

GHGs Other Than Carbon Dioxide:

Emissions, Technology, Mitigation Potential and Research Needs

August 26, 2008

Non-CO2 GHG Emissions Workshop, Stanford University

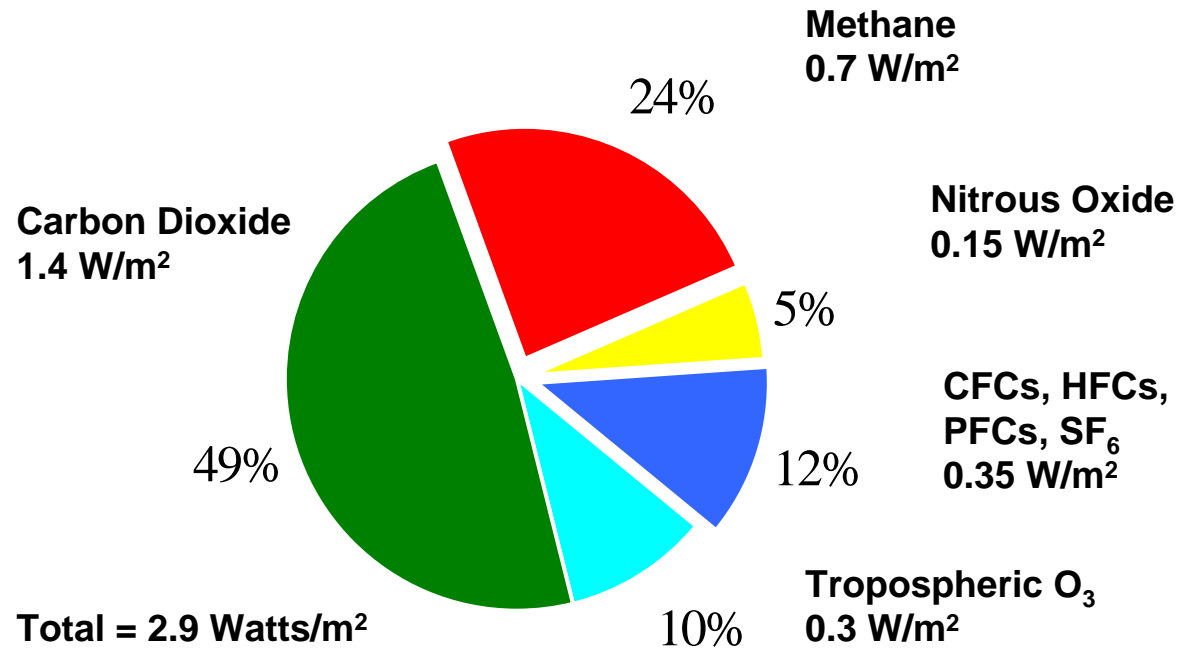


Overview

- Background on Other Gases
 - Key Characteristics
 - Sources, Emissions and Trends
- Current Mitigation Technologies
- Economic Mitigation Potential
- Current Mitigation Efforts
- Potential Research Opportunities
- Concluding Thoughts

Non-CO2 Gases Play an Important Role

Anthropogenic Emissions of Non-CO2 Gases have been important contributors to an enhanced Greenhouse Effect Since Pre-Industrial Times



What Are the “Other Gases”

- Methane (CH₄)
- Nitrous Oxide (N₂O)
- Ozone Depleting Substances (CFC, HCFC)
 - phased out by the Montreal Protocol
- High-GWP Gases (HFC, PFC, SF₆)
 - including substitutes for Ozone Depleting Substances & industrial gases
- Aerosols (sulfate, black carbon)
- Ozone and its precursors (CO, NMVOC, NO_x)

Methane

- Basic information
 - 100-year GWP = 23
 - Lifetime = 12 years
- Emitted by many sources, in energy, agriculture & waste sectors
- Principal component of natural gas (improves mitigation economics)
- Emissions can be reduced but not eliminated
- Mitigation efforts deliver many co-benefits
 - Climate Change, Energy, Air Quality, Mine/Industrial Safety, Water Quality, Odor Control

