

Anaerobic Digestion Electric Power

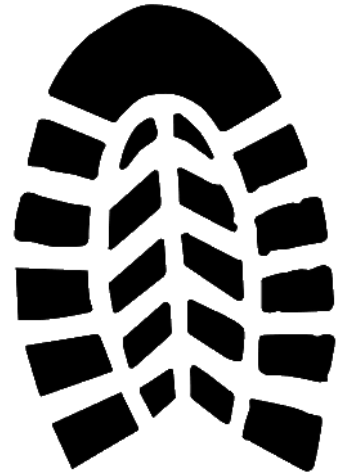
“Garbage to Energy”

Is Dirtier Than Coal

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Electrical Engineer



Coal



AD

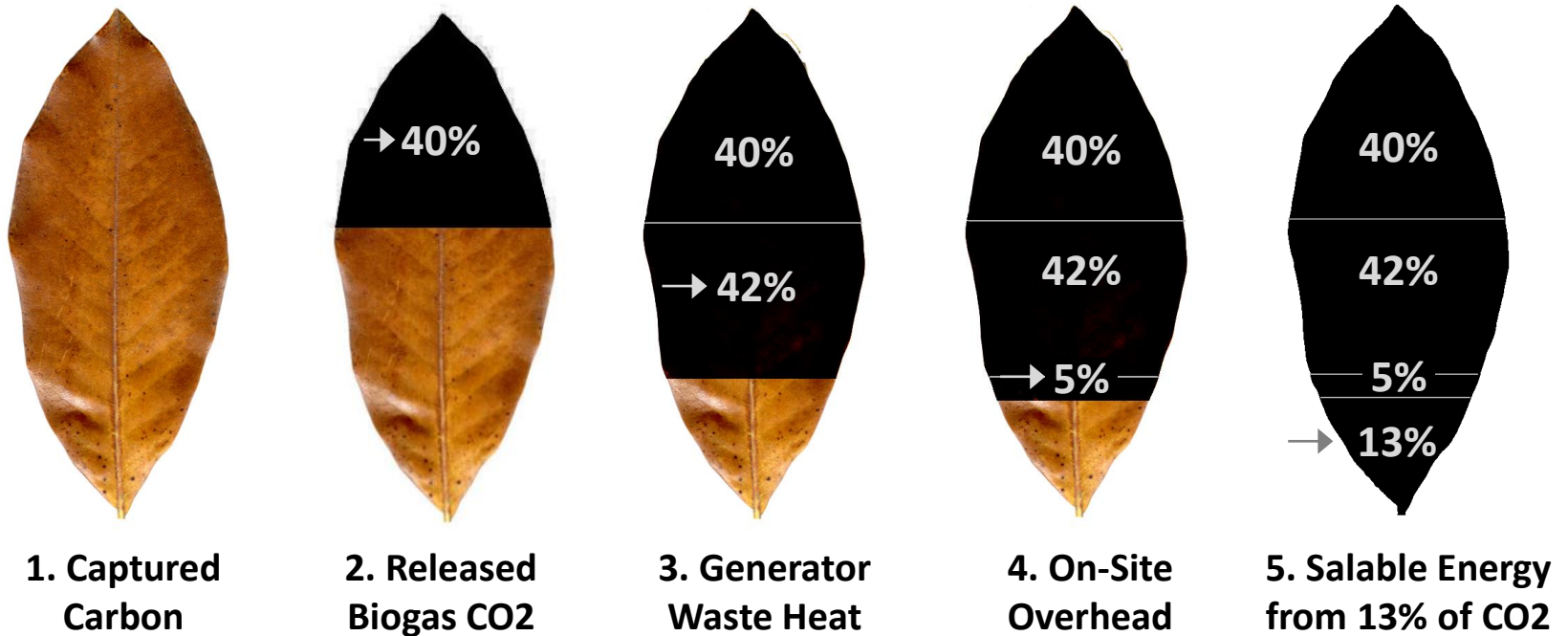
Why de-sequester carbon to make seriously dirty electricity?

