Assessing wastewater treatment plants and agricultural waste emissions

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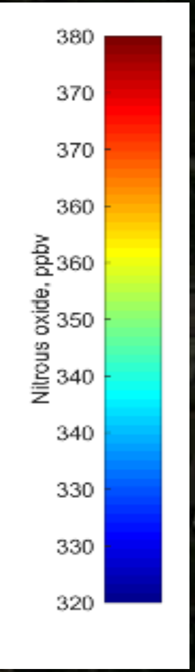
Sensor Technologies to Monitor Energy or Environmental Systems
Alfred P. Sloan Foundation



BACWA AIR Committee meeting

June 10, 2020

Wastewater/agricultural waste emissions are important

<u>wastewater treatment plants (WWTP)</u>

- emit 2% of global non-CO_2 greenhouse gases
- predicted to consume 3% of global electricity
- increasing treatment requirements
- resource recovery potential if CH_4 captured

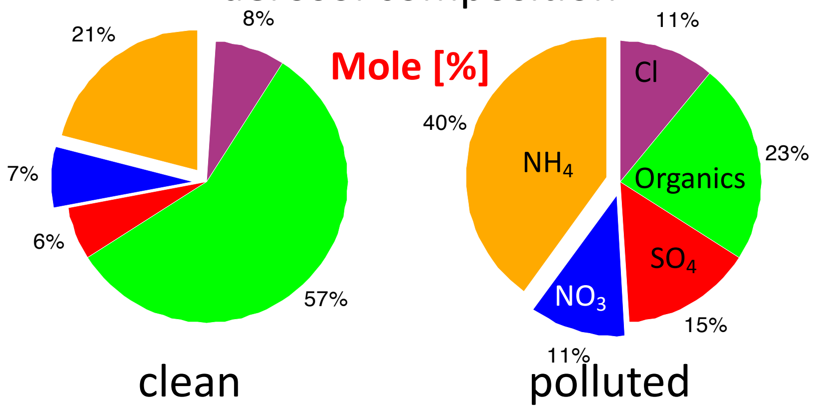
<u>agricultural manure management</u>

- emits 8% global non-CO_2 greenhouse gases
- emits 62% global ammonia, NH_3
    - precursor for PM2.5 (air quality, human health)
    - N deposition leads to biodiversity losses

MMT-CO_2 equiv.	emitted as CH_4	emitted as N_2O	sector total
WWTP	14.3	5.0	19.3
manure	61.7	18.7	80.4
combined	*76.0*	*23.7*	*109.7*
US total	663.3	360.6	1023.9

US EPA, 2019

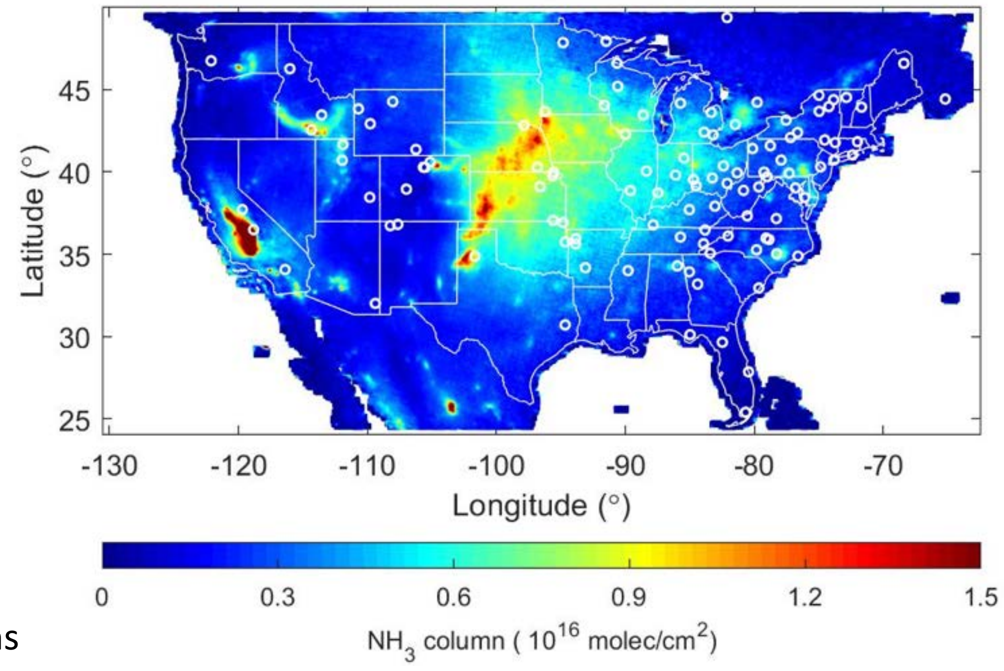
aerosol composition



Guo et al. (2014)

2008-2016, Metop/A & Metop/B, oversampling high resolution map (0.02×0.02°)

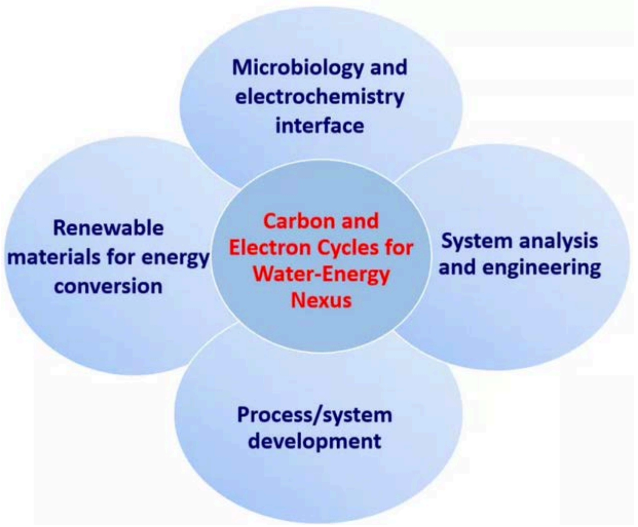
Circles are Ammonia Monitoring Network (AMoN) surface locations



Project objectives

- quantify CH_4, N_2O, and NH_3 emissions at WWTP and feedlots with mobile laboratories
- wet chemistry analyses and operator practices to identify drivers of emissions
- examine seasonal and diurnal emission variabilities
- conduct targeted measurements to investigate episodic drivers of emissions (e.g. rainfall/overflows)
- scale the measurement distributions to sector-wide emissions (normalized to US distribution)
- identify the effectiveness of mitigation plans or best practices on reducing emissions

2 mobile laboratories + aqueous chemistry measurements



Key personnel (*project roles*)

(PI) Mark Zondlo, Associate Professor, CEE / Princeton University

Leads Atmospheric Chemistry and Composition Group

Sensor development (lasers) and field deployment on vehicles, UAVs, towers, aircraft

PI for measurements on NSF-, NASA-, and NOAA-led atmospheric chemistry/composition field studies

Field measurement implementation, emissions quantification and uncertainties, distributions

(co-PI) Francesca Hopkins, Assistant Professor, Environmental Sciences / Univ. Calif.-Riverside

Leads Greenhouse Gas Measurement Laboratory

Lead PI on $4M study of dairy manure greenhouse gas emissions in California (UC Office of President)

System-level approach to emission estimation using multiple techniques at a variety of scales

Connect emission observations to processes with an emphasis on understanding emission drivers

(co-PI) Z. Jason Ren, Professor, CEE + Andlinger Center for Energy and the Environment / Princeton Univ.

