Dairy Farm Emissions in California:
The Impact on Communities of Disadvantage

Brenna Biggs, Ph.D.

Rowland-Blake Lab | UCI Chemistry

Solutions that Scale

Earth Day 2021

California Is Home

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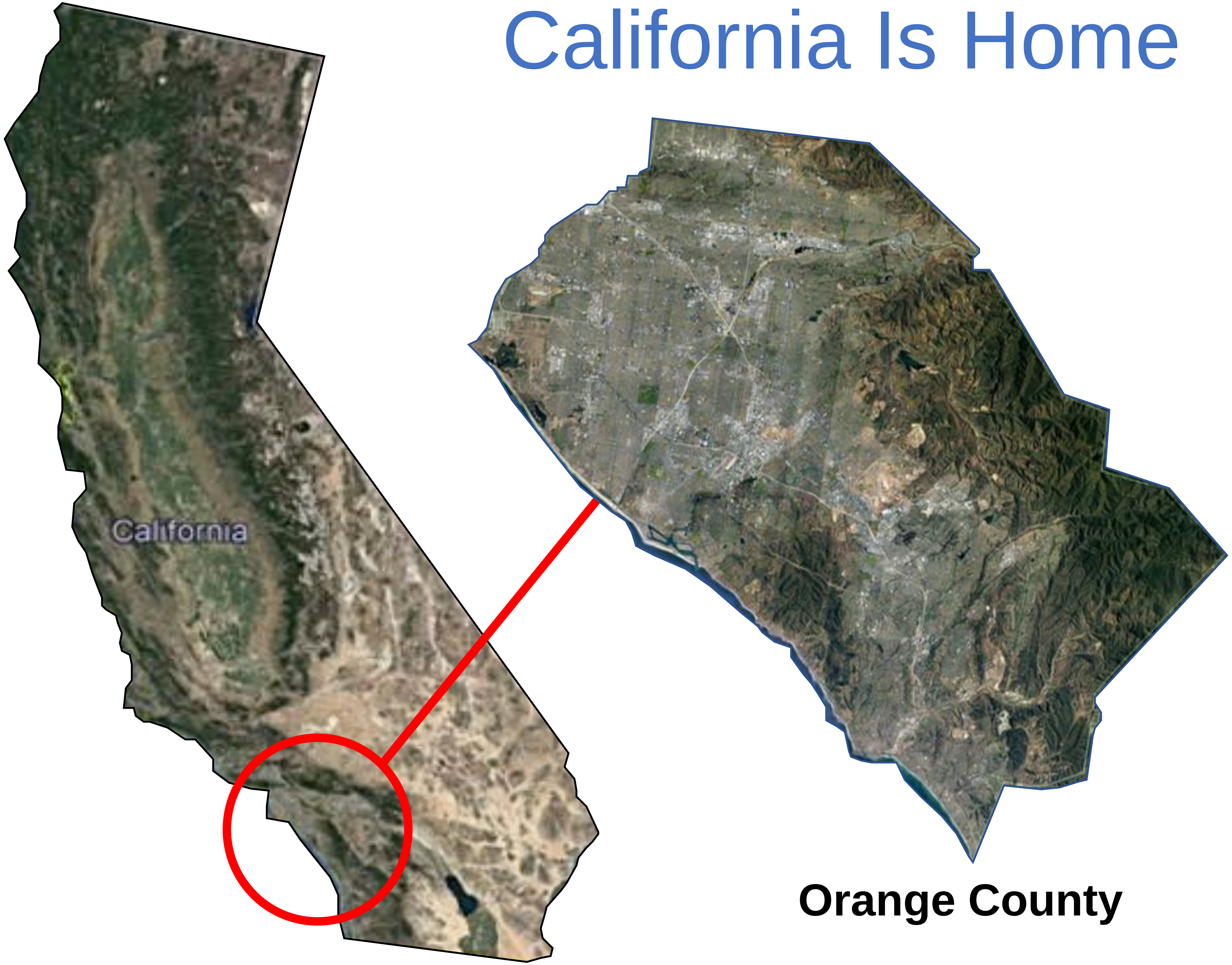

Orange County

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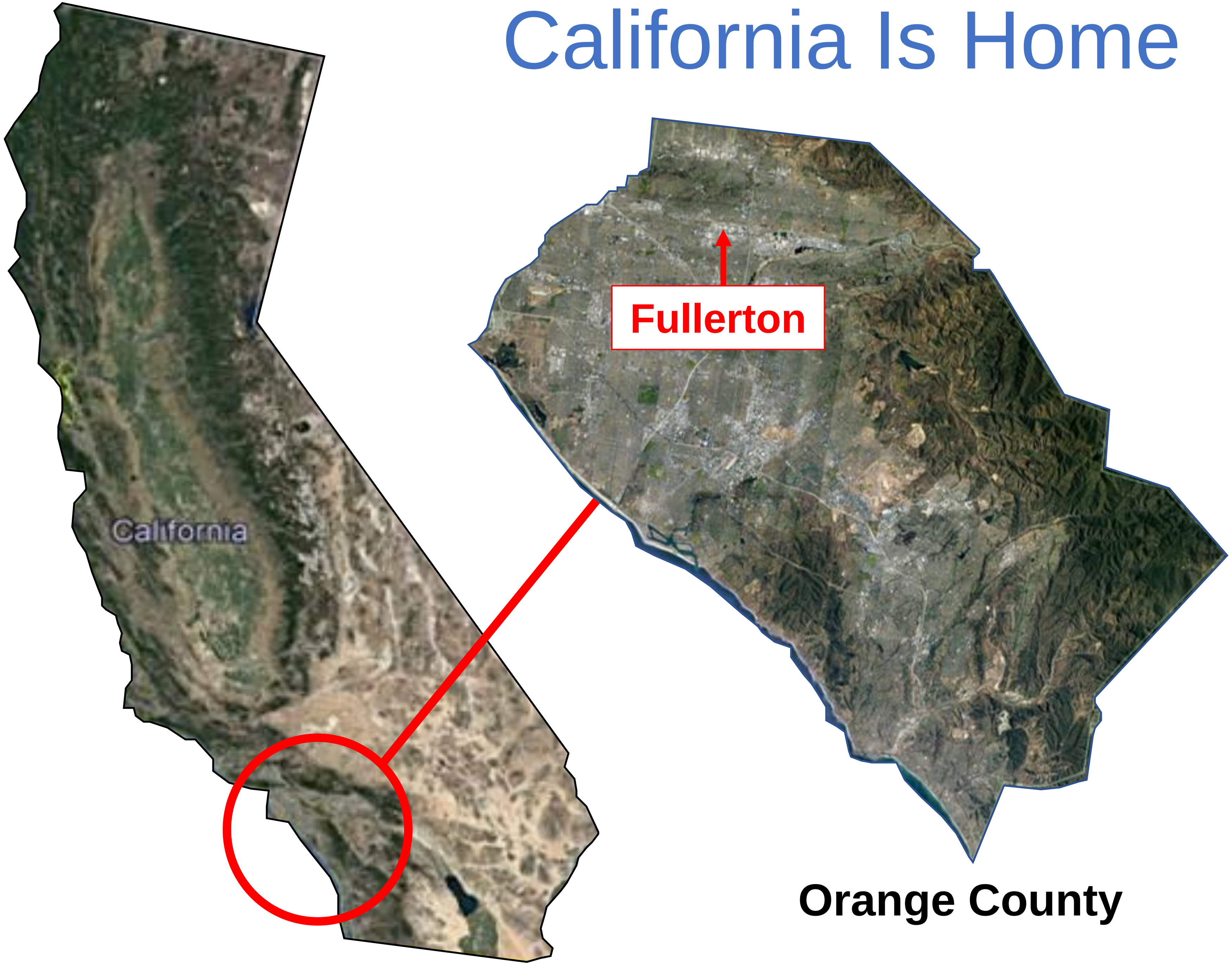

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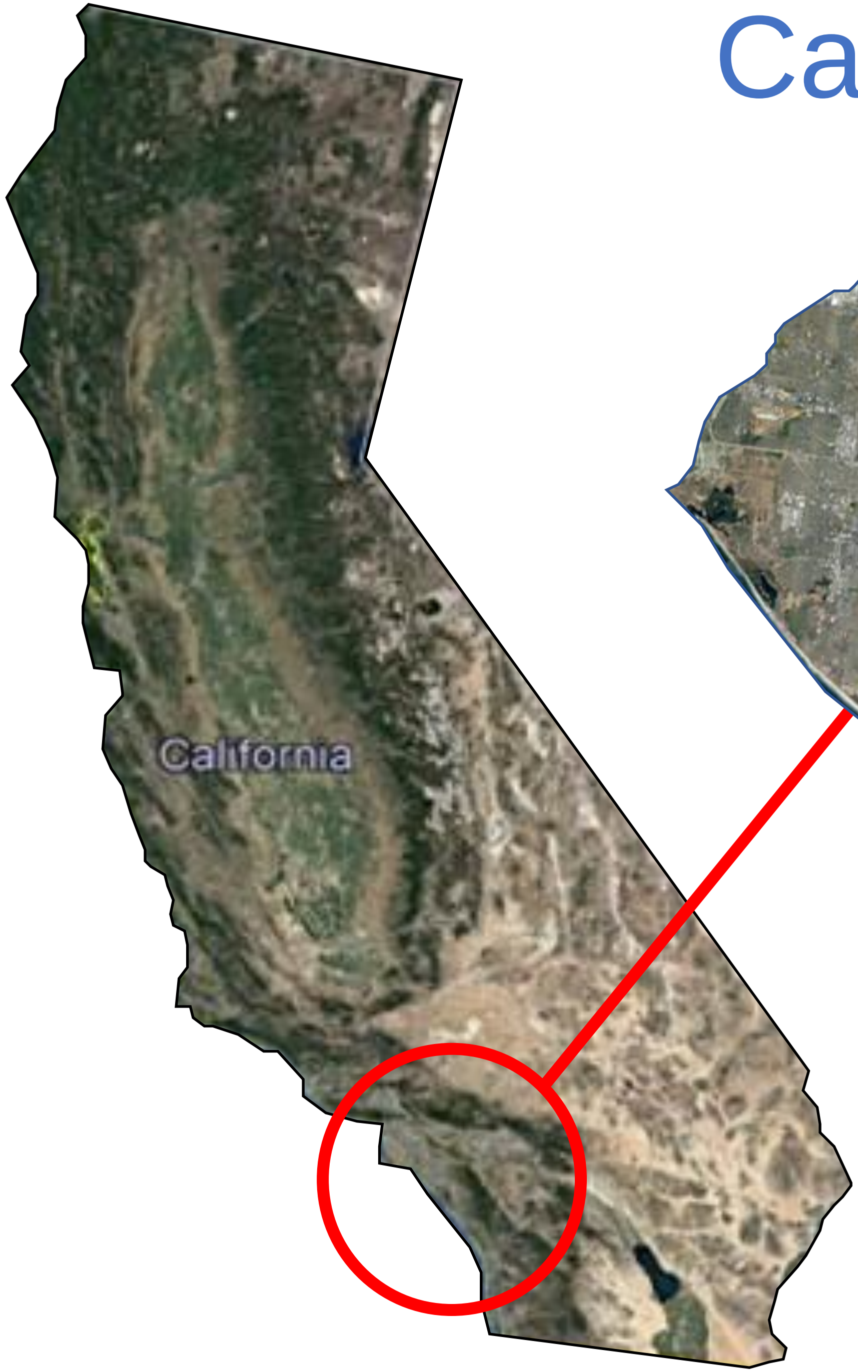

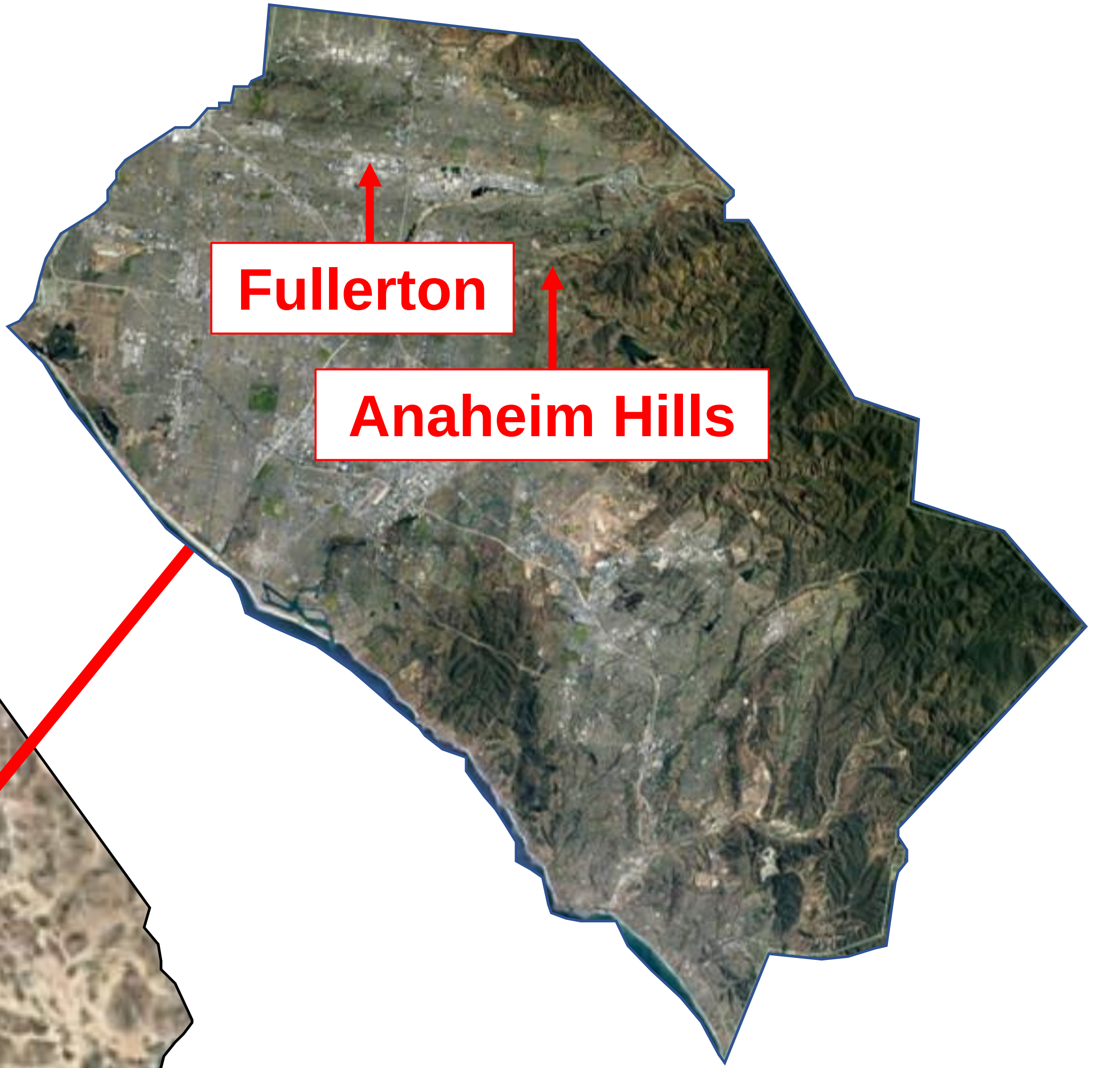

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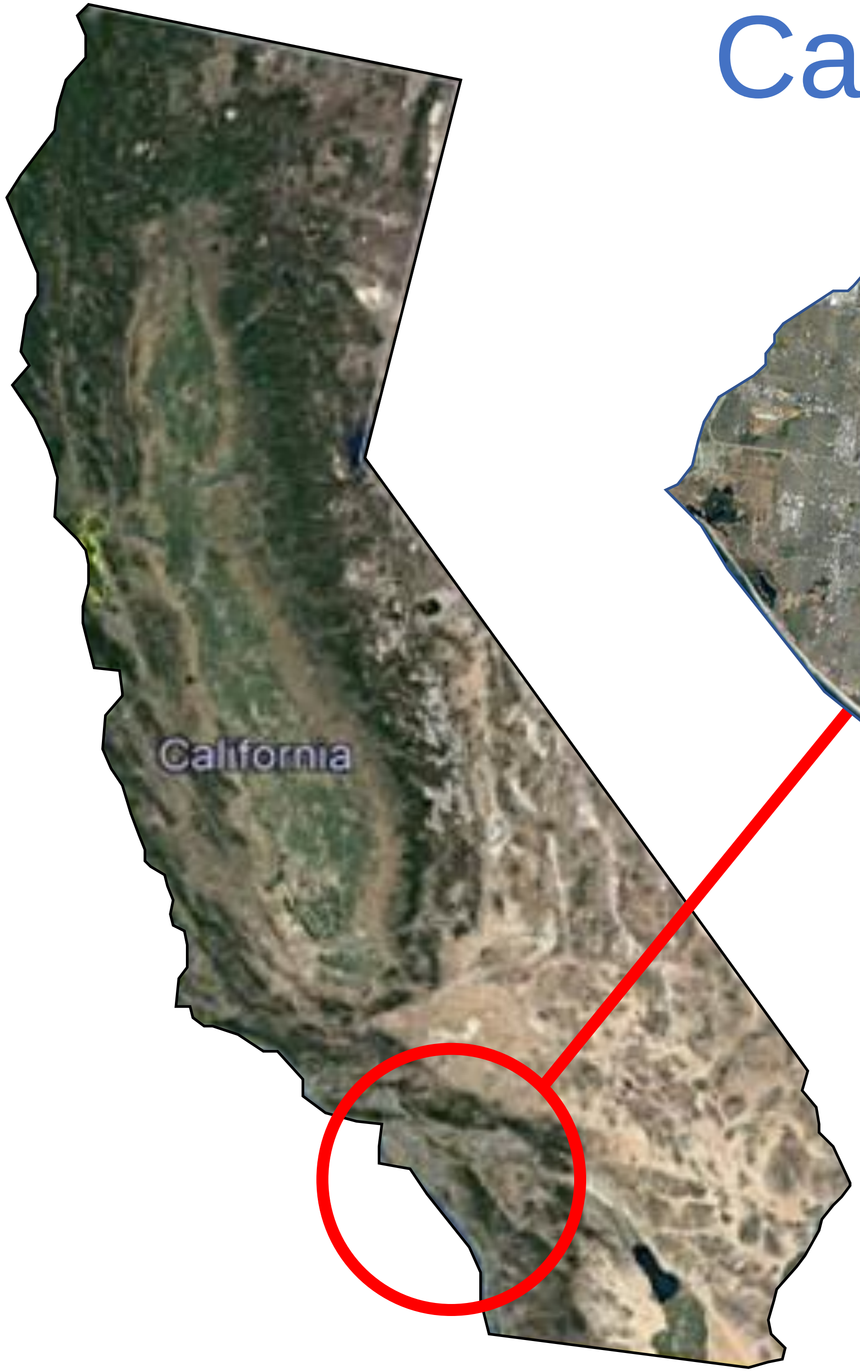

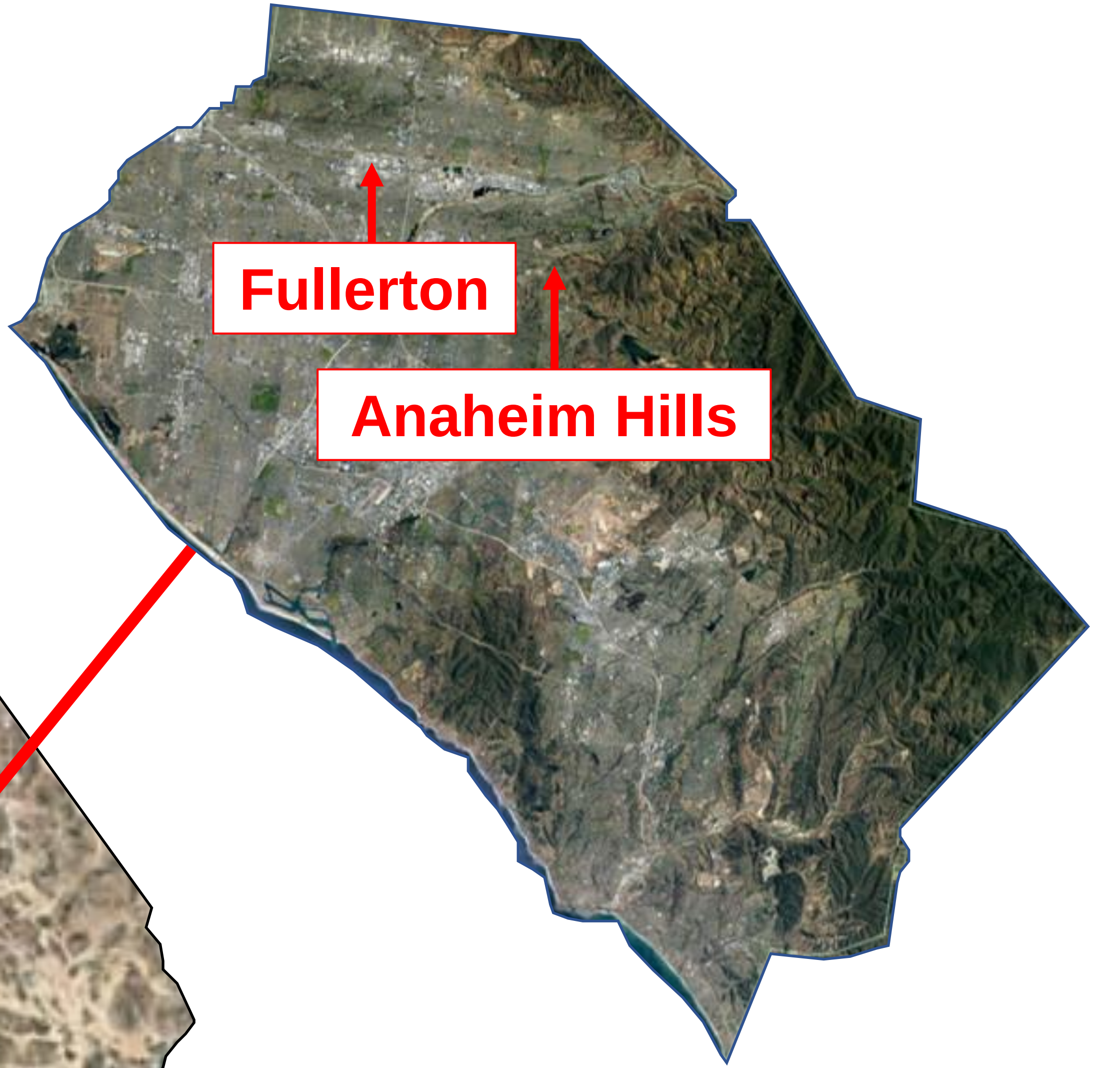

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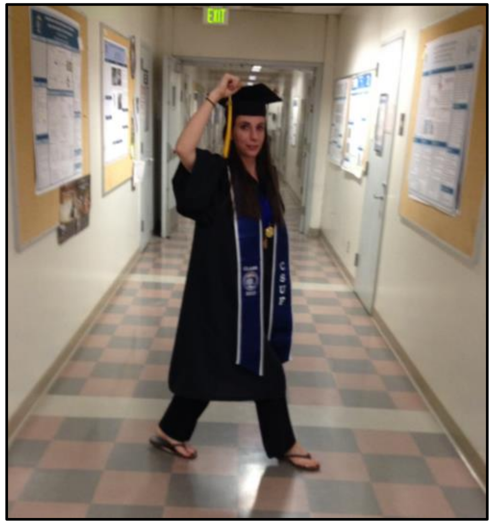

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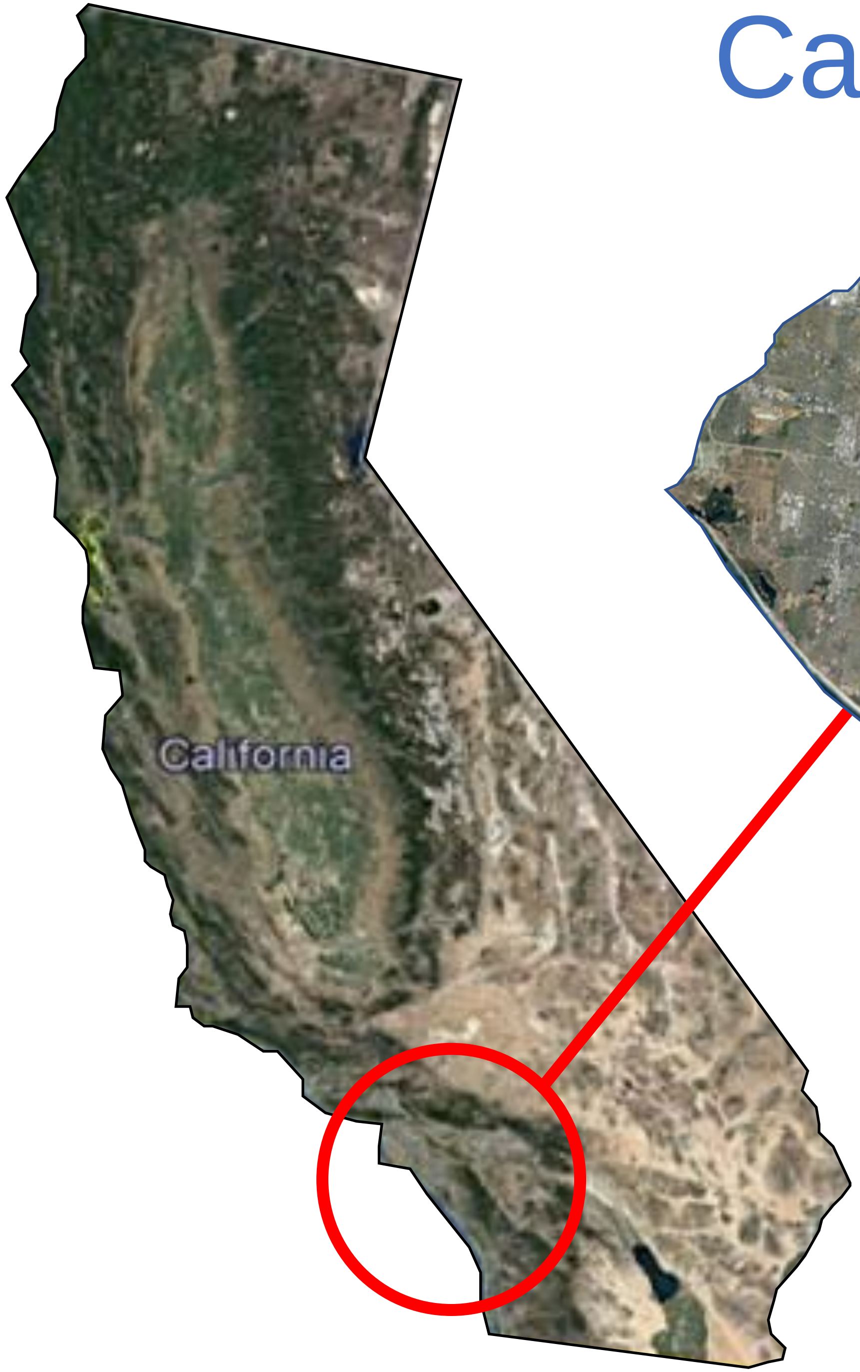

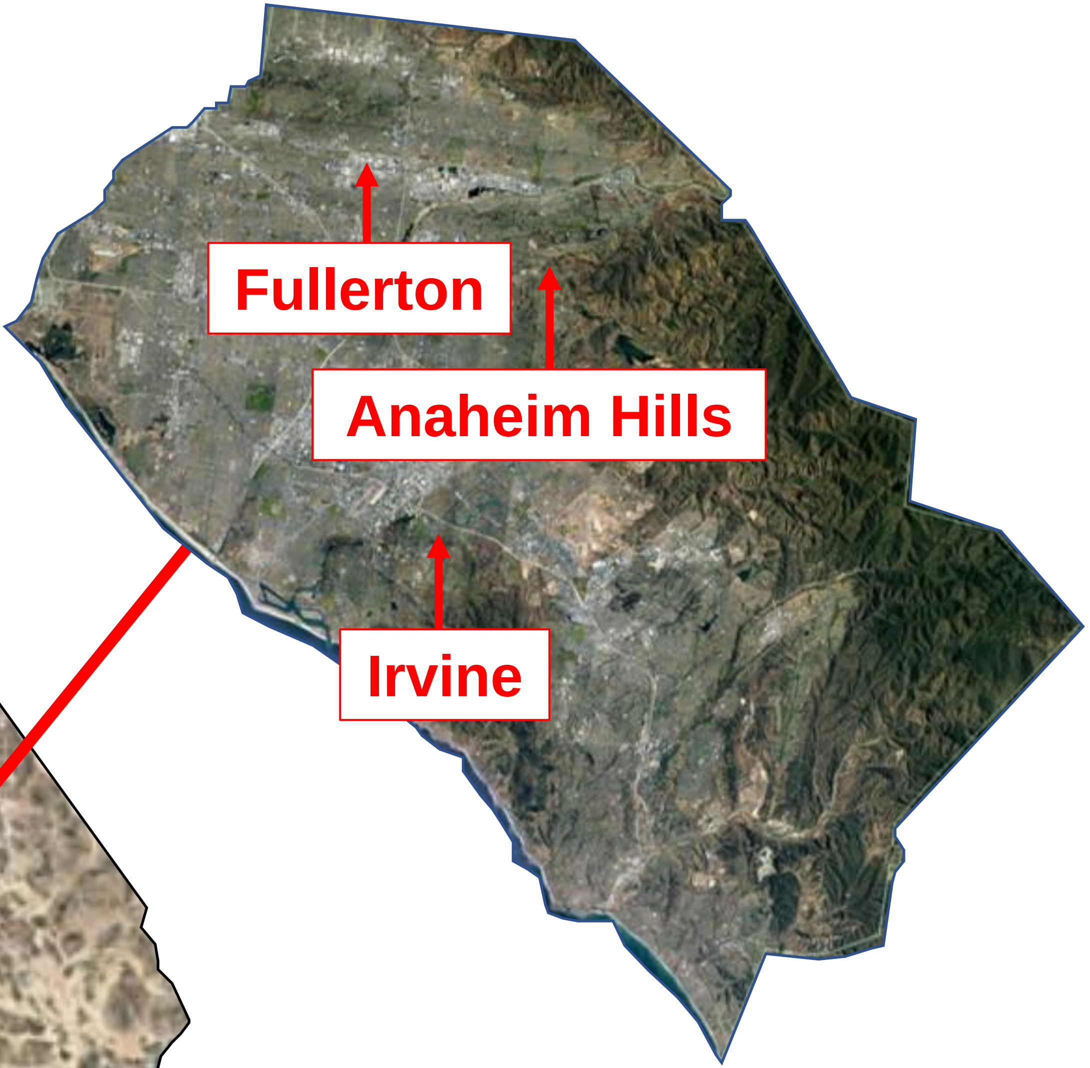

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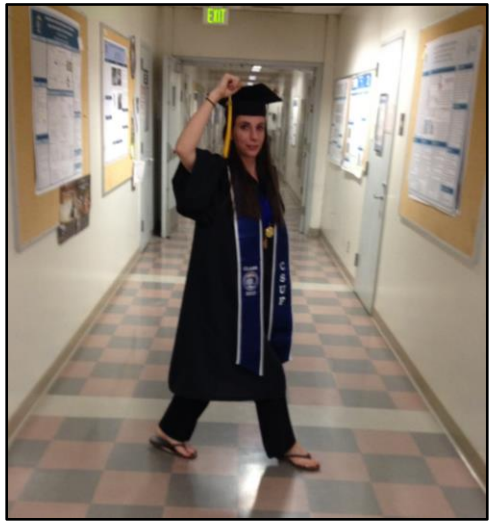

California Is a Leader

California leads the United States in sustainable practices and laws to reduce harmful emissions.

