightly less efficient than NG engines, although some new lean burn models are achieving comparable efficiencies
- Net power output typically decreases by 5-10% compared to NG - this results in a higher $/kW cost

Fuel	Electrical Efficiency	Power Output
Natural Gas	30-40%	100%
ADG/LFG	29-38%	90-95%

Reciprocating Engines: Increased Costs for ADG and LFG

- Some necessary equipment modifications for NG engines to run on ADG and LFG (modified fuel injectors, larger manifolds) cause the $/kW to rise an additional 10%
- Overall, ADG/LFG reciprocating engines cost about 20% more than their natural gas counterparts (not including pretreatment)
- Maintenance usually costs about 80% more than NG engines
- In addition, fuel pretreatment equipment adds $500-$3,000 to installed costs

Reciprocating Engines	**Natural Gas**	**ADG/LFG**
Installed Cost (CHP, $/kW)	800-1,400	1,500-4,700
Maintenance Cost (cents/kWh)	1-3	1.5-4.5

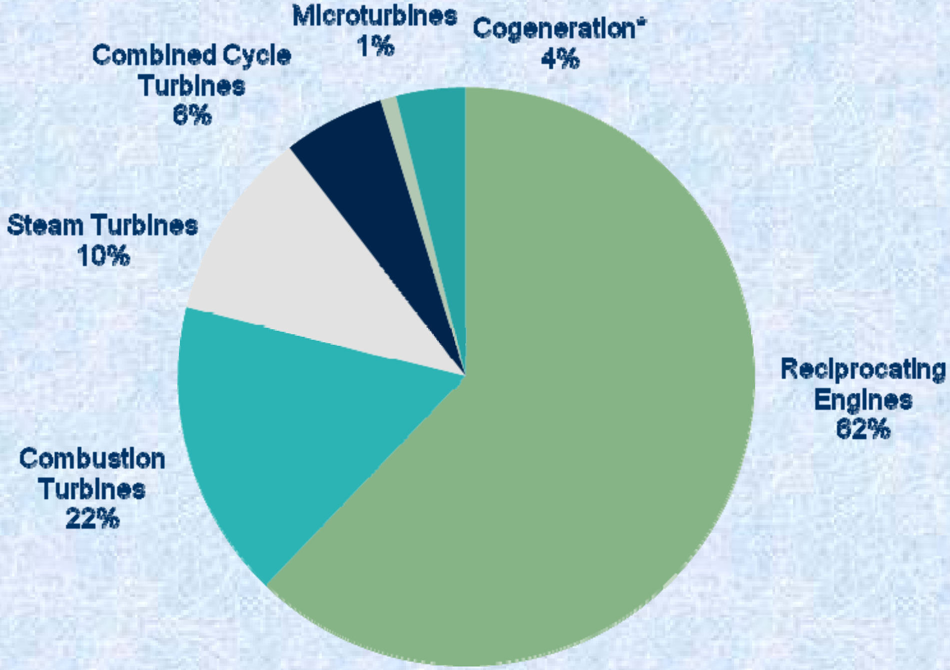
Emissions and Emission Controls for Reciprocating Engines

- Reciprocating engines generate relatively high NOx emissions
- Lean-burn technologies are used with larger engines to control NOx, but burning too lean with low-Btu gases has a negative effect on performance and raises CO and VOC emissions - effective turbocharging can help remedy this problem
- Lean-burn technologies are difficult to employ with smaller (<500 kW) engines, so post-combustion controls may be necessary
- Post-combustion control technologies such as 3-way catalysts and selective catalytic reduction are complicated and expensive to implement, and certain impurities found in ADG/LFG (H_2S, siloxanes) can negate their effects

Applications for Reciprocating Engines

- While reciprocating engines designed for low-Btu fuels have fairly low capital costs, fuel pretreatment and equipment maintenance costs are high, and emissions can become a major challenge
- The best near-term markets for reciprocating engines with opportunity fuels are ADG and LFG operations in areas where emissions regulations are not very strict and capacity needs are less than 5 MW
- In severe or extreme non-attainment areas, required emission controls can kill project economics - microturbines or combustion turbines are usually better options in these locations