In a Nutshell

- To counter climate change, we need to remove CO₂ from the atmosphere
- Green plants remove CO₂ and sequester it in their fruits and detritus
- Anaerobic digestion (AD) fueled “Garbage to Energy” operations return much of that CO₂ to the atmosphere to generate electric power
- The carbon footprint of an AD electric power generator is much larger than that of a coal-burning generator, the benchmark of grungy energy
- “Garbage to Energy” is not carbon neutral. Like coal-fired power, it releases sequestered carbon to make extravagantly dirty electricity
- Let’s help our planet heal. Keep sequestered carbon sequestered

Captured Carbon to Dirty Energy

Step by Step



Details on following pages

Data Sources

<https://webbook.nist.gov/cgi/cbook.cgi?ID=C74828&Mask=1>

<https://www.eia.gov/tools/faqs/faq.php?id=73&t=11>

<http://www.cityofpaloalto.org/news/displaynews.asp?NewsID=2553&TargetID=65>

Follow link: "C. deLa Beaujardiere Numbers (4-2010)"

1. Plants Remove CO₂ from the Atmosphere

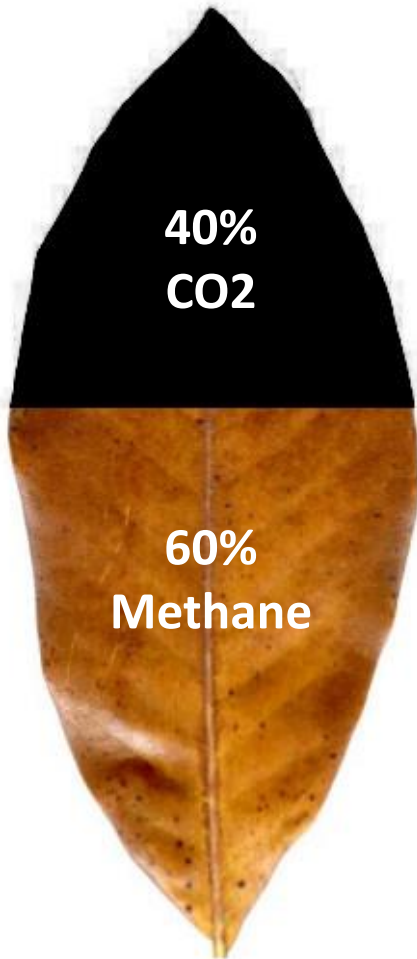


- This magnolia leaf is made of hydrogen, oxygen, and **carbon**
- All of that carbon comes from the CO₂ the leaf sequestered from the atmosphere
- An Anaerobic Digestion fueled “Garbage to Energy” electrical generator returns much of this CO₂ to the atmosphere
 - for a tiny energy return
 - at a major financial cost
 - with a huge carbon footprint
- Follow along and learn why only 1/8 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

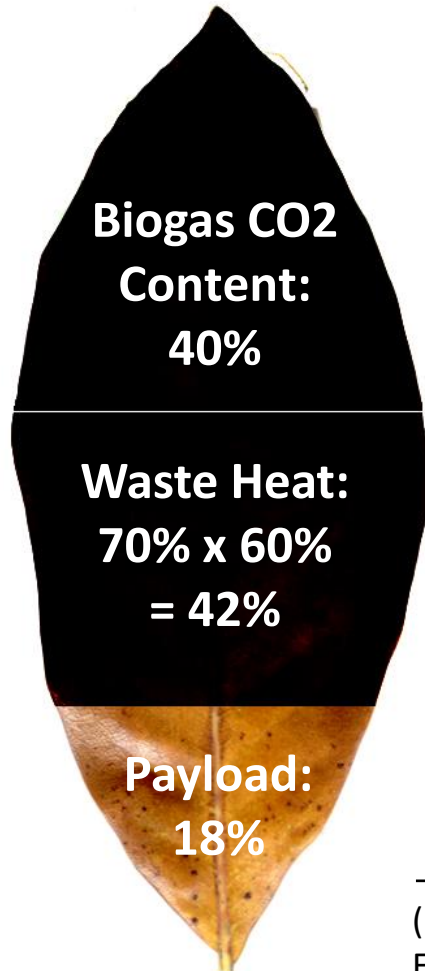


- The anerobic digestion process makes biogas from biological materials
- On average, by volume that biogas consists of ⁽¹⁾
 - Methane: 60%
 - Carbon dioxide: 40%
- The carbon dioxide yields zero energy
 - It is released directly to the atmosphere
- Cumulative score:
 - **Biogas carbon fraction returned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

