Biogas Electricity for Electric Vehicle (EV) Charging
- towards a carbon-neutral U.S. dairy industry

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Manure Management and Utilization Technologies (6)

- Anaerobic Digestion Topics Part 3

Reynolds, IN 47980

Outline

1. US dairy industry
2. Animal manure and anaerobic digestion of biogas production
3. Pathways of farm-based biogas utilization
   - Current pathways of farm-based biogas utilization
   - New pathway of farm-based EV charging
4. Example of farm-based electricity generation for EV charging
5. Dairy farms and commercial EV charging network
6. Summary

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BAE Department of Biosystems and Agricultural Engineering

1. The U.S. dairy industry

- There are approximately 49,000 dairy farms with 9 million cows and 500 milk processing plants in the U.S.
- 97% of U.S. dairy farms are owned by family
- Average dairy farm size is 187 cows per dairy farm
- More than 90% of the U.S. dairy farms are small- and medium-sized farms (less than 1,000 cows)
- The U.S. dairy industry contributed to 1% of GDP in 2019 ($630 Billion)

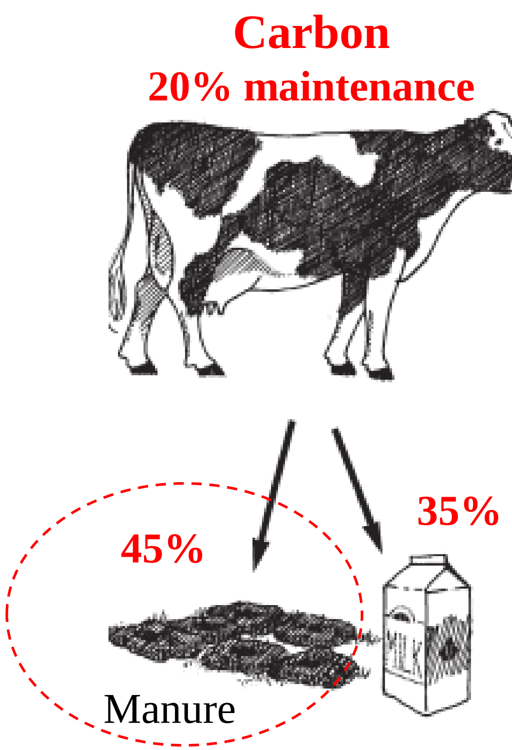
From the MSU dairy farm

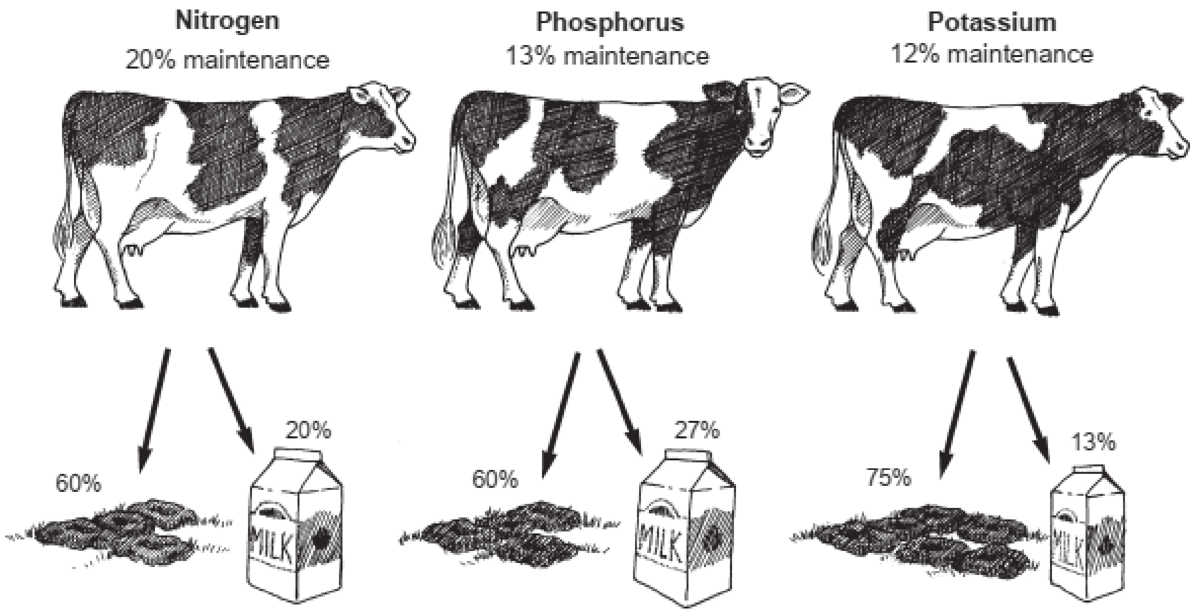
https://diamondv.com/the-top-three-tech-trends-in-the-dairy-farming-industry/

https://www.dairyfoods.com/articles/94516-the-2020-dairy-100-changes-at-the-top

2. Dairy manure and anaerobic digestion

- More than 27 million tons (dry dairy manure) produced in the U.S. annually
- Animal manure rich in carbohydrate and nitrogen
- Average energy content of animal manure around 13.4 MJ/kg
- Dairy manure containing approximately 45% of the gross carbon in forage feeds
- The manure accounts for 1/3 of the global warming potential in the entire dairy supply chain





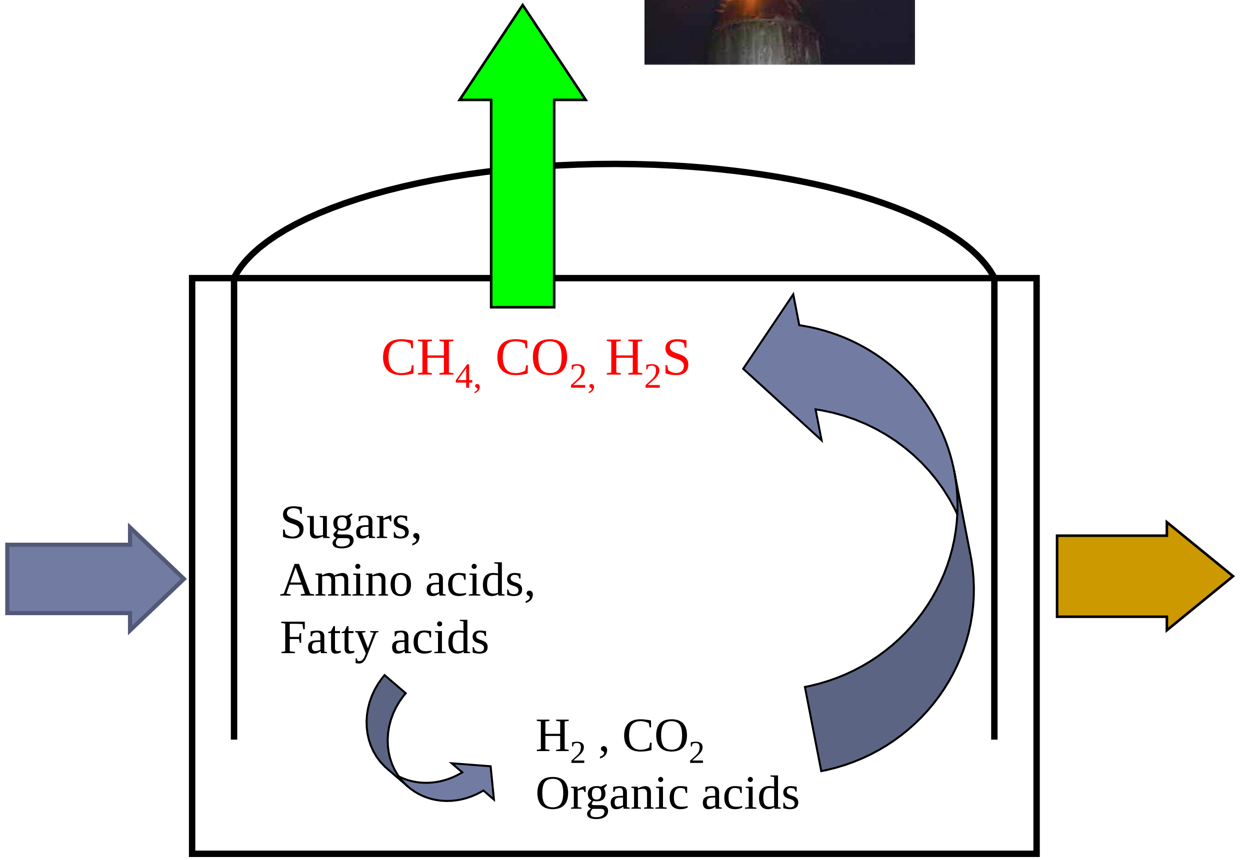
From: J. Hart, et al., Dairy manure as a fertilizer source, , Nutrient management for dairy production, EM8586, 1997
From: J. Blignaut, et al., Agricultural Systems, 195(2022), 103286

