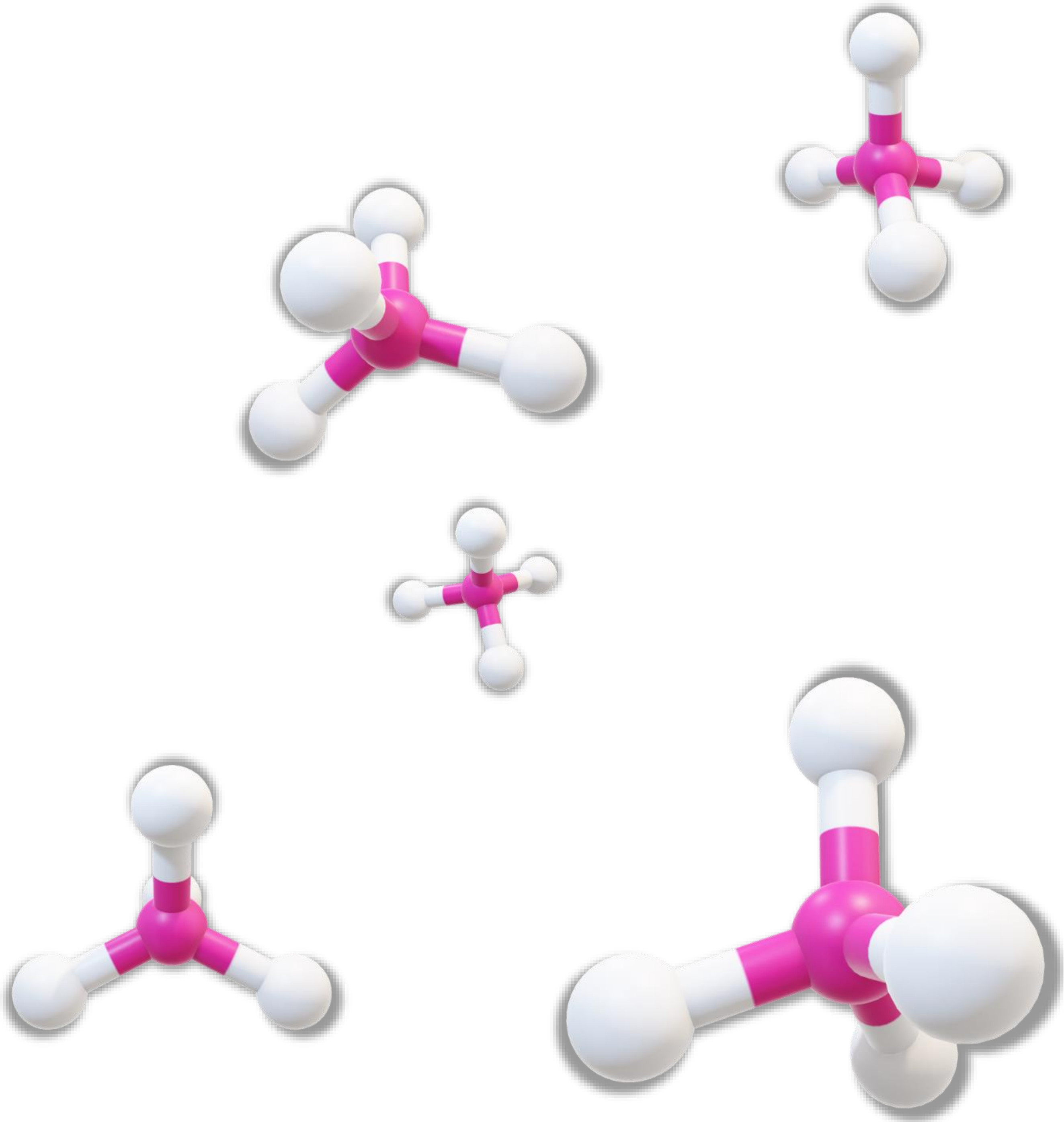
Manure Digester Systems

Gus Simmons, PE

Chief Innovation Officer



CAVANAUGH

Stewardship Through Innovation

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Stewardship Through Innovation

Bioenergy

Water Efficiency

Quick Bio: Gus Simmons, P.E. – Director of Bioenergy

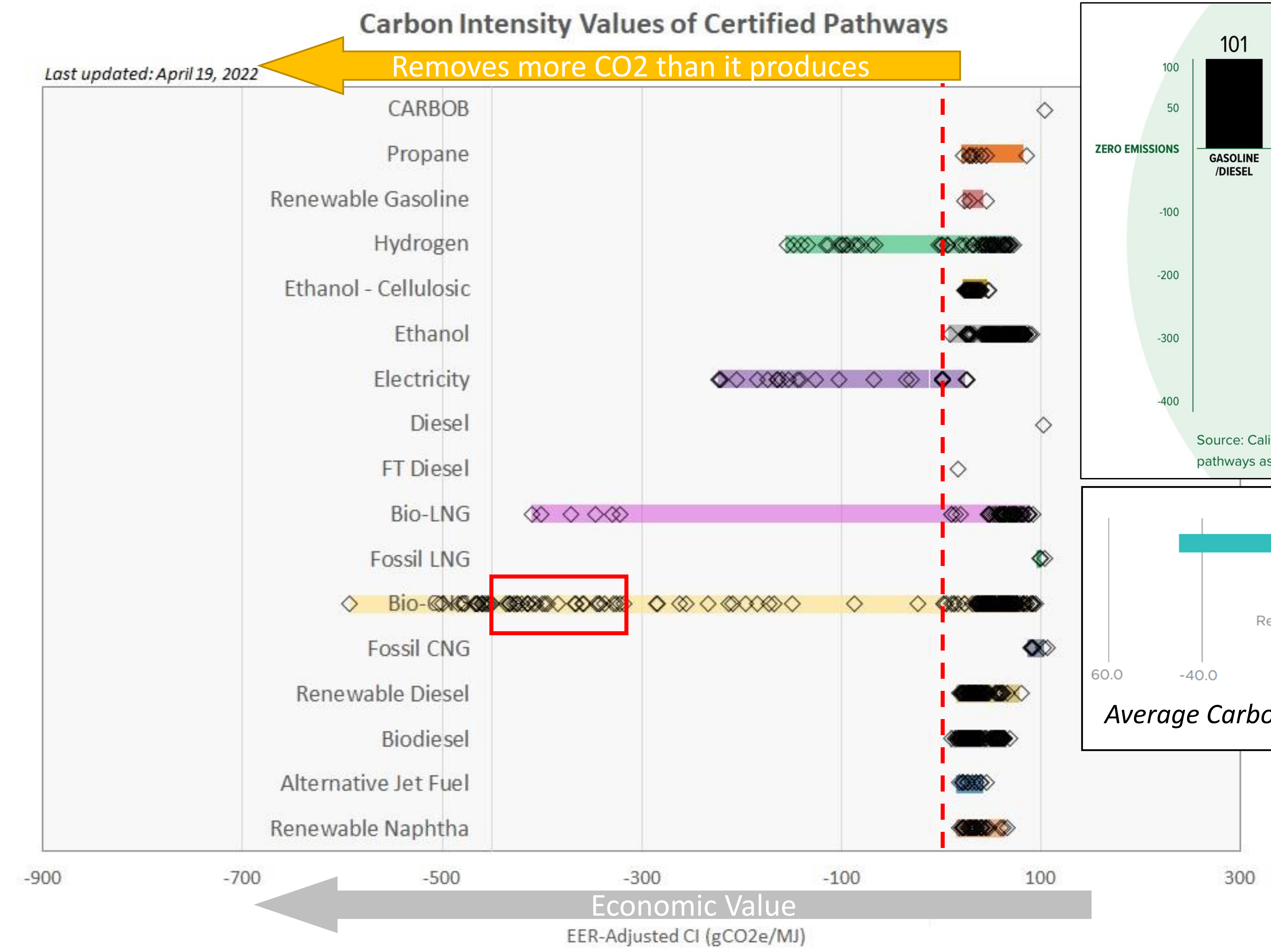
- Graduated from NCSU with BS in BAE in 1997
- Worked as Engineering Tech for a multi-national food and production ag company 1996 – 2001
  - Engineering Design Tech
  - Director of Environmental Affairs & Engineering
- Joined Cavanaugh & Associates, P.A. in 2001 – P.E.
- Made Partner in 2004, Wilmington Branch Manager
- Began Bioenergy Services sector in 2007
- Biogas and Renewable Natural Gas advocate / innovator
- Appointed to North Carolina Energy Policy Council (2x)

