Dairy Digester Emissions Matrix

November 30, 2018

			A	B	C	D	E	F	G	H
			CO_2e (20-yr GWP)	CO_2e (100-yr GWP)	NOx	PM_{10}	$PM_{2.5}$	CO	SOx	VOCs
1	**Uncovered Lagoon**	**Baseline Totals** (Local + Remote)	**70,581**	**24,519**	**<0.1**	**<0.1**	**<0.1**	**<0.1**	**<0.1**	**3.0**
2	**Onsite Reciprocating Engine to Grid and EVs**	Local	17,491	7,474	0.5	0.2	0.2	8.5	<0.1	0.6
3		Remote	765	318	0.1	<0.1	<0.1	0.1	0.1	<0.1
4		**Subtotal** (Row 2 + Row 3)	**18,256**	**7,792**	**0.6**	**0.2**	**0.2**	**8.6**	**0.1**	**0.6**
5		Diesel Displaced	8,609	7,629	5.5	1.1	0.6	5.4	2.4	1.0
6		**Pathway Emissions** (Row 4 - Row 5)	**9,647**	**163**	**-4.9**	**-0.9**	**-0.4**	**3.2**	**-2.3**	**-0.4**
7		**Net Benefit** *vs. uncovered lagoon* (Row 6– Row 1)	**-60,934**	**-24,356**	**-4.9**	**-0.9**	**-0.4**	**3.2**	**-2.3**	**-3.4**
8	**Pipeline Injection to NG Vehicles**	Local	15,448	5,268	0.1	<0.1	<0.1	1.2	<0.1	0.3
9		Remote	4,839	3,568	4.6	0.2	0.2	52.5	0.2	0.6
10		**Subtotal** (Row 8 + Row 9)	**20,287**	**8,837**	**4.7**	**0.2**	**0.2**	**53.7**	**0.2**	**0.9**
11		Diesel Displaced	4,197	3,720	8.8	0.4	0.2	1.6	1.2	12.0
12		**Pathway Emissions** (Row 10 - Row 11)	**16,090**	**5,117**	**-4.1**	**-0.2**	**<0.1**	**52.1**	**-1.0**	**-11.1**
13		**Net Benefit** *vs. uncovered lagoon* (Row 12– Row 1)	**-54,491**	**-19,402**	**-4.1**	**-0.2**	**<0.1**	**52.1**	**-1.0**	**-14.1**
14	**Pipeline Injection to Power Plant, Grid and EVs**	Local	15,448	5,268	0.1	<0.1	<0.1	1.2	<0.1	0.3
15		Remote	3,860	2,957	0.4	0.1	0.1	0.4	0.2	0.1
16		**Subtotal** (Row 12 + Row 13)	**19,307**	**8,226**	**0.5**	**0.1**	**0.1**	**1.6**	**0.2**	**0.4**
17		Diesel Displaced	11,916	10,560	7.6	1.6	0.9	7.4	3.3	1.4
18		**Pathway Emissions** (Row 16 - Row 17)	**7,391**	**-2,334**	**-7.1**	**-1.5**	**-0.8**	**-5.8**	**-3.1**	**-1.0**
19		**Net Benefit** vs. uncovered lagoon (Row 18– Row 1)	**-63,190**	**-26,853**	**-7.1**	**-1.5**	**-0.8**	**-5.8**	**-3.1**	**-4.0**
17	**Pipeline Injection to Hydrogen Vehicles (H_2 from SMR)**	Local	15,448	5,268	0.1	<0.1	<0.1	1.2	<0.1	0.3
18		Remote	6,140	5,017	3.5	0.6	0.6	1.9	2.4	0.4
19		**Subtotal** (Row 17 + Row 18)	**21,588**	**10,285**	**3.6**	**0.6**	**0.6**	**3.1**	**2.4**	**0.7**
20		Diesel Displaced	7,709	6,832	4.9	1.0	0.6	4.8	2.1	0.9
21		**Pathway Emissions** (Row 19 - Row 20)	**13,879**	**3,453**	**-1.3**	**-0.4**	**<0.1**	**-1.7**	**0.3**	**-0.2**
22		**Net Benefit** *vs. uncovered lagoon* (Row 21– Row 1)	**-56,702**	**-21,066**	**-1.3**	**-0.4**	**<0.1**	**-1.7**	**0.3**	**-3.2**
23	**Pipeline Injection to Fuel Cell, Grid and EVs (Solid Oxide Fuel Cell)**	Local	15,448	5,268	0.1	<0.1	<0.1	1.2	<0.1	0.3
24		Remote	3,860	2,957	0.6	<0.1	<0.1	0.5	0.1	0.1
25		**Subtotal** (Row 23 + Row 24)	**19,308**	**8,225**	**0.7**	**0.1**	**0.1**	**1.7**	**0.1**	**0.3**
26		Diesel Displaced	13,292	11,779	8.5	1.8	1.0	8.3	3.7	1.5
27		**Pathway Emissions** (Row 25 - Row 26)	**6,016**	**-3,554**	**-7.8**	**-1.7**	**-0.9**	**-6.6**	**-3.6**	**-1.2**
28		**Net Benefit** *vs. uncovered lagoon* (Row 27– Row 1)	**-64,565**	**-28,073**	**-7.8**	**-1.7**	**-0.9**	**-6.6**	**-3.6**	**-4.2**

