Greenhouse Effects Switching to Natural Gas

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Technical Approach

- Compare the cumulative <u>radiative forcing</u> of natural gas to other fuels:

  vs. gasoline for transportation

  - Emissions from a fleet of gasoline cars vs. CNG-fueled cars

  vs. diesel for transportation

  - Emissions from a fleet of diesel vehicles vs. CNG-fueled vehicles

  vs. coal for electric generation

  - Emissions from a fleet of new supercritical coal fired plants vs new combined cycle natural gas plants

EPA 2011 Methane Leakage Rates

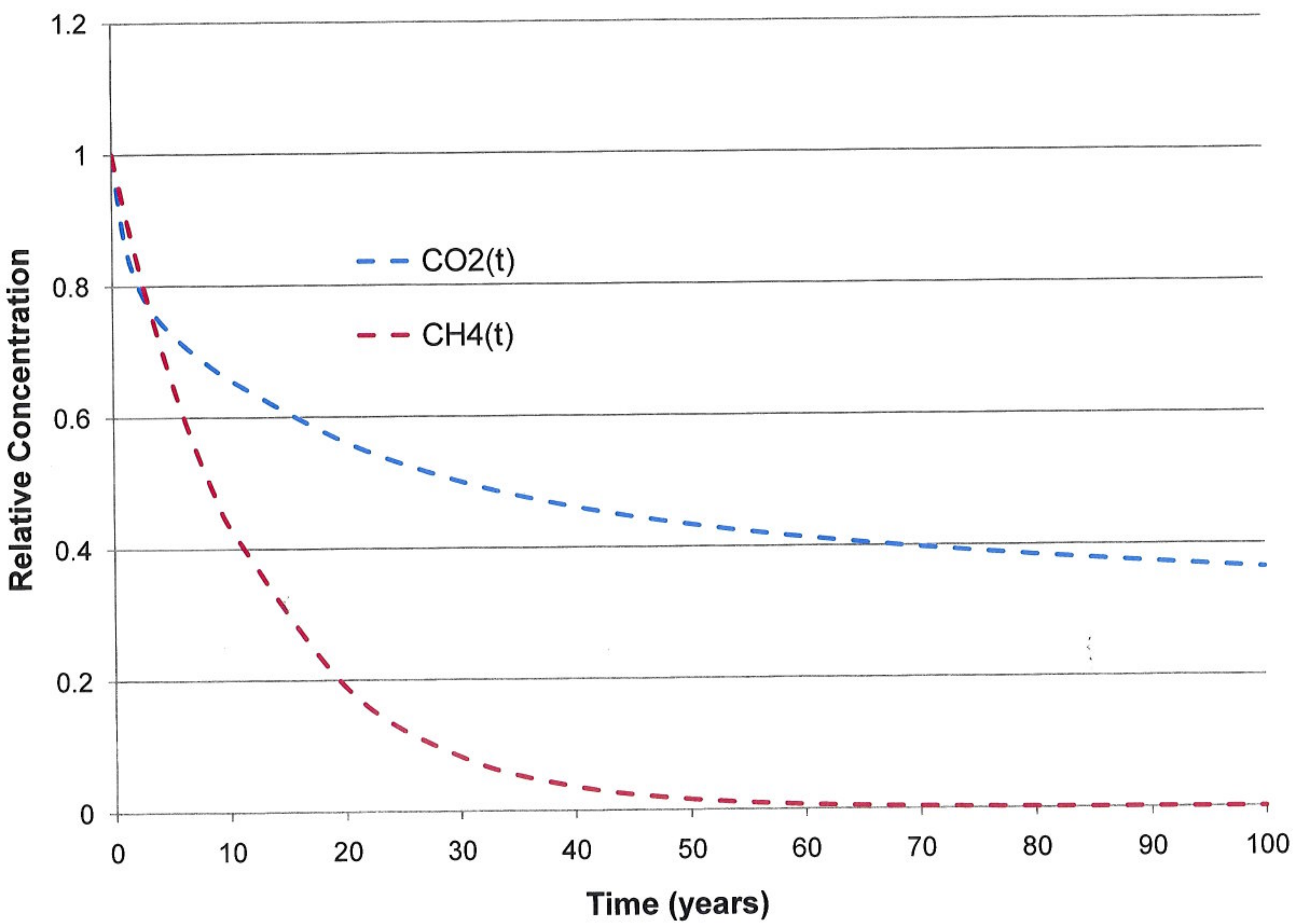
Methane emissions

2.4% of gross natural gas production (2.6% vehicle, 2.2% power plant) leaks before reaching end user. Note EPA estimate increased from 1.4% from 2010 to 2011 . 51% of leakage due to well cleanups at low pressure gas wells.

