The Shale Revolution and Natural Gas in Transportation

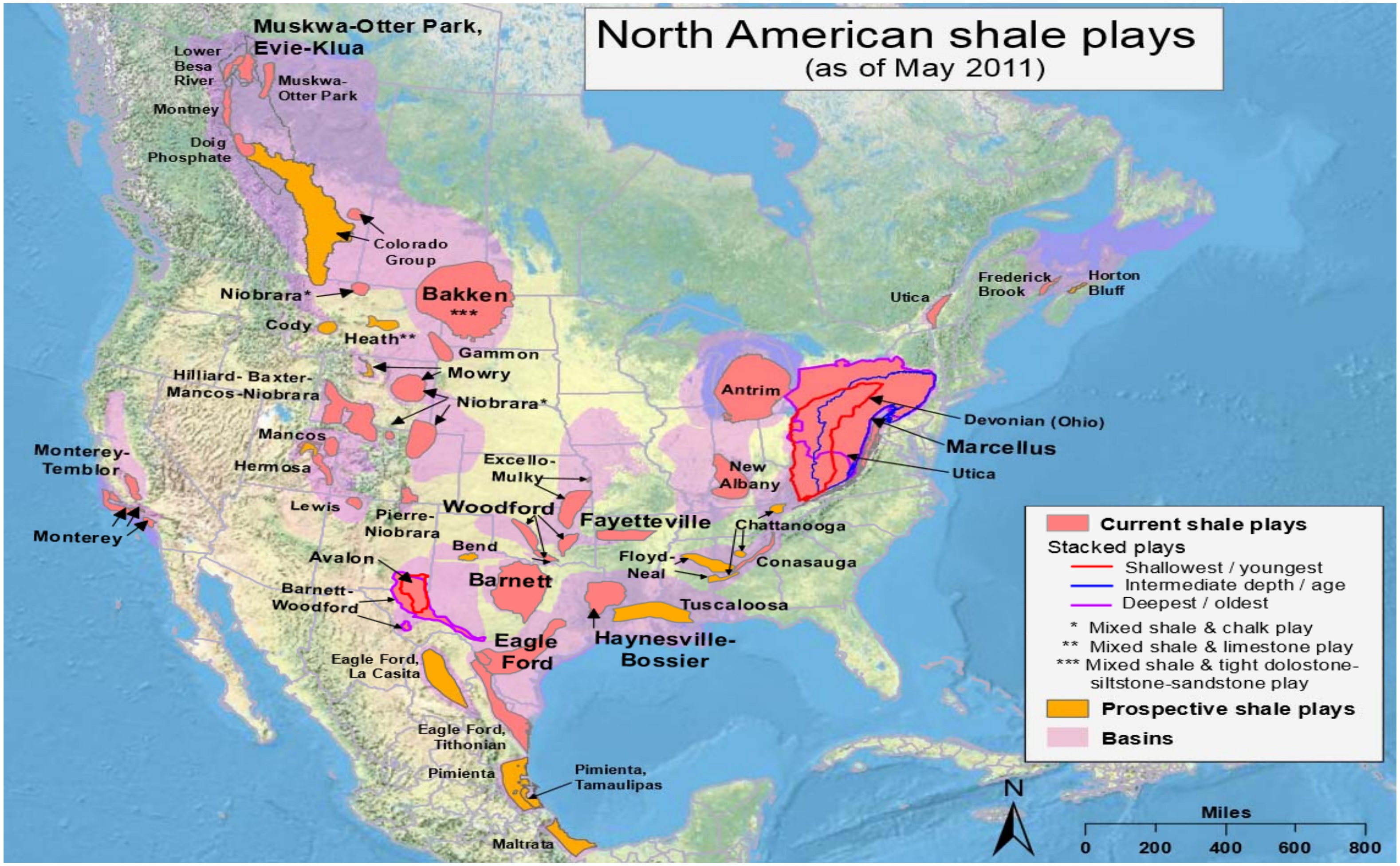
Institute of Transportation Studies, University of California, Davis

Presentation to the California Energy Commission

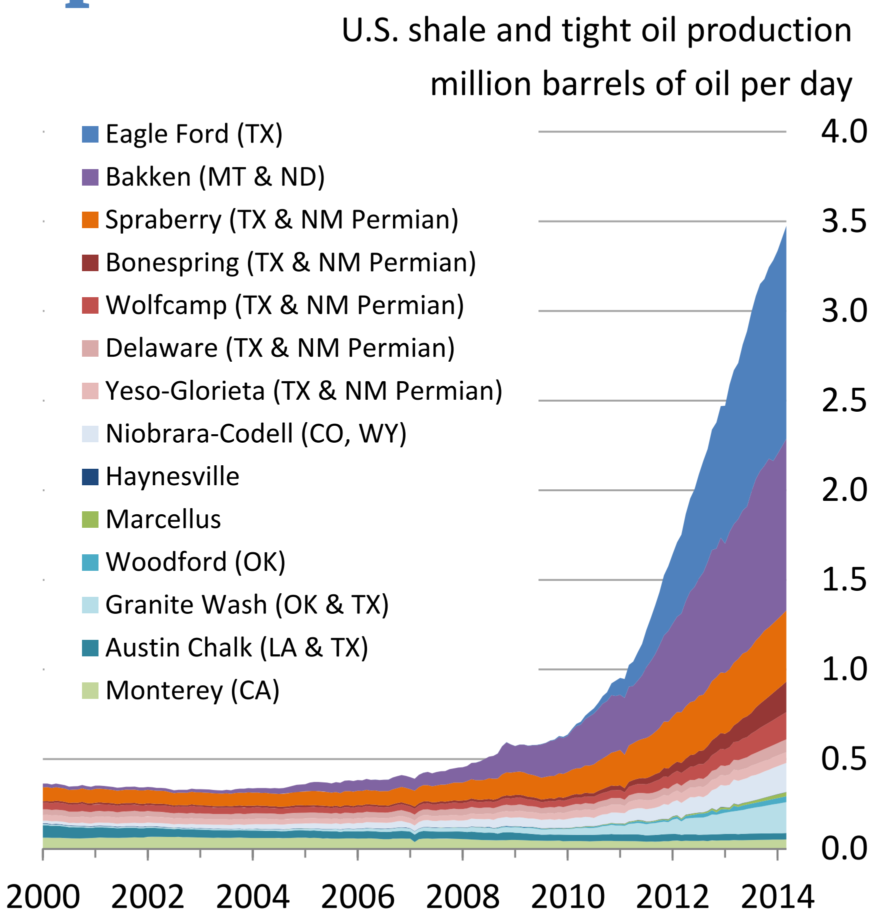
June 23, 2014

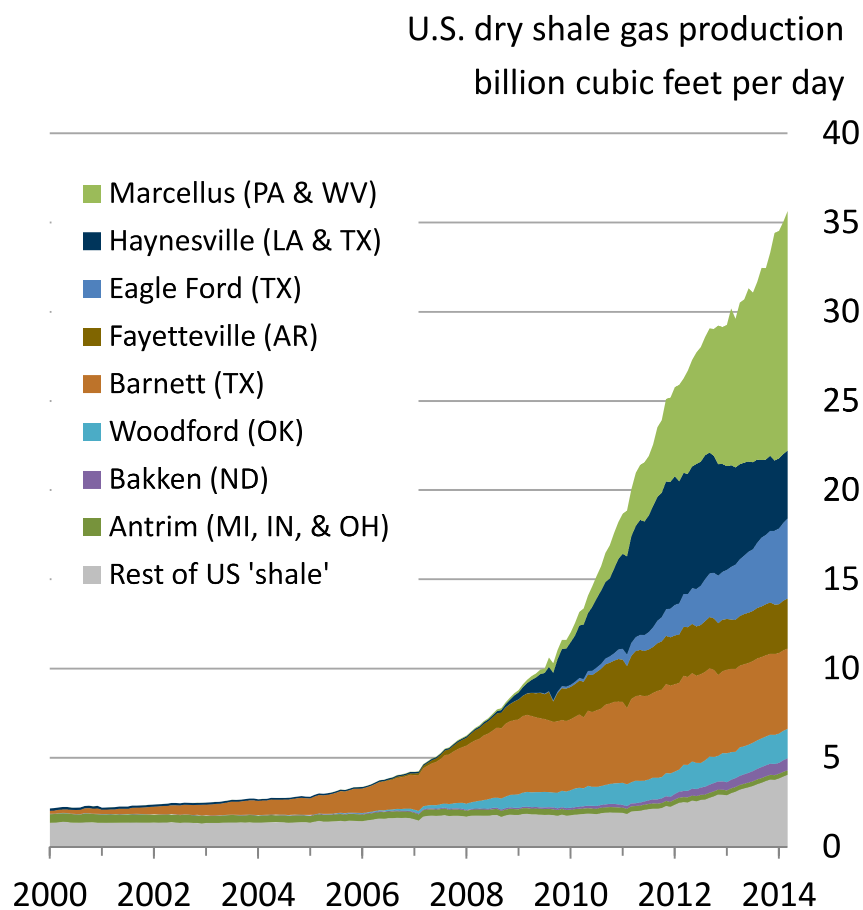
ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

US Shale Gas Is Prolific and Supply Abundance Will Be Sustainable



Sources of US Shale Oil and Gas Are Proliferating and Will Continue to Expand





Sources: EIA derived from state administrative data collected by DrillingInfo Inc. Data are through March 2014 and represent EIA's official tight oil & shale gas estimates, but are not survey data. State abbreviations indicate primary state(s).

