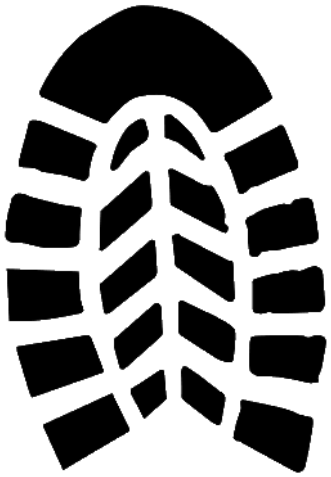
Coal

Anaerobic Digestion Power

"Garbage to Energy"

Is Dirtier than Coal



AD

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Electrical Engineer

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Why desequester carbon to make seriously dirty electricity?

Key Takeaways

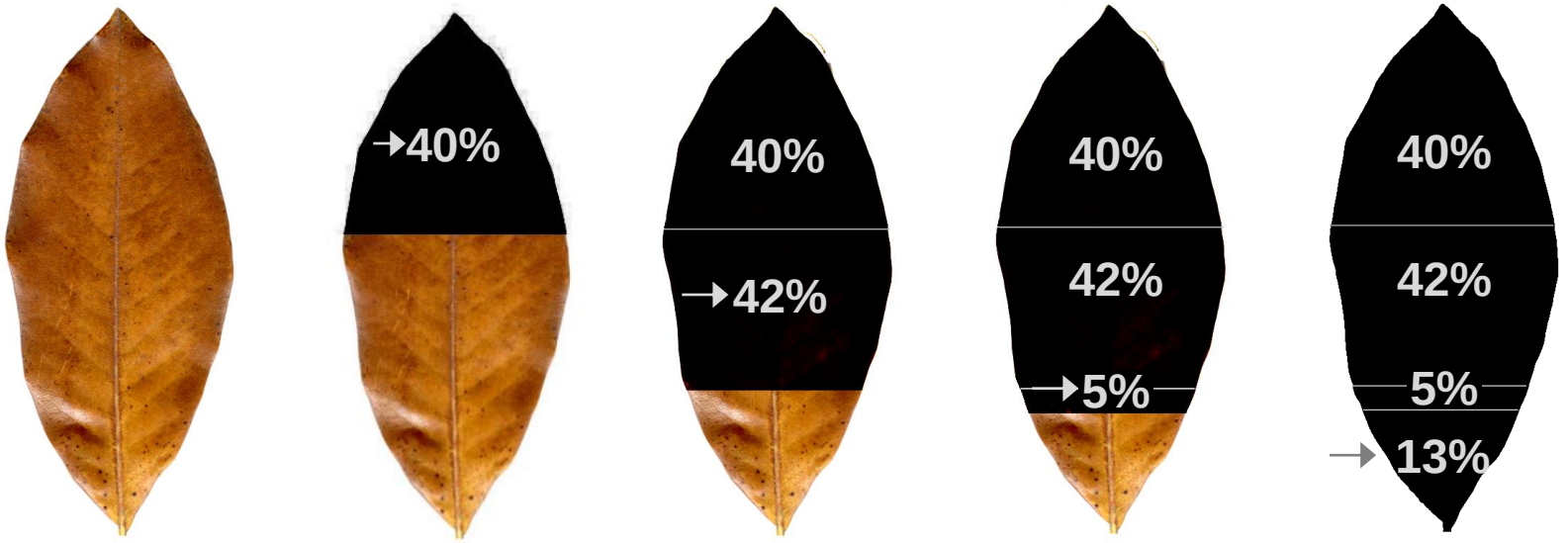
- Using biogas to generate electricity is an extravagantly carbon-dirty process
- If an irremediable biogas source exists, such as a landfill, then the carbon damage is inevitable, and electricity is a fortunate byproduct
- **But creating biogas to generate electricity, as in an anaerobic digestion plant, is an unjustifiably carbon-dirty option**