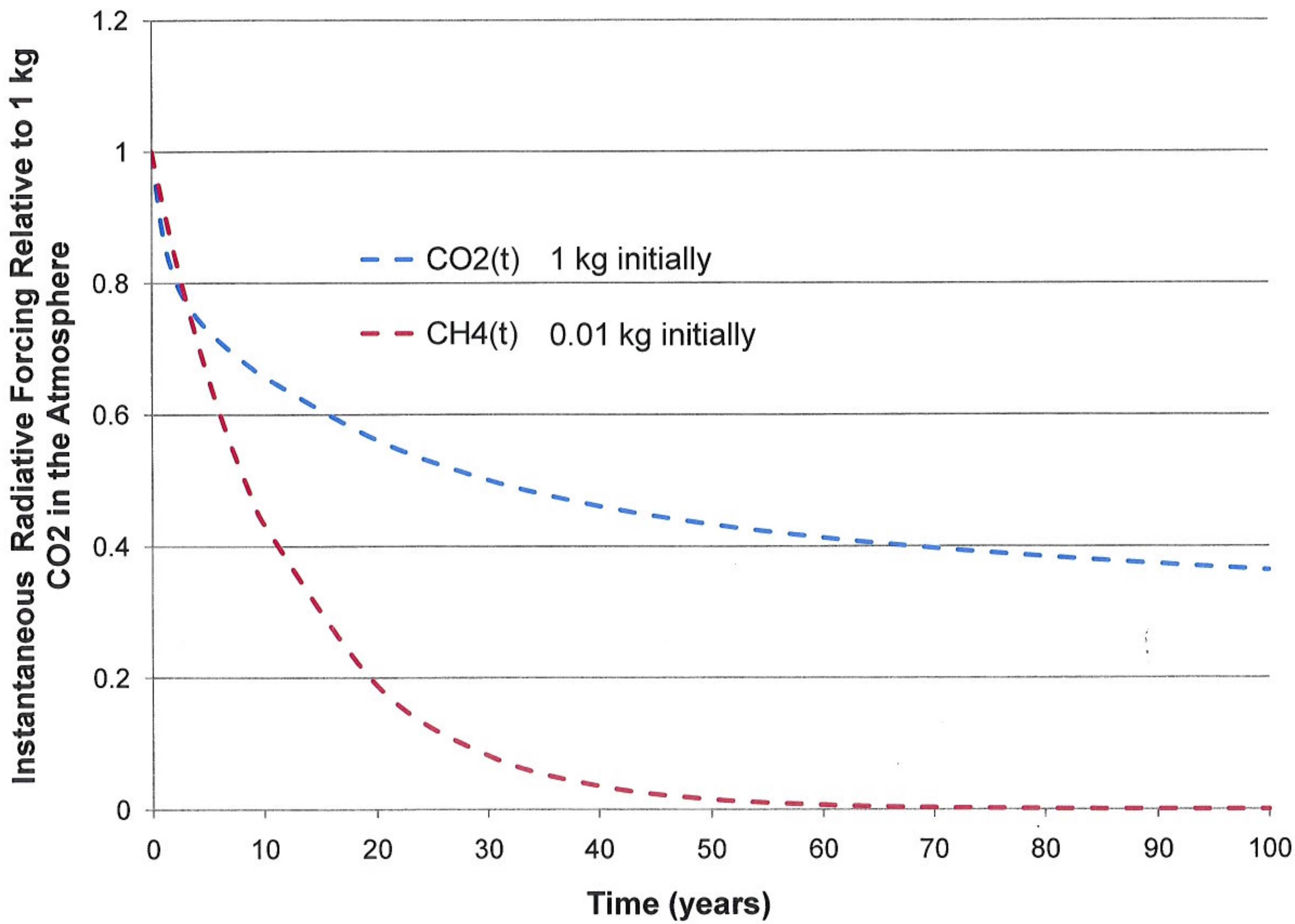
Additional 0.6% from gas used by CNG vehicles (total of 3.0% from CNG vehicles).