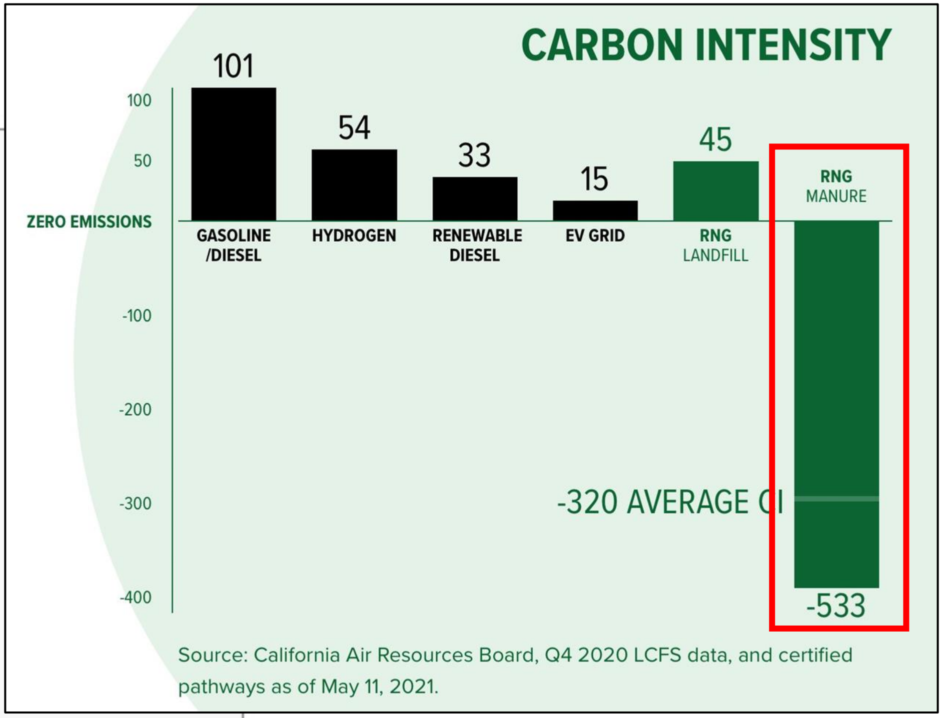
WilmingtonBiz 100

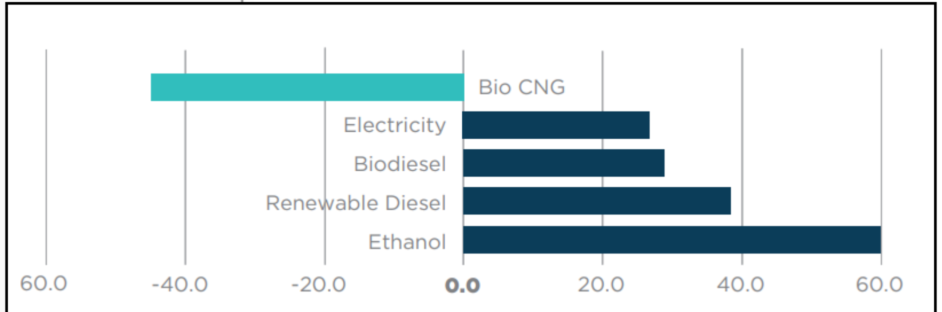
10th ANNIVERSARY COASTAL ENTREPRENEUR AWARDS

So, Why Farm-derived RNG?

1. Ultra-Low Carbon Intensity RNG







Average Carbon Intensity of All Sources - 2022

Why Renewable Natural Gas (RNG)?

"…replacing ***less than 20 percent*** of the traditional gas supply with RNG captured from sources like dairies, wastewater treatment plants and landfills can achieve greenhouse gas (GHG) emissions reductions equivalent to ***converting 100 percent*** of buildings to electric only energy by 2030."

- *Analysis of the Role of Gas for a Low-Carbon California Future*
  Southern California Gas Company

2022

Put into Perspective, Last Year RNG as a Transportation Fuel ...

Lowered GHG emissions equivalent to **13,962,408,760** miles driven by the average passenger car

Reduced CO_2 emissions equal to **632,947,114** gallons of gasoline consumed

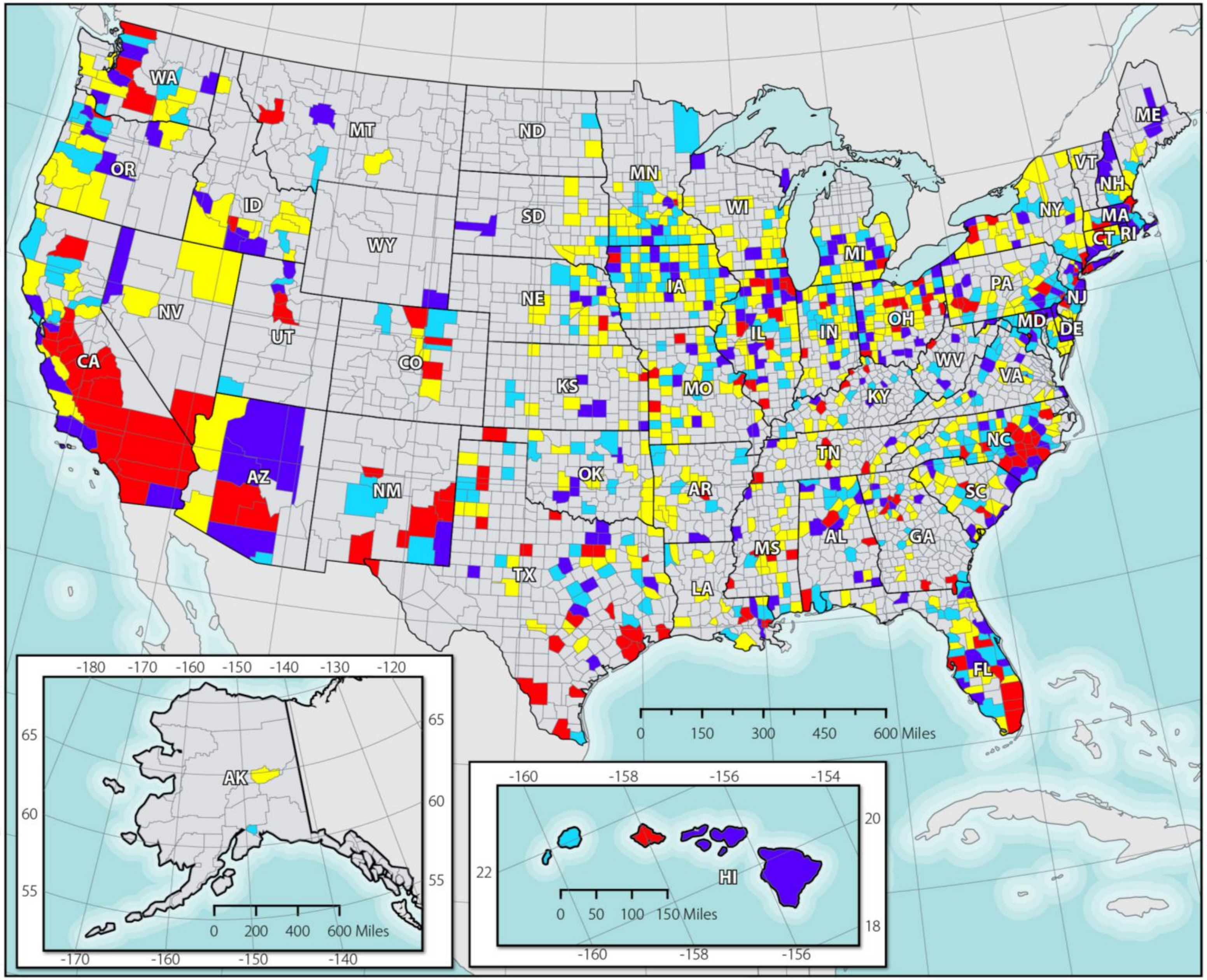
Sequestered carbon equal to growing **93,009,875** tree seedlings for ten years

