Michigan Renewable Natural Gas Study
Stakeholder Meeting #3

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Agenda

- Characterize RNG Production Potential in Michigan
- RNG Production Costs, GHG Emissions, and GHG Cost-Effectiveness
- Comparison to Other Abatement Strategies
- Opportunities and Barriers to RNG Production in Michigan

Renewable natural gas potential in Michigan

Summary

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ICF characterized the potential for renewable natural gas as a greenhouse gas emission reduction strategy in the State of Michigan. Key questions addressed:

- How much renewable natural gas could be produced from in-state resources?
- How much does it cost to produce renewable natural gas?
- How does renewable natural gas compare to other potential abatement strategies?
- What are the opportunities and barriers that exist to renewable natural gas production in Michigan?

Public Act 87 of 2021 defines renewable natural gas as “a biogas that has been processed or upgraded to be interchangeable with conventional natural gas and to meet pipeline quality standards or transportation fuel grade requirements.”

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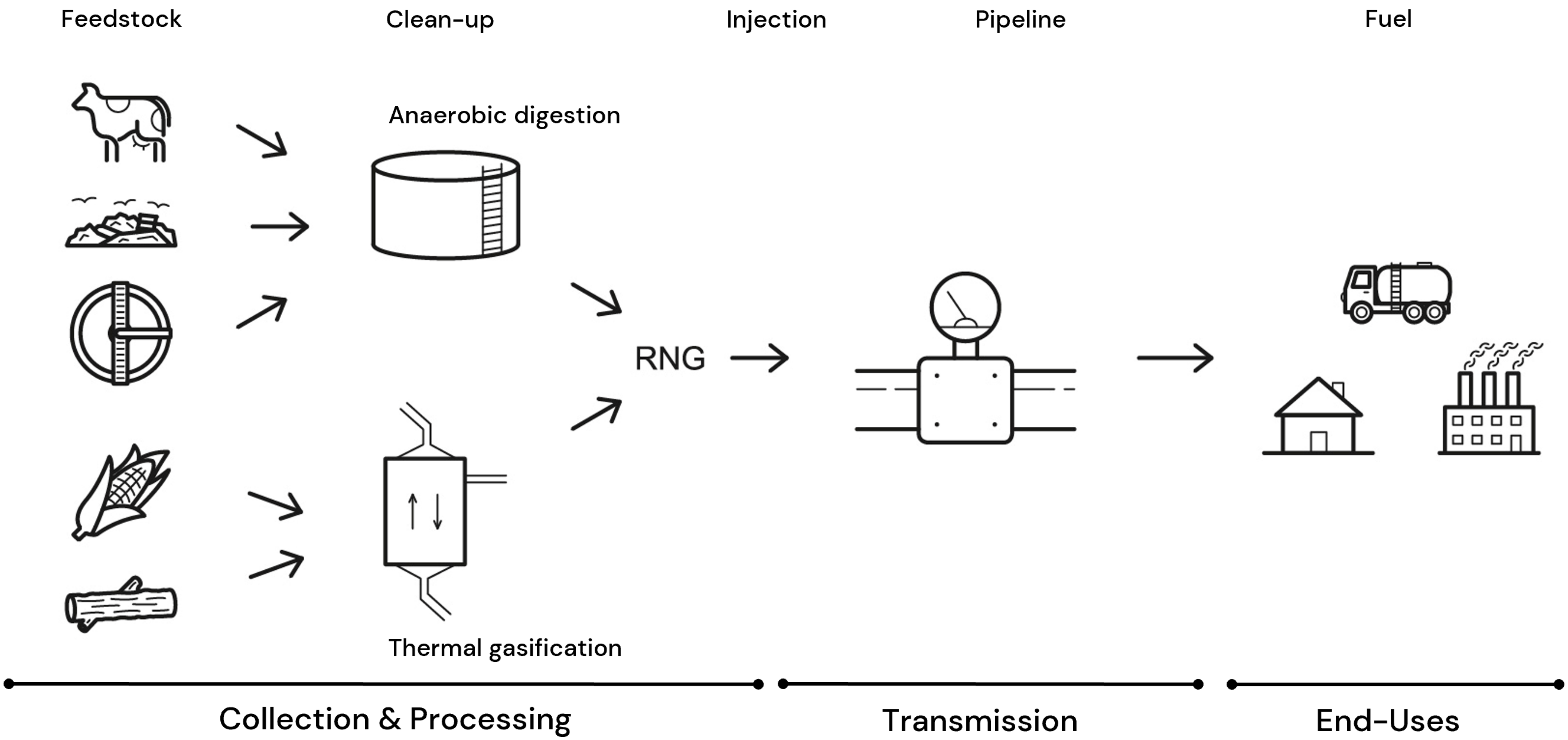
Overview of renewable natural gas production



Feedstocks for renewable natural gas production

	Feedstock for RNG	Description	Competing uses of feedstock
Anaerobic Digestion	Animal manure	Manure produced by livestock, including dairy cows, beef cattle, swine, sheep, goats, poultry, and horses.	RNG, biogas-to-electricity; fertilizers and compost materials; and manure being diverted for existing anaerobic digestion systems.
Anaerobic Digestion	Food waste	Commercial, industrial and institutional food waste, including from food processors, grocery stores, cafeterias, and restaurants.	Animal feed; compost; liquid fuel production.
Anaerobic Digestion	LFG	The anaerobic digestion of organic waste in landfills produces a mix of gases, including methane (40–60%).	Industrial process heat; existing LFG contracts for biogas-to-electricity.
Anaerobic Digestion	WRRF	Wastewater consists of waste liquids and solids from household, commercial, and industrial water use; in the processing of wastewater, a sludge is produced, which serves as the feedstock for RNG.	Industrial process heat; existing biogas-to-electricity production.
Thermal Gasification	Agricultural residue	The material left in the field, orchard, vineyard, or other agricultural setting after a crop has been harvested. Inclusive of unusable portion of crop, stalks, stems, leaves, branches, and seed pods.	Animal feed; livestock bedding (e.g., straw from grains); liquid biofuels (e.g., POET-DSM); carbon sequestration, and; benefits to agricultural land such as reduced soil erosion, soil nutrient recycling, and maintenance of soil organic matter and fertility.
Thermal Gasification	Energy crops	Inclusive of perennial grasses, trees, and annual crops that can be grown to supply large volumes of uniform and consistent feedstocks for energy production.	Electricity production and liquid fuel production.
Thermal Gasification	Forestry and forest product residue	Biomass generated from logging, forest and fire management activities, and milling. Inclusive of logging residues, forest thinnings, and mill residues. Also materials from public forestlands, but not specially designated forests (e.g., roadless areas, national parks, wilderness areas).	Fuel for boilers, kilns, dryers; pulp-and-paper; pellet and briquette manufacturing; landscaping (e.g., bark chips); fertilizer for forest land; particleboard manufacturing, and; animal bedding (e.g., shavings and sawdust).
Thermal Gasification	Municipal solid waste (MSW)	Refers to the non-biogenic fraction of waste that would be landfilled after diversion of other waste products (e.g., food waste or other organics), including construction and demolition debris, plastics, etc.	Electricity production and liquid fuel production.

Renewable natural gas production potential

Three distinct resource potential scenarios with clearly defined characteristics:

1) **Theoretical: a higher-level analysis of all the potential methods of generating RNG by feedstock sources and develop a list of sources.**

2) **Feasible: will include any sources of RNG that are applicable to MI while eliminating sources from the theoretical list due to relative cost effectiveness.**

3) **Achievable: a smaller subset list of sources based on technical, economic, and environmental factors.**