(1) <http://www.sgc.se/ckfinder/userfiles/files/BasicDataonBiogas2012.pdf>
<http://www.cityofpaloalto.org/news/displaynews.asp?NewsID=2553&TargetID=65>,
Follow link: "C. deLa Beaujardiere Numbers (4-2010)"

3. Lose 70% of the Biogas Energy

Biogas CO2 Disposition

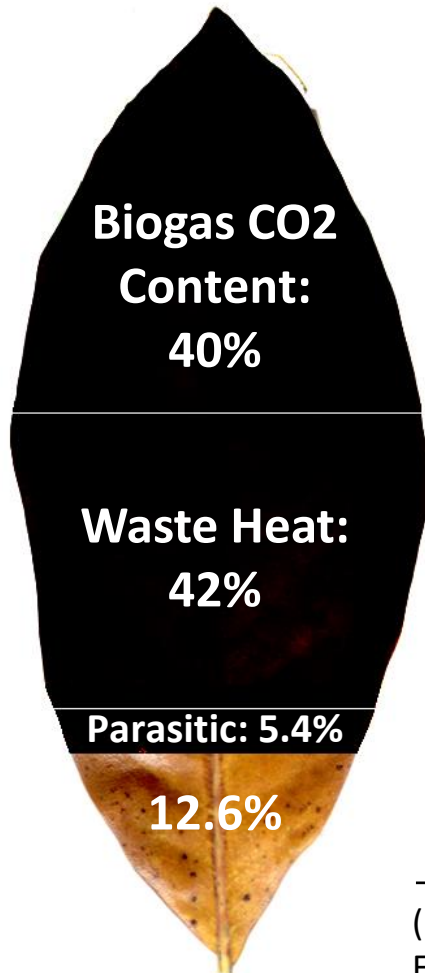


- Burn the biogas methane to H₂O & CO₂
- That yields heat energy...
 - which powers a motor...
 - that drives an electric generator
- But, per the laws of thermodynamics, about 70% of that energy is lost as “waste heat” ⁽¹⁾
- The unblacked “payload” leaf area shows the remaining 100% - 40% - 42% = 18% 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**

(1) <http://www.cityofpaloalto.org/news/displaynews.asp?NewsID=2553&TargetID=65>
Follow link: “C. deLa Beaujardiere Numbers (4-2010)”

4. Pay 30% Overhead

Biogas CO2 Disposition



- About 30% of the generated electrical energy is spent onsite to power the “Garbage to Energy” operation ⁽¹⁾
 - e.g., grinders, pumps, agitators, compressors
 - Trade term: “Parasitic Load”
- Associated CO2 fraction: $30\% \times 18\% = 5.4\%$
- Cumulative score:
 - **Biogas carbon returned to the atmosphere as CO2 so far: $40\% + 42\% + 5.4\% = 87.4\%$**
 - **Salable energy delivered: Zero**

(1) <http://www.cityofpaloalto.org/news/displaynews.asp?NewsID=2553&TargetID=65>
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5. Deliver Energy to Users

Biogas CO2 Disposition



↖ This carbon yields all of the salable energy

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 next page
- CO2 per coal-fired MWh delivered: **1.00 metric tons** ⁽¹⁾
- AD:coal carbon footprint ratio: **1.41/1.00 = 1.41**

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

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

CO₂/Energy Accounting Summary

- 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
 - **6.624 kWh_T** thermal energy
- Generate electricity at 30% thermal efficiency:
 - Electrical energy yield: $6.624 \text{ kWh}_T \times 0.3 = \mathbf{1.987 \text{ kWh}}$
- Subtract 30% parasitic load:
 - Salable electrical energy yield: $1.987 \times (1.0 - 0.3) = \mathbf{1.391 \text{ kWh}}$
- Ratio of CO₂ to salable energy (the carbon footprint):
 - $1.964 \text{ kg CO}_2 / 1.391 \text{ kWh} = \mathbf{1.412 \text{ kg CO}_2 / \text{kWh}}$
 - Which is also **1.412 mT CO₂/MWh**
- Comparing AD to coal:
 - Coal footprint: **1.004 mT CO₂/MWh** ⁽¹⁾
 - AD/coal ratio: $1.412 / 1.004 = \mathbf{1.41}$