Greenhouse Gases Warm Earth

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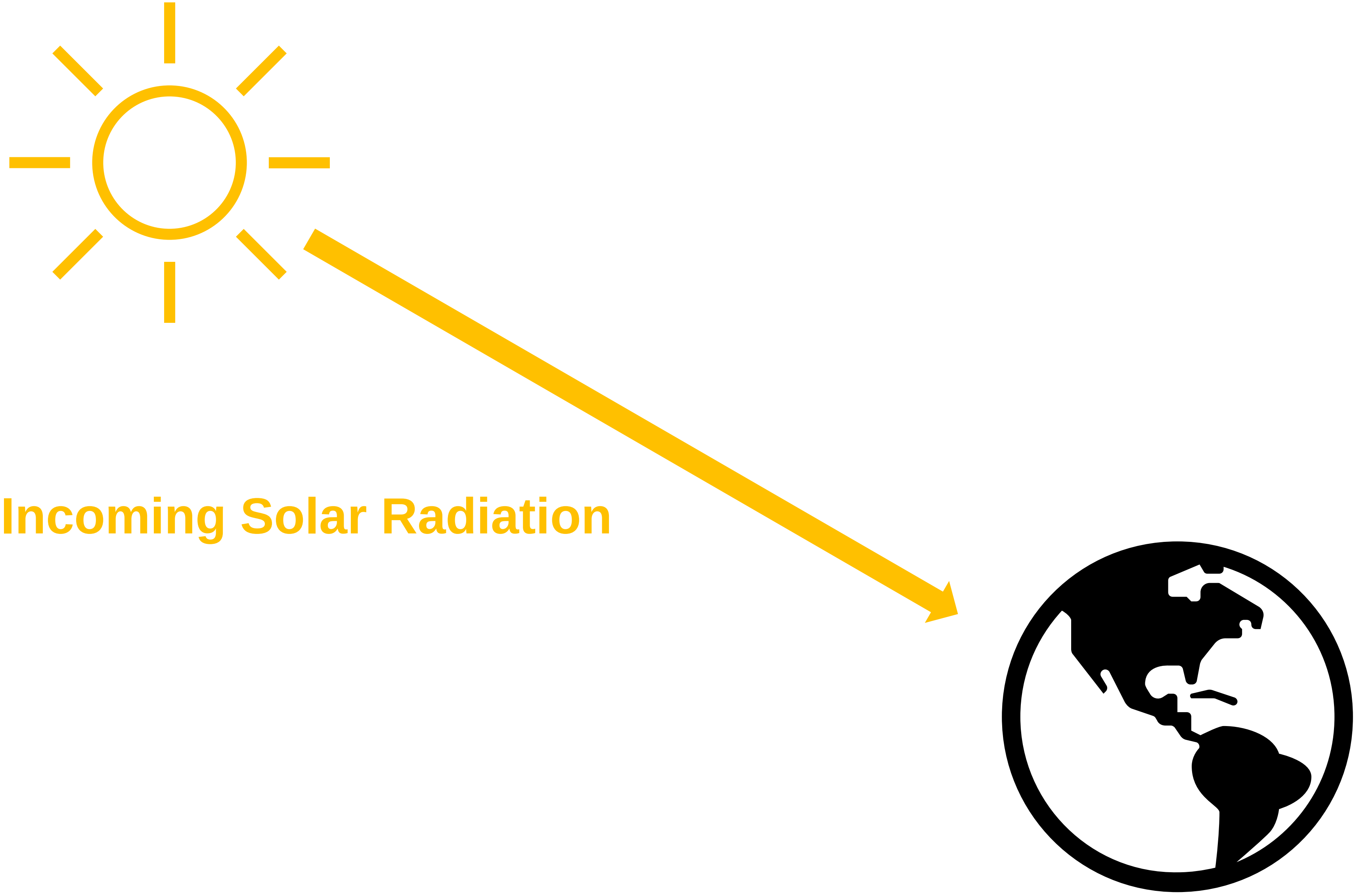

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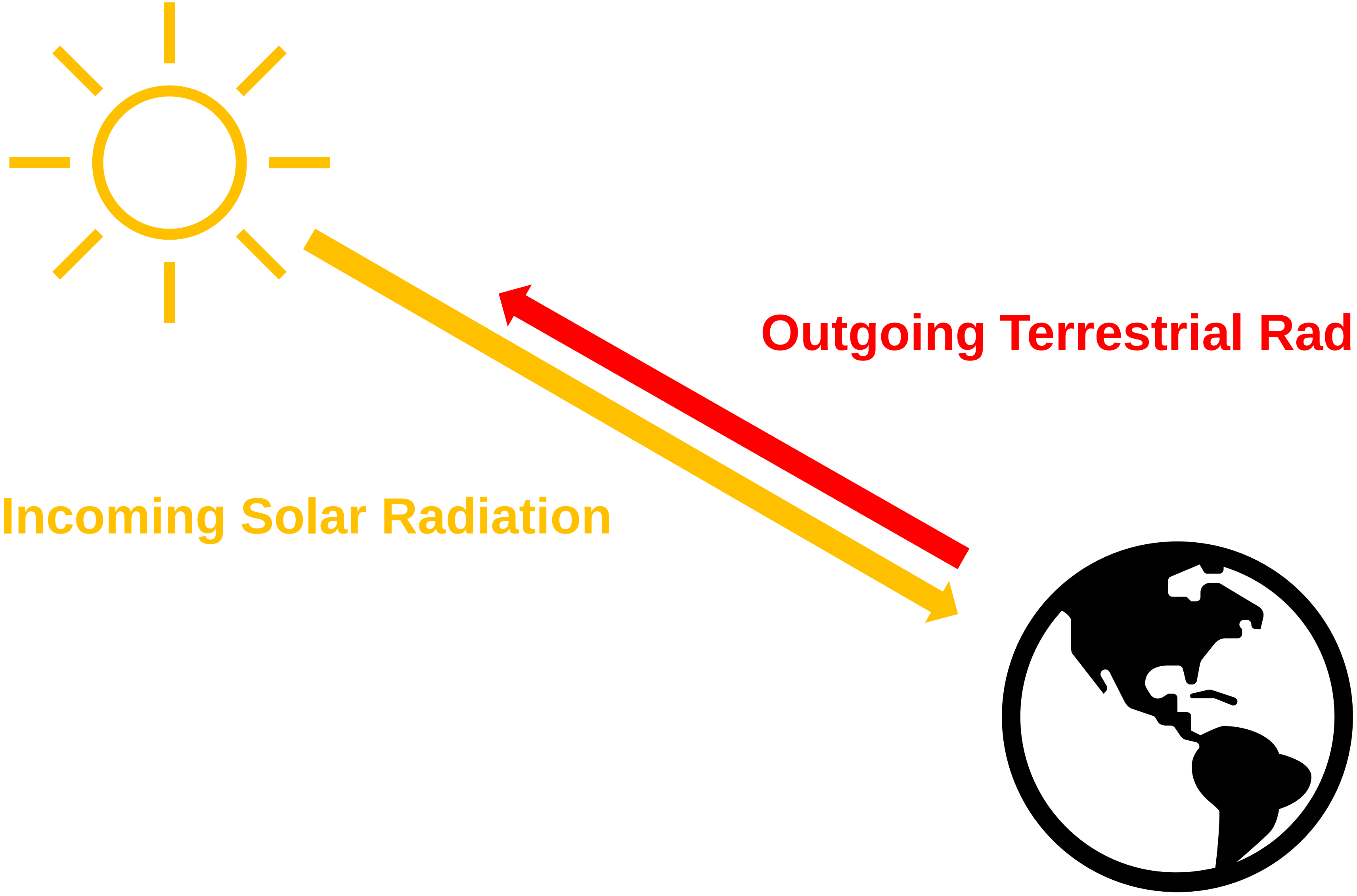

No atmosphere
Earth ~ 0 °F

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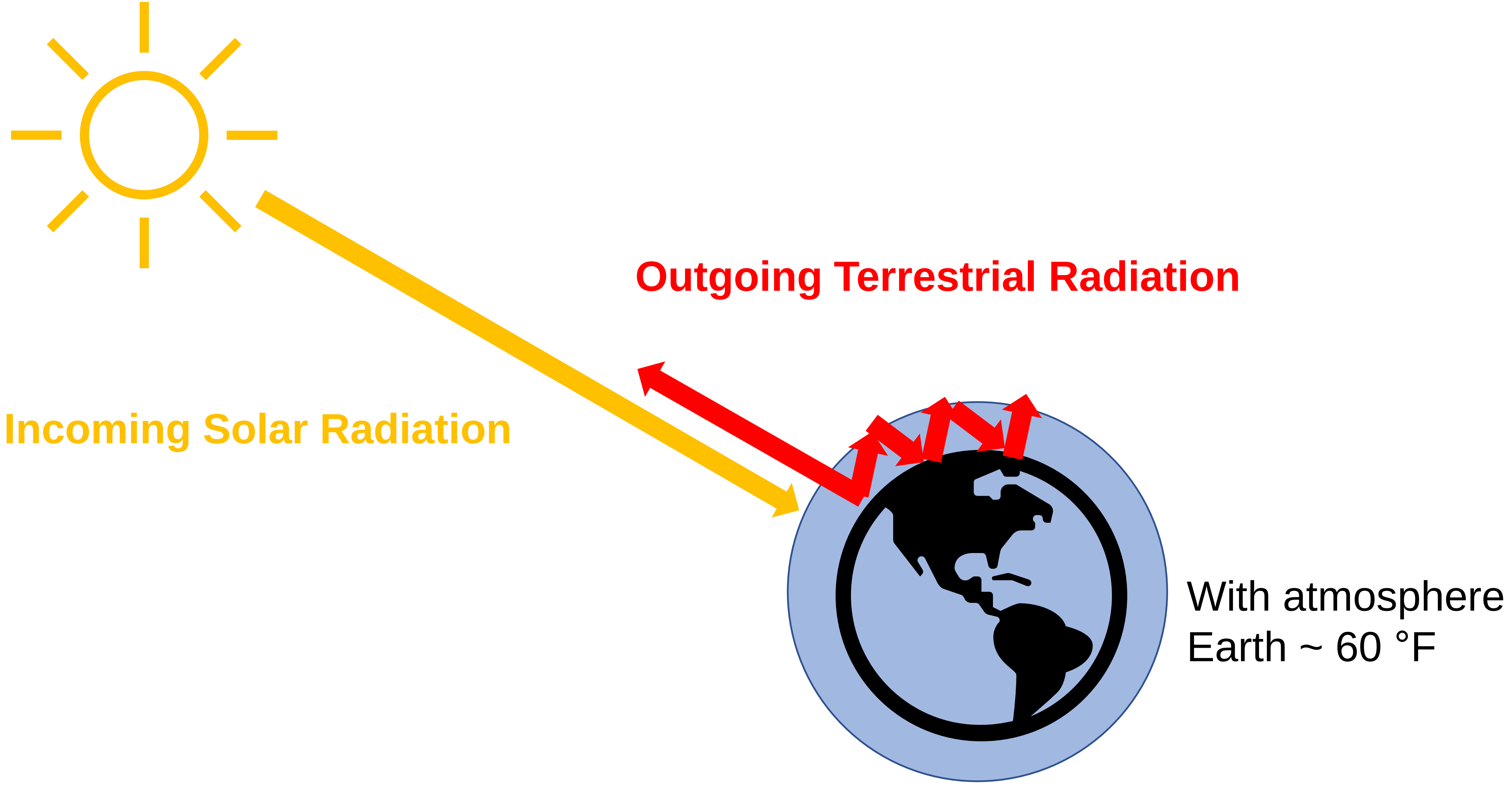

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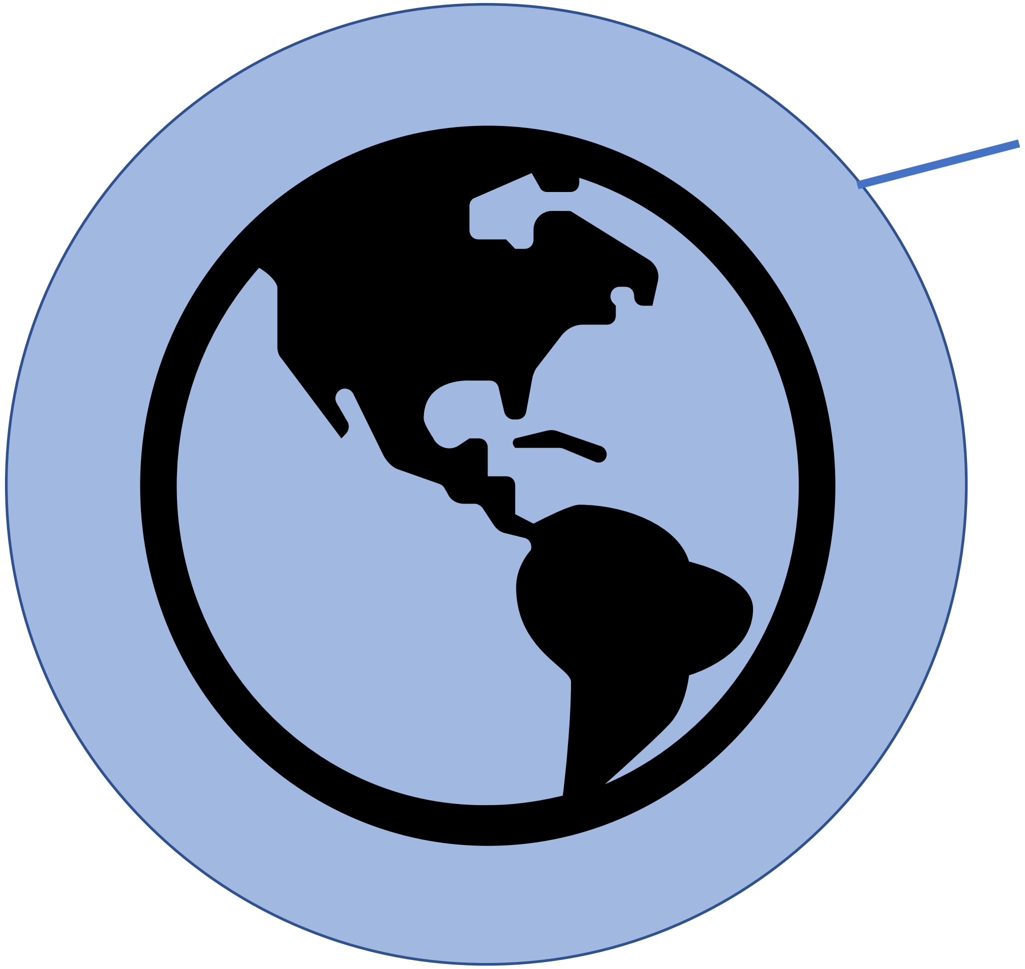

78% Nitrogen
21% Oxygen
1% Trace gases

Trace gases = argon, **carbon dioxide** (CO_2), **methane** (CH_4), helium, **nitrous oxide** (N_2O), **ozone** (O_3), **water** (H_2O), etc.

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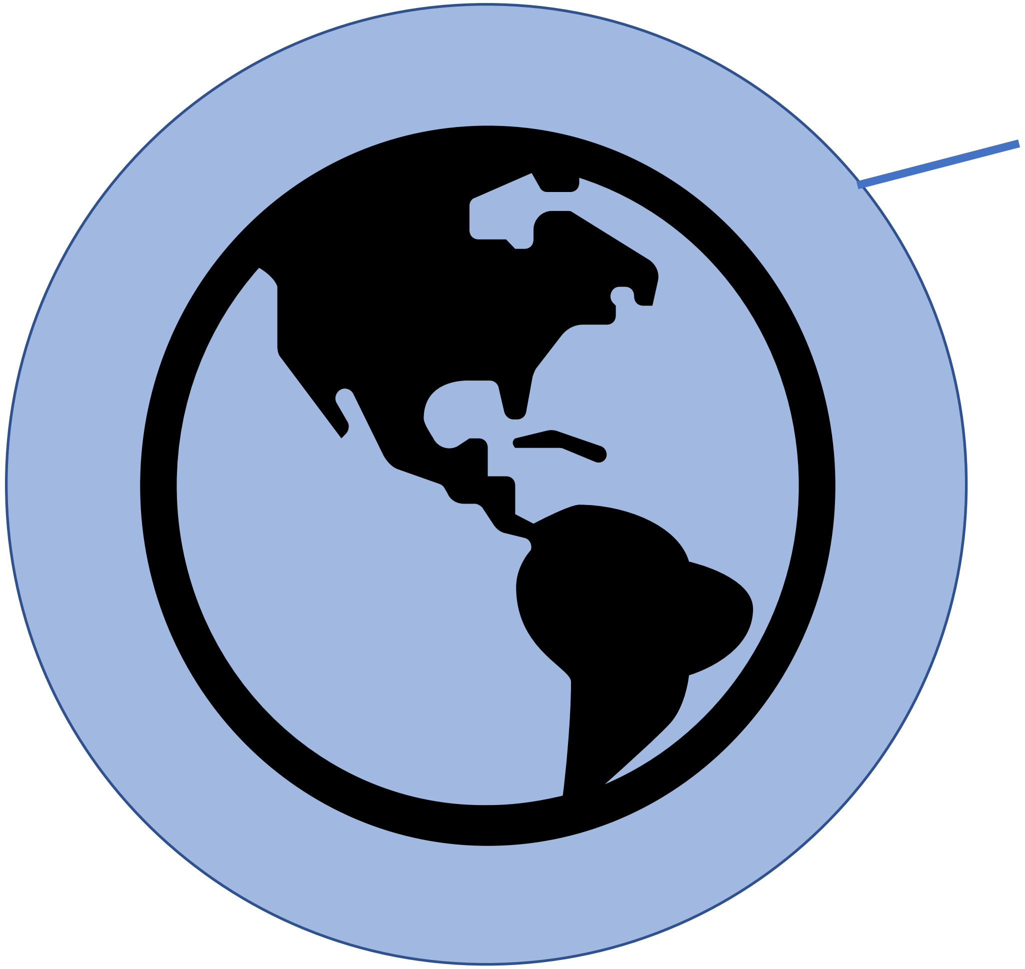

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A greenhouse gas (GHG) can absorb the Earth's terrestrial radiation.

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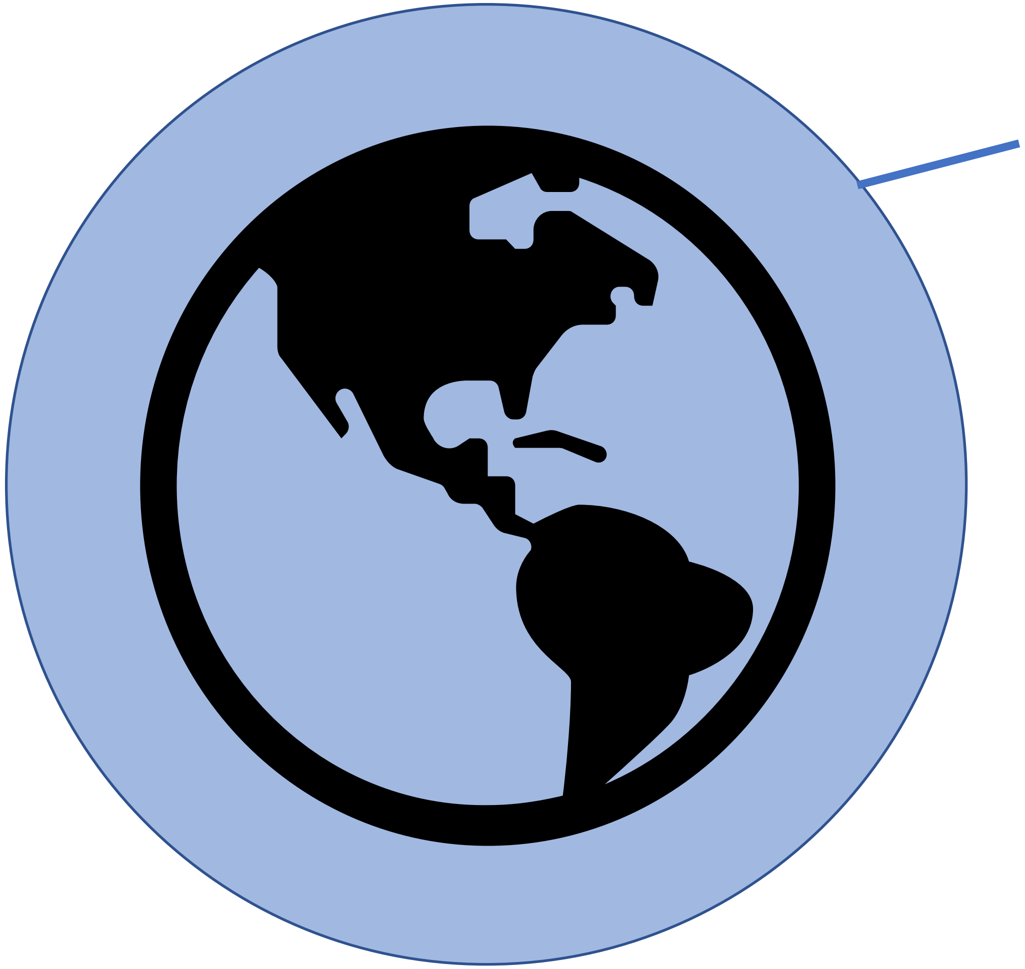

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Problem: ↑ GHG ↑ Temperature

Greenhouse Gases Warm Earth

Global Warming Potential (GWP)

CO_2 = 1
CH_4 = 28 – 36
N_2O = 265 – 298

Trace Gases Cause Pollution and Odor

Trace gases in our environment don’t just cause climate issues.

They can cause pollution (like ozone and particles) and odor.

↓ visibility
↑ physical and mental health problems

State Regulations

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2005: Executive Order S-3-05

- We must ↓ greenhouse gas emissions

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- Regulate greenhouse gases
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What is a disadvantaged community?

Disadvantaged communities are objectively defined with 20 parameters in 4 categories.

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Environmental Effects

- Cleanup sites
- Groundwater
- Hazardous waste
- Impaired water
- Solid waste

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- Asthma rates
- Heart disease
- Low birth rate

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CalEnviroScreen Score 0 – 100%

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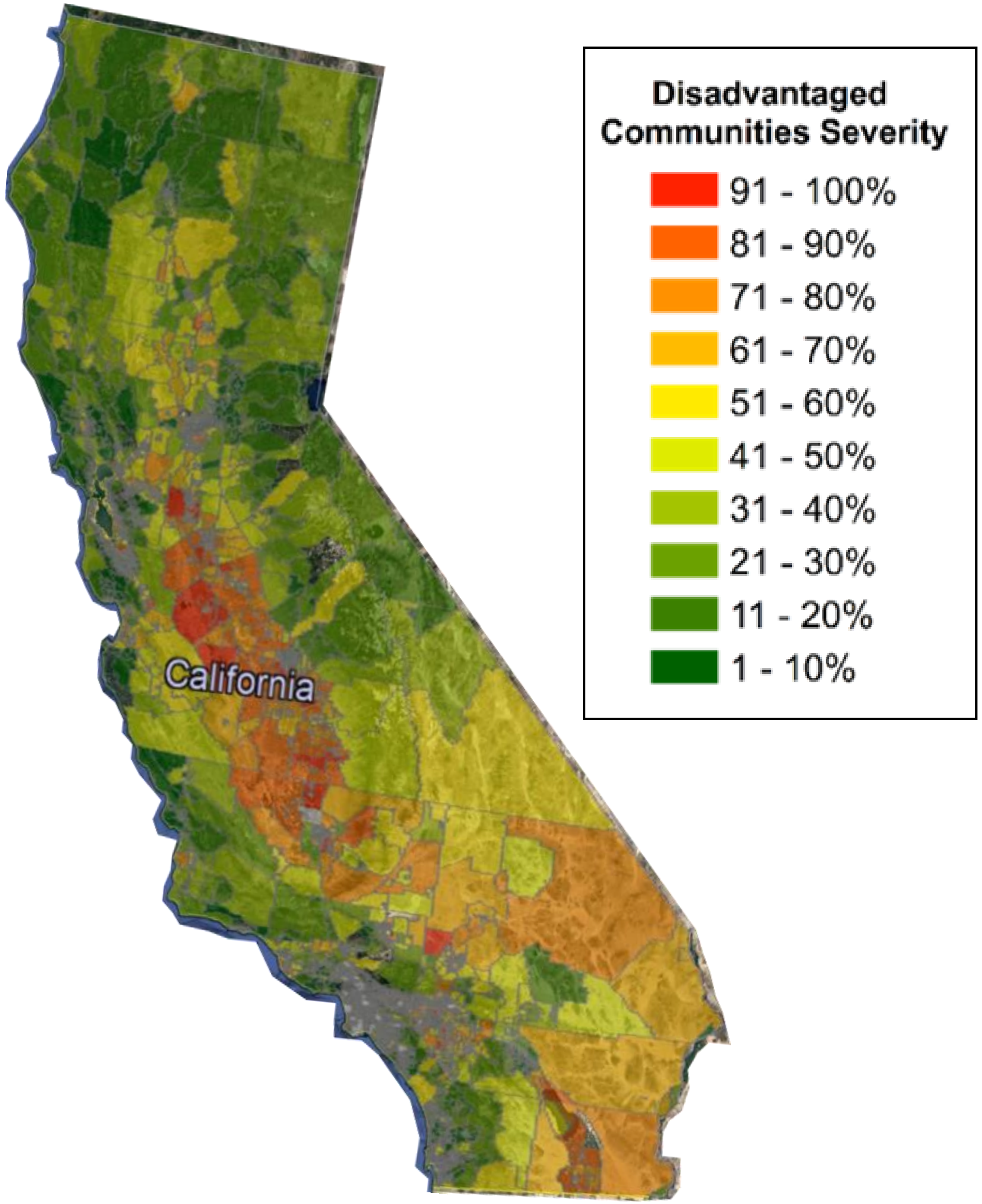

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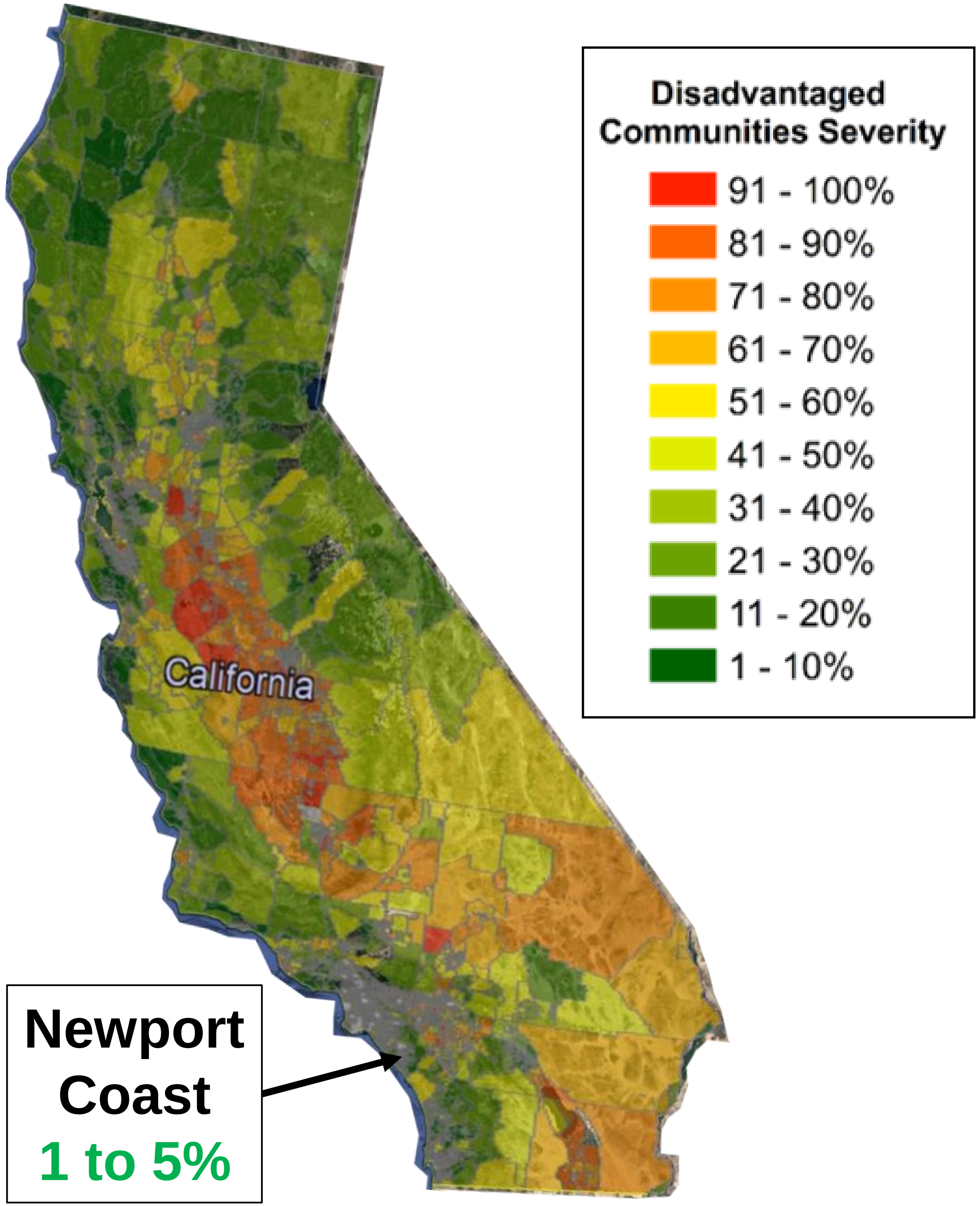

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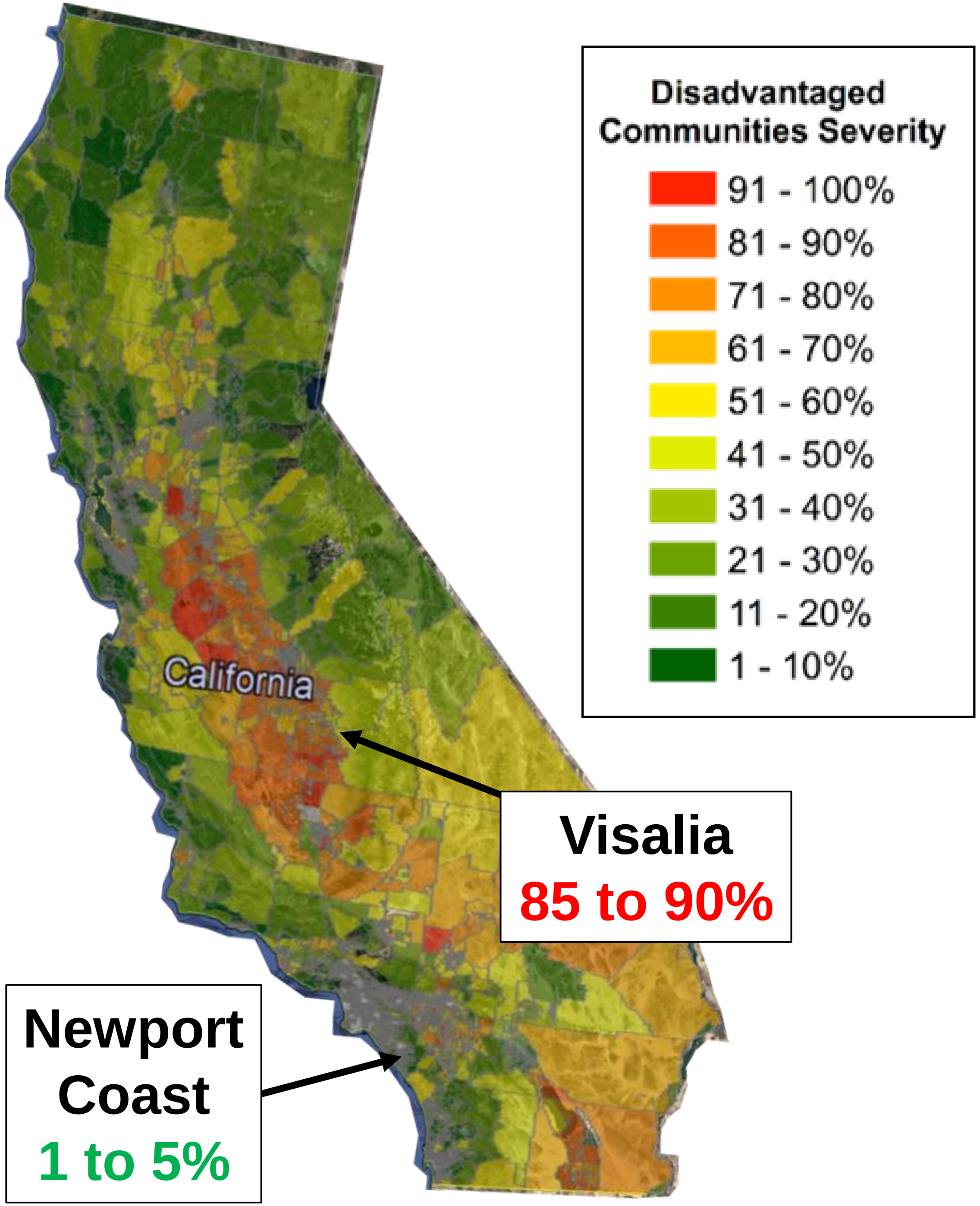

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Methane Sources in California