Illustrative calculation of renewable natural gas production potential

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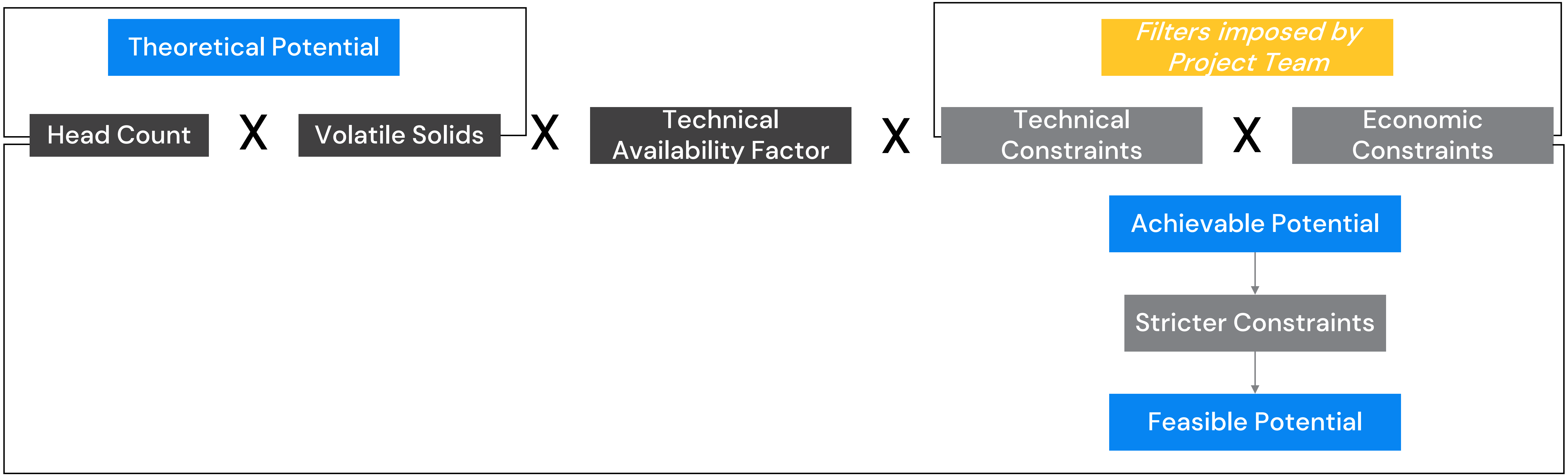
Approach for Animal Manure to RNG Production Potential



Illustrative calculation of renewable natural gas production potential

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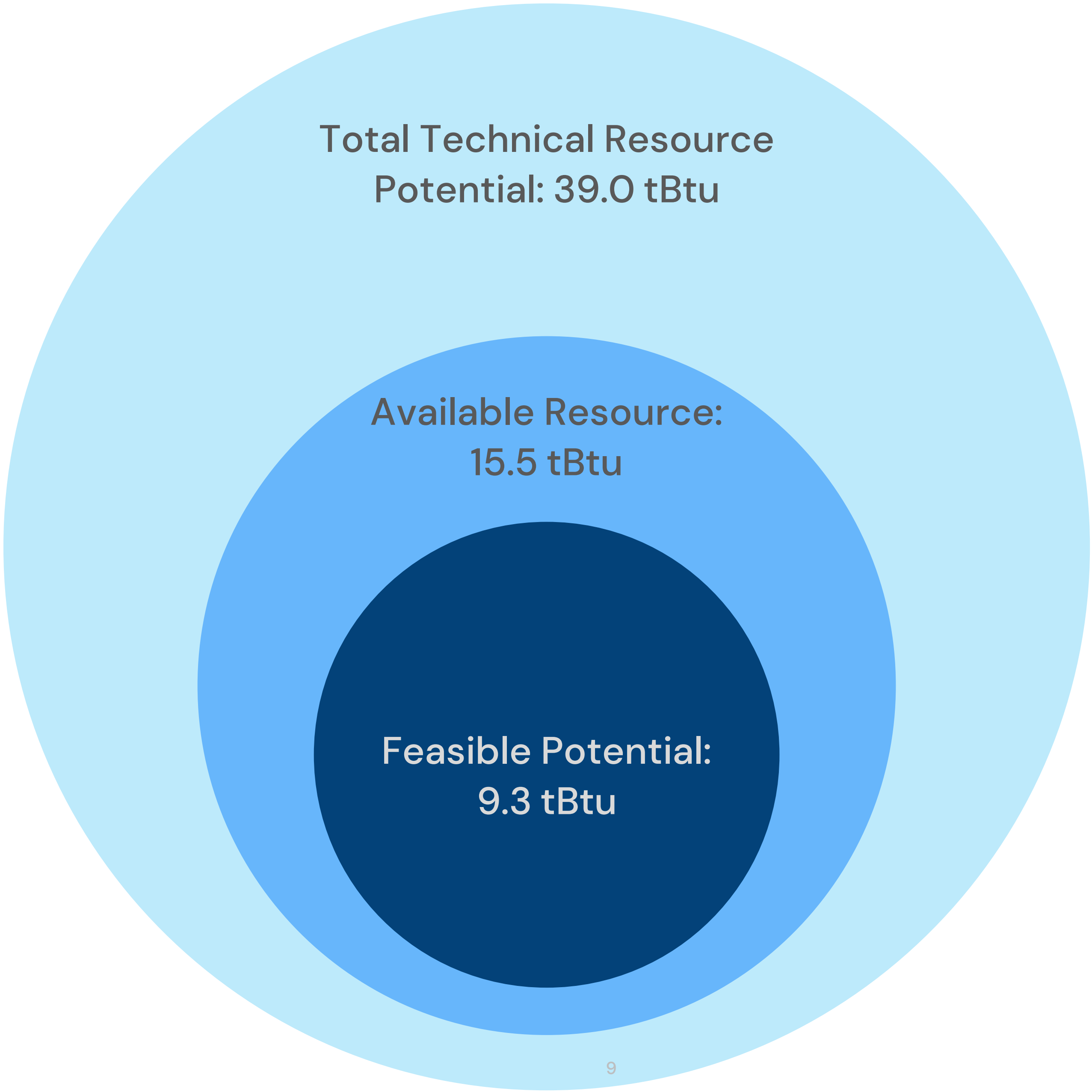
- *Theoretical Potential* reflects all animal manure produced from all animal populations:
  - Biomass estimate derived from daily manure production rates for beef cows, dairy cows, broiler chickens, layer chickens, turkeys and swine.
  - Total reflects collection of all manure for RNG production.
- Technical Availability Factors (TAF) are then applied to estimate an interim Available Resource:
  - From a practical perspective, not all manure can be collected and utilized for RNG production.
  - TAF varies by animal type, e.g. dairy and chickens have TAF of 50%; beef and swine 20%.
- Resource scenarios, such as the *Achievable Potential* and, *Feasible Potential* applies additional constraint on utilization
  - *Achievable Potential* captures 30% of Available Resource.
  - *Feasible Potential* captured 60% of Available Resource.

Animal Manure Feedstock



Feedstock utilization for renewable natural gas production

Feedstock for RNG		Achievable	Feasible
Anaerobic Digestion	Animal manure	30% of technically available	60% of technically available
	Food waste	40% @ $70/ton	60% @ $70/ton
	LFG	Collection in place: 50% Candidate landfills: 50%	Collection in place: 85% Candidate landfills: 85%
	WRRF	50% of facilities w/ >7 MGD	75% of facilities w/ >3.5MGD
Thermal Gasification	Agricultural residue	30% @ $40/ton	50% @ $60/ton
	Energy crops	30% @ $40/ton	40% @ $60/ton
	Forestry & forest product residue	30% @ $40/ton	50% @ $60/ton
	MSW	30% @ $40/ton	50% @ $60/ton
Est Annual RNG Produced		57 tBtu/y	148 tBtu/y
% of Total Feedstock		18%	47%

