The natural gas boom

- The abundance of domestic natural gas presents significant opportunities in the U.S. energy sector
  - Production is predicted to grow roughly **40% by 2040**
  - The share of natural gas used for electricity generation will grow about **58% by 2040**
  - Shale gas will play a predominant role in this growth, increasing from 34% of U.S. natural gas production in 2011 to **50% in 2040**

Figure 91. Natural gas production by source, 1990-2040 (trillion cubic feet)

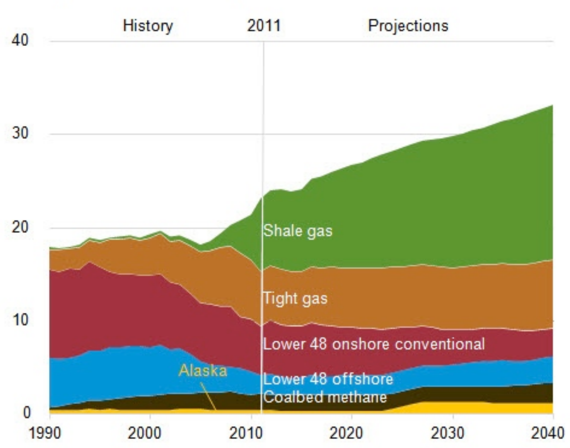


Figure 76. Electricity generation by fuel, 2011, 2025, and 2040 (billion kilowatthours)

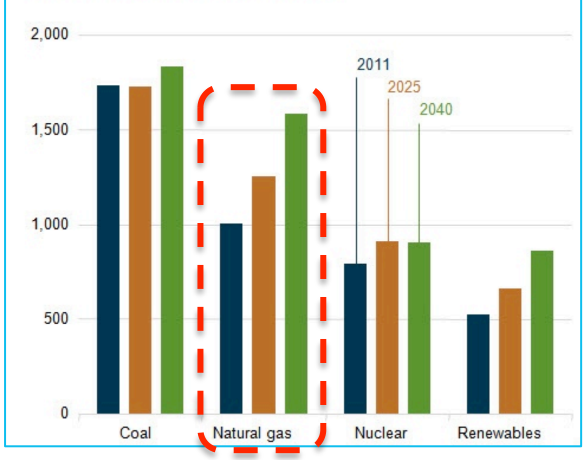
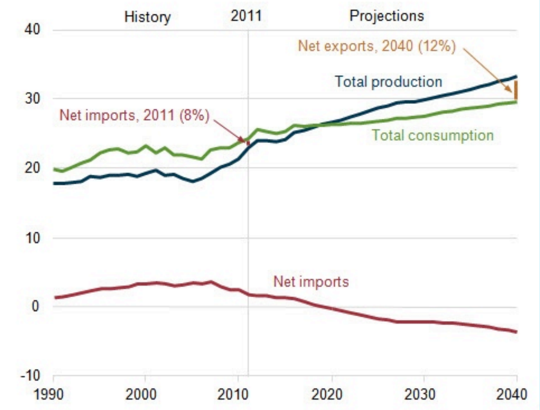
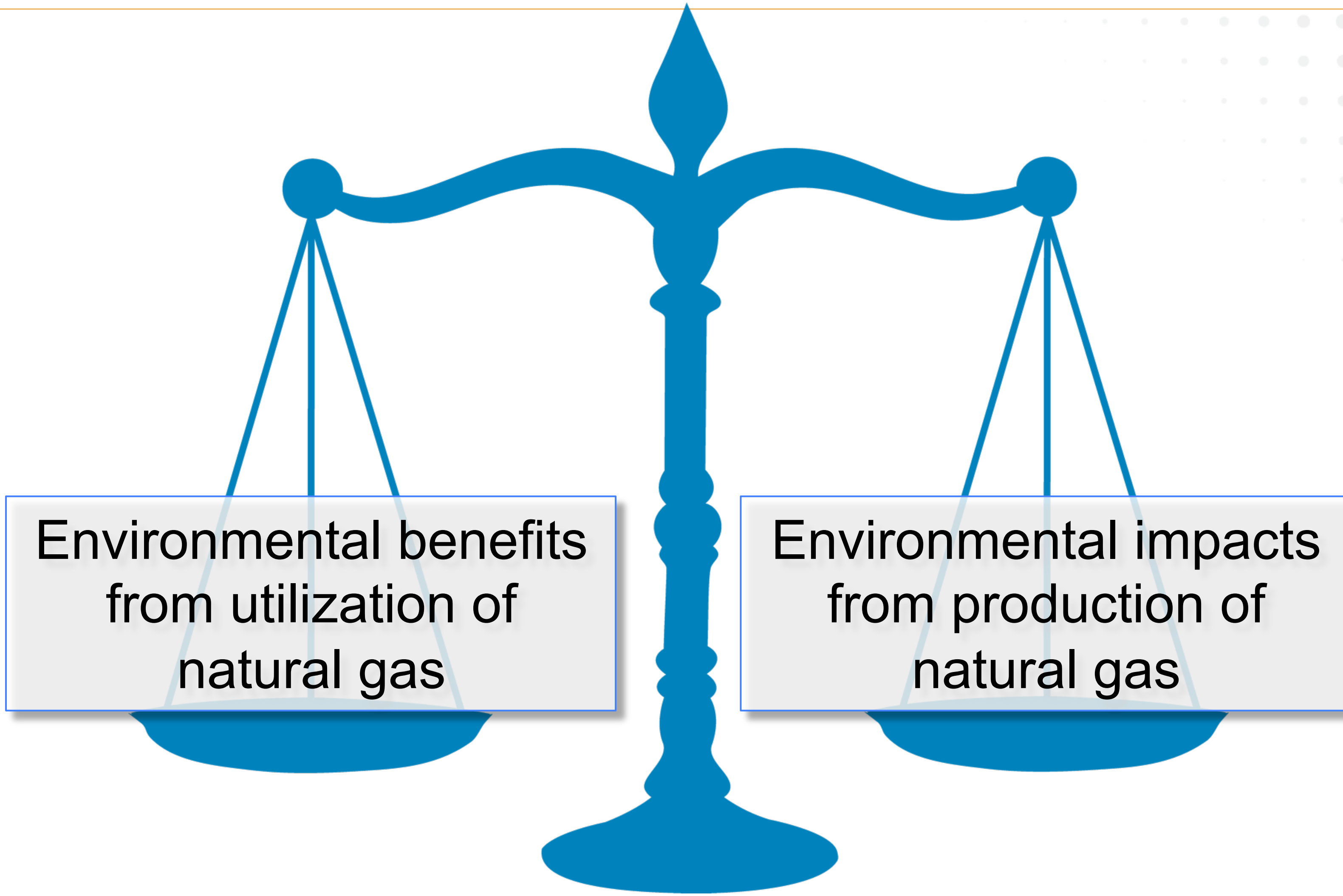


Figure 89. Total U.S. natural gas production, consumption, and net imports, 1990-2040 (trillion cubic feet)