or **6,656,825** acres of U.S. forests for one year

Source: Coalition for Renewable Natural Gas, April 2023

Source: American Gas Association

Estimated Methane Generation Potential from Select Biogas Sources

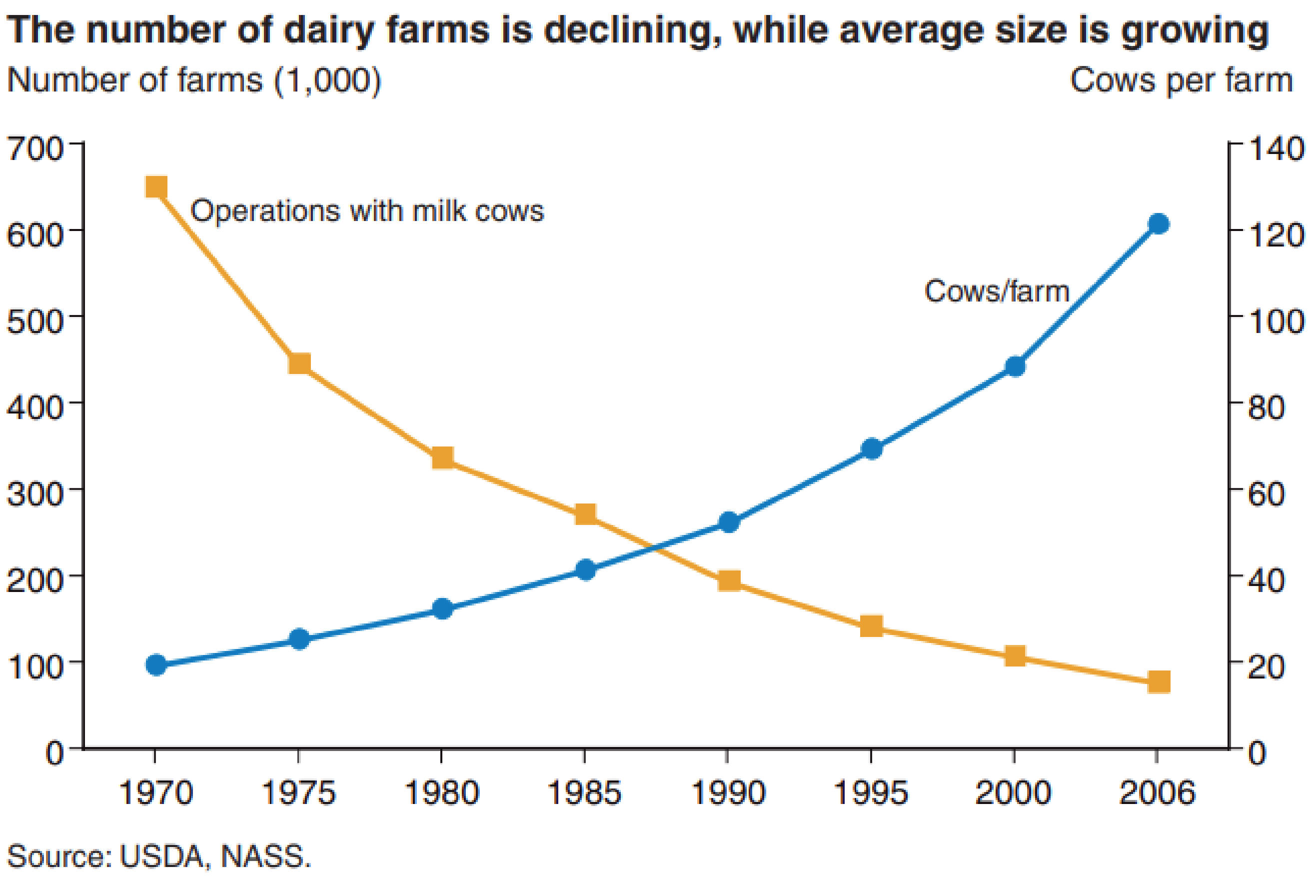


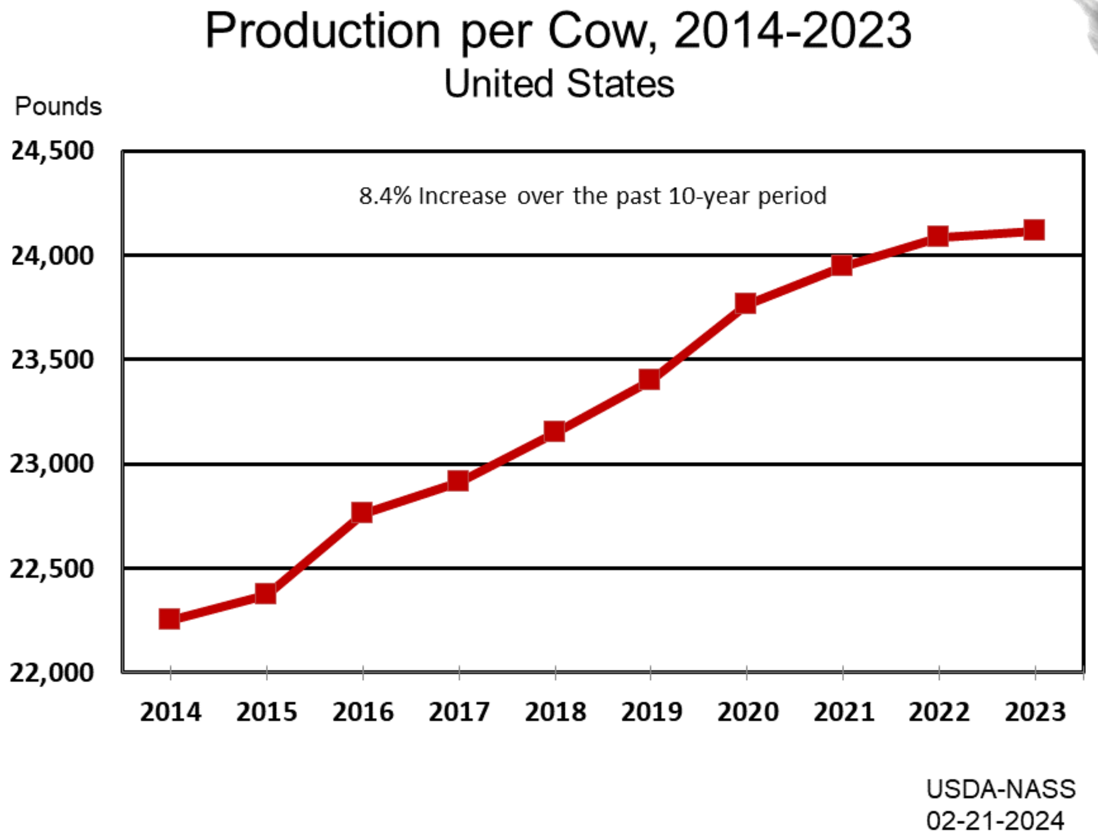
This analysis illustrates the methane generation potential by county from the following biogas sources: landfills; animal manure; wastewater treatment; and industrial, institutional, and commercial organic waste (IIC).

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.
Billy J. Roberts
15 January 2014

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

2. Farm Size, Distribution, & Consolidation


The number of dairy farms is declining, while average size is growing
Number of farms (1,000)
Cows per farm
Operations with milk cows
Cows/farm
700
600
500
400
300
200
100
0
140
120
100
80
60
40
20
0
1970
1975
1980
1985
1990
1995
2000
2006
Source: USDA, NASS.


Production per Cow, 2014-2023
United States
Pounds
8.4% Increase over the past 10-year period
24,500
24,000
23,500
23,000
22,500
22,000
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
USDA-NASS
02-21-2024

