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U.S. DEPARTMENT OF ENERGY

Accelerating Deployment of Recovery Infrastructure—2020 Update

California Bioresources Alliance Symposium

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STATE OF CALIFORNIA ENERGY COMMISSION

zerowaste energy development

CITY OF SAN JOSE CAPITAL OF SILICON VALLEY

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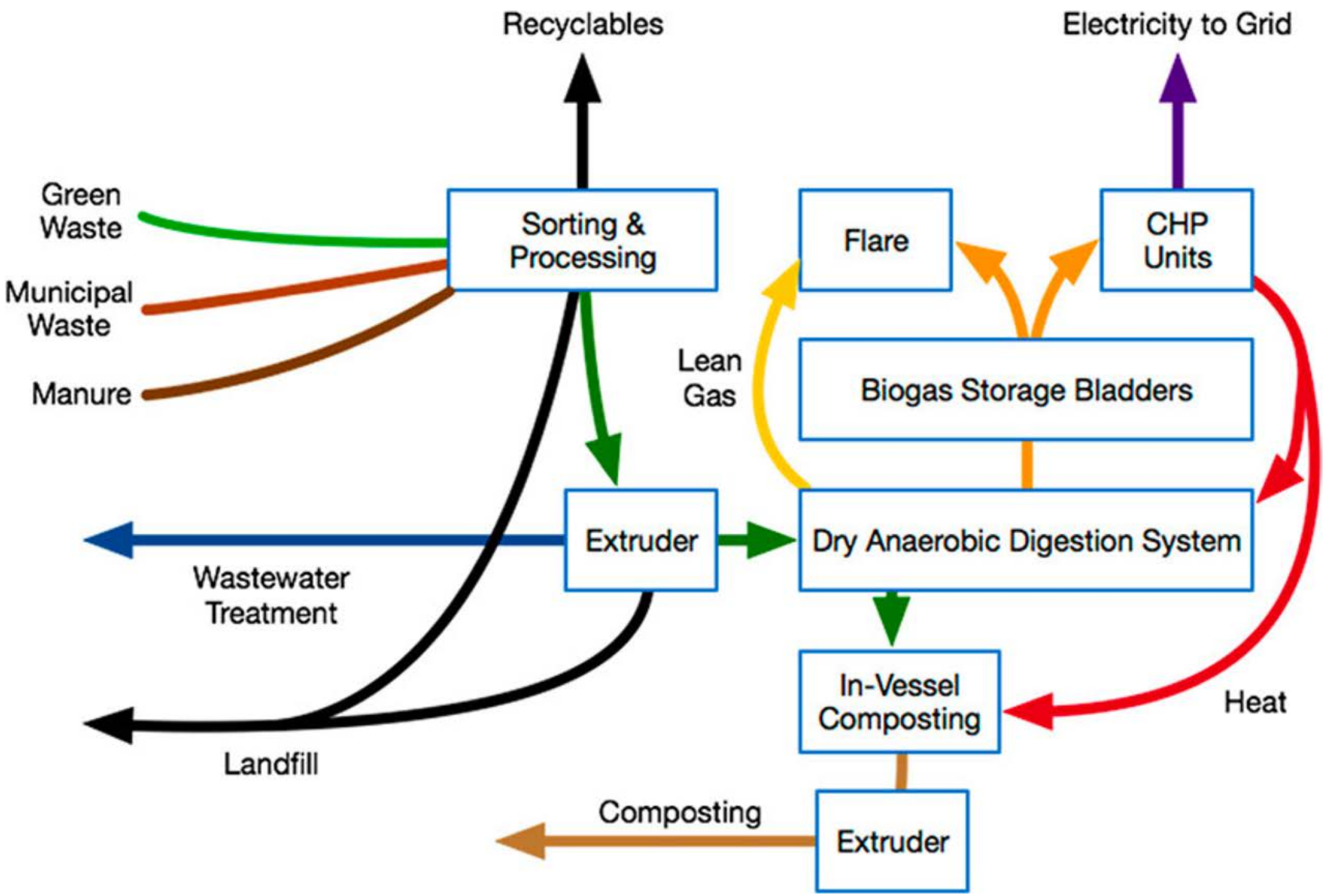
Overview of ZWEDC

- Dry anaerobic digestion facility in San Jose, CA
- Capacity to process 90,000 tons of organic MSW
  - Typically 84% OS4 (35% residual limit), 13% yard waste
- Electricity generation on-site 1.6 MW capacity
  - First enrollees in BioMAT program

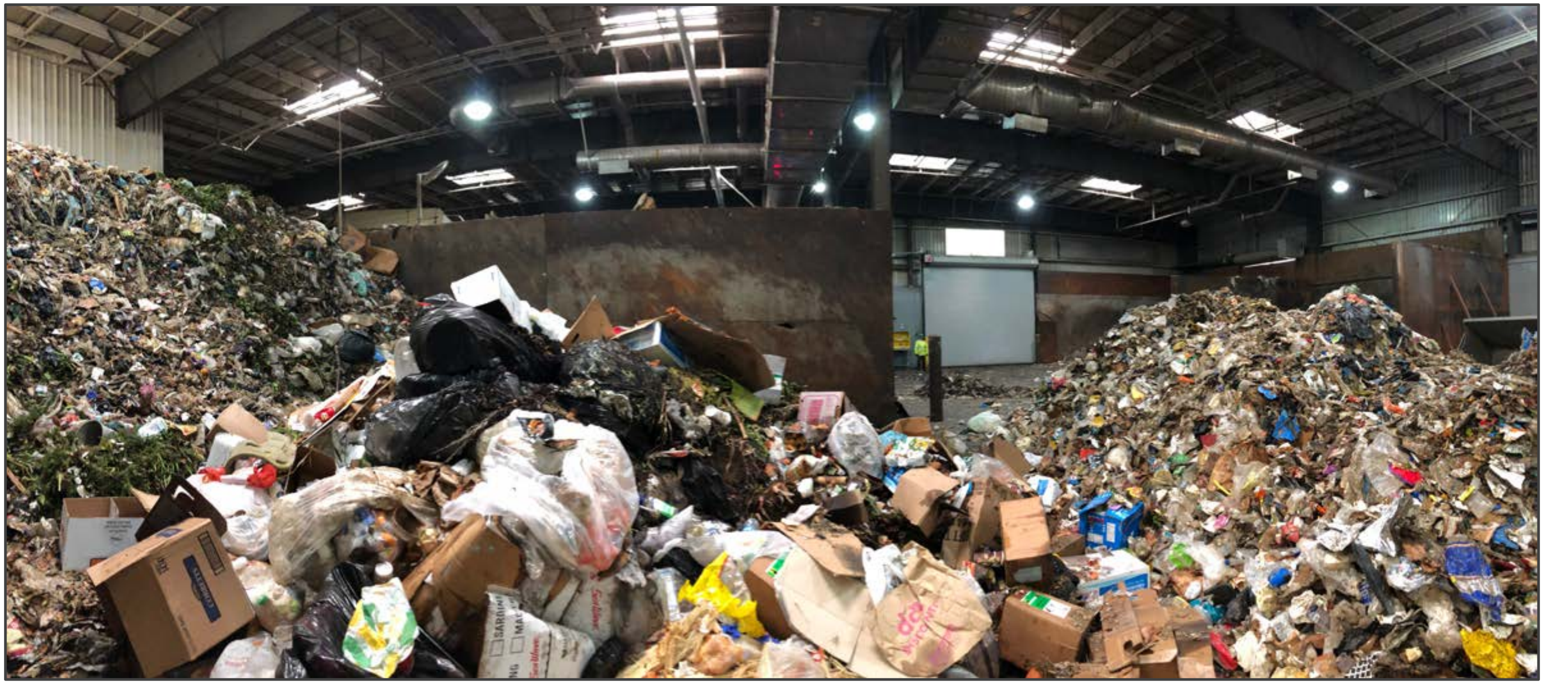
Simplified Process Flow Diagram



Satchwell et al. (*ES&T*, 2018)

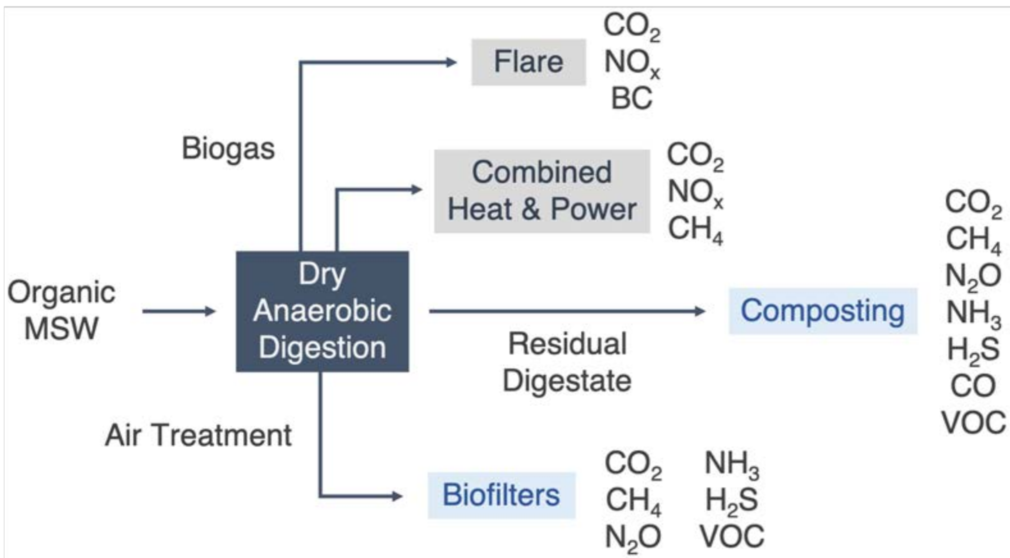
Research Objectives

- Estimate pollutant emission factors that serve odor modeling, life-cycle analysis, and emission inventories
- Compare different waste management strategies on the basis of greenhouse gas emissions and human health impacts
- Evaluate the economics of different waste management strategies by facility design and enabling policies



Emissions Measurements

- Characterized pollutant emission rates across dry AD-composting process
  - Greenhouse gases, odorous/toxic compounds, and criteria air pollutants

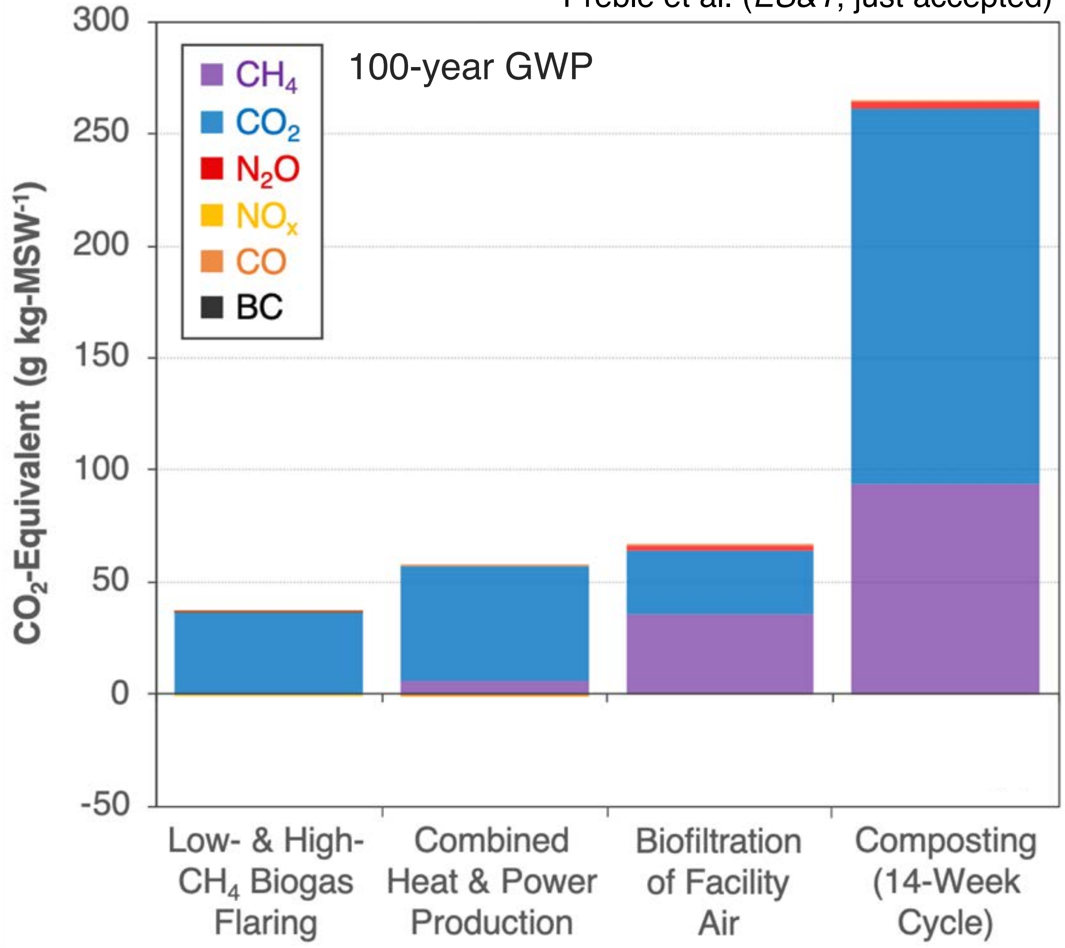


Preble et al. (*ES&T*, just accepted)

Composting is dominant emission source across AD process

- Per kg of MSW anaerobically digested, composting leads emissions of CH_4, CO_2, NH_3, H_2S, CO, and TVOC
- Composting accounts for ~65% of total CO_2-equiv. emissions
- CH_4 responsible for 35% of all CO_2-equiv. emissions from composting, indicating anaerobic activity exists
  - When CO_2 is excluded as biogenic, CH_4 contribution increases to 97% of total GWP-weighted emissions

Preble et al. (*ES&T*, just accepted)

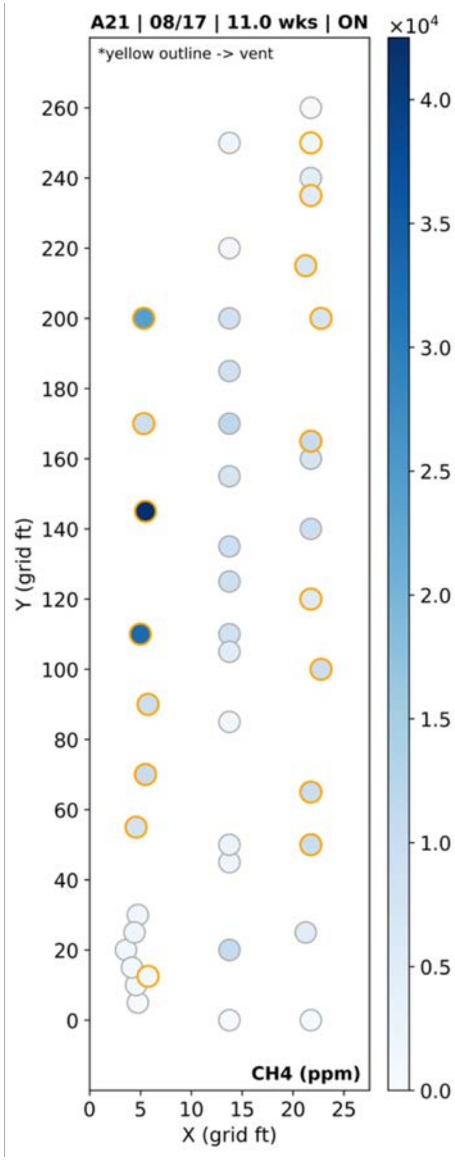


Composting Operations

- Measurements taken offsite at Z-Best composting facility in Gilroy
- Enclosed, force-aerated static piles that are approx. 100 m × 6 m × 3 m
  - Typically filled with ~700 tons of digestate
  - 14-week composting cycle