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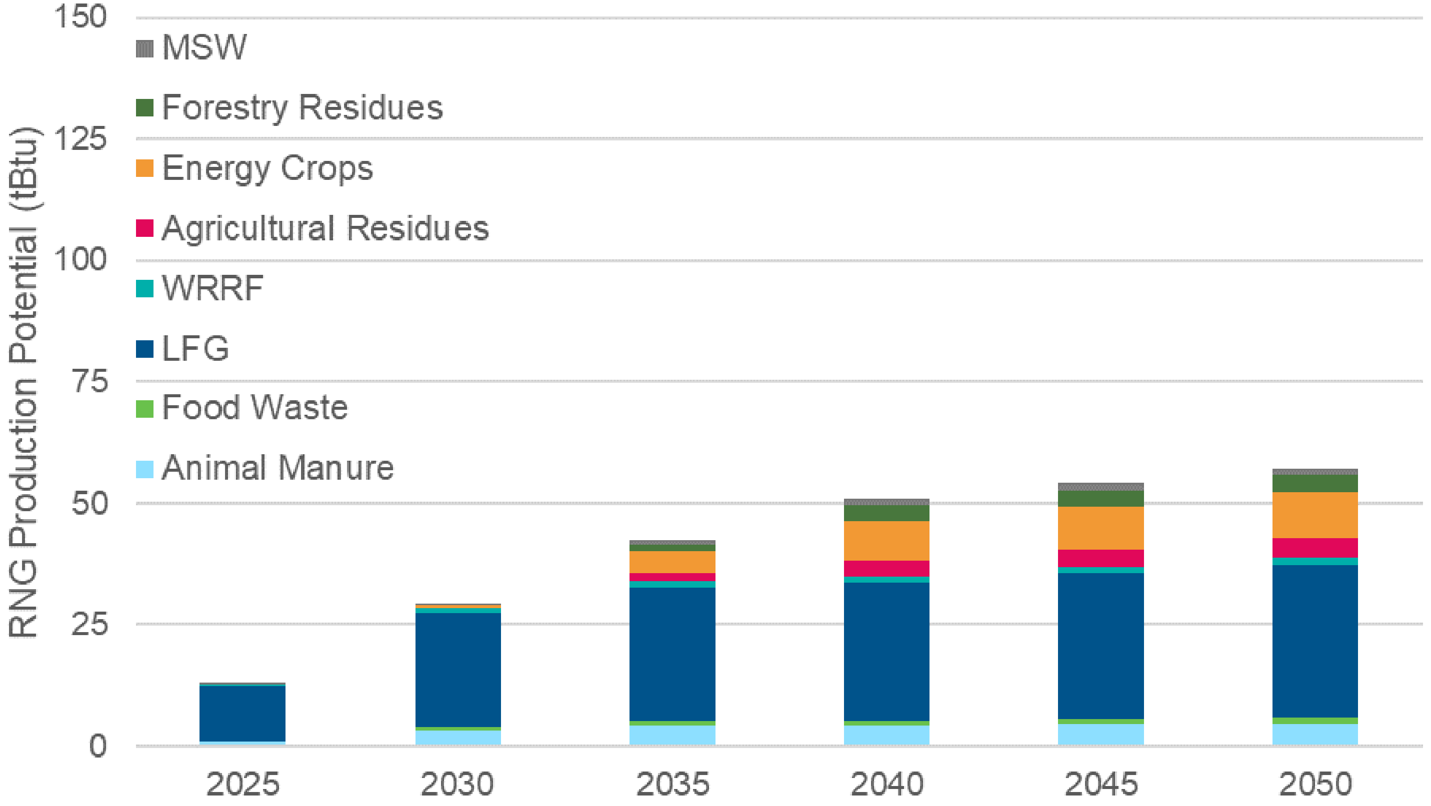
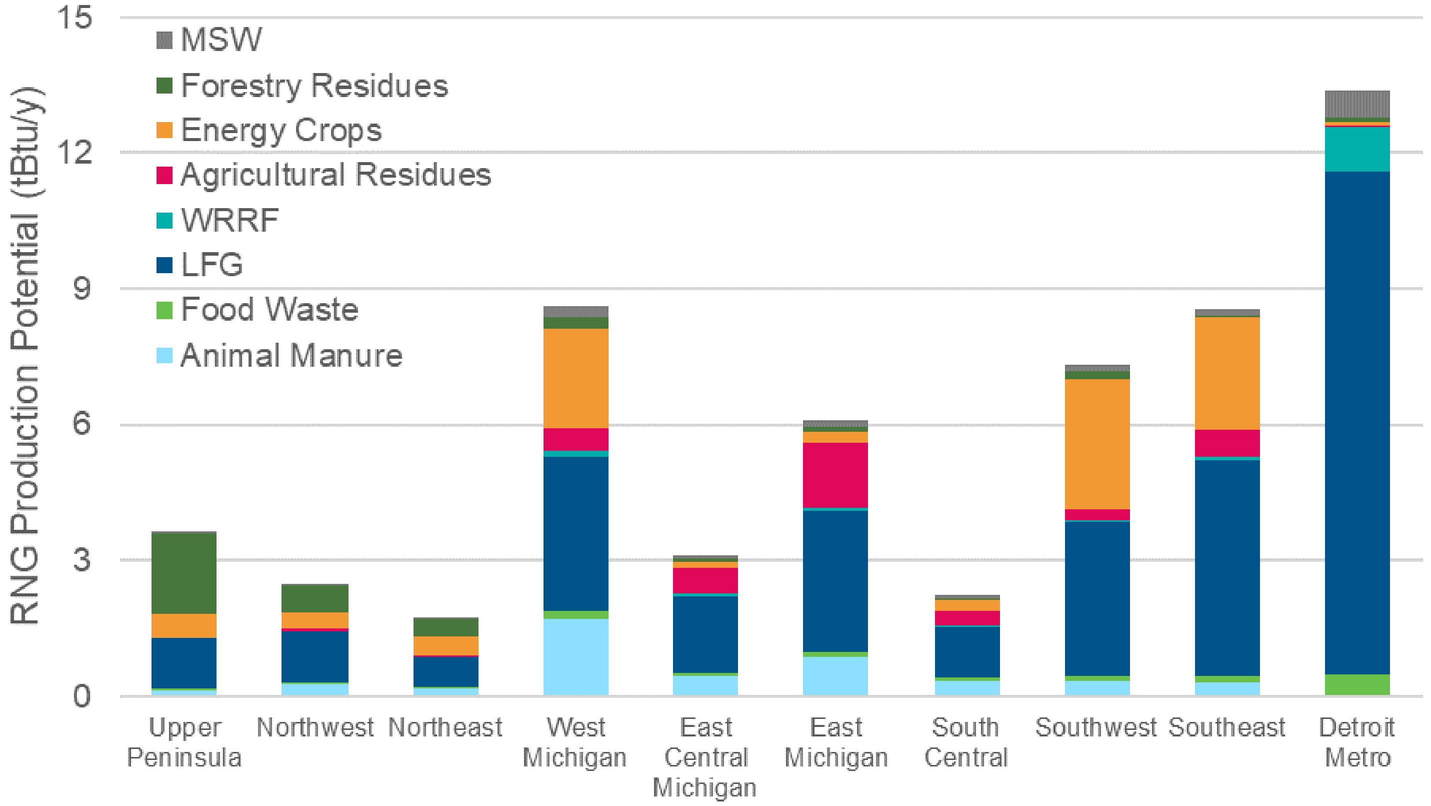
The $/ton price shown for feedstocks refers to the dollar per dry bone ton of feedstock available for use. This should not be confused with $/ton pricing used later in the report related to GHG emissions.

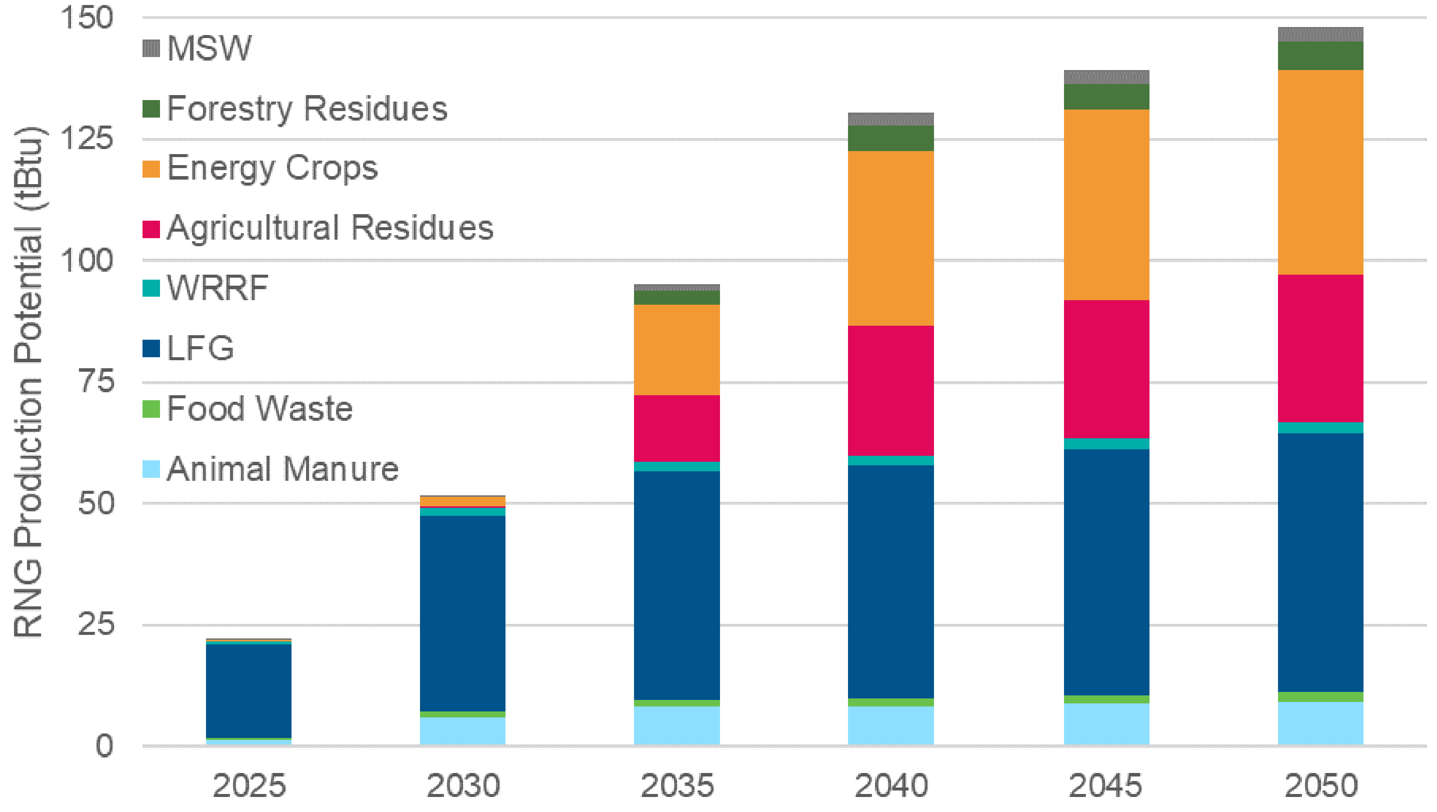
Renewable natural gas production potential: Achievable Scenario

