Climate implications of natural gas operations

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Finding the ways that work

Natural gas offers potential up-sides…

Increased energy security

Jobs

Reduced fuel/feedstock costs

Less air pollution upon combustion

…and potential risks if not done correctly

Greenhouse gas emissions

Other air pollutants

Surface spills and groundwater impacts

Fresh water use

Infrastructure: roads, traffic, pipelines…

Nuisance issues: noise, dust, …

The right way

Greater transparency

- mandatory chemical disclosure throughout well life
- other operations (e.g., air, water discharges)

Modernized rules for well construction and operation

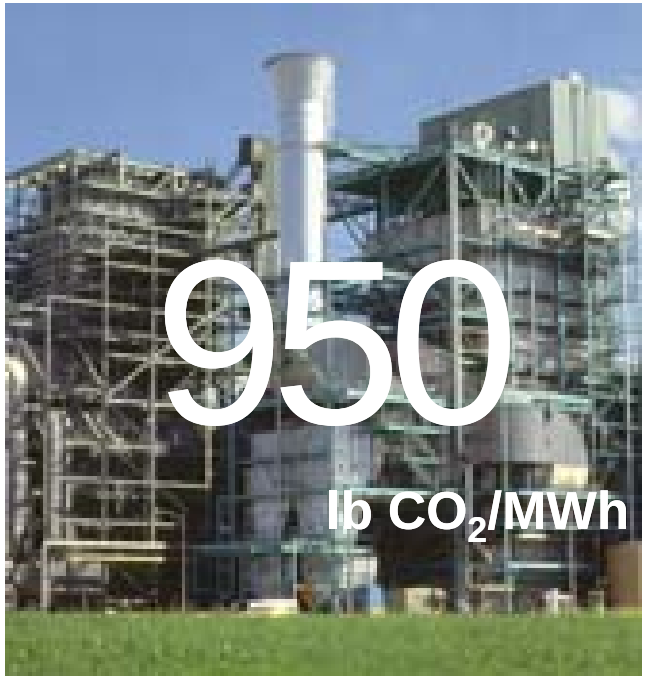
Improved waste and water management

Strong air emission standards including reduced CH_4 leakage

Minimized community and land impacts

Power plant CO_2 emissions…

Coal



Natural Gas

Power plant emissions…aren't whole story

COAL MINING
& PROCESSING

TRANSPORTATION

COAL
COMBUSTION

NATURAL GAS
PRODUCTION

PROCESSING

TRANSMISSION
& STORAGE

NATURAL GAS
COMBUSTION

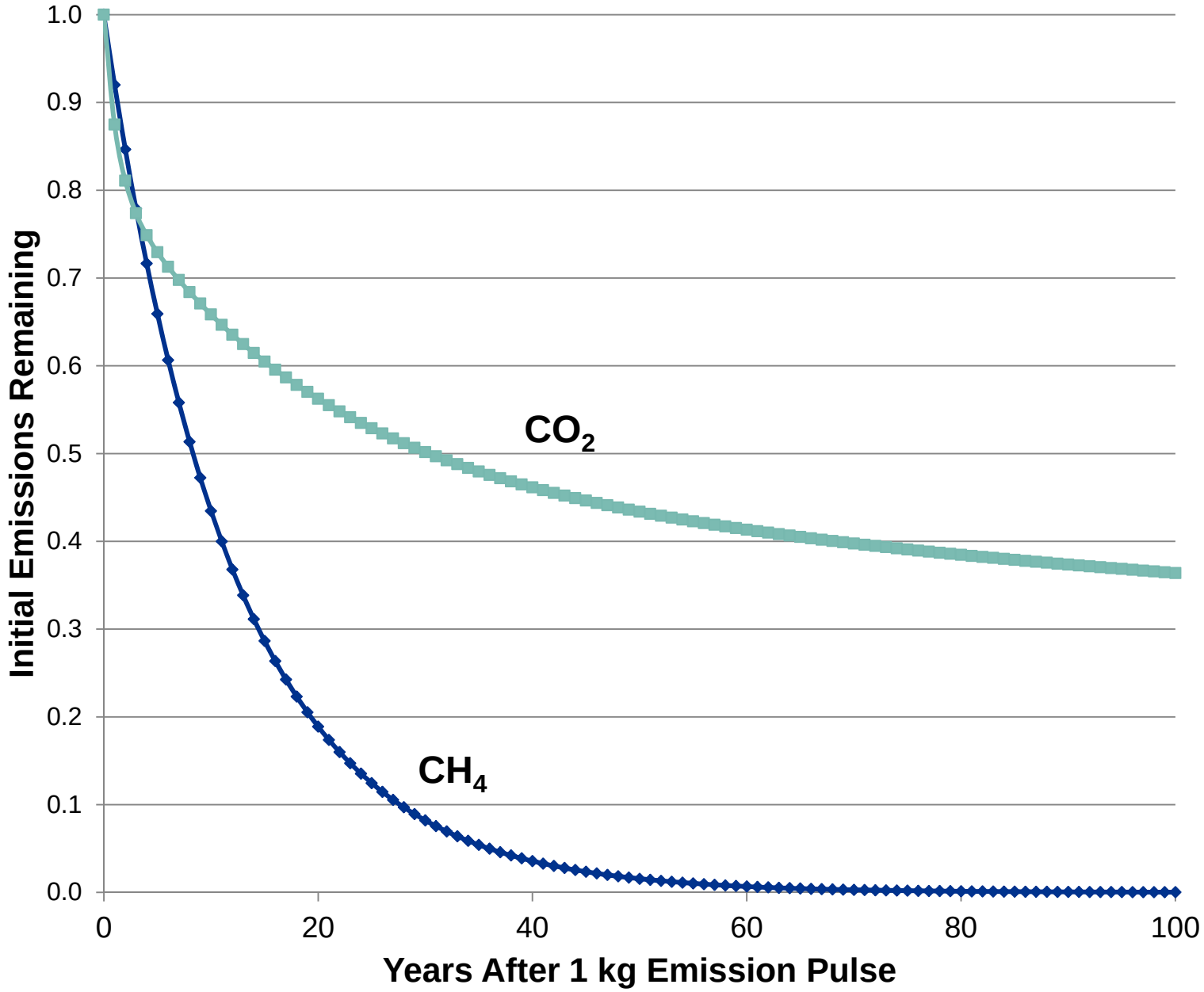
LOCAL DISTRIBUTION
TO OTHER END USERS

