

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

Rosa Dominguez-Faus
NextSTEPS ITS UC Davis

Natural Gas Webinar
April 3, 2015
Davis, California

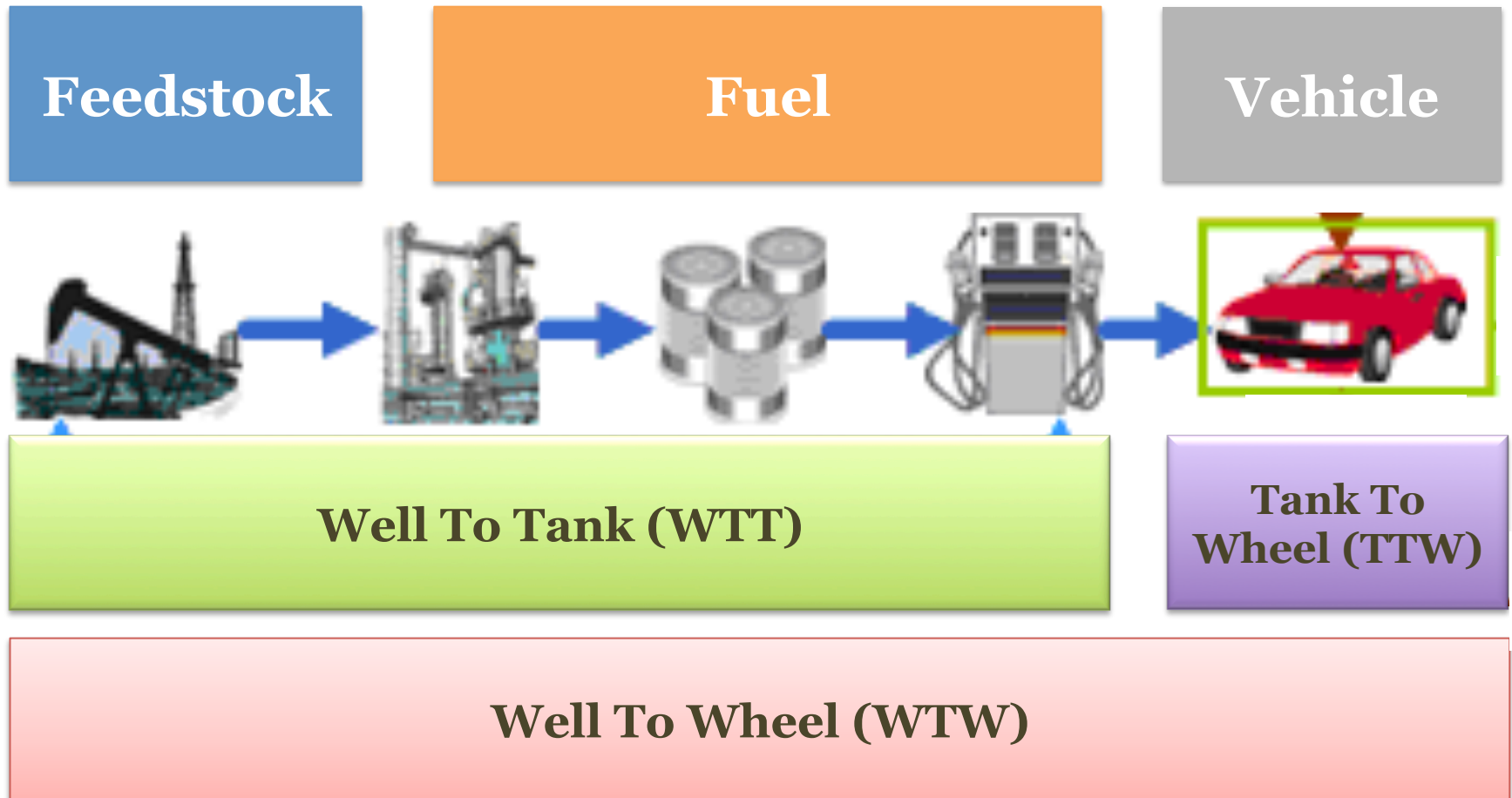
LCA models

- 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)
- **REET1 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.

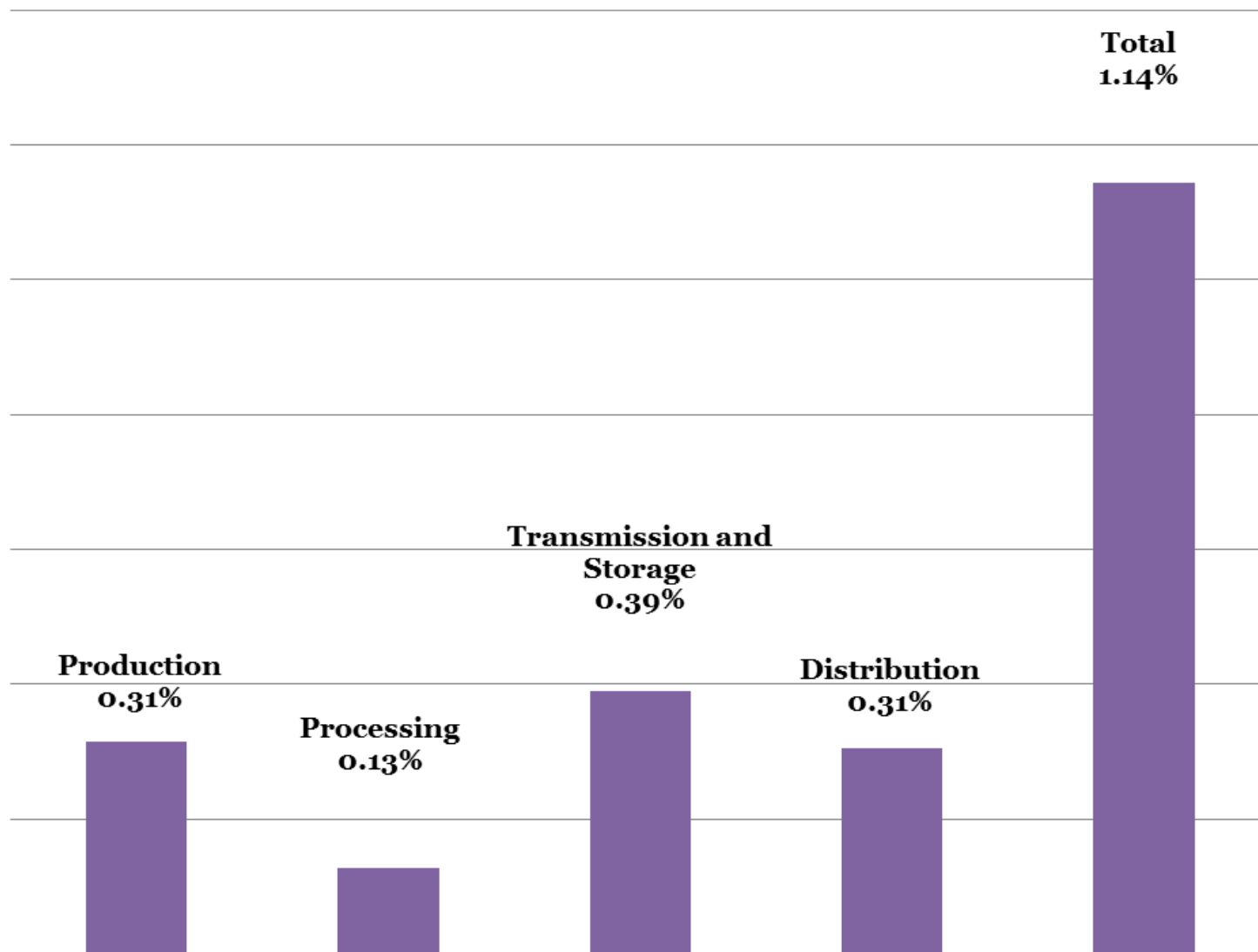
Corrected: **1.87% -2.95 %**

We will test 0 to 3%

Methane Leakage in Natural Gas Systems

REET1 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** gCH₄/mi (methane slip)

