# Fossil and Renewable Natural Gas as a Fuel in California and US

Overview of STEPS research

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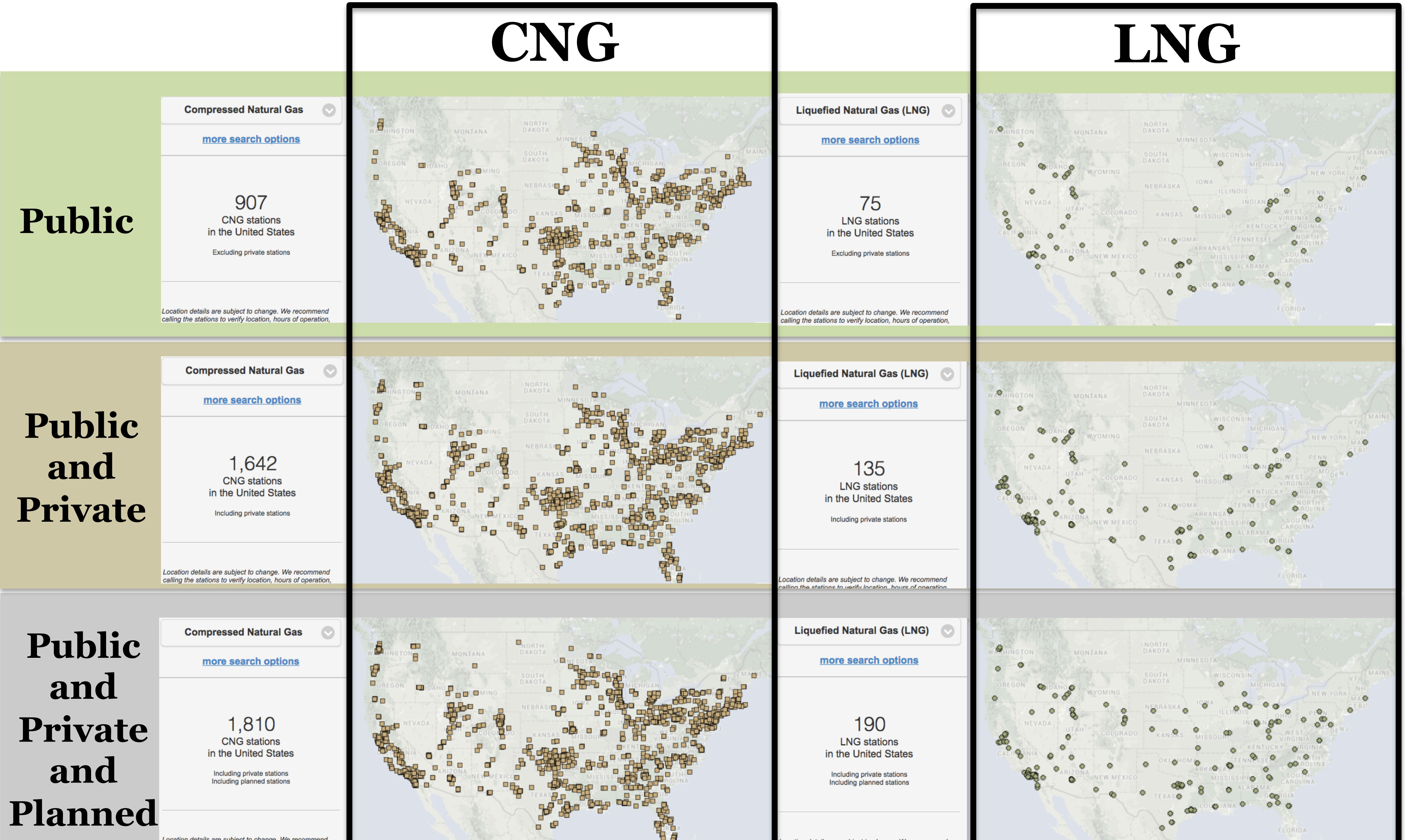
# Quick facts

- Abundant and cheap
- US stopped importing natural gas altogether, could export if economic.
- Can be used as CNG or LNG
- Low NOx and Ultra Low NOx – non attainment ozone areas: ports, South Coast…
- Can be a low carbon fuel
- Limited public refueling infrastructure

- **Natural gas in transportation:**
- **California**: 16,467 million cubic feet —> 126 Million DGE (**4.6**% of California Diesel transportation market)
- **US**: 34,459 million cubic feet —> 263 Million DGE (**0.6**% of US Diesel market)

# Current CNG and LNG stations



# Methane Leakage

# Upstream leakage

**Oil Production**

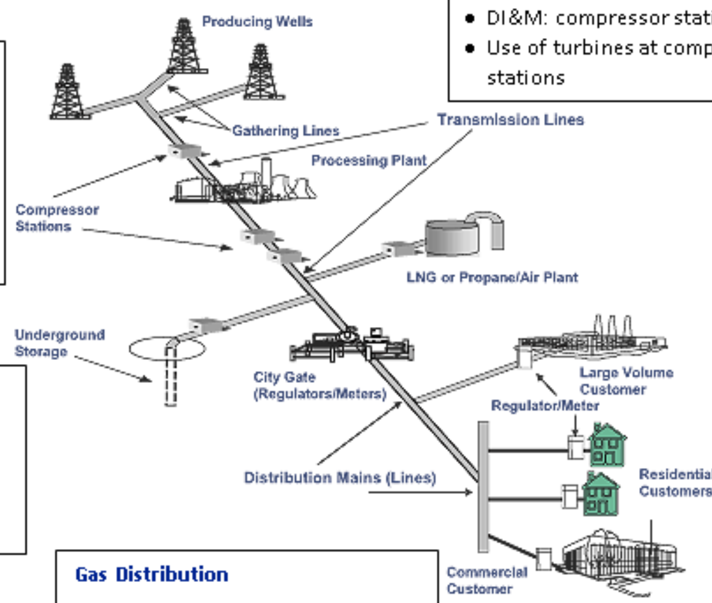
- Perform reduced emissions completions
- Artificial lift: install plunger lifts
- Install vapor recovery units (VRUs)

