CEERT

Natural Gas Market Assessment & Methane Emissions

California Energy Commission
IEPR Workshop

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What’s happening with Methane?

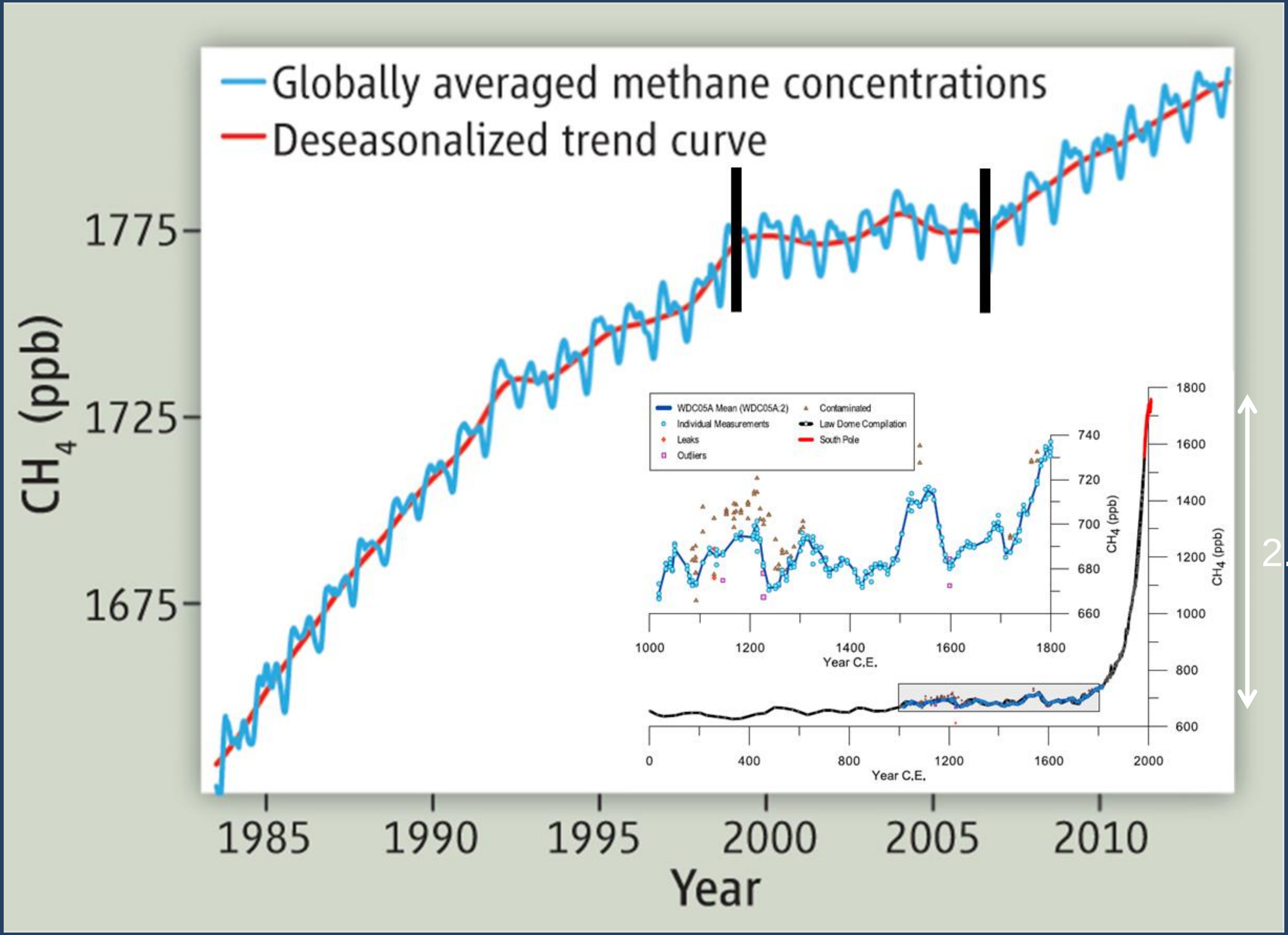
- About two-thirds of the emissions are caused by human activities; the remaining third is from natural sources

- In the northern mid-latitudes, the main sources are the gas and coal industries, agriculture, landfills, and biomass fires.

- Global-scale modeling of these methane observations suggests that in 2007, tropical wetland emissions dominated growth, with output from high northern latitudes also important. Since then, the increase has mostly been driven by the tropics and northern mid-latitudes.