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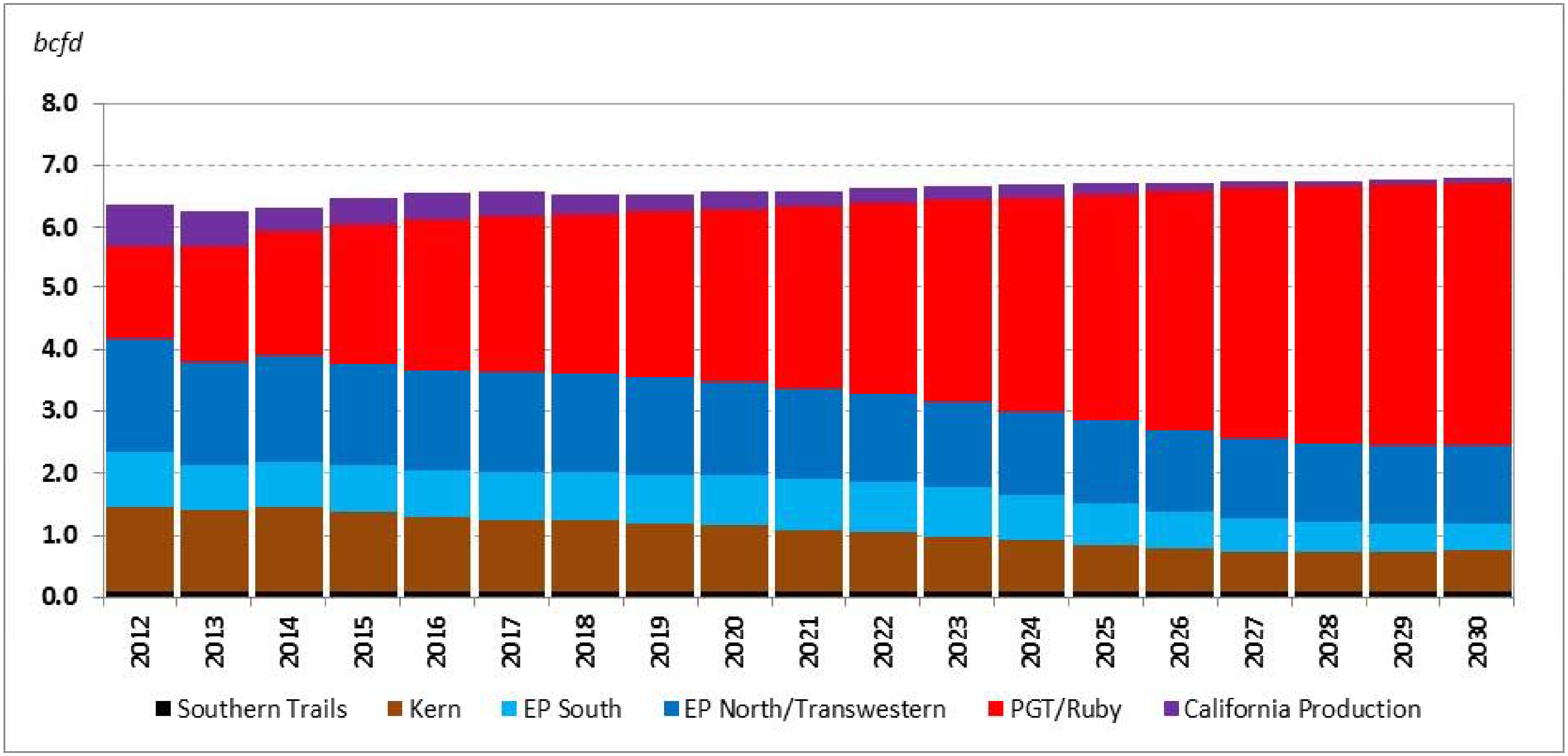
California Supply Disposition

- Indigenous production declines longer term, resulting in higher imports.
- California pull on Canadian gas is expected to increase substantially.



Source: BIPP CES RWGTM

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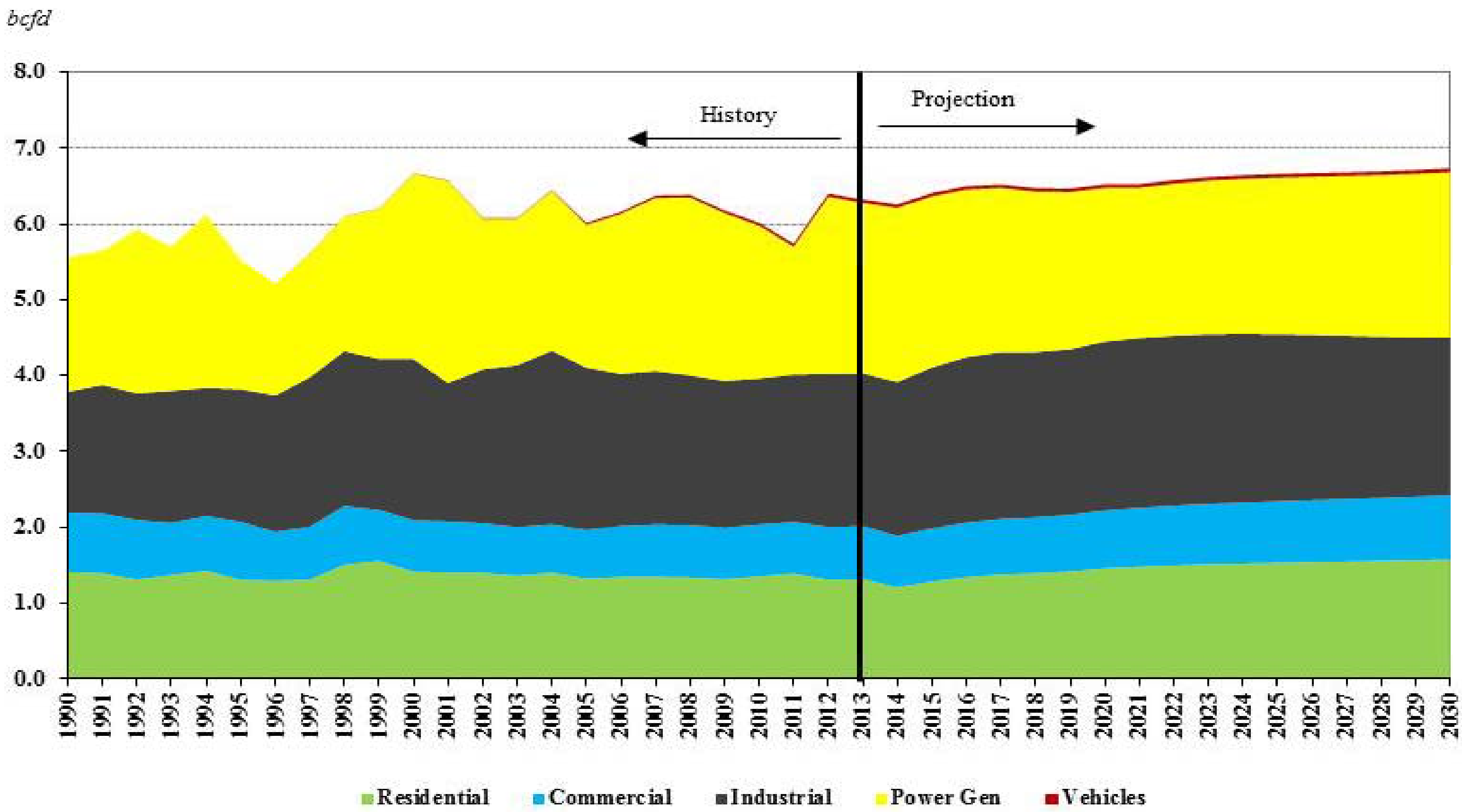
California Demand by Sector

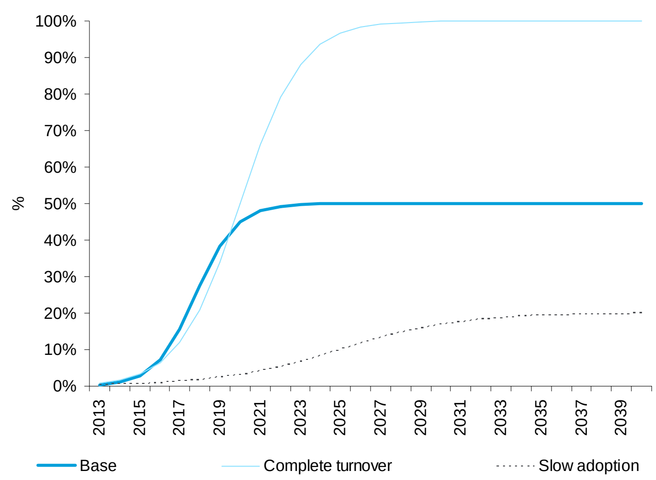
- Modest growth is forecast in the Status Quo Case due to aggressive RPS goals and end-use efficiency programs.



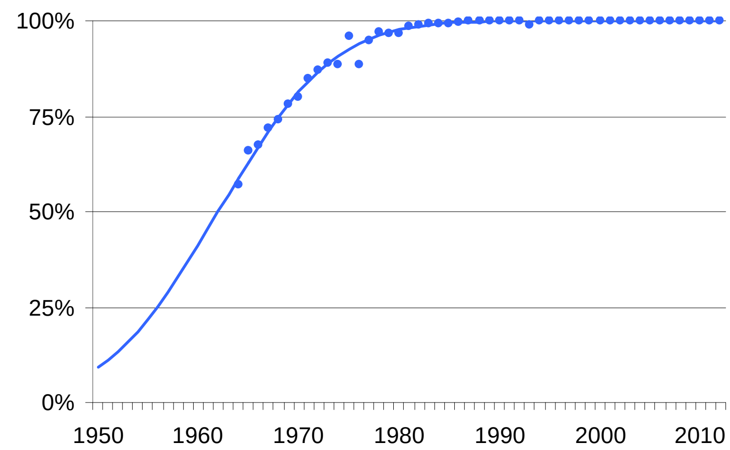
Low Natural Gas Prices Appear To Make Shift to Natural Gas for Heavy Trucks Make Sense

S Curve Start to Diesel Fuel Leading Some Analysts to Argue Natural Gas Will Follow Same Course

Estimated NGVs as % new HDV sales in the US



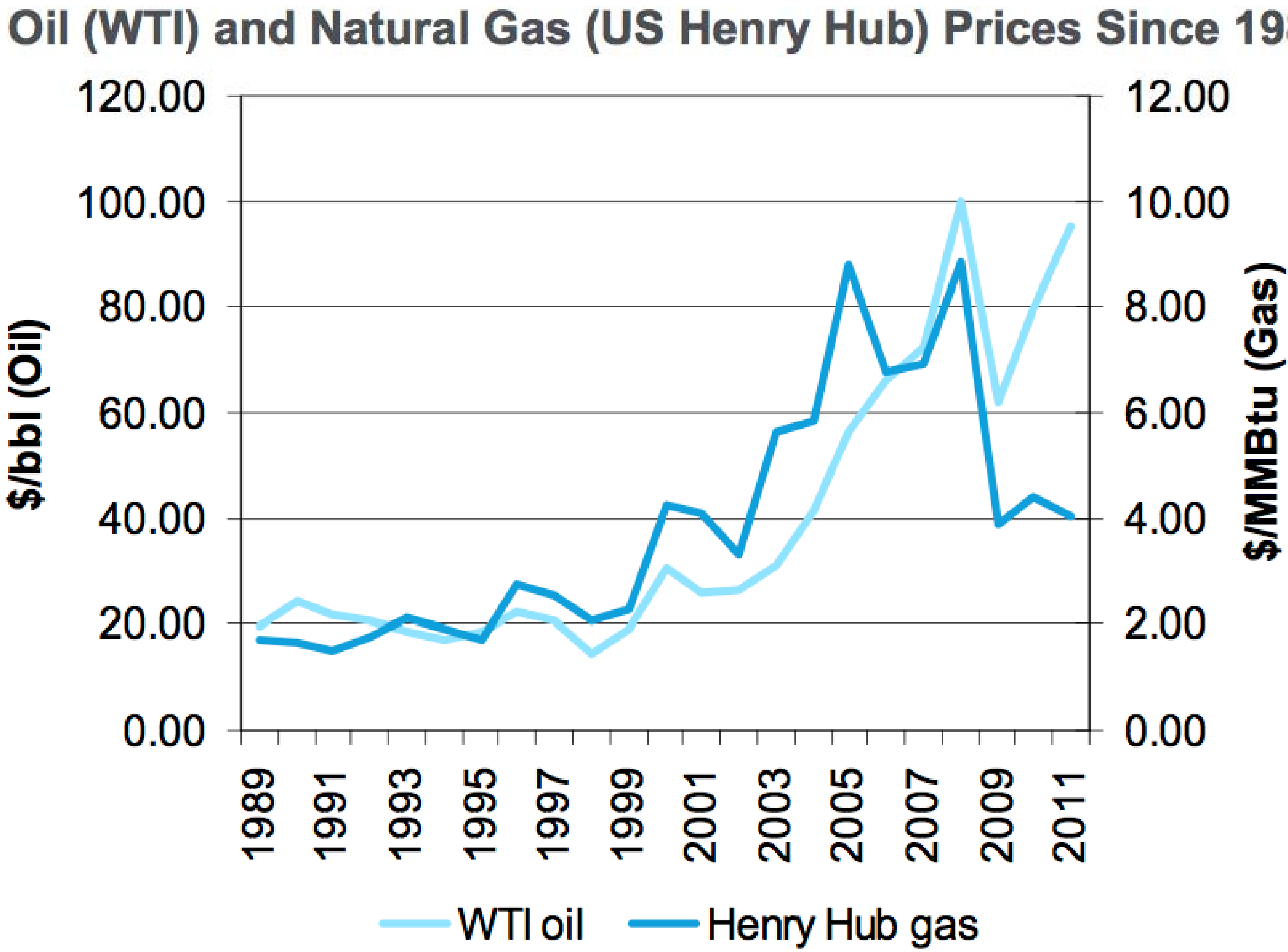
Diesel's share of new Class 8 trucks sales in US, 1950-2010



Source: MacKay, Wards Auto, Westport, Ayres-Ayres-Warr, Citi Research

But Is A Shift to LNG Fuel for Heavy-Duty Freight Trucks Truly Commercial?