**Gas Transmission**

- Use pipeline pumpdown techniques to lower pressure
- DI&M: compressor stations
- Use of turbines at compressor stations

**Gas Production & Processing**

- DI&M: aerial leak detection
- Nitrogen rejection unit optimization
- Eliminate unnecessary equipment and/or systems




**Gas Storage**

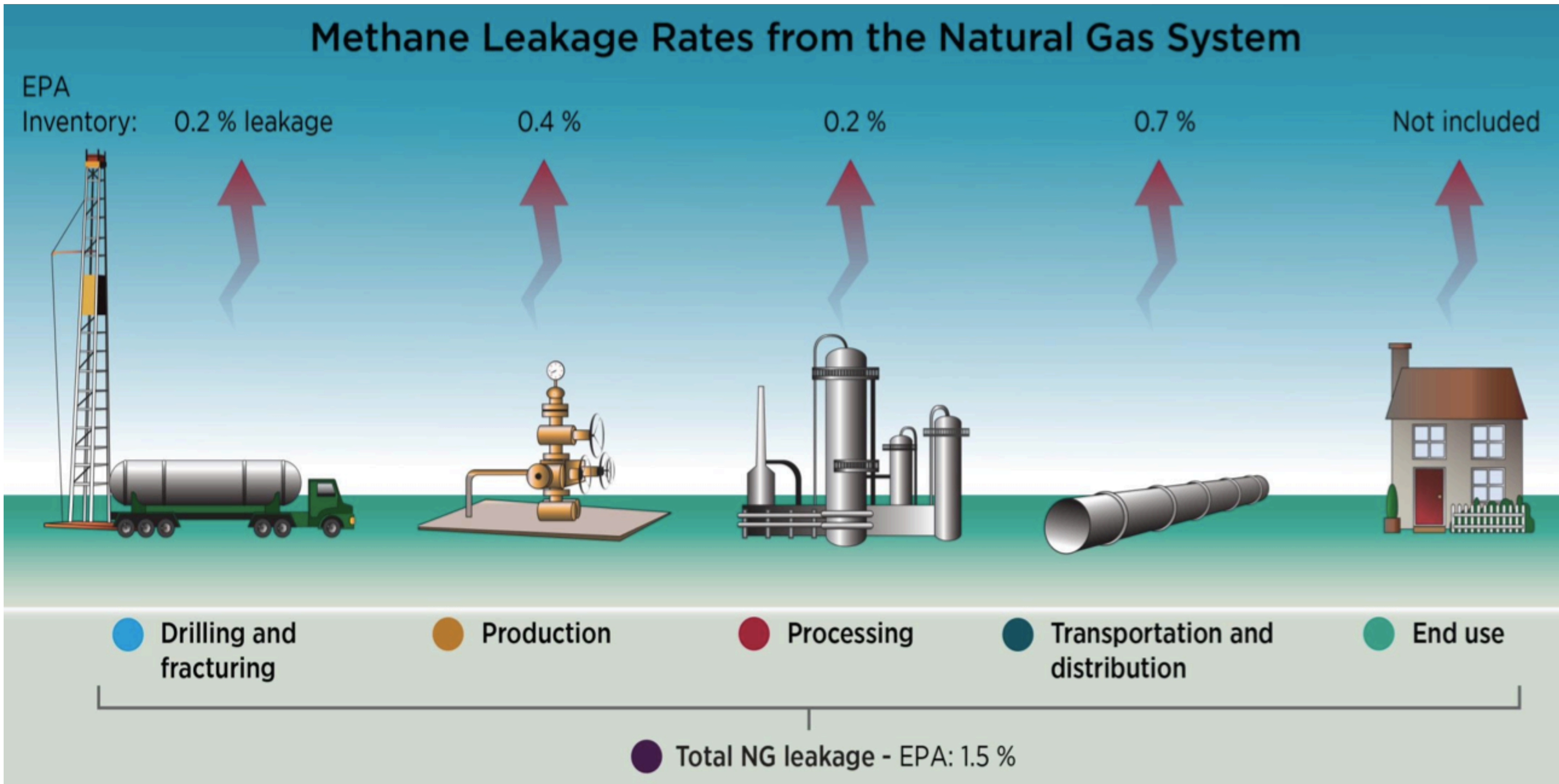
- Convert to instrument air systems
- Replace compressor rod packing systems

**Gas Distribution**

- Identify and rehabilitate leaky distribution pipe
- DI&M: surface facilities
- DI&M: survey and repair leaks

360 BCF annually

# Official estimates of methane leakage




Source: EDF based on 2013 EPA GHGI

# EPA estimates of leakage goes up and down a little

**Table ES-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (MMT $CO_2$ Eq.)**

| Gas/Source | 1990 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|
| Natural Gas Systems | 206.8 | 177.3 | 166.2 | 170.1 | 172.6 | 175.6 | 176.1 |
| Enteric Fermentation | 164.2 | 168.9 | 171.3 | 168.9 | 166.7 | 165.5 | 164.3 |
| Landfills | 179.6 | 154.0 | 142.1 | 144.4 | 142.3 | 144.3 | 148.0 |
| Petroleum Systems | 38.7 | 48.8 | 54.1 | 56.3 | 58.4 | 64.7 | 68.1 |
| Coal Mining | 96.5 | 64.1 | 82.3 | 71.2 | 66.5 | 64.6 | 67.6 |
| Manure Management | 37.2 | 56.3 | 60.9 | 61.5 | 63.7 | 61.4 | 61.2 |
| Wastewater Treatment | 15.7 | 15.9 | 15.5 | 15.3 | 15.0 | 14.8 | 14.7 |
| Rice Cultivation | 13.1 | 13.0 | 11.9 | 11.8 | 11.9 | 11.9 | 11.9 |
| Stationary Combustion | 8.5 | 7.4 | 7.1 | 7.1 | 6.6 | 8.0 | 8.1 |
| Abandoned Underground Coal Mines | 7.2 | 6.6 | 6.6 | 6.4 | 6.2 | 6.2 | 6.3 |
| Composting | 0.4 | 1.9 | 1.8 | 1.9 | 1.9 | 2.0 | 2.1 |
| Mobile Combustion | 5.6 | 2.7 | 2.3 | 2.2 | 2.2 | 2.1 | 2.0 |
| Field Burning of Agricultural Residues | 0.2 | 0.2 | 0.3 | 0.3 | | | |
| Petrochemical Production | 0.2 | 0.1 | + | + | | | |
| Ferroalloy Production | + | + | + | + | | | |
| Silicon Carbide Production and Consumption | + | + | + | + | | | |
| Iron and Steel Production & Metallurgical Coke Production | + | + | + | + | | | |
| Incineration of Waste | + | + | + | + | | | |
| *International Bunker Fuels*[b] | *0.2* | *0.1* | *0.1* | *0.1* | | | |