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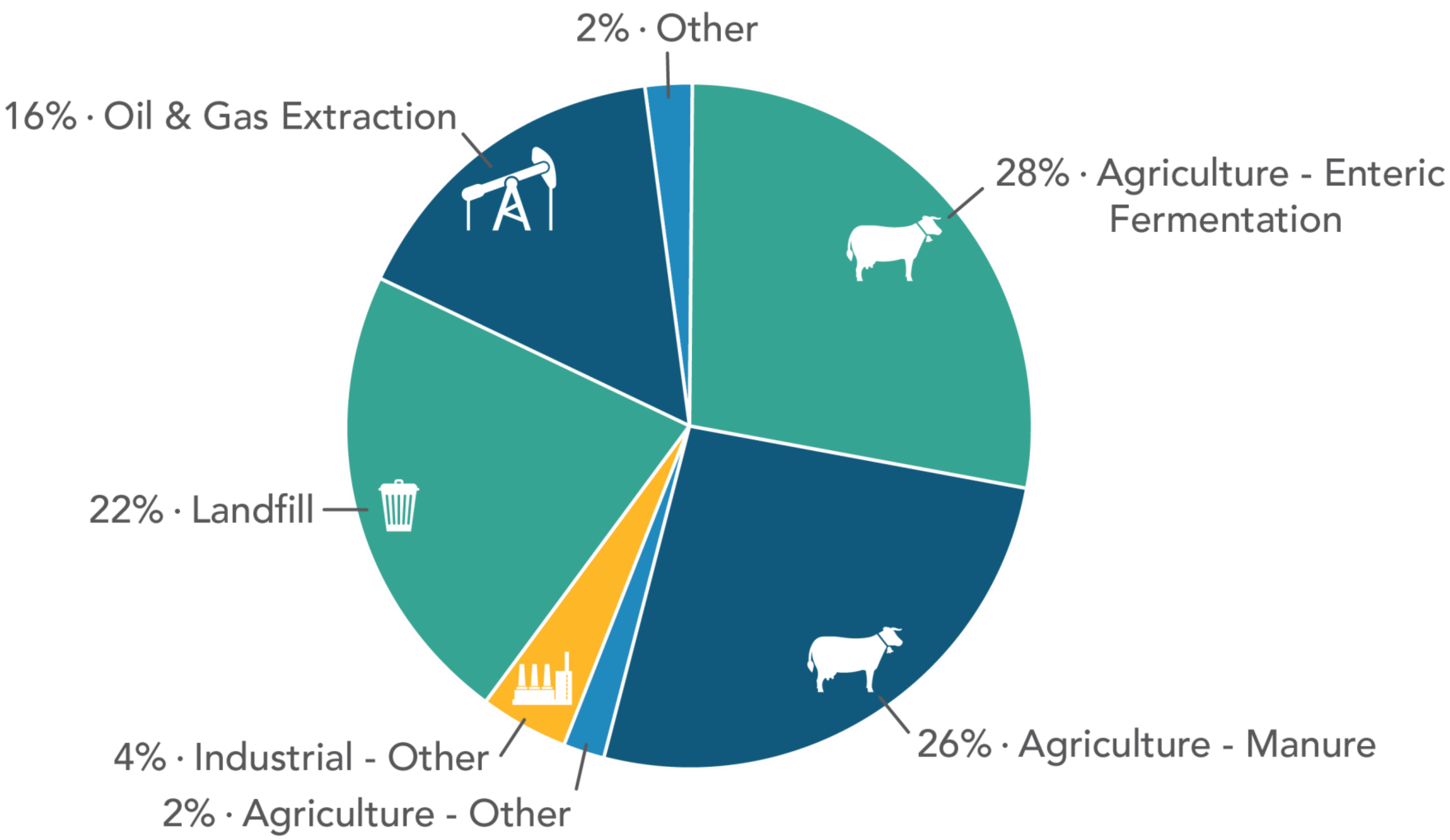

39.8 MMT CO_2e

2018 TOTAL CA CH_4 EMISSIONS

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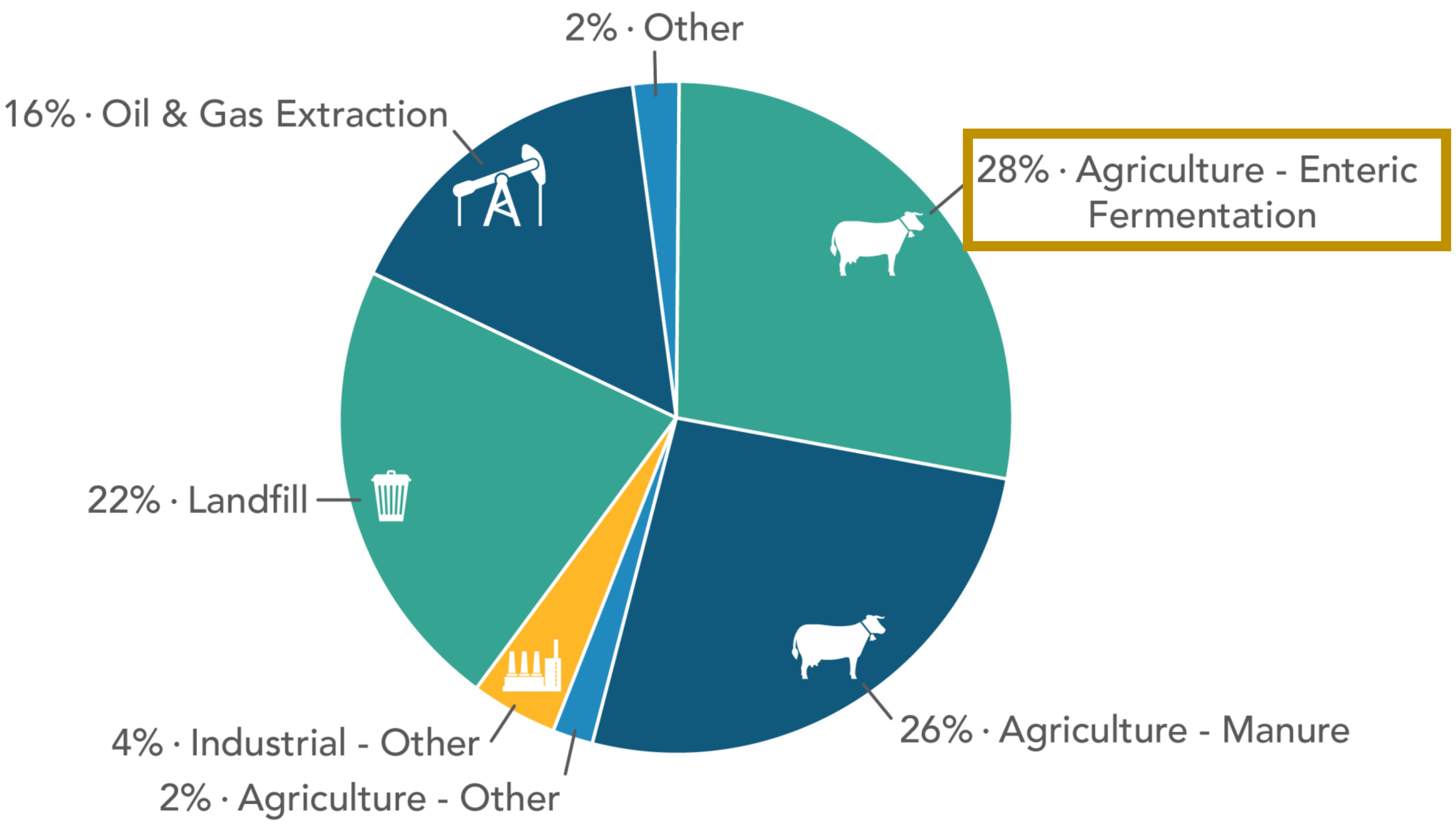

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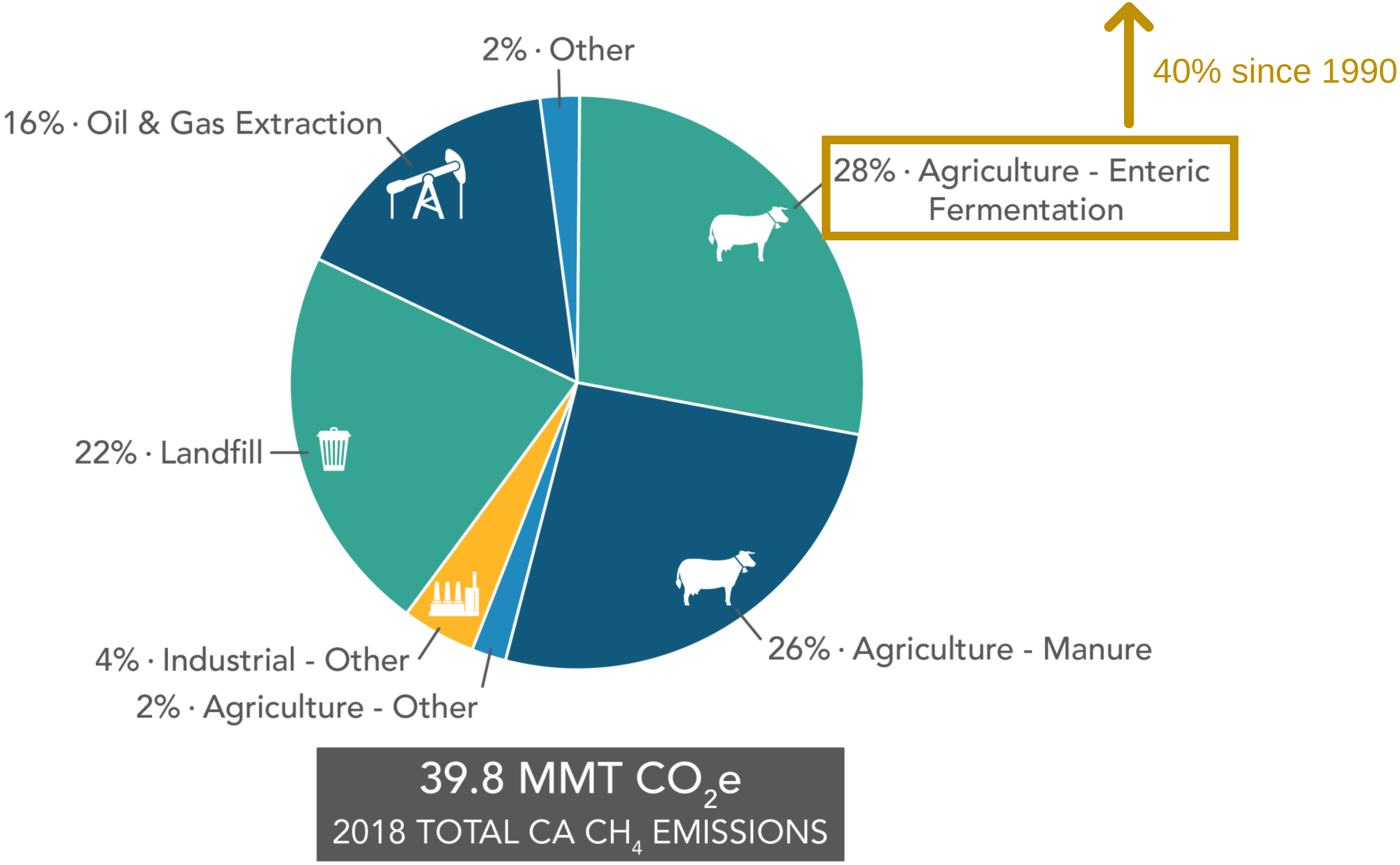

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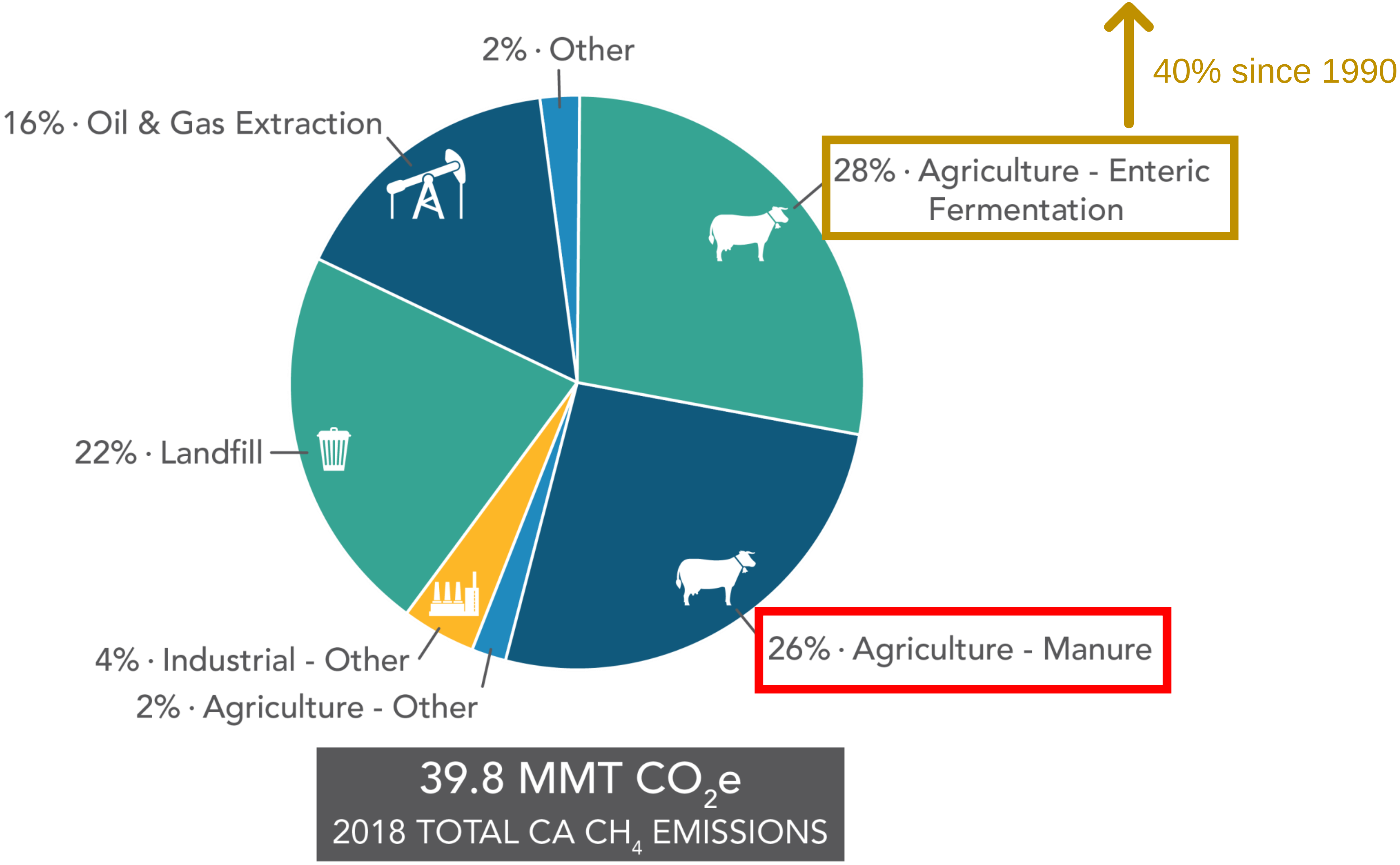

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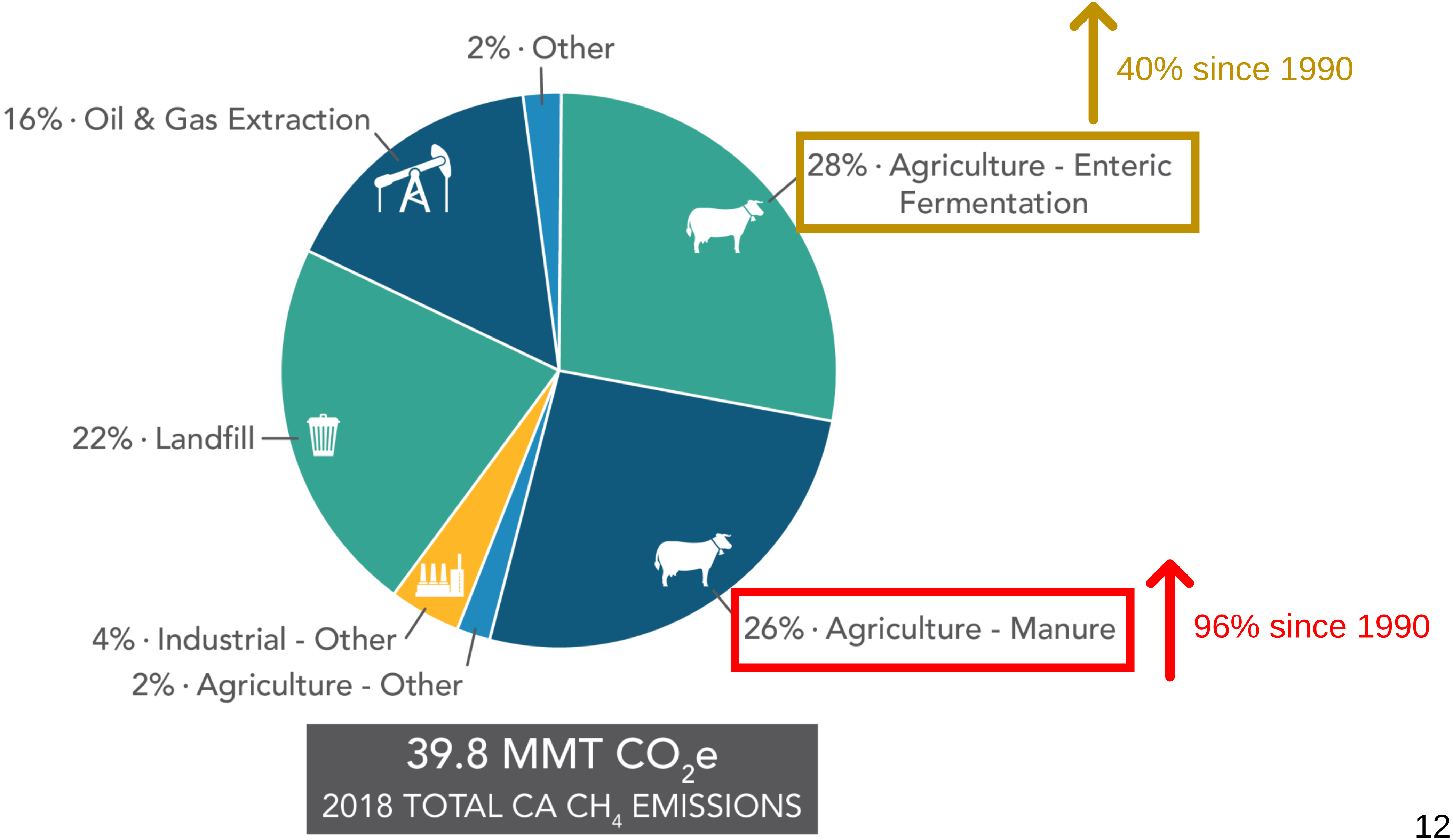


Summary of My Research

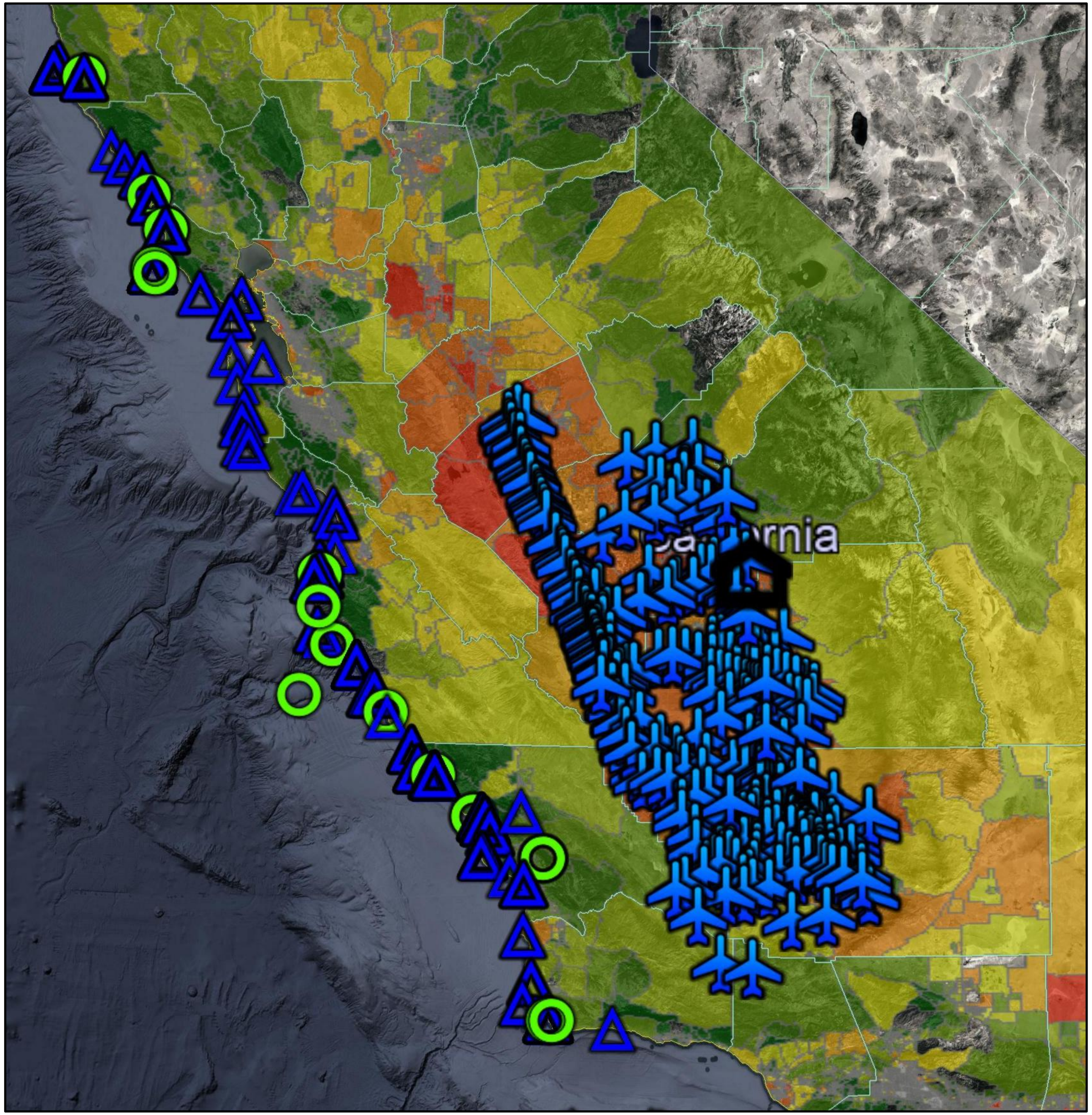
1. Dairy farm in Visalia, California

- Collect air samples upwind, downwind, on-site locations
- Explore seasonality
- Emissions and effect on communities

2. Remote and Airborne Data

- “Background” air entering California
- Effect of dairies on regional air quality

My Research



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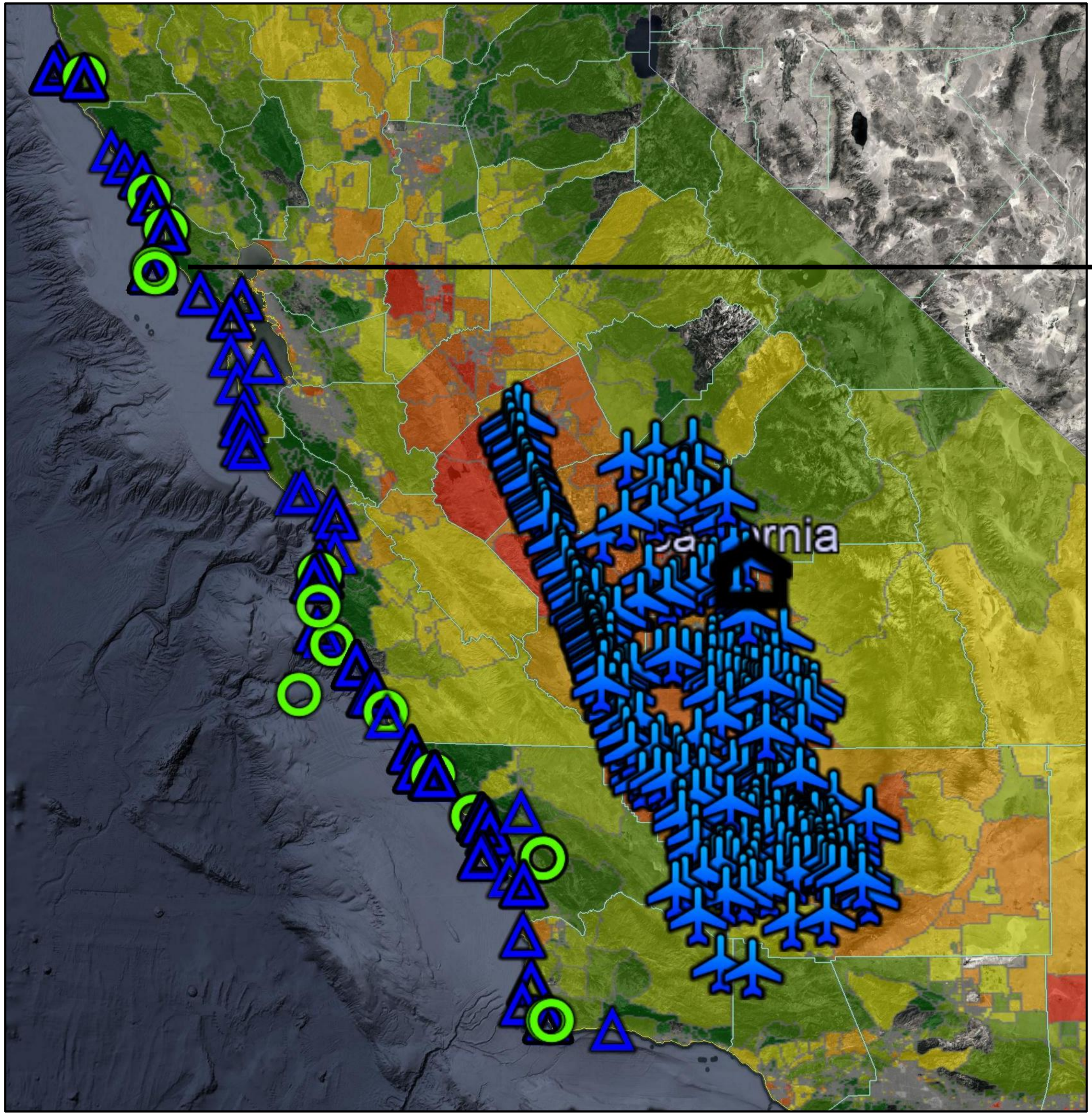

Remote coastal samples
n = 512 from 1980 – 2018
34.5 – 40.0 °N in CA

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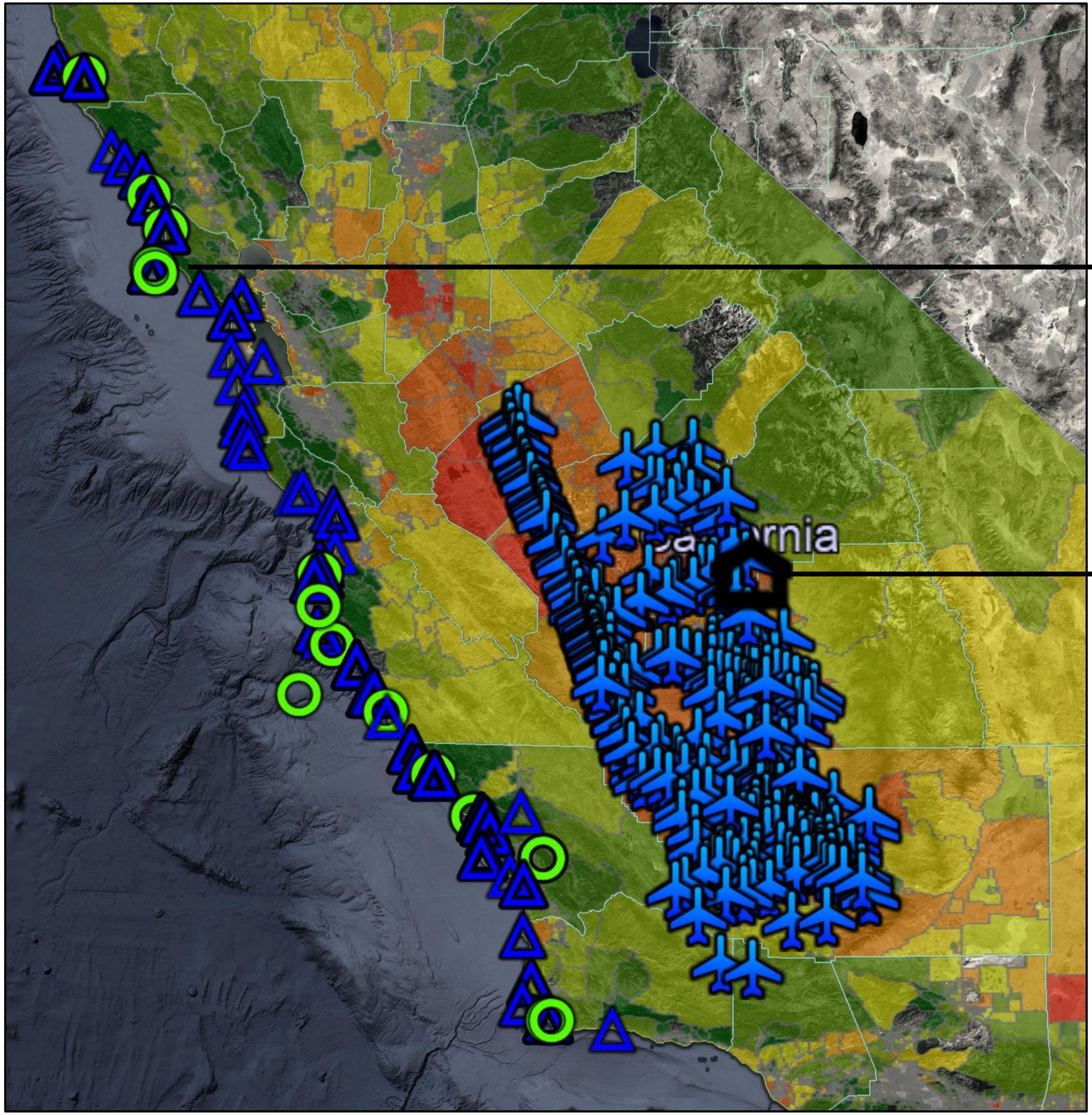

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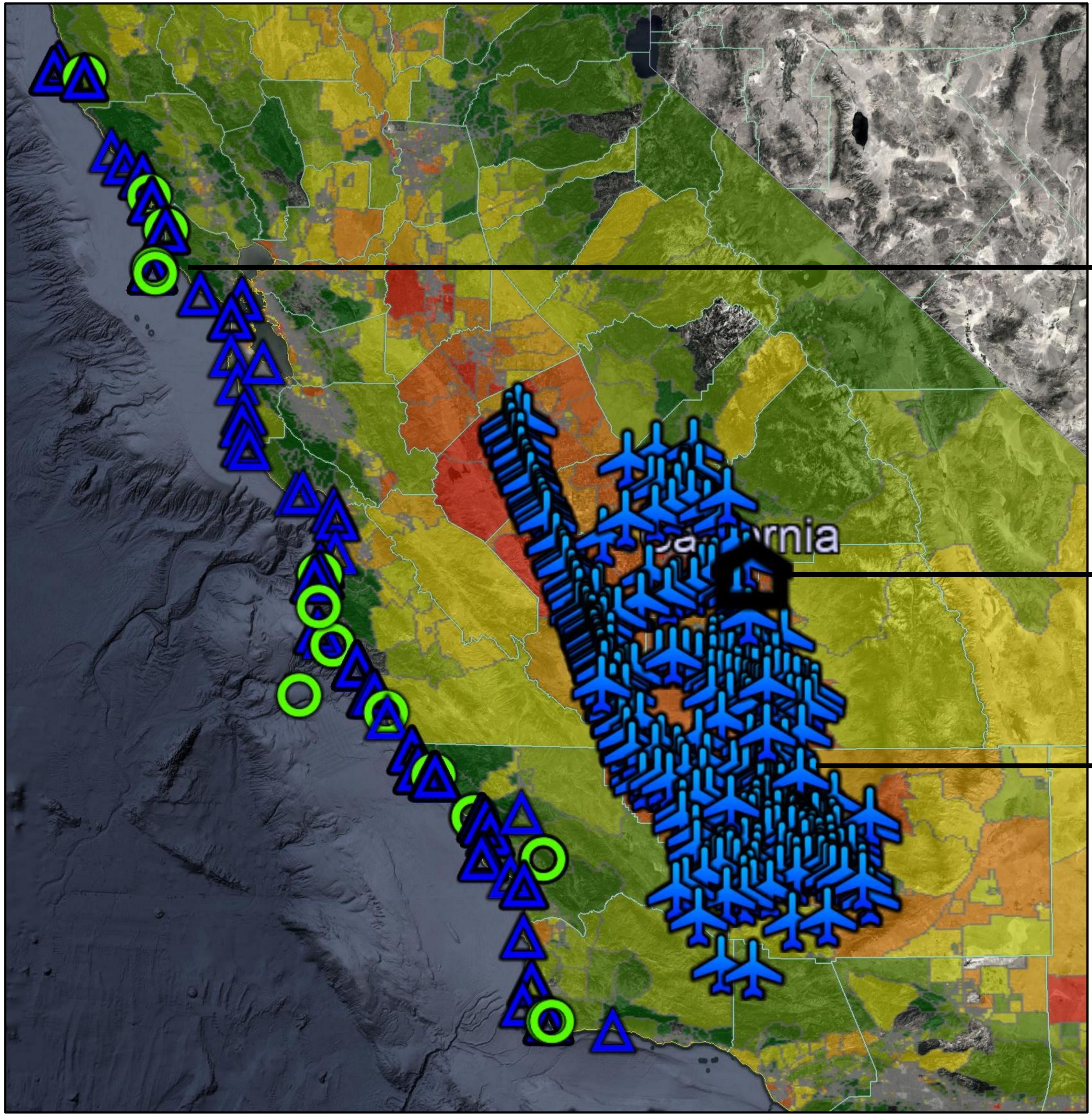

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n = 336 from 2011, 2013, 2014, 2015, 2017
Pressure altitude < 3,000 feet
San Joaquin Valley, CA