Note: Units are metric tons per year (MT/yr.) for all numerical values.

November 30, 2018

Dairy Emissions Matrix
Assumptions

Terminology

- *Biomethane*: methane derived from the digestion of organic material that has been upgraded to a level suitable for pipeline injection
- *Biogas*: digester gas for onsite use that has not been upgraded for pipeline injection
- *On-site*: emissions or fuel use occurring *on* the dairy farm [1]
- *Off-site*: emissions or fuel use occurring *off* the dairy farm
- *Local*: emissions or fuel use occurring on-site plus emissions or fuel use occurring before gas is injected into a pipeline or electricity is placed on the grid
- *Remote*: emissions or fuel use occurring after biomethane is injected into a pipeline or electricity is placed on the grid, including emissions impact of electricity produced by off-site power plants (grid electricity) and used for dairy farm equipment power

General Methods and Assumptions (Applies to All Scenarios)

- Emissions model: CA GREET 2.0 Dairy-CNG Template
- Source of values for entry into model: air quality district emission values, manufacturer specifications, Cap-and-Trade Program Livestock Offset Protocol (Livestock Offset Protocol)
- Methane 20-year global warming potential: 72 [2,3]
- Methane 100-year global warming potential: 25 [2]
- Carbon dioxide equivalent (CO_2e) includes methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O)
- Digester ambient temperature profile: San Joaquin Valley
- Assumed dairy size: 5,000 cows [4]
- Dairy type: freestall with flush manure management
- Baseline: open lagoon with methane emissions of 980 metric tons methane per year per Livestock Offset Protocol [5] estimate
- Diesel Displacement: avoided emissions from a diesel truck that is displaced by either a medium heavy-duty NG truck (renewable natural gas or RNG pathway) or a medium-duty electric truck (all other pathways besides RNG).
- Displaced diesel truck emissions are calculated based on the amount of fuel produced by the pathway and taking into account the energy economy ratio (EER)

---

[1] Includes dairies participating in cluster projects

[2] Intergovernmental Panel on Climate Change Fourth Assessment Report: Climate Change 2007

[3] Same 20-year methane global warming potential as used in the Short-Living Climate Pollutant Reduction Strategy, https://www.arb.ca.gov/cc/shortlived/meetings/03142017/final_slcp_report.pdf

[4] For comparison, average size of Kern County dairy farm in 2017 was 3,253 head. https://www.cdfa.ca.gov/dairy/pdf/Annual/2017/2017_Statistics_Annual.pdf

[5] CARB has determined value based off information from the Livestock Offset Protocol, localized research, industry-provided data, and other publicly available sources.

- The remote value for the RNG pathway includes emissions from generating and supplying natural gas, plus tailpipe emissions from medium heavy-duty RNG-powered trucks
- The remote value for all pathways, except RNG, include emissions from generating and supplying electrical power. These pathways can fuel medium-duty electric trucks that have no tailpipe emissions.