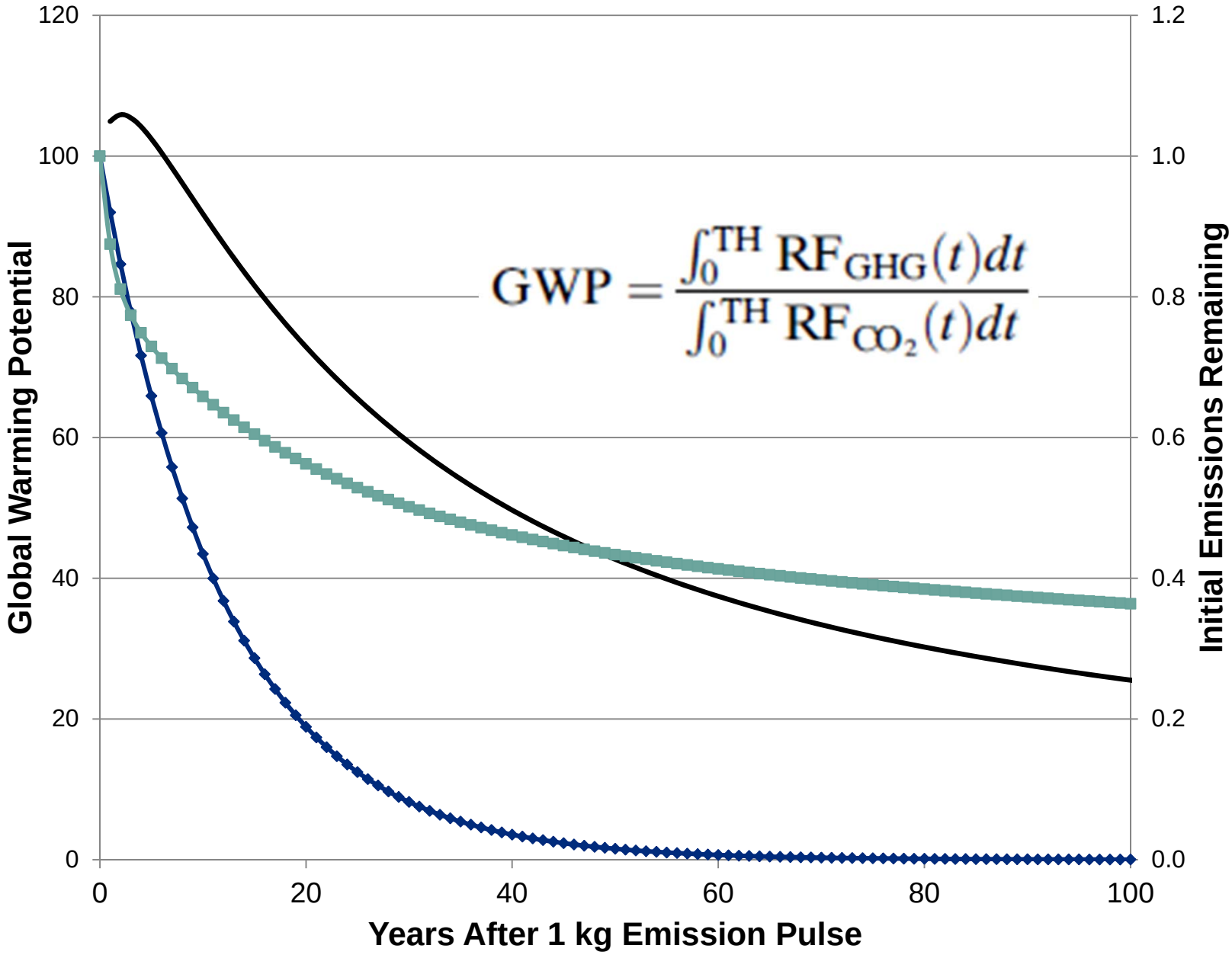
Source: Adapted from Jaramillo et al., (2007) EST 41, 6290, Truck photo by Stephen Petit, SiefkesPetit Communications. Posted at: flickr.com/photos/truckpr/6771598239/. Used under Creative Commons license

Greater focus needed on methane leakage from natural gas infrastructure

Ramón A. Alvarez[a,1], Stephen W. Pacala[b,1], James J. Winebrake[c], William L. Chameides[d], and Steven P. Hamburg[e]

Proceedings of the National Academy of Sciences USA (April 24, 2012) 109: 6435-6440 (doi:10.1073/pnas.1202407109)


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Initial Emissions Remaining
0
20
40
60
80
100
Years After 1 kg Emission Pulse
CO2
CH4


120
100
80
60
40
20
0
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
Global Warming Potential
Initial Emissions Remaining
Years After 1 kg Emission Pulse
$$\mathrm{GWP} = \frac{\int_0^{\mathrm{TH}} \mathrm{RF}_{\mathrm{GHG}}(t)\,dt}{\int_0^{\mathrm{TH}} \mathrm{RF}_{\mathrm{CO_2}}(t)\,dt}$$

Limitations of Global Warming Potential

GWPs established to compare the radiative forcing of emission *pulses* at a single point in time after emission (e.g., 20 or 100 years)

