RESOURCES *for the* FUTURE

Methane Fees' Effects on Natural Gas Prices and Methane Leakage

Issue Brief 21-12 by **Brian C. Prest** — September 2021

1. Introduction

Methane (CH_4) is both the primary component of natural gas and also a highly potent greenhouse gas. Methane routinely leaks out from oil and gas wells, pipelines, and processing facilities into the atmosphere, exacerbating climate change. While there is a private incentive for operators to reduce methane leaks to capture and sell it as a valuable commodity, the private incentive to capture the gas falls far short of — **around 1/10th of** — the social costs imposed by its leakage. As a result, basic economics demonstrates that industry will exert insufficient effort to capture that gas, relative to the social optimum. To combat this problem, economists and policymakers have proposed methane fees to both reduce greenhouse gas emissions and raise federal revenues (for example, as seen in **S.645**, **H.R.4084**).

While, on the one hand, fees on methane leaks will further encourage oil and gas operators to proactively seek out and mitigate methane leaks, the additional fees will also raise the marginal cost of producing each unit of gas (typically measured in either thousand cubic feet, mcf, or million British thermal units, MMBtu). This increase in marginal cost is the net of three effects, two of which are cost increases (+) and one which represents a decrease (–).

1. (+) The methane fee, assessed as a percentage of each MMBtu of gas production, represents a direct increase in gas producers' operating cost;
2. (+) The fee will induce gas producers to deploy more time, effort, and resources to reduce methane leaks, representing an indirect, induced operating cost; and
3. (–) The reduced leakage rate resulting from (2) will mean more produced gas can be sold, reducing the cost of each delivered unit of gas.

On net, these effects are likely to increase the marginal cost of gas production. In this issue brief, I use a simple economic model to estimate the effects of proposed methane fees on the marginal cost of gas production, methane leakage rates, and the resulting increase in wholesale natural gas prices. While the details are presented in the Appendix, the model simulates how a gas producer would respond to alternative methane fees, based on an augmented version of the model in Marks (2018). The model simulates, for each of a variety of potential methane fees (in units of \$/ton CH_4), how much gas producers may mitigate their methane leak rates and how much those fees may increase the cost of producing each unit (MMBtu) of gas, as well as how much of those resulting costs may be passed on to consumers. Finally, as a point of comparison, this brief presents as reference points various natural gas prices, such as wholesale and retail prices of natural gas delivered to different end-users (e.g., residential, commercial, industrial, and electric power).

2. Model Inputs

I consider a range of potential levels of the methane fee (in units of \$/ton CH_4) as alternative levels of the methane fee have been proposed (e.g., \$1800/tCH_4 in S.645 and H.R.4084). In addition, this brief considers the implications of alternative methane leak rates because there is uncertainty about the true level of those leaks in the field. The best available peer-reviewed observational estimates come from Alvarez et al. (2018), which estimates an average leakage rate of 2.3% for the full oil and gas supply chain, about 1.9 percentage points of which is from upstream leaks in production, gathering, and processing. For example, the EPA's GHG inventories are widely believed to understate the true amount of methane leaks from oil and gas infrastructure—while the bottom-up estimates from Alvarez et al. (2018) suggest 1.9% of total gas production is leaked from upstream sources, the corresponding figure from EPA's greenhouse gas inventories only amounts to 0.9%, which is likely an underestimate. I assume fees are assessed on an accurate measurement of methane leaks. If instead

Table 1. Estimated Effects of Alternative Methane Fees on Leak Rates, Production Cost, and Natural Gas Prices, 0.25% Leakage Allowance

	Alvarez et al. (2018) et al., upstream only	Alvarez et al. (2018) full supply chain, lower bound	Alvarez et al. (2018) full supply chain, central estimate	Alvarez et al. (2018) full supply chain, upper bound
	1.9%	2.0%	2.3%	2.7%
Methane fee ($/ton CH_4)	**Modeled methane leakage rate (%)**			
$500	1.0%	1.1%	1.4%	1.8%
$1,000	0.7%	0.8%	1.1%	1.5%
$1,500	0.4%	0.5%	0.8%	1.2%
$1,800	0.3%	0.4%	0.7%	1.1%
$2,000	0.3%	0.4%	0.7%	1.1%
	Increase in marginal production costs of natural gas, relative to no methane fee ($/MMBtu)			
$500	$0.09	$0.10	$0.13	$0.16
$1,000	$0.14	$0.16	$0.21	$0.28
$1,500	$0.17	$0.19	$0.27	$0.38
$1,800	$0.17	$0.20	$0.30	$0.43
$2,000	$0.17	$0.21	$0.31	$0.46
	Impact on wholesale natural gas prices ($/MMBtu)			
$500	$0.05 - $0.08	$0.06 - $0.08	$0.07 - $0.10	$0.09 - $0.13
$1,000	$0.08 - $0.12	$0.09 - $0.13	$0.12 - $0.17	$0.16 - $0.23
$1,500	$0.09 - $0.14	$0.11 - $0.16	$0.15 - $0.22	$0.21 - $0.31
$1,800	$0.10 - $0.14	$0.12 - $0.17	$0.17 - $0.24	$0.24 - $0.35
$2,000	$0.10 - $0.14	$0.12 - $0.17	$0.18 - $0.26	$0.26 - $0.37