2. Dairy manure and anaerobic digestion

Anaerobic digestion of animal manure

Biogas

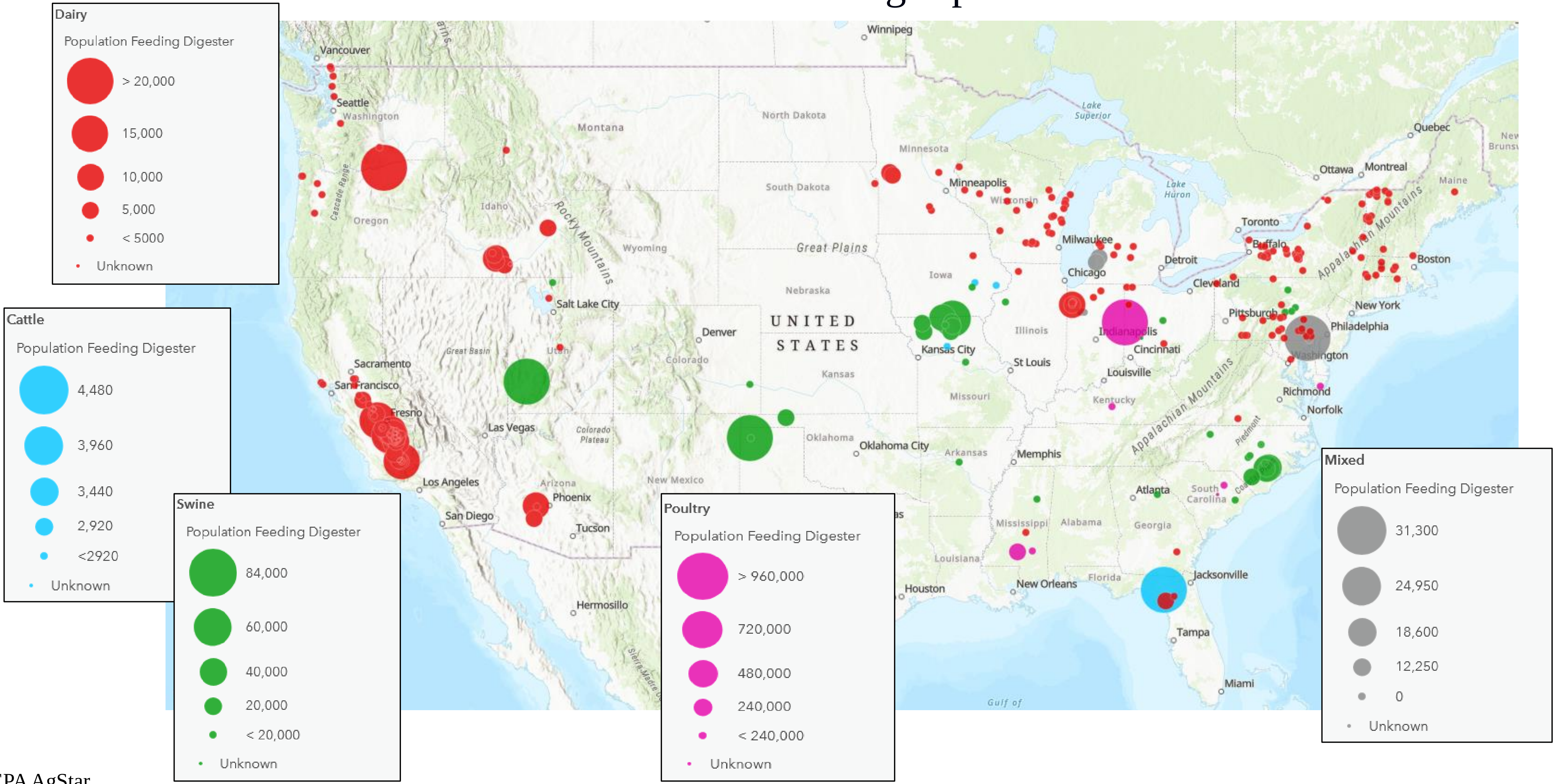
Organic materials in manure (carbohydrate, fat, oil, protein, etc.)



Digestion effluent (digestate) as fertilizer

2. Dairy manure and anaerobic digestion

Current farm-based biogas plants



2. Animal manure and anaerobic digestion

Current operational and potential biogas plants in the U.S.

	Livestock manure	Landfill gas	Wastewater treatment facilities	Total
Currently operational systems	**331**	636	1,241	2,208
Potential biogas systems	**23,000**	1,086	3,681	27,767

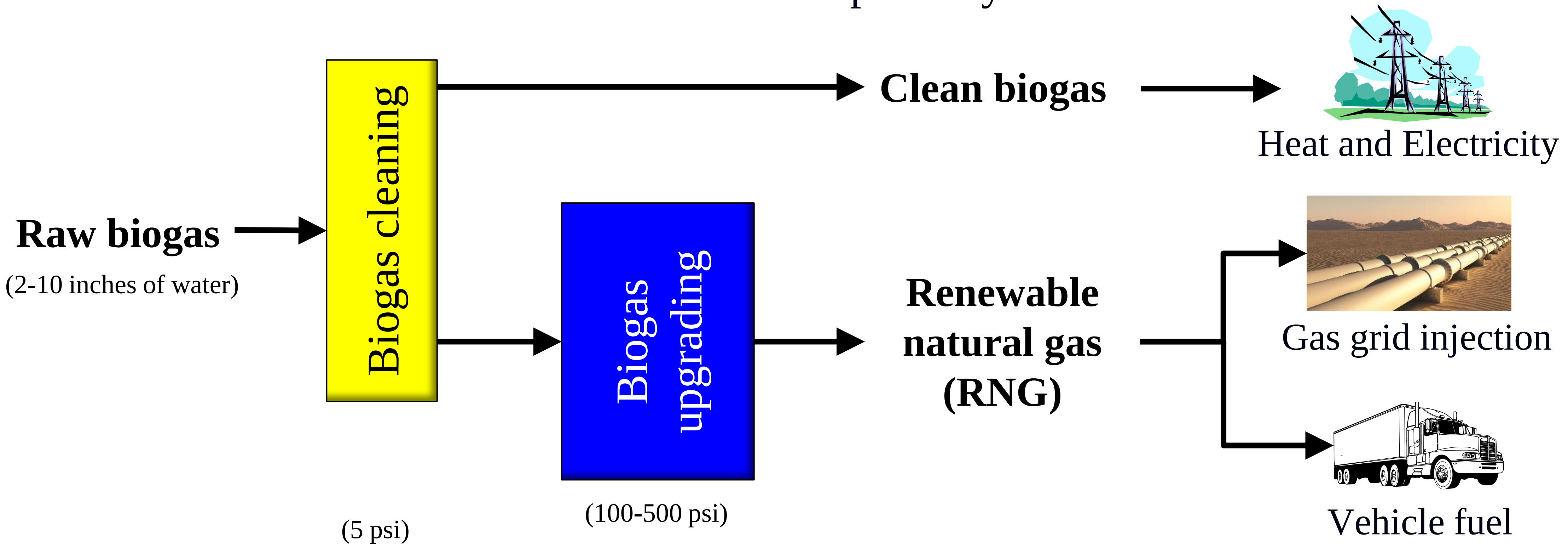
Estimated energy potential from organic wastes in the U.S.

	Livestock manure	Landfill gas	Wastewater treatment facilities	Total
Biogas production potential (billion cubic feet per year)	**257**	284	113	654
Electricity potential (billion kWh/year)	**13.1**	22.5	5.6	41.2
Vehicle fuel (million GGE)	**1031**	1028	441	2499

From EPA AgStar

3. Pathways of farm-based biogas utilization

Current pathways



Challenges:

- For the heat and electricity generation pathway, economic performance is not favorable for small- and medium- farm operations (less than 1,000 cows or equivalent).
- For the RNG pathway, location and size of the farm operation (large farms and near exiting pipeline) are the key factors (along with other factors such as cost, carbon intensity, pipeline leaking etc.) that limit its extension to a large of rural communities.