Uncertainty in Price Differential with Oil



Price Forecasts

Figure 5. Average annual Brent spot crude oil prices in three cases, 1980-2040
2011 dollars per barrel

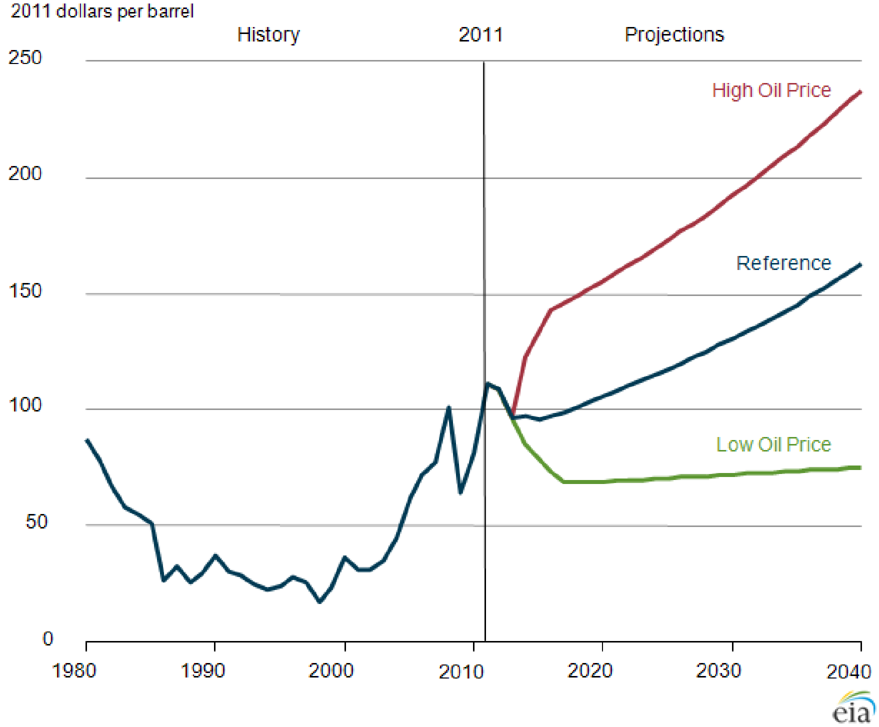
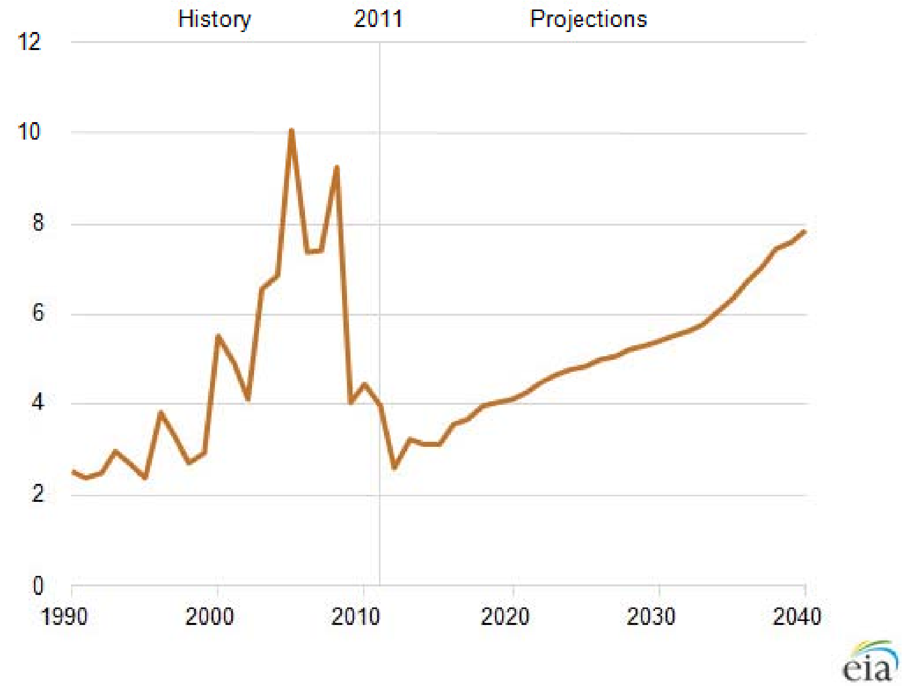


Figure 86. Annual average Henry Hub spot natural gas prices, 1990-2040 (2011 dollars per million Btu)



Class 8 Trucks
Vehicle costs and Fuel Breakeven price

Comparison of Alternative Fuel Vehicles

Vehicle Incremental Cost	Conv. Diesel	Conv. LNG-SI	Conv. LNG-CI	Diesel Hybrid	LNG-SI Hybrid	LNG-CI Hybrid	Battery EV	Fuel Cell
OEM Additional Cost	0	$35,000	$45,200	$16,500	$51,500	$61,700	$214,000	$65,000
Retail Additional Cost [f]	0	$52,500	$67,800	$24,750	$77,250	$92,550	$321,000	$97,500

Breakeven Prices of LNG ($/DGE)

Powertrain / Fuel	Day Drive		Short Haul		Long Haul Drive		
VMT(mile/year)	30k	60k	30k	60k	30k	60k	150k
year payback	5	3	5	3	5	3	3
Today's vehicle incremental costs							
Diesel Hybrid	4.94	3.96	9.74	7.81	26.4	21.17	8.47
LNG-SI Conventional	1.41	1.7	1.57	1.86	1.41	1.75	2.58
LNG-SI Hybrid	0.96	1.53	1.02	1.51	0.64	1.16	2.45
LNG-CI Conventional	1.41	1.94	1.49	1.97	1.12	1.67	2.98
LNG-CI Hybrid	0.5	1.36	0.65	1.35	0.13	0.9	2.76

*Savings in diesel hybrids are realized from reduced fuel use, the more expensive the fuel the better your savings, while saving in NGVs are realized from using a cheaper fuel. The cheaper the LNG the higher the savings.

Function of:

- Type of engine
- Driving cycle
- Annual driving intensity

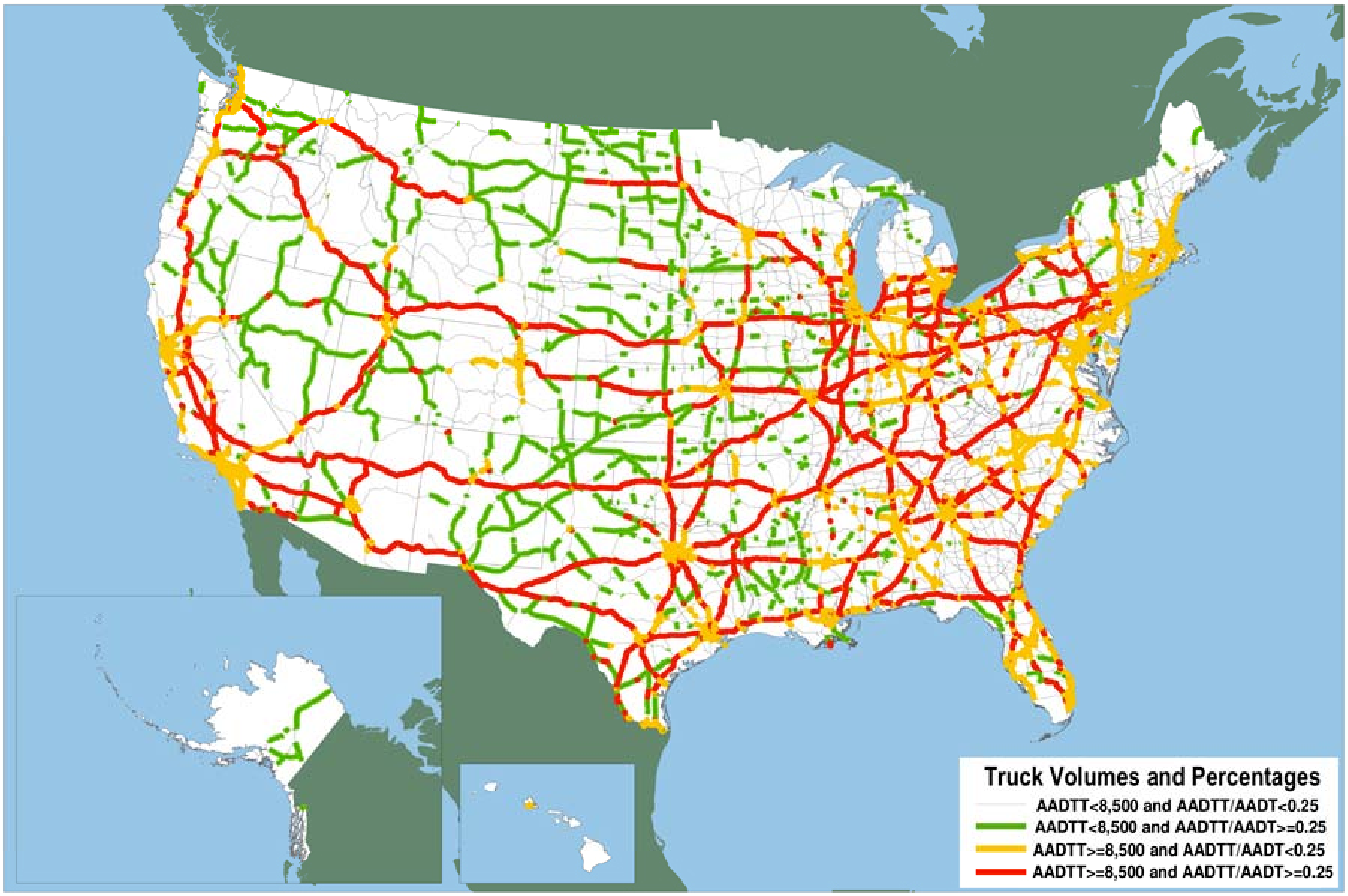
Assumptions:
Diesel $4/gal

DOE Prices

Fuel	Unit of sale	Price ($)
Diesel	gallon	3.5 - 4.0
LNG	gallon	2.9 - 3.0/DGE 1.5 - 2
Hydrogen	kg	4.0 - 5.0
Electricity	kWh	0.1 - 0.15

