



United States Environmental Protection Agency  
Office of Atmospheric Programs (6207J)  
Washington, DC 20005

EPA-430-S1-4-002  
April 2014

# Mitigation of Non-CO<sub>2</sub> Greenhouse Gases in the United States: 2010 to 2030







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## Introduction

Climate change is influenced by a number of social and environmental factors. The change in the Earth's climate is largely driven by emissions of greenhouse gases (GHGs) to the atmosphere. Although some GHG emissions occur through natural processes, the largest share of GHG emissions come from human activities. GHG emissions from anthropogenic sources have increased significantly over a relatively short time frame (~100 years) and are projected to grow appreciably over the next 20 years.

Policy development and planning efforts are underway at all levels of society to identify climate change strategies that effectively reduce future GHG emissions and prepare communities to adapt to the Earth's changing climate. GHG mitigation analysis continues to play an important role in forming climate change policy. A large body of research has been dedicated to analyzing ways to reduce carbon dioxide (CO<sub>2</sub>) emissions.

Although this work is critical to developing effective climate policy, other GHGs can play an important role in the effort to address global climate change. These noncarbon dioxide (non-CO<sub>2</sub>) GHGs include methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and a number of industrial gases such as fluorinated gases.

Non-CO<sub>2</sub> GHGs are more potent than CO<sub>2</sub> (per unit weight) at trapping heat within the atmosphere. Global warming potential (GWP) is the factor that quantifies the heat-trapping potential of each GHG relative to that of CO<sub>2</sub>. For example, CH<sub>4</sub> has a GWP value of 21, which means that each molecule of CH<sub>4</sub> released into the atmosphere is 21 times more effective at trapping heat than an equivalent unit of CO<sub>2</sub>. The table shows the list of GHGs with their GWP values that are considered in this report.

Marginal abatement cost curves (MACC) are an analytical tool commonly used in mitigation analysis to assist policy makers in understanding the opportunities for reducing

GHG emissions and the relative cost of implementing these opportunities. MACCs provide information on the amount of emissions reductions that can be achieved and an estimate of the costs of implementing the GHG abatement measures. This figure shows the MACC for all non-CO<sub>2</sub> GHGs in the United States in 2030. The potential for cost-effective non-CO<sub>2</sub> GHG abatement is significant. The figure shows the U.S. total aggregate MACC for the year 2030. The U.S. total mitigation potential is 569 million metric tons of CO<sub>2</sub> equivalent (MtCO<sub>2</sub>e), or 43% of baseline non-CO<sub>2</sub> emissions in 2030, or 11% of the total net U.S. GHG emissions in 2005. As the break-even price rises, the mitigation potential grows. Significant mitigation opportunities could be realized in the lower range of break-even prices. For example, the mitigation potential at a price of \$10/tCO<sub>2</sub>e is greater than 360 MtCO<sub>2</sub>e, or 27% of the baseline emissions, and greater than 417 MtCO<sub>2</sub>e or 31% of the baseline emissions at \$20/tCO<sub>2</sub>e. In the higher range of break-even prices, the MAC becomes steeper, and less mitigation potential exists for each additional increase in price.

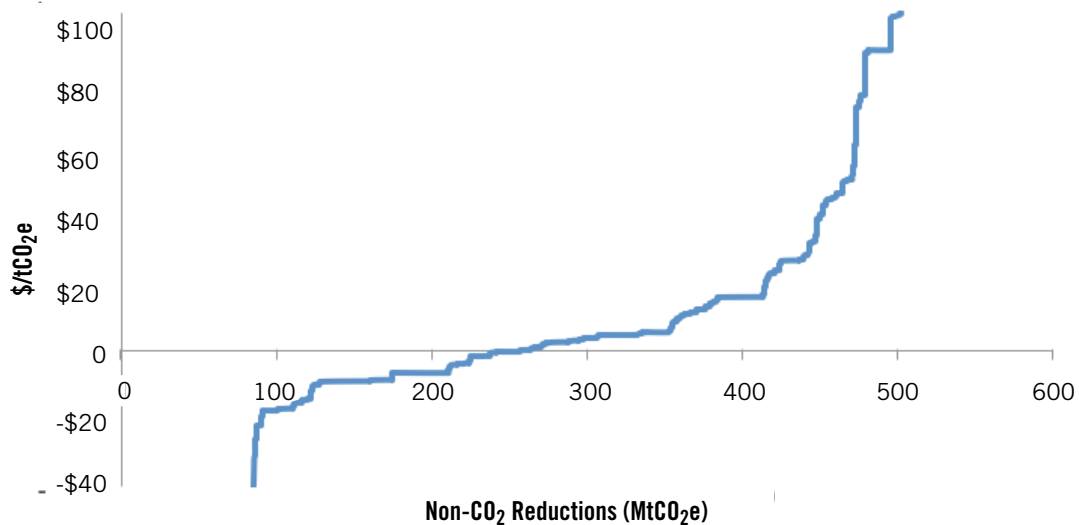
As the figure shows, higher levels of emissions reductions are achievable at higher abatement costs expressed in dollars per metric ton of CO<sub>2</sub> equivalent (\$/tCO<sub>2</sub>e) reduced. The quantity of emissions that can be reduced, or the abatement potential, is constrained by the availability and effectiveness of the abatement measures (emissions reduction technologies).

Greenhouse Gases	Abbreviation	GWP* (100 year)
Carbon Dioxide	CO <sub>2</sub>	1
Methane	CH <sub>4</sub>	21
Nitrous Oxide	N <sub>2</sub> O	310
Hydrofluorocarbons	HFCs	140 to 11,700
Sulfur Hexafluoride	SF <sub>6</sub>	23,900

\*GWP values from IPCC 4th Assessment Report (AR4)



## United States MACC for Non-CO<sub>2</sub> Greenhouse Gases in 2030



### About this Report

This report highlights the United States' mitigation potential from non-CO<sub>2</sub> emitting sectors. These results come from a broader study that the U.S. Environmental Protection Agency (EPA) recently completed. The study served to update the agency's international MACC model for the major anthropogenic sources of non-CO<sub>2</sub> GHG emissions, which include the energy, waste, industrial, and agricultural sectors. EPA used the model to conduct a follow-on study to the 2006 EPA report *Global Mitigation of Non-CO<sub>2</sub> Greenhouse Gases*. The updated model includes improved spatial resolution (country level rather than broad regions), updated data and parameters, and increased transparency in the economic and technological assumptions underlying the abatement measures considered in the analysis. A detailed methodological description and the full results of this analysis are published in the EPA report *Global Mitigation of Non-CO<sub>2</sub> Greenhouse Gases: 2010-2030*. This summary report focuses on the United States, providing a brief overview of the abatement potential and costs of implementing specific abatement technologies nationally. Readers interested in more technical details of the analysis should refer to the full technical report, which is available at EPA's web page on International Non-CO<sub>2</sub> Mitigation.<sup>1</sup>

<sup>1</sup>The Global Mitigation of Non-CO<sub>2</sub> Greenhouse Gases: 2010-2030 report is available at: <http://www.epa.gov/climatechange/EPAactivities/economics/nonco2mitigation.html>

# Coal Mining

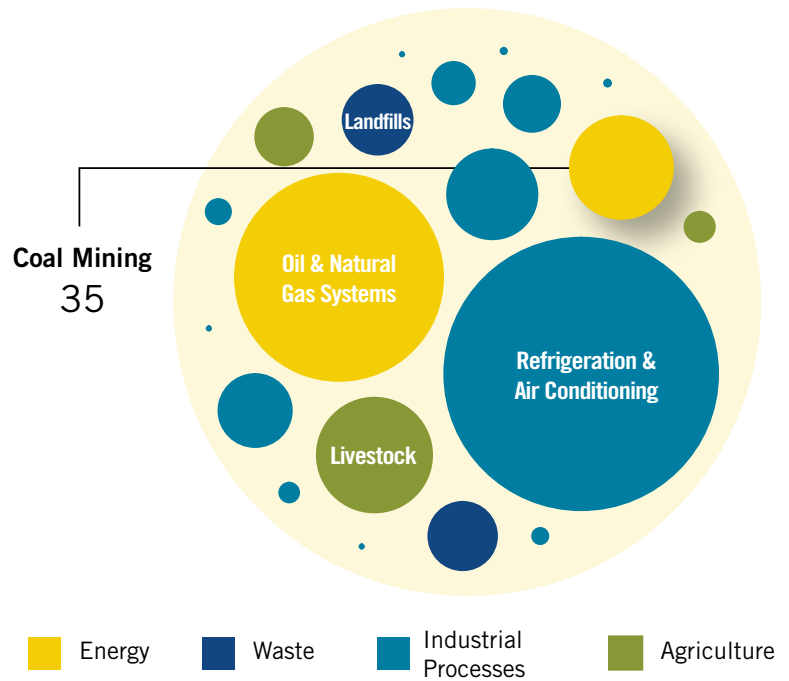
## CH<sub>4</sub> Emissions from Underground Coal Mining

### Sector Description

Coal is an important energy source for many of the world's economies; it is used for energy generation or as a feedstock for industrial production. However, coal mining is a significant source of anthropogenic GHG emissions. Extracting coal through underground and surface mining releases CH<sub>4</sub> stored in the coal bed and the surrounding geology.

### Emissions Reduction Potential

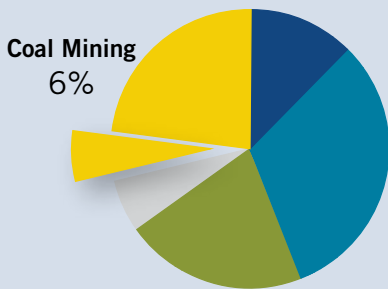
Assuming full implementation of current technology, emissions in the United States' coal mining sector could be reduced by up to 34.5 MtCO<sub>2</sub>e in 2030. This accounts for 6% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in global reduction potential in 2030.



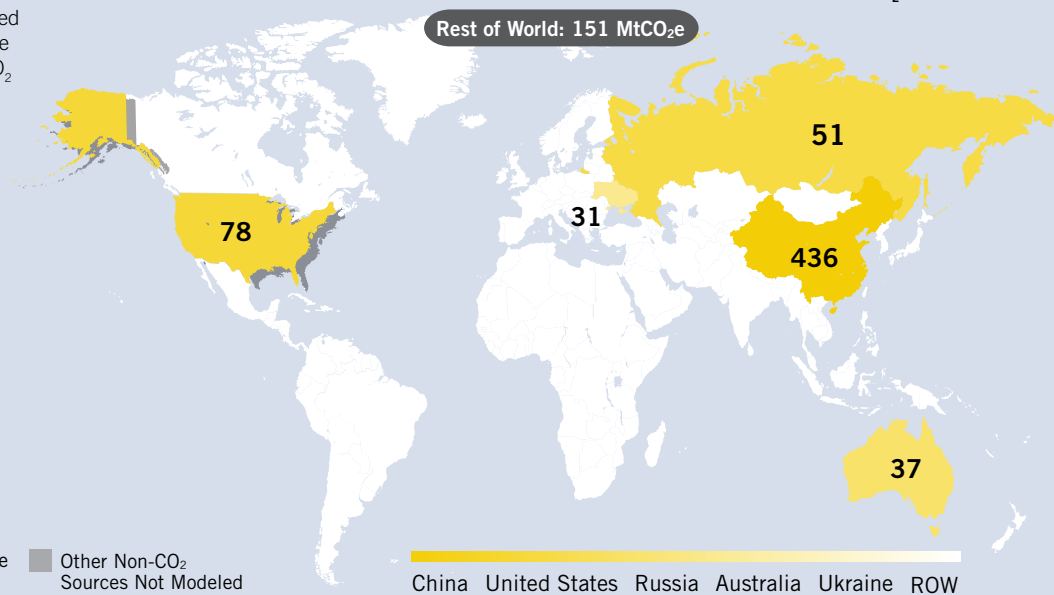
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Coal Mining sector baseline emissions are estimated to be 67 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 78 MtCO<sub>2</sub>e, or 6% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)

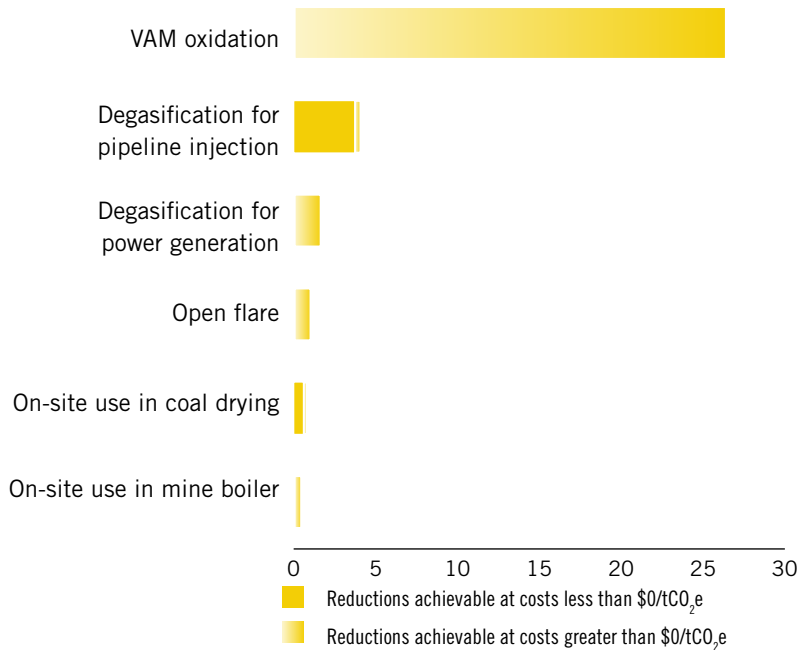


# Key Points

- Coal mining accounted for 9% of total U.S. anthropogenic CH<sub>4</sub> emissions in 2010; these emissions are projected to increase by 16% to 78 MtCO<sub>2e</sub> by 2030.
- The U.S. abatement potential is projected to be 35 MtCO<sub>2e</sub>, or 44% of baseline emissions from coal mining, in 2030.
- Cost-effective abatement potential (\$0 break-even price) is 5 MtCO<sub>2e</sub>, or 6% of baseline.

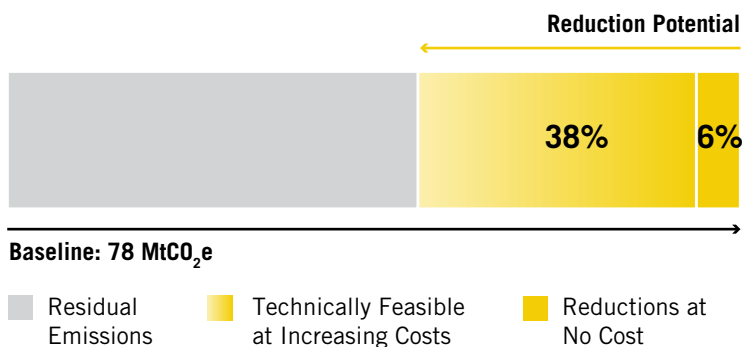
## Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2e</sub> and at higher prices.



## Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 6%, compared with the baseline, in 2030. An additional 38% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Five abatement measures were considered in this analysis: recovery for pipeline injection, power generation, process heating, flaring, and catalytic or thermal oxidation of ventilation air methane (VAM). These reduction technologies consist of one or more of the following primary components: (1) a drainage and recovery system to remove CH<sub>4</sub> from the underground coal seam, (2) the end-use application for the gas recovered from the drainage system, and (3) the VAM recovery or mitigation system.

## Abatement Potential

Approximately 44% of total annual coal mining related CH<sub>4</sub> emissions in 2030 can be reduced by adopting the suite of abatement measures considered. The MACC results suggest that significant reductions in CH<sub>4</sub> emissions can be achieved at break-even prices at or below \$10/tCO<sub>2e</sub>. Nearly 5 MtCO<sub>2e</sub> are cost-effectively achievable at a break-even price of \$0/tCO<sub>2e</sub>.



# Oil and Natural Gas Systems

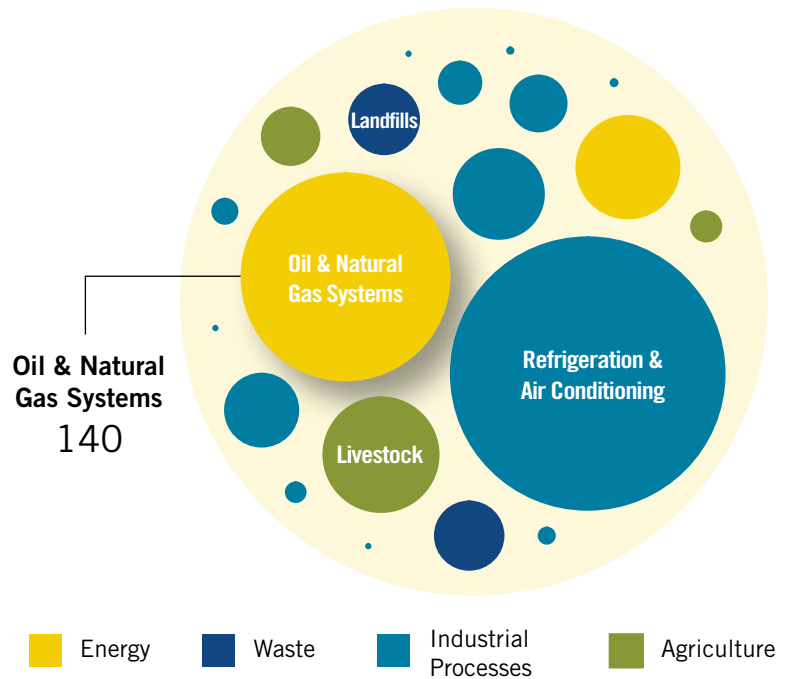
## CH<sub>4</sub> Emissions from Oil and Natural Gas Systems

### Sector Description

Oil and natural gas systems are one of the leading emitters of anthropogenic CH<sub>4</sub>, releasing over 140 MtCO<sub>2</sub>e, or 23% of total U.S. CH<sub>4</sub> emissions in 2010. CH<sub>4</sub> emissions from the oil and natural gas system are projected to grow 26% between 2010 and 2030. Future growth is largely due to the continued expansion of domestic oil and natural gas production in the United States.

### Emissions Reduction Potential

Assuming full implementation of current technology, emissions in the United States' oil and natural gas systems sector could be reduced by up to 140 MtCO<sub>2</sub>e in 2030. This accounts for 25% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



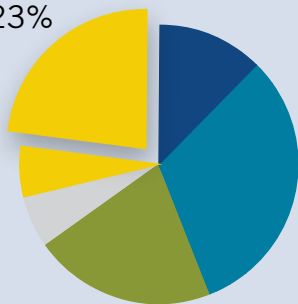
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

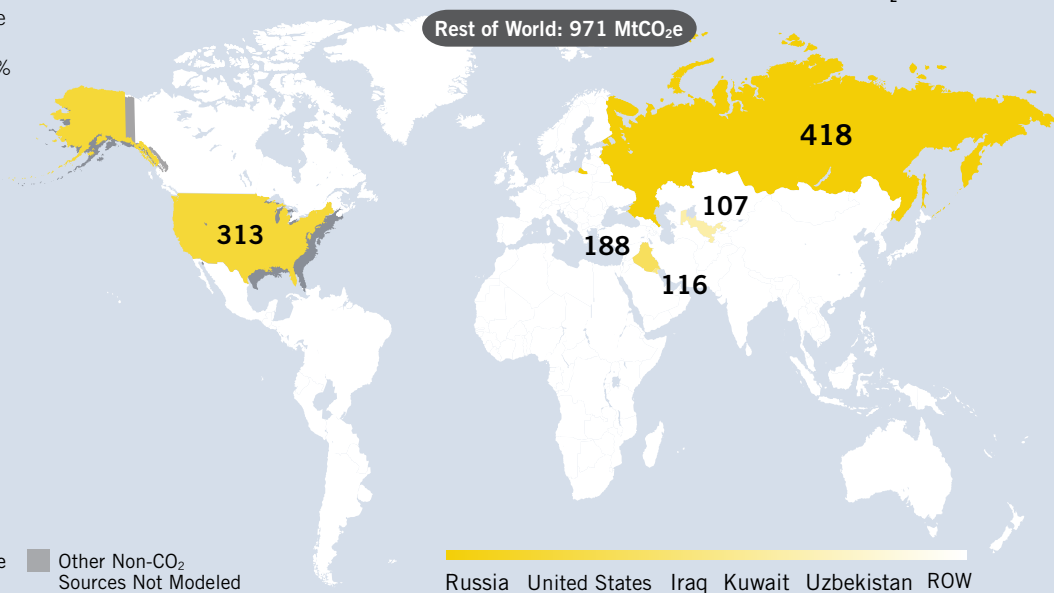
Oil and Natural Gas sector baseline emissions are estimated to be 248 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 313 MtCO<sub>2</sub>e, or 23% of total non-CO<sub>2</sub> emissions.

#### Oil & Natural Gas Systems

23%



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)

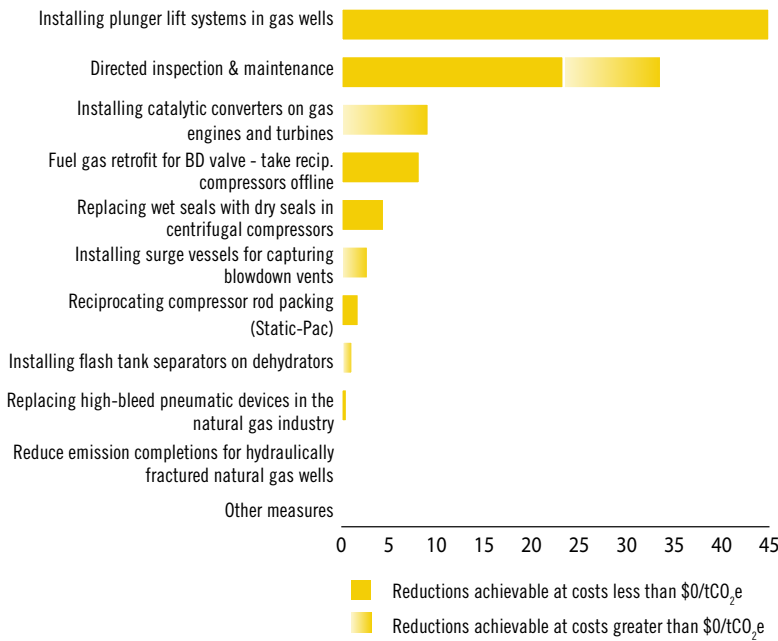


# Key Points

- The technological maximum for emissions reduction potential in oil and natural gas systems in the United States is 141 MtCO<sub>2</sub>e, approximately 45% of projected oil and gas related CH<sub>4</sub> emissions in 2030.
- Because of the energy value of the CH<sub>4</sub> captured, EPA estimates that 84 MtCO<sub>2</sub>e, or 27% of the baseline emissions, can be cost-effectively reduced.
- Over 45% of abatement potential is achieved by adopting abatement measures in the oil and gas production segments.