Nesbitt et al, *Science* v343, 2014

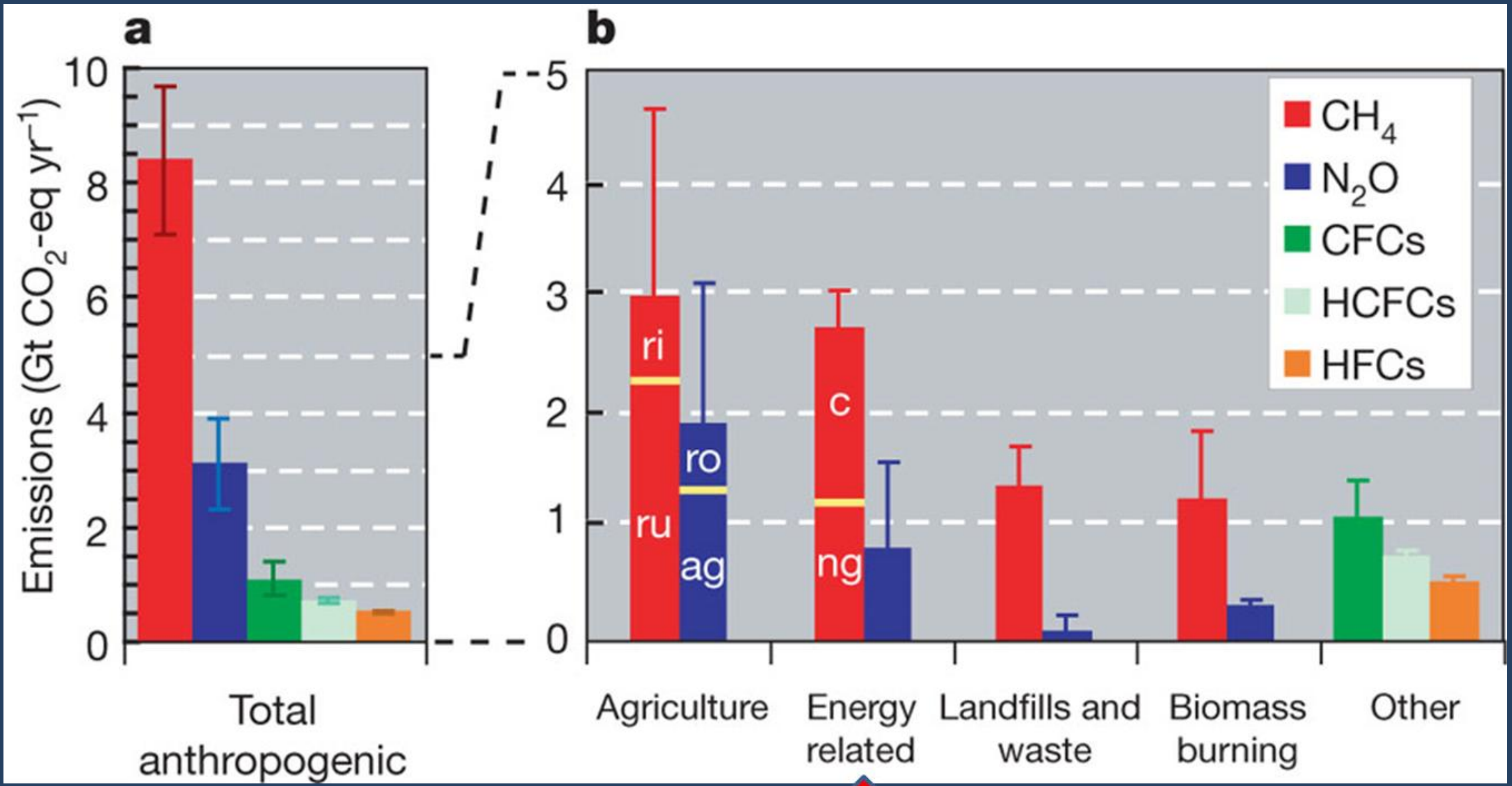
Trends in Global Methane Emissions



Nesbitt et al, *Science* v343, 2014

Inset: Mitchell et al, *JGR* v116, 2011

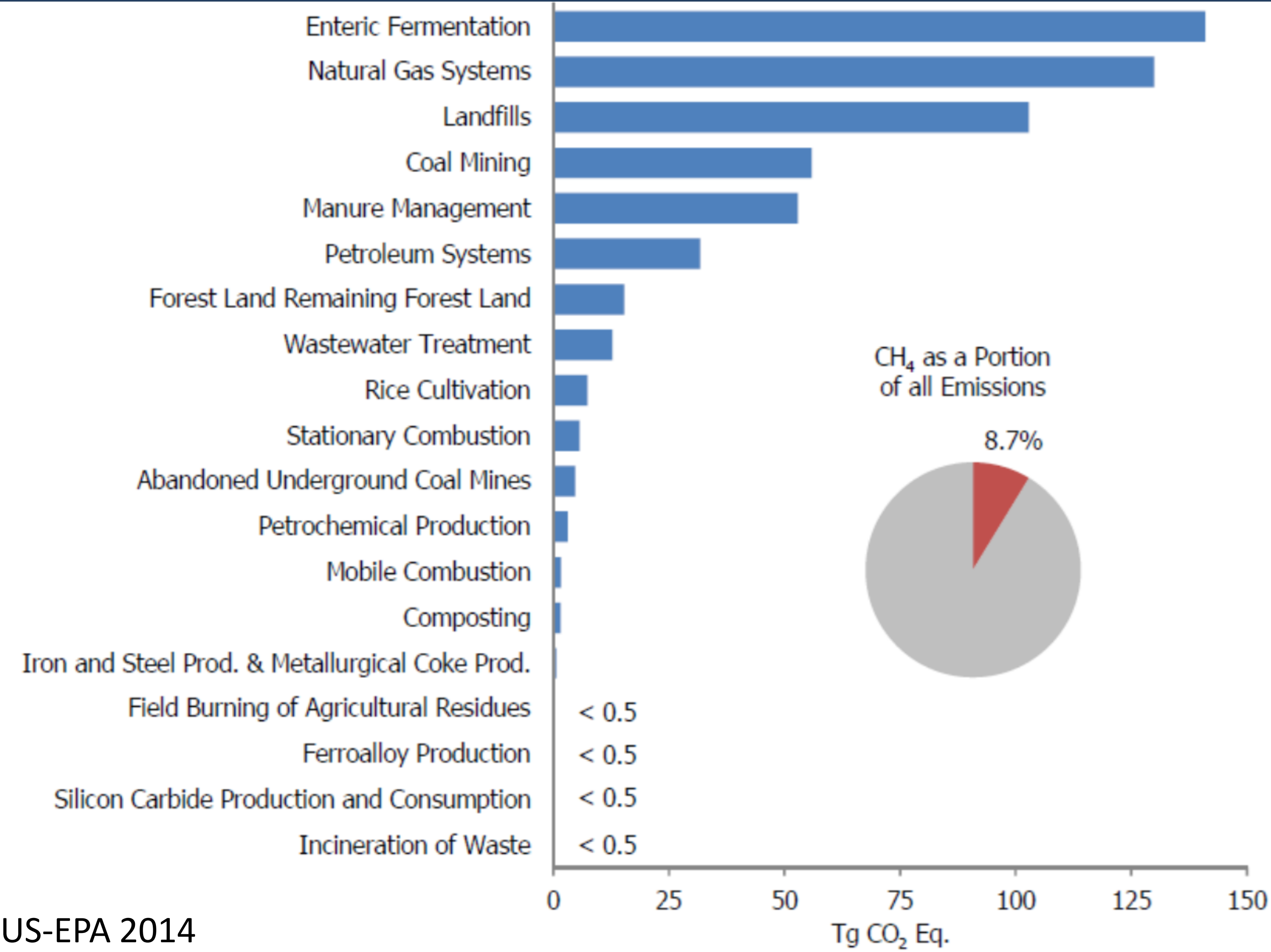
Annual anthropogenic emissions of non-CO_2 GHGs



Coal & Natural Gas

SA Montzka *et al.* *Nature* v 476, 2011

US Sources of CH4 Emissions during 2012



US-EPA 2014

Natural Gas Infrastructure

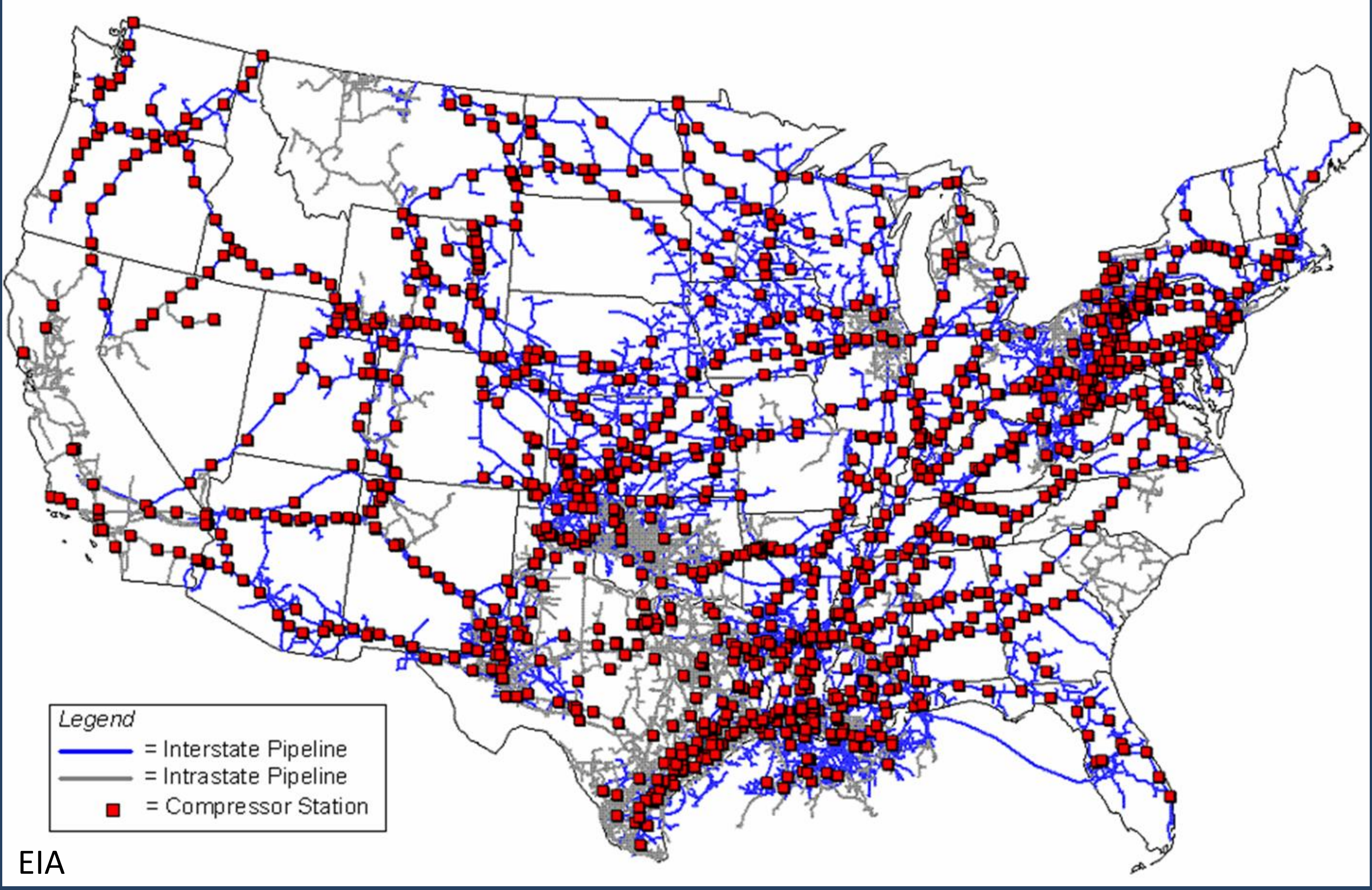
According to the Energy Information Administration:

There are:

- More than 210 natural gas pipeline systems.
- 305,000 miles of interstate and intrastate transmission pipelines.
- More than 1,400 compressor stations that maintain pressure on the natural gas pipeline network and assure continuous forward movement of supplies.
- More than 11,000 delivery points, 5,000 receipt points, and 1,400 interconnection points that provide for the transfer of natural gas throughout the United States.
- 24 hubs or market centers that provide additional interconnections.
- 400 underground natural gas storage facilities.
- 49 locations where natural gas can be imported/exported via pipelines.
- 8 LNG (liquefied natural gas) import facilities and 100 LNG peaking facilities.