Leads Water & Energy Technologies (WET) Laboratory

Specializes in wastewater treatment and resource recovery

Liquid sampling for wastewater facilities and agricultural sites for data coordination

Analyze emission profiles from different treatment processes and develop mitigation strategies

Complementary technologies and skillsets of team allow for robust sampling, analyses, outcomes

Emission estimates are highly uncertain

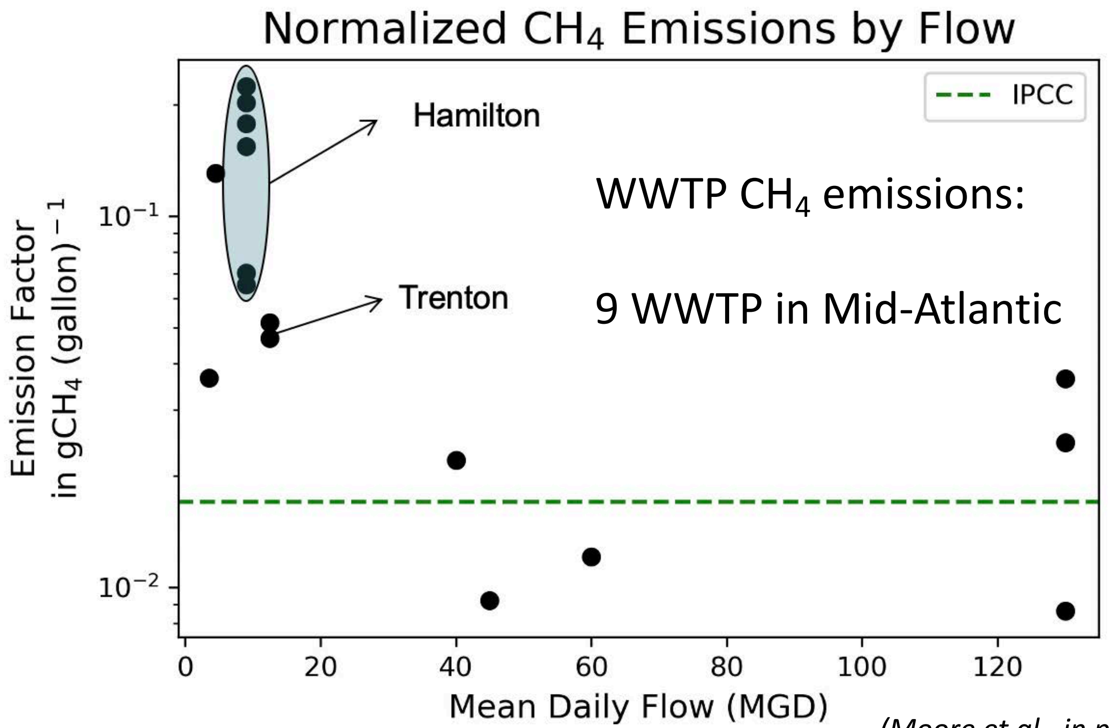
Large intrasite and site-to-site variability in both sectors

CH_4 emissions, liquid manure (measured):
4.7-1028 g CH_4 per animal per day

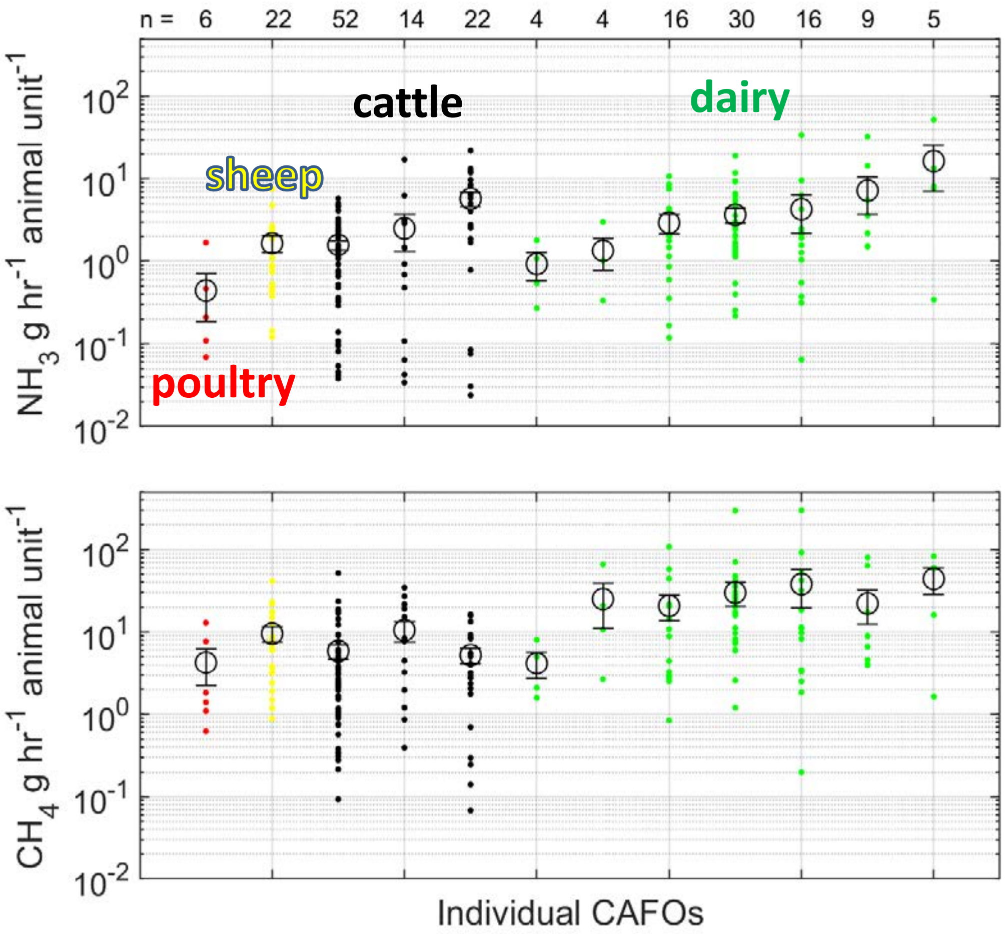
N_2O emission factors, WWTP (measured):
0.001-11.84% N_2O emitted per N input

Source: 2019 Refinement to IPCC GHGI

NH_3 emissions:
limited measurements



(Moore et al., in prep.)