Nitrous Oxide

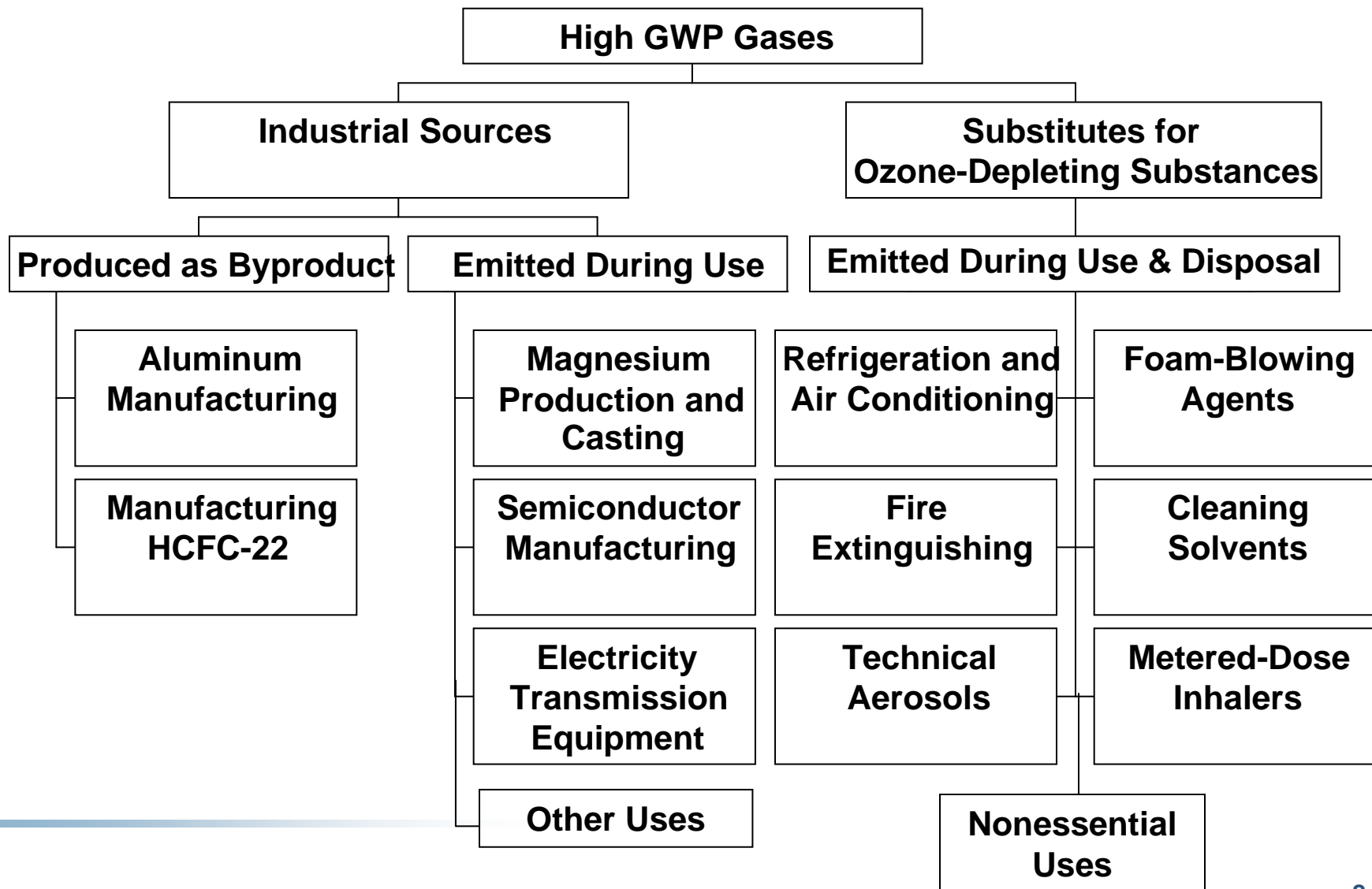
- Basic information
 - 100-year GWP = 310
 - Lifetime = 120 years
- Principal sources are agriculture, combustion, and chemical production
- Better characterization of emission levels is needed for several sources
- Emissions cannot be eliminated, particularly in agriculture sector
- Major reductions are possible through break-through technologies in
 - agriculture
 - combustion
 - transportation