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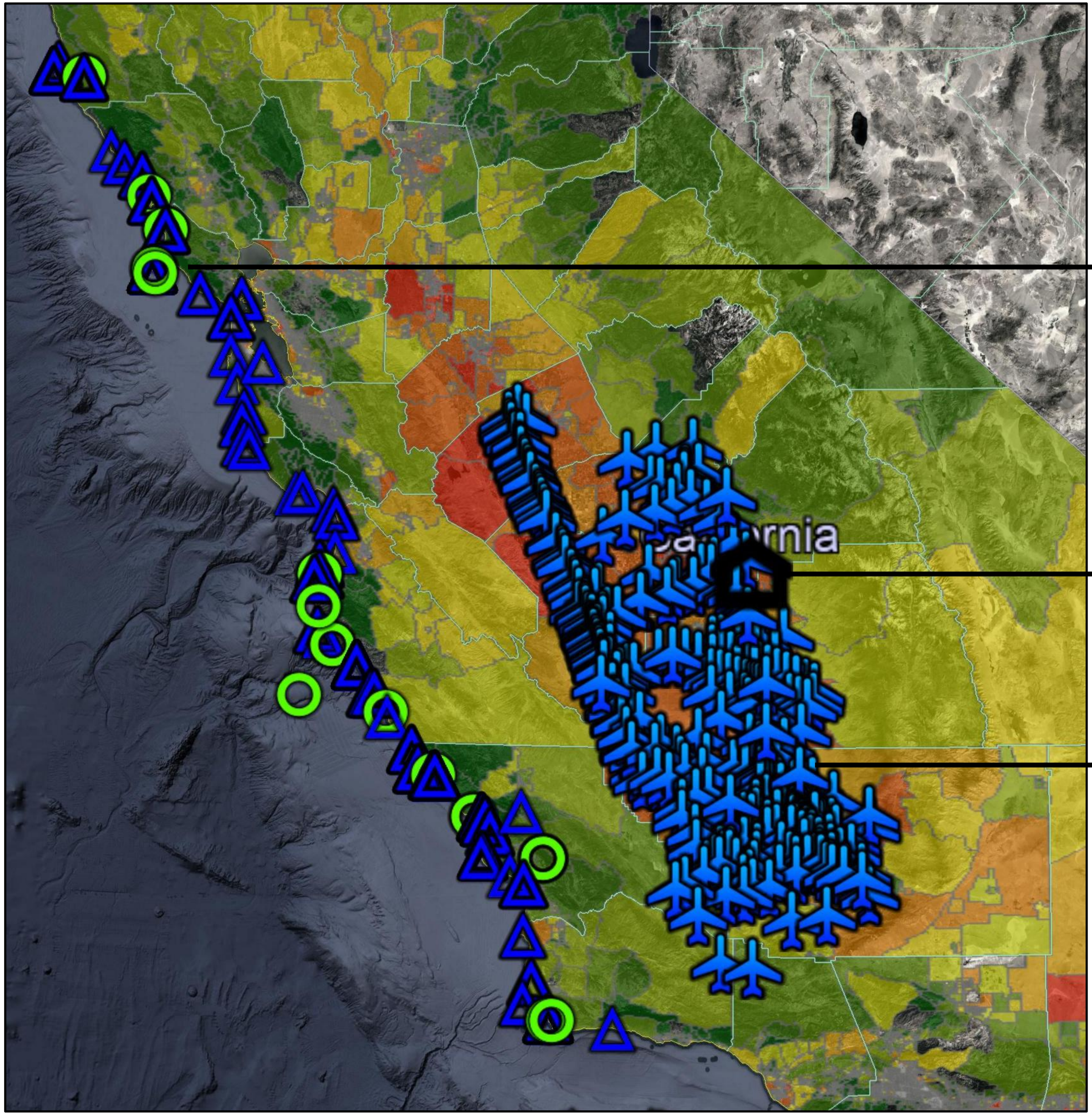

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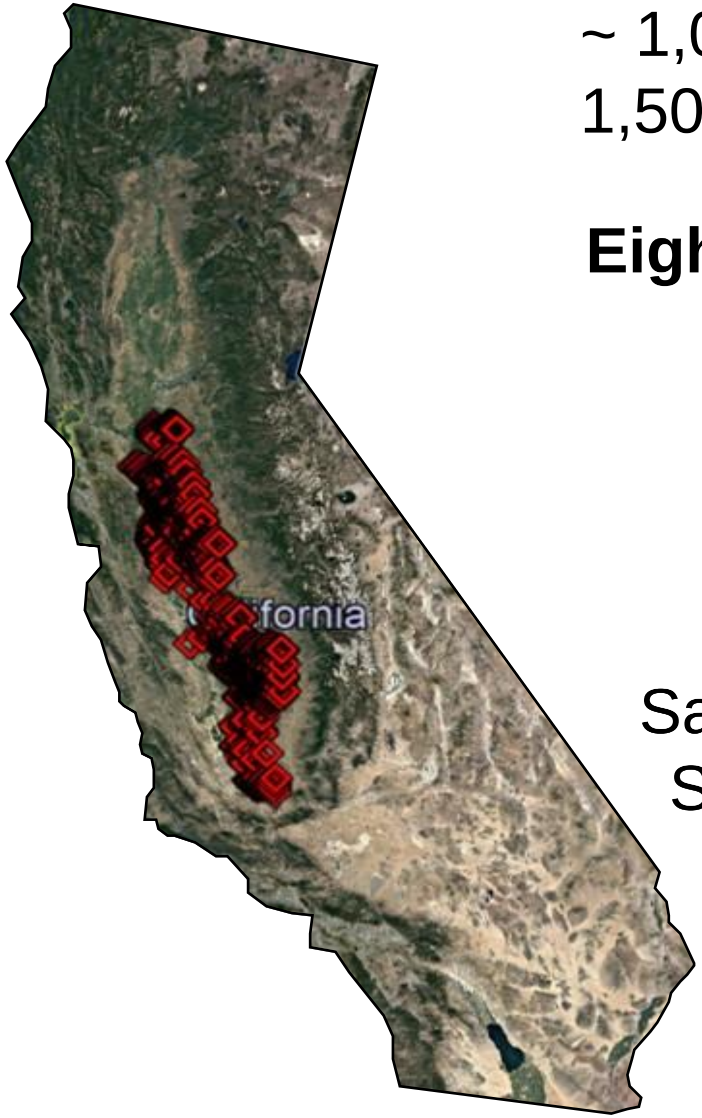
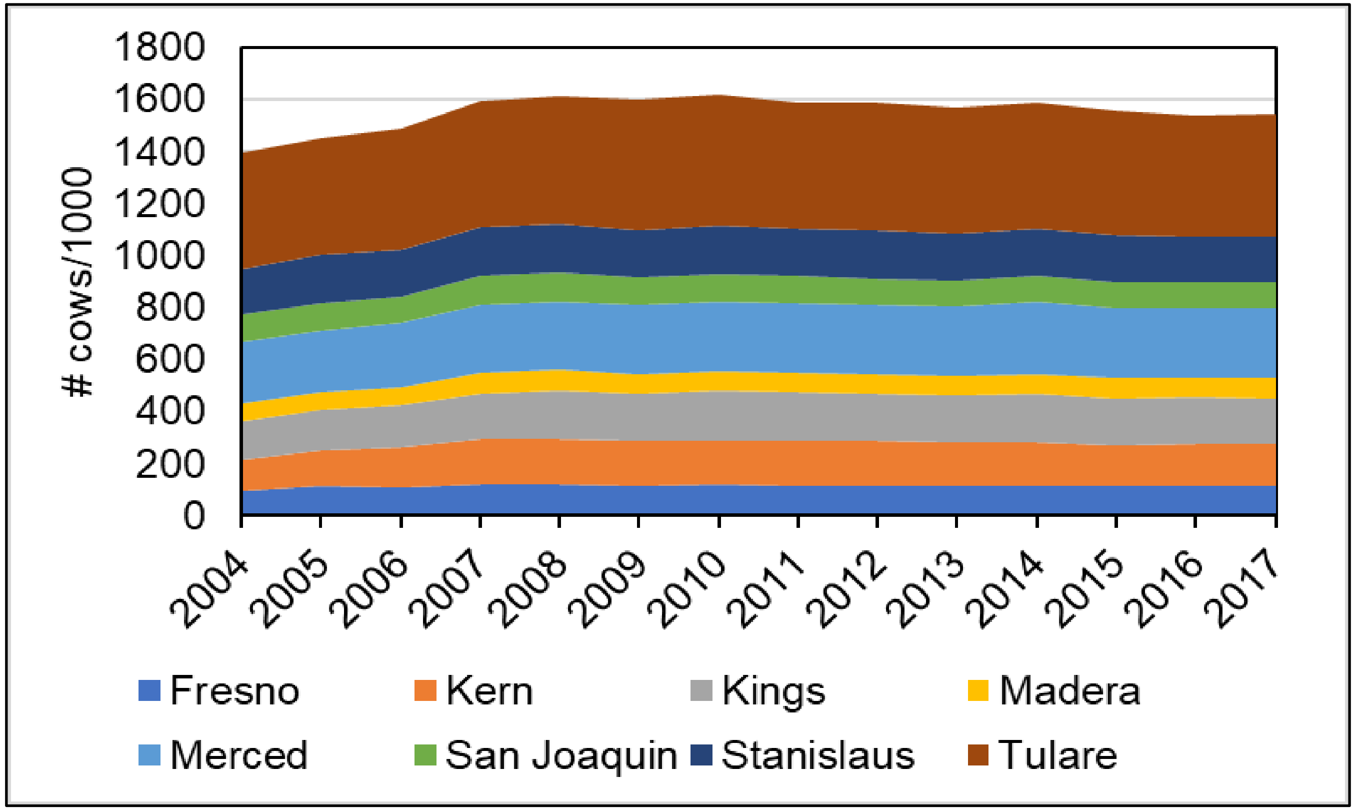
Anatomy of the San Joaquin Valley

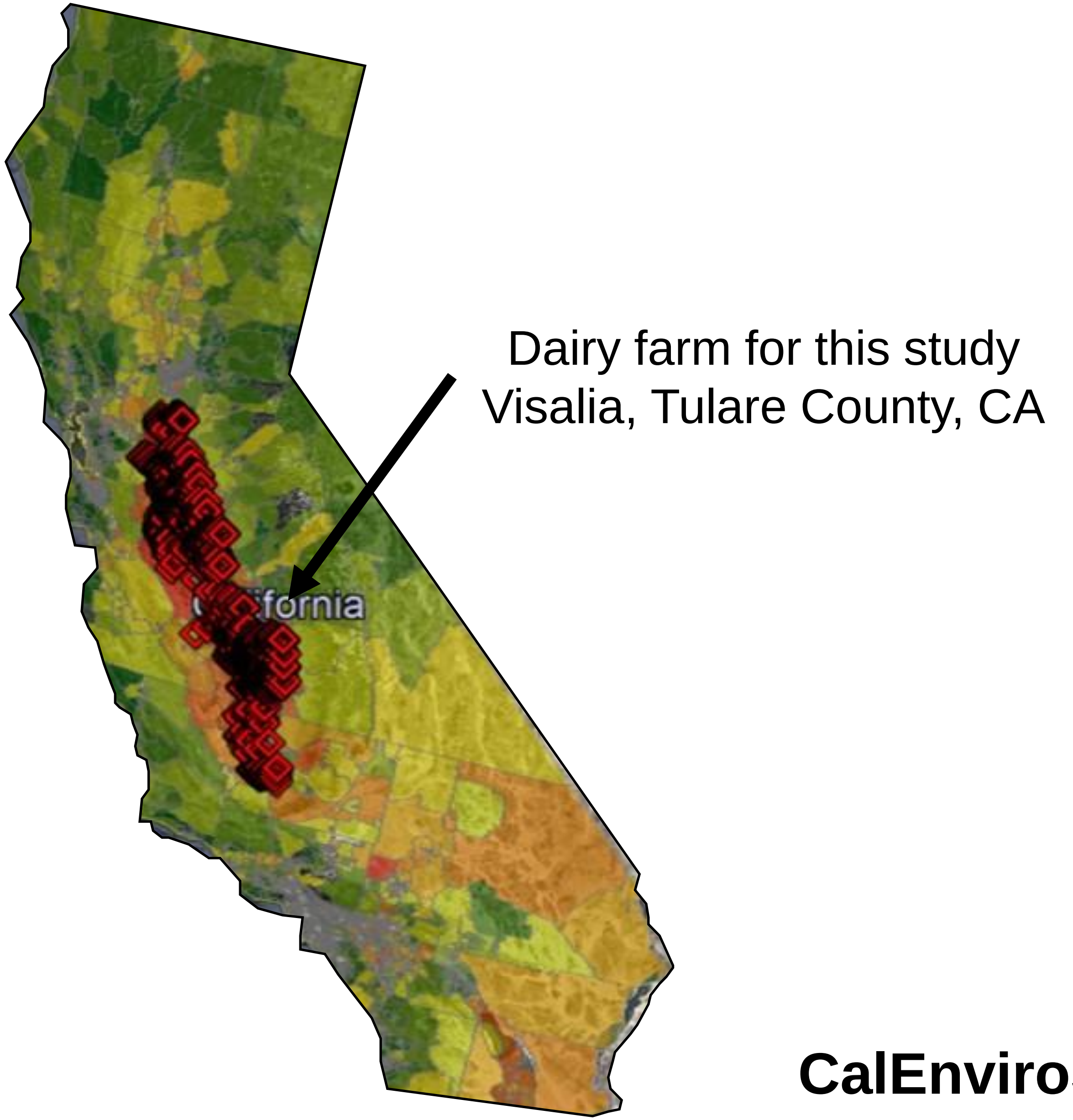


~ 1,012 dairy farms in the San Joaquin Valley (SJV)
1,505,000 dairy cows

Eight counties:
Fresno
Kern
Kings
Madera
Merced
San Joaquin
Stanislaus
Tulare



Visalia Dairy Farm



Cows:
3,106 milk cows
386 dry cows
2,985 heifers

Campaigns (359 air samples):
September 2018
March 2019
June 2019
September 2019
January 2020

CalEnviroScreen Score: 85 – 90% (disadvantaged)

Visalia Dairy Farm

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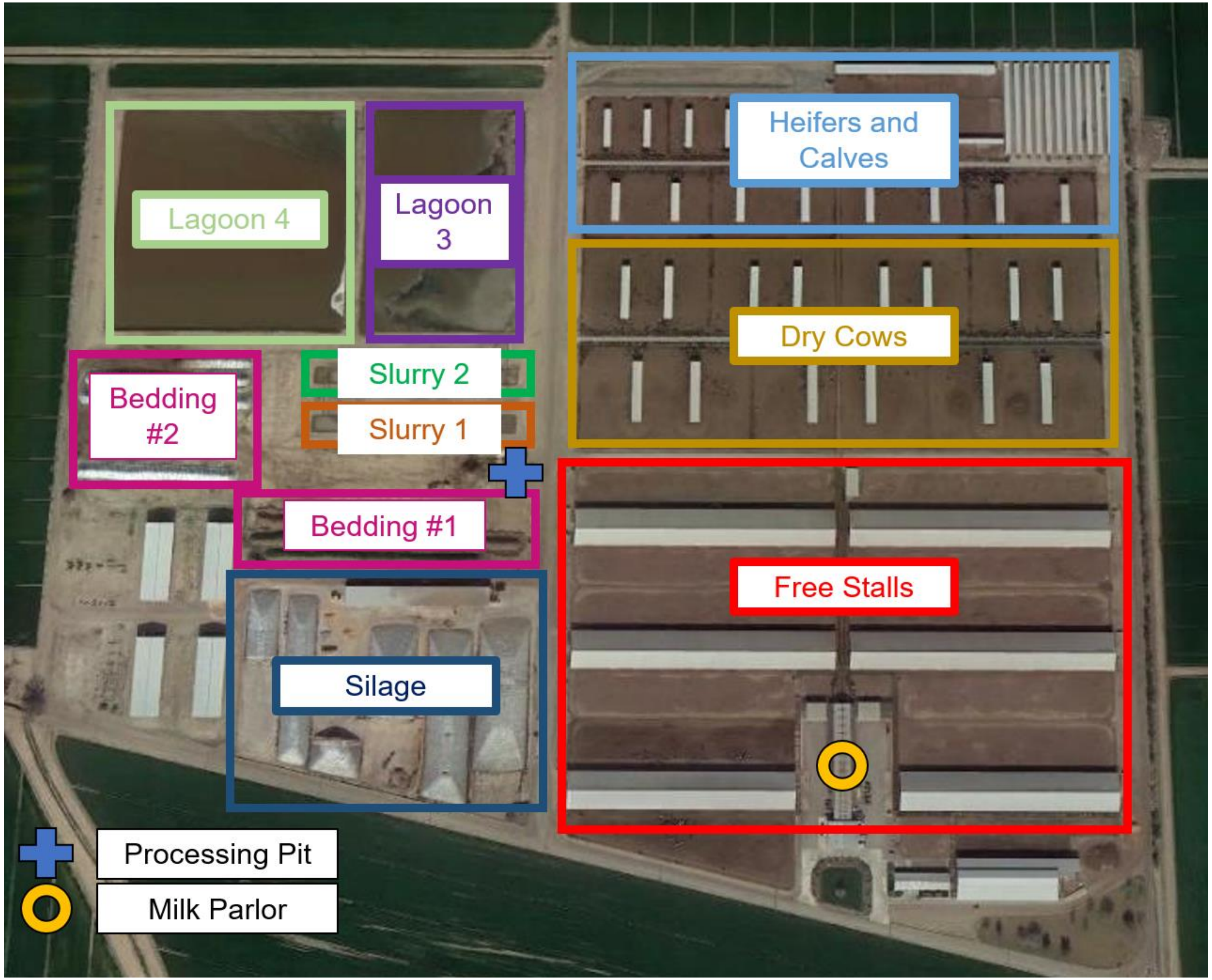
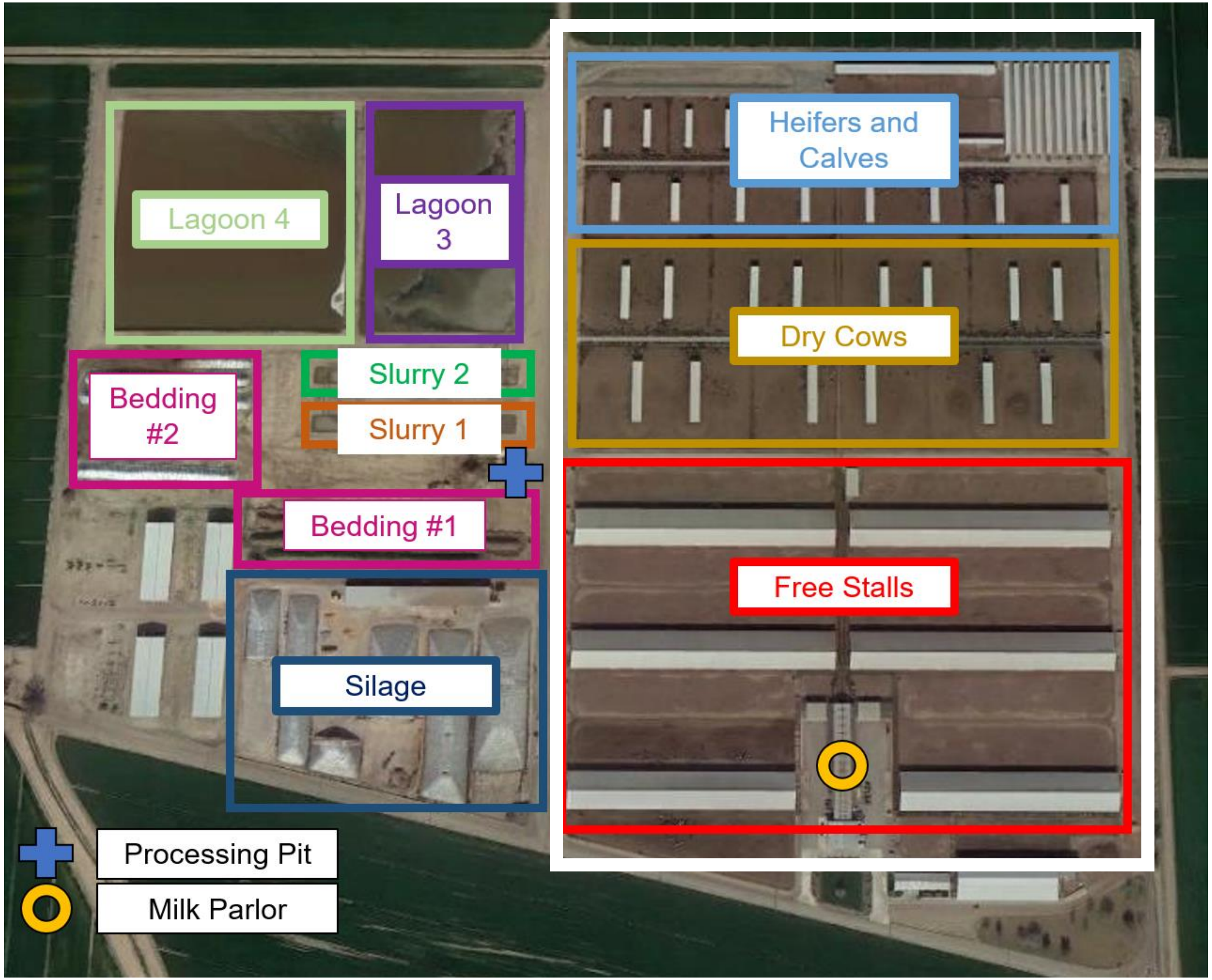


Dairy Farms Produce Gas



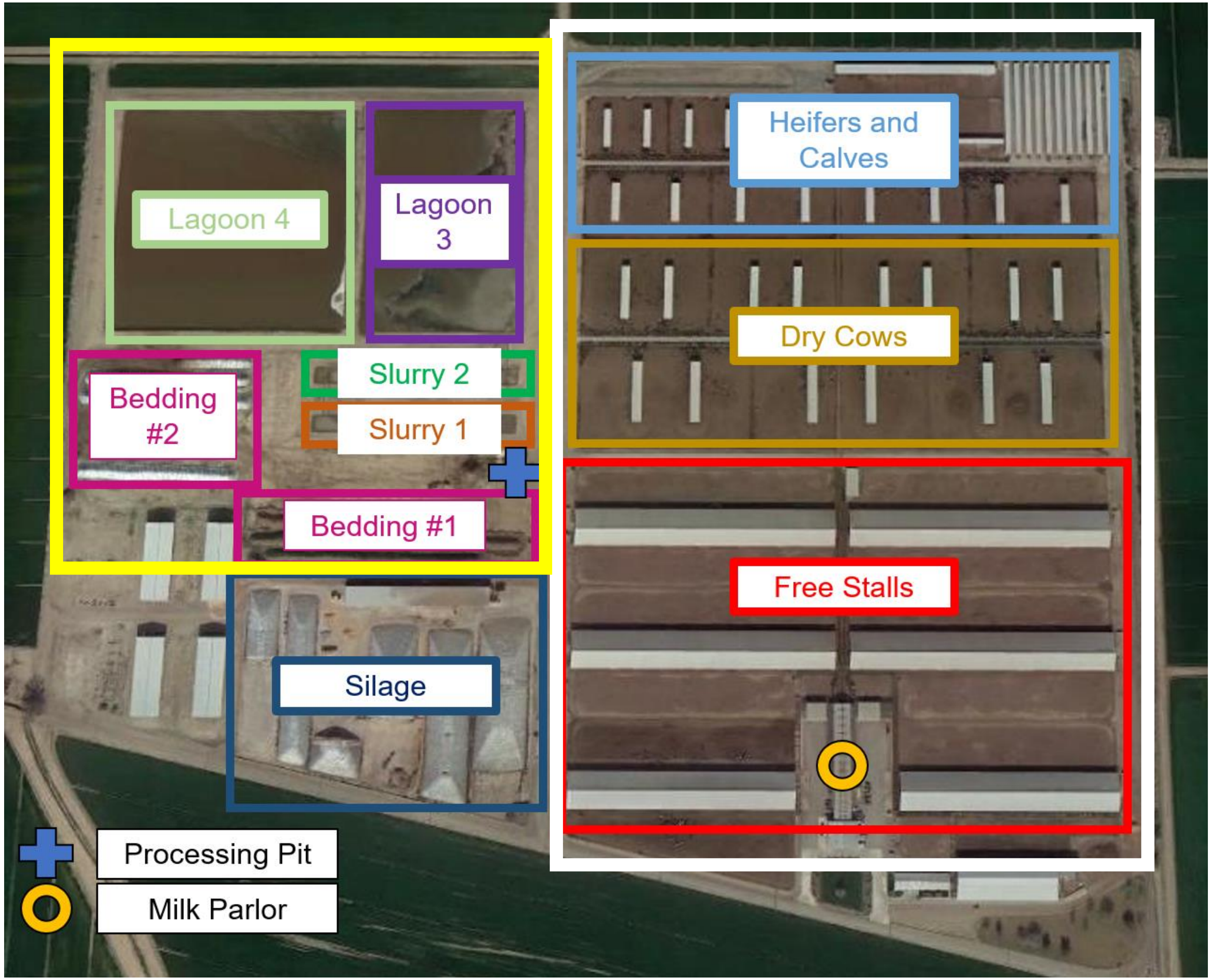
Enteric Emissions:
Cows ruminate

Includes:
Heifers/Calves
Dry Cows
Milk Cows

Dairy Farms Produce Gas

Manure Emissions:
Decomposition

Includes:
Lagoons
Slurries
Bedding
Processing Pit



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Methane

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2016: Senate Bill 1383

- Decrease methane to 40% below 2013 levels by 2030
- Fines starting in 2024

Dairy farms make a lot of methane.
Farmers, who live in disadvantaged communities, will be fined for these emissions starting in 2024.

Manure Management at the Dairy

Photos by Brenna Biggs (2018, 2019).

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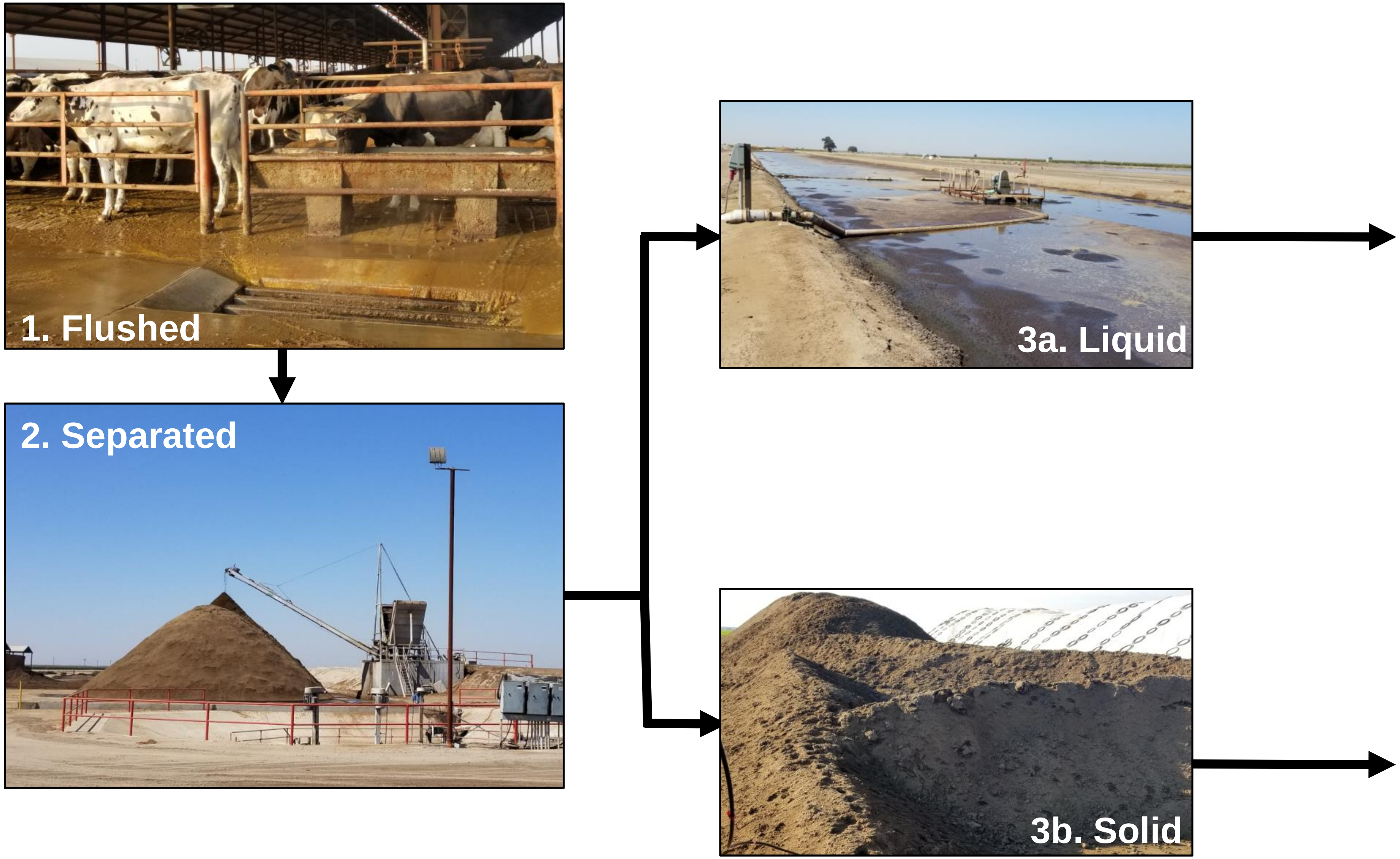

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Manure Management at the Dairy

Slurries
&
Lagoons

Solar
Drying

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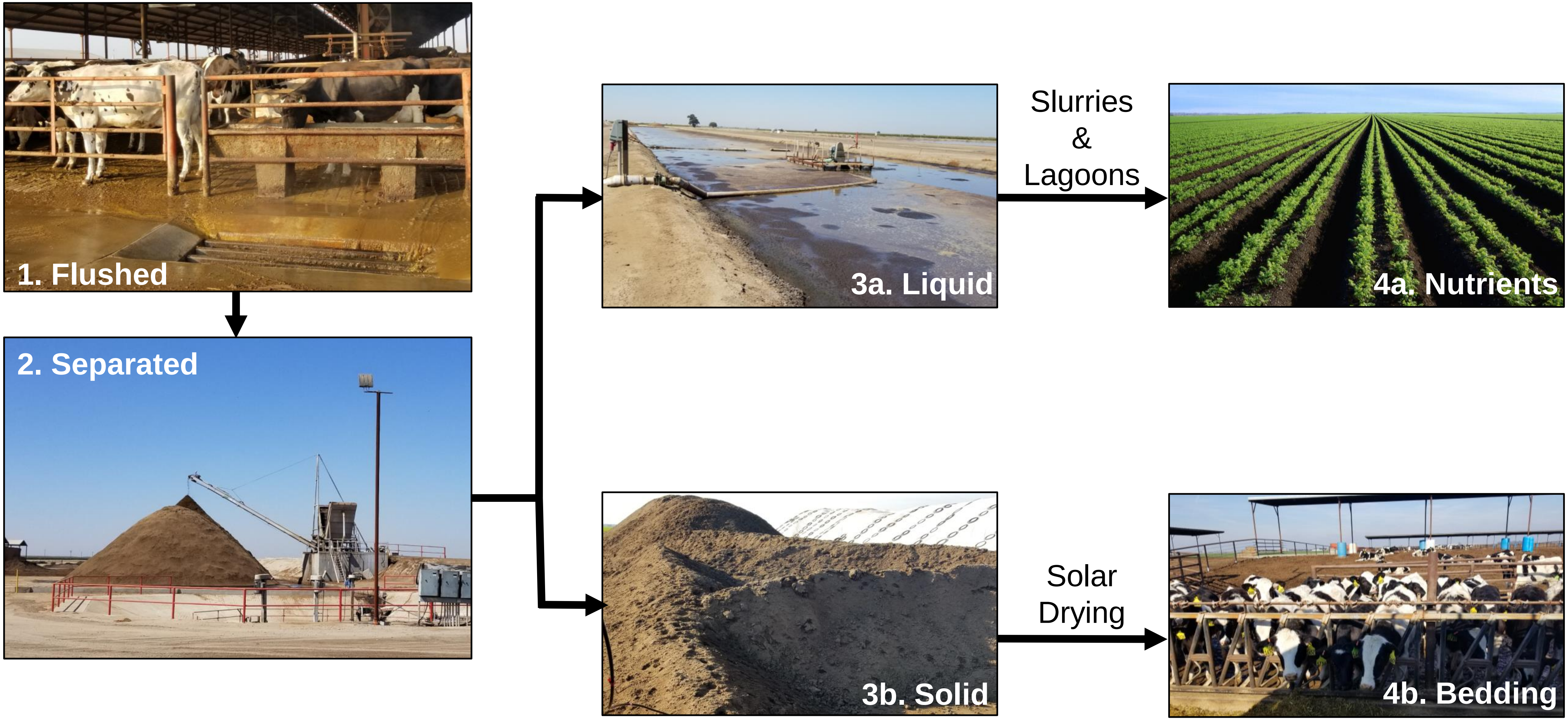

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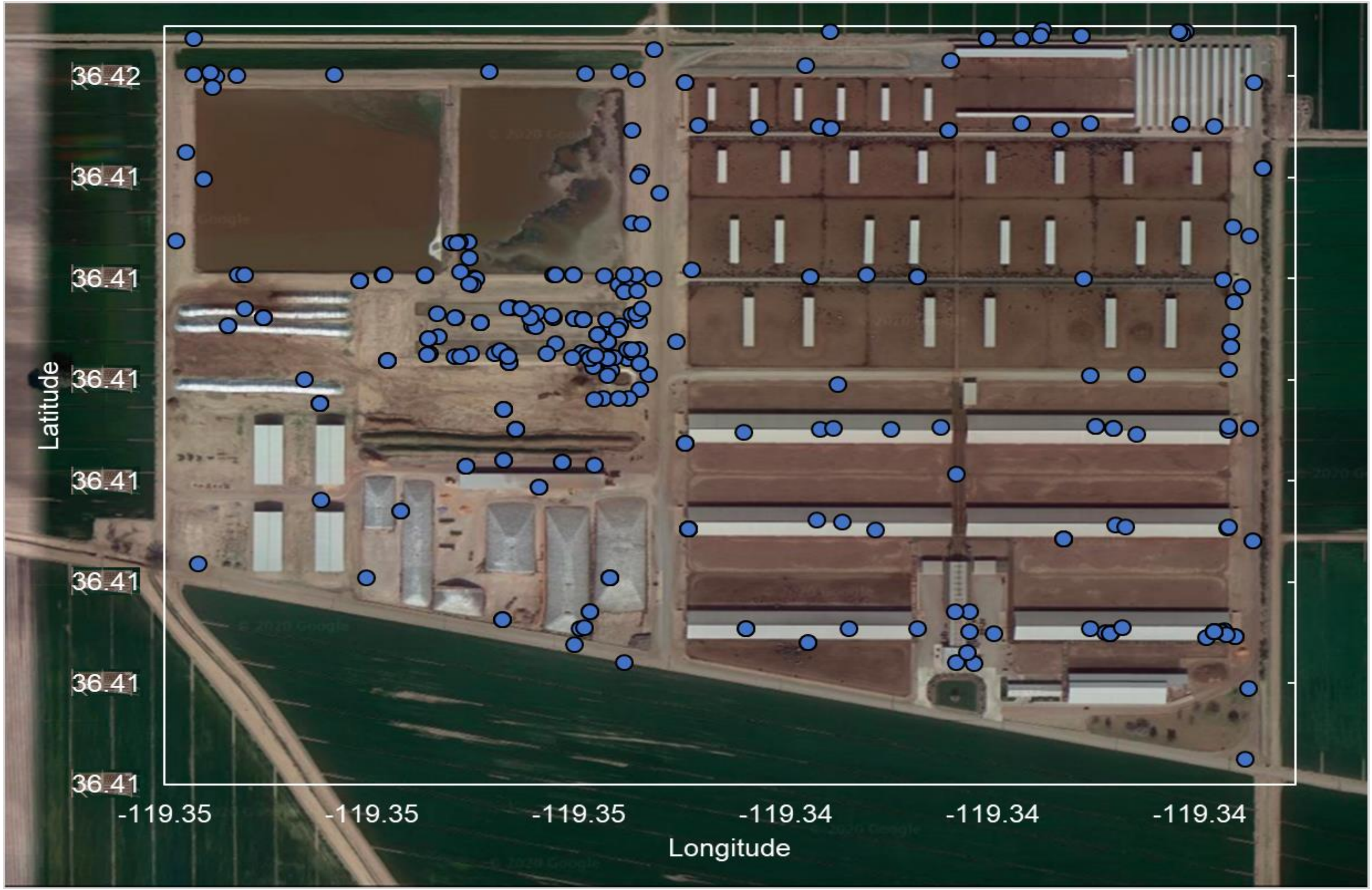

Sample Collection in the Rowland-Blake Lab

Canister

- Samples collected in 2-liter, evacuated, stainless steel canisters

Photos by Brenna Biggs & Alicia Hoffman (2018).