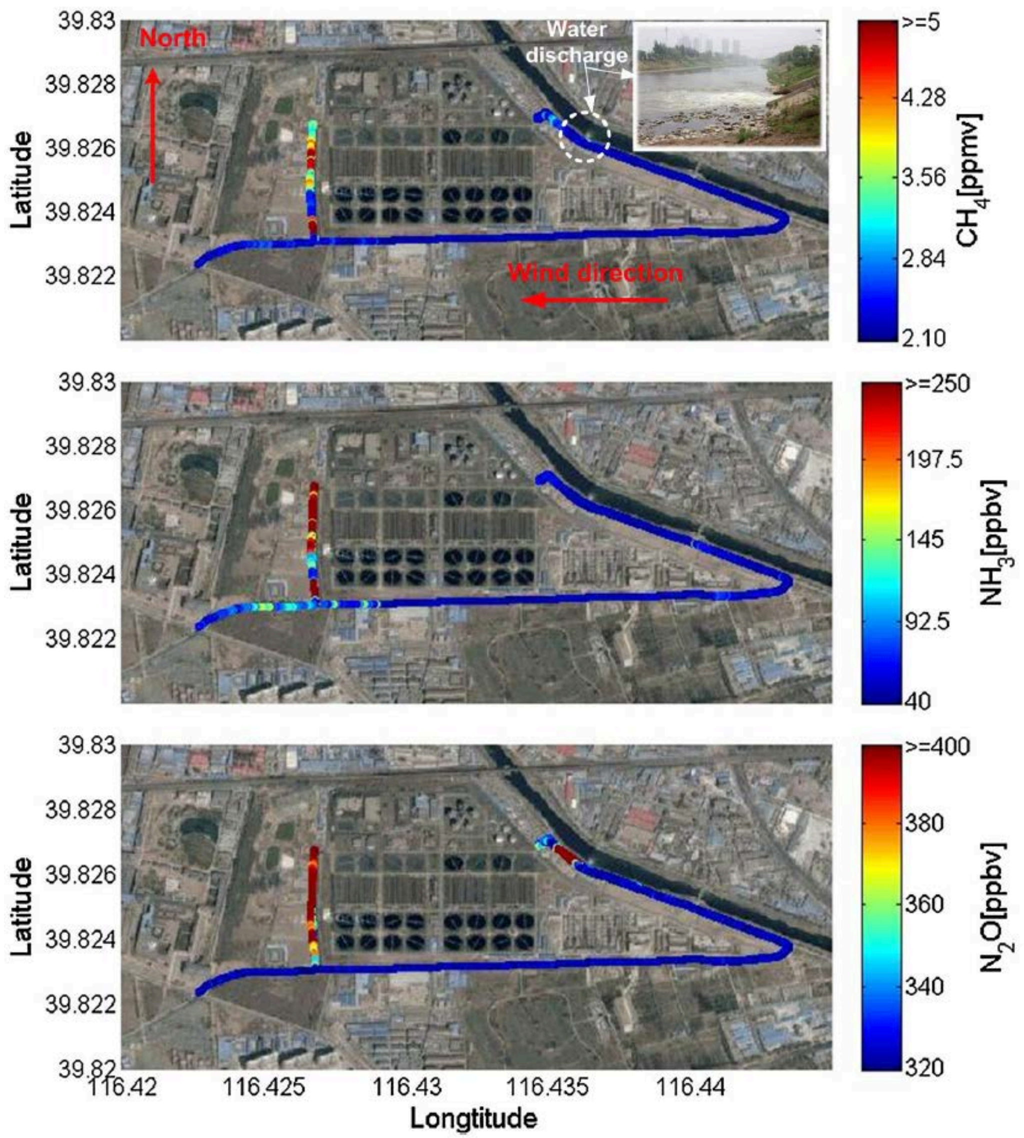
(Golston et al., ES&T, 2020)

→ large site-to-site variabilities, greater than measurement variabilities (turbulence/sampling)

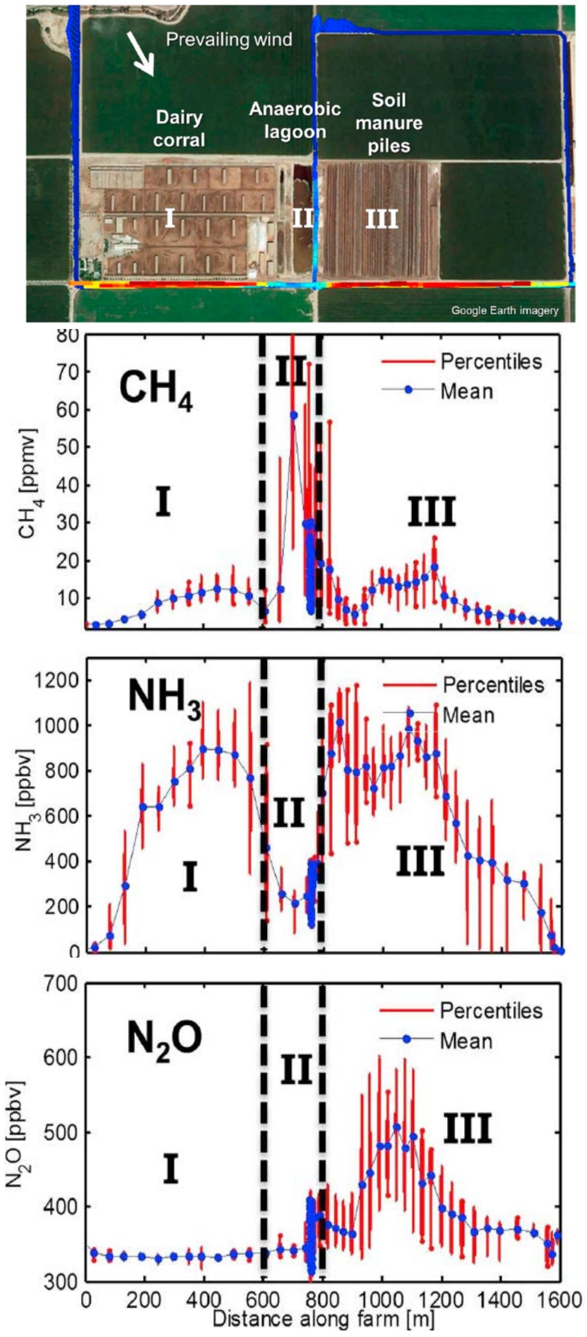
Challenge: high spatial variability

- heterogeneity within a site from different processes / uses
- need to include unexpected or unknown emission sources for total emissions