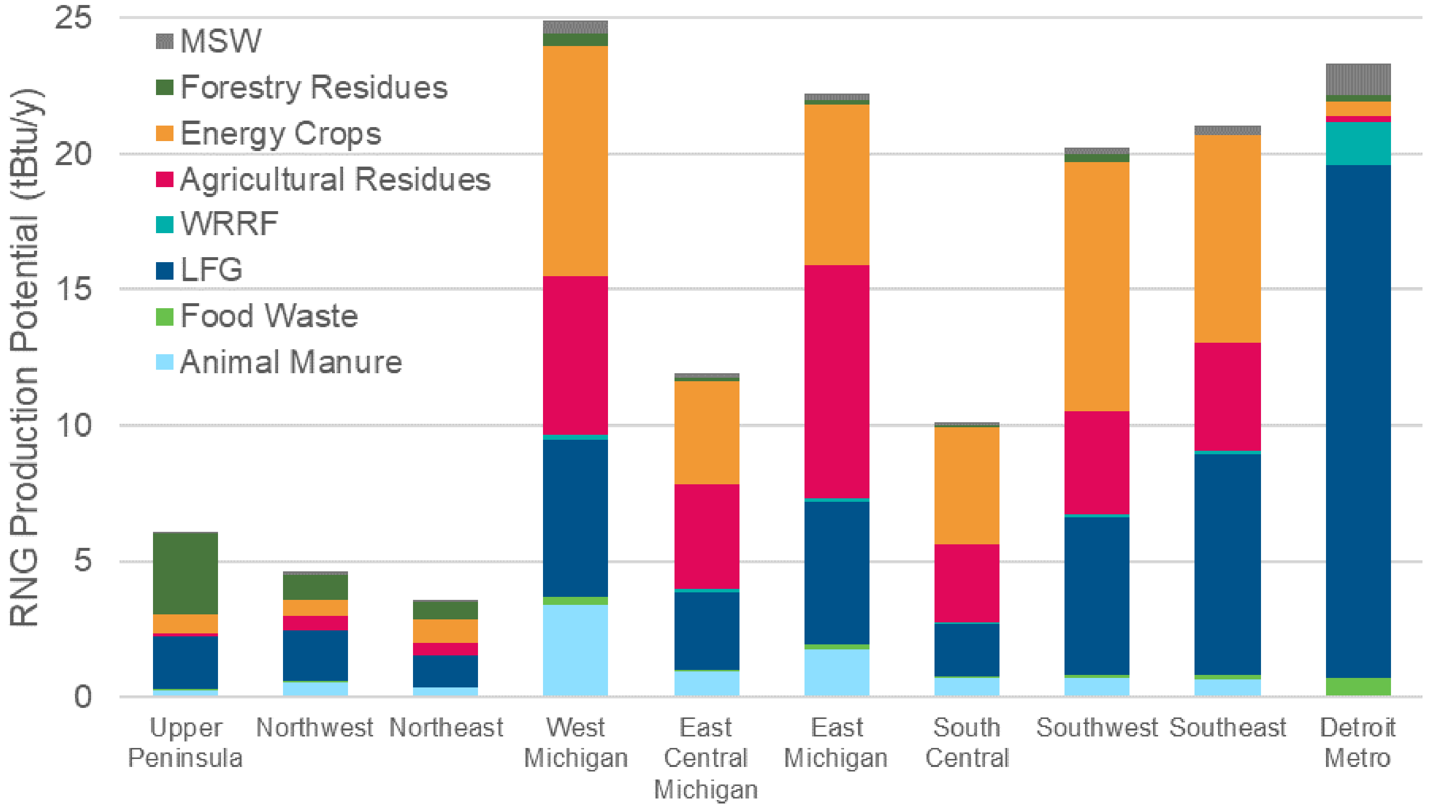




The anaerobic digestion of waste streams (e.g., landfills) is the most significant opportunity in the Achievable Scenario. The size of the opportunity by region correlates well with population centers.

Renewable natural gas production potential: Feasible Scenario





The anaerobic digestion of waste streams (e.g., landfills) helps near-term RNG production potential to 2030 in the Feasible Scenario before other biomass waste streams can be utilized (via thermal gasification). The size of the opportunity by region correlates well with population centers and biomass availability.

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Renewable natural gas production costs

Renewable natural gas production cost: Key inputs

Capital Costs

Facility Sizing
- Differentiate by feedstock and technology type: anaerobic digestion and thermal gasification.
- Prioritize larger facilities to the extent feasible

Gas Conditioning & Upgrade
- Vary by feedstock and technology

Compression
- Capital costs for compressing the conditioned/upgraded gas for pipeline injection

+

O&M Costs

Operational Costs
- Operational Costs for each equipment type including utility charges for estimated electricity and natural gas consumption.

Feedstock
- Feedstock costs (for thermal gasification), ranging from $30 to $100 per dry ton.
- Can be revenue rather than cost e.g., via tipping fees

Delivery
- Financing, constructing, and maintaining a pipeline to deliver RNG: $1 to $5/MMBtu.

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Levelized Cost of Gas $/Mmbtu

Calculated based on the initial capital costs in Year 1, annual operational costs discounted, and RNG production discounted accordingly over a 20-year project lifetime.

Renewable natural gas product costs: Levelized cost of energy

Costs presented as Levelized Cost of Energy (LCOE)

- LCOE is a measure of the average net present cost of RNG production for a facility over its anticipated lifetime. The LCOE enables us to compare across RNG feedstocks and other energy types on a consistent per unit energy basis. The LCOE can also be considered the average revenue per unit of RNG (or energy) produced that would be required to recover the costs of constructing and operating the facility during an assumed lifetime.

Feedstock Costs

O&M Costs

Capital Costs

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Energy Produced

Discount rate

- ICF notes that cost estimates are not intended to replicate a developer's estimate when deploying a project. For instance, ICF recognizes that the cost category "gas conditioning and upgrading" actually represents an array of decisions that a project developer would have to make with respect to CO_2 removal, H_2S removal, siloxane removal, N_2/O_2 rejection or removal, deployment of a thermal oxidizer, among other elements.

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Renewable natural gas production costs: Summary by Feedstock

- Supply curve is built up on a facility-by-facility basis where possible
- Account for cost reductions to the extent feasible
- Characterize resources by production technology and feedstock

	Feedstock	Cost Range ($/MMBtu)
Anaerobic Digestion	Animal Manure	$14.53 – $49.17
	Food Waste	$18.35 – $29.39
	Landfill Gas	$9.92 – $26.85
	Water Resource Recovery Facilities	$10.90 – $70.86
Thermal Gasification	Agricultural Residues	$19.07 – $43.13
	Energy Crops	$19.07 – $43.13
	Forestry and Forest Residues	$19.07 – $43.13
	Municipal Solid Waste	$19.07 – $43.13

