# Comparing Greenhouse Gas Emissions from Organic Waste Disposal Methods

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# Types of Organic Waste

- Food remains
- Livestock manure
- Sewage sludge
- Yard waste

Disposal Methods:

- Landfill
- Incineration
- Composting
- Manure management
- Anaerobic digestion

# Decomposition of Organic Waste

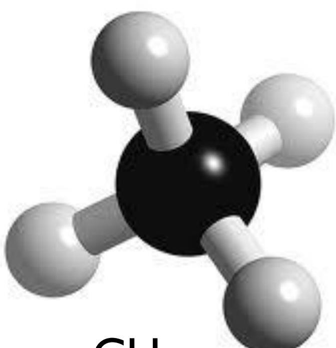
- Biological process: breakdown by microorganisms
- Two main products: digestate and biogas
- Digestate:
  - Solid fraction is similar to late-stage compost, can be used as fertilizer with some further processing

http://www.bebra-biogas.com

- Typical biogas components:
  - 45-75% methane ($CH_4$)
  - 20-45% carbon dioxide ($CO_2$)
  - Less than 5% (typically closer to 1%) of $N_2O$, $H_2S$, other gases
- Biogas composition mainly depends on:
  - The environment where decomposition occurs
  - The type of organic waste

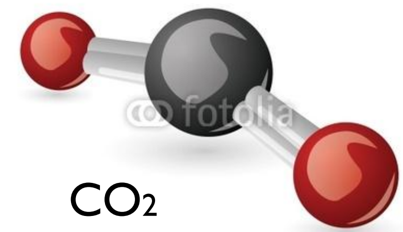
# Greenhouse gases

- **Global Warming Potential (GWP):** mass-based measure of how much heat the gas traps in the atmosphere, relative to carbon dioxide
- GWP values are published by the Intergovernmental Panel on Climate Change (IPCC)

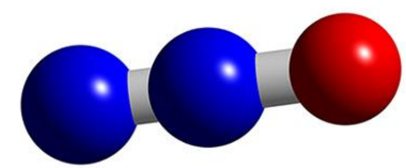


$CH_4$

| gas | Avg. GWP (100 years) |
|---|---|
| Carbon dioxide ($CO_2$) | 1 |
| Methane ($CH_4$) | 25 |
| Nitrous oxide ($N_2O$) | 310 |




$CO_2$



$N_2O$

IPCC. 2007. *Changes in Atmospheric Constituents and Radiative Forcing*. In: *IPCC Fourth Assessment Report: Climate Change*. Intergovernmental Panel on Climate Change, Geneva, Switzerland. (http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf)

# Aerobic vs. Anaerobic Decomposition

- **Aerobic:** extra oxygen is available

  $$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

  products: **carbon dioxide** and **water vapor**

- **Anaerobic:** no additional oxygen, closed environment

  $$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

  products: **carbon dioxide** and **methane**

- **Combustion:** converts methane into CO2

  $$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

  **89% reduction in emissions**

# Power Production

- Typically, organic waste decomposition is at least partially anaerobic, and the gas byproducts generally contain at least 50% methane
  - If gas is released to the atmosphere, we prefer less methane
- Coincidentally, what we think of as natural gas is actually methane gas
  - Biogas can also be used to generate electricity and/or heat
  - Power generated from organic waste is renewable
  - Power production from biogas offsets the use of fossil fuels
  - To make more power, we prefer more methane content in biogas!

# Organic waste disposal

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**Disposal methods**
- Landfill
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- Manure management
- Anaerobic Digestion

**Biogas use**
- Release
- Flaring
- Power production

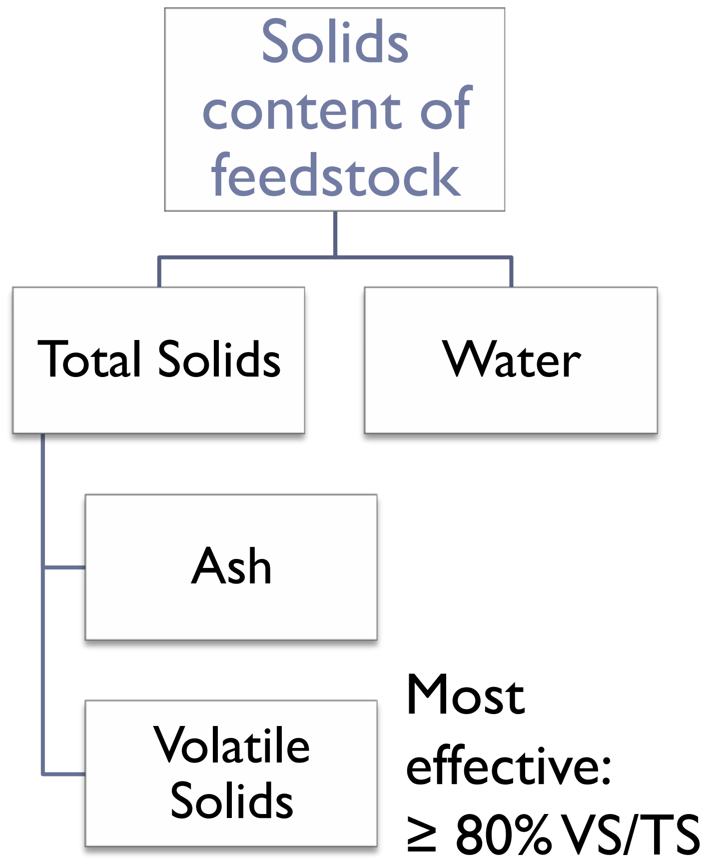
# How to measure biogas emissions

- Waste disposal facilities process organic matter in different forms
  - e.g., with varying moisture contents
- It is misleading to compare GHG emissions potential per weight or volume of organic matter across different disposal methods