Table 2. Natural Gas Price Reference Points ($/MMBtu)

	2019	2020	May-21	Jul-21
Henry Hub Gas Spot Price	$2.57	$2.04	$2.91	$3.84
Electric power customer price	$2.88	$2.39	$3.23	n.a.
Industrial customer price	$3.76	$3.17	$3.94	n.a.
Commercial customer price	$7.34	$7.21	$8.65	n.a.
Residential customer price	$10.14	$10.45	$13.51	n.a.

Note: "n.a." = not available as of publication date. EIA prices converted from $/mcf to $/MMBtu by dividing by 1.037 MMBTu per mcf.

fees are assessed on incomplete measurements, the impacts on emissions, costs, and prices will be smaller; therefore Appendix Tables 3 and 4 show sensitivity analyses where measured emissions are too low by factors of 2 and 4.

In the future, estimates of methane leak rates will improve as monitoring procedures improve and/or if regulators deploy more effective on-the-ground monitoring to enforce potential methane fees. But since leak rates remain uncertain, I consider a range of baseline leak rates, including the Alvarez et al. (2018) upstream-only estimate of 1.9%, as well as their ranges of estimates of full supply chain leaks of 2.0 - 2.7% with a central estimate of 2.3%. The other primary input into the estimates is the leakage allowance rate under the policy (e.g., a leakage allowance of 0.2% as in S.645 means a methane fee would be assessed on the observed leakage rate minus 0.2%). The results are not very sensitive to this input, so the alternative results are included in the appendix. All analyses assume a baseline $3/MMBtu price of gas, but the results are not very sensitive to this assumption.

3. Conclusion

The results yield two major conclusions:

- The price impacts of methane fees are relatively low, particularly for small methane fees (e.g., $500/ton CH_4). The estimated gas price increases in Table 1 are roughly centered around $0.15/MMBtu, across possible methane fee levels and leak rates. Compared to the reference prices in Table 2, $0.15/MMBtu is roughly:
  - 5% of the wholesale price of gas (around $3/MMBtu),
  - 4-5% of the retail prce to electric power and industrial customers (around $3-4/MMBtu),
  - 2% of the retail price to commercial customers (about $7-8/MMBtu), and
  - 1% of the retail price to residential customers (>$10/MMBtu).
- Substantial reductions in methane leaks may be possible with relatively modest methane fees of $1000 to $1500/ton CH_4. Larger fees generate more reductions in methane leakage, but they do so with diminishing returns as capturing smaller leaks becomes more difficult.

4. References

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5. Appendix

Sensitivity Analyses

Table 3. Estimated Effects of Alternative Methane Fees on Leak Rates, Production Cost, and Natural Gas Prices, 0.25% Leakage Allowance, Measurement Understated by Factor of 2