High-density spot sampling for extensive spatial coverage

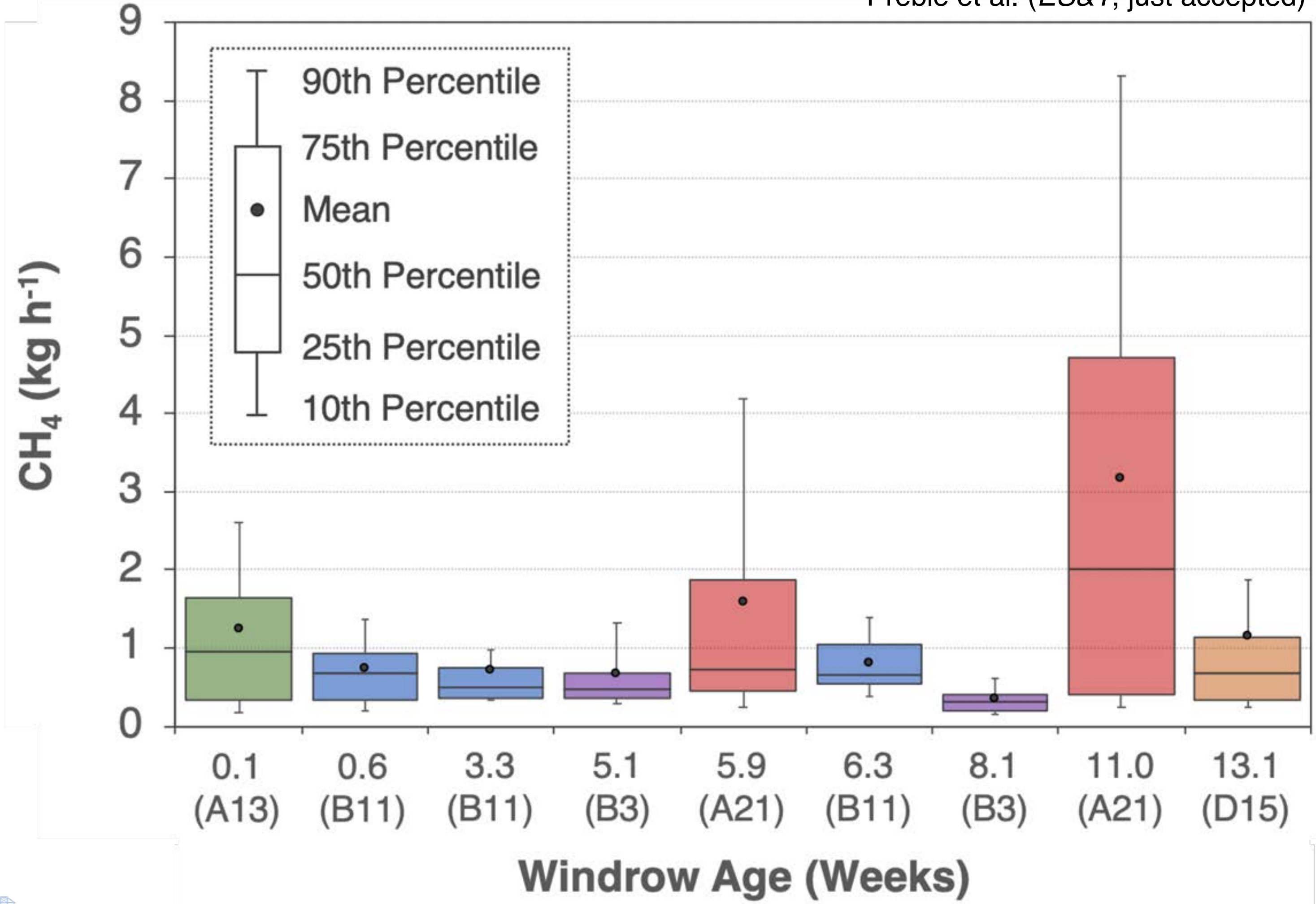
- Single-spot measurements are insufficient to characterize spatial heterogeneity of emissions
- Collected bag samples of emitted gas from across surface of multiple windrows, covering different stages of 14-week composting cycle



Emission rates calculated from spot measurements can vary widely

- Potentially significant sampling bias could result from an insufficient number of spot samples

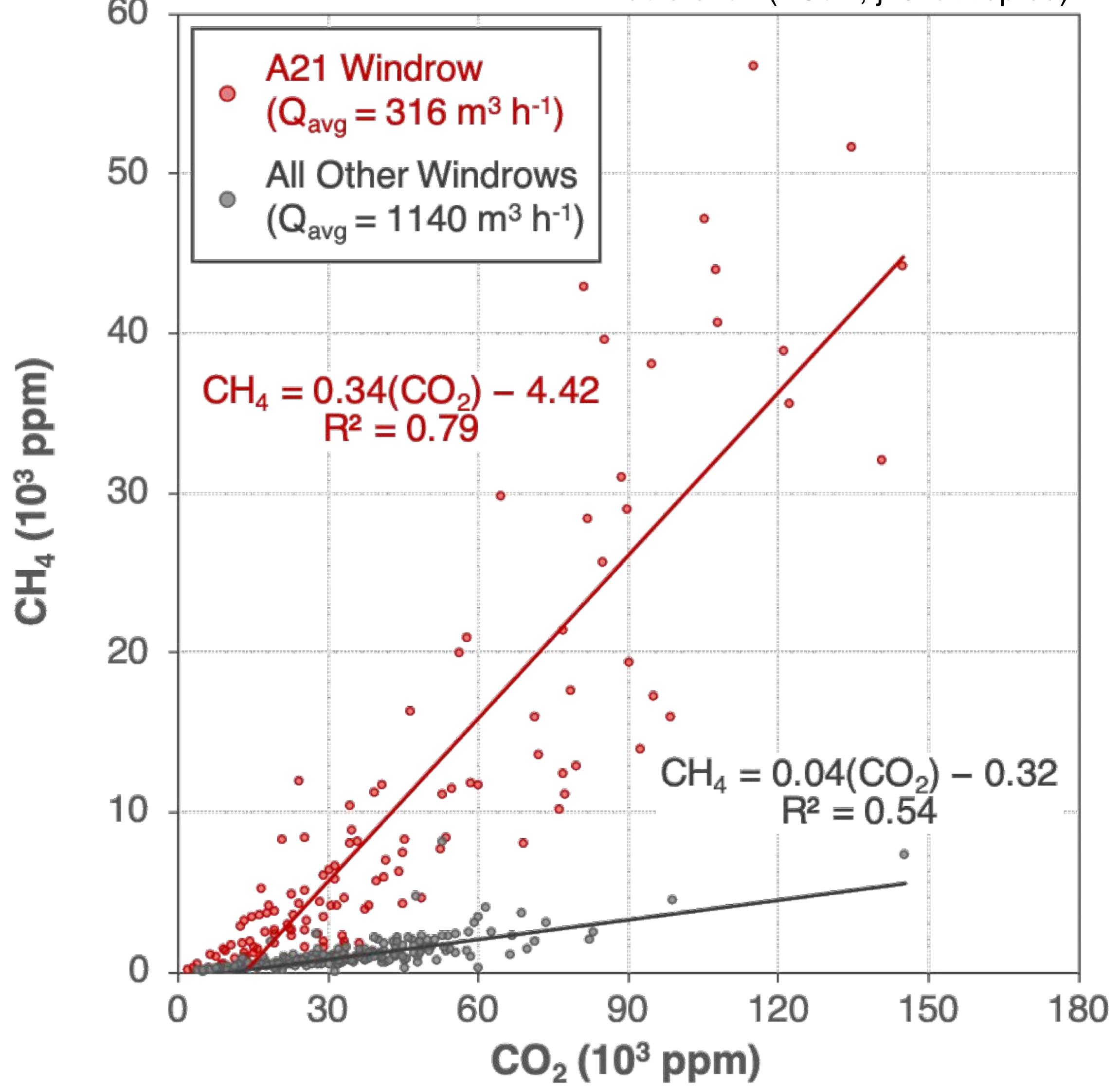
Preble et al. (*ES&T*, just accepted)



CH_4/CO_2 emission ratio further indicates anaerobic activity exists

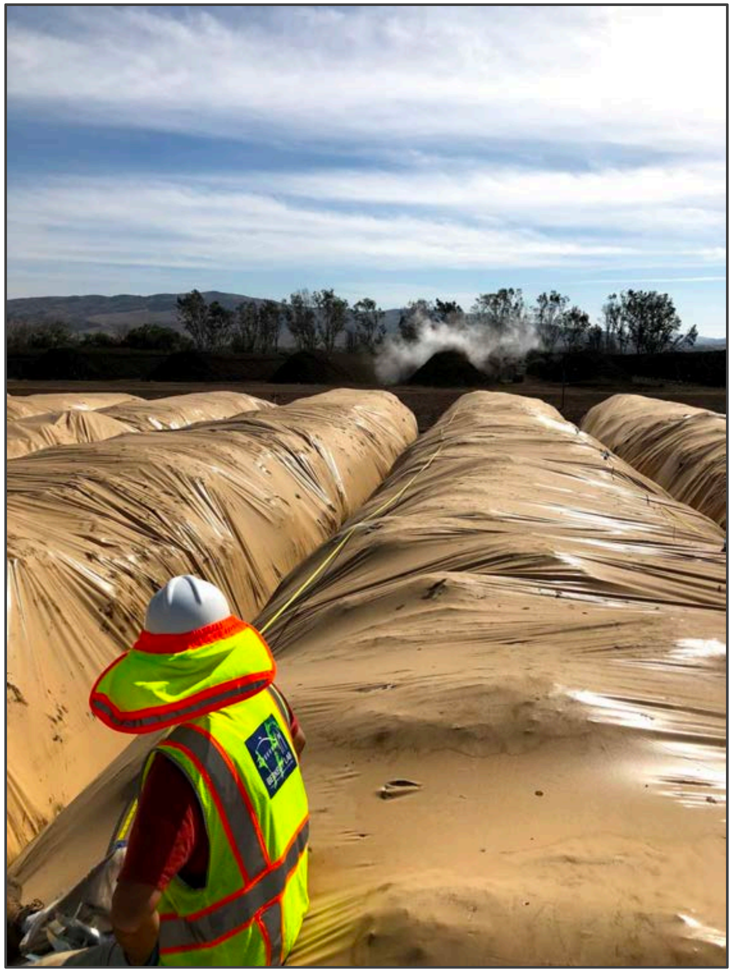
- Strong linear correlation indicates common formation process
- Relationship between aeration rate and CH_4/CO_2 emission ratio, with windrow A-21 as outlier

Preble et al. (*ES&T*, just accepted)



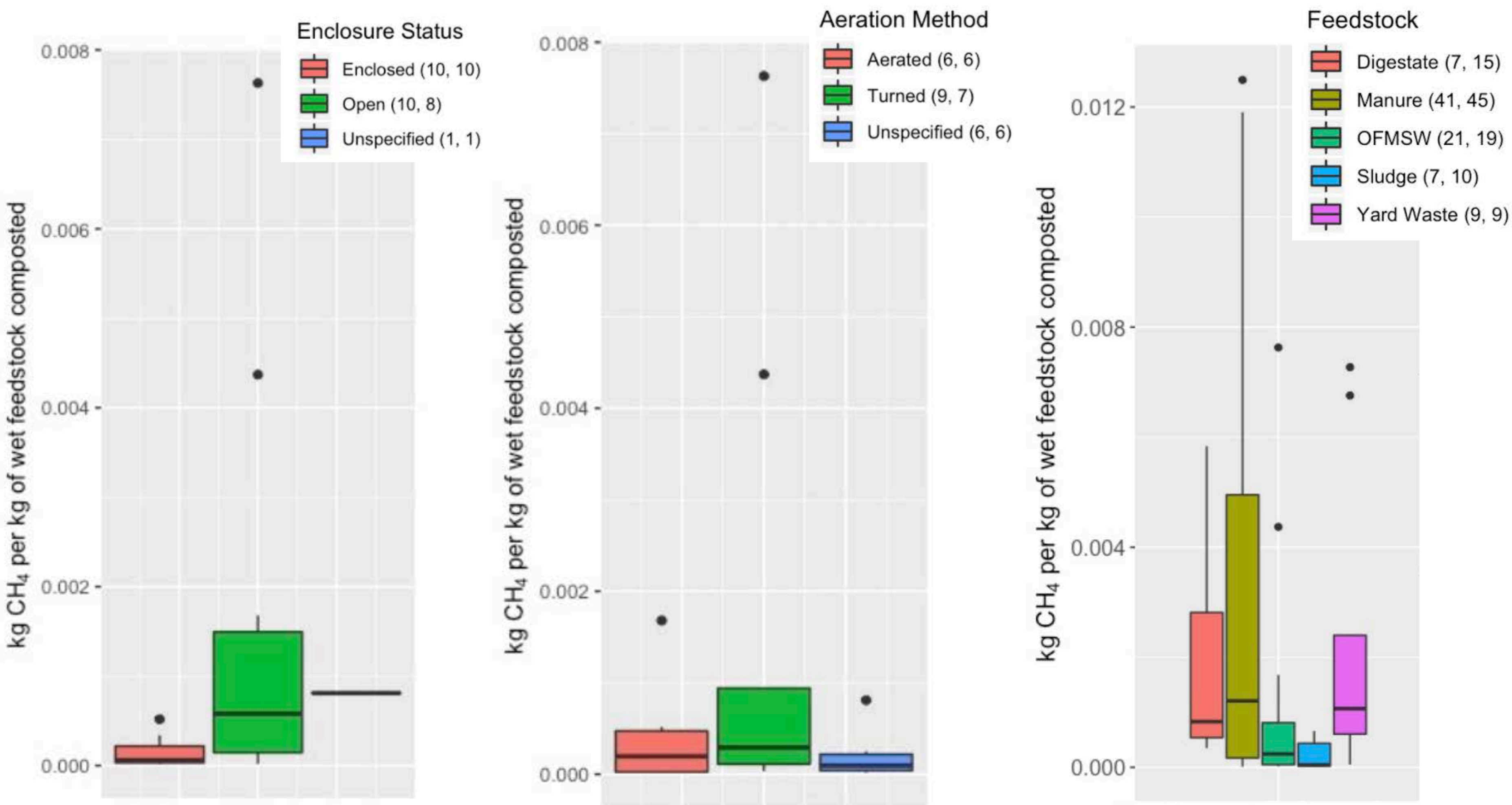
Emissions Measurements: Conclusions

- Identified composting as leading source of GHG & odorous emissions
  - Huge opportunity for new technologies to improve composting process
- Recommend studying other composting activities to evaluate potential mitigation opportunities
  - Optimal windrow management practices to maximize compost yield and minimize emissions
  - Technologies to capture and treat composting effluent prior to emission to the atmosphere



Sneak Peak: Review of Composting Emissions

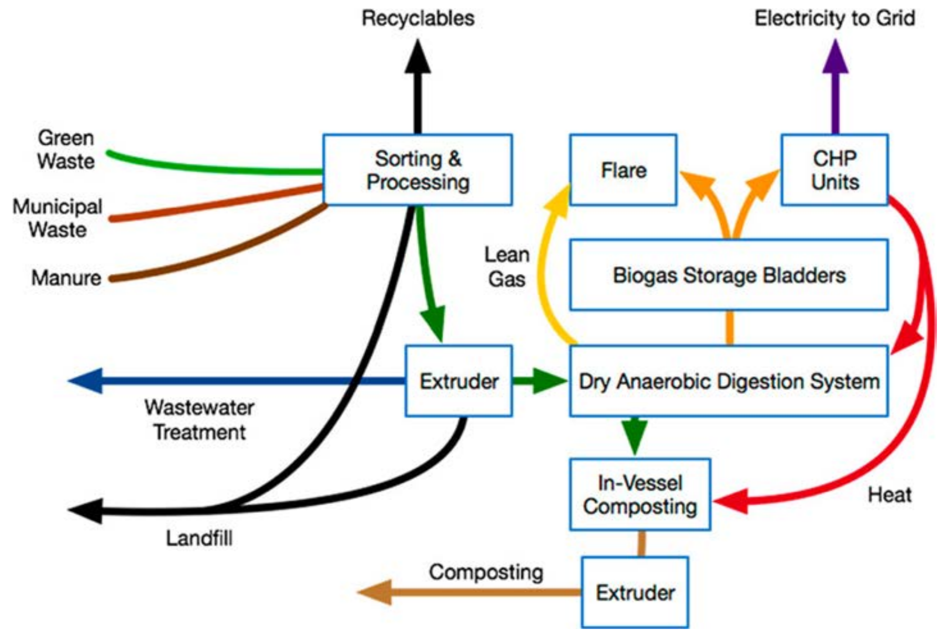
- Upcoming review of gaseous emissions from composting, including different management practices and feedstocks



Nordahl et al. (*in prep*)

