RESOURCES for the FUTURE

Differentiation of Natural Gas Markets by Climate Performance

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1. Introduction

Any commodity can be described by its unique set of attributes. These attributes can include intrinsic characteristics, such as what the commodity is (e.g., natural gas), and where, how, and by whom it was produced. These attributes can quantify the externalities associated with production, processing, transport, and consumption. For instance, in the case of coffee, the price partially reflects how, where, and by whom it is grown and processed, as well as how much, and can also reflect a variety of external benefits. For example, "rainforest alliance" coffee signals protection against deforestation, "shade-grown" coffee signals lower biodiversity loss, and "fair trade" coffee signals that a purchase reduces economic inequality. A range of certification bodies transform these signals of value into an expectation of reality and integrity, often via labeling, facilitating consumer choice and price premiums. In this way, coffee, a commodity, has been transformed into a differentiated product based on the underlying attribute profile.

Commodity differentiation has also taken place in the energy sector. Electricity is a homogeneous commodity, yet electrons are produced in different ways. Electrons produced by a coal-fired power plant have a much different attribute profile than those generated by a wind turbine or solar panel. In the case of power generation, there are established, robust, well-developed, and expanding markets for electricity with "green" attributes, including for voluntary renewable energy credits. Remarkably, similar attribute differentiation has yet to take place for fossil fuels,[1] despite attempts by companies to distinguish their products through advertising. One way hydrocarbon production can be differentiated is by greenhouse gas emissions. Estimates of the life cycle carbon emissions embedded in different US and Canadian oils range from the highest at Canada Abathasca (736 kilograms of carbon dioxide equivalent [kg CO_2e] per barrel) to the lowest at Texas Eagle Ford (458 kg CO_2e per barrel).[2]

How natural gas is produced, processed and moved varies greatly, leading to large heterogeneities in methane emissions that vary temporally by company, sector, and operations. For example, a large body of literature indicates that a relatively small portion of production wells account for the majority of methane emissions, which led scholars to coin the term "super-emitters" to characterize poor (or perhaps unlucky) performers (Alvarez et al. 2012; Caulton et al. 2014; Rella et al. 2015; Zavala-Araiza et al. 2015).

This paper explores the potential issues in the creation of a market for green natural gas—here meaning natural gas with low methane emissions[3] across the value chain—

1 With the possible exception of renewable natural gas, which is natural gas derived from organic waste such as cow manure.
2 Oil-Climate Index, **https://oci.carnegieendowment.org/#supply-chain**.
3 In this paper we sometimes use the term "methane leaks," while recognizing that some methane escapes in the course of normal operations and so is not technically a leak.

(oil with associated gas that has low methane emissions could also be considered green, by analogy, but this is beyond the scope of our paper) as a means of obtaining superior climate performance.[4] The underlying heterogeneity, alongside our belief that greater vigilance can allow for quicker detection of major leaks, is the basis for our interest in considering this market. We narrowly define superior climate performance as the achievement of a low methane leakage rate associated with the life cycle of natural gas. We also include as leakage any deliberate emissions of methane during maintenance events, through venting (which is generally not permitted), or as part of other aspects of normal operations.

We focus on methane emissions from the natural gas sector because of concern about methane as a strong greenhouse gas (35 to 80 times greater than an equivalent amount of CO_2) and because this energy sector has a real and a public relations problem with methane leaks. The extent of these emissions threatens the climatic benefit of transitioning power generation and fleet vehicles to natural gas over other fossil fuels (coal and diesel) and thereby endangers the status of natural gas as a transition fuel (Munnings and Krupnick 2017). However, the factor-based emissions reporting methodologies used by the US Environmental Protection Agency (EPA) significantly underestimate methane emissions (Brandt et al. 2014). Moreover, the Trump administration has pulled back significantly from the Obama administration's attempts to regulate such emissions (although a few states have regulatory programs). Thus, the creation of a market for green natural gas could be a desirable mechanism for incentivizing superior climate performance to reduce greenhouse gases. In addition, those producers that are already operating with superior climate performance, or are planning to do so, may be monetarily rewarded for their efforts.

4 We focus narrowly on green natural gas and methane emissions in this paper, rather than the larger set of attributes involved in the creation of responsibly produced natural gas.

2. Current and Future Activities

To a limited extent, there is already some product differentiation along these lines. As Table 1 shows, producers already report methane leakage from natural gas production through several avenues. Disclosure reports on the methane emissions of corporations enhance transparency and thereby potentially influence investment decisions. For example, the Sustainability Accounting Standards Board (SASB) requires participating companies to report their direct emissions, including methane leaks from natural gas, in their filings to the Securities and Exchange Commission. The advisory group overseeing SASB is committed to improving sustainability-related investment disclosures and collectively represents $21 trillion in assets under management.[5] Disclosure efforts allow investors to differentiate among corporations producing natural gas. Enhancements in quantitative measurement of emissions and also in the frequency and transparency of reporting can also play a significant role in the accurate assessment of corporate environmental performance and associated risks.

Table 1. Voluntary Approaches to Differentiate Natural Gas Based on Upstream Methane Leakage

Category	Example	Intended audience	Signal type
Disclosure	Sustainability Accounting Standards Board	Investors	Reports
Standards	EPA's Methane Challenge Program	Regulators	Labeling
Ratings	Independent Energy Standards Corporation	Wholesale consumers	Labeling
Bilateral negotiation	Southwestern Energy and New Jersey Natural Gas	Distribution companies	Certification

Companies can voluntarily commit to meeting standards by joining government programs. EPA has used voluntary standards to reduce methane emissions from the natural gas sector since 1999. The most recent iteration, the Methane Challenge Program, begun under the Obama administration, gives participating companies a choice of complying via either a technology or a performance approach. The former, which builds on EPA's historical Natural Gas STAR program, requires companies to commit to the adoption of best management practices at certain emissions sources using technologies identified by EPA. The latter, based on a recent industry coalition of

5 See **https://www.sasb.org/**.

22 companies from across the natural gas industry called ONE Future, asks companies to commit to a target methane leakage rate, with an overall goal of achieving an average rate of less than or equal to 1 percent across all four subsectors of the natural gas value chain: production, processing, transmission, and distribution. Regardless of which approach a company takes, successful achievement of targets results in announcement of a partnership with EPA and publicity of that company's achievement. However, it does not appear that this public recognition necessarily leads to price premiums or increased market shares downstream.