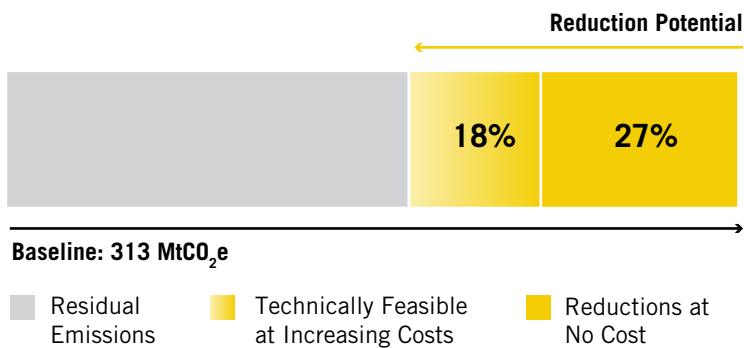
## Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



## Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 27%, compared with the baseline, in 2030. An additional 18% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Numerous abatement measures are available to mitigate CH<sub>4</sub> emissions across the four oil and natural gas system segments of production, processing, transmission, and distribution. The measures can be applied to various components or equipment commonly used in oil and natural gas system segments. The abatement measures typically fall into three categories: equipment modifications/upgrades; changes in operational practices, including direct inspection and maintenance; and installation of new equipment.

## Abatement Potential

In 2030, the abatement potential in the U.S. oil and natural gas systems sector is projected to be 140.6 MtCO<sub>2</sub>e, or 45% of total non-CO<sub>2</sub> emissions. The abatement potential drops over time to 126 MtCO<sub>2</sub>e in 2020 before rising back to 140 MtCO<sub>2</sub>e in 2030. Over 70% of the emissions reductions in 2030 are achievable at prices at or below \$15.

# Landfills

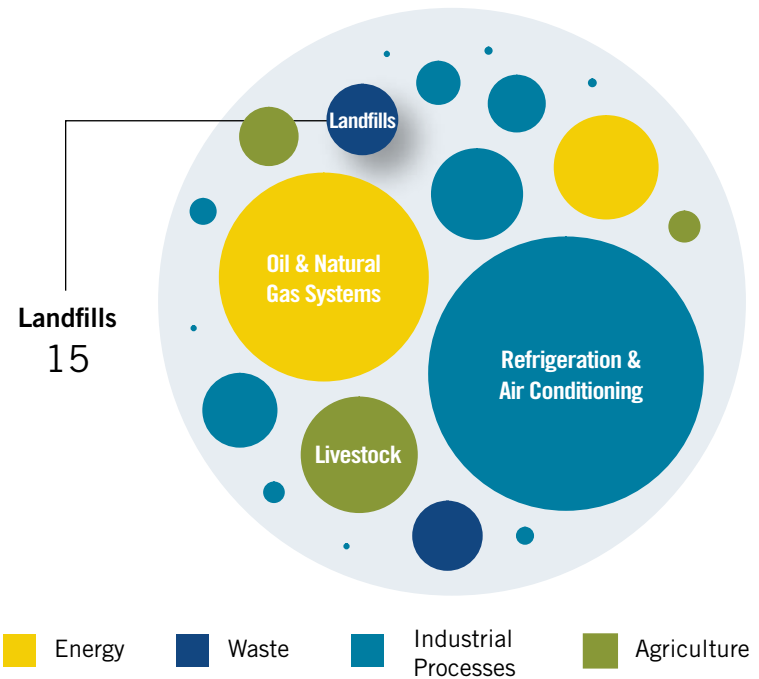
## CH<sub>4</sub> Emissions from Municipal Solid Waste (MSW) Landfills

### Sector Description

Landfills produce CH<sub>4</sub> in combination with other landfill gases (LFGs) through the natural process of bacterial decomposition of organic waste under anaerobic conditions. LFG is generated over a period of several decades with gas flows usually beginning 1 to 2 years after the waste is put in place. The amount of CH<sub>4</sub> generated by landfills per country is determined by a number of factors that include population size, the quantity of waste disposed of per capita, composition of the waste disposed of, and the waste management practices applied at the landfill.

### Emissions Reduction Potential

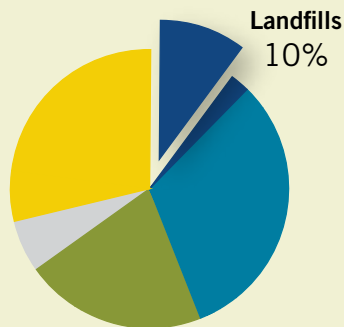
Assuming full implementation of current technology, emissions in the United States' landfill sector could be reduced by up to 14.6 MtCO<sub>2</sub>e in 2030. This accounts for 3% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



### Projected Emissions in 2030

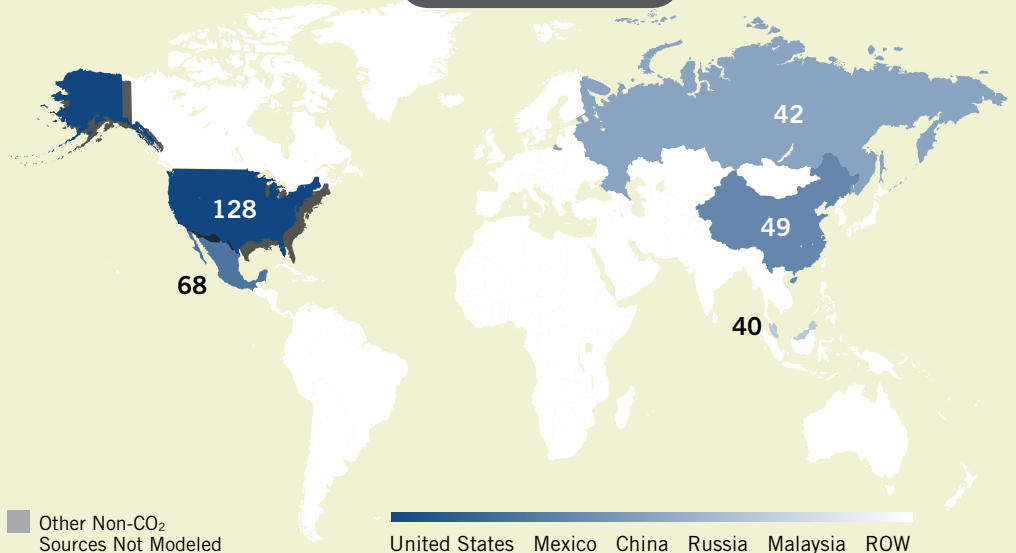
#### Global Non-CO<sub>2</sub> Emissions

Landfill sector baseline emissions are estimated to be 130 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 128 MtCO<sub>2</sub>e, or 10% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)

Rest of World: 632 MtCO<sub>2</sub>e





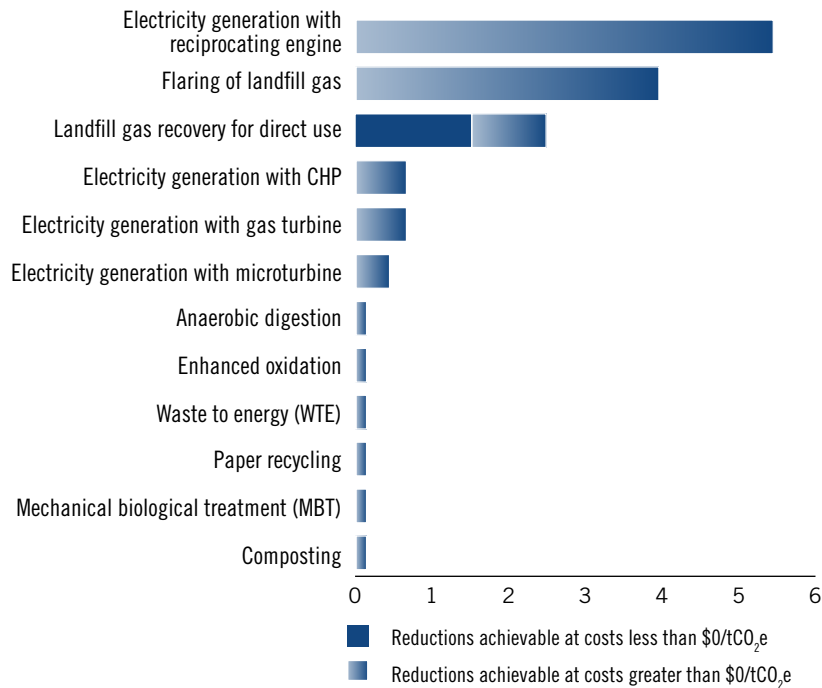


# Key Points

- Abatement potential from U.S. landfills is 15 MtCO<sub>2</sub>e, roughly 11% of projected landfill baseline emissions in 2030.
- Abatement measures with costs below \$20/tCO<sub>2</sub>e can achieve a 9% reduction in baseline emissions.
- Abatement measures include (1) conversion of landfill gas to energy and (2) waste diversion projects that use waste in the production of new products.

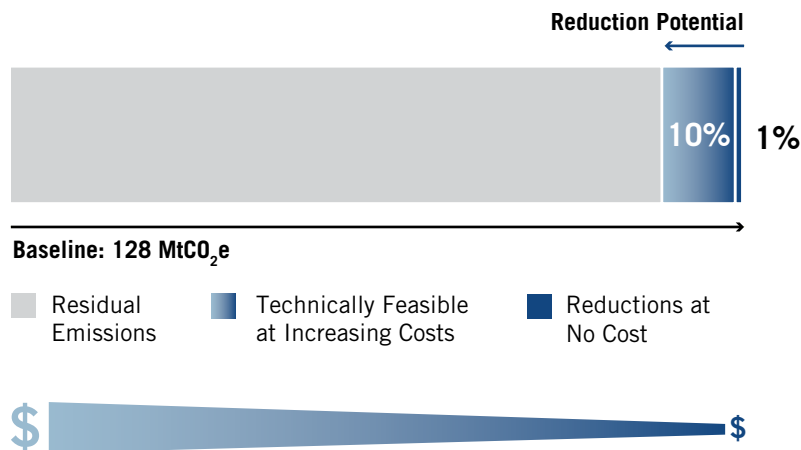
## Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



## Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 1.3%, compared to the baseline, in 2030. An additional 10% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Several abatement measures are available to control landfill CH<sub>4</sub> emissions, and they are commonly grouped into three major categories: (1) collection and flaring, (2) LFG utilization systems (LFG capture for energy use), and (3) enhanced waste diversion practices (e.g., recycling and reuse programs). Although flaring is currently the most common abatement measure, LFG utilization options may be more cost-effective. Under favorable market conditions, recycling and reuse or composting alternatives may provide additional means for reducing emissions from landfills.

## Abatement Potential

Abatement potential in the solid waste landfill sector is estimated to be approximately 14.6 MtCO<sub>2</sub>e of total annual emissions in 2030, or 11% of U.S. landfill baseline emissions. The MACC results suggest that there are significant opportunities for CH<sub>4</sub> reductions in the landfill sector at costs below \$20 per tCO<sub>2</sub>e of emissions reduced. Furthermore, approximately 1.7 MtCO<sub>2</sub>e of reductions are cost-effective.

# Wastewater

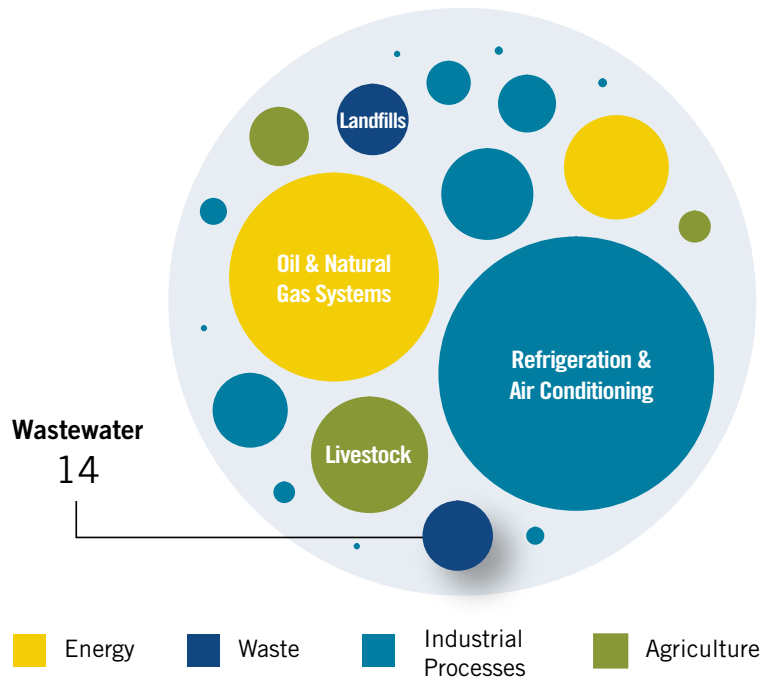
## CH<sub>4</sub> Emissions from Municipal Wastewater Systems

### Sector Description

Wastewater is the sixth largest emitter of anthropogenic CH<sub>4</sub> in the United States, accounting for 25 MtCO<sub>2</sub>e in 2010; wastewater treatment is also a source of N<sub>2</sub>O emissions. Domestic and industrial wastewater treatment activities can lead to venting and fugitive emissions of CH<sub>4</sub>, which are produced when organic material decomposes under anaerobic conditions of wastewater in a facility. Developed countries like the United States use aerobic wastewater treatment systems to minimize the amount of CH<sub>4</sub> generated.

### Emissions Reduction Potential

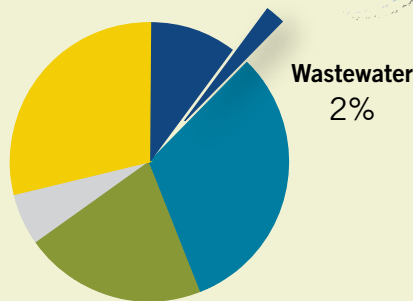
Assuming full implementation of current technology, emissions in the United States' wastewater sector could be reduced by up to 14 MtCO<sub>2</sub>e in 2030. This accounts for 3% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



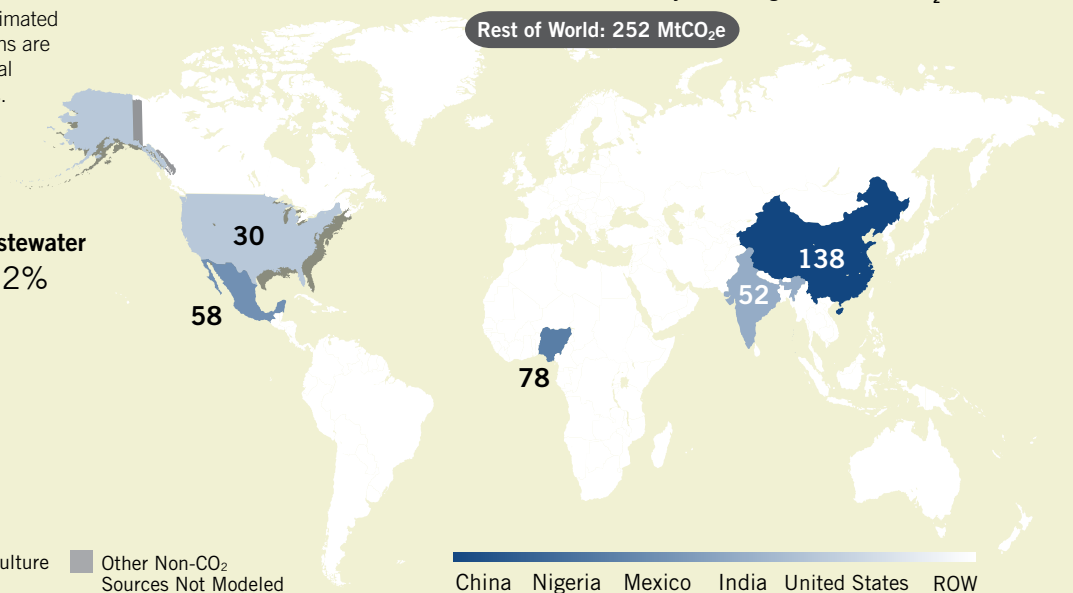
### Projected Emissions in 2030

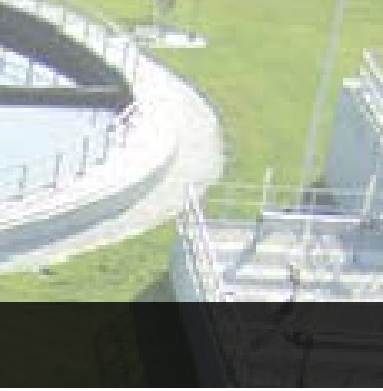
#### Global Non-CO<sub>2</sub> Emissions

Wastewater sector baseline emissions are estimated to be 25 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 30 MtCO<sub>2</sub>e, or 2% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)



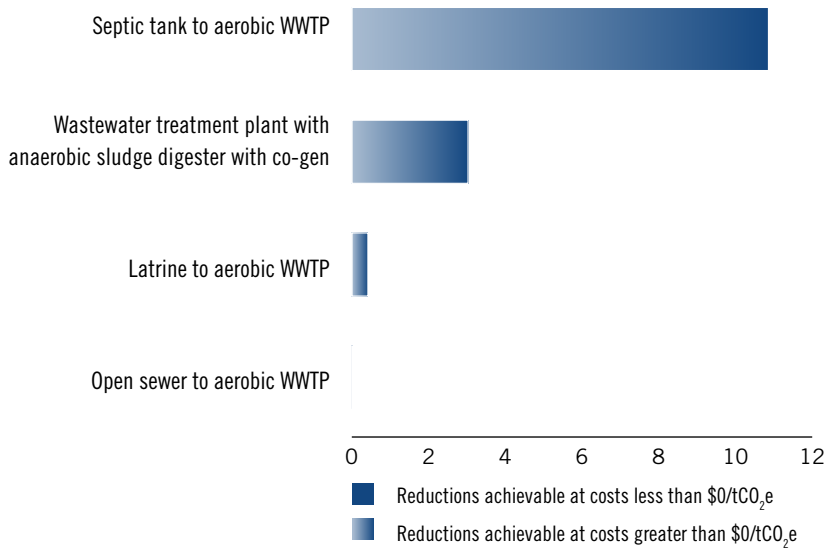


## Key Points

- U.S. CH<sub>4</sub> emissions from wastewater treatment accounted for 25 MtCO<sub>2</sub>e in 2010 and are projected to grow 20% by 2030.
- The estimated maximum abatement potential in 2030 is 14 MtCO<sub>2</sub>e, or 48% of projected wastewater emissions.
- Given the existing level of wastewater treatment infrastructure present in the United States, options for reducing emissions in this sector are limited to the highest cost abatement measures.

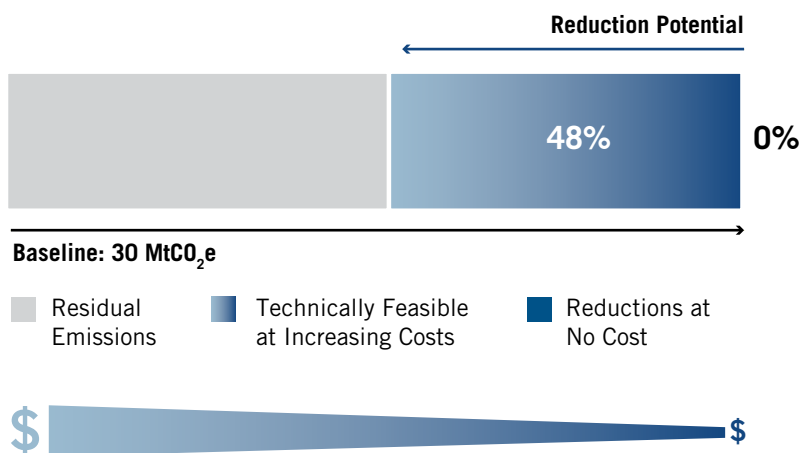
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

There are no cost-effective reductions available in the wastewater sector in 2030. However, a 48% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

CH<sub>4</sub> emissions from wastewater can be significantly reduced by improving infrastructure and equipment.

Abatement measures available in the wastewater sector include installing aerobic wastewater treatment plants on an individual or centralized scale and installing anaerobic wastewater treatment plants with cogeneration. Factors such as economic resources, population density, government, and technical capabilities are important in determining the potential for mitigating emissions from the wastewater sector.

## Abatement Potential

The U.S. abatement potential of CH<sub>4</sub> from wastewater treatment is 10 MtCO<sub>2</sub>e in 2020 rising to 14 MtCO<sub>2</sub>e in 2030. This level of CH<sub>4</sub> mitigation is considered to be the technological maximum abatement potential because high-cost abatement measures in the wastewater treatment sector significantly constrain the abatement achievable at lower carbon prices.



# Nitric and Adipic Acid Production

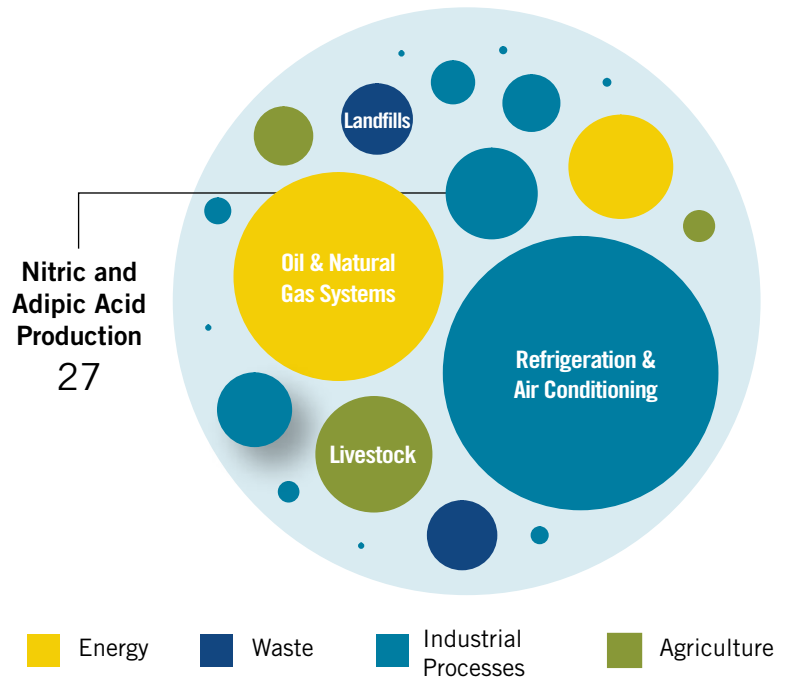
## N<sub>2</sub>O Emissions from Nitric and Adipic Acid Production

### Sector Description

Nitric and adipic acid are commonly used as feedstock in manufacturing a variety of commercial products, particularly fertilizer and synthetic fibers. The process used to produce nitric and adipic acid generates significant quantities of N<sub>2</sub>O as a by-product. The production of nitric and adipic acid is expected to increase over time, driven by continued growth in demand for fertilizer and synthetic fibers.

### Emissions Reduction Potential

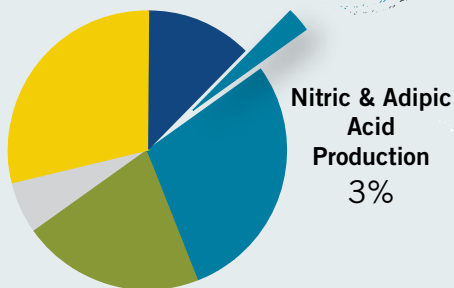
Assuming full implementation of current technology, emissions in the United States' nitric and adipic acid production sector could be reduced by up to 27 MtCO<sub>2e</sub> in 2030. This accounts for 5% of the United States' total reduction potential (569 MtCO<sub>2e</sub>) in 2030.