Obscures time dimension

Not suitable for emission *streams* of *multiple* pollutants

- "CO_2e" faces same limitations

“Technology Warming Potential” (TWP)

$$\mathrm{TWP}(t) = \frac{\frac{L}{L_{\mathrm{REF}}} E_{1,\mathrm{CH_4}} \mathrm{TRF}_{\mathrm{CH_4}}(t) + E_{1,\mathrm{CO_2}} \mathrm{TRF}_{\mathrm{CO_2}}(t)}{E_{2,\mathrm{CH_4}} \mathrm{TRF}_{\mathrm{CH_4}}(t) + E_{2,\mathrm{CO_2}} \mathrm{TRF}_{\mathrm{CO_2}}(t)}.$$

“Technology Warming Potential” (TWP)

$$\mathrm{TWP}(t) = \frac{\frac{L}{L_{\mathrm{REF}}} E_{1,\mathrm{CH_4}} \mathrm{TRF}_{\mathrm{CH_4}}(t) + E_{1,\mathrm{CO_2}} \mathrm{TRF}_{\mathrm{CO_2}}(t)}{E_{2,\mathrm{CH_4}} \mathrm{TRF}_{\mathrm{CH_4}}(t) + E_{2,\mathrm{CO_2}} \mathrm{TRF}_{\mathrm{CO_2}}(t)}.$$

$$\mathrm{TRF}(t) \equiv \int_0^{t_{\max}} \int_{t_E}^{t} \mathrm{RE}\, f(x, t_E) dx\, dt_E.$$

- E’s are assumed to be constant; a more general formulation could be employed to reflect technology improvements over time

- L_{REF} = 2.1% for Power Plant case; 3.0% for <u>both</u> transportation cases
  -- Enables alternative methane leakage assumptions
  -- Allows calculation of cross-over leak rates (i.e., TWP = 1)

“Technology Warming Potential” (TWP)

$$\mathrm{TWP}(t) = \frac{\frac{L}{L_{\mathrm{REF}}} E_{1,\mathrm{CH_4}} \mathrm{TRF}_{\mathrm{CH_4}}(t) + E_{1,\mathrm{CO_2}} \mathrm{TRF}_{\mathrm{CO_2}}(t)}{E_{2,\mathrm{CH_4}} \mathrm{TRF}_{\mathrm{CH_4}}(t) + E_{2,\mathrm{CO_2}} \mathrm{TRF}_{\mathrm{CO_2}}(t)}$$

Case	$\mathrm{TRF}_{\mathrm{CH_4}}(t)$	$\mathrm{TRF}_{\mathrm{CO_2}}(t)$
Pulse TWP	$\mathrm{RE}\{\tau_M(1-e^{-t/\tau_M})\}$	$a_0 t + \sum_{i=1}^{3} a_i \tau_i (1-e^{-t/\tau_i})$
Service Life TWP for $t \leq \mathrm{AMAX}$	$\mathrm{RE}\{\tau_M t - \tau_M^2(1-e^{-t/\tau_M})\}$	$a_0 \frac{t^2}{2} + \sum_{i=1}^{3} a_i(\tau_i t - \tau_i^2(1-e^{-t/\tau_i}))$
Service Life TWP for $t > \mathrm{AMAX}$	$\mathrm{RE}\{\tau_M \mathrm{AMAX} - \tau_M^2 e^{-t/\tau_M}(e^{\mathrm{AMAX}/\tau_M}-1)\}$	$a_0[\mathrm{AMAX}\, t - \frac{\mathrm{AMAX}^2}{2}] + \sum_{i=1}^{3} a_i(\tau_i \mathrm{AMAX} - \tau_i^2 e^{-t/\tau_i}(e^{\mathrm{AMAX}/\tau_i}-1))$
Fleet Conversion TWP	$\mathrm{RE}\{\tau_M t - \tau_M^2(1-e^{-t/\tau_M})\}$	$a_0 \frac{t^2}{2} + \sum_{i=1}^{3} a_i(\tau_i t - \tau_i^2(1-e^{-t/\tau_i}))$

RE in these formulas is the radiative efficiency of CH_4 relative to CO_2 and equals 102.

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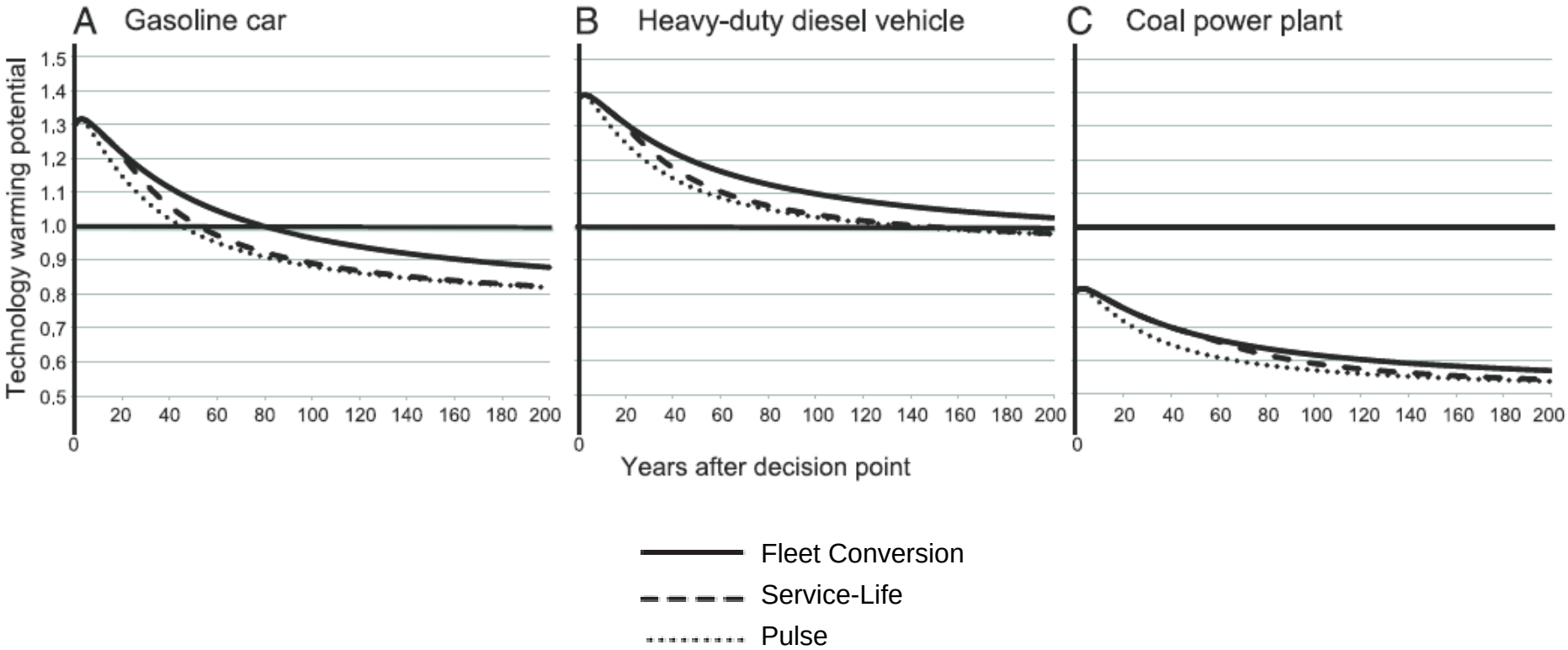