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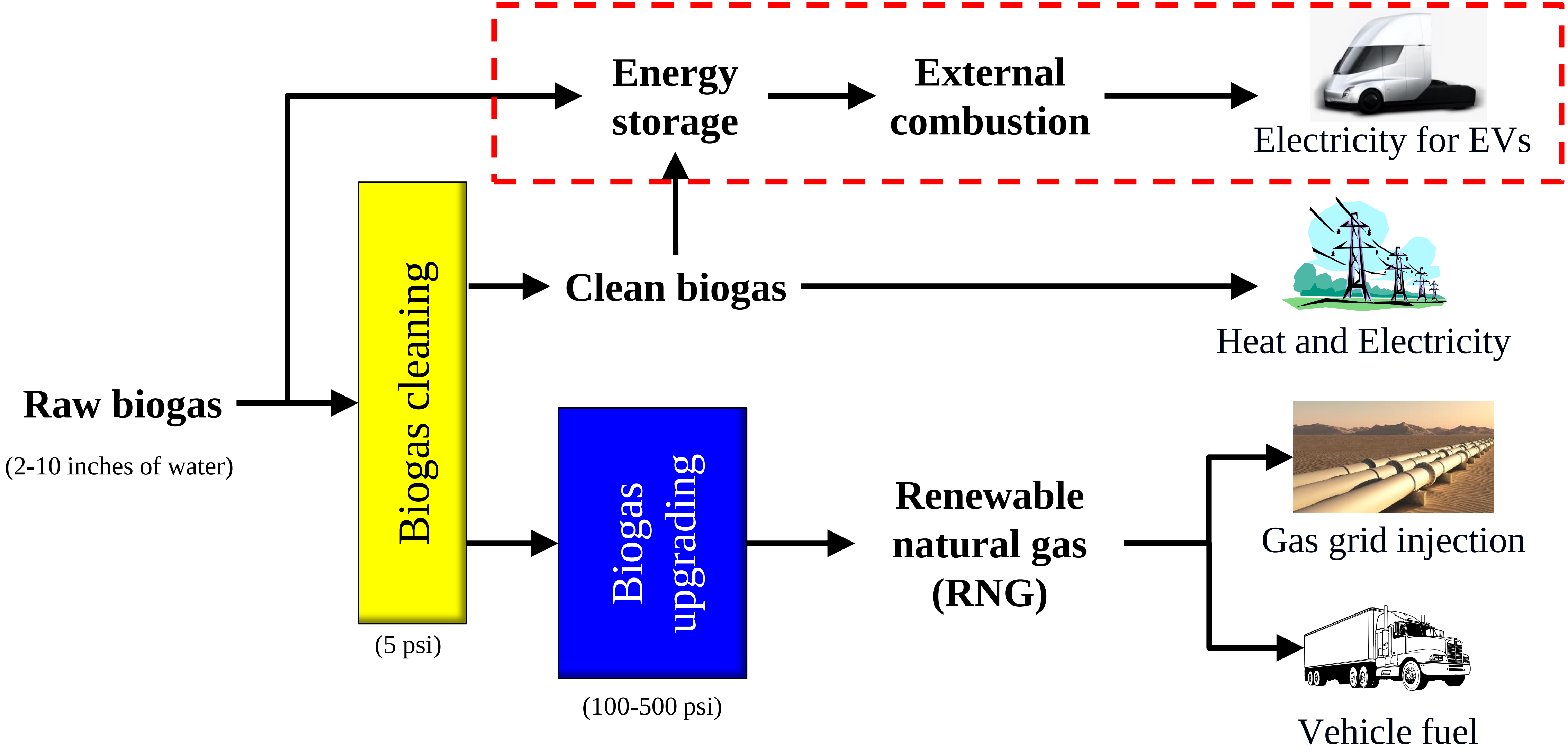
3. Pathways of farm-based biogas utilization

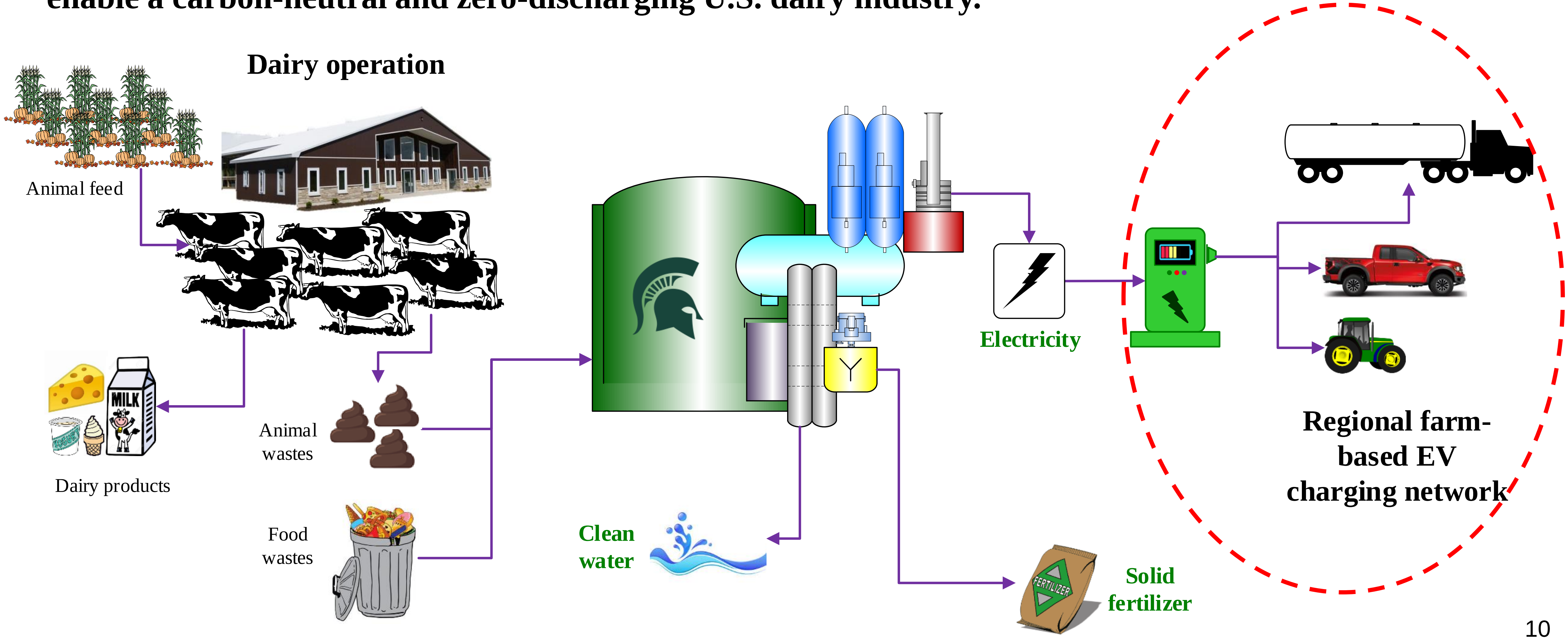
New pathway of farm-based EV charging



3. Pathways of farm-based biogas utilization

Dairy-farm-based renewable electric vehicle (EV) charging solution

The goal of the concept is to establish renewable EV charging solutions as a climate-smart product to enable a carbon-neutral and zero-discharging U.S. dairy industry.



4. Example of farm-based EV charging solution

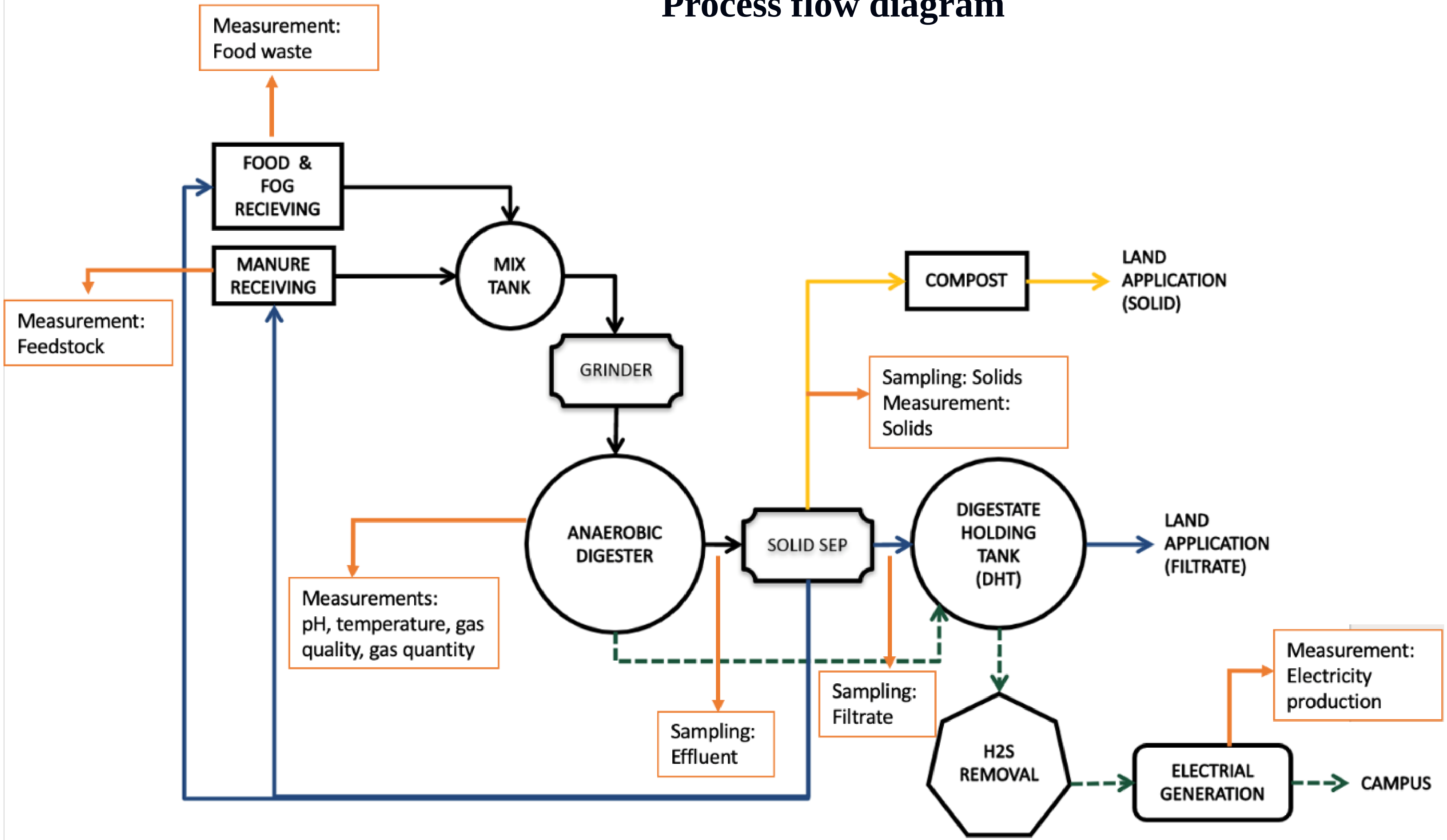
A 200 dairy cow biogas plant -- The MSU biogas plant