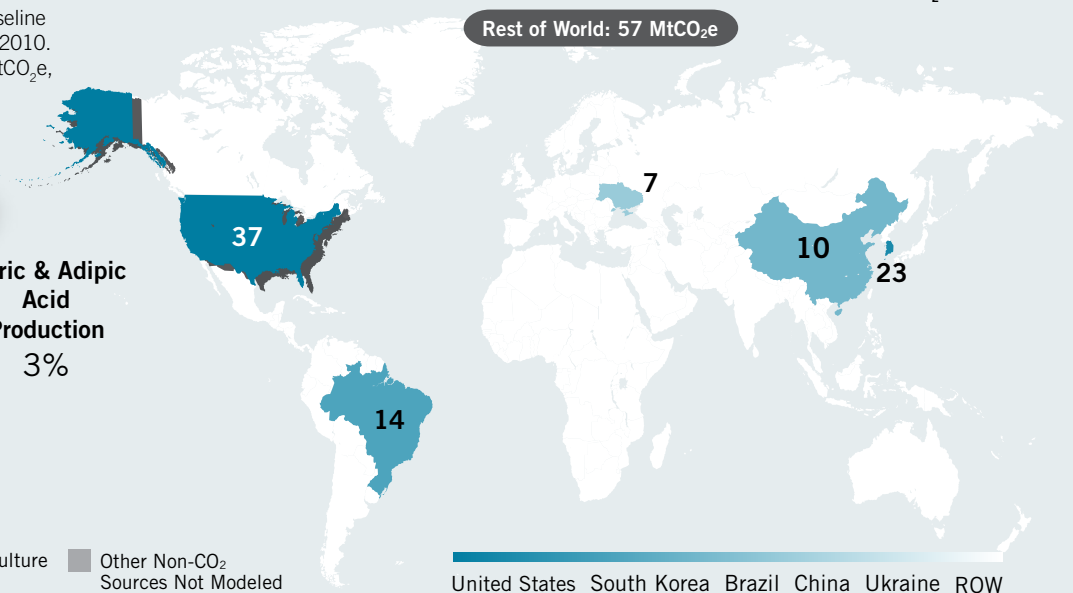
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Nitric and Adipic Acid Production sector baseline emissions are estimated to be 29 MtCO<sub>2e</sub> in 2010. In 2030, emissions are projected to be 37 MtCO<sub>2e</sub>, or 3% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2e</sub>)



Energy Waste Industrial Processes Agriculture Other Non-CO<sub>2</sub> Sources Not Modeled

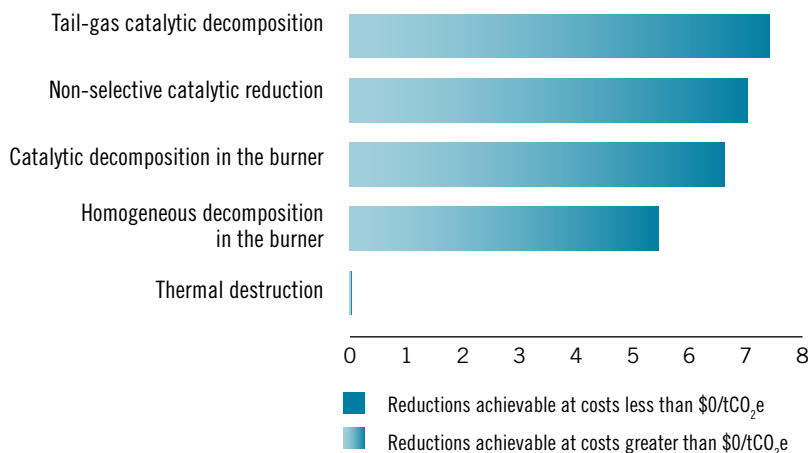
United States South Korea Brazil China Ukraine ROW

## Key Points

- The U.S. abatement potential is 27 MtCO<sub>2</sub>e, or 72% of projected nitric and adipic acid production related emissions in 2030.
- A 55% reduction in emissions is achievable at carbon prices below \$20.
- Abatement measure selection is driven by facility design constraints and/or operating costs.

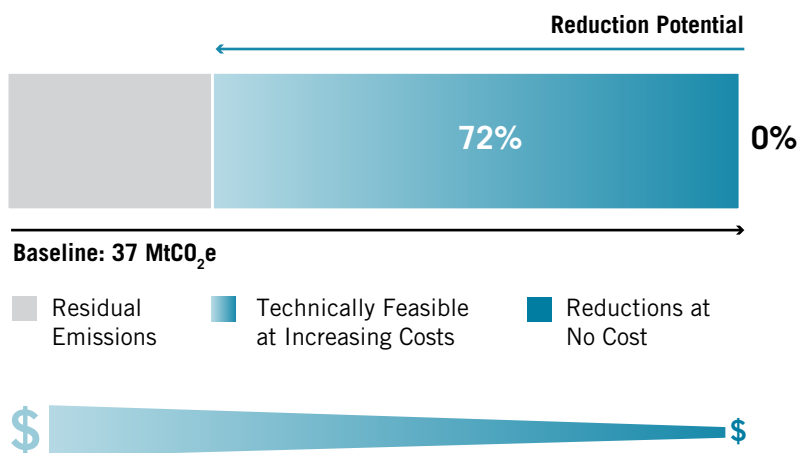
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

There are no cost-effective reductions available in the nitric and adipic acid production sector in 2030. However, a 72% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

N<sub>2</sub>O emissions can be mitigated through a number of alternative abatement measures. In nitric acid production, reduction technologies are categorized by their location in the production process. Secondary reduction technologies, such as homogeneous thermal decomposition and catalytic decomposition, are installed at an intermediate point in the production process. Tertiary reduction technologies, such as catalytic decomposition and nonselective catalytic reduction units, are applied to the tail gas streams at the end of the production process. The implementation of one technology over another is driven largely by facility design constraints and/or cost considerations. Thermal destruction is the single abatement measure considered in this analysis.

## Abatement Potential

The U.S. abatement potential in the nitric and adipic acid sector is approximately 27 MtCO<sub>2</sub>e of total annual emissions in 2030, or 72% of projected baseline emissions from this sector. The MACC results show that maximum reduction potential is achievable at break-even prices below \$50/tCO<sub>2</sub>e.

# Refrigeration and Air Conditioning

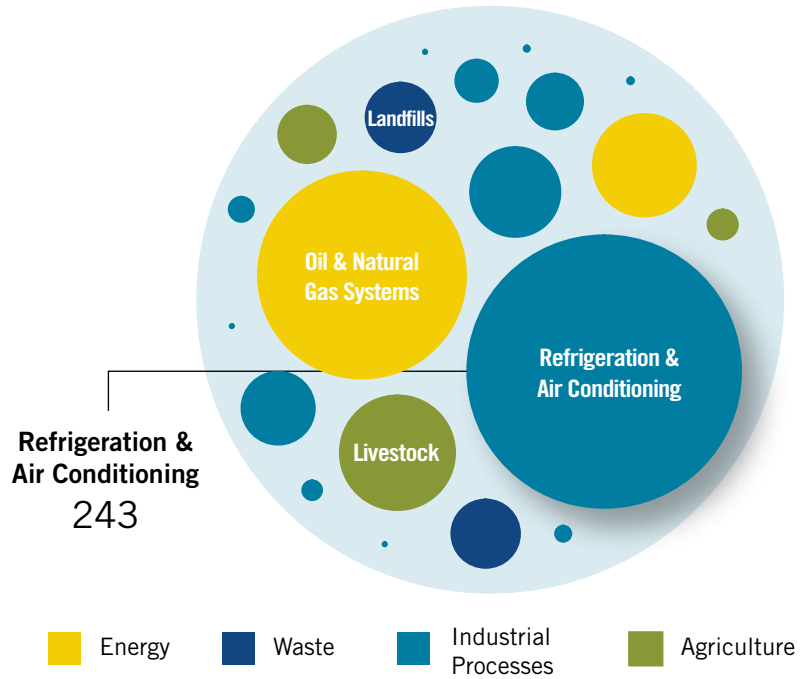
## HFC Emissions from Refrigeration and Air Conditioning Systems

### Sector Description

Hydrofluorocarbons (HFCs) used in refrigeration and air conditioning (AC) systems are emitted to the atmosphere during equipment operation, repair, and disposal, unless recovered, recycled, and ultimately destroyed. Equipment is being retrofitted or replaced to use HFCs that are substitutes for ozone-depleting substances. Some of the most common HFCs are HFC-134a, R-404A, R-410A, R-407C, and R-507A.

### Emissions Reduction Potential

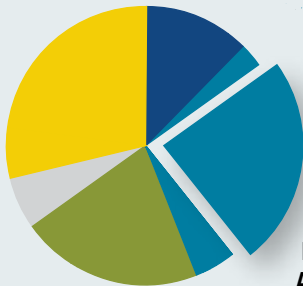
Assuming full implementation of current technology, emissions in the United States' refrigeration & air conditioning sector could be reduced by up to 243 MtCO<sub>2</sub>e in 2030. This accounts for 43% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



### Projected Emissions in 2030

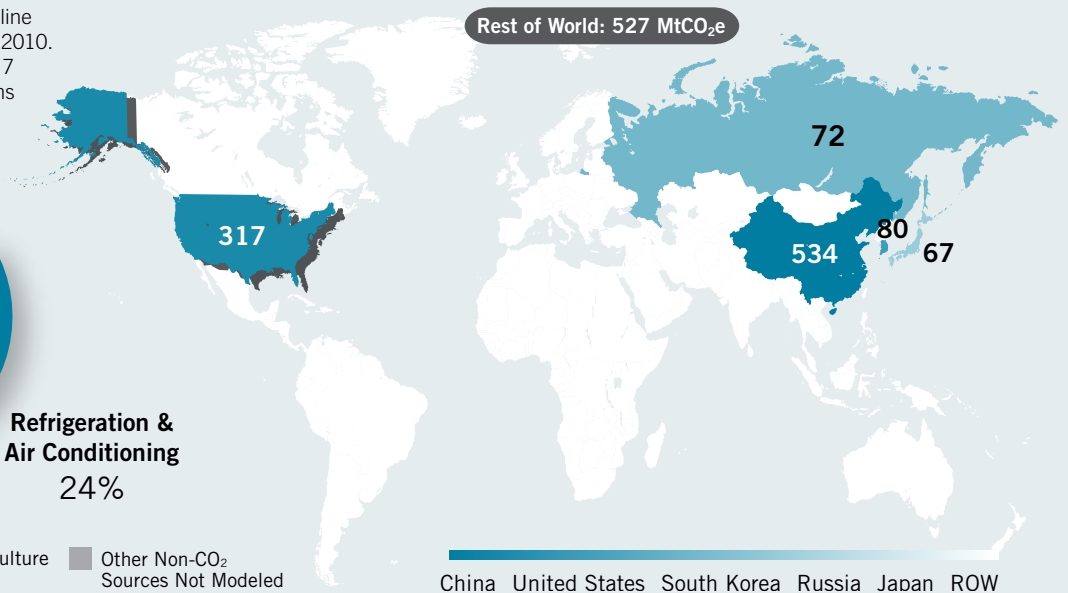
#### Global Non-CO<sub>2</sub> Emissions

Refrigeration & Air Conditioning sector baseline emissions are estimated to be 114 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 317 MtCO<sub>2</sub>e, or 24% of total non-CO<sub>2</sub> emissions in the United States.



Energy Waste Industrial Processes Agriculture Other Non-CO<sub>2</sub> Sources Not Modeled

#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)

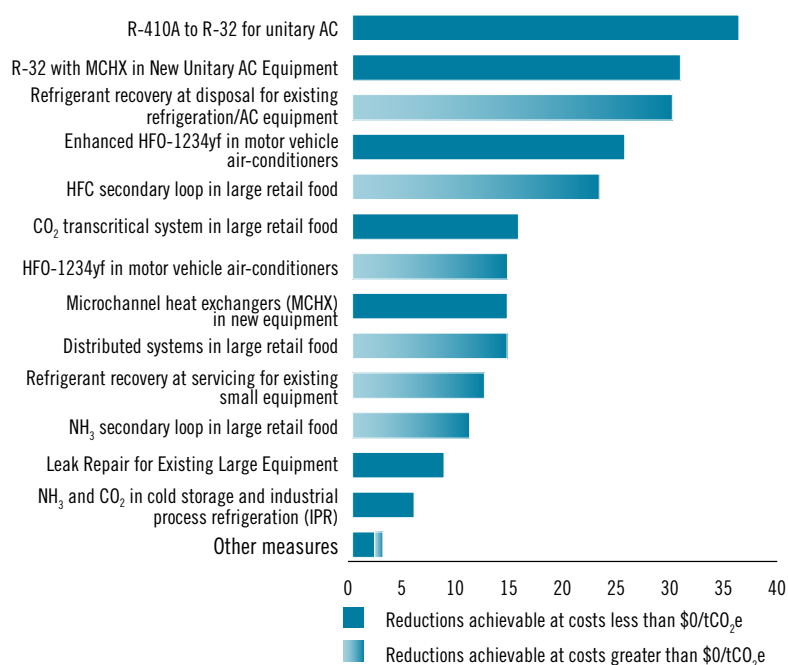


## Key Points

- The U.S. abatement potential from the options quantified is 243 MtCO<sub>2</sub>e, or 77% of projected emissions from this sector in 2030.
- 43% of the baseline 2030 emissions can be abated using cost-effective mitigation measures (\$0 per tCO<sub>2</sub>e).
- This sector is the second largest source of non-CO<sub>2</sub> abatement potential in the United States, accounting for 24% of total abatement potential across all non-CO<sub>2</sub> emitting sectors in 2030.

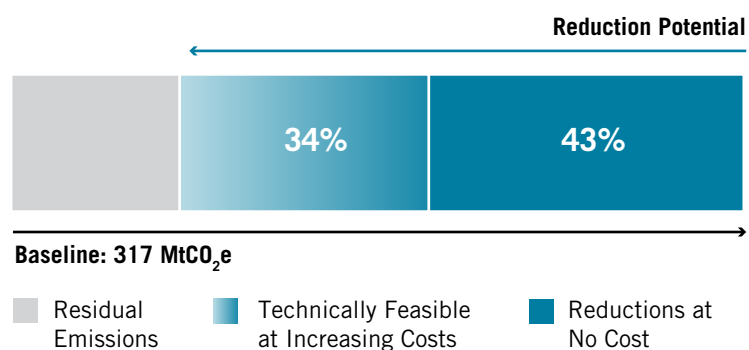
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 43%, compared with the baseline, in 2030. An additional 34% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

HFC abatement measures are categorized into three categories: (1) retrofit of existing systems to use lower-GWP refrigerants; (2) new cooling systems that use lower-GWP refrigerants and/or reduce the charge size; and (3) better refrigerant management practices that reduce emissions during use, servicing, and disposal. Such options are analyzed for end uses such as retail food refrigeration systems, window and unitary AC equipment, motor vehicle AC systems, and other types of cooling systems.

## Abatement Potential

The U.S. abatement potential from refrigeration and AC abatement is calculated to be 243 MtCO<sub>2</sub>e in 2030, or 77% of baseline emissions from this sector; additional uncalculated options are explored qualitatively. The MACC results show that 138 MtCO<sub>2</sub>e, or 43% of 2030 emissions, can be reduced at a cost of \$0 by implementing “no-regret” options. All abatement options quantified are achievable at mitigation costs below \$100/tCO<sub>2</sub>e.



# Solvents

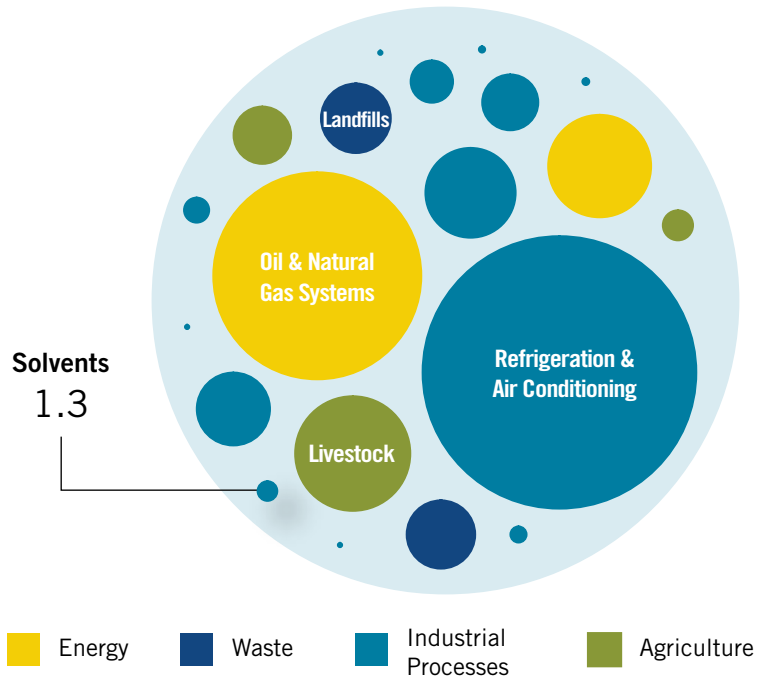
## HFC Emissions from Solvent Use

### Sector Description

HFC solvents are primarily used in precision cleaning applications and electronic cleaning applications. Precision cleaning requires a high level of cleanliness to ensure the satisfactory performance of the product being cleaned, and electronics cleaning is defined as a process that removes contaminants, primarily solder flux residues, from electronics or circuit boards. It is assumed that eventually approximately 90% of the solvent consumed in a given year is emitted, while 10% of the solvent is disposed of with the sludge that remains.

### Emissions Reduction Potential

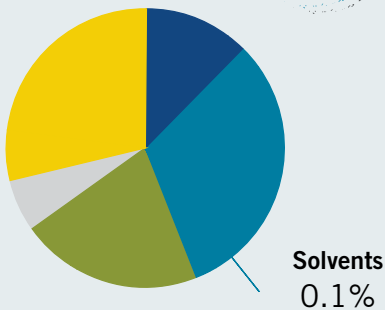
Assuming full implementation of current technology, emissions in the United States' solvent use sector could be reduced by up to 1.3 MtCO<sub>2</sub>e in 2030. This accounts for 0.23% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



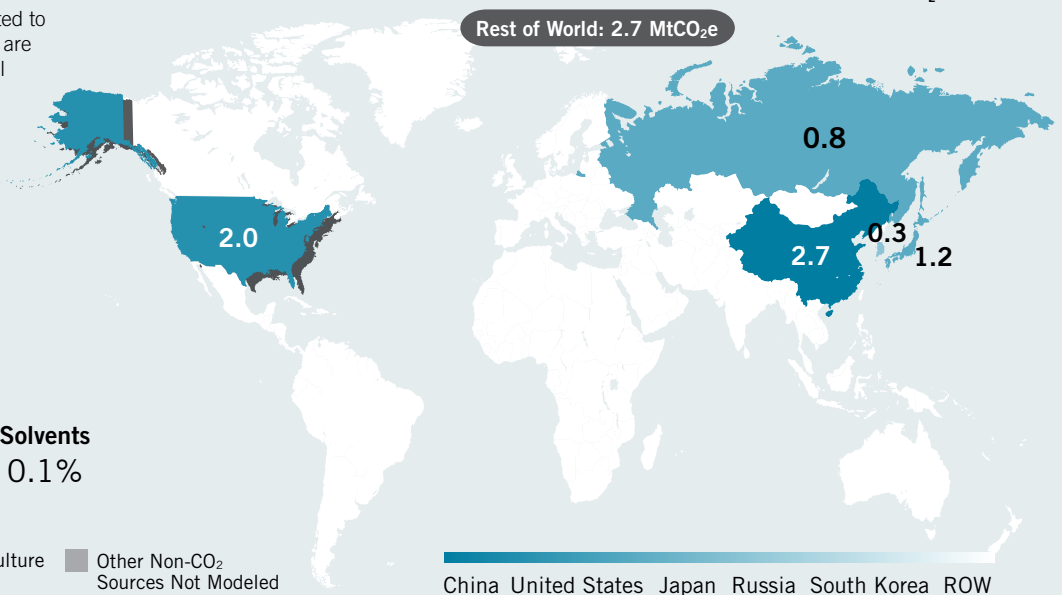
### Projected Emissions in 2030

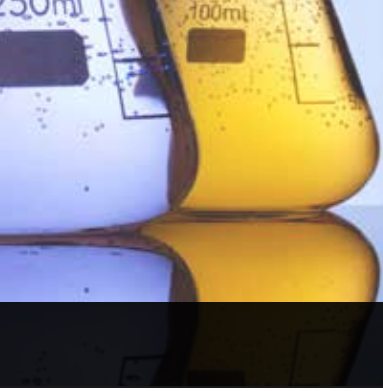
#### Global Non-CO<sub>2</sub> Emissions

Solvents sector baseline emissions are estimated to be 1.3 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 2 MtCO<sub>2</sub>e, or 0.1% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)



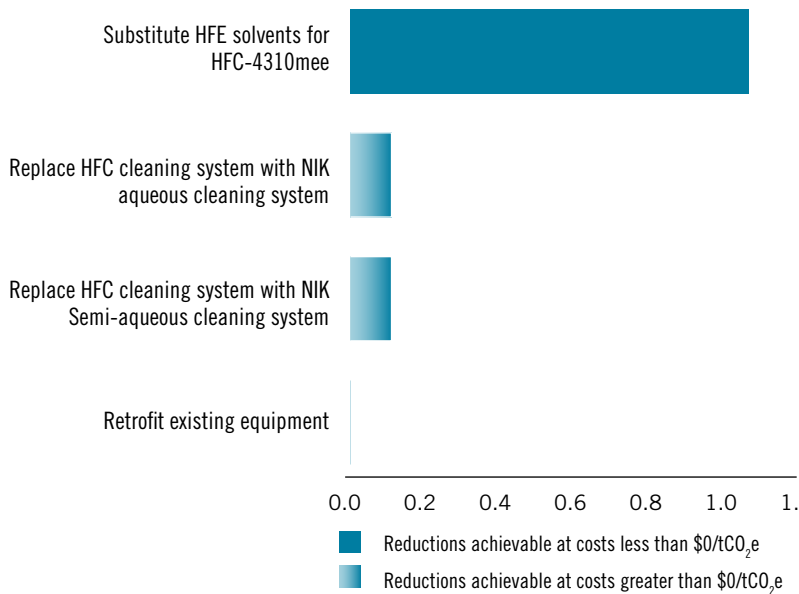


## Key Points

- Emissions from the solvents sector are expected to grow by 50%, growing from 1.3 to 1.9 MtCO<sub>2e</sub> between 2010 and 2030.
- The maximum abatement potential in the solvents sector from the options analyzed is estimated to be 1.3 MtCO<sub>2e</sub>, or 66% of the projected sector baseline in 2030.
- In 2030, 1.1 MtCO<sub>2e</sub> of emissions reductions are cost-effective (i.e., \$0/tCO<sub>2e</sub> or lower break-even prices).