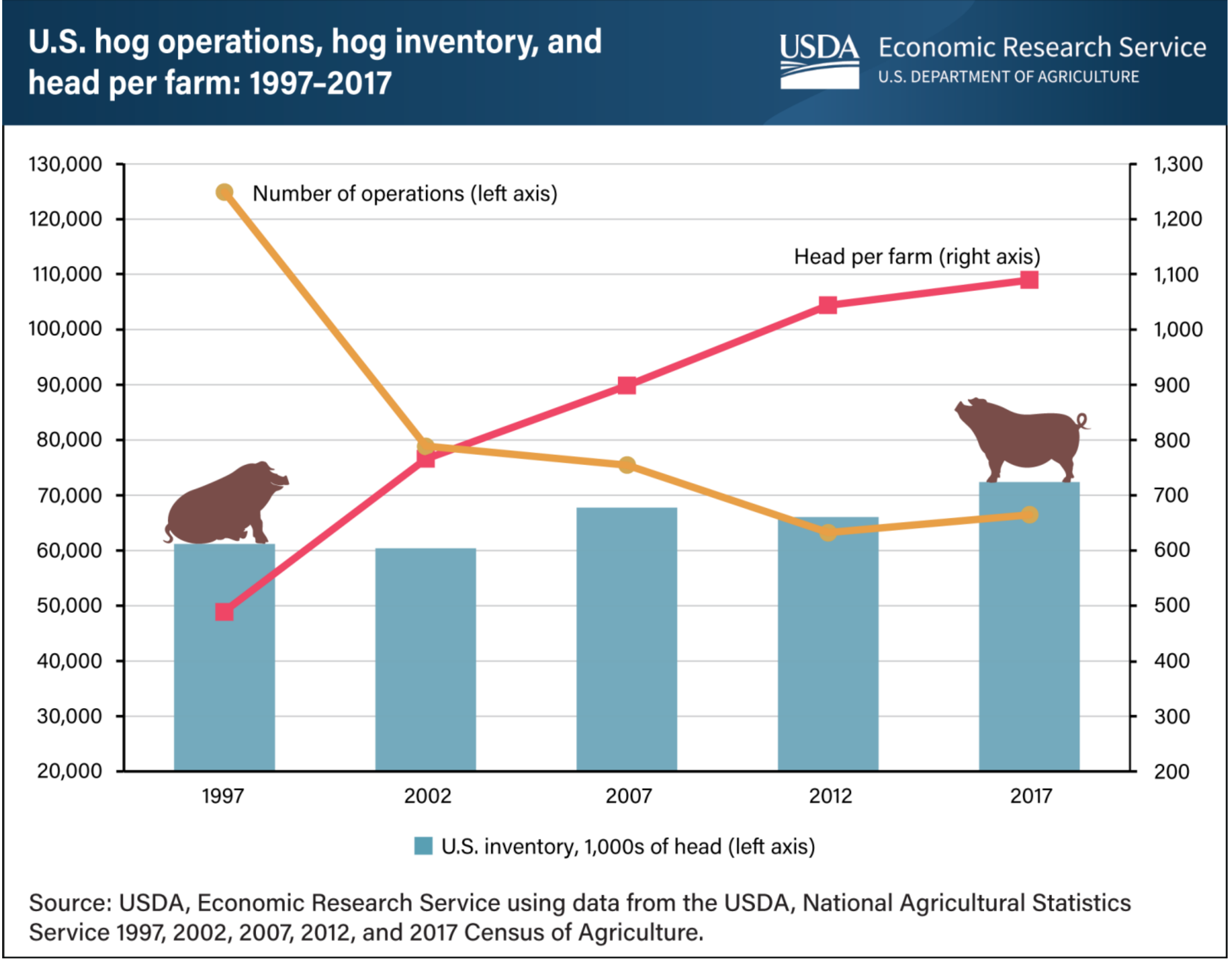
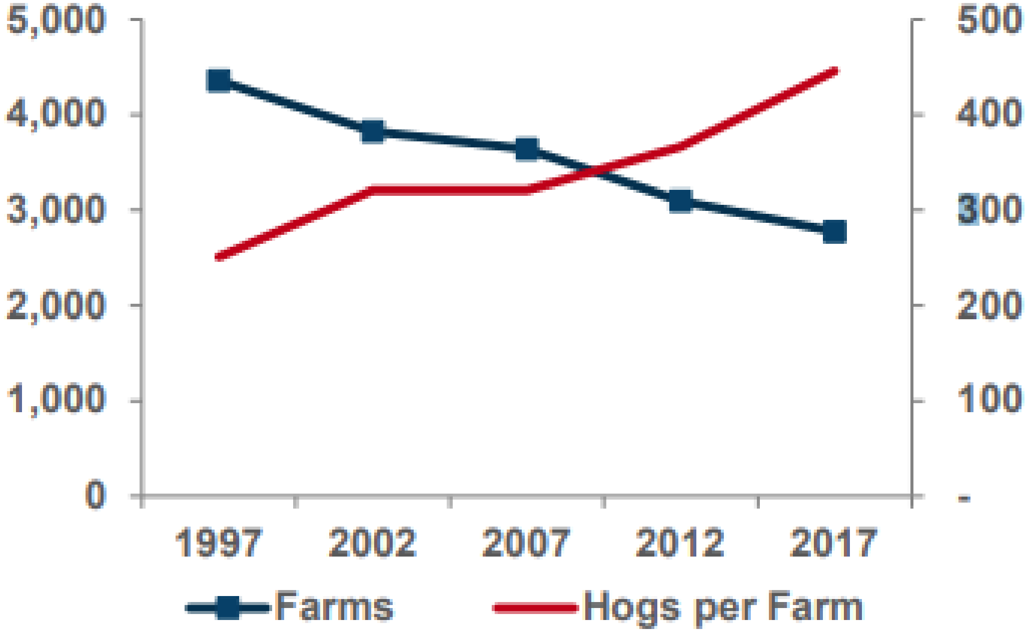
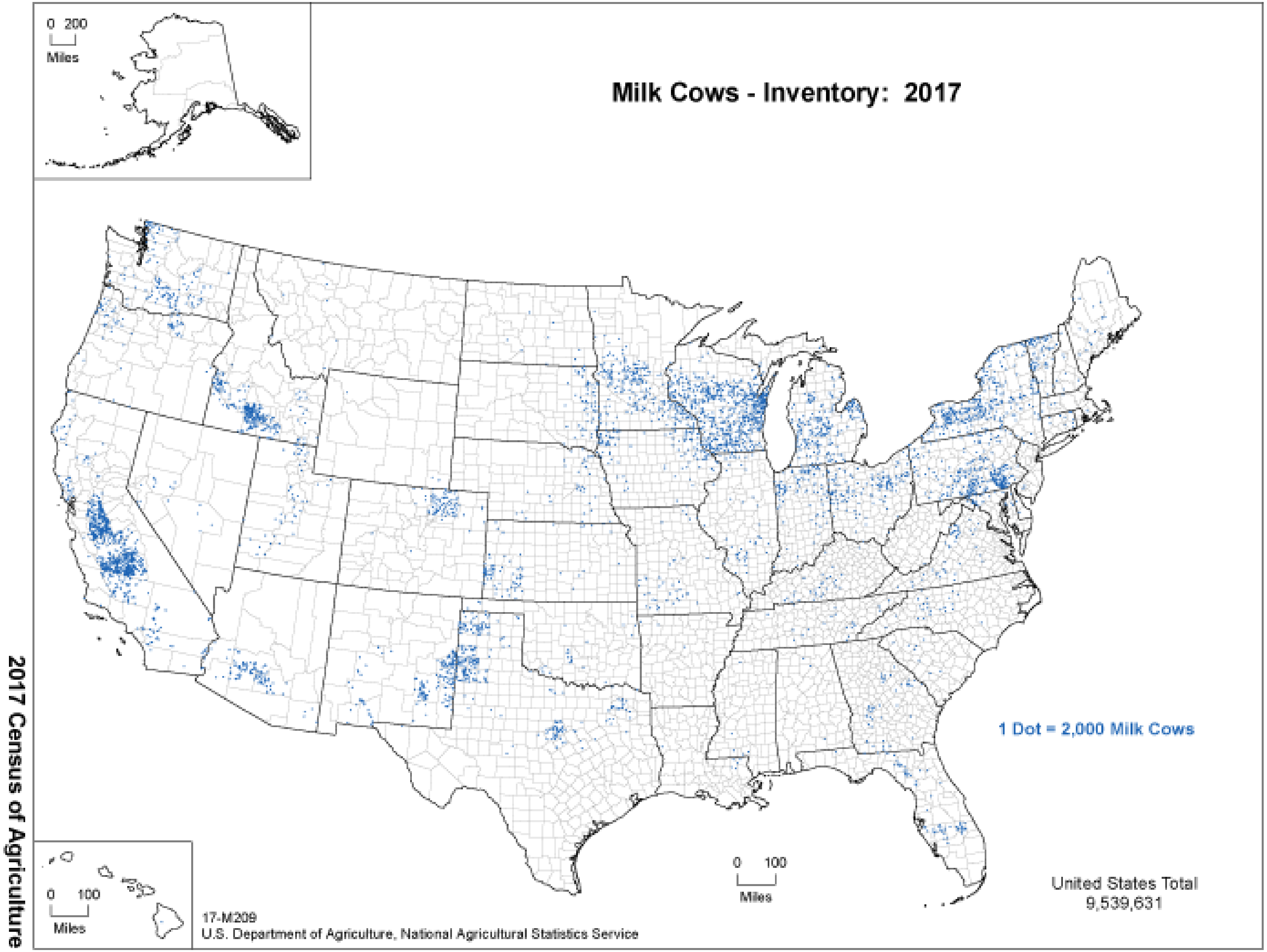


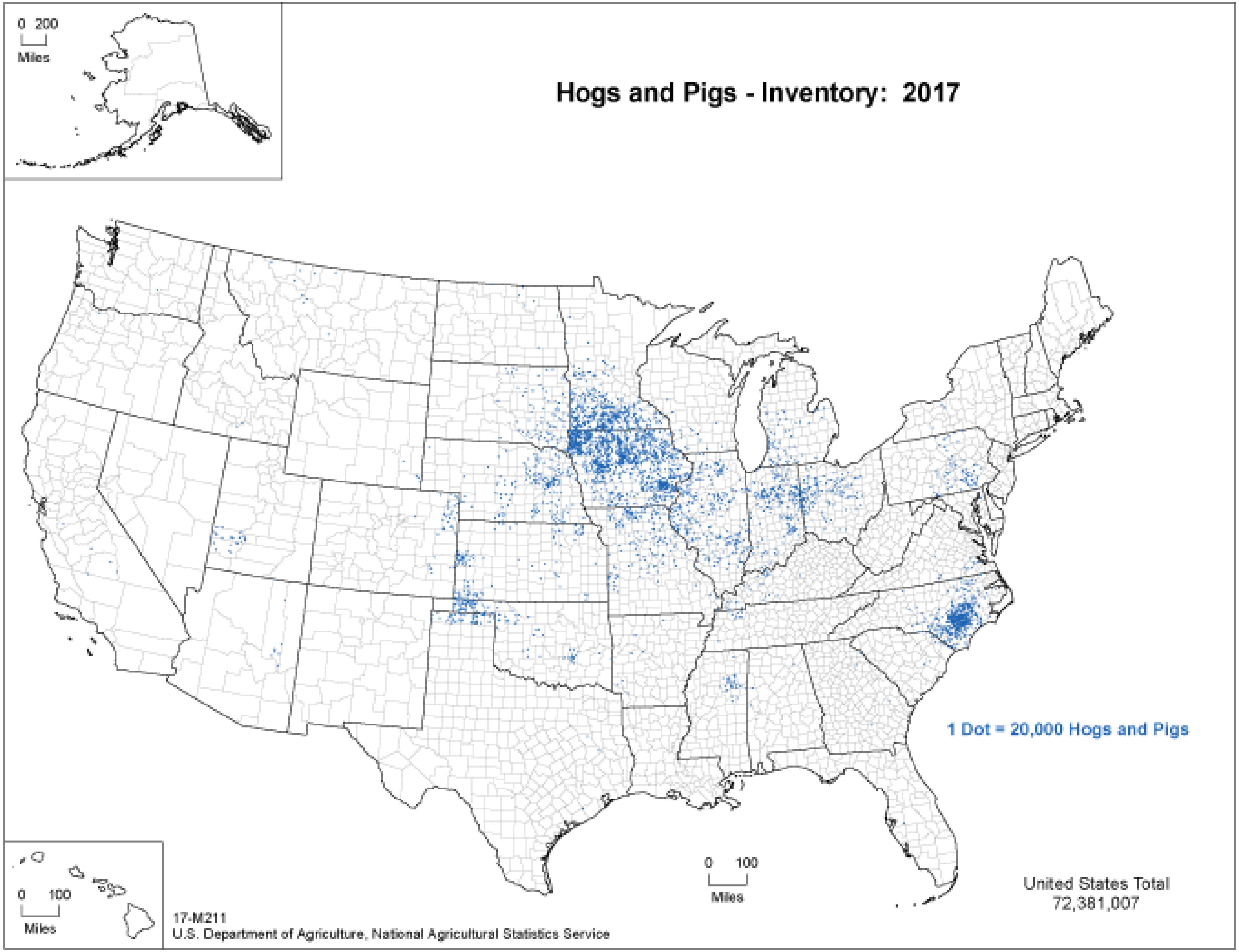
Figure 2. Pennsylvania Hog Farms and Hogs per Farm