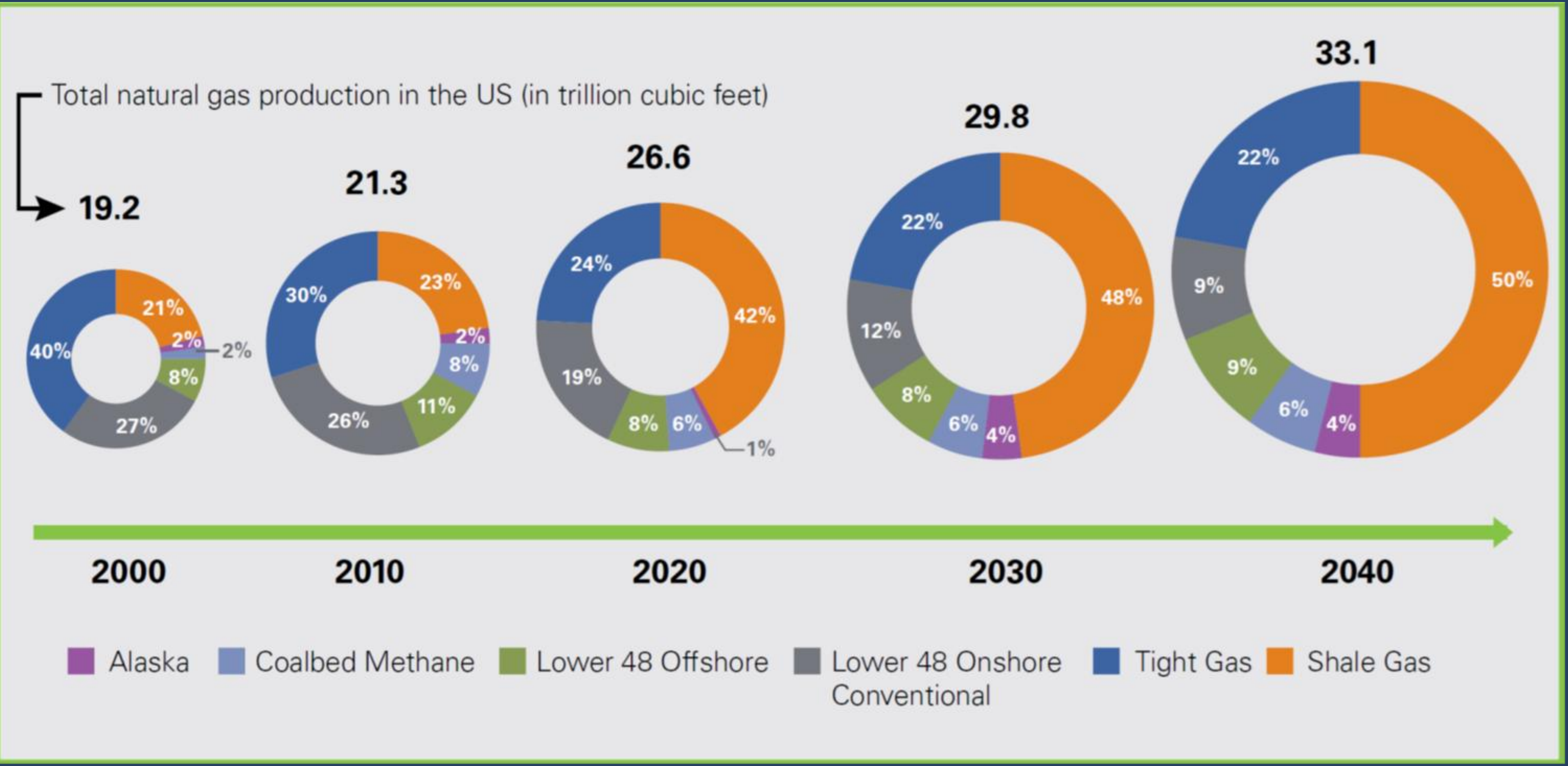
EIA

Pipelines & Compressor Stations



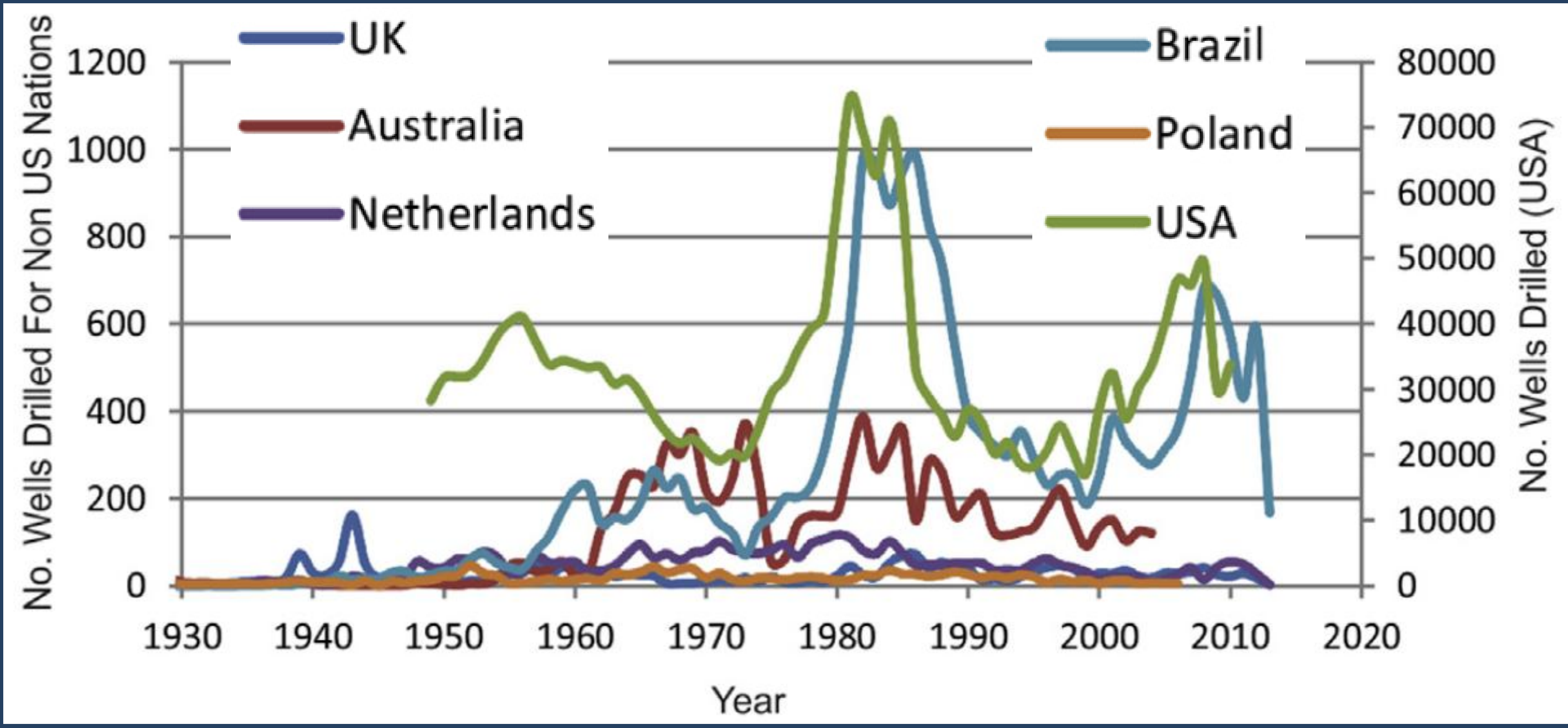
EIA

Conventional natural gas production is forecast to grow at 1.4 percent and unconventional (shale) gas at a 10.4 percent during 2000 to 2040.



Source: EIA

Number of Wells Drilled in Select Countries



Source: Davies et al, *Marine and Petroleum Geology* v56 September 2014.

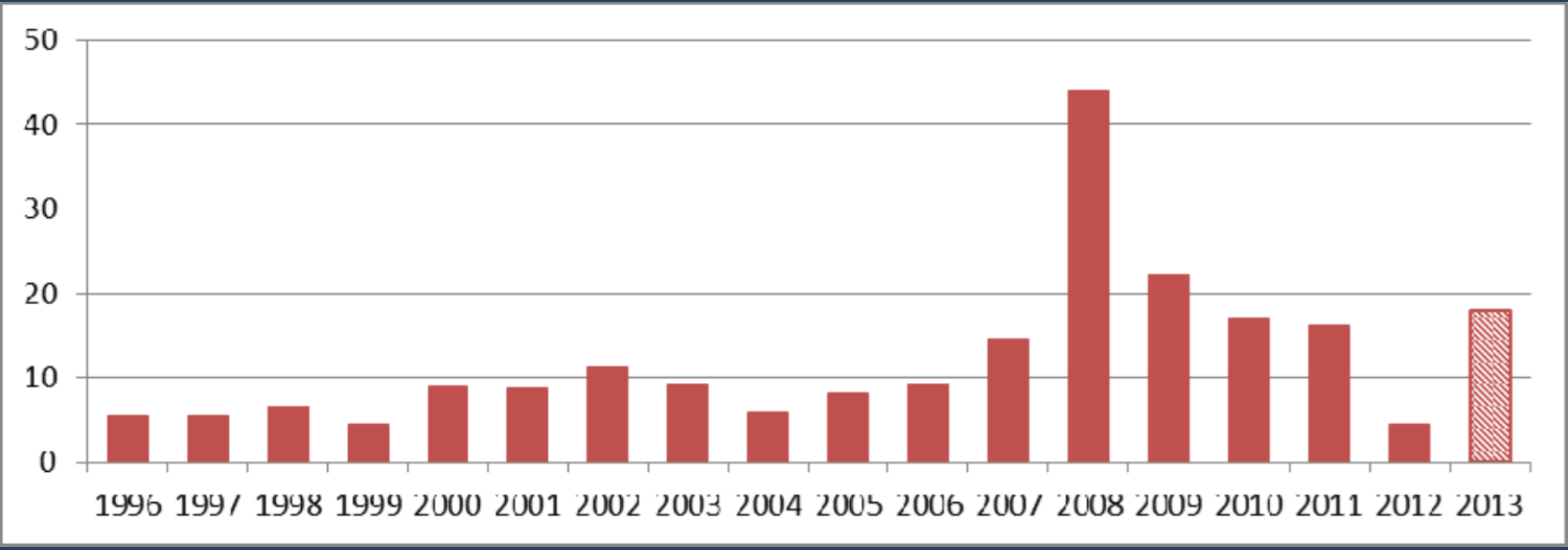
Number of onshore hydrocarbon boreholes in select countries.

Country	Number of wells	Source
Bahrain	750	Sivakumar and Janahi (2004)
Austria	1200	Veron (2005)
UK	2176	DECC, 2014
Netherlands	3231	Geological Survey of the Netherlands
Poland	7052	Polish Geological Institute
Australia	9903	Geoscience Australia
Brazil	21,301	Brazil Database of Exploration and Production
Canada/Alberta	355,724	Watson and Bachu (2009)/ www.nickles.com/ boereport.com
USA	2,581,782	EIA Database

Source: After Davies et al, *Marine and Petroleum Geology* v56 September 2014.