High GWP or Fluorinated Gases

- Basic information
 - 100-year GWPs range from 140 for HFC-152a to 23,900 for SF₆
 - Lifetimes range from 1.4 years for HFC-152a to 50,000 years for CF₄
- Main sources
 - ODS (controlled by Montreal Protocol)
 - ODS Substitutes (mainly HFCs)
 - Used in or by-product from various processes
- Many opportunities to reduce emissions by instituting better handling, improve leak-tightness, developing new chemicals and redesigning processes
- High potential growth

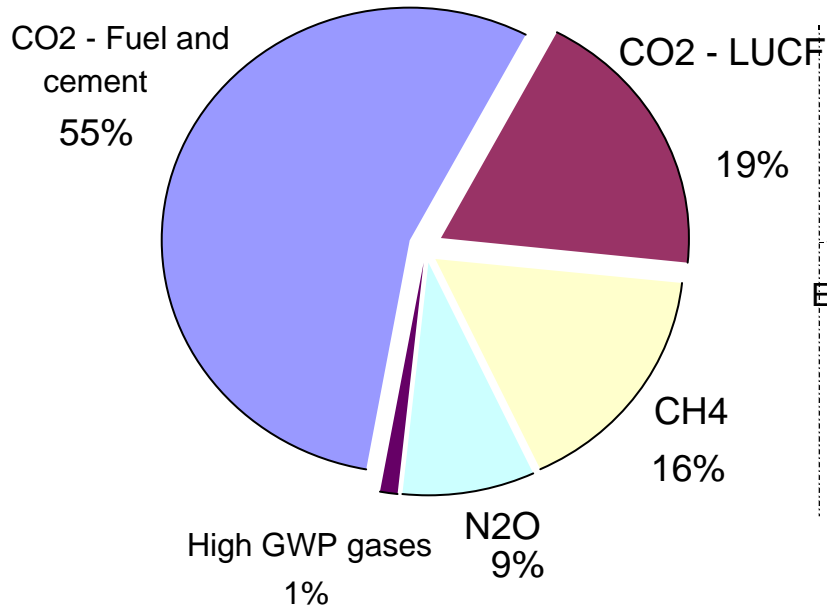
	Chemical	Lifetime (yrs, AR4)	100-year GWP (SAR)
ODS Sub	HFC-32	4.9	650
	HFC-134a	14	1,300
	HFC-143a	52	3,800
	HFC-152a	1.4	140
Industrial	CF ₄	50,000	6,500
	C ₂ F ₆	10,000	9,200
	HFC-23	270	11,700
	SF ₆	3,200	23,900

How Are Fluorinated Gases Emitted?