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

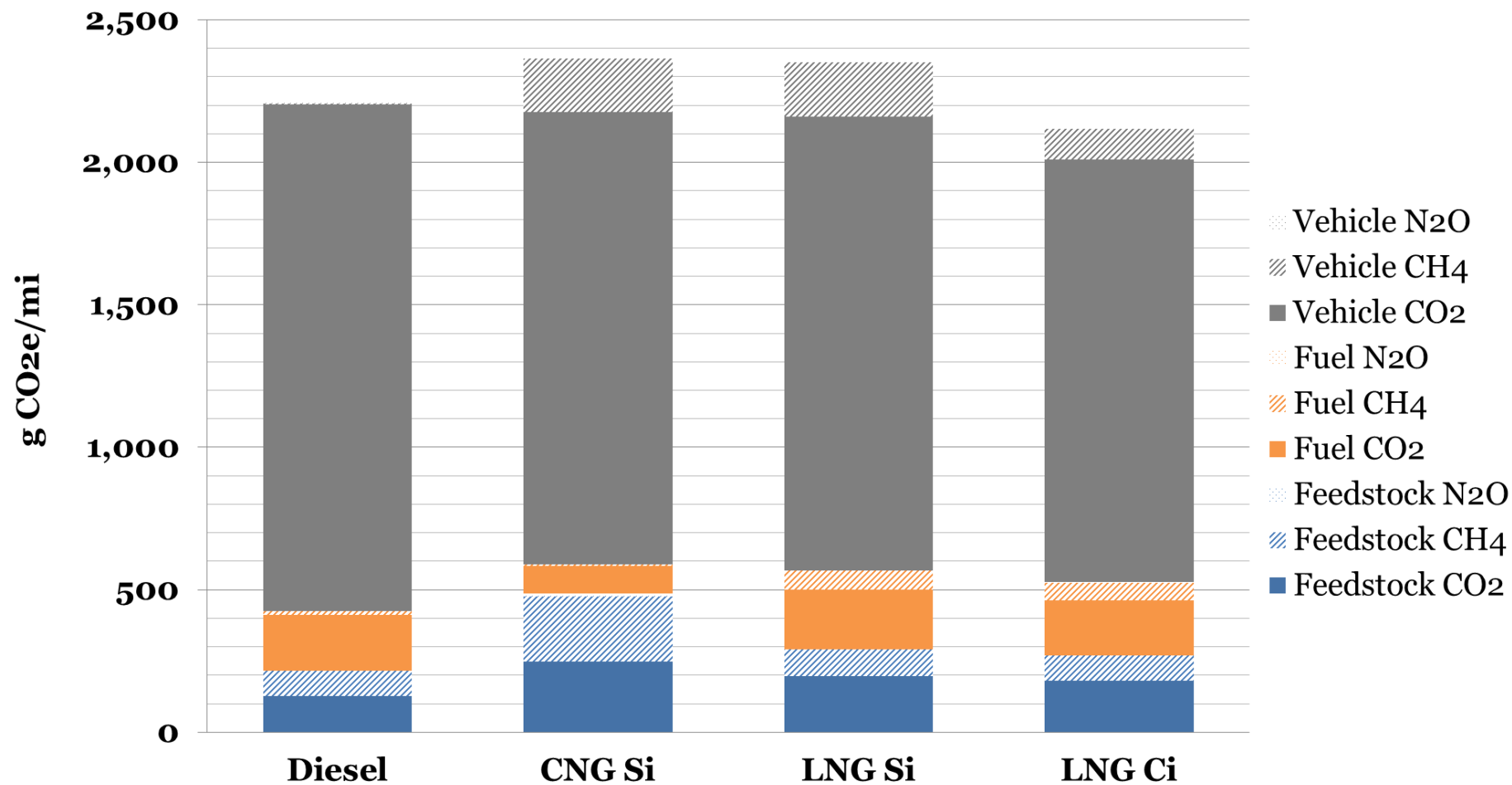


Physical Properties of natural gas, diesel and methane

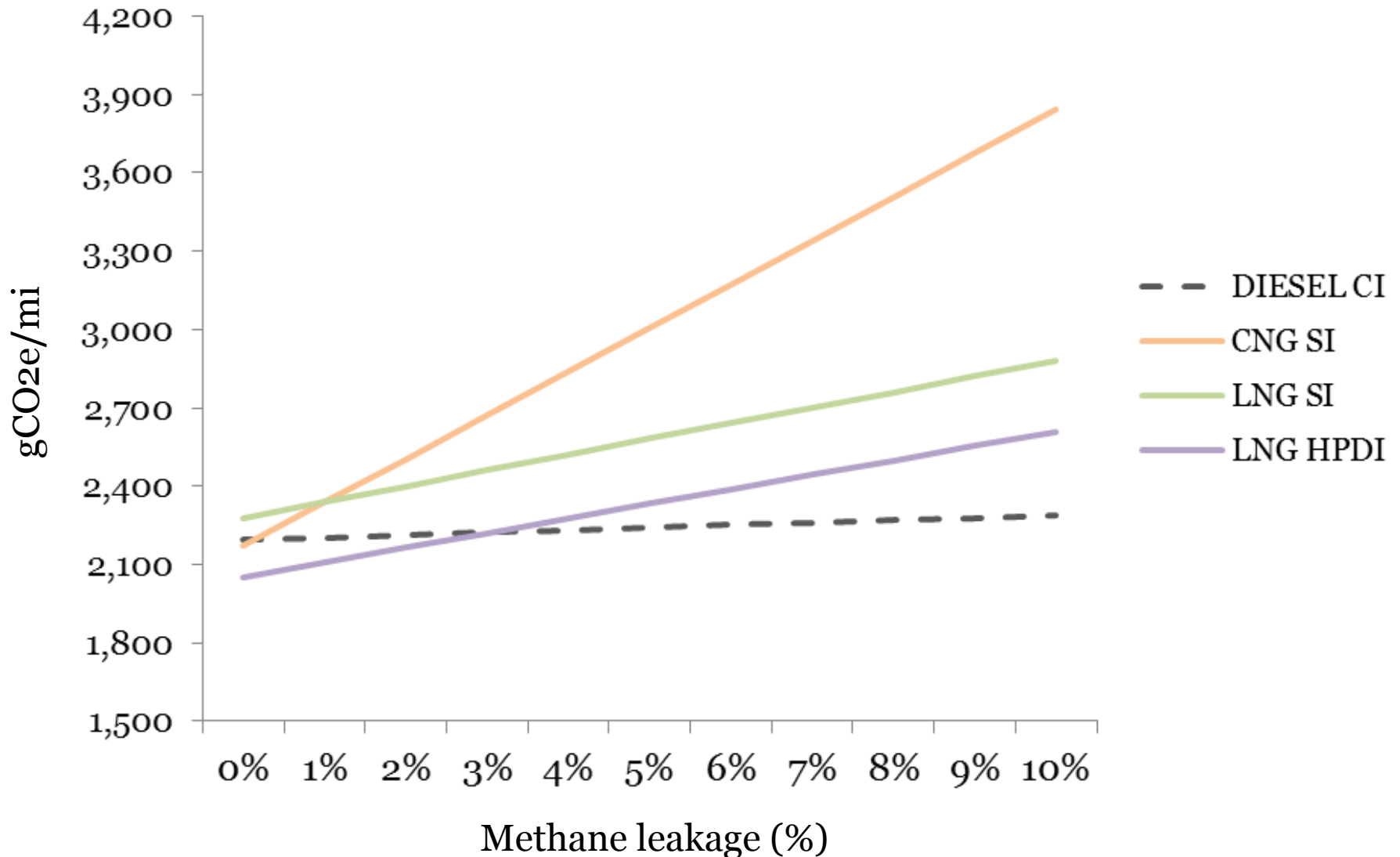
- **GWP₁₀₀: 30**
- **LHV:**
 - 983 Btu/ft³ NG
 - 740,720 Btu/gal LNG
 - 128,450 Diesel

