Princeton's Net-Zero America Project

Annex O: Non-CO_2 Emissions Trends and Abatement Potential

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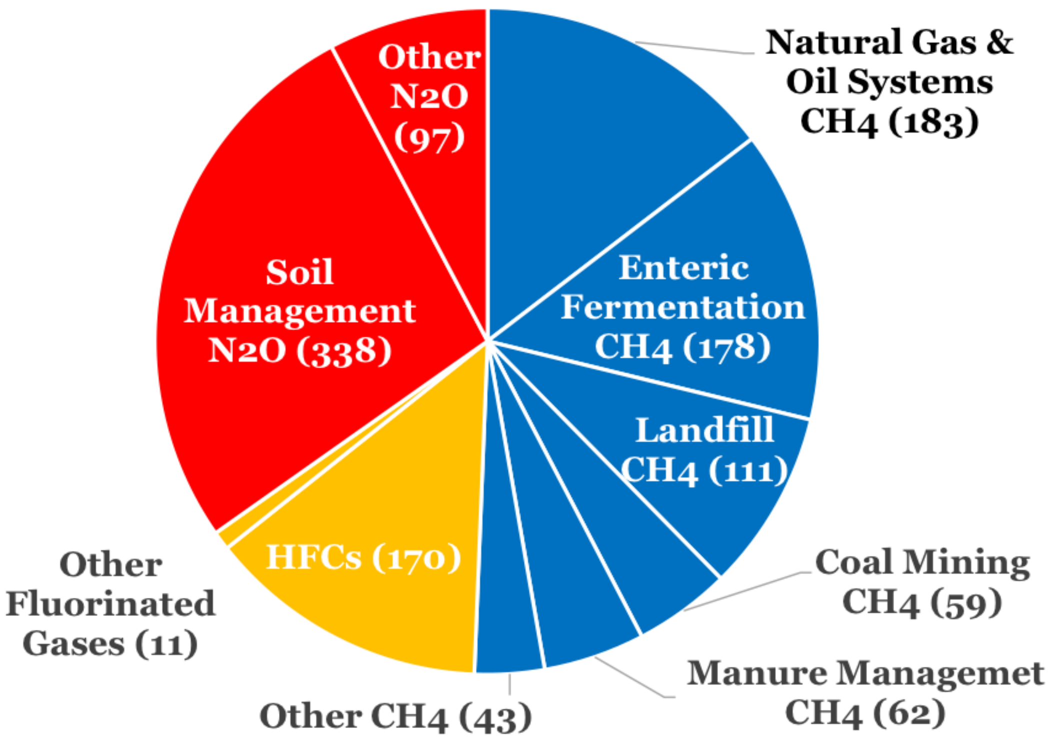
Contents

Today's Non-CO_2 Greenhouse Gas Emissions

According to the U.S. Environmental Protection Agency (EPA) 2020 Greenhouse Gas Inventory, U.S. non-CO_2 emissions were 1.25 Gt in 2018 [1]. Figure 1 shows a breakdown by major source and greenhouse gas, including Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), and other Fluorinated gases (PFCs, SF_6, and NF_3).

Figure 1: Sources of U.S. Non-CO_2 Greenhouse Gas Emissions by Gas, 2018 (Million Metric Tons CO_2e)



The most notable sources include N_2O from application of fertilizer to agricultural soils (i.e., soil management), fossil fuel production, and HFCs used in a range of applications from air conditioners to foams. Table 1 enumerates all of the different non-CO_2 sources tracked by the EPA. EPA follows the Intergovernmental Panel on Climate Change (IPCC) in estimating the global warming potential (GWP) for each of these gases, including a GWP of 25 for methane and a GWP of 298 for N_2O.

Table 1: Non-CO_2 source categories and greenhouse gases tracked by EPA [2].

Sector/Source	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3
Energy						
Coal mining activities	●					
Natural gas and oil systems	●					
Combustion of fossil fuels and biomass	●	●				
Industrial Processes						
Nitric and adipic acid production		●				
Electronics manufacturing[a]			●	●	●	●
Electric power systems					●	
Metals						
Primary aluminum production				●		
Magnesium manufacturing					●	
Use of substitutes for ozone-depleting substances[b]			●			
HCFC-22 production			●			
Agriculture						
Livestock						
Enteric fermentation	●					
Manure management	●					
Croplands (agricultural soils)		●				
Rice cultivation	●	●				
Waste						
Landfilling of solid waste	●					
Wastewater	●	●				