Top U.S. Milk Producing States (2022)

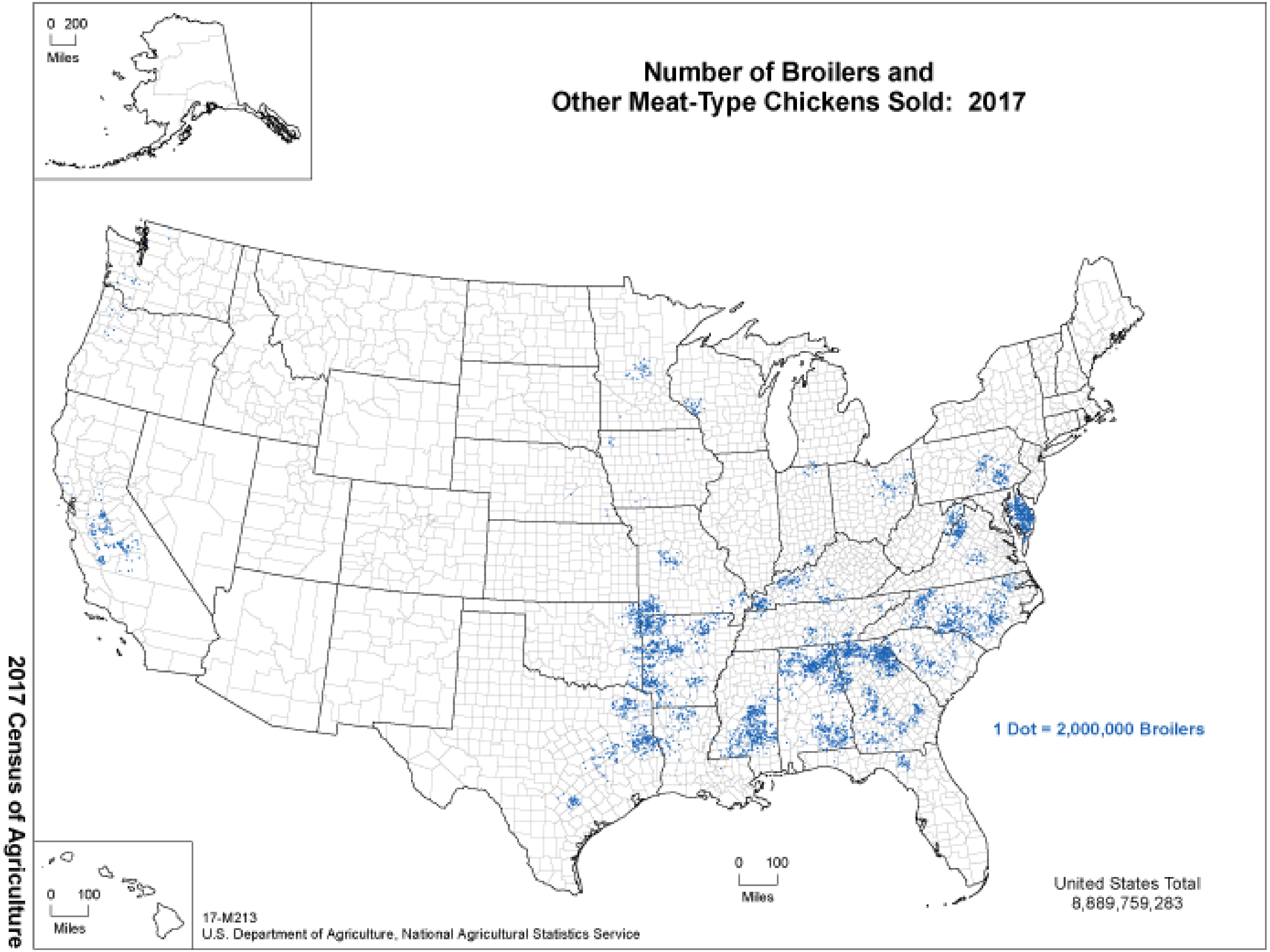
California	3,500,000,000
Wisconsin	2,700,000,000
Texas	1,400,000,000
Idaho	1,400,000,000
New York	1,300,000,000
Michigan	1,000,000,000
Minnesota	883,000,000
Pennsylvania	828,000,000
New Mexico	575,000,000
Washington	502,000,000
Iowa	494,000,000
Ohio	466,000,000
Colorado	443,000,000
Arizona	407,000,000
Indiana	374,000,000
South Dakota	355,000,000
Kansas	352,000,000
Vermont	214,000,000
Oregon	212,000,000
Utah	177,000,000
Georgia	175,000,000
Florida	157,000,000
Illinois	142,000,000
Virginia	115,000,000



2017 Census of Agriculture

Top U.S. Swine Producing States (2022)

Iowa	14,300,000,000
Minnesota	4,700,000,000
North Carolina	4,200,000,000
Illinois	2,900,000,000
Indiana	2,100,000,000
Oklahoma	2,000,000,000
Nebraska	1,500,000,000
Ohio	1,400,000,000
South Dakota	1,400,000,000
Missouri	1,200,000,000
Kansas	952,300,000
Michigan	699,800,000
Pennsylvania	567,800,000
Texas	444,500,000
Utah	401,400,000
Wisconsin	263,700,000
Kentucky	243,300,000
Tennessee	187,700,000
Colorado	186,300,000
Montana	148,500,000
Wyoming	146,900,000
Mississippi	130,400,000
Virginia	97,200,000
Arkansas	96,100,000
North Dakota	84,800,000
Arizona	72,500,000
Georgia	59,900,000
South Carolina	50,400,000
Idaho	33,100,000



Top U.S. Chicken Producing States (2022 estimate)

Iowa	54,765,000
Ohio	48,290,000
Indiana	46,355,000
Texas	31,275,000
Pennsylvania	31,129,000
Georgia	30,938,000
Arkansas	26,504,000
North Carolina	23,853,000
Michigan	21,587,000
California	16,394,000