- Digester tank
  - 400,000 gallons
  - The tank with a diameter of 52 ft and a height of 26 ft plus cover
- Digestate storage tank
  - 2.1 million gallons
  - The tank with a diameter of 101 ft and a height of 42 ft plus cover
- CHP unit
  - 400 kW electrical production & 450 kW of thermal energy recovery
  - Offset power at 8 to 10 south campus facilities
  - Thermal energy used to sustain the process, heat support building and separator area
- Feedstock
  - Dairy manure
  - Food wastes

MSU SCAD

4. Example of farm-based EV charging solution

Process flow diagram



4. Example of farm-based EV charging solution

Organic wastes in manure pit and food waste pit

Organic wastes fed to different pits

No	Manure Pit	Food Pit
1	Digestate (recycle)	Filtrate (recycle)
2	Filtrate (recycle)	Cart Food Wastes (Pre and post-consumer)
3	ANS Other (i.e., eggs)	Fat, Oil, and Grease (FOG)
4	Beef Manure	Other
5	Dairy Gutter Manure (Dairy G)	Pineapple (P.A.) and other Fruits
6	Dairy Freestall Manure (Parlor)	Pulp
7	Poultry Manure	SLS Solids (Coarse digestate fiber)
8	SLS Solids	Waste Forage
9	Swine Manure	
10	Waste Forage	

Food wastes (Pre-consumer)

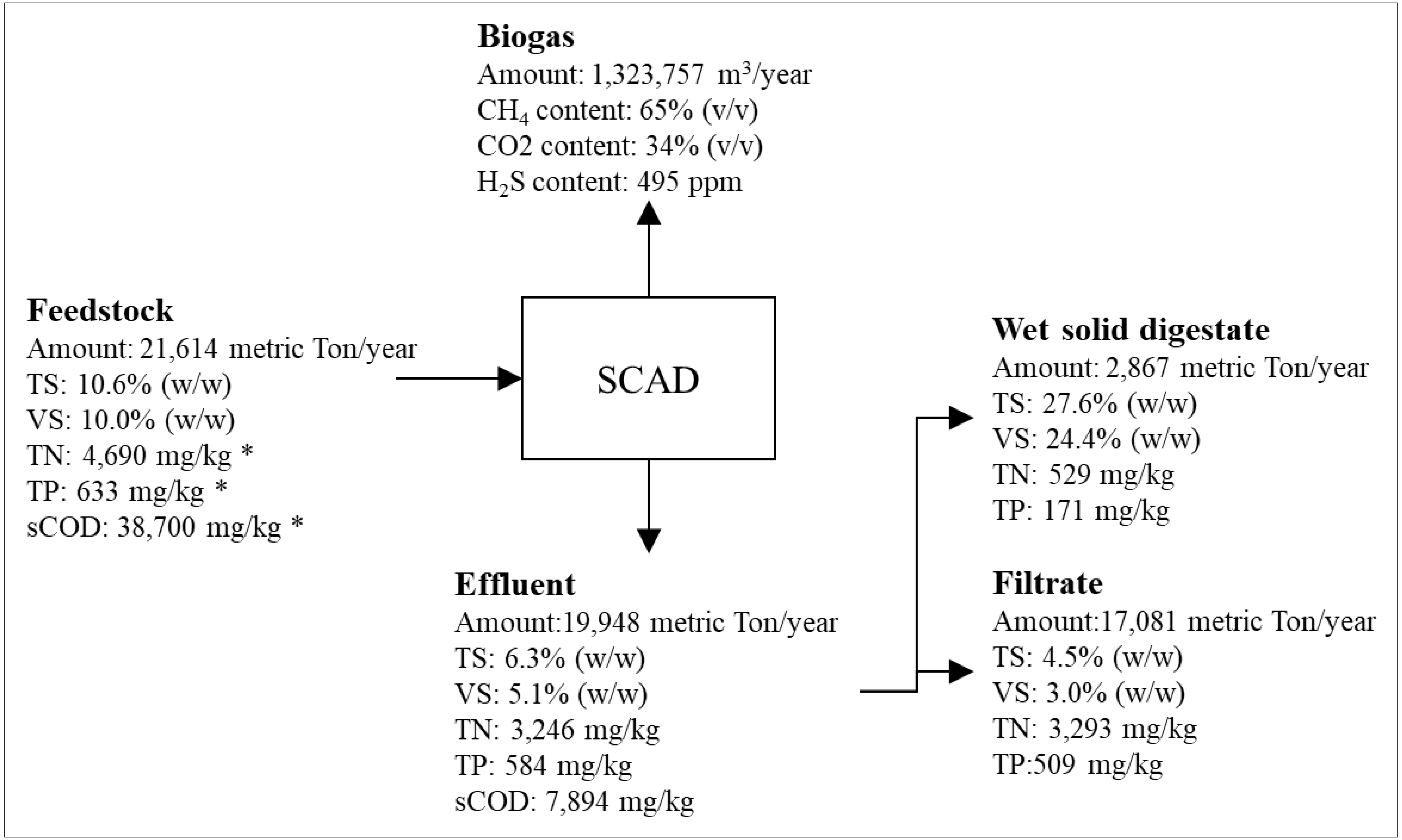
Food wastes (Post-consumer)

Fruit & Vegetable

FOG

4. Example of farm-based EV charging solution

Mass balance of the digestion system *



*: The calculation is based on the data from 2018 - 2020

4. Example of farm-based EV charging solution

Energy balance of the digestion system [a]

	SCAD
Energy input	
Heat input (W_{heat}, kWh-e/year) [b]	-742,090
Electricity input ($W_{electricity}$, kWh-e/year) [c]	-170,320
Energy output	
Energy output as heat (E_{heat}, kWh-e/year) [d]	5,584,551
Energy output as electricity ($E_{electricity}$, kWh-e/year) [e]	2,462,190
Net energy output	
Net heat output (kWh-e/year) [f]	4,842,461
Net electricity output (kWh-e/year) [g]	2,291,870

a. Negative numbers mean energy inputs, and positive numbers mean energy outputs.

b. Eq. 1 was used to calculate the heat input.

c. Eq. 2 was used to calculate the electricity input.

d. The annual biogas production of 1,323,757 m^3 with 65% (v/v) of methane was used to calculate the energy content of the biogas. The low heating value of methane is 35.8 MJ/m^3 methane. The thermal conversion efficiency of the CHP unit is 65%.

e. The electricity output is the metered number of the digestion operation.

f. The net heat output = $E_{heat} - W_{heat}$

g. The net electricity output = $E_{electricity} - W_{electricity}$

4. Example of farm-based EV charging solution

Economic performance of the digestion system [a]

Capital expenditure (CapEX)	Cost	Reference
Feedstock Receiving	$727,927	Data
Digester	$1,442,140	Data
CHP	$778,651	Data
Bond	$38,143	Data
Interconnection	$300,000	Data
Site improvements & excavation	$300,000	Data
Total CapEX	**$3,586,861**	