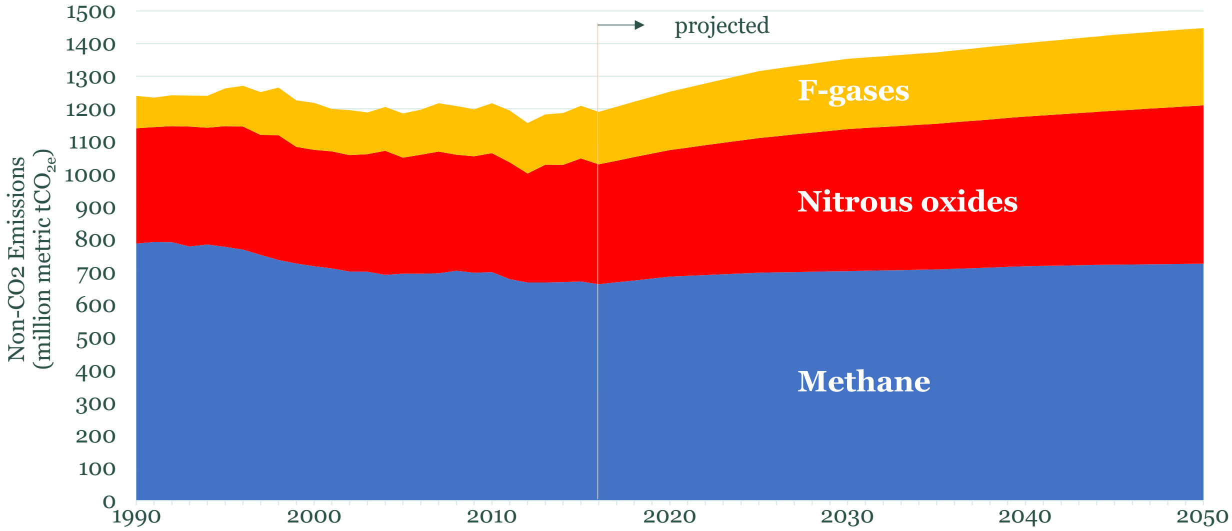
[a] Electronics manufacturing includes semiconductors, photovoltaics, and flat panel displays.

[b] Substitutes for ozone-depleting substances include uses in refrigeration and air-conditioning, solvents, foams, aerosols, and fire extinguishers.

EPA Emissions Projections with "Business-as-Usual"

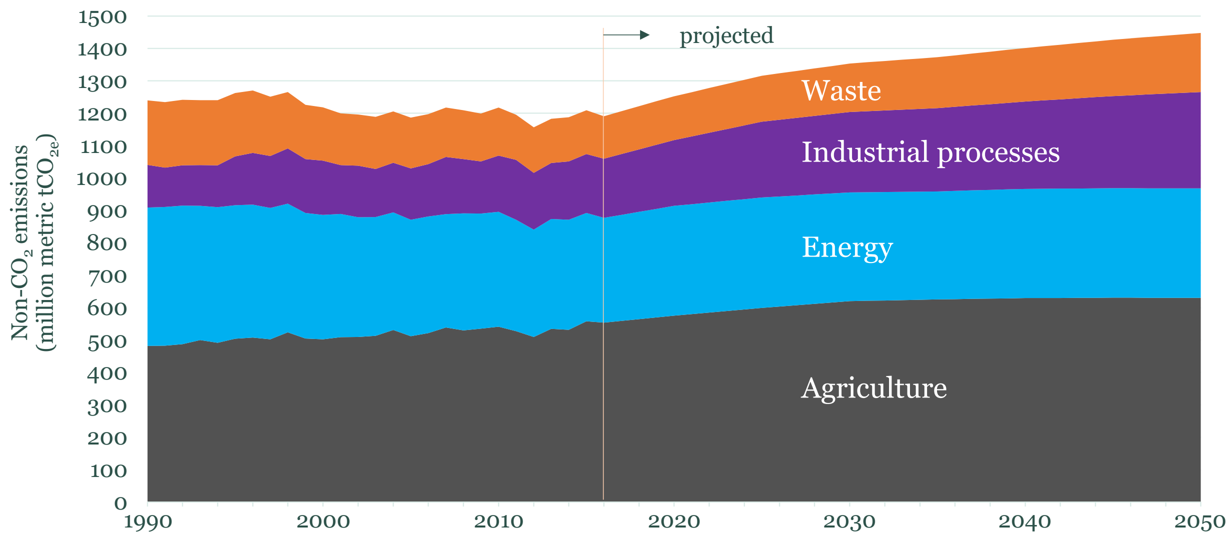
As shown in Figure 2, non-CO_2 emissions were roughly level from 1990 through 2018, as controls on methane emissions from fossil fuel production systems and landfills drove down overall methane emissions by 6.6 percent, roughly offsetting an upward drift in agricultural emissions (methane and N_2O) and a sharp increase in F-gases. Absent new policies or technology breakthroughs, EPA projects that overall non-CO_2 emissions would continue to increase through 2050 [2]. Specifically, non-CO_2 emissions would rise 18 percent from 1.25 to 1.45 Gt annually by 2050 under the EPA reference case, with methane increasing by 7.6 percent, N_2O increasing by 29 percent, and F-gases increasing by 40 percent. Projected F-gas emissions growth does not account for potential future action to implement the Kigali Amendment to the Montreal Protocol, which the United States helped to secure in 2016 and under which it would need to achieve an 85 percent reduction in production and consumption of HFCs by 2036 [3].