360/23,000 = 1.5%
of shale and
conventional natural gas
Production
(compare to 4.4 Billion
cubic feet of methane
from Aliso Canyon)

**Natural Gas Gross Withdrawals and Production**

(Volumes in Million Cubic Feet)

**Area:** U.S. **Period:** Annual

Download Series History | Definitions, Sources & Notes

Show Data By: Data Series | Area — Graph | Clear

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | View History |
|---|---|---|---|---|---|---|---|
| Gross Withdrawals | 26,056,893 | 26,816,085 | 28,479,026 | 29,542,313 | 30,005,254 | 31,895,427 | 1936-2014 |
| From Gas Wells | 14,414,287 | 13,247,498 | 12,291,070 | 12,504,227 | 11,255,616 | | 1967-2013 |
| From Oil Wells | 5,674,120 | 5,834,703 | 5,907,919 | 4,965,833 | 5,427,676 | | 1967-2013 |
| From Shale Gas Wells | 3,958,315 | 5,817,122 | 8,500,983 | 10,532,858 | 11,896,204 | | 2007-2013 |
| From Coalbed Wells | 2,010,171 | 1,916,762 | 1,779,055 | 1,539,395 | 1,425,757 | | 2002-2013 |
| Repressuring | 3,522,090 | 3,431,587 | 3,365,313 | 3,277,588 | 3,331,456 | | 1936-2013 |
| Vented and Flared | 165,360 | 165,928 | 209,439 | 212,848 | 260,394 | | 1936-2013 |
| Nonhydrocarbon Gases Removed | 721,507 | 836,698 | 867,922 | 768,598 | 722,527 | | 1973-2013 |
| Marketed Production | 21,647,936 | 22,381,873 | 24,036,352 | 25,283,278 | 25,690,878 | 27,271,326 | 1900-2014 |
| Dry Production | 20,623,854 | 21,315,507 | 22,901,879 | 24,033,266 | 24,333,709 | 25,718,448 | 1930-2014 |

Click on the source key icon to learn how to download series into Excel, or to embed a chart or map on your website.

- = No Data Reported; -- = Not Applicable; **NA** = Not Available; **W** = Withheld to avoid disclosure of individual company data.

**Notes:** Beginning with monthly data for January 2006, "Other States" volumes include all of the natural gas producing states except: Alaska, Arkansas, California, Colorado, Kansas, Louisiana, Montana, New Mexico, North Dakota, Ohio, Oklahoma, Pennsylvania, Texas, Utah, West Virginia, Wyoming, and the Gulf of Mexico. Data for 2014 are estimated. Monthly preliminary (from January 2014 to present) state-level data for the production series, except marketed

https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Chapter-Executive-Summary.pdf
https://www.eia.gov/dnav/ng/ng_prod_sum_dcu_NUS_a.htm

# But some disagree.....

## Recent findings

- **Barnett Study**
  July 2015
  Scientists estimated regional and facility-level methane emissions in the Texas Barnett Shale, collecting data using aircraft, vehicular, and other ground-based platforms. Researchers estimate regional methane emissions are 50 percent higher than estimates based on the Environmental Protection Agency's Greenhouse Gas Inventory. Learn more »

- **Local Distribution Study**
  March 2015
  The study shows that methane emissions from local natural gas distribution systems are significant, especially in regions such as the Northeast where distribution infrastructure is older, but that progress is being made in reducing emissions from these systems, mainly through regulation

- **UT Study, Phase 1**
  December 2013
  The study found that methane emissions from equipment leaks and pneumatic devices were larger than previously thought and that techniques to reduce emissions from well completions are effective at capturing 99% of the methane that was previously vented to the atmosphere, providing a data-based example of EPA regulations working. Learn more »

- **UT Study, Phase 2**
  December 2014
  The study found that emissions from two sources—pneumatics and liquids unloadings—were responsible for a significant portion of methane emissions from the production sector. Learn more »

- **HARC/EPA Study**
  November 2014
  A statistical analysis of national production data suggests unpredictable events, such as malfunctions and maintenance, have a strong influence on emission rates. Learn more »

- **Methane Maps Release**
  July 2014
  EDF and Google Earth Outreach release interactive maps that show methane leaking from pipelines under city streets. Learn more »

- **Denver-Julesburg Flyover Study**
  May 2014
  The study estimated methane emissions that were three times higher than estimates derived from EPA data. The study also found that levels of smog-forming VOCs were twice as high as EPA estimates, and Benzene levels were 7 times higher than previously estimated. Learn more »

# Methane Research: The 16 Study Series

**AN UNPRECEDENTED LOOK AT METHANE FROM THE NATURAL GAS SYSTEM**

Methane ($CH_4$) is a growing environmental concern. Methane is a potent greenhouse gas that is contributing to climate change. Science confirms methane is a problem that requires urgent attention. Reducing emissions of both methane and carbon dioxide is critical to slowing the rate of earth's warming and limiting peak warming.

