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FACT SHEET

The Promises and Limits of Biomethane as a Transportation Fuel

HIGHLIGHTS

As California explores strategies to reduce global warming emissions from transportation, there is interest in using methane generated at landfills, wastewater treatment centers, and dairies to fuel heavy-duty vehicles. While "biomethane" from waste has climate benefits, it is limited in supply. Biomethane can be used as a direct replacement for natural gas in vehicles, yet policymakers must not conflate the two fuels because they have significantly different life cycle emissions. A large shift to natural gas–powered heavy-duty vehicles with a limited amount of biomethane could increase California's reliance on natural gas and undermine the state's climate goals.

Methane is a potent global warming gas—34 times more powerful than carbon dioxide at trapping Earth's heat over a 100-year period (Myhre et al. 2013). Methane comprises nearly 10 percent of California's total global warming emissions. About half of the state's methane emissions come from decomposing organic waste at landfills, wastewater treatment centers, and dairy farms[1] (CARB 2016a; CARB 2016b). Methane derived from these sources—also called **biomethane**—goes largely uncaptured today but could be used to reduce the consumption of fossil fuels.

Natural gas and biomethane both consist primarily of methane and can be used interchangeably (see Box 1, p. 2). They differ in their source—natural gas coming from ancient plant and animal matter decomposed beneath Earth's surface and biomethane coming from the decomposition of present-day plant or animal matter. Biomethane can be produced under controlled environments (e.g., an anaerobic digester at a wastewater treatment center) or non-controlled environments (e.g., a landfill) (Babson 2015).

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Decomposing waste at landfills—as well as at wastewater treatment centers and dairies—generates methane gas. While reducing waste overall should be a priority for California, methane from these sources can be harnessed and used to displace fossil fuels.

BOX 1.

Natural Gas and Biomethane Terminology

Biogas is the mixture of gases produced from decomposing organic matter in the absence of oxygen (i.e., anaerobic conditions); it consists of methane (50 to 75 percent), carbon dioxide (25 to 50 percent), and trace amounts of other gases. Occasionally, biogas refers to the product of gasification of biomass, but this is more commonly known as "syngas" (see Box 2, p. 3). **Biomethane** and **renewable natural gas** (RNG) both refer to biogas that has been purified ("upgraded") to pipeline-quality natural gas (95 to 98 percent methane), and can be used interchangeably with natural gas.[3] **Landfill gas** is biomethane or RNG derived from landfills, which are the largest existing and future source of biomethane from waste streams (CARB 2017b; NREL 2013). **Compressed natural gas** (CNG) refers to either natural gas or biomethane that has been compressed in fuel tanks under high pressure. As a transportation fuel, CNG has been used mainly in fleets due to limited fueling infrastructure.

[Biomethane from waste in California could meet just 3 percent of the state's demand for natural gas.]

Biomethane offers an important pathway to reduce the climate impacts of landfills, wastewater treatment centers, and dairy farms. There is a critical need, however, to more responsibly manage organic waste and reduce the amount of waste generated in the first place. While not the focus of this fact sheet, there are also significant public health and environmental consequences of landfills and large dairies that are not mitigated through methane capture.

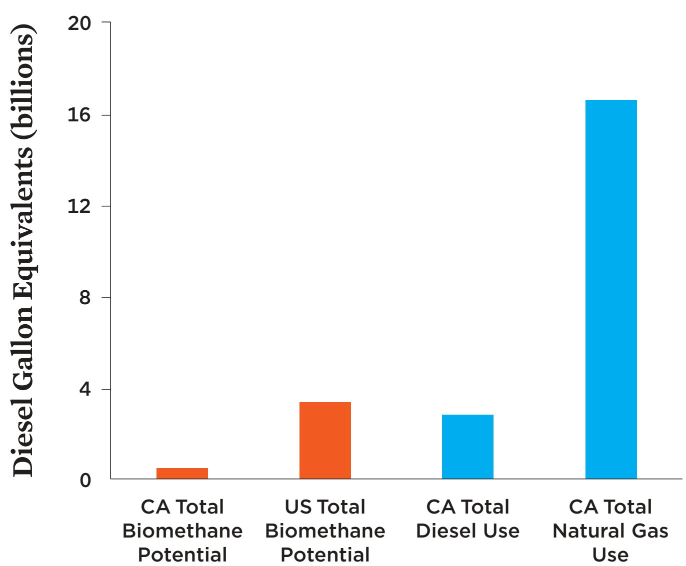
Not Enough Supply to Meet Demand

There are potentially 450 million diesel gallon equivalents (dge) of biomethane available per year from landfills, wastewater, animal manure, and other sources of industrial and commercial waste in California (NREL 2013). This sounds like a lot, but if biomethane were captured from all potential sources of organic waste in California, the resulting supply would meet approximately 3 percent of the state's demand for natural gas (Figure 1) (EIA 2017; NREL 2013).[2]

