Team III: Potent greenhouse gas reduction project
Appendix: Screening and feasibility assessment on potential projects

TABLE OF CONTENTS

INITIAL SCREENING

To reduce the universe of potential potent greenhouse gas reduction projects to a manageable number for our team to handle, we focused on three potent gases: HFCs, nitrous oxide, and methane. We applied several criteria to each project's characteristics to determine which projects seemed like the best candidates for a more in-depth feasibility analysis. On the basis of that screening, we selected agricultural nitrous oxide, coalbed methane, and landfill methane to bring into the feasibility analysis because they appeared to combine the greatest benefits with the fewest likely roadblocks. Descriptions of each project area considered and brief explanations of our findings follow.

	HFCs			**N_2O**			**CH_4**				
	supermarkets	**public schools**	**liquor stores**	**hospitals**	**dentists**	**agricultural**	**coalbed**	**coal mine**	**landfills**	**oil and gas**	**agricultural**
Size of reduction opportunity	2	1	2	1	1	3	3	3	3	3	2
Ease of establishing additionality	1	1	2	2	3	3	2	2	2	2	3
Upfront costs	2	2	1	1	2	3	1	1	1	1	1
Ongoing costs	2	2	2	2	2	2	2	2	3	1	1
Team's topical interest	2	2	2	2	2	3	3	2	3	1	2
Scalability	2	2	2	1	2	3	3	1	3	2	1
Public health co-benefits	1	1	1	1	1	2	2	2	2	2	2
Verifiability	3	3	3	2	2	2	3	3	3	3	3
Partnership opportunities	1	2	1	2	2	2	3	3	2	1	2
Average	**1.78**	**1.89**	**1.78**	**1.56**	**1.89**	**2.56**	**2.44**	**2.00**	**2.44**	**1.78**	**1.89**

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1. HFCs

Hydrofluorocarbons (HFCs) are a class of compounds commonly used as refrigerants in air conditioners and refrigerators. The most common HFCs are very strong greenhouse gases, having 20-year global warming potentials in excess of 2000. Annual leak rates from refrigeration systems can be as high as 20%, and it is estimated that the US emits 180 million metric tons (CO_2 equivalent) of HFCs every year.

a. Supermarkets

There are multiple methods for reducing leaked HFCs. One option is to install leak detection systems that allow leaks to be dealt with quickly, resulting in less gas escaping. Other options include recycling and using recycled refrigerant, and replacing HFCs with less impactful gases, such as propane or CO_2.

Size of reduction opportunity	An average supermarket's refrigeration system leaks 574 metric tons CO_2e of HFCs a year. Completely eliminating the emissions from 88 supermarkets would therefore result in a reduction of over 50 kt CO_2e a year.
Ease of establishing additionality	The EPA has already instituted a program, known as Greenchill, which provides a framework for supermarkets to use these technologies and get certified for their reduced emissions. This program has been a success, for instance the Giant Eagle chain has reduced its leak rate from 15% to 10%, and for 2014 reported a total of 30.5 thousand metric tons CO_2e emission reduction. Many supermarket chains have signed onto the program. Establishing additionality seems difficult, as the project would have to find a way to facilitate supermarkets adopting the Greenchill program, or establish similar practices that otherwise wouldn't have done so.
Upfront costs	The installation of leak detection technology is not prohibitively expensive. Switching to experimental coolants, such as CO_2, is at this time very expensive.
Ongoing costs	There are ongoing costs associated with an aggressive leak detection and maintenance program. The savings associated with not having to purchase as much coolant are minimal. Recycling projects are also not cost effective.
Team's topical interest	The high potency of HFCs make them an attractive target.
Scalability	This type of project is reasonably scalable. Although many of the technologies would have to be purchased by each individual supermarket, large chains are able to split the cost of service contracts and overhead over many stores.
Public health co-benefits	Emissions of HFC refrigerant leaks are in relatively low concentrations and may not pose major public health concerns. Regular exposure to high concentrations of refrigerants can lead to poisoning, causing respiratory

	issues, a buildup of fluid in the lungs, organ failure and sudden death.
Verifiability	The EPA Greenchill program provides an established verification scheme for these reductions, and refrigerant losses can be easily measured.
Partnership opportunities	While many large and small supermarket chains are open to participating in these kinds of mitigation strategies, the Greenchill program has already reached out to them.

b. HFC: public schools

Size of reduction opportunity	A typical school uses substantially less refrigerant than a supermarket. A school may have 15 pounds of coolant, where a supermarket may have 3000 pounds. It would take total leak elimination in more than 17,000 schools to achieve 50 kt CO2e a year.
Ease of establishing additionality	Establishing additionality would be easier in schools than in supermarkets because there is not already an aggressive program in place.
Upfront costs	Since leaks from schools are not substantial, one method would be to switch to recycled HFCs, which would be of moderate cost.
Ongoing costs	The ongoing cost of using recycled HFCs, and recycling HFCs from old systems, would be moderate.
Team's topical interest	*Same as HFCs - Supermarkets*
Scalability	While school systems are large, many schools are needed to make a large impact.
Public health co-benefits	*Same as HFCs - Supermarkets*
Verifiability	Verifying reduced HFC emissions is relatively straightforward.
Partnership opportunities	Schools are typically very receptive to green initiatives, but many already have sustainability offices trying to implement these sorts of strategies.

c. HFC: liquor/convenience stores

Size of reduction opportunity	Convenience stores use large amounts of refrigerant. A typical store could have a total charge of 100 pounds, meaning that total leak elimination from 2700 stores would result in a reduction of over 50 kt CO2e a year.
Ease of establishing additionality	Establishing additionality would be easier in convenience stores than in supermarkets because there is not already an aggressive program in place.
Upfront costs	*Same as HFCs - Supermarkets*
Ongoing costs	*Same as HFCs - Supermarkets*
Team's topical interest	*Same as HFCs - Supermarkets*
Scalability	There are many thousands of convenience stores in the

	United States. For example, there are over 8,000 7-Eleven stores in the US alone. Moderate scalability across chains seems possible.
Public health co-benefits	*Same as HFCs - Supermarkets*
Verifiability	Verifying reduced HFC emissions is relatively straightforward.
Partnership opportunities	Many large chains operate franchise models, which would mean having to work with individual franchise owners.