EDF ENVIRONMENTAL DEFENSE FUND®
Finding the ways that work

- **Gathering and Processing Study**
  February 2015
  Initial findings from the measurement report show wide variations in the amount of methane leaking at U.S. gathering and processing facilities. Researchers with the study suggest leak detection and repair policies can be effective at minimizing emissions from these sources. Learn more »

- **Transmission and Storage Study**
  February 2015
  The paper confirms compressors and equipment leaks are two primary sources for the sector's methane emissions. Learn more »

- **Boston Study**
  January 2015
  Using tower-based measurements, the study found methane emissions were are more than two times higher than inventory data would suggest, with a yearly average loss rate between 2.1 and 3.3 percent. Learn more »

- **Bottom-up** studies coincide with EPA
- **Top-down** studies find EPA underestimates

# **Why!?**

# EPA might be missing a small number of **super** emitters

Table S6. Evidence of heterogeneity of emissions magnitudes across studies.

| Study name | Industry stage | Measurement technique | Degree of heterogeneity noted | Pages with relevant statistics, tables, or quotes. |
|---|---|---|---|---|
| Allen *et al.* 2013 | Production | Direct measurement of unloading events | "Four of nine events contribute more than 95% of total emissions" | Article p. 3. |
| Alvarez 2012 | Production | Analysis of reported emissions | "10% of well sites accounted for 70% of emissions" | Article p. 3. Also see SI dataset in Microsoft Excel format. |
| Chambers 2006 | Processing | Down-wind differential absorption LIDAR | "At plant B a single intermittent leak from a pressure relief valve was located that increased site emissions from 104 kg/hr to 450 kg/h." | p. 6 |
| Clearstone 2002 | Processing | Direct measurement using Hi-Flow sampler | >100,000 devices sampled across 4 facilities. between 35.7% and 64.6% of leakage from each facility was found leaking from top 10 leaks in each facility. | Executive summary, Table 4 (p. 24). |
| Cormack, 2007 | Transmission compressors | Direct measurement with Hi-Flow | Top single leak accounted 40% of leakage. Top 20% of leaking components accounted for 80% of leakage. | Figure p. 15 |
| Harrison *et al.* 2011 | Compressor stations | IR camera, Hi-Flow sampler | Reported data in Appendix B show outliers. For example, ~2,800 valves and flanges were screened with IR camera and 29 leaks were found. The single largest of these leaks (>1000 mscf/year) is >100,000 times larger than valve and flange EF (0.05 or 0.09 mscf/year). Similar results seen elsewhere. See, e.g., blowdown line leaks from centrifugal compressors (table B2) where largest leak represents 70% of the total leakage. | See tabular data in Appendix B. |
| NGML, Clearstone, IES 2006 | Processing, well sites, gathering compressor stations | Direct measurement using Hi-Flow sampler and optical methods | > 74,000 components sampled. Approx. 1600 were found to be leaking (~2%). From executive summary: "Repairs to 10 largest emitting cost-effective-to-repair components at each site…would reduce natural gas losses by approximately…58%" | Executive summary (p. iii). For details, see Appendix 1 (separate PDF) which ranks leaks by emissions rate for ~1600 leaking sources. |
| Picard, 2005 | All stages | Sampling via various methods | "Top 10 leaks typically contribute more than 80% of emissions from leaks." | p. 3 |
| Shorter, 1997 | All stages | Remote sampling via tracer methods | Repeated evidence of skewed emissions distributions: See tables 1–7. Evidence includes: top emitters of size 100x to 10,000x larger than small emitters (table 9); standard deviations in excess of mean emissions rate in many cases, indicating heavy-tailed distribution (table 7). | Tables 1-9 |
| Trefiak 2006 | Compressor stations and gas plants | Optical measurement and Hi-Flow sampler | 23% of the 144 fugitive emissions sources were responsible for 77% of leakage. | Fig. 2.1 |

# EPA misses **abandoned** wells

- Mary Kang (Princeton) Summer 2014 Thesis: Leakage from Abandoned Oil and Gas Wells
- Methane emissions from AOG wells **are not accounted for in any GHG emissions inventories** , either at the state or national levels in the U.S. or abroad.
- Leakage rates are **equivalent to 0.3 to 0.5% of gross gas withdrawal** (in PA for 2010)

More or less established:
Actual leakage **25-75% higher** than EPA's estimate

EPA: **1.5%**
Corrected: **1.85% -2.95 %**
for natural gas systems

Source: Brandt et al. 2014. Methane Leaks from North American Natural Gas Systems. Science 343 ,733.