Renewable natural gas production costs: Combined supply-cost curve

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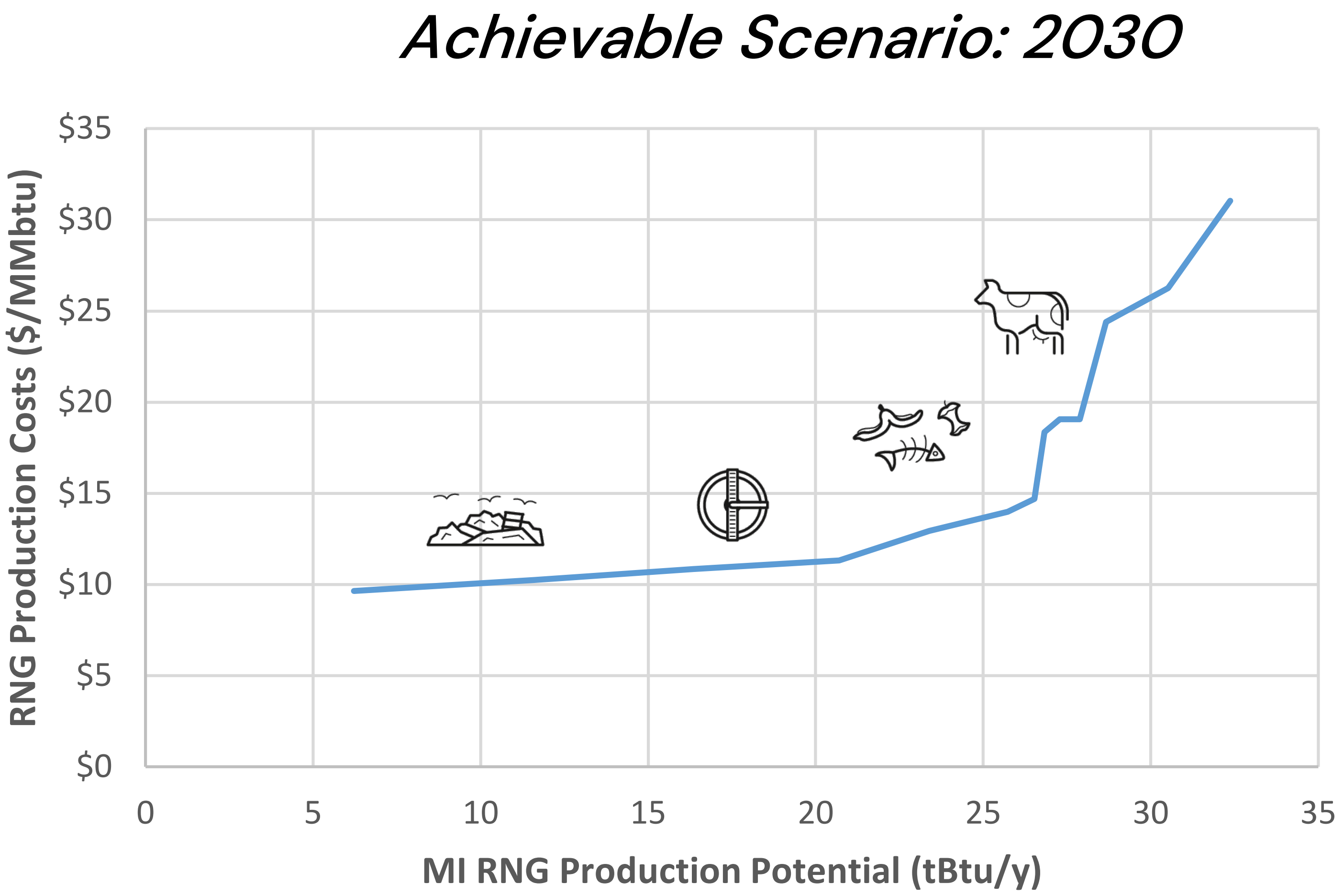

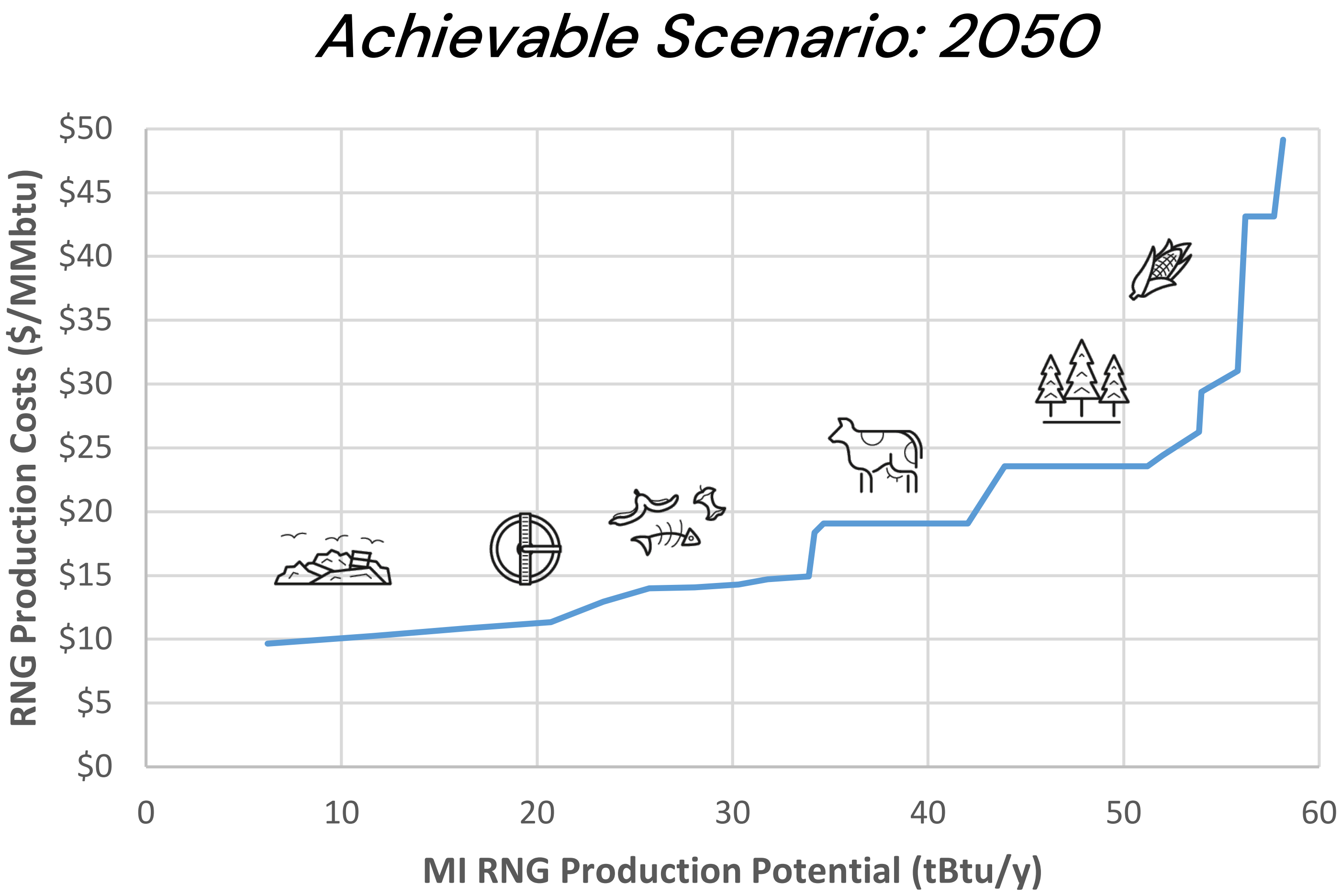

GHG emissions of renewable natural gas

GHG emission accounting is a common practice that is used to evaluate the respective GHG impacts of various energy sources or fuels, and to enable comparison between them. GHG emission accounting is used in practice by regulators and private actors for a variety of reasons, including to develop GHG emission inventories, as part of broader environmental reports, and to track carbon as an environmental commodity in carbon markets.

GHG emission accounting is applied in practice by multiplying a GHG emissions factor and the associated activity data for the fuel of interest. In other words, the total GHG emissions are calculated as a product of the emissions factor and the amount of energy consumed—the equation below highlights this for the case of natural gas, with the GHG emissions factor in units of kilograms of carbon dioxide equivalents per unit energy of natural gas, in units of million British thermal units ($kgCO_{2e}$/mmBtu) and the amount of natural gas used reported in units of mmBtu.

$$GHG\ Emissions = GHG\ Emissions\ Factor\ {}^{Lifecycle}_{Combustion} \left[\frac{kgCO2e}{mmBtu}\right] \times\ Activity\ [mmBtu]$$

