



Distributed Generation and Engines/Turbines for Combustion of Biogas

David Thimsen, Project Manager
EPRI Distributed Energy Resources Program
GCEP Energy Workshop
April 27, 2004

For the next 20 minutes:

- Let's make sure we're talking the same language
- Biogas – from the dark side of the carbon cycle
- Flares, engines, turbines, fuel cells
- Why bother?

Engineers eschew obfuscation!

- Distributed Power
- Renewable Power
- Green Power

Distributed Power, Distributed Generation, Distributed Electrical Resources

Electric Power Sources:

- Connected to utility wires operating at distribution voltages (generally less than 15 kV)
or
- Connected (at transmission voltages) to utility wires in load pockets to relieve transmission system congestion.
or
- Operating disconnected from an available electric utility system.

Can you give me some examples?

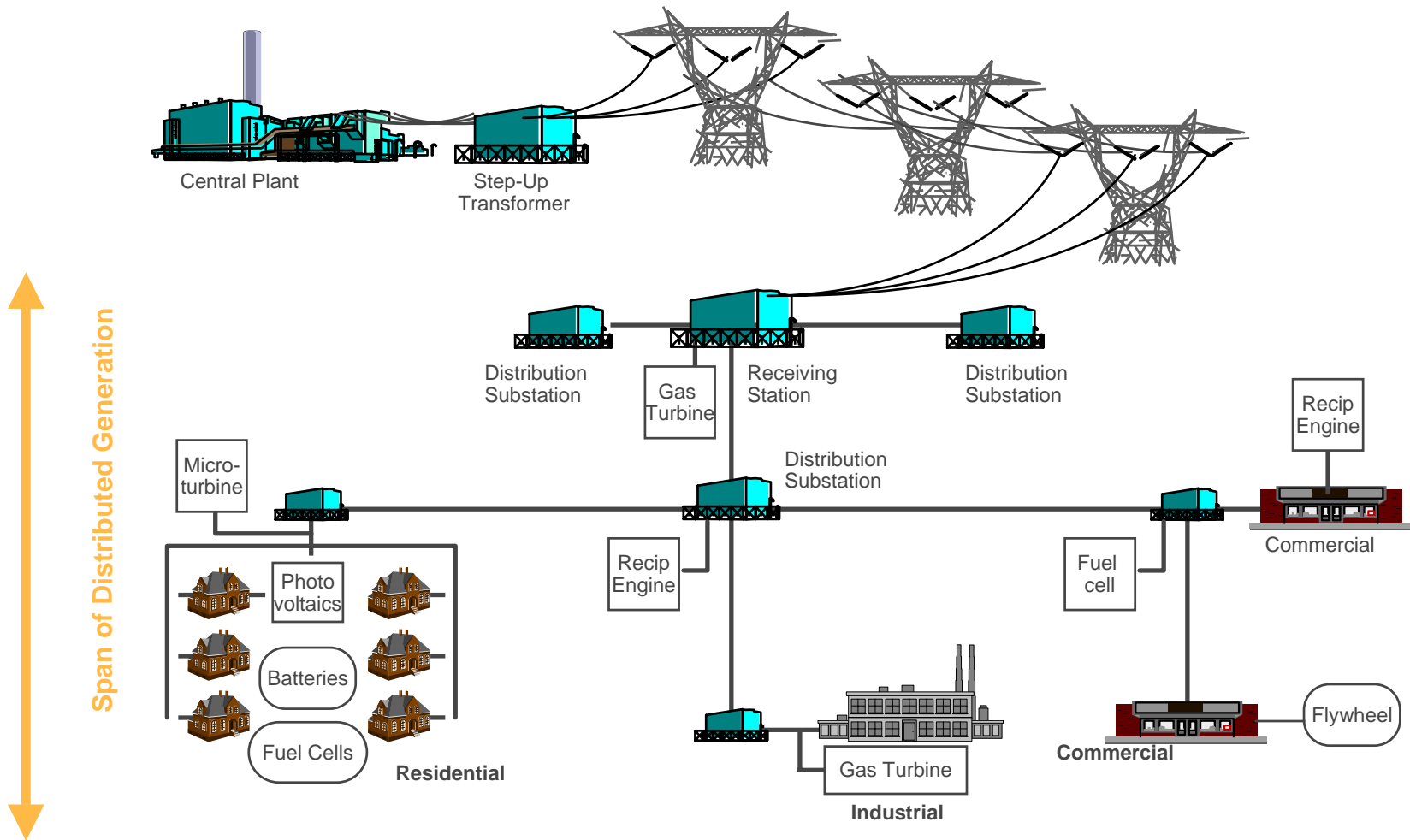
In the electrical marketplace now:

- Natural gas–fueled combustion turbine in combined heat and power (CHP) service
- Diesel generator used to shave peaks or power loads off-line during peak periods.
- Combustion turbine to relieve transmission constraints into a load pocket.
- WWTP sludge digester gas-fueled engine
- Batteries/flywheels/SMES for line voltage regulation

Coming soon?

- Grid-connected residential CHP
- Flow batteries for day-night electricity storage
- Home Depot going off-grid

The grand scheme of things



These generally don't count!

Transmission level connections

- Multi-megawatt wind farms
- Pulp and paper mill steam topping cycle
- Compressed air or pumped hydro storage
- Landfill gas-fueled generators (?)

Operating outside the electrical marketplace

- Remote diesel generator at a gravel quarry
- Standby generators used during grid outages only

Renewable Power

Electrical power generated as a result of recent (5 years?) solar activity

- Photovoltaics
- Wind-hydro-tidal-wave turbines
- Biomass-fueled engines-turbines-fuel cells
 - Wood waste
 - Grasses/crop residues
 - MSW (?)
 - Biogas
 - Grains/oilseeds

What about?

- Geothermal
- Waste heat streams
- Oil/Gas production flares

Green Power

Doesn't pollute! Good for the environment!

Can you be more specific?

- Photovoltaics, but don't shade things that need sunlight.
- Wind, unless I don't like to look at it or it's noisy or it kills birds or bats.
- Hydro, but no reservoirs.
- Geothermal, probably
- Biomass-fueled engines and turbines? Sure, why not?
- RDF/MSW-fueled power plants? You've got to be kidding!
- Fuel cells? Hydrogen? Definitely! No questions asked!
- Nuclear? Don't get me started!
- Clean Coal? An oxy-moron

Biology in action!

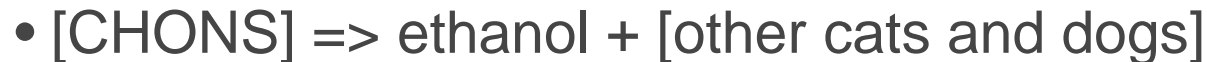
Aerobic:



Anaerobic (the dark side):



Picky anaerobic also:



Exploiting the Dark Side

Why? Reduce the biological activity of organic wastes via anaerobic digestion:

- Municipal Wastewater Treatment Plant (WWTP) sludge
- Animal manure from a Confined Animal Feeding Operation (CAFO)
- High-strength industrial streams

Whether you want it or not:

- Sealed landfills

Some jargon:

- Psychrophilic: < 85F low-rate, large volume
- Mesophilic ~ 95F moderate rate, moderate volume
- Thermophilic ~135F higher rate, lower volume

Raw gas coming from the Dark Side

Typical Values (May be exceeded at specific sites treating unique wastes.)	Municipal WWTP Sludge Digestion	Industrial Waste Digestion	Animal Manure Digestion	Landfill Gas
Methane – CH ₄ Carbon Dioxide – CO ₂	50-70% 30-45%	60-80% 20-40%	50-70% 30-50%	45-60% 35-40%
Water Vapor – H ₂ O (Saturated at digester temperature)	1-4%	1-4%	1-4%	1-2%
Hydrogen Sulfide – H ₂ S and Total Reduced Sulfur – TRS	150-3,000 ppmv	Up to 30,000 ppmv	Up to 5,000 ppmv	10-1,000 ppmv
Siloxanes – HCSi	~10 ppmv	negligible	negligible	~10 ppmv
Hydrocarbons - HC Halogenated Hydrocarbons - HCX	negligible	negligible	negligible	<2500 ppmv <100 ppmv
Nitrogen – N ₂ Oxygen – O ₂	< 5 % < 1%	negligible	< 5 % < 1%	<10% < 3%