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

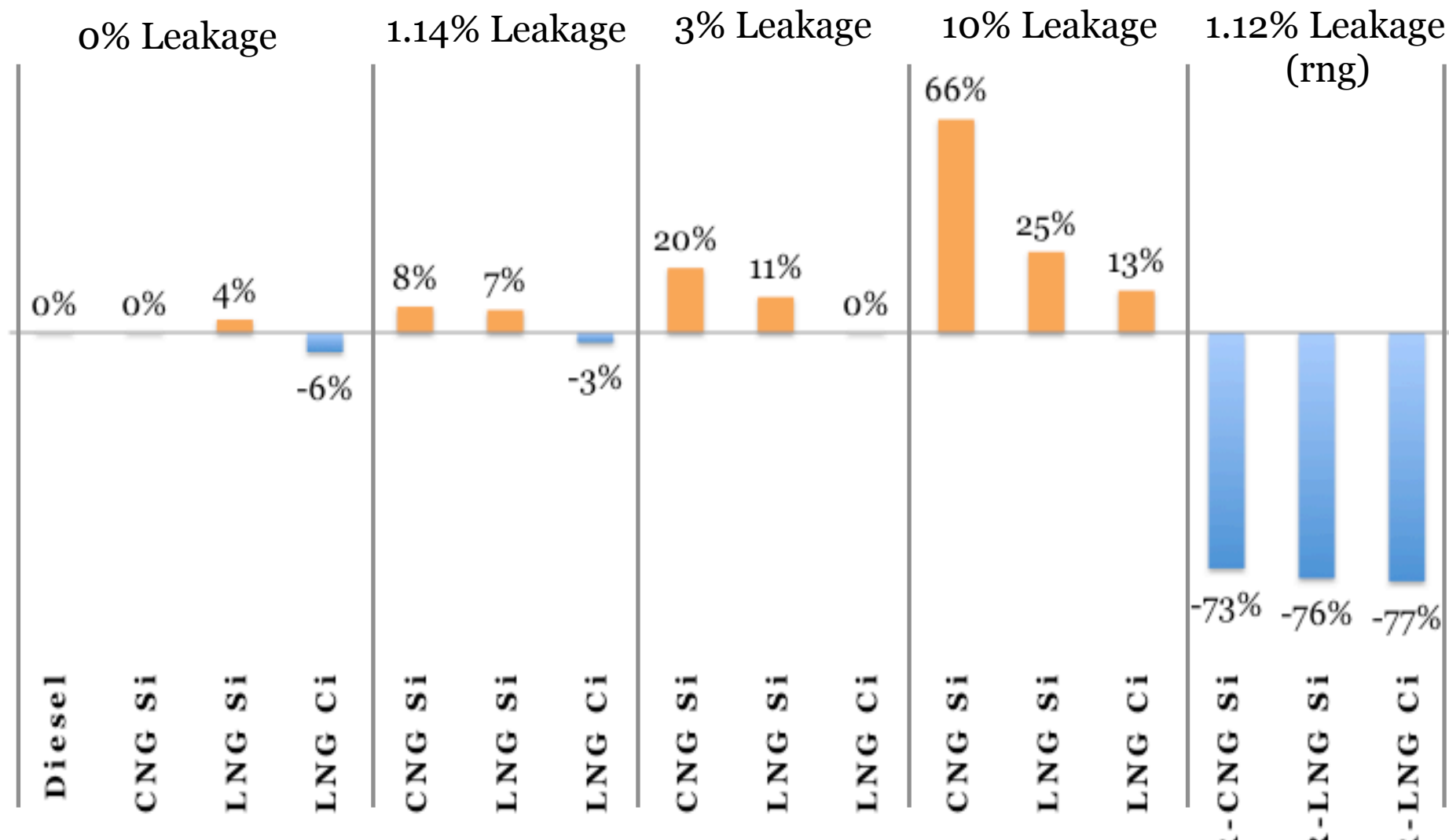
- Majority of emissions happen in TTW
 - Suggests improving fuel economy is key
- WTT CNG is dominated by methane leaks
- WTT LNG is dominated by high energy inputs of liquefaction
- BLR is 3% for HPDI and ~0% for SI