Companies can also be subject to ratings of their performance. The Independent Energy Standards Corporation (IES) recently created the TrustWell Responsible Gas Program, which rates natural gas wells based on their environmental performance, including a wide array of factors such as methane leakage rates. As of a year ago, 2,500 wells carried this certification (Cocklin 2019). IES has stated that it believes about 25 to 50 percent of natural gas will one day carry its "responsible gas" certification label ("Southwestern" 2018).

Most exciting are trades of low-methane-emitting gas (and perhaps gas with other attributes, such as low water use) between producers and distribution companies. One 2018 trade that has been publicized was between Southwestern Energy and a natural gas distribution company, New Jersey Natural Gas (a subsidiary of New Jersey Resources), whose Marcellus gas was certified by the TrustWell program ("Southwestern" 2018). Unfortunately, the price premium, other than that there was one, has not been disclosed.

The future promises more initiatives along the road to green gas markets. Voluntary efforts by the industry were given a boost with the Natural Gas Sustainability Initiative, supported by a partnership between the American Gas Association and Edison Electric Institute. This voluntary initiative aims to "expand and accelerate industry-wide [sustainability] actions" across the natural gas supply chain (Curry 2019). While it has broad goals, it focuses on calculating and reporting methane emissions intensity at a detailed segment level. Logically, developing an agreed-upon metric is a first step toward certification and rating of gas "greenness," which are necessary steps for market development.

The European Commission has issued a policy framework document describing plans to implement the European Green Deal.[6] The Environmental Defense Fund suggested to the commission that a methane intensity standard be set on natural gas imports and domestically produced gas (EDF 2019). While the EC document is not this specific, it says that "the decarbonization of the gas sector will be facilitated, including via enhancing support for the development of decarbonized gases, via a forward-looking

6 **https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&ved=2a-hUKEwijtriI0YnoAhVB7J4KHQ4SDRwQFjAEegQIAhAB&url=https%3A%2F%2Fec.europa.eu%2Finfo%2Fsites%2Finfo%2Ffiles%2Feuropean-green-deal-communication_en.pdf&usg=AOvVaw09aGzz6zB_1HSyO-mMaohO**

design for a *competitive decarbonized gas market* [italics added], and by addressing the issue of energy-related methane emissions."(pg. 6).

This effort comes on the heels of the Oil and Gas Climate Initiative, in which mostly European companies, but recently joined by Exxon, Chevron, and Occidental, pledged to reach a 0.25 percent methane intensity target by 2025 on their marketed gas.

There may also be regulatory pressure from the United States. Several bills in Congress, such as the Clean Energy Innovation and Deployment Act of 2019, introduced by Rep. Diana DeGette (D-CO), would create clean energy credits for renewable generation, as well as natural gas, and would give extra credit for power generated from natural gas with low methane intensity. If a bill like this became law, it would stimulate certification programs and ultimately formation of a green gas market.

Perhaps the most far-reaching development involves plans to create digital platforms for trading in a variety of green commodities, including natural gas. A start-up technology platform created by Xpansiv Data Systems is a digital marketplace for transacting information-based commodities including the environmental attributes of natural gas, such as methane leakage at production wells. The Xpansiv platform is designed to enable natural gas producers with low methane leak rates, certified by independent parties (e.g., TrustWell certification or Equitable Origin's EO100 Standard for Responsible Energy Development), to differentiate their gas in energy and commodity markets. This allows for the prospect of bilateral transactions involving a variety of consumers, potentially including retail sales.[7]

The rest of this article explores creating a green gas market using a certification and labeling program that differentiates units of natural gas by directly or indirectly communicating underlying leakage rates to industrial and residential customers, which therefore may generate a price premium for participating producers. This would remedy the shortcomings of other approaches, and several community choice aggregators in the United States have already demanded such an approach. The following sections introduce conceptual frameworks that facilitate the exploration of a green market for natural gas, identify potential unintended consequences, highlight opportunities to leverage existing approaches, and offer preliminary advice on how to proceed.

7 The Rocky Mountain Institute is also exploring building certification approaches and green gas markets. See RMI's The Role of Gas in the Energy Transition: Using Data and Markets to Curb Methane Emissions, March 2020. https://rmi.org/insight/the-role-of-gas-in-the-energy-transition/

3. Theory and Results

In this section, we present a series of questions related to the economics, design, and governance of certification and labeling of low-leak-rate natural gas. The market signal could take the form of a qualitative or quantitative rating (the latter expressed as percentage of methane emitted per methane produced). If qualitative, it could be a single- or multiple-tier system (distinguishing low from very low methane emitters, for instance). The market could be voluntarily created by the industry or aided by government regulation. We respond to these questions with a list of design options and our initial assessment of their respective pros and cons based on academic literature, economic theory, and experience with green labeling programs.

This section is organized as follows. We first discuss a suite of economic considerations related to a green market for natural gas. Then we explore specific design issues pertaining to the certification and labeling issues. And finally, we identify key issues pertaining to the governance of the green market.

3.1. Economic Considerations

3.1.1. What are the overall objectives of a green gas market?

A green market for natural gas could achieve multiple objectives. It could serve to market and monetize superior climate performance. It could be used as a tool to obtain a social license to operate, although such a license probably would require improved performance on multiple fronts beyond methane emissions. And it could be used to reduce as many emissions as possible or to meet some overall emissions target.