Data sources as
previously cited

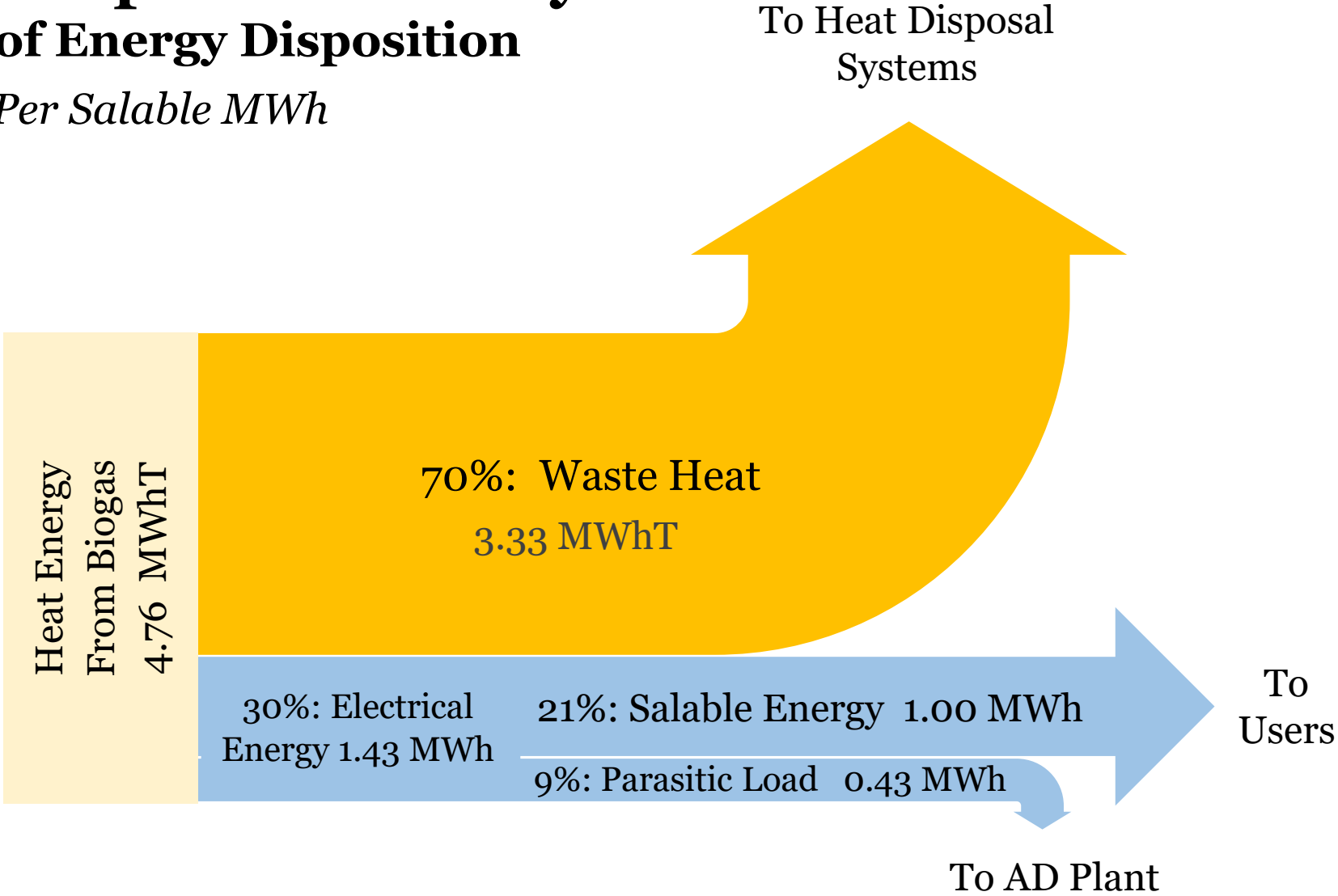
Relative
CO₂
per
MWh



⁽¹⁾ <https://www.eia.gov/tools/faqs/faq.php?id=74&t=11>

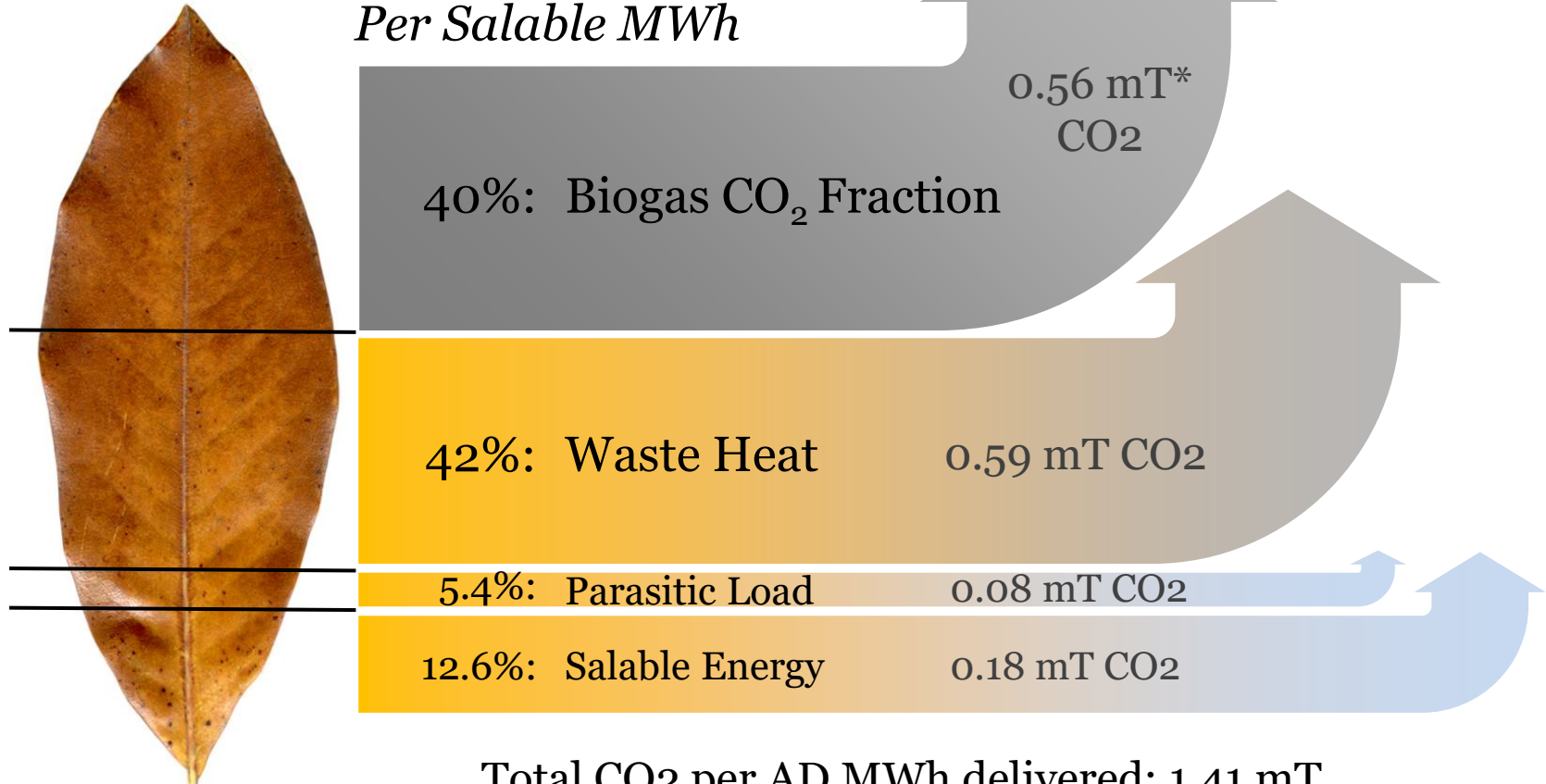
Graphic Summary of Energy Disposition

Per Salable MWh