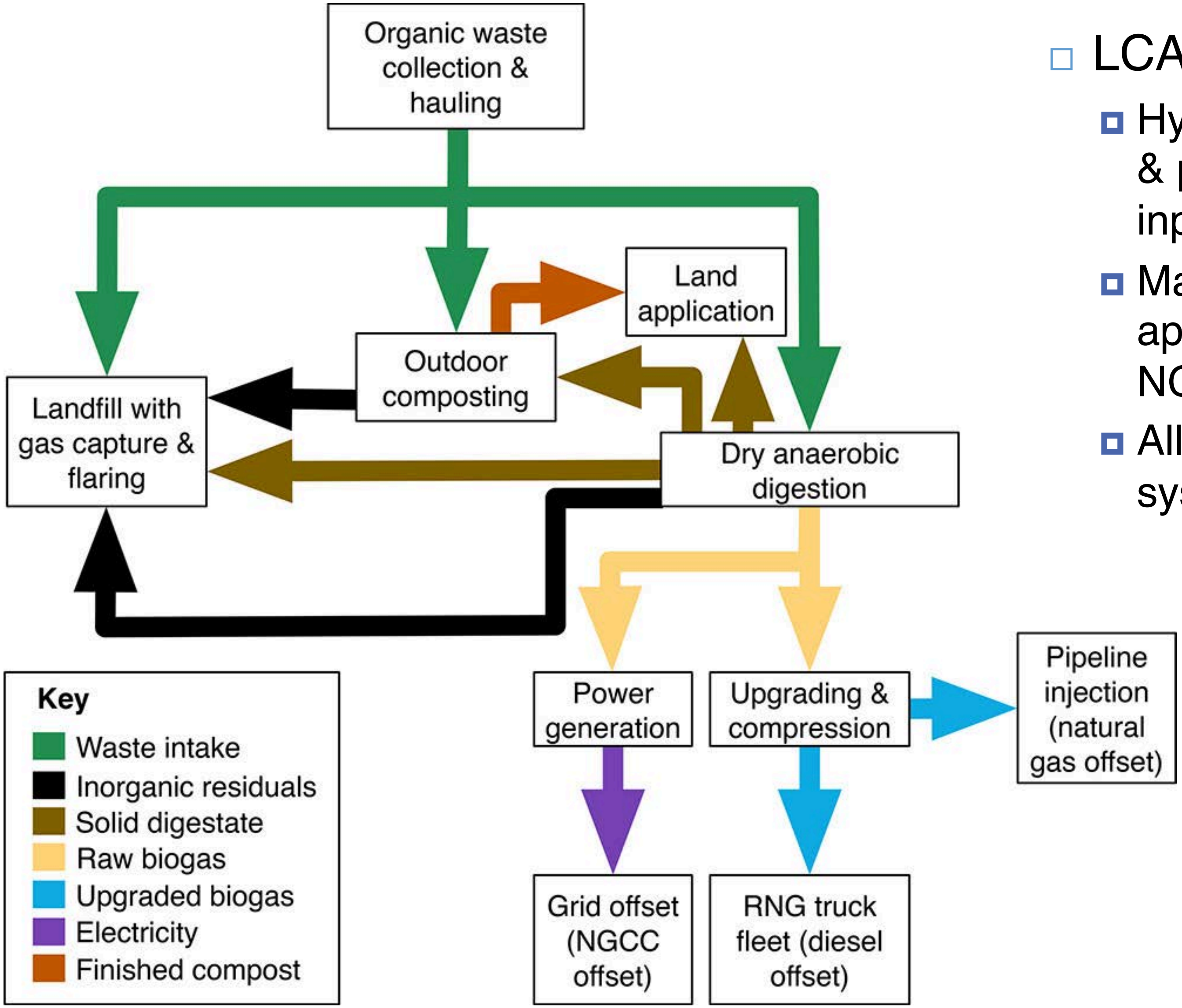
Life-Cycle Assessment Research Questions

- How do different wet organic waste management strategies compare on the basis of greenhouse gas emissions and human health impacts?
- Will dry AD still offer net benefits when we account for real-world practices and what are the biggest emissions sources?
- If we monetize social damages for each scenario, do the higher tipping fees make economic sense?



Source: Satchwell et al. 2018 *ES&T*

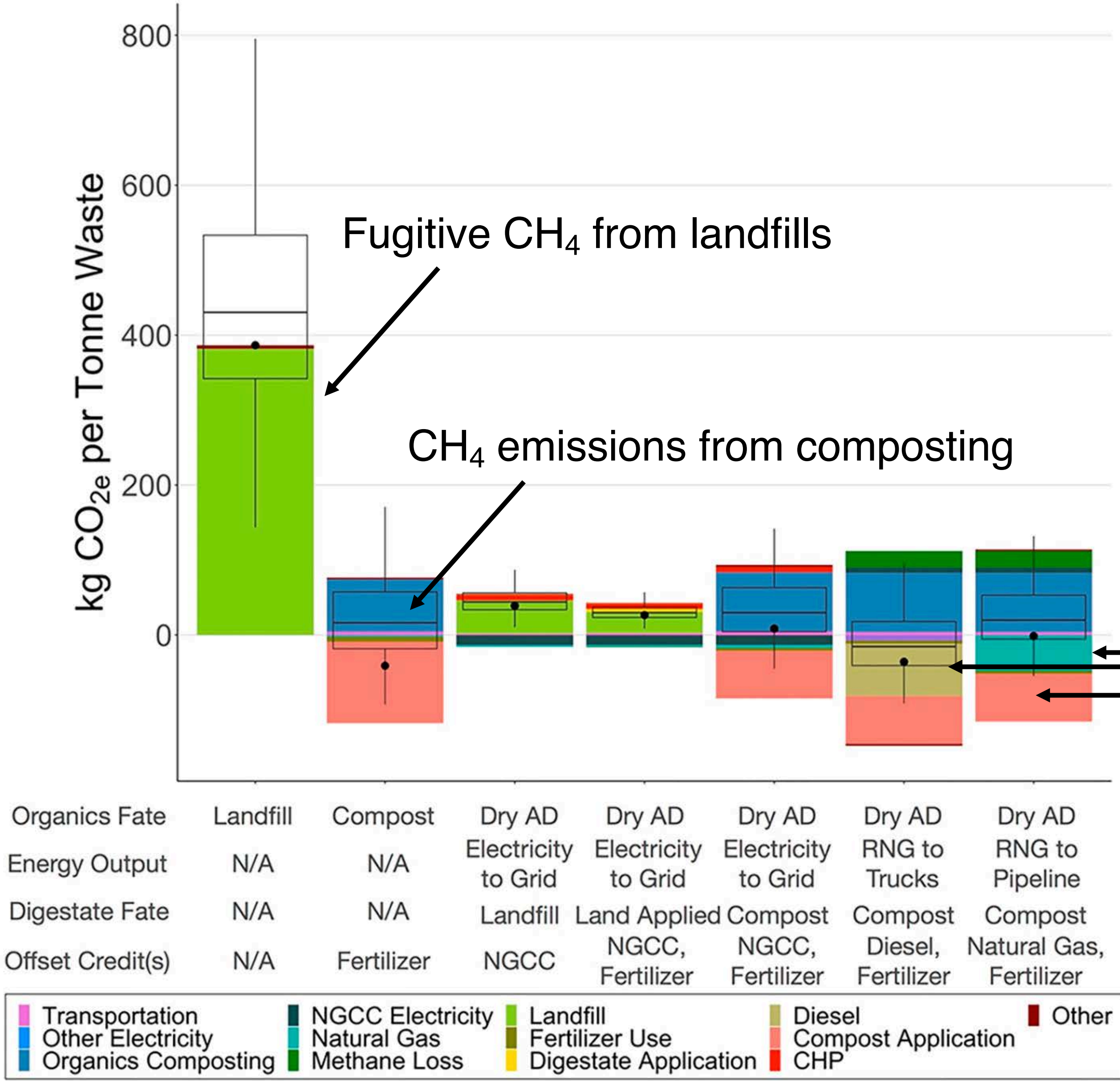
Scenarios Beyond Current Operations



- LCA Methods
  - Hybrid process-based & physical units-based input-output
  - Marginal grid mixed approximated as NGCC
  - Allocation method: system expansion

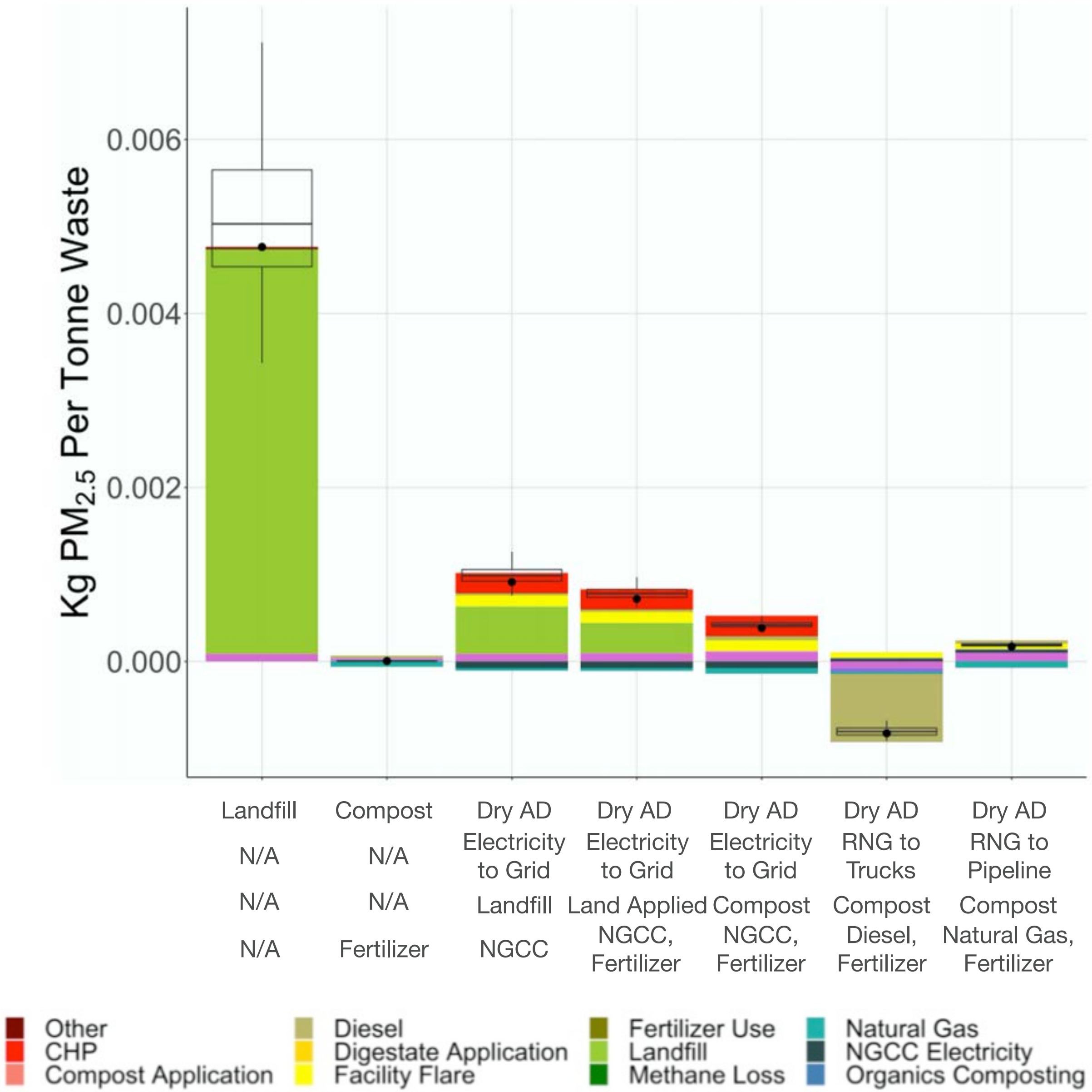
Source: Nordahl et al. 2020 *ES&T*

Life-Cycle Greenhouse Gas Emissions



Source: Nordahl et al. 2020 *ES&T*

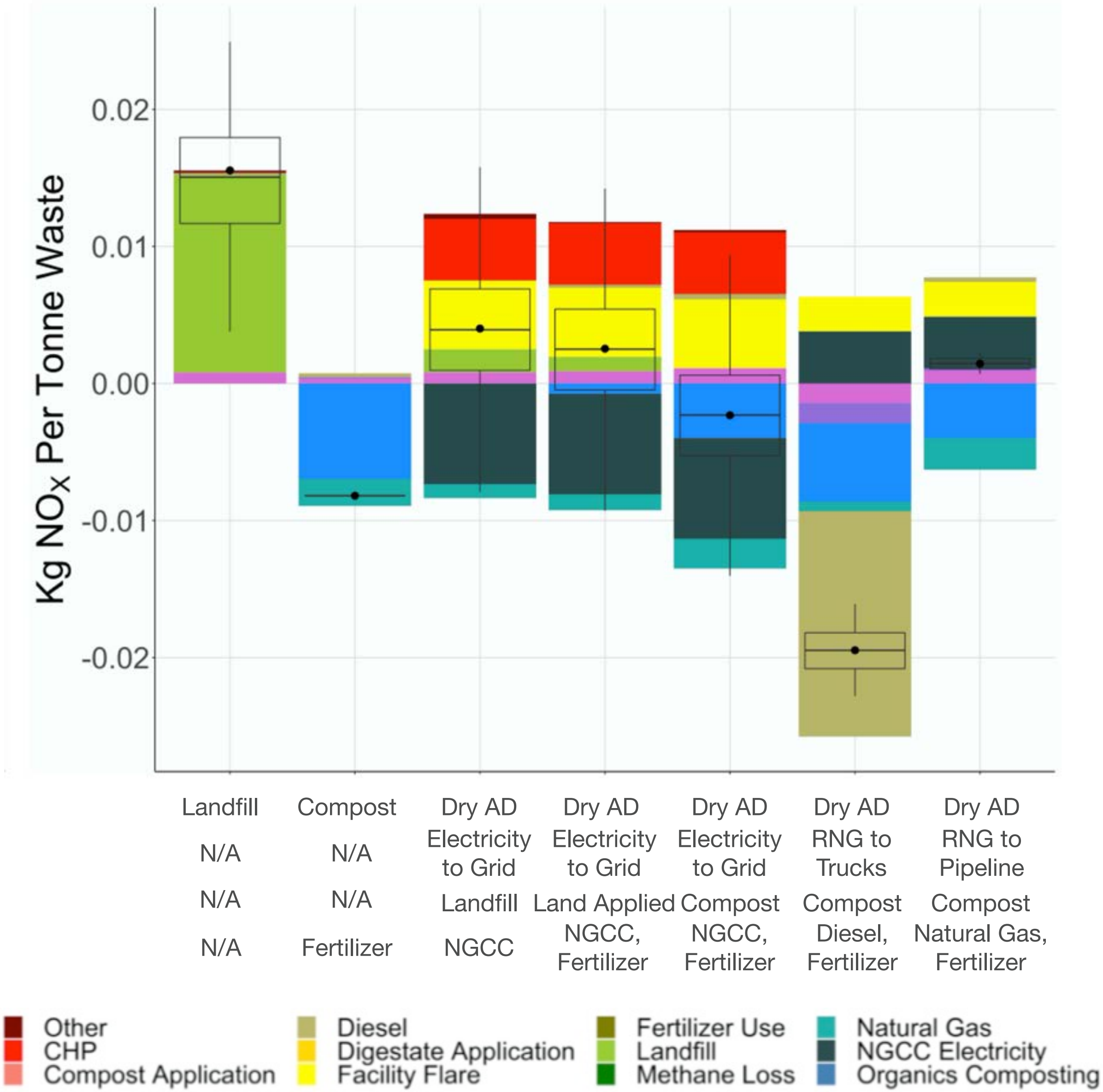
Life-Cycle $PM_{2.5}$ Emissions



- Driven by flaring
- Large offset from displacing diesel with RNG
- Some PM emitted from CHP as well