US Major Truck Routes Are Concentrated, Making Shift In Fuel Infrastructure Easier

Major Truck Routes on the National Highway System: 2040



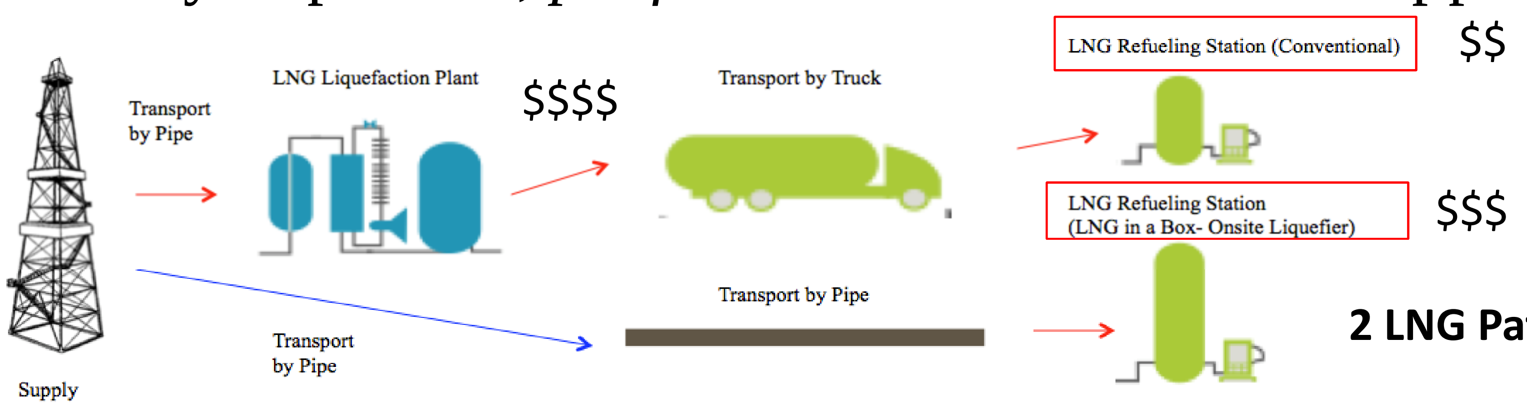
Notes: AADTT is average annual daily truck traffic and includes all freight-hauling and other trucks with six or more tires. AADT is average annual daily traffic and includes all motor vehicles.

Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 3.4, 2012.

Optimization Model Objective

1) Identify if the build-out of LNG and CNG supply chains are sustainable as a commercially profitable venture in the United States and if so, what is the most *cost-effective* supply chain configuration of LNG infrastructure, based:
   a. Distance to existing natural gas infrastructure (i.e. existing pipelines, existing liquefaction plants and stations)
   b. Distance to Supply locations (i.e. natural gas trading points or hubs)
   c. Distance to Demand locations (i.e. refueling stations and ports)

2) Identify important, *profitable* routes which will support



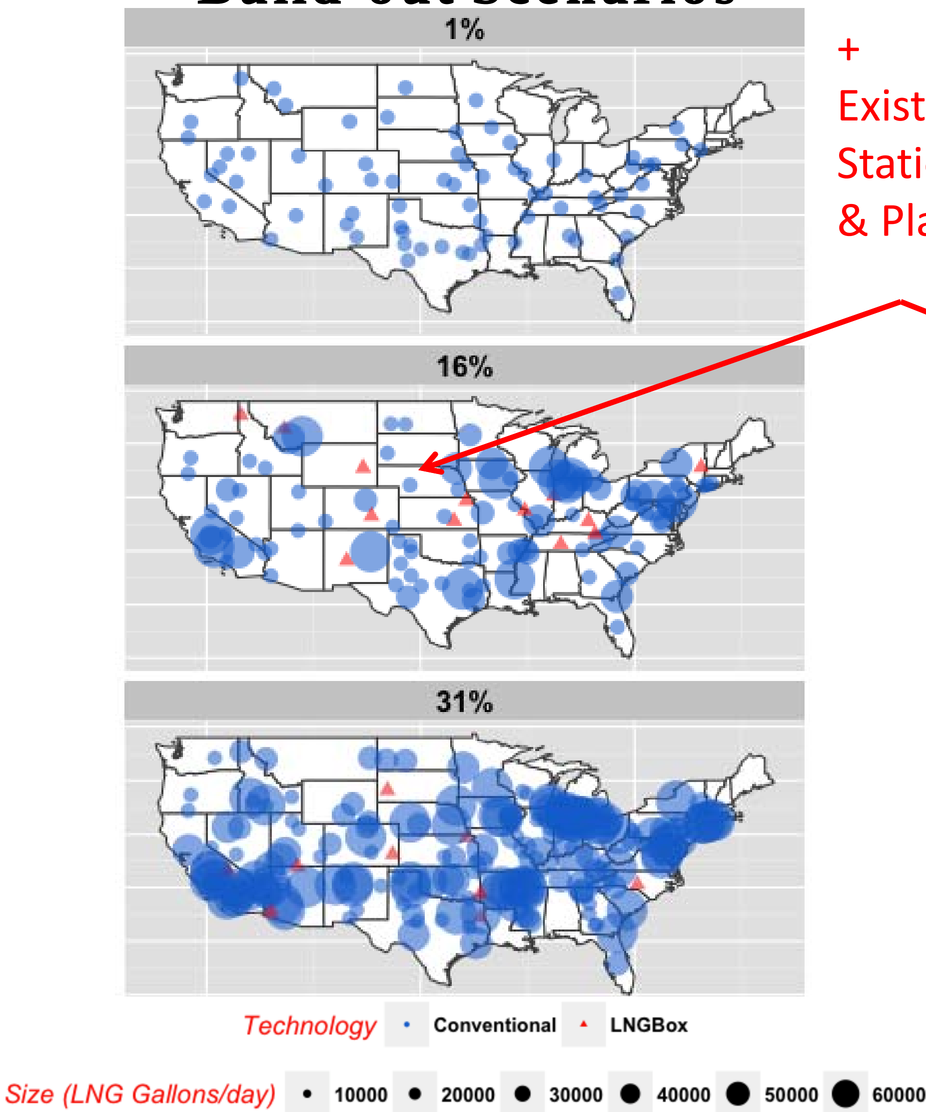
2 LNG Pathways

Key Initial Findings and Thoughts

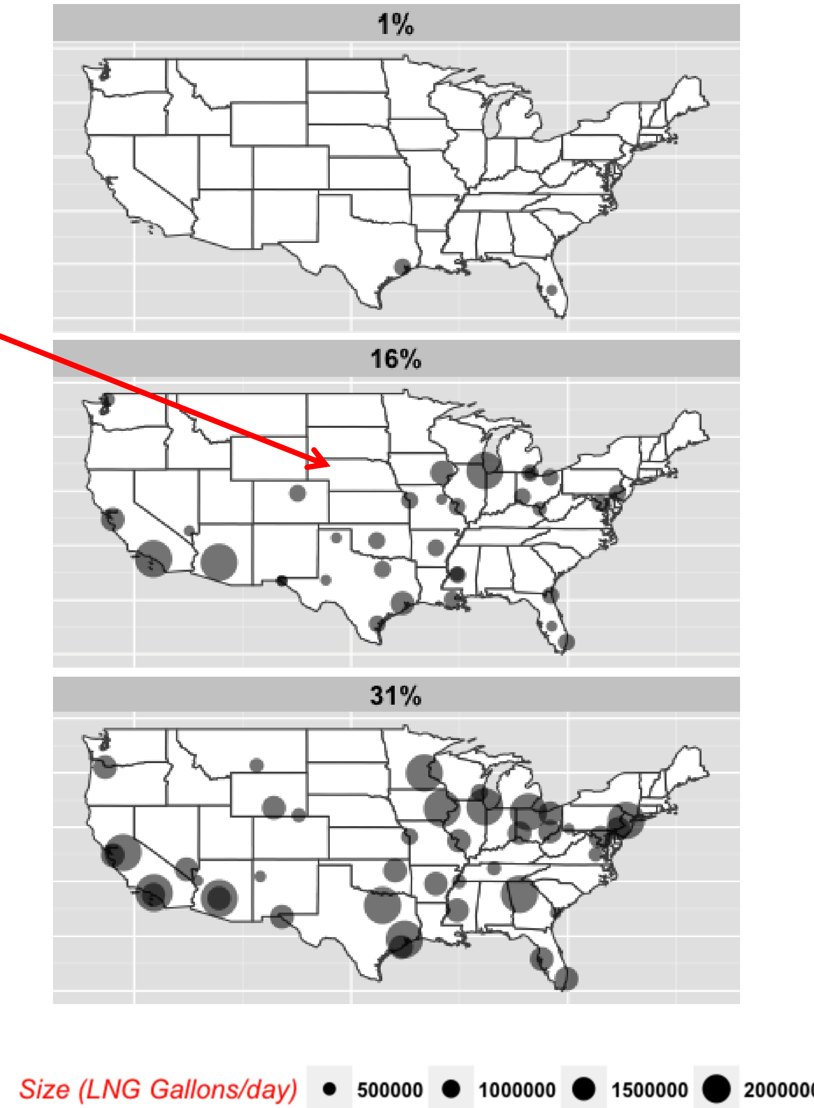
1. Even natural gas fuels (LNG) may require some kind of assistance or subsidy to initiate build out
2. Success of LNG in the Heavy-duty freight market highly sensitive to initial level of penetration rate, but once launched in key markets could be successful
3. Chicken-Egg problem implies station & mini-LNG plant technology still too expensive (high liquefaction costs)
4. This problem is not unique to Natural Gas, it is a problem which all future transportation fuels face in competing with incumbent fuels
5. Further investigation...(Dynamic Model, Stochastic Inputs, Oil Price Scenarios, CNG Technology)