Most of LFG Installed Base is Reciprocating Engines



Total: 1,181 MW

Source: EPA LMOP 2007

***Cogeneration category does not Specify prime mover type**

Example Reciprocating Engine Installations

- Central Weber Wastewater Treatment Plant in Ogden, Utah
  - A 1.2 MW reciprocating engine at this Utah plant has been producing power from ADG for over 6 years – waste heat is utilized by digester
- Metro Wastewater Reclamation District in Denver, Colorado
  - 7 MW of electricity produced from ADG-powered CHP turbines, waste heat used to heat several nearby buildings
- Central Valley Water Reclamation Facility in Salt Lake City, Utah
  - Since 1988, nearly 6 MW of power utilized from ADG reciprocating engines; waste heat utilized on-site
- Davis County Landfill in Layton, Utah (under construction)
  - Ameresco, Inc. is currently installing a 1 MW reciprocating engine at this landfill - this is Utah's first landfill gas to energy project

Microturbines for ADG and LFG

- Microturbine combustor design allows them to easily accommodate low-Btu fuels (down to about 35% methane content)
- Most units have recuperators that utilize waste heat to improve efficiency
- A fuel compressor and fuel treatment equipment are usually necessary, which can add significantly to the capital and maintenance costs

Pretreatment for Microturbines

- Conventional pretreatment technologies using specialized filters would render most microturbine projects too expensive, adding up to $5,000/kW in capital costs
- A combined a chiller/compressor has been developed that effectively eliminates most engine pollutants of concern, as long as the initial levels aren't too high
- This method greatly reduces the pretreatment costs (down to about $1,000/kW), and it has recently been employed in several ADG/LFG applications

Microturbine Performance

- Microturbines have relatively low electric efficiencies - even with a recuperator, electric efficiencies are typically 20-32%, with overall CHP efficiencies of 50-80%
- When using low-Btu fuels, electric efficiency levels are generally maintained, although power output is reduced 5-10%
- A special fuel compressor is necessary for both fuels, requiring about 10% of the power produced by the microturbine, and adding $100-$200 per kW to capital costs
- Fuel pretreatment is usually required, adding to both capital and maintenance costs, although less expensive pretreatment methods are currently being developed

Microturbines: Increased Costs for ADG/LFG

- Combining these cost and performance factors, the installed cost for microturbines running on ADG or LFG are typically 10-15% more than NG, without including pretreatment
- For O&M, gas treatment, extra compressor maintenance and increased cleaning cause maintenance costs to rise about 60%
- Pretreatment costs to remove siloxanes and other contaminants will add anywhere between $1,000 and $5,000 to capital costs

Microturbines	**Natural Gas**	**ADG/LFG**
Installed Cost (CHP, $/kW)	1,400-2,300	2,800-8,000
Maintenance Cost (cents/kWh)	1-2	1.5-3

- Emissions levels for microturbines are low, and their small size usually exempts them, so no post combustion controls are required

Applications for Microturbines

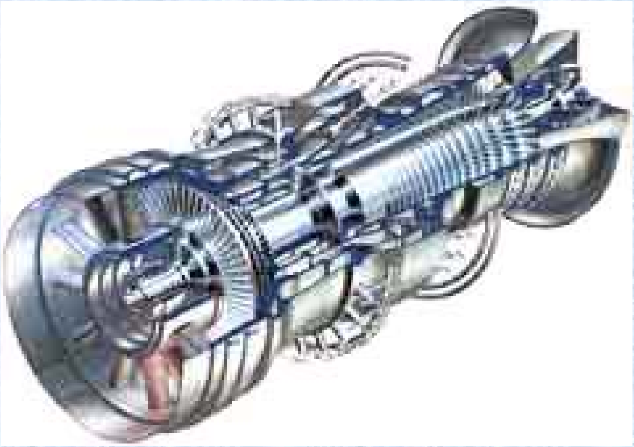
- Microturbines are ideal for small projects in non-attainment areas
- Microturbines have been used extensively in ADG and LFG projects because they are well-suited for small DER/CHP applications, and they can handle these fuels with “off-the-shelf” units, producing very few emissions
- They are most ideal when the electric load is less than 300 kW - microturbines are usually <100 kW, although multiple units can be employed for flexibility
- However, with ADG and LFG applications, many projects fell short of expectations because costs required for fuel treatment and turbine maintenance became too high (especially when siloxane issues were encountered)