U.S. Natural Gas Transmission Pipeline Capacity Additions

(Billion cubic feet per day)



Source: CRS, November 2013 based on EIA data

WELL COUNTS AND PRODUCTION OF OIL, GAS, AND WATER BY COUNTY - 2012

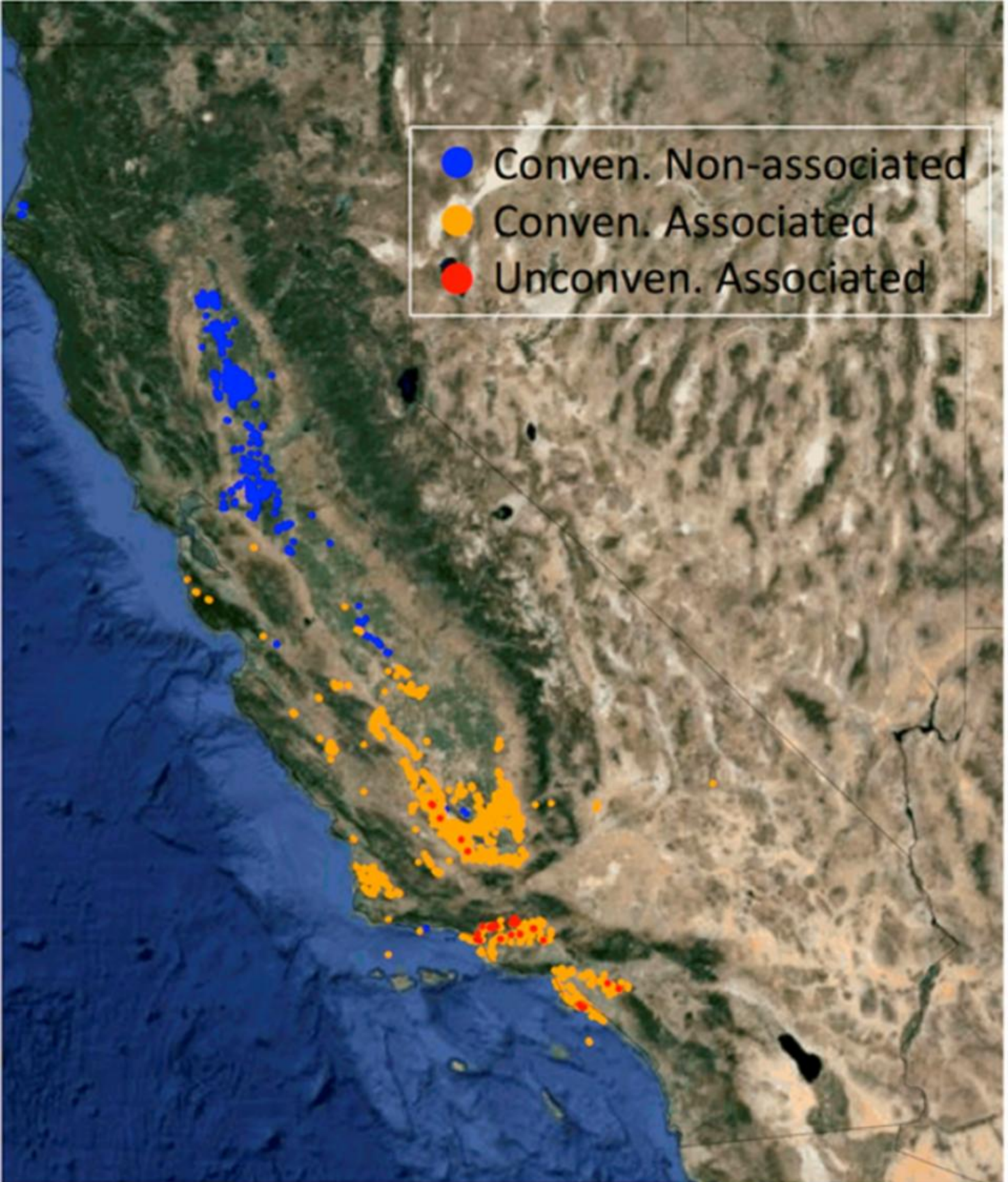
County	Well Count *		Oil Production (bbl) **	Net Gas Production			Water Production (bbl)
	Active	Inactive		Associated Gas (Mcf)	Nonassociated Gas (Mcf)	Total Gas (Mcf)	
Alameda.	6	1	14,601	0	0	0	46,052
Butte.	26	1	0	0	51,839	51,839	420
Colusa	225	129	0	0	9,886,381	9,886,381	104,561
Contra Costa	45	17	454	0	843,518	843,518	8,764
Fresno	1,946	1,571	5,992,763	714,642	357	714,999	66,040,632
Glenn.	259	60	0	0	8,521,530	8,521,530	80,390
Humboldt	26	29	0	0	638,124	638,124	7,420
Kern	42,875	15,803	141,481,290	160,638,575	2,904,518	163,543,093	1,828,374,391
Kings	175	188	137,127	190,197	153,748	343,945	908,558
Los Angeles	3,690	1,552	24,130,729	18,275,394	241,297	18,516,691	798,857,241
Madera	23	18	0	0	967,873	967,873	1,656
Merced	0	3	0	0	0	0	0
Monterey	657	562	7,433,840	1,204,142	0	1,204,142	116,288,726
Orange	1,041	464	4,383,546	2,006,620	0	2,006,620	79,058,939
Sacramento	112	100	21,085	0	8,796,121	8,796,121	141,912
San Benito	18	23	5,007	46,929	7,155	54,084	1,669
San Bernardino	20	18	10,595	111	0	111	2,671
San Joaquin	157	94	184	0	2,970,015	2,970,015	67,689
San Luis Obispo	120	228	414,582	858,768	0	858,768	7,241,378
San Mateo	10	13	1,294	4,675	0	4,675	2,561
Santa Barbara	1,170	1,042	4,595,018	3,274,524	101	3,274,625	105,330,847
Santa Clara	13	2	40,006	39,598	0	39,598	24,765
Solano	126	148	9,932	0	4,796,836	4,796,836	89,955
Stanislaus	2	0	0	0	616,623	616,623	32,201
Sutter	289	130	0	0	10,499,715	10,499,715	114,525
Tehama	111	39	0	0	1,727,083	1,727,083	16,436
Tulare	75	20	48,142	0	0	0	3,954,749
Ventura	1,743	1,263	8,977,459	8,411,316	8,411,316	16,822,632	66,299,114
Yolo	25	56	578	0	229,860	229,860	2,314
Yuba	1	0	0	0	1,006	1,006	0
TOTAL	54,986	23,574	197,698,232	195,665,491	62,265,016	257,930,507	3,073,100,536

Nearly 80,000 Oil & Gas Wells throughout the state of California

* includes well count from Oil & Gas (OG), Dry Gas (DG) and Gas Storage (GS)

** Includes condensate produced from from Dry Gas (DG) and Gas Storage (GS)

Division of Oil, Gas, and Geothermal Resources



Locations of individual oil and gas wells (active and new wells only) in California for the year 2010 (no unconventional nonassociated wells identified)

Jeong et al, ES&T v48, 2014

Why might emissions inventories be below what is observed in the atmosphere?

Based on a review of more than 200 earlier studies that found total U.S. methane emissions of about 25 to 75 percent higher than EPA estimates … And I quote:

Current inventory methods rely on key assumptions that are not generally satisfied.

- Devices sampled are not likely to be representative of current technologies and practices.
    - Production techniques are being applied at scale (e.g., hydraulic fracturing and horizontal drilling) that were not widely used during sampling in the early 1990s, which underlies EPA emissions factors (EFs).
- Measurements for generating EFs are expensive, which limits sample sizes and representativeness.
- Many EPA EFs have wide uncertainties.
- There are reasons to suspect the EFs suffer from sampling bias, as sampling has occurred at self-selected cooperating facilities.

Source: Brandt et al. *Science* v343, 2014

Why might emissions inventories be below what is observed in the atmosphere?

- If emissions distributions have “heavy tails” (e.g., more high-emissions sources than would be expected in a normal distribution), small sample sizes are likely to underrepresent high-consequence emissions sources.
    - Studies suggest that emissions are dominated by a small fraction of “superemitter” sources at well sites, gas-processing plants, coproduced liquids storage tanks, transmission compressor stations, and distribution systems. *

- Activity and device counts used in inventories are contradictory, incomplete, and of unknown representativeness.

* NB: This poses the challenge of being able to reliably detect &/or predict where to find the small number of “superemitters”.

Source: Brandt et al. *Science* v343, 2014

Why might emissions inventories be below what is observed in the atmosphere?

… and to quote other research:

- Although it is clear that analysis of the effect of natural gas use would benefit from better measurements of emissions from unconventional gas wells, the inaccessible and transient nature of these leaks makes them difficult to identify and quantify, particularly at a scale at which they are useful for bottom-up inventories or mitigation strategies (i.e., leak rates of individual components or activities).