New LNG Station Static System Build-out Scenarios

New Liquefaction Plant Static System Build-out Scenarios



\+ Existing Stations & Plants



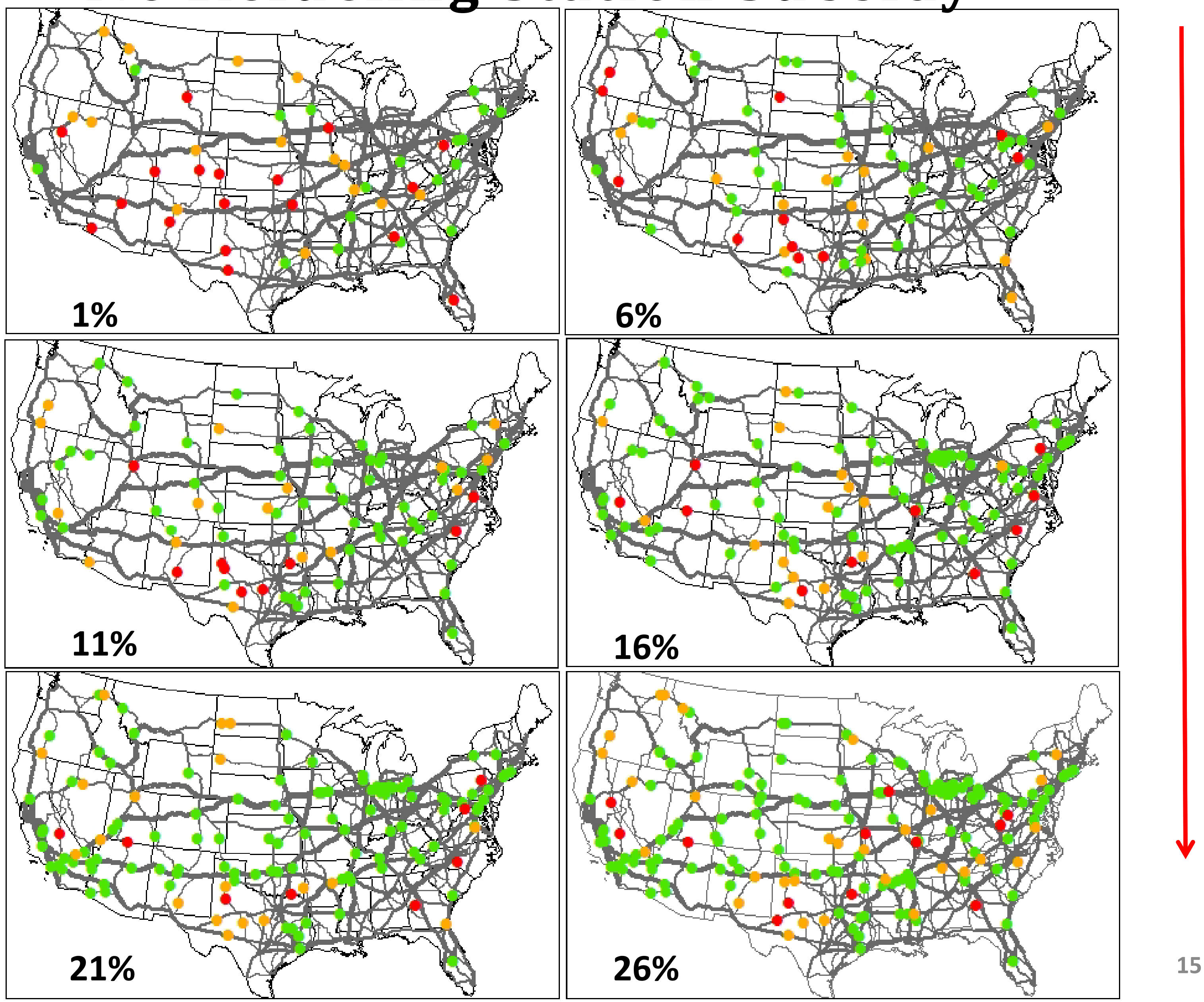
1) Bigger Size 2) More Stations

LNG Box in more remote areas

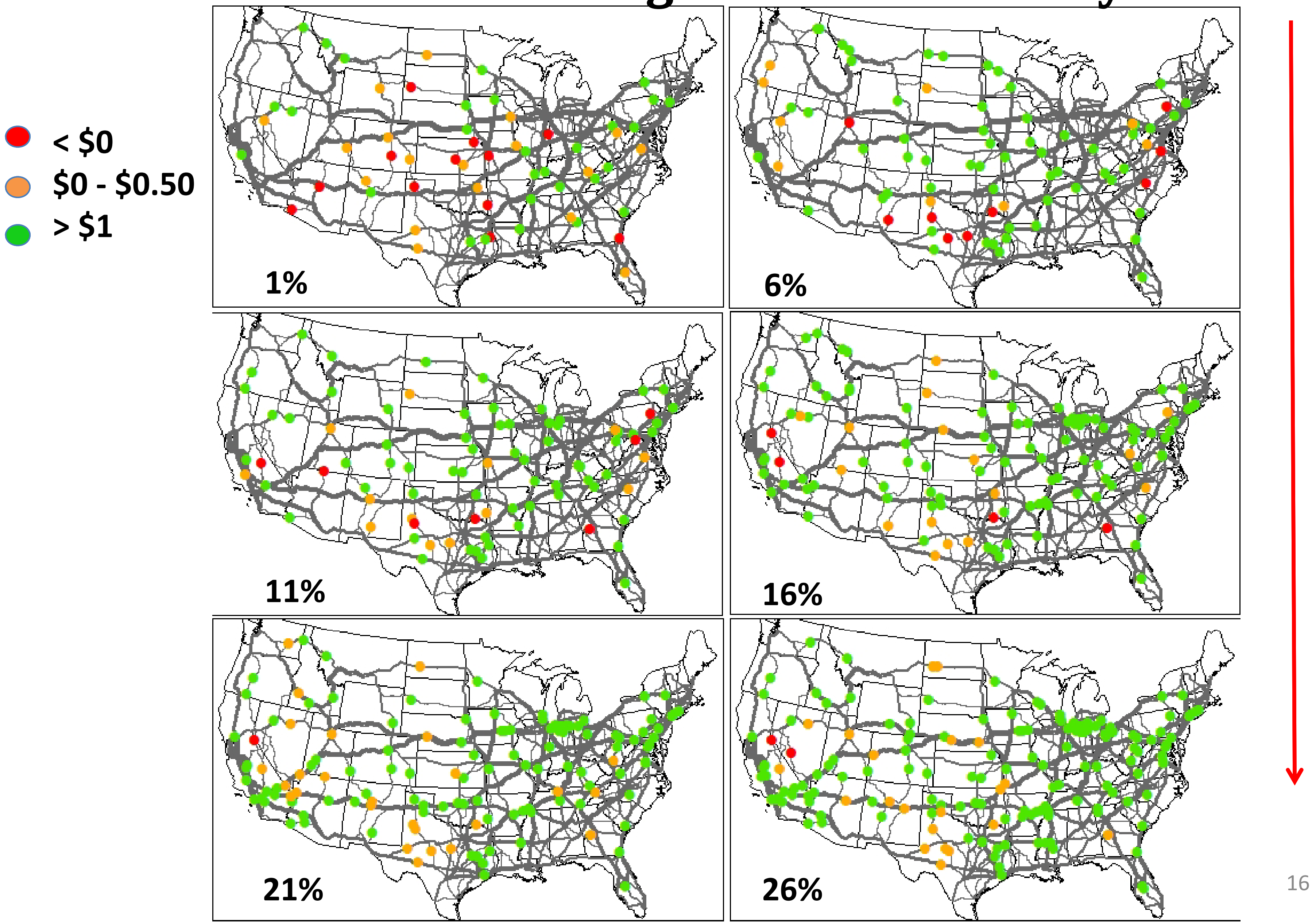
More Plants in Metropolitan Cities (Intercity short haul)

Station Fuel Price Difference with No Refueling Station Subsidy

- < $0
- $0 - $0.50
- > $1



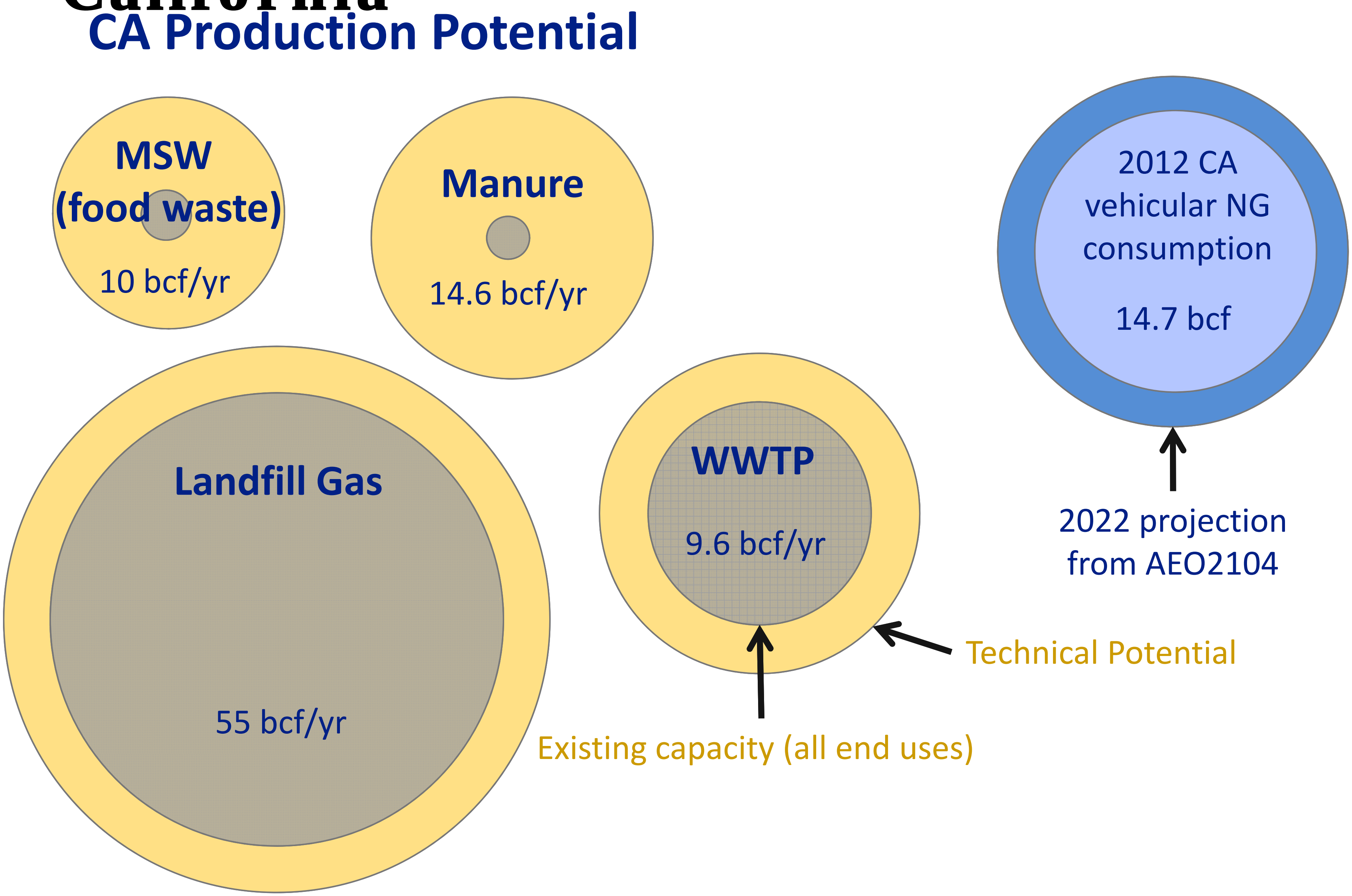
Station Fuel Price Difference under 50% Refueling Station Subsidy