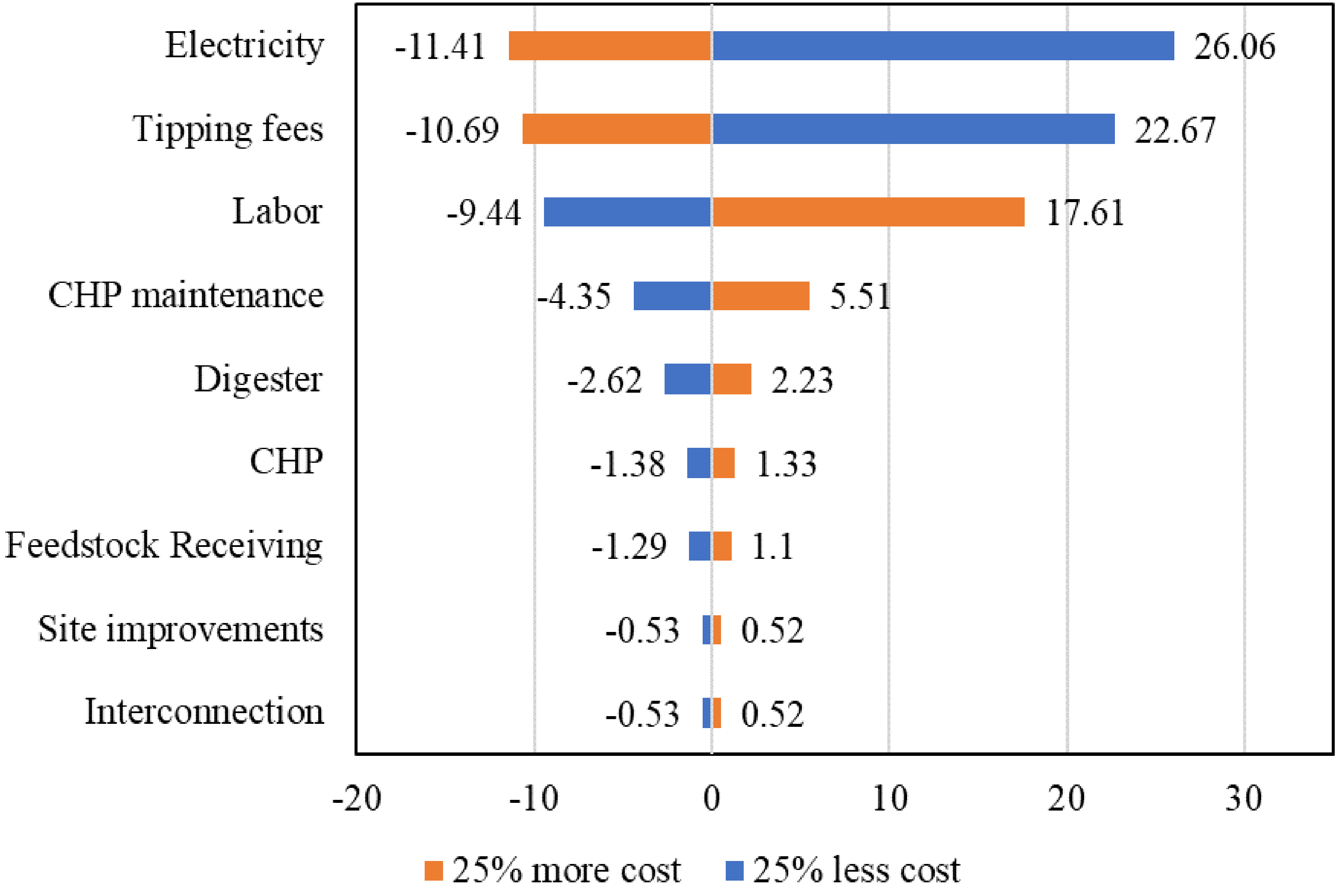
Revenue (per year)	Cost	Reference
Electricity [b]	$237,746	Data
Tipping	$217,854	Data
Total revenue (per year)	**$455,600**	
Total net revenue (per year) [c]	**$157,444**	
Payback time (Years) [d]	**21.5**	

OpEX (per year)	Cost	Reference
AD Repairs	$28,373	Data
ADMIN Fee	$2,948	Data
Bio Analysis	$2,827	Data
CHPS	$74,226	Data
Labor	$123,616	Data
Laundry	$378	Data
Maintenance and Repair	$6,482	Data
MISC	$4,064	Data
Motor Pool / Vehicle	$1,165	Data
Supplies	$396	Data
Telephone	$772	Data
Transport (DHT)	$52,910	Data
Total OpEX (per year)	**$298,156**	

a. The OpEX and revenue are the operational data from 2019-2020.
b. The average electricity price is $0.10/kWh.
c. The net revenue = Total revenue – Total OpEx
d. The 5-year average local inflation of 3.2% in the U.S. is used as the inflation rate. The depreciation period is set at 20 years. The depreciation is just on CapEx. The annual depreciation rates from MARCRS (Modified Accelerated Cost Recovery System) are: 0.100, 0.188, 0.144, 0.115, 0.092, 0.074, 0.066, 0.066, 0.065, 0.065, and 0.033 (after 10 years).

4. Example of farm-based EV charging solution

Sensitivity analysis on the payback period of the digestion system



- Nine variables – feedstock receiving, digester, CHP, interconnections, site improvements, CHP maintenance, labor, electricity, and tipping fees – were taken into consideration for the economic sensitivity.
- The analysis was done by modifying each variable by ± 25% while keeping the other variables constant for the baseline scenario.
- The electricity revenue and tipping fees are the main factor to the economic performance of the commercial digesters. The payback period is reduced to 10 and 11 years, respectively, with 25% increase on electricity cost and tipping fees.

4. Example of farm-based EV charging solution

Economic performance comparison of different biogas applications

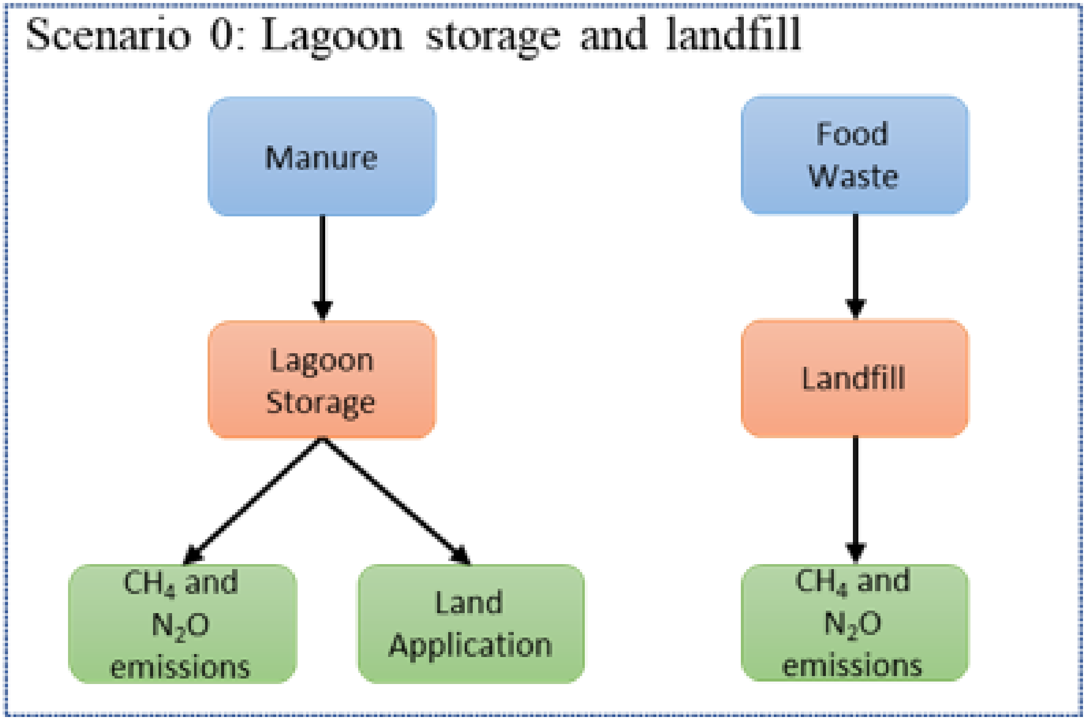
	Heat and electricity	EV charging
Capital expenditure (including, feedstock receiving, digester, CHP, fast charging stations, bond, interconnection, site improvements & excavation)	$3,586,861	$3,800,000
Operating expenditure (including, maintenance, Administration fee, sample analysis, labor, supplies, and others)	$298,156/year	$310,000/year
Revenue 1 (Electricity)	$237,746/year [b]	$832,111/year [c]
Revenue 2 (waste tipping)	$217,854/year	$217,854/year
Total net revenue [d]	$157,444	$739,965
Payback time [e]	21.5 years	**5.2 years**

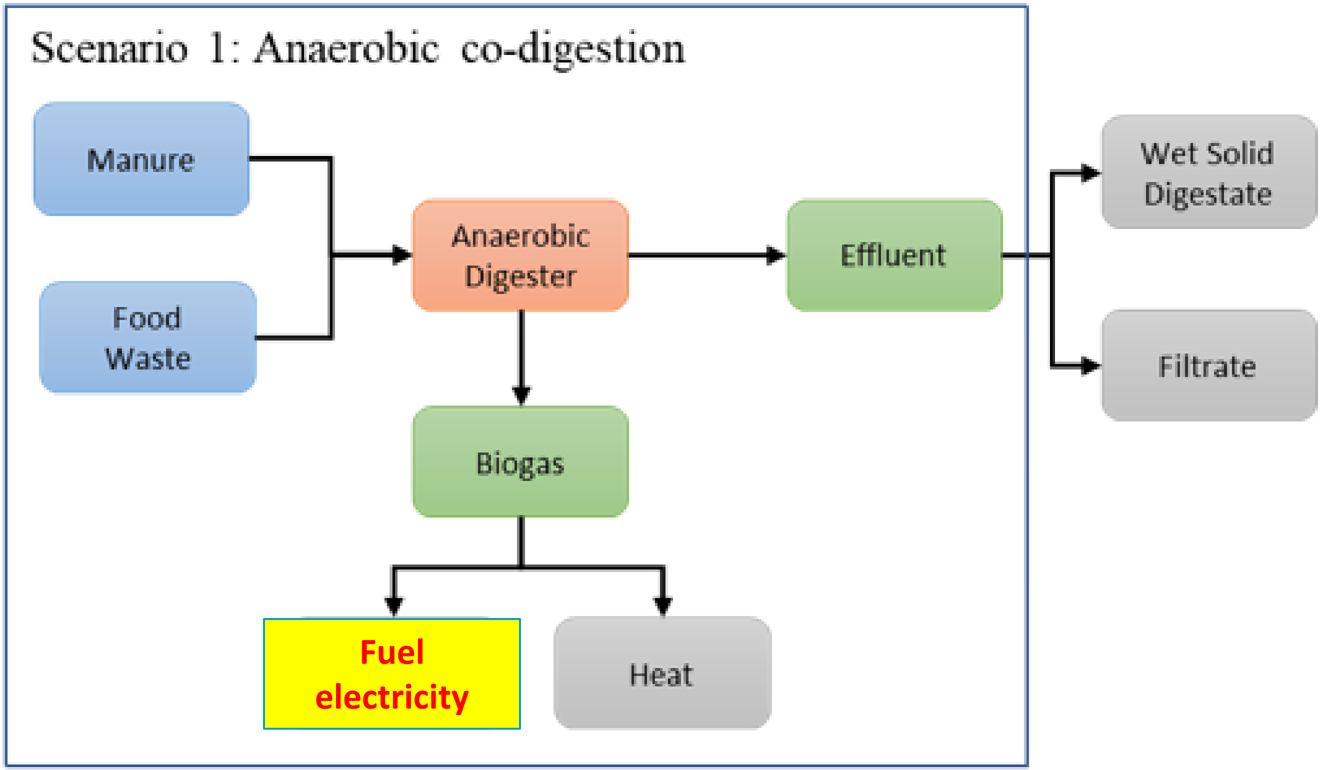
a. The OpEX and revenue are the operational data from 2019-2020.
b. The electricity price for the grid is $0.10/kWh.
c. The electricity price for the EV charging is **$0.35/kWh.**
d. The net revenue = Total revenue – Total OpEx
e. The 5-year average local inflation of 3.2% in the U.S. is used as the inflation rate. The depreciation period is set at 20 years. The depreciation is just on CapEx. The annual depreciation rates from MARCRS (Modified Accelerated Cost Recovery System) are: 0.100, 0.188, 0.144, 0.115, 0.092, 0.074, 0.066, 0.066, 0.065, 0.065, and 0.033 (after 10 years).