…yet on-site access and participation with operators needed to understand process-level and sub-system emissions



Tao et al., 2015

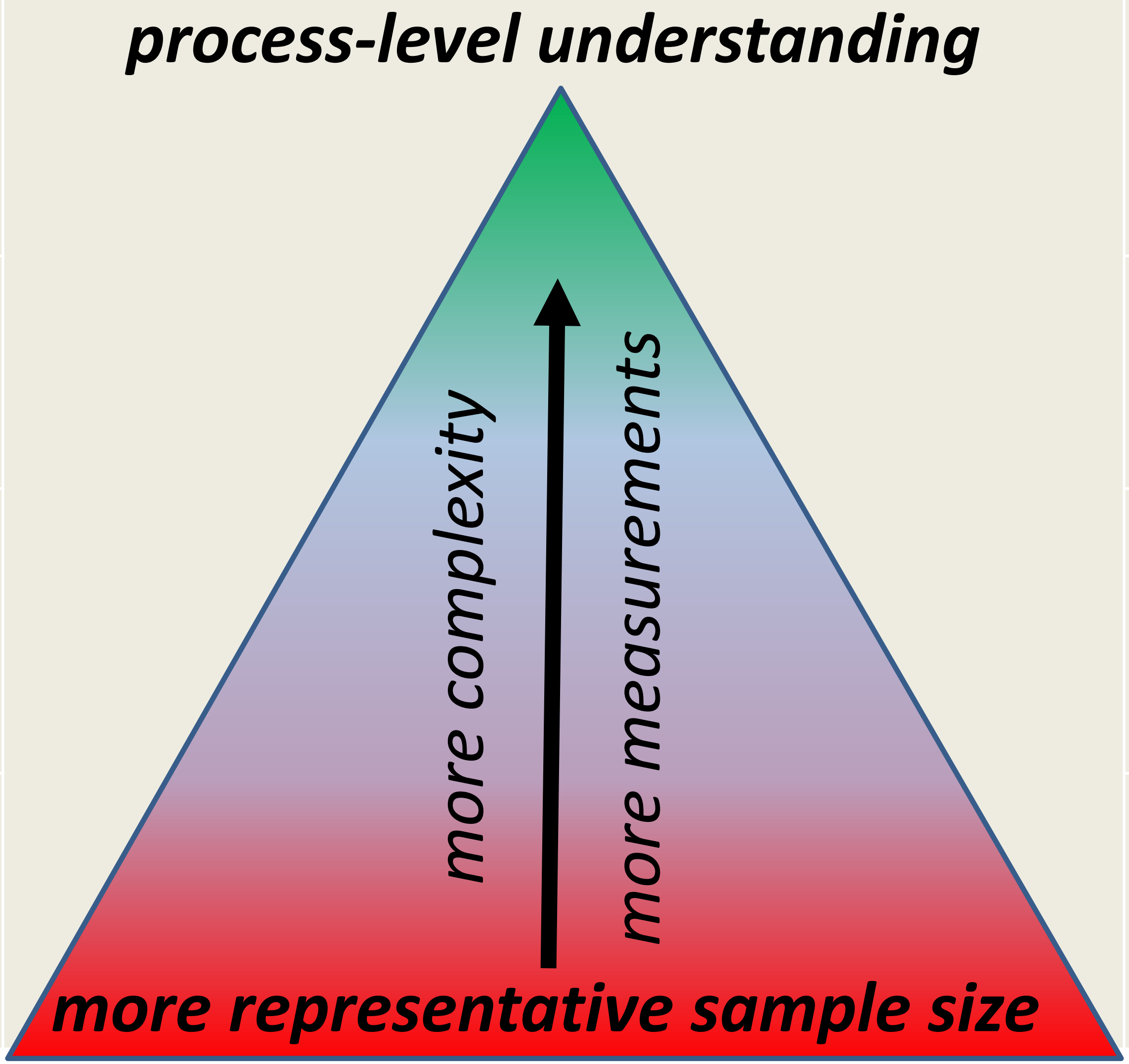


Miller et al., 2015

Hierarchical sampling approach

WWTP

category	# sites	Replicate sampling	Intra-annual variability	Liquid + PACE + LIME/AVOCADO
Supersite	4	X	X	X
Focus	36	X	X	
General	100	X		



farms

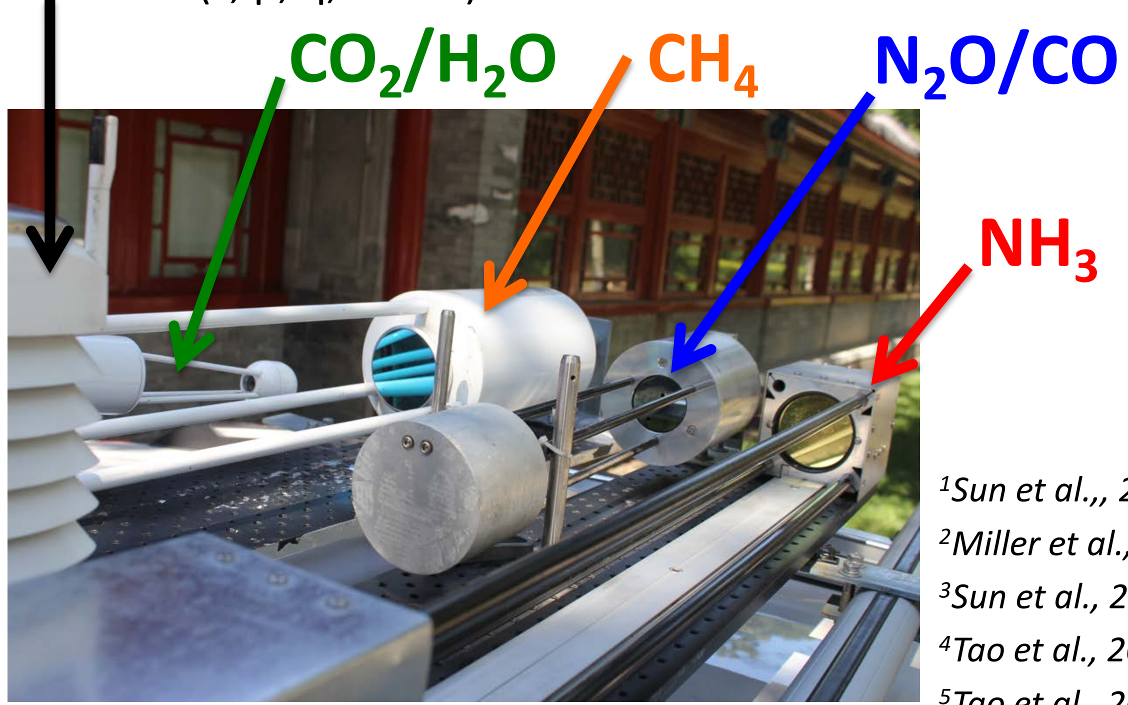
Liquid + PACE + LIME/AVOCADO	Intra-annual variability	Replicate sampling	# sites	category
X	X	X	6	Supersite
	X	X	50	Focus
		X	200	General