2. N2O: Medical

Nitrous Oxide (N2O) is a commonly used anesthetic in both hospitals and dental clinics. With a 20-year global warming potential of 310, even the small amounts used in medical settings can have large effects. Most of the N2O used in medicine leaks into the atmosphere, even though technologies exist to capture the gas after use.

a. Hospitals

Size of reduction opportunity	Even though N2O is a potent greenhouse gas, the amount used in any individual hospital is small. It would take a 100% reduction of N2O emissions from 20 large hospitals to achieve a reduction of over 50 kt CO2e a year.
Ease of establishing additionality	Many hospitals are already doing something to mitigate the effects of their emissions, and have general sustainability initiatives in effect.
Upfront costs	Outfitting hospitals with N2O capture equipment has been done, but is expensive and not many hospitals have adapted the technology.
Ongoing costs	There is ongoing cost associated with sequestering or recycling the N2O.
Team's topical interest	The medical sector is of interest to the team.
Scalability	Most hospitals operate as separate entities, and scalability is possible but could be difficult.
Public health co-benefits	N2O has been safely used in medical settings for a long time, but there is some evidence that elevated N2O levels inside hospitals could be a public health concern.[1]
Verifiability	Verification of N2O emission reduction could be difficult and expensive, as captured gas would have to be monitored.
Partnership opportunities	Partnerships with hospitals or medical groups seems possible.

b. Dental Offices

Size of reduction opportunity	While N2O use among dentists varies, it is likely that hundreds of dental offices would have to eliminate their emissions to achieve a reduction of over 50 kt CO2e a

[1] Brodsky, Jay B., and Ellis N. Cohen. "Adverse effects of nitrous oxide." Medical toxicology 1.5 (1986): 362-374.

	year.
Ease of establishing additionality	Establishing additionality would be moderately difficult.
Upfront costs	Outfitting dentists with N2O capture technology would be of moderate expense.
Ongoing costs	The cost of constantly recycling or sequestering N2O from dentists could be cost prohibitive.
Team's topical interest	The medical sector is of interest to the team.
Scalability	Scalability could be difficult, as individual projects with each dentist would need to be established.
Public health co-benefits	There is some evidence that elevated N2O levels inside dental offices could be a public health concern, but most have ventilation procedures in place.
Verifiability	*Same as N2O:Medical – Hospitals*
Partnership opportunities	Dental associations exist, and could be partners in such a project.

3. N2O: agricultural

Agriculture is the source of a significant portion of emissions of nitrous oxide, a greenhouse gas 310 times more potent that carbon dioxide. Much of these emissions come from the use of nitrogen fertilizers. By reducing the use of such fertilizers and altering other farm management techniques, the amount of nitrous oxide released into the atmosphere by a farm's operations can be significantly reduced without major impact on farm productivity.

Size of reduction opportunity	An acre of corn field that reduces its nitrogen fertilizer use from 225 pounds to 190 pounds annually can expect an emissions reduction of 0.6 tons CO_2e annually. With about 88 million acres of corn planted in the United States, converting the ~87,000 acres necessary to achieve an emissions reduction of 50,000 tons of CO_2e annually seems feasible.
Ease of establishing additionality	Nitrogen use can easily be compared against baseline figures for a given farm to determine foregone emissions. Once foregone, there is no chance of emissions at a later date.
Upfront costs	Upfront costs are likely insignificant because the methodology is already developed and little or no capital equipment is required.
Ongoing costs	Because the cost of nitrogen fertilizer is low compared to the potential cost of low crop yields, it is currently common to overuse fertilizer as a hedge. Consequently, paying farmers to use only as much fertilizer as can be justified by the best available scientific data likely has a reasonable cost.
Team's topical interest	We believe this project has significant potential and interacts with an important and sizable part of the

	American economy.
Scalability	Because corn farming is so widespread and this project requires little new equipment, it could be expanded across a significant range without new infrastructure.
Public health co-benefits	These projects also reduce agricultural nitrogen runoff, resulting in environmental and health benefits from reduced nitrogen leaching.
Verifiability	Validation procedures for agricultural nitrous oxide offsets have already been developed by the American Carbon Registry, the Climate Action Reserve, and the Verified Carbon Standard. These standards include meaningful monitoring standards to ensure that the intended results are achieved. Farmers in the upper Midwest are already eligible to receive offset credits through the Delta Institute's Nitrogen Credit Program.
Partnership opportunities	Farming groups and regional cooperatives could be good partners to help find individual farms interested in modifying their practices to become eligible for the credits this project would make available.

4. **CH_4: coalbed**

Coalbed methane (CBM) is naturally found in coal seams, formed during the process where plant material is transformed into coal. This methane is naturally released even at sites where mining is not occurring, although at a lesser rate compared to methane releases associated with mining activities. Although coalbed methane is considered an unconventional source of natural gas, the methane resources from this source can be valuable and account for about 5% of total national natural gas production each year.[2] Many potential coal mining sites are located on Native American land, and are areas of concern for environmental and social justice.

Size of reduction opportunity	The amount of methane found in coal seams can be large. In an example project in the Southern Ute Tribe in Colorado, a net 60,359 tons of carbon dioxide equivalent was captured and used in 2015. The environmental benefits to CBM projects may be similar to methane captured from landfills or agricultural/dairy offset projects.
Ease of establishing additionality	In the example Southern Ute project, the established criteria included checking comparisons to baseline and ensuring that new instances being evaluated for "but-for" aspects additionality were only eligible when the price of natural gas was below $6.24 per thousand cubic feet.
Upfront costs	While the upfront costs of a methane capture and energy recovery system can be relatively high for a large natural

[2] Energy Information Administration, 2014.

	seepage area, carbon offset funding can help with financing.
Ongoing costs	Ongoing capture, usage, and monitoring also has associated costs, but these are generally lower than the initial capital cost of the systems.
Team's topical interest	The team is interested in coalbed methane because of the environmental impact as well as the potential social impact of finding economically viable alternatives to mining in Native American communities.
Scalability	There are a large number of potential coal mining sites under dispute, which could be candidates for land conservation or methane capture project. A challenge would be that these sites have different interested stakeholders, so each site may require substantial effort to reach project agreement.
Public health co-benefits	Methane release can negatively impact surrounding communities; people exposed to methane have reported nausea, headaches, eye irritation, asthma aggravation and nose bleeds. Capturing methane or preventing coal mining in Native American communities has many other health benefits, such as by reducing potential air and water pollution.
Verifiability	There are precedents for verified projects of this type. The example Southern Ute methane seepage offset project received verification on net emissions reduced by Verified Carbon Standard.
Partnership opportunities	Potential partners include Native American communities where residents wish to prevent mining or mining expansion, but also need to consider generation of economic resources, so methane capture and use could be an alternative that is of interest. Example sites include coal seams in the Navajo, Hopi, Cheyenne, and Crow Nations. One of our teammates has a number of contacts in the Navajo Nation, including community coalitions, local universities and local offices of federal departments, who are interested in working to prevent additional mining and capture methane from un-mined sites.