Sample Collection in the Rowland-Blake Lab

Canister

Collect air sample

- Samples collected in 2-liter, evacuated, stainless steel canisters
- Variety of sample locations (e.g., upwind, downwind)

Photos by Brenna Biggs & Alicia Hoffman (2018).

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Sample Collection at the Dairy

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“Snake”

Photos by Brenna Biggs (2018, 2019).

Sample Collection at the Dairy

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"Snake"

Mobile lab

Photos by Brenna Biggs (2018, 2019).

Sample Collection at the Dairy

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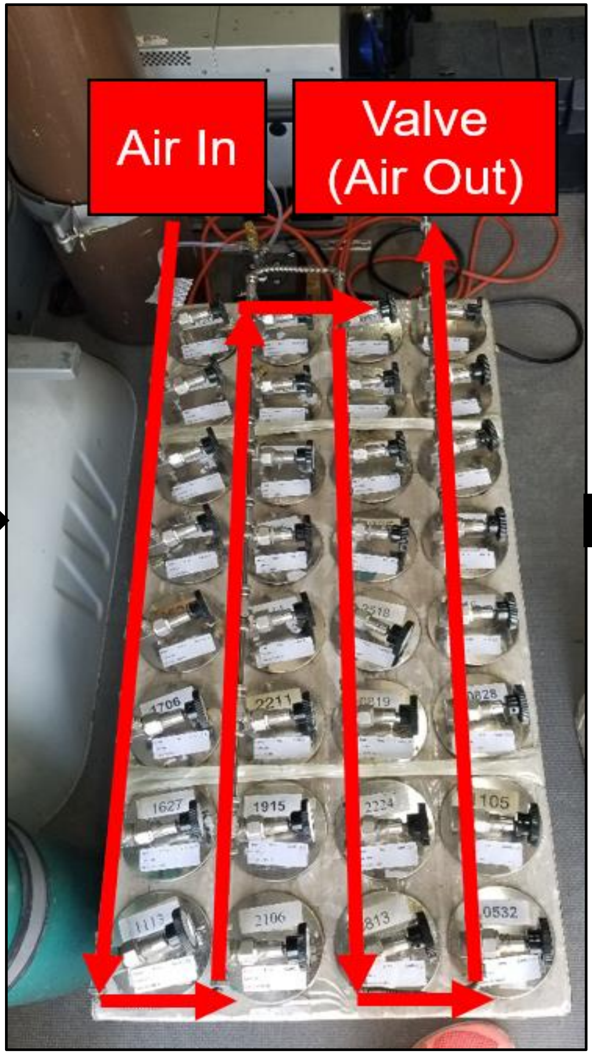

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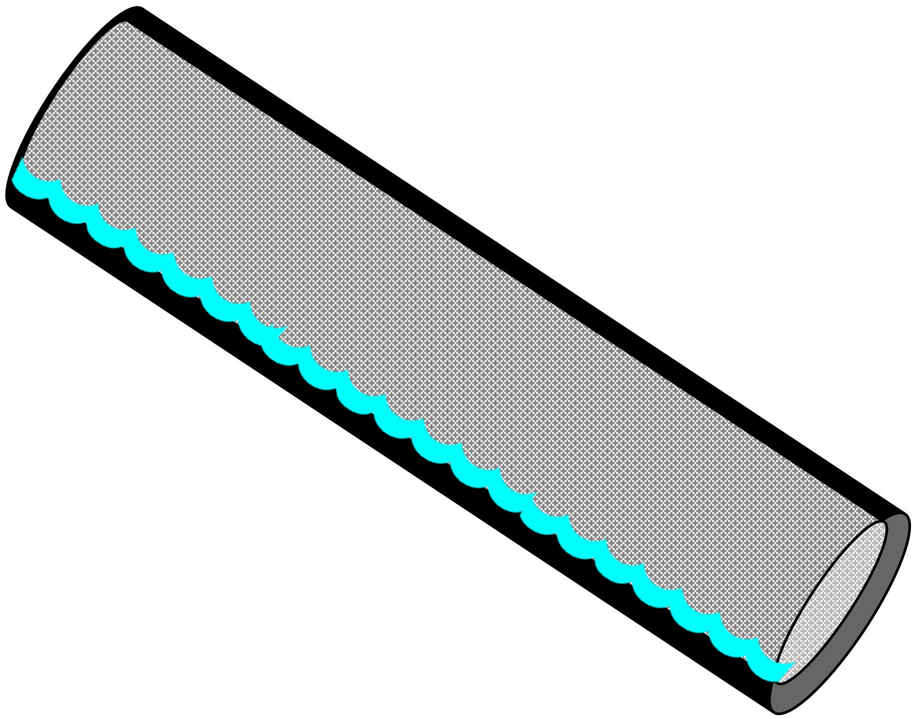

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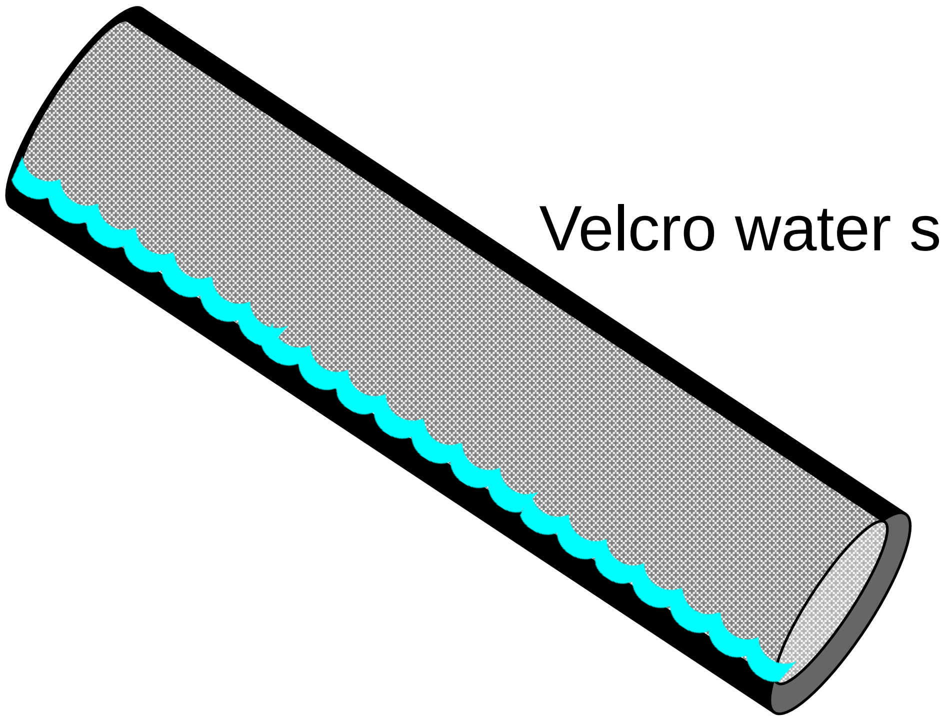

Velcro water slide

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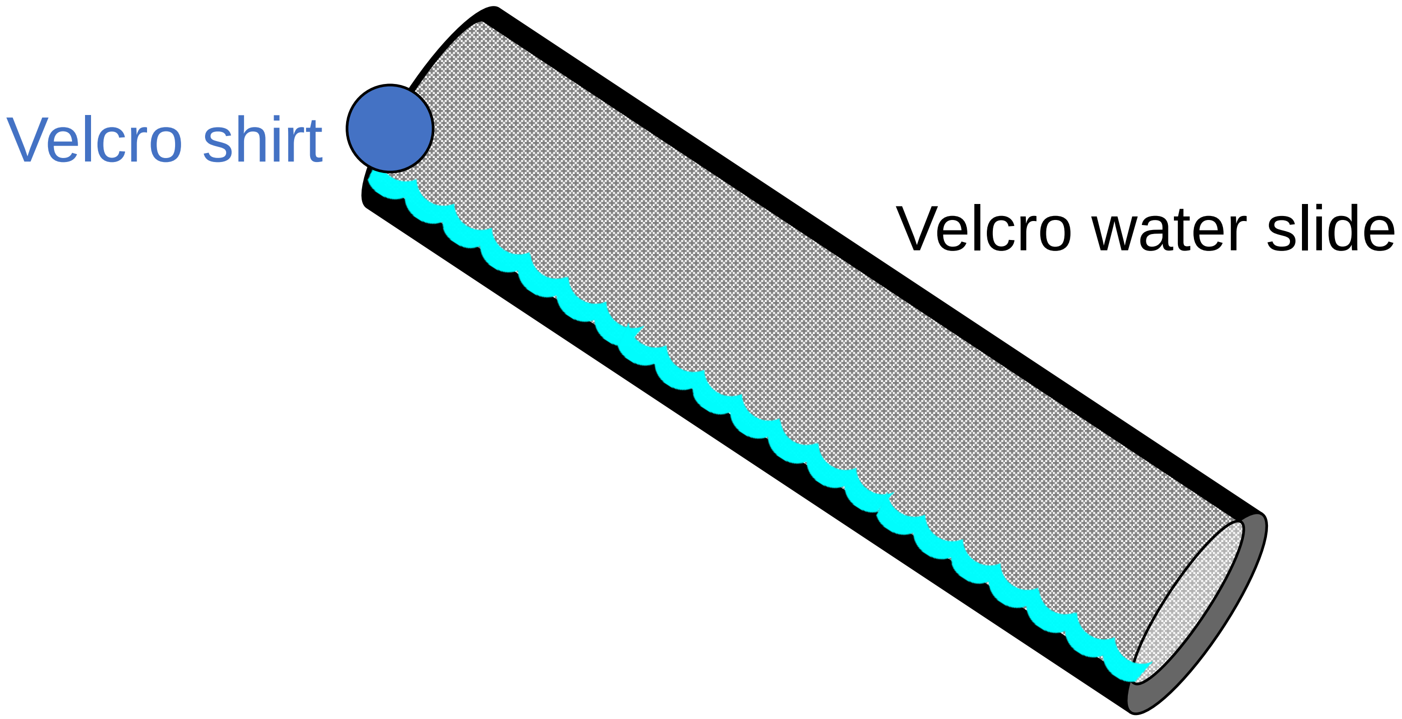

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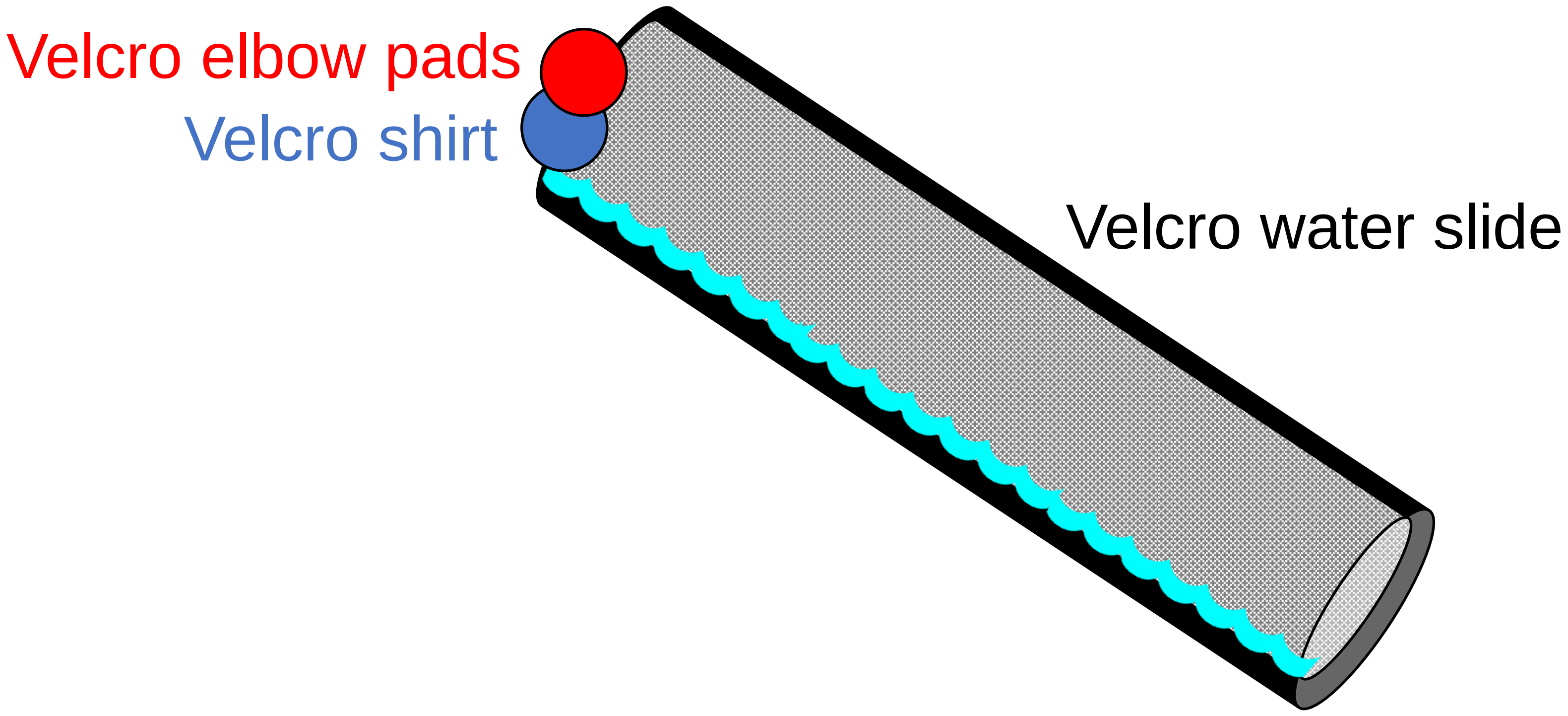

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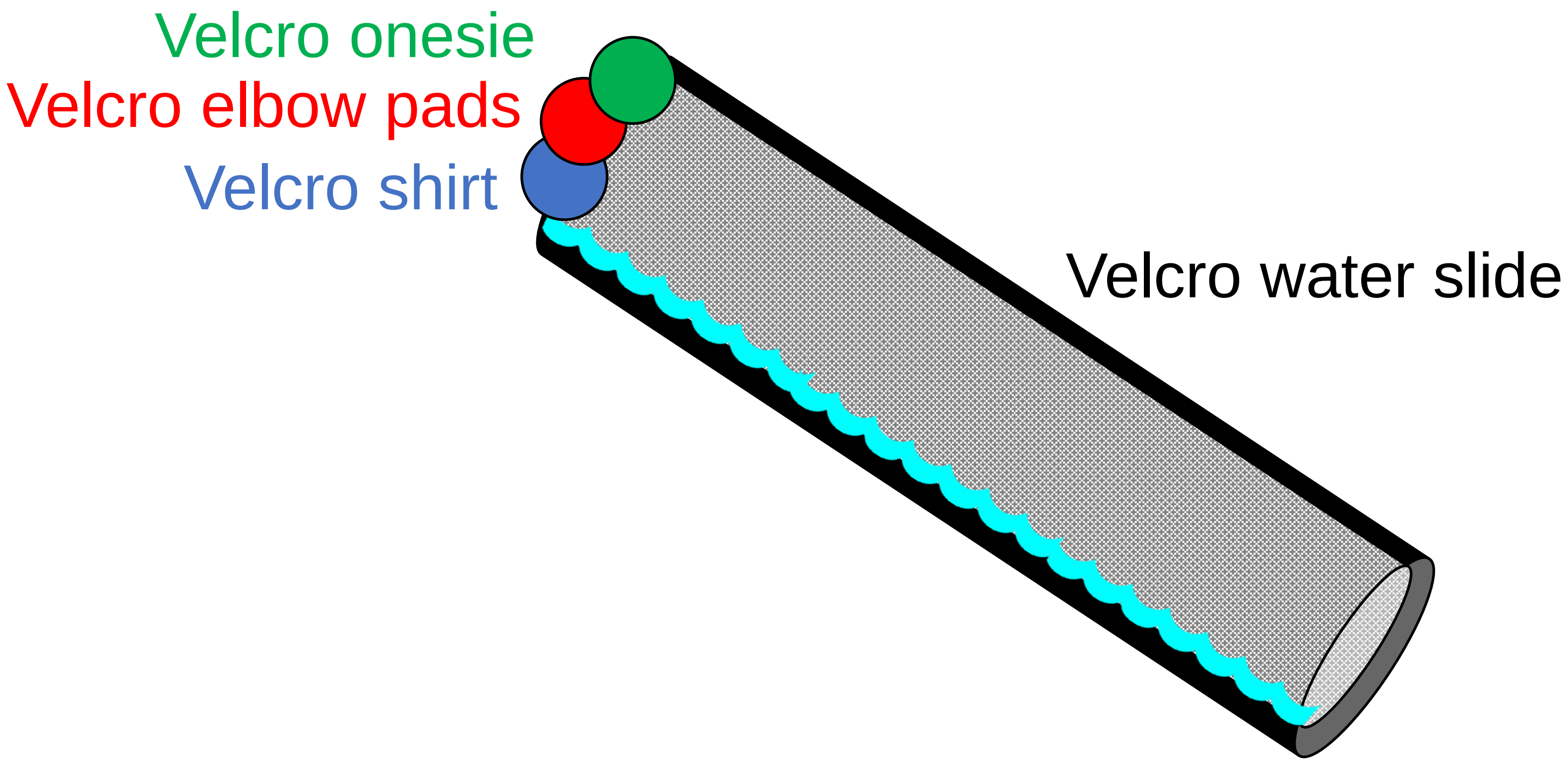

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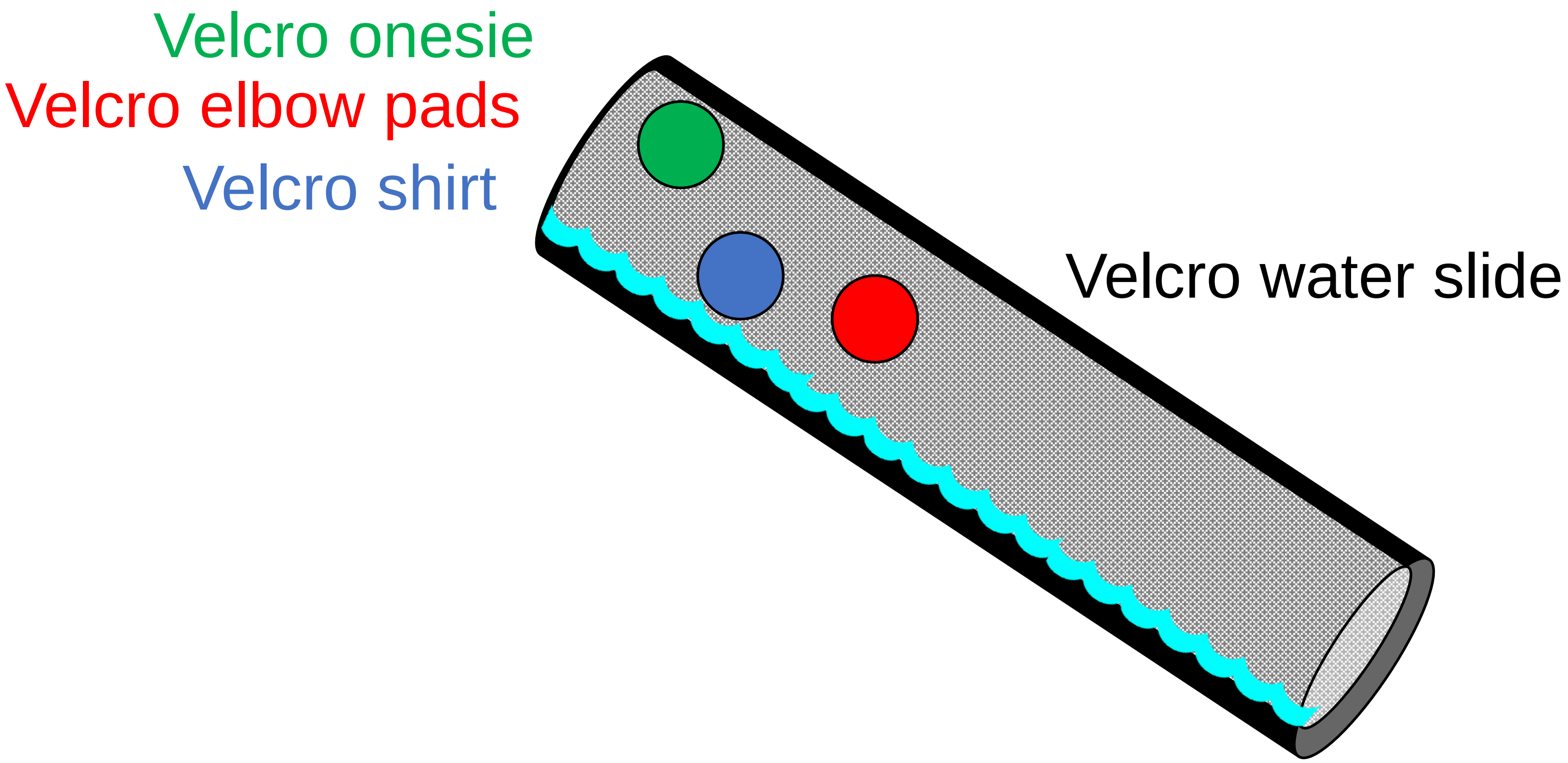

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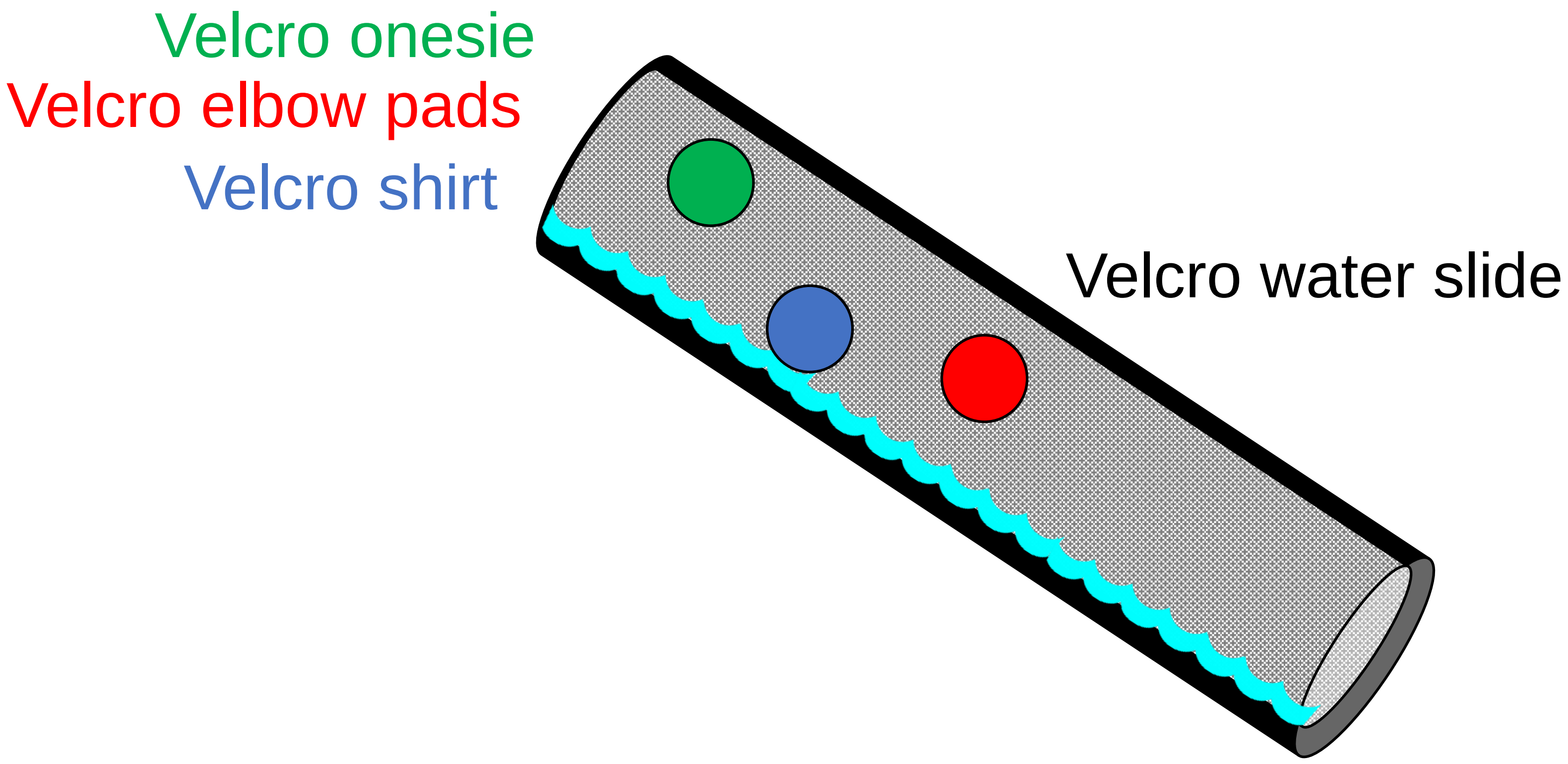

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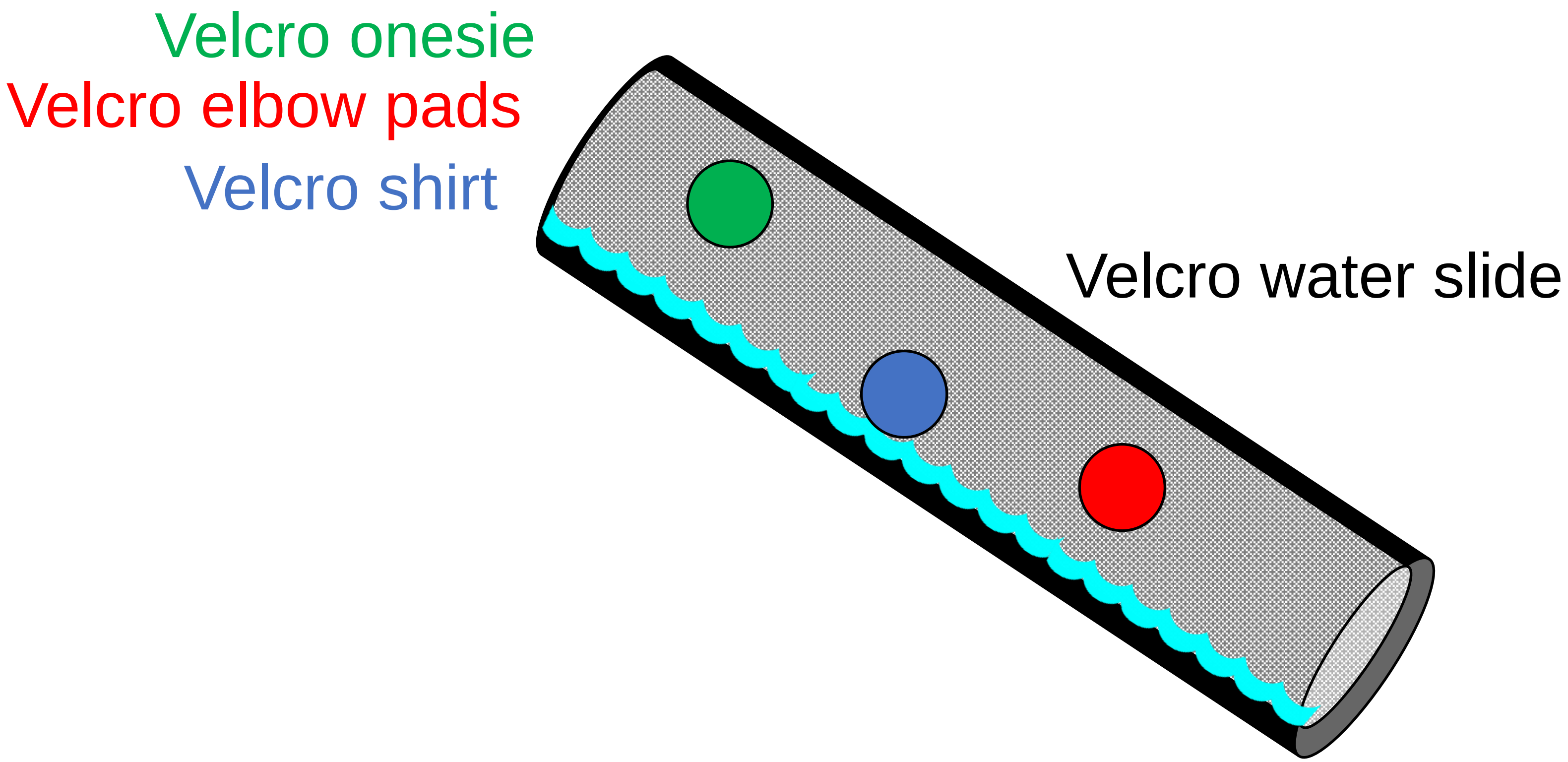