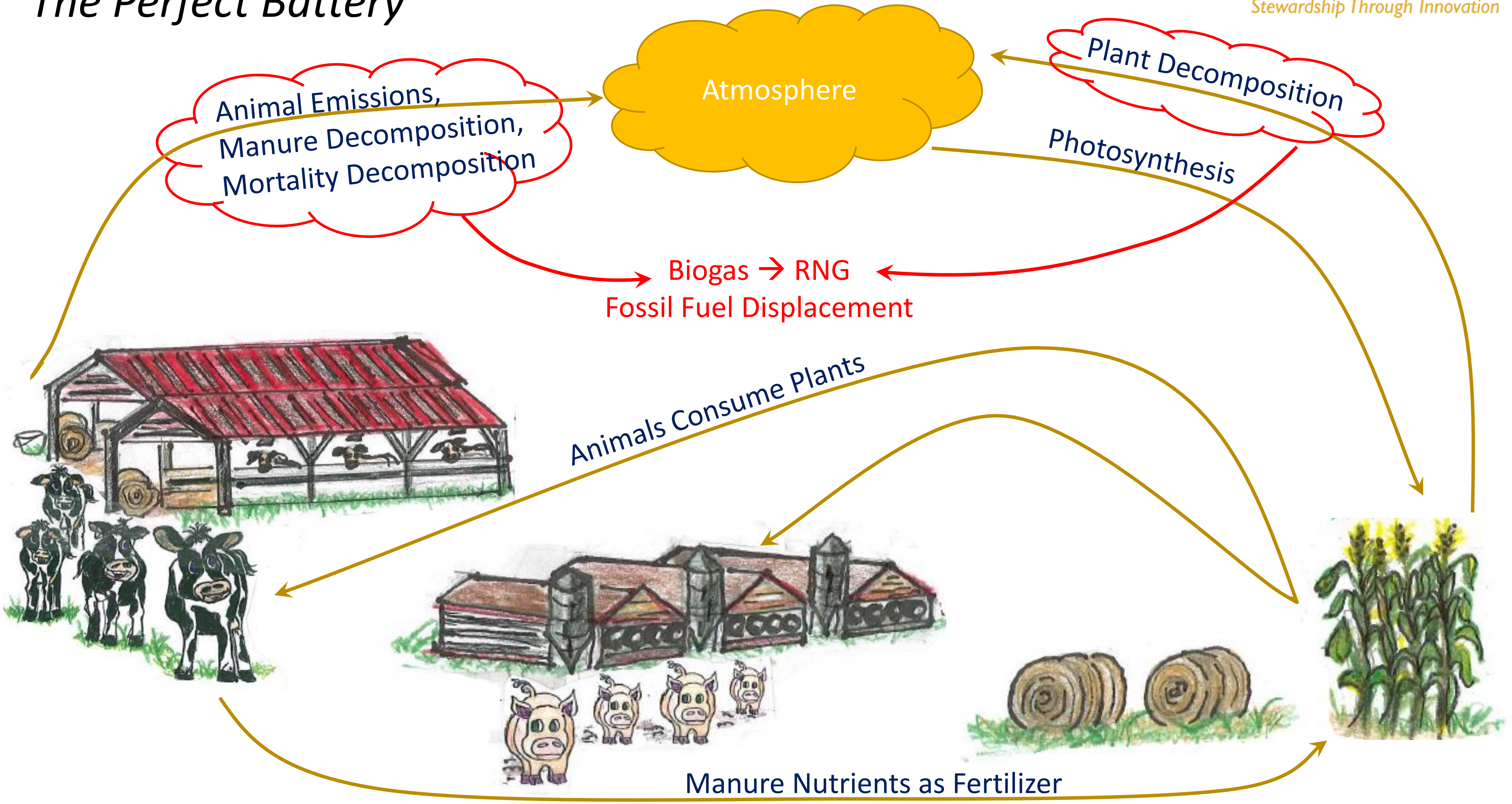
Top U.S. Turkey Producing States (2022 estimate)

Minnesota	37,000,000
North Carolina	28,000,000
Arkansas	26,000,000
Indiana	20,000,000
Missouri	17,000,000
Virginia	15,300,000
Iowa	11,700,000
Pennsylvania	7,700,000

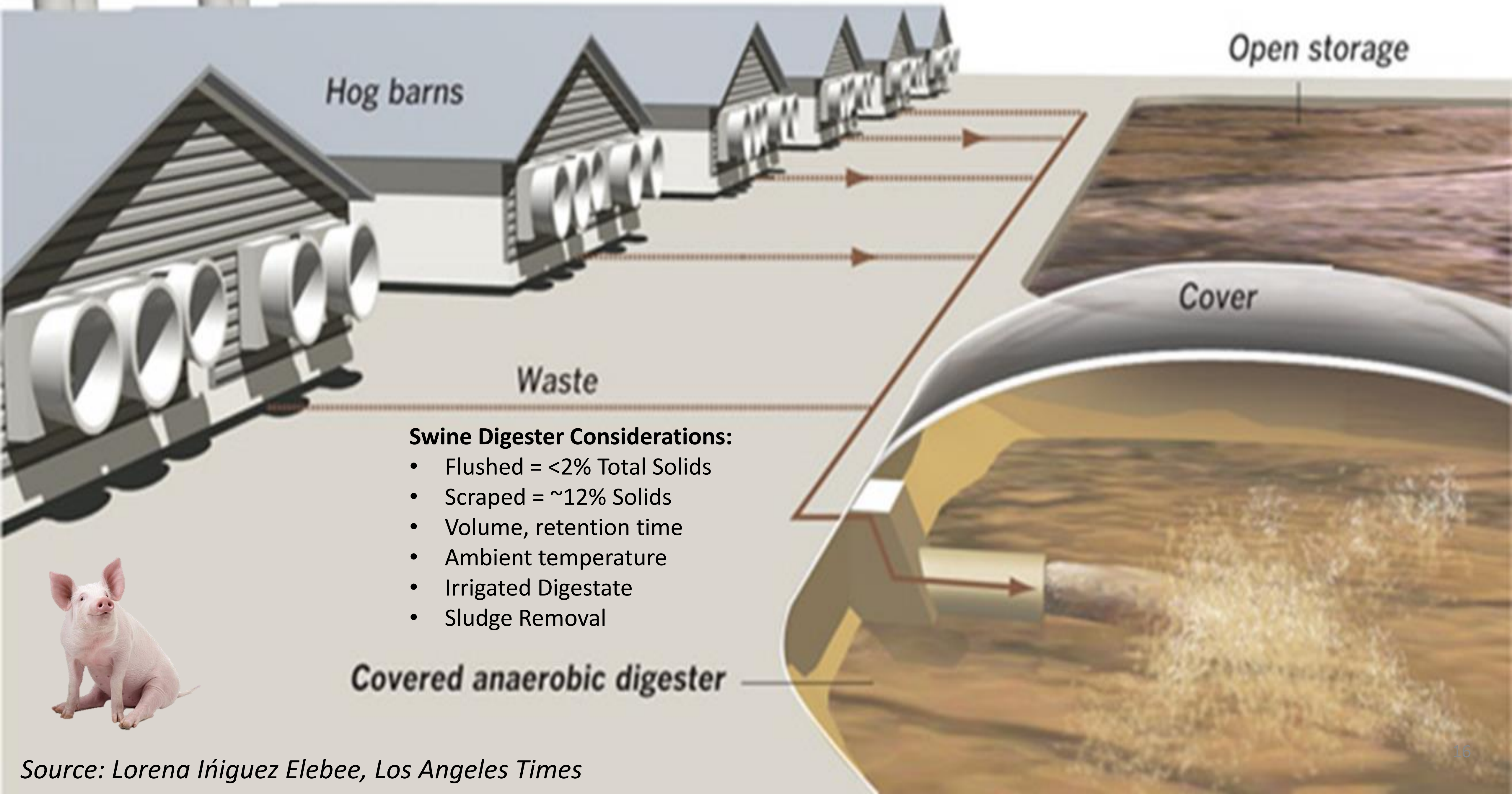
3. Types of Farm-Based Digester Systems

Agricultural Carbon Cycle
"The Perfect Battery"

CAVANAUGH
Stewardship Through Innovation



On-Farm Covered-Lagoon Digester System Schematic



Swine Digester Considerations:

- Flushed = <2% Total Solids
- Scraped = ~12% Solids
- Volume, retention time
- Ambient temperature
- Irrigated Digestate
- Sludge Removal

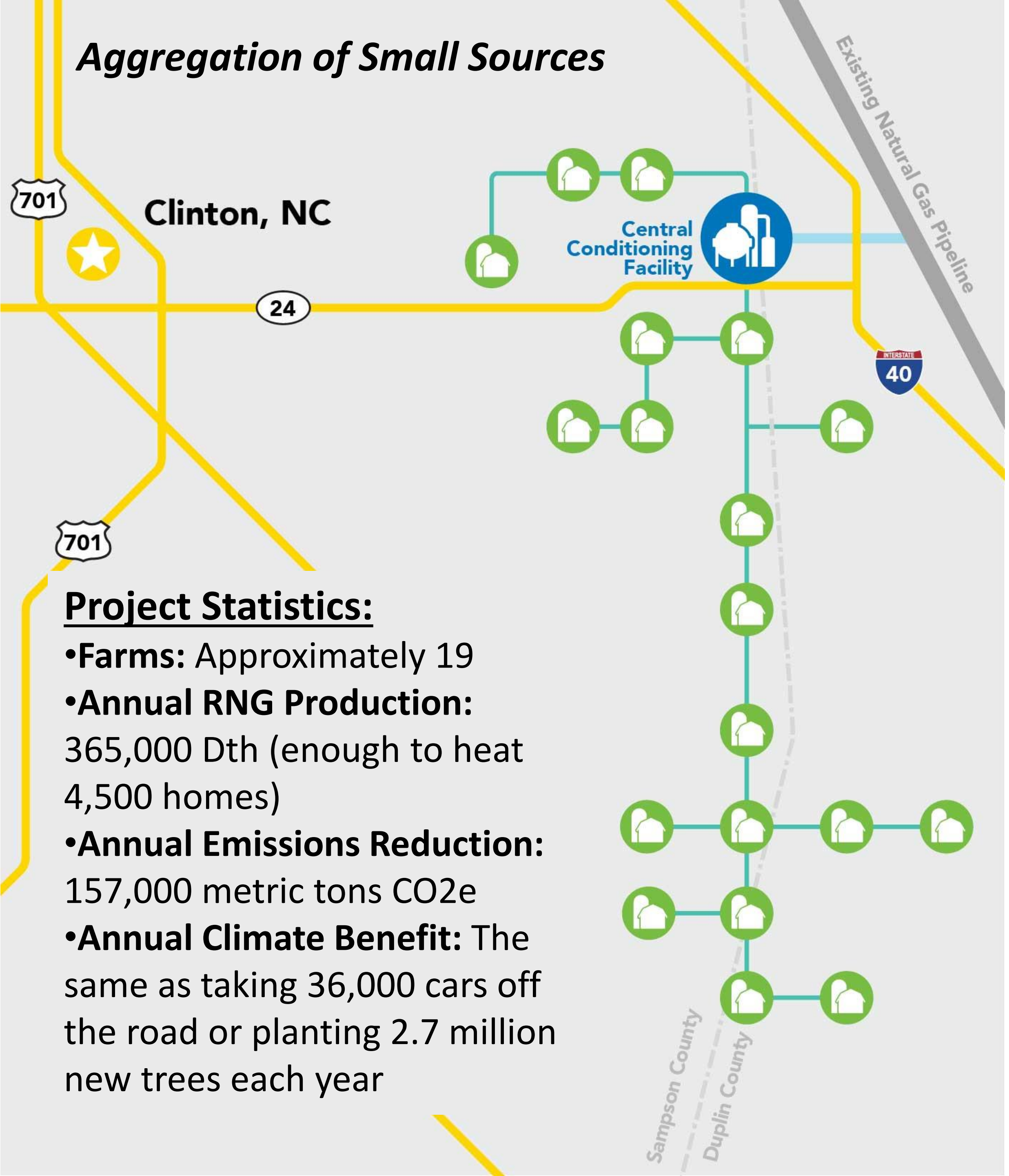
Source: Lorena Ińiguez Elebee, Los Angeles Times