Figure 2: Historical and EPA-projected reference case non-CO_2 emissions by type of gas



As shown in Figure 3, the underlying drivers include a 54 percent increase in industrial process emissions (principally F-gases as well as N_2O from nitric and adipic acid production), a 37 percent increase in waste (mainly methane from landfills and wastewater), and a 12 percent increase in agricultural emissions (principally methane from enteric fermentation and manure management as well as N_2O from fertilizer production and use). Projected energy sector non-CO_2 emissions (principally methane from current and abandoned oil, gas, and coal operations) increase only 2 percent through 2050.

Figure 3: Historical and EPA-projected reference case non-CO_2 emissions by sector



EPA-Estimated Emissions Mitigation Potentials

Figure 4 shows EPA reference case (EPA BAU) non-CO_2 emissions for 2050, broken down by economic sector. It also shows estimates for 2050 of non-CO_2 emissions under the Net-Zero America E+ scenario (E+ BAU), accounting for the near-elimination of coal production and roughly 75 percent reduction in oil and gas production by 2050 in this scenario. This yields a roughly 68 percent reduction in overall energy sector non-CO_2 by 2050 assuming elimination of methane from coal operations, 75 percent reduction in methane from oil and gas operations, 75 percent reduction in N_2O from fossil fuel combustion and roughly unchanged emissions from abandoned fossil extraction facilities and F-gases used in the energy system (e.g. for transformers). Finally, Figure 4 also shows additional abatement potentials identified by EPA, including very low-cost measures (E+ & <$0)/ton) and higher-cost measures (E+ & <$100/ton).

Figure 4: 2050 Non-CO_2 Emissions [4]