Biomethane used in compressed natural gas (CNG) vehicles is being proposed as an alternative to diesel, with proponents advocating for increased adoption of CNG trucks and buses in public and private vehicle fleets. Biomethane generated from California's waste resources, however, could meet just 15 percent of the state's diesel consumption, assuming the biomethane were used exclusively for transportation. Meeting California's total diesel demand would require all of the potential waste-based biomethane from across the United States (Figure 1; and Box 2, p. 3) (CBOE 2017; NREL 2013).

As both California and the United States reduce their use of fossil fuels, sectors already reliant on natural gas could

FIGURE 1. Availability of Biomethane from Waste Compared with Diesel and Natural Gas Use in California

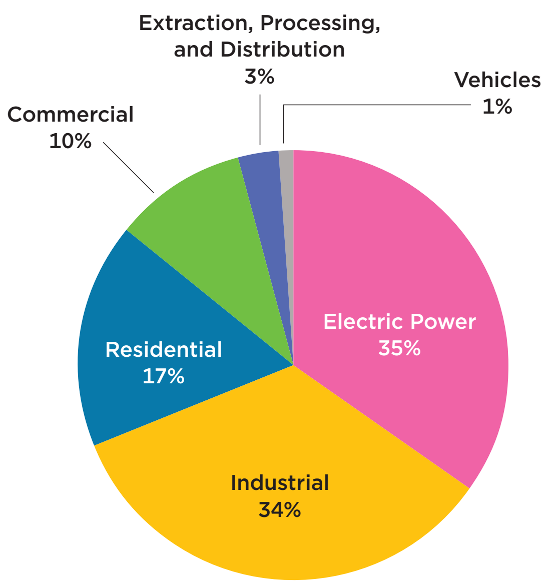


The amount of biomethane potentially available in California is much smaller than the amount of diesel and natural gas used in the state.

Note: Biomethane potential includes sources of waste and not other types of biomass. California diesel and natural gas use refer to consumption in 2015.

SOURCES: NREL 2013 (BIOMETHANE), CBOE 2017 (CALIFORNIA DIESEL), EIA 2017 (CALIFORNIA NATURAL GAS).

FIGURE 2. Natural Gas Consumption by Sector in California, 2015



Transportation consumes little natural gas compared with other sectors in California. These other uses could compete with vehicles for the limited supply of biomethane.

Note: Industrial uses of natural gas include as a chemical feedstock (e.g., fertilizer production and petroleum refining) and as a source of heat for melting, baking, and drying manufacturing products (e.g., steel, food, paper) (EIA 2013). Commercial and residential uses of natural gas include space and water heating; cooling and refrigeration equipment; and non-electric clothes dryers and stoves. Extraction, processing, and distribution refer to natural gas used throughout the production and delivery of the fuel (e.g., drilling equipment, compressors).

SOURCE: EIA 2017.

BOX 2.

Can Gasification Help Increase Biomethane Production?

Reports claiming biomethane can provide large amounts of fuel rely on widespread "gasification" of biomass resources beyond waste at landfills, wastewater treatment centers, or dairies. Gasification is a process that involves heating biomass to high temperatures to form a mixture of gases consisting mostly of hydrogen and carbon monoxide. This mixture, commonly called synthetic gas or "syngas," can be used to generate electricity, as a source of hydrogen gas, or for other industrial processes. With additional chemical processing, syngas can be converted to methane.

The amount of biomethane available from gasification of biomass is potentially larger than the amount available from the decomposition of organic waste, but is still equivalent to just 2 to 15 percent of the total annual natural gas consumption in the United States (NPC 2012), depending on the assumptions of what is technologically and economically practical. High-end estimates of biomethane from gasification rely on dedicated energy crops, diversion of biomass from other uses, and forest harvesting, all of which have been controversial decisions historically.

compete for the limited supply of biomethane, let alone sectors such as transportation that currently use very little natural gas (Figure 2). The industrial sector, for example, is one of largest users of natural gas in California and alternatives to natural gas are less readily available in this sector compared with others (EIA 2017; EIA 2010).