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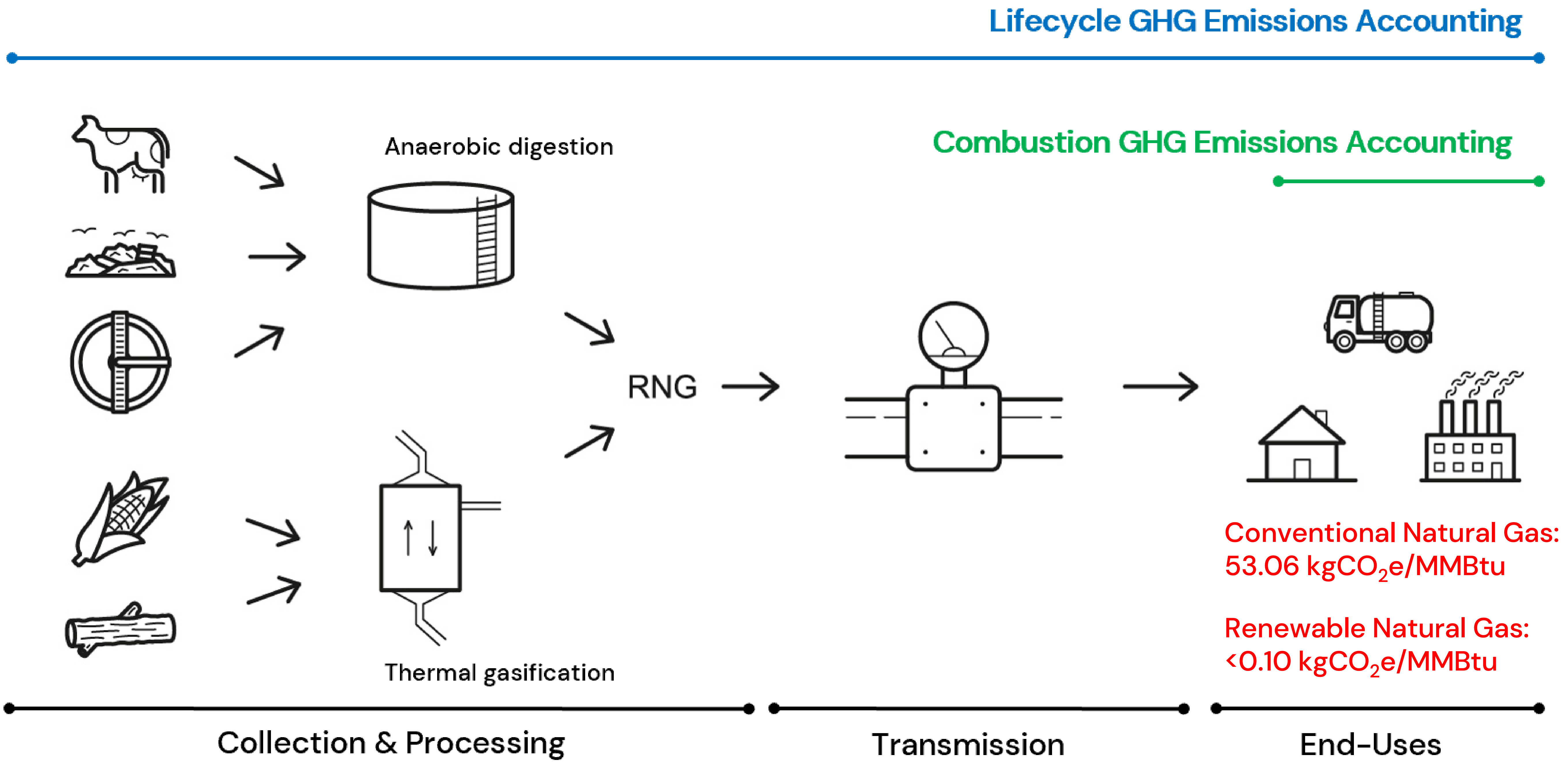
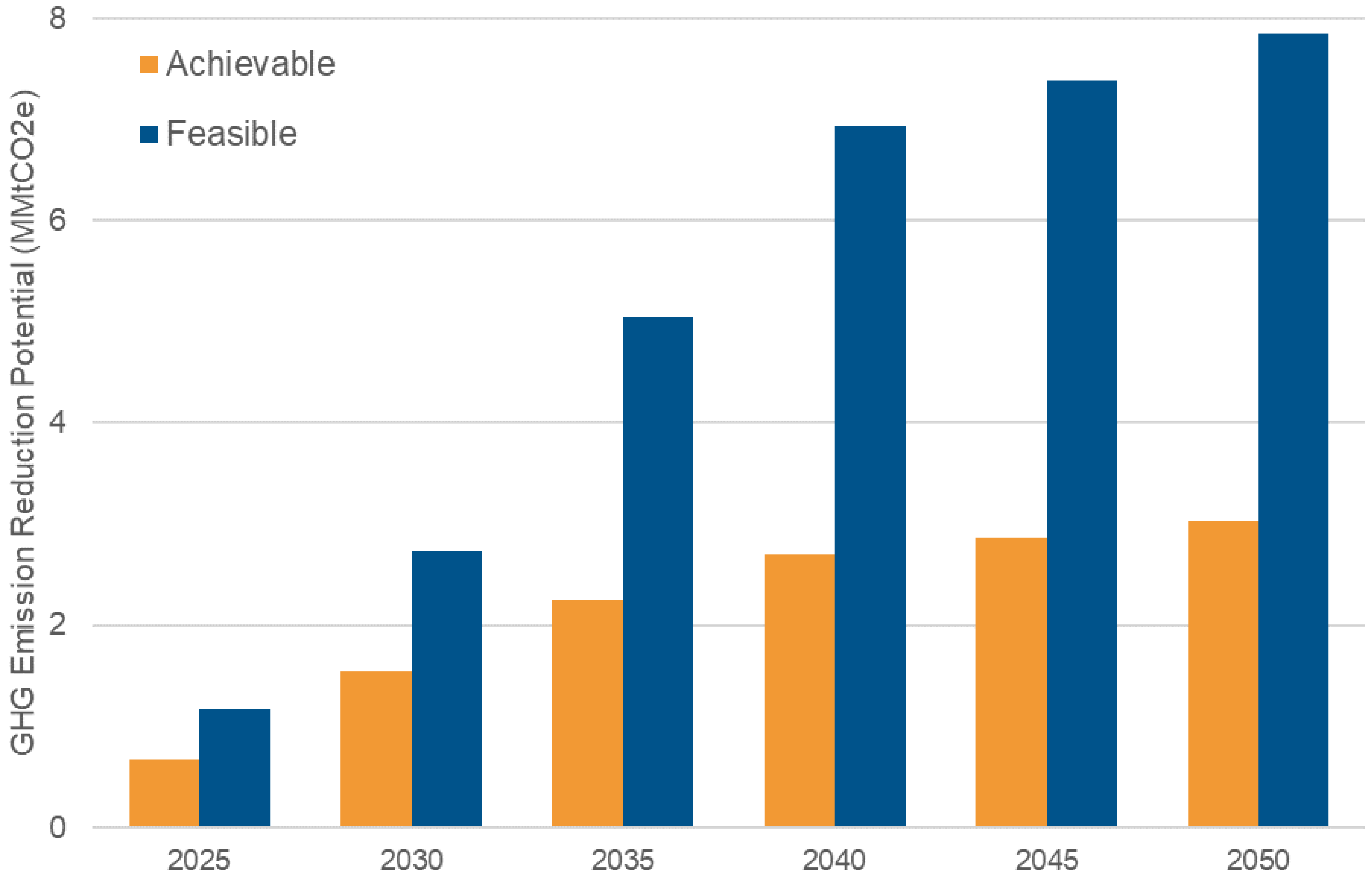
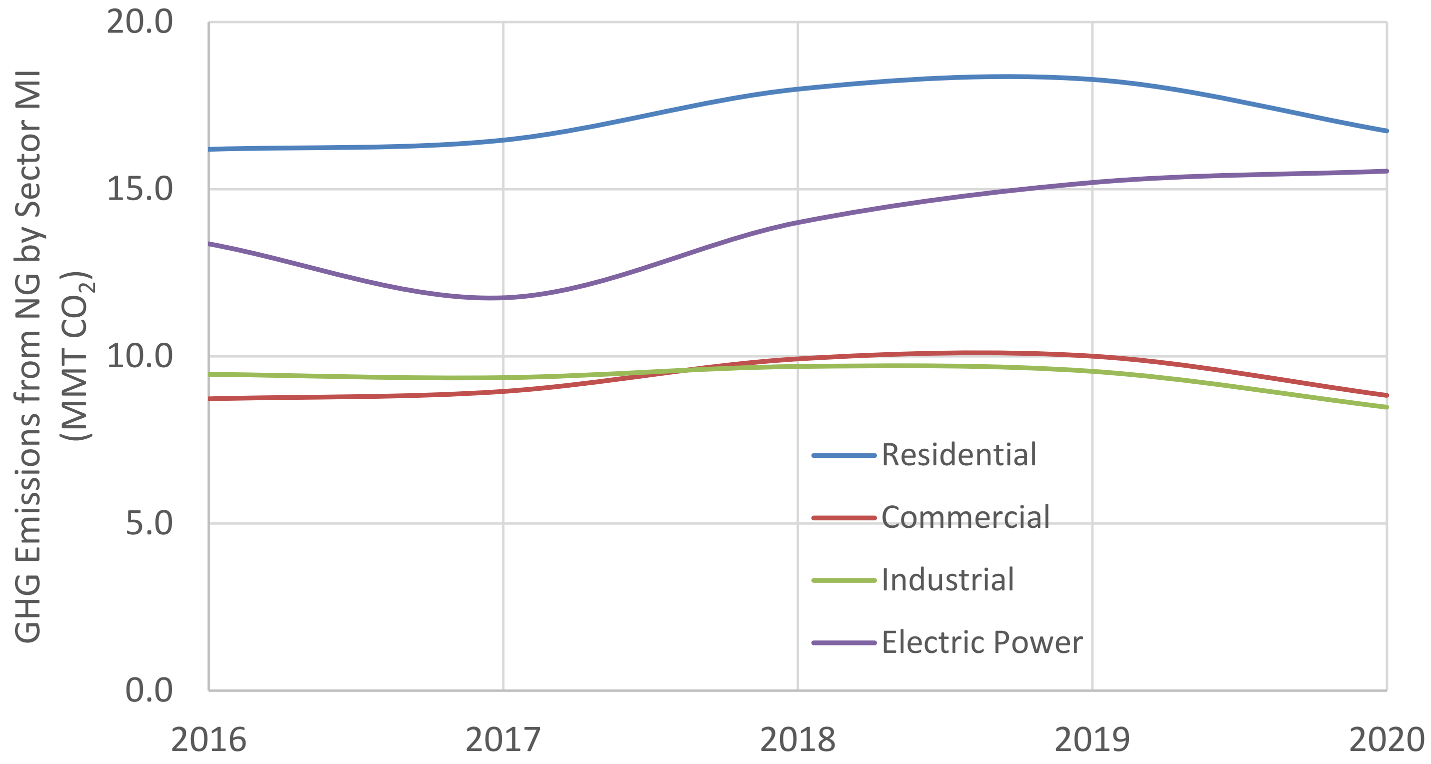
GHG emissions accounting framework