	Alvarez et al. (2018) et al., upstream only	Alvarez et al. (2018) full supply chain, lower bound	Alvarez et al. (2018) full supply chain, central estimate	Alvarez et al. (2018) full supply chain, upper bound
	1.9%	2.0%	2.3%	2.7%
Methane fee ($/ton CH_4)	**Modeled methane leakage rate (%)**			
$500	1.3%	1.4%	1.7%	2.1%
$1,000	1.0%	1.1%	1.4%	1.8%
$1,500	0.8%	0.9%	1.2%	1.6%
$1,800	0.7%	0.8%	1.1%	1.5%
$2,000	0.7%	0.8%	1.1%	1.5%
	Increase in marginal production costs of natural gas, relative to no methane fee ($/MMBtu)			
$500	$0.04	$0.05	$0.06	$0.08
$1,000	$0.07	$0.08	$0.11	$0.14
$1,500	$0.09	$0.10	$0.14	$0.19
$1,800	$0.09	$0.11	$0.16	$0.22
$2,000	$0.10	$0.12	$0.17	$0.24
	Impact on wholesale natural gas prices ($/MMBtu)			
$500	$0.02 - $0.04	$0.03 - $0.04	$0.04 - $0.05	$0.05 - $0.07
$1,000	$0.04 - $0.06	$0.05 - $0.07	$0.06 - $0.09	$0.08 - $0.12
$1,500	$0.05 - $0.07	$0.06 - $0.08	$0.08 - $0.12	$0.11 - $0.16
$1,800	$0.05 - $0.08	$0.06 - $0.09	$0.09 - $0.13	$0.13 - $0.18
$2,000	$0.06 - $0.08	$0.07 - $0.09	$0.10 - $0.14	$0.14 - $0.20

Table 4. Estimated Effects of Alternative Methane Fees on Leak Rates, Production Cost, and Natural Gas Prices, 0.25% Leakage Allowance, Measurement Understated by Factor of 4

	Alvarez et al. (2018) et al., upstream only	Alvarez et al. (2018) full supply chain, lower bound	Alvarez et al. (2018) full supply chain, central estimate	Alvarez et al. (2018) full supply chain, upper bound
	1.9%	2.0%	2.3%	2.7%
Methane fee ($/ton CH_4)	**Modeled methane leakage rate (%)**			
$500	1.5%	1.6%	1.9%	2.3%
$1,000	1.3%	1.4%	1.7%	2.1%
$1,500	1.1%	1.2%	1.5%	1.9%
$1,800	1.0%	1.1%	1.4%	1.8%
$2,000	1.0%	1.1%	1.4%	1.8%
	Increase in marginal production costs of natural gas, relative to no methane fee ($/MMBtu)			
$500	$0.01	$0.02	$0.02	$0.03
$1,000	$0.02	$0.03	$0.04	$0.06
$1,500	$0.03	$0.03	$0.05	$0.08
$1,800	$0.03	$0.04	$0.06	$0.09
$2,000	$0.03	$0.04	$0.06	$0.10
	Impact on wholesale natural gas prices ($/MMBtu)			
$500	$0.01 - $0.01	$0.01 - $0.01	$0.01 - $0.02	$0.02 - $0.03
$1,000	$0.01 - $0.02	$0.02 - $0.02	$0.02 - $0.03	$0.03 - $0.05
$1,500	$0.01 - $0.02	$0.02 - $0.03	$0.03 - $0.04	$0.05 - $0.06
$1,800	$0.02 - $0.02	$0.02 - $0.03	$0.03 - $0.05	$0.05 - $0.07
$2,000	$0.02 - $0.02	$0.02 - $0.03	$0.04 - $0.05	$0.06 - $0.08

Table 5. Estimated Effects of Alternative Methane Fees on Leak Rates, Production Cost, and Natural Gas Prices, 0.20% Leakage Allowance

	Alvarez et al. (2018) et al., upstream only	Alvarez et al. (2018) full supply chain, lower bound	Alvarez et al. (2018) full supply chain, central estimate	Alvarez et al. (2018) full supply chain, upper bound
	1.9%	2.0%	2.3%	2.7%
Methane fee ($/ton CH_4)	**Modeled methane leakage rate (%)**			
$500	1.0%	1.1%	1.4%	1.8%
$1,000	0.7%	0.8%	1.1%	1.5%
$1,500	0.4%	0.5%	0.8%	1.2%
$1,800	0.3%	0.4%	0.7%	1.1%
$2,000	0.3%	0.4%	0.7%	1.1%
	Increase in marginal production costs of natural gas, relative to no methane fee ($/MMBtu)			
$500	$0.10	$0.11	$0.13	$0.17
$1,000	$0.15	$0.17	$0.22	$0.29
$1,500	$0.18	$0.21	$0.28	$0.39
$1,800	$0.19	$0.22	$0.31	$0.44
$2,000	$0.19	$0.23	$0.33	$0.47
	Impact on wholesale natural gas prices ($/MMBtu)			
$500	$0.06 - $0.08	$0.06 - $0.09	$0.08 - $0.11	$0.10 - $0.14
$1,000	$0.08 - $0.12	$0.09 - $0.14	$0.12 - $0.18	$0.17 - $0.24
$1,500	$0.10 - $0.15	$0.12 - $0.17	$0.16 - $0.23	$0.22 - $0.32
$1,800	$0.11 - $0.15	$0.12 - $0.18	$0.18 - $0.26	$0.25 - $0.36
$2,000	$0.11 - $0.16	$0.13 - $0.19	$0.19 - $0.27	$0.27 - $0.39

