Carbon Intensity of Natural Gas C8 trucks in Transportation (focus on long haul)

Rosa Dominguez-Faus
NextSTEPS ITS UC Davis

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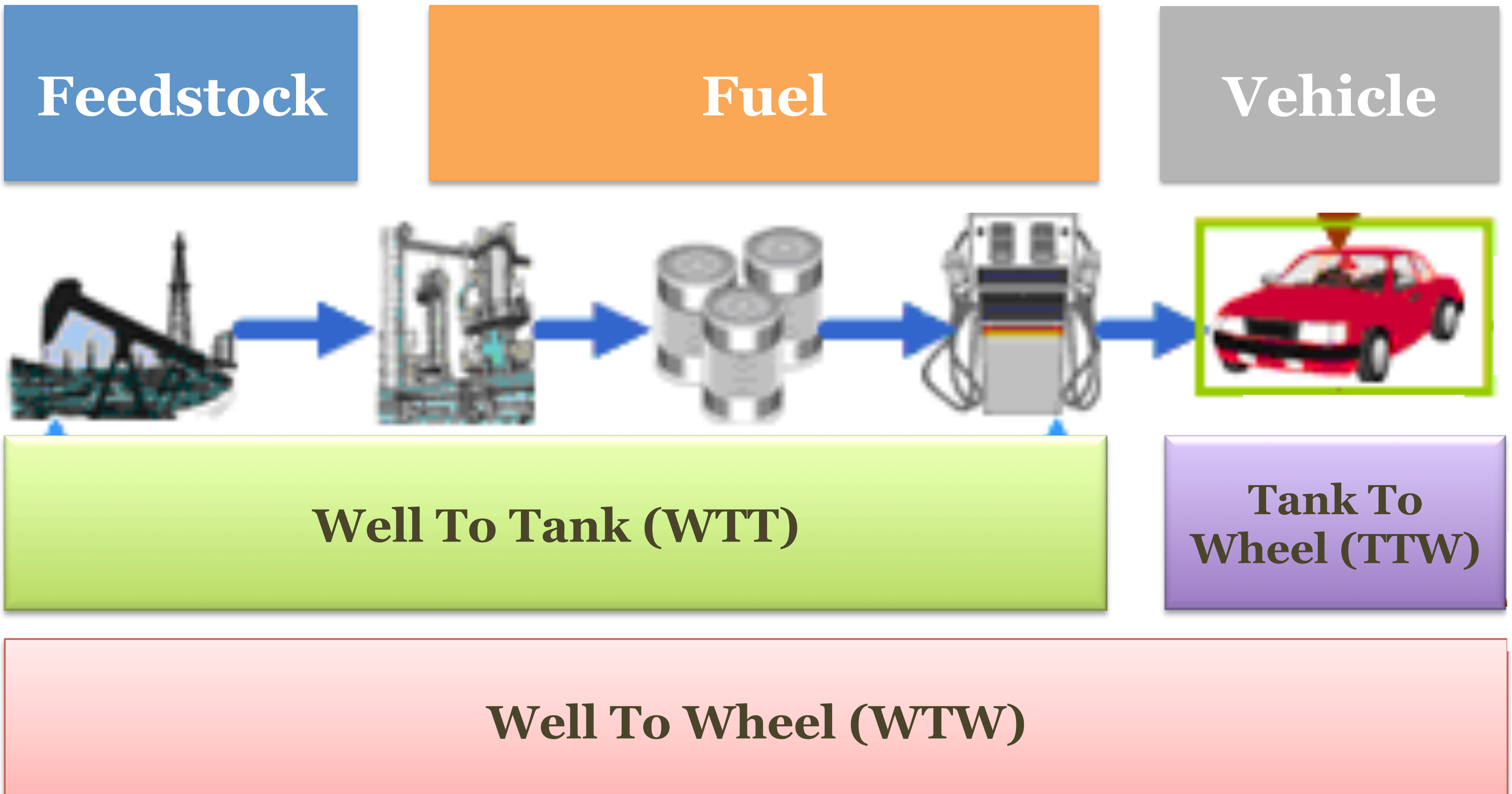
LCA models

- LEAP and BioGRACE (EU)
- EPA models (RFS2)
- CAGREET1.8 (LCFS)
- CAGREET2.0 (updated LCFS)
- OPGEE (ARB) for upstream carbon intensity of 270 individual crude oil producing fields and crude blends
- GHGGenius (Canada)
- **GREET1 2014 (this study)**

Updates in GREET1 2014

- **Added Heavy Duty Vehicle module**
- Added Black Carbon and Organic Carbon (SLCP- short lived climate pollutants)
- Added emissions of oil drilling (still not shale oil pathway)
- Updated stationary combustion emission factors
- Update of refining efficiency and GHG of petroleum products
- Expanded oil sands modeling

Boundaries of Life Cycle Analysis



Are NGV trucks less carbon intensive than diesel trucks? **It depends**

- Geographic scope
- Upstream leakage
- Vehicle type
  - Fuel economy
  - Methane slip
- GWP100
- LHV/HHV

Our scope is national: National average for methane leakage

EPA/EIA= **1.2-1.5%**

Actual leakage 25-75% higher than EPA's 1.5% estimate (Brandt et al.)

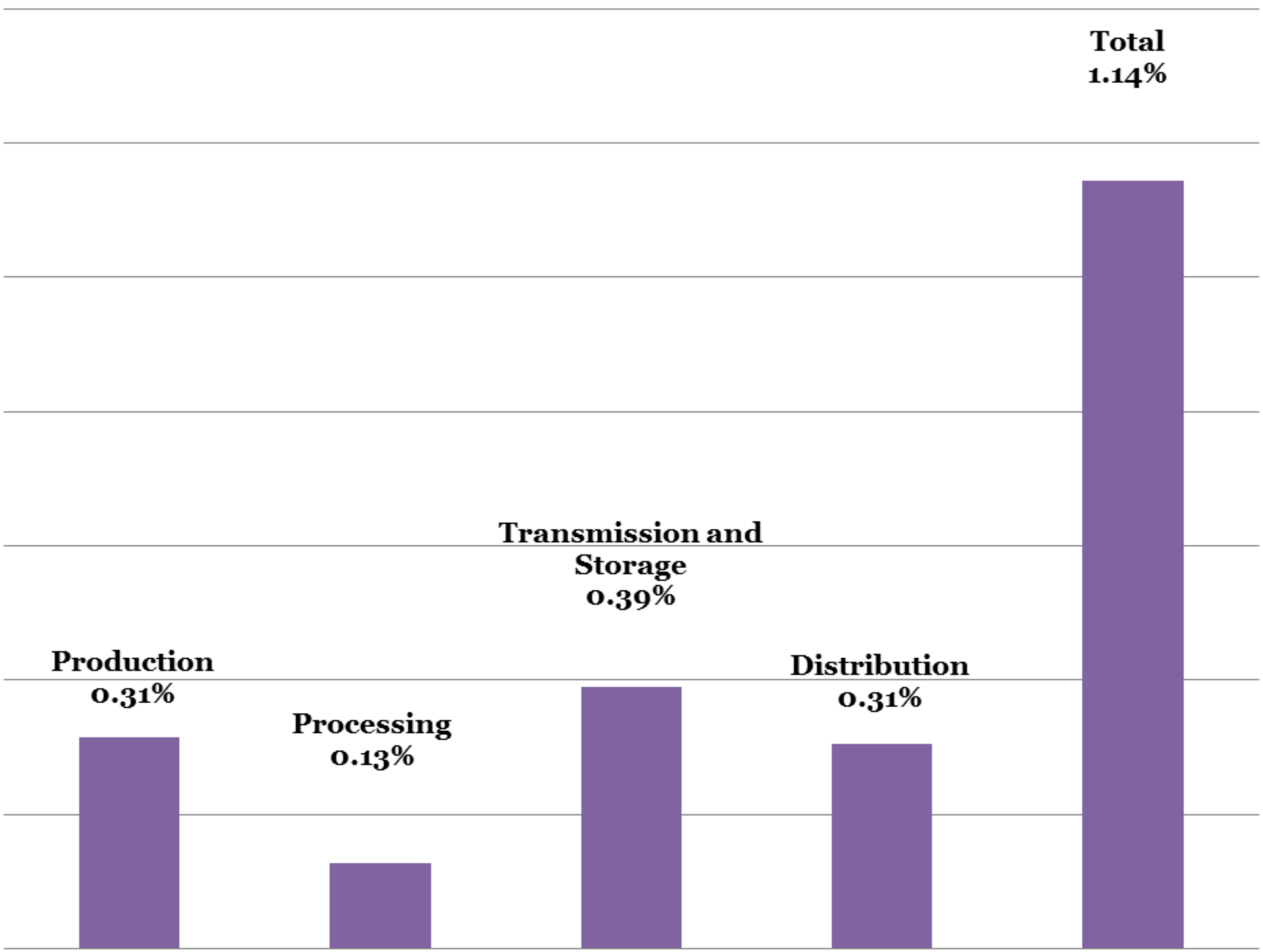
"superemitters" (e.g. sources with extremely high emissions, much larger than normal operation) (Brandt et al.)
Abandoned wells (Kang et al.)