Bad Actors in Raw Biogas

- Hydrogen sulfide, organic sulfur (all sources)
 - Emitted as SO_2 after combustion
 - Iron weight loss corrosion in liquid water
 - Leaks can be toxic
 - Poisons fuel cell catalysts
 - Poisons SCR, CO_x , and 3-way exhaust catalysts
- Condensed water vapor (all sources)
 - Weight loss corrosion when combined with H_2S
 - Instrument fouling
 - Compressor/fan impact/erosion damage
- Siloxanes (WWTP sludge, landfill gas)
 - Burns to solid silica – imagine close-tolerance machines and small flow passages
- Halogenated hydrocarbons (landfill gas)
 - Poisons fuel cell catalysts
 - Depletes Molten Carbonate Fuel Cell electrolyte
 - Weight loss corrosion in carbon steel, stress crack corrosion in SS (liquid water)

Biogas is a byproduct of digestion!

- Vent – generally a no-no!
 - H_2S can be lethal in small concentrations.
 - Landfill gas has VOCs and refrigerants.
 - CH_4 is a more potent greenhouse gas than CO_2 .
- Incinerate locally in a heating appliance or flare (if no local heat loads)
 - $\text{H}_2\text{S} \Rightarrow \text{SO}_2$
 - $\text{CH}_4, \text{VOC} \Rightarrow \text{CO}_2$
 - Refrigerants $\Rightarrow \text{HX}$
 - Flares are not 100%!
- Upgrade to commercial natural gas (need nearby markets)
- Incinerate in an engine or turbine or fuel cell for power

Power Generation Technologies Employed

- Spark Ignition Internal Combustion Engines
- Combustion Turbines/MicroTurbines
- Fuel Cells
- Stirling Engines

Spark Ignition Internal Combustion Engines

Fuel Specs:

- H₂S < 1000 ppmv
- HCX < 0.15 ppmv
- Siloxanes < 0.03 ppmv (?)
- Dew point 20F less than gas temperature

Typical Uncontrolled Emissions:

- NO_x 1.8 lb/MWh
- CO 7.8 lb/MWh
- SO₂ depends on fuel S

Typical Yields:

- Electrical 95 kWh/MMBtu
- Thermal 125 kWh/MMBtu



Combustion Turbines

Fuel Specs:

- H₂S ? ppmv
- HCX ? ppmv
- Siloxanes < 0.03 ppmv (?)
- Dew point 20F less than gas temperature

Typical Uncontrolled Emissions:

- NO_x 1.3 lb/MWh
- CO 4.6 lb/MWh
- SO₂ depends on fuel S

Typical Yields:

- Electrical 69 kWh/MMBtu
- Thermal 151 kWh/MMBtu



MicroTurbines

Fuel Specs:

- H₂S 70,000 ppmv (?)
- HCX ? ppmv
- Siloxanes < 0.03 ppmv (?)
- Dew point 20F less than gas temperature

Typical Uncontrolled Emissions:

- NO_x < 0.4 lb/MWh
- CO < 0.3 lb/MWh
- SO₂ depends on fuel S

Typical Yields:

- Electrical 82 kWh/MMBtu
- Thermal 138 kWh/MMBtu



Fuel Cells

Fuel Specs:

- H₂S < 0.10 ppmv
- HCX < 0.10 ppmv
- Siloxanes < 0.03 ppmv (?)
- Dew point 20F less than gas temperature

Typical Uncontrolled Emissions:

- NO_x < 0.07 lb/MWh
- CO < 0.10 lb/MWh
- SO₂ negligible

Typical Yields:

- Electrical 132 kWh/MMBtu
- Thermal 88 kWh/MMBtu



Stirling Engines

Fuel Specs:

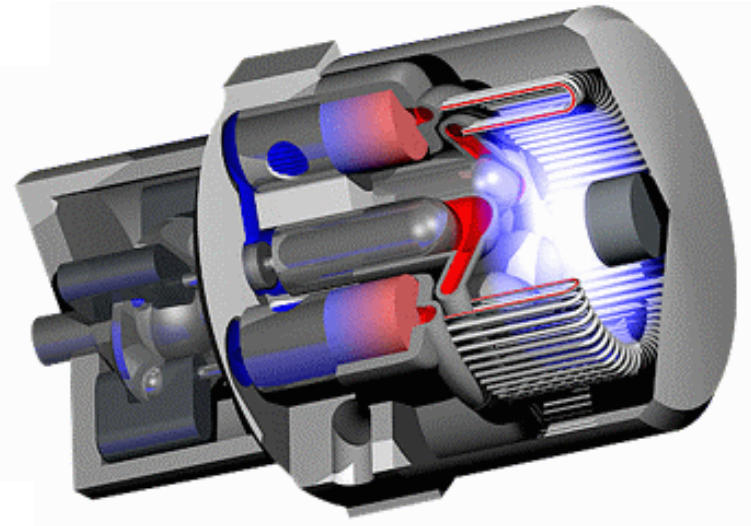
- H₂S high
- HCX ?
- Siloxanes ?
- Dew point 20F less than gas temperature

Typical Uncontrolled Emissions:

- NO_x < 0.5 lb/MWh (?)
- CO < 6.0 lb/MWh (?)
- SO₂ depends on fuel S

Typical Yields:

- Electrical 88 kWh/MMBtu
- Thermal 132 kWh/MMBtu



Why bother?

- Raw gas is free. Usually.
- Electricity isn't free. Ever.
- Natural gas, propane and fuel oil aren't free. Ever.
- Flares are embarrassing!

Value Propositions:

1. Use the raw gas for a local heating load (to displace commercial fuels)
2. Upgrade to commercial natural gas.
3. Cogenerate power and heat
4. Generate power

Putting it all together – the requirements

Capital

- Gas Processing
 - Drying
 - Compressor/blower?
 - Gas storage?
 - Sulfur removal?
 - Siloxane removal?
 - HCX removal?
 - Polishing for fuel cells?
- Power Generation
 - Prime mover/fuel cell
 - Generator/inverter
 - Switchgear/interconnection
 - HRHX?
- Electrical/Mechanical/Controls
- Project Management/Permitting

Operating

- Operating Labor
- Scheduled Maintenance
- Gas Processing consumables?
- Gas Processing wastes?
- Compressor Power?

- Fuel?

- Power Purchase agreement?
- Standby Power reserve?
- Space Lease?
- Insurance?

Business Arrangements

- Parties:
 - Gas producer/site owner
 - Electric Utility
 - Third party to own and/or operate
- Relatively Easy: Gas producer owns/operates the equipment, uses all power on the customer side of the electric meter, uses heat in local process.
- Complications:
 - Who provides power during maintenance outages and at what cost?
 - If generation exceeds the local electrical load, power must be exported and a power purchase agreement must be made.
 - If the electrical utility or a third party generates the power and connects on the utility side of the local electrical meter: How is gas valued? How is thermal output valued? Is rent paid for real estate? Insurance/Liability?
 - Who gets “green tags” or renewable credits or incentives?

The next to the last slide.

EPA resources for biogas production technologies:

- Animal Manure: AgStar (www.epa.gov/agstar)
- Landfill Methane Outreach Program: (www.epa.gov/lmop)

Stay Tuned:

- More animal manure digesters are on the way. (3,000 cows or 5,000 hogs can make themselves noticed for miles.)
- Industrial waste digesters are becoming more common. At present they largely flare but 3rd party projects are being developed.
- Renewable Portfolio standards will encourage utility interest in biogas-to-electricity projects.
- Look for flares! That's the best indicator of opportunity.
- How can we make these generators dispatchable?
- How can gas processing requirements be minimized?
- Are there liquid streams currently being dried that could more profitably be digested?

Are there questions?

Lights Please.

David Thimsen
dthimsen@epri.com
www.epri.com
(651) 766-8826