Instantaneous Radiative Forcing in year t from a leak of 1 kg In year t_L.	=	$IRF(t\|t_L)$	=	Total gas left in the atmosphere in year t from a leak in year t_L.	X	RE
IRF for Methane:				Decays quickly.	X	~100
IRF for CO_2 :				Decays slowly.	X	1

Fate of emissions pulses (equal mass)



Radiative Forcing



Cumulative Radiative Forcing in year t from a leak of 1 kg in year t_L. = $CRF(t|t_L)$ =

$$IRF(t_L|t_L) + IRF(t_L+1|t_L) + IRF(t_L+2|t_L) + \ldots\ldots + IRF(t-1|t_L) + IRF(t|t_L)$$

CRF for Methane: Starts large but equilibrates quickly.

CRF for CO_2 : Starts small, but keeps building for centuries.

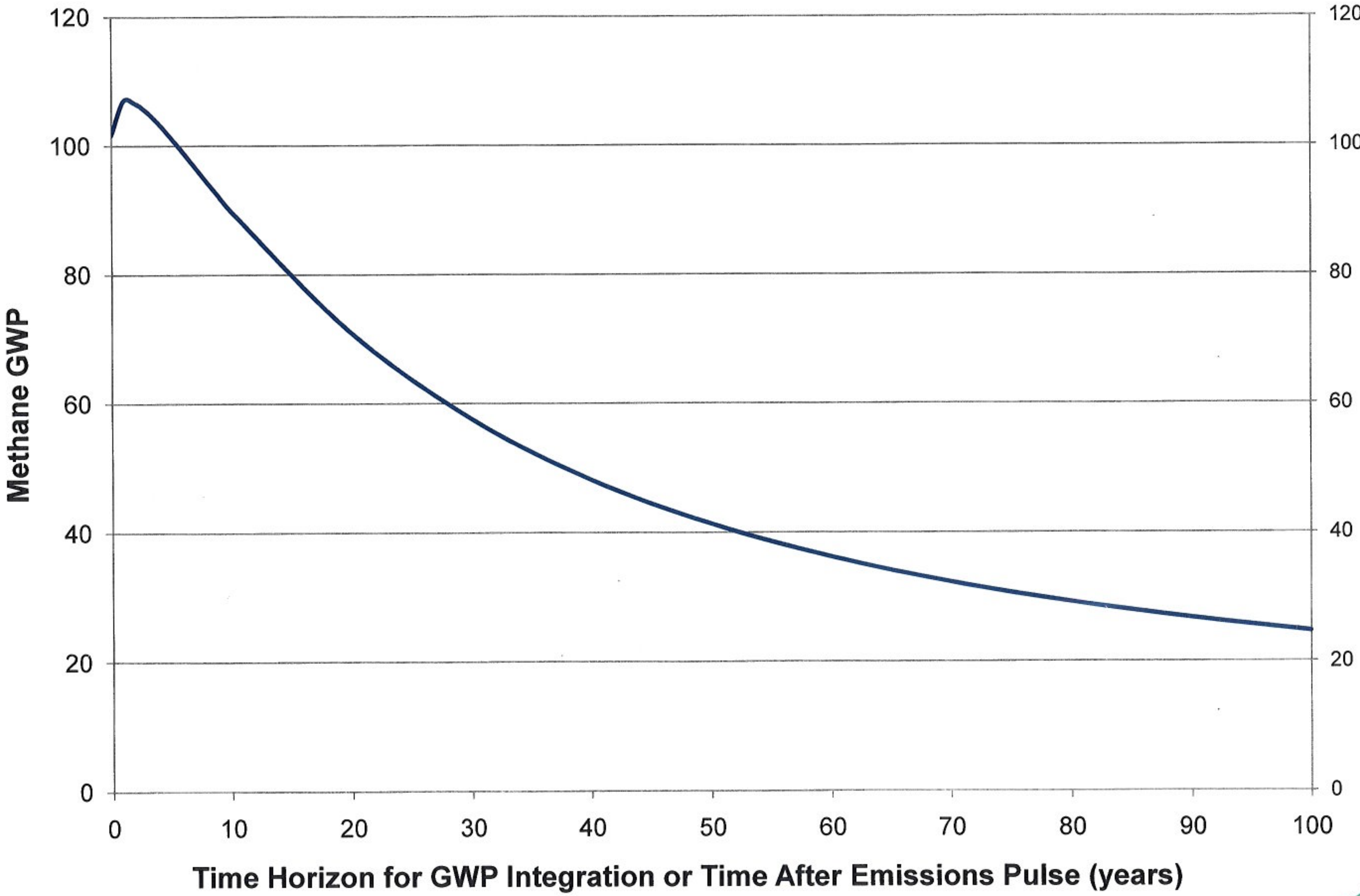
Global Warming Potential (GWP)