# How does methane leakage affect the Carbon Intensity of CNG and LNG?

Conventional wisdom suggests a 20% reduction from diesel based

# Some disagree

CNG Passenger Vehicles

CNG Buses

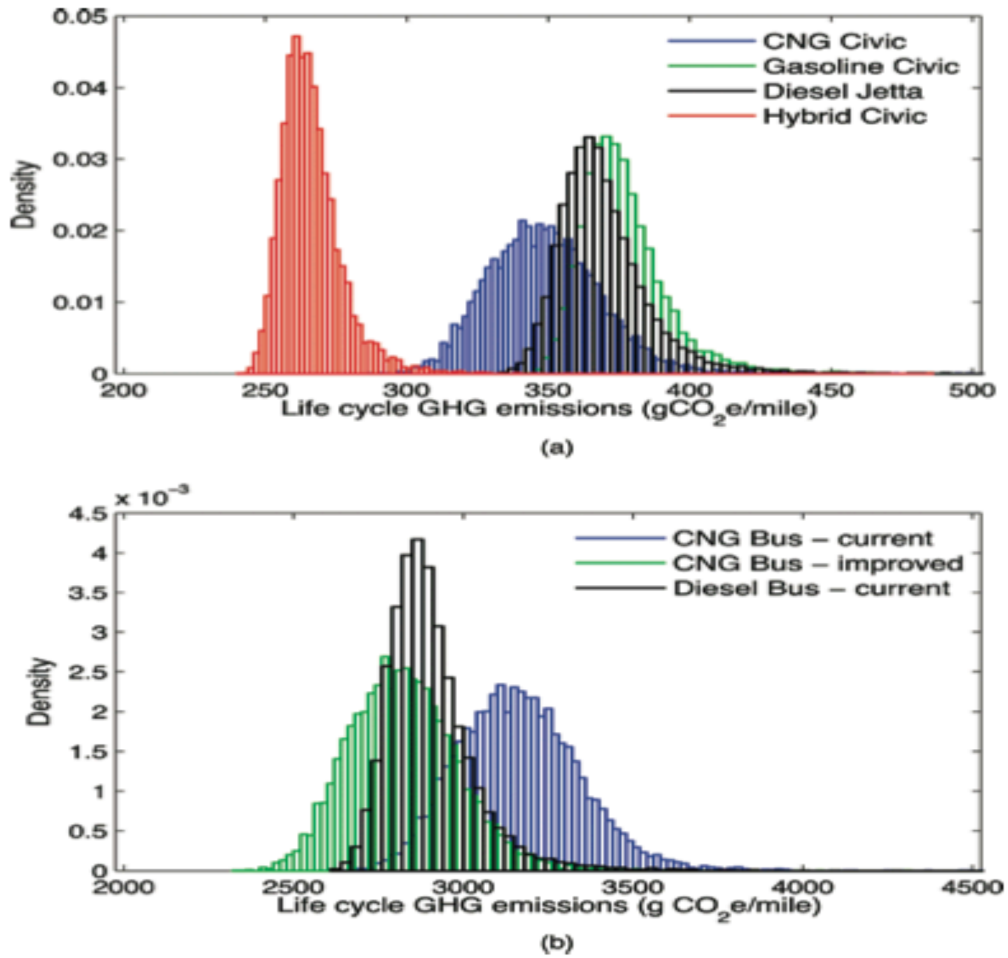



**Figure 2.** Comparison of the sample output probability distributions representing GHG emissions per mile driven in (a) small cars using CNG, gasoline, diesel and gasoline hybrids and (b) in buses using CNG and diesel.

Source: Venkatesh et al. 2013

# Variability in:

- Upstream methane leakage
  - Regions (regulations)
  - Company culture

- Upstream energy uses
  - Geology
  - Fuel type
  - Refinery efficiency
  - Distribution distances

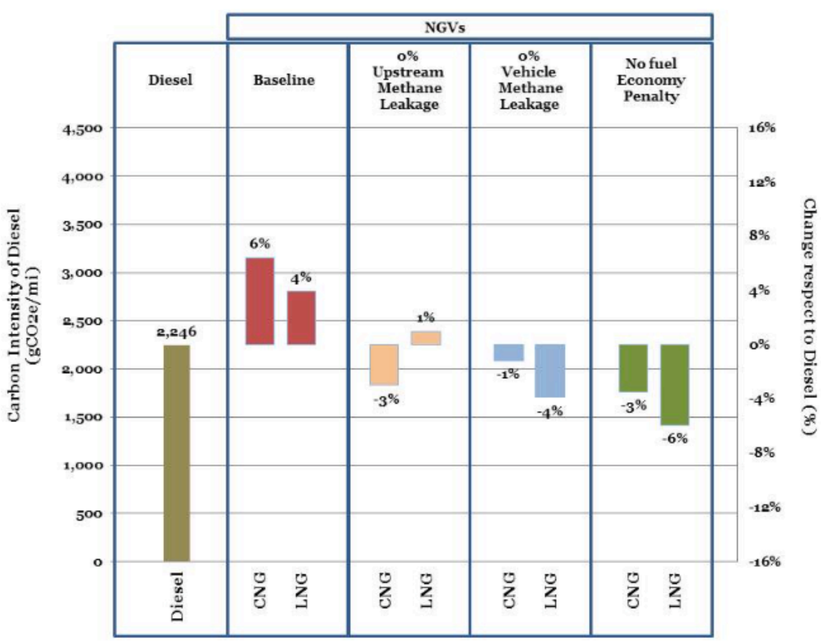
- Vehicle slip and fuel economy
  - Application: Heavy/Medium/Light
  - Drive Cycle
  - Model
  - Model year

**But which variables are important?**

# Sensitivity Analysis suggest vehicle leakage and vehicle efficiency is the highest contributor to WTW carbon?

OAT Sensitivity Analysis

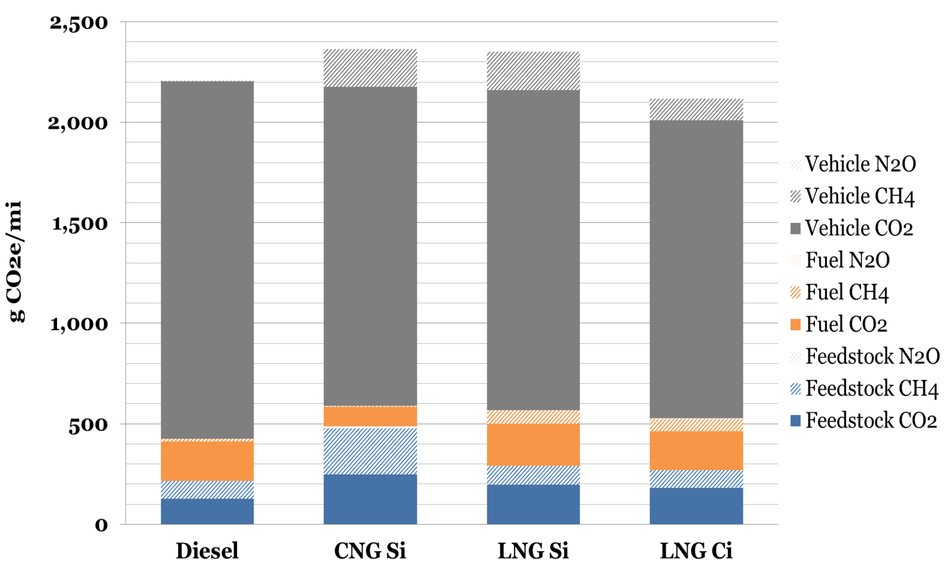
**Baseline leakage** is 1.5%




Upstream vs. vehicle / $CO_2$ vs. $CH_4$

**Fuel economy**: 5.9 mpg (Diesel), 5.6 (HPDI NGV) (95%), 5.0 (SI NGV) (85%)

**Methane slip**: 0.005 $gCH_4$/mi (Diesel), 4.2 g/mi (Si NGV), 3.84 g/mi (HPDI NGV)




Si vs hpdi

# One type of methane leakage greatly **overlooked:** **Vehicle Methane Slip**

Diesel methane slip:
**0.005** gCH4/mi

Natural gas methane slip:
**4.2** g CH4/mi HPDI
**3.84** g CH4/mi Si

Crank case:

Exhaust:

# Renewable Natural Gas Potential


Animal manures

Waste water biogas

Food & green waste

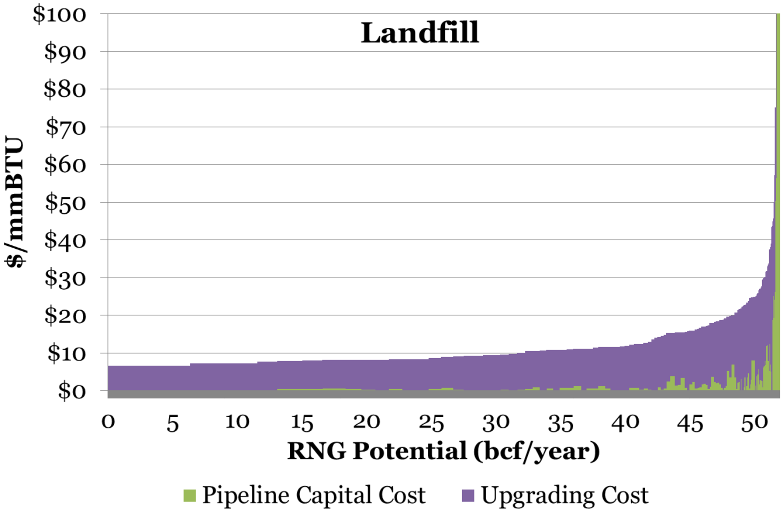
Landfill gas

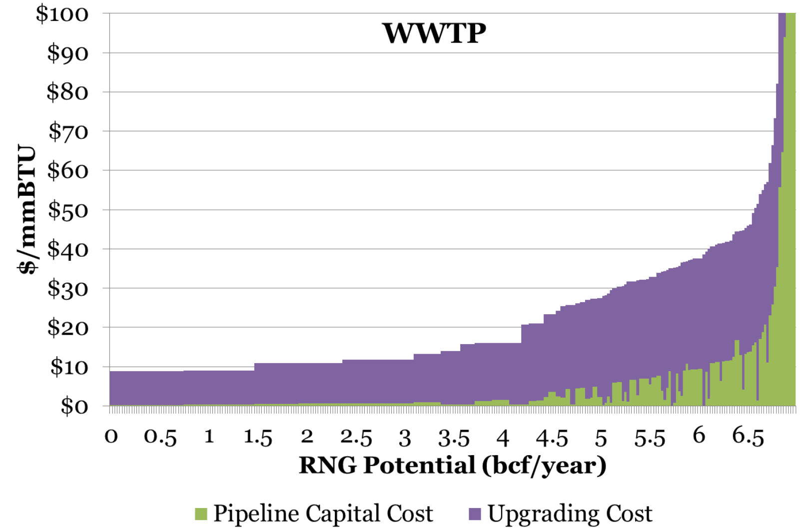
# 3 levels of estimates

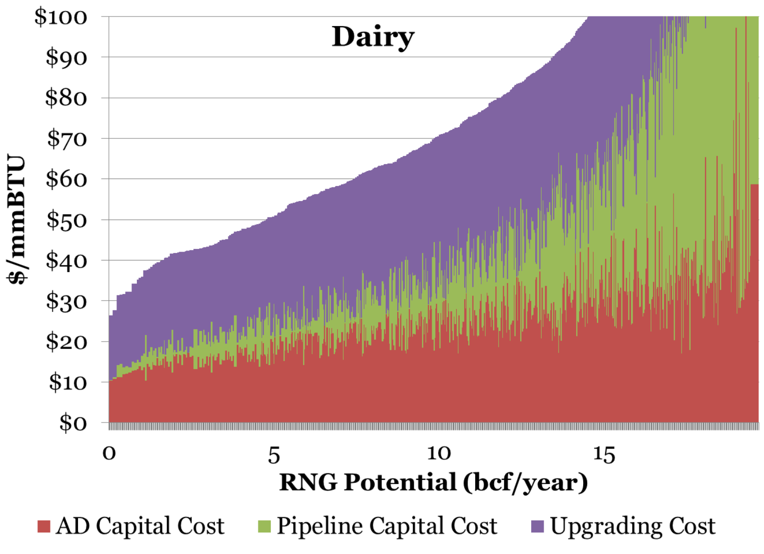
- **Theoretical (stoichiometric)**
- **Technical/Gross**
- **Commercial**

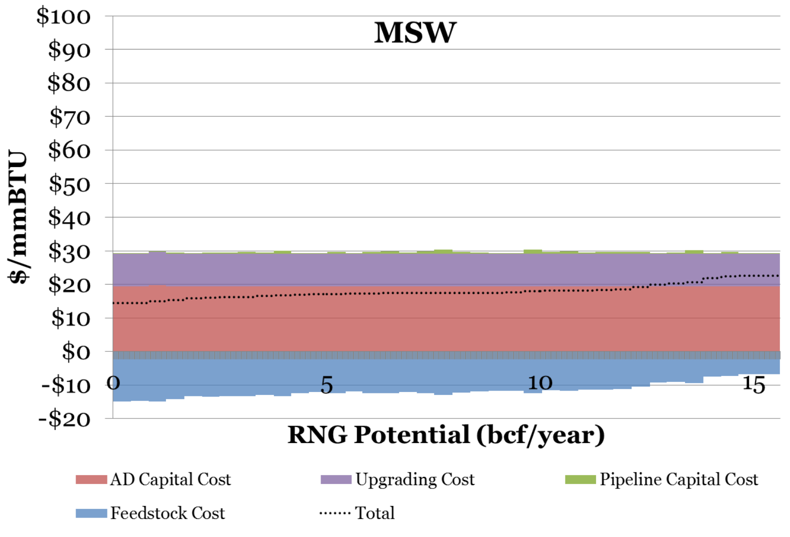
definitions are not standard across studies!!