- The current range of observed CH_4 emissions from US natural gas systems (2.3–11.7%), if it were …, applied to the reported 2011 unassociated gas production number, yields a range of CH_4 emissions between 5.6 and 28.4 Tg CH_4, whereas the EPA reports 6.7 Tg CH_4 from natural gas systems in 2011 and only 28 Tg CH_4 total anthropogenic emissions

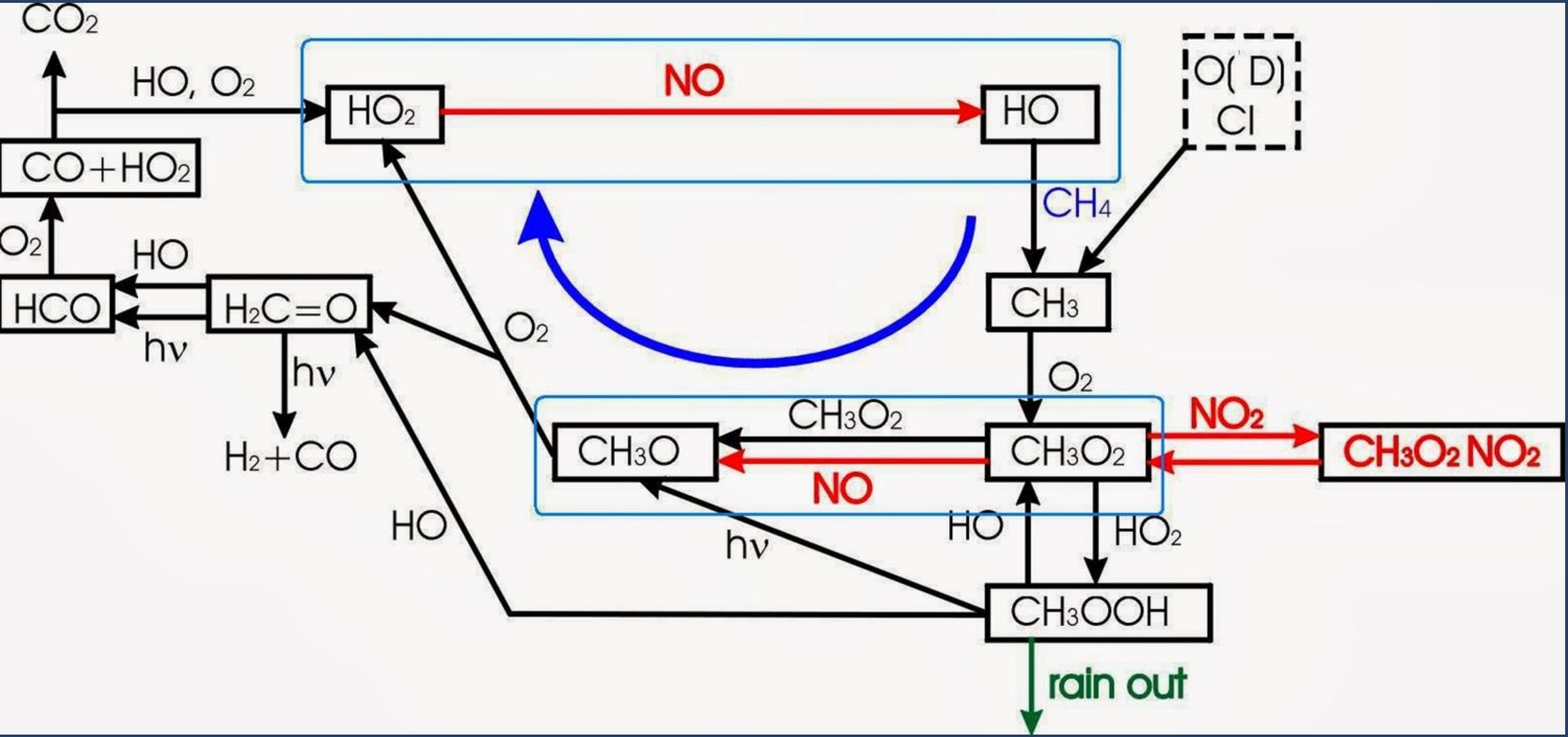
Source: Caulton et al. *PNAS* v111, 2014

IPCC Assessment of the Global Warming Potential of Methane

CH_4	Lifetime (years)	GWP_{20}	GWP_{100}	
AR5 (2013)	12.4	86	34	w/ CC FB
		84	28	w/o CC FB
AR4 (2007)	12	72	25	
TAR (2001)	12	62	23	
SAR (1995)	12	56	21	

Methane as a Reactive Pollutant

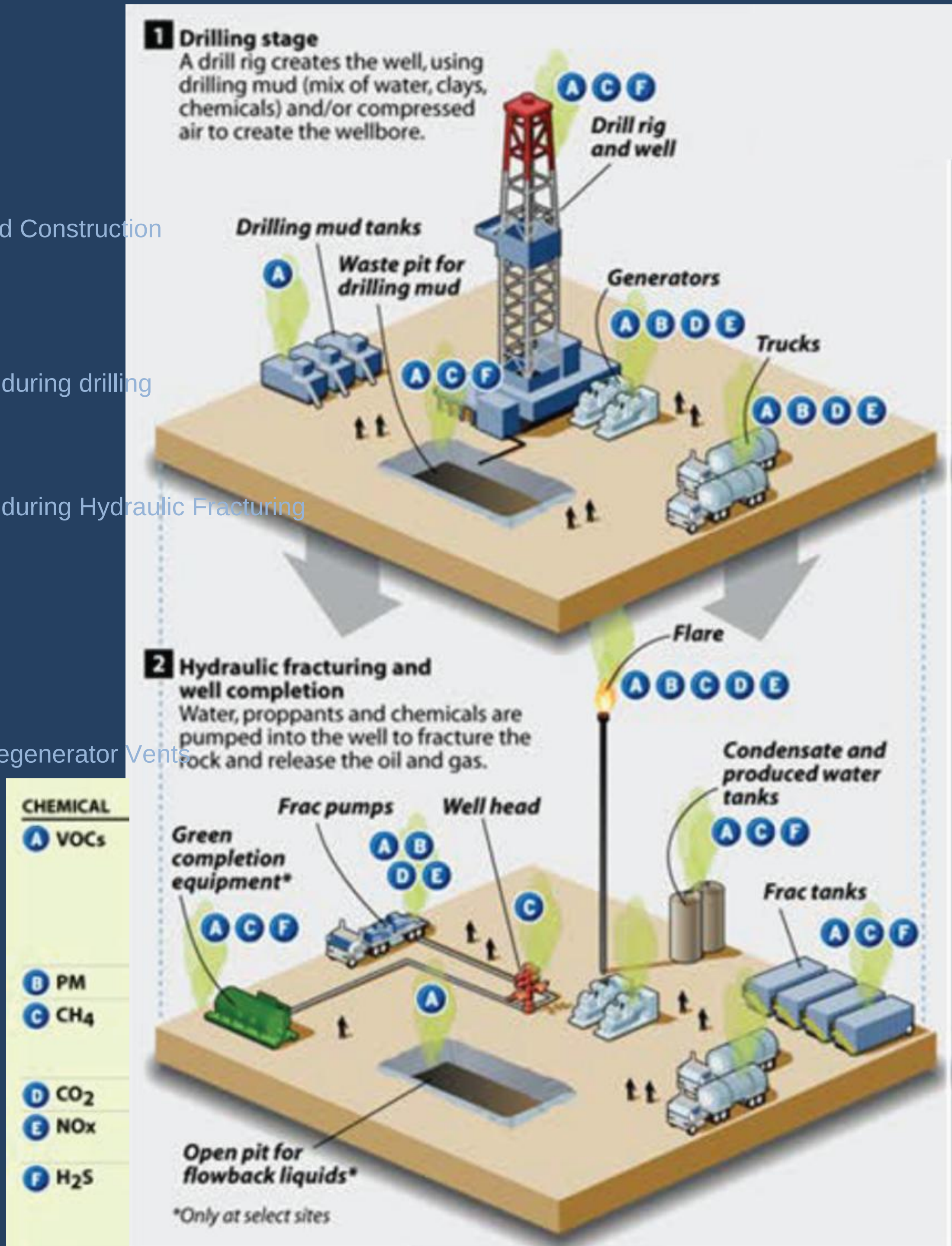
Stratoshpere – involved in reactions that <u>reduce</u> ozone
Troposphere – involved in reactions that <u>increase</u> ozone