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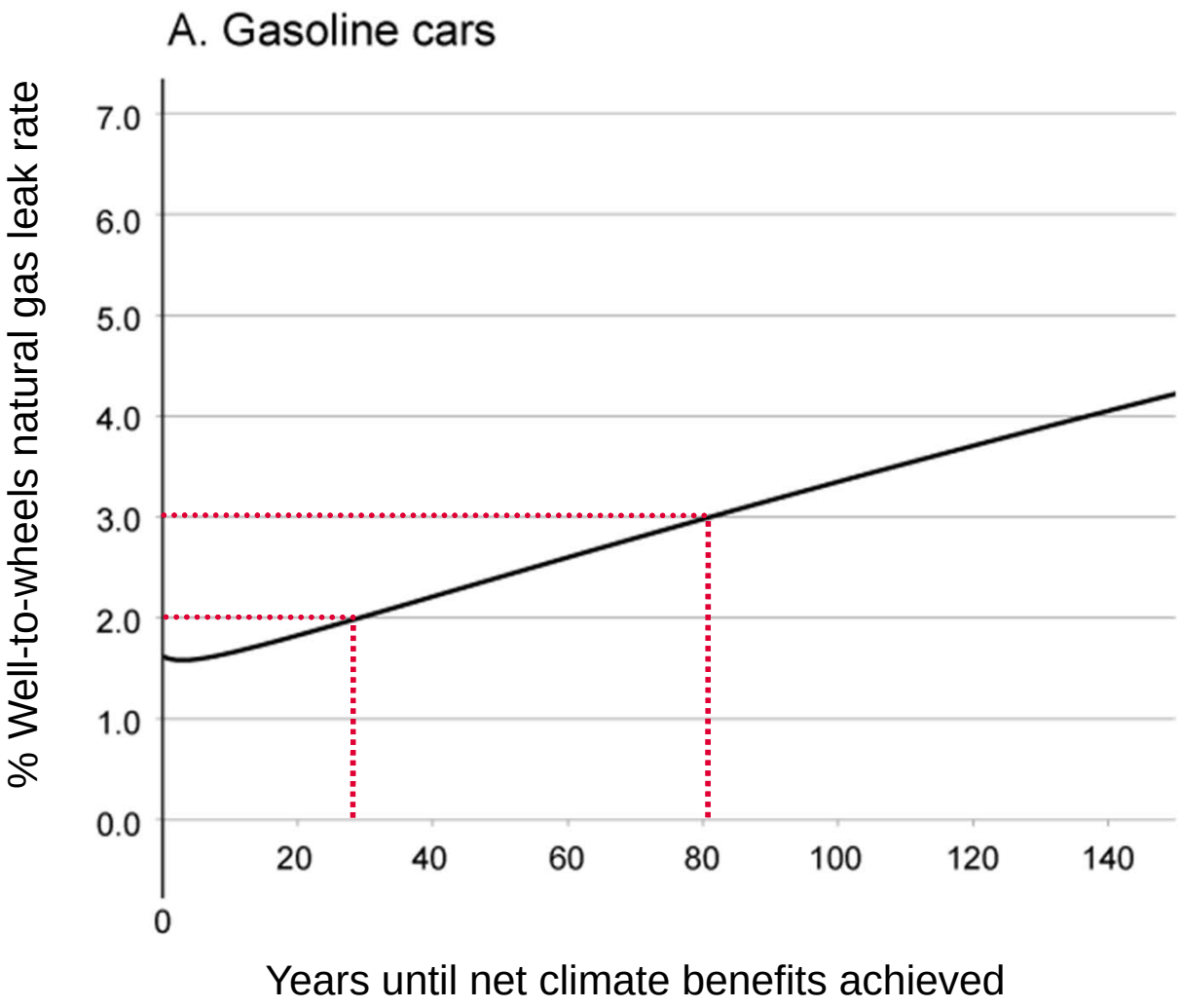
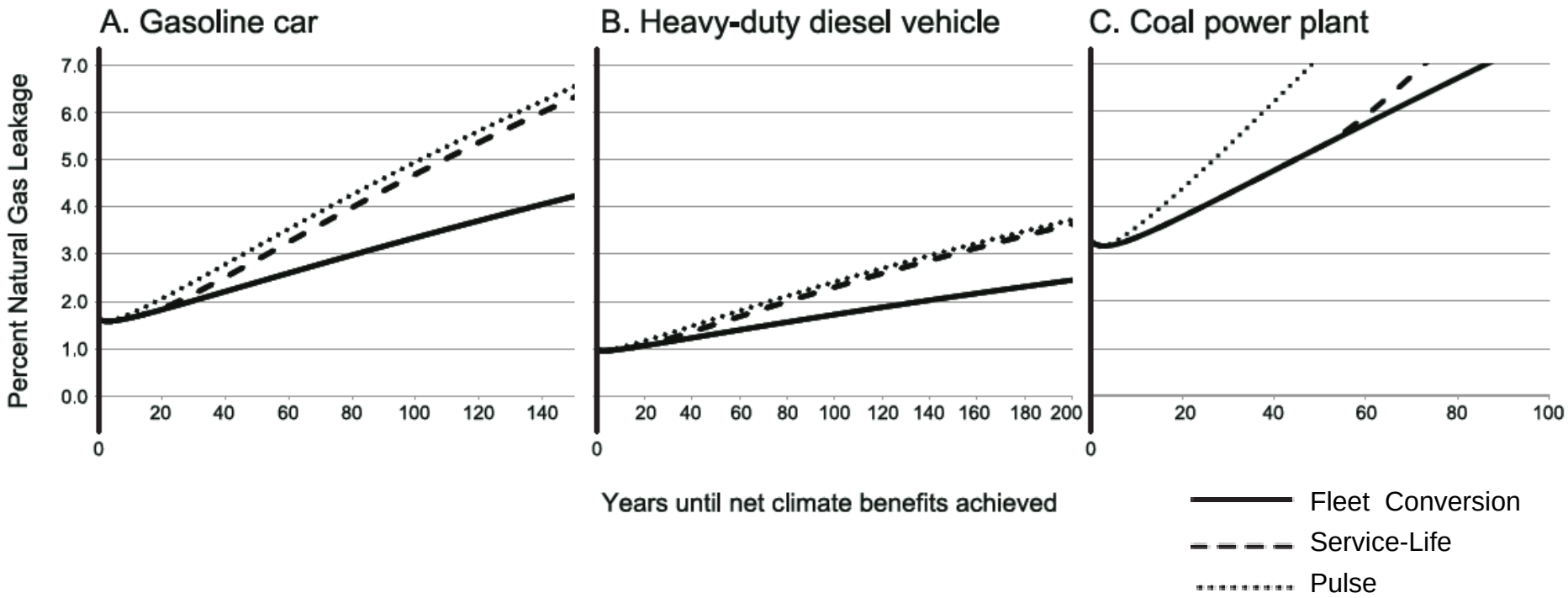
Leak rate affects time to climate benefits



