

# Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies

California Bioresources Alliance

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UCDAVIS
UNIVERSITY OF CALIFORNIA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

# Today’s presentation

- The Opportunity
- The Conundrum
- Our Goals
- Technologies
- Scope and Methods
- Results
  - Efficiency
  - Costs
  - Emissions
  - Technical Conclusions
- Conclusions

# The Opportunity

| Feedstock | Amount Technically Available | Biomethane Potential (billion cubic feet) | Million gasoline gallon equivalent (GGE) |
|---|---|---|---|
| Animal Manure | 3.4 MM BDT | 19.7 | 170 |
| Landfill Gas | 106 BCF | 53 | 457 |
| Municipal Solid Waste (food, leaves, grass fraction) | 1.2 MM BDT | 12.6 | 109 |
| Water Resource Recovery Facility (WRRF) | 11.8 BCF (gas) | 7.7 | 66 |
| Total | | 93 | 802 |

# The Opportunity

March, 1922 67

## Gas from Sewage Waste Runs City Power Plant

How the sewage disposal plant at Birmingham, England, supplies its own power is described in the illustration. [Gas] from the sewage drives an engine of 20 brake horsepower, which operates a centrifugal sludge pump

SEWAGE that costs large cities tremendous sums each year can be turned into a source of power equivalent to thousands of tons of coal! The waste now dumped into rivers or shipped to sea may be used to run factories or to light buildings!

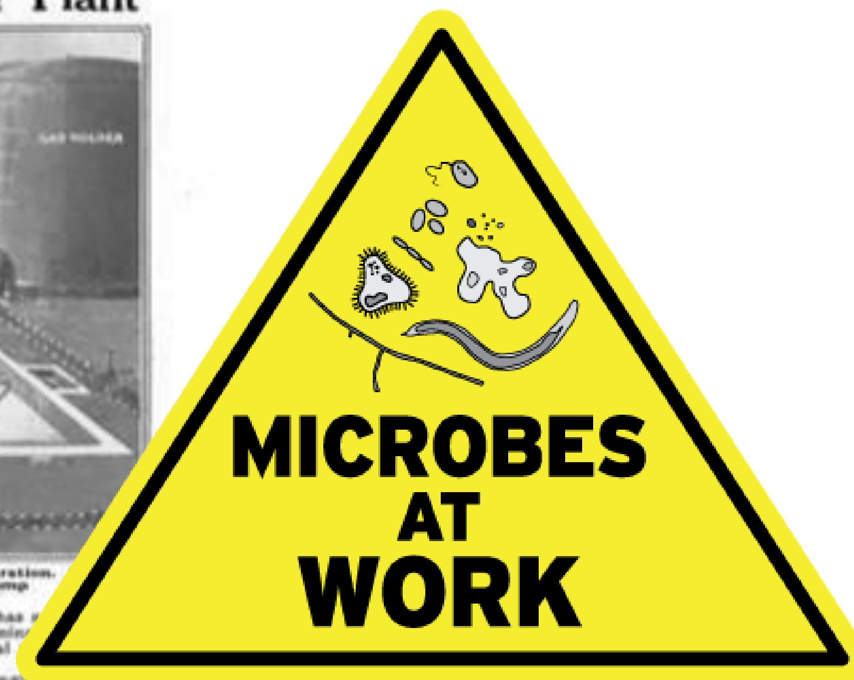
That conversion of sewage into power is possible has been proved conclusively by the city of Birmingham, England. There a suction gas engine of 20 brake horsepower has been successfully driven by the gases given off by sewage sludge.

On the basis of the Birmingham experiments, an American city that must now pay for the disposal of 400,000 tons of sewage sludge a year might produce 320,000,000 cubic feet of gas suitable for heat and power, or, in terms of energy, 16,000,000 horsepower hours at 20 cubic feet per brake horsepower.

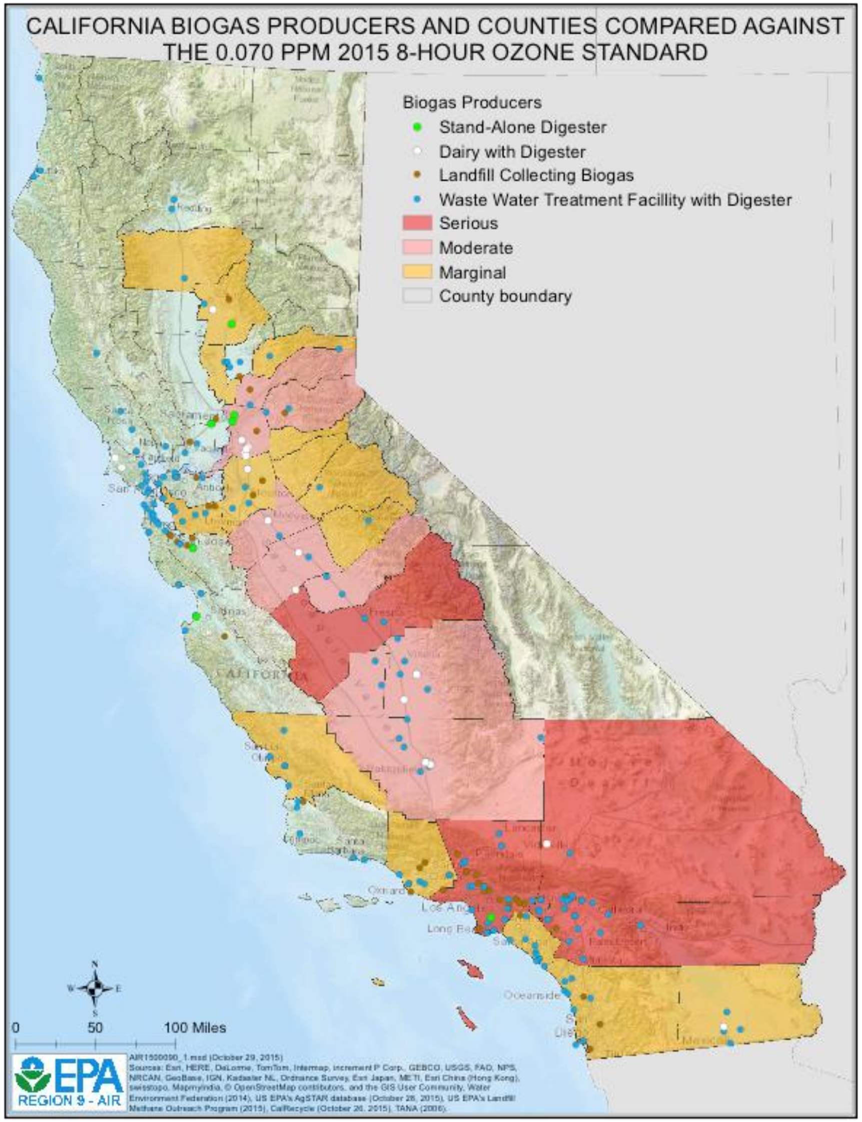
The apparatus for producing gas from sewage consists of two sludge digestion tanks in which the sewage is allowed to ferment. The gases given off are composed of from 25 to 75 per cent of methane, or marsh gas.

A gas engine of the usual type will run on sewage gas without adjustment of the valves. Sewage gas has [illegible] value than some illumin[illegible] ing about 650 thermal [illegible] foot, as against 550.

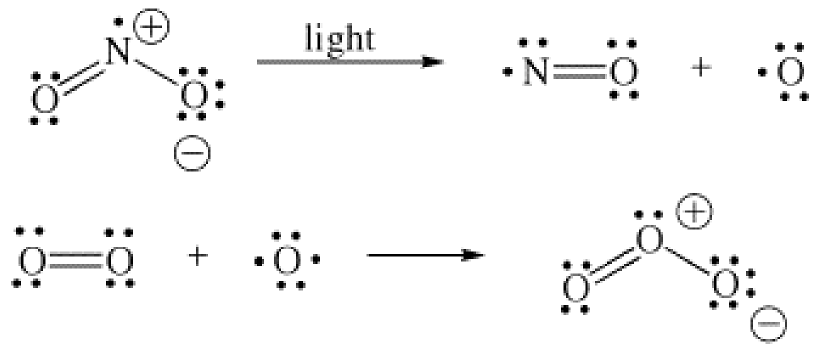
The Birmingham eng[illegible] hours a day and is used to operate a centrifugal sludge pump that moves the wet sludge from the gas-generating tank to the drying grounds. In this process a small proportion of the waste material produces enough power to run the pumps of the sewage disposal plant. If all the material were used, there would probably be enough gas available to light the city.