After: Ravishankara *Ann. Rev. Phys. Chem.* v39, 1988

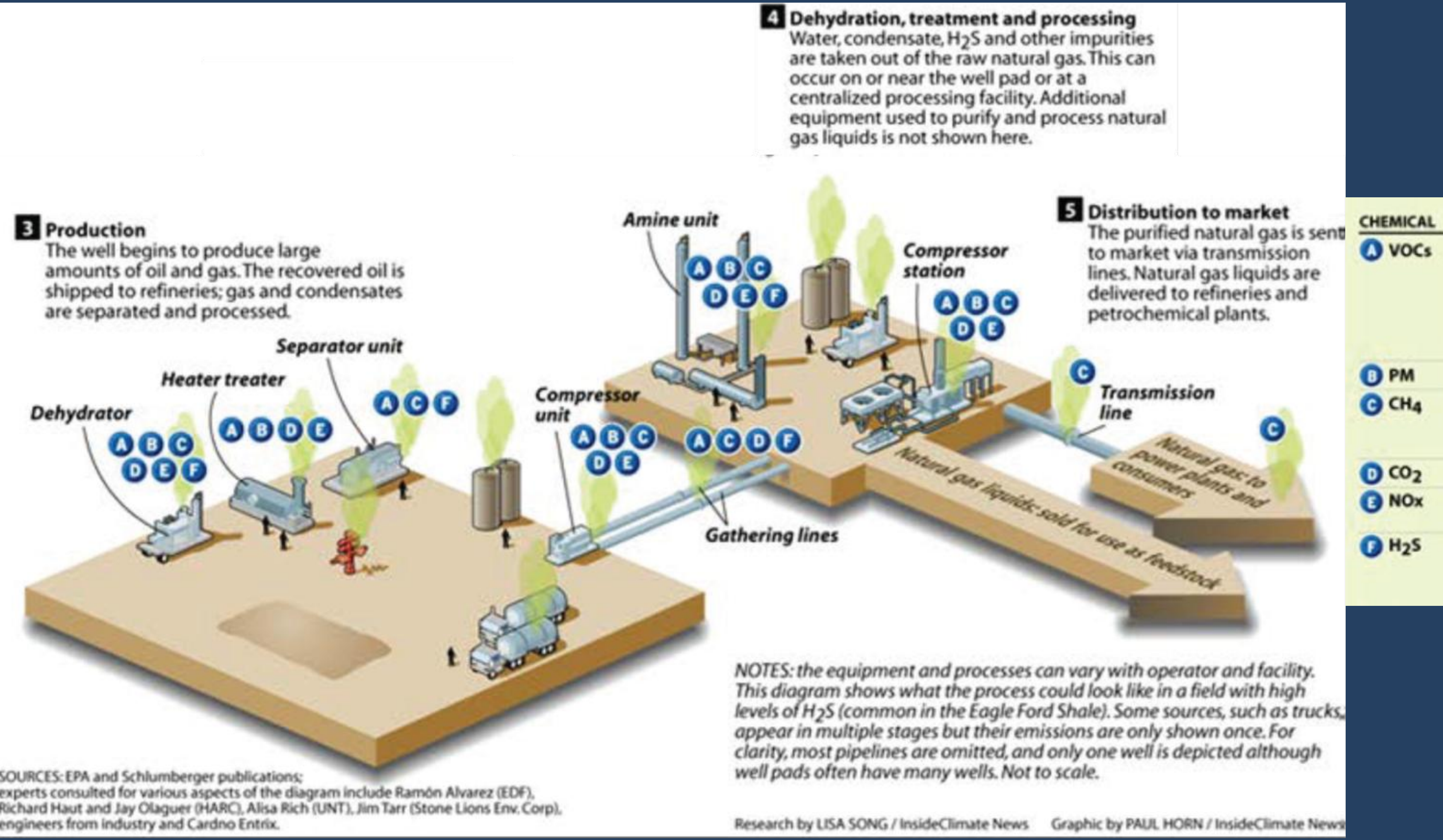
Other Emissions

Phase	Emission Sources
Exploration and Pad Construction	• Seismic Trucks • Non-Road Equipment used for Pad Construction • Heavy Duty Trucks • Light Duty Trucks
Drilling Operation	• Electric Drill Rigs • Mechanical Drill Rigs • Other Non-Road Equipment used during drilling • Heavy Duty Trucks • Light Duty Trucks
Hydraulic Fracturing and Completion Operation	• Pump Trucks • Other Non-Road Equipment used during Hydraulic Fracturing • Heavy Duty Trucks • Light Duty Trucks • Completion Venting • Completion Flares
Production	• Wellhead Compressors • Heaters • Flares • Dehydrators Flash Vessels and Regenerator Vents • Storage Tanks • Fugitives (Leaks) • Loading Fugitives • Well Blowdowns • Pneumatic Devices • Heavy Duty Trucks • Light Duty Trucks
Mid-Stream Sources	• Compressor Station • Production Facilities • Other Mid-Stream Sources



Inside Climate News

Other Emissions



Inside Climate News

If total CH_4 emissions are greater than ~3% of production, the immediate net radiative forcing for natural gas use is worse than for coal when used to generate electricity.

Source: Alvarez et al. *PNAS* v109, 2012

CEERT

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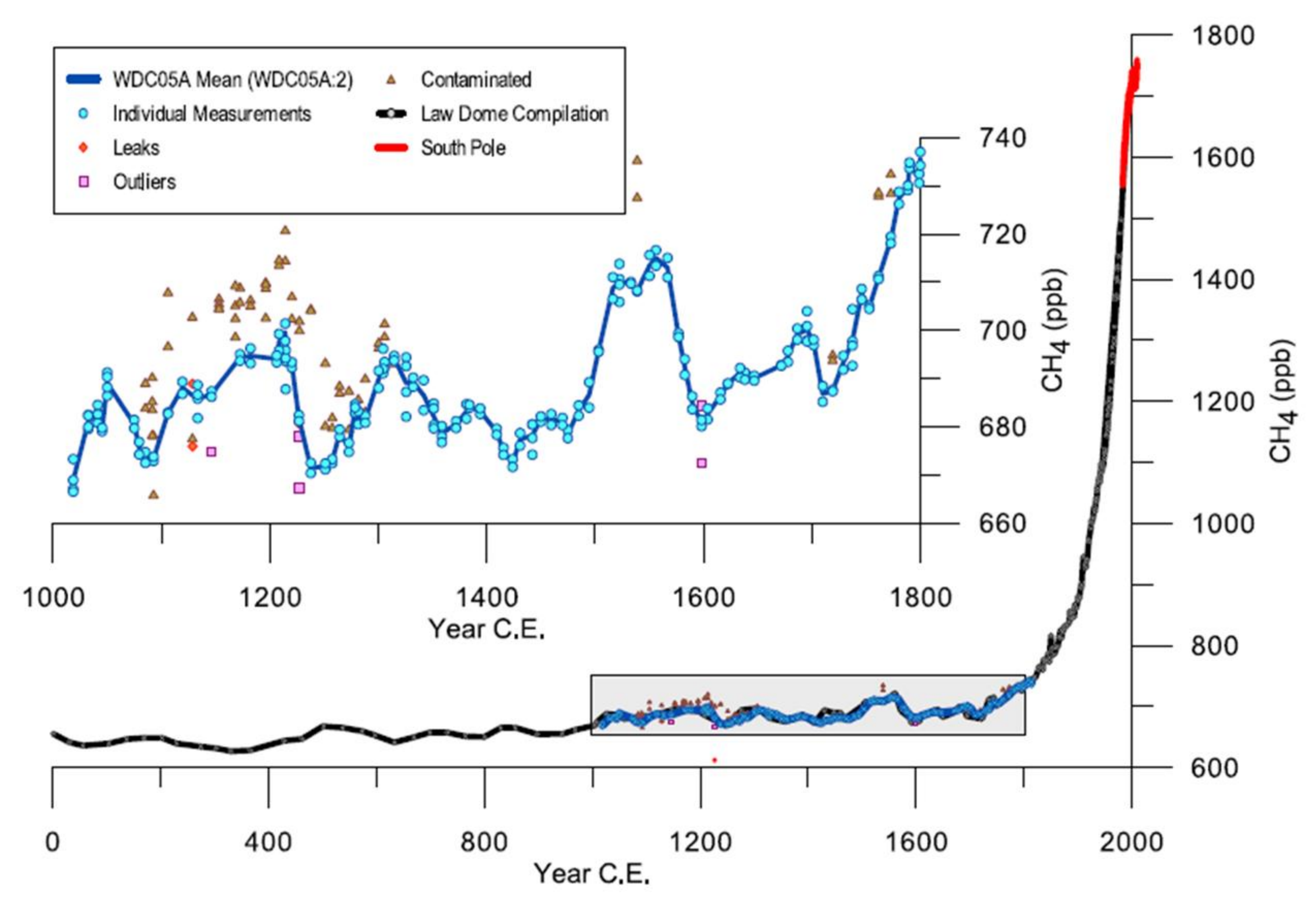
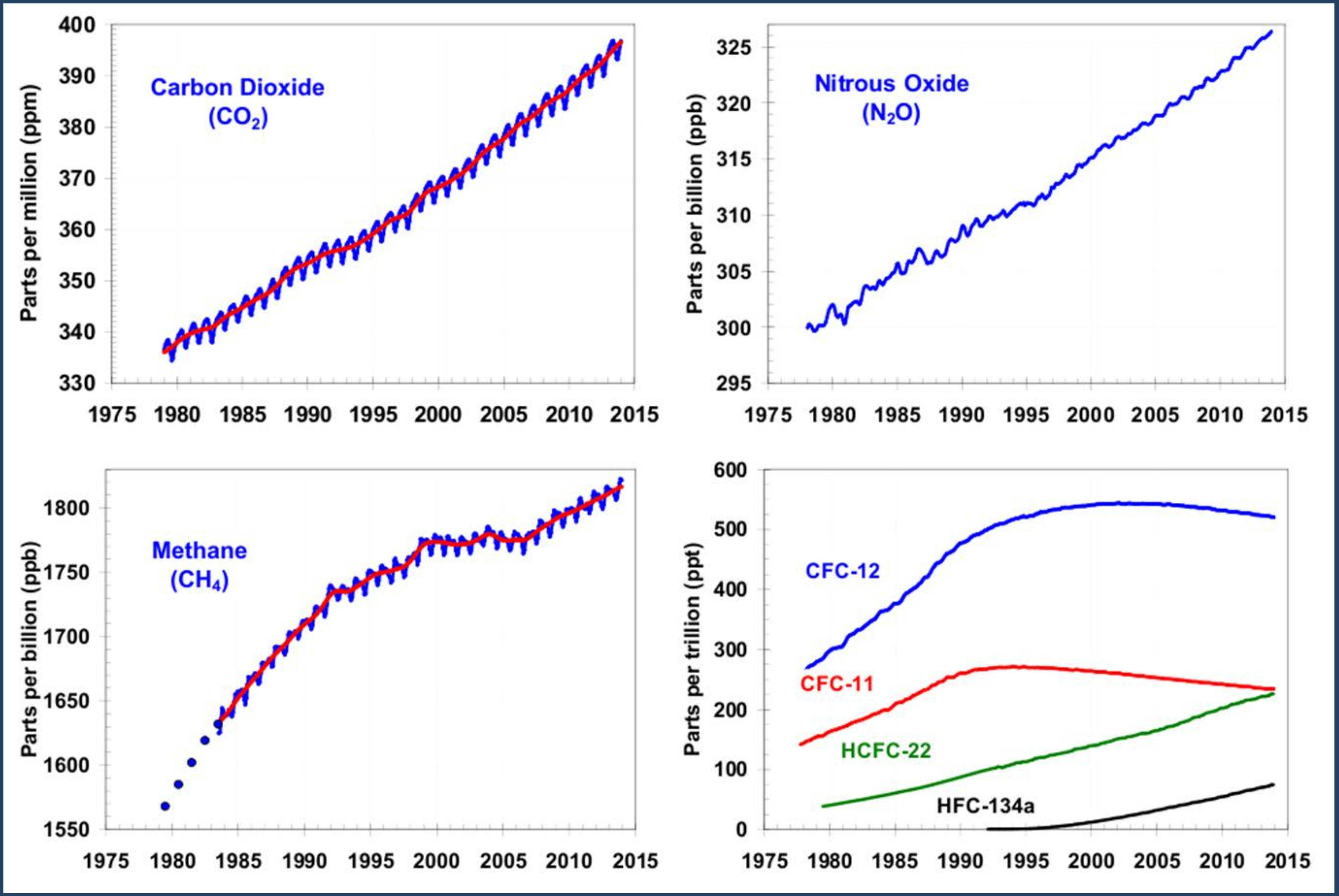
Supplemental Slides