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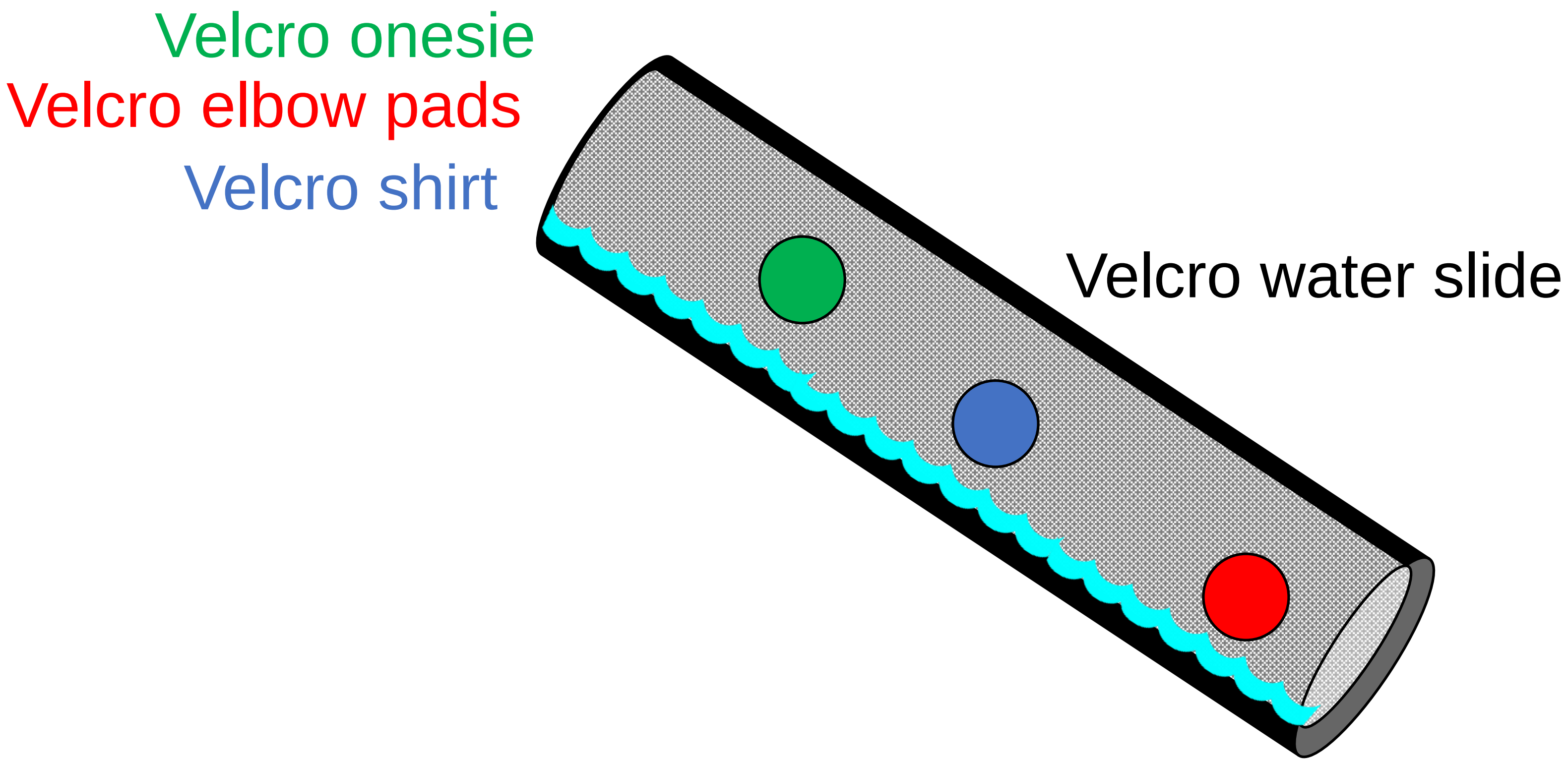

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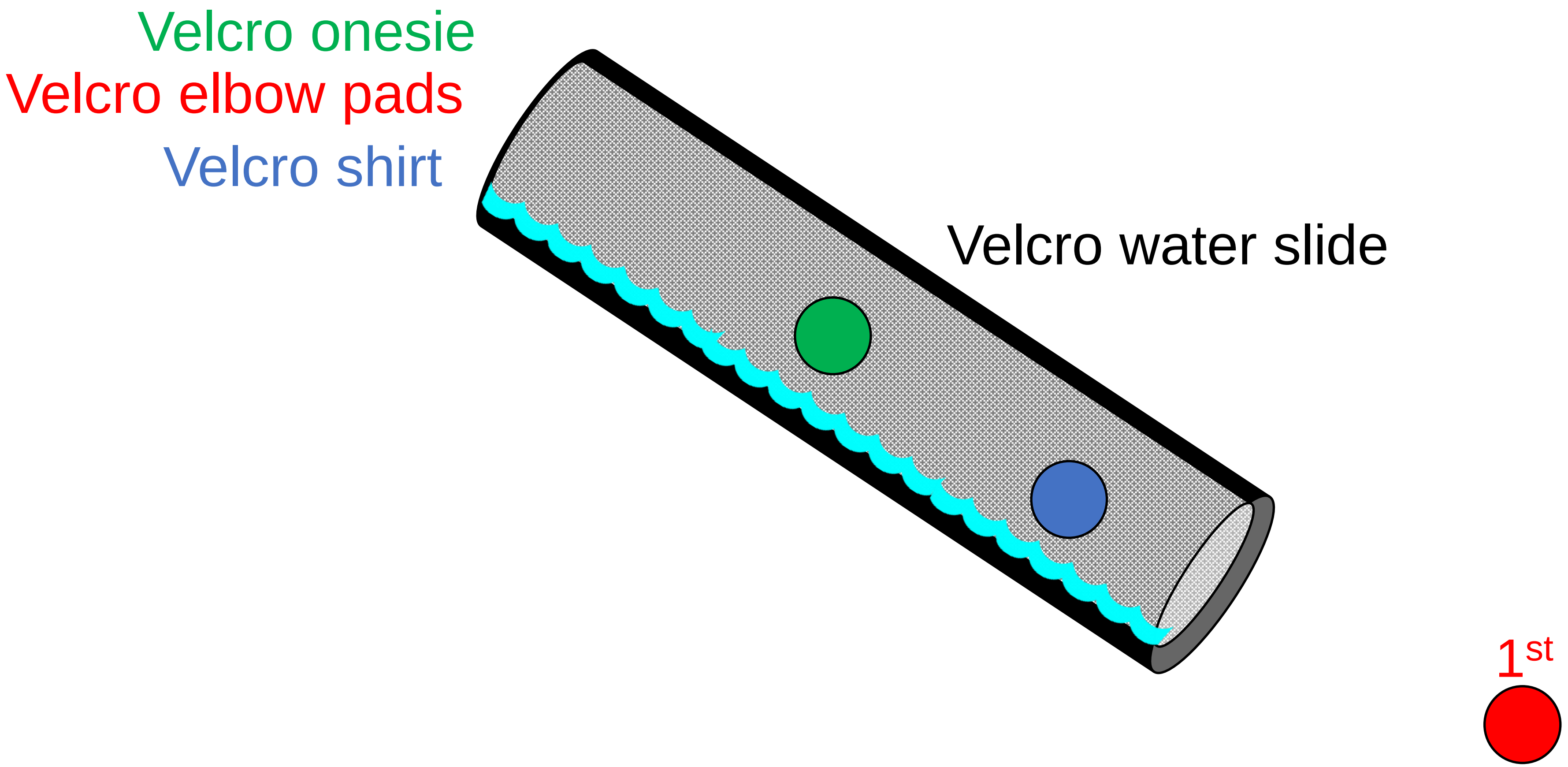

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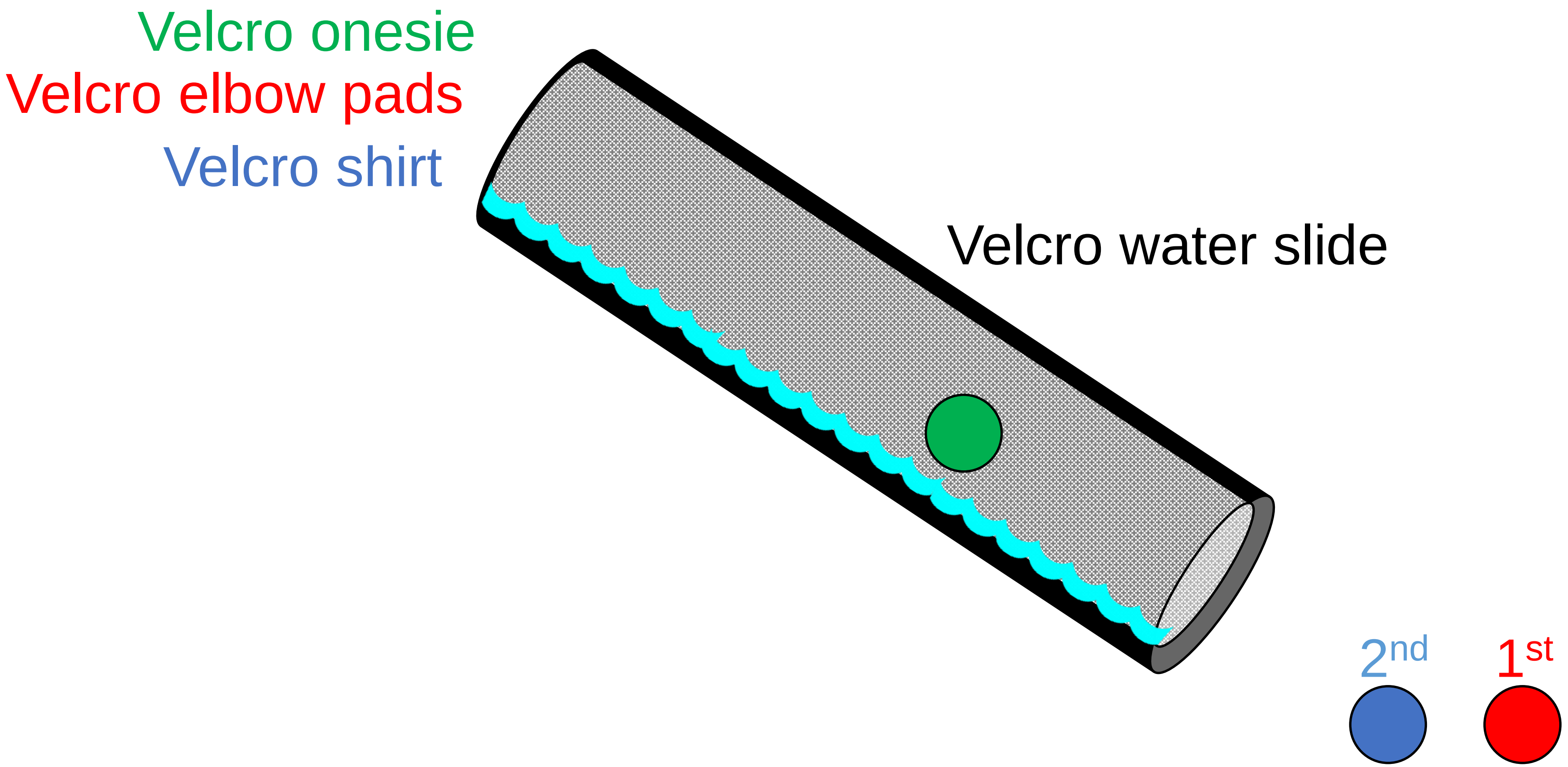

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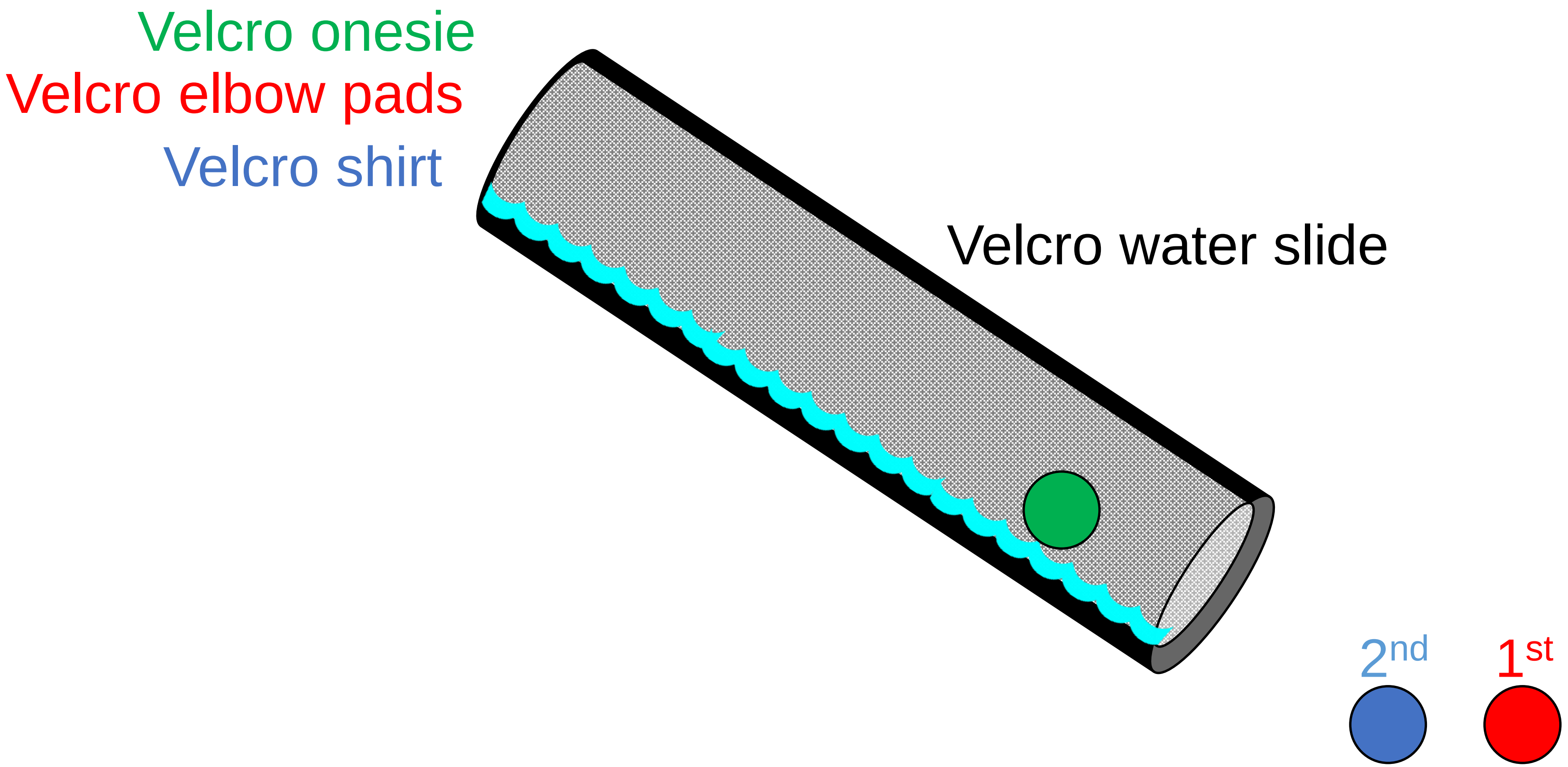

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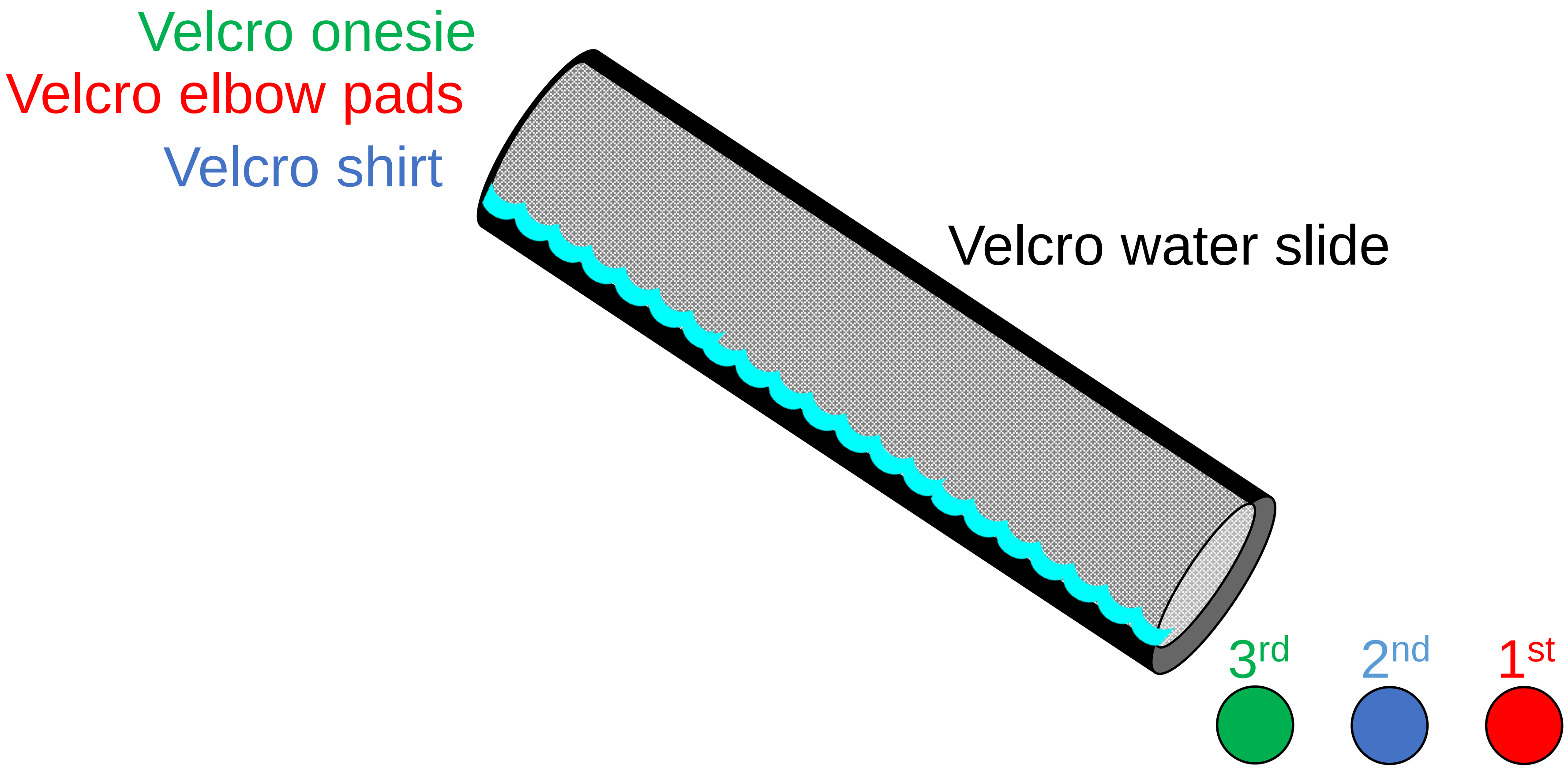

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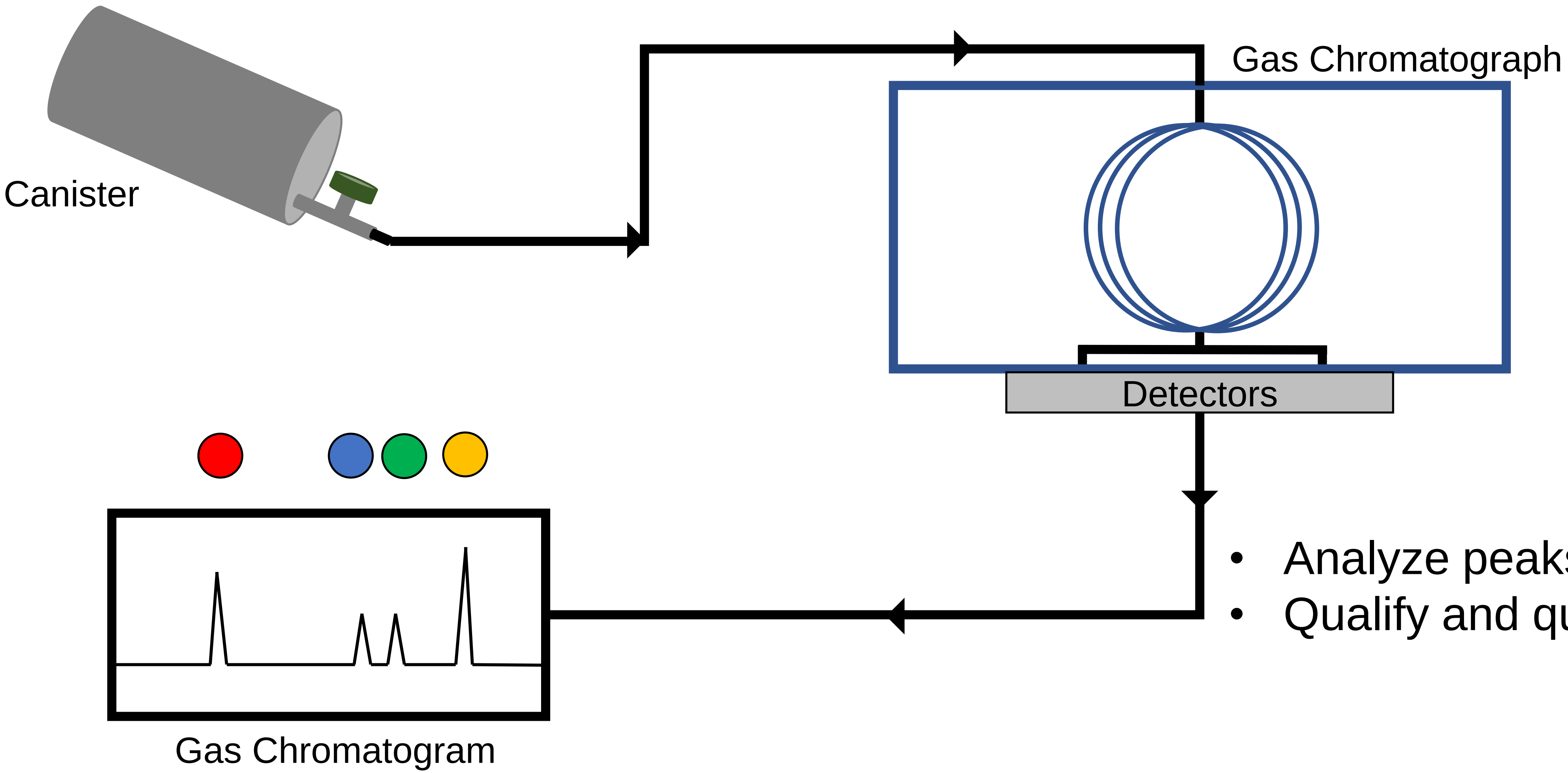
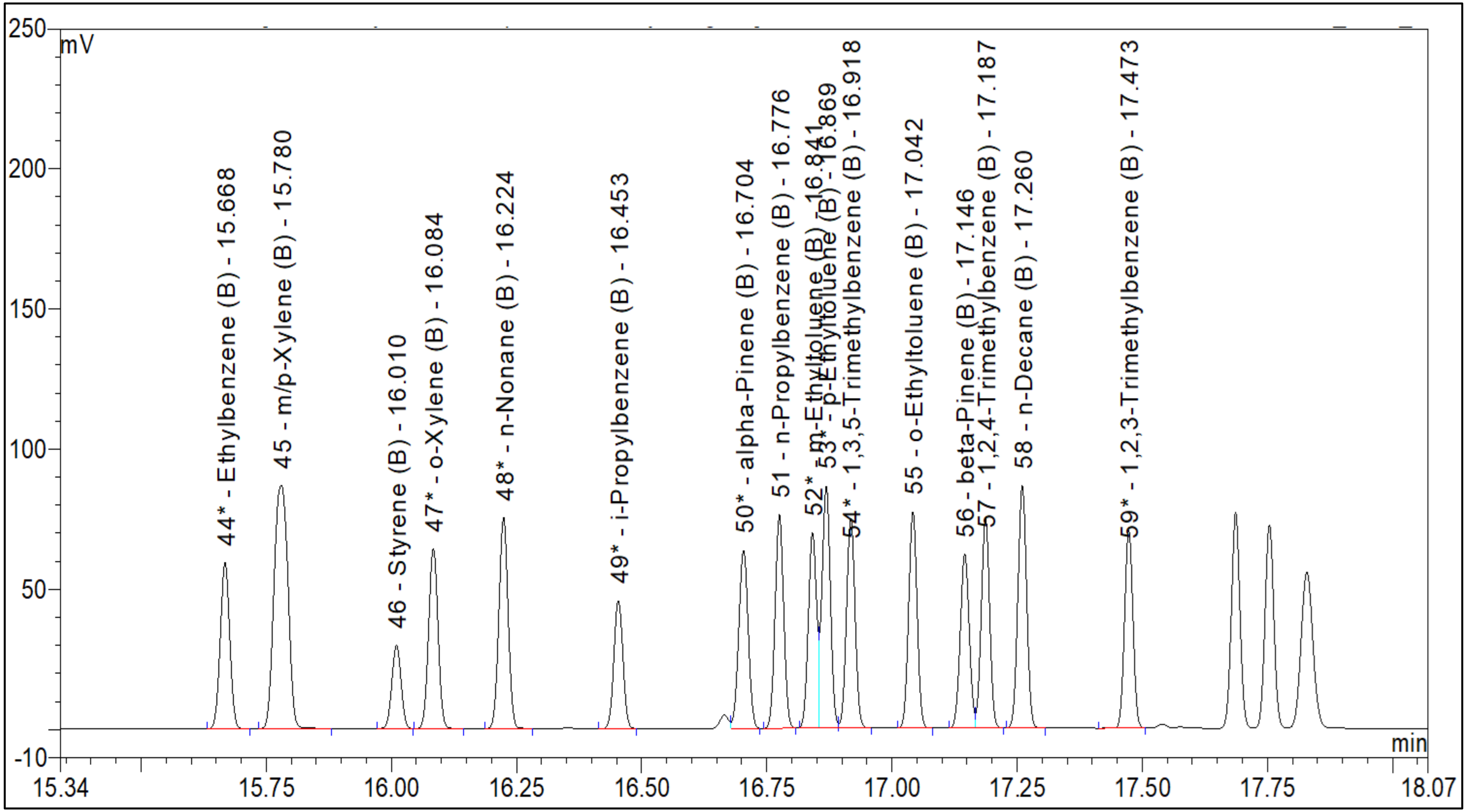


- Analyze peaks on computer
- Qualify and quantify

Analysis Using Gas Chromatography



Gas Chromatogram

Select Gases in Whole Air Samples

Alkanes:
Methane
Ethane
Propane
i/n-Butane
i/n-Pentane
n-Hexane
Cyclohexane
2,3-Dimethylbutane
2,2-Dimethylbutane
Methylcyclopentane
n-Heptane
Methylcyclohexane
2,4-Dimethylpentane
2-Methylhexane
3-Methylhexane
n-Octane
2,2,4-Trimethylpentane
n-nonane

Alcohols:
2-Butanol
Ethanol
Isopropanol
Methanol

Aromatics:
1,2,4-Trimethylbenzene
1,3,5-Trimethylbenzene
Ethylbenzene
i-Propylbenzene
n-Propylbenzene
m+p-Xylene
o-Xylene
Toluene
m-Ethyltoluene
o-Ethyltoluene
p-Ethyltoluene
Benzene

Extra Greenhouse Gases:
Nitrous Oxide
Carbon Dioxide

Alkenes:
1-Butene
i-Butene
α-Pinene
β-Pinene
Isoprene
Limonene
Myrcene
γ-Terpinene
α-Terpinene
3-Carene
Propene
trans-2-butene
cis-2-butene

Sulfur Species:
Carbon Disulfide
Dimethyl Disulfide
Dimethyl Sulfide
Carbonyl Sulfide

Halocarbons:
Tetrachloroethylene
Chloroform
CFC-11
CFC-12
Dichloromethane
Trichloroethylene
Carbon Tetrachloride
Methyl Chloroform
Methyl Chloride
1,2-Dichloroethene
Bromoform

Ketones:
Acetone
Butanone
Methylisobutylketone

Aldehydes:
Acetaldehyde
Butanal

Select Gases in Whole Air Samples

Alkanes:
Methane
Ethane
Propane
i/n-Butane
i/n-Pentane
n-Hexane
Cyclohexane
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3-Methylhexane
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n-nonane

Alcohols:
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Ethanol
Isopropanol
Methanol

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Sulfur Species:
Carbon Disulfide
Dimethyl Disulfide
Dimethyl Sulfide
Carbonyl Sulfide

Halocarbons:
Tetrachloroethylene
Chloroform
CFC-11
CFC-12
Dichloromethane
Trichloroethylene
Carbon Tetrachloride
Methyl Chloroform
Methyl Chloride
1,2-Dichloroethene
Bromoform

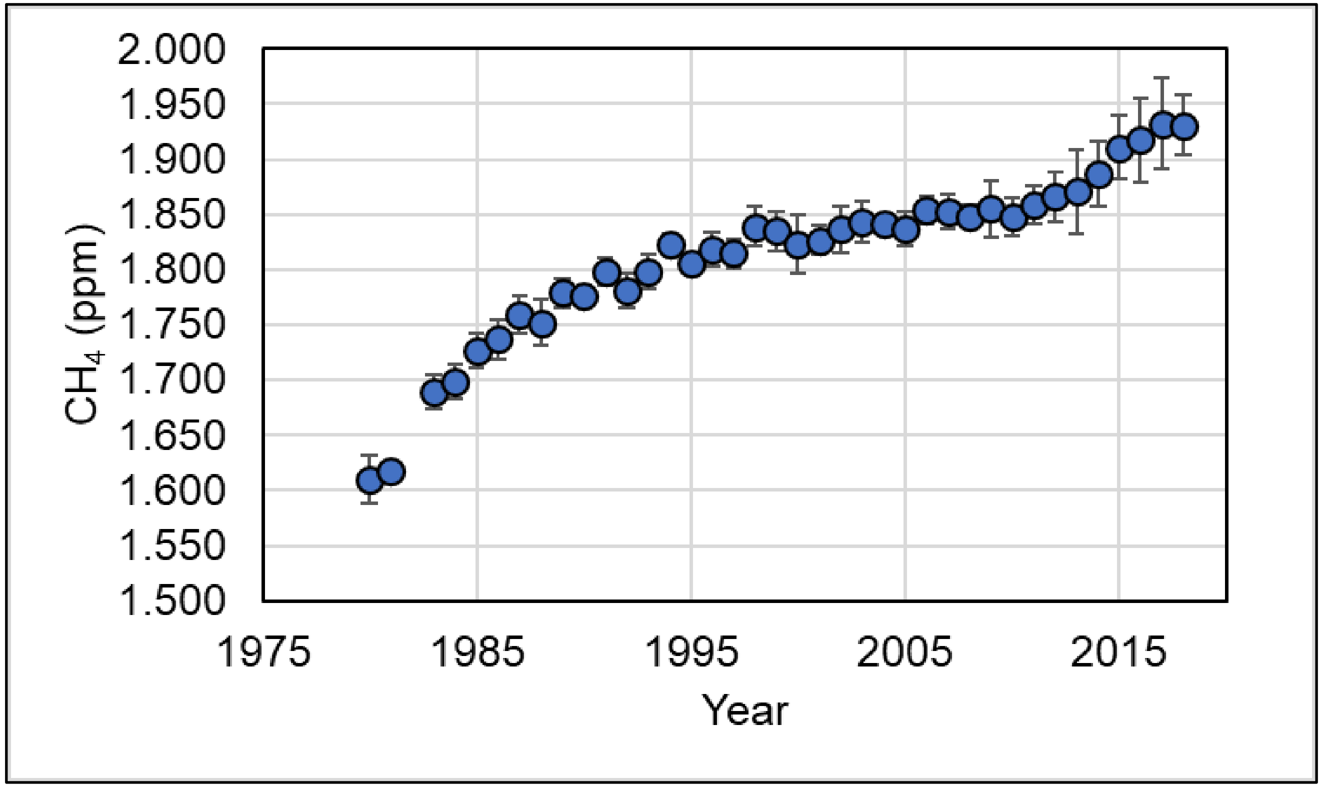
Ketones:
Acetone
Butanone
Methylisobutylketone

Aldehydes:
Acetaldehyde
Butanal

Summary of Findings

Issue	Dairy	Suggestions
CH_4		
N_2O		
DMS		
OCS		
Pollution		
Odor		

“Background” Methane Entering CA



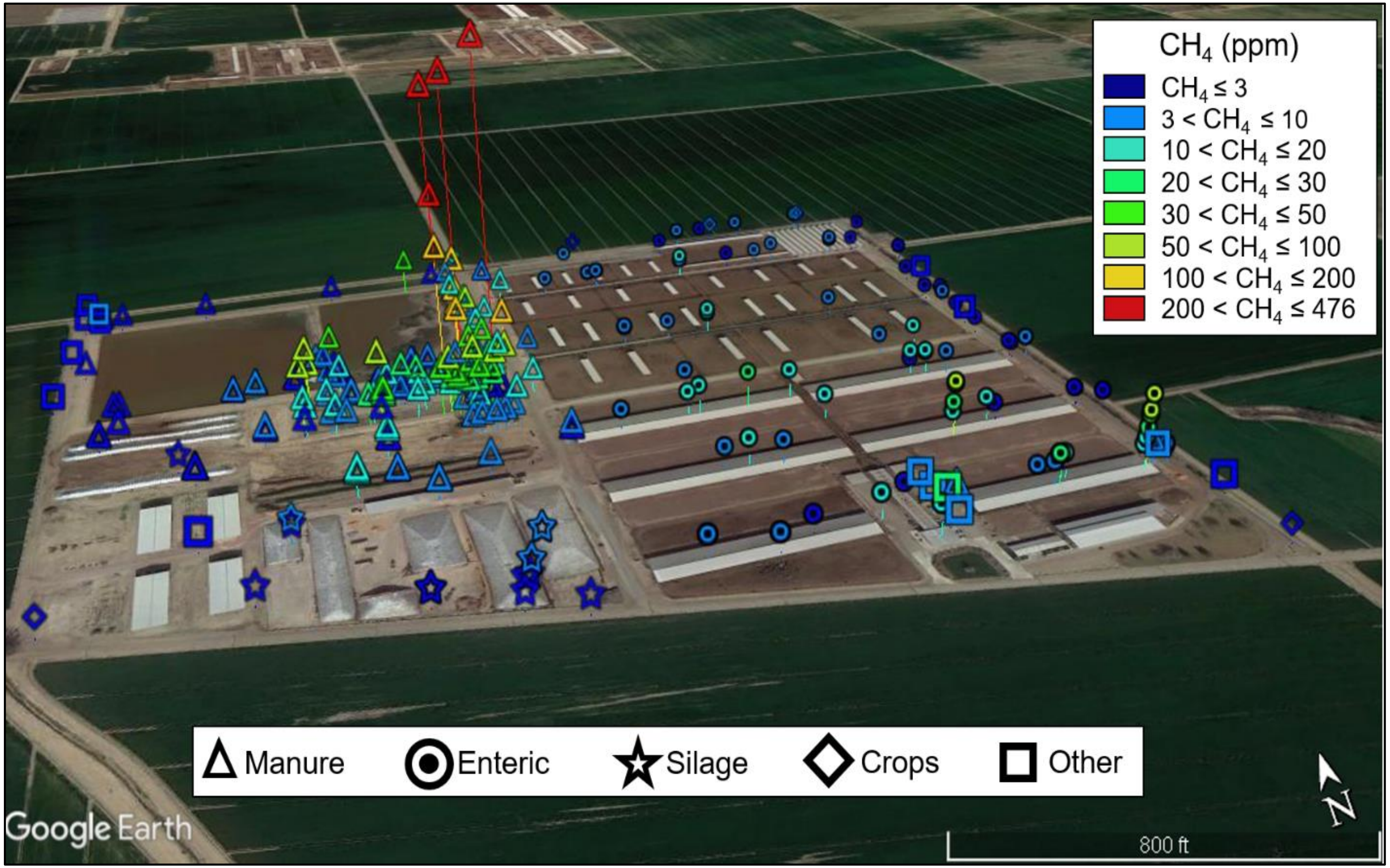
Coastal samples (34.5 to 40.0 °N)
1980 – 2018

↑ methane over time

Now 1.931 ppm CH_4

Samples with CH_4 > 1.931 ppm assumed to be enhanced by inland sources.