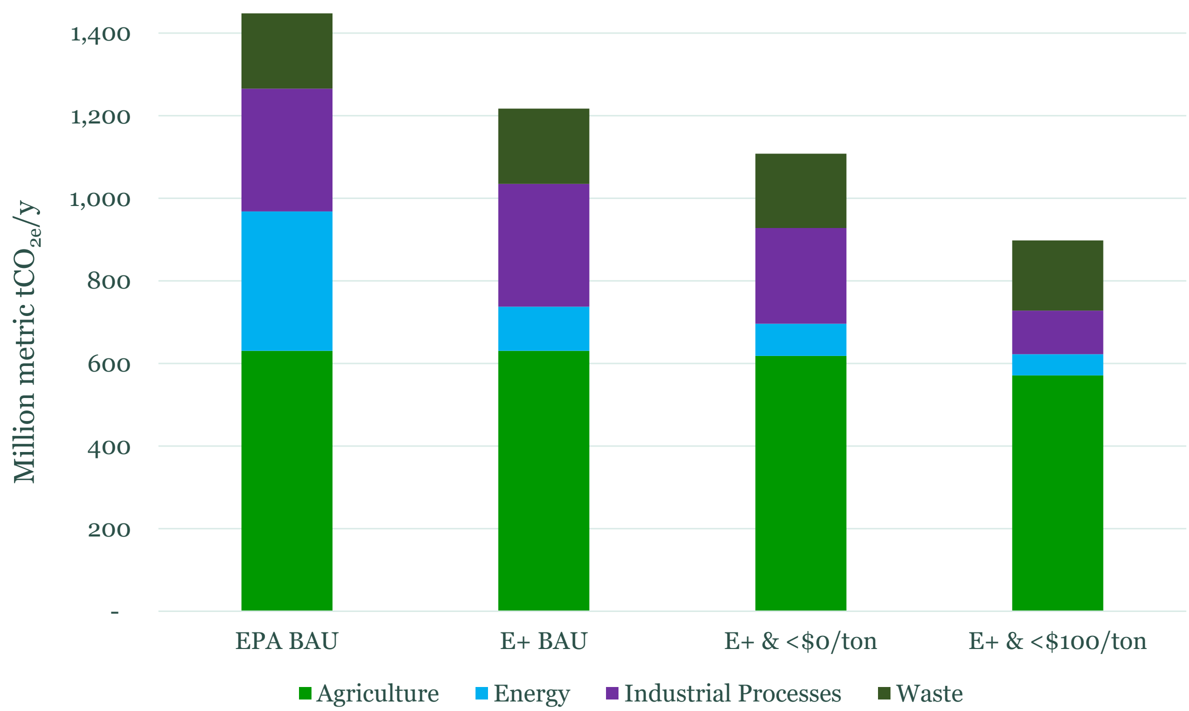


Table 2 shows the abatement potential for various sectors and sources under the 2050 <$100/ton scenario building off of the E+BAU, as explained above. The sources with the largest abatement potential are livestock CH_4, oil and gas system CH_4, and refrigeration/air-conditioning (AC) F-gases. The abatement potential of specific measures and technologies for these three sources are discussed in further detail in the sections below.

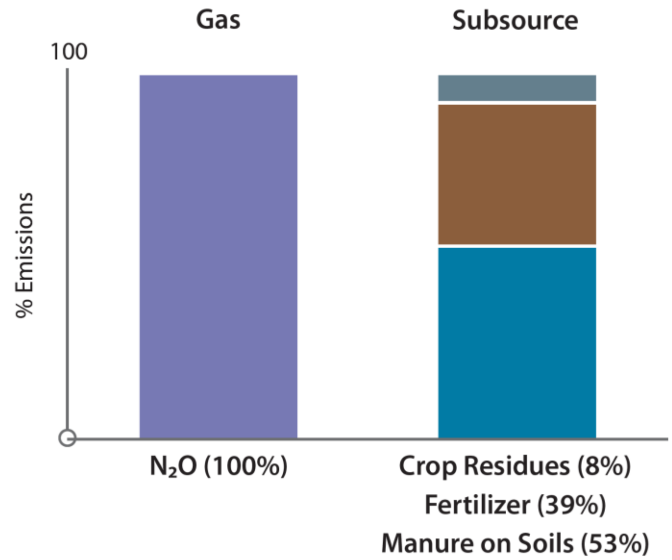
Table 2: Abatement by Sector and Source under <$100/ton Scenario

	Source	2050 Abatement (10^6 tCO2e/y)
Agriculture	Croplands/Rice	11
	Livestock	49
Energy	Coal	5
	Oil and gas	48
Industrial	Nitric & Adipic Acid Production (N_2O)	36
	Refrigerants/AC (F-gases)	146
	Other	9.0
Waste	Landfill	13
	Total	**316**

Croplands (N_2O) and Rice (methane)

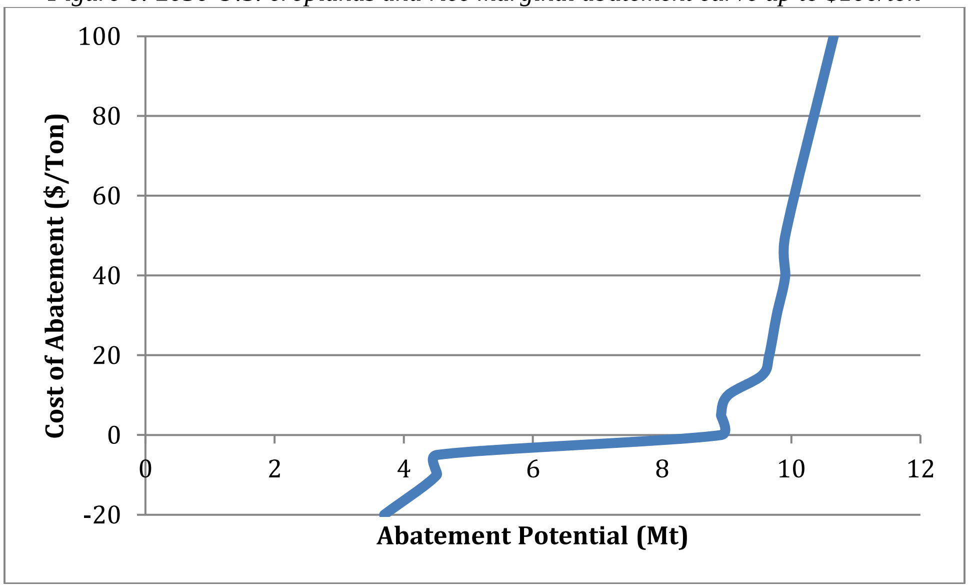
As indicated in Figure 5, EPA projects N_2O from manure and synthetic fertilizers will account for 92% of total global N_2O from croplands, with crop residues representing the remainder. Rice cultivation primarily emits methane.