Contextualizing GHG emissions from renewable natural gas





3-8 MMT of GHG emission reductions by 2050

Natural gas from key sectors: 36 MMT

Focus on natural gas in Residential, Commercial, and Industrial end uses. RNG in the Achievable and Feasible Scenarios could decrease GHG emissions by 8-22% (assuming no changes in natural gas consumption e.g., through efficiency measures)

Introduction to GHG cost-effectiveness

GHG cost effectiveness is a measure of the cost of an abatement strategy per unit of GHG emissions abated (or reduced) per metric ton. It provides a basis to compare across GHG abatement strategies.

- Numerator: Abatement cost expressed as difference between abatement strategy and the conventional alternative. In the case of RNG, alternative is conventional natural gas.

$$Abatement\ Cost = Cost_{RNG} - Cost_{NatGas}\ [\$/MMBtu]$$

- Denominator: GHG emissions reduced compared to conventional alternative i.e., conventional natural gas.

$$GHG\ Abatement = EF_{NatGas} - EF_{RNG}\ [MTCO_2e/MMBtu]$$

GHG cost-effectiveness of renewable natural gas

Cost of natural gas: 3-year average of Henry Hub spot price (2019-2021), adjusted for inflation to $2022. Reference point: $3.11/MMBtu

Note: Henry Hub spot prices are nearly double that price today. If these higher prices were to persist, then it would *decrease* the abatement cost of RNG as a replacement for conventional gas in real terms, and likely the relative abatement costs of non-gas alternatives

The front end of the supply-cost curve is showing RNG of less than $10/MMBtu, which is equivalent to about $130 per metric ton of carbon dioxide equivalent (tCO2e).

As the estimated RNG cost increases to $25/MMBtu, we report a cost-effectiveness of ~$400/tCO2e.

Renewable natural gas compared to other GHG abatement strategies

Alternatives to RNG: Comparison Template

Abatement Technology

- Provide a brief description
- Contextualize technology and the opportunity

- Provide an abatement cost range in $/ton CO_2e

Abatement Cost Range	Low	High
Technology	$XXX	$YYY

Alternatives to RNG: Renewable hydrogen blending

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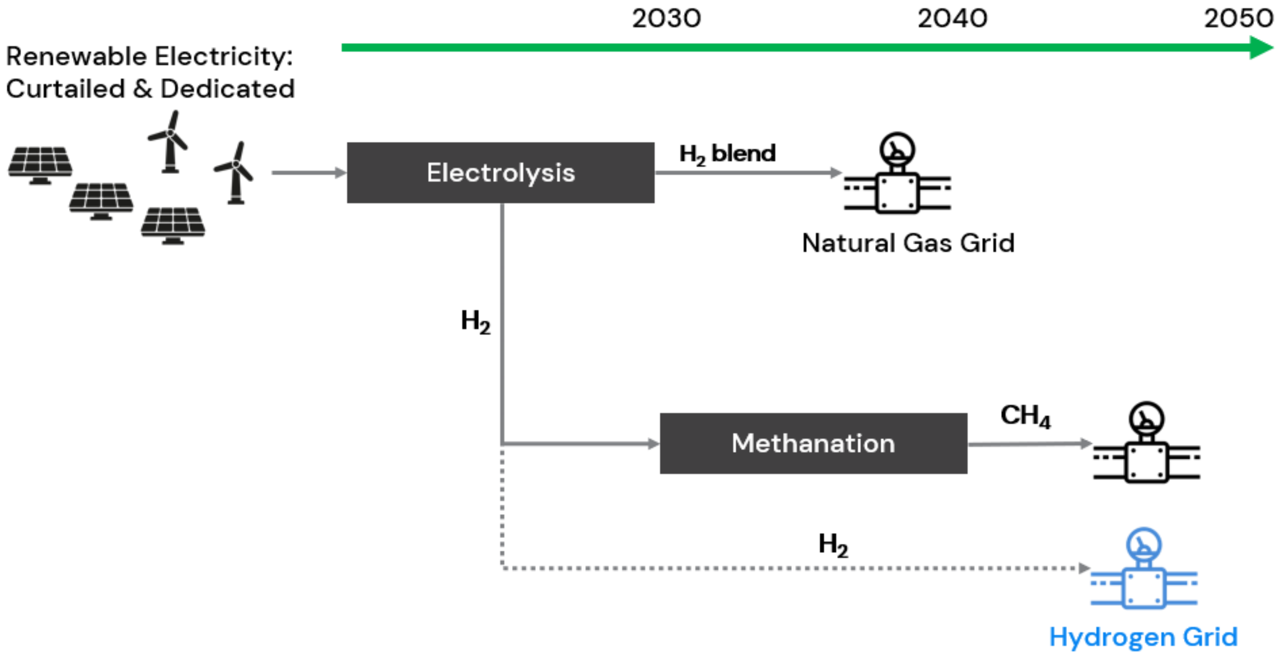
Renewable hydrogen blending

- Renewable hydrogen refers to hydrogen generated from electrolysis using renewable electricity, also referred to as power to gas (P2G). Electrolyzers split water into hydrogen and oxygen, and the hydrogen can be further processed to produce methane. The electricity is typically sourced from renewable resources, such as wind and solar.
- Renewable hydrogen can then be blended into the existing gas pipeline system (with constraints on volume).



Abatement Cost Range	Low	High
Renewable H2	$180	$300

Alternatives to RNG: Building electrification

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Building electrification

- Describes the strategy of shifting to use electricity for building energy uses like space heating and cooking.
- To be clear: Building electrification is NOT the same as grid decarbonization. The underlying principle of building electrification assumes that the electric-powered equipment used for space heating and cooking is powered by renewable electricity.
- Determining the impact of building electrification (e.g., via costs and GHG emissions) relies on assumptions and sophisticated analysis regarding how renewable electrons are delivered on an as-needed basis (i.e., dispatched) to align electricity demand with renewable electricity generation.

Abatement Cost Range	Low	High
Building Electrification	$0	$1,000

Alternatives to RNG: Electricity generation

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Electricity generation: Renewables + Nuclear

- This can also be referred to as grid decarbonization.
- For the purposes of this study, ICF considered the abatement costs for renewable electricity production and nuclear electricity production.
- LCOE of Renewables via NREL (c/kWh)

Solar PV	Onshore Wind	Offshore Wind	Natural gas, Combined Cycle	Natural gas, Combustion Turbine	Conventional Coal	Biogas
6.3	5.9	13.8	4.9	9.9	10.3	8.2-19.6