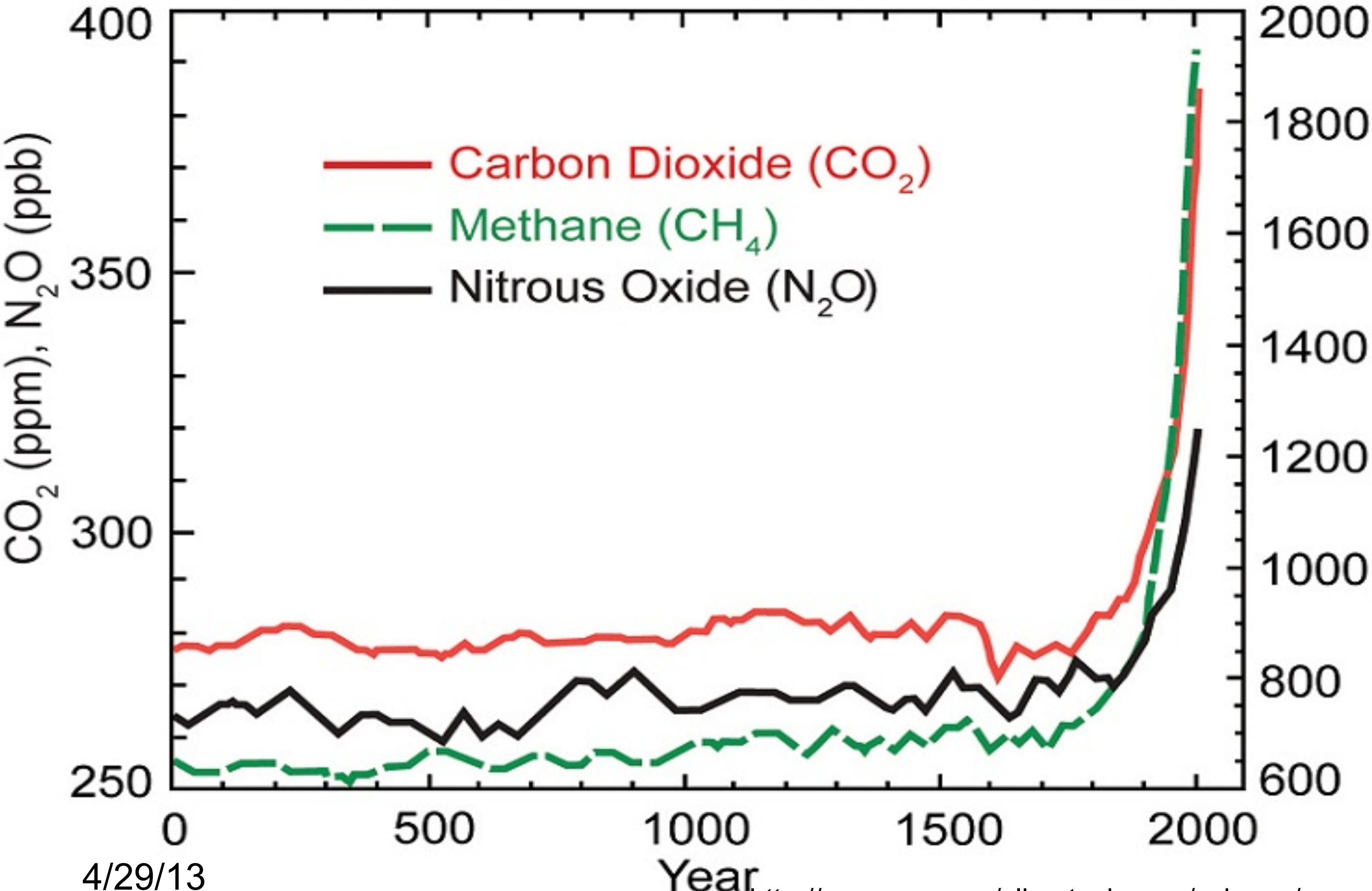


But there are tradeoffs



Definition: “Production” has a precise definition in the oil & gas community. Here it is used as shorthand for exploration, production, gathering, processing, transmission, and distribution of natural gas – from wellhead to burner.

CH_4 follows similar trends as CO_2



http://www.epa.gov/climatechange/science/causes.html

Global Warming Potential (GWP) of CH_4

	MW	Radiative Efficiency (W m^{-2} ppb^{-1})	4th IPCC report	Shindell w/ aerosols	2nd IPCC report	3rd IPCC report	4th IPCC report	Shindell w/ aerosols
			20-yr		100-yr			
Mass Basis								
CO_2	44	1.4×10^{-5}	1	1	1	1	1	1
CH_4	16	3.7×10^{-4}	**72**	105	21	23	**25**	33
Molar Basis								
CO_2	44	1.4×10^{-5}	1	1	1	1	1	1
CH_4	16	3.7×10^{-4}	26.2	38.2	7.6	8.4	9.1	12

The perturbation lifetime for methane is 12 years and includes indirect effects from enhancements of ozone and stratospheric water vapour (see IPCC FAR Section 2.10.3.1).