Source: Nordahl et al. 2020 *ES&T*

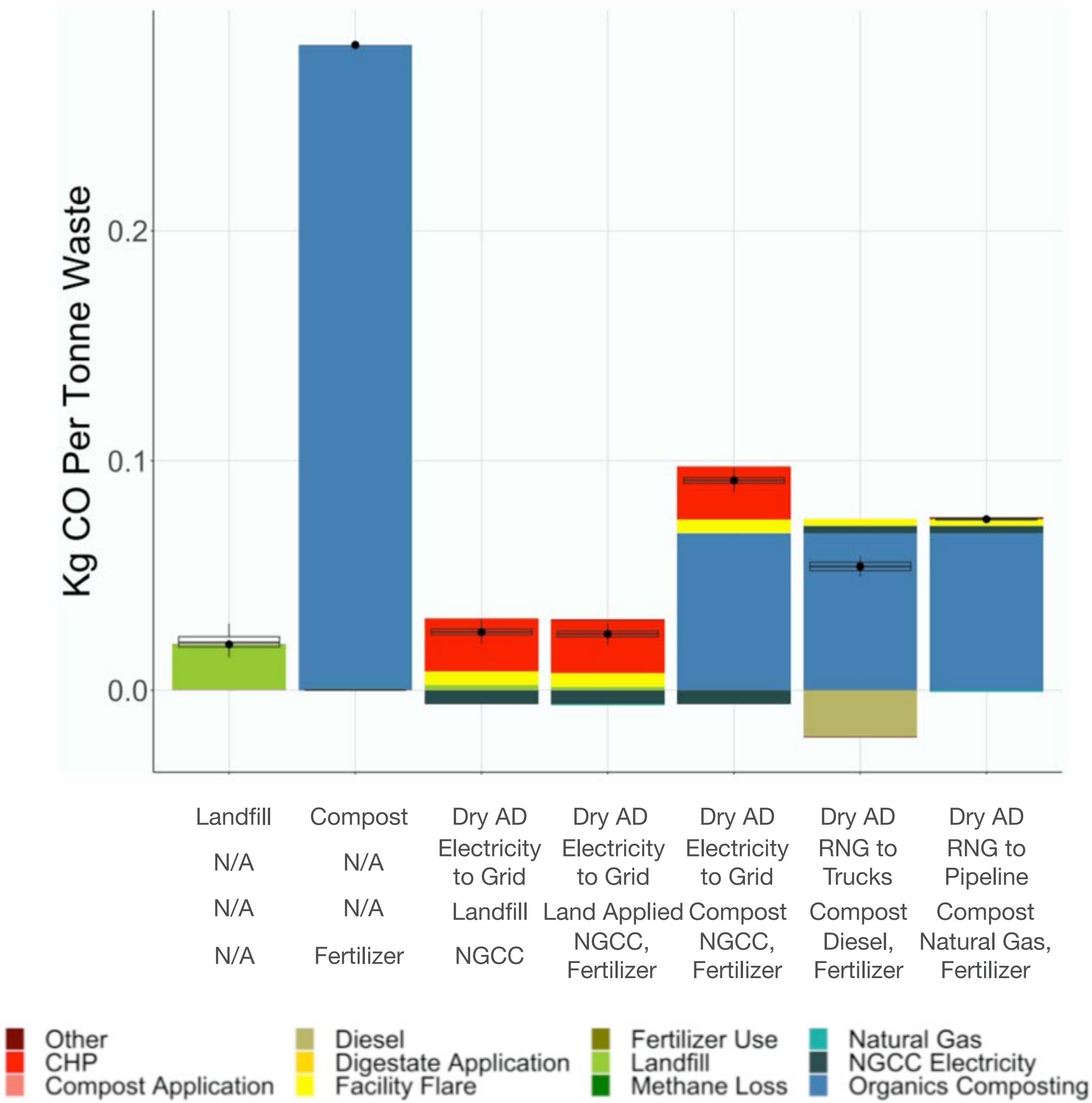
Life-Cycle Nitrogen Oxide (NO_x) Emissions



- Positive correlation between NH_3 present in biogas and NO_x emissions
- NO_x is emitted from CHP but would be 10X w/out SCR

Source: Nordahl et al. 2020 *ES&T*

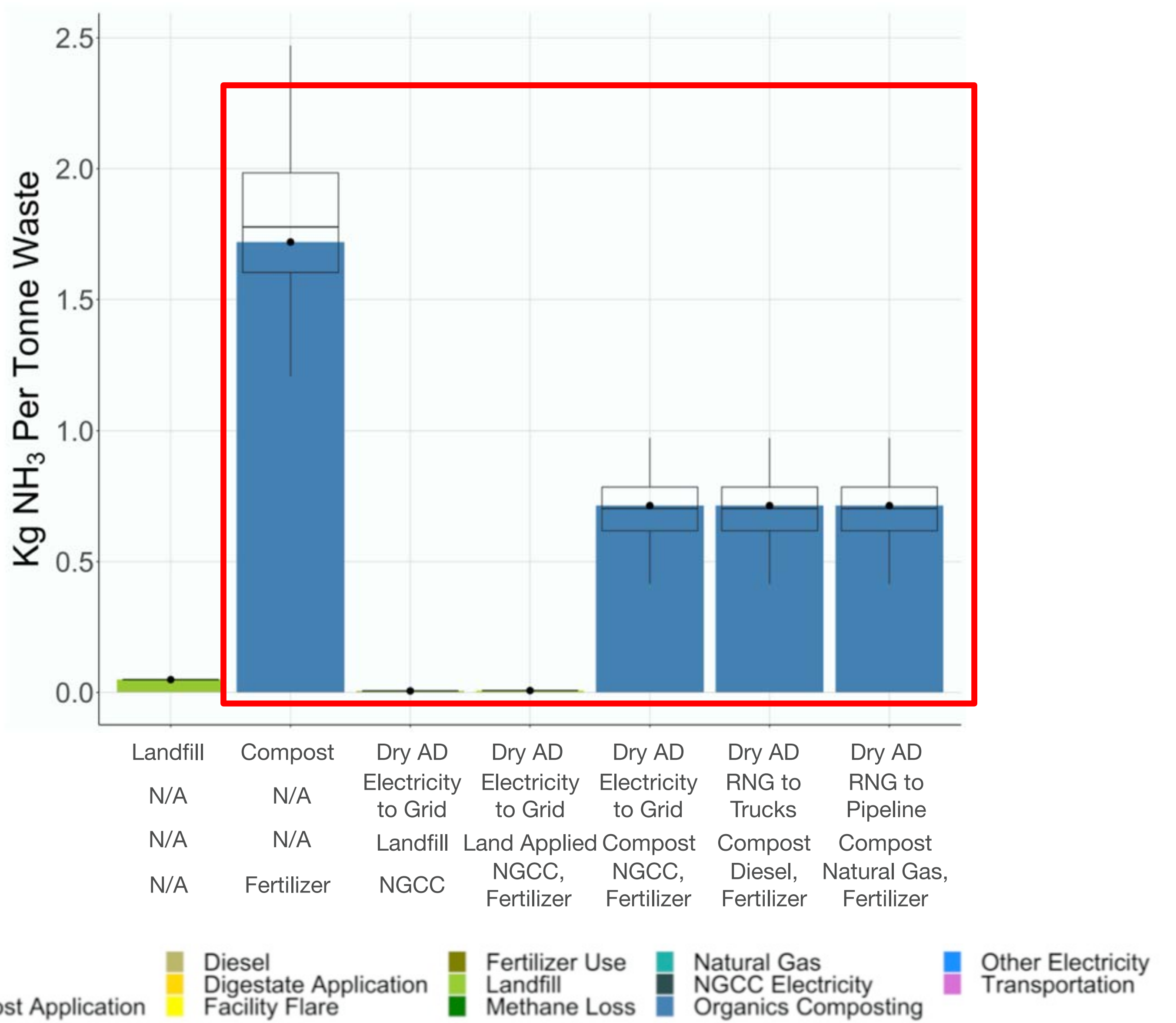
Life-Cycle CO Emissions



- Mechanisms not well understood
- Previously thought to be formed only through thermochemical processes
- Now thought to be both biological and thermochemical

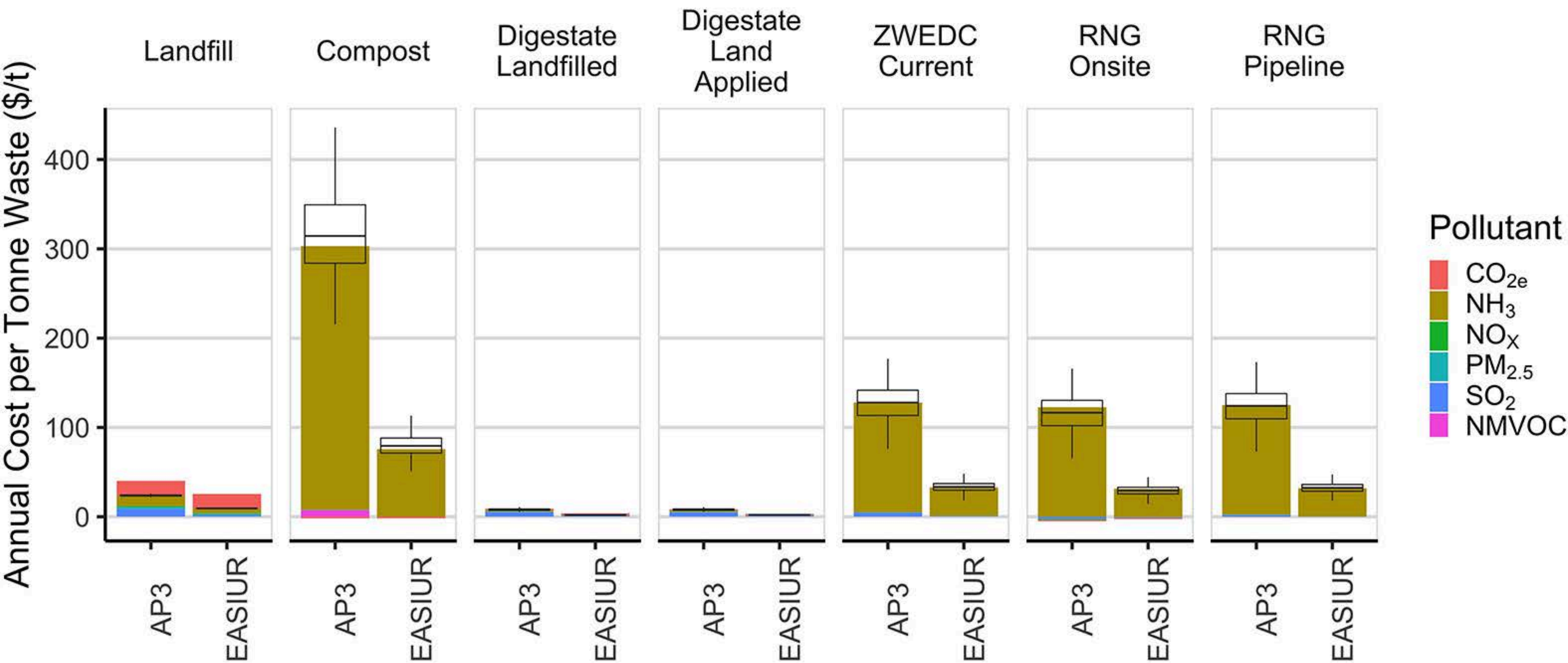
Source: Nordahl et al. 2020 *ES&T*

Life-Cycle NH_3 Emissions



Source: Nordahl et al. 2020 *ES&T*

Social Damages for GHG and Air Pollutant Emissions

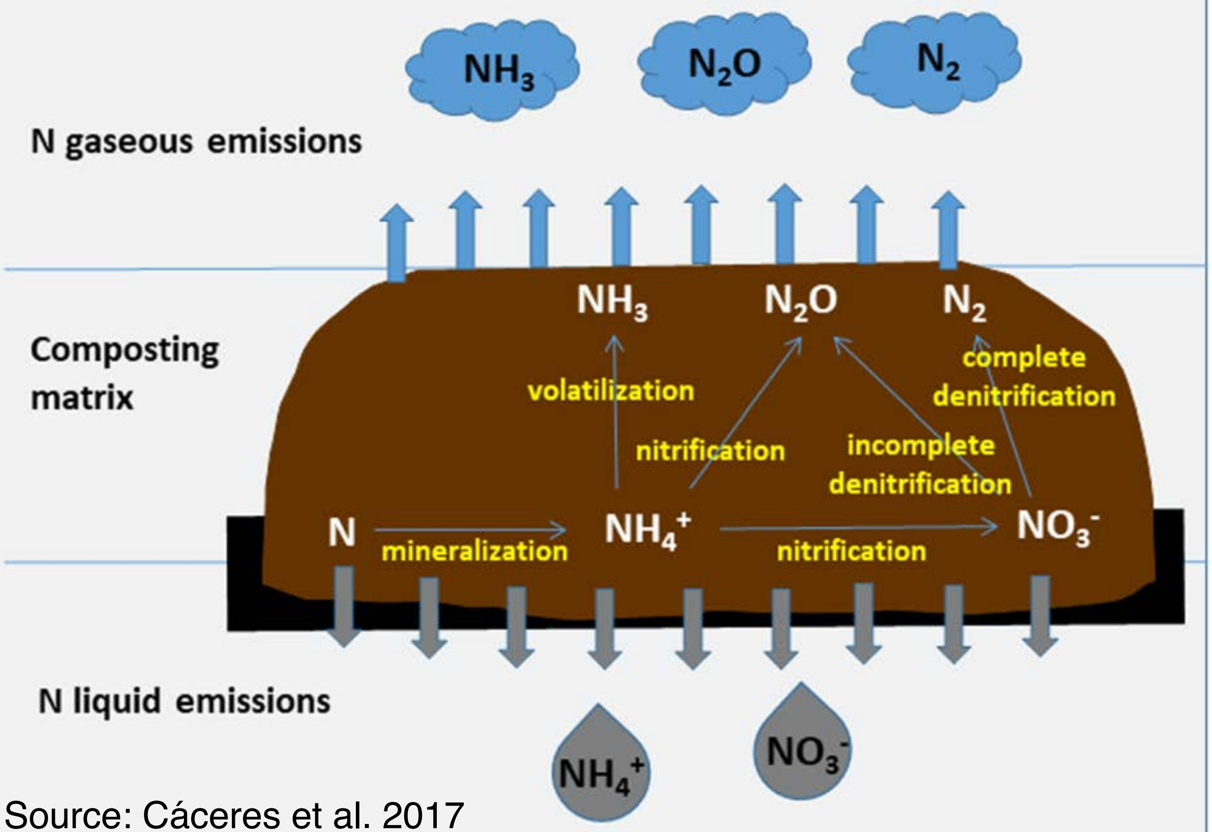


- NH_3 emissions from composting completely dominate social costs for all except landfilling
- Does this mean we are better off landfilling or land applying digestate?

Source: Nordahl et al. 2020 *ES&T*

What's going on with NH_3 emissions?

- NH_3 emissions from composting increase w/ increasing aeration, higher pH, higher temperature
  - Not easy to control in outdoor facilities without negatively impacting conditions for microbes
- Gaseous NH_3 losses occur mostly during thermophilic phase
- NH_3 can deposit in water bodies and cause indirect N_2O emissions
- Possible solutions: struvite, nitrification inhibitor, increase C:N ratio

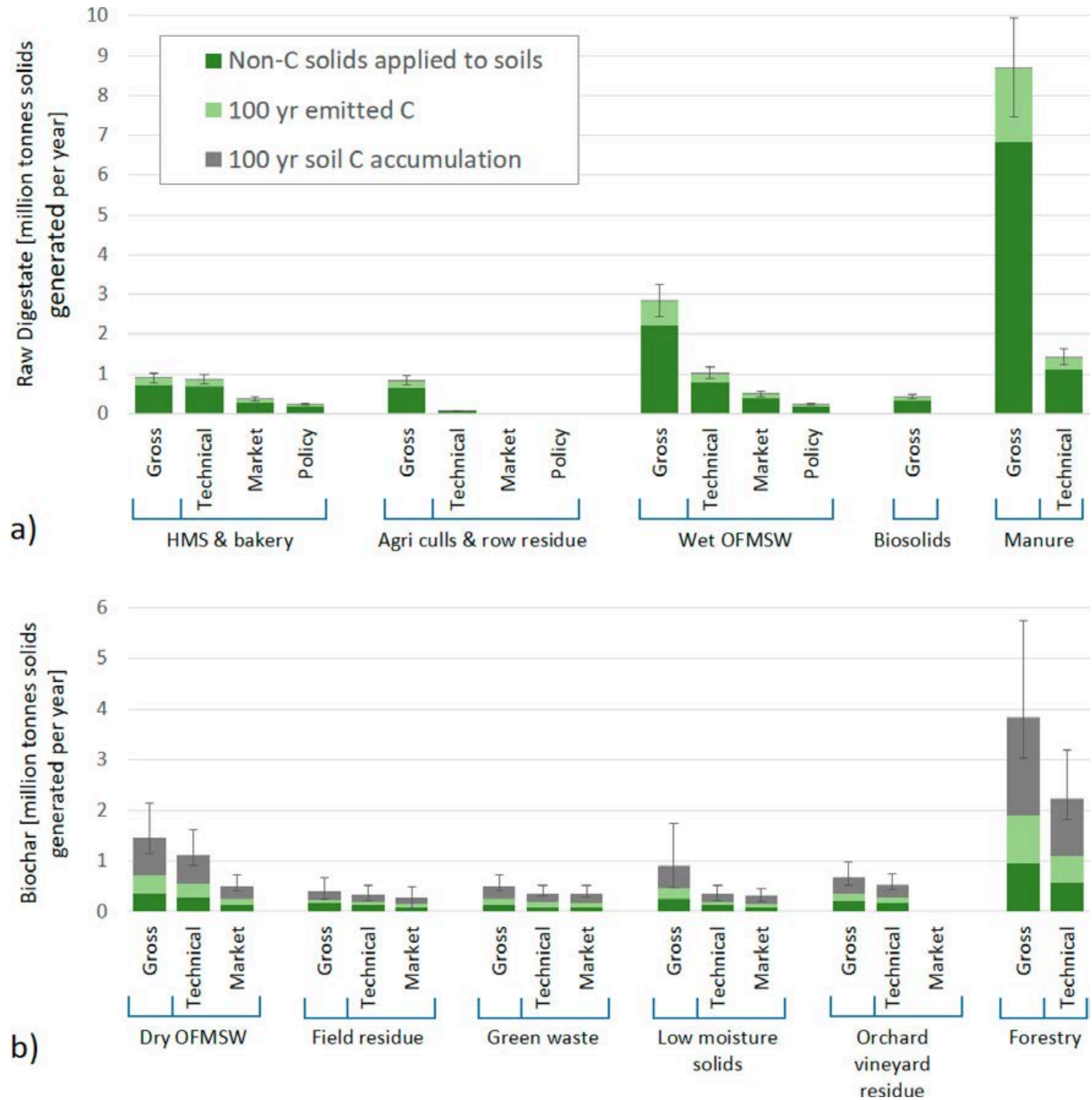


Source: Cáceres et al. 2017

Broader Impacts of Residual Solids

- California has a lot of manure and MSW
- Biosolids from AD are not necessarily adding value
- Do we:
  - Land apply it raw?
  - Compost it?
  - Landfill it?
  - Reduce net output?