Estimates from airborne measurements were typically higher than inventories…. studies estimating high leakage rates, such as those done by the National Oceanic and Atmospheric Administration, including Karion et al. (2013), were unlikely to be representative of the NG industry since those emissions would exceed the unaccounted emissions from all sources.

Corrected: **1.87% -2.95 %**

We will test 0 to 3%

Methane Leakage in Natural Gas Systems
GREET1 2014
(total: 235 gCH4/mmBtu)



Vehicle type: **long haul** trucks

Diesel **5.9** mpg (fuel economy)

Natural gas **5.6** HPDI (95%), **5.0** SI (85%)

Diesel **0.005** gCH_4/mi (methane slip)

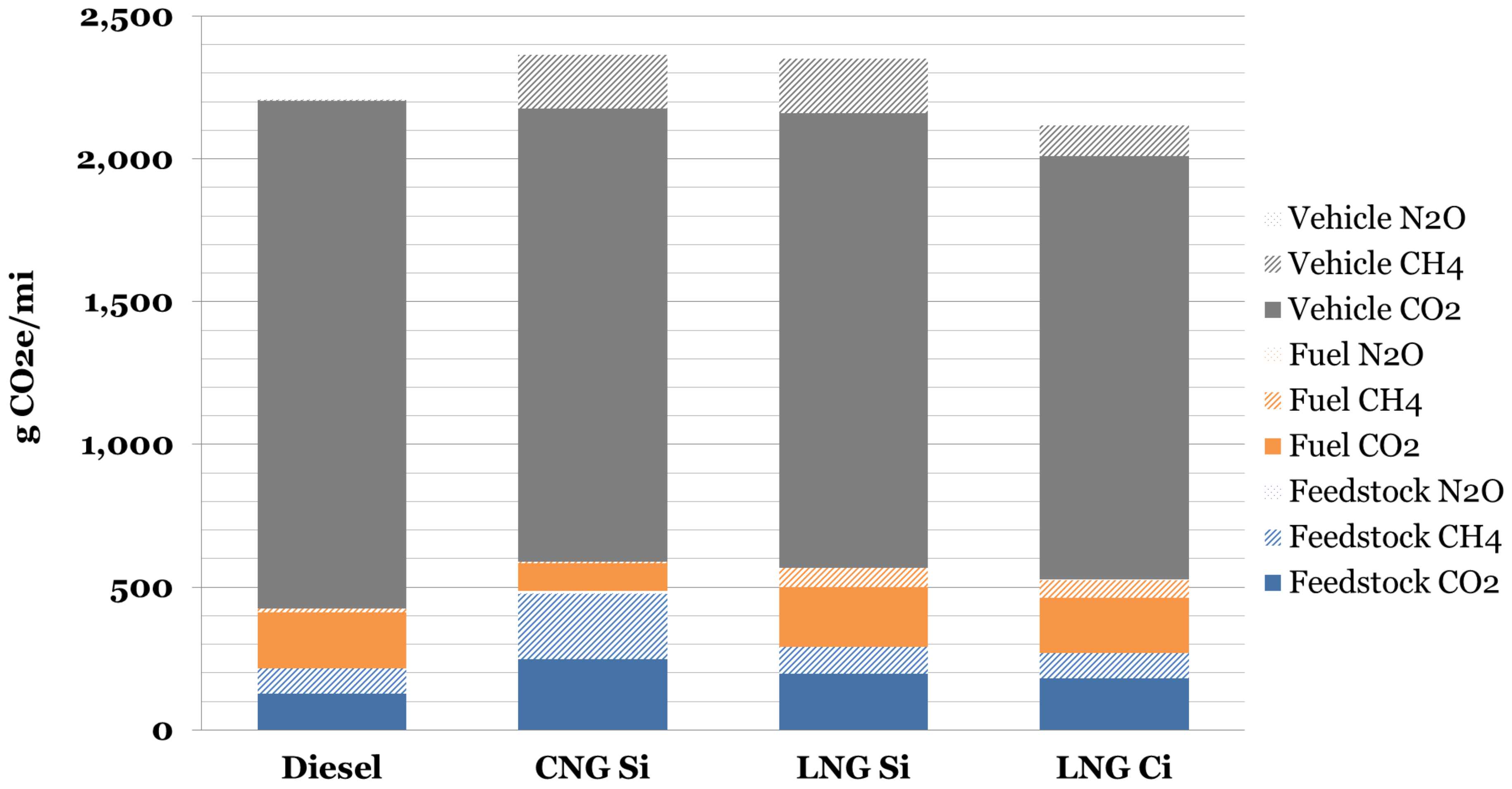
Natural gas **4.2** g/mi HPDI, **3.84** g/mi Si