Example Microturbine Installations

- Columbia Blvd Wastewater Treatment Plant in Portland, Oregon
  - A fuel cell and several microturbines have been installed
- Jamacha Landfill in Jamacha, California
  - Working with SCS and San Diego County, (4) 70 kW Ingersoll Rand microturbines were installed at the Jamacha Landfill in 2001
- Lopez Canyon Landfill in Lake View Terrace, California
  - At this demonstration project, (50) 30 kW microturbines work together to produce 1.3 MW of total power
  - Largest microturbine power plant to run strictly on landfill gas

Combustion Turbines for ADG and LFG

- Combustion turbines can range from small 1 MW units to 100+ MW power plants, although most ADG/LFG applications are 3-15 MW
- Many NG turbines require significant modifications to accommodate low-Btu fuels



- Most ADG/LFG turbine installations use a natural gas blend, so that fewer modifications are required, but this presentation focuses on units burning 100% ADG or LFG

Combustion Turbine Performance

- Natural gas combustion turbines have electric efficiencies of 25-40%, and overall CHP efficiencies of up to 80%
- Like microturbines, efficiency can be improved with the use of recuperators
- Efficiency is reduced by about 10% for turbines utilizing ADG or LFG
- Power output is also reduced by about 10%

Fuel	Electric Efficiency	Power Output
Natural Gas	25-40%	100%
ADG/LFG	23-36%	90%

Combustion Turbines: Increased Costs for Opportunity Fuels

- With ADG and LFG, many equipment modifications (modified nozzles, more filters, diffusion combustors, etc.) are required, as well as fuel pretreatment equipment
- Overall, equipment costs are increased by about 50% for ADG and LFG units, while fuel pretreatment adds $500-$1,000/kW
- The turbine systems require more inspections, cleaning and general maintenance with ADG and LFG - costs are typically 50-100% more than natural gas

Combustion Turbines	**Natural Gas**	**ADG/LFG**
Installed Cost (CHP, $/kW)	600-1,400	1,400-3,100
Maintenance Cost (cents/kWh)	0.5-1	1-2

Emissions and Emission Controls for Combustion Turbines

- In order to reduce NOx emissions, most natural gas combustion turbines pre-mix with large volumes of air, but low-Btu fuels can not sustain combustion with with low NOx burners
- Most turbines designed for ADG/LFG use a diffusion combustor to burn low-Btu fuels, which produces about 25-35 ppm of NOx emissions
- To bring emissions below 25 ppm, selective catalytic reduction could be used - but in order to use SCR with ADG/LFG, extensive fuel cleaning prior to combustion would be necessary (even trace amounts of hydrogen sulfide or siloxanes could poison the catalyst) and capital costs would be much higher

Applications for Combustion Turbines

- Combustion turbines are common for DER/CHP applications greater than 3 MW in size
- Combustion turbines have been used for large ADG/LFG operations with relatively few problems, but most of these use a NG blend
- For ADG and LFG, potential is generally limited to: 1) very large wastewater treatment plants, and 2) landfills with a third party company/utility nearby to take on the project
- For small (<3 MW) ADG/LFG applications, reciprocating engines and microturbines are more common
- The vast majority of potential ADG/LFG projects are too small to consider combustion turbines as an option

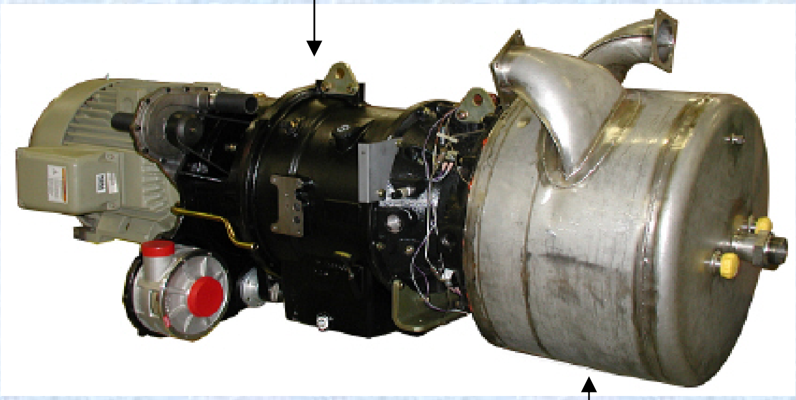
Example Combustion Turbine Installations