# Biogas Potential of Organic Wastes

How much carbon the waste contains / How much of the waste decomposes

- Chemical Oxygen Demand (COD)
  - 318 $m^3$ of $CH_4$ can be generated per ton of COD destroyed
- Carbon-to-Nitrogen (C/N) Ratio
  - Optimal ratios for decomposition: 16-30
  - Livestock manure: high in nitrogen (~3-10)
  - Food remains: high in carbon (~15)
  - Yard waste: very high in carbon (~35-400)
- Volatile Solids Destruction
  - Degree of decomposition
  - Tends to be higher for food waste than sewage sludge or livestock manure
- Co-Digestion
  - Common mix: manure + food/yard waste



# How to measure biogas emissions

- Waste disposal facilities process organic matter in different forms
  - e.g., with varying moisture contents
- It is misleading to compare GHG emissions potential per weight or volume of organic matter across different disposal methods
- More reliable to compare GHG emissions per amount of organic matter volatile solids (decomposable)
- Units for biogas potential:

  **$m^3$ gas/ton VS**

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# Landfills

- Typically accept food and yard waste (but not in MA)
  - EPA estimate: each constitutes approx. 13-14% of municipal solid waste (MSW) in the United States
  - 17.1% of U.S. methane emissions in 2009 were from landfills
- Type of decomposition:
  - Initially aerobic
  - Quickly becomes anaerobic as waste sinks in the landfill
- Bulk of gas production occurs within 20-25 years of waste disposal
- Typical methane/$CO_2$ composition of landfill gas: 50/50
- Some have gas collection systems, ~75% effective

EPA. Landfill Methane Outreach Program. (http://www.epa.gov/lmop)

# Incineration

- Can reduce waste volume and destroy pathogens
- Has been in use in US for over 100 years
- Facilities typically sort out recyclable items before combustion
- Incineration facilities have come up with strategies to minimize emissions; much better overall than backyard waste burning
- Accurate emissions comparisons to other methods are difficult because GHGs come not just from organic matter

# Composting

- Organic matter decomposes much more readily than in landfills, produces a beneficial, reusable product
- Exposure to oxygen means more $CO_2$ relative to $CH_4$
- Large-scale composting:
  - 90% emissions reductions as compared to landfilling (GCC)
  - (probably more like 85%)
- Small-scale composting:
  - Even more sustainable, because there are no emissions from transportation
  - Variety of projects make estimates difficult

*Becoming Carbon Neutral*, Green Communities Committee, Ministry of Environment, Province of British Columbia