4. Example of farm-based EV charging solution

Scenarios and boundaries for life cycle impact assessment

- Scenario 1: Co-digestion system of manure and food wastes
- Scenario 0: Lagoon storage and landfill application of manure and food waste





4. Example of farm-based EV charging solution

Inventory for the life cycle impact assessment [a]

	Value	Unit	Source
Raw materials			
Manure wastes	10,913	Metric ton/year	Data
Total solids of manure wastes	11.4	%	Data
Volatile solids of manure wastes	10.0	%	Data
TN of manure wastes	4,143	mg/kg	Data
TP of manure wastes	413	mg/kg	Data
sCOD of manure wastes	59,446	mg/kg	Data
Food wastes	10,701	Metric ton/year	Data
Total solids of food wastes	10.1	%	Data
Volatile solids of food wastes	9.3	%	Data
TN of food wastes	5,318	mg/kg	Data
TP of food wastes	449	mg/kg	Data
sCOD of food wastes	17,525	mg/kg	Data

	Value	Unit	Source
Anaerobic digestion and energy production inventory			
Biogas production	1,323,757	m^3/year	Data
CH_4 content in biogas	65	% v/v	Data
CO_2 content in biogas	34	% v/v	Data
Electricity production from biogas	2,462,190	kWh-e/year	Data
EV electricity consumption	34	kWh-e/100 miles	Ref.
Conventional gas-powered vehicle fuel consumption	3.5	Gallon gasoline/100 miles	Ref.
GWP of gasoline	8,780	g CO_2-e/gallon	Ref.
Heat production from biogas	5,584,551	kWh-e/year	Data
Effluent	19,948	Metric ton/year	Data
TS of effluent	6.3	% (w/w)	Data
TN of effluent	3,246	mg/kg	Data
TP of effluent	584	mg/kg	Data
sCOD of effluent	7,894	mg/kg	Data
N_2O emission from the effluent	0.005	g N_2O/g TN	Ref.
GWP of N_2O	298	g CO_2-e/g N_2O	Ref.
CH_4 emission from effluent	3.08×10^{-4}	Metric ton CO_2-e/metric ton TS	Ref.
Water eutrophication potential (WEP) of TN	0.9864	g N-e/kg TN	Ref.
WEP of TP	7.29	g N-e/kg TP	Ref.
WEP of COD	0.05	G N-e/kg COD	Ref.

4. Example of farm-based EV charging solution

Inventory for the life cycle impact assessment [a] (cont'd)

	Value	Unit	Source
Animal wastes lagoon storage and land application inventory			
CH_4 emission	0.127	Metric ton CH_4/metric ton VS	(Owen & Silver, 2015)
N_2O emission	0.005	g N_2O/g TN in the waste	(RTI International, 2010)
Water eutrophication potential (WEP) of TN	0.9864	g N-e/kg TN in the waste	(RTI International, 2010)
Water eutrophication potential (WEP) of TP	7.29	g N-e/kg TP in the waste	(RTI International, 2010)
Water eutrophication potential (WEP) of COD	0.05	g N-e/kg COD in the waste	(RTI International, 2010)

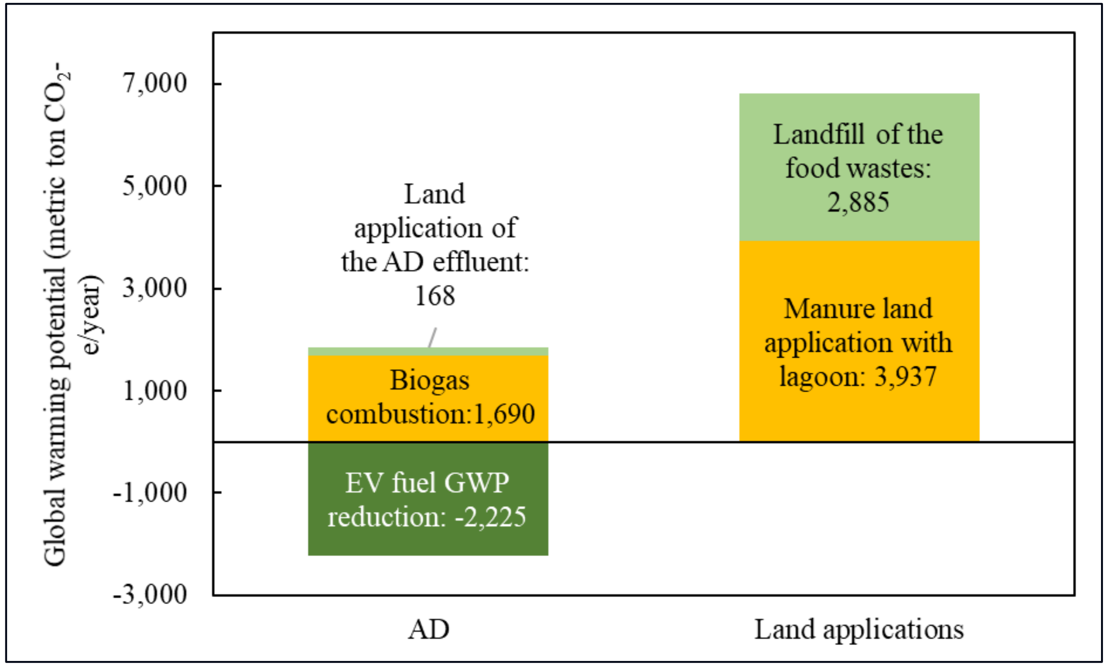
	Value	Unit	Source
Food wastes landfill inventory with landfill gas (LFG) combustion			
CH_4 emission, food wastes landfill	2.3	Metric ton CO_2-e/ton TS food waste	(Environmental Protection Agency, 2020)[b]
N_2O emission	0.005	g N_2O/g TN in the waste	(RTI International, 2010)
Water eutrophication potential (WEP) of TN	0.9864	g N-e/kg TN in the waste	(RTI International, 2010)
Water eutrophication potential (WEP) of TP	7.29	g N-e/kg TP in the waste	(RTI International, 2010)
Water eutrophication potential (WEP) of COD	0.05	G N-e/kg COD in the waste	(RTI International, 2010)
Water eutrophication potential (WEP) of COD	0.05	G N-e/kg COD	Ref.

a. CO_2 from manure wastes and food wastes is not counted in the calculation of greenhouse gas emissions because the CO_2 is considered of biogenic origin and therefore is assumed to be offset by CO_2 capture by regrowth of the plants.
b. The moisture content of the typical food wastes in the reference is set at 70%.