In our view, the goal of creating a market for green gas is to induce marginal reductions in methane emissions. In other words, the market for green gas must cause additional reductions compared with a counterfactual scenario where the market does not exist. We grant that there are high-performing companies already minimizing methane emissions and that such companies may be able to earn rents (higher profits) from being able to market their green gas that would have been produced anyway. But if that were the sole benefit of a market, it would not improve social welfare by addressing the underlying pollution externality. Rather, the benefits come from incentivizing (1) lower-performing companies to add to their abatement efforts so they can qualify to sell their green gas in the market and (2) higher-performing companies to produce more green gas.

3.1.2. Is there a market demand?

A key question is whether enough demand exists to support a price premium for low-leak-rate natural gas. This demand rests with preferences of various parts of society, including shareholders who want to see their companies become greener, investors who want to put their money into greener companies, industrial users of natural gas who want to burnish their environmental credentials and position themselves for a climate-constrained world, and ultimately consumers, who may demand greener products. For companies supplying natural gas directly to consumers (be they industrial, commercial, or residential), demand may be derived from consumer preferences.

At this time, little organized information exists on the strength of these derived demands. With respect to consumers, we ask how many people may be willing to pay, and how much more they may be willing to pay for low leak rate natural gas. The broader literature sends an overall skeptical message regarding whether consumers would be willing to pay for low-leak-rate natural gas. Morgenstern and Pizer (2007) question whether voluntary programs in industrialized countries lead to price premiums or environmental benefits. Blackman and Rivera (2012) review sustainable certifications for five commodities (bananas, coffee, fish products, forest products, and tourism operations) and find limited evidence that certifications benefit the environment or participating producers. However, natural gas is a new context for eco-labeling, and therefore we aim for more specificity than can be provided by the existing literature.

We suspect that most residential consumers of natural gas would be indifferent without a major publicity campaign. Industrial customers that have residential consumers may see commercial opportunities for marketing "low leak rate" natural gas. Of those who would understand and buy into the implications of methane leaks for climate change, most would be part of either the industry or the environmental community. We could assume the former would support the idea. A fraction of the environmentally conscious population may not be willing to pay a premium because they prefer that fossil fuels be kept in the ground and are therefore inclined to view an eco-rating as greenwashing. Of course, insofar as they consume natural gas, they may still prefer that it emit less carbon. Others may view low-leak-rate methane as a legitimate bridge fuel to a low-carbon future and therefore want to support efforts to reduce emissions. Still others may care about safety and therefore support efforts to reduce methane leaks.

Empirically, we can look to parallels in the voluntary renewable electricity market to inform as to whether consumers may be willing to pay for superior climate performance in the natural gas sector. O'Shaughnessey et al. (2017) find that over 6 million residential customers purchase renewable energy credits, amounting to nearly 7 percent of total residential electricity consumed. If natural gas retail customers behaved similarly, that would amount to a market of 4.8 million consumers, averaging 64,000 cubic feet (cf) consumption annually, for a market size of 307 billion cf (using 2017 data). Between renewable portfolio standards that are pushing utilities to boost their use of renewables and widespread enrollment campaigns, this degree of penetration is probably on the optimistic side.

Regarding the amount consumers might be willing to pay, we can again look to the clean electricity market for parallels. Roe et al. (2001) find that premiums for green electricity offerings range from $102 to $263 per year. Borchers et al. (2007) find a positive willingness to pay of $15 per month for green energy, amounting to roughly 8 percent of a monthly bill and differing by source. Green Mountain Energy Resources, a renewable energy producer, reports having success in marketing green power to residential customers at premium prices ranging from $3 to $12 per month. Summarizing these markets, Bird et al. (2004) write that "product prices vary significantly across programs, but the median premium is around 2.5 cents per kWh." In summary, the experience with electricity markets seems promising.

3.2. Certification

For a market to develop, a process to certify green gas is needed. The certification process can be industry based, government based, or based on third parties, and it can be either paid for directly by industry or paid indirectly into a pool to reduce incentives for capture of certifiers (e.g., auditors).

Certification can be viewed as a means to correct a market failure from asymmetric information. Producers know (or could know) the degree to which their natural gas is being emitted unburned into the atmosphere, but farther down the supply chain, all the way to the ultimate consumers, such information is unavailable. And leaks from downstream segments are similarly known by those segments, but not by segments farther downstream.

We note that producers may not know their methane emissions rates. Costs to obtain such knowledge may be high, and the more stochasticity in the leak process, the higher detection costs will be. Of course, if stochasticity is so high that producers can't determine their leak rates, then the presumed information asymmetry is gone, and there is no basis for a green gas market.

Mason (2011, 2012) provides a theoretical model of the economics of certification. He distinguishes absolute from "noisy" certification. The former allows buyers to perfectly identify compliance with the green standard. The latter is defined as anything less. The model posits green and brown firms subjected to costly certification and permits type I and II errors in classification of their commodity. An extension allows for brown firms to turn green, given the appropriate price signal.

Mason comes to several important conclusions: The less noisy the certification process, the greater the welfare gain. Implementing a certification process raises the price of the green product and lowers the price of the original (brown) product (assuming there is a demand for the green product over and above the original demand). Mason also finds, counterintuitively, that a more expensive certification process can actually increase welfare by screening out brown sellers and raising green seller profits.