# California RNG Supply Curves

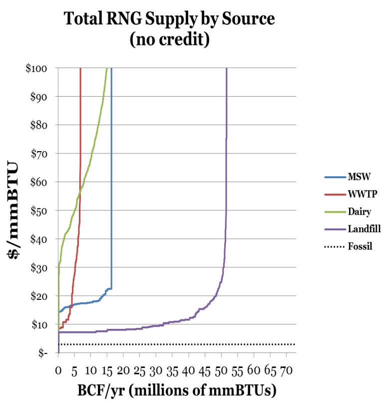


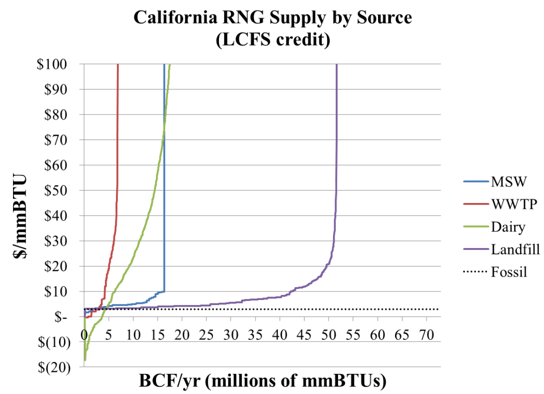



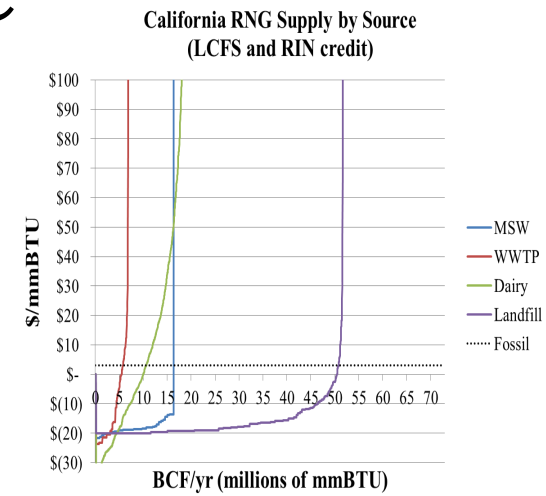
# What happens when we add carbon and renewable credits?




Most sources of biogas are not commercial



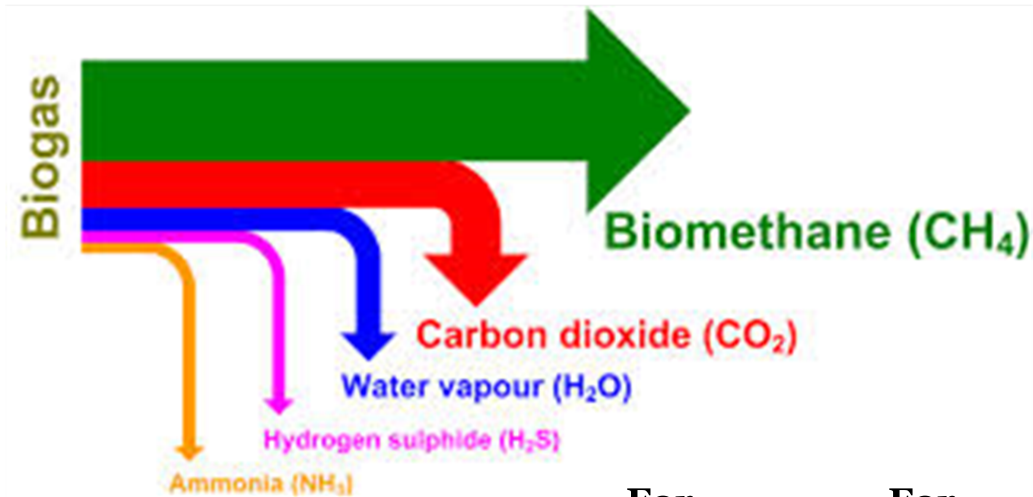

About **8.1 BCF/year** are commercially feasible with an LCFS credit of $120/ton of carbon:
8.1 (total) = 0 (Landfill) + 4.3 (Dairy) + 3.1 (WWTP) +1.7 (MSW)
(**50%** of all transportation NG use in California[2])
(**2.5%** diesel use)




About **83.5 BCF/year** are commercially feasible with an LCFS credit of $120/ton of carbon and a RIN credit of $1.78 per gallon of ethanol equivalent:
83.5 (total) = 50.8 (Landfill) + 16.3 (MSW) + 10.6 (Dairy) + 5.8 (WWTP)
**(5X** all transportation NG currently used in California[2]**)**
**(25%** diesel use**)**

[2] 16,467 Million Cubic Feet of Natural Gas were used for transportation in California in 2015 http://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SCA_a.htm

# Barrier 1: Biogas specs for injections are the stringest




| | | For power | For Injection |
|---|---|---|---|
| Illustration for Landfill Diverted Waste | Biogas | "Treated" Biogas | Biomethane* |
| **Gas Composition and Heating Value** | | | |
| CH4 | 62.0% | 62.0% | 98.5% |
| CO2 | 37.6% | 37.6% | 0.8% |
| O2, H2, N2, Others | 0.4% | 0.4% | 0.7% |
| Heating Value (btu/scf) | 625 | 625 | 990+ |
| **Two of the Key Trace Constituents** | | | |
| H2S | 300 ppm | 1 ppm | 1 ppm |
| Siloxanes | 4,000 ppb | 70 ppb | Non-detectable |