- Compares the cumulative radiative forcing of a gas (methane) over a fixed time horizon (TH), relative to CO_2:
- $GWP = CRF_{CH4}(TH) / CRF_{CO2}(TH)$

Methane GWP varies with time horizon:

TIME	GWP
20 years	72
100 years	25

Cummulative Radiative Forcing of 1 kg Methane Relative to 1 kg CO2



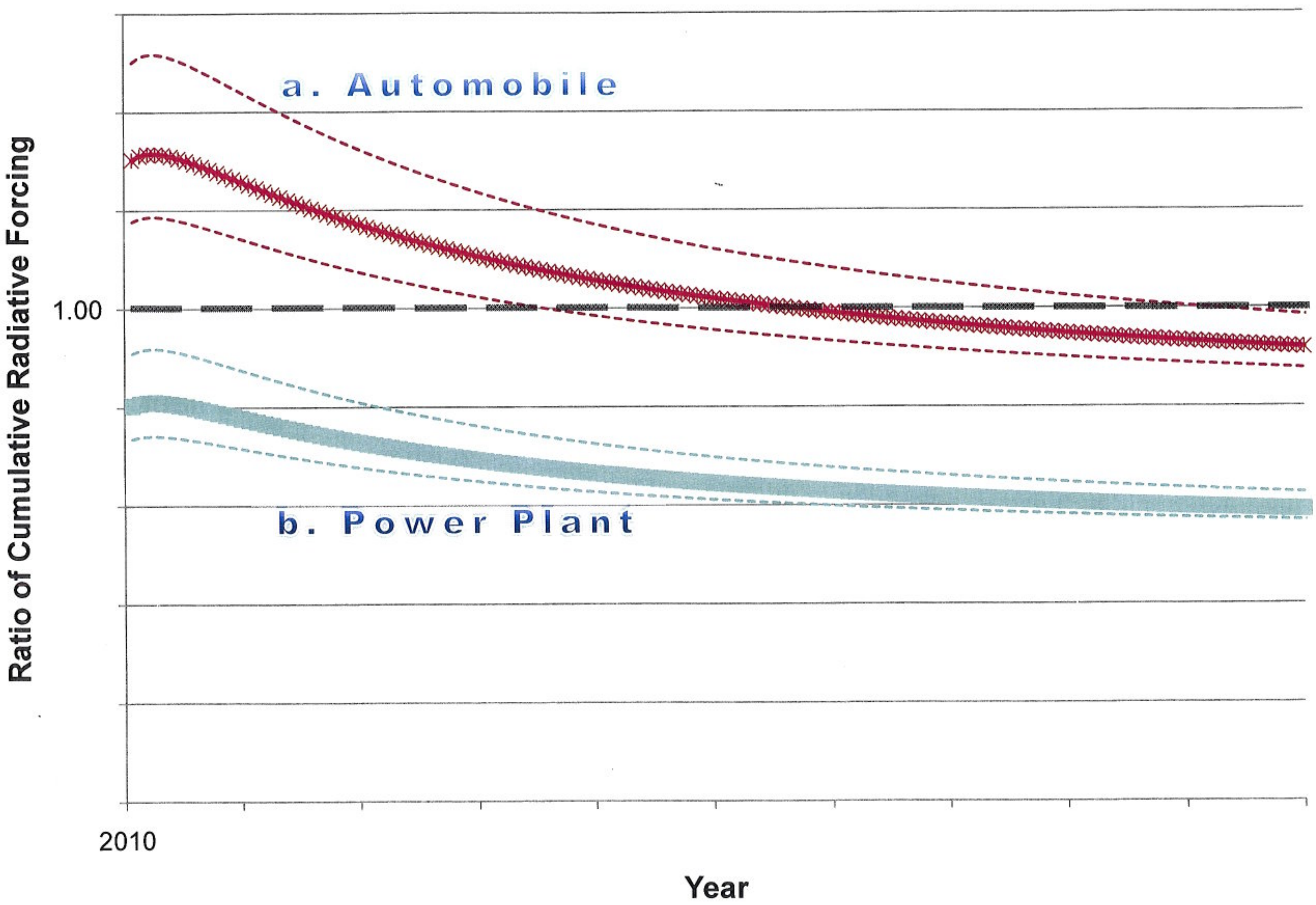
Fleet Cumulative Radiative Forcing in year t from a from a fleet established in year zero. = FCRF(t) = { CRF(t|0) + CRF(t|1) + …+ CRF(t|t) } X {Ann. Leak Size}