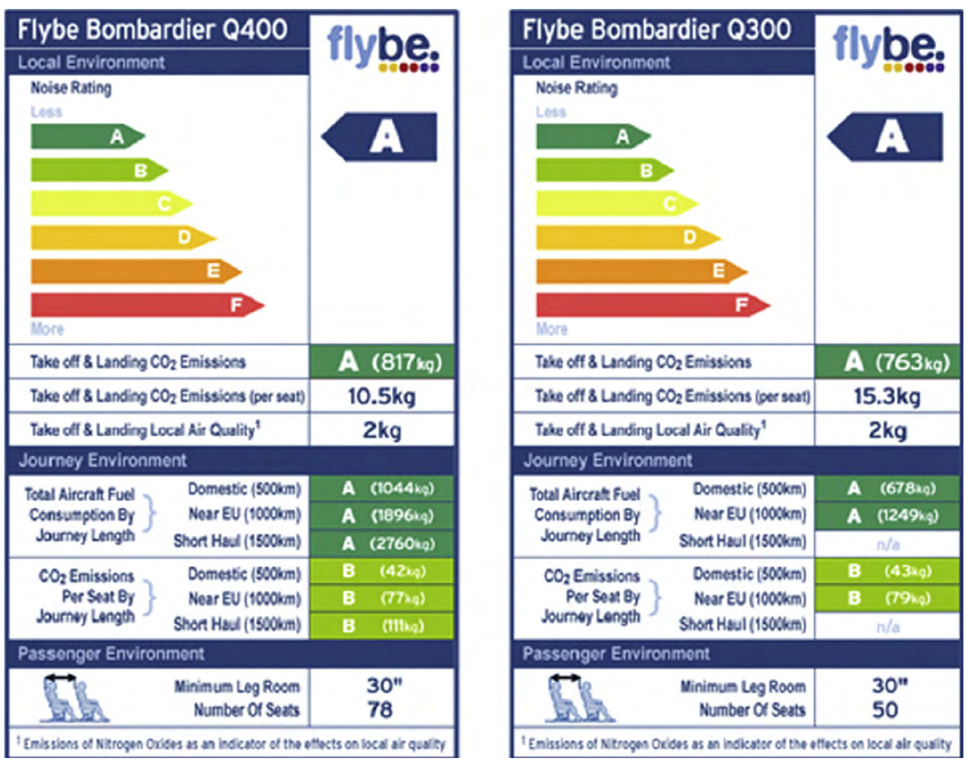
3.3. Design Issues

As part of the certification process, the results must be communicated to buyers. Labeling serves this purpose. This might involve a literal label, such as is found on packages of shade-grown coffee, or an information packet that discusses the green attributes at issue and how well the commodity meets the target or standard. A formal label might be more appropriate for ultimate consumers, while the information packet may be preferable for the (possibly) more sophisticated upstream buyers and industrial users. In the discussion below, we use the term *eco-label* in a broad sense.

3.3.1. How can the eco-label communicate superior climatic performance?

The information that the eco-label provides can be quite nuanced, so long as the environmental attribute to which the eco-label refers is clearly stated and communicated, including how the superior performance was achieved (Baumeister and Onlika 2017; see Figure 1).

Figure 1. Hypothetical Eco-Labels for Airline Industry



Source: Baumeister and Onlika (2017).

For a given eco-label, there are at least two sensible ways to communicate superior climate performance. The first approach involves a label with a qualitative certification that is positive when an entity emits below a benchmark leakage rate. For example, if we assume a benchmark leakage rate of 1 percent, then producers emitting 1.1 or 2.1 percent would not receive certification, while those emitting 0.1 or 0.9 percent would receive a certified label. The second approach involves reporting a quantitative certification of an entity's leakage rate. Thus, a consumer would know that a natural gas producer has a leakage rate of 1.1 percent, for example. Either type of certification could include multiple tiers, such as for low and medium leakage rates. We find academic support for a multitiered system (Fischer and Lyon 2019), because control costs are likely to be heterogeneous, and what are considered to be significant differences in the leak-rate attribute can be identified and communicated by experts.

A related issue is whether brown gas is also scored and reported. One could focus on positive incentives only (that is, every firm that demonstrates emissions below a certain methane leak rate receives certification, termed "blanket certification"), or one could introduce negative incentives as well (that is, the eco-label gives a poor rating to firms that emit over a certain methane leak rate). The literature suggests that using the latter approach, which is referred to as "relative scoring," is superior to blanket certification, prompting both attraction toward superior products and disincentives to purchase and market high-methane-leak gas (Araghi et al. 2014; Grankvist et al. 2004). In another example, Allcott (2011) finds that simply providing a smiley face on the bills of those residential electricity customers who have outperformed the average of their neighbors and not on the bills of those residential electricity customers who have underperformed the average of their neighbors had a significant effect on energy savings. The challenge of relative scoring is that it requires estimates of methane leaks from firms that are unlikely to voluntarily participate in the eco-labeling scheme, given their presumed high rate of leakage. Therefore, a policy mandate or technological advance may well be required to implement relative scoring. However, the time required to create a policy mandate and the benefits of relative scoring may not be as great as starting sooner with a blanket certification that over time lowers its emissions rate for certification.

3.3.2. How should superior climate performance be defined?

Defining superior climate performance for green gas necessitates a benchmark leakage rate (or set of rates for a multitiered system), with the goal of inducing additional methane leak reductions. If one were devising an economically efficient methane regulation, one would want to equalize the marginal cost of abatement with the marginal benefit via a tax or cap-and-trade program. That benefit would equal the social cost of methane. The optimal methane leakage rate would vary by play, topographical conditions, the baseline leak rate (which could depend on corporate culture), and doubtless other variables. Munnings and Krupnick (2017) outline an option for designing a tax on methane emissions from the natural gas sector in the United States.

Use of a benchmark for labeling purposes is farther away from the first-best policy approach, but similar concerns apply. To induce new methane-reducing behavior, there could be one benchmark or many, varying by the most salient factors affecting the marginal costs of reducing leaks. In practice, there are many ways to think about setting the benchmark rate. One is to reference a regulation, such as a performance standard, that limits methane leaks. The federal government would have had several regulations, had the Trump administration not repealed, stopped, and modified those regulatory efforts. Still, some states, such as Colorado and New Mexico, regulate methane emissions from oil and gas operations. But these typically are not based on performance standards (that is, quantity of methane emissions per unit of natural gas). Rather, their regulations require periodic monitoring for leaks and fixing them when found. Ultimately, basing a benchmark on regulations seems practical but idiosyncratic.