# The Conundrum

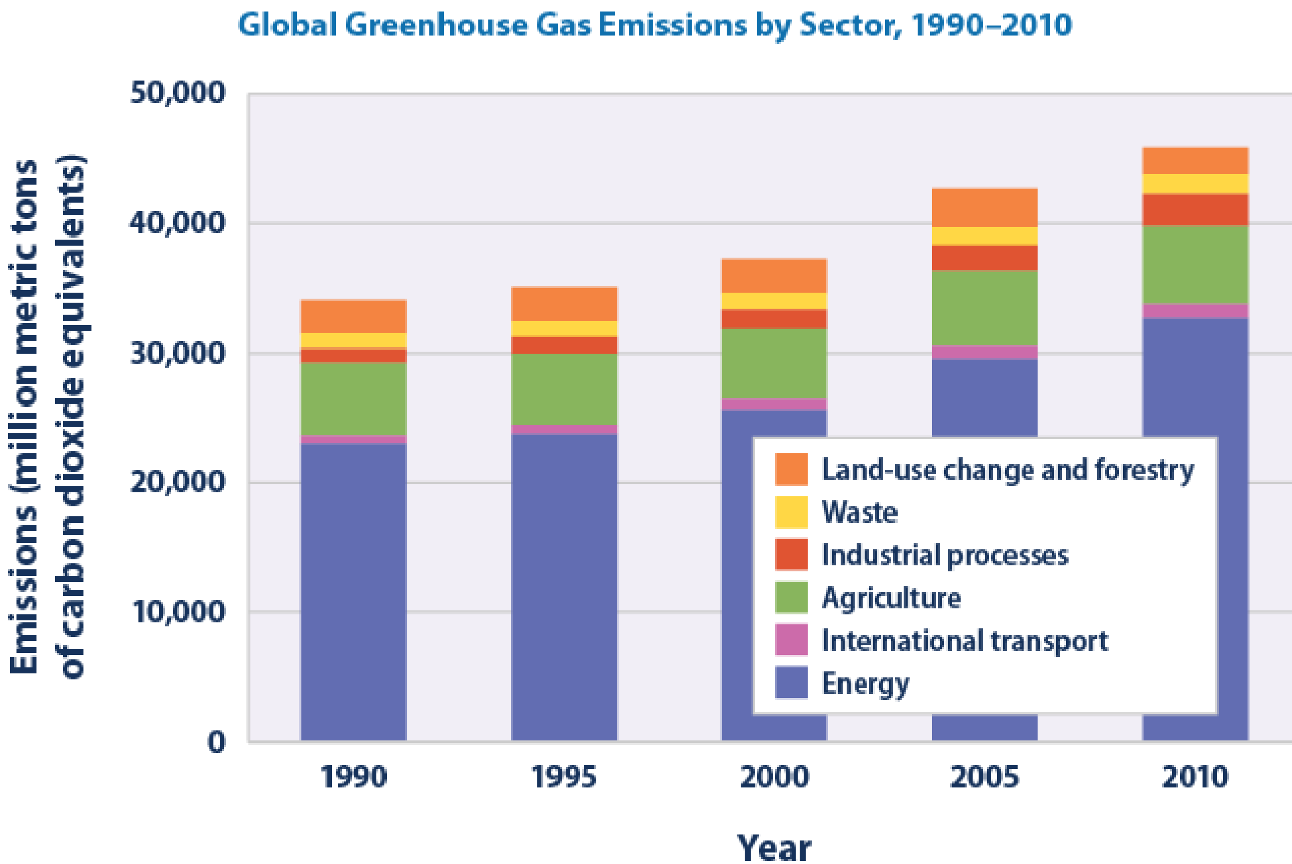



- Sunlight, Oxygen, and $No_x$ → "bad" ozone




- ½ of CA counties —where 80% of Californians live — exceed ozone NAAQS

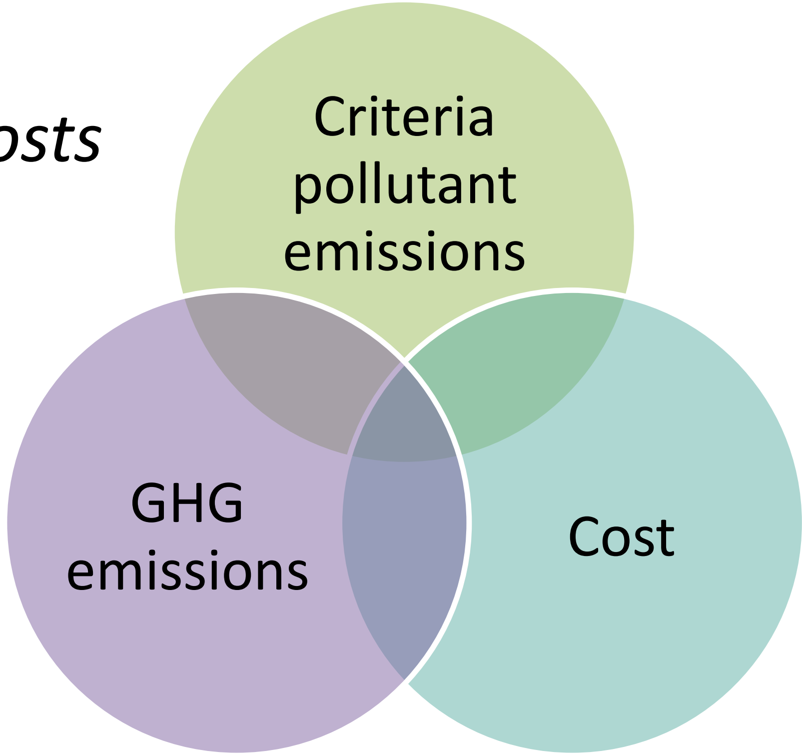
# The Conundrum




- Energy production & use = largest source of GHGs
- Biogas is **biogenic,** w/ a smaller carbon footprint

# Our Goals

- EPA Strategic Plan's #1 goal:
  - *Address climate change **and** improve air quality*
- Report's goals:
  - *Compare emissions and costs*
  - *Identify options*
  - *Engage stakeholders*
  - *Move us forward*



# Project Goals

– Inform organic waste managers and regulators
– Compare cost and performance of biogas utilization technologies
  - Efficiency
  - Cost of energy
  - Criteria pollutant emissions
  - Greenhouse gas (GHG) emissions

# Technologies

- Reciprocating engines
- Gas turbines
- Microturbines
- Fuel cells
- Processing to create Renewable Compressed Natural Gas Vehicle Fuel (RNG / CNG)
- Processing for pipeline injection
- Flaring

# Reciprocating Engines

- Also known as: Reciprocating Internal Combustion Engines (RICE)

- RICE is a piston engine (i.e., reciprocating)
  - Intermittent combustion of fuel-air mixture to
  - create mechanical energy that is
  - converted to electricity by a generator.

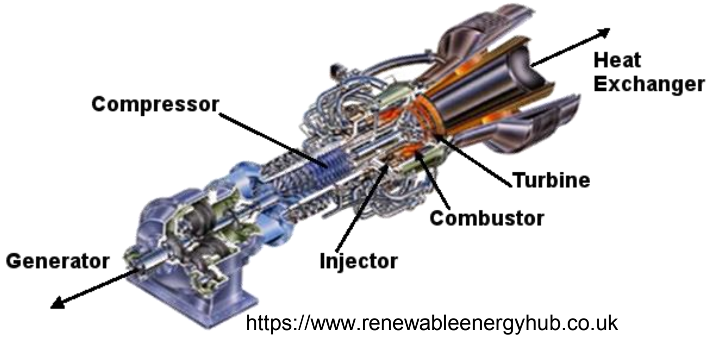
- Used extensively throughout the world for stationary power generation

- Size ranges from < 100 kW to several MW.

*https://www.clarke-energy.com/*

# Gas Turbines (or combustion turbines)

- Similar to jet engines but optimized to produce shaft power (rather than high velocity exhaust gas).
- Fuel is burned continuously with compressed air.
- Hot exhaust gases expand through a turbine to create mechanical energy that is converted to electricity by generator.
- Gas turbine-generator size ranges about 1 to 500 MW.




https://www.renewableenergyhub.co.uk

*Mark McDannel, LA County San*

# Microturbines

- Small gas turbines
- available in capacities ranging from 30 kW to 333 kW
- Combine units to achieve up to several megawatt (MW) facility size.

http://www.sheboyganwwtp.com/

http://www.agenziauniklima.it/

# Fuel Cells

- Use hydrogen and oxygen to produce direct current power through an electrochemical process, rather than combustion-to-mechanical energy process.
- Biogas methane ($CH_4$) is reformed to make hydrogen available for the fuel cell.
- Systems available from <100 kW to several MW.


*Jeff Wall, Moreno Valley Regional WRF*

http://www.fuelcellenergy.com/

# Processing for pipeline injection

- Biogas must be "upgraded" to biomethane, which generally requires:
  - removing trace contaminants and water from biogas and then
  - separating carbon dioxide ($CO_2$) from methane
- Methane portion is then compressed and injected to the natural gas system
- Finished gas must meet pipeline owner specifications

*Könnern, Germany (Harasek, 2011)*

# Processing to create Renewable Compressed Natural Gas Vehicle Fuel

## (RNG /CNG)

- Processing system is similar to creating pipeline quality gas:
  - Remove trace contaminants, water and $CO_2$
- Product must meet vehicle fuel standards (which may or may not be different than pipeline quality standards).
- Biomethane product is compressed and can be used like CNG vehicle fuel.

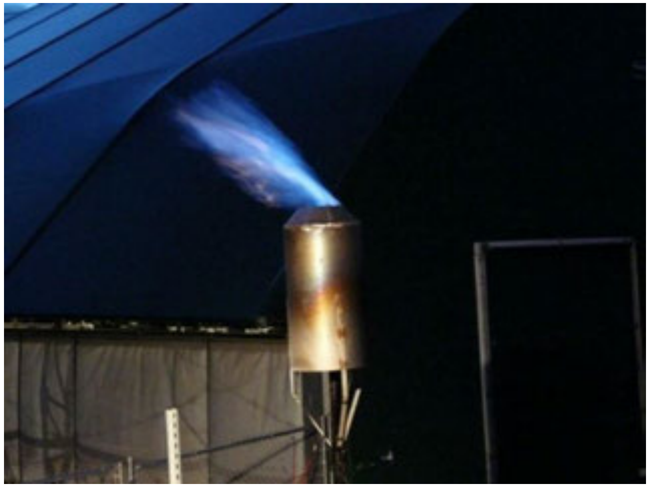
http://www.unisonsolutions.com

*Sean Moen, ReFuel*

# Flare

- Method for methane (biogas) disposal when other utilization technologies are not practical or economic.
- Methane converted to $CO_2$ and water vapor by burning in a flare.