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

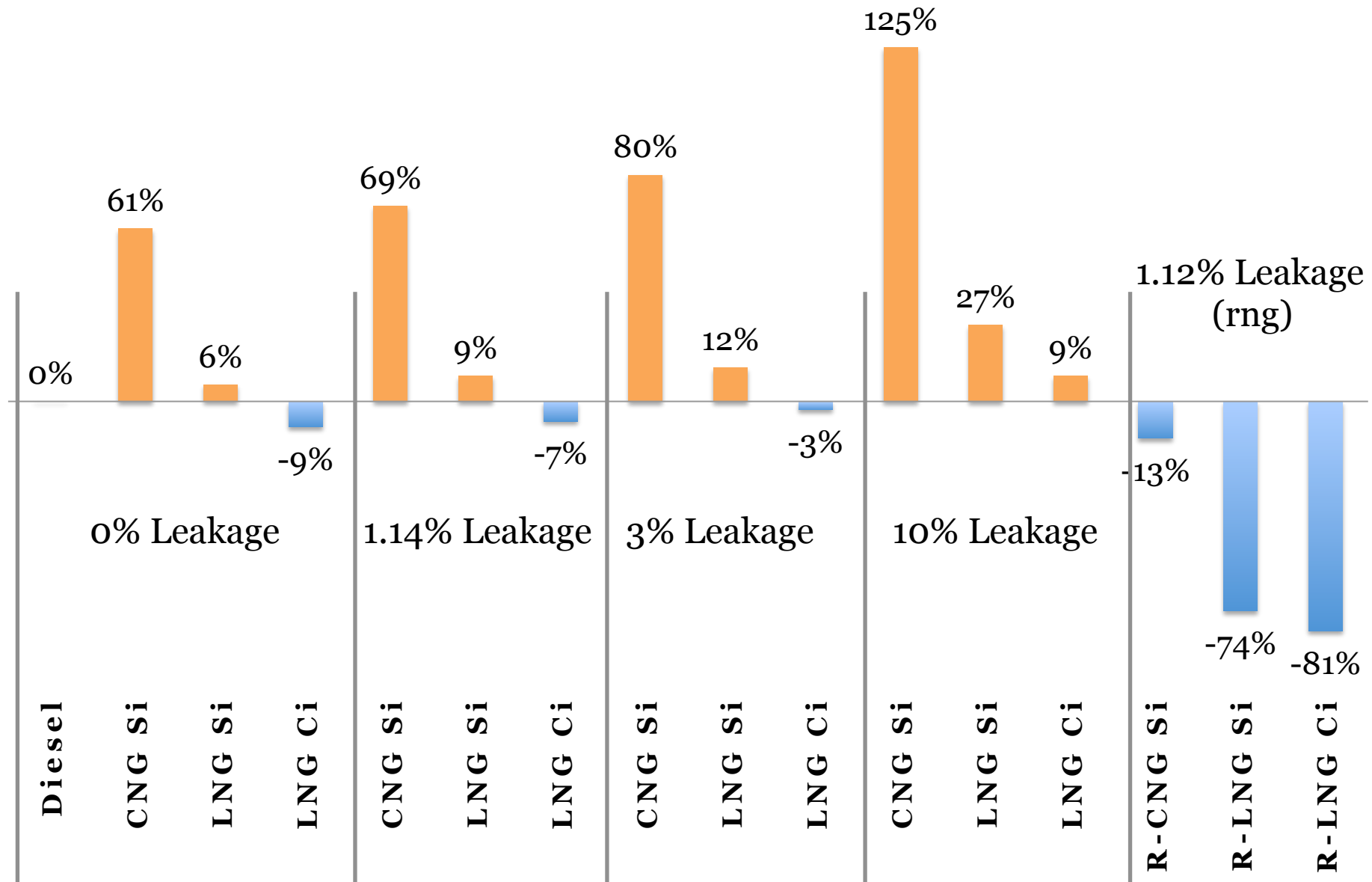
% difference in carbon intensity of long haul trucks **(baseline is diesel)**



**% difference short haul trucks
(baseline is diesel)**

5.8 mpg (diesel) vs. 4.9 (SI) vs. 5.5 (CI)

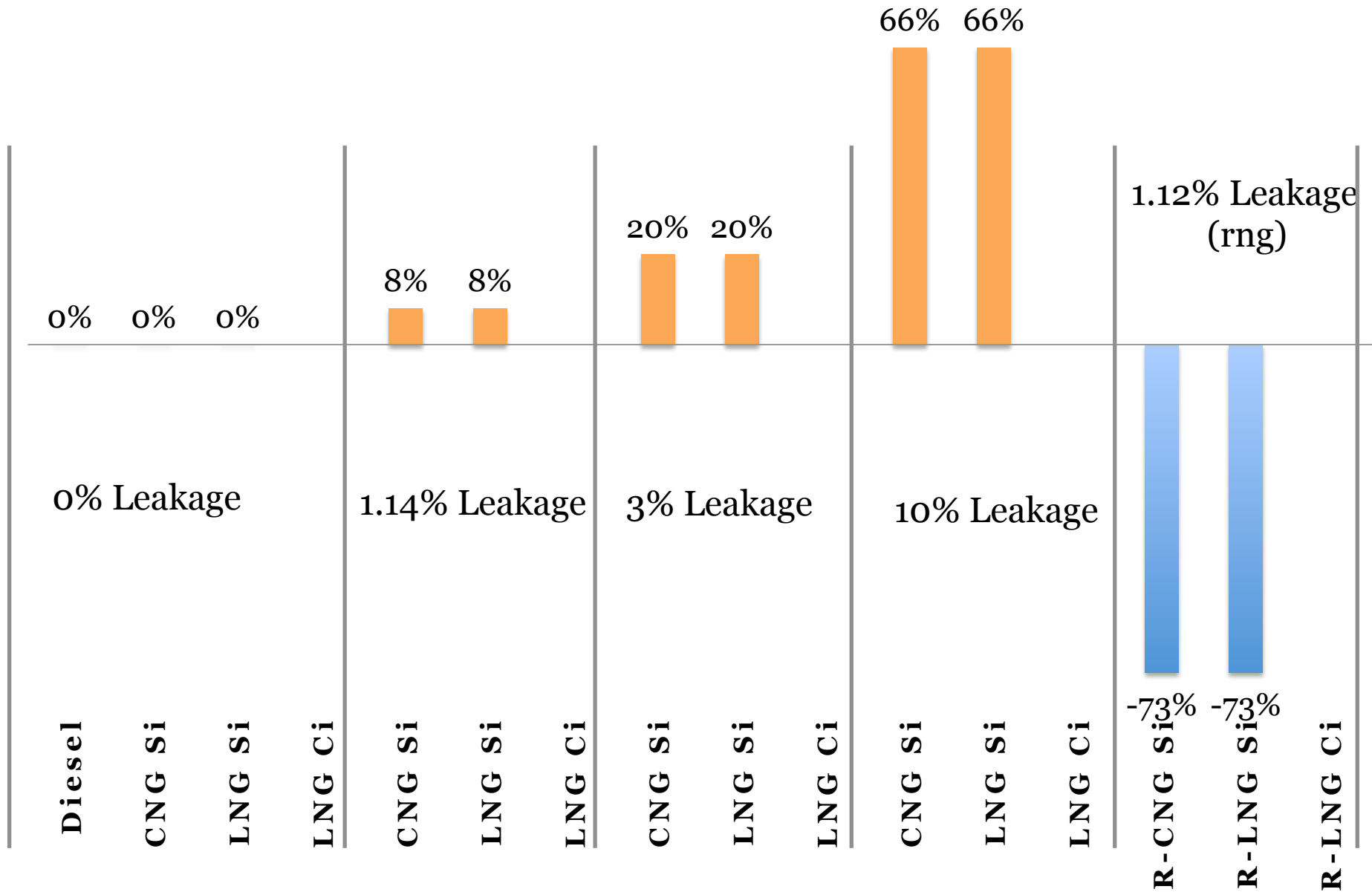
0.002 gCh₄/mi (diesel) vs. 5.225 (SI) vs 1.663 (CI)



**% difference refuse trucks
(baseline is diesel)**

3.0 mpg (diesel) vs. 2.6 (natural gas)