Graphic Summary of Carbon Disposition

Per Salable MWh



Total CO₂ per AD MWh delivered: 1.41 mT

CO₂ per coal-generated MWh: 1.00 mT

AD to Coal CO₂ ratio: 1.41

* mT = metric ton = 2,201 lbs

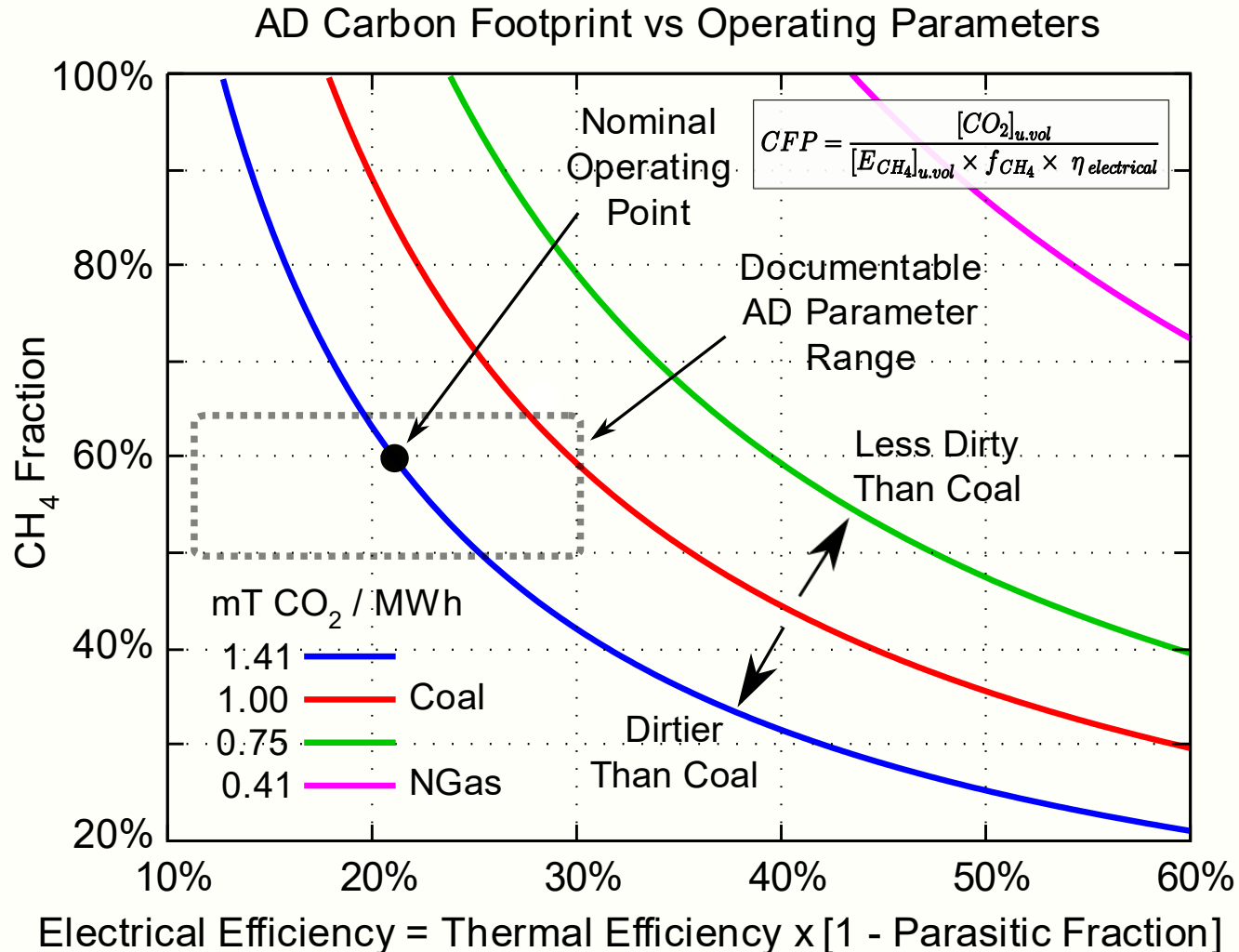
Takeaways

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- Green plants remove CO₂ and sequester it in their fruits and detritus
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The Wonkery

$$CFP = \frac{[CO_2]_{u.vol}}{[E_{CH_4}]_{u.vol} \times f_{CH_4} \times \eta_{electrical}}$$