www.johnzink.com



hulsdairy.com/

# Scope and Methods

- Evaluated on-site use (conversion or upgrading) of already-produced biogas

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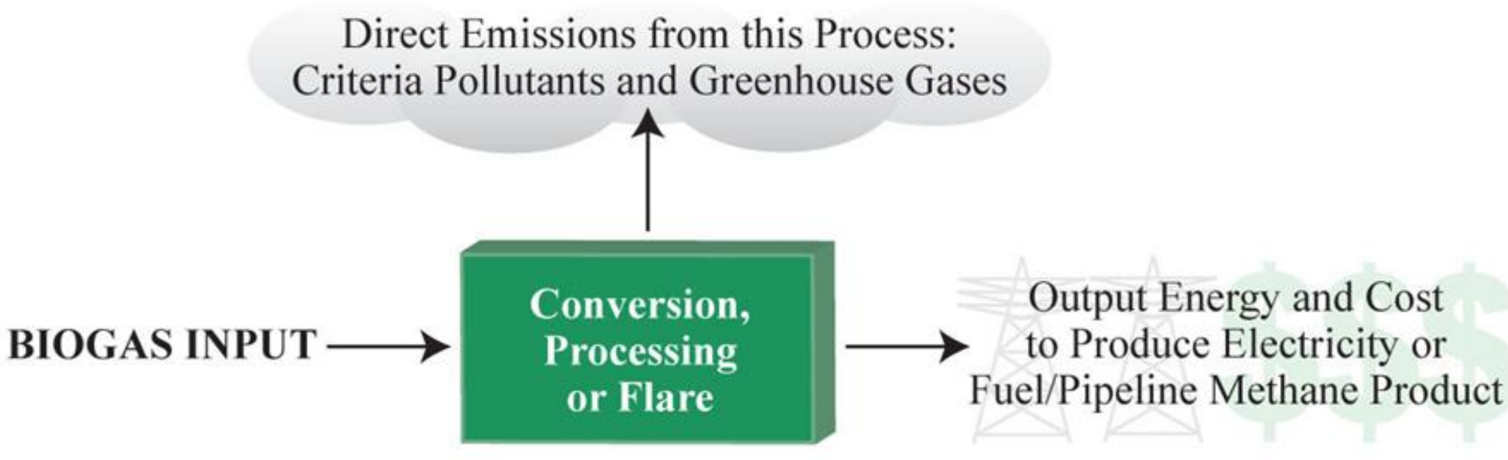
- Evaluated on-site use (conversion or upgrading) of already-produced biogas
- Conversion efficiency:
  - % energy efficiency for electricity production systems, higher heating value basis
  - % yield for renewable CNG and pipeline injection processes
- Costs
  - Levelized Cost of Energy (LCOE) [output basis]
  - Cost to process biogas [input basis]
  - Includes biogas pre-treatment and emissions control costs
- On-site criteria air pollutant and GHG emissions

# Scope and Methods




- Limited Scope – starts with existing biogas.
- Does not include the costs and emissions associated with biogas production, & other upstream and downstream processes.
- It is not a full system or life-cycle emissions accounting.

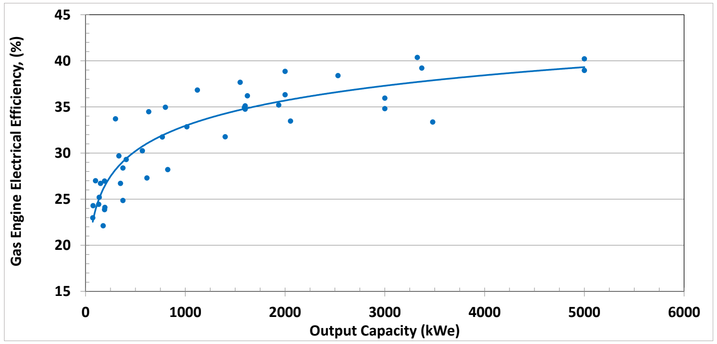
# Scope and Methods

**Source information included**

- peer-reviewed and ‘gray’ literature,
- operating permits,
- source test reports and
- expert and developer interviews.

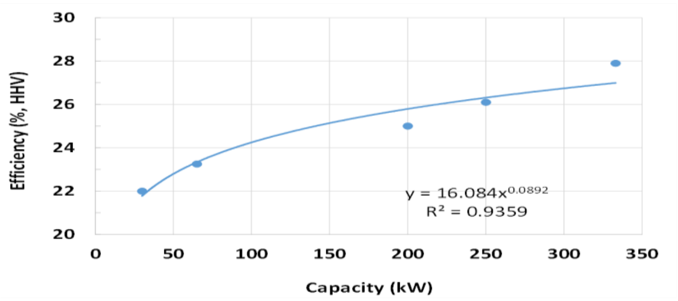
# Efficiencies

**Reciprocating Engine**



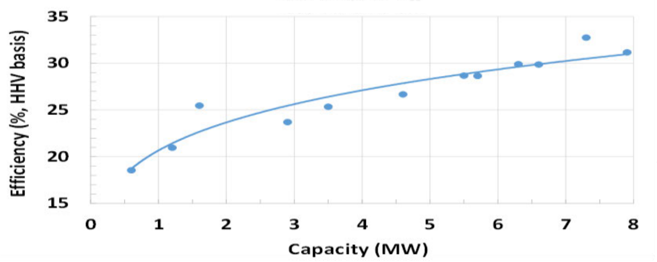

*Sources; (ICF 2012, Rutgers 2014, Caterpiller 2015)*

**Microturbine**



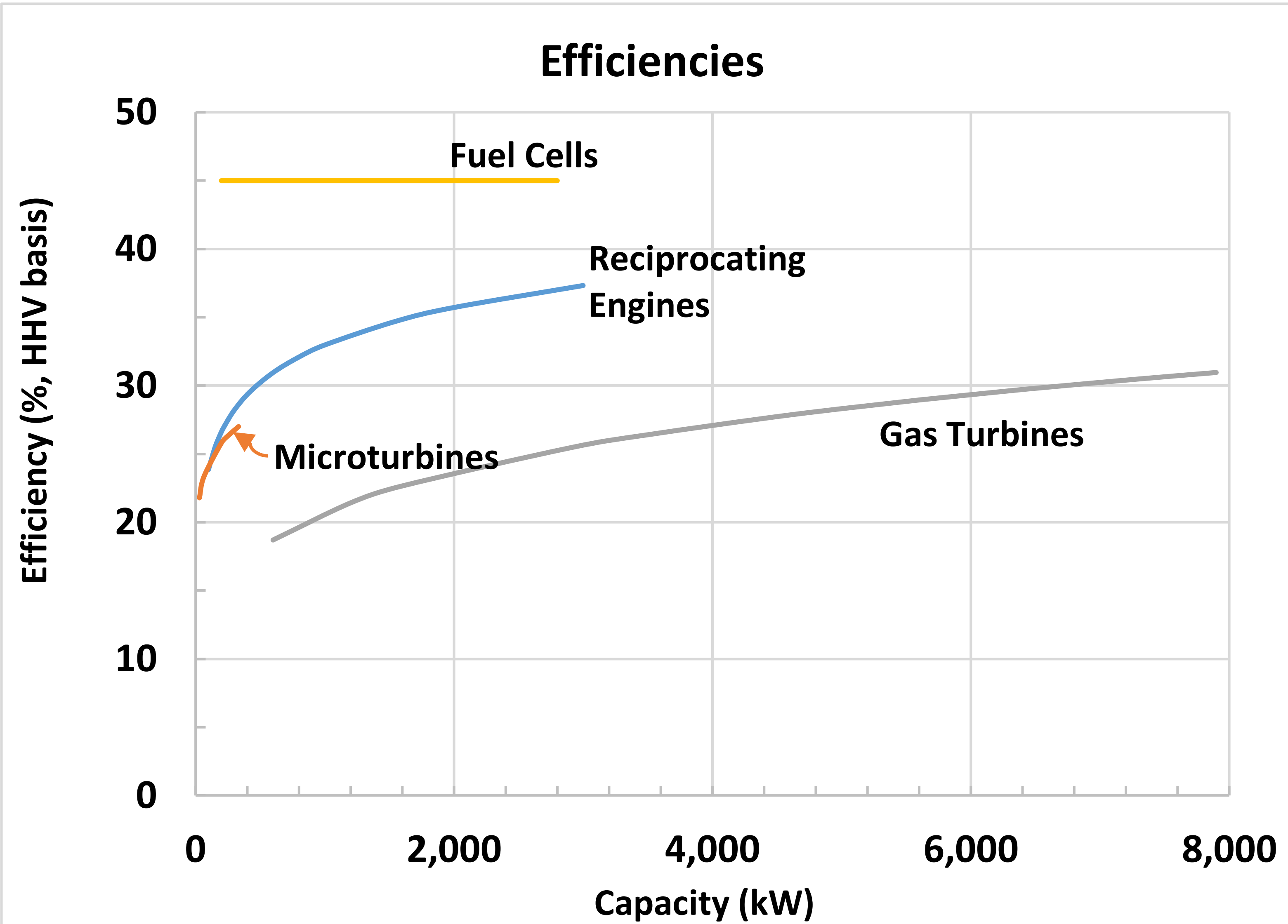

*Sources: (Itron 2011, Darrow et al., 2015, FlexEnergy)*

**Gas Turbine**




*Sources: (Itron 2011, Solar Turbines 2015, Kawasaki Gas Turbines 2015)*

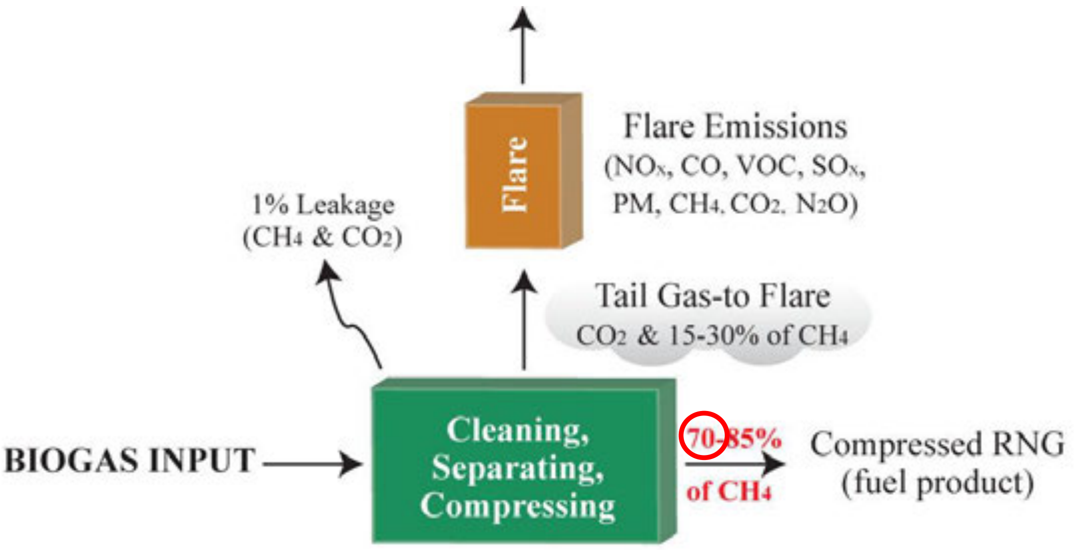
# Electricity producing technologies compared



# RNG/CNG Biomethane "Yield"

| Biogas Flow Input (SCFM) * | Methane Recovery or "Yield" (%) | RNG Fuel Product Output (GGE / day) * | Separation Technology | Source Information |
|---|---|---|---|---|
| **50 - 200** | 70 | 240 - 965 | **Single-pass membrane** | BioCNG |