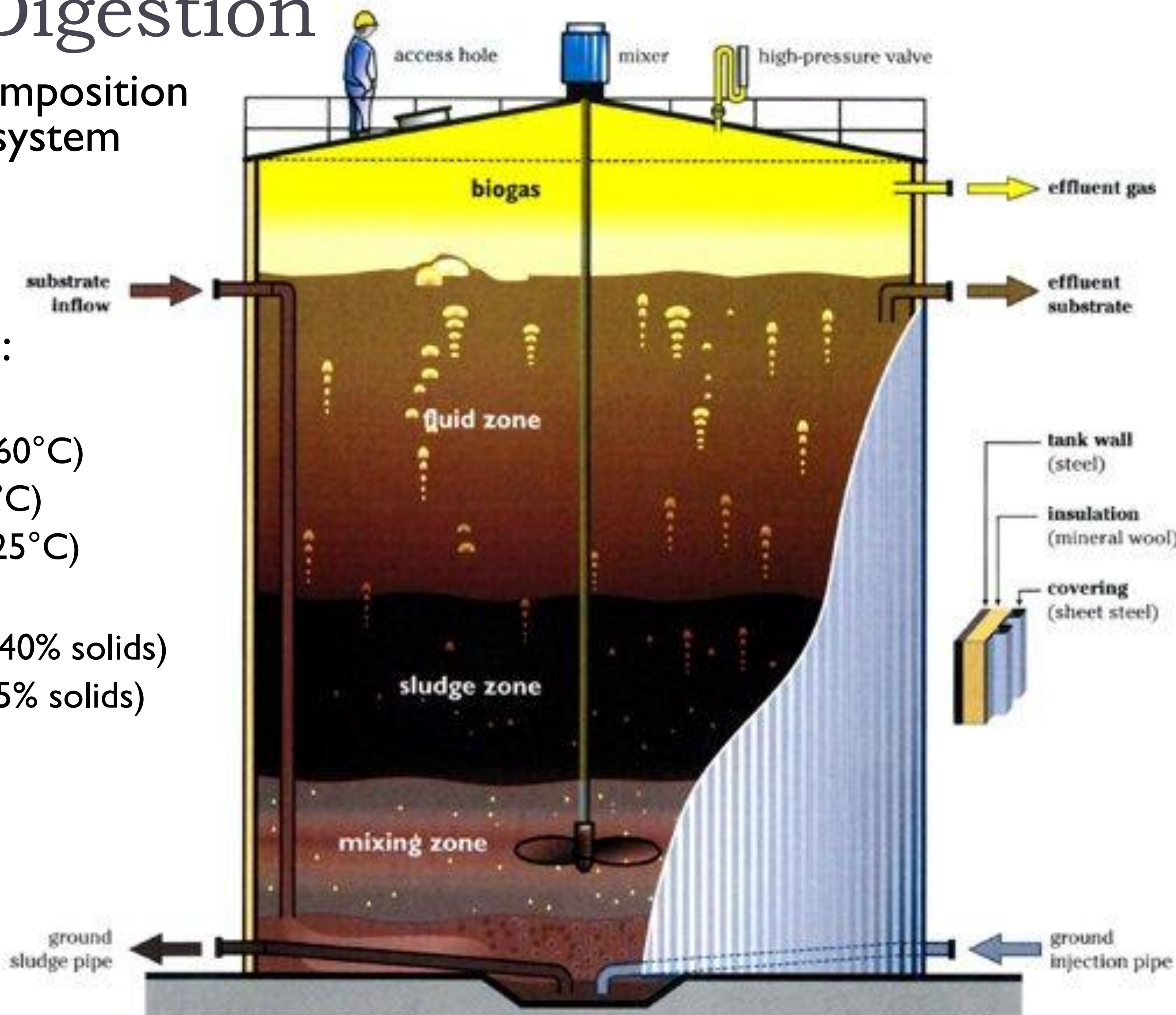
# Livestock Manure Management

- One fully-grown milking cow can produce >100 lbs of manure per day
- Emissions from manure made up 10% of total U.S. methane emissions in 1997
- Emissions vary based on:
  - Type of livestock
  - Waste disposal method
  - Temperature and moisture content
- Common practices:
  - Aerobic (low methane emissions)
    - Dry systems
    - Daily spreading as fertilizer
  - Anaerobic
    - Liquid slurries
    - 4-20 times higher methane emissions
    - More common on larger farms

Mangino et al. 2011; EPA 1999; Climate Action Reserve 2009

# Anaerobic Digestion

- Mimics natural decomposition process in a closed system
- Much more efficient decomposition (days vs. years in LF)
- Many different types:
  - Temperature:
    - Thermophilic (50-60°C)
    - Mesophilic (35-40°C)
    - Psychrophilic (15-25°C)
  - Feedstock type:
    - Dry digesters (25-40% solids)
    - Wet digesters (<15% solids)
  - Digester setup:
    - Continuous
    - Batch system
  - Complexity:
    - Single-stage
    - Multi-stage