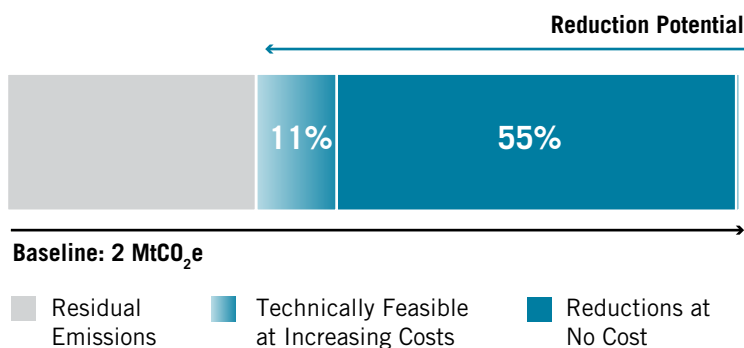
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2e</sub> and at higher prices.



### Emissions Reduction Potential, 2030

It would be cost effective to reduce emissions by 55%, compared with the baseline, in 2030. An additional 11% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Four abatement options were identified for the solvent sector:

- (1) replacement of HFCs with HFEs,
- (2) retrofitting of vapor degreaser equipment to reduce emissions,
- (3) transition to not-in-kind (NIK) aqueous cleaning, and
- (4) transition to NIK semi-aqueous cleaning.

These technologies have reduction efficiencies of between 50% and 100%. Retrofitting equipment and controls is limited to facilities that have not already been retrofitted.

Transition to NIK aqueous and NIK semi-aqueous applicability is limited to some electronic cleaning processes.

## Abatement Potential

The U.S. abatement potential in 2020 and 2030 is 0.8 and 1.3 MtCO<sub>2e</sub>, respectively. In 2030, reduction of 1.1 MtCO<sub>2e</sub>, or 55%, of total projected sector emissions, is achievable at mitigation costs below \$0/tCO<sub>2e</sub>. Additional abatement of approximately 0.2 MtCO<sub>2e</sub> is achievable at mitigation costs greater than \$50/tCO<sub>2e</sub>.

# Foams

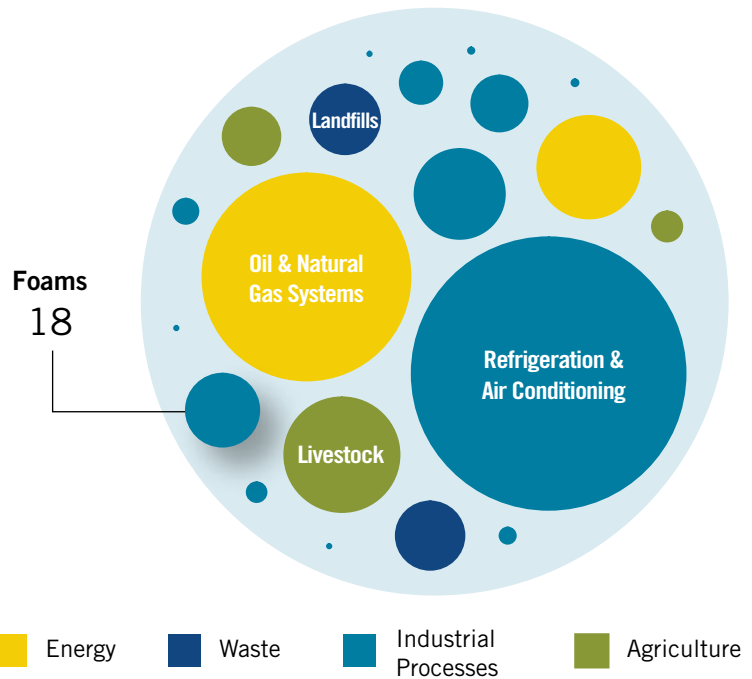
## HFC Emissions from Foams Manufacturing, Use, and Disposal

### Sector Description

Foam is used as insulation in a wide range of equipment, structures, and other common products. Foams were historically produced with ozone-depleting substances (ODSs), which have been phased out under the Montreal Protocol in developed countries and are being phased out in developing countries. In some end uses, HFC blowing agents have largely replaced ODSs. HFC emissions from the foams sector were approximately 6.1 MtCO<sub>2</sub>e in 2010 and are projected to increase substantially to 16.5 MtCO<sub>2</sub>e and 30.5 MtCO<sub>2</sub>e by 2020 and 2030, respectively.

### Emissions Reduction Potential

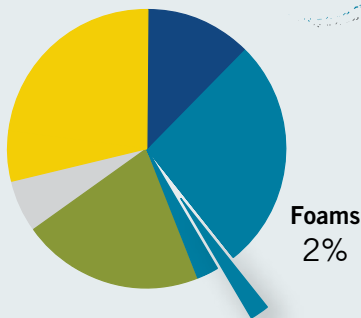
Assuming full implementation of current technology, emissions in the United States' foams sector could be reduced by up to 17.5 MtCO<sub>2</sub>e in 2030. This accounts for 3% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



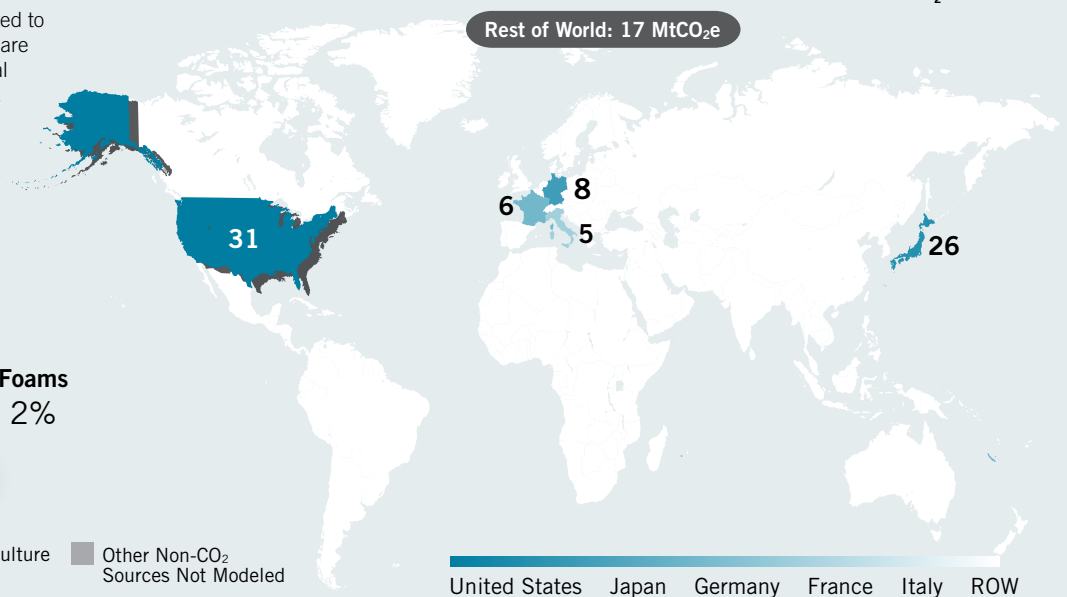
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Foams sector baseline emissions are estimated to be 6 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 31 MtCO<sub>2</sub>e, or 2% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)

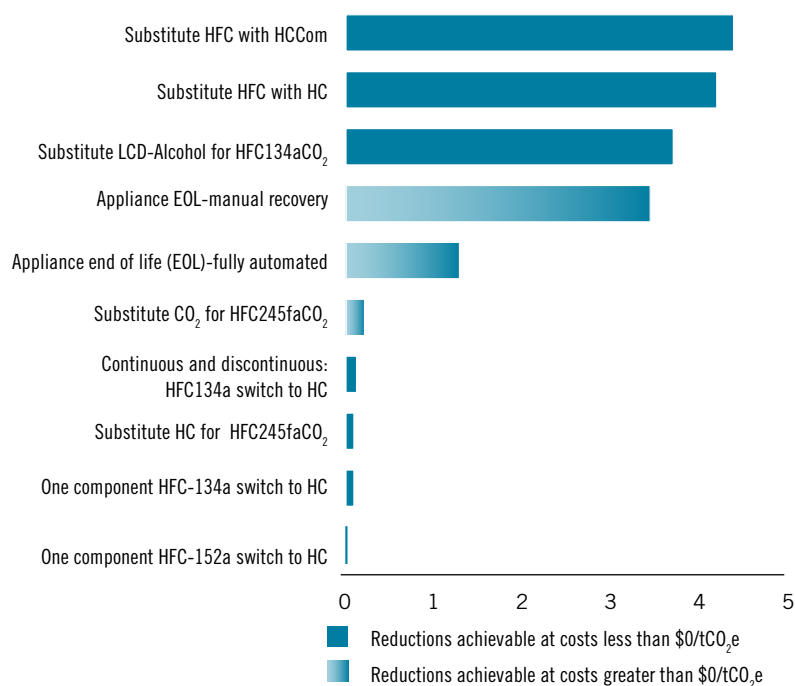


## Key Points

- In the United States, HFC emissions from foams are projected to quintuple over the next 20 years.
- Abatement measures include replacing HFCs with low-GWP blowing agents and proper recovery and disposal of foam present in existing systems at their end of life.
- In 2030, the U.S. abatement potential quantified is 12.6 MtCO<sub>2</sub>e (41% of business-as-usual [BAU] emissions from the foam sector) at cost-effective prices (\$0 per tCO<sub>2</sub>e). At higher prices, the abatement options analyzed have the potential to abate up to 17.5 MtCO<sub>2</sub>e (57% of BAU emissions) in 2030.

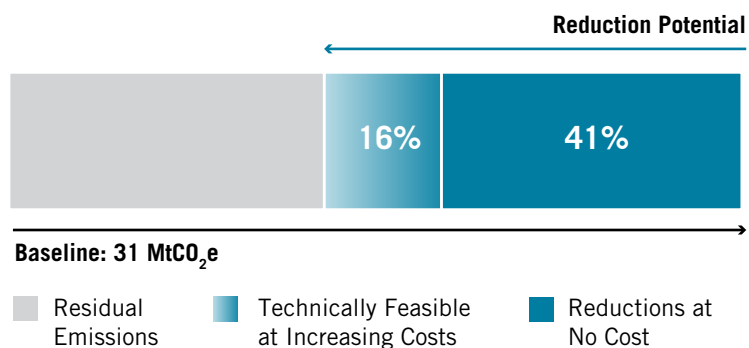
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 41%, compared with the baseline, in 2030. An additional 16% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Abatement options considered include replacing HFCs with various low-GWP blowing agents and properly recovering and disposing of foam contained in equipment and other products after its useful life. More specifically, the use of hydrocarbon or CO<sub>2</sub> blowing agents instead of HFCs is assessed quantitatively as an abatement measure in the foam sector noting that other low-GWP agents (e.g., HFO-1234ze, -1233zd[E]) would achieve similar abatement levels.

## Abatement Potential

The total abatement potential in the foams sector from the options explored is 17.5 MtCO<sub>2</sub>e—57% of total annual foams sector emissions in 2030—while 12.6 MtCO<sub>2</sub>e, or 41%, is achievable at cost-effective carbon prices for the same year. Total replacement of HFC blowing agents in foams is limited in the near term by the installed base of foam products. All abatement options analyzed replace blowing agents in newly manufactured foams or destroy the blowing agent only at the foam's natural end of life.



# Aerosols

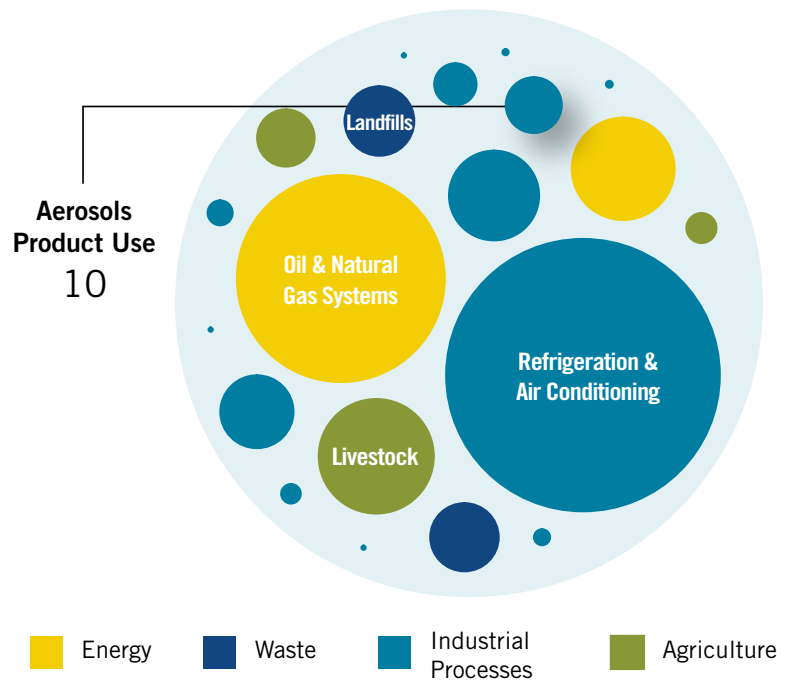
## HFC Emissions from Aerosols Product Use

### Sector Description

Aerosol propellant formulations containing HFCs are present in a wide variety of consumer products—such as hairsprays, deodorants, and cleaning supplies—as well as technical and medical aerosols. Baseline HFC emissions from aerosols in the United States were estimated at 8.9 MtCO<sub>2</sub>e in 2010 and are expected to increase to 15.6 MtCO<sub>2</sub>e by 2030.

### Emissions Reduction Potential

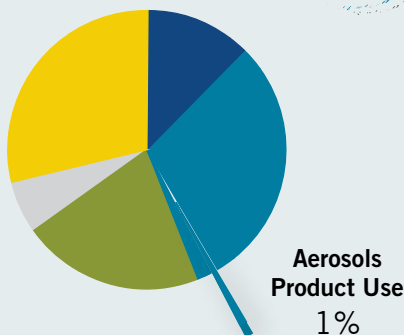
Assuming full implementation of current technology, emissions in the United States' aerosols product use sector could be reduced by up to 10.3 MtCO<sub>2</sub>e in 2030. This accounts for 2% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



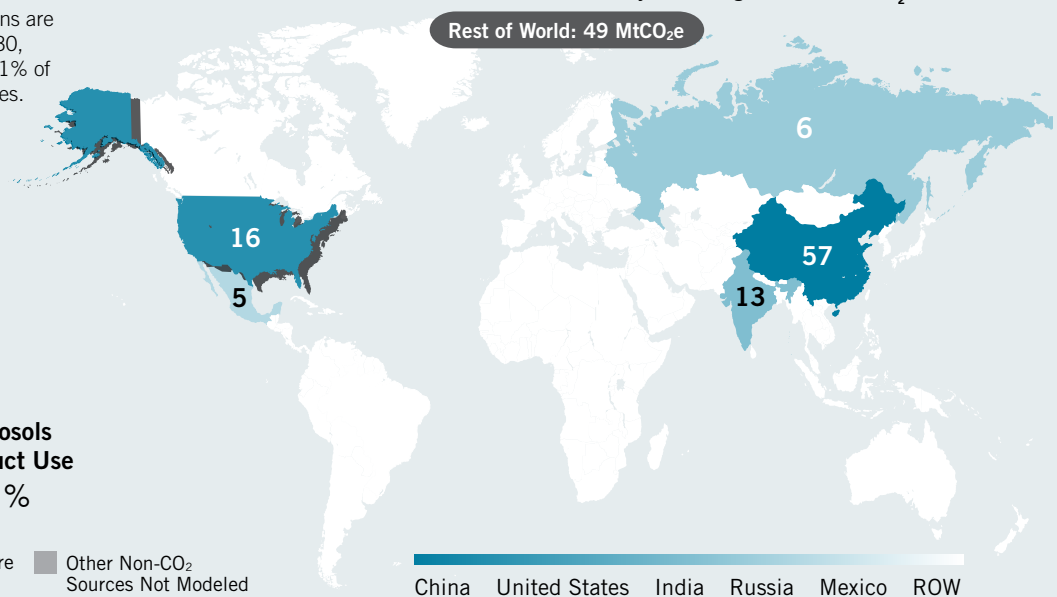
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Aerosols Product Use sector baseline emissions are estimated to be 9 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 16 MtCO<sub>2</sub>e, or 1% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)

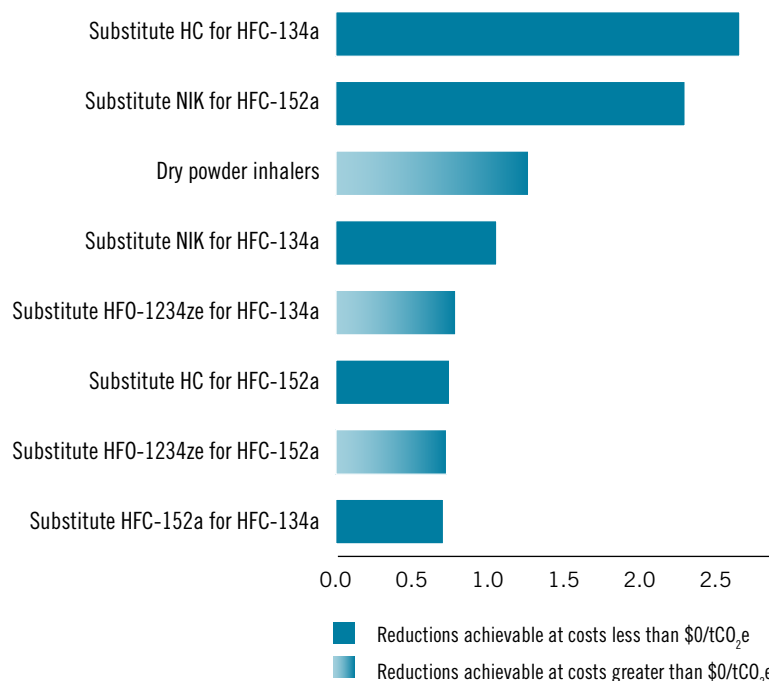


## Key Points

- U.S. baseline emissions in 2010 for aerosols were estimated at 8.9 MtCO<sub>2</sub>e and projected to climb to 13.0 MtCO<sub>2</sub>e and 15.6 MtCO<sub>2</sub>e by 2020 and 2030, respectively.
- Five abatement measures were considered for the aerosols sector, including transitioning away from HFC use to lower-GWP propellants and producing alternative nonaerosol consumer products, such as a stick or roller.
- Relatively low-cost abatement measures ( $\leq \$5/\text{tCO}_2\text{e}$ ) are projected to be capable of mitigating 53% of the sector emissions in 2030.

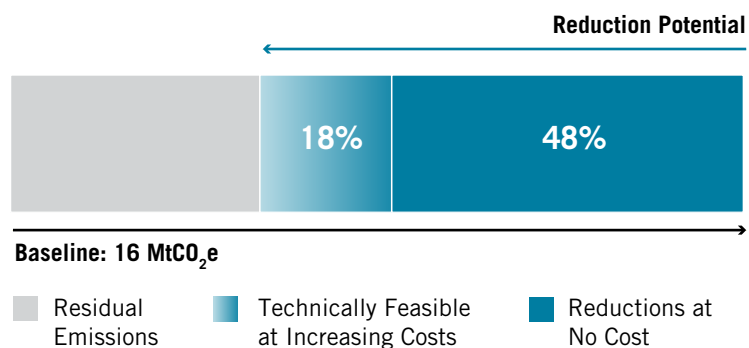
### Abatement Measures

Emissions reductions by technology in 2030 at  $\$0/\text{tCO}_2\text{e}$  and at higher prices.



### Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 48%, compared with the baseline, in 2030. An additional 18% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Abatement options available to reduce emissions for consumer aerosol products include transitioning to replacement propellants with lower GWPs—HCs, HFO-1234ze, and HFC-152a (where HFC-134a is used)—and converting to an NIK alternative, such as sticks, rollers, or finger/trigger pumps.

## Abatement Potential

The U.S. abatement potential from aerosols containing HFCs is estimated to be 10.3 MtCO<sub>2</sub>e—66% of baseline emissions from this sector and 3% of total annual emissions from all sectors that use ODS substitutes in 2030. At  $\$5$  per tCO<sub>2</sub>e, the abatement potential is estimated to be 53.4% of baseline sector emissions, or 8.3 MtCO<sub>2</sub>e. Furthermore, the abatement potential at break-even prices  $\leq \$0$  per tCO<sub>2</sub>e is 7.5 MtCO<sub>2</sub>e (48.2% of baseline sector emissions) in 2030.

# Fire Protection

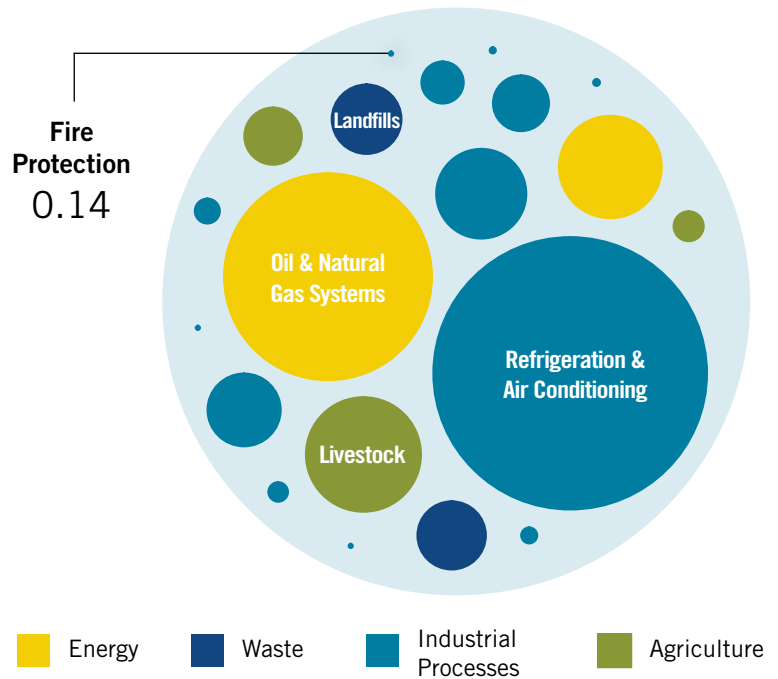
## HFC and PFC Emissions from Fire Protection Equipment

### Sector Description

The fire protection sector emits HFCs and PFCs when total flooding fire suppression systems and portable fire extinguishers are used. U.S. GHG emissions from this sector were estimated at 0.8 MtCO<sub>2</sub>e in 2010. Under the baseline scenario, emissions are projected to increase to 2.2 MtCO<sub>2</sub>e in 2030.