Figure 5: Global Croplands N_2O emissions by Subsource, 2030 projection [2].



In the United States, fertilizers applied to croplands currently emit about 340 $MtCO_{2e}$ of N_2O, while rice cultivation emits only about 13 $MtCO_{2e}$. These emissions are projected to grow steadily through 2050 and, as shown in Figure 6, there are only modest cost-effective opportunities to reduce this growth. The main mitigation measures are to optimize fertilizer quantities and the timing of fertilizer applications, no-till agriculture, and shifting to fertilizer formulations that inhibit nitrification. All of these options involve complex tradeoffs affecting agricultural production costs and yields.

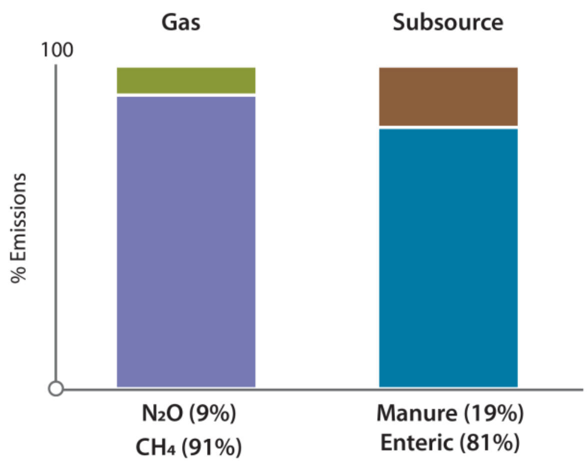
Figure 6: 2050 U.S. croplands and rice marginal abatement curve up to $100/ton



Livestock (CH_4 and N_2O)

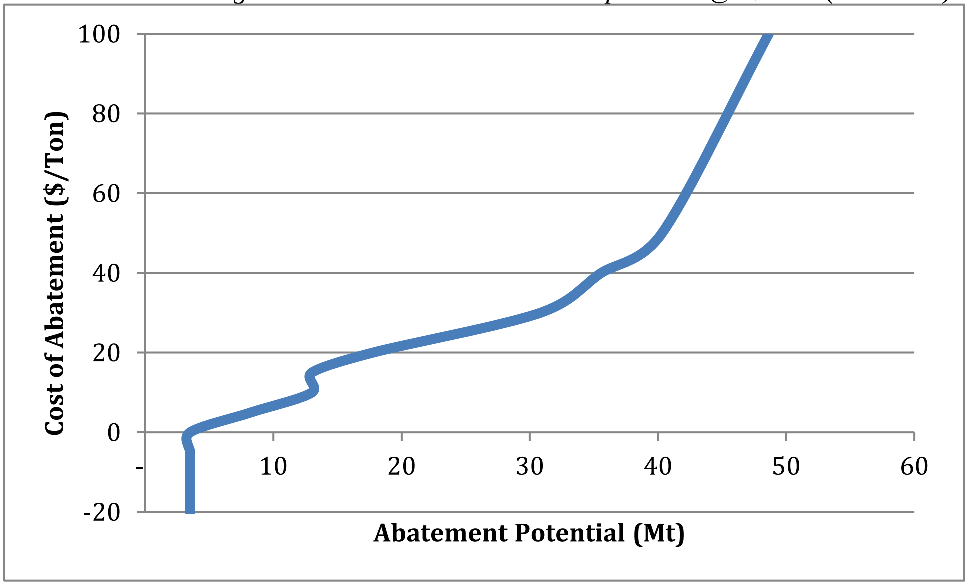
As indicated in Figure 7, globally enteric methane emissions from digestive systems account for about 80 percent of livestock emissions. The remainder are methane and N_2O emissions from manure management, where the latter derives from the organic nitrogen content in both manure and urine.