Physical Properties of natural gas, diesel and methane

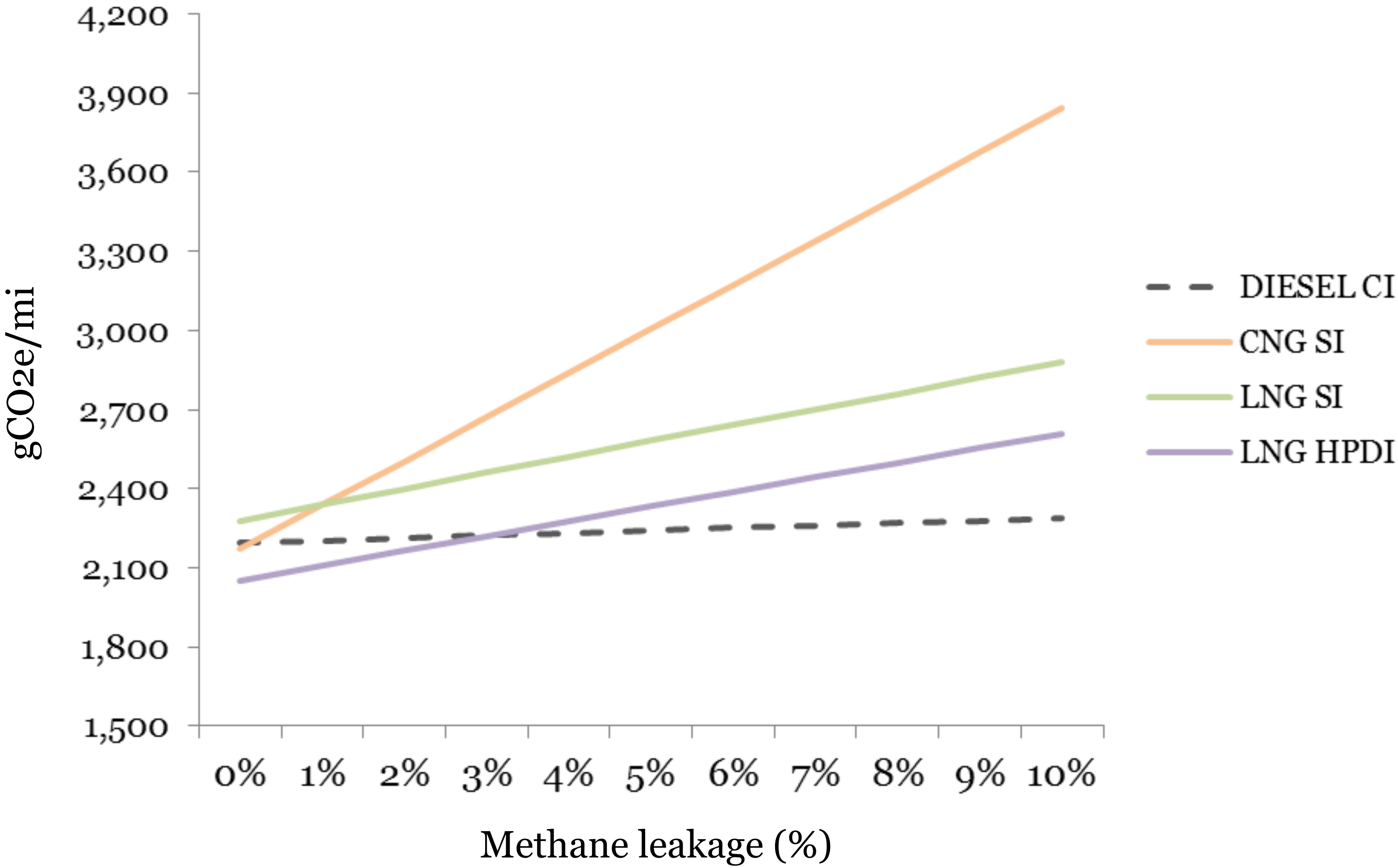
- GWP100: **30**
- **LHV**:
  - 983 Btu/ft3 NG
  - 740,720 Btu/gal LNG
  - 128,450 Diesel

What does this mean for the carbon intensity of NGV C8 trucks?

Grams of CO2e per mile



Carbon Intensity under different methane leakage



Summary of results

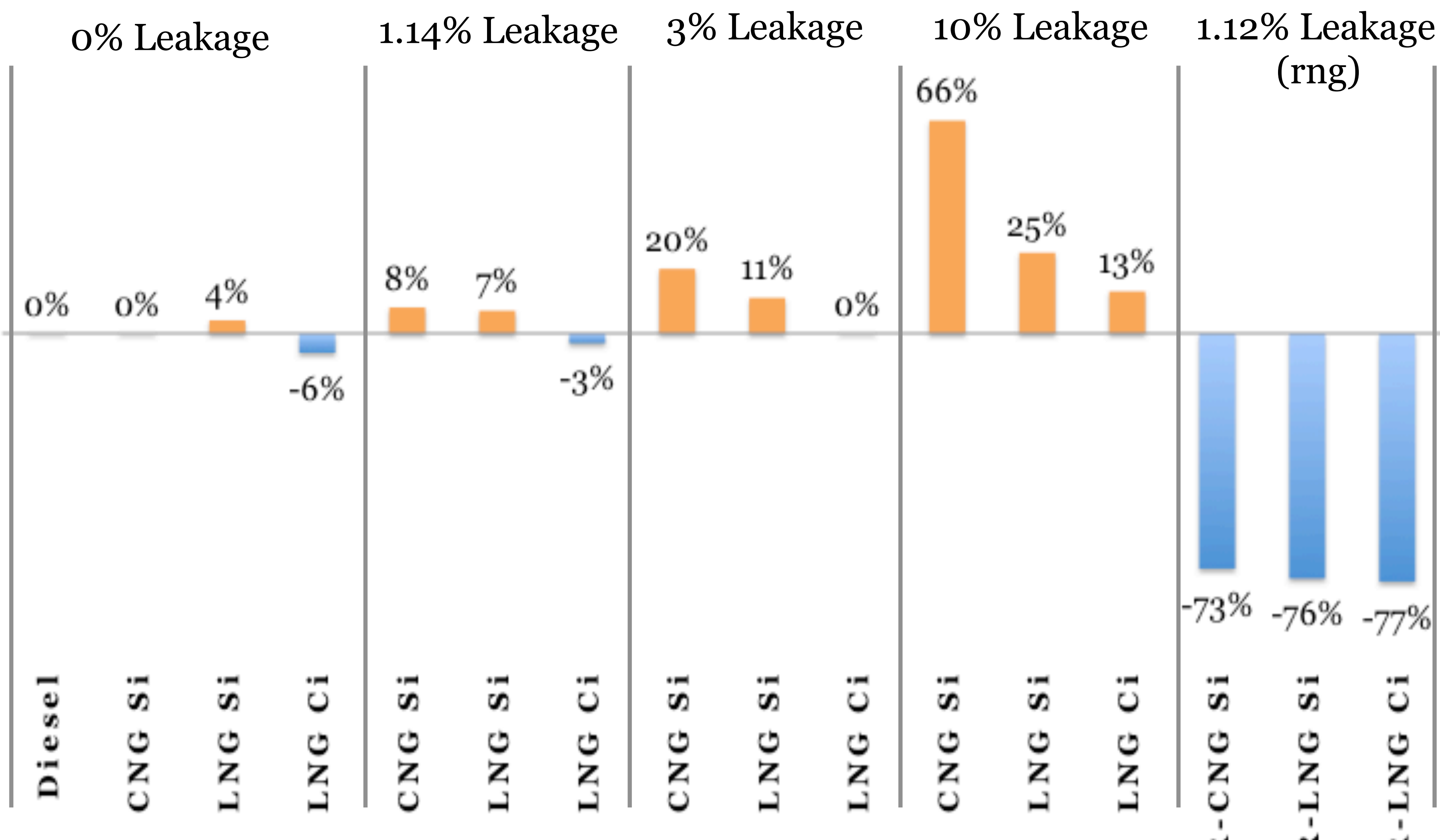
- Majority of emissions happen in TTW
  - Suggests improving fuel economy is key
- WTT CNG is dominated by methane leaks
- WTT LNG is dominated by high energy inputs of liquefaction
- BLR is 3% for HPDI and ~0% for SI