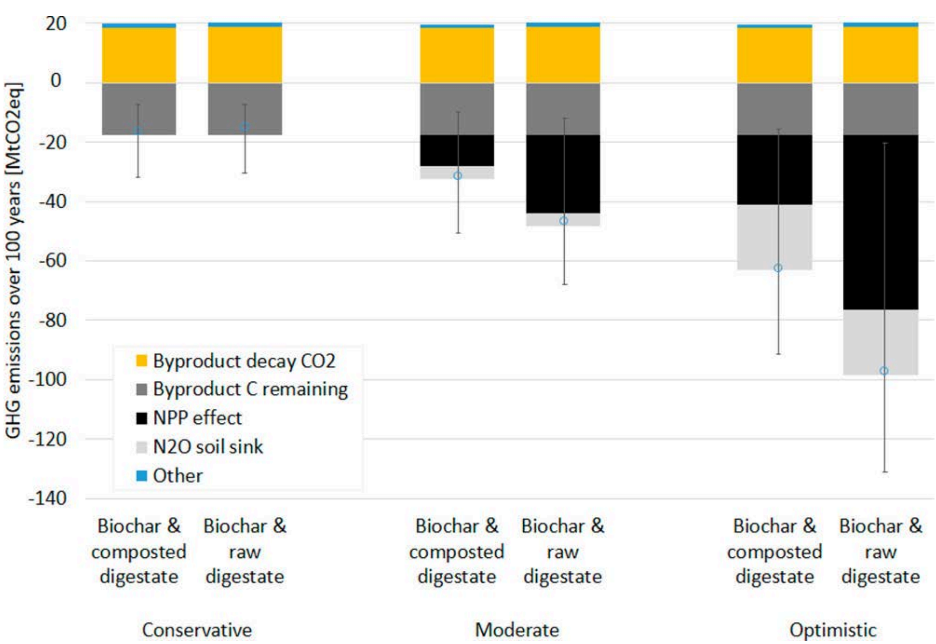
  E.g. Anaergia drying + pyrolysis, recycle bio-oil to digester (80% mass reduction)

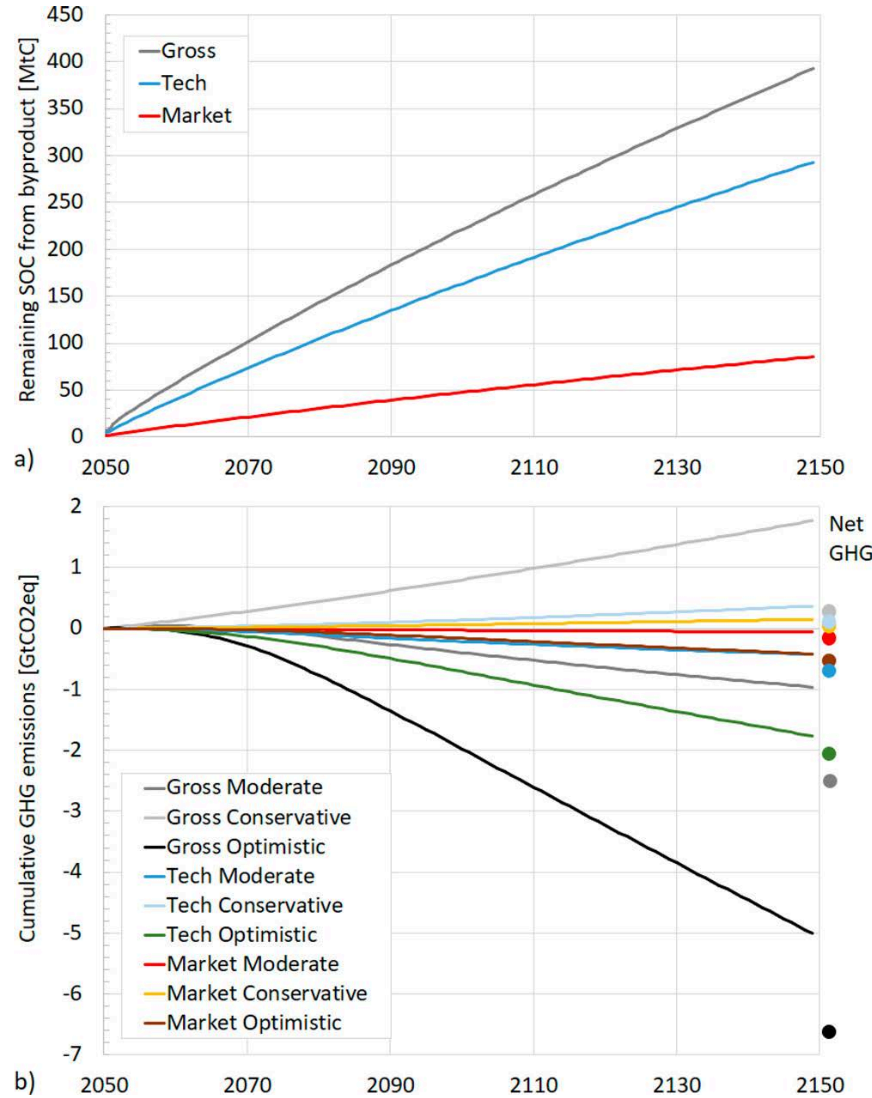


Source: Breunig et al. 2019 *ES&T*

Broader Net Emissions Impacts

- Climate impacts of digestate not limited to process emissions
- Depending on where it is applied, it can increase NPP, reduce N_2O
- Raw digestate poses water quality concerns
- One time application can mitigate ~0.3% of CA annual GHG emissions over 100 years





Source: Breunig et al. 2019 *ES&T*

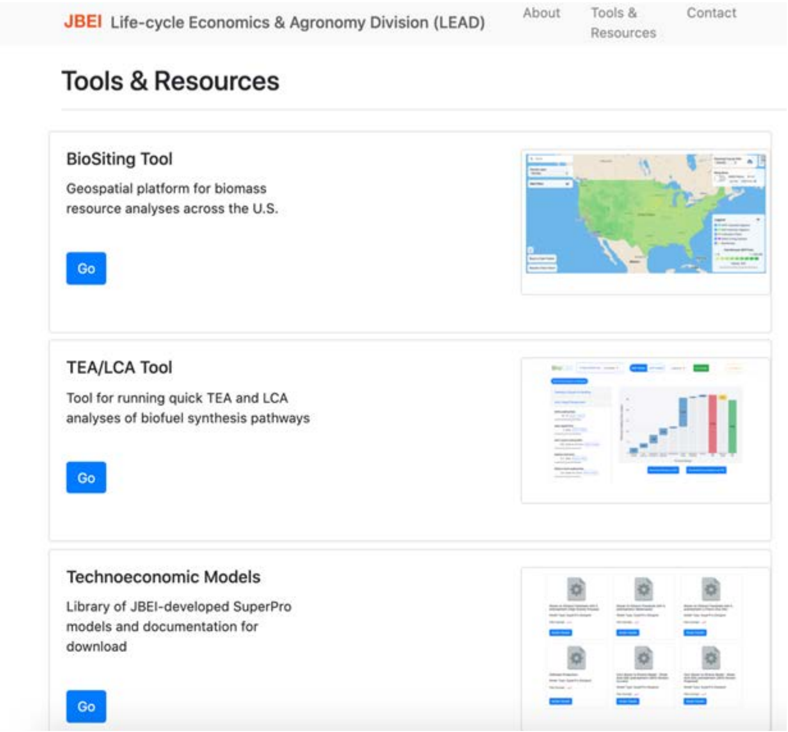
LCA Takeaways

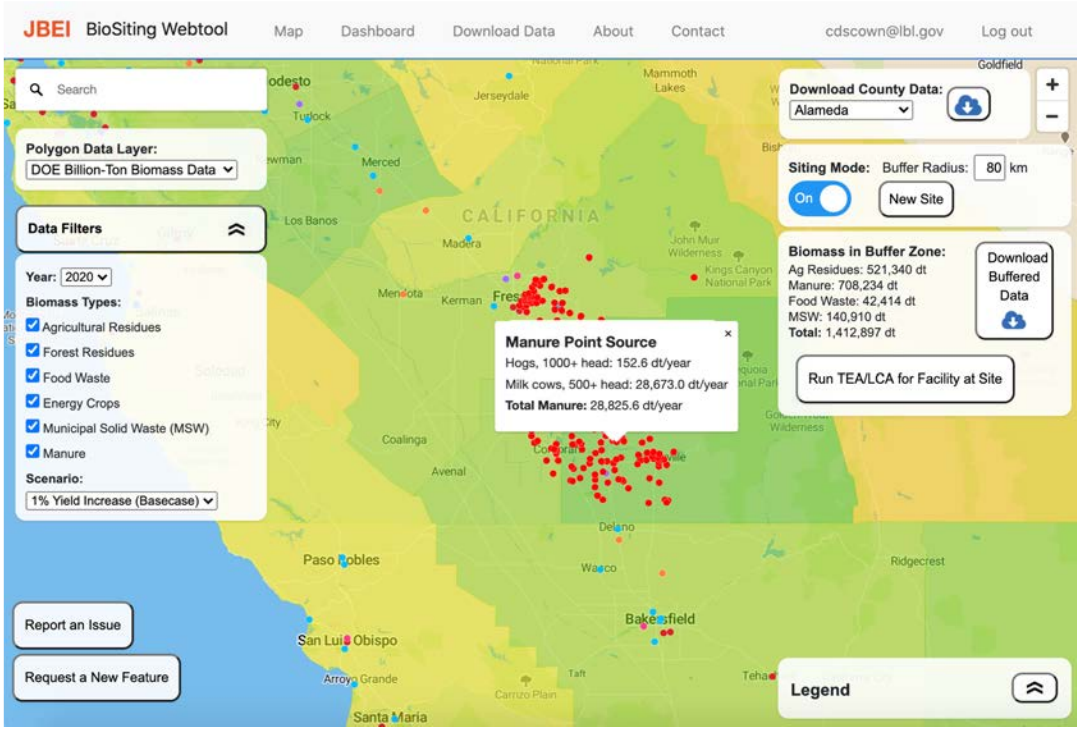
- Landfill emissions are uncertain, but from a GHG perspective, any other option is far better.
- Best options for GHG mitigation are either composting or dry AD w/ upgrading to RNG and digestate composting
- Social costs dominated by NH_3 emissions from composting, but impacts very uncertain and dependent on background emissions of NO_x and SO_x (atmospheric concentrations of sulfuric acid & nitric acid)
- Social cost of GHG and air pollutant impacts of landfills is around $50/tonne, whether dry AD provides net savings or net costs depends on NH_3

Play With Our Tool!

Go to **lead.jbei.org** – free and easy to create an account or log in w/ your existing google account, get access to downloadable datasets

Play around with real or hypothetical facility locations to assess organic waste nearby, explore existing WWT facilities, district energy facilities, MRFs, standalong AD facilities, biomass combustion power plants, and biorefineries





Facility and System-wide Economic Analysis Research Questions

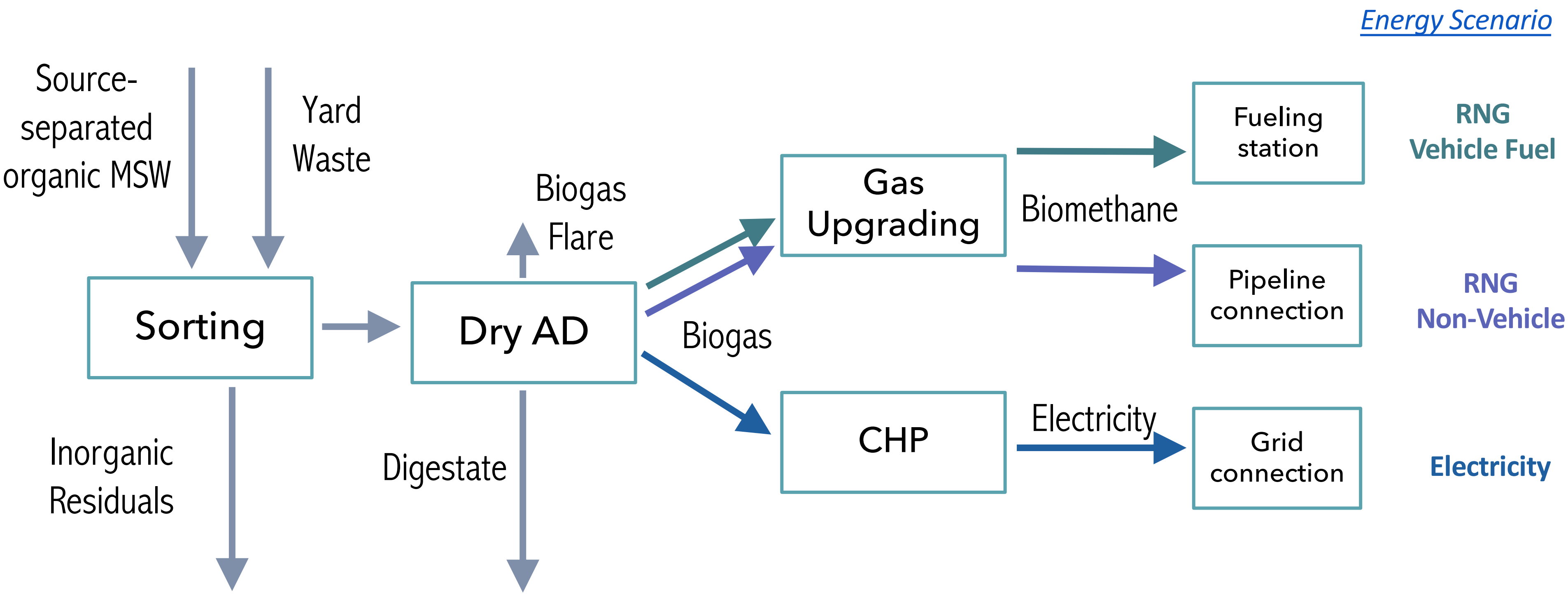
Part 1: Dry AD Facility-Level Economic Modeling

- What are the key economic drivers for dry AD facilities?
- To what extent do operational and cost uncertainties impact total cost?
- How do current policies impact costs, and where are there gaps?