5. CH_4: coal mine

Methane is released from coal seams and surrounding rock during surface and underground mining activities. Coal mine methane (CMM) is differentiated from coalbed methane (CBM), which would never be mined. In underground mining operations, methane is typically removed from the mining site through ventilation to reduce explosion risk, but this diffuse methane is sometimes simply flared to convert to CO_2 and then released. In surface mining operations, methane can escape to the atmosphere through natural fissures or other sources. Abandoned mines are also a source of methane release. Many coal mines are located on Native American land, and are areas of concern for environmental and social justice.

Size of reduction opportunity	The magnitude of methane emissions associated with coal mines can be large. For example, in a back-of-the-envelope calculation, the methane released from a single pit out of the 3-pit Kayenta mine, which is just one mine in a site in the Navajo Nation, is estimated to be nearly 450 kt CO_2eq.
Ease of establishing additionality	The EPA considers some recovery and use of coal mine methane to be emissions avoidance, as the methane would otherwise be released into the atmosphere during mining activities. If methane is captured and used, the additionality depends in part on the electricity source mix that would have been used in the absence of the generation. That said, many electrical grids have at least one natural gas plant on them and could use natural gas as a fuel, and there are also multiple uses for natural gas.
Upfront costs	Methane capture and use systems can be relatively expensive to install. Methane can be captured for energy generation pre-drainage, or before mining commences, which may reduce the cost of necessary ventilation during mining by half. There are sometimes financing sources such as low-interest loans and grants available to corporations for these systems.
Ongoing costs	After installation, methane capture and use systems take money and energy to operate. During ongoing mining, ventilation air methane (VAM) units cost about $20-30 per standard cubic feet per minute, but the captured methane is more diffuse and more difficult for energy recovery. Methane can also be captured post-drainage, after mining activities are completed, for offsets.
Team's topical interest	The team is more interested in coal bed methane than methane release associated with coal mining.
Scalability	There are a large number of coal mining projects that are not currently capturing methane, which could be candidates for a project. A challenge would be that these mines are often under different management and affect different stakeholders, so each site may require substantial effort to reach project agreement.
Public health co-benefits	Methane is an occupational health hazard for underground coal mine workers, as it can lead to explosion risk. Ventilation is typically used, but unanticipated high amounts of methane emissions can lead to the ventilation controls being insufficient. Methane release can also negatively impact surrounding communities; people

	exposed to methane have reported nausea, headaches, eye irritation, asthma aggravation and nose bleeds.
Verifiability	Methane can be measured from existing mines and used as a baseline to determine future reductions, for certification by a third-party organization. There are existing protocols and previous examples for doing this, such as the Compliance Offset Protocol Mine Methane Capture (MMC) Projects, but measurement of methane across a large coal mine may be more challenging than measuring methane in a smaller landfill.
Partnership opportunities	Potential partners include Native American communities where mines are located, motivated by a desire to reduce environmental impact and use the captured methane for economic benefit. Where rights have already been sold to mining corporations, it may be more difficult to partner with the stakeholder in power, since coal companies may be less likely to be interested in the current administrative environment. Example sites include Kayenta mine in Navajo Nation, Arch Coal West Elk mine in Colorado, Dos Republicas Coal projects at the Texas / Mexico border, coal mines in Northern Cheyenne and Crow Reservation.

6. CH_4: landfills

Municipal solid waste (MSW) landfills are a significant source of methane emissions as their contents begin to decompose. Harvesting the energy contained in that methane both reduces the need for other energy sources and converts the methane to less harmful carbon dioxide. Unregulated entities could invest in landfill energy projects so that they become financially viable.

Size of reduction opportunity	Landfill projects exist in several locations and often produce well over the 50,000 tons of CO_2e required. Spreading the project concept to more landfills has significant potential, and EPA estimates that over 400 additional landfills could cost-effectively have their methane turned into an energy resource.
Ease of establishing additionality	The most significant challenge to additionality is demonstrating that the landfill emissions would not have been avoided except for the involvement of the unregulated entity.
Upfront costs	Each project requires significant upfront investments in the facilities needed to convert the landfill gas to energy, but the payback may be realistic.
Ongoing costs	On an operating basis, the projects are likely profitable or nearly so, given the energy produced.

Team's topical interest	The scalability and relevance of this project type appeals to our team.
Scalability	Because there are so many "candidate" landfills remaining, projects of this kind could be spread across the country somewhat easily despite the likely significant upfront costs.
Public health co-benefits	Eliminating methane emissions from the local atmosphere can contribute to quality of life and health improvements. Due to environmental injustice issues, landfills are often located near vulnerable communities who may experience the related negative health impacts more acutely.
Verifiability	Methane can be measured from existing landfills and used as a baseline to determine future reductions. Standards already exist for doing so, and several existing projects have been certified by the various organizations.
Partnership opportunities	Large organizations, such as universities, may be interested in power purchase agreements to increase their use of renewable energy sources.

7. **CH_4: oil and gas**
   Methane can be released during the production, processing, storage and transport of oil and natural gas, especially if there are leaks in the piping and container systems. A famous recent example is the large natural gas storage leak in Porter Ranch, California. The EPA under Obama's administration released standards to reduce emissions (including methane) from the oil and gas sector in 2016, but the future is uncertain.

Size of reduction opportunity	The oil and gas sector is one of the largest sources of methane, but the reduction opportunities may be relatively dispersed, potentially requiring repair of leaks and installation of methane capture systems in many locations.
Ease of establishing additionality	The reduction in waste methane can be measured, but the total emissions reduction and its additionality could depend in part on the electricity source mix that would have been used in the absence of the generation.
Upfront costs	Technologies to detect / repair leakage and capture / use waste methane can have a relatively high capital cost. Many of the current systems in place are older, and may cost more to replace.
Ongoing costs	There are costs associated with the operation and maintenance of methane capture and use systems.
Team's topical interest	The team is less interested in methane emissions from oil and gas production than from other sources, particularly if the leakages in the oil and gas system are relatively disperse.
Scalability	Scalability could be a challenge, despite the size of the oil and gas production system, because of the many different

	stakeholders and geographical regions involved in production.
Public health co-benefits	Researchers at USC studying a major natural gas leak in Porter Ranch, California have reported concerns about respiratory, cardiovascular, and neurological impacts as well as stress. People exposed to methane in higher concentrations during leakage incidents have reported nausea, headaches, eye irritation, asthma aggravation and nose bleeds.
Verifiability	There are some precedents for verified projects in this space. For example, the Alberta province in Canada has established a joint initiative to reduce and verify reductions in methane from the oil and gas sector.
Partnership opportunities	Oil and gas companies may be less likely to be interested in partnerships during the current political and regulatory administrative environment.