Like any new source of fuel, reaching the amount of biomethane potentially available from waste will occur over many years. Economic and policy factors will both influence the rate of biomethane development. Increasing biomethane production will require improvements in waste disposal and handling (to divert more organic waste, such as food scraps, to dedicated facilities); installation of equipment to generate biogas and upgrade it to biomethane; and build-out of infrastructure to use the gas on-site or distribute it by pipelines or tanker trucks. Given these and other factors, biomethane is generally more expensive to generate than extracting conventional (i.e., fossil) natural gas (Jaffe et al. 2016). Also, while biomethane is limited in supply, availability of natural gas has greatly increased in recent years as a result of hydraulic fracturing ("fracking") of shale formations (EIA 2016).

Given the limited quantity of biomethane potentially available compared to demand for natural gas across sectors (CARB 2017b; EIA 2017; NREL 2013), policymakers should be realistic about biomethane's potential to meet the needs of more than a small fraction of heavy-duty vehicles. Increasing the number of CNG vehicles in California could ultimately increase the state's consumption of natural gas—making it harder to meet climate targets (Deyette et al. 2015).

[Policymakers should be realistic about biomethane's potential to meet the needs of heavy-duty vehicles.]

BOX 3.

Life Cycle Emissions and "Negative" Emissions Credits

The specific emissions benefits of biomethane from landfills, wastewater treatment centers, or dairy farms—whether used directly in a CNG vehicle or to power electric vehicles—arise from the amount of emissions avoided compared with the original fate of the gas, which varies with the source. Avoided emissions are reported under the California Air Resources Board's (CARB's) Low Carbon Fuel Standard, which assigns life cycle emissions to different transportation fuels (CARB 2016c). Life cycle emissions include those from the production of the fuel ("upstream" emissions) and use of the fuel ("tailpipe" emissions).

CARB credits avoided upstream emissions with negative values. If the negative credit is large enough, it can completely offset—or even exceed—the tailpipe emissions of using biomethane in a CNG vehicle, resulting in "negative" *life cycle* emissions. This is the case in biomethane from dairy manure, which has significant negative upstream emissions (CARB 2017b).

Landfills are required to capture and flare (burn) methane. Flaring converts methane into carbon dioxide, which traps less heat than methane and results in a lower global warming impact than if the methane were released directly into the atmosphere. Dairies, however, are not required to capture and flare methane, so biomethane from dairies results in much larger avoided emissions than biomethane from landfills.

California will require dairies to control their methane emissions as soon as 2024 (per Senate Bill 1383). When these requirements take effect, biomethane from dairies will not receive as large of a negative upstream credit. In the meantime, the large negative credit provides a significant, if temporary, incentive for dairies to install methane pollution controls sooner than they would otherwise be required by law.

The Benefits of Biomethane Depend on How It Is Used

In vehicles, natural gas provides limited climate benefits compared with diesel (Chandler, Espino, and O'Dea 2017; Cohan and Sengupta 2016; Camuzeaux et al. 2015; Tong, Jaramillo, and Azevedo 2015; Hesterberg, Lapin, and Bunn 2008). Biomethane, however, offers measurable climate benefits compared with these conventional fuels (Figure 3, p. 6).

Because they have the same chemical composition (i.e., methane), biomethane combusts the same as natural gas. As a result, there are no benefits of using biomethane compared with natural gas at the point of combustion (i.e., the tailpipe of a vehicle). In addition, nearly all biomethane production certified by the California Air Resources Board (CARB) is from out-of-state sources. This biomethane is injected into pipelines and mixed with much larger volumes of conventional (fossil) natural gas (CARB 2017b). Unless biomethane is generated and used on-site, actual molecules of biomethane are not directly consumed by those purchasing biomethane, similar to contracts for other types of energy.

Emissions benefits of biomethane come from reduced "upstream" emissions—those associated with fuel extraction, production, and/or distribution (e.g., powering drilling equipment or gas compressors). Upstream emissions are lower for biomethane than natural gas because its use offsets emissions from landfills, wastewater treatment centers, and dairy farms (Box 3).

