“Garbage to Energy”
Anaerobic Digestion

Much Dirtier than Coal

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Executive Summary

- The Anaerobic Digestion (AD)-fueled "Garbage to Energy" process returns 1.42 metric tons of CO2 to the atmosphere for each MegaWatt-hour (MWh) of energy it delivers
- A coal-burning generator—the benchmark of carbon-dirty energy—releases 0.8 metric tons CO2 per delivered MWh
- AD / Coal CO2 ratio = 1.42/0.8 = 1.77:1
- **The carbon footprint of "Garbage to Energy" is 77% greater than a coal-burning generator**
- The carbon in the biomass fuel for AD "Garbage to Energy" comes from the CO2 nature sequestered from the atmosphere
  - A carbon-smart policy would keep that carbon sequestered
  - Shouldn't Palo Alto be carbon-smart?

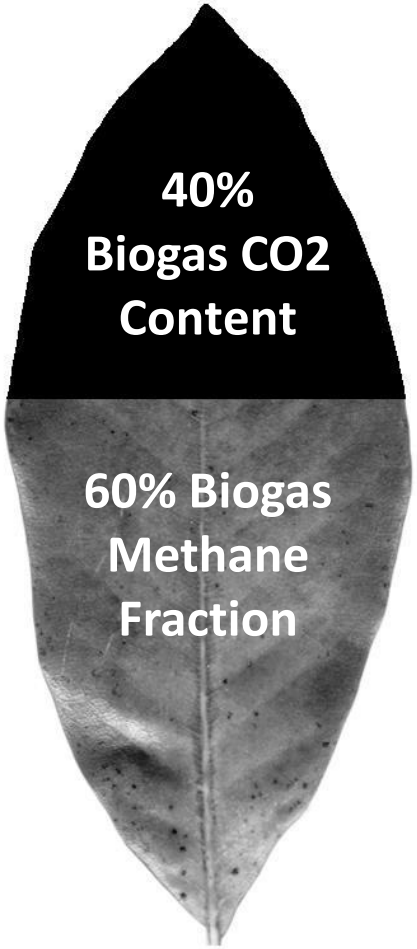
Data Source:
http://www.cityofpaloalto.org/news/displaynews.asp?NewsID=2553&TargetID=65
Follow link: "**C. deLa Beaujardiere Numbers (4-2010)**"

1. Plants Remove CO_2 from the Atmosphere

- This magnolia leaf is made of hydrogen, oxygen, and carbon
- All of that carbon comes from the CO_2 the leaf sequestered from the atmosphere
- An Anaerobic Digestion "Garbage to Energy" electrical generator would return much of this CO_2 to the atmosphere
  - for a tiny energy return
  - at a major financial cost
  - with a huge per-kWh carbon footprint
- Why would anybody want to do that?

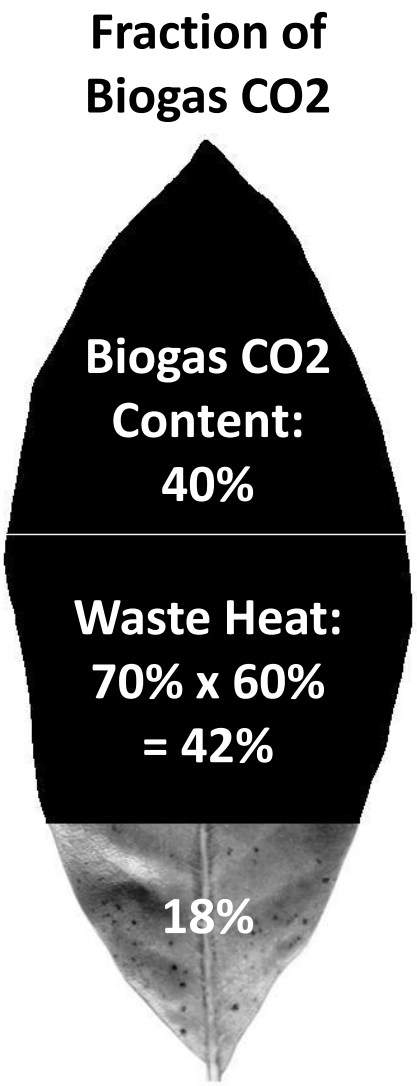
I use a leaf as a visualization aid for aesthetic reasons. The discussion and conclusions apply to any AD feedstock: sludge, food scraps, …