8. CH_4: agricultural

Installing anaerobic digesters at farms can harness the methane contained in manure, among other things, to produce energy that can then be used on the farm or sold onto the grid. To ensure efficient operation, the digester must be operated by an organization that has the correct skills and expertise. The digester reduces the methane that would be emitted by the manure, instead converting it into carbon dioxide while also reducing the need for electricity produced through other means.

Size of reduction opportunity	The reduction opportunity is significant at any one anaerobic digester project, but each project requires significant new infrastructure. The Barstow's Longview Farm installation in Hadley, Mass., offsets nearly 20,000 tons of CO_2 emissions annually.
Ease of establishing additionality	The eliminated emissions from the methane can be measured, but the total emissions reduction and its additionality depends in part on the electricity source mix that would have been used in the absence of the generation. Further, if Vanguard Renewables is already rolling the technology out across New England, it is not certain that another unregulated entity's involvement would actually create significant additionality.
Upfront costs	Constructing each project requires significant upfront investment in the necessary infrastructure.
Ongoing costs	Maintaining each project requires ongoing costs, e.g. for management, and ongoing supervision of the use or sale of the electricity generated.
Team's topical interest	We believe this project interacts with an important and sizable part of the American economy.

Scalability	Because each project requires new and likely unique arrangements, it cannot easily be brought to scale except by deploying one bespoke project after another, likely at significant cost.
Public health co-benefits	Eliminating methane emissions from the local atmosphere can contribute to quality of life and health improvements. A project of this nature could have public health impacts by reducing direct exposure to particles, as well as by reducing methane as an ozone precursor.
Verifiability	The manure tonnage provides a solid proxy for the emissions prevented.
Partnership opportunities	Each project requires a strong partner in the form of a farm willing to radically change its manure management. It also requires a partner with experience in renewable energy who can manage the generation and transmission component.

IN-DEPTH FEASIBILITY ASSESSEMENT

Having selected agricultural nitrous oxide, coalbed methane, and landfill methane to bring into the feasibility analysis because they appeared from our screening analysis to have the most promising combination of benefits and potential drawbacks, our team then performed a feasibility analysis on each of those three project areas.

1. Agricultural nitrous oxide

Agriculture is the source of a significant portion of emissions of nitrous oxide, a greenhouse gas 310 times more potent that carbon dioxide. Much of these emissions comes from the use of nitrogen fertilizers. Agricultural nitrous oxide emissions, which have grown 3.4 percent since 1990, make up nearly 70 percent of total nitrous oxide emissions and just over 3 percent of total U.S. greenhouse gas emissions.[3] By reducing the use of such fertilizers and altering other farm management techniques, the amount of nitrous oxide released into the atmosphere by a farm's operations can be significantly reduced without major impact on farm productivity.

Design and engineering

An acre of corn field that reduces its nitrogen fertilizer use from 225 pounds to 190 pounds annually can expect an emissions reduction of 0.6 tons CO2e annually.[4] With about 88 million acres of corn planted in the United States, converting the ~87,000 acres necessary to achieve an emissions reduction of 50,000 tons of CO2e annually seems feasible. These figures depend on the development and application of a so-called Tier 2 standard that accounts for national and

[3] Climate Action Reserve, "Nitrogen Management Project Protocol" (January 17, 2013).
[4] Fact sheet about Millar et al. 2010. *Nitrogen fertilizer management for nitrous oxide (N2O) mitigation in intensive corn (Maize) production: an emissions reduction protocol for US Midwest agriculture.* Mitigation and Adaptation Strategies for Global Change, 15:185–204.

regional variations in soil and farming to produce accurate reduction estimates, particularly because corn in the American Midwest is a particularly heavy user of nitrogen fertilizer.

Because American farmers have long used yield-goal estimates to derive nitrogen fertilizer application rates, reductions in fertilizer use below such estimates represent additionality above the business-as-usual scenario.

Validation procedures for agricultural nitrous oxide offsets have already been developed by the American Carbon Registry, the Climate Action Reserve, and the Verified Carbon Standard. These standards include meaningful monitoring standards to ensure that the intended results are achieved. Farmers in the upper Midwest are already eligible to receive offset credits through the Delta Institute's Nitrogen Credit Program. However, these multiple certification programs also have different specific requirements and thus may create perverse incentives for farmers and other actors to game the system to maximize claimed offsets. The project will need to establish which offset best serves its purposes and be certain to mandate contractually the use of that offset's measurement standards.

The most significant factor in predicting nitrous oxide emissions from agricultural fertilizer use appears to be fertilizer rate (i.e. the amount used), rather than source, timing, or placement.[5] Consequently, the most effective way to reduce emissions is to reduce usage rates. Further, though some nitrous oxide emissions from agriculture are inevitable, there is significant potential for reduction.[6] Nitrogen usage rates can easily be compared against baseline figures for a given farm to determine foregone emissions. Once foregone, there is no chance of emissions at a later date.

The CAR protocol covers only 12 Midwestern states and uses region-specific data to increase the measurable amount of emissions foregone.[7] Given this advantage, it may make sense to focus projects on those states, particularly given the abundance of agriculture and of nitrogen fertilizer use there in general.