Experimental: Princeton Atmospheric Chemistry Experiment (PACE)

A mobile environmental sensing laboratory with >25,000 km sampling in US and China

Species	Prec.	Mass	Power	Make
NH_3	0.15 ppbv	15 kg	50 W	QCL, ref 1-3
N_2O	0.07 ppbv	10 kg	40 W	QCL, ref 4
CO	0.2 ppbv	-	-	QCL, ref 4
CH_4	2 ppbv	4 kg	15 W	LICOR
H_2O	<1%	2 kg	5 W	LICOR
CO_2	0.1 ppmv	-	-	LICOR
met. data (T, p, q, winds)				Vaisala

Electric vehicle (no self-emissions) with suite of trace gas, air pollutant, and meteorological sensors



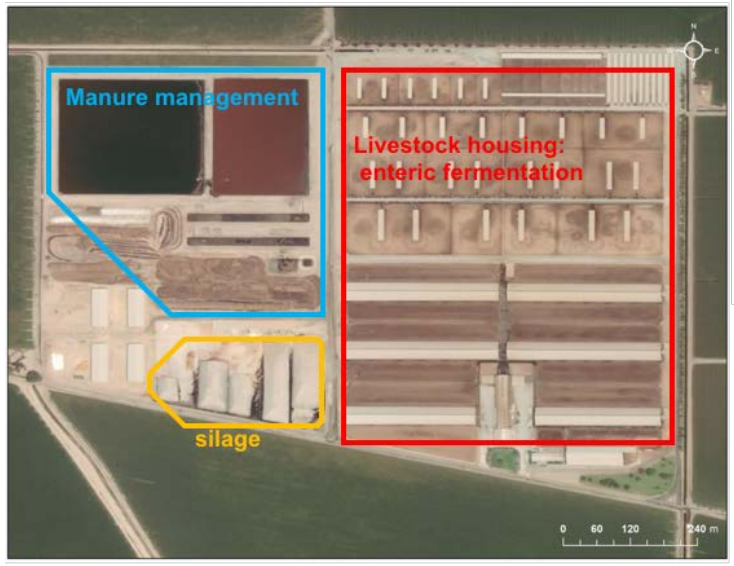
[1]*Sun et al.,, 2012*
[2]*Miller et al., 2013*
[3]*Sun et al., 2013, 2015, 2017*
[4]*Tao et al., 2012*
[5]*Tao et al., 2015*

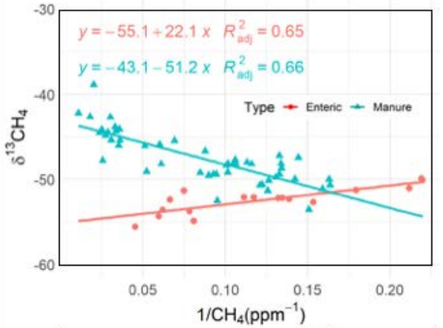
PACE sensors are operated by a battery and can be readily deployed on a golf cart, boat, or similar.

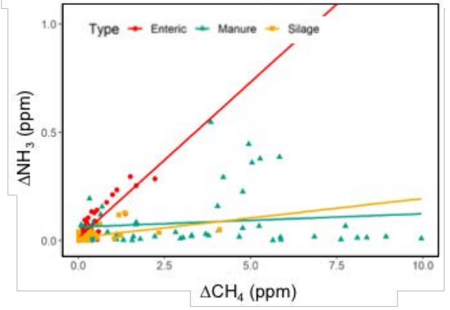
Recent "off-site" deployments (vehicle):
- ***Island of Hawaii (2018)***
- ***North China Plain (2013, 2014)***
- ***Colorado (2014)***
- ***Houston (2013)***
- ***California (2013)***

Mobile Laboratory for Isotope Measurements in the Environment/Analysis Vehicle for On-road Capture of Atmospheric Data and Observations (UCR LIME/AVOCADO)

Mobile survey measurements of CH_4, CO_2, N_2O, NH_3, and stable isotopes of CH_4, CO_2 and N_2O