### Emissions Reduction Potential

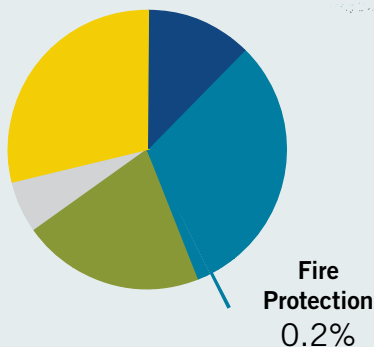
Assuming full implementation of current technology, emissions in the United States' fire protection sector could be reduced by up to 0.14 MtCO<sub>2</sub>e in 2030. This accounts for 0.02% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



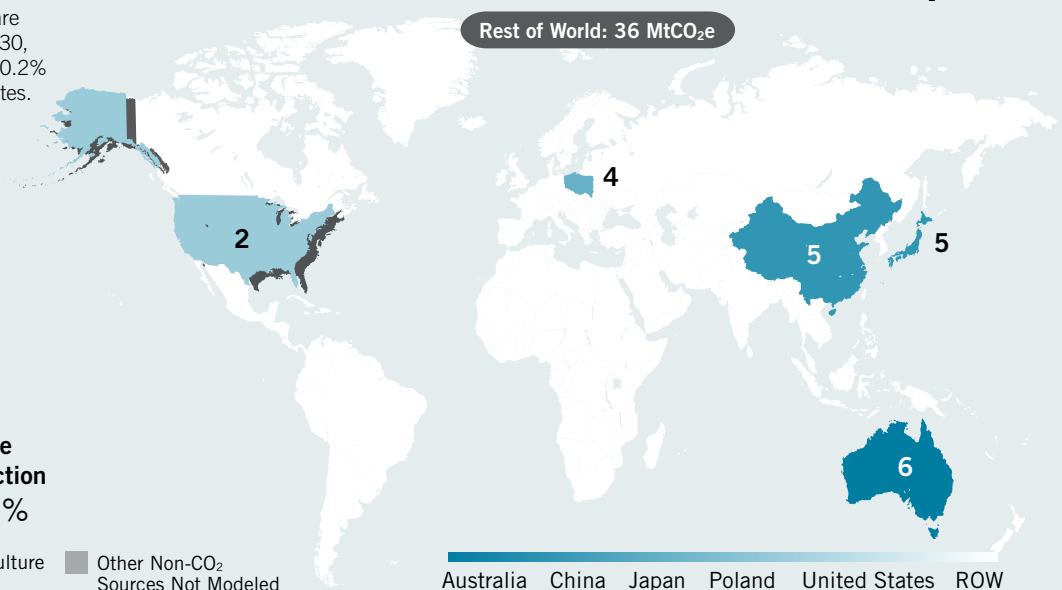
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Fire Protection sector baseline emissions are estimated to be 0.8 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 2.2 MtCO<sub>2</sub>e, or 0.2% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)



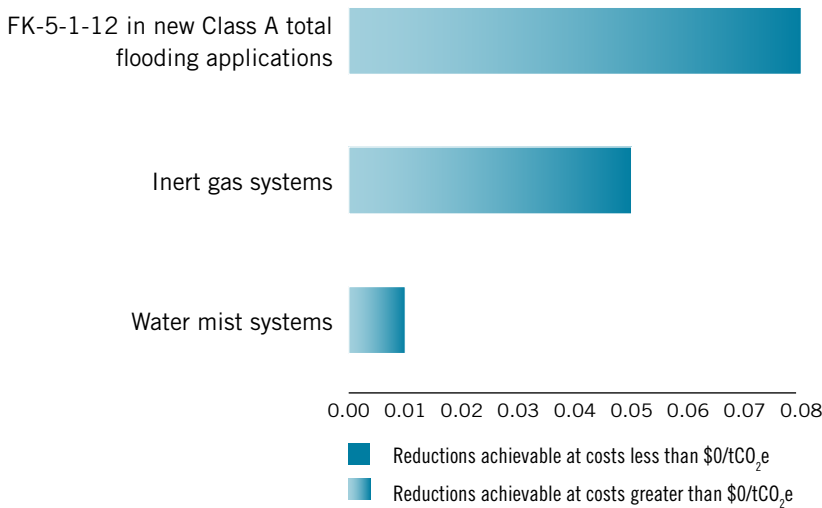


## Key Points

- GHG emissions from fire protection equipment are projected to more than double between 2010 and 2030.
- Total flooding fire suppression abatement options involve replacing HFCs and perfluorocarbons (PFCs) with lower-GWP alternatives, including both in-kind and NIK measures.
- There is no abatement potential in the U.S. fire protection equipment sector in 2030.

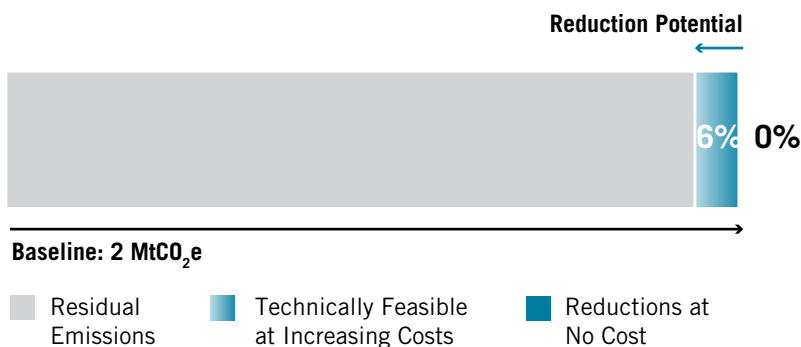
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2e</sub> and at higher prices.



### Emissions Reduction Potential, 2030

There are no cost-effective reductions available in the fire protection sector in 2030. However, a 6% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

The abatement options explored replace HFCs and PFCs with zero- or low-GWP extinguishing agents to reduce CO<sub>2e</sub> emissions from the fire protection sector's total flooding equipment. The alternatives to HFCs and PFCs in total flooding equipment are both in-kind gaseous agents and NIK options. The in-kind gaseous alternatives include CO<sub>2</sub>, inert gases, and fluorinated ketones, and the NIK alternatives include varying materials and systems such as dispersed and condensed aerosol extinguishing systems, water sprinklers, water mist, foam, and inert gas generators.

## Abatement Potential

From the options quantified, U.S. abatement potential of emissions from total flooding fire suppression applications is projected to be 0.14 MtCO<sub>2e</sub>, or nearly 7% of baseline sector emissions, in 2030. There is little abatement potential at carbon prices below \$50 per tCO<sub>2e</sub> in 2030, which is projected to have the potential to abate 41.3 MtCO<sub>2e</sub> from the fire protection sector, or 6% of baseline sector emissions.



# Aluminum Production

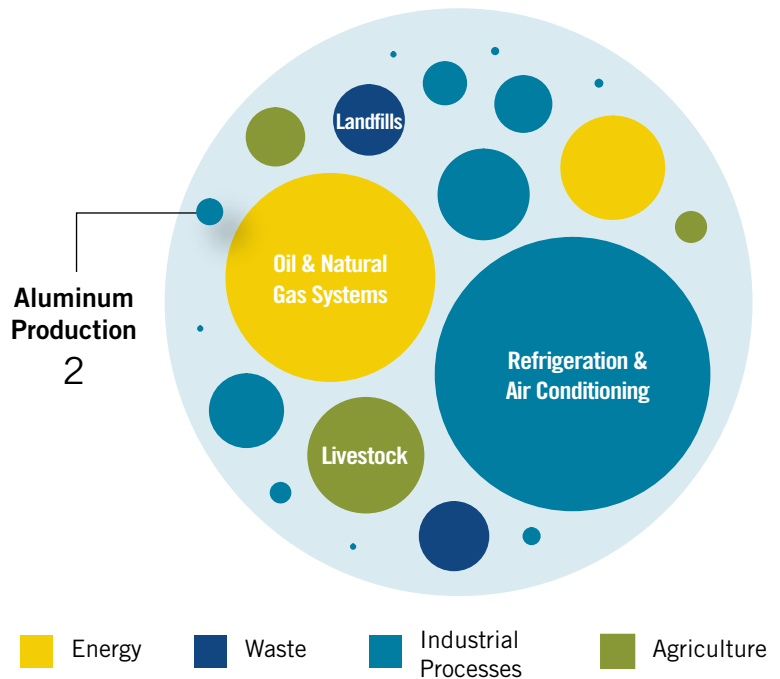
## PFC Emissions from Primary Aluminum Production

### Sector Description

The primary aluminum production industry produces PFC emissions during brief process upset conditions in the aluminum smelting process. PFCs from primary aluminum production in the United States are projected to decrease by 2%, from 3.7 MtCO<sub>2</sub>e in 2010 to 3.6 MtCO<sub>2</sub>e in 2030.

### Emissions Reduction Potential

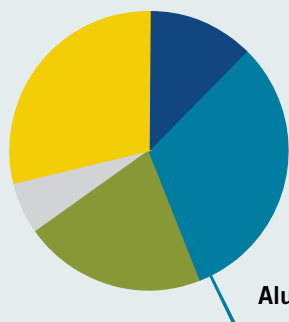
Assuming full implementation of current technology, emissions in the United States' primary aluminum production sector could be reduced by up to 2.1 MtCO<sub>2</sub>e in 2030. This accounts for 0.37% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



### Projected Emissions in 2030

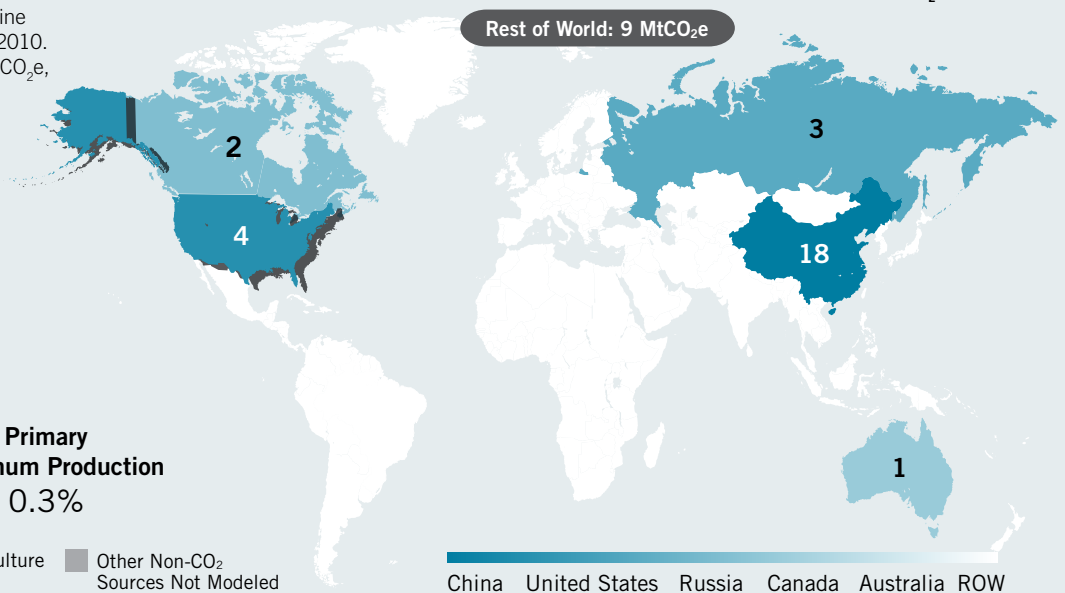
#### Global Non-CO<sub>2</sub> Emissions

Primary Aluminum Production sector baseline emissions are estimated to be 3.7 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 3.6 MtCO<sub>2</sub>e, or 0.3% of total non-CO<sub>2</sub> emissions in the United States.



**Primary Aluminum Production**  
0.3%

#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)



Energy Waste Industrial Processes Agriculture Other Non-CO<sub>2</sub> Sources Not Modeled

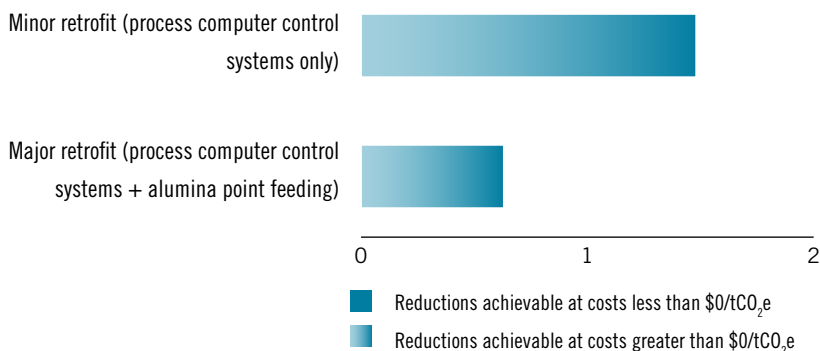
China United States Russia Canada Australia ROW

## Key Points

- PFC emissions from primary aluminum production represent the fourth largest source of fluorinated greenhouse gas (F-GHG) emissions in the U.S. industrial sector.
- Primary abatement measures include installation of or upgrades to process computer control systems and the installation of systems to allow more precise alumina feeding.
- Abatement measures in this sector have the potential to reduce over half of the projected baseline emissions.

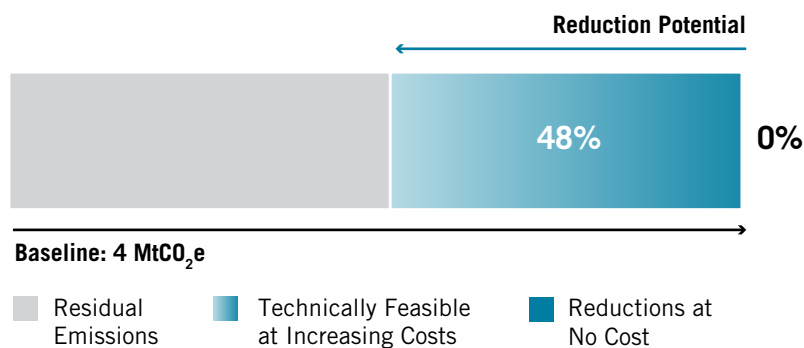
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

There are no cost-effective reductions available in the primary aluminum production sector in 2030. However, a 58% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Abatement options in the primary aluminum production sector are primarily associated with installing or upgrading process computer control systems and alumina point-feed system. The options considered involve (1) a minor retrofit to upgrade the process computer control systems and (2) a major retrofit to the process computer control systems coupled with the installation of alumina point-feed systems.

## Abatement Potential

U.S. abatement potential in the primary aluminum sector is projected to be 2.1 MtCO<sub>2</sub>e, or nearly 58% of baseline sector emissions in 2030. There are no cost-effective reductions available in 2030 for this sector, but mitigation is feasible with the adoption of more costly mitigation measures. In 2030, mitigation measures that cost less than or equal to \$30/tCO<sub>2</sub>e have the potential to reduce emissions by 1.7 MtCO<sub>2</sub>e, or 81% of the total abatement potential.

# HCFC-22 Production

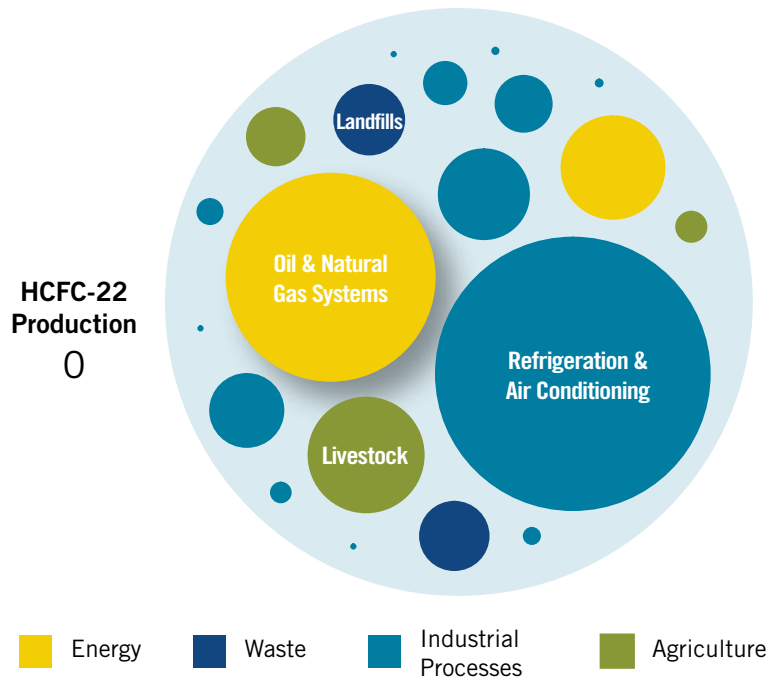
## Fluorinated Greenhouse Gas (F-GHG) Emissions from HCFC-22 Production

### Sector Description

Chlorodifluoromethane (HCFC-22) is used in emissive applications (air conditioning and refrigeration) as well as in feedstock for synthetic polymer production. The production of HCFC-22 generates HFC-23 as a by-product, which is separated as a vapor from the condensed HCFC-22; emissions occur through HFC-23 venting to the atmosphere. HFC-23 emissions were estimated at 128 MtCO<sub>2</sub>e and are projected to increase to 259 and 286 MtCO<sub>2</sub>e in 2020 and 2030, respectively. Because HCFC-22 depletes stratospheric ozone, its production is being phased out under the Montreal Protocol in areas apart from feedstock production.

### Emissions Reduction Potential

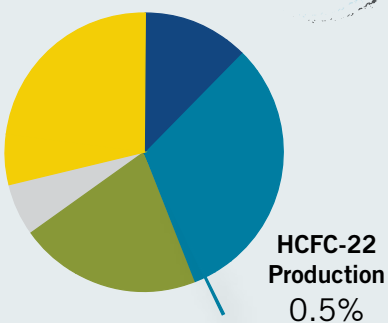
It is assumed that HCFC-22 production facilities in the United States have voluntarily adopted measures to control emissions and the baseline represents residual emissions. Hence, the United States has no additional abatement potential in 2030.



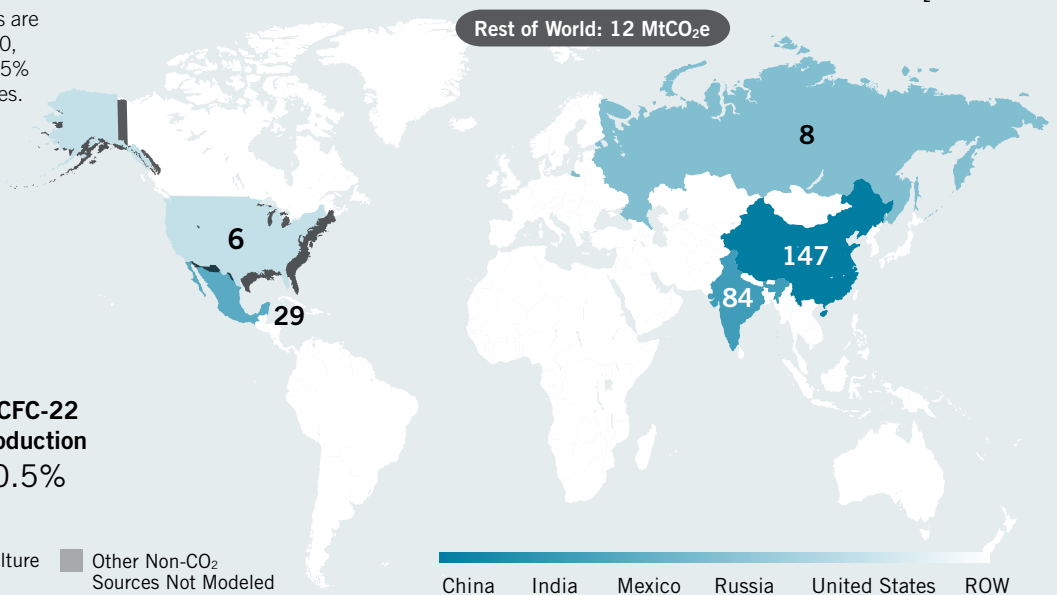
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

HCFC-22 Production sector baseline emissions are estimated to be 12 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 6 MtCO<sub>2</sub>e, or 0.5% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)



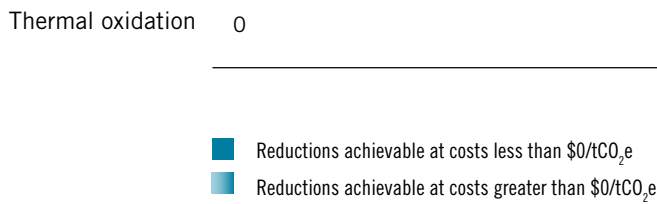


## Key Points

- Existing voluntary measures adopted by HCFC-22 producers in the United States mean that additional abatement from domestic sources will be limited in the future.
- Although the United States is projected to have no abatement in this sector, it remains an important opportunity for additional abatement internationally in other HCFC-producing countries that do not have abatement measures in place.
- Thermal oxidation is the only abatement option considered for the HCFC-22 production sector.
- The maximum abatement potential is achievable at costs below \$1 per tCO<sub>2</sub>e.

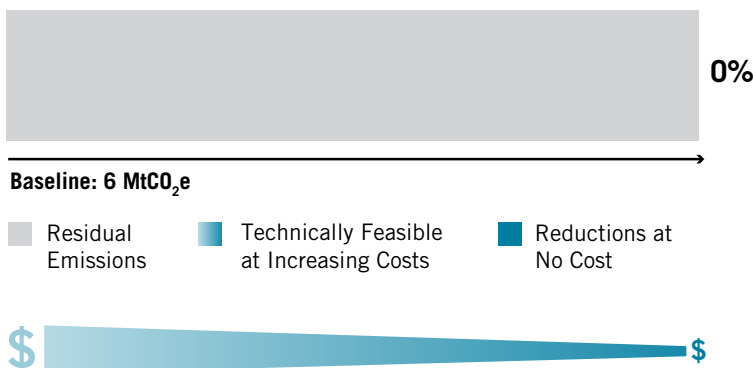
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

The United States has no additional abatement potential because it is assumed that existing voluntary actions have already reduced emissions by the maximum potential in 2030. Additional reductions are not technologically feasible based on the current suite of abatement measures available in this sector.



## Abatement Measures

Thermal oxidation is the only abatement option considered in this analysis for the HCFC-22 production sector. Thermal oxidation is a demonstrated technology that oxidizes HFC-23 to CO<sub>2</sub>, hydrogen fluoride, and water for the destruction of halogenated organic compounds. This process is assumed to be compatible with all facilities.

## Abatement Potential

The baseline emissions from HCFC-22 production facilities in the United States represent residual emissions from facilities with abatement measures already in place. For this reason, the abatement potential is zero for the United States. Despite the lack of domestic abatement opportunities, this sector remains an important source of low-cost abatement opportunities internationally.



# Semiconductor Manufacturing

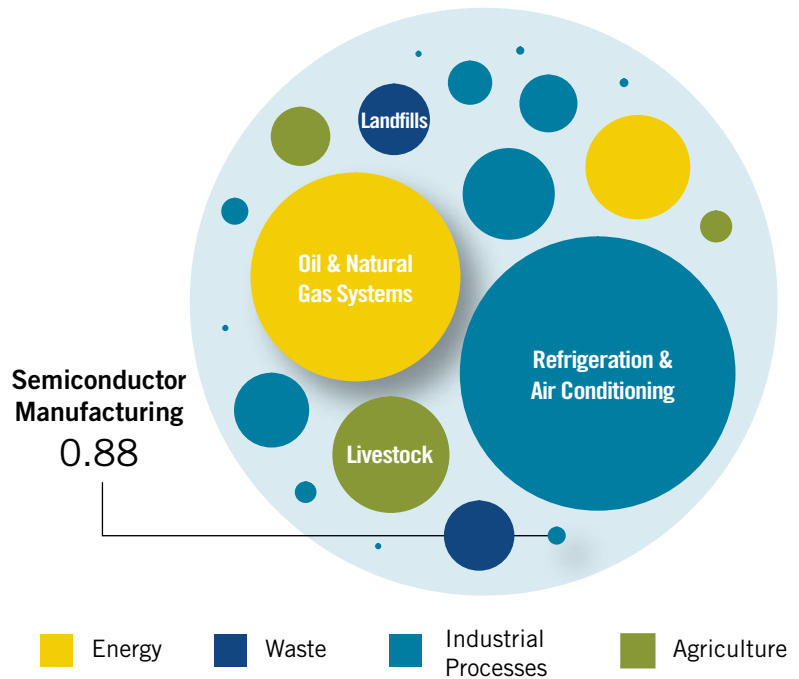
## F-GHG Emissions from Semiconductor Manufacturing

### Sector Description

The semiconductor industry uses several F-GHGs, including sulfur hexafluoride (SF<sub>6</sub>), nitrogen trifluoride (NF<sub>3</sub>), and PFCs during fabrication. Trace amounts of these gases are incidentally released into the atmosphere through normal fabrication activities. In 2010, 4.5 MtCO<sub>2</sub>e of emissions were produced from the U.S. semiconductor sector.