2. Make Biogas, Release 40% as CO2



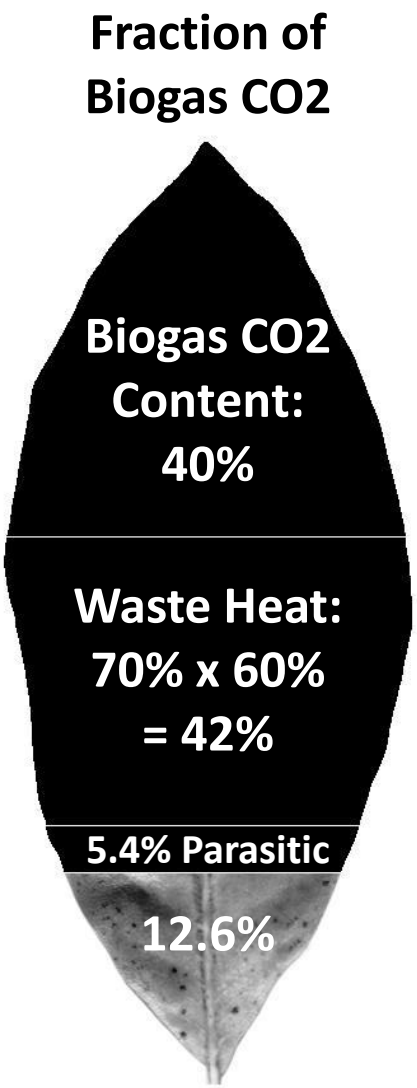
- The AD process converts the feedstock to biogas
- On average, that biogas consists of
  - Methane: 60%
  - Carbon dioxide: 40%
- The carbon dioxide yields zero energy
  - It is returned directly to the atmosphere
- Cum score:
  - Sequestered carbon returned to the atmosphere as CO2: 40%
  - Saleable energy delivered so far: Zero

3. Burn the Usable Biogas, Lose 70%



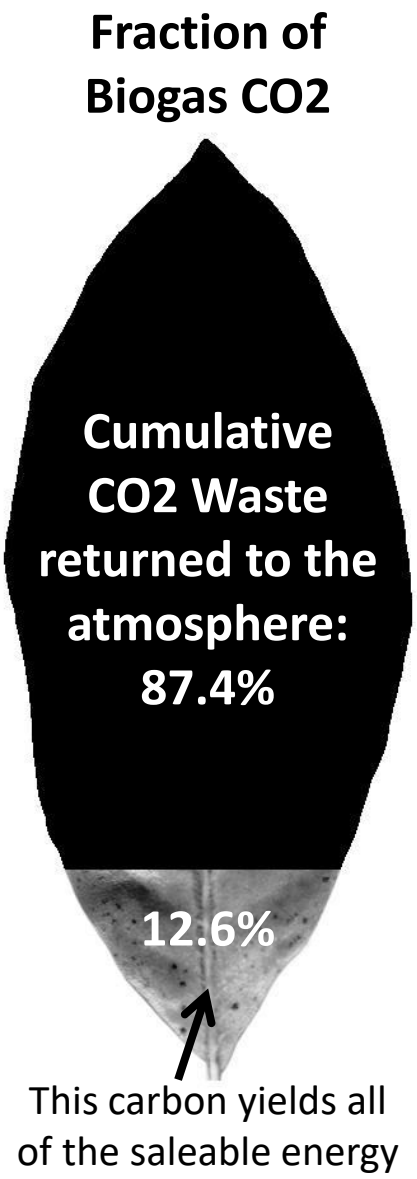
- Burn the biogas methane to H_2O & CO_2
- That yields heat energy…
  - which powers a motor…
  - that drives an electric generator
- But, per the laws of thermodynamics, 70% of that heat energy is lost as "waste heat"
  - That's also why your car's engine needs a radiator
- The unmasked leaf area shows the 60% x 30% = 18% carbon fraction that produces electrical energy
- Cum score:
  - Plant-sequestered carbon returned to the atmosphere as CO_2: 82%
  - Saleable energy delivered so far : Zero

4. Pay 30% Operating Tax



- Thirty percent of the generated electrical energy is spent upfront to power the "Garbage to Energy" operation
  - e.g., pumps, blowers, compressors, lights
  - Trade term: "parasitic load"
- Associated carbon release: 30% x 18% = 5.4%
- Cum score:
  - Sequestered carbon returned to the atmosphere as CO2: 40% + 42% + 5.4% = 87.4%
  - Saleable energy delivered so far : Zero