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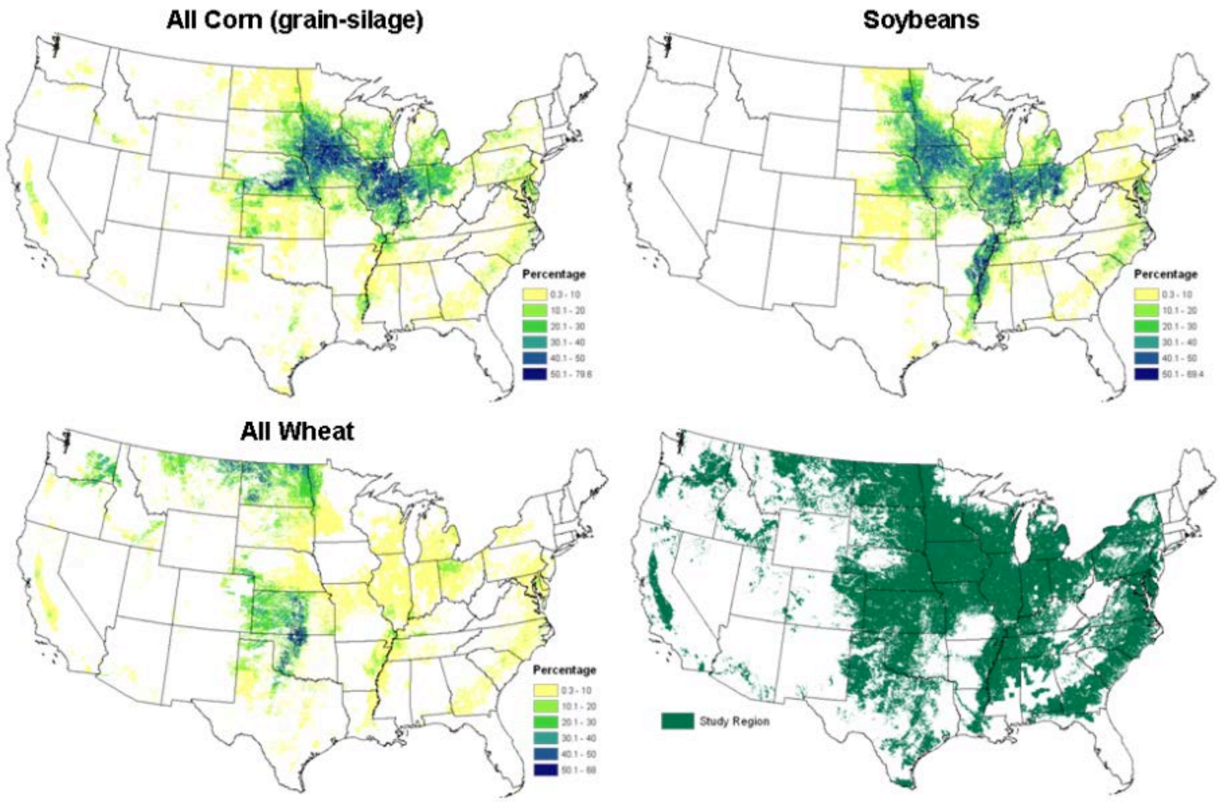
[5] Electric Power Research Institute, "Creating Nitrous Oxide (N2O) Emissions Offsets in Agricultural Crop Production in the United States: Background Paper for the EPRI Greenhouse Gas Emissions Offset Policy Dialogue Workshop #11" (November 2011).
[6] *Id.*
[7] Climate Action Reserve, "Nitrogen Management Project Protocol" (January 17, 2013).



Legal and public policy concerns

There are no significant legal barriers to farmers' usage of less nitrogen fertilizer. Nitrogen fertilizer use is not currently regulated at the national level for either emissions or runoff purposes, though some states have begun proposing or adopting regulations.[8] Farmers will need to provide documentation of their ownership of the land in question and records of their prior use of the land for at least five years.

The MSU-EPRI standard applies only to 12 north-central states, whose estimated annual technical potential for reducing emissions of N2O by reducing N fertilizer rate is the equivalent of approximately 6 million metric tons of carbon dioxide.[9] The California Air Resources Board has been considering adopting a nitrogen management standard that could reduce or eliminate additionality for projects in California, though the existing CAR protocol that allows maximum emissions credit based on regional data does not cover California. The prevalence of nitrogen

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[8] *See, e.g.*, Minnesota Department of Agriculture, "Proposed Nitrogen Fertilizer Rule," available at https://www.mda.state.mn.us/~/media/Files/chemicals/nfmp/nitrogenproprule.pdf (November 2016).

[9] Electric Power Research Institute, "Creating Greenhouse Gas Emissions Offsets by Reducing Nitrous Oxide (N2O) Emissions in Agricultural Crop Production: Experience Developing and Implementing the World's First On-Farm N2O Offset Project," July 2014 ("Experience Developing").

fertilizer use in those states and the absence of forthcoming regulation may make additionality most feasible in that area.

Business

Upfront costs are likely insignificant because the methodology is already developed and little or no capital equipment is required. Because the cost of nitrogen fertilizer is low compared to the potential cost of low crop yields, it is currently common to overuse fertilizer as a hedge. Consequently, paying farmers to use only as much fertilizer as can be justified by the best available scientific data likely has a reasonable cost.

Because corn farming is so widespread and this project requires little new equipment, it could be expanded across a significant range without new infrastructure. Farming groups and regional cooperatives could be good partners to help find individual farms interested in modifying their practices to become eligible for the credits this project would make available.

Successful N fertilizer reduction projects likely also depend on strong relationships with the farmers chosen to participate in the offset program. Such farmers should be commercial long-term corn producers and have interest in taking part in new environmental initiatives.[10] Ideally, farmers may even have taken part in similar programs before, to minimize the potential complexity of reporting and other requirements.

EPRI's report on the first pilot offset project involving nitrogen fertilizer reduction found that future projects should work to reduce verification cost and leverage greater scale. "The relatively high costs for validating/verifying new N2O mitigation and other N management-related offsets projects is a strong disincentive that can be expected to discourage crop producers from participating in these types of voluntary activities," the report found. "Only offset projects located on large aggregated parcels of land are likely to be able to generate the considerable volume of offsets (i.e., on the order of thousands of tons) needed to make a proposed project economically viable, particularly if validation costs remain high and carbon offset values remain low. The direct cost to validate/verify the MSU-EPRI Offsets Project was approximately $10,000. This does not include the substantially greater cost in terms of MSU staff time and the producer's time dedicated to developing, implementing and helping guide the project through registration, validation and verification. This figure also does not include any financial and other costs associated with developing the underlying MSU-EPRI N2O Offsets Methodology."[11]

Consequently, projects developed to reduce nitrogen fertilizer emissions will need to develop standardized, lower-cost processes for accounting as well as strategies to find farmer partners who control large parcels of land, maximizing the potential economies of scale of rolling out one fertilizer methodology across a significant area, rather than having to repeat the process several times with several farmers who each control less land area. Earlier experience also suggested that a key problem with the earlier project was that it required an investment from at least one party that lacked any incentive to make such an investment other than altruism. If a project in this field could bring such interested parties to the table, that could make these projects more viable.

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[10] Electric Power Research Institute, "Experience Developing."
[11] Electric Power Research Institute, "Experience Developing."

Public health

Nitrous oxide is not harmful to human health at normal concentrations found in the atmosphere, but inhalation of higher concentrations could limit oxygen and cause dizziness, nausea, or unconsciousness - particularly in enclosed spaces. Additionally, nitrous oxide emissions affect the ozone layer and decreased stratospheric protection can lead to higher exposure to UV rays, which cause skin cancers.