While biomethane generates lower global warming emissions than natural gas when used in CNG vehicles, it produces even lower emissions when used to make electricity or hydrogen for battery or fuel cell electric vehicles (Figure 3, p. 6).[4] This is due to the greater efficiency of electric vehicles and natural gas power plants compared with CNG vehicles (DOE 2015). Likewise, using biomethane to power battery and fuel cell electric vehicles results in lower emissions of smog-forming nitrogen oxides (NO_x) than using biomethane directly in a CNG vehicle (Figure 4, p. 7).[5]

As many fleets explore different technologies to reduce their climate impacts, an important comparison is the emissions of CNG vehicles fueled by biomethane with electric vehicles powered by the grid. Despite the climate benefits of biomethane compared with natural gas, battery electric vehicles powered by *today's grid* provide 30 percent lower global warming emissions and 20 percent lower NO_x emissions than low-NO_x CNG vehicles fueled with biomethane from landfills. As California's electricity sources become even cleaner, the benefits of grid-powered electric vehicles will become even greater. This underscores the importance of shifting heavy-duty vehicle fleets away from diesel and natural gas and toward electric vehicles. Electric vehicles are becoming increasingly available across the heavy-duty sector, with transit buses and delivery trucks showing the greatest deployment to date (Chandler, Espino, and O'Dea 2017).

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Manure from dairy farms generates a significant amount of heat-trapping methane. Capturing methane from dairies and other sources helps keep the potent global warming gas out of the atmosphere and can also offset use of conventional natural gas.

It is important to note that once biomethane is generated and injected into a natural gas pipeline, its environmental impacts parallel those of natural gas. Small leaks throughout the natural gas distribution system, and catastrophic leaks such as the one in Aliso Canyon,[6] can erode any climate benefits associated with using methane as a fuel. Strong state, federal, and utility standards are critical to monitoring and minimizing methane leaks at all stages of production and transport.

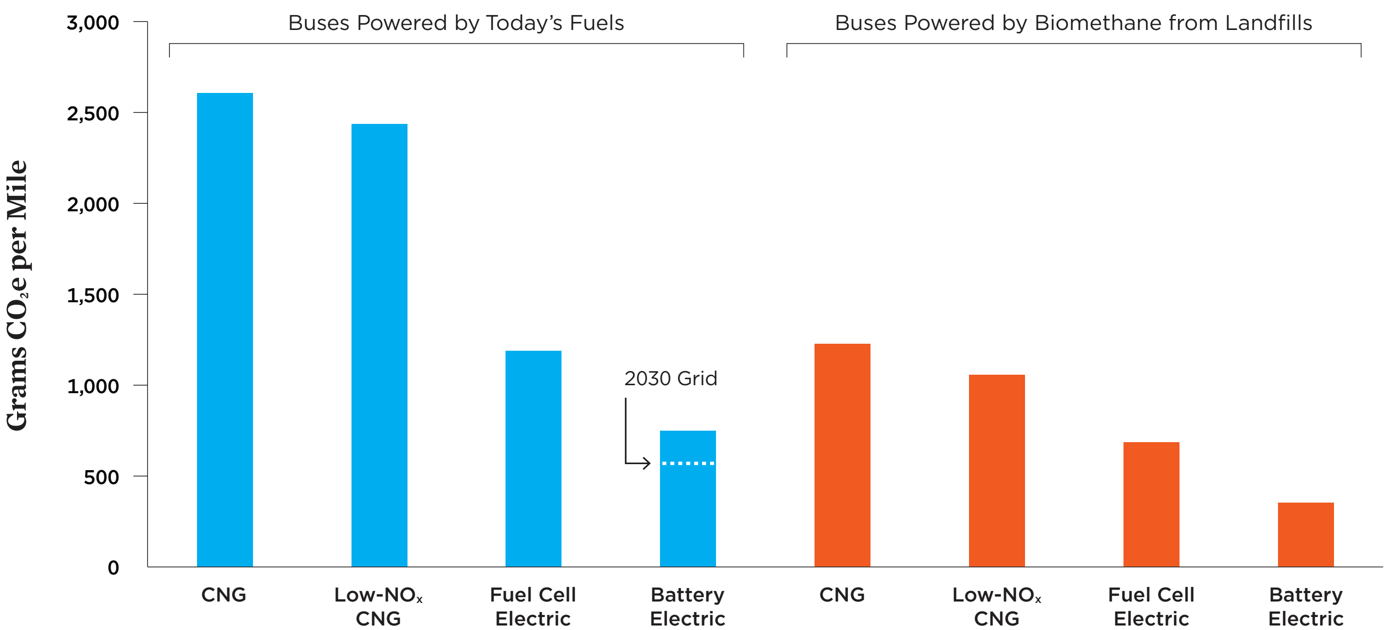
> ***Small leaks throughout natural gas pipelines can erode any climate benefits associated with using methane as a fuel.***