### Emissions Reduction Potential

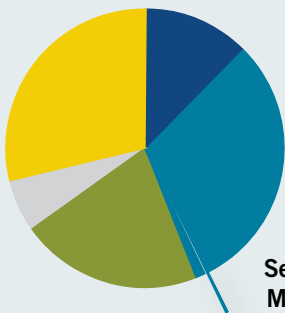
Assuming full implementation of current technology, emissions in the United States' semiconductor manufacturing sector could be reduced by up to 0.9 MtCO<sub>2</sub>e in 2030. This accounts for 0.16% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

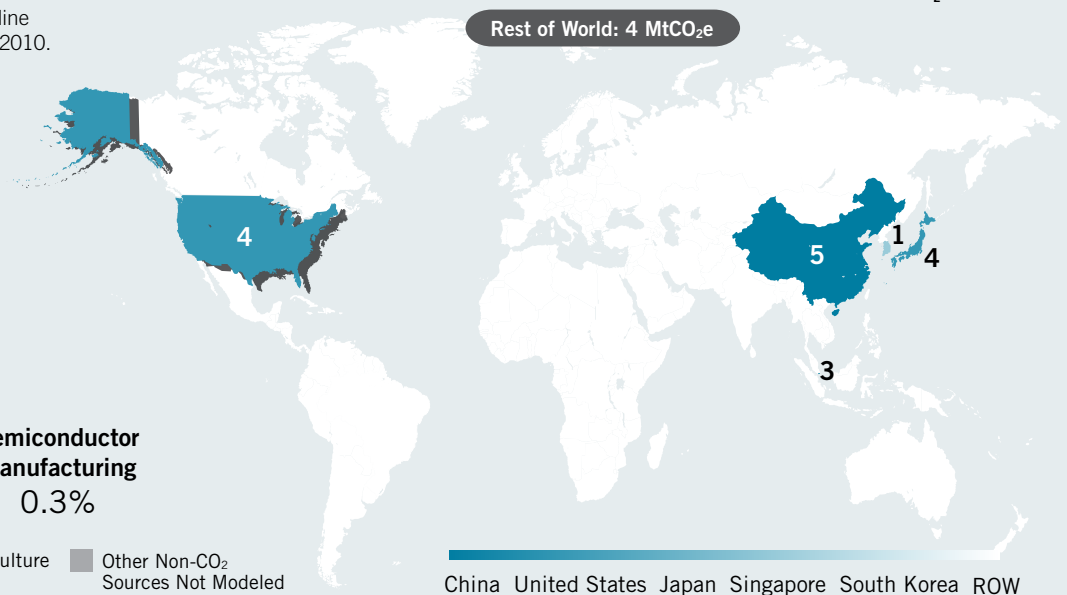
Semiconductor Manufacturing sector baseline emissions are estimated to be 4.5 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 4.5 MtCO<sub>2</sub>e, or 0.3% of total non-CO<sub>2</sub> emissions in the United States.



**Semiconductor Manufacturing: 0.3%**

Energy Waste Industrial Processes Agriculture Other Non-CO<sub>2</sub> Sources Not Modeled

#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)



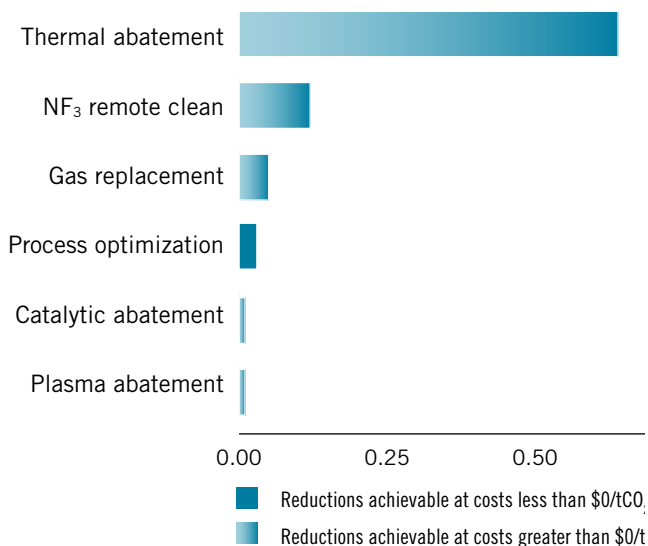
China United States Japan Singapore South Korea ROW

## Key Points

- Baseline emissions from semiconductor manufacturing in the United States will remain constant between 2010 and 2030.
- The U.S. abatement potential is 1 MtCO<sub>2</sub>e in 2030.
- 10% of the total abatement potential in this sector is achievable at costs at or below \$30/tCO<sub>2</sub>e in 2013.

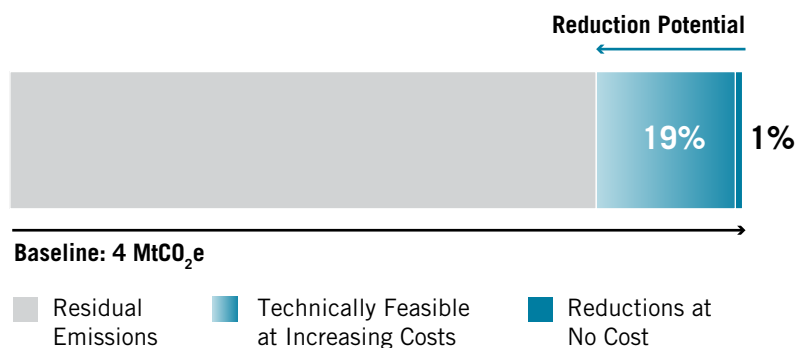
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 0.85%, compared with the baseline, in 2030. An additional 19% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Despite rapid growth between 2000 and 2010, the semiconductor manufacturing industry experienced a stark decline in F-GHG emissions, decreasing from 7 MtCO<sub>2</sub>e in 2000 to 4.5 MtCO<sub>2</sub>e in 2010. This decline can be attributed to voluntary emissions reduction goals set by the World Semiconductor Council. Additionally, six abatement technologies were considered to further reduce emissions from this sector: thermal abatement systems, catalytic abatement systems, plasma abatement systems, NF<sub>3</sub> remote chamber clean process, gas replacement, and process optimization.

## Abatement Potential

U.S. F-GHG abatement potential in the semiconductor manufacturing industry is estimated to be 1.0 MtCO<sub>2</sub>e and 0.9 MtCO<sub>2</sub>e in 2020 and 2030, respectively, which correspond to 23% and 20% of BAU emissions from this sector. In 2030, the abatement potential of 0.1 MtCO<sub>2</sub>e, or 2%, is achievable at abatement costs below \$30 per tCO<sub>2</sub>e.

# Electric Power Systems (EPS)

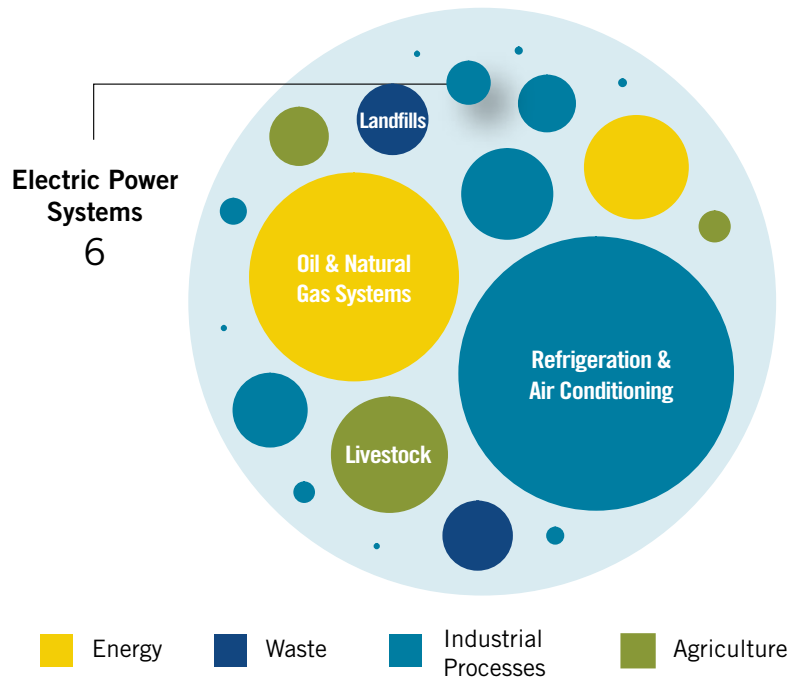
## SF<sub>6</sub> from Electric Power Systems

### Sector Description

Electric power systems (EPSs) use transmission and distribution equipment that contains SF<sub>6</sub>, a potent GHG with a GWP 23,900 times that of CO<sub>2</sub>. Emissions occur through unintentional leaking of equipment and improper handling practices during servicing and disposal. U.S. baseline emissions from this sector were estimated at 12.1 MtCO<sub>2</sub>e in 2010. Emissions are projected to drop to 10.3 MtCO<sub>2</sub>e in 2030, a 15% decrease.

### Emissions Reduction Potential

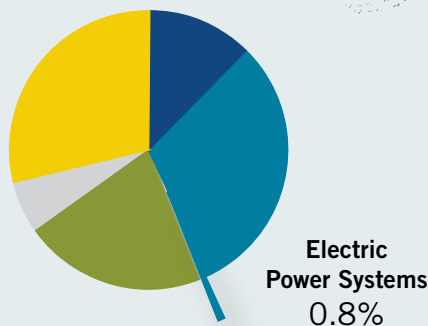
Assuming full implementation of current technology, emissions in the United States' electric power systems sector could be reduced by up to 5.9 MtCO<sub>2</sub>e in 2030. This accounts for 1% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



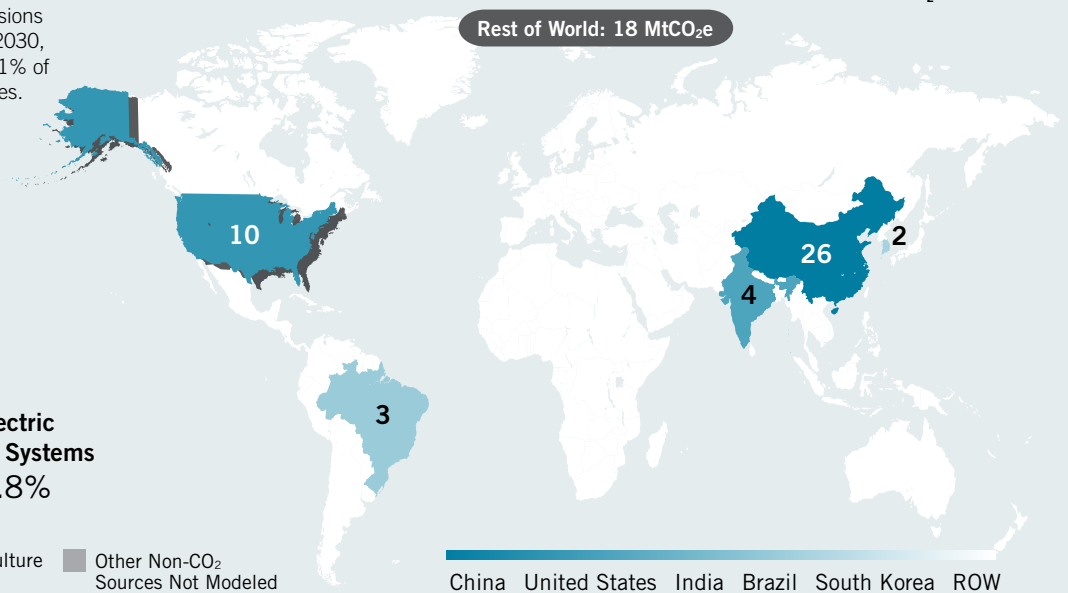
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Electric Power Systems sector baseline emissions are estimated to be 12 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 10 MtCO<sub>2</sub>e, or 1% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)

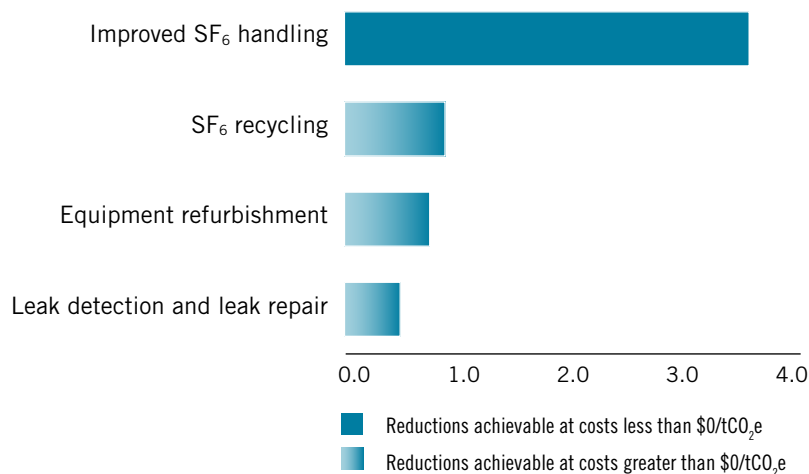


## Key Points

- The U.S. abatement potential ranges from 3.7 MtCO<sub>2</sub>e to 5.9 MtCO<sub>2</sub>e in 2030.
- Abatement measures include technologies and handling practices to manage SF<sub>6</sub> emissions and prevent leakage during servicing and disposal.
- The abatement potential at cost-effective break-even prices (\$0/tCO<sub>2</sub>e) is projected to reduce baseline sector emissions by 36% in 2030.

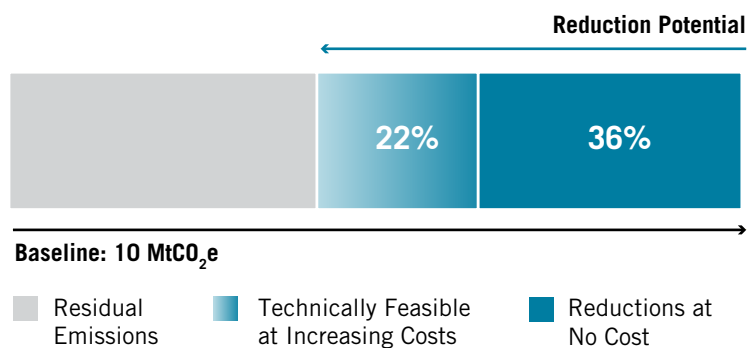
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 36%, compared with the baseline, in 2030. An additional 22% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Abatement measures that reduce emissions in the EPS sector include SF<sub>6</sub> recycling, leak detection and repair, equipment refurbishment, and improved SF<sub>6</sub> handling. These new technologies and handling practices have largely been adopted in Europe and Japan. SF<sub>6</sub> recycling is commonly practiced in the United States, but there remains significant potential for further reductions through improved SF<sub>6</sub> handling and upgraded or refurbished equipment.

## Abatement Potential

U.S. abatement potential in this sector is projected to be 6.4 MtCO<sub>2</sub>e in 2020 and 5.9 MtCO<sub>2</sub>e in 2030, which corresponds to 58% of the BAU baseline sector emissions, respectively. Significant reductions are available at relatively low cost. For example, emissions reduction technologies that cost up to \$5 per tCO<sub>2</sub>e, can reduce emissions by 3.7 MtCO<sub>2</sub>e, accounting for 63% of the technologically feasible emissions reductions in 2030.

# Magnesium Production

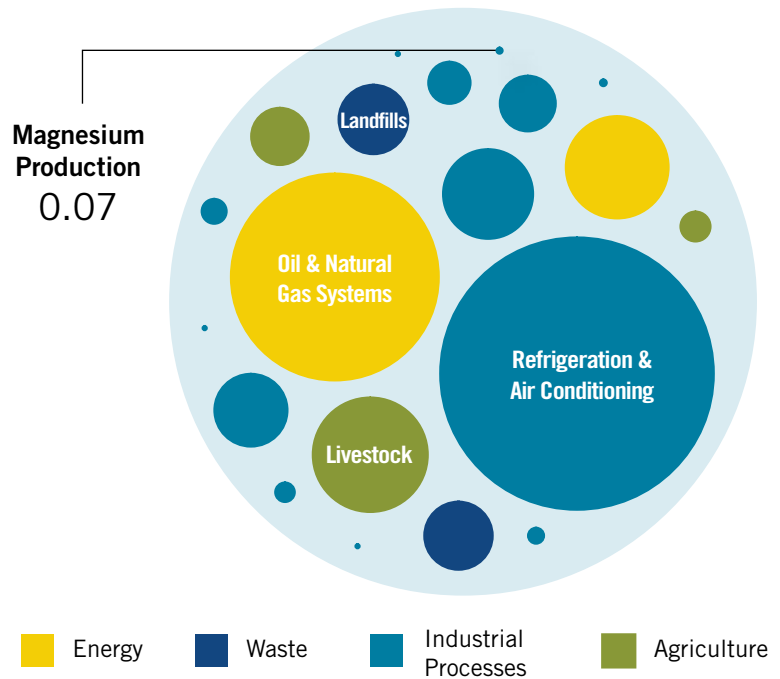
## SF<sub>6</sub> Emissions from Magnesium Production

### Sector Description

Magnesium manufacturing uses SF<sub>6</sub> as a cover gas during production and casting to prevent spontaneous combustion of molten magnesium in the presence of air. The use of SF<sub>6</sub> can result in fugitive emissions during manufacturing processes. Advanced initiatives in the magnesium industry to phase out the use of SF<sub>6</sub> have resulted in a 60% reduction in SF<sub>6</sub> emissions from 3 MtCO<sub>2</sub>e to 1.2 MtCO<sub>2</sub>e between 2000 and 2010.

### Emissions Reduction Potential

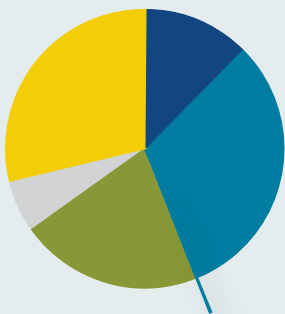
Assuming full implementation of current technology, emissions in the United States' magnesium manufacturing sector could be reduced by up to 0.1 MtCO<sub>2</sub>e in 2030. This accounts for 0.01% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



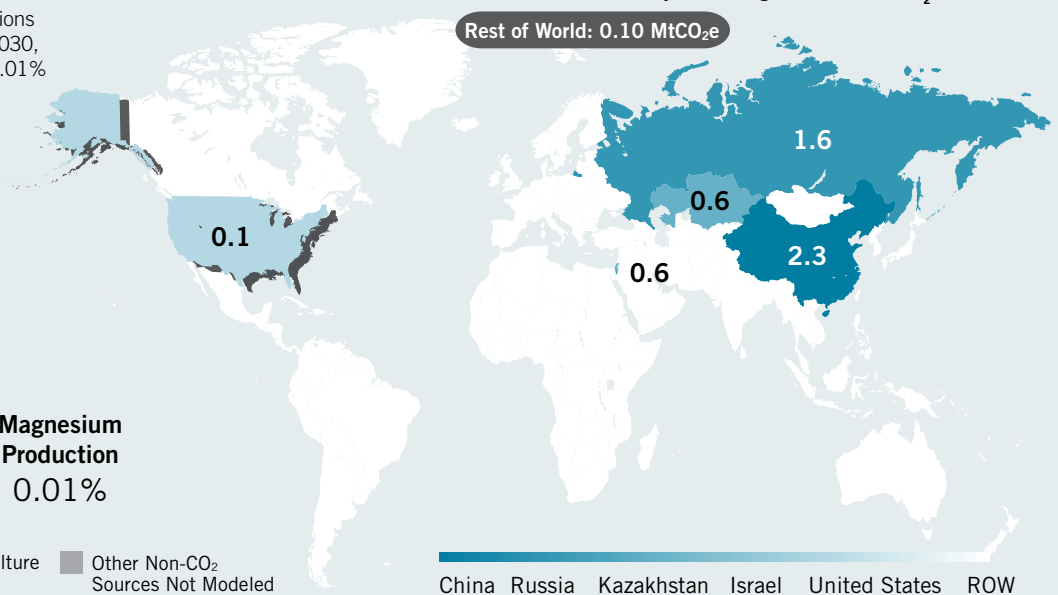
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Magnesium Production sector baseline emissions are estimated to be 1.2 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 0.1 MtCO<sub>2</sub>e, or 0.01% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)



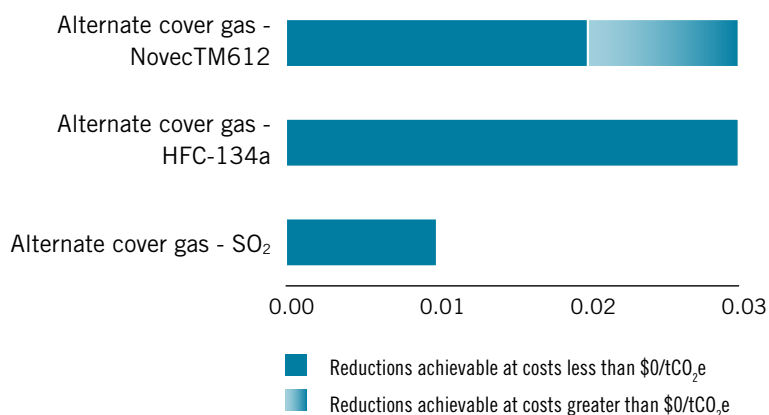


## Key Points

- The U.S. abatement potential of 98% is achieved through three abatement measures that substitute SF<sub>6</sub> with alternative gases.
- From 2010 to 2030, SF<sub>6</sub> emissions are projected to drop from 1.2 MtCO<sub>2</sub>e to 0.1 MtCO<sub>2</sub>e.
- Full abatement potential can be achieved at break-even prices of \$5/tCO<sub>2</sub>e or less.