In a Nutshell

- To counter climate change we need to remove CO2 from the atmosphere
- Plants remove CO2 and sequester it in their fruits and detritus
- Anaerobic digestion fueled “Garbage to Energy” operations return much of that CO2 to the atmosphere to generate electric power
- The net electric energy yield from releasing that carbon is so small that it is cleaner to generate that energy by burning coal
- In fact, **the carbon footprint of an AD electric generator is much larger than that of a coal-burning generator**, the benchmark of grungy energy
- “Garbage to Energy” is not green energy
- Let’s help our planet heal. Keep sequestered carbon sequestered

Captured Carbon to Dirty Energy

Step by Step



Captured Carbon

Released Biogas CO2

Generator Waste Heat

On-Site Overhead

13% (1/8) of CO2 Yields Salable Energy

The accounting, numbers, and data sources are given on the following pages

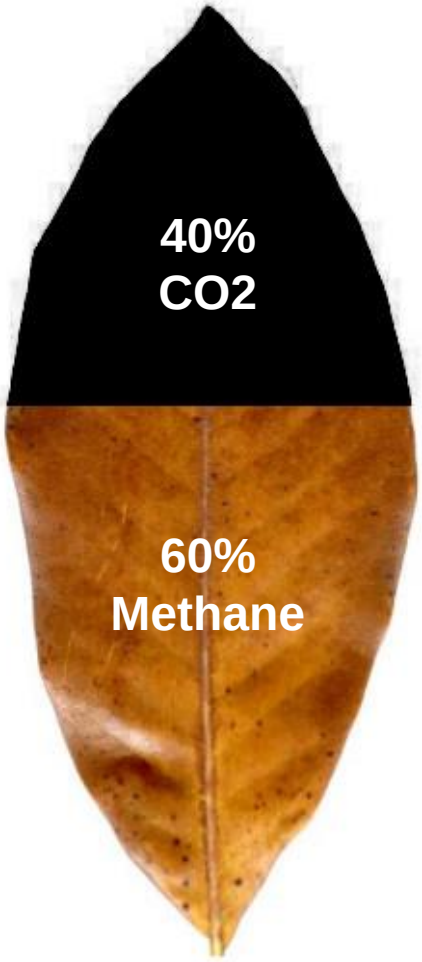
1. Plants Remove CO2 from the Atmosphere

- This magnolia leaf is made of hydrogen, oxygen, and **carbon**
- All of that carbon comes from the CO2 the leaf sequestered from the atmosphere
- An Anaerobic Digestion fueled "Garbage to Energy" electrical generator returns much of this CO2 to the atmosphere
  - for a tiny energy return
  - at a major financial cost
  - with a huge carbon footprint
- Follow along to learn why only one-eighth of that released CO2 is utilized productively

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

2. Make Biogas, Release 40% CO2

Typical Biogas Composition

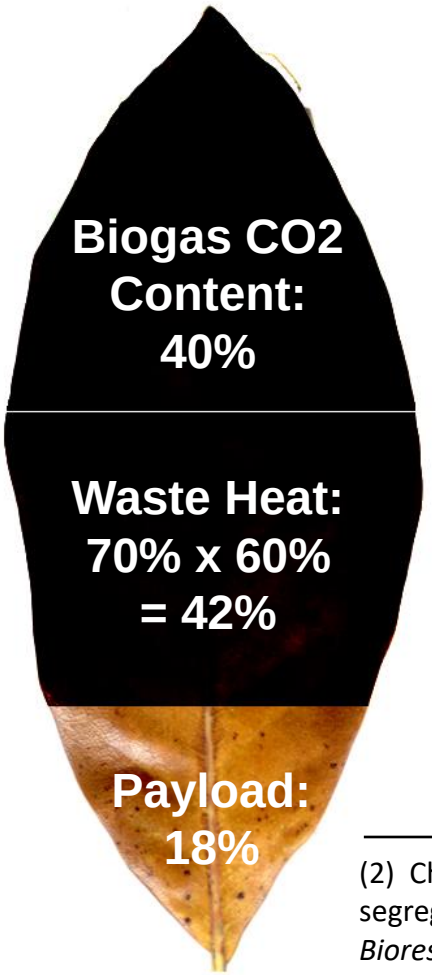


- The anerobic digestion process makes biogas from biogenic materials
- On average, by volume that biogas consists of (1)
  - Methane: 60%
  - Carbon dioxide: 40%
- The carbon dioxide yields zero energy
  - It is just released directly to the atmosphere
- Cumulative score:
  - **Biogas carbon fraction returned to the atmosphere as CO2: 40%**
  - **Salable energy delivered: Zero**