Part 2: Statewide Costs and Emissions Modeling

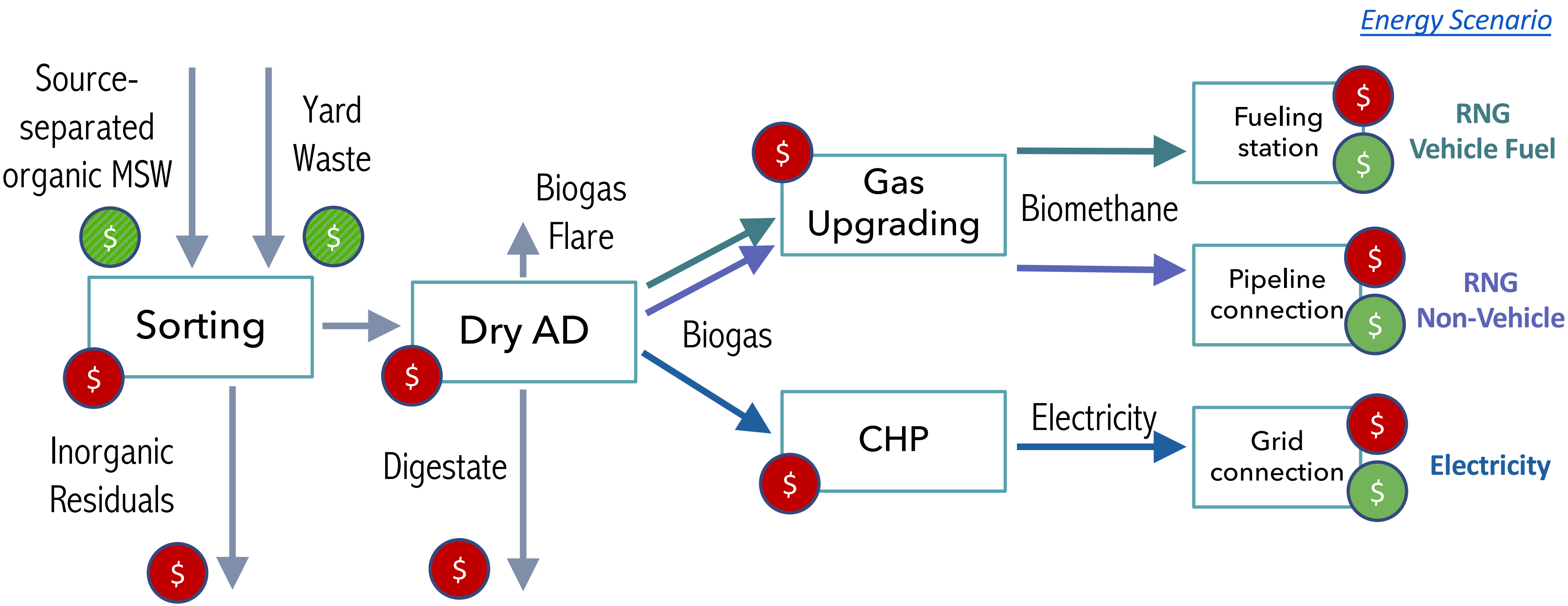
- What does an optimal organics recovery sector look like in California?
- How do costs and emissions goals align or conflict?
- Where are the main uncertainties and opportunities in creating this system for the future?

Dry AD Facility Operational Modeling



- Numerous parameters define mass and energy flows
- Low, Base, and High Operational scenarios to capture performance uncertainty

Key Costs Modeled



$ Costs: Capital, O&M, Labor, Outgoing Tipping Fees, Trucking

$ Revenues: Incoming Tipping Fees, Energy Sales, Environmental Credits

Calculations and cost metrics

Calculations

- 25-year facility lifetime
- Annual cash flows
  - Inflation, loan payment period and interest rate, etc.
- Discounted and summed to Net Present Value

Metrics

- Results are shown in **$/tonne**
  - NPV of each cost normalized by the total waste intake over the life of the facility (discounted)
- Net costs and revenues (excl. tipping fees) is **Levelized Cost of Disposal (LCOD)**
  - Analogous to the break-even tipping fee given the assumed discount rate

(Reminder, 1 metric tonne is ~ 1.1 U.S. tons)

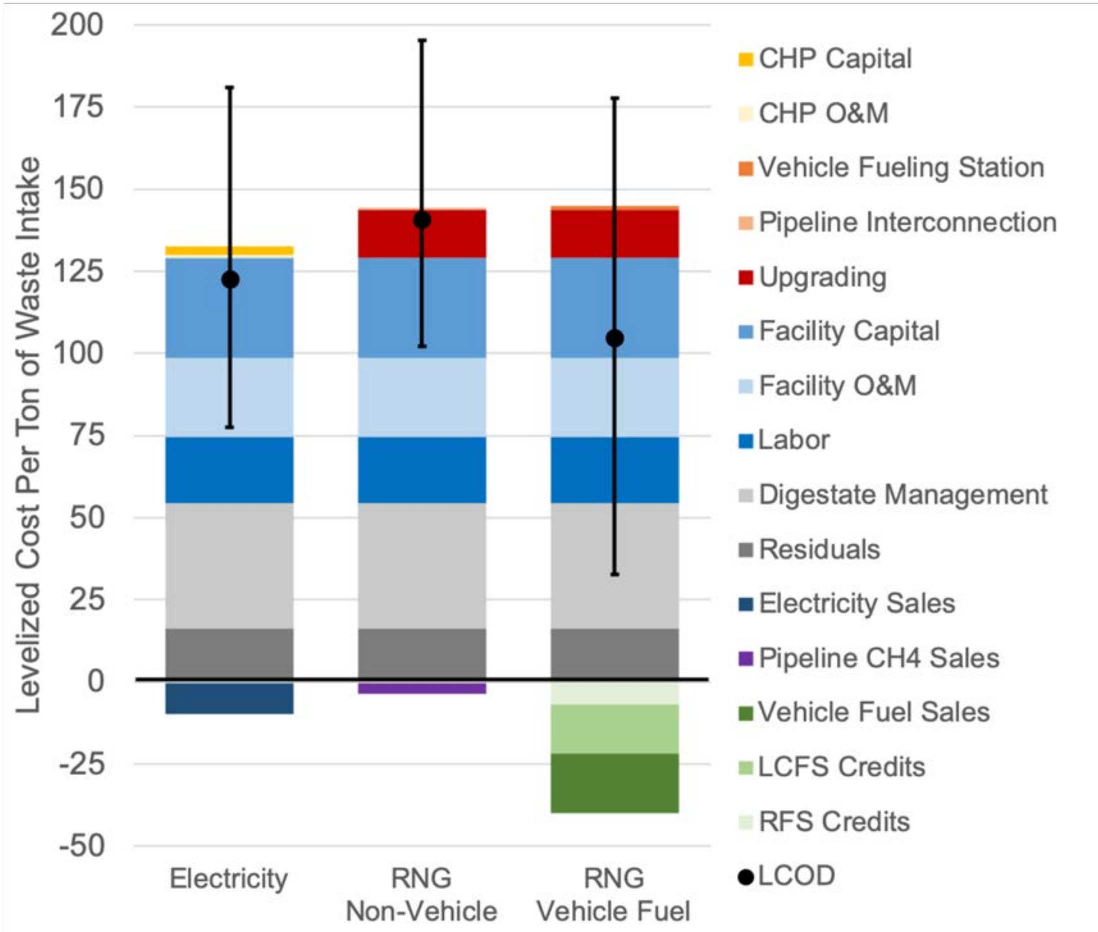
Scenarios

- Three energy use pathways
- Facilities sized 25-300 thousand tonnes per year
- Low, base, high performance
- Low, base, high costs

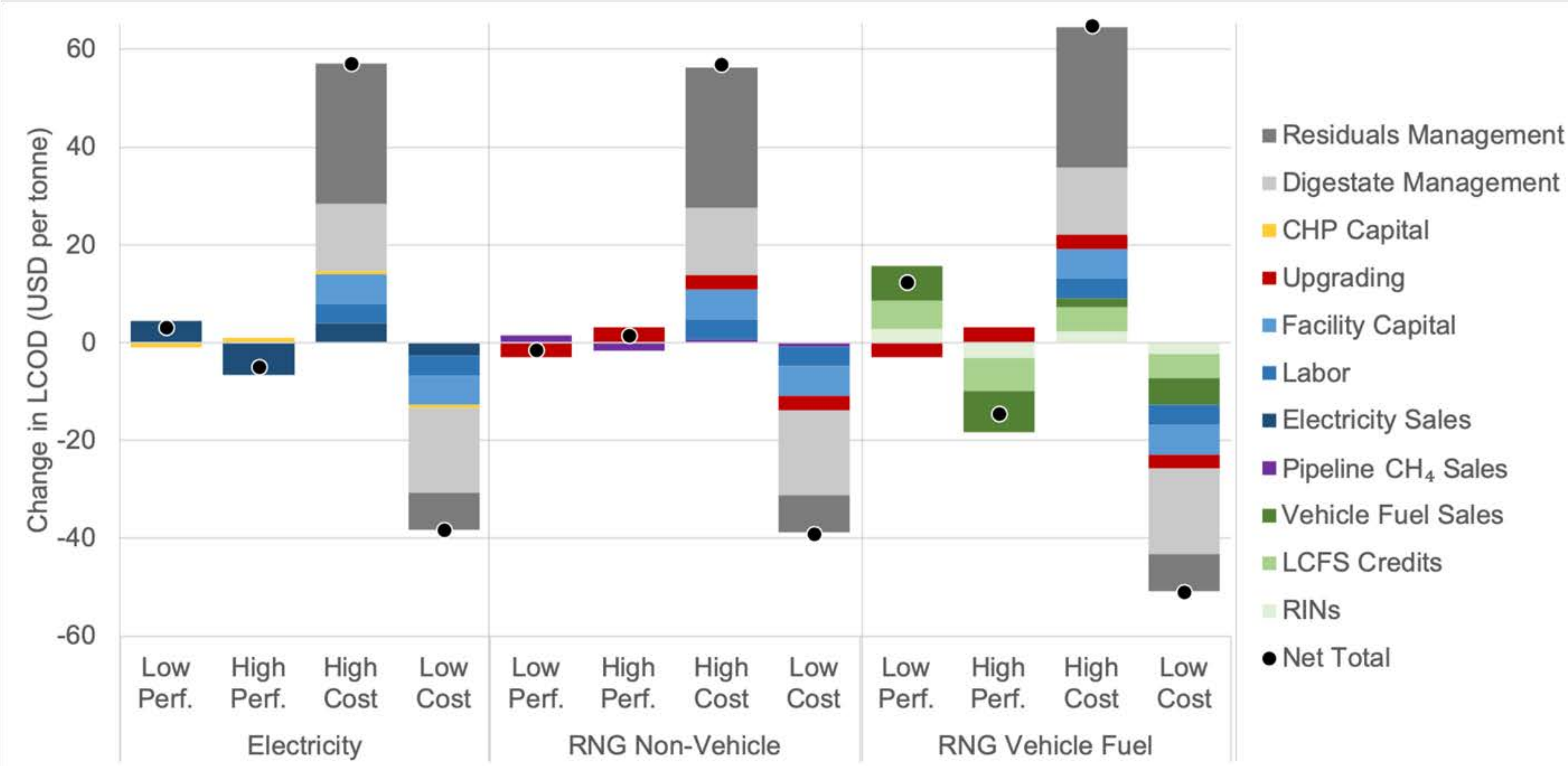
Results - 100,000 tpy facility

- Electricity $75-180
- RNG Non-V $100-195
- RNG Vehicle $33-177

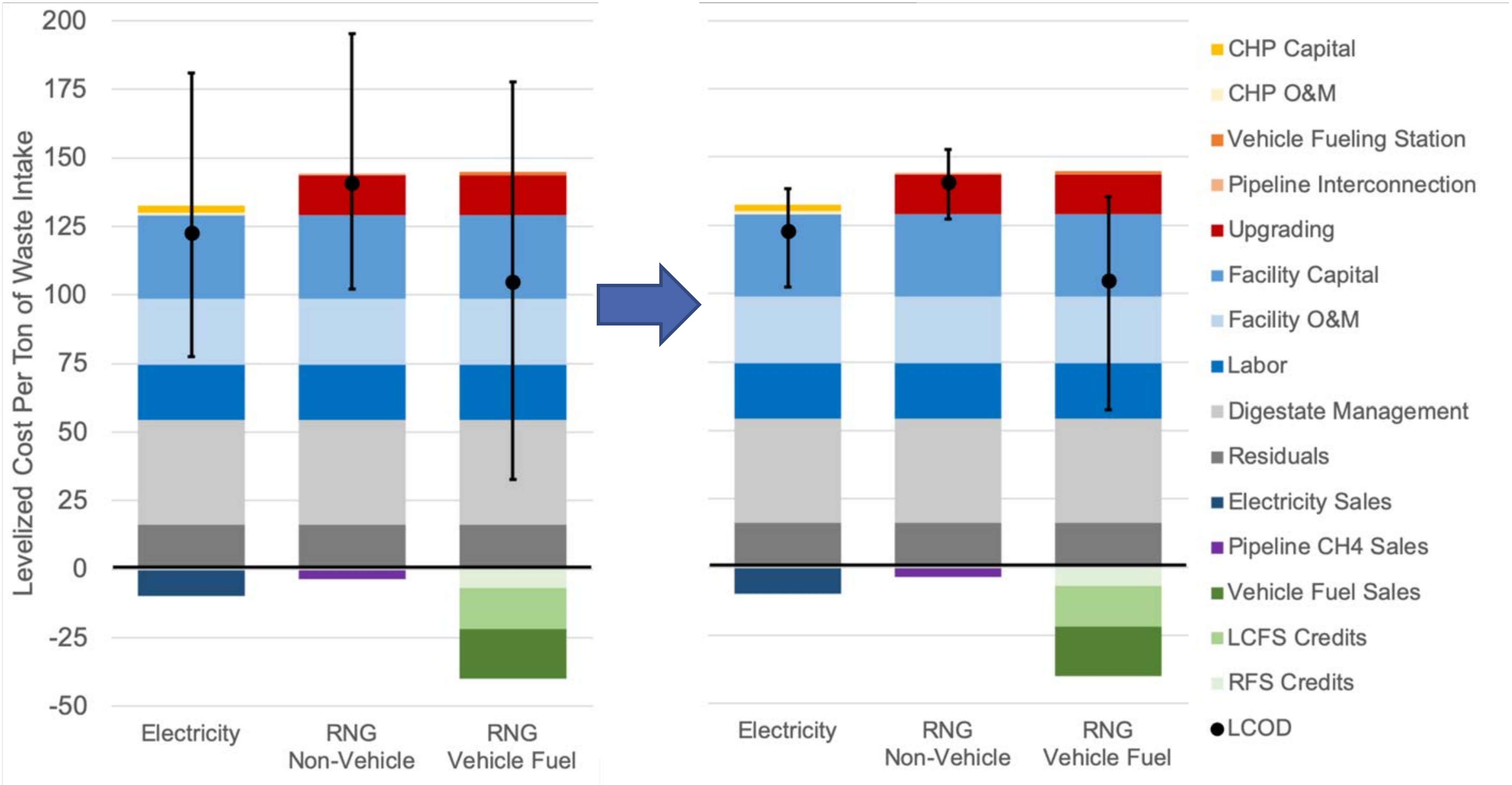
- Wholesale gas prices not enough to offset upgrading costs alone
- Fuel credits are significant, but introduce additional uncertainty



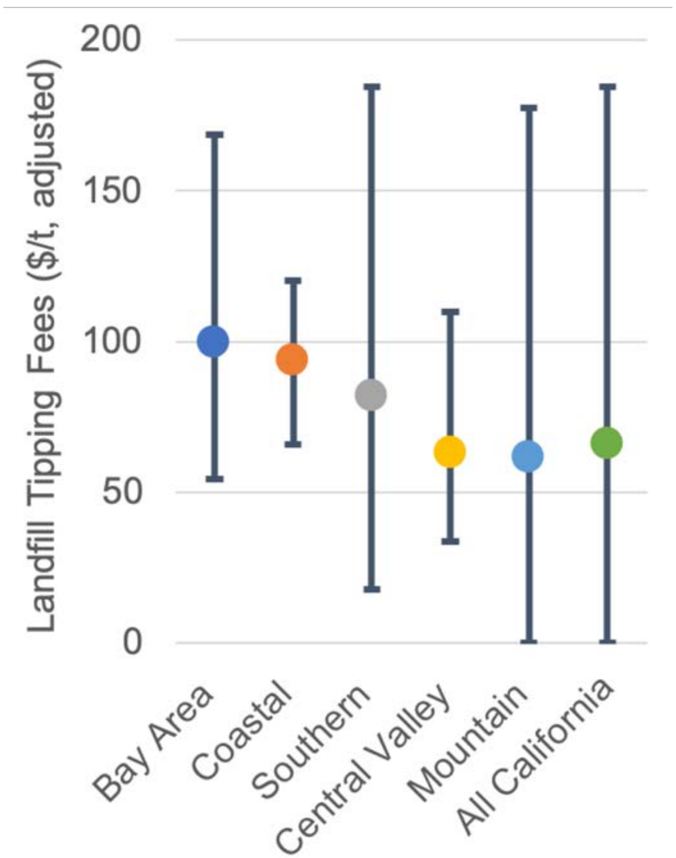
Results – Majority of uncertainty is in materials disposal