Another approach is to use average industry practice, where the benchmark is set to the average of the overall natural gas sector or based on individual subsectors. Recent academic studies (e.g., Alvarez et al. 2018; EDF 2019) contain information that could be used to estimate leakage rates for the overall natural gas sector and individual subsectors. Such estimates could serve as a benchmark.

A separate approach is to adopt an environmental perspective. For example, a benchmark could be set at the natural gas equivalency, from a climatic perspective, to coal, diesel, and oil. Alvarez et al. (2012) and Hamburg (2013) estimate that a leakage rate of 0.8 percent for the entire natural gas sector would achieve this goal. Such an estimate has already informed a voluntary industry effort, ONE Future, which has selected a value of 1.0 percent as a benchmark methane emissions rate for the natural gas sector (because such a benchmark unambiguously favors natural gas over coal as a generation fuel). Twenty-two companies throughout the value chain participate in ONE Future.

Another approach would be to set company-specific benchmarks. Company methane reporting under EPA's Quad O reporting requirements could be used to establish the baseline leak rate, and then beating that performance would earn the green gas label. The Natural Gas Sustainability Initiative mentioned earlier aims to be a more inclusive source of methane leak rates.

A final approach would be to set facility-specific benchmarks. This type of benchmark could be facilitated by platforms such as that run by Xpansiv. For example, a facility could beat its observed historical leakage rates and receive associated credit.

A potential problem with some of these options is that high performers are discriminated against, and buyers could get green gas from some producers with emissions rates exceeding the benchmark of other producers. It should also be noted that the definition of superior climatic performance will be made by some subset of stakeholders, underlying the importance of considering who should be involved in making this decision, which implies some level of normative judgment.

3.3.3. How should leak rates be measured?

The difficulty of accurately measuring methane emissions is apparent in a recent explosion of academic literature on this topic. Understanding the full range of measurement technologies is crucial for market development, since it is imperative to accurately measure leaks in order to manage them, and the measurement technology that ends up being used will inform other design choices. For example, preferences over benchmark leakage rates may inform preferences over measurement technologies, and vice versa. Preferences over the scope of the label present similar relationships. This section reviews four categories of methane emissions measurement technologies, starting with the simplest and ending with the most novel.

The simplest approach would use default emissions factors calculated by EPA as a starting point for “measuring” methane emissions. For example, a well may produce 100 tons of natural gas, using a certain number of different equipment types, each with an assigned default emissions factor. These emissions factors can be adjusted based on various types of mitigation technologies that the well owner may or may not have installed. The result would be an estimate of methane emissions, which can be divided by the well’s throughput to calculate that well’s specific leakage rate. It is possible that EPA’s default emissions factors have high levels of uncertainty and significantly underestimate actual methane emissions (e.g., Alvarez et al. 2018). Moreover, activity factors tracked by EPA, which are statistics that include numbers of each type of equipment, are thought to be inaccurate and depend on the industry subsector.

Another approach is to use a suite of remote-sensing technologies (contained in satellites, airplanes, drones, and trucks) to directly measure methane emissions at a relatively disaggregated scale depending on the technology used. In recent years, the Environmental Defense Fund has been funding and researching such technologies, offering the prospect of more accurate estimates of methane emissions. Currently, this suite of technologies yields estimates of methane emissions with improved accuracy (compared with EPA’s activity and default factors) at relatively disaggregated scales, depending on the size and density of the methane plume, and further disaggregation is anticipated with advances in technology. These top-down approaches have the advantage of providing a more rapid assessment of broader operations, lowering the cost, but they can lack the sensitivity of ground-based assessment.

Another, more speculative approach would be to directly calculate methane emissions from each unit of produced natural gas. For instance, the Xpansiv platform combines primary and secondary data with independent standards to generate and transact environmental attributes (including methane emissions) for each unique unit of natural gas produced by a well. However, this calculation relies on both the willingness of well owners to share their production data with Xpansiv and the high quality and fidelity of these data. So far, the owners of at least 2,500 wells have shared their data. More narrowly, the Obama-era EPA had been considering requiring use of hand-held monitoring devices to periodically monitor on site leaks as part of its methane regulatory activities.

One could imagine an integrated approach where traditional emissions factor methods, although generalized and static, could establish a basis for an inventory. This inventory could then be augmented with remote-sensing measurement approaches, which quantify emissions events. However, they can miss intermittent releases because these technologies are not operated continuously. Approaches that allow for the direct and continuous measurement of production data can fill in the gaps by detecting and quantifying intermittent releases. Additional research is needed to operationalize an integrated approach.

Table 2 presents a qualitative categorization of the three measurement technologies according to accuracy (the technical capability of the technology to accurately estimate methane leakage rates), cost (the financial cost of operating these technologies), scalability (the likelihood of achieving high market penetration), and practicality.

Table 2. Comparison of Measurement Technologies for Methane Leakage Rates

Category	Remote sensing	Emissions factors	Unit-specific
Accuracy	Medium	Low	Uncertain
Cost	Medium	Low	High
Scalability	High	High	Low to medium
Practicality	Low to medium	High	Low

The traditional factor-based approach is the least accurate (a growing body of research finds that EPA tends to underestimate methane emissions), yet it is the most practical, in part because cost is low and scalability is high (given that default emissions factors already exist). The EPA Methane Challenge ONE Future option is an improved method, as it includes additional potential sources of emissions. A remote-sensing approach can provide an improvement in accuracy, but the required equipment is advanced, and therefore this approach comes with price, and possibly practicality penalties. The unit-specific approach described above generates more questions than answers, and thereby draws a designation of low practicality. Lower costs would lead to higher scalability, although the extent of market penetration would be limited to medium at best, given that producers must opt in, and presumably, under a stringent standard, not all producers would meet the requirements for producing low-leak-rate natural gas. Finally, the accuracy of this approach has not been tested by third parties. Ultimately, we conclude that the emissions factor approach alone, while offering several advantages, currently comes with the critical flaw of significantly inaccurate emissions estimates. This motivates a focus on further development of the other approaches, while exploring the benefits of a combined integrated approach that can significantly increase integrity though the layering of multiple methodologies.