Methane at the Visalia Dairy Farm



How much from cows?
How much from manure?

Coastal CH_4 was 1.931 ppm.

Manure Management Methane Estimates at the Dairy Farm

- International Panel for Climate Change (IPCC) *2006 Guidelines for National Greenhouse Gas Inventories* gives emission factor methodology for manure management

Tier	What You Need
1	Average annual air temperature of the region Number of animals
2	Specific animal and temperature characteristics Manure management practices
3	Measurements Models

Increasing complexity

IPCC (2006)
EPA (2020)

Manure Management Methane Estimates at the Dairy Farm

- International Panel for Climate Change (IPCC) *2006 Guidelines for National Greenhouse Gas Inventories* gives emission factor methodology for manure management

Environmental Protection Agency (EPA) uses these to calculate our GHG inventory (Tiers 1 and 2)

Tier	What You Need
1	Average annual air temperature of the region Number of animals
2	Specific animal and temperature characteristics Manure management practices
3	Measurements Models

Increasing complexity (Tier 1 → Tier 3)

EPA Tier 2 formula: $\mathrm{EF} = \mathrm{VS} * \mathrm{B}_0 * \mathrm{MCF} * \rho_{CH4} * \mathrm{MDP}$

IPCC (2006)
EPA (2020)

Manure Management Methane Estimates at the Dairy Farm

EPA Tier 2 formula:

$$EF = VS * B_0 * MCF * \rho_{CH4} * MDP$$

EF = methane emission factor, in (kg CH_4/month)
VS = volatile solids entering the lagoon each month, in (kg VS)
B_0 = maximum CH_4-producing capacity of manure, in (m^3 CH_4/kg VS)
MCF = temperature-dependent methane conversion factor
ρ_{CH4} = 0.662, the density of CH_4 at 25 °C, in (kg CH_4/m^3 CH_4)
MDP = manure management and design practices factor

IPCC (2006)
EPA (2020)

Manure Management Methane Estimates at the Dairy Farm

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IPCC (2006)
EPA (2020)

Manure Management Methane Estimates at the Dairy Farm

EPA Tier 2 formula:

$$EF = VS * B_0 * \boxed{MCF} * \rho_{CH4} * MDP$$

MCF = temperature-dependent methane conversion factor

Directly proportional to the amount of methane that can be produced.

IPCC (2006)
EPA (2020)

Modelled Liquid Manure Temperatures

Modified van’t Hoff-Arrhenius explains biological systems

$$f = \exp\left[\frac{E(T_2 - T_1)}{RT_1T_2}\right]$$

Safley & Westerman (1990)

Modelled Liquid Manure Temperatures

Modified van't Hoff-Arrhenius explains biological systems

$$f = \exp\left[\frac{E(T_2 - T_1)}{RT_1T_2}\right]$$

Safley & Westerman (1990)

→

How bacteria make methane in manure

$$\mathbf{MCF} = \exp\left[\frac{E(\mathbf{T_2} - T_1)}{RT_1\mathbf{T_2}}\right]$$

Mangino et al. (2002)

where
E = activation energy, in (cal/mol)
R = ideal gas constant (1.987 cal/mol)
T_1 = reference temperature (K)
T_2 = temperature (K)

Liquid temperatures, not air temperatures, would ideally be used as T_2 to calculate MCF.

MCF Temperature Requirements

Method	Type of Temperature Data Needed	Example
IPCC Tier 1	Average annual **air** temperature of a region	SJV annually
EPA Tier 2	Average monthly **air** temperature of a county	Tulare per month
This study	Modelled daily lagoon/slurry temperatures	Daily for liquid manure

IPCC (2006)
EPA (2020)

Modelled Lagoon and Slurry Temperatures

$$TL_i = \frac{TA_i\alpha_i + TA_{i-1}\alpha_{i-1} + \cdots + TA_{i-n}\alpha_{i-n}}{\alpha_i + \alpha_{i-1} + \cdots + \alpha_{i-n}}$$

From Smith & Franco (1985)

TL_i = lagoon or slurry temperature (°C) for day *i*
TA_i = mean air temperature (°C) for day *i*
$\alpha = e^{-bt}$, a weight factor that simulates the response of the lagoon to air temperature
b = constant
t = number of days (0, 1, 2, …, 365)

This study uses daily air temperatures in Visalia to calculate lagoon and slurry temperatures at the dairy farm.

Methane Emission Factor Calculation

$$\mathbf{TL_i} = \frac{TA_i\alpha_i + TA_{i-1}\alpha_{i-1} + \cdots + TA_{i-n}\alpha_{i-n}}{\alpha_i + \alpha_{i-1} + \cdots + \alpha_{i-n}}$$

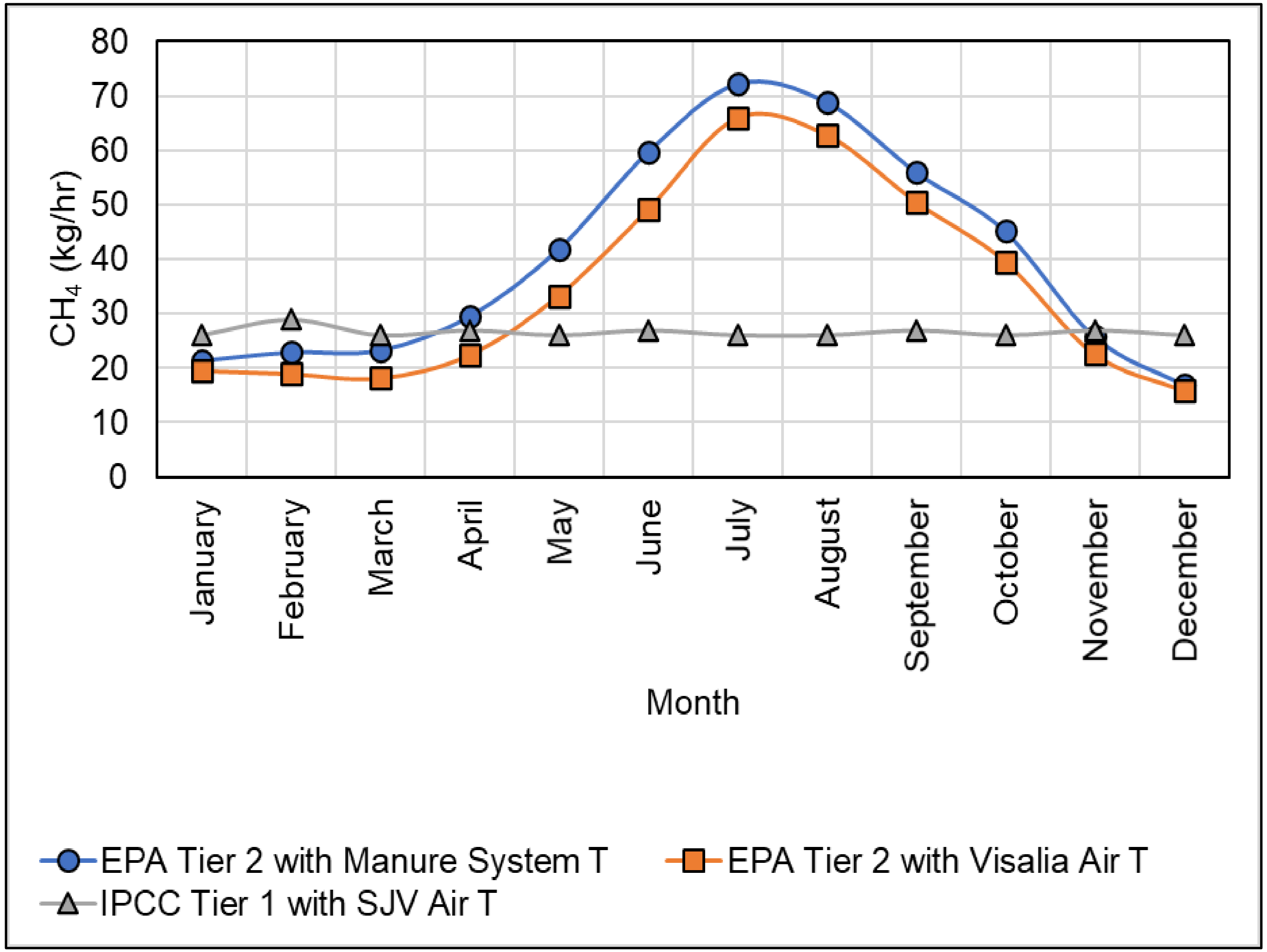
Plug **TL** into **MCF** equation

$$\mathbf{MCF} = \exp\left[\frac{E(\mathbf{TL} - T_1)}{RT_1\mathbf{TL}}\right]$$

Plug **MCF** into Emission Factor **EF** equation

$$EF = VS * B_0 * \mathbf{MCF} * \rho_{CH4} * MDP$$

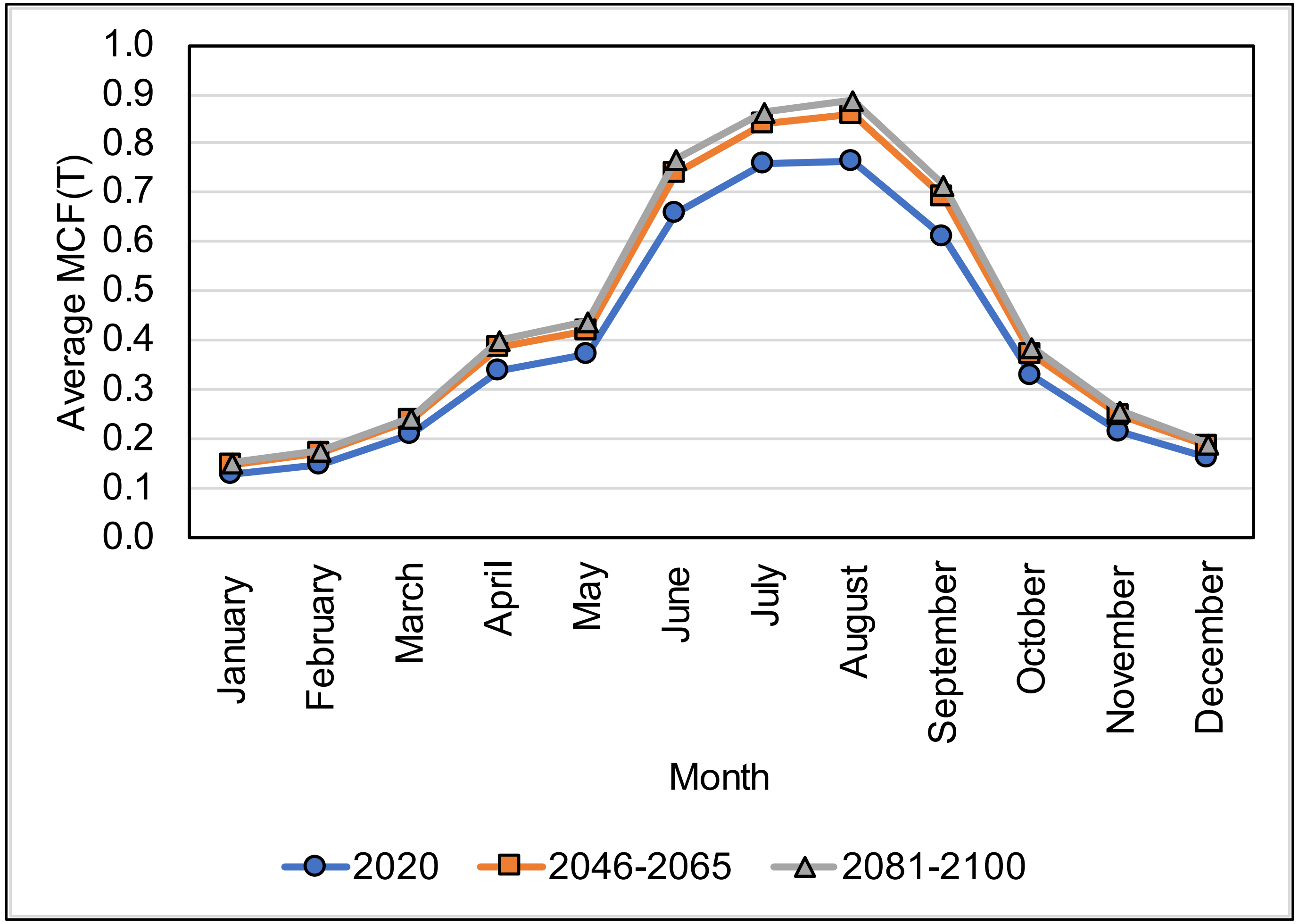
Methane Emission Factors Calculated from Liquid Temperature MCF



- The EPA and IPCC use air temperatures and longer temperature averages.
- They **underestimate** methane emissions from manure management.

This dairy releases 350 metric tonnes of CH_4 annually from manure management.

Manure Management Methane Will Increase with Climate Change



Assume Representative Concentration Pathway 4.5

Predicts average temperature increases:

- 1.4 °C between 2046 and 2065
- 1.8 °C between 2081 and 2100

Important for counties with many cows, like Tulare.

Thomson et al. (2011)
Moss et al. (2008, 2010)

Enteric Methane Estimates at the Dairy Farm

Tier	What You Need	Milk Cow EF (kg CH_4 hd^{-1} yr^{-1})	
		IPCC (2006)	EPA (2020)
1	Number and type of animals	128	146
2	Information about cows' lifestyle	$EF = \frac{GE * \left(\frac{Y_m}{100}\right) * 365}{55.65}$	-

Increasing complexity

where
EF = emission factor, in (kg CH_4 hd^{-1} yr^{-1})
GE = gross energy intake, in (MJ hd^{-1} day^{-1}), which depends on various other parameters
Y_m = methane conversion factor (i.e., the % of gross energy in the feed that is converted to methane)
55.65 = energy content of methane, in (MJ/kg CH_4)
365 = days in a year, in (day/yr)

Enteric Methane Estimates at the Dairy Farm

Category	Enteric EF (kg CH_4 hd^{-1} yr^{-1})	# Cows
Milk Cow	134	3106
Dry Cow	53	386
Heifer (15 months)	55	2985

[a] Eggleston et al. (2006)

[b] EPA (2020c)

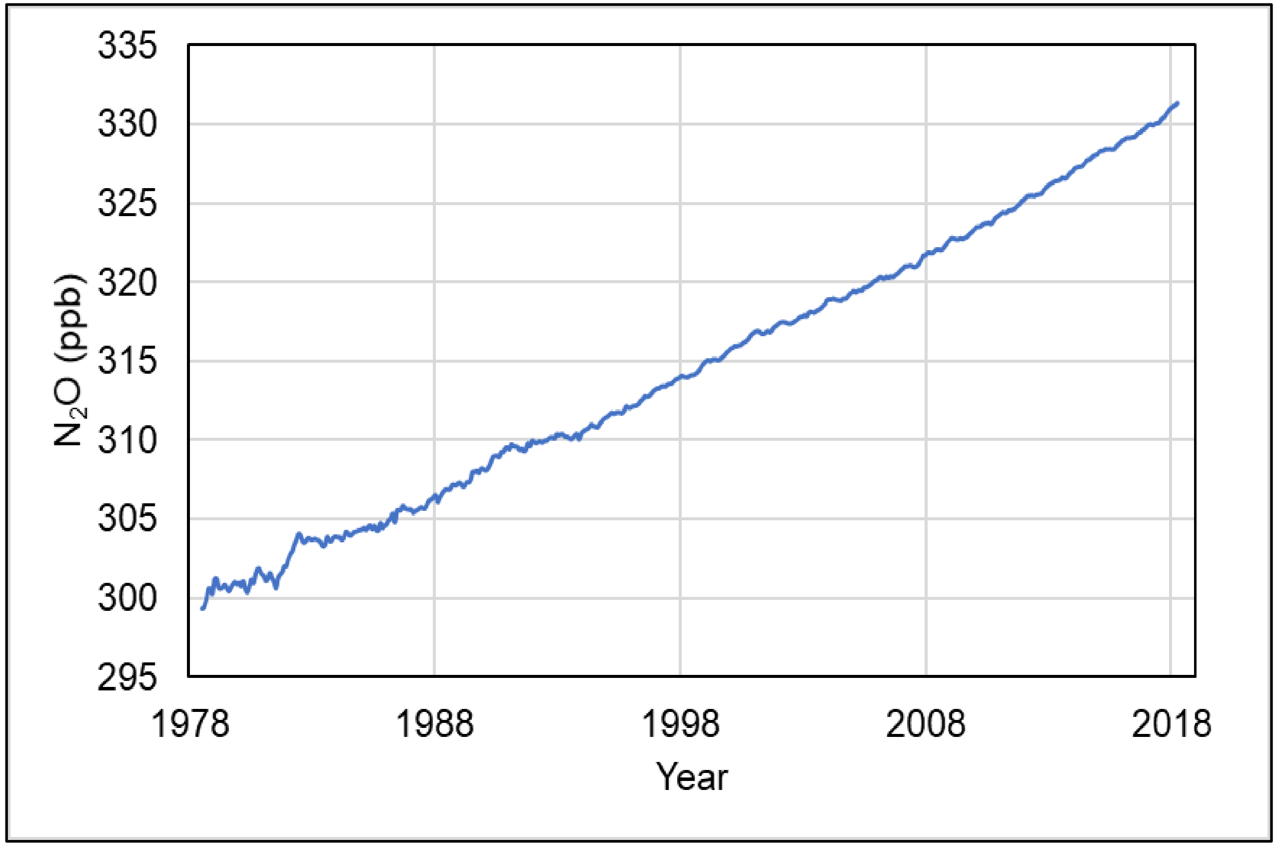
This dairy releases 600 metric tonnes of CH_4 annually from enteric emissions.

Total methane at the dairy = 954 metric tonnes CH_4 annually.

Summary of Findings

Issue	Dairy	Suggestions
CH_4	**CH_4 EFs calculated** **954 metric tonnes CH_4/yr** **↑ T ↑ CH_4**	**Use liquid T**
N_2O		
DMS		
OCS		
Pollution		
Odor		

Nitrous Oxide at the Dairy Farm

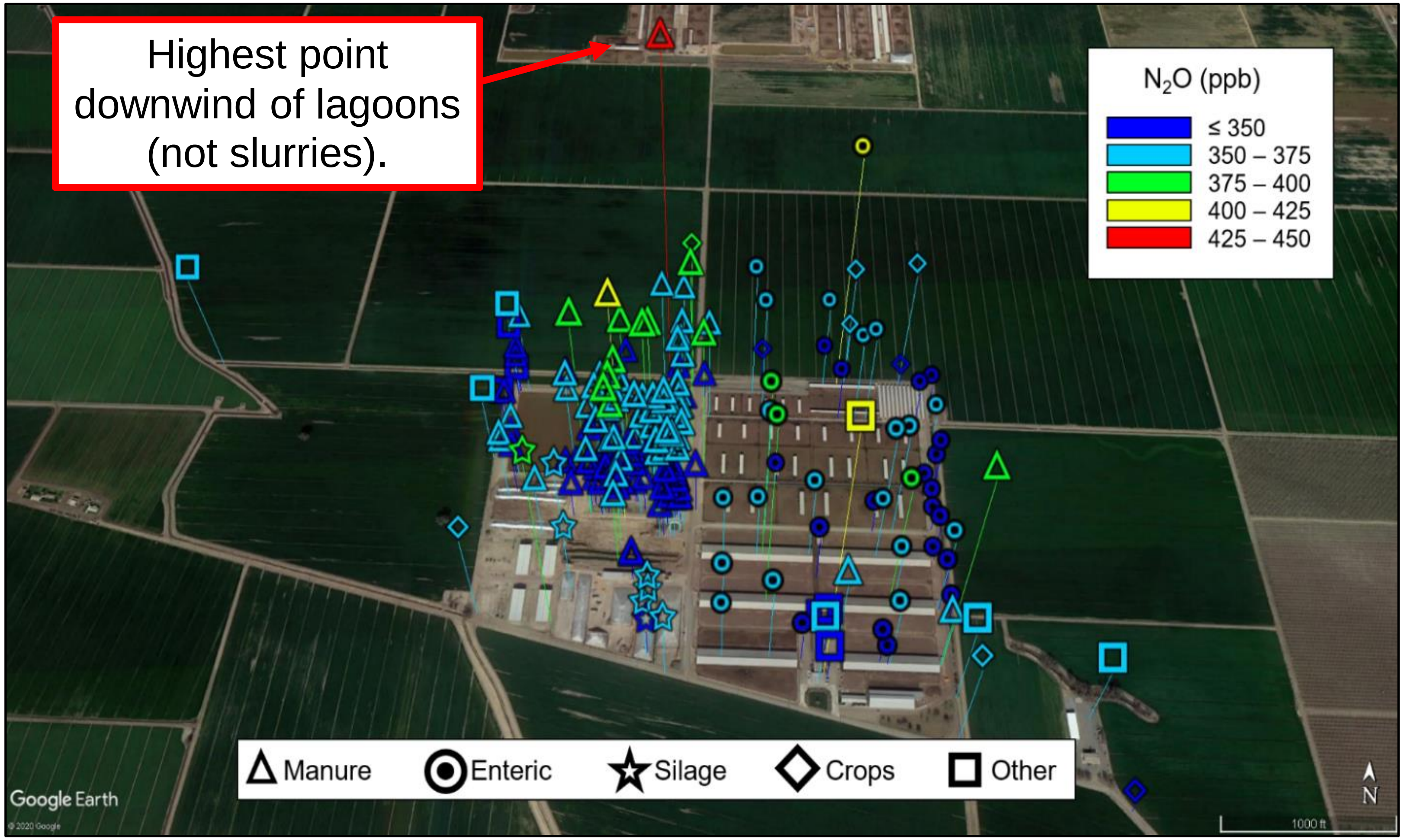


Data from AGAGE (Prinn et al., 2018)

- Nitrous oxide steadily increasing
- ↑ 7,300 Gg N_2O/yr
- Currently 331 ppb N_2O
- Over 298 times stronger GHG than CO_2
- Lifetime ~120 years

↑ 126% since 1990 from manure management sources only (CARB, 2019)

Nitrous Oxide at the Dairy Farm

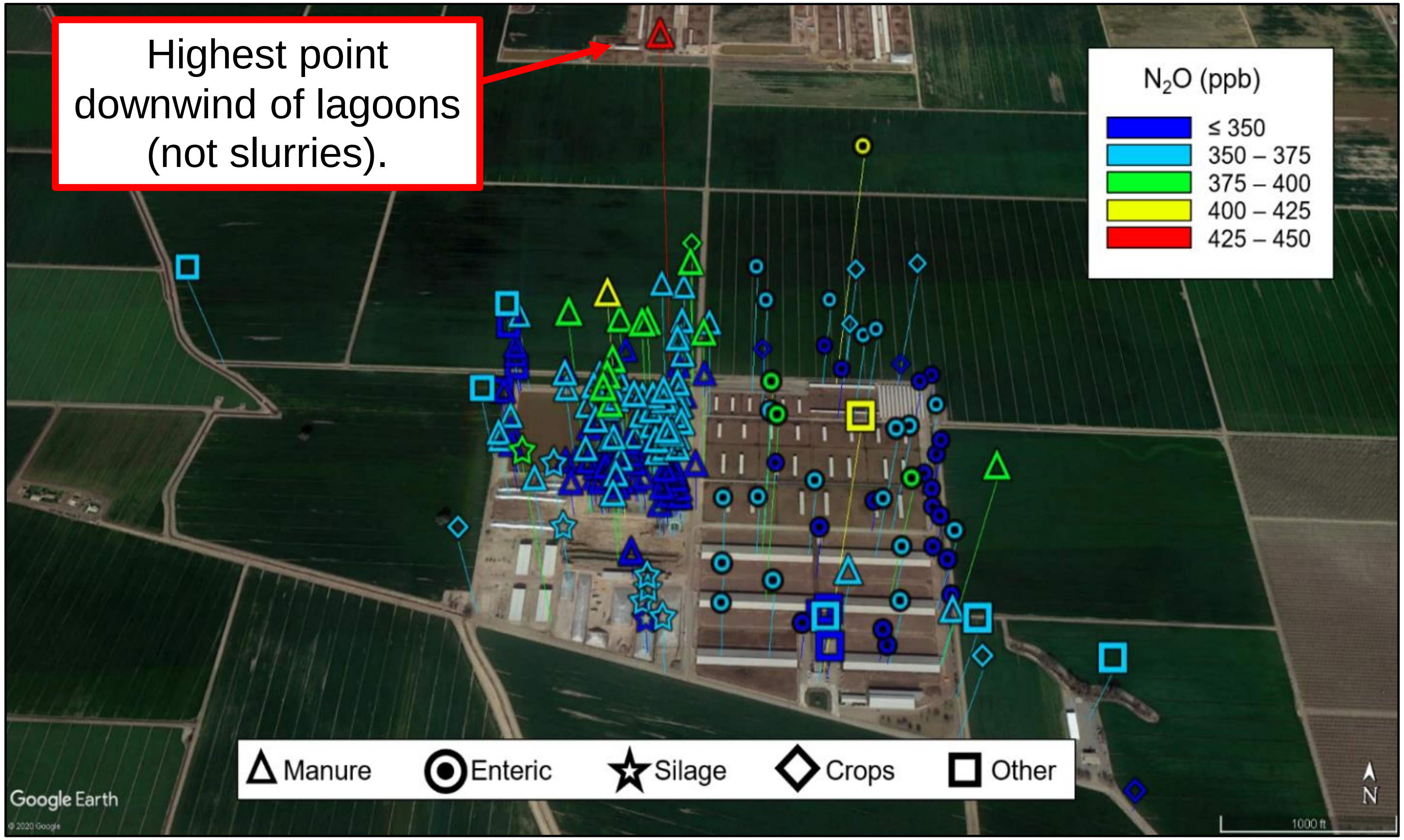


"Background" is 331 ppb N_2O (Prinn et al., 2018)
N_2O > 331 ppb is "enhanced"

Average = 356±16 ppb

Most enhanced N_2O found near manure management.

Nitrous Oxide at the Dairy Farm



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Average = 356±16 ppb

Most enhanced N_2O found near manure management.

Owen and Silver (2015):
Lagoons emit 0.9±0.5 kg N_2O hd^{-1} yr^{-1}

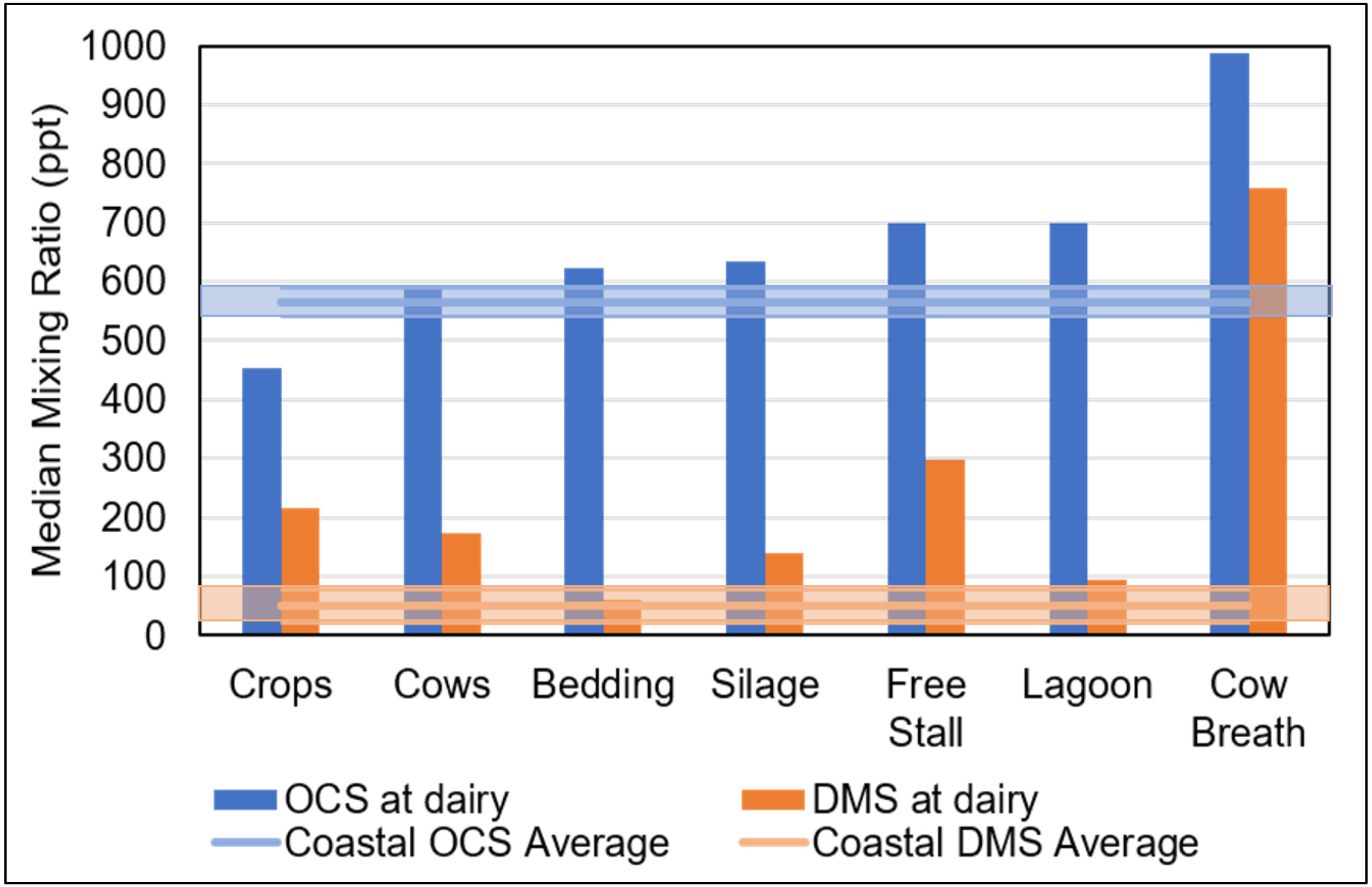
EPA (2020):
Lagoons emit 0 kg N_2O hd^{-1} yr^{-1}

Lagoons would actually emit 1.4±0.8 Gg N_2O/yr in the SJV.