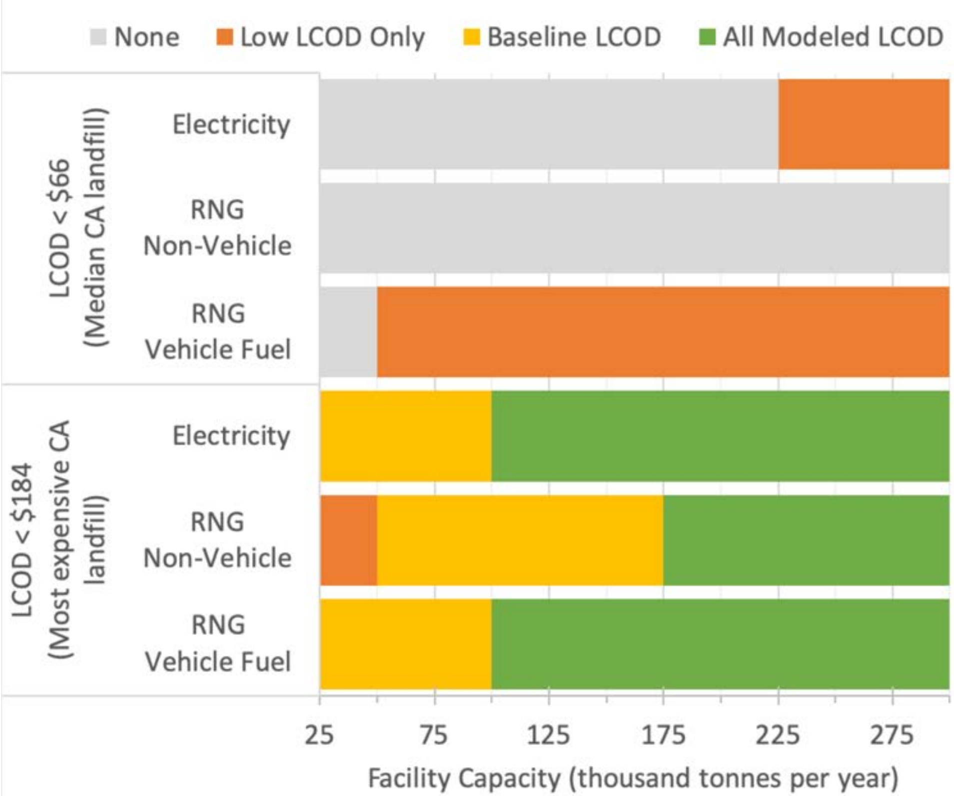


The importance of materials contracts



Comparison to (Adjusted) Landfill Tipping Fees





Dry AD Economic Modeling Conclusions

- Dry AD facilities are well-suited to help meet landfill diversion and renewable energy goals
- Economies of scale - largest facilities (300,000 tonnes per year) had LCOD 55-70% of the smallest facilities modeled (25,000 tonnes per year)
- Digestate & residual materials handling costs vary considerably and have the potential to be well over half of the total per-tonne costs incurred by a facility
- Regarding energy pathways:
  - RNG for use as a vehicle fuel is currently most lucrative
  - Electricity generation is viable option for facilities that cannot utilize biomethane
  - Gas upgrading costs outweigh wholesale natural gas revenues - incentives required to support the production of RNG for non-vehicle applications

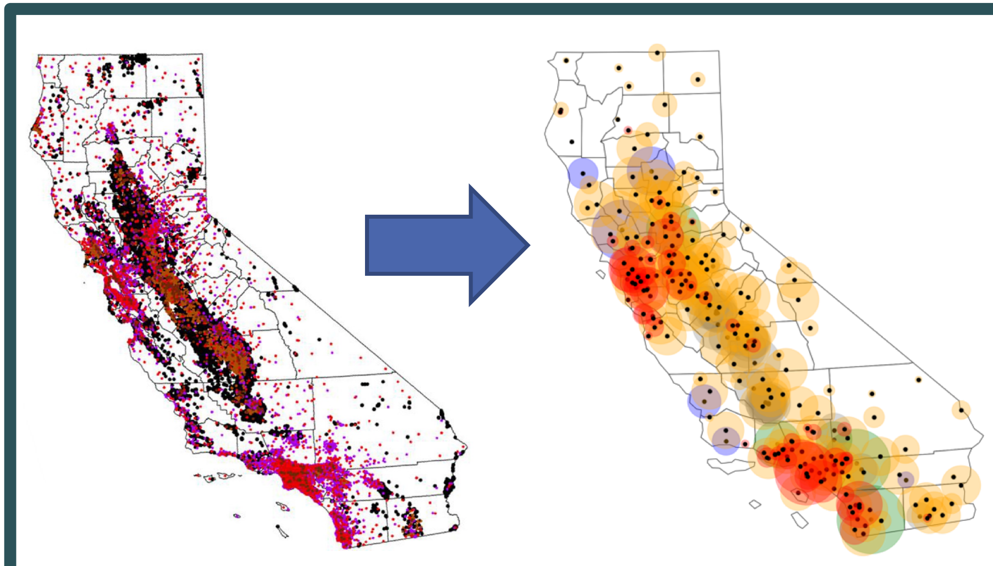
System-wide Economic and Emissions Optimization Overview

Life cycle emissions analysis
Sarah Nordahl, Jay Devkota, Corinne Scown, et al.

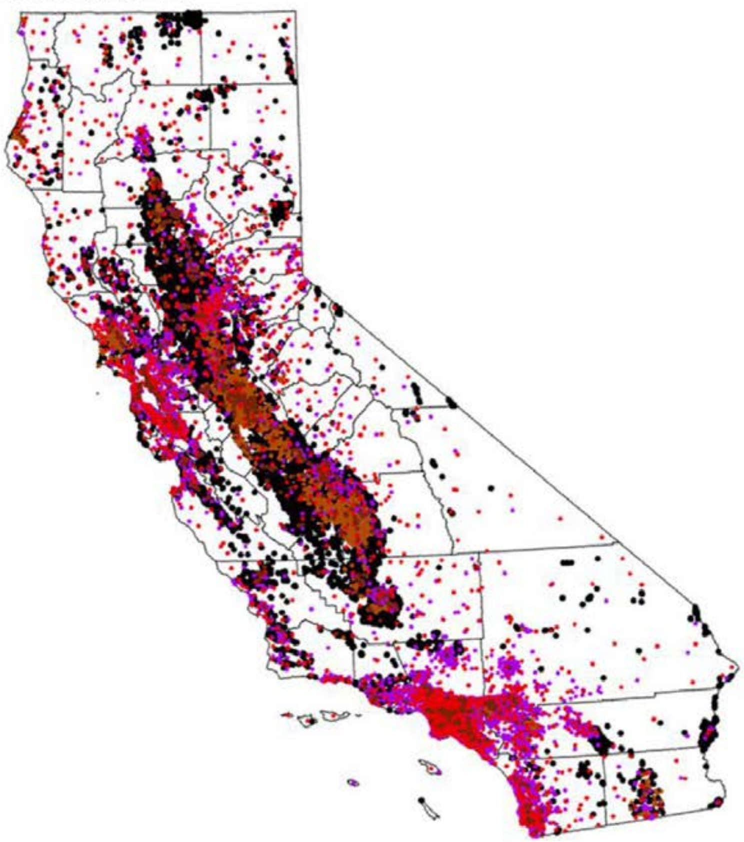
Facility operations and cost modeling

Geospatial biomass inventory
JBEI Biositing Tool
Hanna Breunig, Corinne Scown, et al.

Organic Recycling Facility Optimization (ORFO) Model



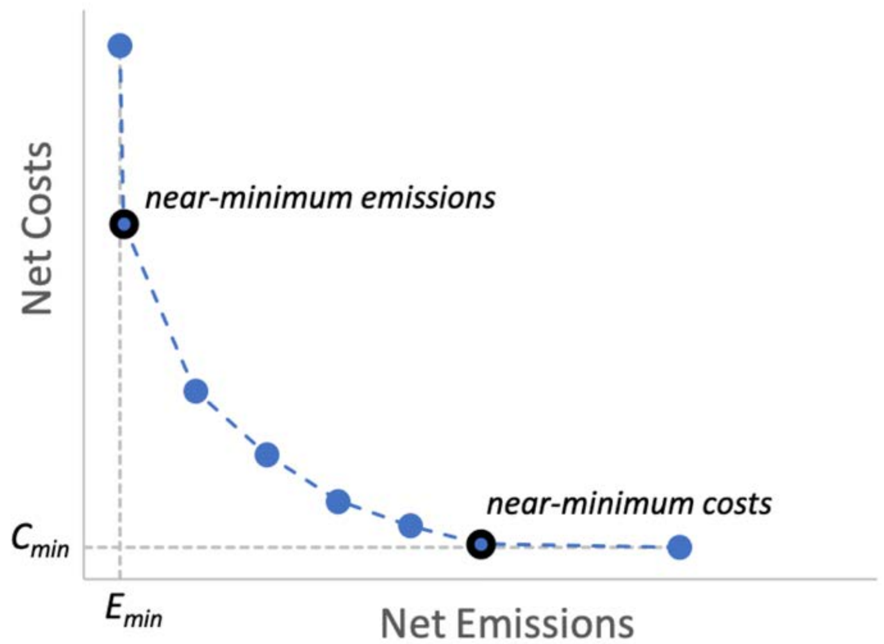
Scope of ORFO Model



- Over 60,000 waste feedstock points
- 125 types of waste, defined by:
  - baseline disposal pathway
  - acceptability at facilities
  - methane and/or syngas yield
- 4 facility types:
  - Dry AD
  - Wet AD
  - WWTP co-digestion
  - Gasification
- 2 energy products:
  - Electricity
  - Biomethane
- Potential sites:
  - Existing waste handling operations
  - Existing WWTP with excess digester capacity

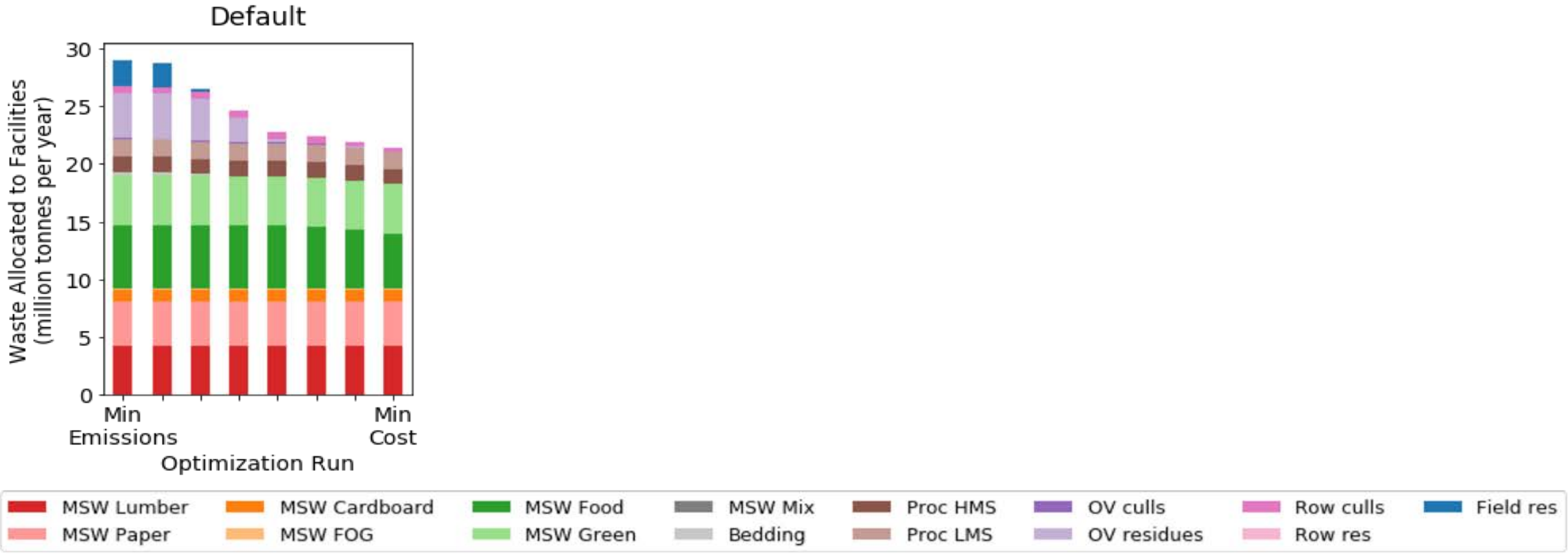
ORFO Formulation and Scenario Overview

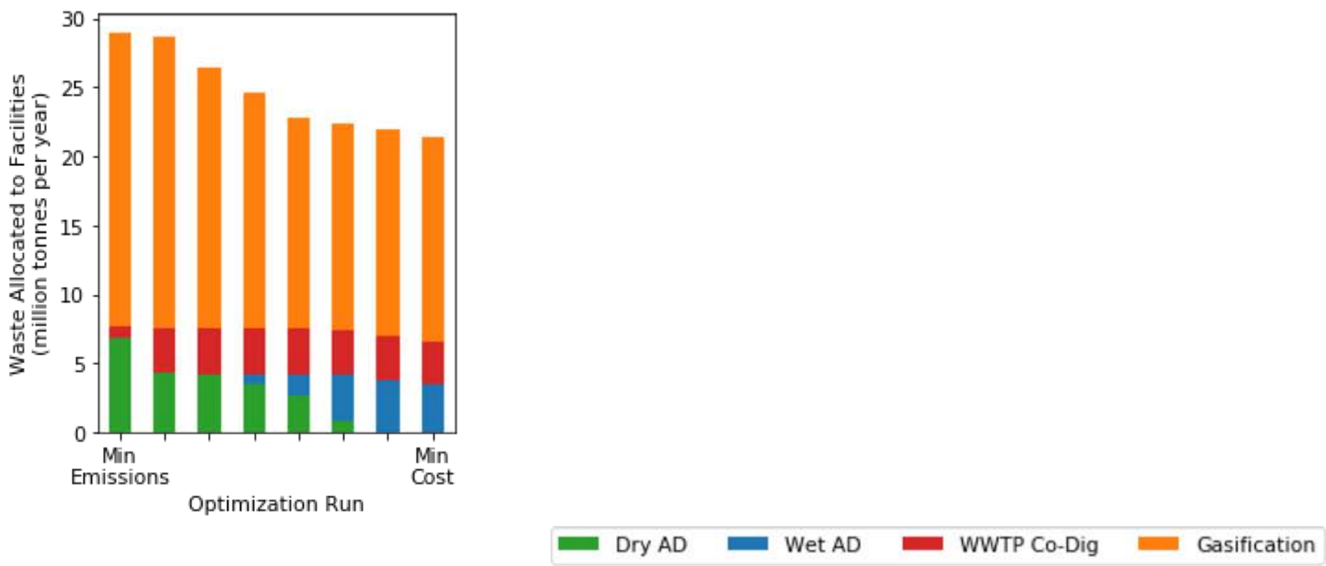
- Mixed-Integer Linear Program (MILP)
- Objective: minimize costs or emissions
  - Multi-criteria optimization
  - ε-constraint method
- Facility capital and operating costs
- Market value for energy products



- Costs & emissions relative to assumed baseline
  - Landfill: distance based on jurisdiction, cost using median landfill tip fee as a proxy
  - On-field decomposition (agricultural residues): baseline 0 transportation and 0 emissions

ORFO Results





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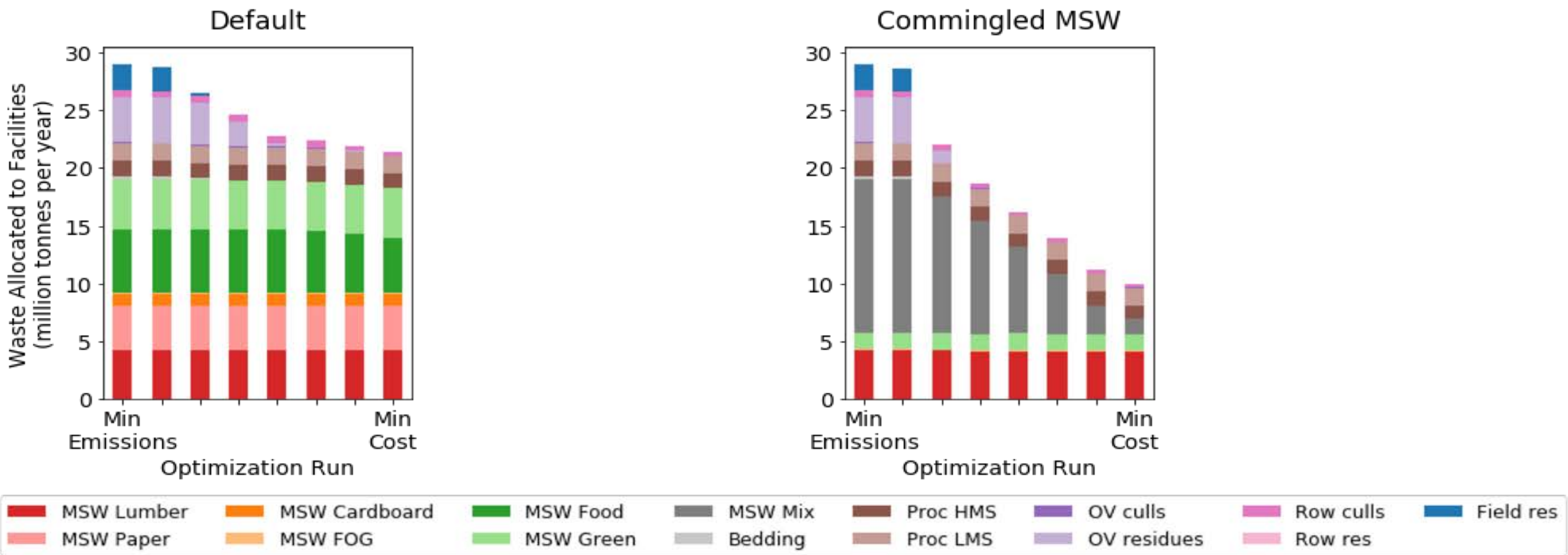