One clear next step is to assess the accuracy of all approaches. The integrated approach implies the potential for simultaneous and continuous study that measures a producer's methane emissions using all three techniques. Ideally, results would be made public. If the emissions factor approach aligns with estimates from the unit-specific approach, then that would be evidence that the accuracy of the latter is high or at least in accordance with cutting-edge technology backed by academic research.

Another step would be to explore potential synergies between measurement approaches. For example, if we assume that a unit-specific approach is highly accurate, then the problem remains that only producers willing to share their private information would decide to opt in to the market for green gas. For these producers, remote sensing might be used to estimate methane emissions. Remote sensing might also be used to provide an eco-rating for producers that have not opted to participate in the market for green gas; in other words, poor performers could also receive an eco-rating via the remote-sensing approach.

The Natural Gas Sustainability Initiative, mentioned earlier, aims to improve reporting of methane emissions intensity, defined as methane emissions divided by throughput. The reporting framework leverages the existing inventories created by EPA and creates additional standards for participating companies to follow (AGA 2019).

3.3.4. How can the market avoid perverse incentives and unintended consequences?

A smooth market for green gas would need to handle two issues: adverse selection and moral hazard. The particular pathway through which these phenomena might occur depends on the type of benchmark selected, among other issues. We outline illustrative concepts and examples here.

Adverse selection refers to potential miscertification based on information asymmetry, where the certifier has less information on performance than the entity being certified. For example, a certifier may award a certification even though a firm put in no additional effort to achieve superior performance (type I error) or may fail to award a certification even though a firm put in additional effort to achieve superior performance (type II error). The underlying information asymmetries may be technical in nature (e.g., measurement error) or behavioral (e.g., deliberate manipulation or withholding of information from the producer). One challenge for a certification program is whether the relevant standard can be met instantly by some of relevant companies. Avoiding adverse selection helps ensure that certified producers take action that they would not have otherwise taken without the award of the certification.

However, some degree of adverse selection may be warranted to reward early actors and incentivize early adopters. A balance should be struck between the two trade-offs of environmental performance and credit for early action. Strategies for avoiding adverse selection depend on the specific context. For a firm-level or company-level benchmark design, for example, participants might be required to share historical data on leakage rates and to do significantly better than historical performance to qualify for certification. Such a strategy would be more difficult to implement for industry-level benchmarks. In this case, if participation rates are deemed too high to signal environmental improvements, then benchmark rates could be dynamically adjusted—although the precise algorithm for this would be a topic for future research.

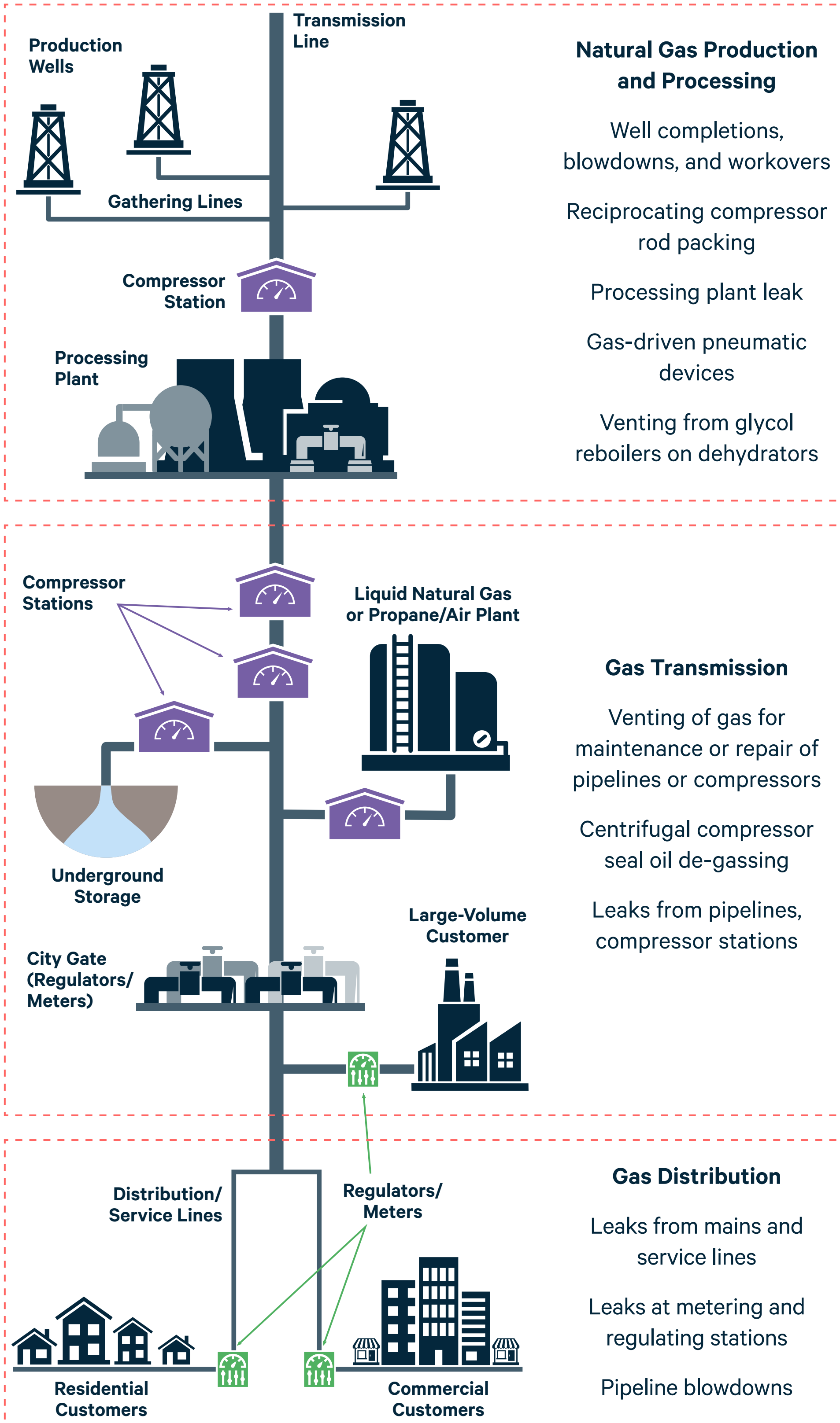
Moral hazard refers to incentives provided to producers to intentionally manipulate their performance to attain certification. Wara (2008) identifies moral hazard in the context of the Clean Development Mechanism, describing a case where the program rules were announced *before* the time period during which benchmarks could be influenced by production, giving a particular type of offset project the opportunity to inflate its benchmark by artificially inflating production. In the context of natural gas, insofar as historical data is used to determine a benchmark rate, participants ideally should not know about the opportunity to participate in the certification program. Barring this possibility, a larger set of historical data and the application of statistical methods (e.g., a difference-in-difference regression pegged to the announcement of the certification program) may be useful in detecting or preventing moral hazard.