OPTIMA KV

North Carolina’s First RNG Project

- *5 Participating Farms, 2 Farm Owners*
- *~60,000 Pigs Wean-to-Finish (combined)*
- *Biogas collected from each digester, piped together*
- *Centralized Gas Upgrading*
- *Pipeline injection of Renewable Natural Gas*

Aggregation of Small Sources



Project Statistics:

- **Farms:** Approximately 19
- **Annual RNG Production:** 365,000 Dth (enough to heat 4,500 homes)
- **Annual Emissions Reduction:** 157,000 metric tons CO2e
- **Annual Climate Benefit:** The same as taking 36,000 cars off the road or planting 2.7 million new trees each year

align RENEWABLE NATURAL GAS

Smithfield RENEWABLES

Dominion Energy

"This project implements proven 'manure-to-energy' technology across a number of farms to produce reliable renewable energy for our community and contributes to our company's ambitious goal to reduce our greenhouse gas (GHG) emissions 25% by 2025."

- Kraig Westerbeek,
Fmr Senior Director
Smithfield Renewables

On-Farm Dairy Digester Systems

Plug Flow Digester System

CSTR Digester System

Source: National Dairy Council

Dairy Digester Considerations:

- Sand Bedding?
    - Sand Lanes
    - Mechanical Removal
- Flush, Vacuum, or Scrape?
    - Thickening
- Debris Screening
- Digestate Management
    - Screened fiber / solids
    - Irrigated Liquids
- Sludge/grit/sand Removal

Poultry Litter AD: A Different Animal All Together

Poultry Digester Considerations:

- *Bedding*
- *Lignocellulosic*
- *Moisture Content*
- *Hydrogen Sulfide*
- *Nitrogen*
- *Scale*

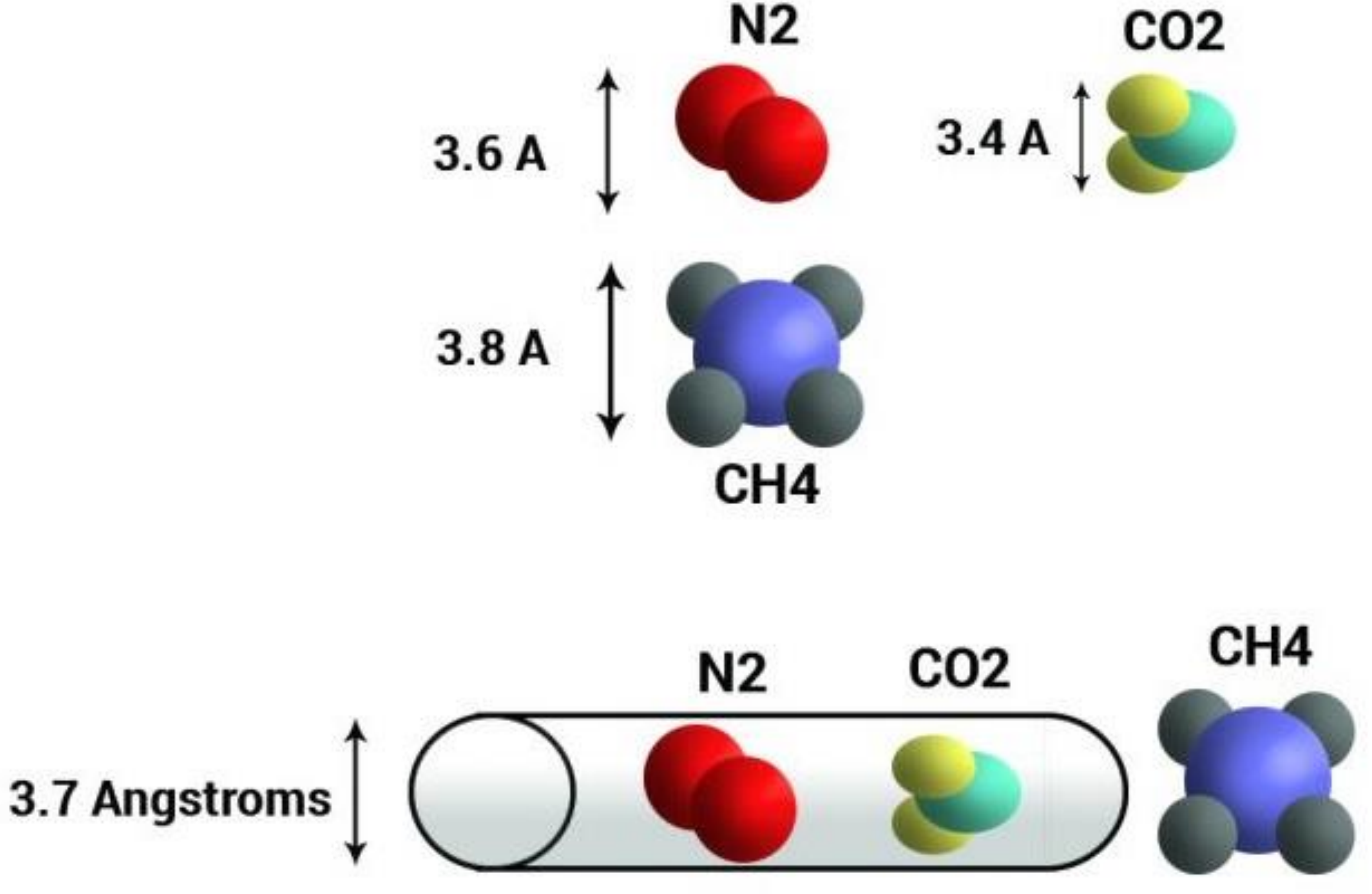
Source: University of Maryland Extension

Source: Delaware Business Times

Source: EPA AgSTAR

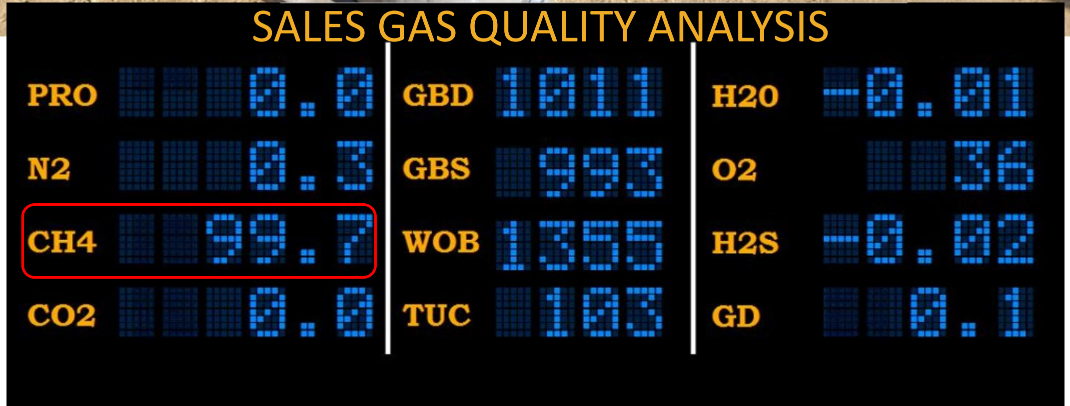
4. Gas Upgrading, Briefly


Biogas Separation – Its all about size.