(1) http://www.sgc.se/ckfinder/userfiles/files/BasicDataonBiogas2012.pdf

3. Lose 70% of the Biogas Energy

Biogas CO2 Disposition



- Burn the biogas methane to H2O & CO2
- That yields heat energy…
  - which powers a motor…
  - that drives an electric generator
- But, per the laws of thermodynamics, about 70% of that energy is lost as "waste heat" (2)
- The unblacked "payload" leaf area shows the remaining 100% - (40% +42%) = 18% fraction of carbon that actually produces electrical energy
- Cumulative score:
  - **Biogas carbon returned to the atmosphere as CO2: 40% + 42% = 82%**
  - **Salable energy delivered: Zero**

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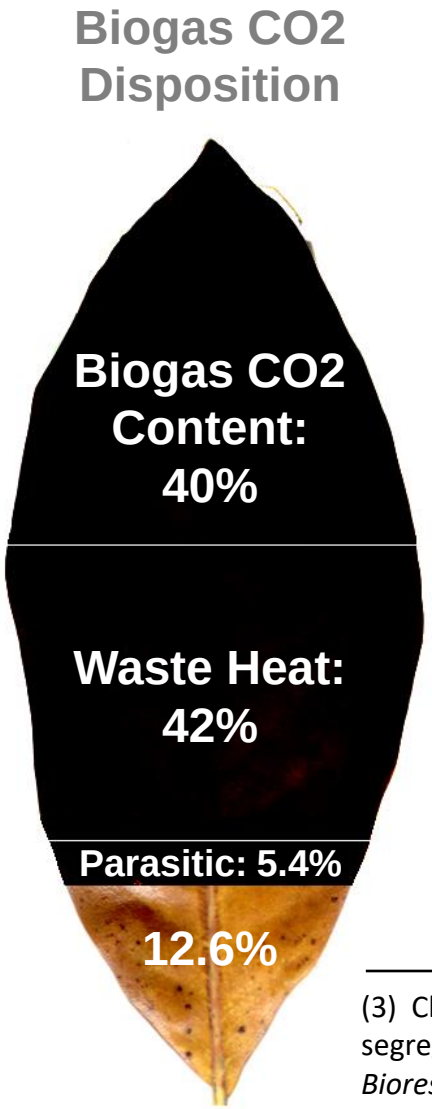
(2) Charles J. Banks, Michael Chesshire, Sonia Heaven, Rebecca Arnold, Anaerobic digestion of source-segregated domestic food waste: Performance assessment by mass and energy balance, Table 4, *Bioresource Technology, Volume 102*, Issue 2, January 2011, Pages 612-620, ISSN 0960-8524, 10.1016/j.biortech.2010.08.005. (http://www.sciencedirect.com/science/article/pii/S0960852410013404)

4. Pay 30% Overhead



- About 30% of the generated electrical energy is spent on site to power the "Garbage to Energy" operation [3]
  - e.g., grinders, pumps, agitators, compressors
  - Trade term: "Parasitic Load"
- Associated CO2 fraction: 30% x 18% = 5.4%
  - (18% = fraction of carbon that generates electricity. See prior slide)
- Cumulative score:
  - **Biogas carbon returned to the atmosphere as CO2 so far: 40% + 42% + 5.4% = 87.4%**
  - **Salable energy delivered: Zero**

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(3) Charles J. Banks, Michael Chesshire, Sonia Heaven, Rebecca Arnold, Anaerobic digestion of source-segregated domestic food waste: Performance assessment by mass and energy balance, Table 5, *Bioresource Technology, Volume 102*, Issue 2, January 2011, Pages 612-620, ISSN 0960-8524, 10.1016/j.biortech.2010.08.005. (http://www.sciencedirect.com/science/article/pii/S0960852410013404)

5. Deliver Energy to Users

Biogas CO2 Disposition

Fraction of biogas carbon that delivers "Garbage to Energy" electricity to users: 12.6% (1/8)