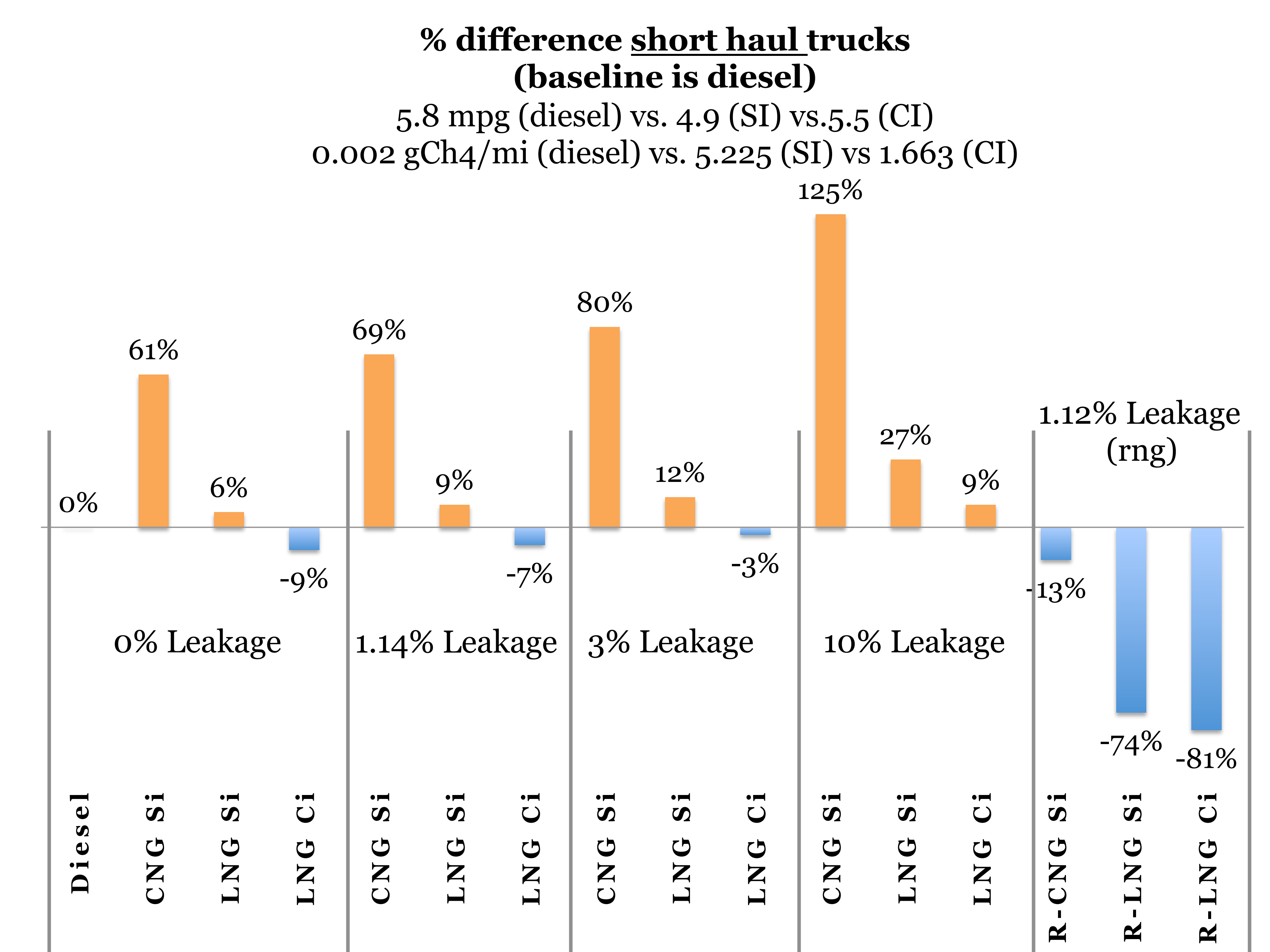
Limitations of this analysis

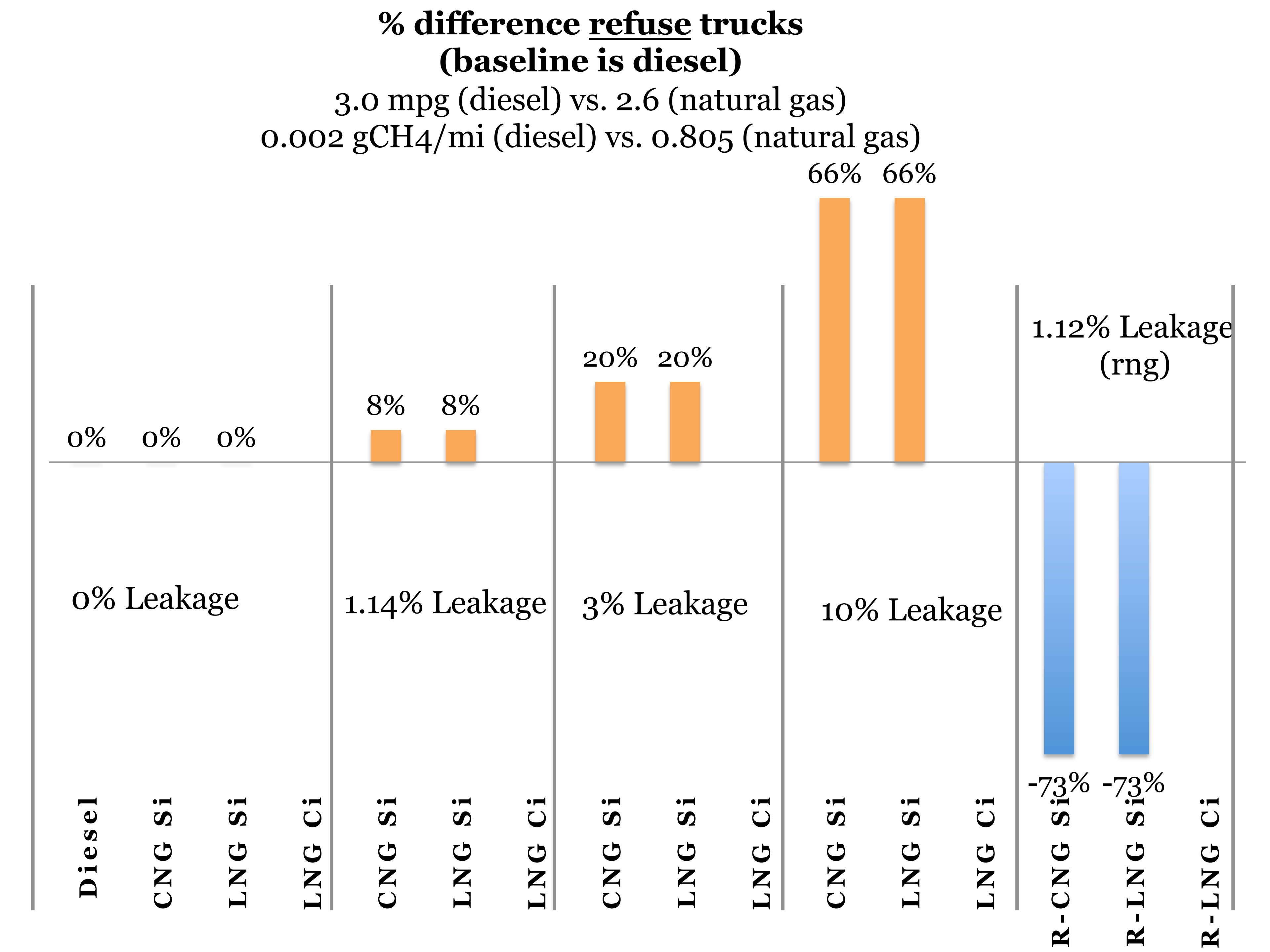
- What if leakage was higher/lower?
- What about biogas?
- Only long-haul trucks, what about refuse trucks, buses?