Abatement Cost Range	Low	High
Grid Decarbonization	$70	$450

Alternatives to RNG: Transportation electrification

<u>Transportation electrification</u>

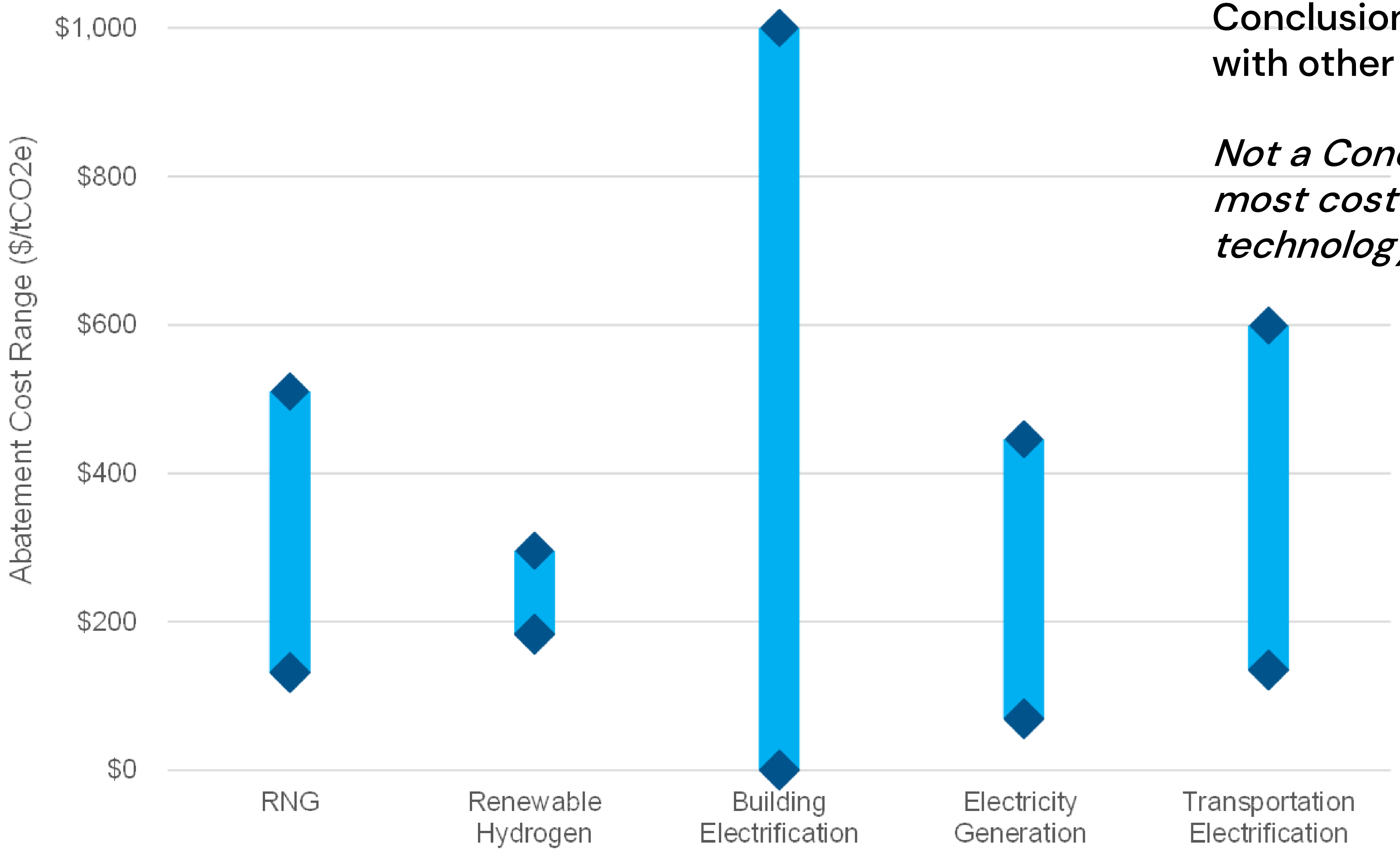
- Refers to the use of electric vehicles in the light-, medium-, and heavy-duty segments, rather than internal combustion engines.
- Transportation electrification and RNG are unlikely to be "competitors" in Michigan in the mid- to long-term future.
  - RNG is not a substitute for gasoline.
  - Most RNG is used in CNG vehicles in the medium- and heavy-duty market segments (e.g., transit buses, refuse haulers, regional haul trucks, etc.)
- For the sake of reference:
  - Fewer than 25 CNG stations in all of Michigan.
  - Estimated annual consumption of CNG is ~3-5 million diesel gallon equivalents (DGE).
  - Comparatively, there are about 1 billion gallons of diesel and 4.5 billion gallons of gasoline consumed in Michigan.

Abatement Cost Range	Low	High
Transp Electrification	$150	$600

Renewable natural gas in context

Emission Reduction Measure	Abatement Cost ($/tCO2e)	
	Low	High
RNG (this study)	**$132**	**$510**
Renewable Hydrogen Blending Range	**$183**	**$296**
ICF Production Cost Estimates in 2050	$183	$296
Comparisons (Columbia Center on Global Energy Policy and US DOE)	$85	$791
Building Electrification Range	**$0**	**$1,000**
Pennsylvania Climate Action Plan[55]	-	$502
Energy Futures Initiative (EFI): California Deep Decarbonization[56]	$380	$540
University of Texas, Carnegie Mellon & University of Michigan[57]	$0	$1,000
Electricity Generation	**$69**	**$446**
E3: PJM 80-100% RPS 2050 (2020)[58]	$69	$220
EFI & E3: New England Net Zero (2020)[59]	-	$446
Transportation Electrification	**$135**	**$599**
ICF Comparison of Medium and Heavy-Duty Truck Technologies[60]	$135	$400
E3: Deep Decarbonization in a High Renewables Future[61]	$359	$599

Renewable natural gas is cost competitive



Conclusion: RNG is cost-competitive with other abatement measures

Not a Conclusion: RNG is always the most cost-effective GHG abatement technology in Michigan

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Renewable natural gas: Opportunities and barriers to deployment in Michigan

Opportunities and Barriers to RNG Deployment in Michigan

- **The deployment of, and end-use demand for RNG is nascent but growing. With the ongoing expansion of the RNG market, there is increasing attention given to the opportunities and barriers associated with RNG production, delivery and end-use.**

- **ICF considered the highest-value opportunities and the corresponding challenges to realizing the potential of these opportunities in the RNG market.**

- **Characterized these opportunities and barriers across the following dimensions :**
  - **Technical**
  - **Market**
  - **Regulatory and policy**
  - **Environmental & health impacts**

Opportunities & Barriers: Technical

p. 90-93

Opportunity	Barrier
▪ RNG fulfills current definitions of a **renewable resource** in Michigan with carbon neutral characteristics. ▪ RNG utilizes the **same existing infrastructure** as conventional natural gas.	▪ Feedstock **location and accessibility** will constrain RNG production potential. ▪ **Competition for feedstocks** will constrain RNG production potential. ▪ **Gas quality and gas composition** for RNG remains an engineering concern. ▪ **Seasonal variability** in Michigan's natural gas systemwide demand may require the RNG production market to adapt.

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Opportunities & Barriers: Market

Opportunity	Barrier
▪ RNG can deliver **cost-effective greenhouse gas emission reductions** for decarbonization. ▪ RNG helps maximize the utilization of evolving waste streams. ▪ **RNG markets are evolving** to reflect utilities and corporations with climate and sustainability goals. ▪ RNG helps give suppliers and consumers a **viable decarbonization option** in an evolving market and policy environment.	▪ **Changes in existing programs** may negatively impact the economic feasibility of existing Michigan-based RNG projects or limit the near-term growth potential for RNG projects in Michigan. ▪ The long-term growth potential for RNG is dependent on **transitioning beyond transportation**. ▪ **RNG production and processing costs** need to be reduced to improve cost-competitiveness. ▪ **Limited availability of qualified and experienced RNG developers** to expand RNG production in the near-term future. ▪ The value of RNG is **dependent on appropriately valuing environmental benefits** compared to conventional alternatives. ▪ **Interconnection costs can be high** for RNG suppliers and developers.

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Opportunities & Barriers: Regulatory

Opportunity	Barrier
▪ **Conditioning and Interconnection Tariffs** can help decrease the costs to developers of biogas conditioning and upgrading, and thereby providing more competitive pricing to consumers. ▪ Emergence of **legislation and regulations can help spur investment** using both mandatory and voluntary programs. ▪ **Complementary policies could facilitate RNG feedstock collection** (e.g., waste diversion and management), that help improve the accessibility of feedstocks while improving project development economics.	▪ The **pathway for policies and incentives** promoting RNG in non-transportation market segments is unclear and not uniform. ▪ The industry will face limits as technical and market constraints emerge in the near- to mid-term future, and the **pathway for cost recovery may become less clear** as incentives from out-of-state programs become less effective at promoting RNG deployment.

Opportunities & Barriers: Environmental & Health Impacts

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Opportunity	Barrier
▪ Investments in RNG production can **yield positive environmental impacts beyond GHG emissions**, including helping to achieve waste management targets (e.g., waste diversion and waste utilization), support sustainable management practices in the agricultural and forestry sectors, and reduce the environmental impacts of concentrated animal feeding operations. ▪ If new policies are implemented to support RNG deployment in Michigan, they should ensure **no back-sliding** on other environmental indicators and avoid environmental injustices that have impacted at-risk communities.	▪ RNG development will face scrutiny as it relates to **fugitive methane emissions**. ▪ **There are a variety of environmental impacts of CAFOs**. *At present*, there is no clear indication that RNG policies or RNG production will impact industry trends related to CAFOs or contribute to the expansion of CAFOs in Michigan. However, it is important that there are controls put in place to ensure that RNG development would not lead to increased environmental harms or increase the risk of exposure to environmental injustices in at risk communities.

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