FCRF for Methane: Starts fast but quickly reaches maximum rate of increase.

FCRF for CO_2 : Starts small, but keeps on accelerating.

$$\text{Ratio of Fleet Cumulative Radiative Forcing} = \frac{FCRF_{CH4}(t) + FCRF_{CO2}(t) \text{ from a natural gas powered fleet}}{FCRF_{CH4}(t) + FCRF_{CO2}(t) \text{ from the alternative fleet}}$$

Ratio of Cumulative Radiative Forcing



Conclusion

- CNG vehicles initially create higher greenhouse forcing than gasoline or diesel vehicles. This effect is large (several tens of percent).
- CNG vehicles cause greater greenhouse warming than gasoline vehicles for nearly a century, and greater warming than diesel vehicles for more than a century.
- At the expected peak of climate change (one to two centuries), the greenhouse benefit of CNG vehicles is modest.
- CNG vehicles would always cause less greenhouse forcing than gasoline vehicles if methane leak rates were approximately halved, and less forcing than diesels if leak rates were reduced by ~2/3.
- Natural gas power plants always result in less radiative forcing than coal plants, but reducing leakage by 1/2 or 2/3 would make this benefit substantially larger.

Emissions – Transportation Fuel

	Natural Gas	Gasoline
Vehicle CO_2 (kg/mmBtu)	53.1	70.3
Vehicle CH_4 (kg/mmBtu)	0.11	0.006
Upstream CO_2 (kg/mmBtu)	9.4	15.9
Upstream CH_4 (kg/mmBtu)	0.5	0.1

- Natural Gas: Upstream CO_2 reflects well to pump, including CO_2 from CNG compression assuming 0.6kWh/therm (TIAX 2007 DRAFT Table 7-6); vehicle CH_4 is assumed to be 20 times the gasoline value, based on Lipman and Delucchi (2002); Upstream methane is the same as used in power plant case, but adds distribution system emissions. CNG refueling emissions are not explicitly included, but may be insignificant (TRB 1998)

- Gasoline: National Energy Technology Laboratory. Values obtained from Excel spreadsheet model downloaded from http://www.netl.doe.gov/energy-analyses/refshelf/detail.asp?pubID=283 on April 27, 2011. Selected EPA RFS2 tailpipe values (EPA November 2009 Profile under "Vehicle Operation" tab) and 2007 IPCC GWPs. Methodology described in "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels," DOE/NETL-2009/1346, November 26, 2008.

- For both fuel cycles, the emissions factors are based on higher heat values (HHV)

Emissions – Power Plants

	New Natural Gas Combined Cycle	New Supercritical Pulverized Coal*
Power Plant CO_2 (kg/MWh)	361	807
Upstream CO_2 (kg/MWh)	35.9	7.0
Upstream CH_4 (kg/MWh)	3.1	2.6
Heat Rate (Btu/kWh)	6,798	8,687

- NGCC values developed by EDF following Jaramillo et al. (2007) methodology, updated with CH_4 emissions from EPA 2011
- Heat Rates used were taken from NETL
- SCPC emissions values from NETL SCPC-LCA Table ES-2 (divided by 1.07 to reflect MWh produced)

*Unadjusted methane value. Our baseline scenario assumed the use of "low gassy" coal (i.e. from a mine considered to produce less than 71 scf/ton), with only 25% of the upstream methane value of 2.6 kg/MWh assumed in NETL's analysis.