Biogas-Producing Covered Digester Scenario/Assumptions

- Emissions calculated on local and remote basis
- Stationary screen manure separation
- Digester type: double-lined [6] covered lagoon (no heating or mixing)
- Digester cover leak rate: 5% [7]
- Projects must meet applicable air district's best available control technology (BACT) emission standards
- Peripheral operations use grid electricity [8]

On-Site Use Scenario/Assumptions

- *Reciprocating engines*
  - Biogas is upgraded to air district and manufacturer's requirements (not pipeline quality)
  - Efficiency: 32.8% [9]

Off-Site Use Scenario/Assumptions

- All off-site use of fuel will be from pipeline quality biomethane processed from an on-site upgrading unit [10]
- *Renewable natural gas* – for natural gas vehicle fueling
  - Distance from initial pipeline injection to fueling station: 100 miles
- *Power plant generation* – producing electricity fed to grid
  - Facility is a large combined cycle power plant [11]
  - Efficiency: 51%
- *Renewable hydrogen* [12] – for fueling
  - Produced from pipeline biomethane using steam methane reformation (SMR)
  - Distance from biomethane injection point to reforming facility in model: 100 miles [13]

---

[6] Adopted order of California Regional Water Quality Control Board, https://www.waterboards.ca.gov/rwqcb5/board_decisions/adopted_orders/general_orders/r5-2013-0122.pdf

[7] CARB Livestock Offset Protocol (Table A.4) and U.S. EPA determined leak rate for covered lagoons https://www.arb.ca.gov/regact/2010/capandtrade10/cappt4.pdf

[8] CA grid electricity emission factor is 105.15 g/MJ (as utilized in CA GREET model)

[9] CA GREET 2.0 value

[10] Total upgrading efficiency is a user input value for CA GREET 2.0 and 80% is a common calculated value

[11] Large combined cycle power plant is identified as 400MW capacity in CA GREET 2.0

[12] No current pathways available for renewable hydrogen from biomethane

[13] Centralized upgrading facility location will be mapped to determine distances

    - Distance hydrogen trucked/pipelined from reforming facility to fueling station in model: 100 miles [13]
    - Efficiency: 72%
- *Fuel cells (solid oxide)* [14] – producing electricity fed to the grid
    - Efficiency: 57% [15]
- Transportation emissions comparison baseline (for all pathway options intended for transportation fuel use): medium heavy-duty diesel trucks [16]
    - All tailpipe emissions calculated using 2017 EMFAC emission factors [17]

Qualitative Emissions Assumptions

- Hydrogen Sulfide: Hydrogen sulfide removal is required for utilizing biogas or biomethane in pathways, either by Air District requirement, requirements imposed by equipment manufacturers, and/or utilities operating natural gas common carrier pipeline systems. Quantification of the reduction in hydrogen sulfide emissions would require accounting for the associated equipment or pipeline quality requirements, and the initial hydrogen sulfide concentration in the raw biogas.
- Ammonia: Some ammonia will be captured and removed by the digester and biogas upgrading and conditioning systems. Further investigation of ammonia emissions sources and potential emissions tradeoffs would be necessary to determine the potential for reductions (or increases) in ammonia emissions. Nitrogenous compounds like ammonia are difficult to track and quantify at dairies.
- Nitrous Oxide: Some nitrous oxide will be captured and removed by the digester and biogas upgrading and conditioning systems. Further investigation of nitrous oxide emission sources and potential emissions tradeoffs would be necessary to determine the potential for reductions (or increases) in nitrous oxide emissions, especially for land application of digester effluent. Nitrogenous compounds like nitrous oxide are difficult to track and quantify at dairies.
- Water Quality: It is assumed that all pathways will include the addition of a new digester with a double-lined membrane. The addition of a membrane may provide a water quality improvement due to greater protection against leakage and leaching of nutrients compared to unlined anaerobic storage lagoons. Potential water quality impacts associated with land application of digester effluent have not been assessed.

[14] Expanding the Use of Biogas with Fuel Cell Technologies, June 11, 2012, https://www.energy.gov/sites/prod/files/2014/03/f11/june2012_biogas_workshop_satyapal.pdf

[15] Higher heating value efficiency number from DG scenario, National Energy Technology Laboratory (Department of Energy), https://www.netl.doe.gov/File%20Library/research/coal/energy%20systems/fuel%20cells/Natural-Gas-DG-FC-paper-update-090330a.pdf

[16] CARB compliant engine, operating within a single calendar year

[17] EMFAC 2017 technical support document, https://www.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf

Matrix Categories

- Methane (CH_4)
- Carbon dioxide equivalent (CO_2e)
- Nitrogen oxide (NOx)
- Particulate matter (PM)
- Carbon monoxide (CO)
- Sulfur dioxide (SOx)
- Volatile organic compounds (VOCs)
- Hydrogen sulfide (H_2S)
- Ammonia (NH_3)
- Nitrous oxide (N_2O)
- Water quality (WQ)