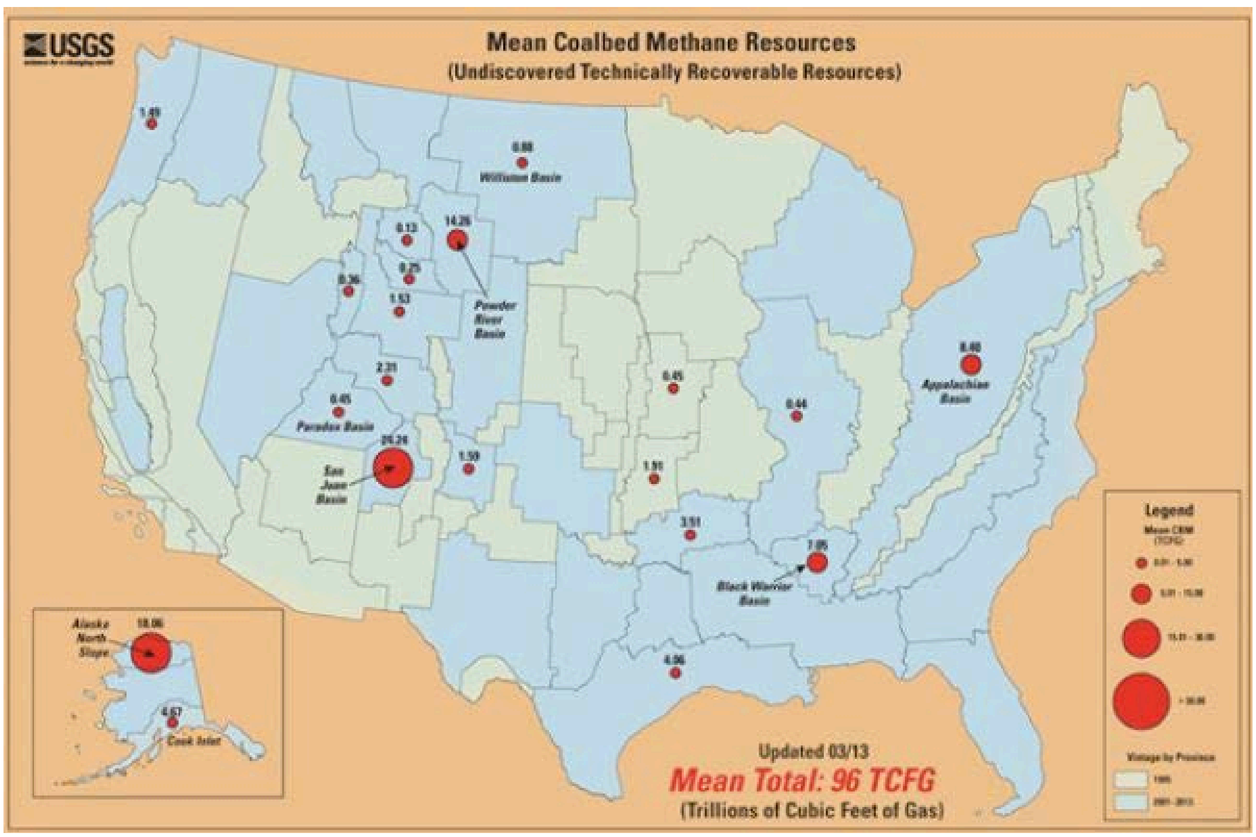
The proposed projects would also reduce agricultural nitrogen runoff, resulting in environmental and health benefits from reduced nitrogen leaching.

Summary

Reducing nitrous oxide emissions from agriculture is a promising project area. Reducing the usage rates of fertilizers that contribute to emissions is feasible from a technical standpoint, and validation procedures for agricultural nitrous oxide offsets have already been established. Interventions are relatively inexpensive, and there are no significant legal barriers.

2. Coalbed methane

Methane is a potent greenhouse gas, with a global warming potential that is 56 times that of carbon dioxide over a 20-year time horizon.[12] Coalbed methane (CBM) is naturally found in coal seams, formed during the process where plant material is transformed into coal. This methane is still naturally released in sites where mining is prevented, although at a lesser rate compared to methane releases associated with mining activities. Although coalbed methane is considered to be an unconventional source of natural gas, the methane resources from this source can be valuable and account for about 5% of total national natural gas production each year.[13] Many coal seams are located on Native American land, and are sites where it is important consider issues of environmental and social justice.



Source: U.S. Geological Survey, 2013

[12] Global Warming Potentials Table. 1995. United Nations Framework Convention on Climate Change. Accessed in March 2017 at http://unfccc.int/ghg_data/items/3825.php
[13] Coalbed Methane Outreach Project. 2016. Environmental Protection Agency. Accessed in March 2017 at: https://www.epa.gov/cmop/faq.html

Design and engineering

The magnitude of methane found in coal seams can be large. For example, with a methane seepage offset project in the Southern Ute Tribe in Colorado, an estimated net 60,359 tons of carbon dioxide equivalent was captured and used in 2015, with an estimated net 288,180 tons of carbon dioxide equivalent reduced or removed in total over the 10-year project period.[14] In a methane capture and utilization project, the quantity of the greenhouse gas that would have gone into the atmosphere can be more easily established.

One of the major challenges with coalbed methane projects, however, is the cost of the infrastructure required to capture methane seepage from a large area and concentrate it for use. For example, a large active soil vapor extraction (SVE) unit could cost upwards of $80,000, and installing a positive pressure blower within a sealed space and sealing the space could cost $10,500 for 1,500 square feet.[15] There is also a wide variance in how invasive as well as how proven are the technologies that are currently available.

Validation procedures for methane seepage offsets have already been established by Verified Carbon Standard, which was used by Southern Ute project. American Carbon Registry is also able to register methane capture, flare and utilization projects. However, coal mine methane protocols are more common and unfortunately coalbed methane projects are often not eligible, which is the situation with Climate Action Reserve. These standards include meaningful monitoring standards to ensure that the intended results are achieved. The project will need to establish which offset best serves its purposes and be certain to mandate contractually the use of that offset's measurement standards.

Legal and business

Methane utilization can bring in revenue to contribute towards covering the costs of methane capture. Additional financing options include low-interest loans and grants. In addition to the large capital cost, the feasibility of coalbed methane projects from a legal and business standpoint depend greatly on the specifics of the site context. For this reason, given the length of time remaining in the semester and the lack of a concrete site partner, this project would be difficult for our student team to undertake at this time. There are a large number of potential coal mining sites under dispute, which could be candidates for land conservation or methane capture project. A challenge would be that these sites have different interested stakeholders, so each site may require substantial effort to reach project agreement.