* Assumes 60% methane in the Biogas. GGE = gallons gasoline equivalent



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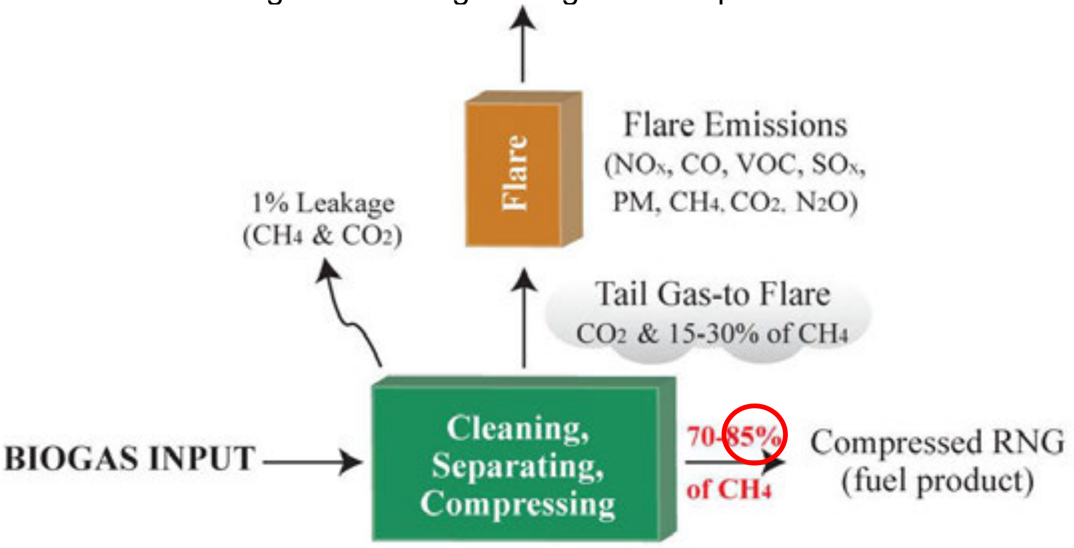
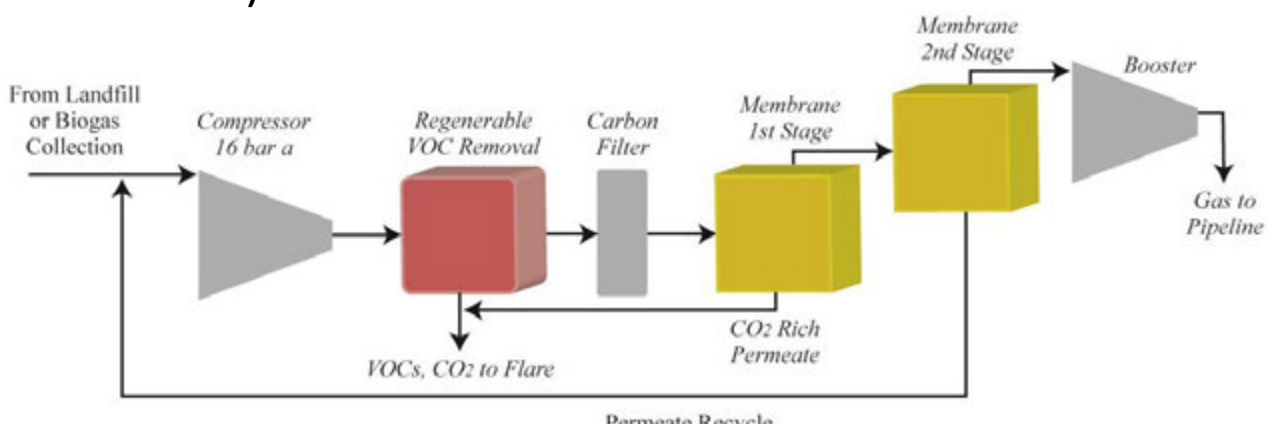
| **50 - 200** | 70 | 240 - 965 | **Single-pass membrane** | BioCNG |
| **1600** | 85 | 9,360 | **Pressure Swing Adsorption** | Guild,<br>Santos, Grande et al. 2011,<br>Wu, Zhang et al. 2015 |

* Assumes 60% methane in the Biogas. GGE = gallons gasoline equivalent



# Upgrade & Pipeline Injection Biomethane "Yield"

- Achievable methane recovery for commercial upgrading technologies is reported to be as high as 96-99%.*
- Facility at Point Loma, California reportedly recovers 85-87% of input methane in the upgrading system (an Air Liquide two-stage permeable membrane system) [Frisbie, 2015]
- Our analysis assumed 90% methane recovery to final product (which needs to have energy content of 990 Btu $ft^{-3}$ , or 98% methane concentration)




*Adapted from Air Liquide: http://www.medal.airliquide.com/en/biogaz-systems.html*

* (Petersson and Wellinger 2009, Ryckebosch, Drouillon et al. 2011, Bauer, Hulteberg et al. 2013, IEA 2014)

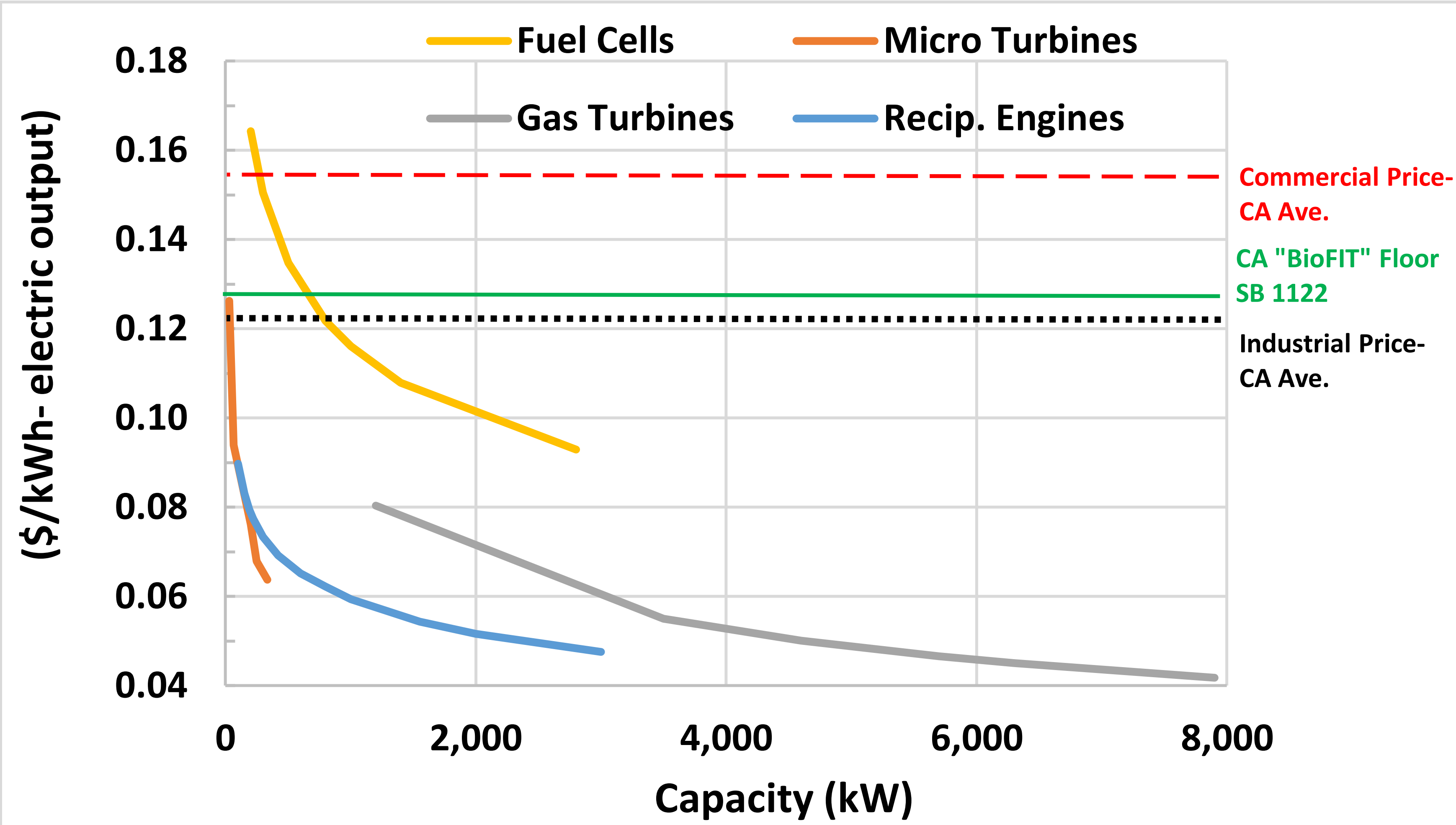
# Cost of Energy

- Capital and operating costs taken from literature and discussions with developers;
- Reflects California costs or “cost adders” above U.S. average
- Includes costs for
  - raw biogas cleanup ($H_2S$ and siloxane reduction)
  - air pollution control (APC) equipment for reciprocating engines and gas turbines; APC is presumed **not needed** for microturbines, fuel cells, fuel and pipeline pathways, and flares
- RNG / CNG pathway cost includes on-site fueling equipment
- The upgrade to pipeline injection pathway includes interconnection or injection costs.