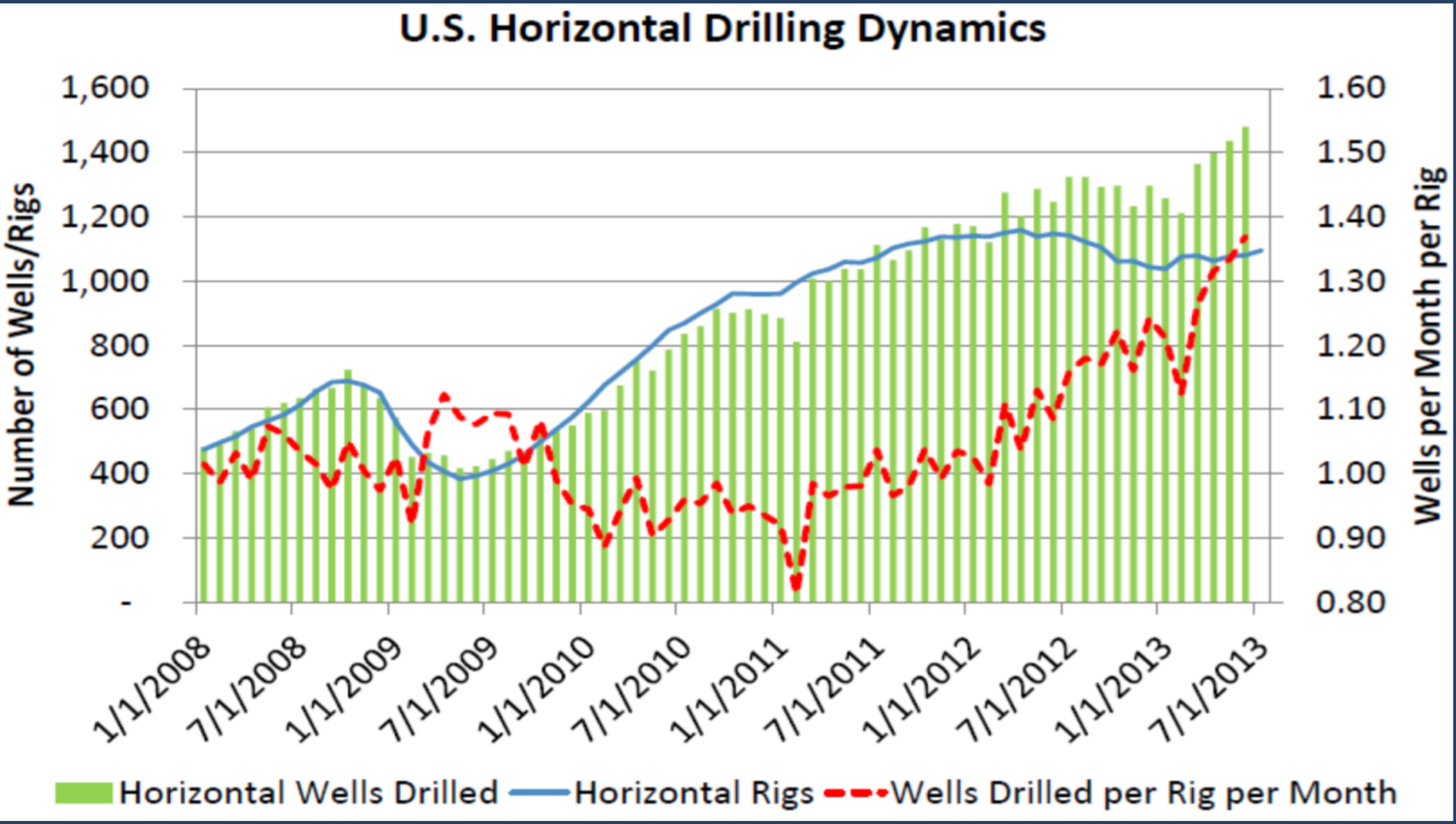


Source: Mitchell et al, JGR v116, 2011

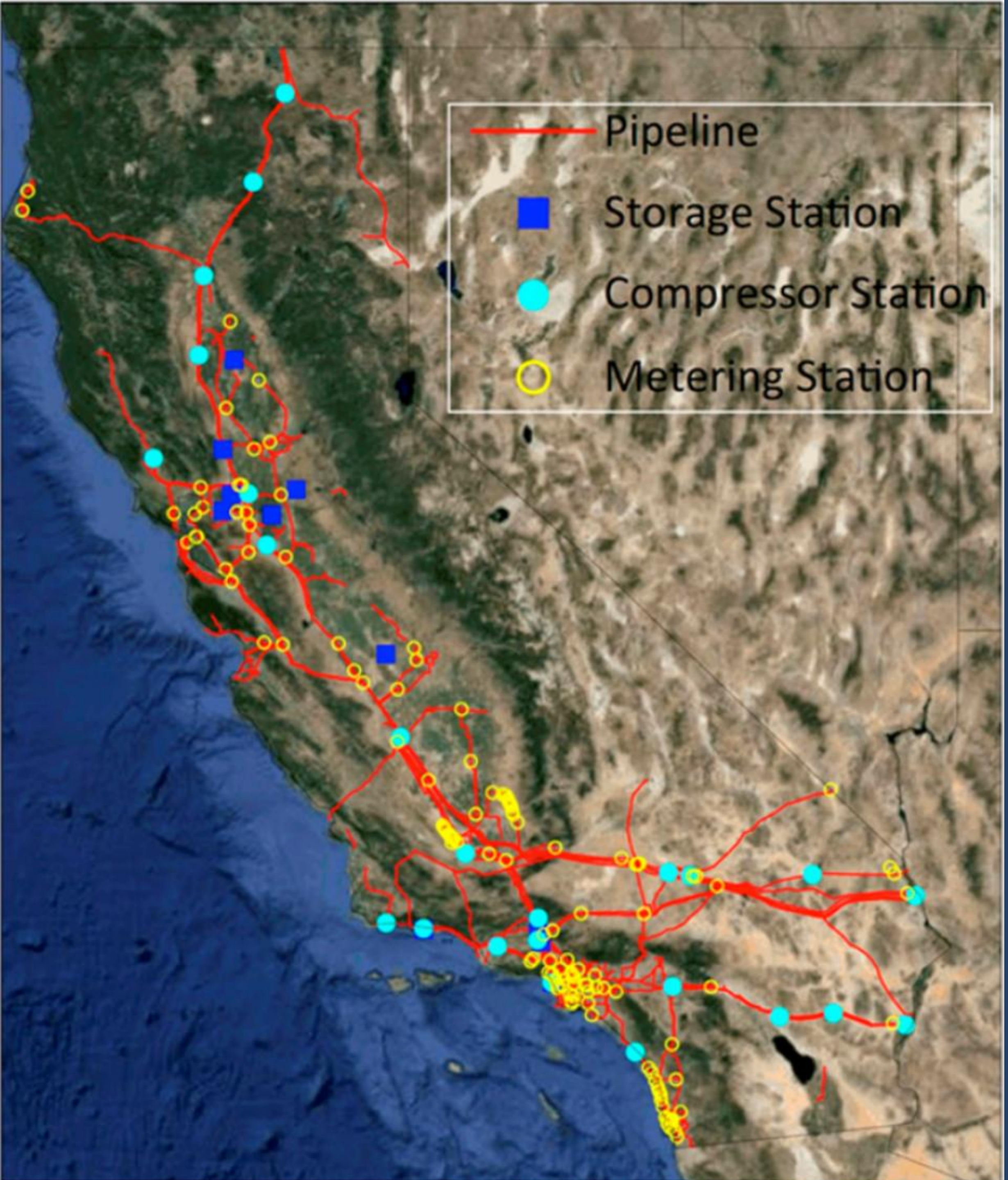

Carbon Dioxide
(CO_2)
Parts per million (ppm)
400
390
380
370
360
350
340
330
1975
1980
1985
1990
1995
2000
2005
2010
2015
Nitrous Oxide
(N_2O)
Parts per billion (ppb)
325
320
315
310
305
300
295
Methane
(CH_4)
Parts per billion (ppb)
1800
1750
1700
1650
1600
1550
CFC-12
CFC-11
HCFC-22
HFC-134a
Parts per trillion (ppt)
600
500
400
300
200
100
0