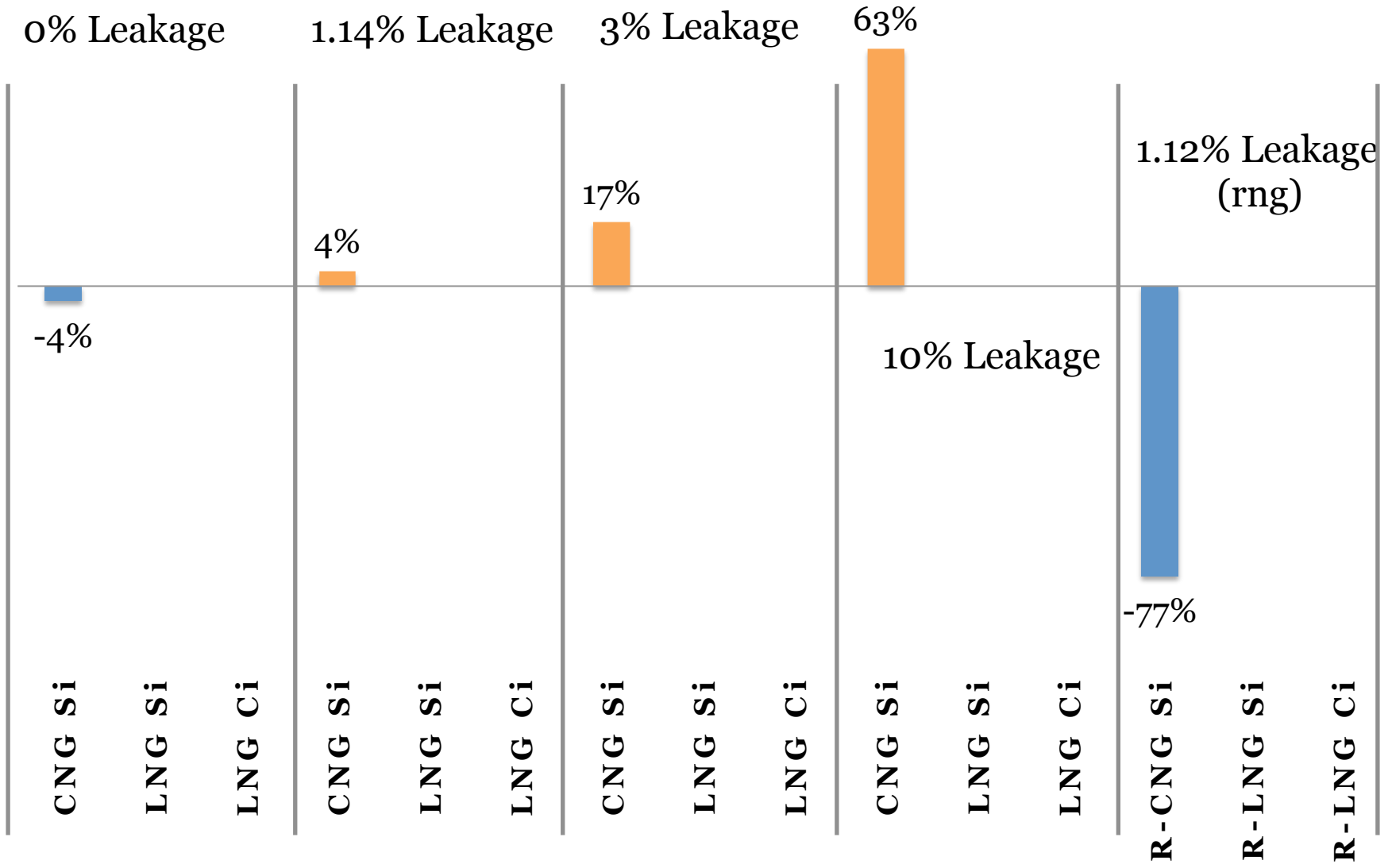
0.002 gCH₄/mi (diesel) vs. 0.805 (natural gas)



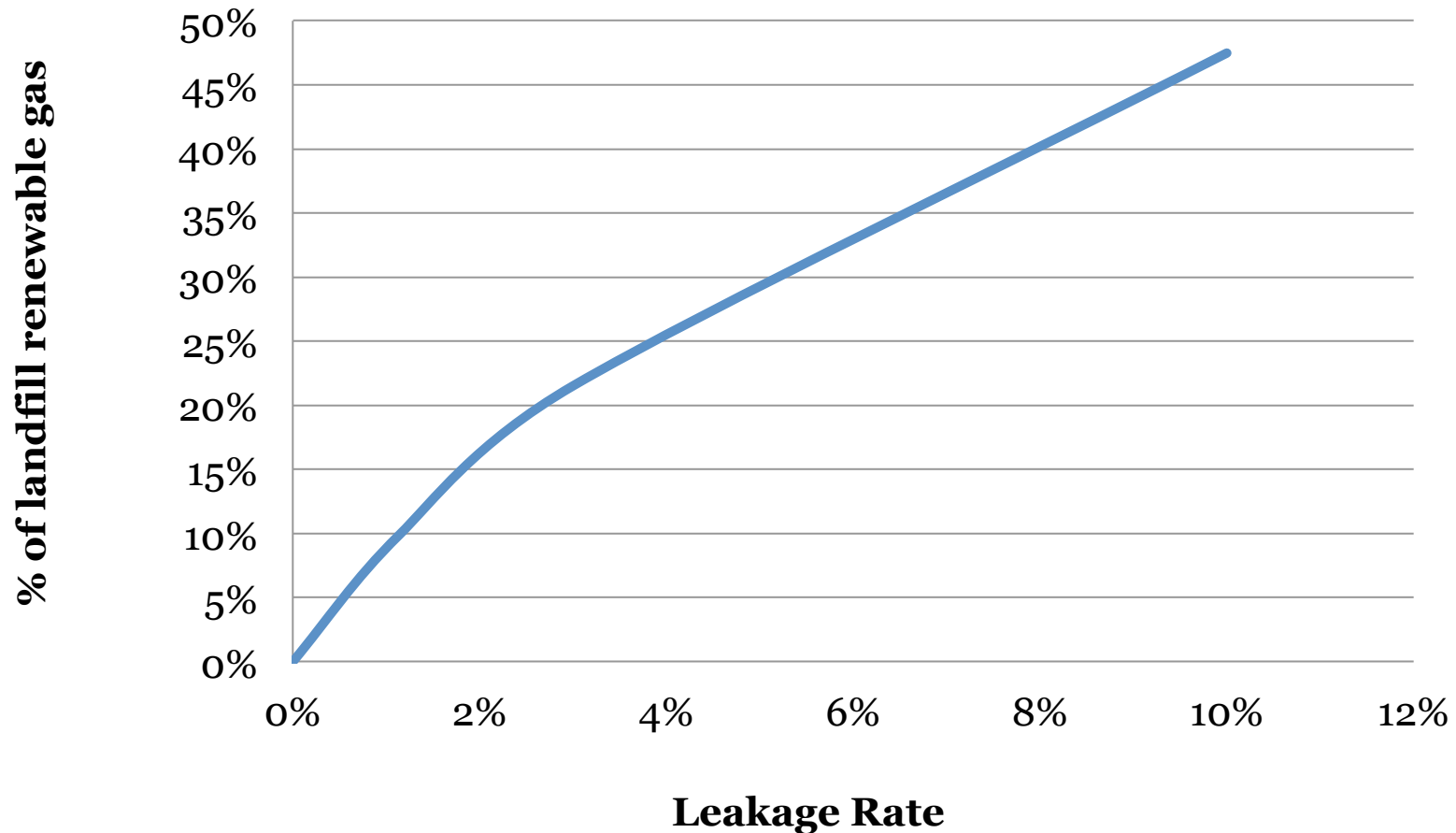
**% difference school buses
(baseline is diesel)**