100-yr vs. 20 yr

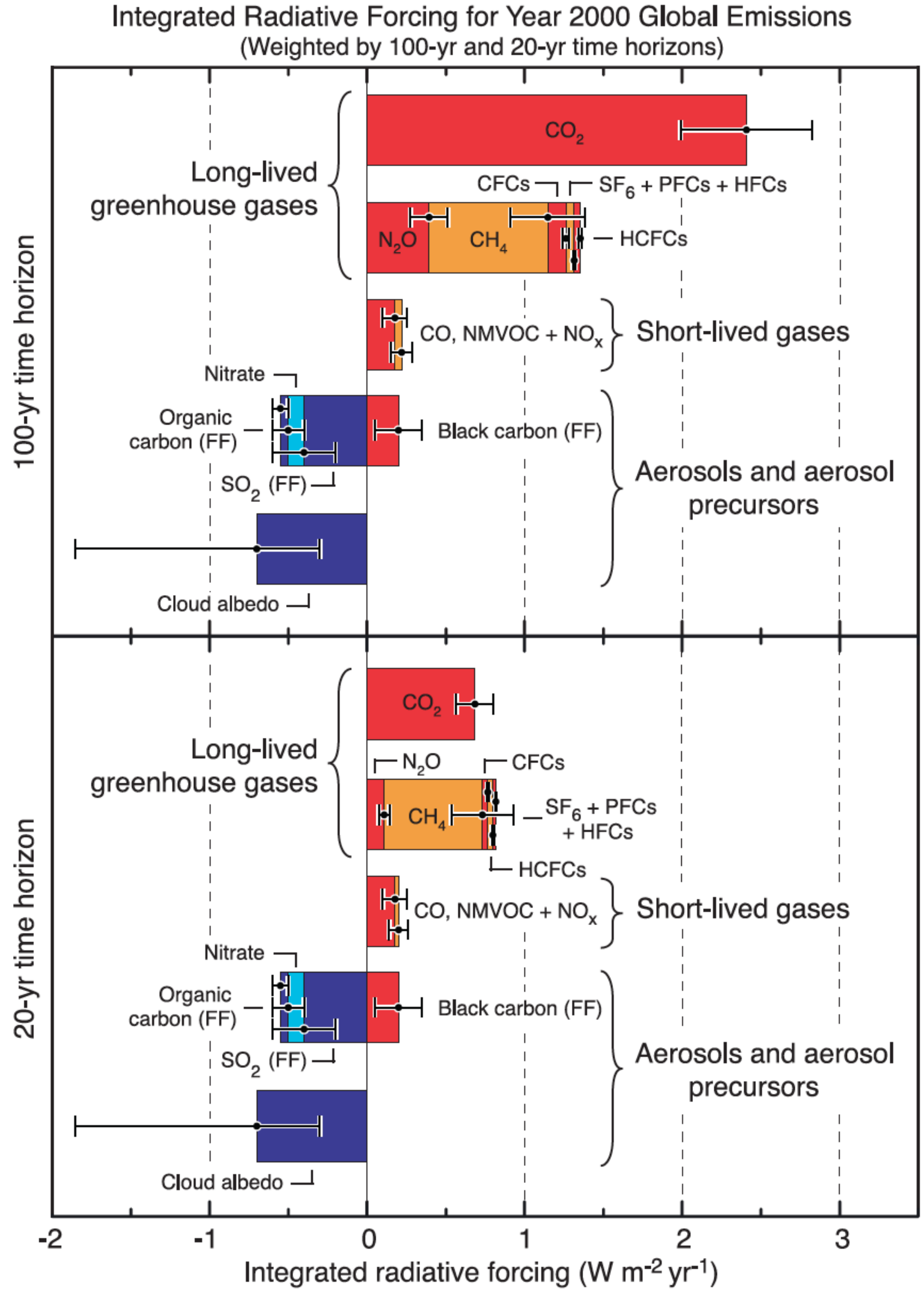
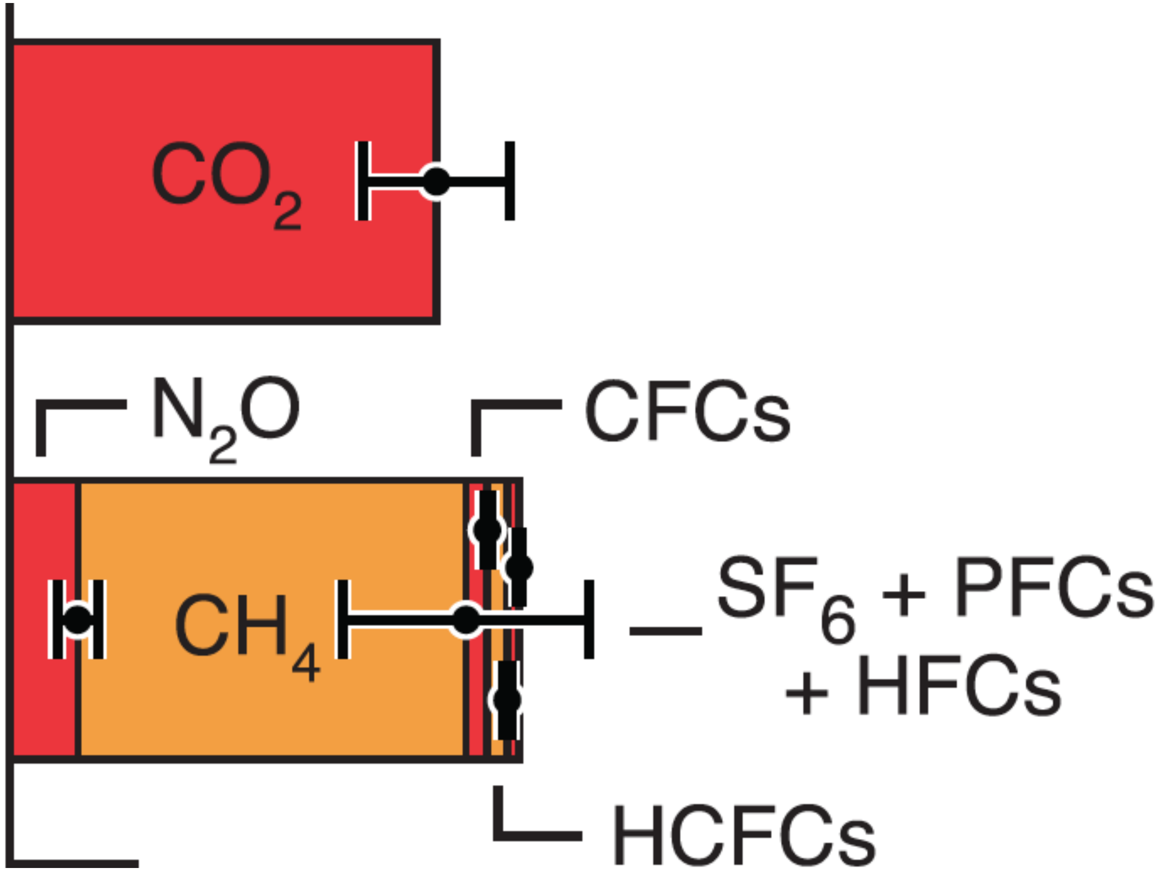


Figure 2.22. Integrated RF of year 2000 emissions over two time horizons (20 and 100 years). The figure gives an indication of the future climate impact of current emissions. The values for aerosols and aerosol precursors are essentially equal for the two time horizons. It should be noted that the RFs of short-lived gases and aerosol depend critically on both when and where they are emitted; the values given in the fi gure apply only to total global annual emissions. For organic carbon and BC, both fossil fuel (FF) and biomass burning emissions are included. The uncertainty estimates are based on the uncertainties in emission sources, lifetime and radiative efficiency estimates.

AR4, p 206

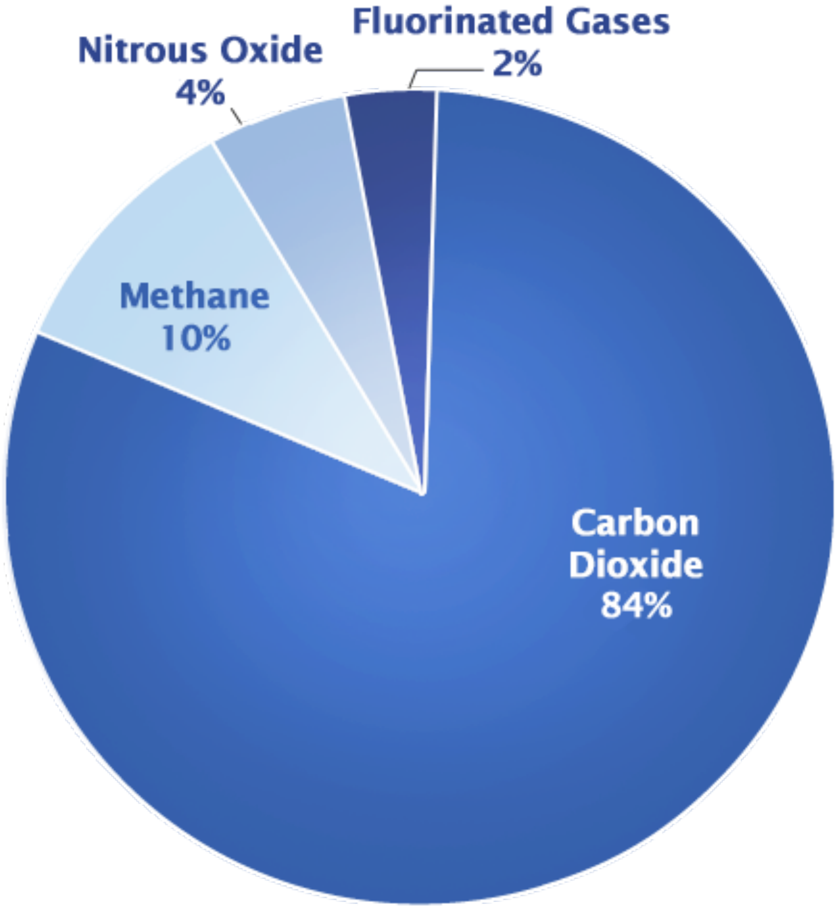
Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

In the near (20) term, radiative forcing by CH_4 may dominate!