Figure 7: Global livestock emissions by gas and subsource, 2030 projection [2].



In the U.S., livestock emissions from manure are relatively more important, accounting for about 30 percent of livestock emissions. Nonetheless, enteric emissions are still dominant and thus account for most of the livestock abatement potential [5]. As shown in Figure 8, EPA estimates abatement potential of 49 Mt CO_{2e} in 2050 at a cost of <$100/ton of CO_{2e}.

Figure 8: 2050 Livestock marginal abatement curve. Abatement potential @<$500/t (not shown) is 70 Mt.



EPA considers six technologies to directly reduce enteric fermentation from livestock and multiple options to manage emissions from manure. They also note that many of these measures improve livestock productivity, thereby reducing the total number of animals needed per unit of meat or milk produced.

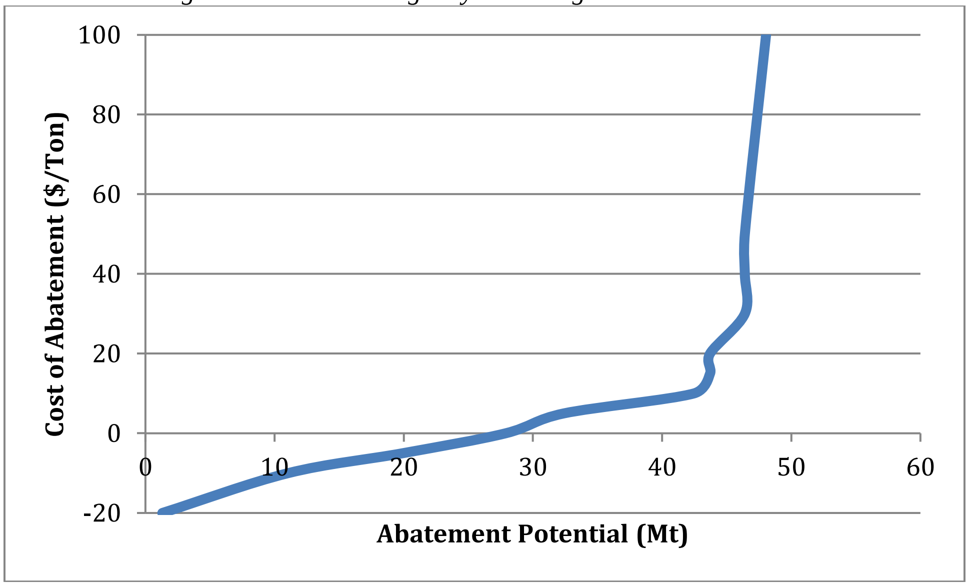
To address enteric methane, vaccines and additives that reduce methane-producing gut bacteria in livestock are the most important measures identified by EPA; however, substantial further research and development will be required to scale these solutions. While there are many different technologies under active development, a recent review article concludes that vaccines remain largely unproven and "most of these anti-methanogenic compounds or substances often show inconsistent results among studies and also lead to adverse effects on feed intake and digestion and other aspects of rumen fermentation when fed at doses high enough to achieve effective mitigation" [6].

To address methane from livestock manure, the technologies are well-established but more costly. The main solutions capture methane in biodigesters or covered lagoons and use the captured methane to generate heat or electricity. In smaller biodigesters the methane can at least be flared to reduce its GWP by a factor of 25.

Energy Systems (CH_4)

As discussed above, most coal methane emissions will be eliminated under the NZA scenarios by near elimination of coal production by 2030. Accordingly, we focus our discussion here on oil and gas systems. Figure 9 estimates abatement potential at less than $100 per ton for oil and gas systems, assuming that oil and gas production, emissions and abatement potential are about 75 percent lower in the E+ BAU scenario than in the EPA BAU scenario.