Additional Thoughts On Modeling Results

- This modeling solution does not account for perceived quality of LNG trucks or constraints on their availability.
- Supplier may have to consider a diesel-minus pricing package to shippers (third party hedging?)
- Policy incentives from environmental drivers or need to limit flaring; enabling to renewable natural gas

Renewable natural gas potential in California



Methane leaks in Context

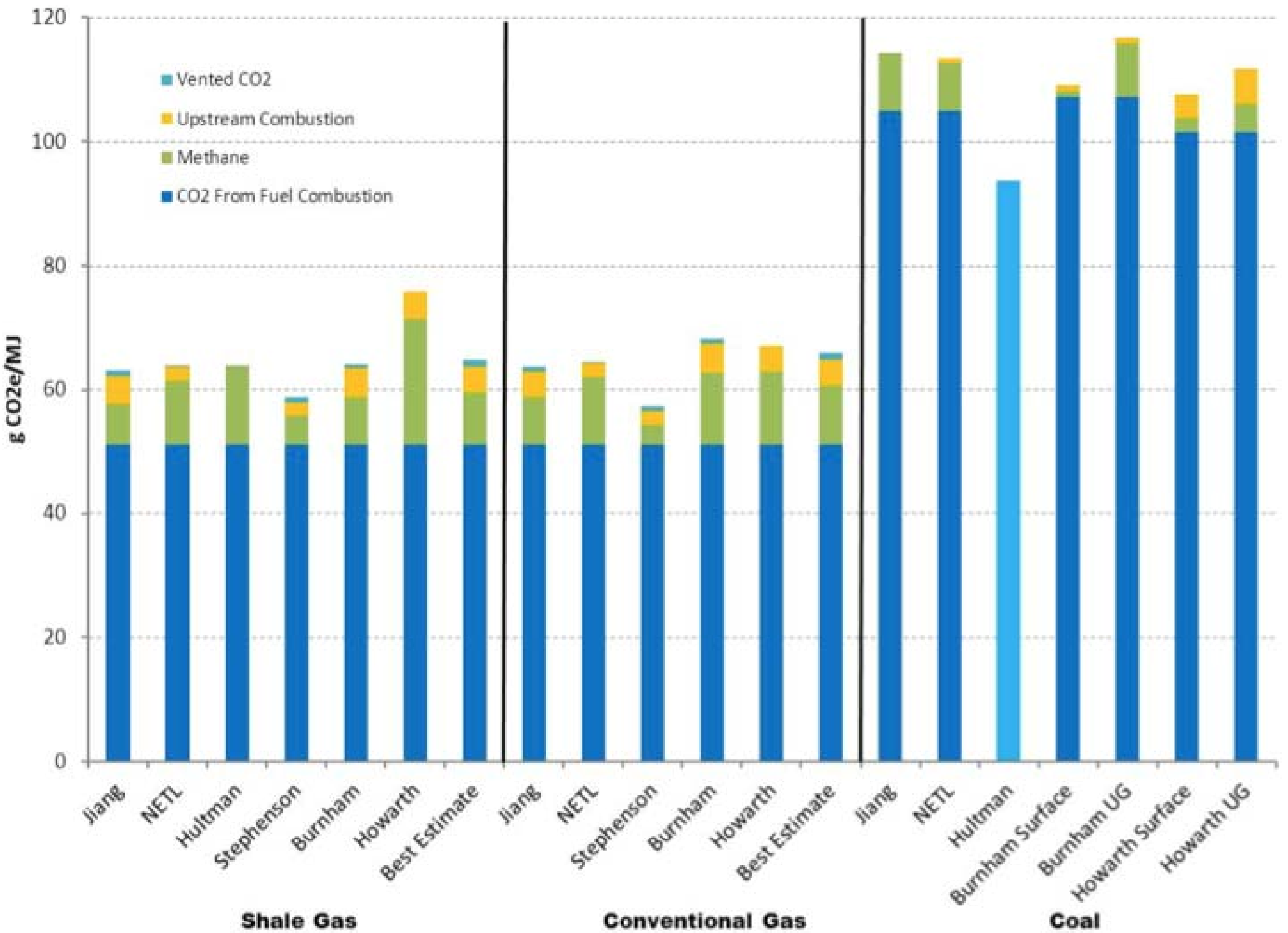
Rosa Dominguez-Faus
Post-doctoral Researcher
UC Davis ITS

Methane leaks

Source: http://www.epa.gov/gasstar/tools/videos.html

LCA power generation (100y GWP)

Figure 4. Natural Gas and Coal LCA Comparison



Source: ICF 2012

Data source: Cited Studies, Weber and Clavin, ICF Analysis

Breakeven leakage rate for **power generation**

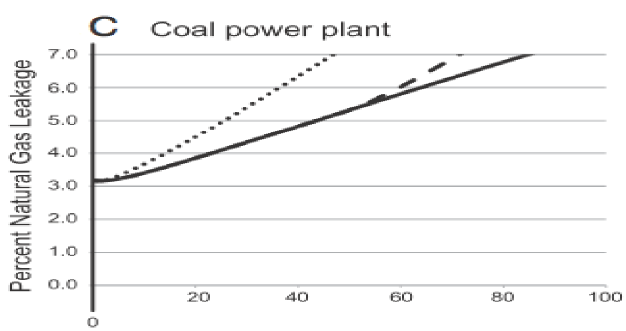
- 8-14% (Richard Muller)

  Source http://static.berkeleyearth.org/memos/epa-report-reveals-lower-methane-leakage-from-natural-gas.pdf

- 6 % (Larson, using 100y GWP)

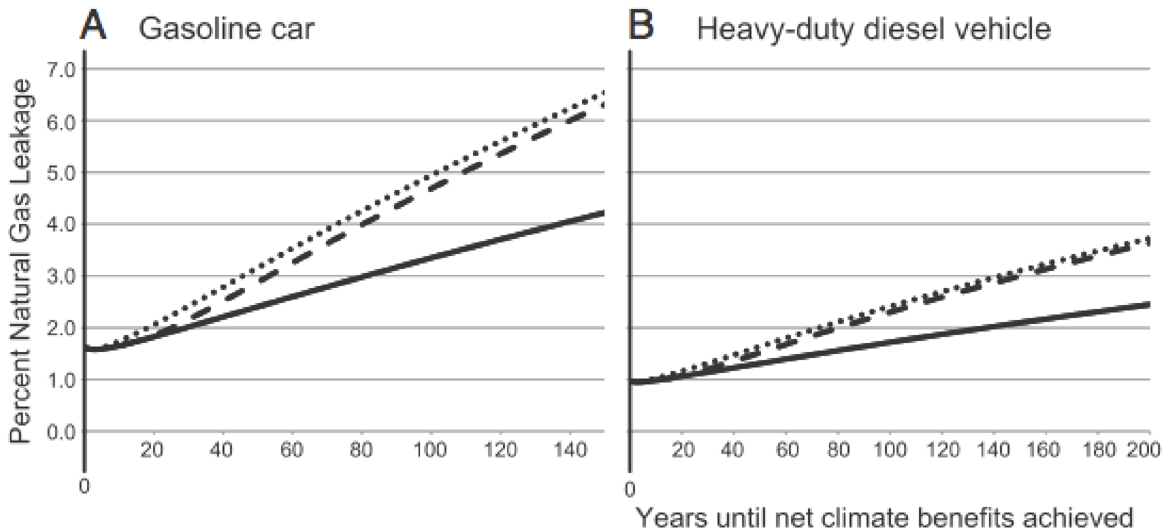
  Source: Eric Larson (2013) Natural Gas & Climate Change.

- 3.2% (Alvarez, Immediate benefit using TWP)



Source: Alvarez et al. (2012) Greater focus needed on methane leakage from natural gas infrastructure. PNAS

Breakeven Leakage Rate for **Transportation** is: 1.6%(LDV) 1% (HDV- bus)



Source: Alvarez et al. (2012) Greater focus needed on methane leakage from natural gas infrastructure. PNAS

Caveats: HDV not well represented, dated technology, 20% GHG in vehicle, NGVs 20% less efficient than diesel vehicles

Actual Rate?

EPA/EIA= **1.5%**

Source:
EPA Greenhouse Gas Inventory 2014 (2009)
EIA Natural Gas Data (2009)

EPA methodology criticized

- Extrapolation based on inventories and EF from 1990 data
- Corrected based on NG STAR program
- Emission factors Underestimation

Recent scientific literature

Actual leakage 25-75% higher than EPA's estimate

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

EPA: **1.5%**

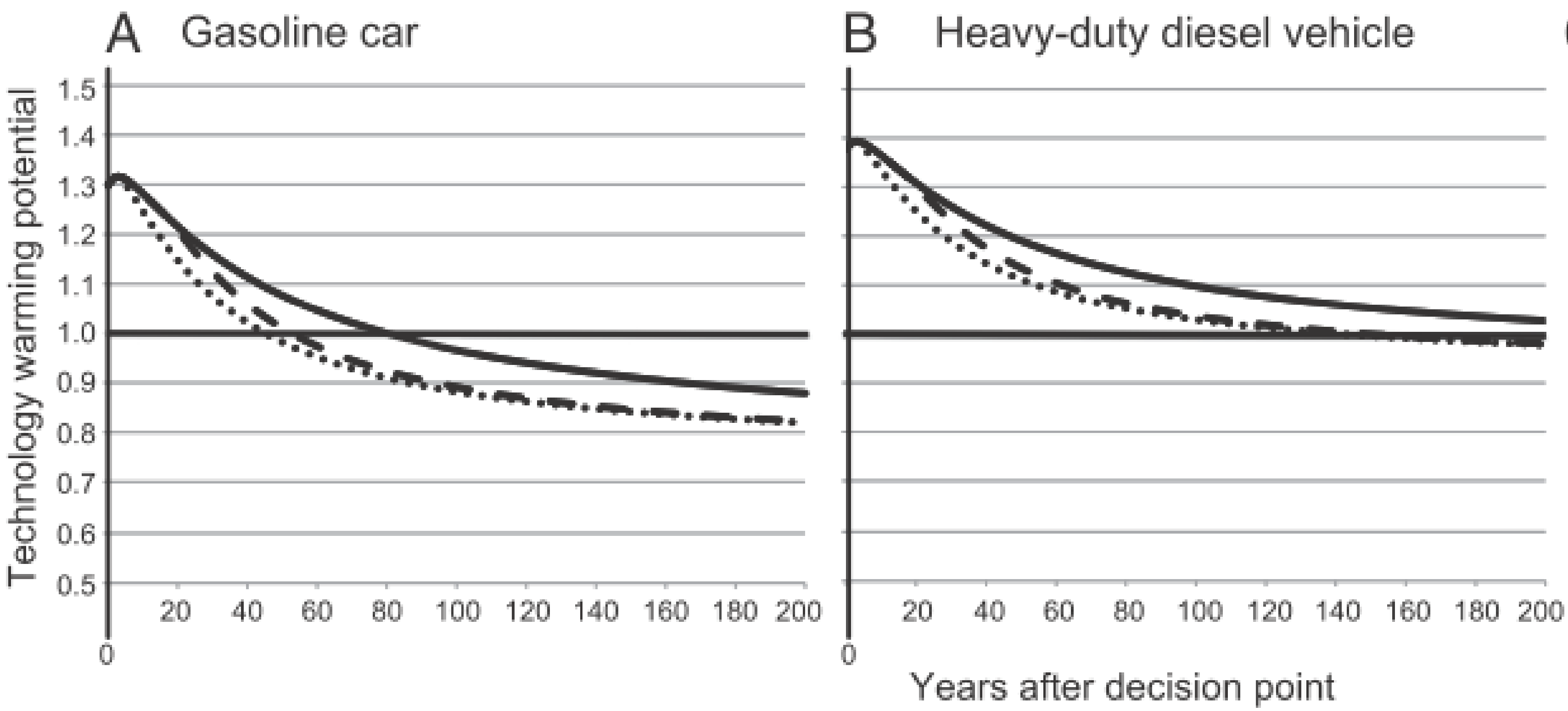
Corrected: **1.85% -2.63 %**

EPA 1.5%

Corrected
2.25% -2.95 %

This Study 2.5%

2.5% leakage means benefits in transportation after 40 in LDV (using CNG)