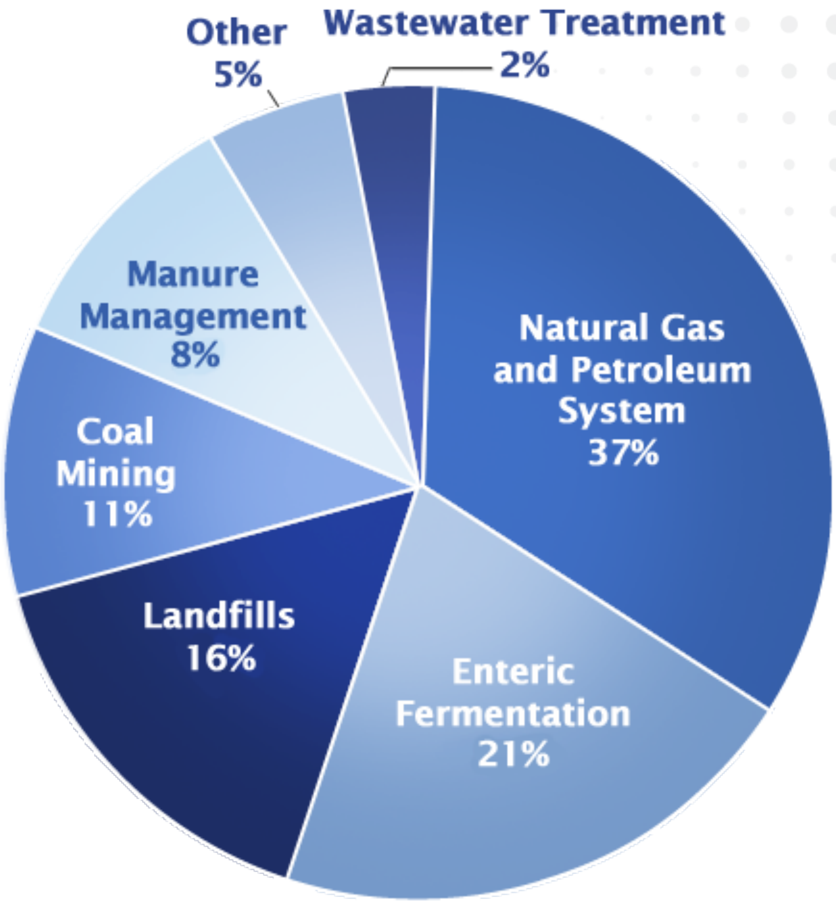


U. S. Greenhouse Gas Emissions EPA "bottom-up" estimate

On the 20 year basis, CH_4 from oil & gas is around 9% of US GHG impact



US Greenhouse Gas Emissions in 2010



U.S. Methane Emissions, By Source

Proposed solution

An potential program is being considered, with two elements:

1. Applications of advanced science & technology to improve the detection and quantification of natural gas emissions from oil & gas production to within 0.5% of production
2. Application of advanced science & technology to reduce the quantity of natural gas emissions from oil & gas production by 1%* of production

*1% reduction from a 2.8% base.

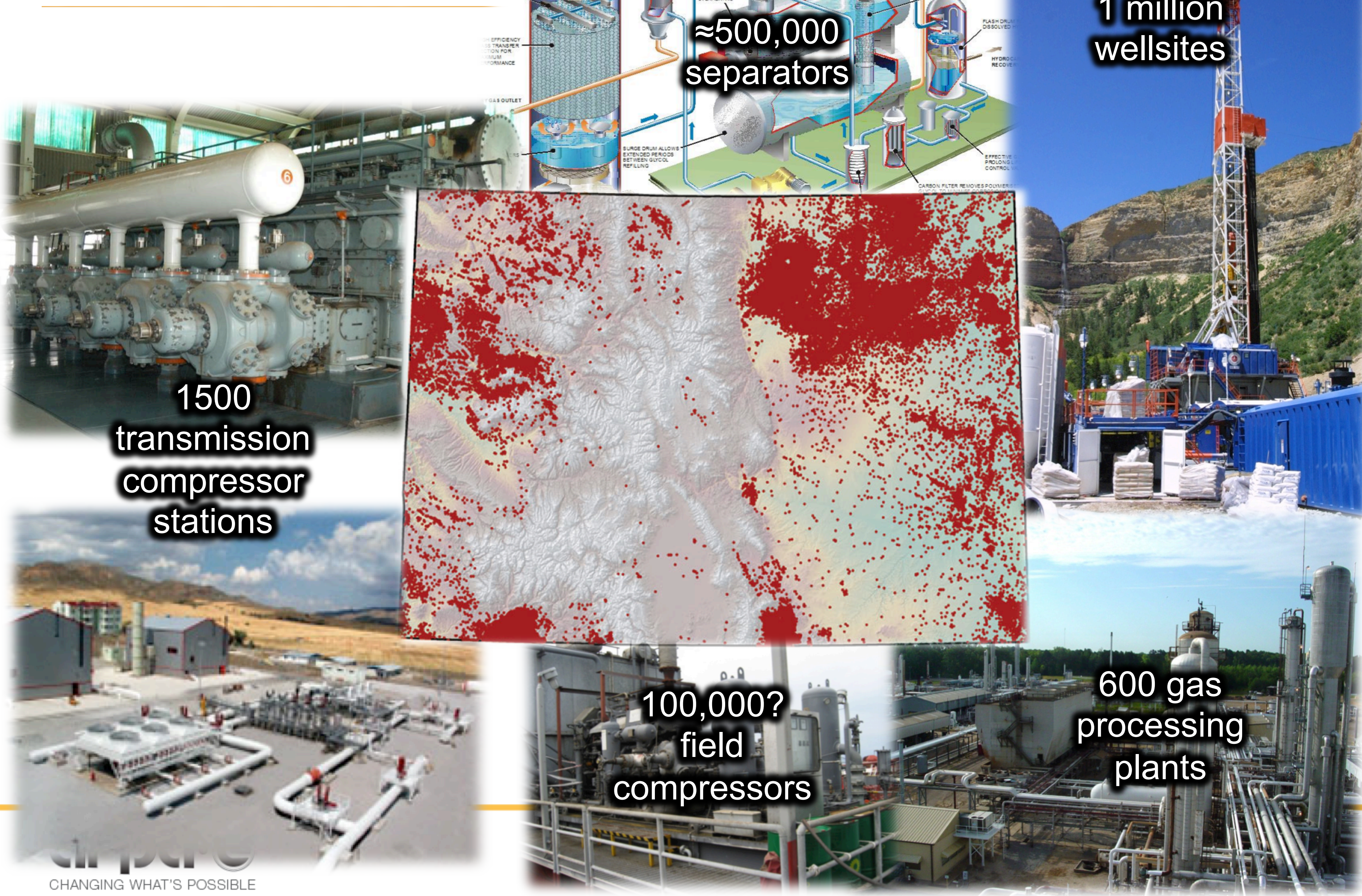
Impact of program

- Current NG leakage estimates are 1.5%-8% of production
- Expected range of program impact – 1%-2.5% of production
- Realistic goal is reduction of 1%reduction in losses
- GHG reduction of:
  - 1% ≈ elimination of 82 million vehicles using AR4 of 72
- Significant co-benefits:
  - Reductions of VOCs & ozone
  - Reduction of Hazardous Air Pollutants
  - Applications to global sources