# Levelized Cost of Energy (LCOE)

- The LCOE represents the required revenue per unit of energy for the project to break even.
- In this analysis, LCOE = Total Annual Cost ÷ Annual Energy Produced
  - $/kWh (electricity systems),
  - $/gallon-gasoline equivalent ($/GGE) for RNG/CNG systems,
  - $/MMBtu for pipeline injection systems & RNG/CNG
- Capital costs were amortized over 20 years at 6% annual interest
- Recall scope starts with existing biogas so biogas has **ZERO** cost in our financial model (the biogas production is already paid for)
- If the biogas did not yet exist, e.g., a digester needed to be built, then the LCOE would be higher

# LCOE Comparison –Electricity Systems



# RNG/CNG Fuel Cost Estimate

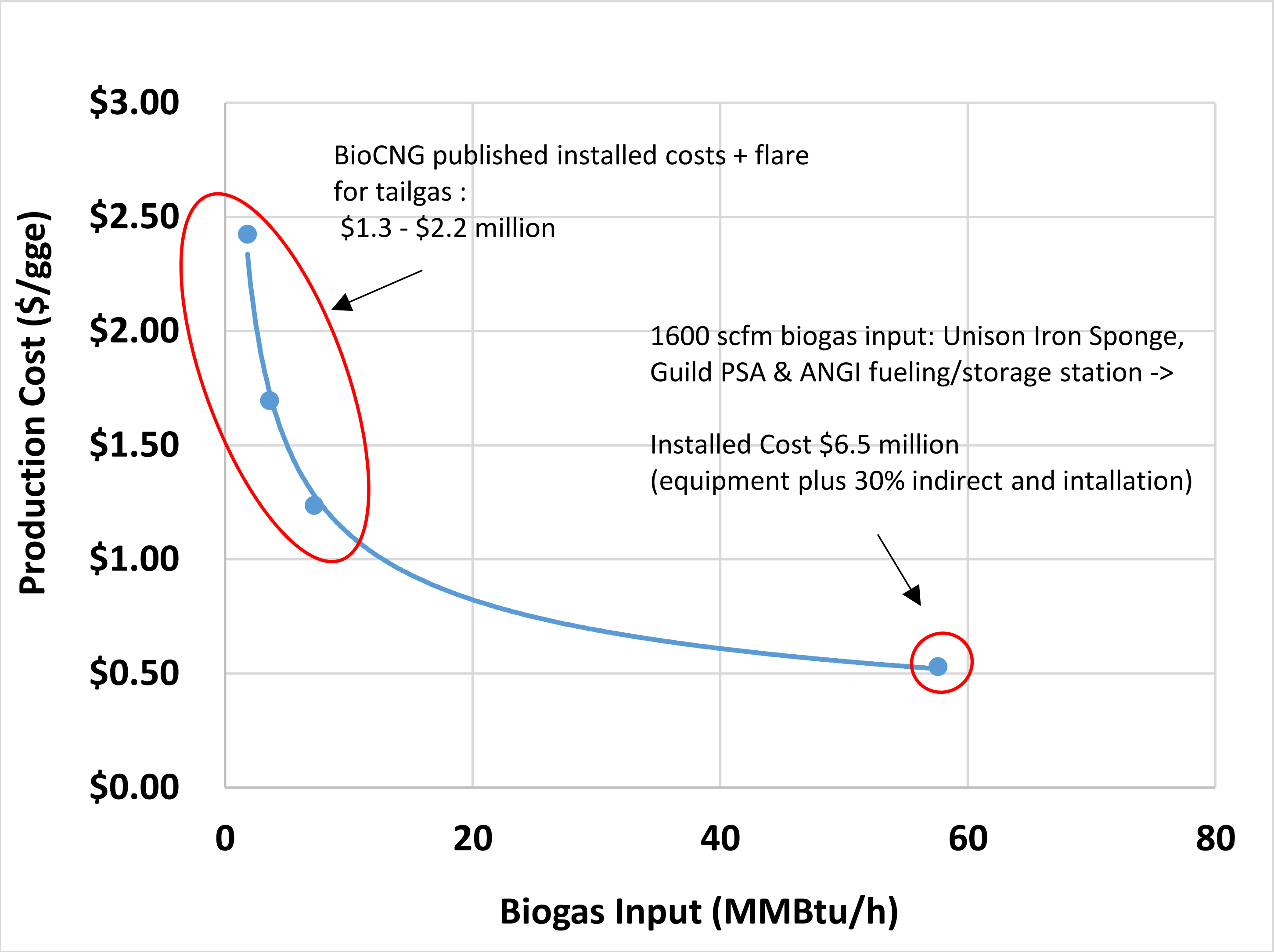
| Input- (scfm biogas)[2] | Fuel Output (GGE/day) | RNG Equipment Cost (MM $) [1] | Flare Cost ($) [3] | Total Capital ($) | Annualized Capital ($/y)[4] | O&M CNG ($/GGE) [1] | CNG O&M ($/y) | O&M (CNG + Flare) ($/y) | $/GGE | $/MMBtu (output) |
|---|---|---|---|---|---|---|---|---|---|---|
| **50** | 240 | 1.2 | 69,800 | 1,270,000 | 111,000 | 1.06 | 88,000 | 91,000 | **$2.42** | $18.30 |
| **100** | 480 | 1.5 | 116,000 | 1,620,000 | 141,000 | 0.82 | 137.000 | 142,000 | **$1.69** | $12.79 |
| **200** | 960 | 2.0 | 192,000 | 2,190,000 | 191,000 | 0.64 | 214,000 | 221,000 | **$1.23** | $9.34 |
| **1600** | 9400 | 6.54 | 511,000 | 7,050,000 | 615,000 | 0.34 | 1,090,000 | 1,110,000 | **$0.53** | $4.02 |

Sources and Notes:

1. Based on BioCNG project sheets, conference presentations, Geosyntec report to Flagstaff Landfill and personal communication, Jay Kemp and Christine Polo, Black and Veatch. 70% methane recovery for single-pass membrane system (BioCNG 50-200 scfm input) and 85% methane recovery for PSA system (1600 scfm input).
2. 60% methane in biogas.
3. Tailgas (methane slip) is flared in this scenario. Added flare capital and operating costs using data from flare scenario.
4. 6% APR, 20-year financing of capital - $0.12/kWh electricity cost.