Table 6. Estimated Effects of Alternative Methane Fees on Leak Rates, Production Cost, and Natural Gas Prices, 0.30% Leakage Allowance

	Alvarez et al. (2018) et al., upstream only	Alvarez et al. (2018) full supply chain, lower bound	Alvarez et al. (2018) full supply chain, central estimate	Alvarez et al. (2018) full supply chain, upper bound
	1.9%	2.0%	2.3%	2.7%
Methane fee ($/ton CH_4)	**Modeled methane leakage rate (%)**			
$500	1.0%	1.1%	1.4%	1.8%
$1,000	0.7%	0.8%	1.1%	1.5%
$1,500	0.4%	0.5%	0.8%	1.2%
$1,800	0.3%	0.4%	0.7%	1.1%
$2,000	0.3%	0.4%	0.7%	1.1%
	Increase in marginal production costs of natural gas, relative to no methane fee ($/MMBtu)			
$500	$0.09	$0.10	$0.12	$0.16
$1,000	$0.13	$0.15	$0.20	$0.27
$1,500	$0.15	$0.18	$0.26	$0.36
$1,800	$0.16	$0.19	$0.28	$0.41
$2,000	$0.16	$0.19	$0.30	$0.44
	Impact on wholesale natural gas prices ($/MMBtu)			
$500	$0.05 - $0.07	$0.06 - $0.08	$0.07 - $0.10	$0.09 - $0.13
$1,000	$0.08 - $0.11	$0.09 - $0.12	$0.11 - $0.17	$0.16 - $0.22
$1,500	$0.09 - $0.13	$0.10 - $0.15	$0.15 - $0.21	$0.21 - $0.30
$1,800	$0.09 - $0.13	$0.11 - $0.15	$0.16 - $0.23	$0.23 - $0.34
$2,000	$0.09 - $0.13	$0.11 - $0.16	$0.17 - $0.24	$0.25 - $0.36

Technical Appendix

Model Documentation

This model is based closely on Marks (2018), but modified to model for an allowance (or deduction) to the leakage rate, here denoted R^a. A gas producer maximizes profits, denoted as:

$$\pi = \max_{Q,R} P(1-R)Q - C_1(Q) - Qc_2(R) - \tau(mR - R^a)Qe$$

where P is the price of gas ($/MMBtu), Q is gas produced (in MMBtu), R is the leak rate, $C_1(Q)$ is the cost of production ($C_1'(Q) > 0$), $c_2(R)$ is the per-unit leak abatement cost, mR is the legally measured methane leak (with $m \in [0,1]$ is the share of leaks actually measured by the regulator), R^a is the allowed emissions rate, τ is the methane charge ($/ton CH_4), e is the amount of CH_4 per MMBtu of gas (taken to be 0.01726 tCH_4/MMBtu (Brandt et al. 2014)). For example, if $m = 100\%$, $R^a = 0.25\%$ and the leak rate is $R = 1.25\%$ and $\tau = \$1000/$$tCH_4$, then the total methane charge is ($1,000/$tCH_4$)(100%*1.25% - 0.25%)(0.01726 tCH_4/MMBtu)=$0.1726/MMBtu times the number of MMBtu (Q).

The operator chooses Q and R to maximize profits. The first-order conditions are:

$$\partial\pi/_{\partial Q} = 0 \Rightarrow P(1-R) = C_1'(Q) + c_2(R) + \tau(mR - R^a)e$$
$$\partial\pi/_{\partial R} = 0 \Rightarrow c_2'(R) = -(P + \tau me)$$

We can solve the last equation for the equilibrium leakage rate if we knew the functional form of $c_2'(R)$, or its inverse $R = c_2'^{-1}(-p)$ which maps any given per-MMBtu price p to a leak rate R.

Marks (2018) estimates a good approximation of the *inverse* leakage function, $c_2'^{-1}(-p)$ as:

$$R = c_2'^{-1}(-p) = \alpha + \beta \log p$$

with an estimate of $\beta = -0.0061$. The term α is a well or facility constant. I don't observe the industry average α, so I back it out of this cost curve for each prospective baseline leak rate. For example, using the central Alvarez et al. (2018) estimate of $R = 2.3\%$ for the year 2015, and 2015 average Henry Hub prices $p = \$2.63$/MMBtu,[1] this implies $\alpha = 2.89\%$.