Conclusion

Capturing methane from waste streams and using it in place of natural gas—whether for CNG vehicles, electricity generation, or hydrogen production—keeps a potent global warming gas out of the atmosphere and can reduce fossil fuel consumption. Sources of waste are limited, however, making it critical to implement policies and incentives that encourage biomethane production without encouraging greater use of natural gas. Increasing consumption of natural gas in the transportation sector is not a solution for significantly reducing climate emissions.

The best approach to meeting climate goals is to promote the wide-scale adoption of battery and fuel cell electric vehicles while continuing to decarbonize all transportation fuels. Electric vehicles are becoming increasingly available in heavy-duty applications, where they can make a significant dent in transportation-related emissions. With zero tailpipe emissions and the potential to be powered by plentiful sources of renewable energy like wind and solar, electric vehicles provide the greatest benefits for California.

FIGURE 3. Life Cycle Global Warming Emissions from Transit Buses, by Vehicle and Fuel Type



Biomethane generates the lowest carbon emissions when used to produce electricity or hydrogen for battery and fuel cell electric vehicles. Battery electric vehicles on today's grid also have lower global warming emissions than low-NO_x CNG vehicles fueled with biomethane.

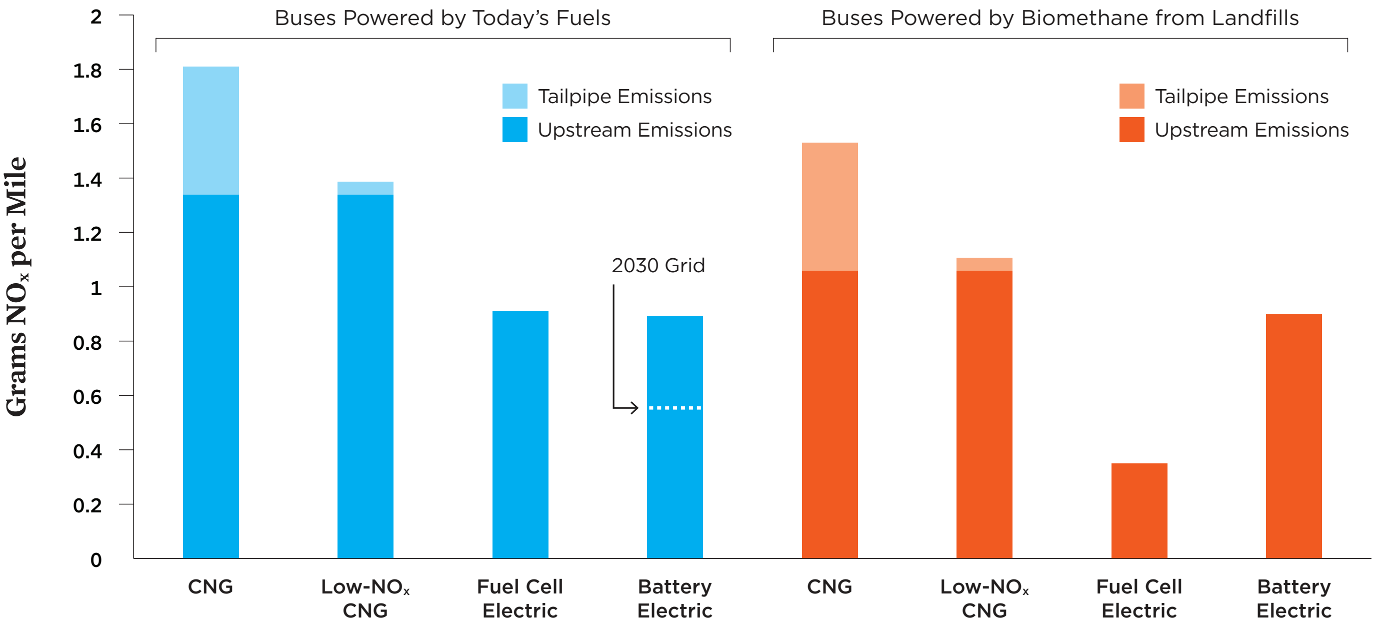
Notes: CO_2e stands for carbon dioxide equivalent. Bus-related emissions are a representative example of emissions from other heavy-duty vehicles. Electricity emissions are based on the 2016 grid mix in California; hydrogen emissions assume 33 percent is generated using renewable energy (per Senate Bill 1505). Biomethane emissions are based on landfill gas, as it is the predominant source of biomethane consumed in California (CARB 2017b). The dashed line indicates emissions from a battery electric bus using an estimate of California's grid mix in 2030; it assumes 50 percent of electricity comes from renewable energy (per Senate Bill 350) and 50 percent of electricity comes from natural gas power plants. This represents a conservative estimate of California's future sources of electricity. Life cycle emissions include those from fuel production ("upstream") and fuel consumption ("tailpipe").