In general, participating communities need to provide documentation of their ownership of the land in question. For land owned by a federally-recognized tribe, the emissions are also owned by the tribe and could be sold by the tribe. In the Southern Ute project example, credits were only sold in the voluntary carbon market and not used for any compliance programs. Also important to note is that in the first year of operation, sufficient revenue was not brought in to

[14] Mike Huisenga, WSP Environment & Energy. 2012. Southern Ute Indian Tribe Westside CBM Capture and Use Project. Version 10 Reissue.
[15] LT Environmental, Inc. 2006. Preliminary Evaluation of Methane Seepage Mitigation Alternatives.

cover the expenses for contracted operations and maintenance. The gas price often needed to be relatively high, in order for the cash flow to be positive. If common infrastructure from established natural gas producers are used, as they have been in the Southern Ute project, additional permits would be needed to cover burning engine compressors, reboilers, and process heating equipment.

To establish additionality in the Southern Ute project, VM0014 and the "Combined tool to identify the baseline scenario and demonstration of additionality" V 3.0 was used. The project was evaluated against tests for additionality to ensure that the project reduces anthropogenic GHG emissions to a level above and beyond what would have occurred in the absence of the project activity, or compared to the project baseline. In this project, the established criteria included ensuring that new instances being evaluated for regulatory additionality were only eligible when the price of natural gas was below $6.24 per thousand cubic feet.[16]

Public policy

No legislation currently exists that covers coalbed methane seepage, nor is likely to come to pass in the foreseeable future given the current political administration. Legislation that is passed in the future may also not be enforceable on tribal lands, so there may not be a requirement to address coalbed methane emissions.

Public health

One primary concern with coalbeds methane migration into residential neighborhoods. Methane release can negatively impact surrounding communities; people exposed to high levels of methane have reported nausea, headaches, eye irritation, asthma aggravation and nose bleeds. Methane release may also create hazards when entering structures, including explosion risks that can endanger human welfare. Production of methane from coalbeds could help reduce emissions by removing methane that would otherwise be released to the atmosphere during coal mining.[17] Preventing coal mining in Native American communities has other health benefits, such as by reducing potential air and water pollution. The safe disposal of water used in coal production is a major challenge, and a point of dispute in several communities located near coal production.

Summary

Although addressing methane seepage from coalbeds is an important issue, the legal and financial challenges associated with such projects are substantial. Given the high degree of variance between coal seam sites and the dependence on stakeholder engagement, it is more appropriate to explore a coalbed methane project after selecting a specific site and partner organizations.

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[16] Mike Huisenga, WSP Environment & Energy. 2012. Southern Ute Indian Tribe Westside CBM Capture and Use Project. Version 10 Reissue.

[17] U.S. Geological Survey. Coalbed Methane: Potential and Concerns. Accessed at https://pubs.usgs.gov/fs/fs123-00/fs123-00.pdf

Team III: Potent greenhouse gas reduction project
Appendix: Screening and feasibility assessment on potential projects

3. Landfill methane

Landfills that store municipal solid waste (MSW) emit large amounts of gas to the atmosphere as the stored material decomposes. This emission, known as landfill gas (LFG), can consist of 50% methane, a greenhouse gas that has a global warming potential of over 80 times that of carbon dioxide. LFG are such a large source of methane that they represent 20% of US methane emissions, even though the EPA has imposed regulation requiring large landfills to capture the gas. The rate at which a particular landfill is emitting LFG, and the exact composition of that gas, vary depending on a number of factors, including size and design of the landfill, weather conditions, and age and composition of the waste. Models exist, such as the EPA's LandGEM, that use these variables to predict emissions from particular landfills over time. Using these tools, the EPA estimates that, for every 1 million tons of MSW in a landfill without a capture system, an average of 430,000 cubic feet of landfill gas is emitted to the atmosphere. According to the EPA's landfill outreach program (LORP), there are still a large number of landfills that do not have adequate LFG capture systems, and a portion of these emit more than 50 thousand tons CO_2e of methane a year.

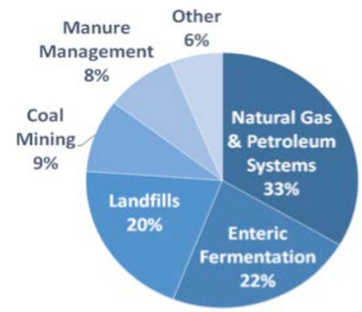

Figure 1: US methane emissions by sector. [Source: Greenhouse Gas Inventory Report 1990-2014]

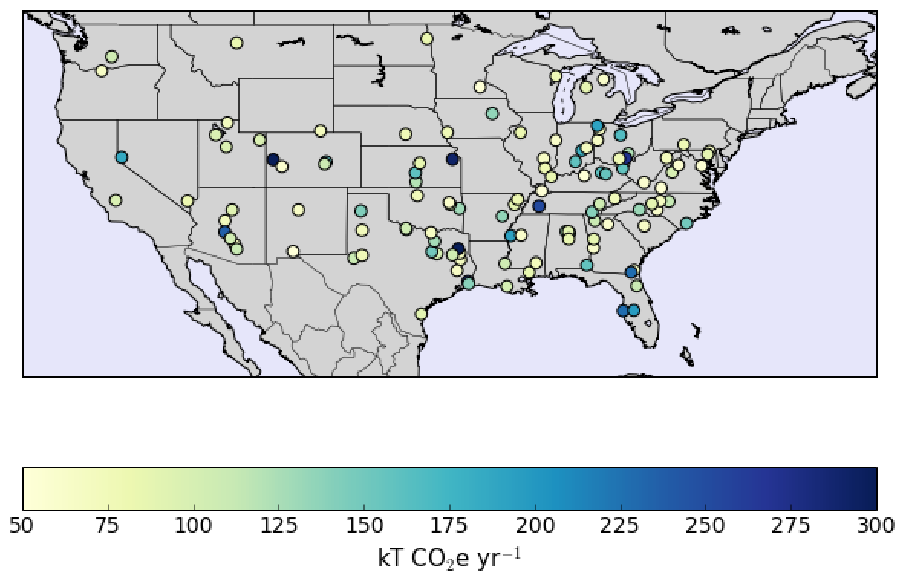

Figure 2: US Landfills with significant fugitive methane emissions. [Source: EPA LORP]

Design and engineering

A typical landfill gas capture system consists of an array of wells that pump the gas into a central storage tank. Once the LFG is in that tank, it can be dealt with in a number of ways. Emissions from a landfill containing 1 million tons of MSW could be used to generate about 800 kilowatts of electricity if fed into a turbine. This electricity could be used directly by the landfill site, and excess can be sold to the grid. There are additional possible uses for the captured LFC, as shown in Figure 3.