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 (GCO_{2e}/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

- Robert Harriss
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- *Andrew Burnham*
(*ANL*)

Our team

- Amy Jaffe (*leader*)
- Rosa Dominguez-Faus
(*researcher*)
- Daniel Scheitrum (*graduate student*)
- 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

EXPLORING the ROLE of NATURAL GAS in U.S. TRUCKING

A NextSTEPS white paper by: Amy Myers Jaffe,¹ Rosa Dominguez-Faus,¹ Allen Lee,¹ Kenneth Medlock,¹ Nathan Porkec,¹ Daniel Scheinon,¹ Andrew Burke,¹ Hengsheng Zhao,¹ Yuesha Fan¹

NextSTEPS
(Sustainable Transportation Energy Pathways) Program
UC Davis Institute of Transportation Studies

February 18, 2015
Final Version

¹ Institute of Transportation Studies, UC Davis
Rice University

The CARBON INTENSITY of NGV C8 TRUCKS

A NextSTEPS working paper by: Rosa Dominguez-Faus, Ph.D.

NextSTEPS
(Sustainable Transportation Energy Pathways) Program

UC Davis Institute of Transportation Studies

March 2, 2015
Final Version



1. Introduction

The US role gas revolution has raised the prospect that the United States can play a more active role in the global energy market. The US role gas revolution has raised the prospect that the United States can play a more active role in the global energy market. The US role gas revolution has raised the prospect that the United States can play a more active role in the global energy market.

¹ Corresponding author.
E-mail address: medlock@ucdavis.edu (K.B. Medlock).

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Natural Gas as a Bridge to Hydrogen Fuel Cell Light-duty Vehicles

Andrew Burke¹, Lin Zhu¹
¹ University of California, Davis, Institute of Transportation Studies
1 Shields Ave, Davis, CA 95616 USA (aburke@ucdavis.edu)

Abstract

In this paper, detailed comparisons are made between various types of light-duty vehicles fueled with natural gas and hydrogen. The natural gas vehicles are designed to range existing hybrid vehicles (HEV) and the hydrogen fueled vehicles (FCV) are powered by a fuel cell. All the vehicles have a range of 400 miles between refueling stops. The paper discusses the on-board storage of natural gas (3800 psi) and hydrogen (10000 psi) in terms of the volume and weight of the tanks required and how fuel storage affects the vehicle design. Detailed computer simulations are presented for vehicle classes from compact cars to midsize SUVs. The fuel economies of these vehicles are calculated for several driving cycles. The energy (MJ) and volume (L) of fuel storage required to meet the 400 mile range target for each vehicle using natural gas and hydrogen are compared. The costs of the vehicles simulated are projected for 2015-2030. The differences between the costs of the natural gas hybrid vehicles and the fuel cell vehicles are calculated for the various vehicle types on the cost of the fuel cells, batteries and other powertrain components. The CO₂ emissions from the CNG hybrid and fuel cell vehicles are determined and compared for hydrogen and electricity from natural gas. As a first step, the ways in which the introduction of the natural gas fueled vehicles could be a bridge to the mass marketing of fuel cell vehicles are considered.

Keywords: natural gas; hydrogen; fuel cell; light-duty; energy storage; hydrogen

1 Introduction

There is considerable interest [1–3] in increasing the use of natural gas as a fuel in the transportation sector. Presently 2014 most of the activity in this area is the United States is concerned with the use of natural gas in the light-duty passenger cars and medium-duty trucks and medium-duty trucks and medium-duty trucks. There is much less interest in using natural gas in light-duty passenger cars, SUVs, and pickup trucks. There is, however, considerable discussion of the use of hydrogen fuel cells in these light-duty vehicles. In fact, several auto manufacturers are planning to begin marketing fuel cell vehicles in 2015-2016. One of the impediments to marketing fuel cell vehicles is the lack of an extensive infrastructure for the hydrogen fuel. In addition, there is considerable concern about the acceptance of the public to the use of a poison fuel in their cars. In the past, there has been considerable discussion [4, 7] of the use of natural gas in light-duty vehicles as a bridge to the use of hydrogen in vehicles. One of the

EEVC European Electric Vehicle Congress

1

Analysis of Medium Duty Hybrid-Electric Truck Technologies using Electricity, Diesel, and CNG/LNG as the Fuel for Port and Delivery Applications

Andrew Burke¹, Lin Zhu¹
¹ University of California, Davis, Institute of Transportation Studies
1 Shields Ave, Davis, CA 95616 USA (aburke@ucdavis.edu)

1 Abstract

This paper is concerned with the analysis of the fuel economy and greenhouse gas emissions from medium duty trucks (MDT) using various alternative powertrain/fuel combinations for deliveries in urban and inter-city service. The powertrain/fuel combinations considered included hybrid-electric designs consisting of a diesel engine, electric motor, and a lithium battery, a CNG engine, electric motor, and lithium battery, battery powered, and a hydrogen fuel cell. Simulations were performed for a number of driving cycles appropriate for these applications using a special version of the ADVISOR program developed at UC Davis. Comparisons are given of the economics of the various options in terms vehicle initial price differences and the breakeven fuel prices for the various alternative fuels. The comparisons are made for today's costs (2014) and future costs (2025) including expected improvements in technology. Special attention is given to the use of natural gas in the delivery trucks. For the medium-duty trucks, the economic results using today's technologies and costs indicated that CNG conventional trucks are attractive in most urban applications for a range of annual VMT and payback time combinations. CNG-hybrid vehicles are also attractive under 20K VMT/yr payback scenarios. In 2025, all the powertrain/fuel combinations are attractive in varying degrees due to the improvements in fuel economy and the reduction in equipment costs.

Keywords: fuel cell; battery; medium duty truck; light-duty; energy storage; hydrogen

1 Introduction

In the United States, medium duty trucks (Class 4 to Class 6) are those with GVWR from 10,000 to 26,000 lbs., including city trucks (including city trucks), school buses, etc. Medium duty trucks are the backbone for the American economy and are responsible for the delivery of goods and services. The use of natural gas in light-duty vehicles as a bridge to the use of hydrogen in vehicles. One of the

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1

Analysis of Class 8 Hybrid-Electric Truck Technologies Using Diesel, LNG, Electricity, and Hydrogen, as the Fuel for Various Applications

Hengsheng Zhao, Andrew Burke, Lin Zhu
¹ University of California, Davis, Institute of Transportation Studies
1 Shields Ave, Davis, CA 95616 USA

Abstract

Class 8 trucks using various powertrains and alternative fuel options have been analyzed to determine their fuel economy, greenhouse gas emissions, and economic attractiveness at the present time (2013) and in the future. This was done by modeling the vehicles and simulating their operation on day, short haul, and long haul driving cycles. The economic attractiveness was determined by calculating the differential vehicle cost of each powertrain option and the corresponding breakeven alternative fuel price needed to recover the additional cost in a specified payback period with a diesel engine truck. The baseline vehicle was a diesel engine truck of the same weight and road load using 54-gallon diesel fuel. The use of some of the powertrains resulted in a energy saving and others resulted in higher energy consumption, but compared to the conventional Class 8 diesel trucks, conventional LNG-CI trucks, LNG-RI and LNG-CI hybrids, battery electric trucks, and fuel cell trucks can reduce CO₂ emissions by 24-39% over the day cycle and 12-29% over the short haul and the long haul day cycle.