3.3.5. What is the scope of the market?

We define scope in two ways: stages of the natural gas value chain and jurisdictional extent. Regarding the first, the discussion so far has focused on the production stage of the natural gas value chain (see Figure 2). Here we consider whether other stages of the life cycle—processing, transmission in major pipelines, and distribution to consumers—should be included in the market system. In principle, wider coverage of the natural gas value chain would be better, since it could give final consumers a more comprehensive understanding of the methane emissions associated with their purchasing decisions.

At the outset, though, there is a potential trade-off between accuracy and coverage. For example, Hausman and Muehlenbachs (2019) find that data on methane emissions from the distribution sector is particularly unreliable, given that around 30 percent of reported information indicates more gas coming out of the lines than going in, which is physically impossible. A practical approach would be to certify natural gas subsectors for which reliable data exist and assume that downstream portions of that value chain emit at an average rate. However, in this case, the incomplete coverage of the certification program should be clearly communicated, and this may drive certain customers away at first. That said, a natural progression could occur over time, with the customer base changing as accuracy of data improves. For example, the initial customer base may be transmission line operators choosing the production facilities from which to source their natural gas. When data on methane emissions for these pipelines improve, then perhaps utilities would use certification to source their purchases. And finally, when data on methane emissions for distribution lines improve, then perhaps final commercial and residential customers may be attracted to the market. A single eco-label could be used to communicate which portions of the natural gas value chain are covered by the overarching certification for different transactions.

Figure 2. Natural Gas Value Chain



Source: Adapted from ICF (2014) by RFF staff

As for the appropriate geographic extent of a green gas market, we can envision several scenarios: a single national market, markets for gas from given plays, or state-level markets. State-specific markets would have obvious advantages over a market that includes multiple jurisdictions in that a given state's regulations could provide a less ambiguous baseline for judging superior performance. The main problem is that pipeline transmission (and sometimes distribution) networks cross state lines. So that consumers can be certain that their purchased natural gas is green, there should not be ambiguity about the product source. Impossibly close examination of natural gas distribution systems would need to occur for each subsector to be monitored and compared, an observation that favors a national scope.

3.3.6. How should existing regulations be factored in?

One pervasive issue is whether to certify a unit of green gas if a regulation already mandates or encourages low leakage rates. Differences between regulations could occur at the national and regional levels (e.g., National Ambient Air Quality Standards) or at the state level (e.g., stringent regulations in Colorado versus those of another state). The simplest approach would be to disregard the regulations and certify gas based on performance rather than causes of performance. However, this may amount to adverse selection to some extent, insofar as producers that were already achieving low leakage rates would receive certification.

3.3.7. How should nonparticipants be treated?

Platforms like Xpansiv are enabling the tracking of granular data for companies willing to participate in certification programs. While these data are not public, they are perhaps verifiable by a third-party auditor. The question is what to do with firms that do not want to participate in a certification program.

So far, we have assumed that nonparticipating entities would be able to keep their individual methane leakage rates private, not disclosing them to the regulator, other producers, and consumers. However, potential policies and technological advancements may allow for accurately estimating methane emissions of nonparticipants. A simple solution, which may not be possible without legislation, would be for EPA to disclose estimates of methane emissions for each producer not participating in the eco-label program, based on default activity and emissions factors or its Quad O submissions.[8] Alternatively, remote sensing by governments or private groups might provide more accurate estimates of regional methane fluxes, which could inform a default leakage rate for certain production regions that opt in. Entities could then outperform by, for example, employing a more novel measurement approach, including distributed sensors or the Xpansiv platform.

8 EPA does this at the facility level under its Greenhouse Gas Reporting Program (**https://www.epa.gov/ghgreporting**)

3.4. Governance of the Green Market and Certification

3.4.1. Who should create the market?

In determining whether industry or government should take responsibility for market creation, one must consider multiple issues. First is the justification for government intervention. While firms have some incentive to reduce methane leaks (where the value of the captured gas exceeds the cost of finding and fixing the leak), that value is far below the social value of reducing methane (i.e., the social cost of methane). As methane is a powerful greenhouse gas, this value has been estimated by over the USEPA (Marten and Newbold, 2012) $1,100 per ton, relative to a social cost of carbon of $42 per ton.9 However, we would not expect consumers to be willing to pay this kind of a premium. So, in the absence of a traditional government regulation on methane, and assuming consumers' willingness to pay is below the social cost of methane, a government-sponsored market creation for green gas might be defensible as a method to help internalize this externality.