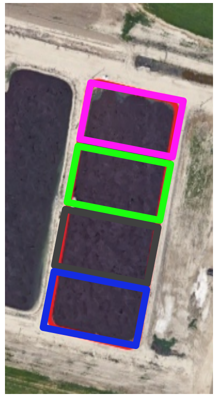


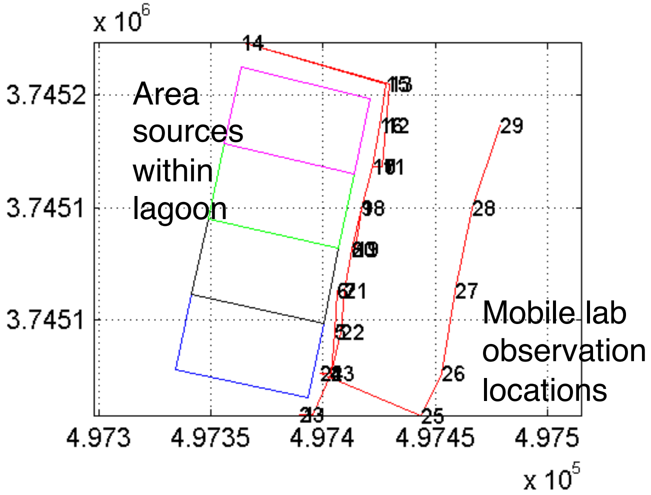


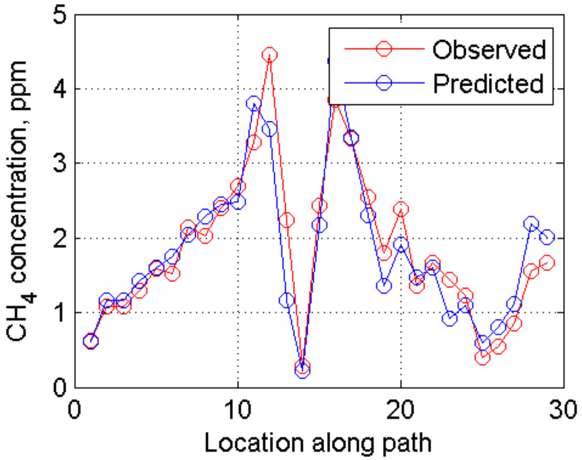


Winds (2D) measured from vehicle roof

Trailer with 10 m tower (e.g. to measure 3D wind profile)







Estimation of manure lagoon emissions with mobile lab observations and numerical dispersion model

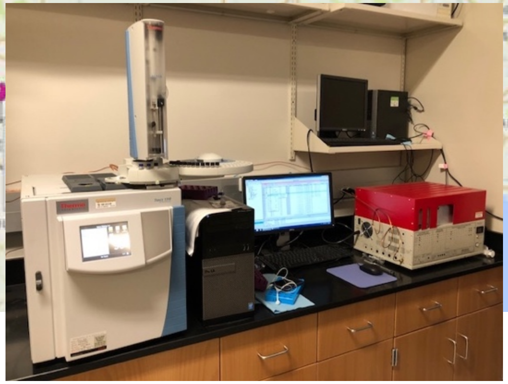
Emissions: 393 (328-456) kg CH_4/day for whole lagoon

Experimental: liquid sampling on-site

Princeton Water and Energy Technologies Laboratory (WET Lab) – Prof. Z. Jason Ren (CEE / Princeton)

THE Water Research FOUNDATION

By J. Wolfe



Lab analysis instrument

- National Water Resource Recovery Test Bed Network by Water Research Foundation and utility partners on sampling
- Water parameters will be monitored on site and in the WET lab to coordinate with air parameters:

- Solid content (TSS, VSS)
- Organic content (COD, BOD)
- Aqueous nitrogen species
- Dissolved O_2, CO_2, temp., pH, conductivity, etc.

- Understand how different treatment processes lead to different GHG and NH_3 emissions, and develop strategies to reduce emissions without compromising treatment performance

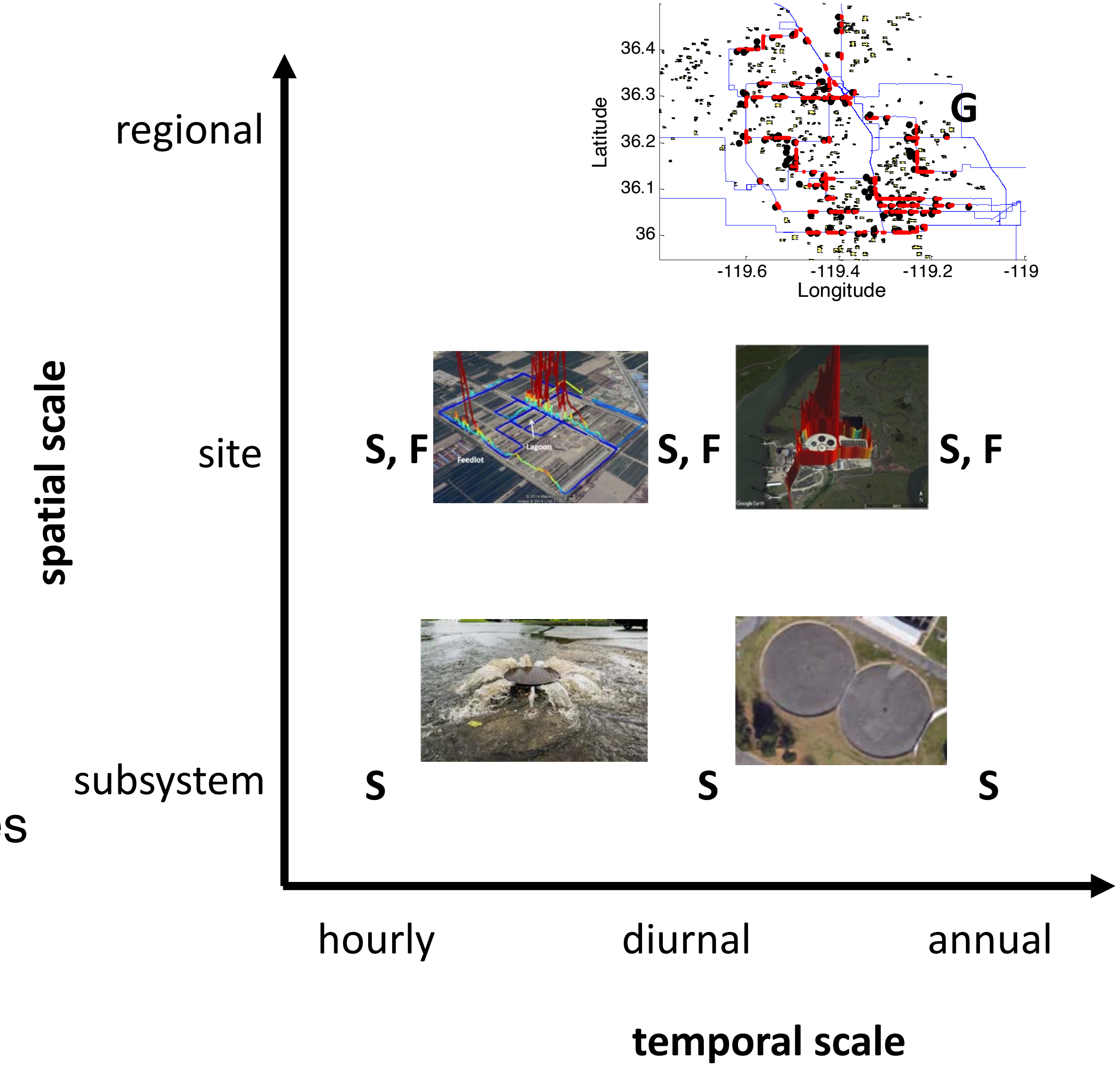
Hierarchical sampling strategy

3 classes of sample sites:

<u>General (G)</u>
PACE mobile lab only, fast sampling
→ *large #s of samples, site-to-site variability*

<u>Focus (F)</u>
Both mobile labs, repeated/return sampling (diurnal, seasonal, extreme)
Intrasite mobile lab sampling
→ *quantify variability over timescales*

<u>Supersite (S)</u>
Mobile labs, wet chemistry analyses, operator partnership, in-site sampling, management practices
→ *intrasite variability, management practices, process-level understanding to scale others*



Site access / stakeholder engagement

WWTP

Access:

Water Research Foundation

testbed: Facilities Accelerating Science and Technology (FAST) Water Network

(10 in Calif., 12 in Mid-Atlantic)

Bay Area Air Quality Management District (BAAQMD, Phil Martien)

Existing relationships with NJ plants (Mount Holly, Camden)

Supersite/focus sites: 4 categories of treatment x 3 capacity ranges (~1, 10, 100 million gallons/day) x 3/class

Management practices:

Treatment methods, recovery mechanisms (e.g. odor control), guidance on where/when to sample

farms

Access:

co-PI Hopkins existing CA project at 6 farms

Partnership with CARB

Management practices:

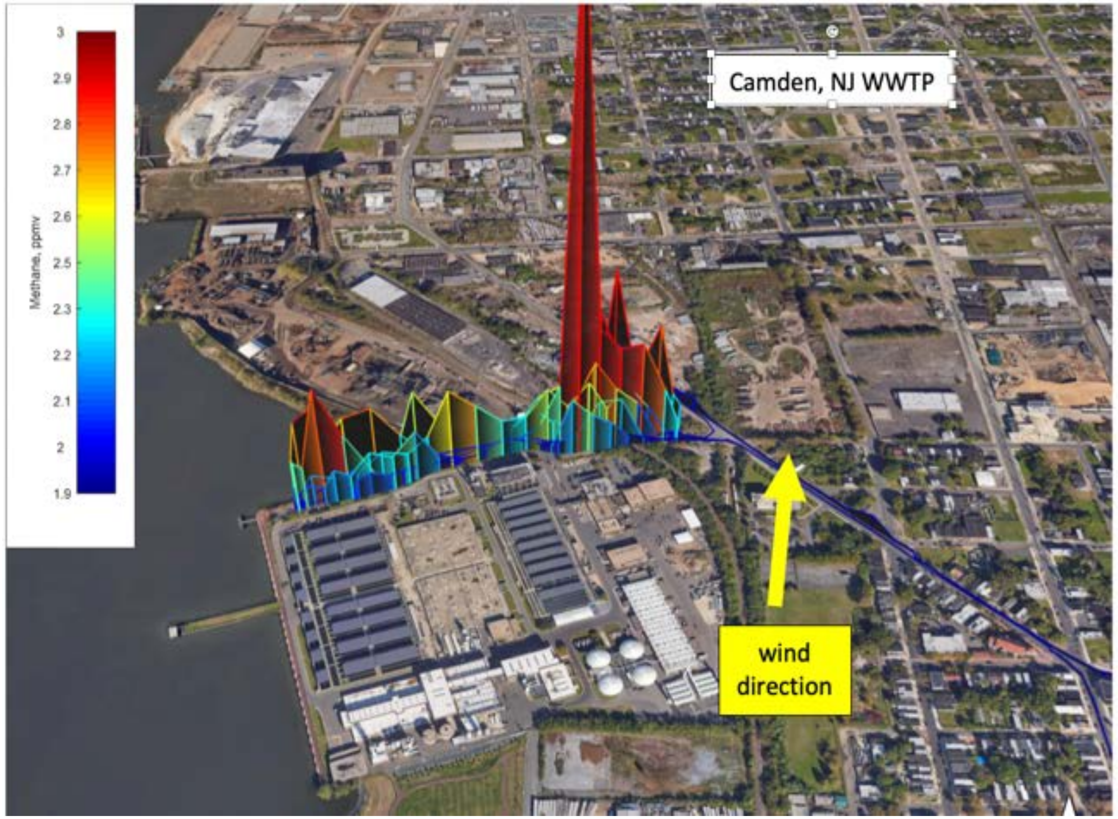
dairy-related technologies (e.g. digesters, lagoons, pen scraping) on NH_3 and CH_4 emissions

Understand details of facilities, practices – share results with operators to aid interpretation

Expected outcomes / implications

Emissions

- distributions of emissions across a wide variety of sites, conditions, age, capacity, management practices
- robust, bottom up constraints of WWTP and agriculture waste emissions for US



Technologies / methodologies

- develop an optimal approach to use mobile labs for quantifying areal emissions, large # sources
- advancing developments of mid-infrared and quantum cascade laser-based sensing

Practical outcomes

- quantify how changes of management practices at farms yield different emissions (Calif.)
- recommendations on best practices moving forward to control emissions

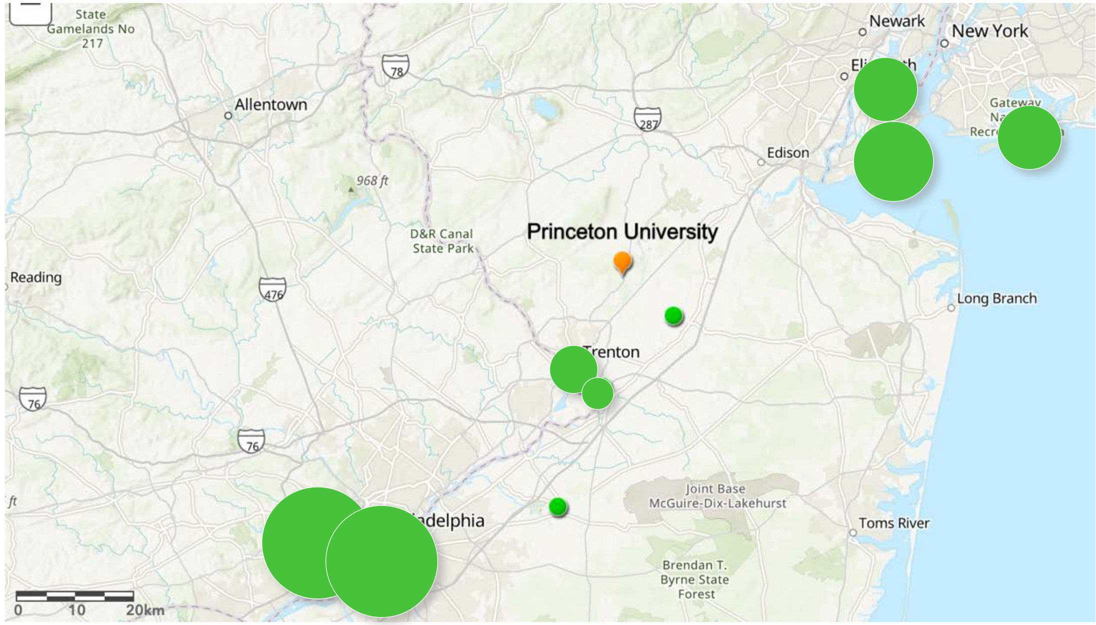
Increasing urbanization and food supply demands will only increase the importance of wastewater and agricultural emissions in the future