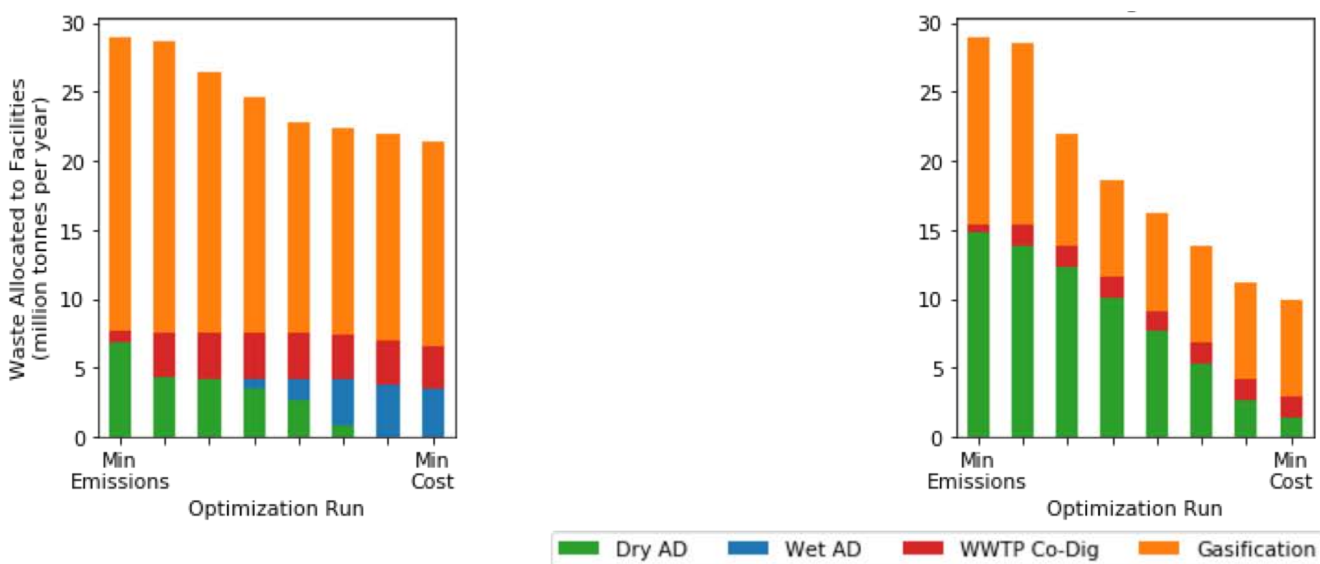

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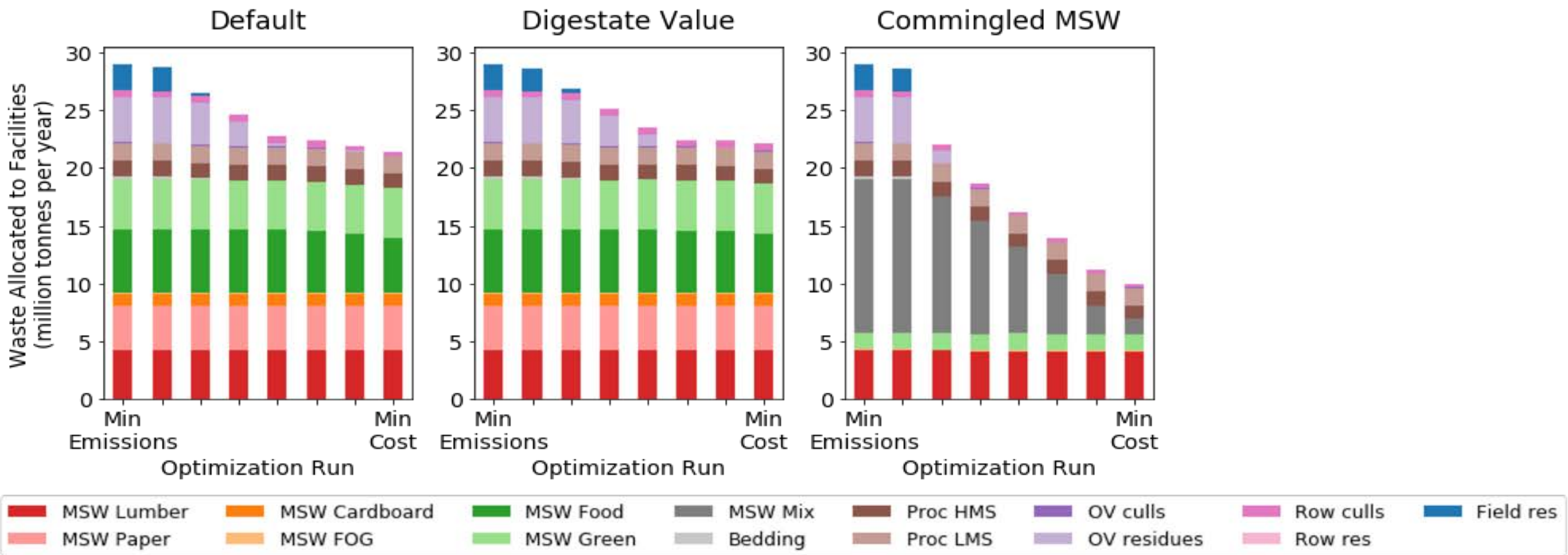

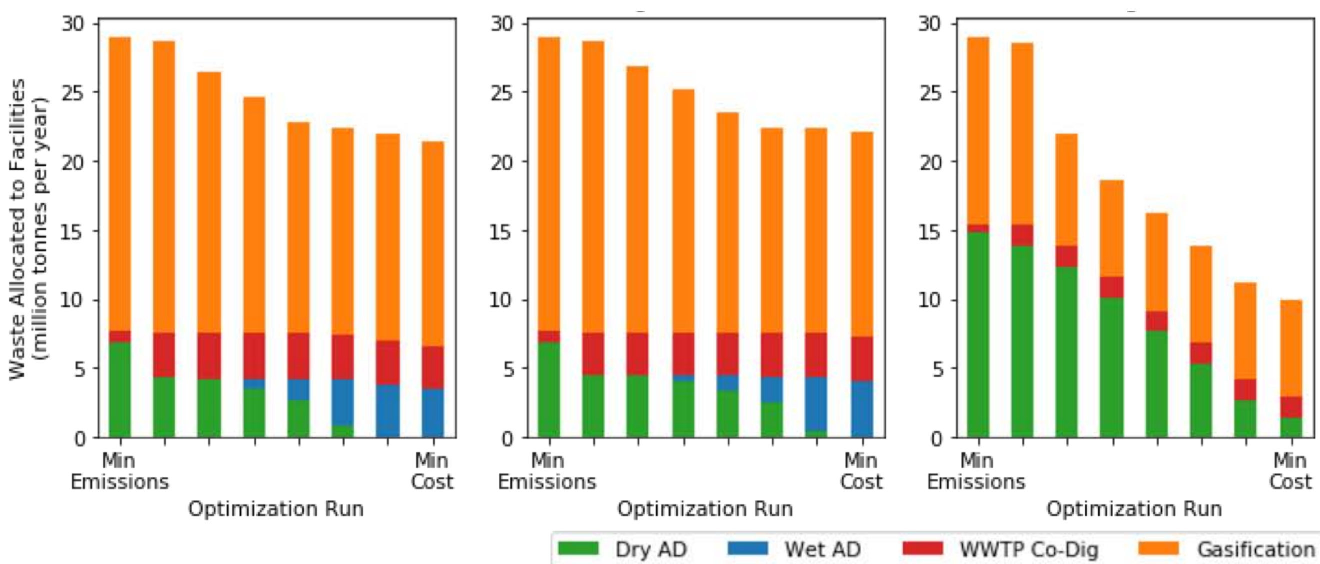

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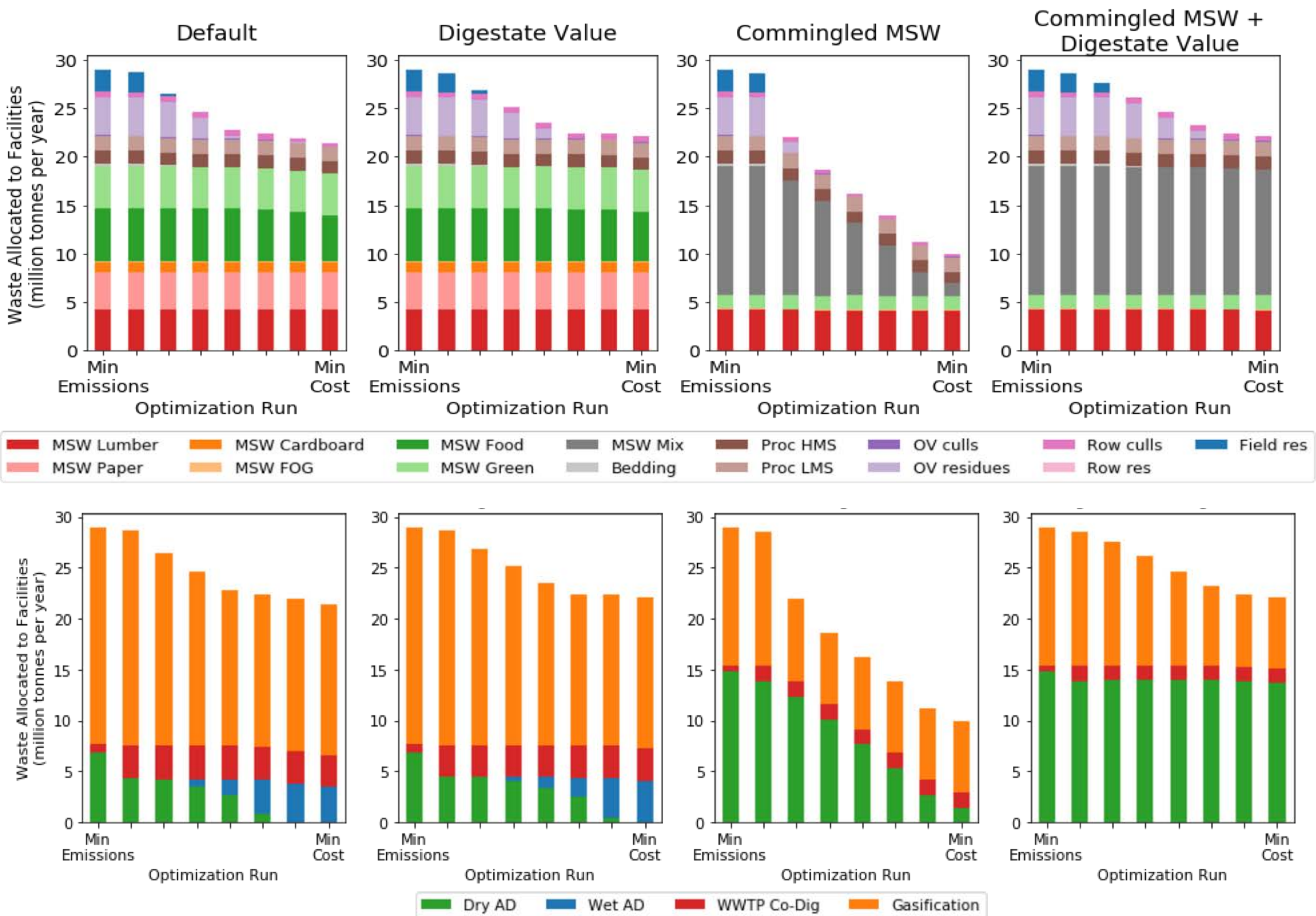
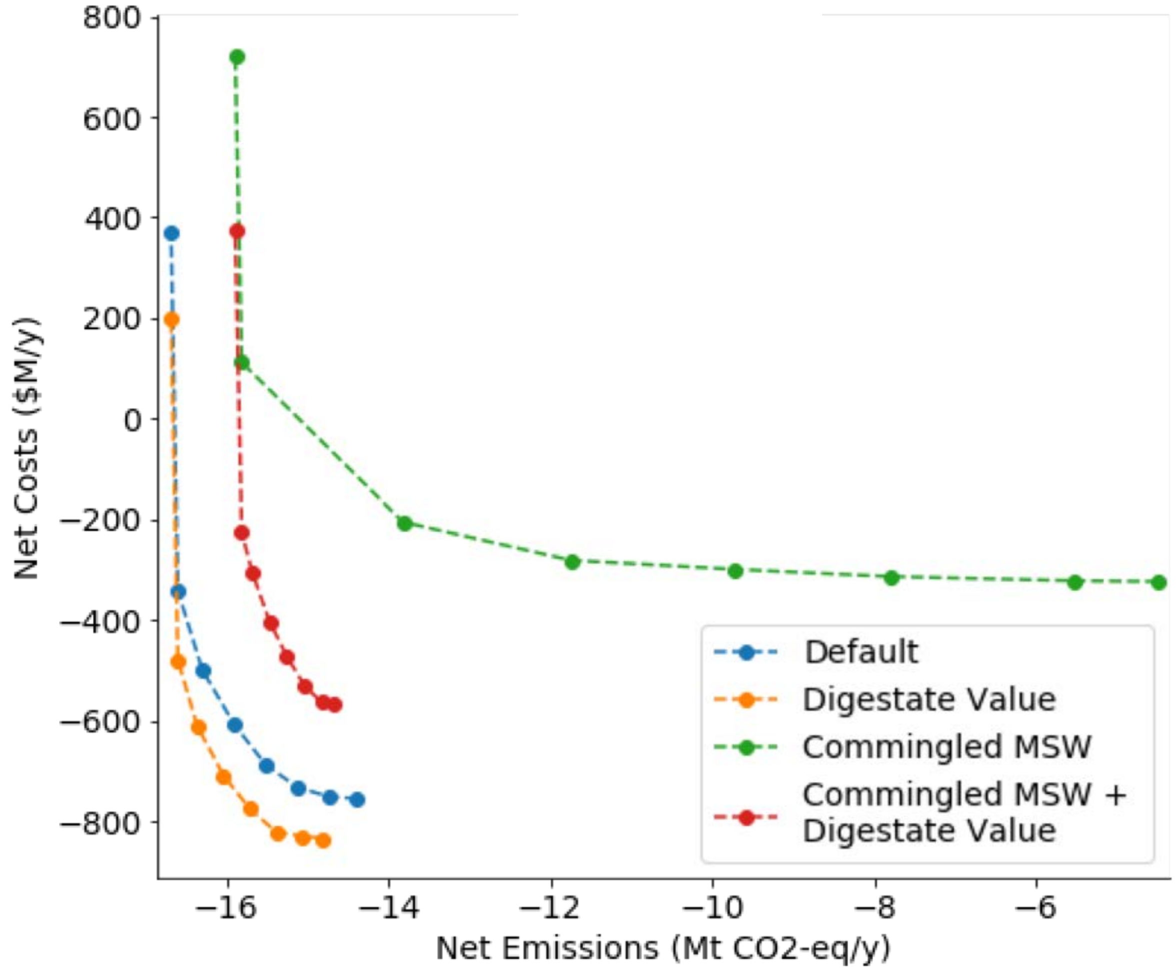


Statewide Net Costs and Emissions



Statewide Costs and Emissions Optimization Conclusions

- MSW landfill diversion will result in **significant costs & emissions savings**
- **Complete separation of MSW** greatly lowers system costs
  - $750 M annual savings possible, though $325 M savings still possible with complete commingling
- Creation of a **digestate byproduct market** creates:
  - $80-140 M annually in value in the default scenario
  - $100-340 M annually when waste is commingled
- Low-moisture wastes should be **gasified** as much as possible
  - facilities as small as 15,000 tpy have a role, even if minimizing costs is priority
- **Dry AD** facilities as small as 40,000 tpy can provide value in low-cost Commingled MSW scenarios, with facilities as small as 8,000 tpy built in near-minimum emissions runs (all scenarios)
- Existing **WWTF infrastructure** is valuable, but do not over-develop if we will not have the separate waste streams for it