Figure 9: 2050 oil and gas system marginal abatement curve



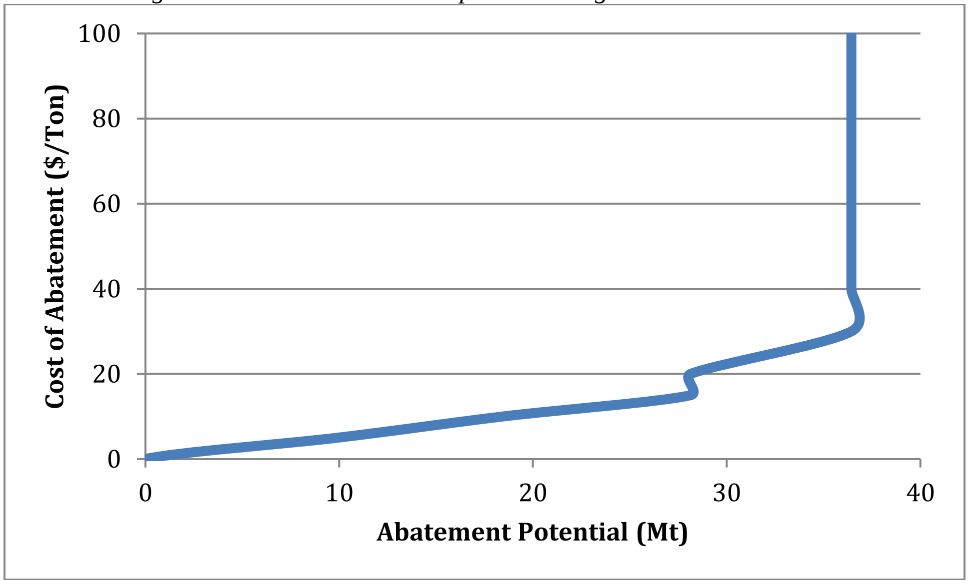
Of the CH_4 abatement measures EPA considers in their analysis, inspection and maintenance to find and fix leaks represent the most important set of measures, accounting for 39% of the national abatement potential. Installing vapor recovery units on oil storage tanks has the second highest abatement potential, followed by flaring instead of venting on shallow water platforms, and improving pneumatic controls. All of these measures use well-established technologies and methods.

Nitric and Adipic Acid

Nitric acid is used to manufacture synthetic fertilizer while adipic acid is used to manufacture a wide range of products including plastics, foams, fibers and lubricants. In the United States, currently nitric and adipic acid production each account for about half of the N_2O from this sector but EPA projects rapid growth in adipic acid production and related N_2O emissions.

Figure 10 indicates 36 $MtCO_{2e}$ of cost-effective abatement potential by 2050, principally through thermal destruction of N_2O as well as catalytic decomposition and reduction of N_2O. These abatement strategies are all low-cost, well-established and, in principle, easy to regulate since these emissions originate from a small number of large sources.

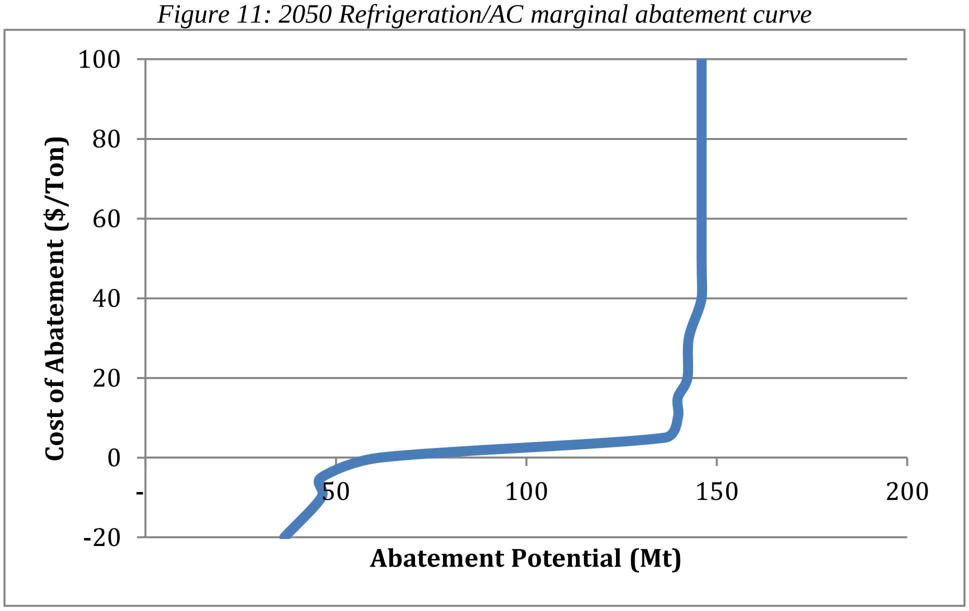
Figure 10: 2050 Nitric and adipic acid marginal abatement curve.



F-Gases

As shown in Figure 11, EPA estimates abatement potential of 146 $MtCO_{2e}$ per year by 2050 in just the refrigeration and air-conditioning sectors, at a cost of <$100/ton. There are modest additional F-gas abatement opportunities addressing other applications.