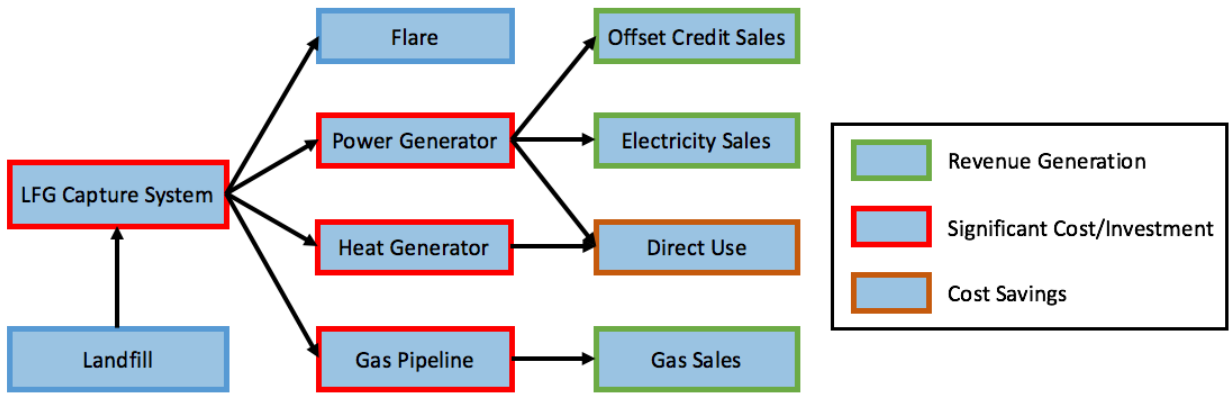

Figure 3: Schematic of possible uses of captured LFG

Direct-use projects utilizing LFG include heating; ethanol and vehicle fuel (LNG or CNG) production; and kilns for glassblowing, pottery, and blacksmithing operations. The difficulty in designing direct-use systems is that a specific type of operation (like an ethanol plant) needs to be located close to the landfill, making each of this projects unique and not scalable.

Legal

There is both state and national regulation pertaining to landfills. Pursuant to regulations promulgated by EPA under the Resource Conservation and Recovery Act, new landfills must be lined as part of their construction, and covered once they are decommissioned.[18] This regulation is done under the Resource Conservation and Recovery Act. The EPA also regulates methane emissions from landfills under the Clean Air Act. As of August 2016, municipal solid waste (MSW) landfills that contain over 2.5 million cubic meters (or 2.5 million metric tons) of waste must install technology that captures methane. Once captured, the methane can either be flared or used in electricity or heat generation.

Business

The cost of installing methane capture systems depends on the size of the landfill and how the gas is used after capture. If there is no capture system on the landfill, the EPA estimates that the cost of installing the capture system and a 3 Megawatt turbine would be approximately $8.5 million. The electricity from the turbine could then be sold into the grid, however this won't cover the high initial cost, and the system is projected to have a net loss of about $3.5 million by the end of its 15-year lifetime. This also generates offsets. The American Carbon Registry, the Climate Action Reserve, and the Verified Carbon Standard all have systems in place to generate offsets from LFG capture utilization. Heat generation systems and systems that directly use the methane for industrial purposes are cheaper than power generators, but the methane cannot be transported without pipelines or truck transport, which would be an increased cost.

[18] *See generally* 40 C.F.R. § 258.

Installing electricity or heat generation on pre-existing capture systems is much less expensive, and can be profitable. However, although the generation of electricity or heat from this methane could offset greenhouse gas emissions, it does not result in less methane being emitted to the atmosphere, and is therefore not aligned with the goals of this project.

Public policy

Because the EPA requires all landfills of a certain size to practice landfill gas capture, it is difficult to envision a project that reduces methane emissions by addressing landfills. The EPA also has a program, known as the Landfill Methane Outreach Program (LMOP) which promotes the adoption of technologies to use the captured gas for electricity generation and other purposes.

Public health

Direct emissions of methane from landfills may be in low enough concentrations to not be a direct public health concern. However, there are other components of LFG that are harmful, and landfill gas capture systems have been shown to reduce levels of these pollutants. Electricity that is generated by LFC can be used to offset emissions by more toxic conventional power plants, such as coal.

Summary

Although fugitive emissions from landfills are a significant source of methane in the atmosphere (accounting for a third of US anthropogenic methane emissions), legislation and strong government outreach to address this problem already exists. It would be difficult and expensive, though not impossible, to devise a project that could reduce methane emissions from SMW landfills.

PROJECT SELECTION

The results of the feasibility analysis brought agricultural nitrous oxide to the forefront of challenges to tackle for our final project, based on the relatively lower cost of design and engineering interventions, more straightforward legal considerations, contacts with possible partner organizations and potential scalability across farms. We also believe that the nitrous oxide option has the potential to address a segment of greenhouse gas emissions that currently goes largely unaddressed, while also creating significant environmental and public health co-benefits. Our team will focus on reducing nitrous oxide emissions from agriculture, but recommend that future teams continue to screen projects around reducing methane from landfills or coalbeds.

<u>Appendix</u>

Contacts for coalbed methane (CBM) projects

Looking to the future, potential partners for coalbed methane projects include Native American communities where residents wish to prevent mining or mining expansion, but also need to consider generation of economic resources, so methane capture and use could be an alternative that is of interest. Example sites include coal seams in the Navajo, Hopi, Cheyenne, and Crow Nations. Our team has preliminary contacts in the Navajo Nation, including community coalitions, local universities and local offices of federal departments, who are interested in working to prevent additional mining and capture methane from un-mined sites.

Navajo Technical University: http://www.navajotech.edu/
Black Mesa Water Coalition: http://www.blackmesawatercoalition.org/
Navajo Land Department: http://www.dinehbikeyah.org/
U.S. Department of the Interior Bureau of Indian Affairs Navajo Regional Office:
https://www.indianaffairs.gov/WhoWeAre/RegionalOffices/Navajo/index.htm

Another potential partner is Harvard's Four Directions Summer Research Program, which brings Native American undergrads to Boston for the summer to explore careers in medicine and public health under the supervision of staff from HMS and Brigham & Women's Hospital. Involving students from this program in analyzing the public health impacts of a coalbed methane project could be an innovative cross-campus partnership.

We recommend that the next team leverages these and other contacts, such as from the Harvard University Native American Program led by Professor Dennis Norman, to select specific sites to screen the feasibility of potential coalbed methane projects.