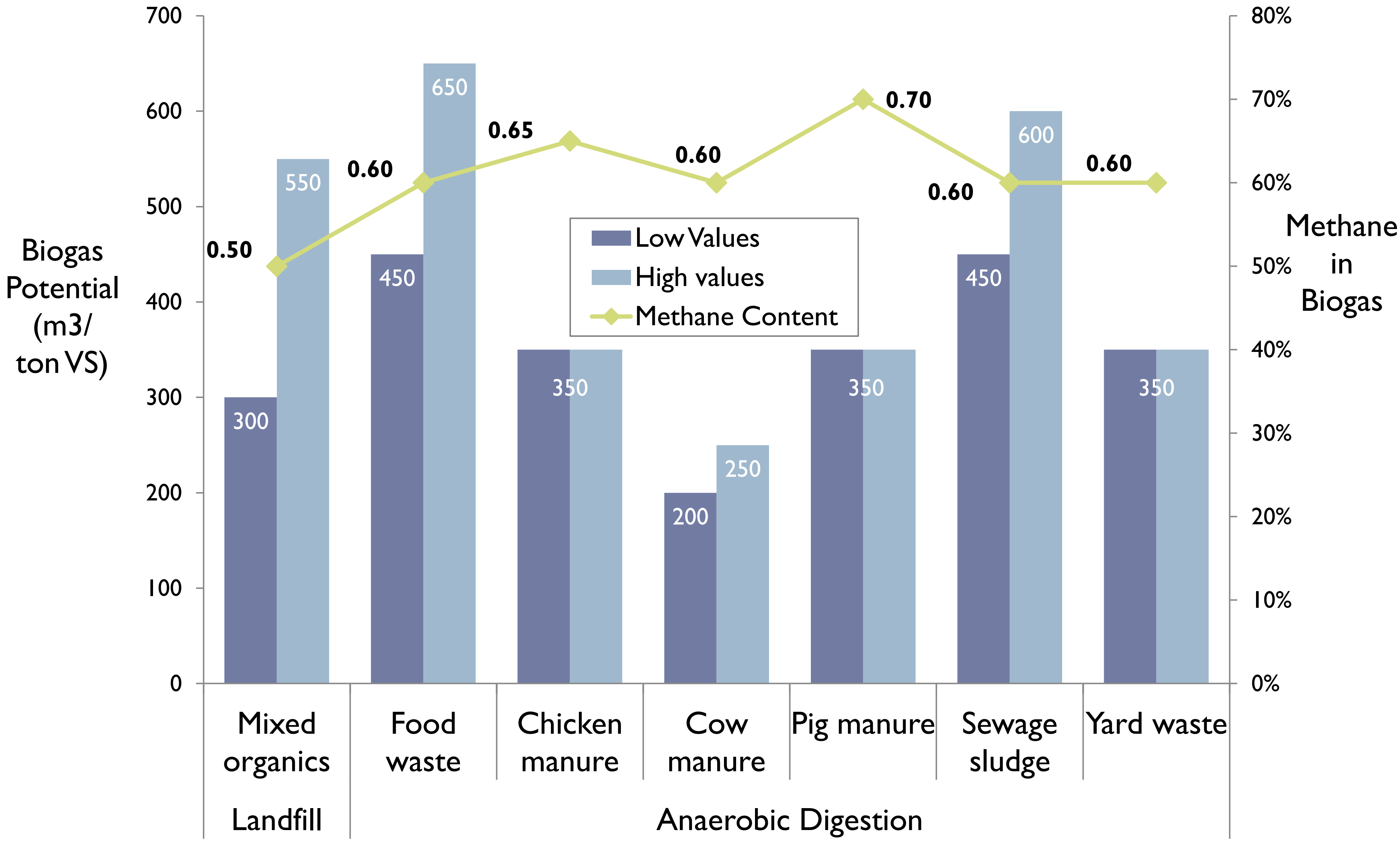


Holly Wastewater Treatment Plant, Michigan

# Biogas production from disposal methods

| | Landfills | Incineration | Composting | Manure | AD |
|---|---|---|---|---|---|
| type | Anaerobic | Combustion | Aerobic | Anaerobic | Anaerobic |
| $\%CH_4/\%CO_2$ | 50/50 | Unknown | Unknown | ~60/40 | 60/40 |
| Gas collection (% effective) | 0-75% | Unknown | 0 | Varies | 100% |

# Estimated Amount and Quality of Biogas from SSO Disposal



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# Calculating Carbon Emissions

**$CO_2eq$ = direct emissions**

(e.g., from GHG release or power production)

Calculated directly for release and flaring, Climate Registry values used for power production

**+ indirect emissions**

(e.g., transportation of feedstock, building materials)

**– direct offsets**

(e.g., replacing fossil fuels)

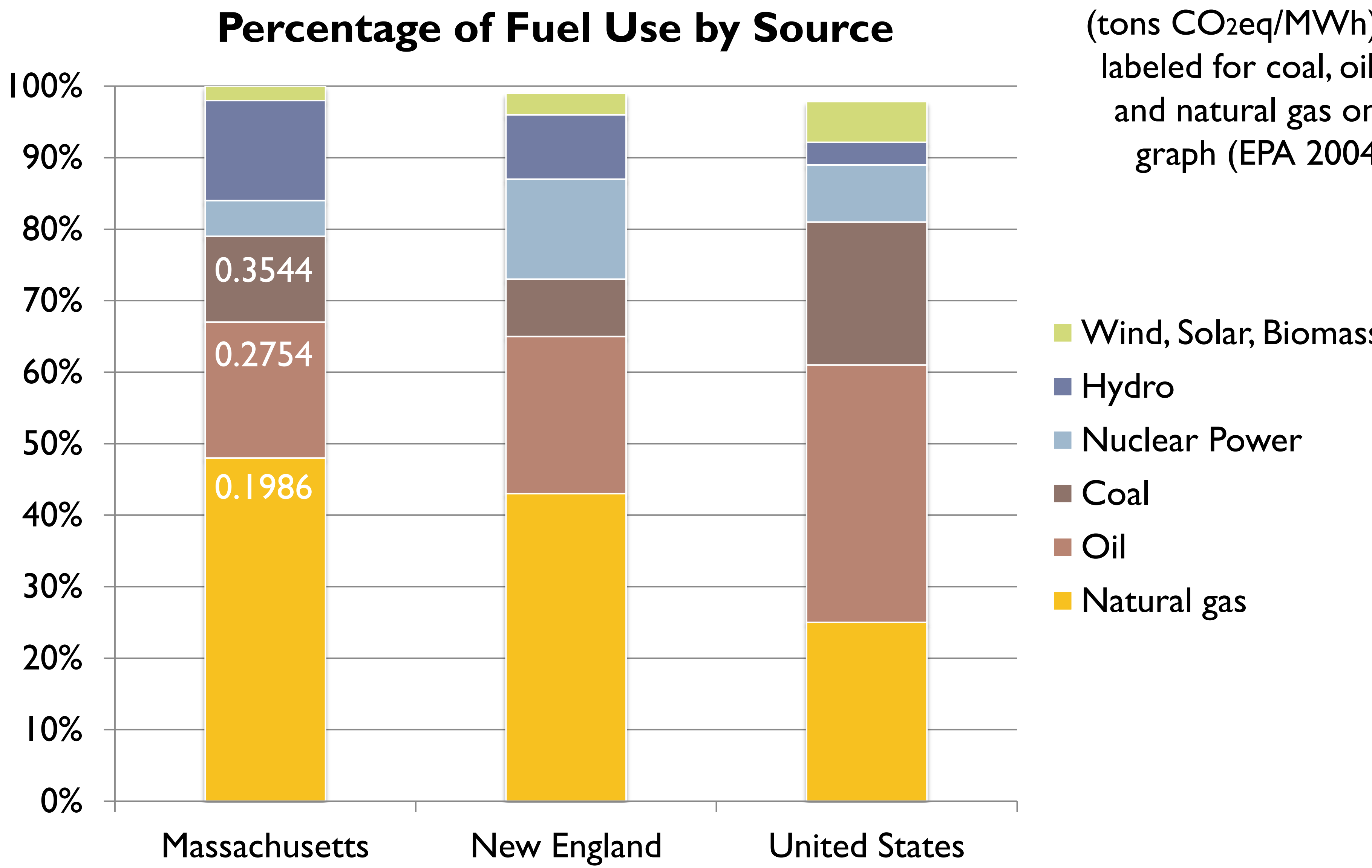
Calculated from weighted fuel carbon emission factors