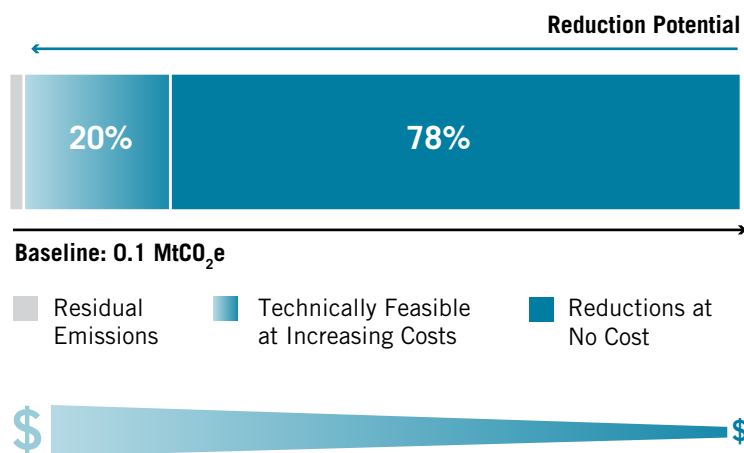
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 78%, compared with the baseline, in 2030. An additional 20% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Three abatement measures are available for reducing SF<sub>6</sub> emissions in production and processing, all of which involve replacing SF<sub>6</sub> with an alternative cover gas: sulfur dioxide (SO<sub>2</sub>), HFC-134a, or Novec 612. Although toxicity, odor, and corrosive properties are a concern of using SO<sub>2</sub> as a cover gas, it can potentially eliminate SF<sub>6</sub> emissions entirely through improved containment and pollution control systems. HFC-134a, along with other fluorinated gases, contains fewer associated health, odor, and corrosive impacts than SO<sub>2</sub>, but it does have global warming potential. Novec 612 is currently being used in a diecasting facility, and the replacement of SF<sub>6</sub> with Novec 612 is under evaluation.

## Abatement Potential

The U.S. abatement potential of SF<sub>6</sub> emissions in the magnesium sector is 1.1 MtCO<sub>2</sub>e, approximately 98% of projected sector emissions. The maximum reduction potential for the suite of reduction technologies is 98% of projected emissions in 2030. These reductions can be achieved at a cost of less than \$5/tCO<sub>2</sub>e.

# Photovoltaic Cell Manufacturing

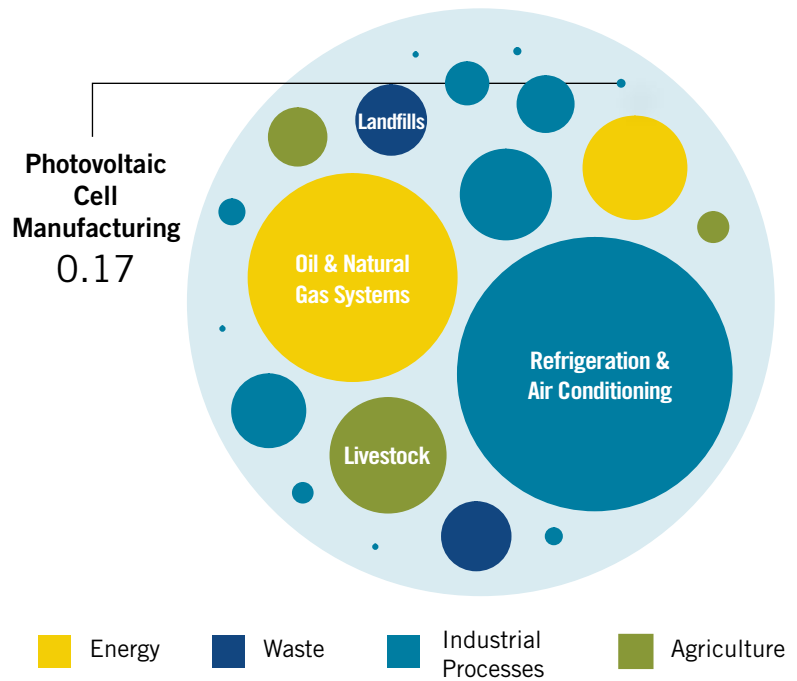
## F-GHG Emissions from Photovoltaic Cell Manufacturing

### Sector Description

The photovoltaic (PV) cell manufacturing process often uses multiple F-GHG during production, some of which are released into the atmosphere. Baseline emissions in 2010 were 0.18 MtCO<sub>2e</sub> and are expected to increase slightly to 0.19 MtCO<sub>2e</sub> in 2030.

### Emissions Reduction Potential

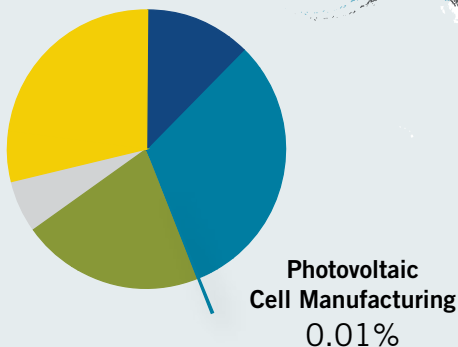
Assuming full implementation of current technology, emissions in the United States' photovoltaic cell manufacturing sector could be reduced by up to 0.2 MtCO<sub>2e</sub> in 2030. This accounts for 0.03% of the United States' total reduction potential (569 MtCO<sub>2e</sub>) in 2030.



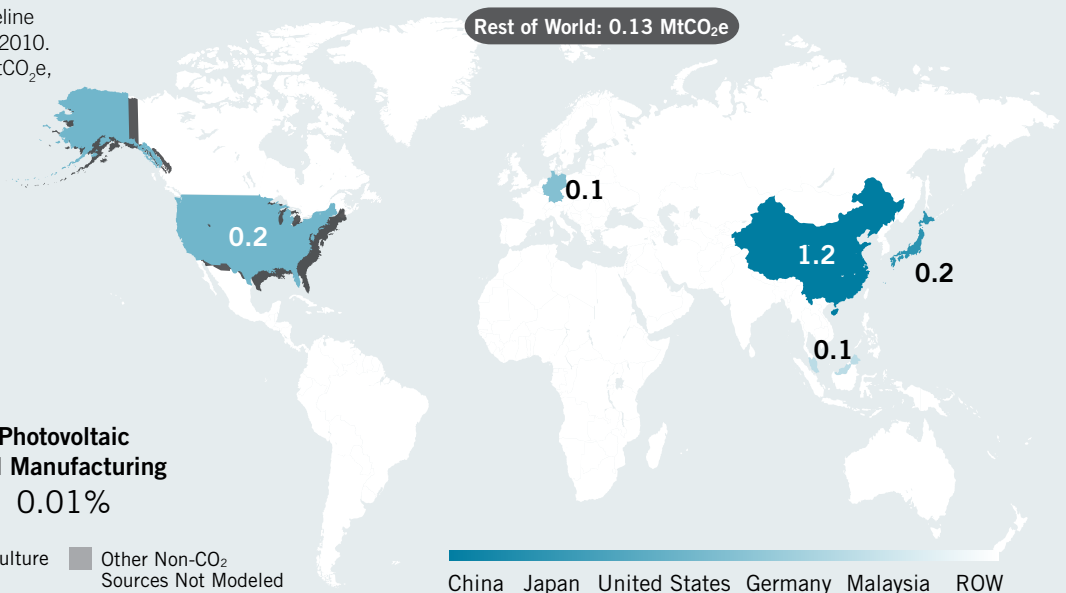
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Photovoltaic Cell Manufacturing sector baseline emissions are estimated to be 0.2 MtCO<sub>2e</sub> in 2010. In 2030, emissions are projected to be 0.2 MtCO<sub>2e</sub>, or 0.01% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2e</sub>)



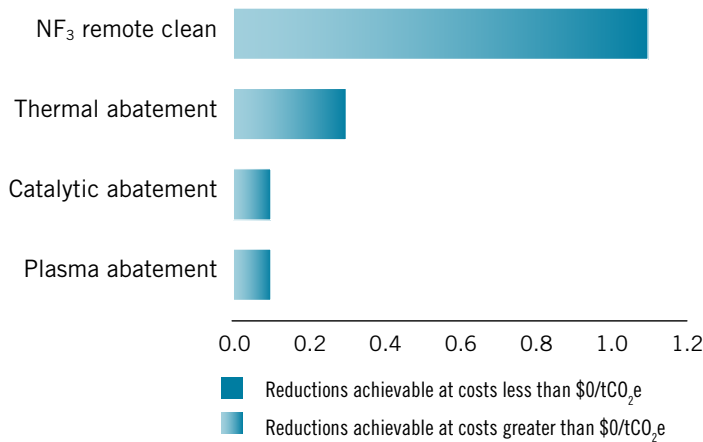


## Key Points

- The U.S. abatement potential in the PV manufacturing sector is 0.2 MtCO<sub>2e</sub> in 2030.
- Reduction technologies include technologies that reduce F-GHG emissions through etch and/or chamber cleaning processes.
- The high costs of emissions reduction technologies combined with low emissions reductions lead to abatement costs greater than \$300/tCO<sub>2e</sub>.

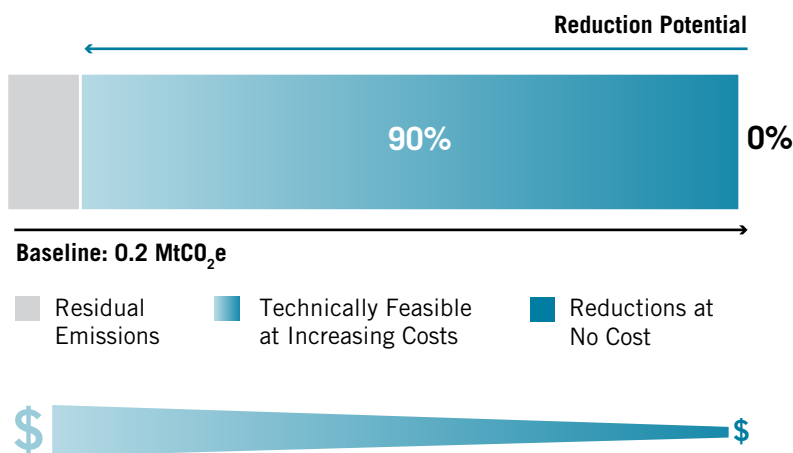
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2e</sub> and at higher prices.



### Emissions Reduction Potential, 2030

There are no cost effective reductions available in the PV cell manufacturing sector in 2030. However, a 90% reductions are available using technologies with increasingly higher costs.



## Abatement Measures

Abatement measures considered for reducing F-GHG emissions from the PV manufacturing sector include thermal abatement systems, catalytic abatement systems, plasma abatements systems, and the NF<sub>3</sub> remote chamber clean process. These technologies have the potential to reduce emissions from etch and/or chamber clean processes by 90%.

## Abatement Potential

The U.S. abatement potential in the PV manufacturing sector is estimated to be 0.17 MtCO<sub>2e</sub> from 2020 through 2030, or 90% of baseline emissions in each year. High capital costs and low emissions reductions associated with the available abatement measures result in abatement costs greater than \$300/tCO<sub>2e</sub>.

# Flat Panel Display Manufacturing

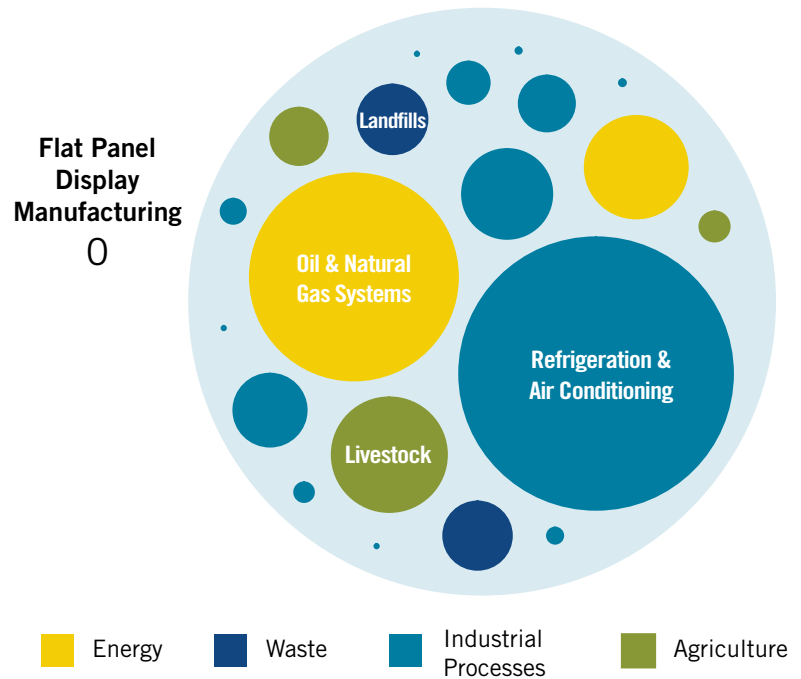
## F-GHG Emissions from Flat Panel Display Manufacturing

### Sector Description

Flat panel display (FPD) manufacturing processes produce F-GHG emissions, including SF<sub>6</sub>, NF<sub>3</sub>, and carbon tetrafluoride (CF<sub>4</sub>). FPD manufacturing industry is located outside the United States. Despite the lack of activity in the United States, this sector remains an important source of international GHG emissions and abatement potential.

### Emissions Reduction Potential

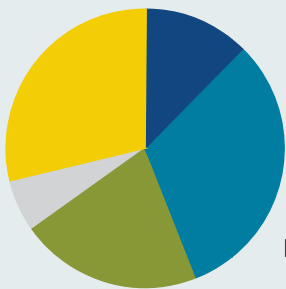
While the United States has no abatement in this sector, globally emissions from this sector can be reduced by approximately 10 MtCO<sub>2e</sub>.



### Projected Emissions in 2030

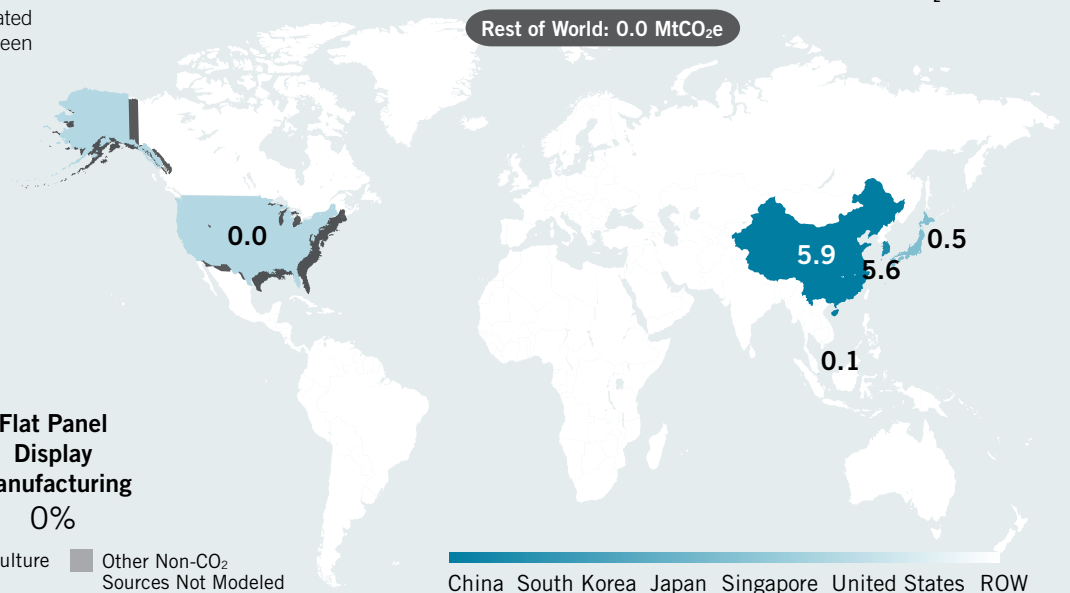
#### Global Non-CO<sub>2</sub> Emissions

The United States has no emissions associated with Flat Panel Display manufacturing between 2010 and 2030.



Energy Waste Industrial Processes Agriculture Other Non-CO<sub>2</sub> Sources Not Modeled

#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2e</sub>)

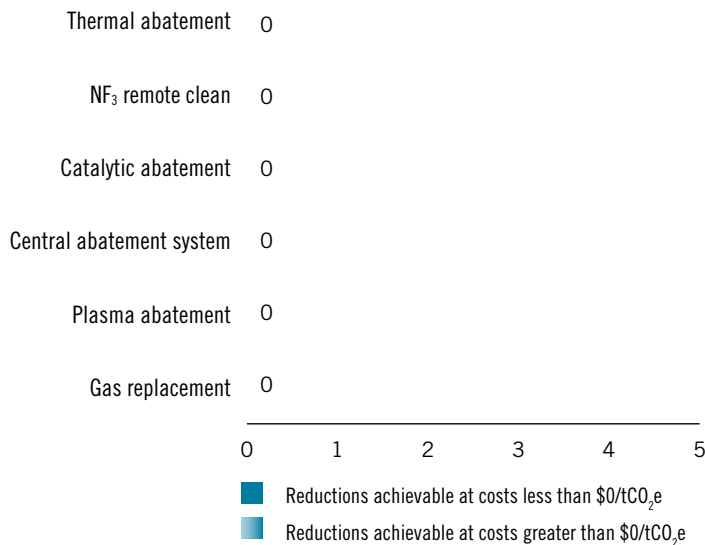


## Key Points

- FDP manufacturing is located outside the United States and is projected to remain outside the United States out to 2030.
- The United States is projected to have zero emissions in this sector between 2010 and 2030.
- Six abatement options were analyzed to reduce emissions from etch and/or clean processes.

### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.

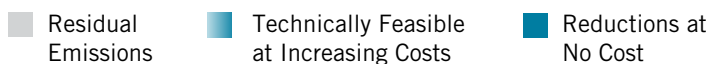


### Emissions Reduction Potential, 2030

The United States has no baseline emissions and subsequently no abatement potential in the flat panel display manufacturing sector.

0%

Baseline: 0 MtCO<sub>2</sub>e



## Abatement Measures

Six abatement options were considered for the FPD manufacturing sector: central abatement, thermal abatement, catalytic abatement, plasma abatement, NF<sub>3</sub> remote chamber clean, and gas replacement. These systems are applicable to reducing emissions from etch and/or clean processes. Thermal abatement systems represent the largest abatement potential, accounting for 40% of emissions reductions in the FPD manufacturing sector.

## Abatement Potential

Although the United States has no abatement potential in this sector, there are international opportunities to reduce emissions. Global abatement of F-GHGs in the FPD manufacturing sector is estimated to be 10 MtCO<sub>2</sub>e in 2030, which equates to an 80% reduction in emissions.



# Livestock

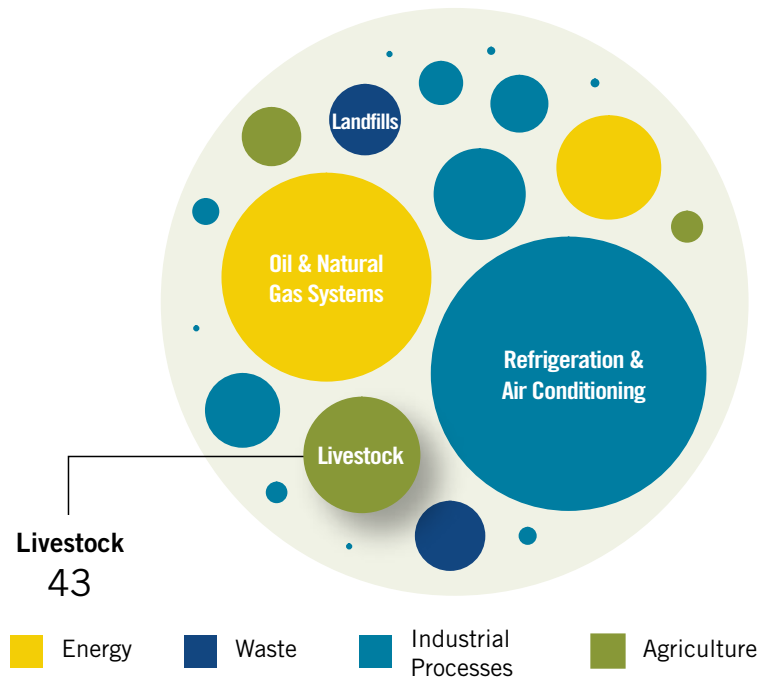
## Emissions from Livestock Operations

### Sector Description

Livestock operations generate CH<sub>4</sub> and N<sub>2</sub>O emissions. The GHG emissions mainly come from two sources: enteric fermentation and manure management. CH<sub>4</sub> is produced as a by-product of the digestive process in animals through a microbial fermentation process. Manure N<sub>2</sub>O emissions result from nitrification and denitrification of the nitrogen that is excreted in manure and urine. U.S. baseline emissions from the livestock sector are estimated to grow from 174.4 to 185.9 MtCO<sub>2</sub>e from 2010 to 2030.

### Emissions Reduction Potential

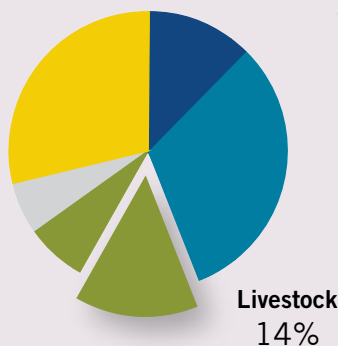
Assuming full implementation of current technology, emissions in the United States' livestock sector could be reduced by up to 43 MtCO<sub>2</sub>e in 2030. This accounts for 8% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



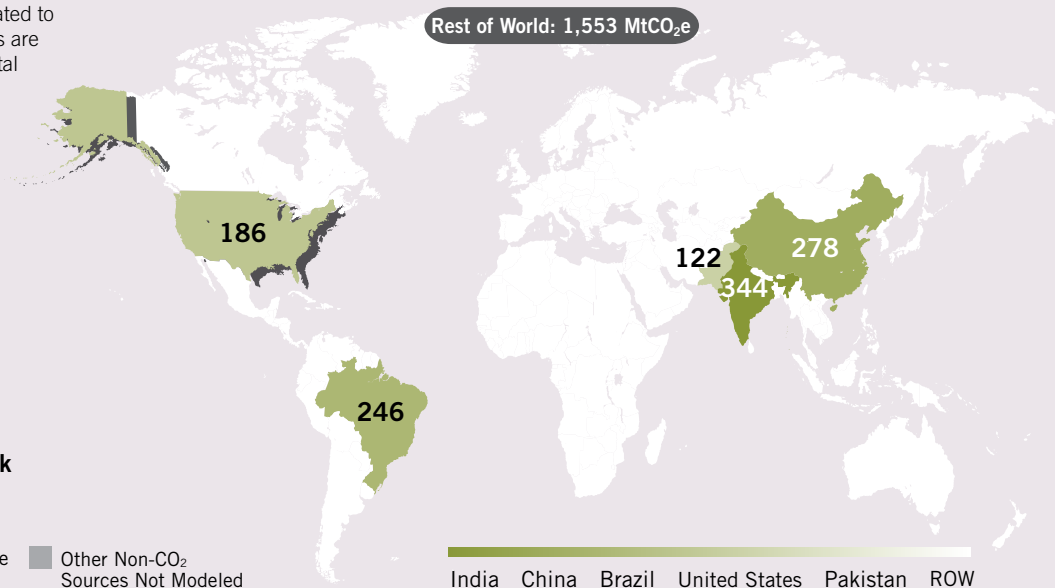
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Livestock sector baseline emissions are estimated to be 174 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 186 MtCO<sub>2</sub>e, or 14% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)



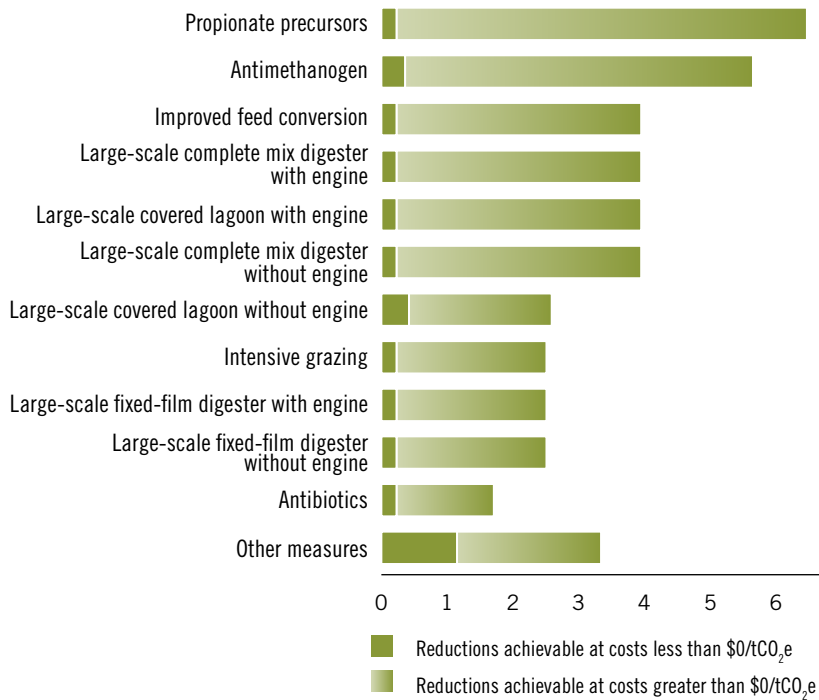


## Key Points

- The livestock sector accounts for 14% of baseline non-CO<sub>2</sub> emissions in the United States in 2030.
- The largest low-cost reductions in emissions resulted from implementing strategies to improve feed conversion efficiency, incorporating feed supplements, and increasing the use of large-scale complete mix anaerobic digesters.
- The technologically feasible abatement potential of the livestock sector is 43.2 MtCO<sub>2</sub>e in 2030, or 23% of baseline sector emissions.