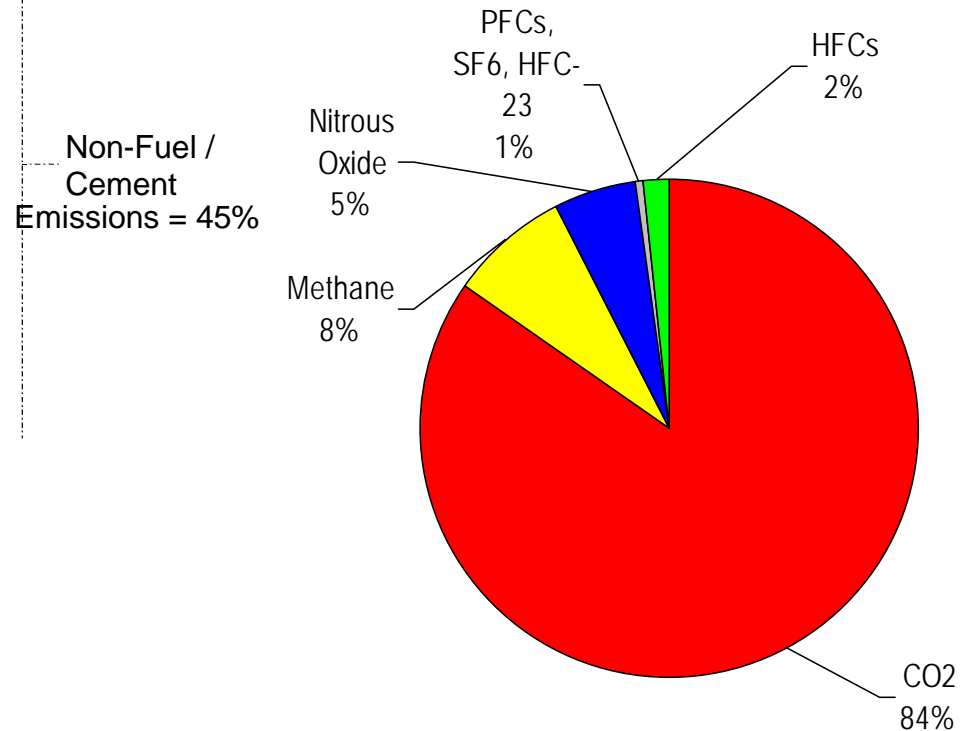


Emissions of Non-CO2 Gases

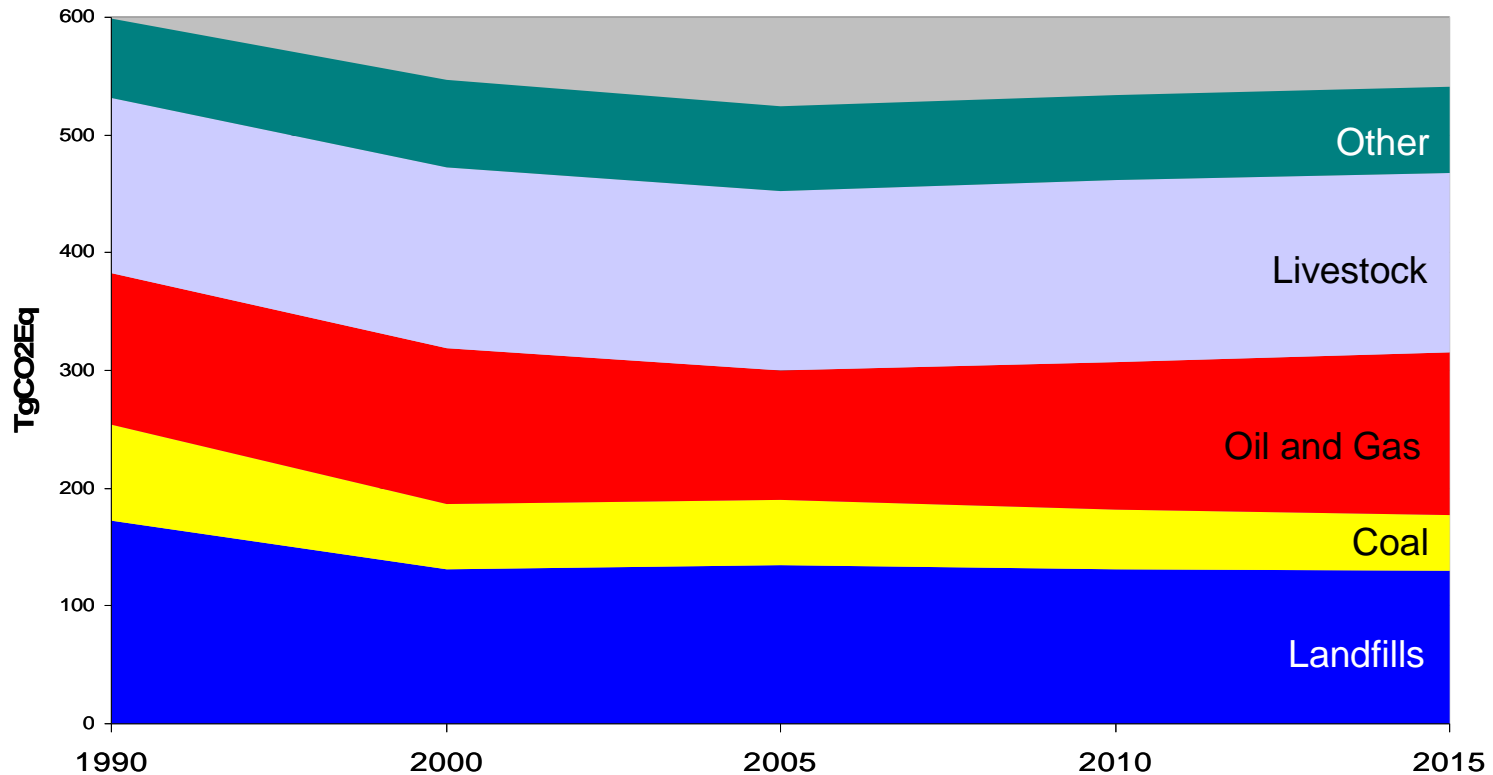
Global Net Emissions of CO₂, CH₄, N₂O, High GWP gases, and LUCF (Total 40,702 Tg CO₂ Eq.)