**– avoided emissions (i.e., indirect offsets)**

(e.g., no emissions from more GHG-intensive disposal methods, such as landfill)

Within each category, there are even more choices to be made about parameters to include or exclude.

**Carbon Emissions Factors**
(tons $CO_2$eq/MWh)
labeled for coal, oil,
and natural gas on
graph (EPA 2004)




| 0.1902 | 0.1743 | 0.2197 | ← Weighted CEFs |
|---|---|---|---|

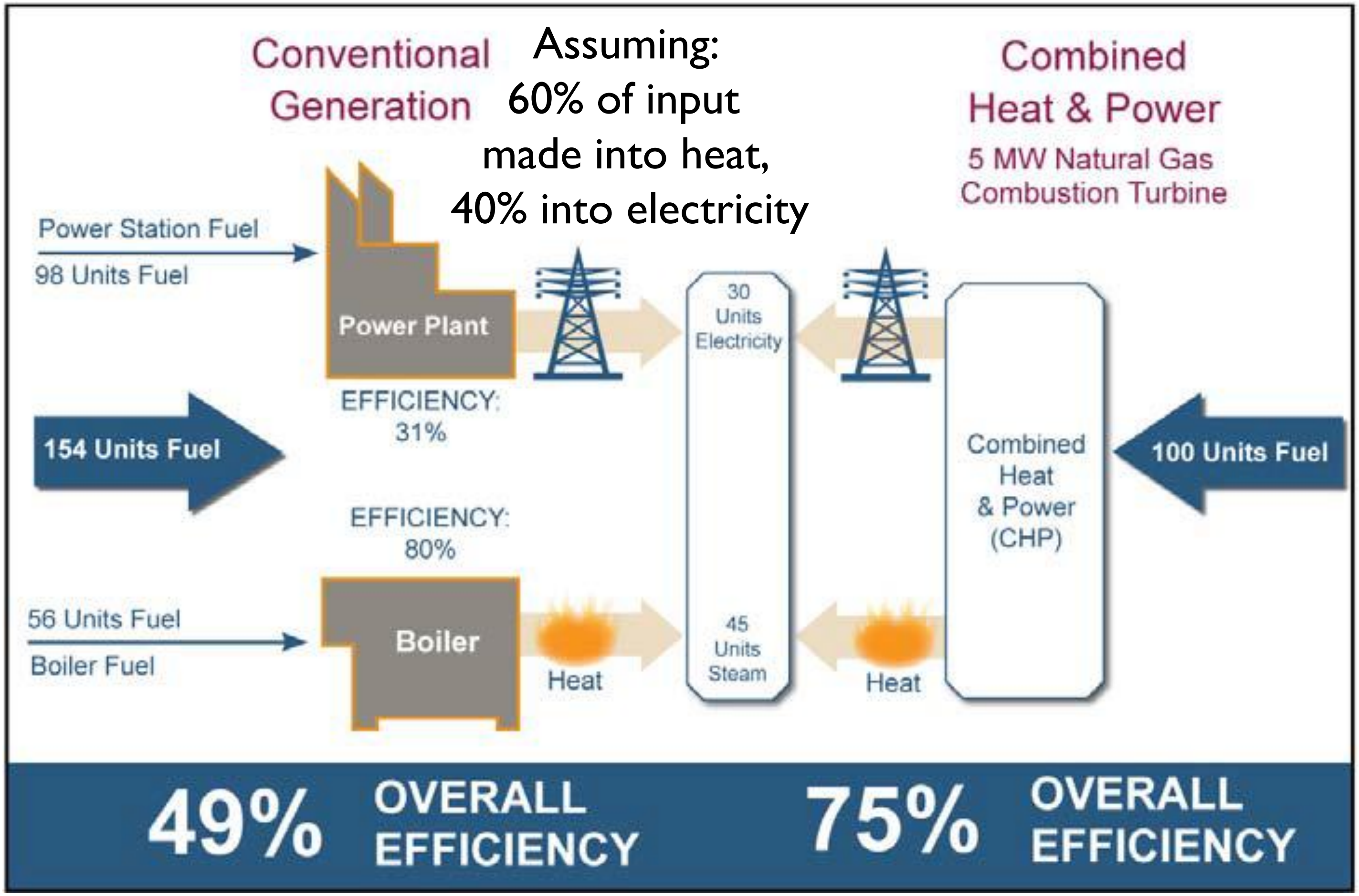
- Massachusetts and New England data from ISO-NE (2011), U.S. data from EIA (2012).