5. Deliver Energy to Users



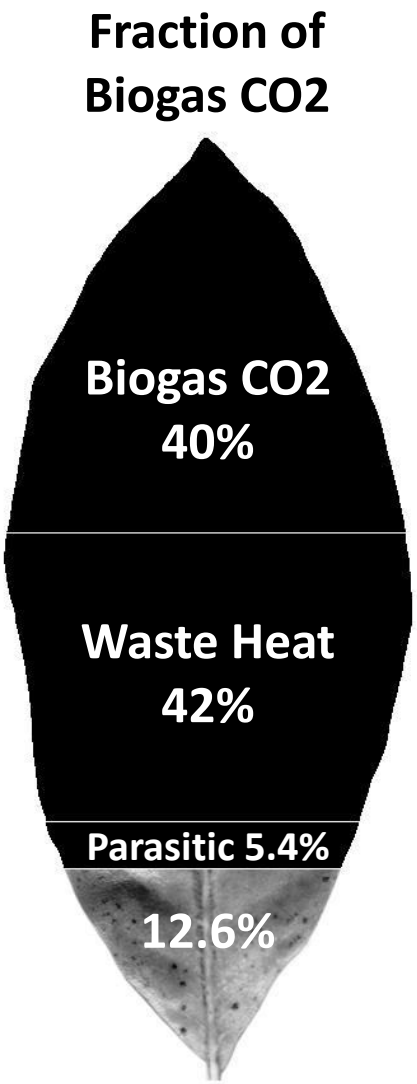
- Fraction of the feedstock carbon that delivers "Garbage to Energy" electricity to users: 100% - 87.4% = 12.6%

  Fraction for a coal-fired generator: ~30%

  Final score:
  - Sequestered CO_2 returned to the atmosphere: 100%
  - Sequestered CO_2 returned unproductively: 87.4%
  - CO_2 per AD-generated MWh delivered: 1.42 metric tons
    - Details on following slide
  - CO_2 per coal-fired MWh delivered: 0.8 metric tons
  - **CO_2 ratio: AD "G2E" / Coal = 1.42/0.8 = 1.77**

Bottom Line: The carbon footprint of an AD-fueled generator is 77% greater than the carbon footprint of a coal-burning generator

6. CO2 vs. Energy Accounting



- Burning one cubic meter of biogas methane yields:
  - **10.35 kWh thermal** energy
  - **1.85 kg CO2**
  - CO2/energy ratio: **0.18 kgCO2/kWh**
- Account for the 40% CO2 content of raw biogas
  - Solve: *Methane-produced CO2 = (1 – 0.4) Total CO2*
  - Net CO2/energy ratio: 0.18/0.6 = **0.30 kgCO2/kWh**
  - Corresponding thermal energy/CO2 ratio: **3.36 kWh/kgCO2**
- Account for 30% thermodynamic efficiency
  - Electrical energy yield: 3.36 x 30% = **1.01 kWh/kgCO2**
- Account for 70% yield after 30% parasitic load
  - Salable electrical energy yield: 0.96 x 70% = **0.70 kWh/kgCO2**
- Ratio, AD to coal CO2
  - AD CO2: 1/0.70 = 1.42 kgCO2/kWh = **1.42 mTCO2/MWh**
  - 1.49/0.8 mTCO2/MWh coal generator = **1.77**

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Graphic Summary
of AD Carbon Utilization
- Per Salable MWh

40%: Biogas CO_2 Fraction — 0.57 mT* CO2

42%: Waste Heat — 0.59 mT CO2

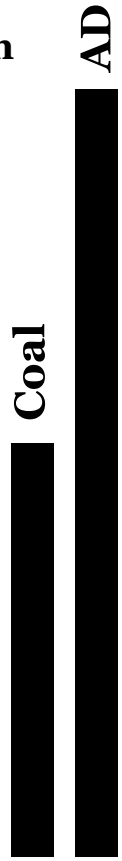
5.4%: Parasitic Load — 0.08 mT CO2

12.6%: Net Energy Yield — 0.18 mT CO2

Total CO2 per AD MWh delivered: 1.42 mT

CO2 per coal generated MWh: 0.80 mT

AD to Coal CO2 ratio: 1.77



* mT = metric ton = 2,200 lbs

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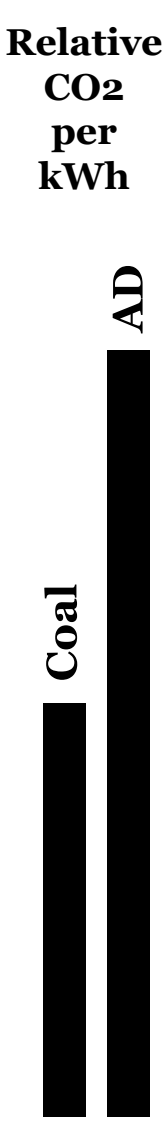
Takeaways