The breakeven fuel price was calculated for all the powertrain/fuel options. The economic results indicate that at "today's" differential vehicle costs, none of the alternative powertrain/fuel options are economically attractive except for the LNG-CI engine in the long-haul application (VMT=150,000 miles) for which the DOE cost is \$2.80/GGE and the LNG cost is \$1.70/GGE. If the differential costs of the alternative powertrains are reduced by 10%, their economics is improved markedly. In the case of LNG-CI engine, the breakeven fuel costs are \$3.42/GGE, \$1.96/LNG gallon for the long haul applications (VMT= 150,000 miles) with payback periods of 2-3 years. This makes LNG cost competitive with diesel fuel. In the case of battery electric trucks, the breakeven fuel cost is also nearly cost competitive at VMT= 150,000 miles, but this requires a fuel cell cost of less than \$25/kW. Hydrogen is not attractive except for the conventional diesel vehicle operating on the day cycle (same day and go operation) for which the breakeven diesel price is about \$3/gallon at today's differential vehicle costs. The regulated exhaust emissions from the LNG-CI engines will meet the same standards (EPA 2010) as the new diesel engines and use the same exhaust emission technology.

Keywords: Class 8 truck; hybridization; alternative; fuel cell; fuel economy; emissions

Featured Papers on Plenary Session Themes:

Climate, Air Quality and Security:

The Policy Push for Alternative Fuels in Transportation



Rosa Dominguez-Faus
Ph.D. Graduate Fellow
Institute of Transportation Studies
University of California, Davis

and
Amy Myers Jaffe
Executive Director, Energy & Sustainability
Graduate School of Management
Institute of Transportation Studies
University of California, Davis

High global oil prices have encouraged innovation and conservation in many key use sectors, and environmental and security drivers are also driving rapid acceptance of new technologies. This trend is now gaining momentum globally in the transportation sector. Governments are under increasing pressure from many directions, including climate change, air quality, rising urbanization, and national security, to consider policies and incentives to hasten the pace of penetration of new more efficient vehicles and adoption of alternative fuels. The period of historic volatility across the oil-producing regions of the Middle East gives added impetus to programs aimed to diversify national transport fuel sources, especially in the face of increasing demand for mobility among rising middle classes in the developing world.

Oil's current dominance in the transportation sector is unquestionable. Roughly 93 percent of all fuel used in the transport sector globally is petroleum-based. The International Energy Agency forecasts that almost all of the net growth for oil will come in the next two decades from the transport sector in emerging economies. Road transport for freight and personal mobility will be responsible for 75% of future oil use in transportation, according to the IEA. With the global passenger vehicle fleet expected to double in the coming decades to 1.7 billion by 2020, governments and companies alike are looking for new opportunities to meet some of the demand in alternative ways. DOE, in their annual energy projections, the U.S. Energy Information Administration (EIA, 2012) as well as ExxonMobil (ExxonMobil, 2012) and BP (BP, 2012), expect the transportation sector to be dominated by petroleum fuels well into the future. However, increasingly, governments are beginning to look at ways to accelerate fuel source diversification and greater efficiency in transportation, especially in the vehicle areas.

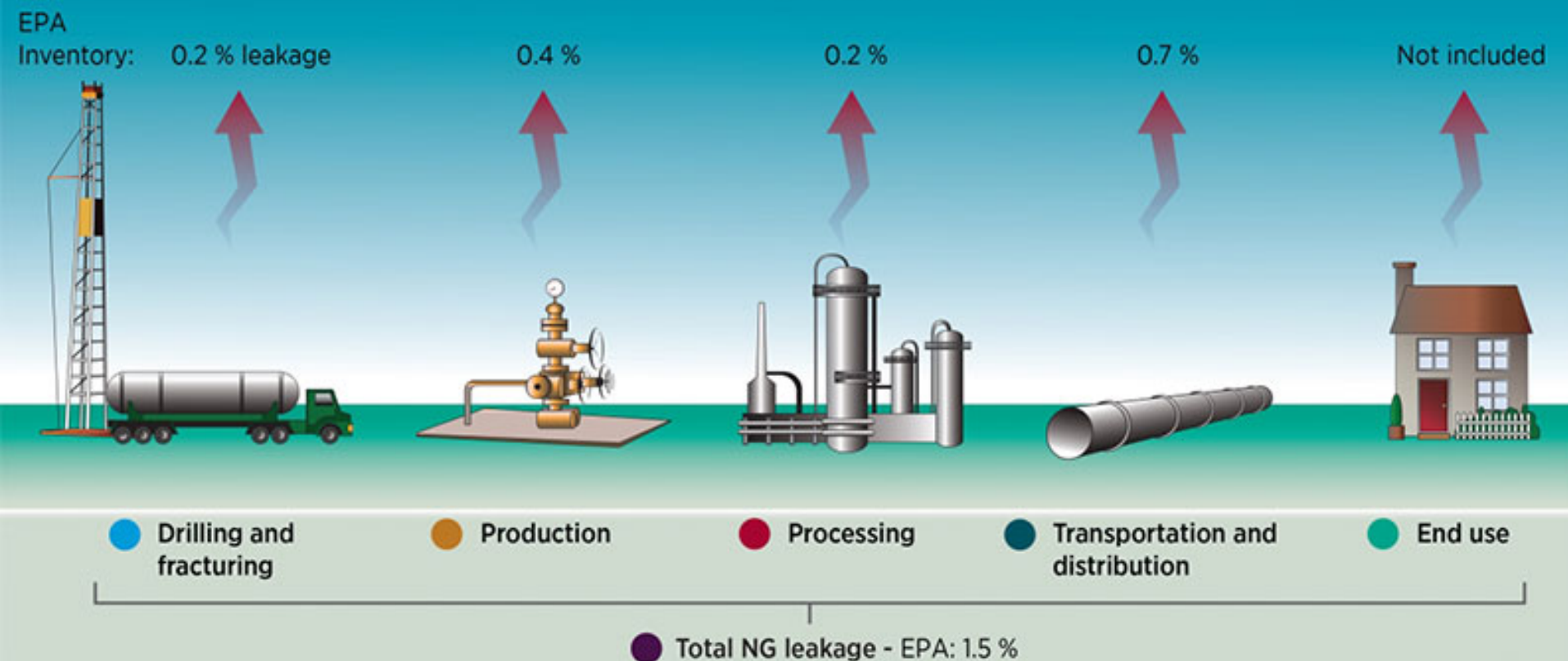
Thank you!

rdominguezfaus@ucdavis.edu

Extras

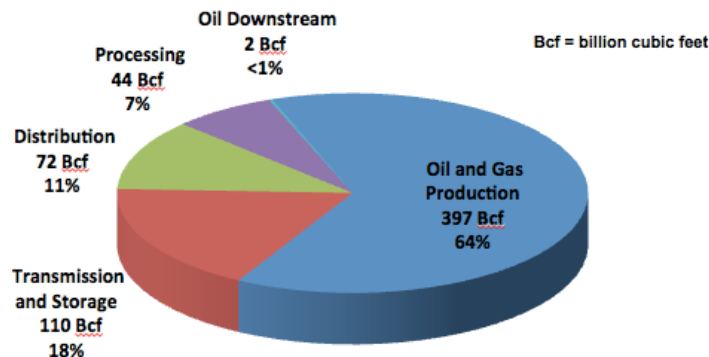
Drilling/Production/Processing = 0.8%
Transmissions/Distribution = 0.7%
Refueling stations/Vehicles = NA

Methane Leakage Rates from the Natural Gas System

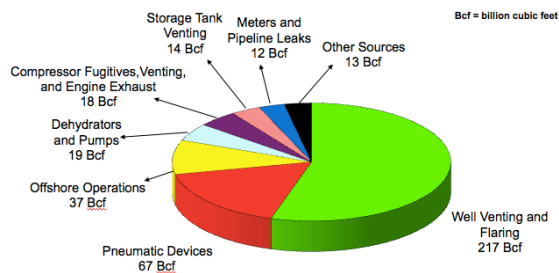


Where are the leaks?