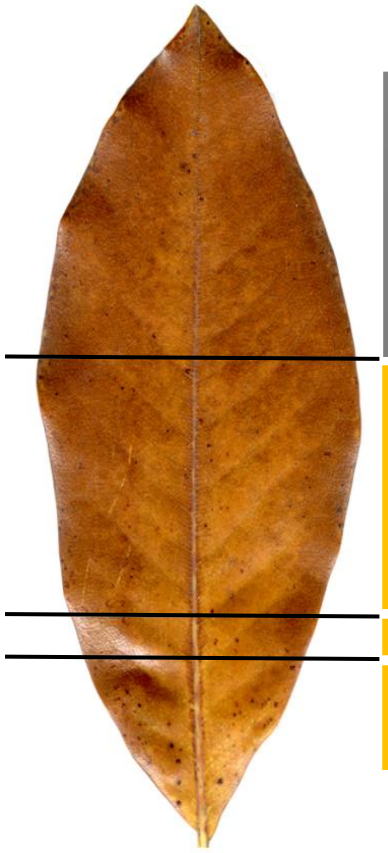
Final score:

- Biogas CO2 returned to the atmosphere: **100%**
- Biogas CO2 spent unproductively: **87.4%**
- CO2 per AD MWh delivered: **1.41 metric tons**
  - As derived on following page
- CO2 per coal-fired MWh delivered: **1.01 metric tons** (4)
- AD:coal carbon footprint ratio: **1.41/1.01 = 1.40**

Bottom Line: The carbon footprint of an AD biogas-fueled generator is 40% greater than the carbon footprint of a coal-fired generator

(4) https://www.eia.gov/tools/faqs/faq.php?id=74&t=11

Graphic Summary
of Carbon Disposition
Per Salable MWh



40%: Biogas CO_2 Fraction — 0.56 mT* CO2

42%: Waste Heat — 0.59 mT CO2

5.4%: Parasitic Load — 0.08 mT CO2

12.6%: Salable Energy — 0.18 mT CO2

Total CO2 per AD MWh delivered: 1.41 mT

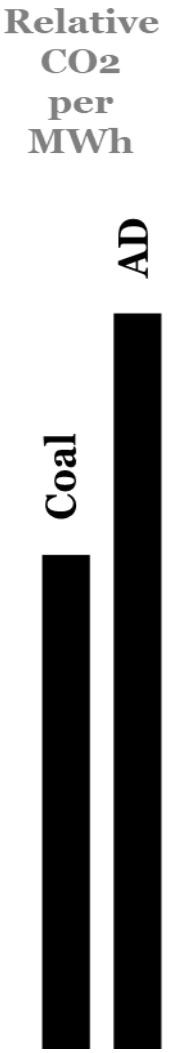
CO2 per coal-generated MWh: 1.01 mT

AD to Coal CO2 ratio: 1.40

* mT = metric ton = 2,201 lbs

CO2 per Net Energy: The Numbers

- Burning one cubic meter of common 60/40 biogas yields:
  - **1.964 kg CO2** total:
    - **1.179 kg CO2** from 60% methane fraction
    - **0.785 kg CO2** from 40% CO2 fraction (1)
  - **6.624 kWhT** thermal energy (5)
- Generate electricity at 30% thermal efficiency: (2)
  - Electrical energy yield: 6.624 kWhT x 0.3 = **1.987 kWh**
- Subtract 30% parasitic load: (3)
  - Salable electrical energy yield: 1.987 x (1.0 - 0.3) = **1.391 kWh**
- Ratio of CO2 to salable energy (the carbon footprint):
  - 1.964 kg CO2 / 1.391 kWh = **1.412 kg CO2 / kWh**
  - Which is also **1.412 mT CO2 / MWh**
- Comparing AD to coal:
  - Coal footprint: **1.01 mT CO2 / MWh** (4)
  - AD/coal ratio: 1.412 / 1.01 = **1.40**



(4) https://www.eia.gov/tools/faqs/faq.php?id=74&t=11
(5) https://webbook.nist.gov/cgi/cbook.cgi?ID=C74828&Mask=1

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(4) https://www.eia.gov/tools/faqs/faq.php?id=73&t=11

(5) https://webbook.nist.gov/cgi/cbook.cgi?ID=C74828&Mask=1