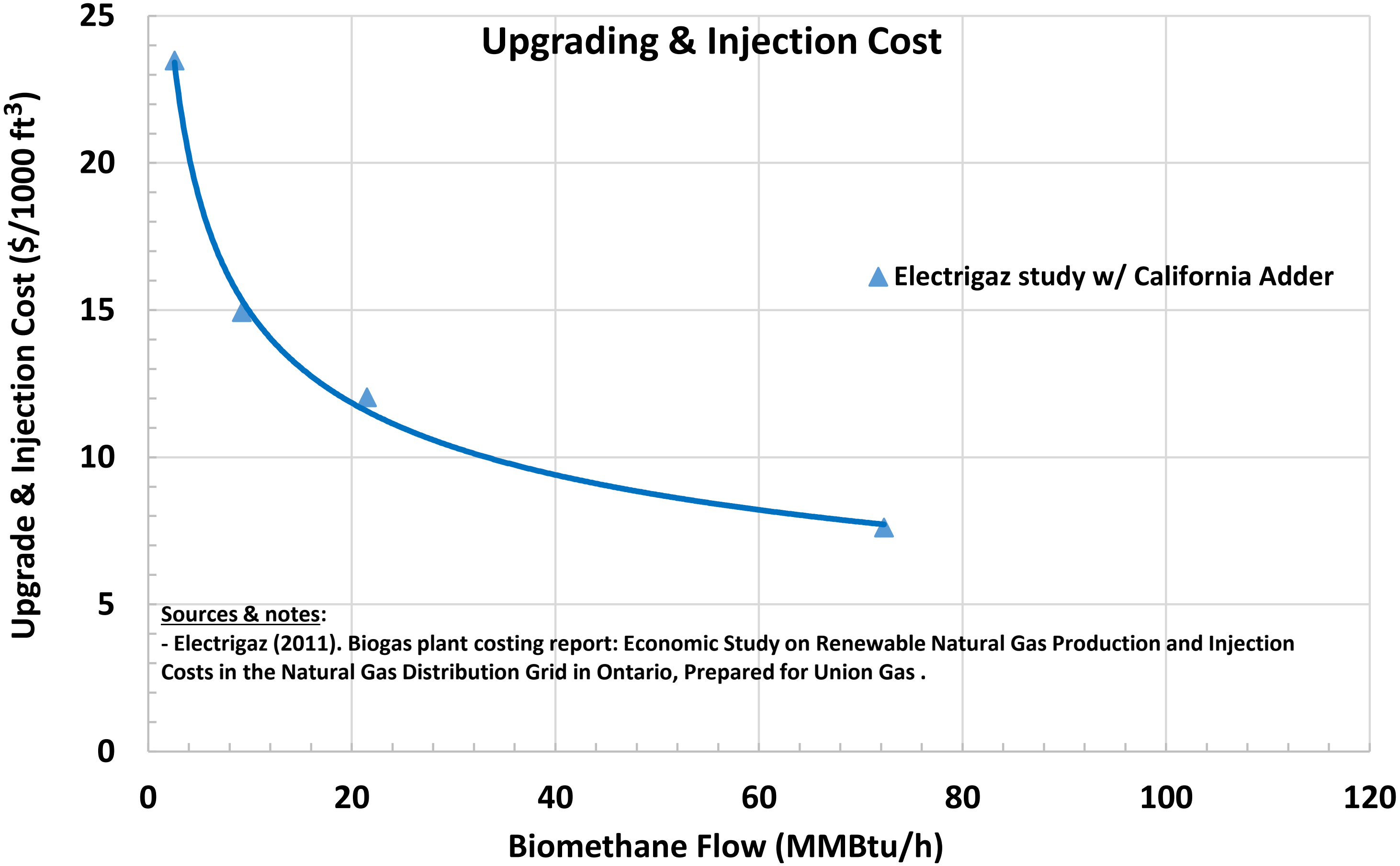
GGE = gallon gasoline equivalent

# RNG/CNG Cost Estimate




GGE = gallon gasoline equivalent

# Upgrading & Injection Cost



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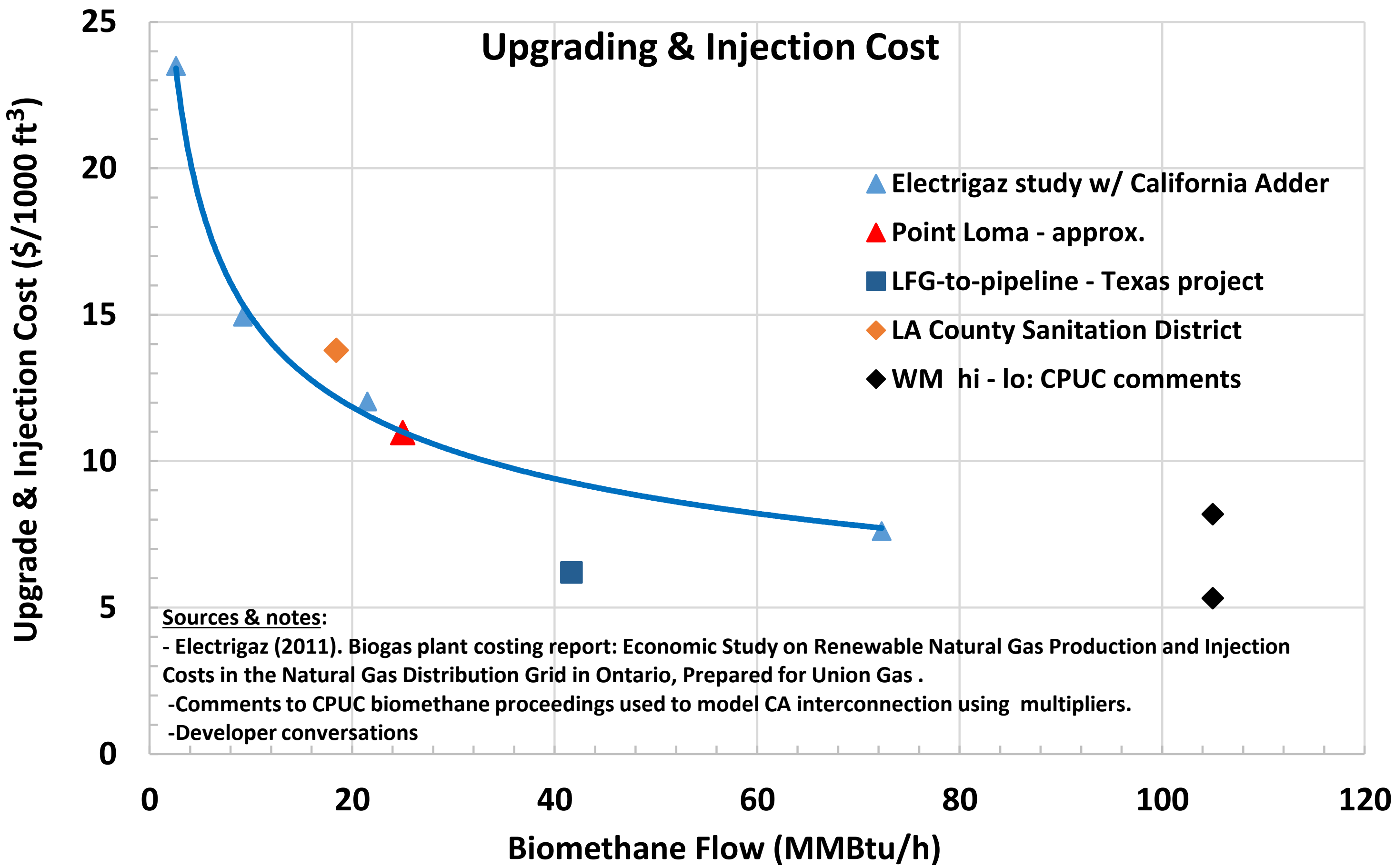
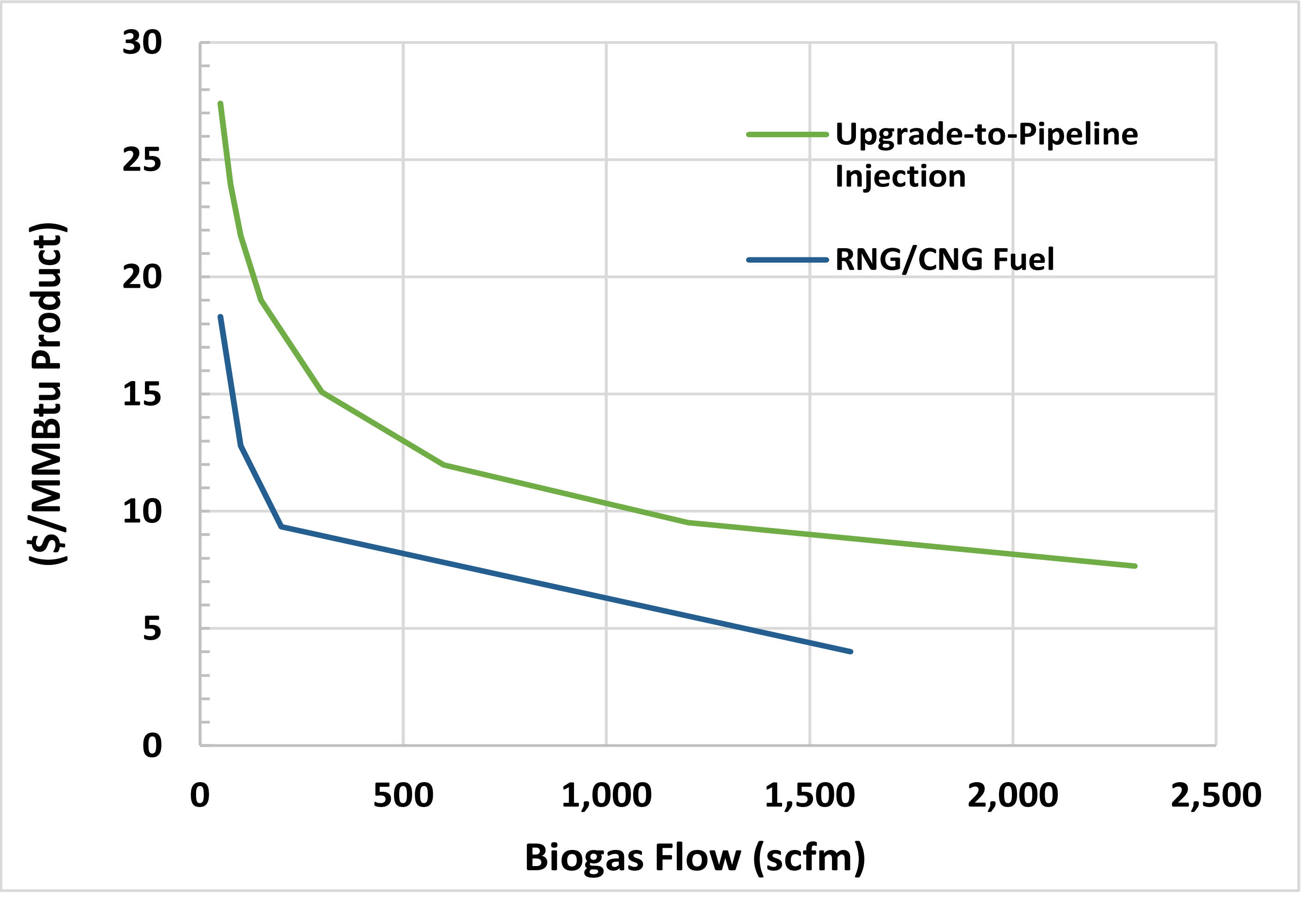
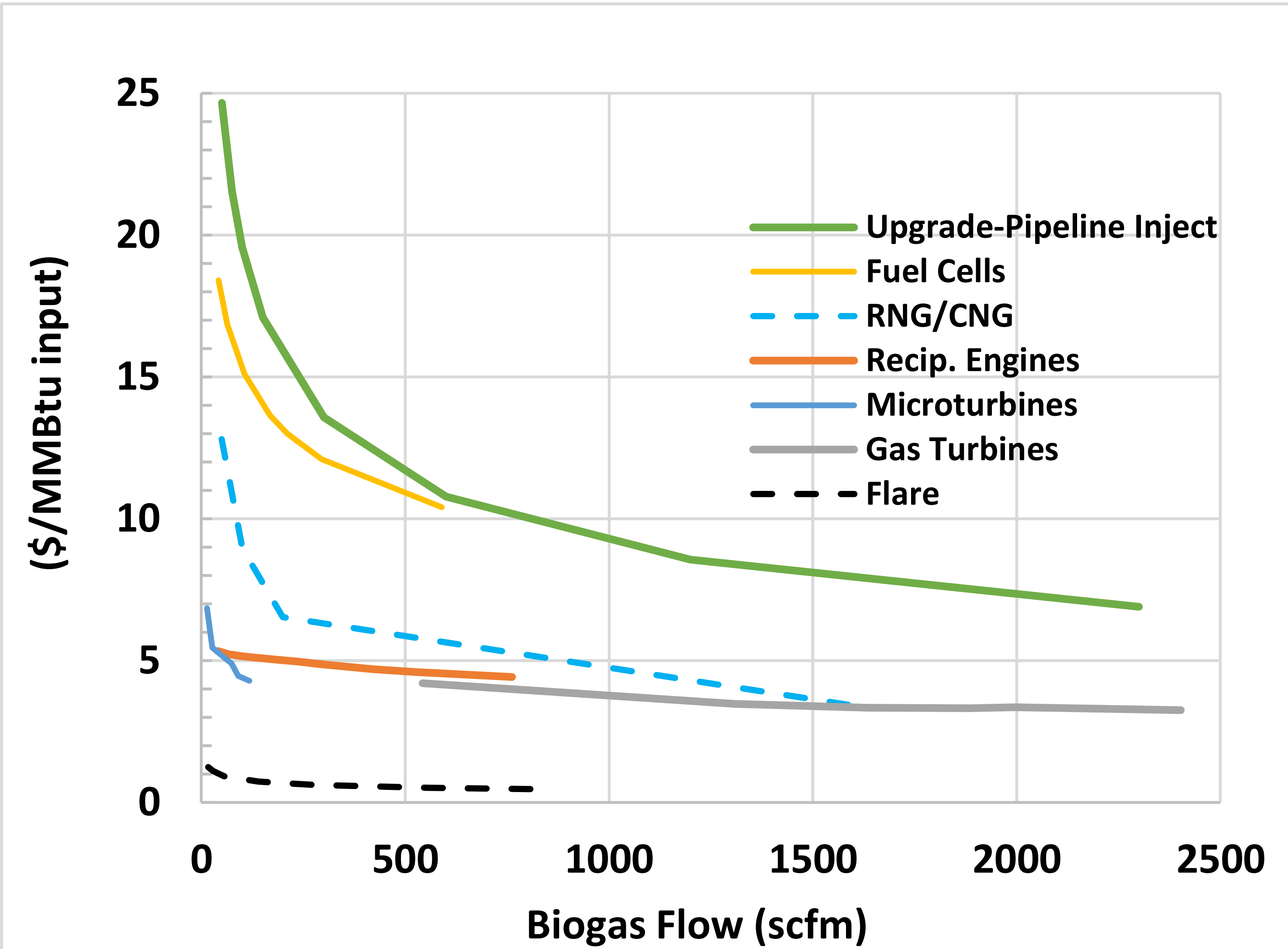