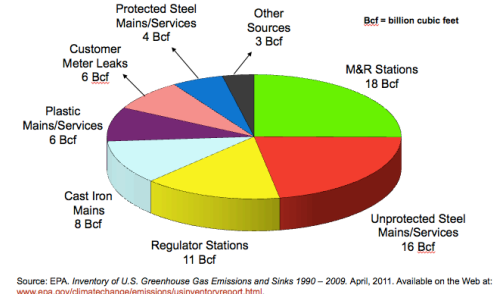
2009 U.S. methane emissions from oil and natural gas industry:
624 Bcf (3.8% of total U.S. greenhouse gas emissions)



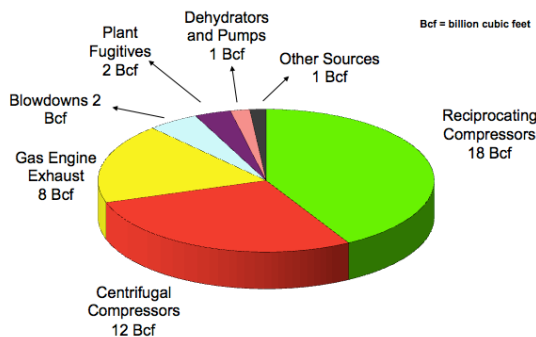
Production



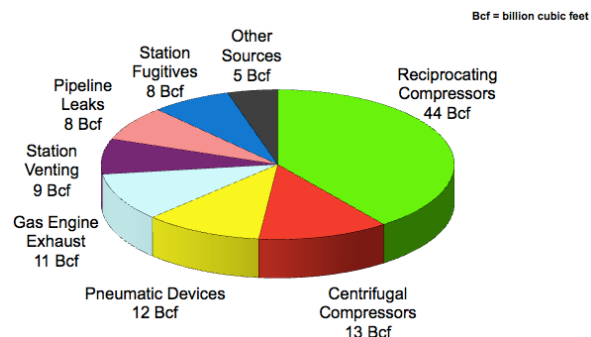
Distribution



Gathering and Processing



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

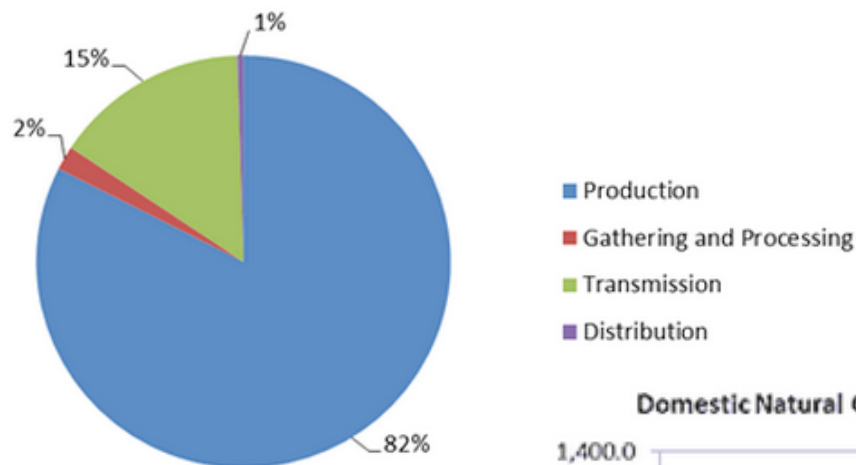
Note: Profit includes revenue from deployment of technology plus any O&M savings or costs, but excludes depreciation. Additional details provided in Appendix A.

Source: NRDC analysis of available industry information. Individual technology information sources cited in Chapter 4.

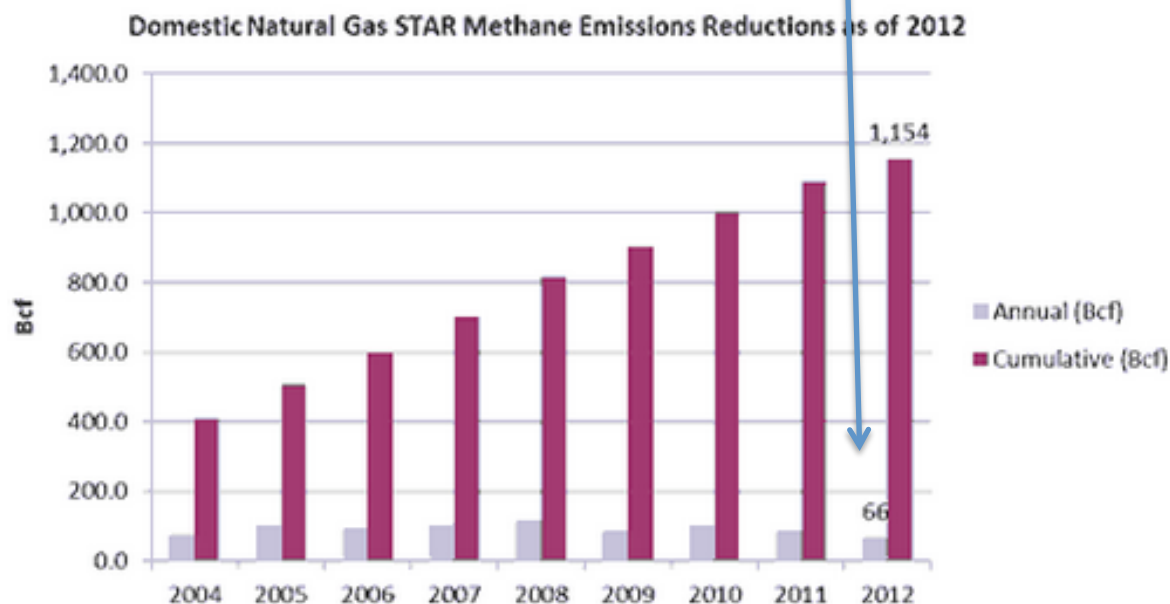
Source: EPA Natural Gas STAR Program. NRDC leaking profits

EPA Natural Gas STAR Program

2012 Methane Emissions Reductions by Sector (66 Bcf)



10% of what is being emitted



Source: EPA Natural Gas Star Program

<http://www.epa.gov/gasstar/accomplishments/index.html>