- Stickney Water Reclamation Plant in Cicero, IL
  - 3 MW turbine has been operating on the plant's ADG since 1991
- Santa Cruz Landfill and San Marcos Landfill in California
  - In 1989, Gas Recovery Systems installed a small 740 kW turbine at the Santa Cruz facility to produce power for PG&E, and two of the 740 kW turbines at San Marcos to produce power for SDG&E
- Altamont Landfill in Livermore, CA
  - Bio Energy Partners and Waste Management, Inc. teamed up to install two 3 MW Solar turbines at this landfill in 1989 - the facility also installed two 1.3 MW recips in 2002 to produce additional power
- SC Johnson's Waxdale Manufacturing Facility in Racine, WI
  - 3.5 MW turbine provides power and steam for the manufacturing facility, and is powered by LFG from a nearby landfill

Stirling Engines for ADG and LFG

- Although Stiring engine technology has been around for many years, it is only now entering commercialization for DER/CHP applications
- Stirling engines rely on external combustion - inside the engine, trapped hydrogen gas pushes the pistons towards the heat source created by the fuel

Engine (hydrogen gas)



External Combustor
(ADG/LFG)

Stirling Engines: Advantages and Drawbacks

- Stirling engines are very fuel flexible, and better control of emissions is possible due to the external combustion design
- Stirling engines can handle fluctuating Btu levels (which can be a problem with ADG/LFG streams) and they do not require compressors - a simple blower will suffice
- The burners can be modified to handle fuels with different Btu contents without any modification to the engine itself
- Stirling engine burners have a high tolerance for siloxanes and other particulates, so gas pretreament may not be necessary
- The primary drawbacks to Stirling engines are limited CHP capability (hot water only) and a capital cost higher than most DER/CHP technologies (i.e. recips and combustion turbines)

Stirling Engines: The Future Market

- STM Power has developed a 28% efficient, fuel-flexible 55 kW Stirling Engine, which is now commercially available
- An Oregon WWTP has installed one of these units for testing, and two units were installed at the NextEnergy Microgrid Power Pavillion in Detroit, Michigan
- Projected costs are $1,200-$1,500 per kW (installation not included), with maintenance at around 1 cent per kWh

Fuel Cells for ADG and LFG

- Fuel cells are a developing technology, but 200 kW phosphoric acid units have been produced by UTC and installed at wastewater treatment plants utilizing ADG
- Several installations in California, Oregon, Washington, New York, and other locations have proven the technology's reliability

- Fuel cells produce very few emissions (no combustion) and have high electric efficiencies (30-40%), but require more maintenance (2-4 cents/kWh)

Fuel Cells: Still Challenged by Costs

- Although many different types of fuel cells are in development (PEM, SOFC, etc.), phosphoric acid fuel cells (PAFCs) are the only type currently available, and they cost several times more than traditional DER/CHP technologies ($3,000-$5,000/kW vs. ~$1,000/kW)
- Hydrogen sulfide poisoning is an important issue with fuel cells - serious damage could occur with stack exposure to H_2S
- ADG/LFG fuel reformers require more filters, a larger fuel injector, larger piping, and more maintenance than natural gas fuel reformers, so they are more expensive
- Until the price of fuel cell technologies drops significantly, they will not have a significant impact on the ADG/LFG market

Summary Table for ADG/LFG Technologies

Technology	Size Range (Current)	Electric Efficiency	Installed Cost ($/kW)	Maintenance (cents/kWh)	Emission Controls
Reciprocating Engine	75 kW - 5 MW	29-38%	1,500-4,700	1.5-4.5	Lean Burn, Possibly 3WC/SCR
Microturbine	30-300 kW	20-32%	2,800-8,000	1.5-3	None Required
Combustion Turbine	> 1 MW	23-36%	1,400-3,100	1-2	Possibly SCR (<25 ppm)
Stirling Engine	55 kW	25-30%	1,500-2,500*	0.8-1	None Anticipated
Fuel Cell	200 kW	30-40%	5,000-9,000	2-4	None Required

*Assuming a $300-$500/kW installation cost for Stirling engines, and up to $500 for pretreatment

Note: Installed costs include pretreatment equipment ($500-$5,000/kW)

Important Issues When Selecting a Technology

- Size dictates choices
- Emissions can be a major consideration
- Location of maintenance personnel can be a big factor
- Efficiency contributes to size more so than to fuel cost