# Pipeline Injection & RNG/CNG



# Cost to process Biogas – All technologies shown



# Criteria Pollutants

- Nitrogen Oxides (NOx), Carbon Monoxide (CO), Volatile Organic Compounds (VOC), Sulphur Oxides (SOx), and Particulate Matter (PM)
- Reviewed a large number of air permits and source tests
- Used 54 source tests to develop some emission factors

| Application* | No. of Source Tests Reviewed | Biogas Source Type | Source Test Air District |
|---|---|---|---|
| **Reciprocating Engine** | 35 | 6 @ Landfill,<br>26 @ WRRF,<br>3 @ Dairy Digester | – South Coast<br>– Bay Area<br>– San Joaquin Valley<br>– Yolo-Solano<br>– Mojave Desert |
| **Microturbine** | 4 | 1 @ WRRF,<br>3 @ Food Waste Digester | – South Coast<br>– Bay Area |
| **Combustion Turbine** | 10 | 5 @ Landfill,<br>5 @ WRRF | – South Coast<br>– Bay Area<br>– San Joaquin Valley |
| **Fuel Cells** | 3 (2 permits) | 3 @ WRRF | – South Coast<br>– San Joaquin Valley |
| **Flare** | 4 | 1 @ Landfill,<br>3 @ WRRF | – South Coast<br>– San Joaquin Valley |

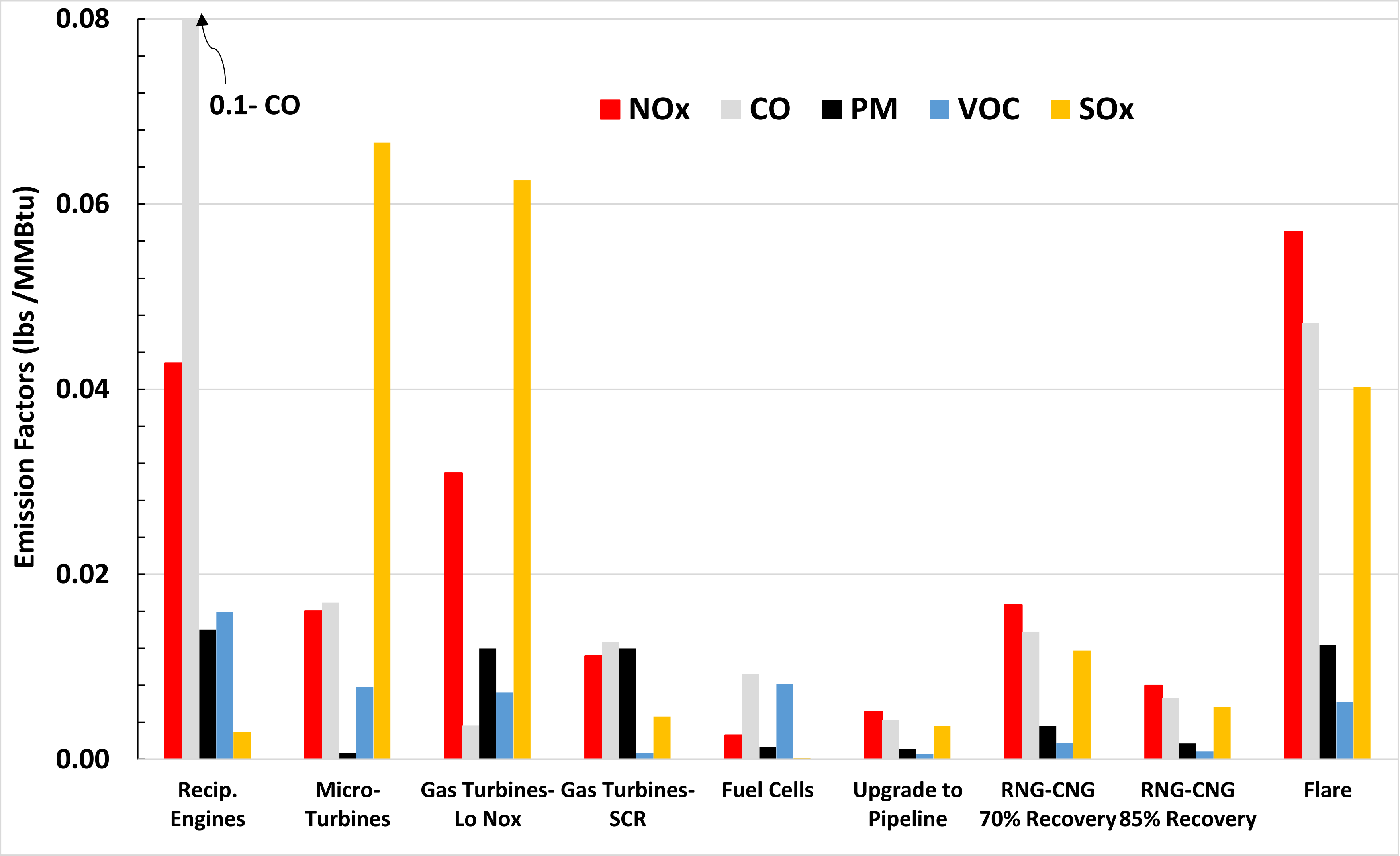
# Criteria Pollutants

- Emission Factors:

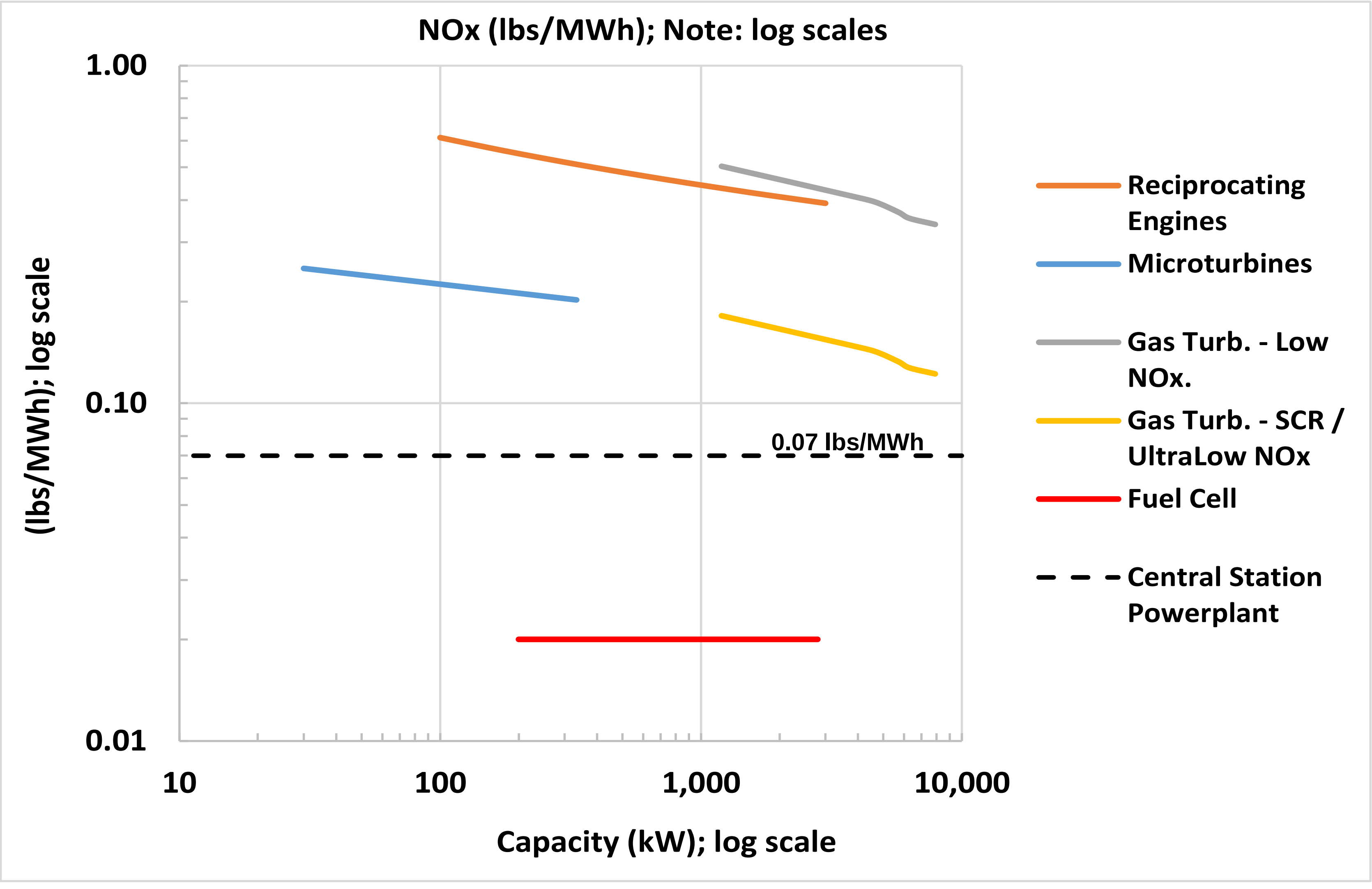
  Pounds of pollutant per MMBtu of biogas **input** (lb/MMBtu)

- Reciprocating Engines
  - NOx: Emission factor is based on the South Coast Air Quality Management District (SCAQMD) Rule 1110.2 (11 ppm NOx)
  - VOC, SOx & CO: Based on source test results with SCR NOx control and catalytic oxidation (CatOx) exhaust treatment
  - PM: From US EPA AP-42
- Microturbines, Combustion Turbines and Flares
  - Source Test Results plus AP-42 for some PM
- Fuel cell emissions are based on permit values and one source test report
- RNG/CNG and Pipeline Quality Gas (Biomethane)
  - Emission factors are based on flaring the tailgas, a process byproduct gas which contains some methane that needs to be destroyed.
  - Downstream emissions from use of biomethane (fuel or pipeline gas) are not included