Nine WWTPs sampled in three states

Facility Name	State	Influent (MGD)	Times Sampled
Hamilton WWTP**	NJ	7.8	6
Trenton WWTP**	NJ	12.5	2
Mount Holly WWTP	NJ	3.5	1
East Windsor WWTP	NJ	4	1
Oakwood Beach WWTP**	NY	40	1
Rockaway Beach WWTP**	NY	45	1
Port Richmond WWTP**	NY	60	1
SW Philadelphia Pollution Control**	PA	~130	2
SE Philadelphia Pollution Control**	PA	~130	1

** Anaerobic Digesters on site

Map of Sampled WWTPs



Created using ArcGIS Online

Range of treatment processes

US EPA: Medium (1-10 MGD) and Large (>10 MGD) WWTPs serve 89% of the US population

97% of plants are <10 MGD

Larger plants emit less per gallon treated

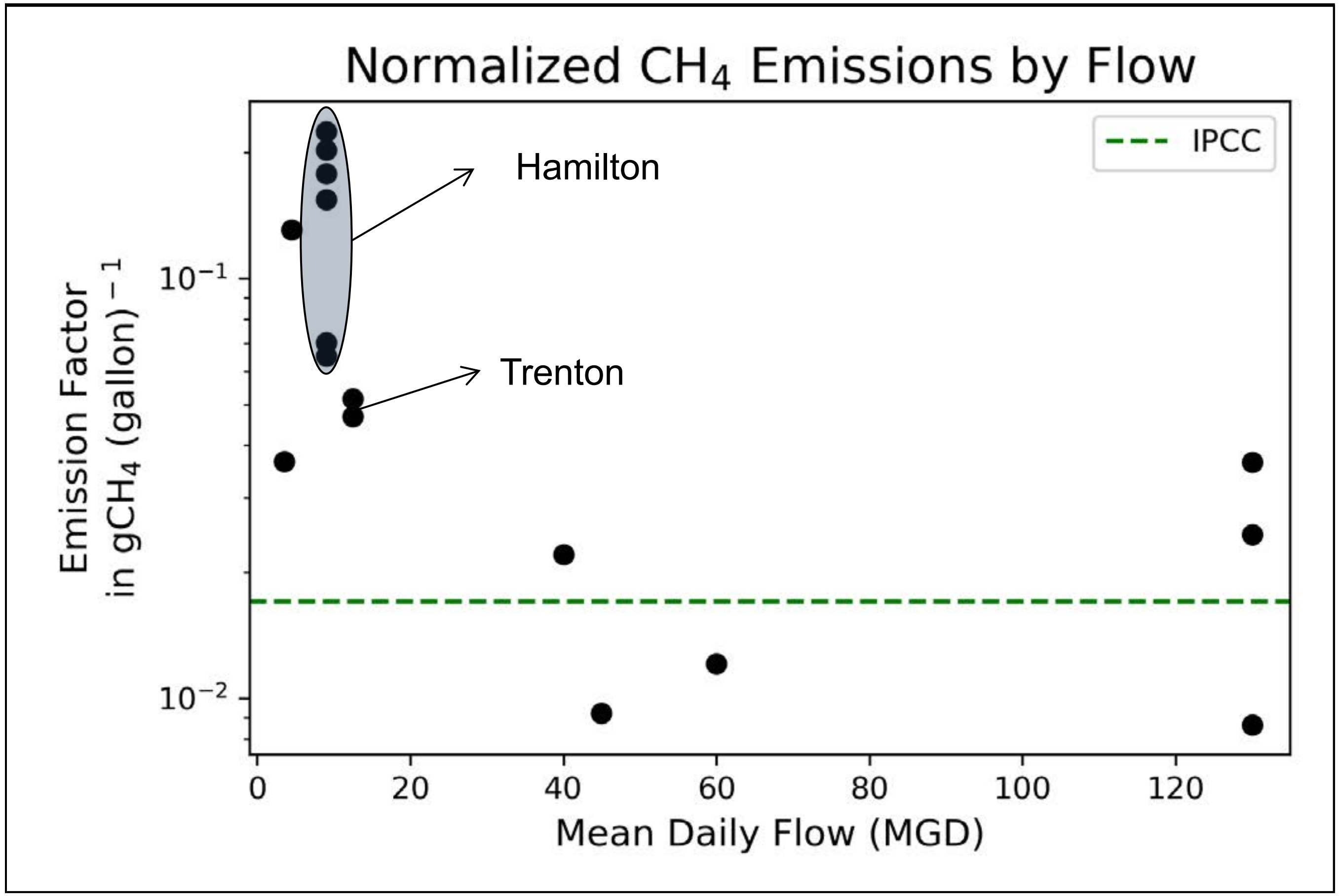
Median estimated emission factor = 0.05 gCH_4 (gallon treated)$^{-1}$

IPCC-Recommended emission (green line) highly dependent upon influent chemical content (e.g. BOD) and treatment type

- Represents worst-case scenario assuming no anaerobic digestion

Larger plants:

- Better technology?
- More intense regulation/monitoring?



A portable, open-path NH_3 sensor

9.06 μm quantum cascade laser: fundamental NH_3 absorption band optimized for open-path detection

No sampling process: fast response; no sampling artifacts

Comparison with state-of-the-art NH_3 sensors:

Sensors	NH_3 sensitivity	Mass	Power	Response time
Open-path QCL (Sun et al. 2013; Miller et al., 2014)	150 pptv (10 Hz)	7 kg	45 W	< 0.1 s
Aerodyne QCL (Aerodyne website)	42 pptv (1 Hz)	25 kg + pump	500 W	15 s
CIMS (Nowak et al. 2010)	70 pptv (1 Hz)	~100 kg	> 1 kW	1-2 s
Picarro CRDS (G2103)	<1 ppbv (0.2 Hz)	32 kg	185 W	< 30 s