* Gas composition and trace constituent limits will/may differ by utility

# Injection standards vary by company

Table 7-3 Basic Pipeline Quality Standards for Major California Distributors

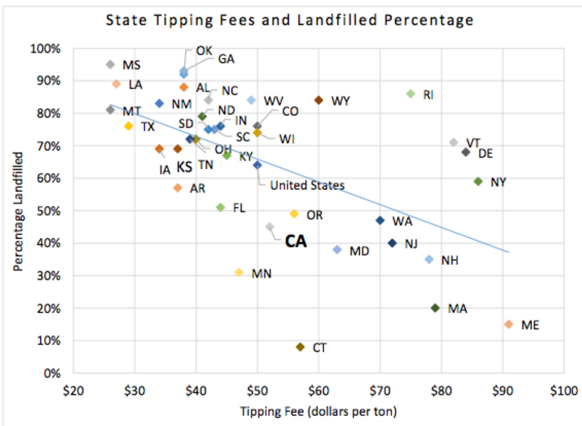
| Gas Component or Characteristic | Pacific Gas and Electric Company | Southern California Gas Company |
|---|---|---|
| Carbon dioxide ($CO_2$) | ≤1% | ≤3% |
| Oxygen ($O_2$) | ≤0.1% | ≤0.2% |
| Hydrogen sulfide ($H_2S$) | ≤0.25 grains/100 scf | ≤0.25 grains/100 scf |
| Mercaptan sulfur | ≤0.5 grains/100 scf | ≤0.3 grains/100 scf |
| Total sulfur | ≤1 grain/100 scf | ≤0.75 grains/100 scf |
| Water ($H_2O$) | ≤7 lb/million scf | ≤7 lb/million scf |
| Total inerts | No requirement | ≤4% |
| Heating value | Specific to receipt point | 970 – 1,150 Btu/scf |
| Landfill gas | Not allowed | No requirement |
| Temperature | 60 – 100° F | 50 – 105° F |
| *Gas Interchangeability* [a] | | |
| Wobbe number | Specific to receipt point | Specific to receipt point |
| Lifting index | Specific to receipt point | Specific to receipt point |
| Flashback index | Specific to receipt point | Specific to receipt point |
| Yellow tip index | Specific to receipt point | Specific to receipt point |

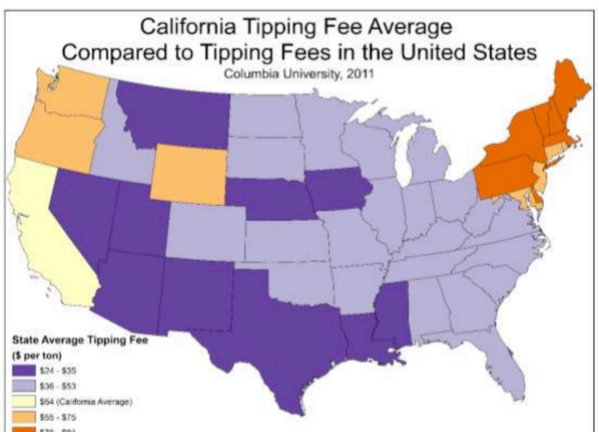
scf = Standard cubic feet

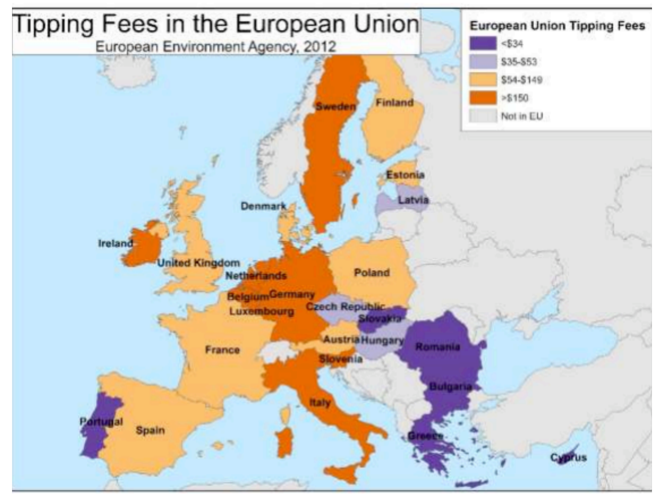
Btu = British thermal units

[a] The various indices— Wobbe number, Lifting index, Flashback index, and Yellow tip index—are all means of determining the gas interchangeability (AGA, 1946)

# Barrier 2: In the case of solid waste, it is cheaper to dump



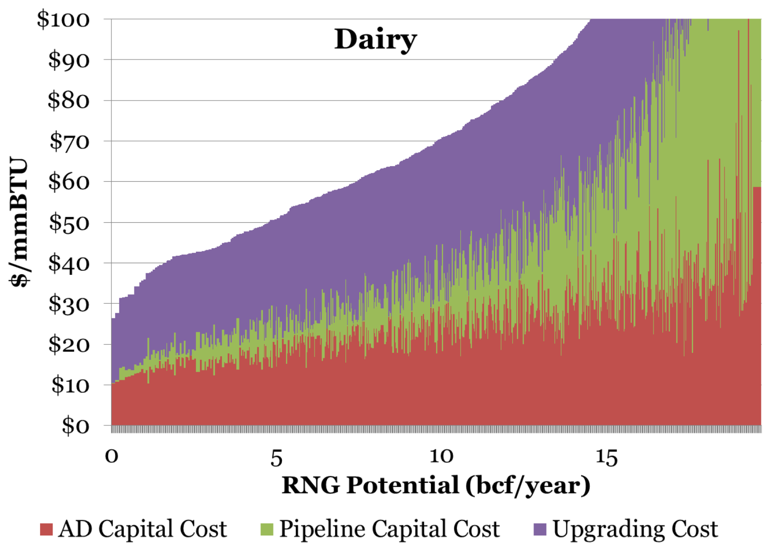




Mind the scale!

Source: http://www.calrecycle.ca.gov/publications/Documents/1520%5C20151520.pdf

# Barrier 3: For Manure Biogas

- Capital costs are high
- Productivity is low since feedstock has already been stripped of most CH4 in the cow.



# Thank you!

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