Drivers for CH_4 reduction

- ~~GHG value: carbon tax or cap & trade~~
- ~~Direct regulation of CH_4~~
- **Recovery of lost product – gas & liquids**
- Reduction of VOCs & HAPs
- ______________________________
- ______________________________

CH_4 from production is dominated by millions of small sources



The natural gas system

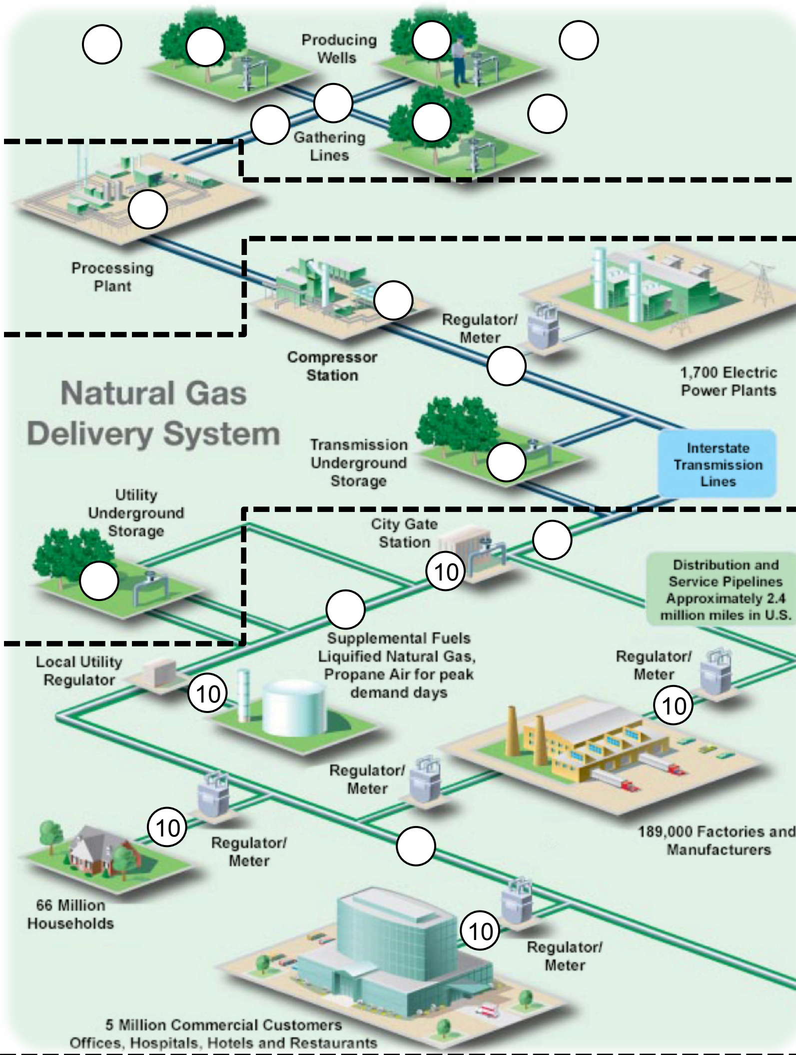
Share of emissions

Production
37%

Processing
14%

Transmission & Storage
30%

Distribution
19%

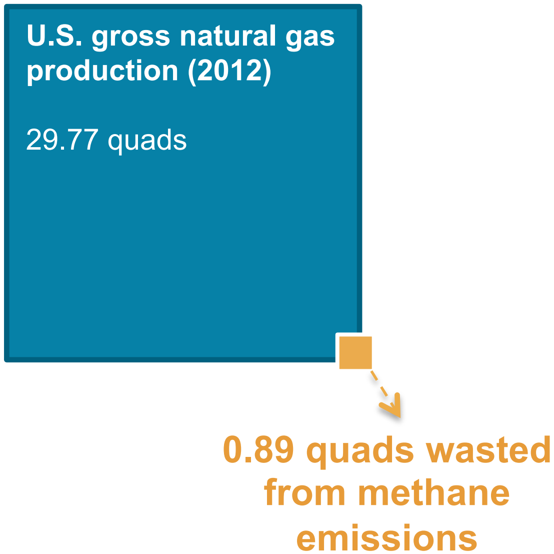


1. Drilling & well completion
2. Producing wells
3. Gathering lines
4. Gathering/boosting stations
5. Gas processing plant

6. Transmission compressor stations
7. Transmission pipeline
8. Underground storage

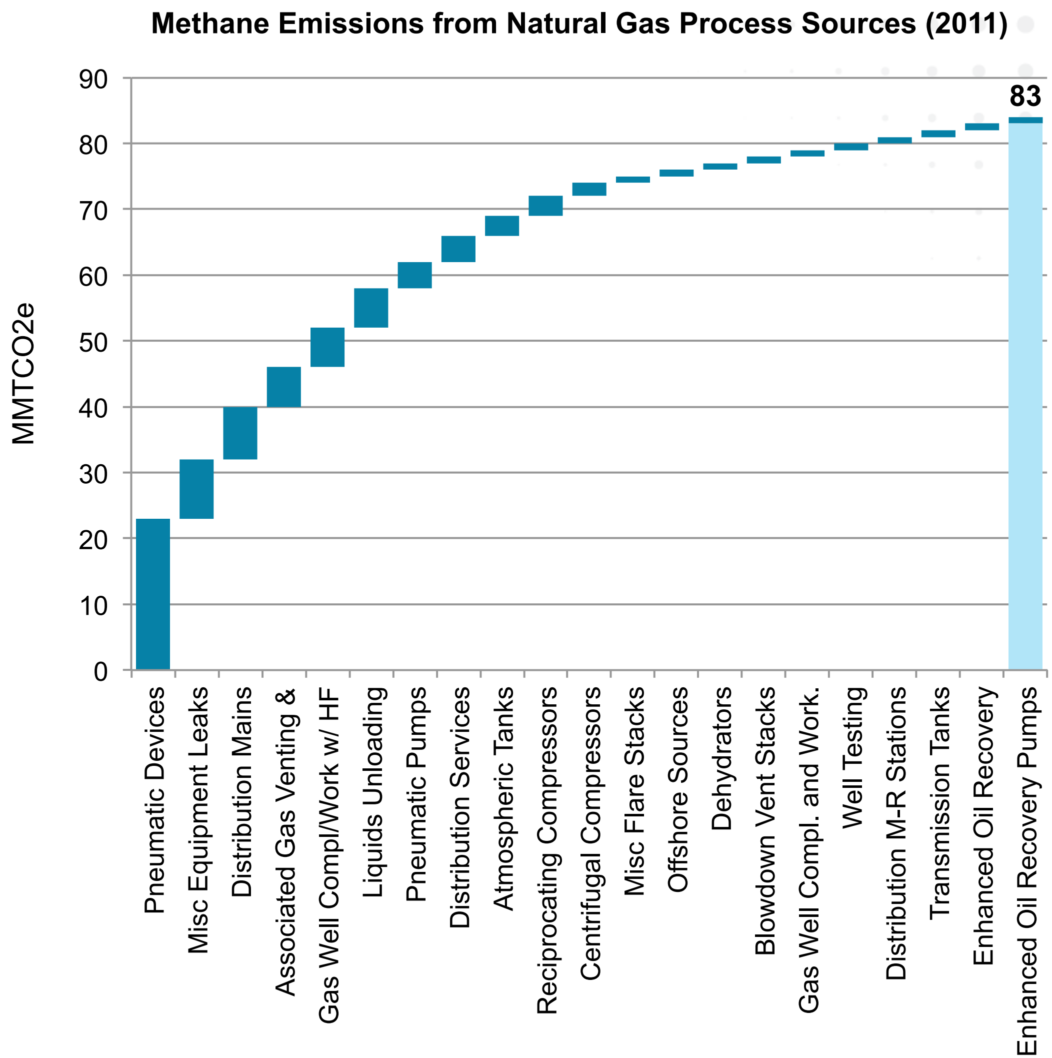
9. Distribution mains
10. Regulators and meters
    - City gate
    - Large volume customers
    - Residential customers
    - Commercial customers