# Methods of Power Production

33% efficiency

80% efficiency

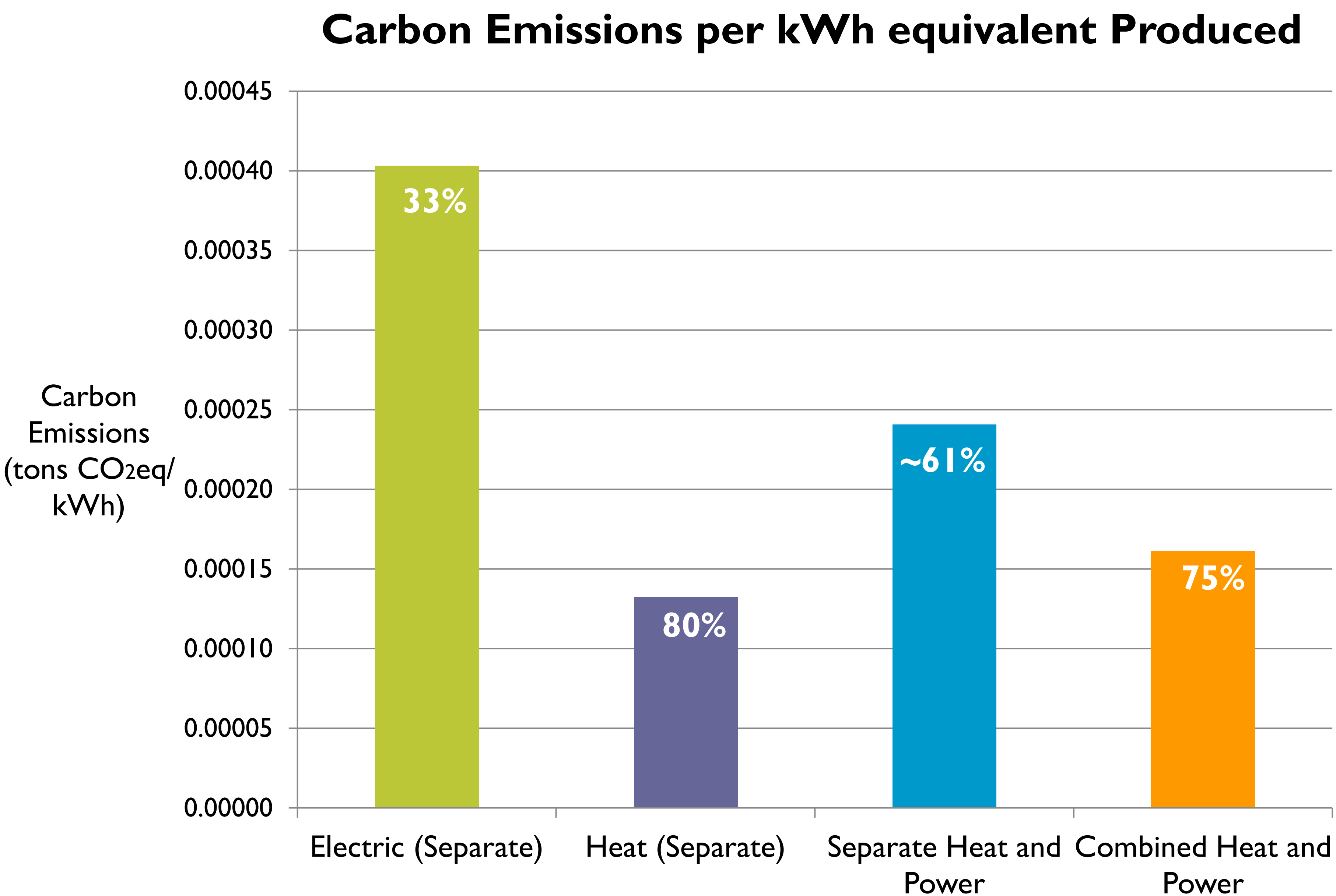
Assuming: 60% of input made into heat, 40% into electricity