More generally, the extent of government involvement could range from playing no role at all to being critically involved at each step. It is feasible that an industry-run coalition could define a benchmark and provide certification and verification, but perceived credibility may be low, and in practice, third-party certification and verification are common. The government could perhaps limit its involvement to defining the benchmark—similar to definitions for organic products—and leave certification and verification to industry. Regarding the definition of the benchmark, the government could play a variety of roles. It could write prescriptive and lengthy benchmarks (similar to compliance carbon offsets in California) or define a benchmark and allow industry to propose prescriptive elaborations of that benchmark, subject to government approval (as is done by the low-carbon fuel standard in California). Given the uncertain nature of methane emissions and the growing academic literature on this topic, it would likely be useful to have some government involvement in a green gas certification program. Another possibility is that industry could take the initiative, with government involvement only if the industry-driven market has major issues.

3.4.2. Who should participate in the design process?

Whether industry or government is the prime mover in creating the green gas market, other interested parties could participate in the design process. Would that be wise? The literature suggests that the participation of many stakeholders is important for the design process, as it can avoid controversy, improve the benchmark decision, and enhance overall credibility (e.g., Balzarova and Castka 2012; Thogersen et al. 2010).

9 **https://www.epa.gov/sites/production/files/2016-12/documents/social_cost_of_carbon_fact_sheet.pdf**. The Trump administration has dramatically reduced these numbers by basing them on damage to the United States rather than globally.

While it is difficult to pin down which specific stakeholders ought to be involved, it seems obvious that the participation of researchers and nonprofits that have been working on detection of methane leakage would be essential.

3.4.3. Who would certify performance?

A key element in constructing the green gas market is who certifies performance, as it goes to the credibility of the program to potential consumers. There are generally three options for who certifies: (1) self-certification by the operator, (2) certification by a regulating agency, or (3) third-party certification by engineering firms, consultants, or others. Self-certification has the advantage of being very easy to implement, but it may suffer from credibility problems with the public and industrial and utility consumers. Closely related would be a third-party audit program where the auditors are paid by the firms they audit (see below). EPA's continuous emission monitoring system (CEMS) for electric utilities was set up by the agency and is largely autonomous, except for a required audit of the accuracy of the system every year, paid by the utility. Some researchers have stressed the importance of third-party verification (e.g., Chkanikova and Lehner 2015). Given the technological challenge of accurately estimating methane leaks off-site, it may be difficult (barring technological advances) to find a third party that could reliably audit producers without on-site access. Audits could be performed by statistical sampling of specific sites using on-site surveys, however.

3.4.4. How would certifiers be paid?

In general, there are three options for how certifiers would receive payment: (1) from the operator, (2) from the government, or (3) from a third party. Duflo et al. (2013) provide compelling evidence (although for India) that when regulated firms pay auditors, the auditors tend to underreport emissions. Rather, payments from the government directly to the auditors (after collecting funds from industry) incentivized truth-telling. Short and Toffel (2016) summarize much of the literature on third-party monitoring, including in the contexts of smog checks, global supply chains, and the financial sector. Based on their findings, Short and Toffel advise against verifiers being paid directly by the firms they verify. Banerjee and Solomon (2003) find that government-administered programs are more successful, in general, than private programs in the content of energy efficiency and renewable energy.

Given the above, we suggest that a fixed administrative cost could be assessed on every opt-in firm, then pooled and used to fund a third-party auditor at arm's length from any one market participant. The government could be involved at various points in the funding and auditing process. The trend under the current administration has been to remove such involvement, however. The rollback of the Obama administration's well-control rule by the Department of the Interior in spring 2019 removed the government from its role of certifying the certifiers, leaving that to industry (DOI 2019).

3.4.5. What should be the frequency of certification?

Frequent certifications are ideal because methane leakage rates vary temporally. Bottom-up, emissions factor measurement approaches update quite infrequently. Top-down, remote-sensing measurement approaches could update more frequently, but at a significant cost. A unit-specific approach would provide automatic and continuous certification, although accuracy and costs are uncertain at the moment.

4. Summary and Conclusions

The extent of methane emissions from the natural gas sector in combination with the relative dearth of regulations to identify and abate these emissions motivates the consideration of creating a market for green gas, defined in terms of methane emissions from natural gas development.

The academic literature estimating the willingness to pay for green electricity and recent transactions of low-leak-rate natural gas suggest that producers or firms elsewhere in the value chain can indeed secure a premium for selling green natural gas. Such premiums could facilitate additional reductions in methane emissions from producers.

To motivate market transactions, a number of issues must be addressed: (1) The "greenness" of the natural gas needs to be identified, and this information should be communicated clearly. Our review of the academic literature suggests that if labeling is used, a single, multitiered label would be preferable. (2) Superior climate performance needs to be defined, with pros and cons associated with various definitions. Emissions need to be credibly measured or estimated. (3) New technologies for measuring emissions offer the prospect of improvements but must be further vetted through independent studies. (4) The scope of the market needs to be defined. Ideally, to create incentives for better performance from nonparticipants, their methane emissions should also be reported. Yet given current challenges in measuring methane emissions, further advances in policy or technology would be needed to collect and publicize this type of data. (5) The market should be designed with adverse selection and perverse incentives in mind to avoid unintended consequences.

Governance issues are also important, although the literature provides little guidance. Verification by third parties with no direct financial link to the underlying companies or certification body appears to be ideal, although an indirect financial link should not derail such an effort. If industry could achieve this on their own, so much the better, as we want the transaction costs to be minimal so the market can develop more fully and quickly. Intervention from government is always a possibility, if necessary.

Finally, we note that the definition of *green* in this paper—limited to low methane emissions—could be broadened to include low or net-zero water use or could be defined to focus more on CO_2 over the value chain. Markets for green oil or even industrial products, such as cement, could also be developed.

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