# Emission Factors by Technology (lbs/MMBtu input)



# Output Based NOx Emissions (lbs/MWh)



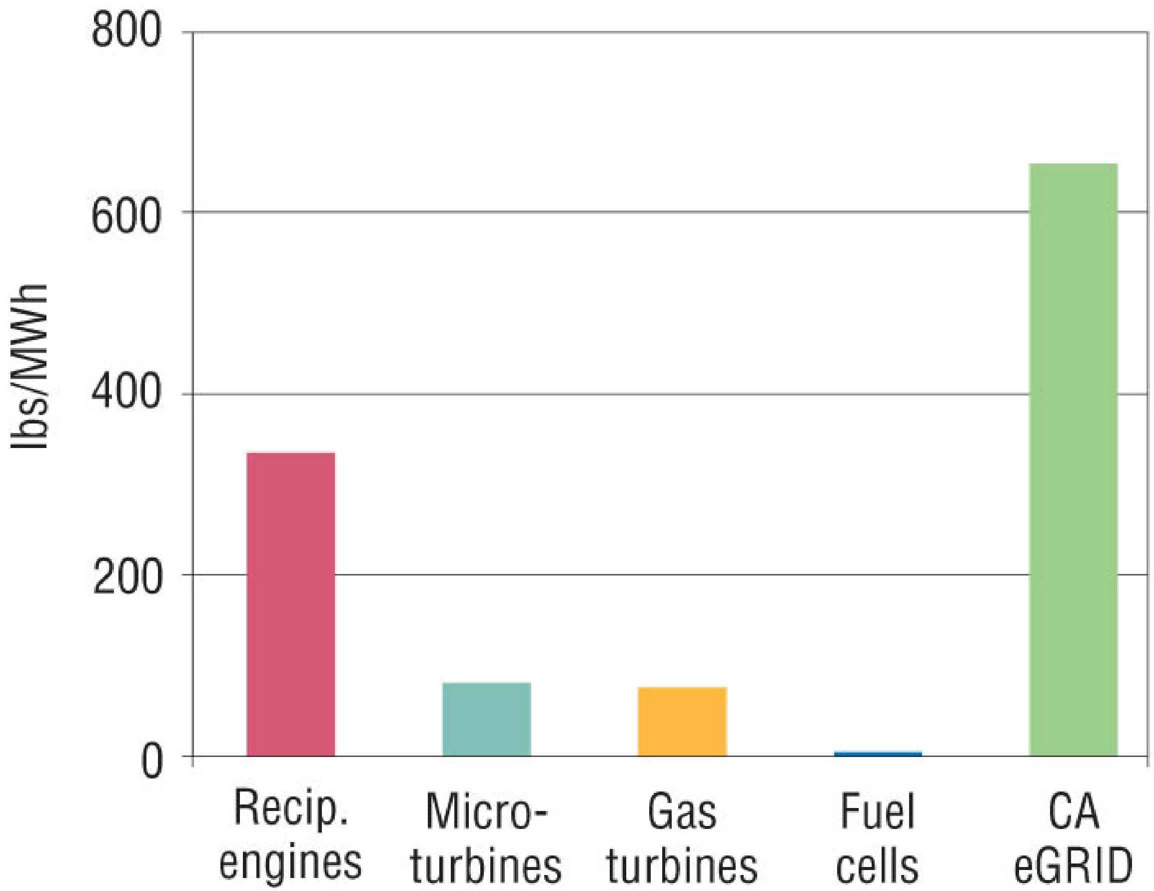
# GHG Emissions

- Evaluated:
  - Methane ($CH_4$)
  - Nitrous Oxide ($N_2O$)
  - Carbon Dioxide ($CO_2$)
- Methane Emissions (methane "Slip" & fugitive)
  - 0.2 – 2.0% Methane Slip (or unburned methane) from combustion devices (engines, gas turbines, flares)
  - 1% Fugitive Methane loss (leaks) from processing & upgrading systems (pipeline injection and RNG/CNG) was assumed (Han, Mintz et al. 2011)
- $N_2O$ emissions are taken from source-specific literature when found or default factors from IPCC Guidelines
- $CO_2$ emissions are calculated based on stoichiometric (or complete) combustion of biogas
  - For biogas with 60% methane content, the $CO_2$ emission factor is 191.3 lb/MMBtu

# GHG Emission Factor Summary

| Technology | GHG Emission Factor (lb/MMBtu) | | | Notes |
|---|---|---|---|---|
| | $CH_4$ | $N_2O$ | $CO_2$ | |
| **Recip. Engines** | 0.838 | 1.92E-03 | 191.3 | Average of SCS (2007) & Mintz (ANL), $N_2O$ & ~ 97.99% $CH_4$ destruction efficiency (2% slip). |
| **Micro-Turbines** | 0.167 | 2.56E-04 | 191.3 | Average SCS (2007) & CAR (2011): $CH_4$ 99.6% destruction efficiency, $N_2O$ Emission Factor from Table 2.2 in 2006 IPCC Guidelines. |
| **Gas Turbines** | 0.167 | 2.56E-04 | 191.3 | Average SCS (2007) & CAR (2011): $CH_4$ 99.6% destruction efficiency, $N_2O$ Emission Factor from Table 2.2 in 2006 IPCC Guidelines. |
| **Fuel Cell** | 0.003 | 2.56E-04 | 191.3 | $CH_4$ & $N_2O$ Emission Factor from 2006 IPCC Guidelines. |
| **Flare** | 0.07 | 2.43E-03 | 191.3 | Mintz et al., (2010) $CH_4$ 99.8% destruction efficiency, $N_2O$ also from Mintz (2010). |
| **RNG/CNG (70% recovery)** | 0.437 | 7.03E-04 | 106.5 | 1% $CH_4$ leakage in upgrade process + flare emissions from tailgas combustion. No vehicle or downstream combustion emissions included. |
| **RNG/CNG (85% recovery)** | 0.427 | 3.40E-04 | 88.3 | |
| **Upgrade-Injection** | 0.436 | 2.18E-04 | 86.1 | |

# $CO_2$eq emissions for the bio-power technologies & CA eGRID




- California electricity grid carbon footprint values (CA eGRID) are from (USEPA 2012)
- Biogenic $CO_2$ emissions are not counted in eGRID (neutral in eGRID)
- Only $CH_4$ and $N_2O$ emissions from biopower are converted to CO2eq here

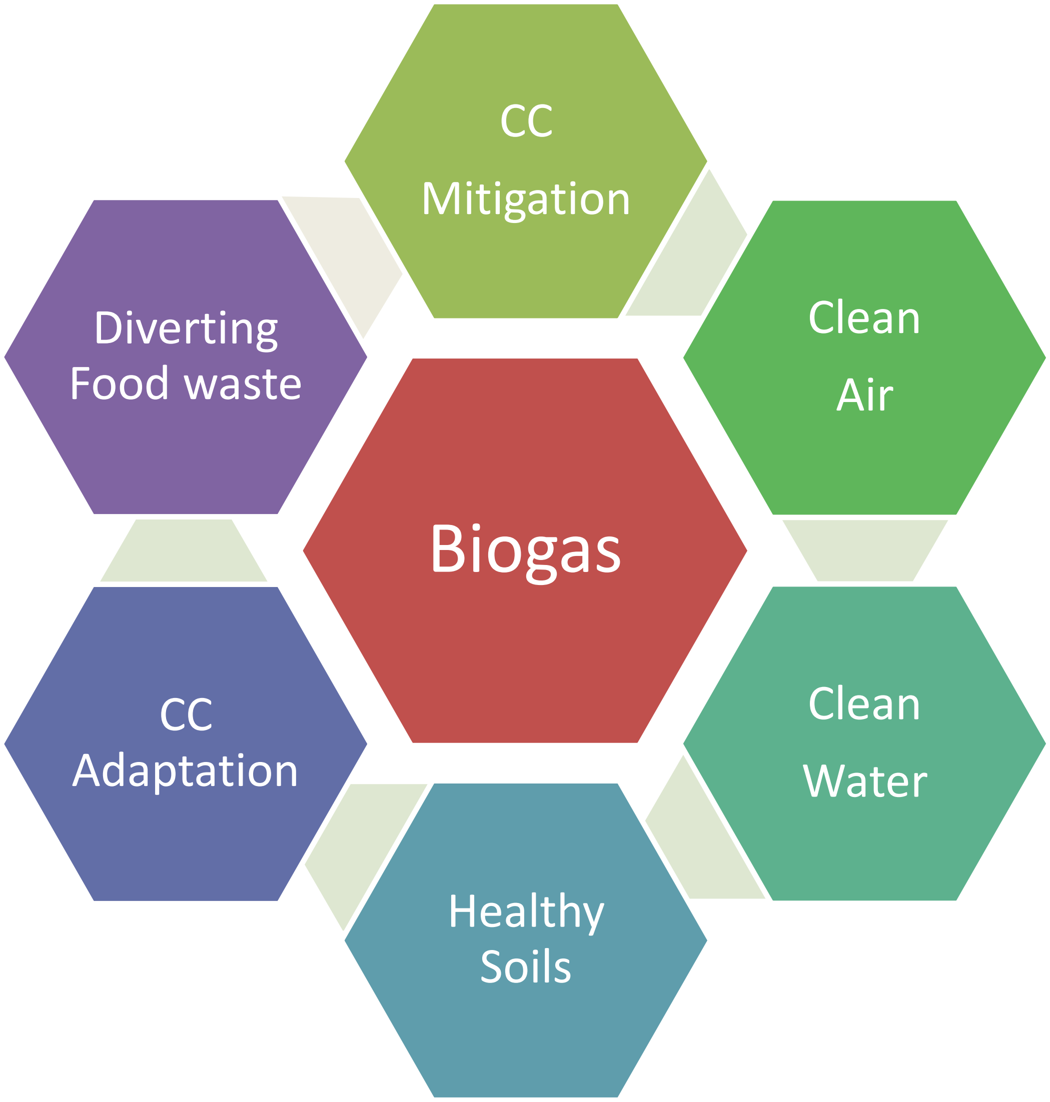
$GWP_{100}$ : $CH_4$ = 34, $N_2O$ = 298, $CO_2$ = 1

# Technology Summary

- Examined seven biogas utilization technologies
- Evaluated and compared
  - Cost and performance
  - Criteria pollutants
  - Greenhouse gas emissions
- See EPA report, EPA/ORD/R-16/099, for details (link not yet available- email Rob Williams for copy : rbwilliams@ucdavis.edu )

# Conclusions

- Additional research needed:
  - Sources of biogas
  - Geography
  - Offsetting costs
  - Net enviro. benefit
- What did we do?
  - Baseline



# Thank you

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