4. Example of farm-based EV charging solution

The life cycle impact assessment

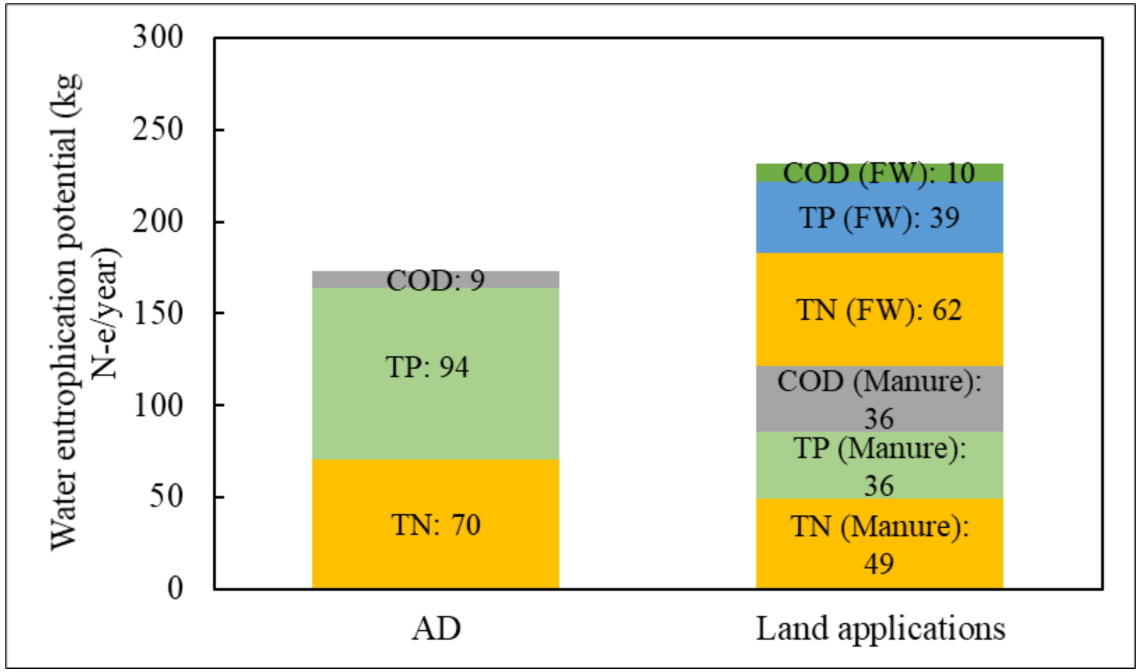
Global warming potential (GWP)



-368 ton CO_2-e/year

6,822 ton CO_2-e/year

Water eutrophication potential (WEP)



173 kg N-e/year

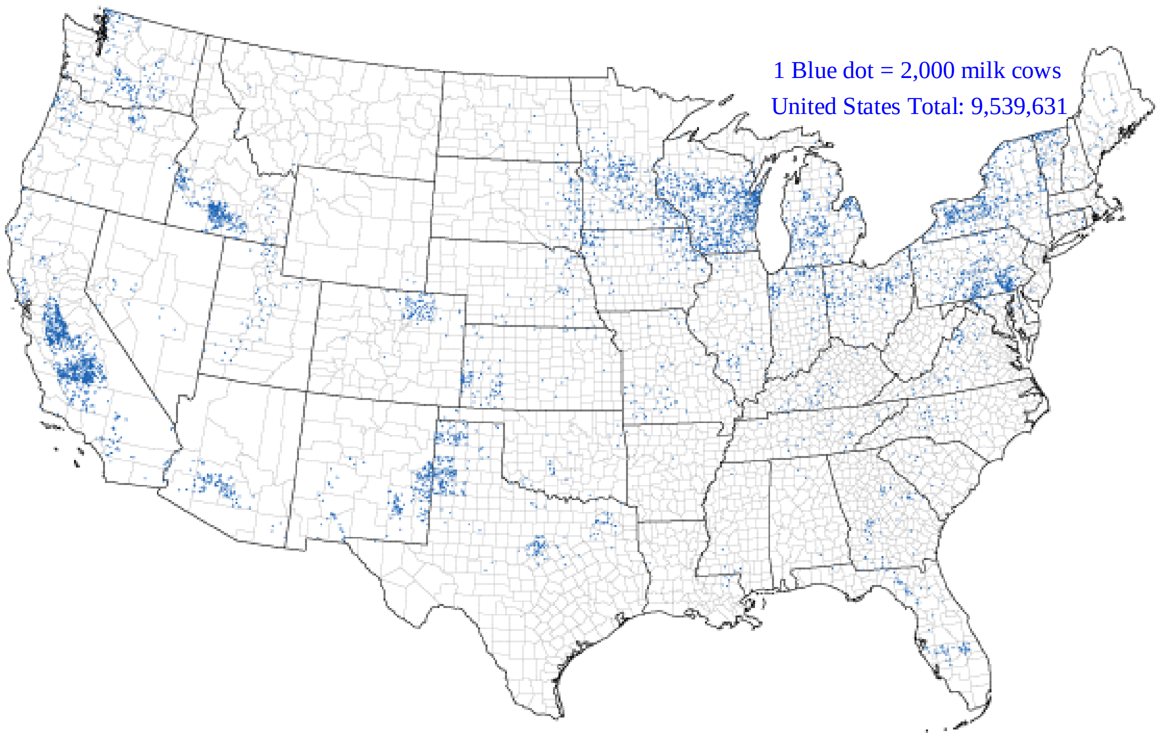
232 kg N-e/year

- With the EV charging, manure utilization is carbon negative.
- The SCAD reduces WEP up to 25%.

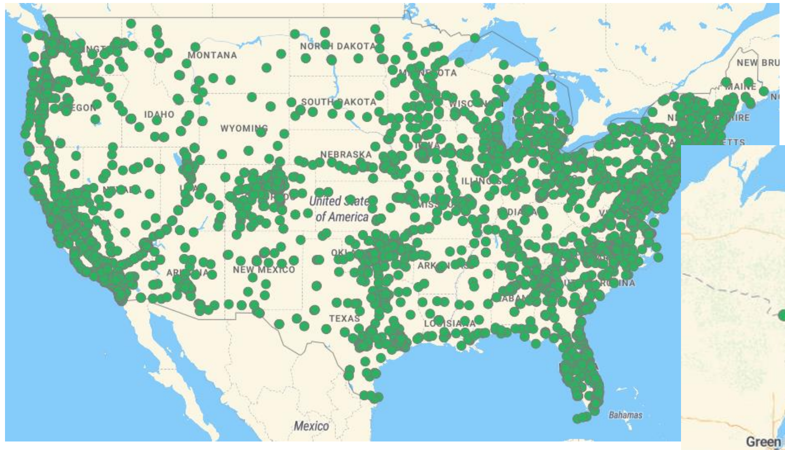
5. Dairy farms and commercial EV charging network

Dairy industry and commercial EV charging in the U.S.

Distribution of the U.S. dairy farms

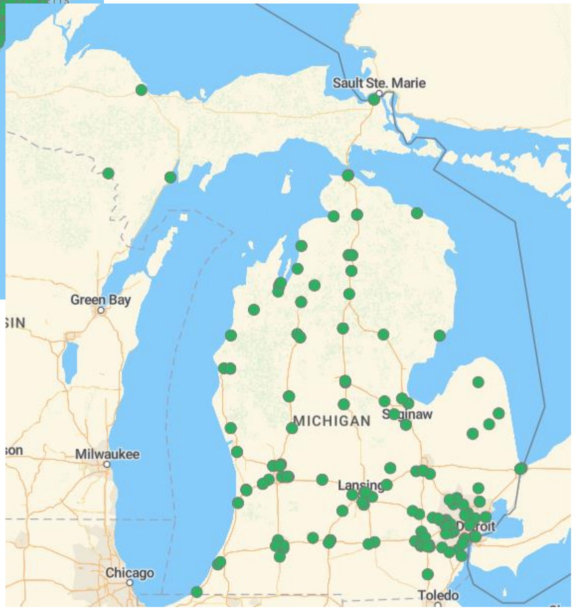


Distribution of the DC fast EV charging stations [a, b]



DC fast EV charging stations in the U.S.

DC fast EV charging stations in Michigan



a: There are 6,478 DC fast EV charging stations, mainly located in the major cities and highways.
b: There are 200 DC fact EV charging stations in Michigan.
b: As a comparison, the U.S. has more than 115,000 gas stations.

5. Dairy farms and commercial EV charging network

Dairy industry and commercial EV charging in the U.S. – Long-haul electric trucks

Facts of electric vehicles (trucks)

- Four million Class-8 trucks are running in the U.S.
- Regional trucks travel 30,000-40,000 miles per year. Other long-haul trucks travel 150,000 – 200,000 miles per year.
- If all Class-8 trucks are electric trucks, they require 504 TWh per year in the U.S.
- The U.S. dairy industry can generate up to 118 TWh electricity per year using the co-digestion technology (23% of the demand from long-haul electric trucks).

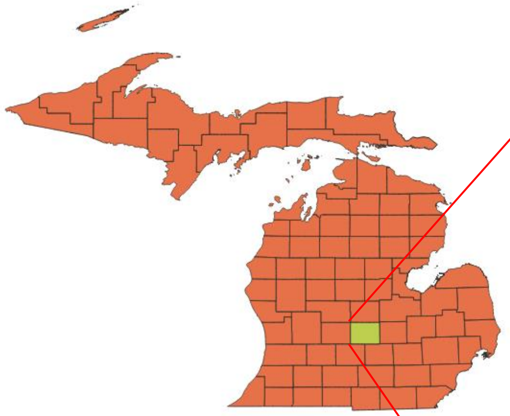
Challenges

- The fast charging station for EV Class-8 trucks requires a 1 MW capacity (Tesla V4 supercharger).
- The most of dairy farms are in the range of 100 to 1,000 cows, the biogas capacity is between 50 kW to 500 kW.
- A rural biogas network is needed to support regional high-capacity fast charging station.