This functional form for $c_2'^{-1}(\cdot)$ corresponds to a total abatement cost function:

$$c_2(R) = -\beta\, e^{(R-\alpha)/\beta}$$

The first-order condition for the leakage rate, $\partial\pi/\partial R = 0$, allows us to solve for the firm's optimal leakage rate, $R^*(P, \tau, m)$, for any given gas price P, methane fee τ, and measurement rate m. This R^* can be plugged into the first-order condition for Q to calculate new delivered marginal costs of gas for a given methane fee τ:

$$MC(P,\tau,m) = (C_1'(Q) + c_2(R^*(P,\tau,m)) + \tau(mR^*(P,\tau,m) - R^a)e)/(1 - R^*(P,\tau,m))$$

for each τ and m. I use $\tau \in \{\$0, \$500, \$1000, \$1500, \$1800, \$2000\}$ per ton CH_4, based on recent proposals. $m \in \{0.25, 0.5, 1\}$. $m = 1$ corresponds to perfect measurement, $m = 0.50$ roughly corresponds to estimates of the current degree of understatement of existing GHG inventories programs according to Alvarez et al. (2018), and $m = 0.25$ roughly corresponds to estimates of the degree of understatement of the GHG reporting program. Improvements to the GHG reporting program could increase the value of m and make fees more effective at reducing emissions. The change in marginal costs is then given by

$$\Delta\, MC(P,\tau,m) = MC(P,\tau,m) - MC_0(P,0,m)$$

1. https://fred.stlouisfed.org/series/MHHNGSP

As noted in Marks (2018), footnote 22, the effect of a fee on gross (pre-leak) output, and hence on $C_1'(Q)$ is very small, so I ignore it for simplicity. Therefore, the change in marginal production cost is the combination the change in the fee ($\tau(mR - R^a)e$) and the abatement costs ($c_2(R)$), which are partially offset the benefits of selling more gas at the same gross marginal cost. The relative sizes of these effects depend on the allowable leakage rate (more generous (higher) allowances mean smaller fees, but as a lump-sum transfer this has no effect on leakage abatement on the margin). The effects also depend on the level of the methane fee (higher means larger emissions and cost impacts) and the price of gas (at high prices, leak rates are lower even without the fee, so the effect of the fee is smaller at high prices).

Finally, the effect on wholesale prices is the change in marginal costs multiplied by the pass-through ratio, $\backslash theta = \eta_s/(\eta_s - \eta_d)$, where η_s is the elasticity of gas supply and η_d is the elasticity of gas demand. I use supply elasticities of 0.55 to 0.90 based on the supply elasticities estimated in the recent literature (Newell, Prest, and Vissing 2019; Prest 2021), and I use the same range of demand elasticities as in Prest (2021): -0.20 to -0.42. These lead to low-end and high-end pass-through ratios of 57% and 82%, respectively. These are multiplied by the change in marginal costs ($\Delta MC(P, \tau)$) to yield estimates of the change in wholesale natural gas prices.

Caveats and Uncertainties

The results are based on a simplified model of abatement activity, based on Marks (2018). As with any modelling activity, there are uncertainties associated with model assumptions and the data used to parameterize the model. Perhaps the largest source of uncertainty in this model is the estimation of the inverse marginal abatement cost equation which governs how much leak rates are expected to decline with the levels of gas prices and methane fees—i.e.,

$$R = c_2'^{-1}(-p) = \alpha + \beta \log p.$$

This shape of this equation and its estimated parameters are approximations based on the model and results of Marks (2018). Alternative functional relationships would lead to different estimates of abatement activity. While the shape of the fitted relationship in that paper appears to be quite robust to other approaches (see Figure 4 and Table 1 of that paper), there nonetheless remains uncertainty about the shape of this function for methane fees outside of the range of historical gas price data, as noted in Marks (2018).

To the extent that leakage abatement is less (more) price-sensitive, the methane fees would be expected to have less (more) effect on methane leaks. While higher (lower) leak rates would lead to higher (lower) methane fees charged on each MMBtu produced, they would also mean less (more) abatement activity and lower (higher) abatement costs. Because these two effects act in opposite directions, the estimated effect on marginal production costs and market prices is likely to be relatively insensitive to the calibration of the abatement cost function. However, the estimated effects of the methane fees on leak rates are likely to be sensitive to the calibration of this equation.