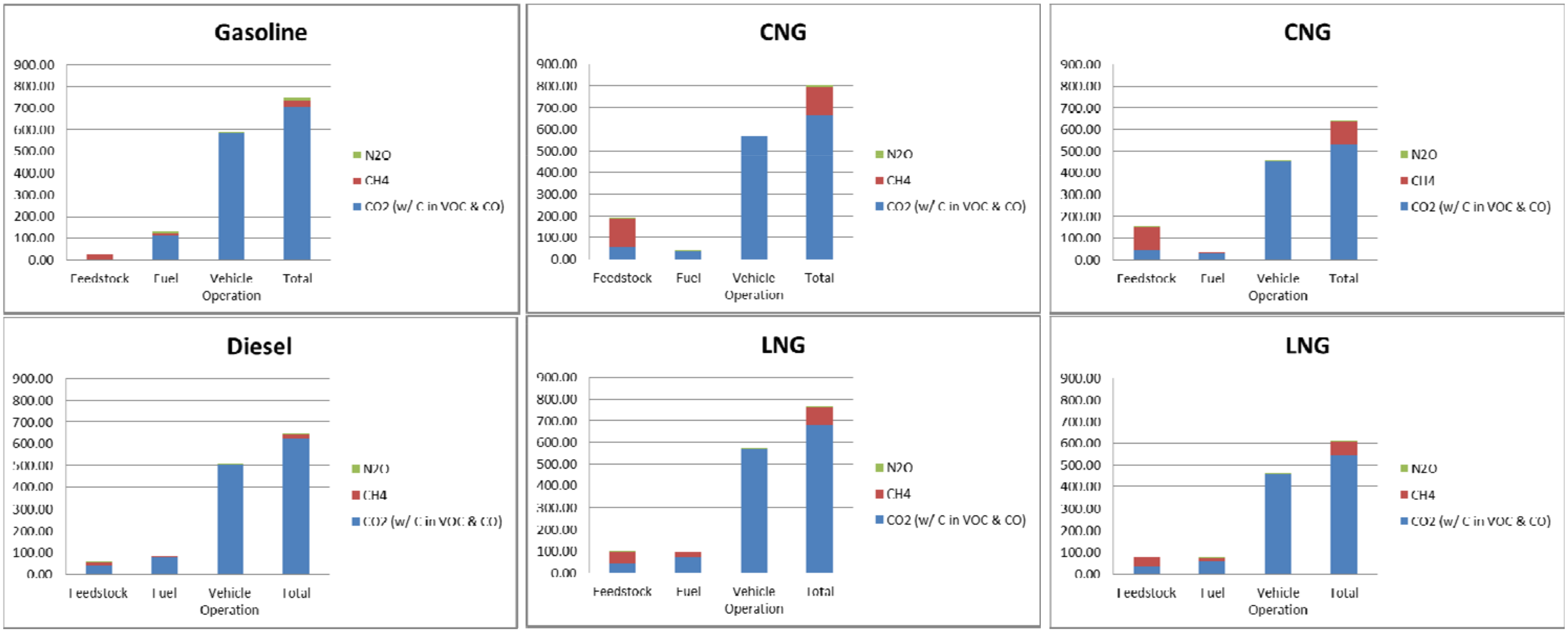
Source: Alvarez et al. (2012) Greater focus needed on methane leakage from natural gas infrastructure. PNAS

Caveats: 20% GHG in vehicle, HDV not represented- NGVs are 20% less efficient than diesel

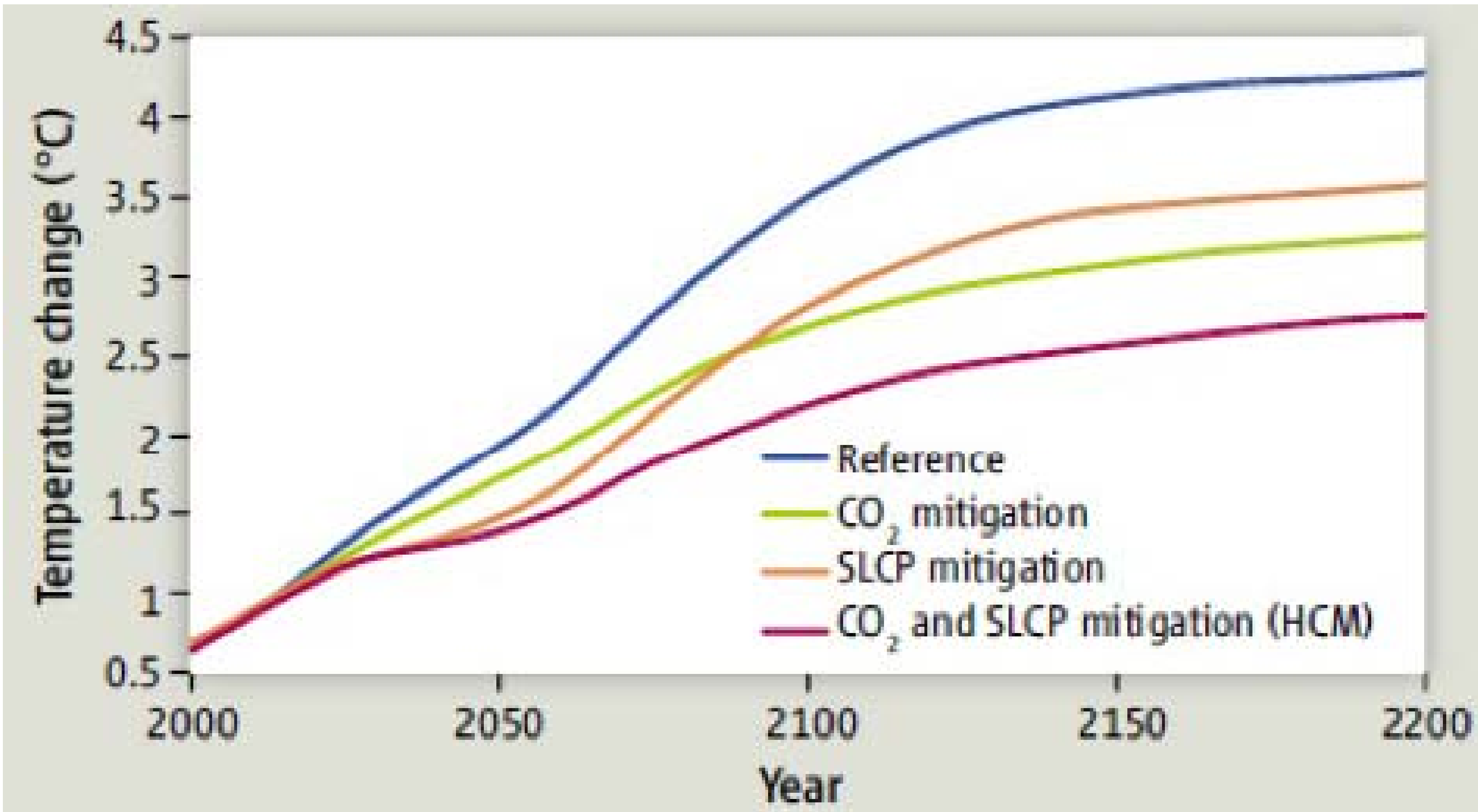
Majority of emissions are from the exhaust 2.6% leakage (75% higher than EPA's)

20% lower mpg

Same mpg

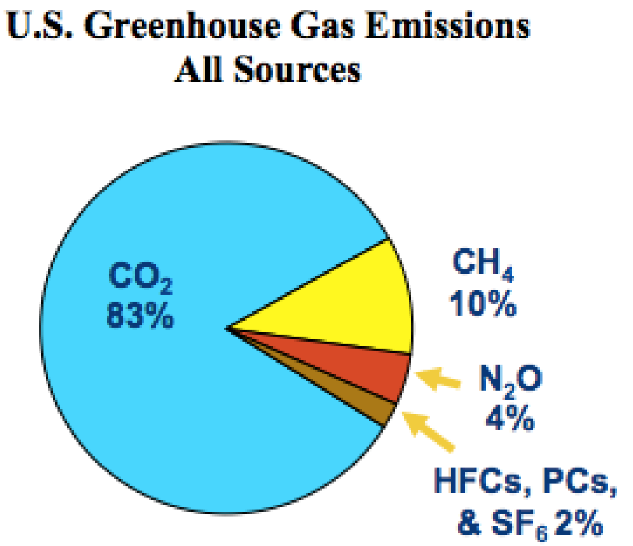


Short and Long Lived Climate Pollutants

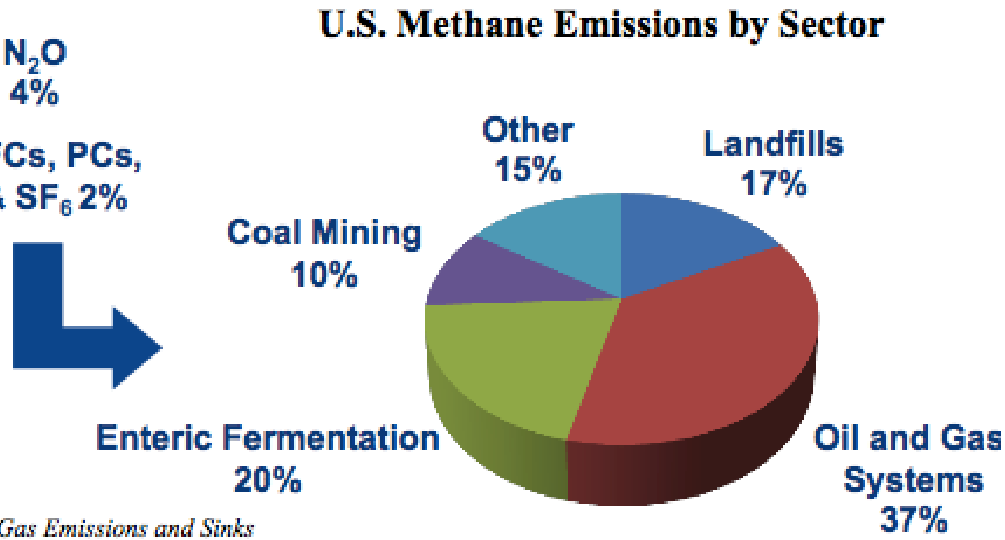


Source: http://igsd.org/documents/PrimeronShort-LivedClimatePollutantsFeb192013.pdf