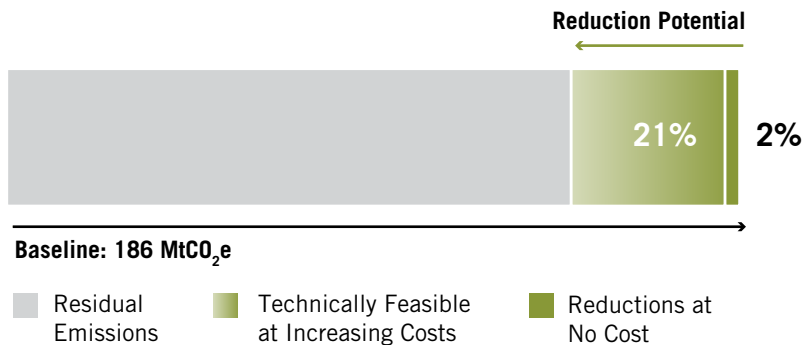
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 2%, compared with the baseline, in 2030. An additional 21% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

The report considered six enteric fermentation (CH<sub>4</sub>) abatement measures: improved feed conversion efficiency, antibiotics, bovine somatotropin, propionate precursors, antimethanogen vaccines, and intensive pasture management. It also included two manure management (N<sub>2</sub>O) abatement measures: small and large digesters (complete-mix, plug-flow, fixed film) and covered lagoons. The largest reductions resulted from implementing antimethanogen vaccines, propionate precursors, and large-scale complete-mix digesters.

## Abatement Potential

Technologically feasible U.S. abatement potential for the livestock sector was estimated at 43.2 MtCO<sub>2</sub>e in 2030, a 23% reduction compared with the sector baseline. In 2030, a reduction of 4.1 MtCO<sub>2</sub>e is cost-effective under current projections and 15.5 MtCO<sub>2</sub>e would be possible at an abatement cost of \$30/tCO<sub>2</sub>e.

# Rice Cultivation

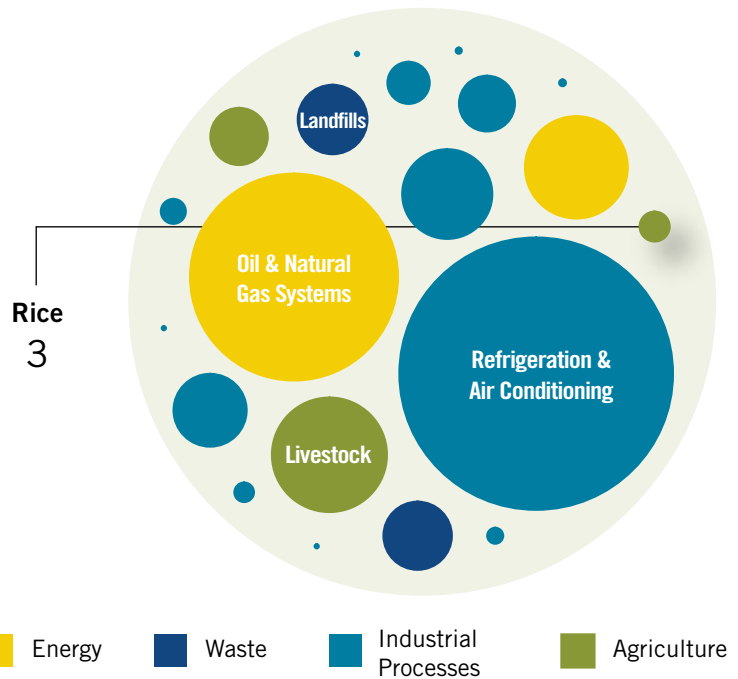
## Methane (CH<sub>4</sub>) and Nitrous Oxide (N<sub>2</sub>O) Emissions from Rice Cultivation

### Sector Description

Rice cultivation results in CH<sub>4</sub> and N<sub>2</sub>O emissions, and changes in soil organic C stocks. When paddy fields are flooded, decomposition of organic material depletes the oxygen in the soil and floodwater, causing anaerobic conditions. Human activities influence soil N<sub>2</sub>O emissions (use of fertilizers and other crop management practices) and soil C stocks (residue and crop yield management). The United States ranks as the 11th largest emitter of GHG emissions from rice cultivation. Baseline emissions from the rice cultivation sector in the United States are projected to grow from 5.7 to 8.8 MtCO<sub>2</sub>e from 2010 to 2030.

### Emissions Reduction Potential

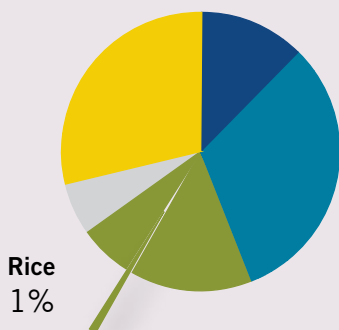
Assuming full implementation of current technology, emissions in the United States' rice sector could be reduced by up to 3 MtCO<sub>2</sub>e in 2030. This accounts for 1% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



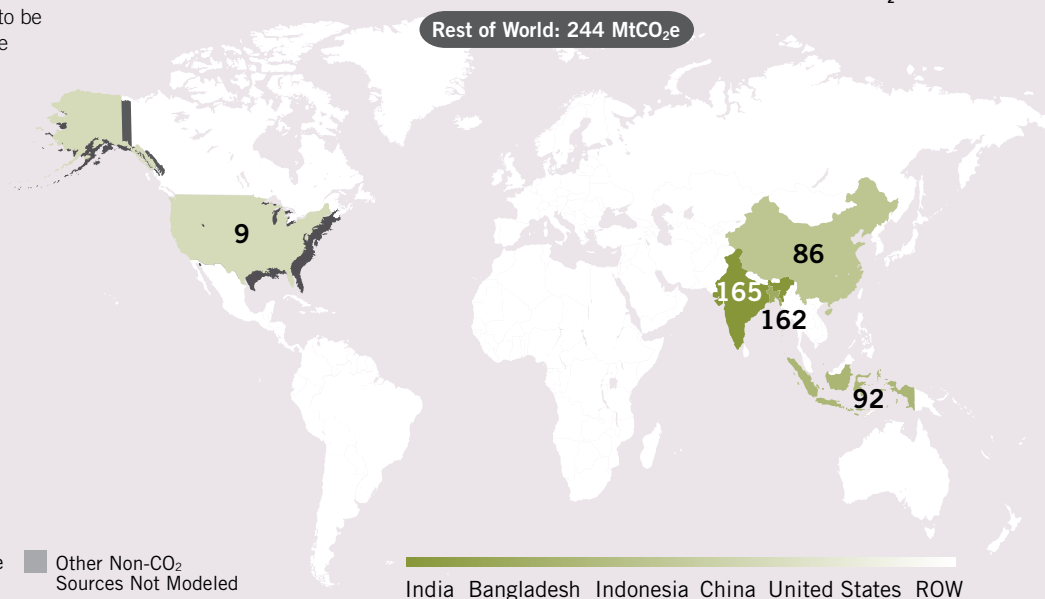
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Rice sector baseline emissions are estimated to be 6 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 9 MtCO<sub>2</sub>e, or 1% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)



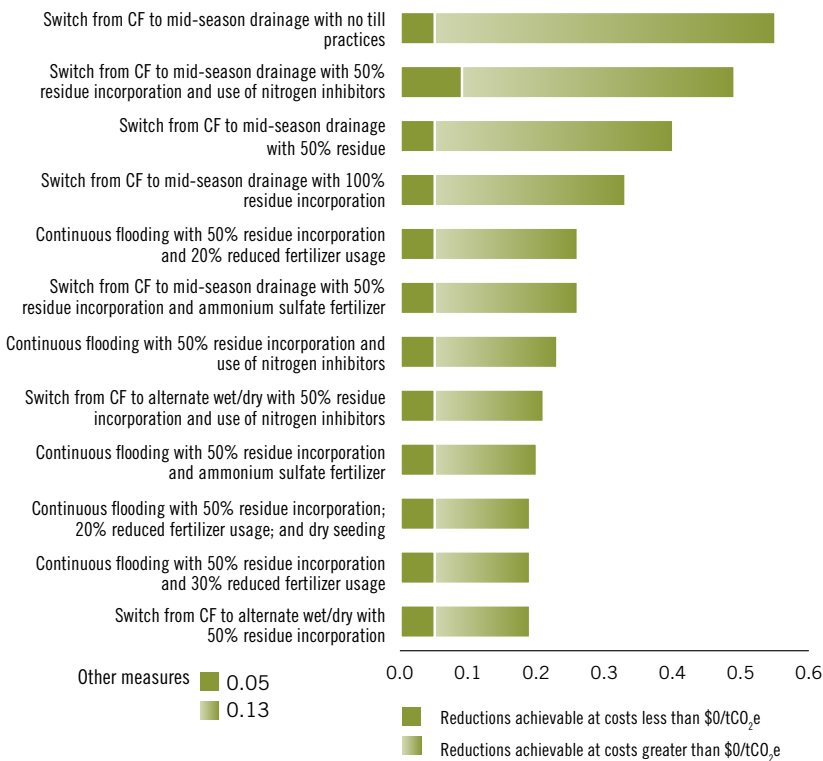


# Key Points

- The rice cultivation sector accounts for 1% of baseline non-CO<sub>2</sub> emissions in the United States in 2030.
- Among the abatement measures evaluated, switching from continuous flooding to mid-season drainage with residue utilization and implementation of no tillage practices provides the largest emission reductions in the United States.
- The technologically feasible reduction potential of the rice cultivation sector is 3.0 MtCO<sub>2e</sub> in 2030, 35% of baseline sector emissions.

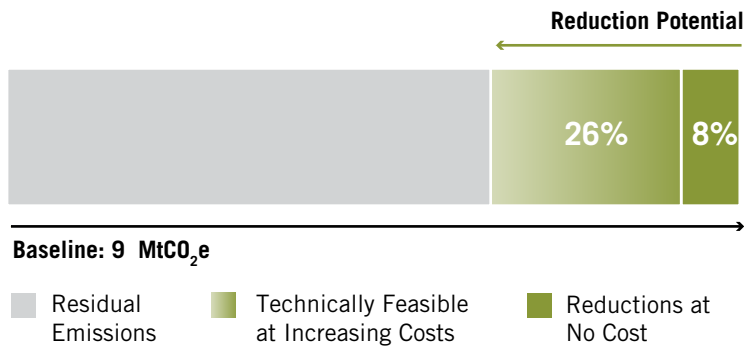
## Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2e</sub> and at higher prices.



## Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 8%, compared with the baseline, in 2030. An additional 26% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Five types of abatement measures were considered: paddy flooding (continuous, midseason, alternating, dry), crop residue incorporation (50% and 100%), tillage (conventional and no till), fertilization application (conventional, ammonium sulfate, nitrification inhibitor, slow release, reduced use, auto fertilization), and direct seeding. Switching continuous flooding to mid-season drainage in combination with 50% residue incorporation and adopting no-tillage practices in rice cultivation provide the largest emissions reductions but may also lower rice yields to some degree.

## Abatement Potential

Technologically feasible U.S. abatement potential for the rice cultivation sector was estimated at 3.3 MtCO<sub>2e</sub> in 2020 and 3.0 MtCO<sub>2e</sub> in 2030, 39% and 35% reductions compared with the sector baseline. In 2030, a reduction of 0.7 MtCO<sub>2e</sub> at an abatement cost of \$0/tCO<sub>2e</sub> and 1.7 MtCO<sub>2e</sub> would be possible at a cost of \$30/tCO<sub>2e</sub>.



# Croplands

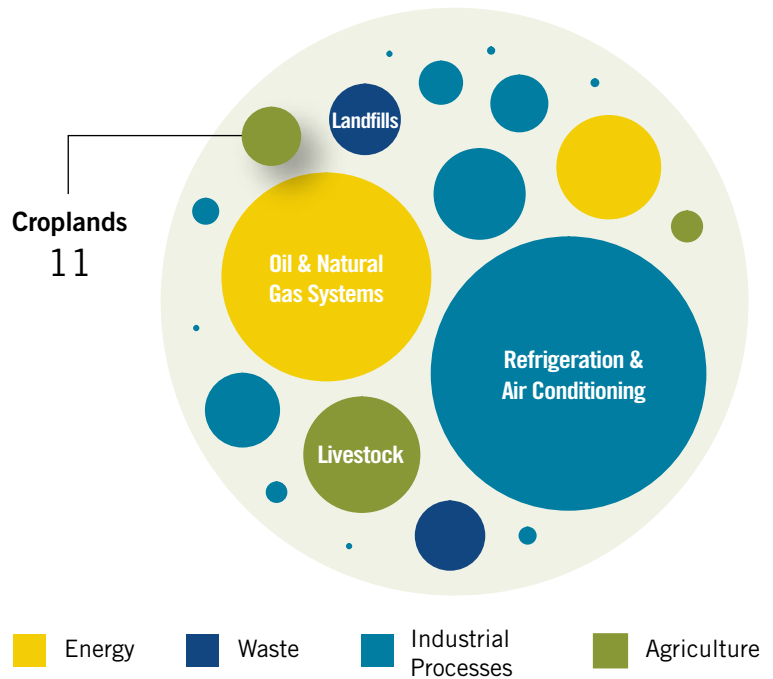
## Non-rice Croplands

### Sector Description

Land management in croplands influences soil N<sub>2</sub>O emissions (influenced by fertilization practices, soil drainage, and nitrogen mineralization), H<sub>4</sub> fluxes, and soil organic carbon (C) stocks (and associated CO<sub>2</sub> fluxes to the atmosphere). The report considers only major crops (barley, maize, sorghum, soybeans, and wheat) and minor crops closely related to these (rye, lentils, other beans, and oats). U.S. baseline emissions from the croplands sector in 2010 were estimated at 82.1 MtCO<sub>2</sub>e. Projected emissions are relatively constant, decreasing to approximately 71.3 MtCO<sub>2</sub>e in 2020 and rebounding to 86.1 MtCO<sub>2</sub>e by 2030.

### Emissions Reduction Potential

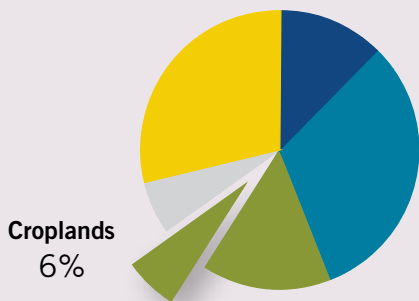
Assuming full implementation of current technology, emissions in the United States' soil sector could be reduced by up to 11 MtCO<sub>2</sub>e in 2030. This accounts for 2% of the United States' total reduction potential (569 MtCO<sub>2</sub>e) in 2030.



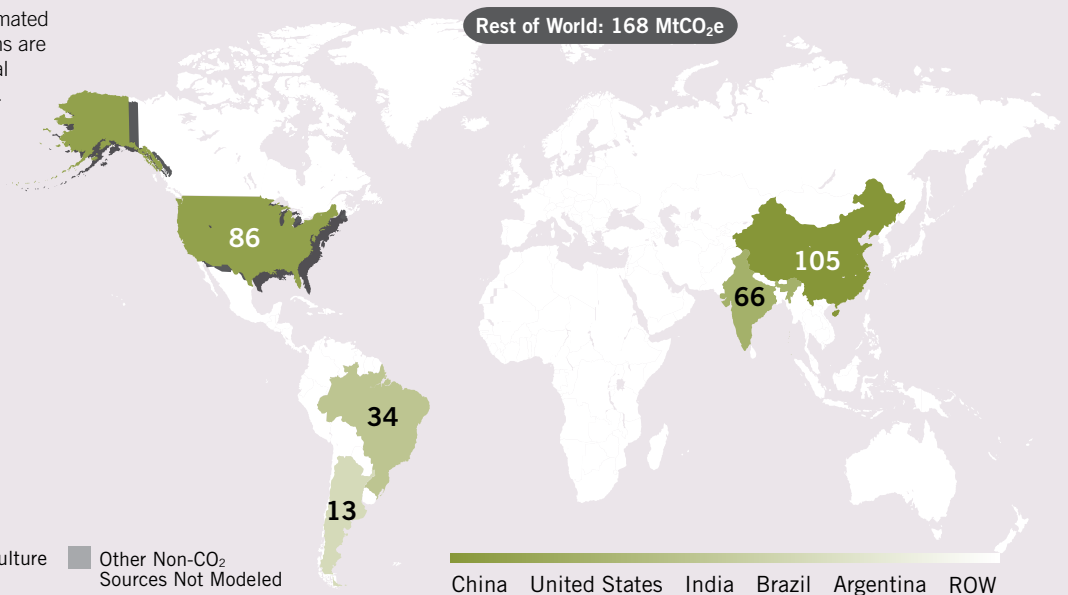
### Projected Emissions in 2030

#### Global Non-CO<sub>2</sub> Emissions

Croplands sector baseline emissions are estimated to be 82 MtCO<sub>2</sub>e in 2010. In 2030, emissions are projected to be 86 MtCO<sub>2</sub>e, or 6% of total non-CO<sub>2</sub> emissions in the United States.



#### Emissions from the United States and other Major Emitting Countries (MtCO<sub>2</sub>e)





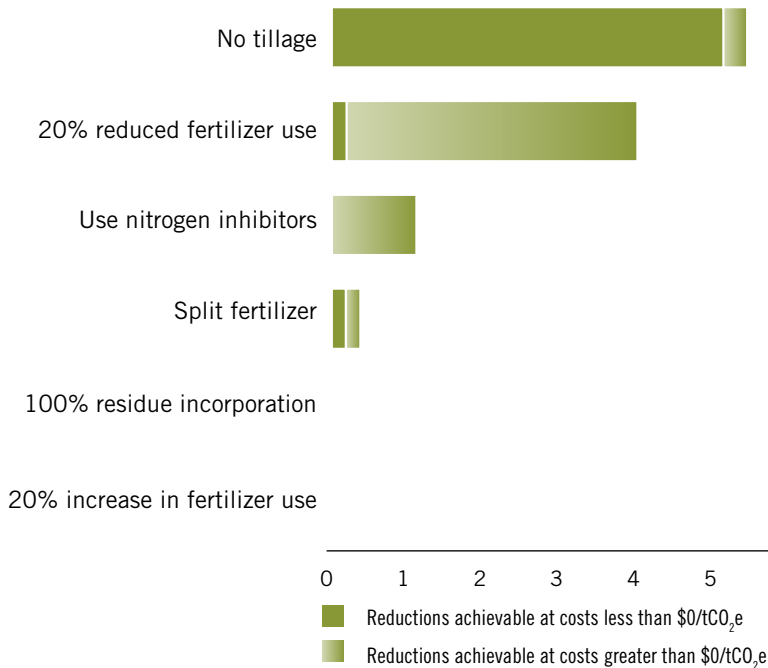


## Key Points

- The U.S. emission reduction potential of the croplands sector is 10.9 MtCO<sub>2</sub>e in 2030, 13% of baseline sector emissions.
- Seven abatement options were analyzed to reduce soil management emissions.
- 86% of potential reductions in the United States are achievable by implementing no-till cultivation and reducing fertilizer applications.

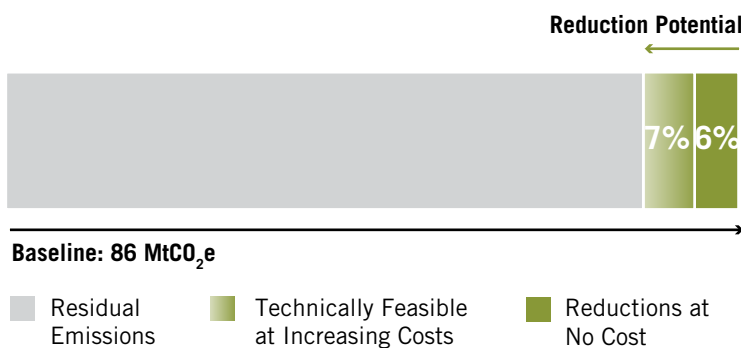
### Abatement Measures

Emissions reductions by technology in 2030 at \$0/tCO<sub>2</sub>e and at higher prices.



### Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 6%, compared with the baseline, in 2030. An additional 6.6% reduction is available using technologies with increasingly higher costs.



## Abatement Measures

Six abatement measures were considered for the cropland sector: adoption of no-till cultivation, reduced fertilizer application, increased fertilizer application, split nitrogen fertilization, application of nitrification inhibitors, and crop residue incorporation. In 2030, the majority of reductions result from implementing no-till cultivation (50% of total abatement). Additional reductions can be achieved by reducing fertilizer usage and adopting nitrification inhibitors.

## Abatement Potential

Technologically feasible U.S. abatement potential in the croplands sector is estimated to be 14.5 MtCO<sub>2</sub>e in 2020 and 10.9 MtCO<sub>2</sub>e in 2030, representing 20% and 13% reductions compared with the sector baseline. In 2030, abatement measures that break even (i.e., ≤\$0/tCO<sub>2</sub>e) can reduce 5.5 MtCO<sub>2</sub>e in cropland emissions. Additional reductions are achievable when including more costly abatement measures. For example, the level of reduced emissions increases to 8.7 MtCO<sub>2</sub>e when including abatement measures at break-even prices less than or equal to \$30/tCO<sub>2</sub>e.



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