Methane leakage is a missed opportunity

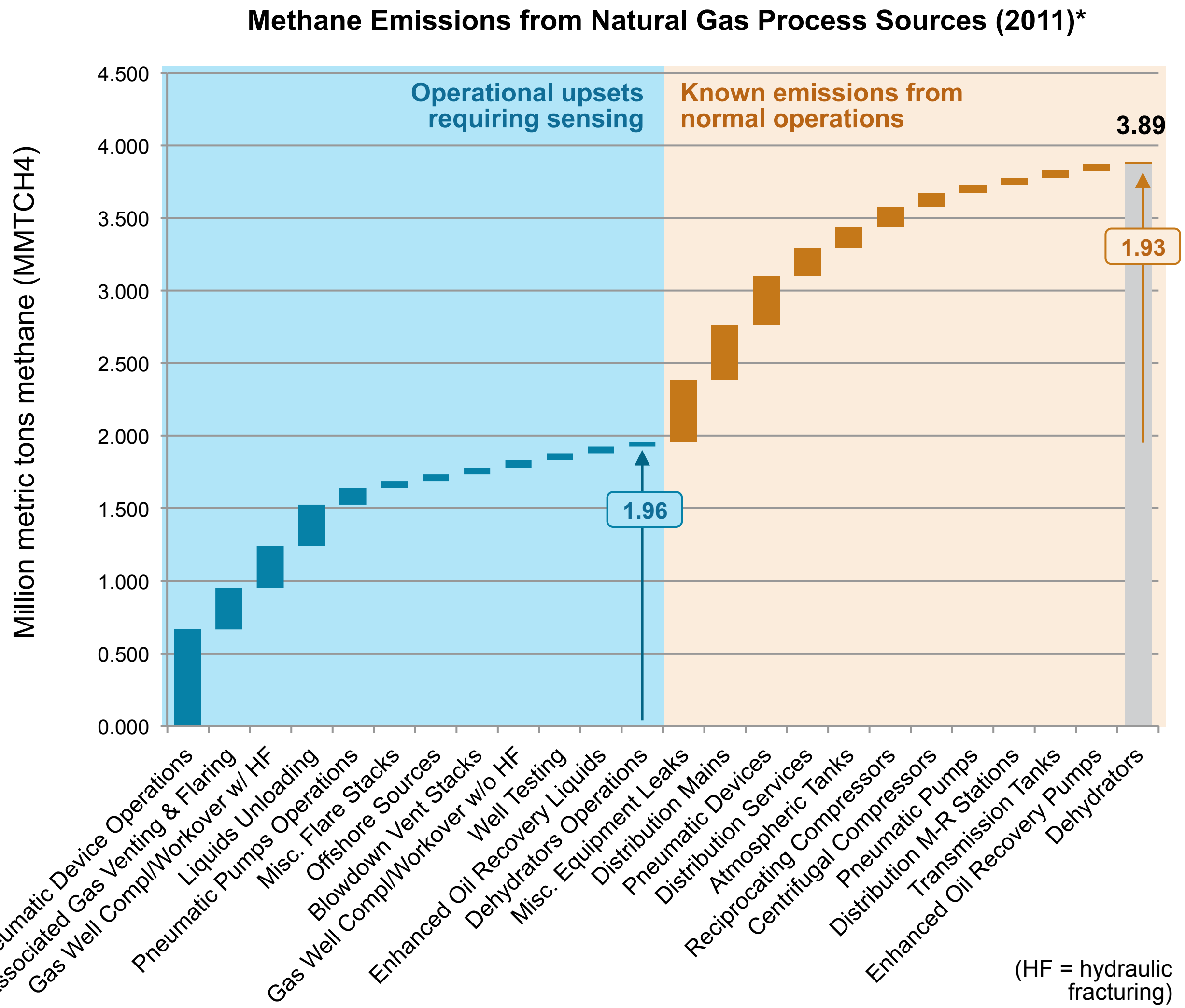


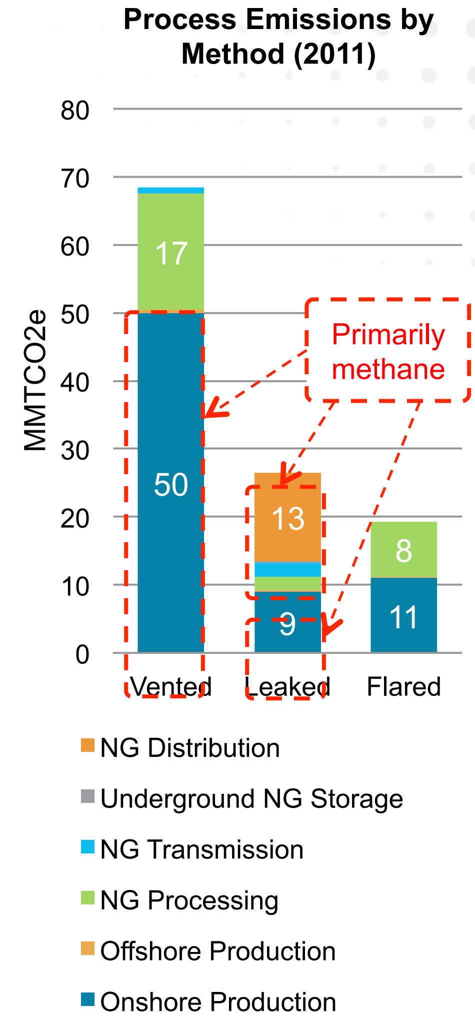
- Methane emissions total roughly 0.89 quads of lost energy
- Valued at over $3.24 billion per year