- All the carbon in the biomass that fuels an Anaerobic Digestion "Garbage to Energy" electrical generator comes from the CO2 that plants sequestered from the atmosphere
- An AD-fueled generator returns much of that CO2 to the atmosphere
  - for a small energy return
  - at a major financial cost
  - with a huge per-kWh carbon footprint
- Per unit of energy delivered, the AD process has 177% the carbon footprint of a coal-fired generator—the benchmark of carbon-dirty energy
- A truly carbon-smart policy would keep the sequestered carbon sequestered
- Shouldn't Palo Alto adopt one?



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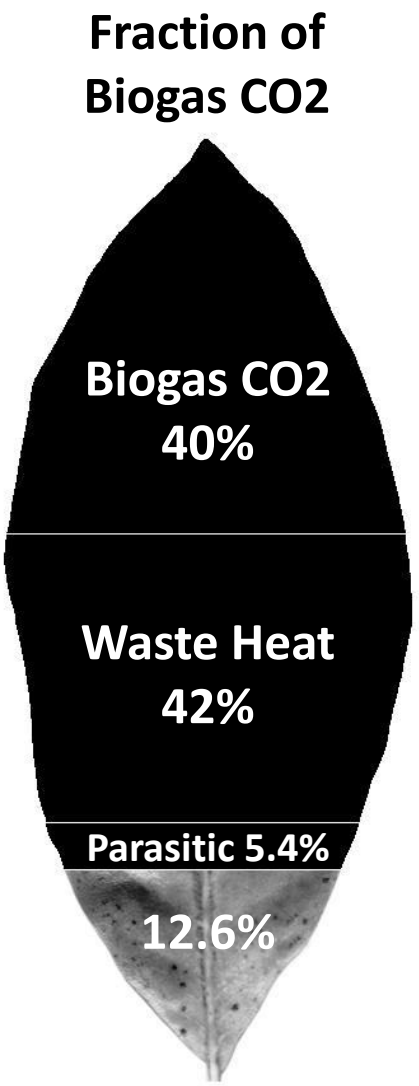
EIA - Based CO2 vs. Energy Accounting



- Burning a cubic meter of biogas methane yields:
  - **10.45 kWh thermal** energy
  - **1.96 kg CO2**
  - CO2/energy ratio: **0.19 kgCO2/kWh**
- Account for the 40% CO2 content of raw biogas
  - Solve: Methane-produced CO2 = (1 – 0.4) Total CO2
  - Net CO2/energy ratio: 0.19/0.6 = **0.31 kgCO2/kWh**
  - Corresponding thermal energy/CO2 ratio: **3.20 kWh/kgCO2**
- Account for 30% thermodynamic efficiency
  - Electrical energy yield: 3.20 x 30% = **0.96 kWh/kgCO2**
- Account for 70% yield after 30% parasitic load
  - Salable electrical energy yield: 0.96 x 70% = **0.67 kWh/kgCO2**
- Ratio, AD to coal CO2
  - AD CO2: 1/0.67 = 1.49 kgCO2/kWh = 1.49 mTCO2/MWh
  - 1.49/1.00 mTCO2/MWh coal generator = **1.49**

Data Source: EIA
https://www.eia.gov/tools/faqs

Graphic Summary
of AD Carbon Utilization
- Per Salable MWh

EIA Data

40%: Biogas CO_2 Fraction — 0.58 mT* CO2

42%: Waste Heat — 0.60 mT CO2

5.4%: Parasitic Load — 0.08 mT CO2

12.6%: Net Energy Yield — 0.18 mT CO2

Total CO2 per AD MWh delivered: 1.44 mT

CO2 per coal-generated MWh: 1.00 mT

AD to Coal CO2 ratio: 1.44

* mT = metric ton = 2,200 lbs

Data Source: EIA
https://www.eia.gov/tools/faqs