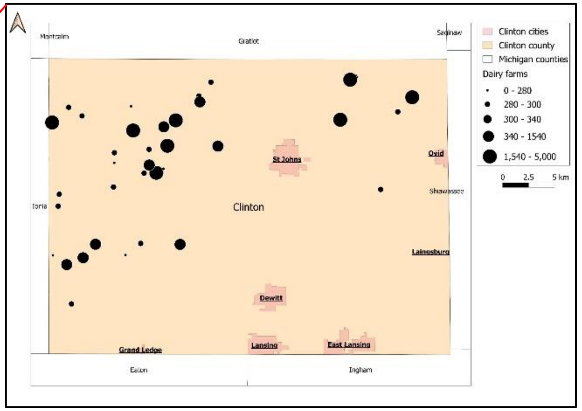
5. Dairy farms and commercial EV charging network

The EV charging solution for Clinton county

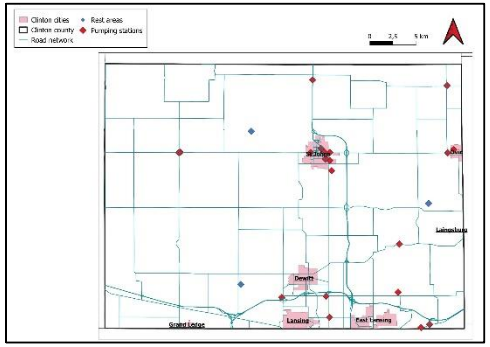
- Michigan has around 1,000 grade A milk producers.
- Clinton county has 42 Grade A milk producers for the analysis.
- The milk producers in Clinton county produce 277,525 kg/day of dry manure, and can **generate and store 103 MWh/day of electricity**.
- **Four charging stations with V4 superchargers (1 MW)** can be set up in Clinton county to charge **100 long-haul electric trucks per day**.



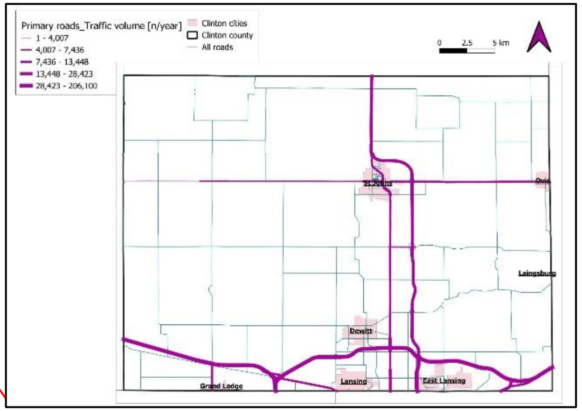
Clinton county in Michigan



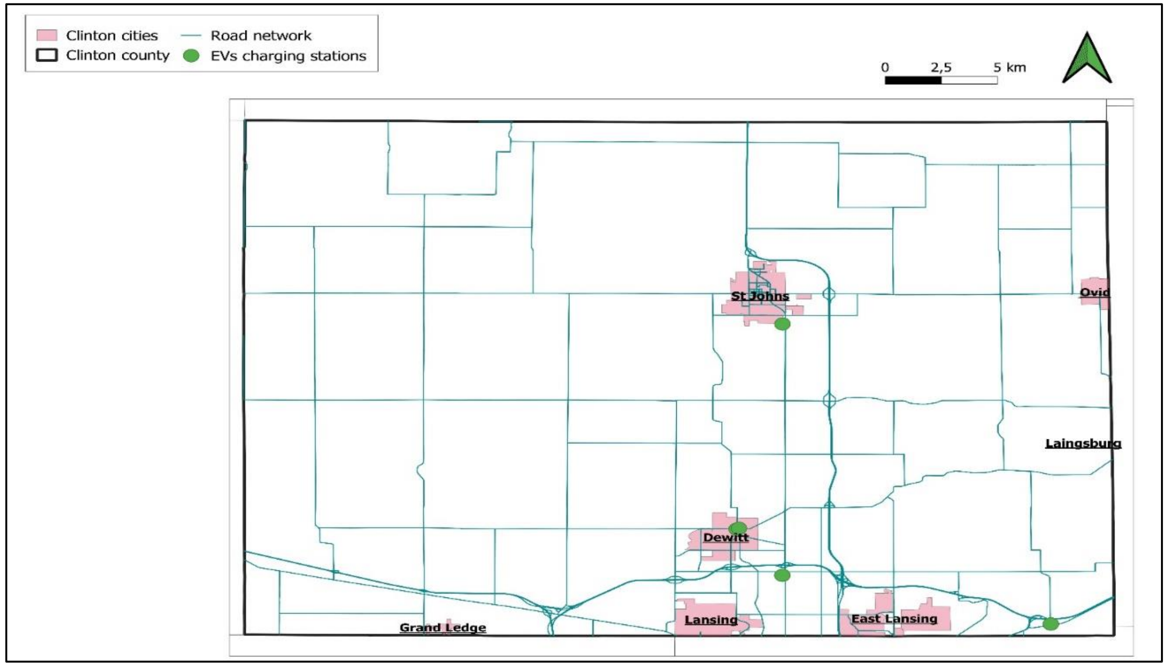
Dairy farms in the county



Current rest areas and pumping stations



Road traffic analysis

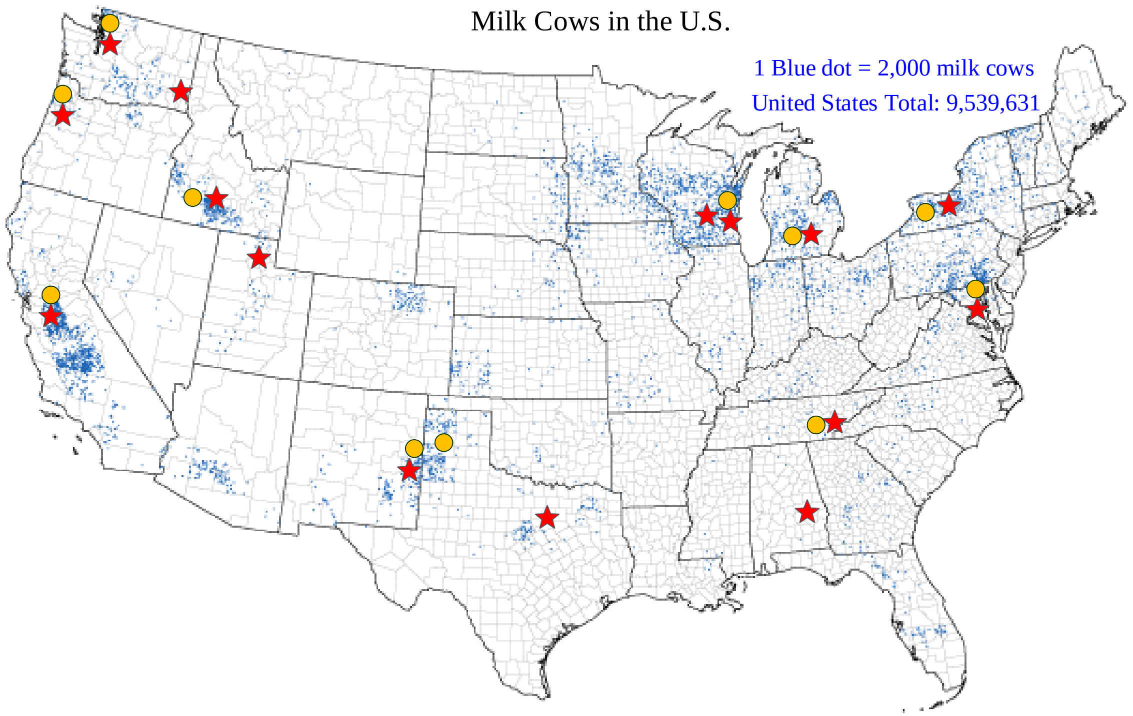


Four EV supercharging stations in the county

6. Summary

- The revenues from biogas EV charging can cover up to **41% of the milk production cost**, especially for small- and medium-dairy operation.
- Carbon capture from manure and renewable electricity will reduce the carbon footprint of the dairy operation by **at least 45%** (including both reduced GHG emissions and renewable electricity replacing fossil fuels).
- The farm-based EV charging solution can facilitate establishment of the charging network in rural areas.
- The U.S. dairy industry with the farm-based biogas EV charging solution can satisfy more than 20% of the demand of **4 million long-haul electric trucks in the U.S.**
- The new MSU dairy farm with the EV charging station will provide a platform for demonstrating and optimizing the EV charging solutions for rural communities.

Collaboration of researching and developing farm-based EV charging solutions *



*: Yellow dots are potential demonstration farms; Red stars are R&D institutions.

Thank You!

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- MSU AgBioResearch
- Michigan Economic Development Corporation (MEDC)
- USDA Agricultural Research Service (ARS)

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BAE Department of Biosystems and Agricultural Engineering

MSU Anaerobic Digestion Research and Education Center (MSU ADREC)


Main building


High-bay area


External combustion engine

Mobile charging unit


CSTR system
(2000 m^3, 0.4 MW)


Plug flow system
(1000 m^3)


Pilot water and energy testing site


Mobile solar-bio-powered waste utilization system

Homepage: http://www.egr.msu.edu/bae/adrec/