NOAA, ESRL

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

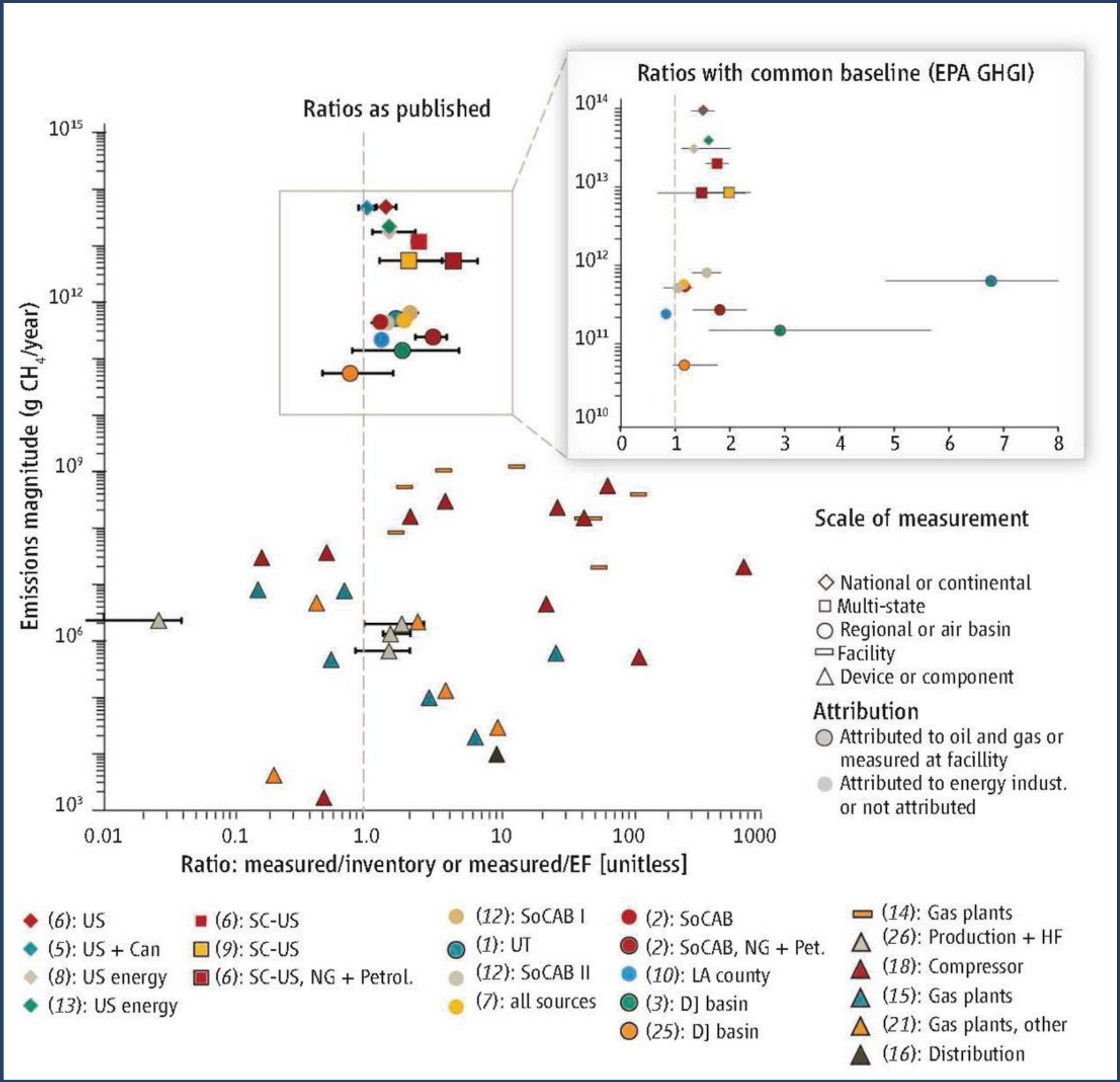


Source: Platts

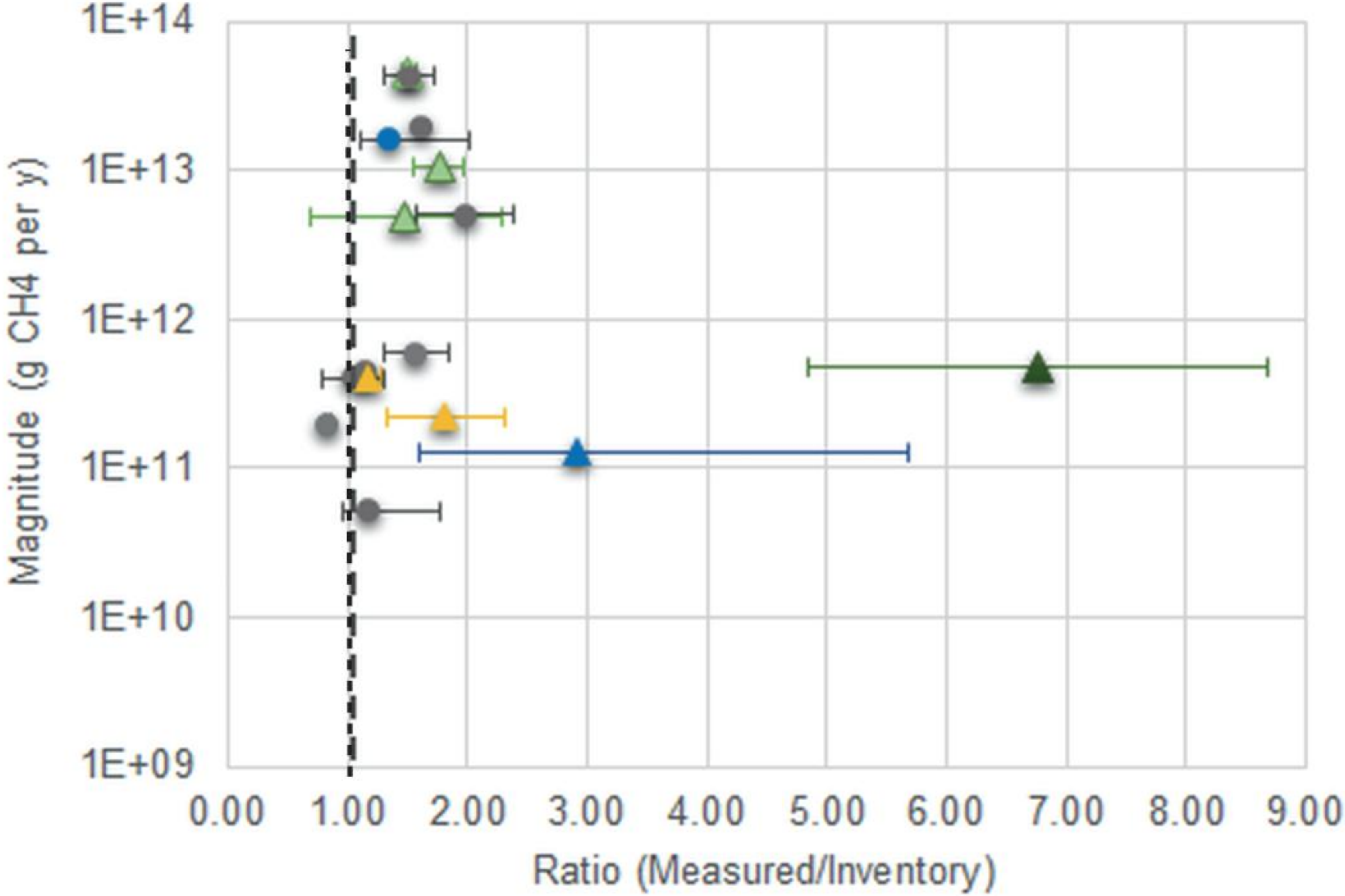


Map of the natural gas transmission system in California based on the CEC GIS database

Jeong et al, ES&T 2014



Source: Brandt et al. *Science* 2014



1E+14
1E+13
1E+12
1E+11
1E+10
1E+09
Magnitude (g CH4 per y)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
Ratio (Measured/Inventory)

Sources of GHGs and Air Pollutants during differing phases of well development

Phase	Source
Exploration and Pad Construction	Diesel Seismic Trucks
	Diesel Dozer
	Diesel Excavator
	Diesel Scraper
	Diesel Grader
	Diesel Tractors
	Diesel Loader
	Diesel Roller
	Heavy Duty Trucks Exhaust
	Heavy Duty Trucks Idling
	Light Duty Trucks Exhaust
	Light Duty Trucks Idling

Phase	Source
Drilling Operation	Diesel Mechanical Drill Rigs
	Diesel Electric Drill Rigs
	Diesel Cranes
	Diesel Pumps
	Diesel Excavators
	Heavy Duty Trucks Exhaust
	Heavy Duty Trucks Idling
	Light Duty Trucks Exhaust
	Light Duty Trucks Idling
Hydraulic Fracturing and Completion Operation	Diesel Pump Engines
	Diesel Cranes
	Diesel Backhoe
	Diesel Bulldozer
	Diesel Forklift
	Diesel Generator Sets
	Diesel Water Pumps
	Diesel Blender Truck
	Diesel Sand Kings
	Diesel Blow Out Control Systems
	Heavy Duty Trucks Exhaust
	Heavy Duty Trucks Idling
	Light Duty Trucks Exhaust
	Light Duty Trucks Idling
	Completion Flares – Oil Wells
	Completion Flares – Natural Gas Wells

Alamo Area Council of Governments/
Texas Commission on Environmental Quality

Production

Natural Gas, Lean - 2 Cycle Compressors
Natural Gas, Lean - 4 Cycle Compressors
Natural Gas, Rich - 2 Cycle Compressors
Natural Gas, Rich - 4 Cycle Compressors
Diesel Compressors
Wellhead Heaters
Flares - Natural Gas Wells
Flares - Oil Wells
Wellhead Dehydrators - Natural Gas Wells
Wellhead Dehydrators - Oil Wells
Condensate Tanks
Oil Tanks
Fugitives - Natural Gas Wells
Fugitives - Oil Wells
Loading Loss - Condensate
Loading Loss - Oil
Blowdowns - Gas Wells
Blowdowns - Oil Wells
Pneumatic Devices
Heavy Duty Trucks Exhaust
Heavy Duty Trucks Idling
Light Duty Trucks Exhaust
Light Duty Trucks Idling