- Short haul trucks

% difference in carbon intensite of long haul trucks (baseline is diesel)



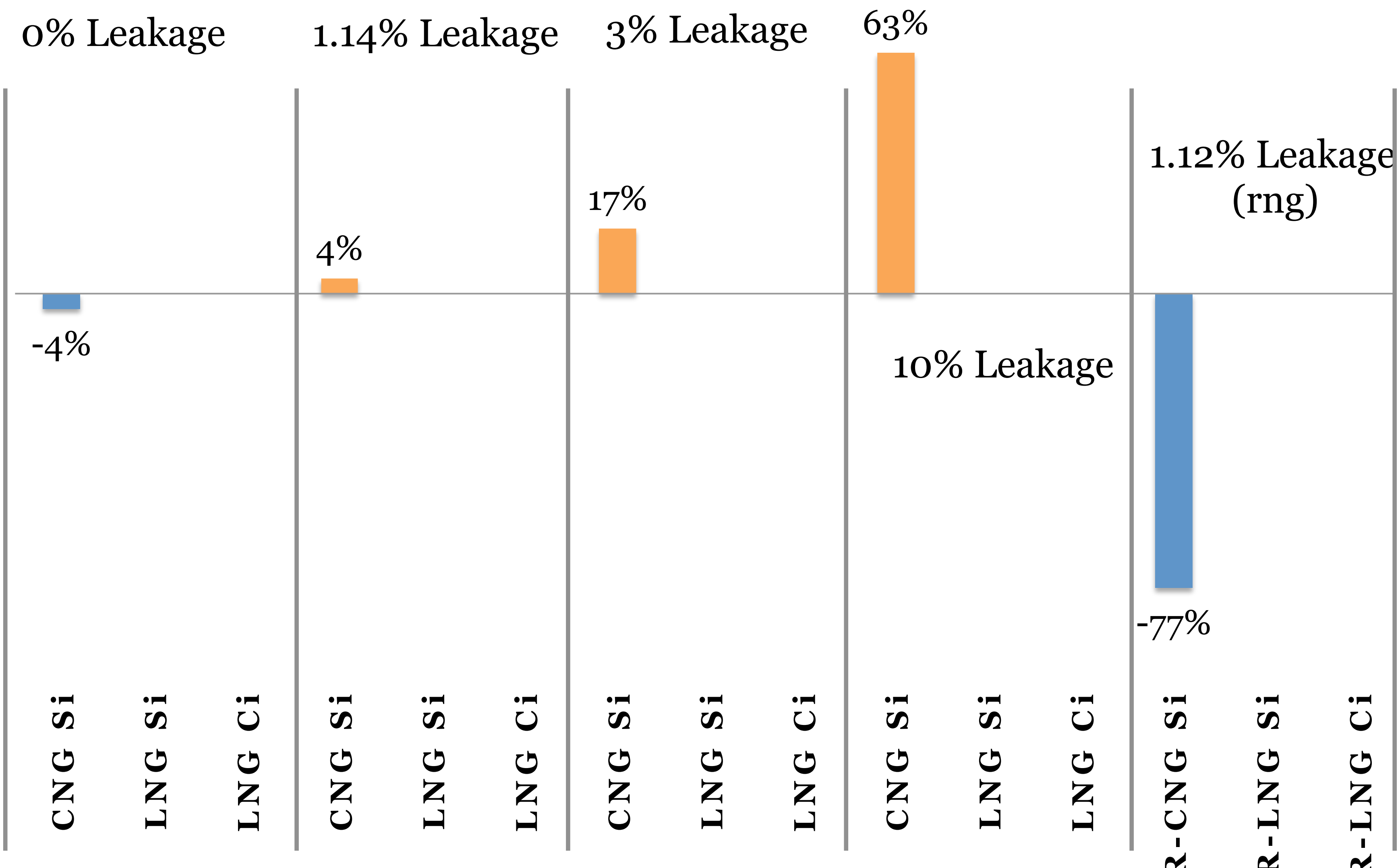

% difference short haul trucks
(baseline is diesel)
5.8 mpg (diesel) vs. 4.9 (SI) vs.5.5 (CI)
0.002 gCh4/mi (diesel) vs. 5.225 (SI) vs 1.663 (CI)
0%
61%
6%
-9%
69%
9%
-7%
80%
12%
-3%
125%
27%
9%
-13%
-74%
-81%
0% Leakage
1.14% Leakage
3% Leakage
10% Leakage
1.12% Leakage (rng)
Diesel
CNG Si
LNG Si
LNG Ci
CNG Si
LNG Si
LNG Ci
CNG Si
LNG Si
LNG Ci
CNG Si
LNG Si
LNG Ci
R-CNG Si
R-LNG Si
R-LNG Ci


% difference refuse trucks
(baseline is diesel)
3.0 mpg (diesel) vs. 2.6 (natural gas)
0.002 gCH4/mi (diesel) vs. 0.805 (natural gas)
0% Leakage
1.14% Leakage
3% Leakage
10% Leakage
1.12% Leakage (rng)
0%
0%
0%
8%
8%
20%
20%
66%
66%
-73%
-73%
Diesel
CNG Si
LNG Si
LNG Ci
CNG Si
LNG Si
LNG Ci
CNG Si
LNG Si
LNG Ci
CNG Si
LNG Si
LNG Ci
R-CNG Si
R-LNG Si
R-LNG Ci