Summary of Findings

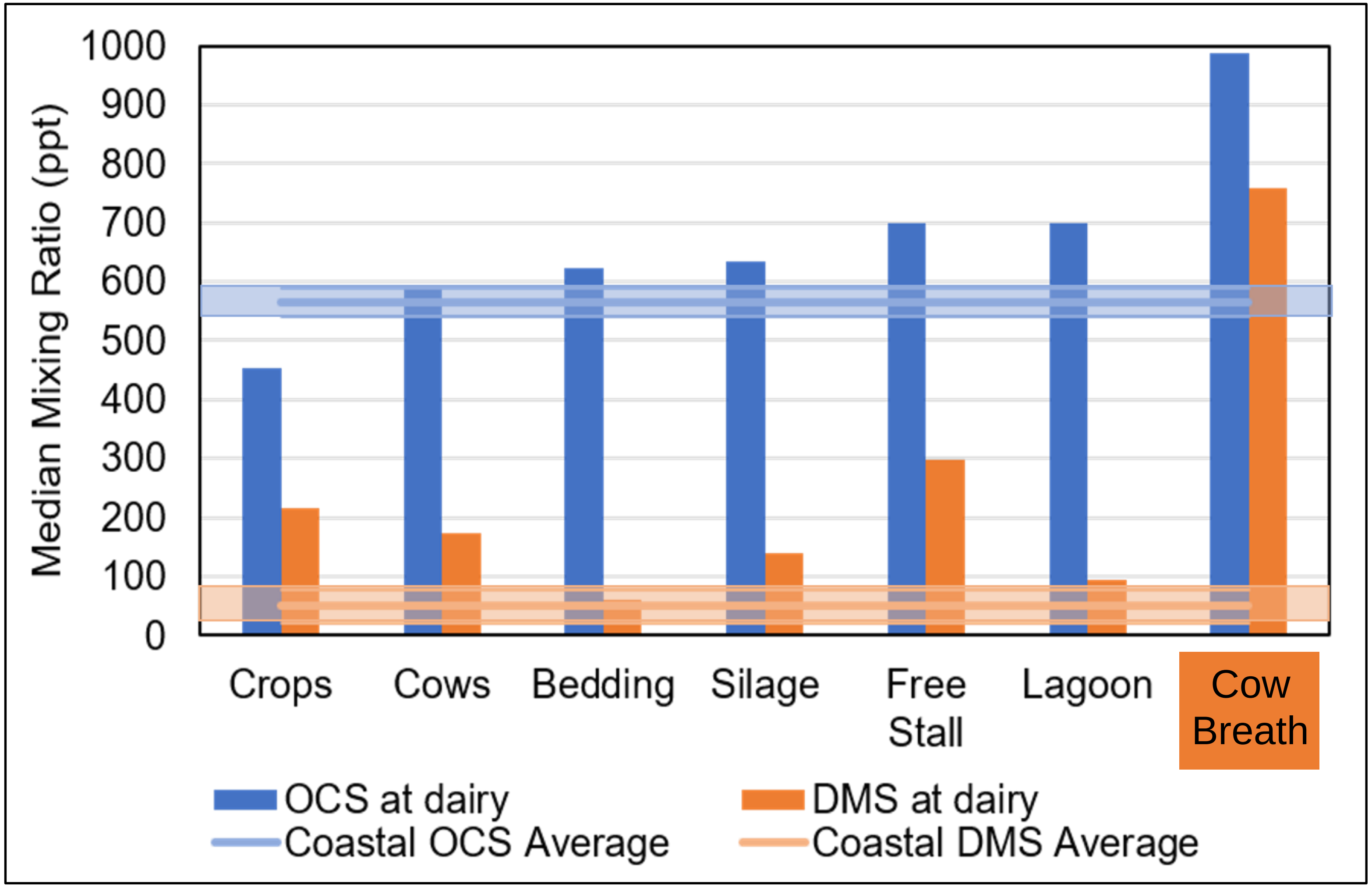
Issue	Dairy	Suggestions
CH_4	CH_4 EFs calculated 954 metric tonnes CH_4/yr ↑ T ↑ CH_4	Use liquid T
N_2O	**Most enhanced near manure management**	**Count lagoons in inventory**
DMS		
OCS		
Pollution		
Odor		

DMS and OCS at the Dairy



Coastal “background:” 560±24 ppt OCS and 50±30 ppt DMS

DMS and OCS at the Dairy



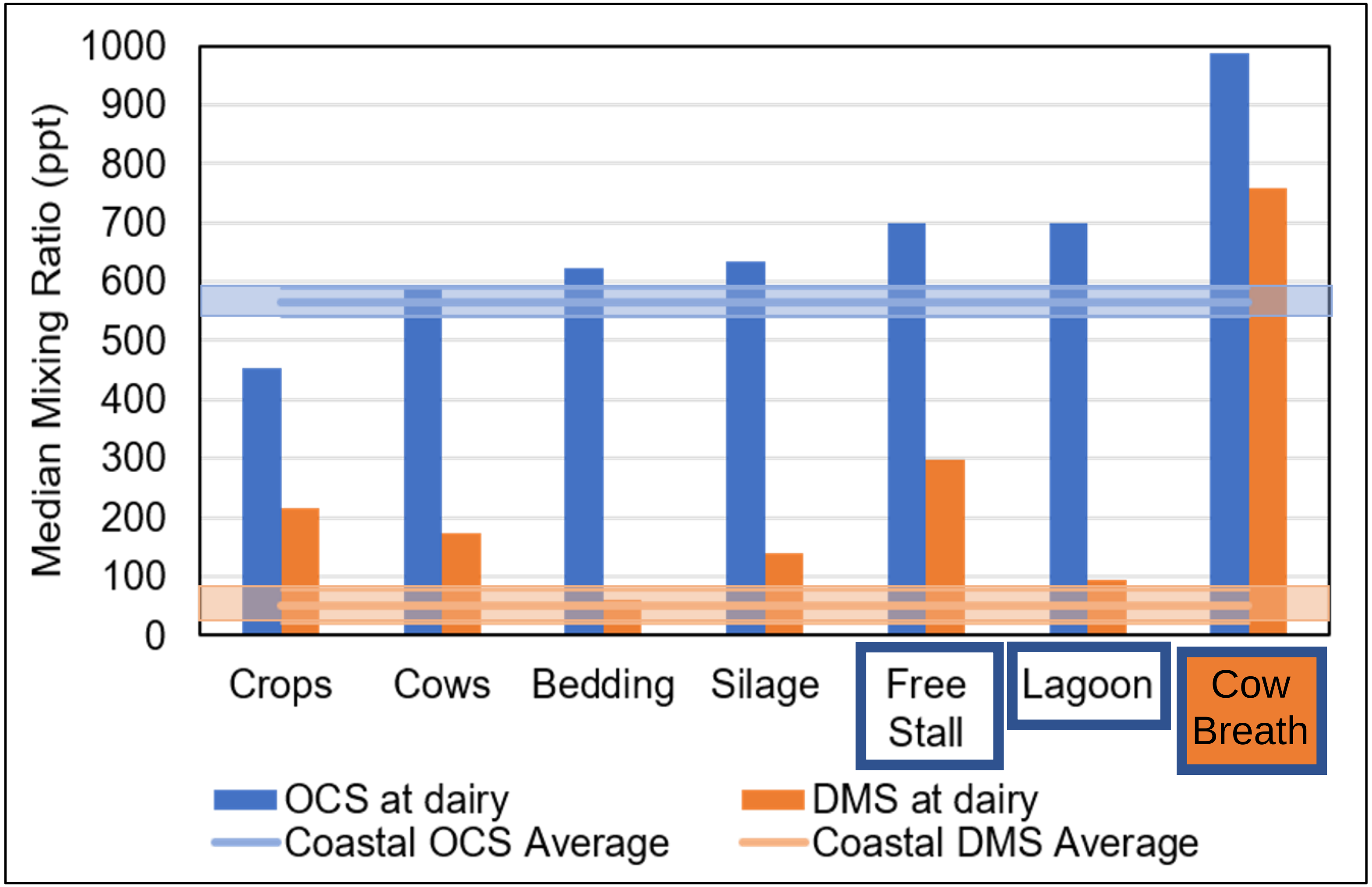
Coastal “background:” 560±24 ppt OCS and 50±30 ppt DMS

DMS primarily an “ocean gas”
Important for climate and particles

Hobbs et al. (1998)
Hobbs & Mottram (2000)

- Cows with high protein diets expel excess sulfur as DMS
- Mixing ratios of 0 to 25 ppm DMS in cow breath

DMS and OCS at the Dairy



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- Mixing ratios of 0 to 25 ppm DMS in cow breath

OCS primarily an “ocean gas”
Important for aerosol layer
Used as proxy for CO_2 calculations

Lennartz et al. (2017)
Missing OCS source:
Between 230 and 800 Gg S/yr

DMS Estimates for the SJV from Enteric Milk Cow Emissions

- DMS from cow breath at dairy farms in SJV was calculated:
  - 4,600 metric tonnes DMS/yr
- Global DMS flux (Aumont et al. 2002; Bopp et al., 2003; Kloster et al., 2006):
  - 15.4 – 28.0 Tg S/yr

DMS fluxes: Aumont et al., 2002; Bopp et al., 2003; Kloster et al., 2006

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Milk cows in the SJV could contribute:

- **Up to 15.4% of the global DMS flux**
- **Up to 5% particles in the SJV**

Bad for health and air quality of the disadvantaged communities.

DMS fluxes: Aumont et al., 2002; Bopp et al., 2003; Kloster et al., 2006

Bovine Activity Contribution to OCS Missing Source

- OCS from bovine activities was calculated:
  - 39.5 Gg S/yr from dairy cows worldwide
  - 28.2 Gg S/yr from other cattle worldwide
  - 11.3 Gg S/yr from manure management worldwide
- Missing OCS Source (Suntharalingam et al., 2008; Berry et al., 2013; Kuai et al., 2015; Glatthor et al., 2015):
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Bovine activities worldwide may contribute up to 34% of the missing OCS source.

Summary of Findings

Issue	Dairy	Suggestions
CH_4	CH_4 EFs calculated 954 metric tonnes CH_4/yr ↑ T ↑ CH_4	Use liquid T
N_2O	Most enhanced near manure management	Count lagoons in inventory
DMS	**Cow breath** **Particle/aerosol formation** **Air quality concern**	**Study SJV inland sources**
OCS	**Possible contribution to missing source** **Cow breath/manure**	**Include cow breath as possible source**
Pollution		
Odor		

Air Pollution in the San Joaquin Valley

As of March 31, 2021:

SJV: nonattainment zone for ozone and particulate matter (PM)

Air Pollution in the San Joaquin Valley

As of March 31, 2021:

SJV: nonattainment zone for ozone and particulate matter (PM)

O_3 depends on VOC and NO_x concentrations.

Ozone (O_3) formation:

NO_2 + hv ($\lambda \leq 420$ nm) → NO + $O(^3P)$

$O(^3P) + O_2 + M \rightarrow O_3 + M$

Air Pollution in the San Joaquin Valley

As of March 31, 2021:

SJV: nonattainment zone for ozone and particulate matter (PM)

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Ozone (O_3) formation:

NO_2 + hv (λ ≤ 420 nm) → NO + $O(^3P)$

$O(^3P) + O_2 + M \rightarrow O_3 + M$

With volatile organic compounds (VOC):

O_3 + hv (λ ≤ 310 nm) → $O_2 + O(^1D)$

$O(^1D) + H_2O \rightarrow 2{\bullet}OH$

$CH_4 + {\bullet}OH \rightarrow {\bullet}CH_3 + H_2O$

${\bullet}CH_3 + O_2 + M \rightarrow CH_3OO{\bullet} + M$

$CH_3OO{\bullet} + NO \rightarrow CH_3O{\bullet} + NO_2$

$CH_3O{\bullet} + O_2 \rightarrow HCHO + HOO{\bullet}$

$HOO{\bullet} + NO \rightarrow {\bullet}OH + NO_2$

Ozone Formation from Dairies

$$\text{Ozone formation potential (OFP)}\left(\frac{\mu\text{g}}{\text{m}^3}\right) = \text{VOC (ppb)} * \frac{\text{molecular weight }\left(\frac{\text{g}}{\text{mol}}\right)}{22.4\text{ mol}^{-1}} * \text{POCP}$$

Shin et al. (2013)
Derwent et al. (2007)

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O_3 Contributors at the Dairy Farm:

Oxygenates: Methanol, Ethanol, 2-Butanol, Acetaldehyde, Acetone
Alkenes: Limonene, Isoprene

Likely sources:

Shin et al. (2013)
Derwent et al. (2007)

Aerosol Formation from Dairies

To form secondary organic aerosols (SOA):

- Oxidize VOCs to eventually ↓ vapor pressure (makes them sticky)
- They participate in heterogenous chemistry and contribute particles (bad air pollution)

$$\text{SOA formation potential}\left(\frac{\text{ng}}{\text{m}^3}\right) = \text{VOC (ppb)} * \text{SOA yield}\left(\frac{\mu\text{g}}{\text{ppm m}^3}\right) * \frac{1\text{ ppm}}{1000\text{ ppb}} * \frac{1000\text{ ng}}{1\ \mu\text{g}}$$

Shin et al. (2013)
Turpin & Huntzicker (1995)

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SOA Contributors at the Dairy Farm:

Aromatics: Toluene, Benzene

Sulfur: DMS

Likely sources:

Shin et al. (2013)
Turpin & Huntzicker (1995)

Summary of Findings

Issue	Dairy	Suggestions
CH_4	CH_4 EFs calculated 954 metric tonnes CH_4/yr ↑ T ↑ CH_4	Use liquid T
N_2O	Most enhanced near manure management	Count lagoons in inventory
DMS	Cow breath Particle/aerosol formation Air quality concern	Study SJV inland sources
OCS	Possible contribution to missing source Cow breath/manure	Include cow breath as possible source
Pollution	**Silage, enteric, manure form O_3**	**Study SJV inland sources**
Odor		

Odor from the Dairy Farm

Schiffman et al. (1995): livestock odors ↑ tension, depression, anger, fatigue, and confusion — **Mental Health Concerns**

Schiffman (1998): livestock odors ↑ teary eyes, headaches, dry eyes, congestion, and nasal irritation — **Physical Health Concerns**

Murnane et al. (2013), Nagata and Takeuchi (2003), Hellman and Small (1974), Leonardos et al. (1974), Ruth (1986), Rodríguez et al. (2017)

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Reduction Factor (RF):

$$\mathrm{RF} = \frac{\text{maximum mixing ratio (ppb)}}{\text{odor threshold (ppb)}}$$

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Gases with RF > 1	RF_{max}	Odor	Likely Source
Limonene	132	Citrus	Feed, croplands
DMS	26	Decayed cabbage	Cows
Ethanol	14	Sweet, alcoholic	Feed
Butanal	7	Sweet, rancid	Regional

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Odor	**Cow breath, cows, feed, regional**	**-**

Solution: Change Cow Diet

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<u>Burt et al. (1954)</u>

- Scientists fed seaweed diets (10% *Ascophyllum nodosum* and *Laminaria Clouston*) to Scottish cows to improve butterfat production
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Could this work in the SJV?

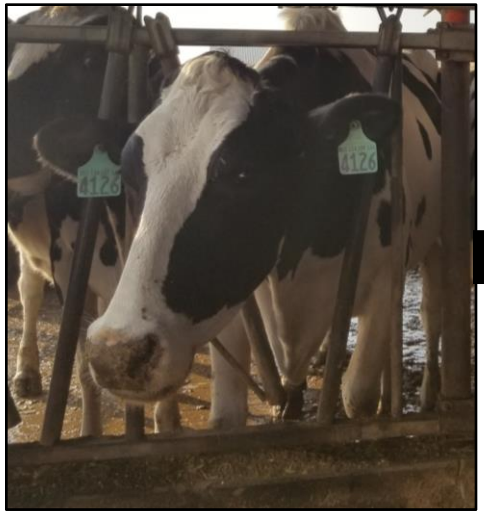
Solution: Change Cow Diet

Bessie

Bessie Fun Facts:

- Weighs 1,500 pounds
- Eats 3% of her body weight daily (45 pounds!)
- Would need 2 pounds of seaweed daily

Solution: Change Cow Diet



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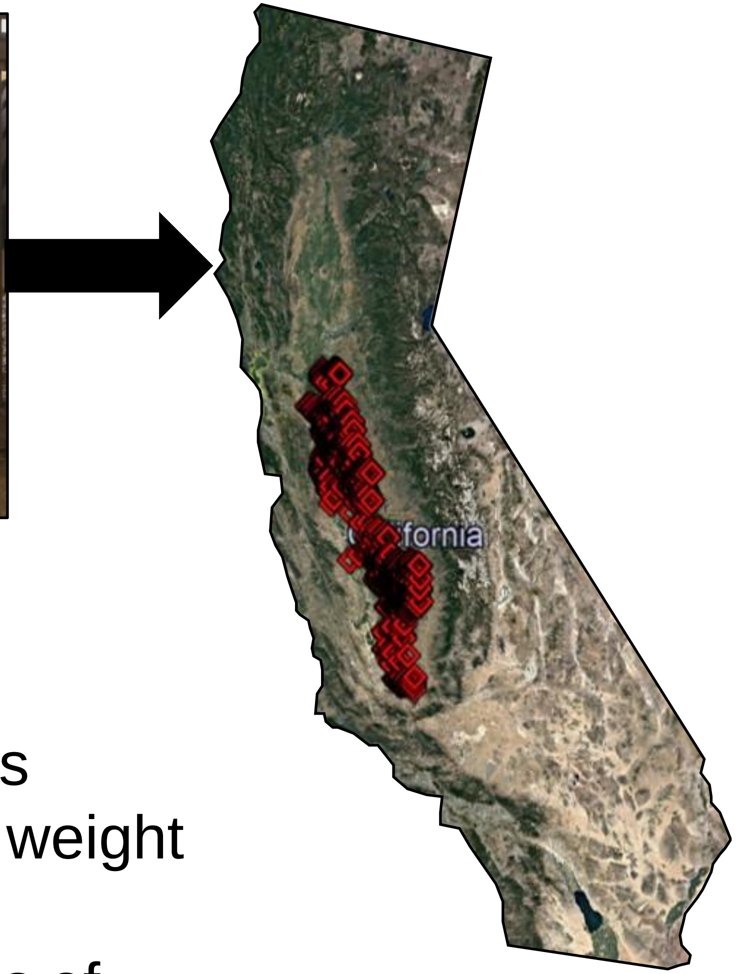

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1.5 million Bessies

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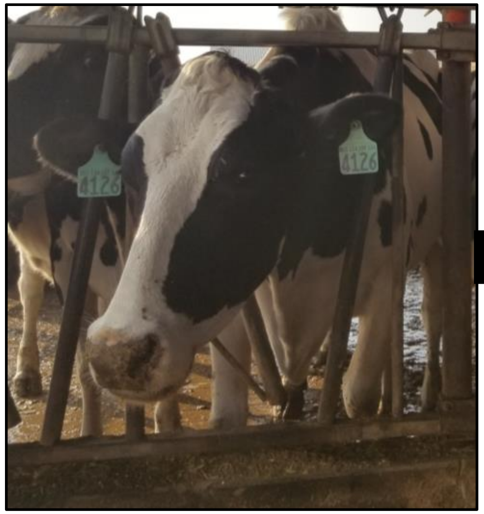

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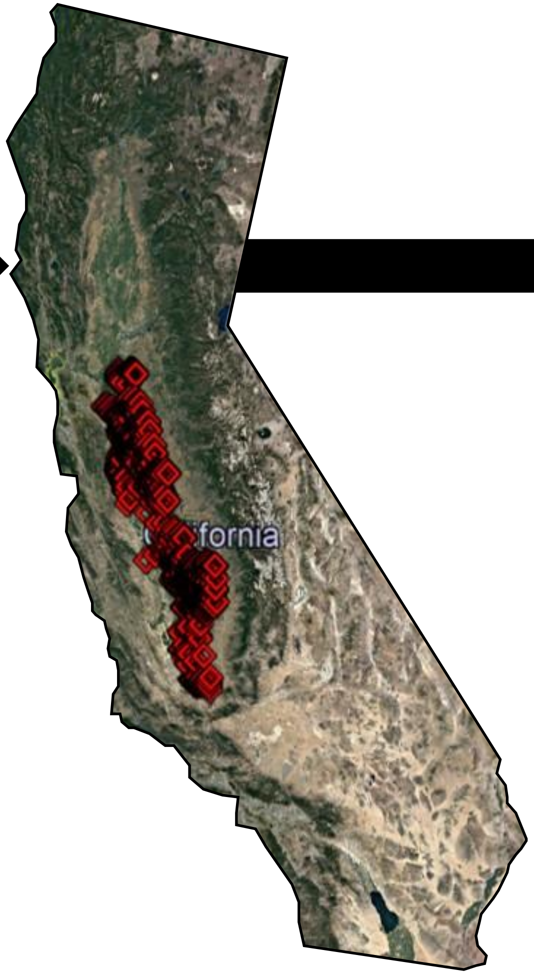

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- 1×10^{10} pounds of seaweed needed in SJV daily!
- This seaweed is tropical
- Costs of growing and hauling
- Nutritional side effects
- No incentive for farmers

Solution: Install Anaerobic Digesters

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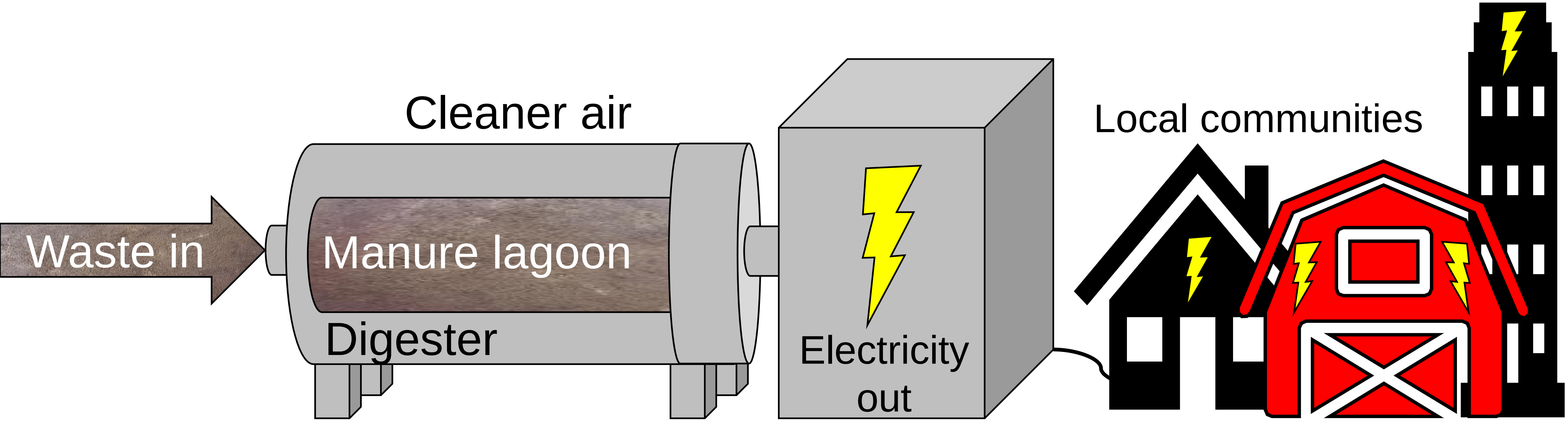
- California government funding dairies to install digestors to prepare for SB-1383
- Feasible for large dairies (~2,000 cows)
- Visalia dairy farm will install (2021) for $5 million
  - Will reduce GHG emissions by nearly 200,000 MT CO_2e over a 10-year period



(CDFA, 2020)

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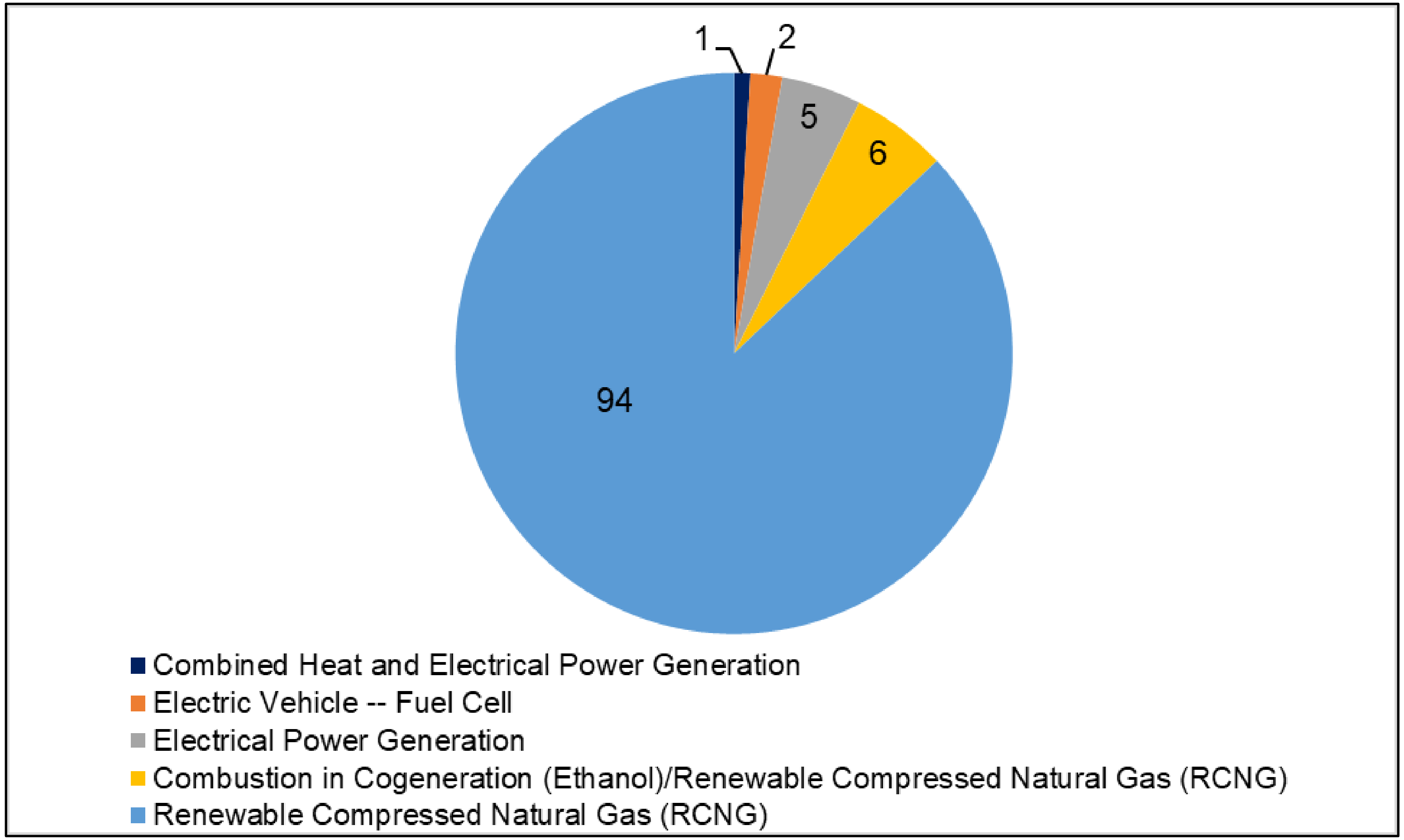
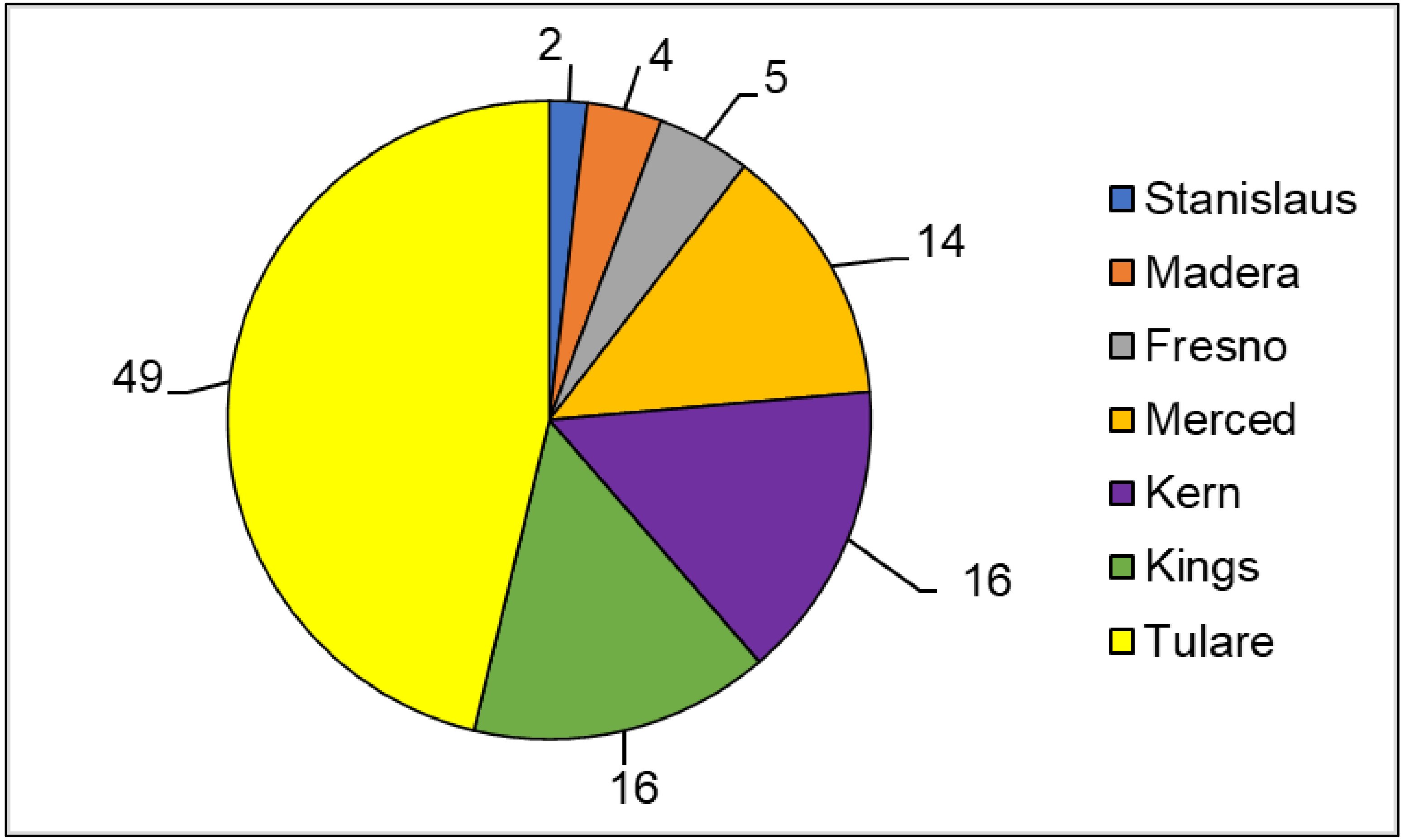


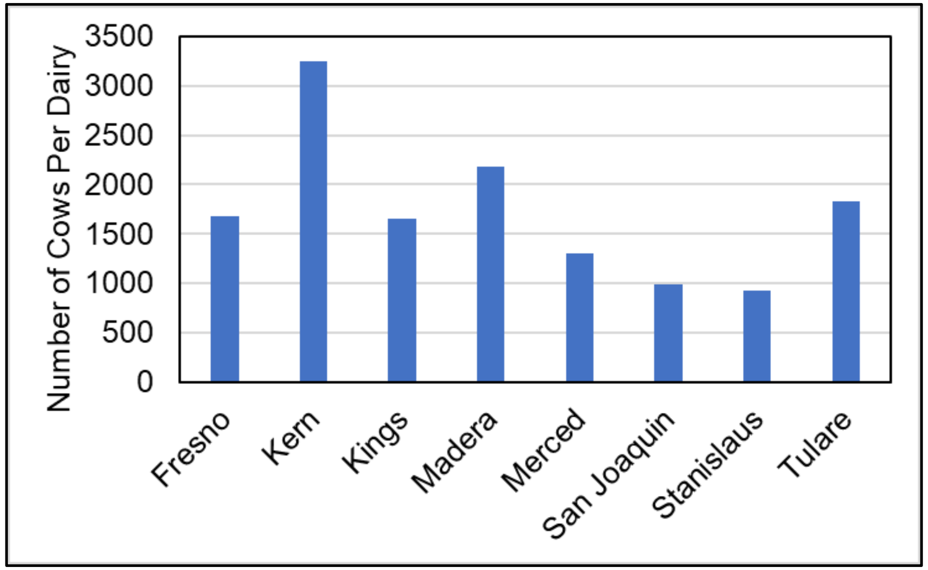
- Most projects create RCNG
- Can be added to our existing natural gas pipeline

CDFA DDRDP (CDFA, 2020)

Solution: Install Anaerobic Digesters



- Tulare, Kings, Kern counties most participation
- Counties with few cows per dairy look for other options



CDFA DDRDP (CDFA, 2020)

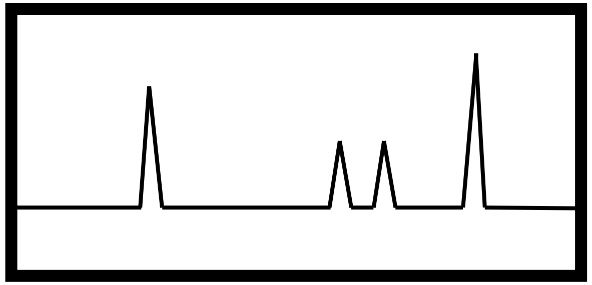
Solution: Alternative Manure Management

- California funds non-digester manure management practices
- Remove solids from the manure before lagoon storage

↓ GHG emissions

Counties where this is still not feasible may consider flaring the methane like landfills.

Summary of Research and Suggestions



CH_4, N_2O, DMS, OCS, pollution, odor

Disadvantaged communities

Proposed solutions for scientists:

- Use liquid system temperature and short time intervals, not air temperature over long intervals, when calculating emissions
- Count N_2O from lagoons in future GHG inventories
- Further explore sulfur contribution from bovine-related activities

Proposed solutions for farmers:

- Focus on reducing manure emissions rather than enteric emissions
- Use CA funds!
    - Install anaerobic digesters
    - Implement alternative manure management practices

Thank You!

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