Assumes 3% average leakage rate
900,000,000 MMBtu
@ $3.60/MMBtu = $3,240,000,000



App 50% of CH_4 emissions require sensing

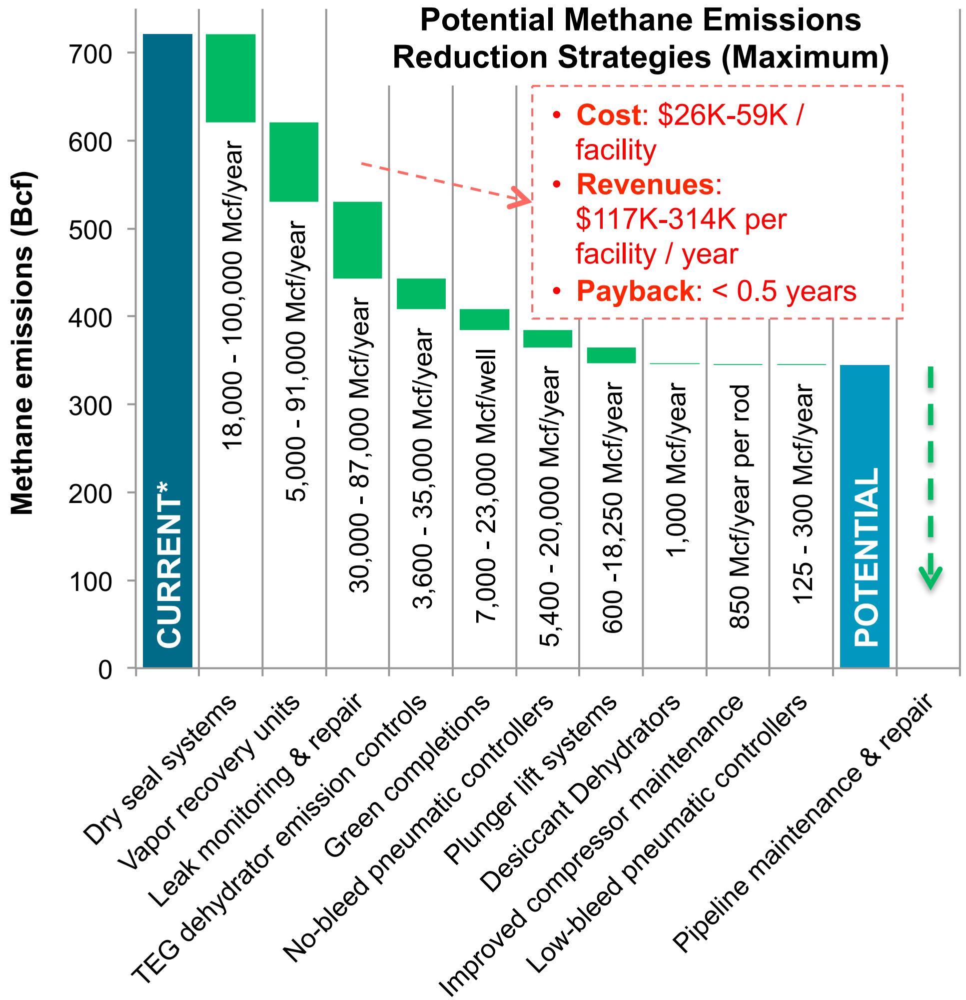




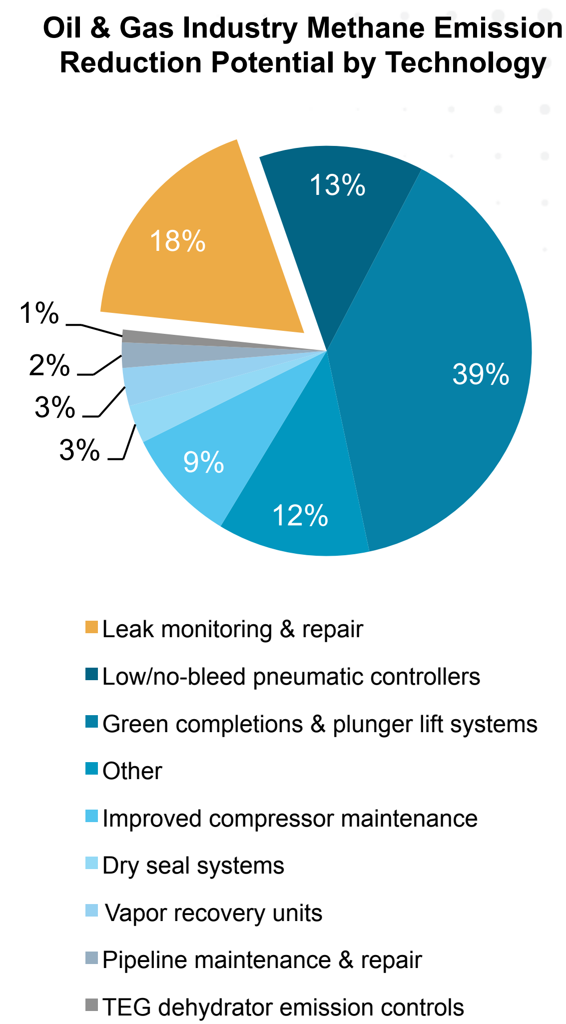
* Represents reported emissions, not total

Sources: EPA (pg. 5-6), EPA

Methane emissions: solutions



*based on 3% leakage rate



Sources: NRDC

Value of lost product

2012 production: 30 TCF (29.7 TCF)

EPA "midpoint" leakage rate – 2.8%

2012 leakage – 840 BCF - 840,000,000 MCF

Assume $6/MCF gas price*

Value of 2.8% lost product = $5B

Value of 1% lost product = $1.8 - $2.0B

*Currently trading at $4.40, but using a midpoint estimate of $6 in 2016 when results would be implemented

Value of 1% loss reduction

	Sector Volume	Sector Value	Units	Vol Loss / Unit	$ Loss / Unit
Production 37%	110 BCF	$666 M	800,000 wells 4,000,000 points[1]	140,000 CF / well 27,500 CF / pt	$832 / well $166 / pt
Processing 14%	42 BCF	$252 M	600 gas plants 90,000 points[2]	70 MMCF / plant 470,000 CF / pt	$420,000 / plant $2,800 / point
Transmission 30%	90 BCF	$540 M	1500 comp stations 150,000 points[3]	60 MMCF / station 600,000 CF / pt	$360,000 / station $3,600 / point
Distribution 19%	57 BCF	$570 M[4]	62,000,000 homes[4]	920 CF / home	$9.2 / home[4]
	300 BCF	$2,03B	4.25M (w/o homes)		

Assumes:

30 TCF gross production
1% of gross production
$6 / 1000 ft^3
$1.8B annual loss (wellhead)
$2.03B annual loss (blended)
35,000 sq mile production area
800,000 wells

Notes:

[1]5 points/well, including wellhead & field treatment
[2]150 points/plant – includes gas gathering & field compression
[3]100 points/compressor station
[4]Uses retail price of $10 / MCF