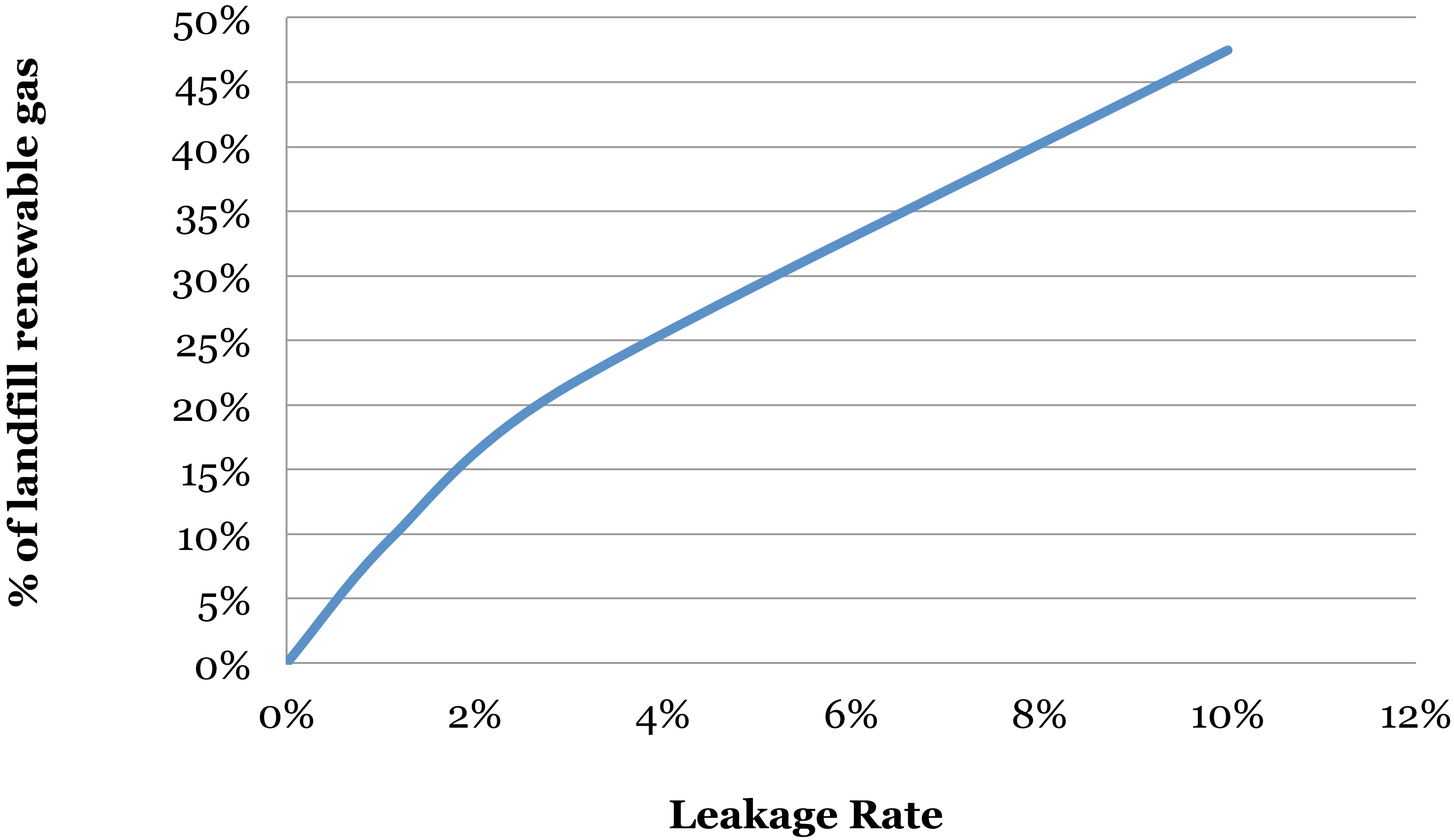
% difference school buses (baseline is diesel)

7 mpg (diesel) vs 6 (natural gas SI)

0.003 g CH4/mi (diesel) vs 0.098 (natural gas)



What percentage of renewable under each leakage?



Another limitation to this analysis

- GREET1 Lacks granularity
- Not good for state specific analyses (e.g. LCFS)

Differences with LCFS

- Different functional unit: Carbon Intensity of Fuel vs. Carbon Intensity of Transportation

  gCO2e/mi vs. gCO2/MJ
- CAGREET1.8 (2009)
  - No shale
  - No drilling/fracking emissions
  - No methane leakage
  - Old GWP numbers
  - ....
- California specific numbers (CAGREET2.0)

LCFS vs. new LCFS (GCO2e/MJ)

- ARB has very recently proposed new LCA numbers for NGVs via the LCFS that are ~10% worse than before (and even more so for LNG).
- They are proposed for adoption in February, to take effect in 2016.

Important differences between national and California results

- It's not the Leakage Rate!
- Other factors that affect upstream emission:
  - Distribution distances
  - Oil mix /Gas mix
  - Renewable electricity
  - Co-benefit of tighter air quality control for stationary sources

Take home points

- US
  - NGV trucks only better than diesel if equal or better fuel economy
  - When a high efficiency engine option is not available (refuse trucks, buses…) natural gas always performs worse.
  - Majority of emissions happen in TTW
    - Suggests improving fuel economy and reducing methane slip is key
  - WTT CNG is dominated by methane leaks whereas WTT LNG is dominated by high energy inputs of liquefaction
  - BLR is 3% for HPDI and ~0% for SI
  - 1% leakage is offset by 10% RNG blend,
  - 3% leakage is offset by 20% RNG blend
  - 10% leakage is offset by ~50% RNG blend

- In California,
  - All fuels have a lower carbon intensity due to
    - Renewable electricity
    - Tighter air quality standards
  - Leakage rate assumed as the US average but distances and distribution option change.
  - CNG could be better than LNG if compressors use renewable electricity
  - Vehicle fuel economy is still key

Acknowledgements

Advise

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Our team

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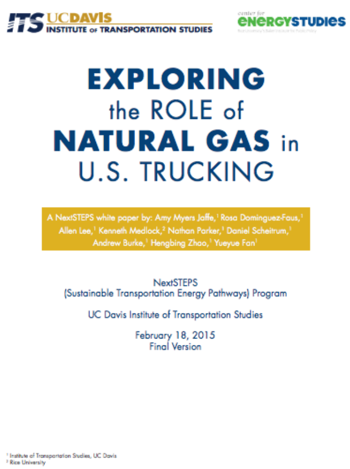
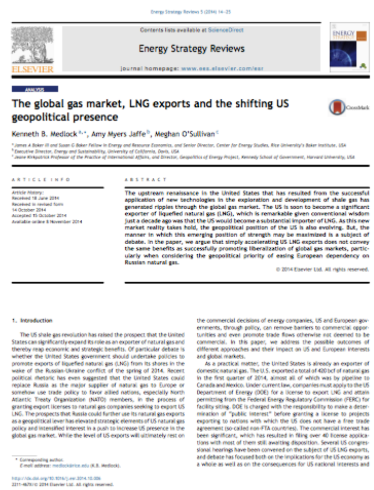
- Nathan Parker *(researcher)*
- Andy Burke *(researcher)*
- Hengbing Zhao *(researcher)*
- Allen Lee *(graduated)*
- Lin Zhu *(graduated)*

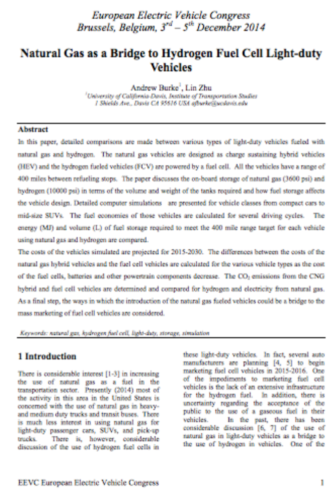
Outside collaborators:

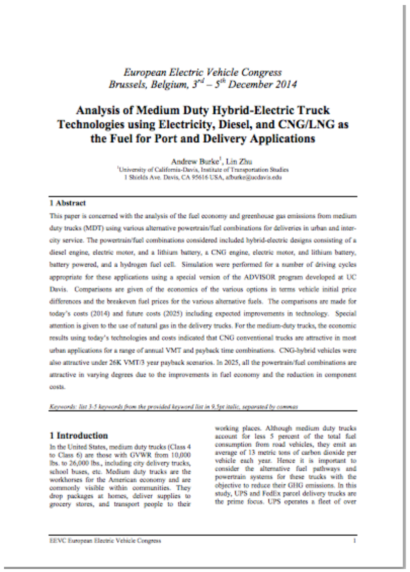
- Robert Harriss *(EDF)*
- Ken Medlock *(Rice University)*