AD Parameters Influence



Biogas Generator Properties

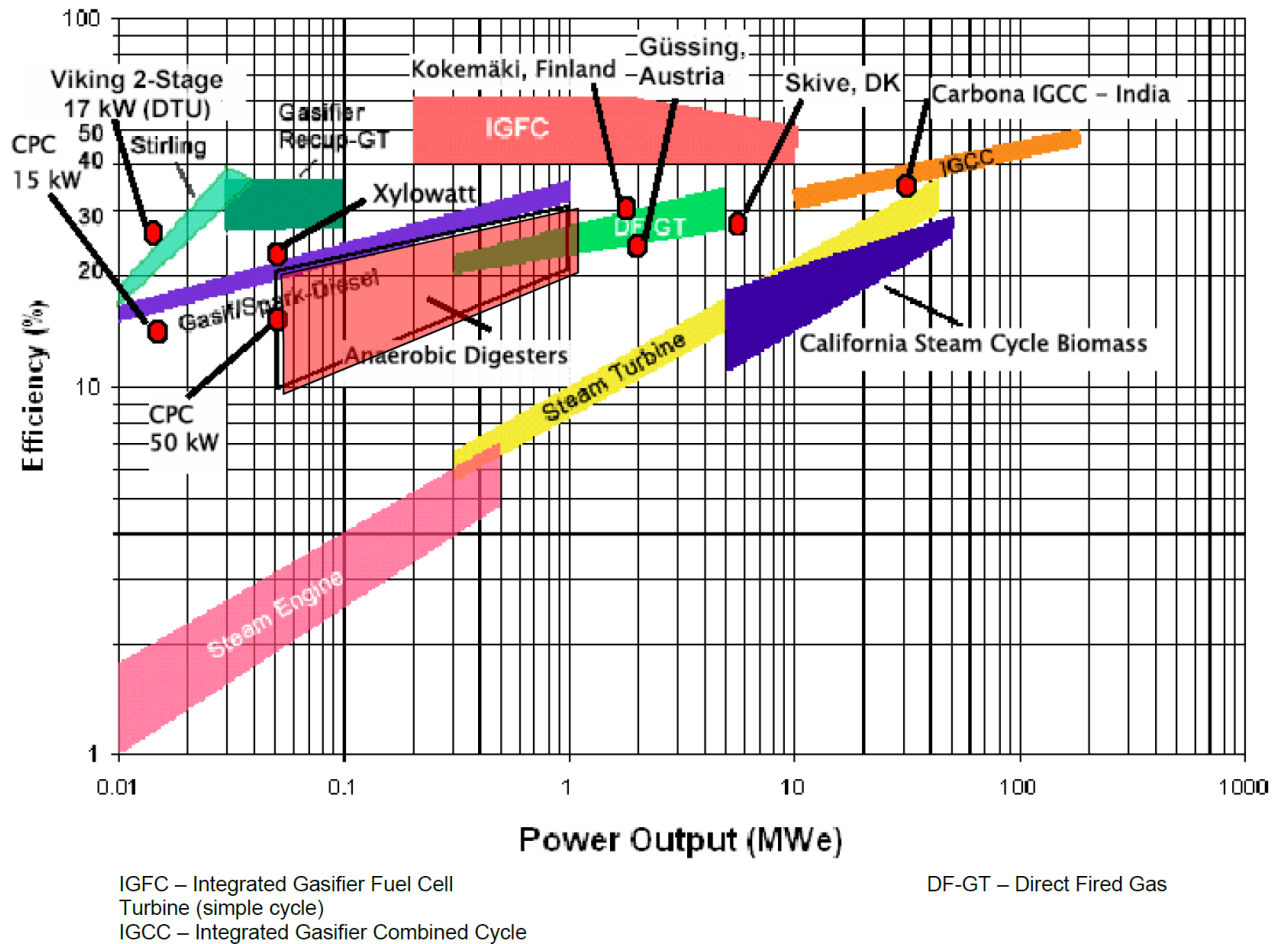


Figure 1-11. Efficiency versus net electrical power output for several prime movers.

Photo Credit: Adapted from R.P. Overend, 1998.

Source: Public Interest Energy Research (PIER) Program Final Project Report, CEC-500-2012-060, University of California at Davis, May 2012

US Carbon Footprints by Fuel

U.S. electric utility and independent power electricity generation and resulting CO2 emissions by fuel in 2019

	Electricity generation	CO2 emissions		
	million kWh	million metric tons	million short tons	pounds per kWh
Coal	947,891	952	1,049	2.21
Natural gas	1,358,047	560	617	0.91
Petroleum	15,471	15	17	2.13

Electricity generation is [net electricity generation](#).

Includes electricity-only power plants. [Combined heat and power plants](#) are excluded because some of their CO2 emissions are from heat-related fuel consumption.

<https://www.eia.gov/tools/faqs/faq.php?id=74&t=11>