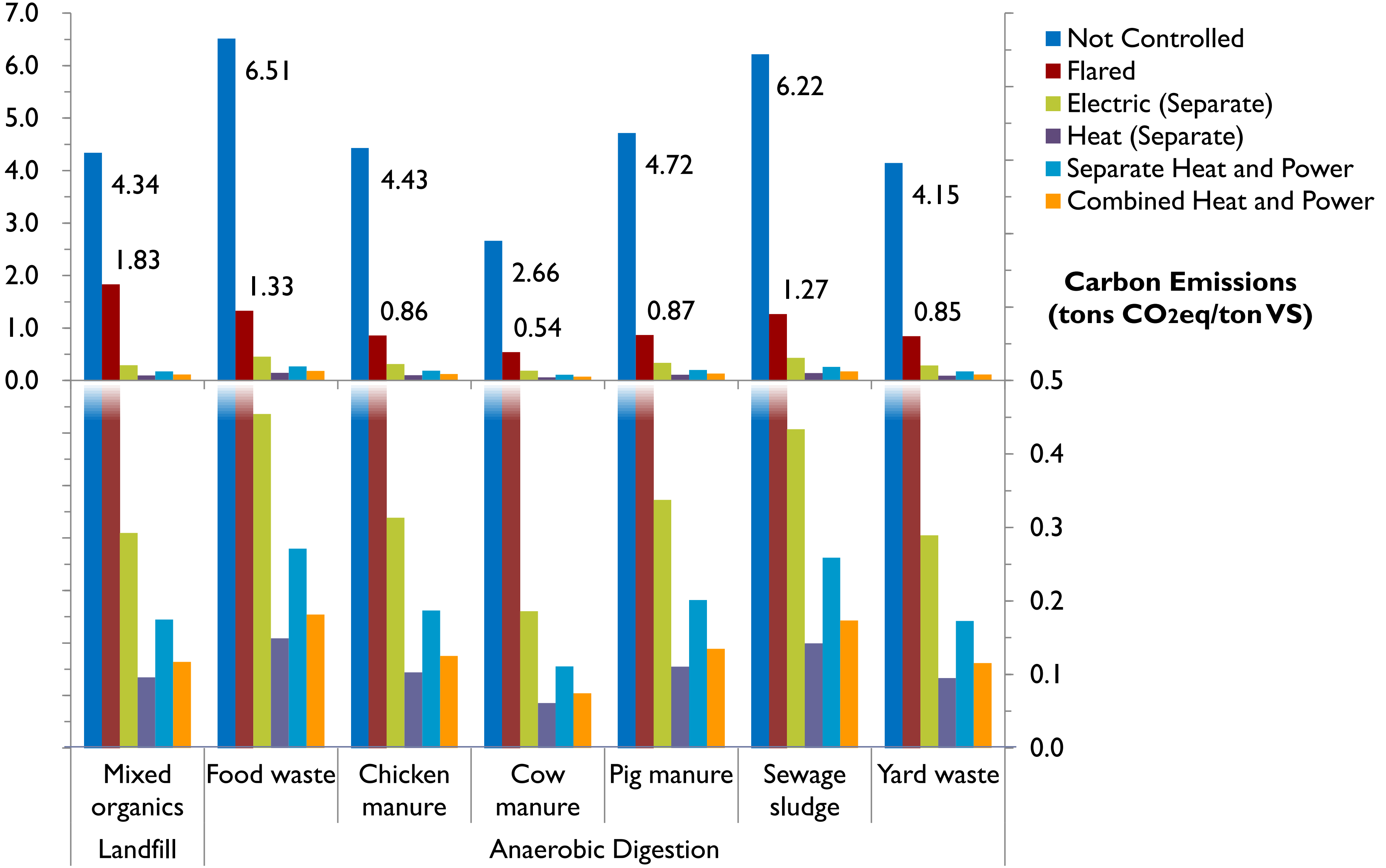

Assuming: 60% of output is heat, 40% is electricity

~61.2% efficiency

- Catalog of CHP Technologies, EPA Combined Heat and Power Partnership, 2008.