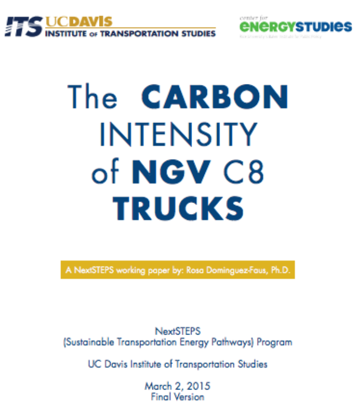
Our Recent Studies

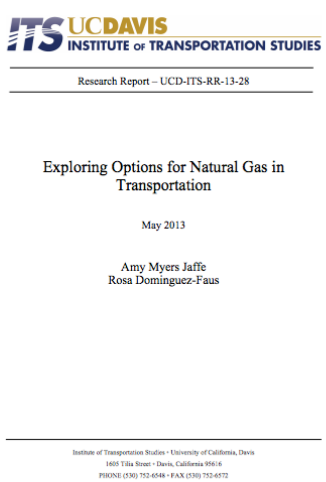


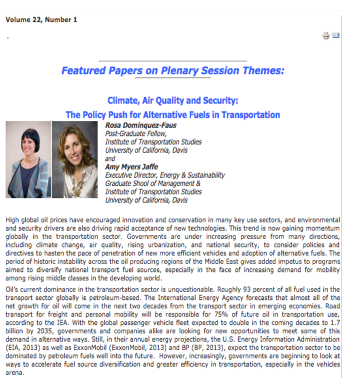










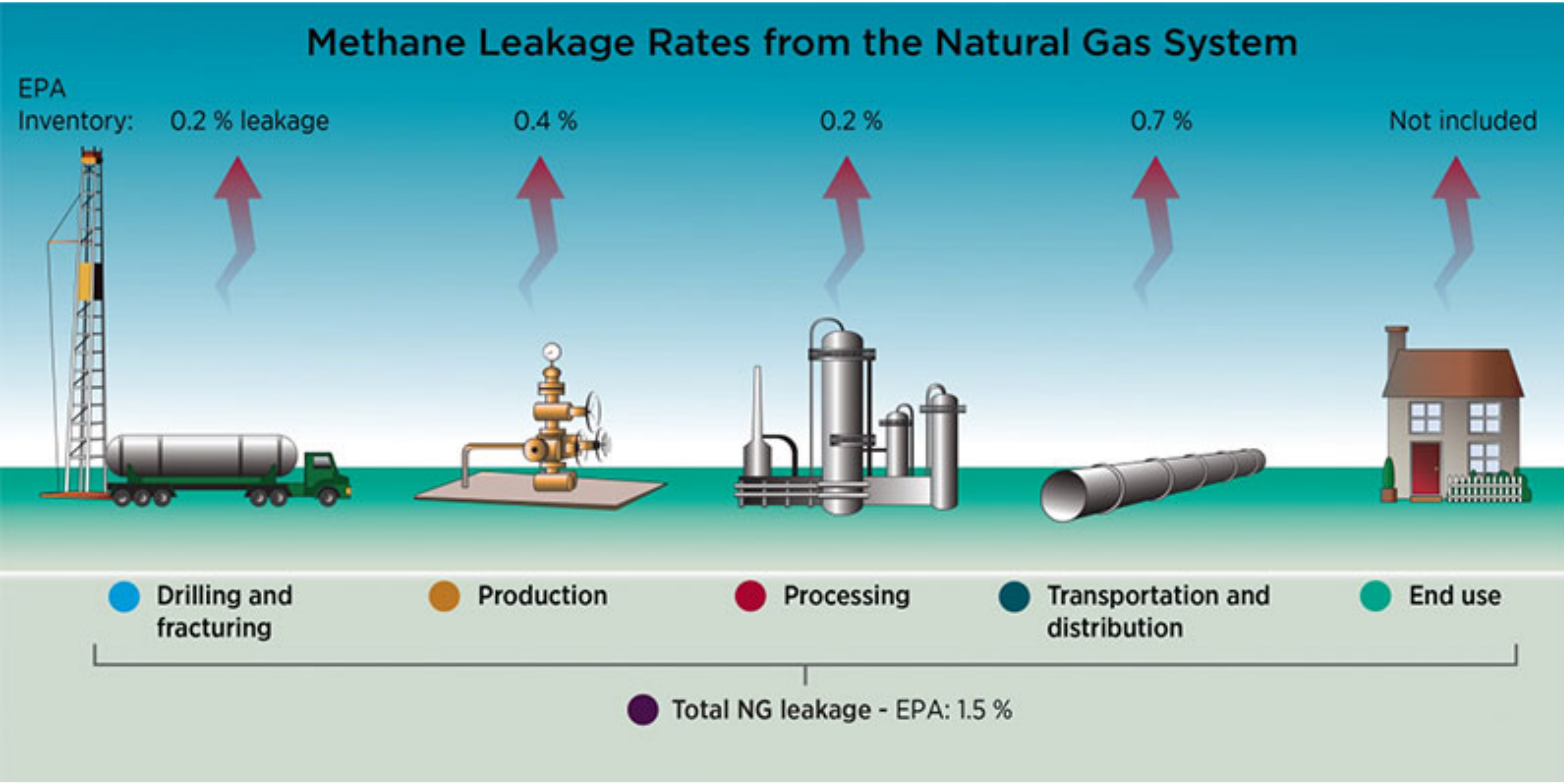


Thank you!

rdominguezfaus@ucdavis.edu

Extras

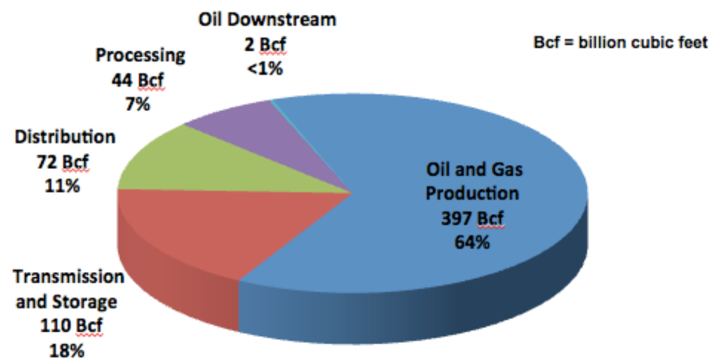
Drilling/Production/Processing = 0.8%
Transmissions/Distribution= 0.7%
Refueling stations/Vehicles = NA



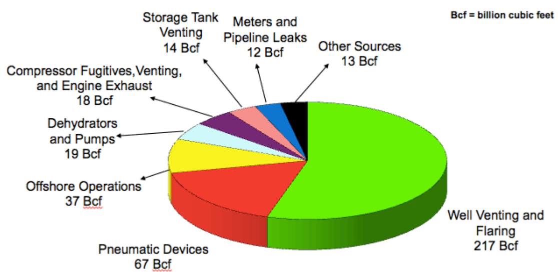
Picture: EDF

Where are the leaks?