Recoverable Value from Sensing

	Annual Recoverable Value from Sensing[1]	Annual Leakage Mitigation Cost[2]	Annual Savings from Sensing[3]	Allowable Sensor Price[4]	Allowable Sensor Mfg Cost[5]
Production 37%	$416 / well $83 / point	$200 / well	$216 / well $43 / point	$650 / well $130 / pt	$260 / well $52 / pt
Processing 14%	$210,000 / plant $1,400 / point	$100,000 / plant	$110,000 / plant $733 / point	$330,000 / plant $2,200 / pt	$132,000 / plant $880 / pt
Transmission 30%	$180,000 / station $1,800 / point	$75,000 / station	$105,000 / plant $1,050 / point	$315,000 / plant $3,150 / pt	$126,000 / plant $1,260 / pt
Distribution 19%	$9.2 / home	$5 / home	$4.20 / home	$12.60 / home $630 / block	$5.00 / home $250 / block

Assumptions:

[1]50% of lost product is leakage
[2]Estimate, value being explored
[3]Annual value – Annual cost
[4]Simple 3-year payback
[5]Mfg. materials + labor;
Assumes 50% for installation & profit
[6]Assumes sensing at block level
50 homes / block

Suggests the market for a:
$50* sensor for equip sensing
$1,000* sensor for ambient sensing

*based on manufacturing cost

arpa·e
CHANGING WHAT'S POSSIBLE

Potentially Enabling Technology

1. On-site power generation for wellsite operation, 3kW
2. On-site power generation for export
3. On-site power generation for condensate tank vapor recovery
4. Plug-in “HEV” approach for instant power & fast start
5. “Zero emissions” engines on wellhead gas – aggressive NOx, VOC, & CH_4 control
6. Continuous operation of separators, VRUs, etc. using control valves vs. dump valves
7. “Buffer layer” tank management to eliminate “oxidizer” “flare”
8. Improved liquids unloading?
9. Collapsible solutions for blowdown events?
10. Low temperature oxidation (biological & photocatalytic) for small sources
11. Commercial sensor networks ESCO-like (energy services companies) provide a potential structure for commercialization
12. What else________?

Metrics

- Power generation for use onsite at $0.25/kw-hr, including wellhead cost of gas at $6/MMBTU
- Onsite availability of 99.95%, similar reliability
- Onsite power export at $0.03/kW-hr from flare gas ($0.06/kW-hr), $0.06/kW-hr from product gas (at $6/MMBTU)
- Condensate tank recovery at 1-year payback

Value of “oxidized” condensate gas

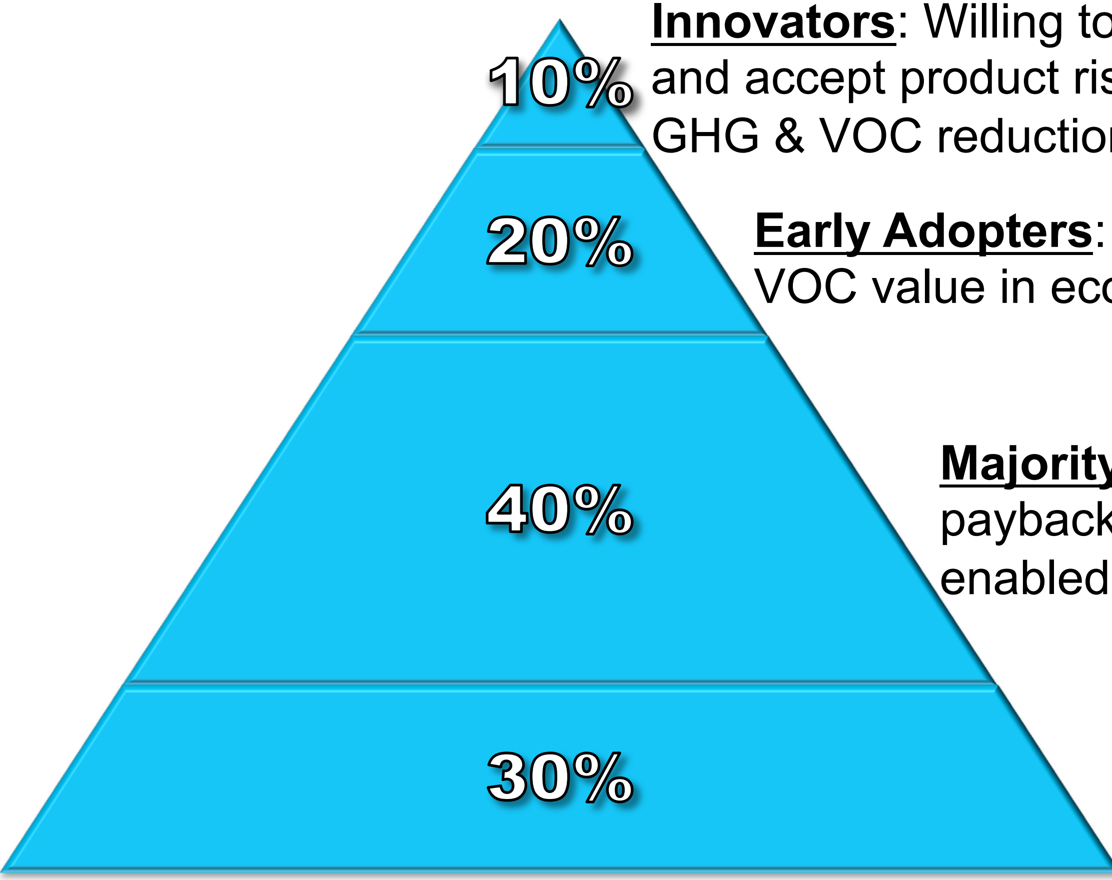
- App. 2% of production
  - Relatively wet gas, but 2-stage separator
  - Less with very dry gas
  - Greater with single-stage separator
- 2% x 30 TCF = 600 BCF
- 600 BCF:
  - 4,600,000,000 gal gasoline
  - 518 gall avg. fuel consumption / vehicle
  - 8,900,000 vehicles
  - 3.8% of US vehicle fleet of 234,468,000 vehicles

Condensate Tank Vent Recovery

- Roughly 40,000 SCF / day,
- $240/day, 88,000/year as product
- 40,000,000 BTU/day – 12,000 kW-hr
- $33% efficiency, 4,000 kW-hr, 167 kW continuous
- 4,000 kW-hr has value of $120-$320 ($0.03-$0.08/kW-hr)
- 1 year payback give allowable cost of $44,000 - $117,000
- High-efficiency, low-life industrial IC engines cost $250/kW - $500/kW installed, installed cost of $42,000-$83,000
- Appears to be in the ballpark

1. What are the barriers to doing this at every site with export access?

Potential Adoption Profile*



Innovators: Willing to accept early premium pricing and accept product risk for perceived leadership on GHG & VOC reduction

Early Adopters: Willing to monetize GHG and VOC value in economic justification

Majority adopters: Motivated by economic payback from product savings. Potentially enabled by 3rd party service companies.

Laggards: Require significantly higher ROI on environmental / product savings. Strongly enabled by 3rd party performance contracting.

*Likely to vary by sector, e.g. higher innovation population in Transmission, lower in Production