What it takes to avoid climate damages



$$L^* = L_{\mathrm{REF}}\left\{\frac{E_{2,\mathrm{CH}_4}}{E_{1,\mathrm{CH}_4}} + \frac{E_{2,\mathrm{CO}_2} - E_{1,\mathrm{CO}_2}}{E_{1,\mathrm{CH}_4}}\frac{\mathrm{TRF}_{\mathrm{CO}_2}(t^*)}{\mathrm{TRF}_{\mathrm{CH}_4}(t^*)}\right\}$$

$$L_0 = L_{\mathrm{REF}}\left\{\frac{E_{2,\mathrm{CH}_4}}{E_{1,\mathrm{CH}_4}} + \frac{E_{2,\mathrm{CO}_2} - E_{1,\mathrm{CO}_2}}{\mathrm{RE}\ E_{1,\mathrm{CH}_4}}\right\}$$

Data Gaps/Uncertainties

Methane emissions across fuel cycle

Effects of methane on climate

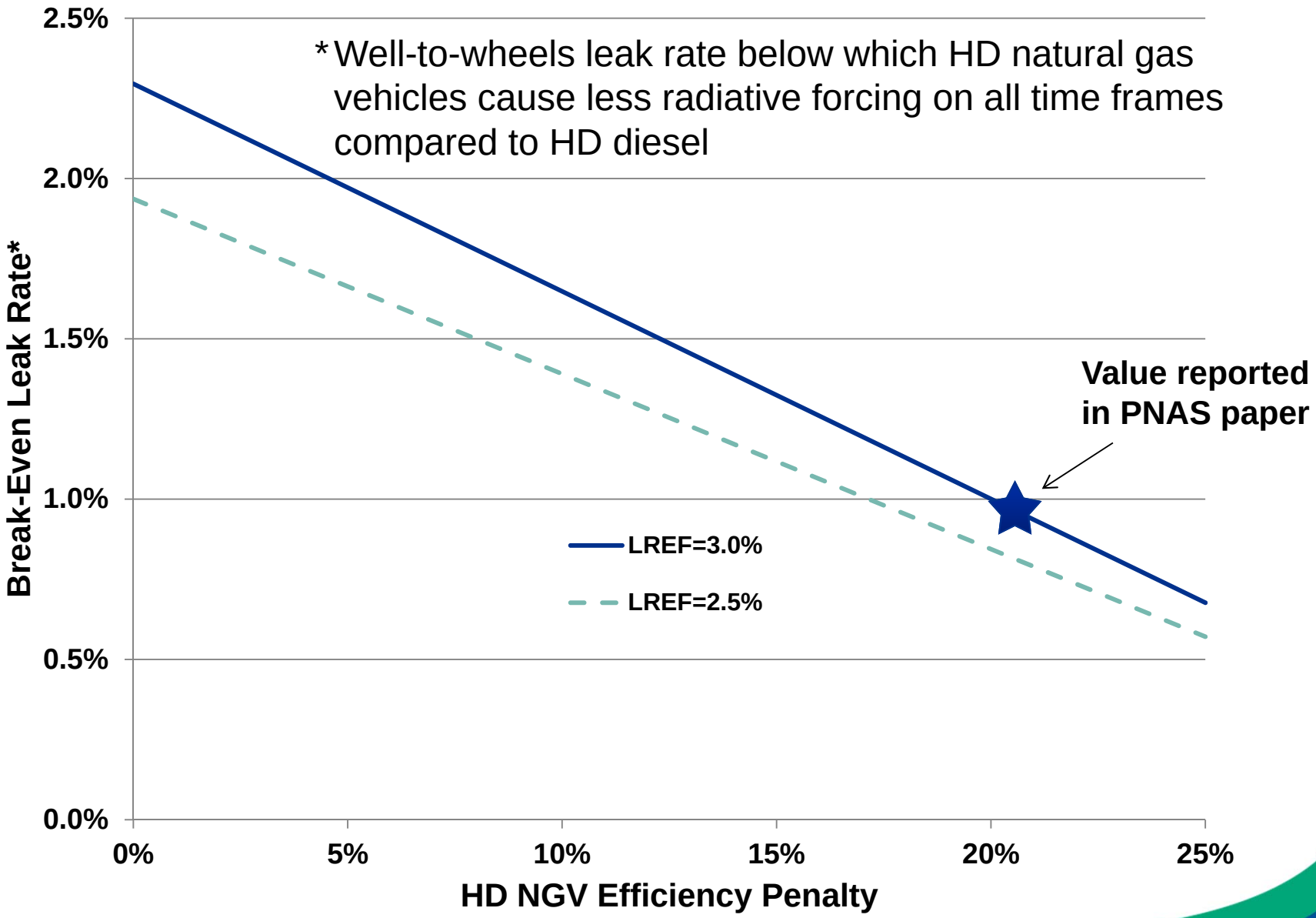
- Alternative climate metrics

Emissions of other pollutants

- Climate implications
- Air quality benefits

Efficiency of NGVs

Results Sensitive to Assumed Vehicle Efficiency



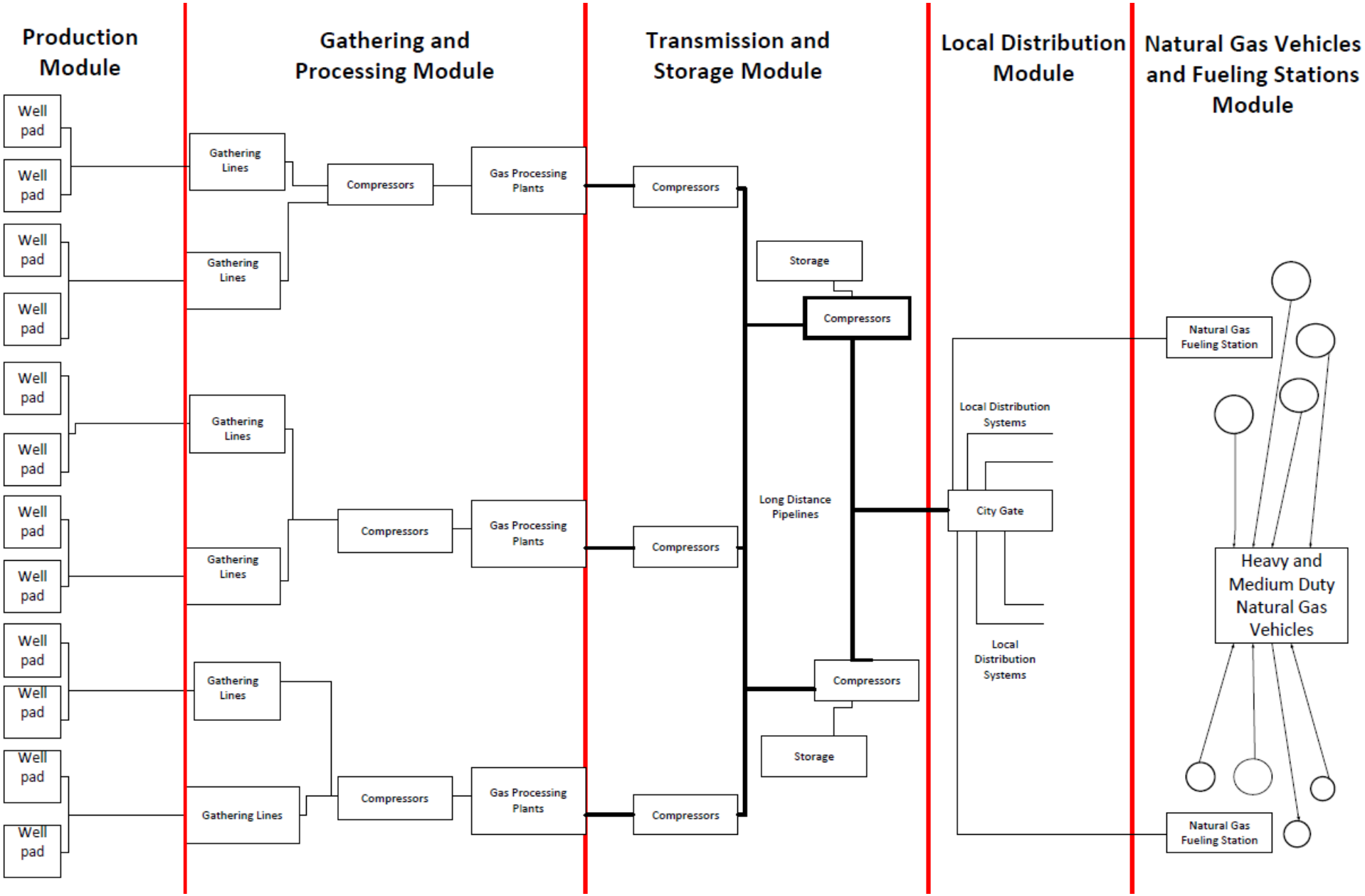
Conclusions

Improved science and data are needed to quantify CH_4 leakage

Critical leakage thresholds exist above which natural gas use leads to climate damages for some period of time