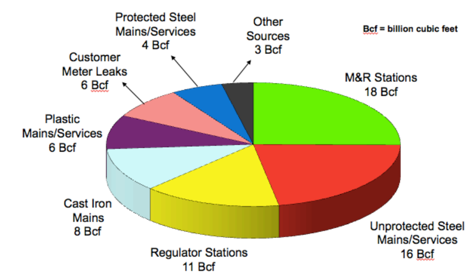
- 2009 U.S. methane emissions from oil and natural gas industry: 624 Bcf (3.8% of total U.S. greenhouse gas emissions)



Production

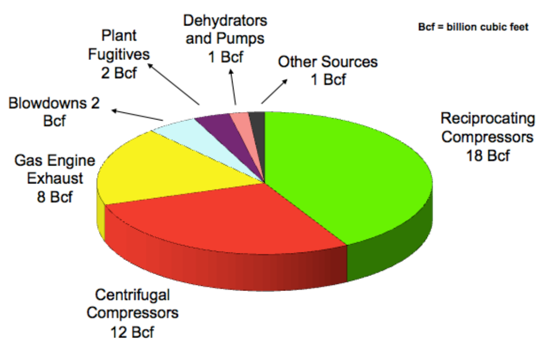


Distribution



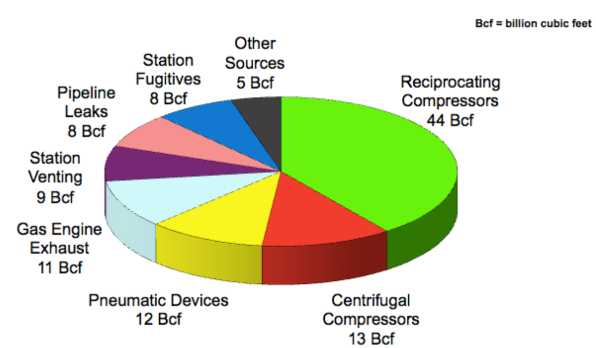
Source: EPA. *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 – 2009.* April, 2011. Available on the Web at: www.epa.gov/climatechange/emissions/usinventoryreport.html.

Gathering and Processing



Source: EPA. *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 – 2009.* April, 2011. Available on the Web at: www.epa.gov/climatechange/emissions/usinventoryreport.html.

Transmission



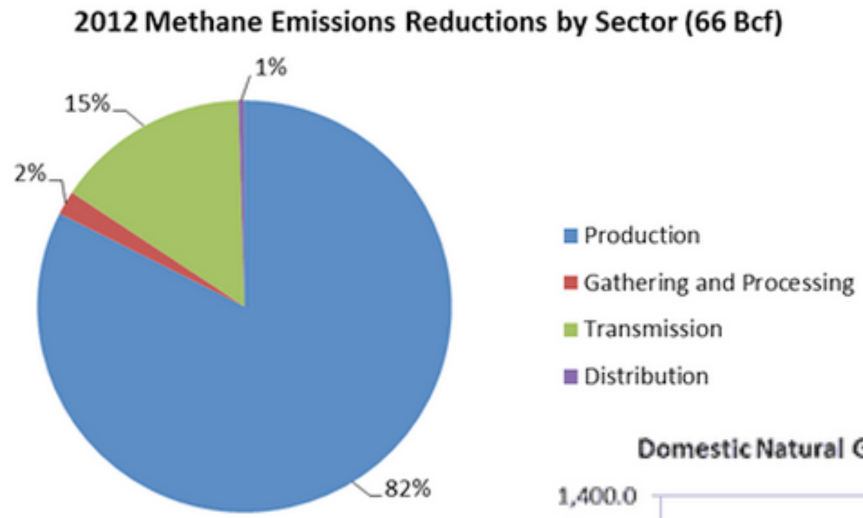
Technology Payback

Table 4: Methane Capture Technology Costs and Benefits				
Technology	**Investment Cost**	**Methane Capture**	**Profit**	**Payout**
Green Completions	$8,700 to $33,000 per well	7,000 to 23,000 Mcf/well	$28,000 to $90,000 per well	< 0.5 – 1 year
Plunger Lift Systems	$2,600 to $13,000 per well	600 to 18,250 Mcf/year	$2,000 to $103,000 per year	< 1 year
TEG Dehydrator Emission Controls	Up to $13,000 for 4 controls	3,600 to 35,000 Mcf/year	$14,000 to $138,000 per year	< 0.5 years
Desiccant Dehydrators	$16,000 per device	1,000 Mcf/year	$6,000 per year	< 3 years
Dry Seal Systems	$90,000 to $324,000 per device	18,000 to 100,000 Mcf/year	$280,000 to $520,000 per year	0.5 – 1.5 years
Improved Compressor Maintenance	$1,200 to $1,600 per rod packing	850 Mcf/year per rod packing	$3,500 per year	0.5 years
Pneumatic Controllers Low-Bleed	$175 to $350 per device	125 to 300 Mcf/year	$500 to $1,900 per year	< 0.5 – 1 year
Pneumatic Controllers No-Bleed	$10,000 to $60,000 per device	5,400 to 20,000 Mcf/year	$14,000 to $62,000 per year	< 2 years
Pipeline Maintenance and Repair	Varies widely	Varies widely but significant	Varies widely by significant	< 1 year
Vapor Recovery Units	$36,000 to $104,000 per device	5,000 to 91,000 Mcf/year	$4,000 to $348,000 per year	0.5 – 3 years
Leak Monitoring and Repair	$26,000 to $59,000 per facility	30,000 to 87,000 Mcf/year	$117,000 to $314,000 per facility per year	< 0.5 years

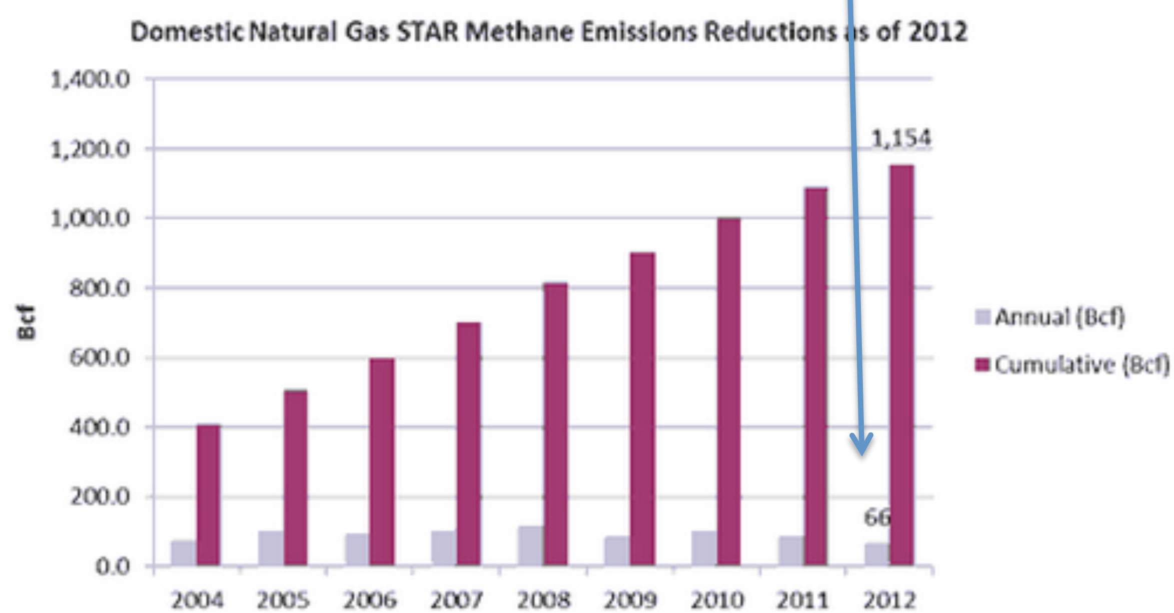
Note: Profit includes revenue from deployment of technology plus any O&M savings or costs, but excludes depreciation. Additional details provided in Appendix A.
Source: NRDC analysis of available industry information. Individual technology information sources cited in Chapter 4.

Source: EPA Natural Gas STAR Program. NRDC leaking profits

EPA Natural Gas STAR Program



10% of what is being emitted



Source: EPA Natural Gas Star Program
http://www.epa.gov/gasstar/accomplishments/index.html