EPA Natural Gas STAR Program



Oil and natural gas systems are the largest man-made source of methane emissions in the United States (37%) and make up 3.8% of total U.S. greenhouse gas emissions



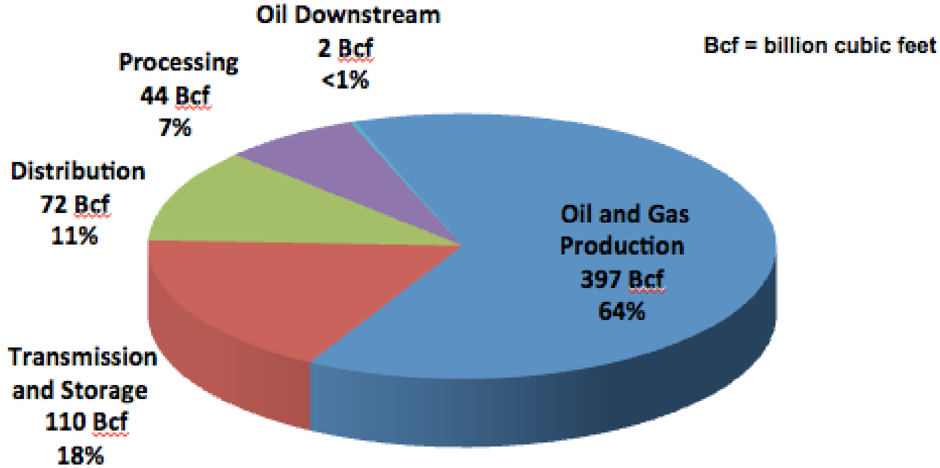
Source: EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 – 2009*, April, 2011.

Note: Totals may not sum due to independent rounding.

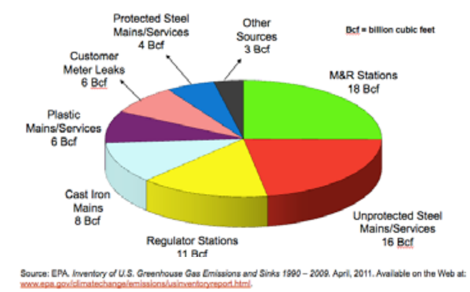
Oil and gas 4% of all GHG in 2011

Where are the leaks?

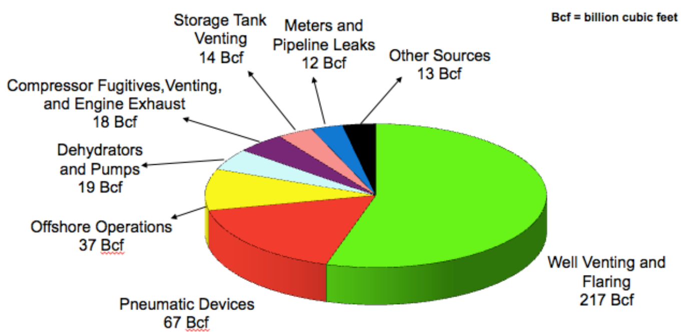
- 2009 U.S. methane emissions from oil and natural gas industry: 624 Bcf (3.8% of total U.S. greenhouse gas emissions)



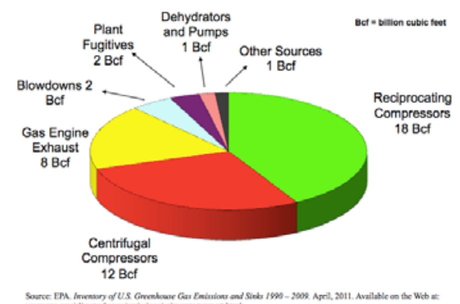
Distribution



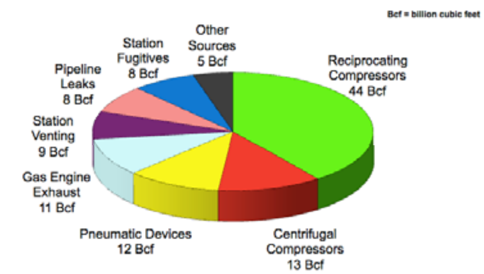
Production



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

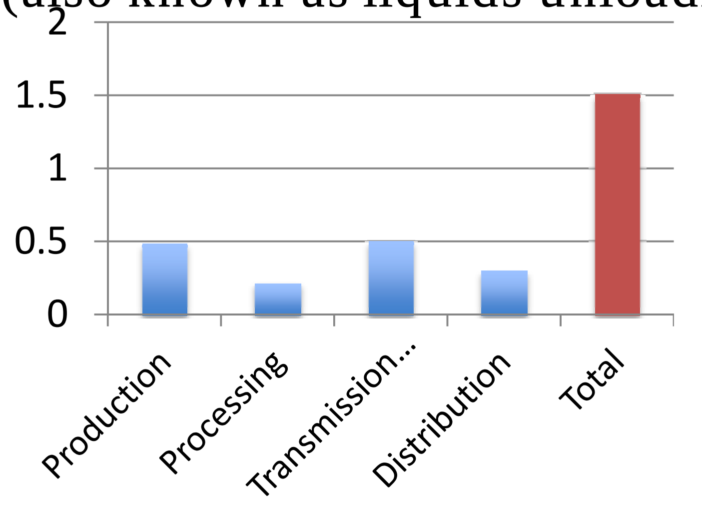
Note: Profit includes revenue from deployment of technology plus any O&M savings or costs, but excludes depreciation. Additional details provided in Appendix A.
Source: NRDC analysis of available industry information. Individual technology information sources cited in Chapter 4.

Source: EPA Natural Gas STAR Program. NRDC leaking profits

Obama: Green completions obligatory by Jan 2015 (2016)

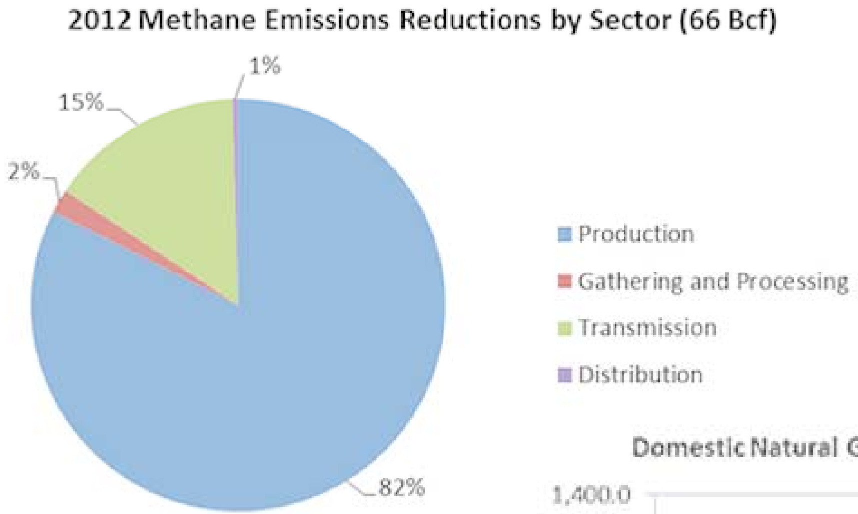
- **Green completions,** closed loop systems that capture liquids and gases coming out of the well during "completions" using temporary processing equipment brought to a well site, then routing fluids and gases to a tank for separation to enable sale of gas and condensate.
- **Historically**, the fluids and gases flowing back out of the well have been routed to an open air pit or perhaps a tank, allowing substantial amounts of methane to vent directly into the atmosphere.
- **completions and workovers** (68 Bcf).
- **cleanups of low pressure wells** (also known as liquids unloading) (237 Bcf/year)

Example of Green Completion Equipment (FracmasterUSA)

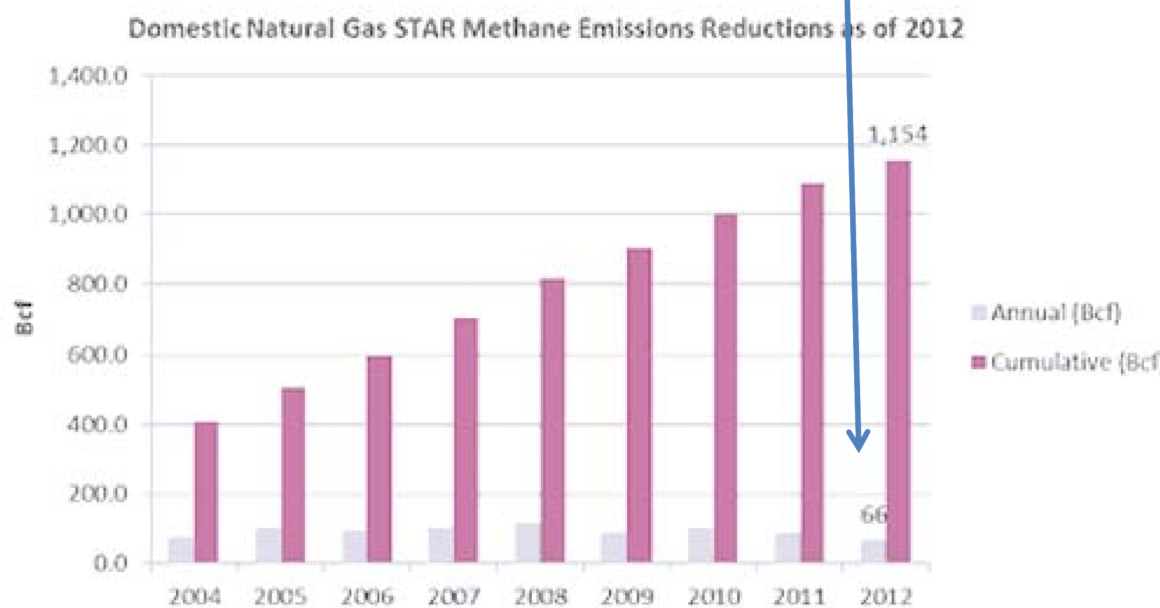


Source: NRDC leaking profits

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

Examples:
Devon Energy and Northern Natural Gas

3% of 2010 earnings

Examples: Key Achievements and Contributions

- After thorough review of well completion practices and Gas STAR opportunities, implemented Reduced Emission Completions (RECs) in Fort Worth Basin
- Through REC's and other activities, **achieved methane emission reductions of 23.6 Bcf valued at $165 million** (through 2006)
- Awarded multiple Gas STAR awards i.e., "2005 Production Partner of the Year"
- Donated STARtracker to Gas STAR and generously shared successes

Examples: Key Achievements and Contributions

- Sponsored workshops and provided hands-on experience to operations staff on tools and methods to detect and quantify methane leaks at Sprayberry compressor station
- **Company saved over 14.5 Bcf of gas from 2003 through 2006** by identifying and fixing emission sources such as scrubber dump valves and reciprocating compressor rod packing, and from avoiding blow downs when performing maintenance, etc.
- Recipient of multiple Gas STAR awards including a Continuing Excellence award in 2007

Thanks!

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