Reductions in CH_4 leakage are needed to maximize the climate benefits of natural gas

EDF's CH_4 Emissions Field Studies



Questions

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Finding the ways that work

Table 1. Emission factors used for TWP calculations in this paper

	Power Plants		Vehicles			
	Natural gas combined cycle* (kg/MW*h*)	Supercritical pulverized coal† (kg/MW*h*)	Light-duty CNG car (kg/mmBtuHHV)‡	Light-duty gasoline car (kg/mmBtuHHV)	Heavy-duty CNG truck (mg/ton-mile)	Heavy-duty diesel truck (mg/ton-mile)
Upstream CH_4	3.1	0.65	0.51	0.1	590	100
Upstream CO_2	36	7	9.4	15.9	10,000	15,000
In-Use CH_4	0	0	0.11	0.0056	15	0
In-Use CO_2	361	807	53.1	70.3	80,000	85,000
Fuel cycle CH_4	3.1	0.65	0.62	0.11	605	100
Fuel cycle CO_2	397	814	62.5	86.2	90,000	100,000

*Heat rate = 6,798 Btu/kWh.
†Heat rate = 8,687 Btu/kWh.
‡1 mmBtu = 10^6 Btu = 1.055 GJ.

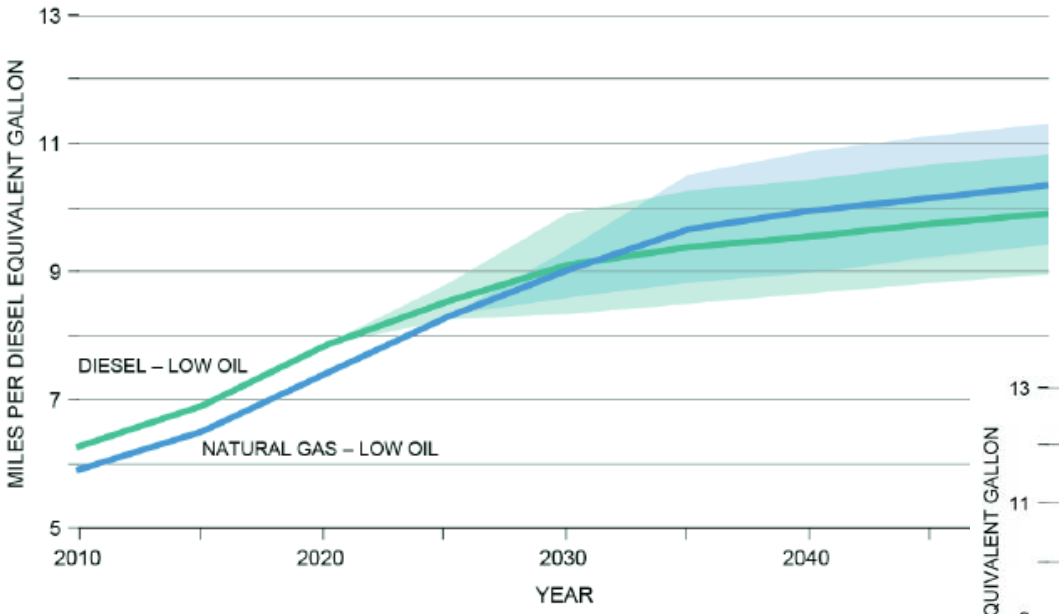


Figure 3-9. Fuel Economy Over Time for New Diesel and Natural Gas Class 7&8 Combination Trucks – Low Oil Price Case

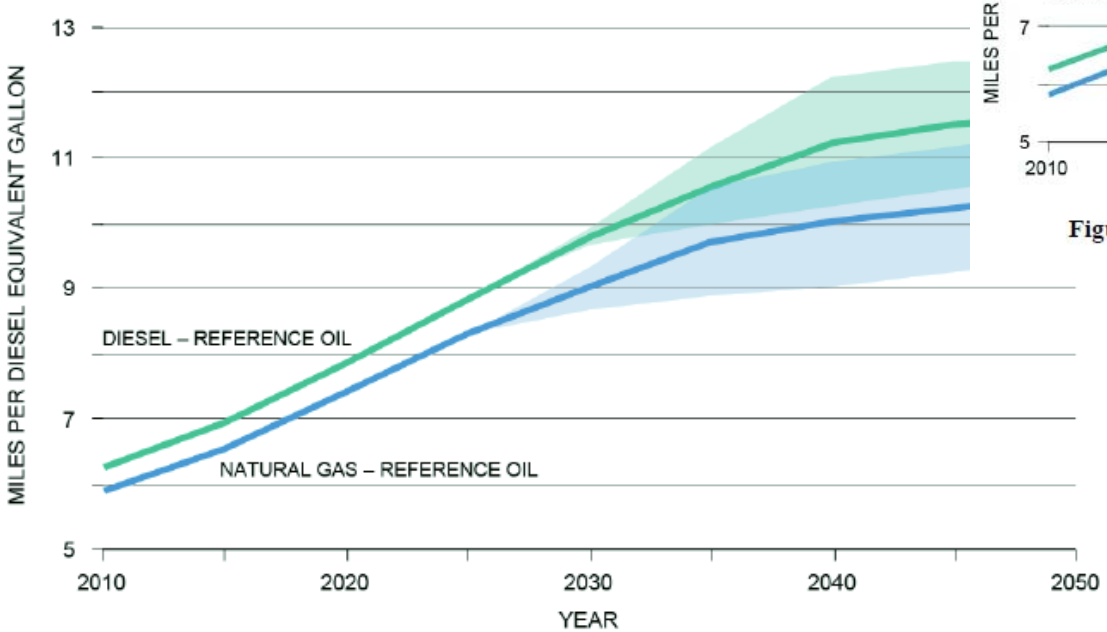


Figure 3-10. Fuel Economy Over Time for New Diesel and Natural Gas Class 7&8 Combination Trucks – Reference Oil Price Case