SOURCE: CHANDLER, ESPINO, AND O'DEA 2017.

Foothill Transit

While biomethane can directly replace natural gas in heavy-duty vehicles, it can also be used to generate electricity or hydrogen for battery or fuel cell electric vehicles (such as the electric bus shown here). This results in greater carbon emissions reductions, due to the higher efficiency of electric vehicles compared with conventional vehicles.

FIGURE 4. Life Cycle NO_x Emissions from Transit Buses, by Vehicle and Fuel Type



The lowest life cycle emissions of nitrogen oxides (NO_x) from biomethane results from generating electricity or hydrogen for use in battery or fuel cell electric vehicles.

Notes: Bus-related emissions are a representative example of emissions from other heavy-duty vehicles. Electricity emissions are based on the 2016 grid mix in California; hydrogen emissions assume 33 percent is generated using renewable energy. Biomethane emissions are based on landfill gas, as it is the predominant source of biomethane consumed in California (CARB 2017b). The dashed line indicates emissions from a battery electric bus using an estimate of California's electricity sources in 2030 and assumes 50 percent of electricity comes from renewable energy (per Senate Bill 350) and 50 percent of electricity comes from natural gas power plants. This represents a conservative estimate of California's future sources of electricity.

SOURCE: CHANDLER, ESPINO, AND O'DEA 2017.

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ENDNOTES

1 *Biomethane from dairies is derived from animal manure, which contributes 25 percent of California's methane emissions. Enteric fermentation (e.g., cow belches and flatulence) comprises an additional 30 percent of methane emissions in California, yet is not commonly counted as a source of biomethane (CARB 2016a). Strategies for reducing methane from enteric fermentation instead focus on animal diet, breeding, and gut microbes (CARB 2017a).*

2 *California has the largest potential to generate biomethane from waste in the United States, nearly twice the amount of the next state, Texas (NREL 2013). The National Renewable Energy Laboratory (NREL) estimates that 3.2 billion diesel gallon equivalents (dge) of biomethane could be produced each year in the United States from landfills, wastewater, animal manure, and other sources of industrial and commercial waste. Similar estimates have been made by the National Petroleum Council (4 billion dge/year) and American Gas Foundation (2.4 billion to 6.2 billion dge/year) (NPC 2012; AGF 2011). Similar to the NREL analysis, a study from the University of California–Davis estimates 650 million dge/year of biomethane are potentially available from waste sources in California (Jaffe et al. 2016).*

3 *Natural gas extracted from the earth must also be upgraded to remove non-methane impurities before it can be injected into a pipeline.*

4 *This analysis uses emission factors for electricity generated from biomethane in utility-scale natural gas power plants (e.g., combined cycle). Small-scale combustion engines that generate electricity from biomethane on-site typically have higher emissions per unit of power than utility-scale power plants. Solid-oxide fuel cells represent a low-emission technology option for on-site generation of electricity from biomethane.*

5 *Because biomethane can be used to produce electricity or hydrogen, an apples-to-apples comparison of emissions across vehicle types includes biomethane used for these purposes.*

6 *For four months, from October 2016 to February 2017, methane leaked from the Aliso Canyon natural gas storage site in Southern California. The leak was the largest in US history and displaced 8,000 families from their homes (Khan 2016).*

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