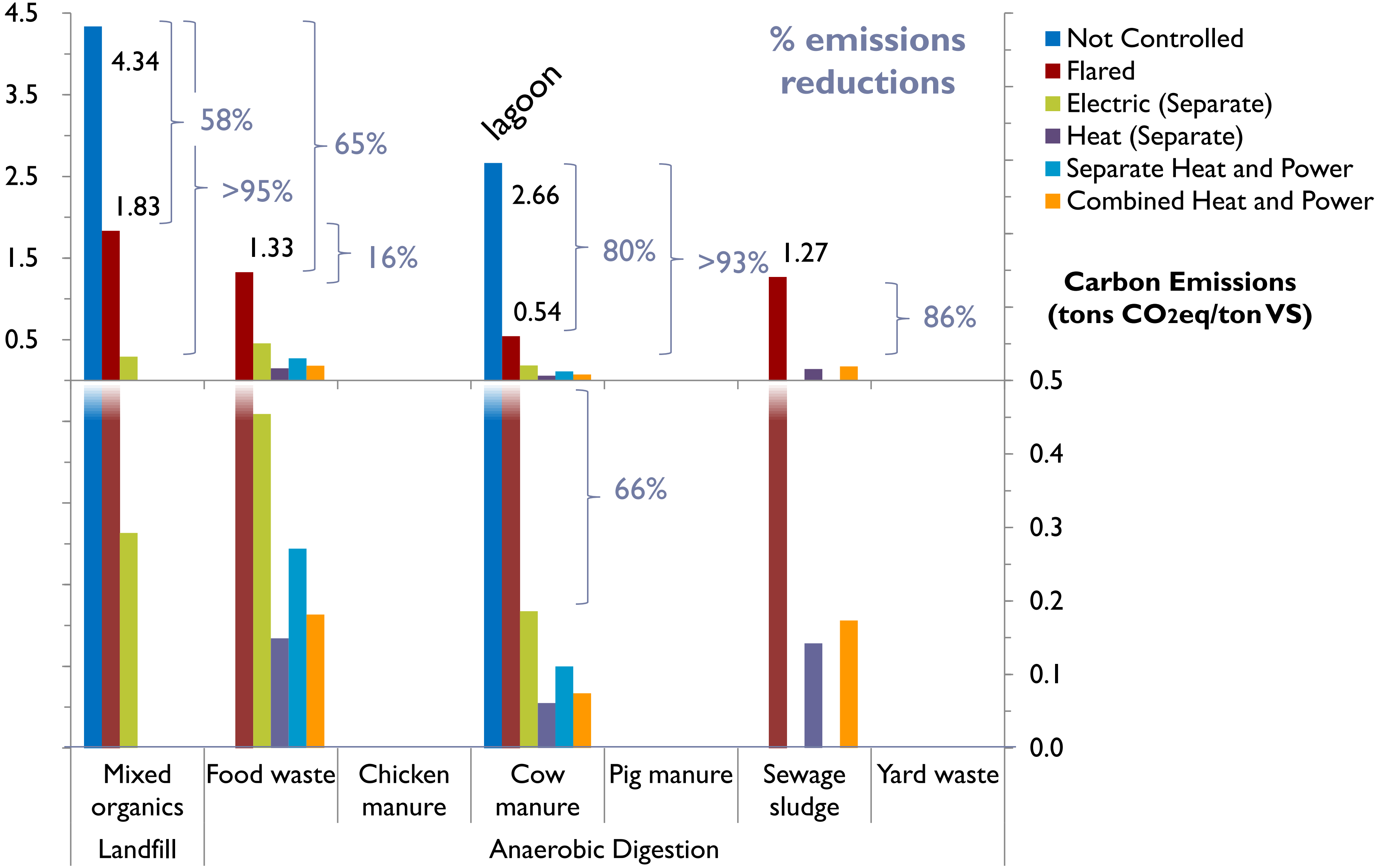

Carbon Emissions per kWh equivalent Produced
Carbon Emissions (tons CO2eq/ kWh)
0.00045
0.00040
0.00035
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
33%
80%
~61%
75%
Electric (Separate)
Heat (Separate)
Separate Heat and Power
Combined Heat and Power

# Carbon Emissions
## from SSO Disposal and Power Production



# Actual Scenarios: Carbon Emissions

## from SSO Disposal and Power Production



# Takeaways

- There are many, many factors that influence the amount and composition of greenhouse gases produced from organic waste decomposition
- There are even more factors to consider when calculating the possible power production and emissions offsets from renewable biogas
- Anaerobic digestion reduces emissions versus landfill disposal because more gas is captured
- Flaring significantly reduces landfill gas emissions; power production reduces emissions even further
- When evaluating a particular site for AD and/or power production, the characteristics of the site must be determined and transportation emissions considered

# Thank you

- Massachusetts Clean Energy Center
- Amy Barad
- Jason Turgeon, Will Space, and Mike Thayer for helpful comments

# Questions?

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# Equations

$$CO_2eq_{released} = m^3_{gas} \times [(\%CH_4 \times den_{CH4} \times GWP_{CH4}) + (\%CO_2 \times den_{CO2})]$$

$$CO_2eq_{flared} = m^3_{gas}\left\{ \%eff \left[ \%CH_4 \times den_{CH4} \times \left[ \left( 0.99 \times \frac{mm_{CO2}}{mm_{CH4}} \right) + (0.01 \times GWP_{CH4}) \right] \right] + \%eff\,[\%CO_2 \times den_{CO2}] + (1 - \%eff)\,[(\%CH_4 \times den_{CH4} \times GWP_{CH4}) + (\%CO_2 \times den_{CO2})] \right\}$$

$$CO_2eq_{elec} = m^3_{gas} \times \%CH4 \times \frac{35{,}315\ Btu}{m^3_{CH4}} \times \frac{0.293071\ kWh}{1000\ Btu} \times (emBG - 0.33 \times WCEF)$$

$$CO_2eq_{therm} = m^3_{gas} \times \%CH4 \times \frac{35{,}315\ Btu}{m^3_{CH4}} \times \frac{0.293071\ kWh}{1000\ Btu} \times (emBG - 0.8 \times WCEF)$$

$$CO_2eq_{separate} = 0.4 \times CO_2eq_{elec} + 0.6 \times CO_2eq_{therm}$$

$$CO_2eq_{CHP} = m^3_{gas} \times \%CH4 \times \frac{35{,}315\ Btu}{m^3_{CH4}} \times \frac{0.293071\ kWh}{1000\ Btu} \times (emBG - 0.75 \times WCEF)$$