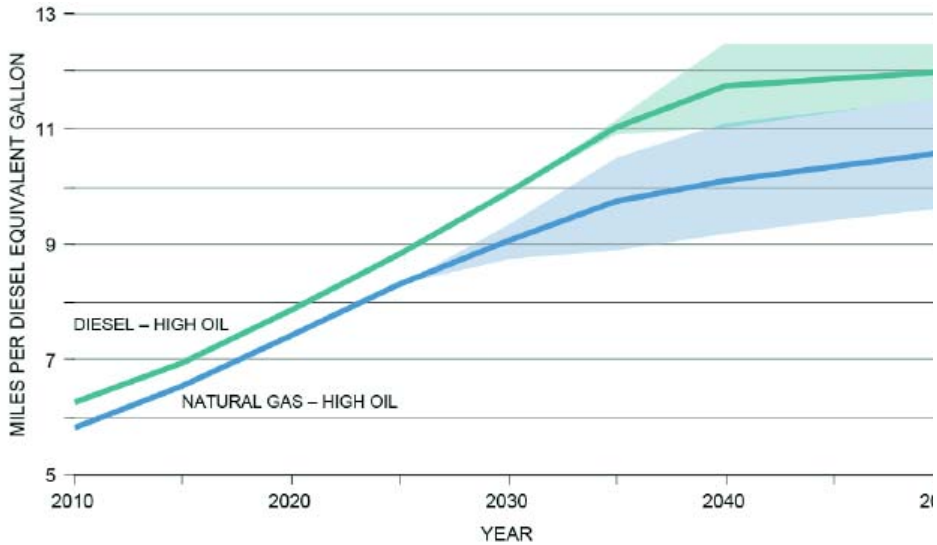
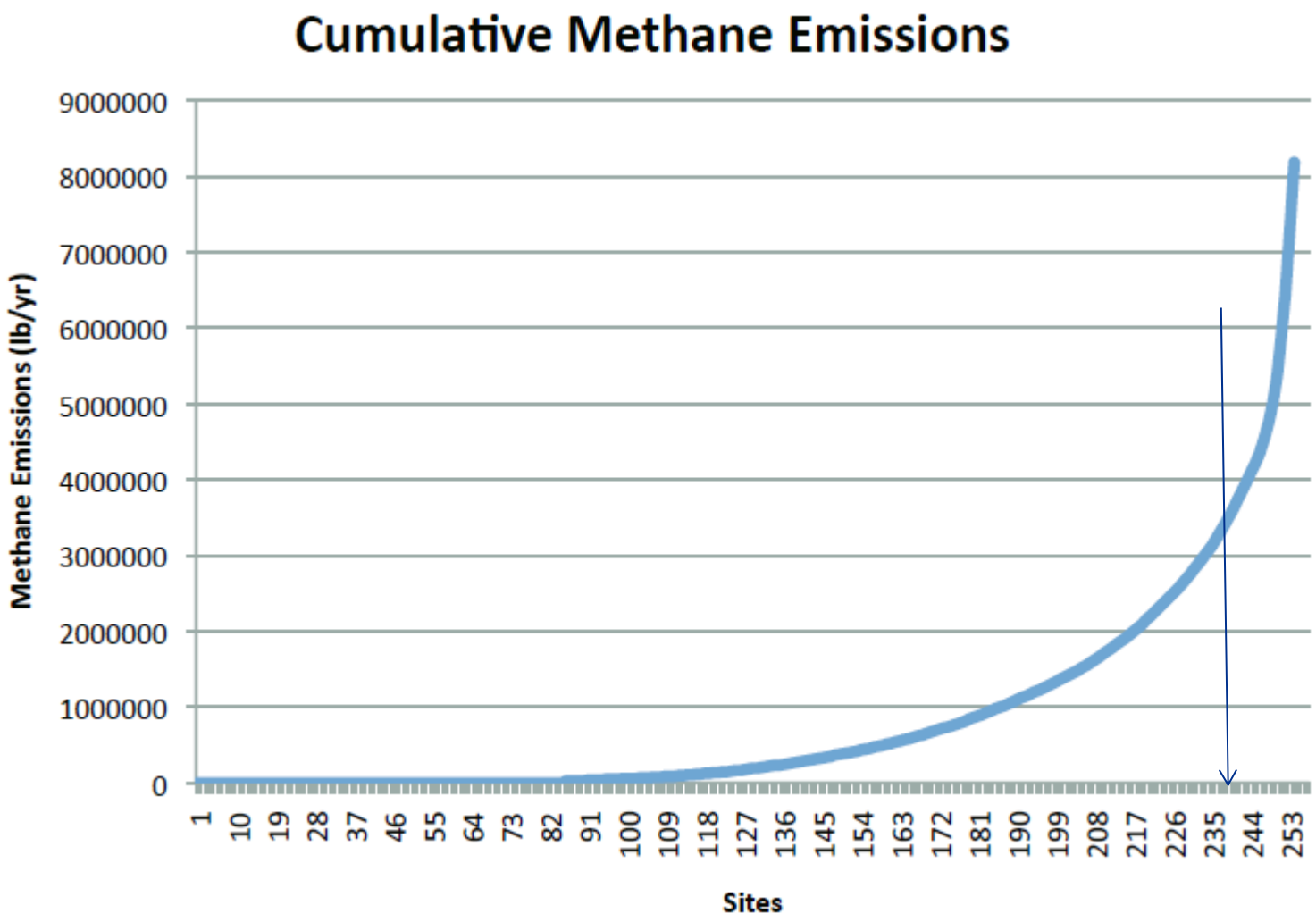


Figure 3-11. Fuel Economy Over Time for New Diesel and Natural Gas Class 7&8 Combination Trucks – High Oil Price Case

City of Fort Worth Air Quality Study (2010-2011)



www.fortworthgov.org/gaswells/