Membrane Filter or Media

BIOGAS 3000
LANDTEC
25/04/24 12:33
Sample Point 1
CH4 57.3% H2S 520ppm
CO2 9.1%
O2 2.8%
00:01
07:58:31
214 ml/m
View Alarms
Stop Sampling
View Faults



SALES GAS QUALITY ANALYSIS
PRO 0.0
N2 0.3
CH4 99.7
CO2 0.0
GBD 1011
GBS 993
WOB 1355
TUC 103
H20 -0.01
O2 36
H2S -0.02
GD 0.1

Characteristic / Constituent	Limit
Delivery Temperature:	40°F to 120°F.
Methane:	>94%.
Heating Value:	980 - 1100 Btu/SCF
Interchangeability: WOBBE	1290 - 1370.
Hydrogen Sulfide (H2S):	<0.25 grain/100 SCF.
Mercaptan:	<0.5 grain/100 SCF.
Total Sulfur:	<10 grain/100 SCF, including H2S
Water:	<7 pounds/MMSCF
CHDP:	<20°F.
Carbon Dioxide (C02):	<2% by volume
Nitrogen:	<2% by volume
Oxygen:	<0.2% by volume
Carbon Monoxide (CO):	<0.1% by volume.
Total Inerts:	<3.2% by volume
Hydrogen:	<600 ppm.
Solid Particle Size:	remove 99.99% >3 microns
Dust, Gums & Solid Matter:	0
Biologicals:	$<4 \times 10^4$ count/scf active bacteria
Organic Silicon (Siloxanes):	<0.40 mg of SJ/Nm^3
Odorization Masking/Fading Agents (VOC):	0
VOC:	0 dioxins.

Constituent	Limit mg/m^3 (ppmv)
Arsenic	0.48 (0.15)
p-Dichlorobenzene	140 (24)
Ethylbenzene	650 (150)
n-Nitroso-di-n-propylamine	0.81 (0.15)
Vinyl Chloride	21 (8.3)
Antimony	30 (6.1)
Copper	3.0 (1.2)
Lead	3.8 (0.44)
Methacrolein	53 (18)
Alkyl thiols (mercaptans)	N/A (610)
Toluene	45,000 (12,000)

Varying Gas Testing Standards

- ~32 Constituent Parameters that must be tested (multiple times) via independent, 3rd party laboratory, prior to injection & ongoing
- Manure-derived biogas typically returns ~6 detectable constituents
- Additional testing required if online systems indicate potential excursion
- Additional testing per discretion of the Utility (perception, safety)

5. Manure FAQs & Myths

The FAQs & Myths of Manure Digestion – Physics & Laws of Conservation

What comes out cannot be greater than what goes in

1. Conservation of Matter
   - Digesters do not make matter disappear!!!
   - Feed grains and ingredients size;
   - Typical manure particle size
   - Converting liquid/solid carbon to gaseous carbon
   - Mass balance must be "zero sum game"

2. Conservation of Energy:
   - The energy extracted cannot be greater than what is fed to the animal!!!
     - Feed conversion improvements
   - Energy balance!

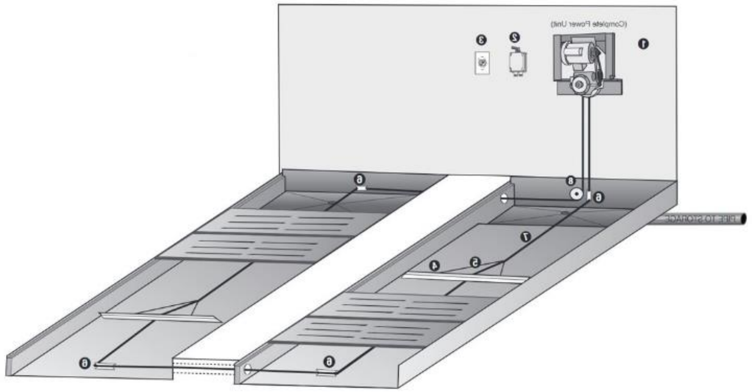
The FAQs & Myths of Manure Digestion – Pay Attention to Feedstock!

1. Manure Collection Practices
   - Flushed systems (flush tanks, shallow pit recharge) *=> 0.5% - 1.0% Solids*
   - Deep pit collection and storage *=> 8% - 10% Solids*
   - Scraper / vacuum system => *10% - 15% Solids*

2. Model vs. Reality
   - Published data is “nationalized” and sometimes aged…
   - Multi-site production, varying animal sizes, climate/weather…

3. “Ingredients”
   - Biocides (cleaners, disinfectants)
   - Inorganic substances (sand, debris)

4. Elegantly Simple vs Complex



6. Stepping-Stone to Additional Resource Stewardship

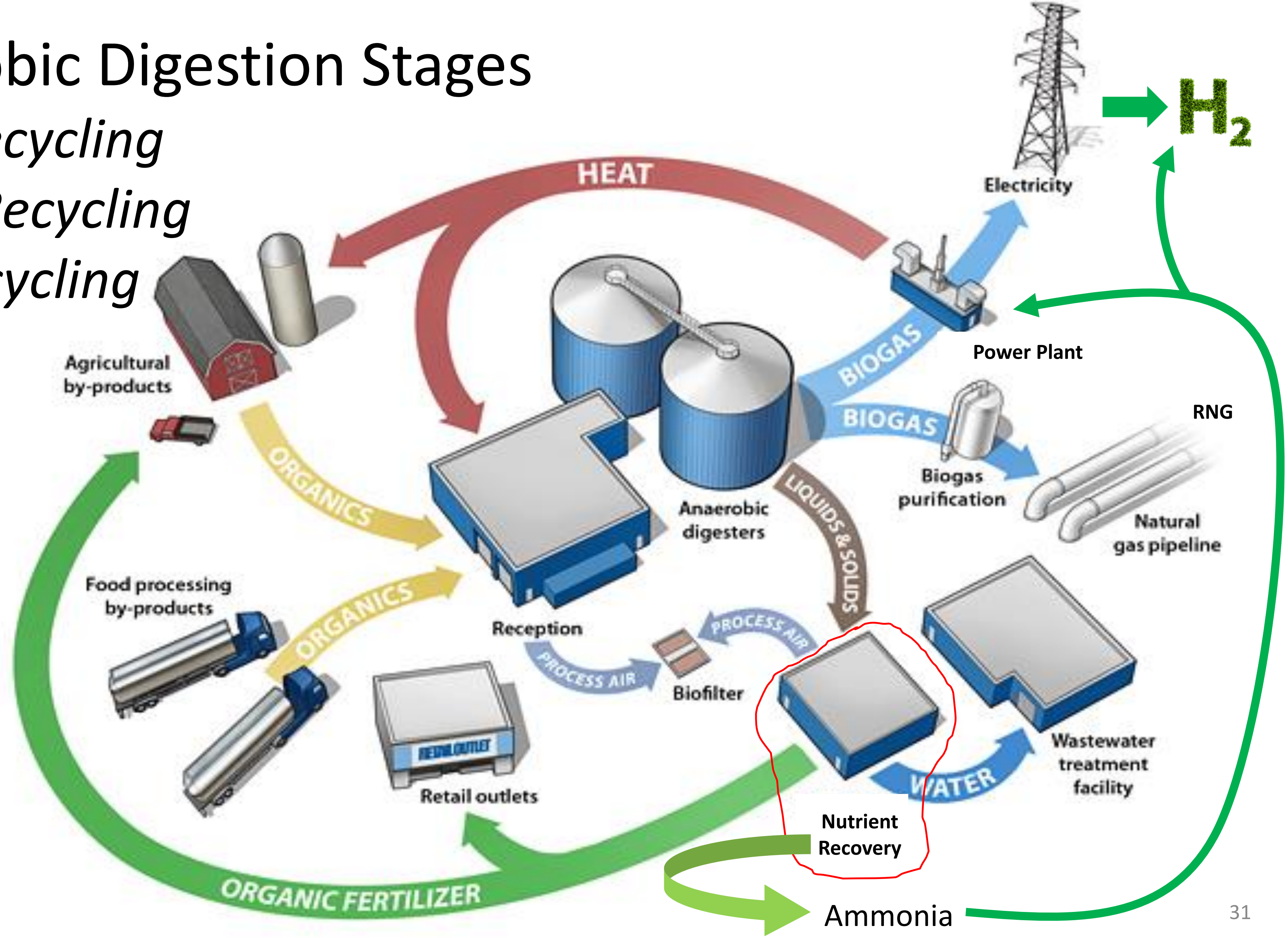
Manure Anaerobic Digestion Stages

Step 1: Carbon Recycling

Step 2: Nutrient Recycling

Step 3: Water Recycling

Step 4: Repeat



Summary Thoughts:

1. Low or Ultra-Low Carbon Intensity
2. Large number of small farms, consolidation
3. Farm density and clustering / aggregation
4. Technically Practical / Low Technology Risk
5. Feedstock Management is Key
6. Future Added Resource Stewardship & Value
   (Ammonia, Hydrogen, Nutrients, Water)