Figure 11: 2050 Refrigeration/AC marginal abatement curve



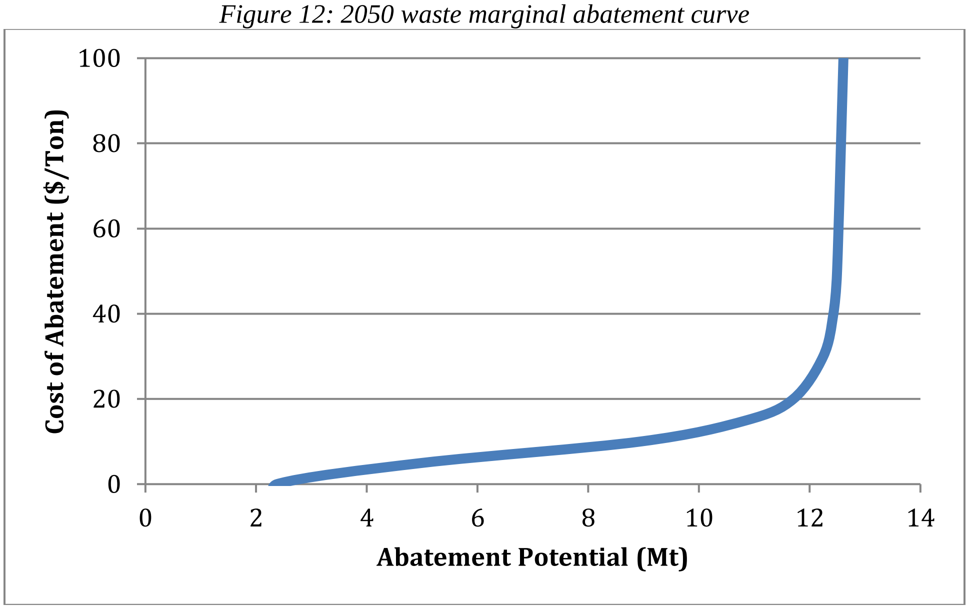
EPA considers three technician practices for reducing F-gas emissions in residential, retail, and transportation settings, including 1) leak repair for existing large equipment; 2) refrigerant recovery and disposal for existing refrigeration/AC equipment; and, 3) use of alternative lower-GWP working fluids such as NH_3 and CO_2 instead of F-gases for cold storage and industrial process refrigeration. EPA also considers 20 additional technologies offering cost-effective emission reductions potential. There are a wide variety of well-established options to reduce reliance on F-gases with many more under active development.

Moreover, there is strong private sector and bipartisan political support for implementing the Kigali Amendment [7]. As noted above, this would commit the United States to reducing production and consumption of HFCs by 85 percent by 2036. Implementing Kigali would not translate immediately into HFC emission reductions since emissions lag consumption by many years in most applications, but it suggests a potential policy pathway to drive down HFC emissions substantially by midcentury.

Waste

EPA estimates current methane emissions from the waste sector of 134 Mt CO_{2e} per year, with landfills accounting for 82 percent of this total, wastewater treatment accounting for 14 percent, and composting representing the remaining 4 percent. The principal abatement strategy is to collect methane from landfills and convert it to electricity. The United States has, however, already substantially addressed methane emissions, particularly from large landfills, meaning it has relatively little cost-effective abatement potential remaining, as shown in Figure 12.

Figure 12: 2050 waste marginal abatement curve



References

1. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018*. (last accessed 7 August 2021)

2. EPA, *Global Non-CO_2 Greenhouse Gas Emission Projections & Mitigation Potential: 2015-2050*, 2019. (last accessed 7 August 2021)

3. EPA, *Recent International Developments under the Montreal Protocol*. (last accessed 7 August 2021)

4. Source: EPA BAU from 2020 EPA GHG Inventory [1], E+ BAU from author's estimates of reductions in non-CO_2 emissions due to declining coal, oil, and gas production under the E+ NZA scenario, and further non-CO_2 mitigation potential from [2].

5. Table ES-4 in [1].

6. A. Patra, T. Park, M. Kim, and Z. Yu, "Rumen methanogens and mitigation of methane emission by anti-methanogenic compounds and substances," *Journal of Animal Science and Biotechnology*, 8: 13, 2017.

7. T. Cama (reporter), "GOP senators push Trump to submit pollution treaty amendment for Senate approval," *The Hill*, 11 June 2018. (last accessed 7 August 2021)