US Emissions (Total 7,260 Tg CO₂ Eq.)

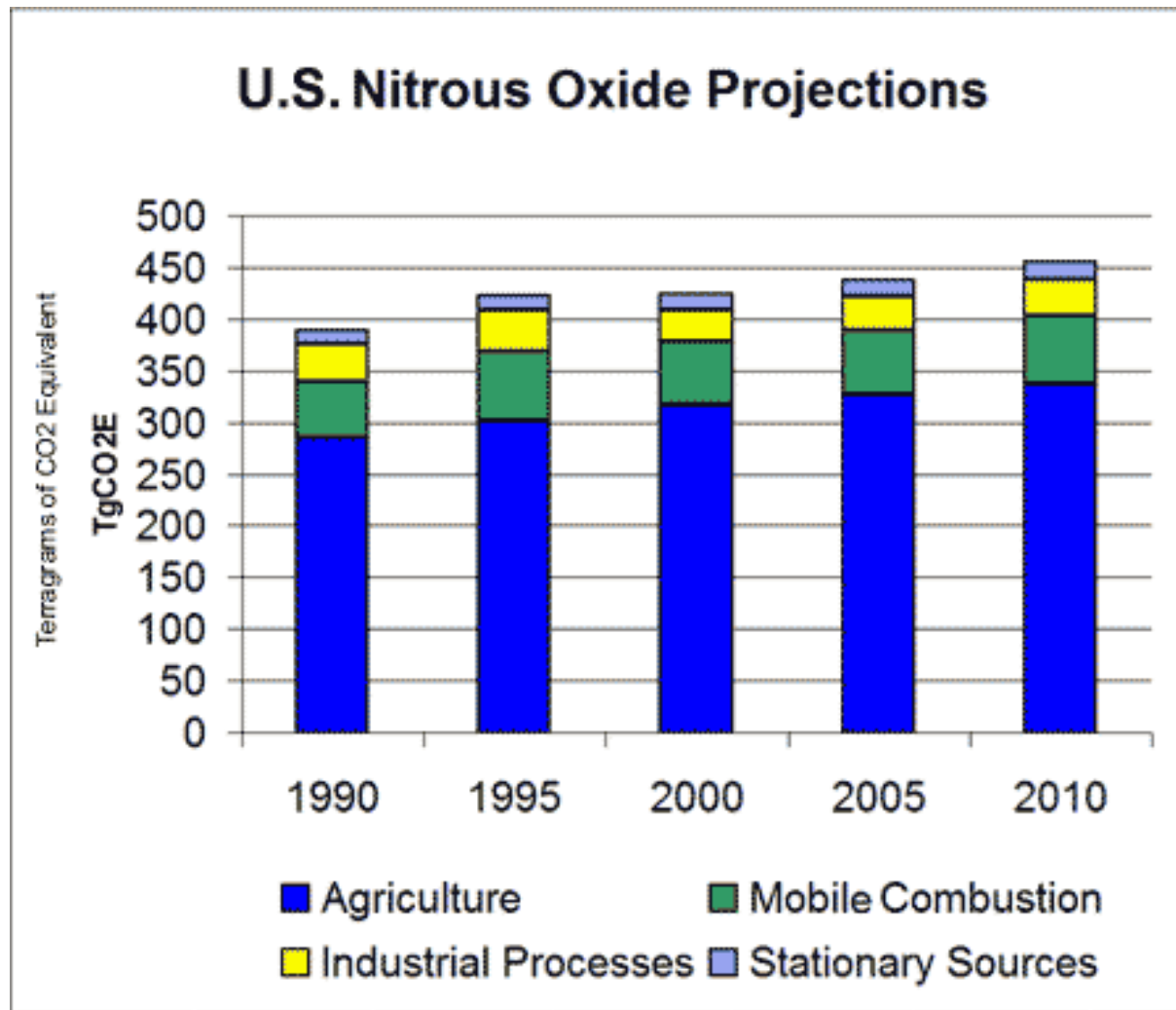


Trends - Methane

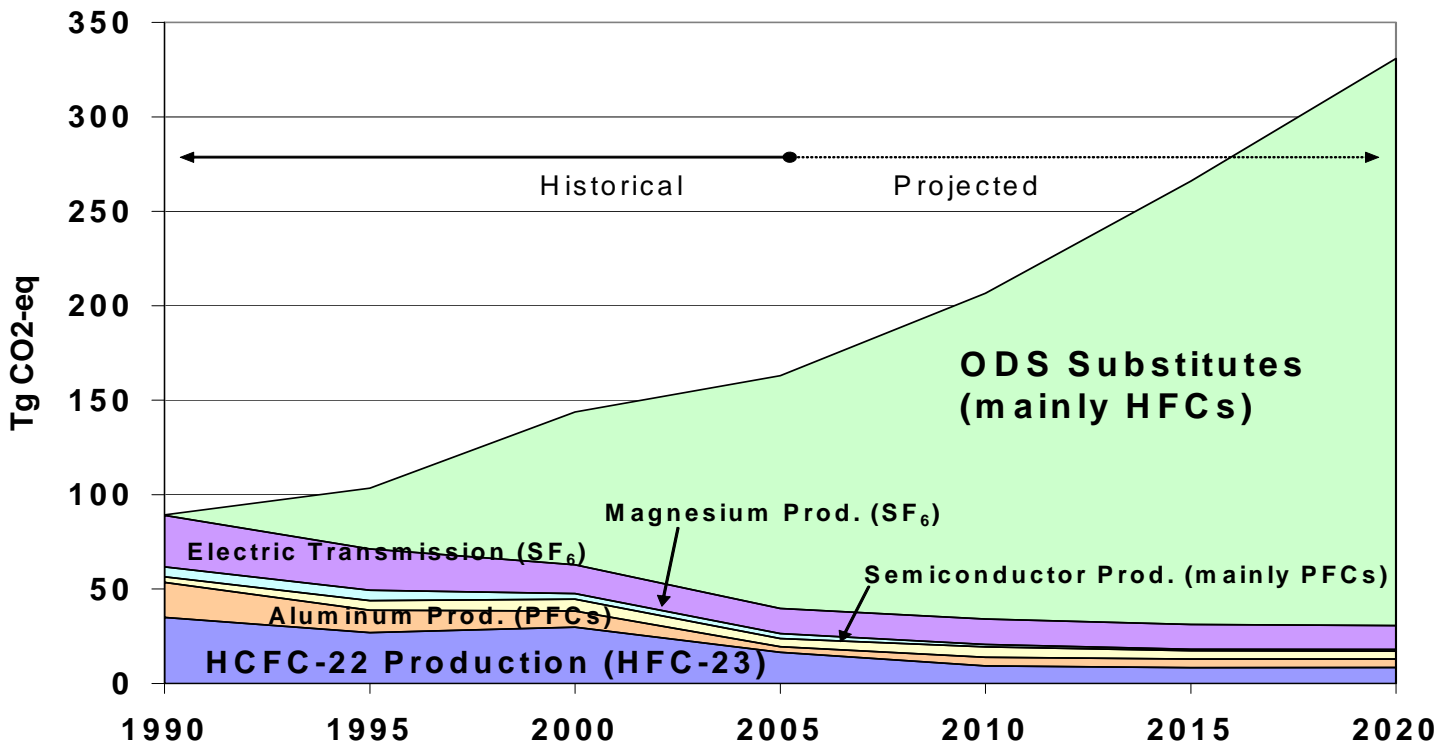


- As of 2005, the CH₄ partnership programs have successfully reduced US emissions 11% below 1990 levels
- With continued efforts, emissions are expected to remain below 1990 level in spite of economic growth through 2020

Trends – Nitrous Oxide



Trends – High GWP Gas Emissions



- Emissions from ODS substitutes have risen from nearly zero in 1990 to 123 MtCO₂-eq today; rise will continue through 2030 as ODS phaseout continues.
- Emissions of HFCs, PFCs, and SF₆ from “industrial sources” have fallen by 55%, primarily due to EPA-industry partnership programs.

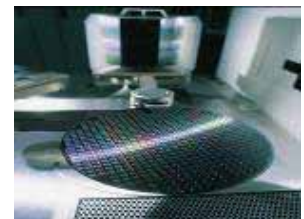
Trends – (short-term) why HFCs expand but still result in GHG reductions

HFCs are:

- Solution linked to an international environmental accord
 - The path forward for 191 countries under Montreal Protocol
- Created as substitutes for ODS
 - same sectors regulated under Montreal Protocol cap and trade regime, predominately air-conditioning and refrigeration
 - Prevents ‘backsliding’ or delaying transition
 - complementary policies and measures for further emissions reductions like CAA Title VI, Sections 608, 609, 610, 611 & 612
- Technical experts worldwide recognized both difficulties of transition away from HFCs and implications for completing Montreal Protocol tasks:
 - IPPC TAR: “[for] some HFC applications, alternatives are not technically and economically feasible”

High GWP Mitigation Opportunities

Source	Key Technology
Aluminum	Reduce anode effects
Magnesium	Improved process management, SF6 substitutes
Electric Power	Improved gas handling, recycling, new equipment
Semiconductors	Improved process management, thermal destruction, alternative chemicals
HFC-23	Improved process management, thermal destruction
ODS Substitutes	Improved gas management, alternative chemicals, ban nonessential uses – approaches and costs are highly dependent on end-use



Methane Mitigation Opportunities

Source	Key Technologies
Landfills	Methane recovery and combustion (i.e., power generation, industrial uses, flaring)
Coal Mines	Methane recovery and combustion, flaring, ventilation air use
Gas/Oil Systems	Use of low-bleed equipment, and better management practices
Livestock Waste	Methane collection from anaerobic digestors and combustion (power, flaring)
Ruminant Livestock	Improved production efficiency through better nutrition and management
Rice Production	Water management, organic supplements



Nitrous Oxide Mitigation Opportunities

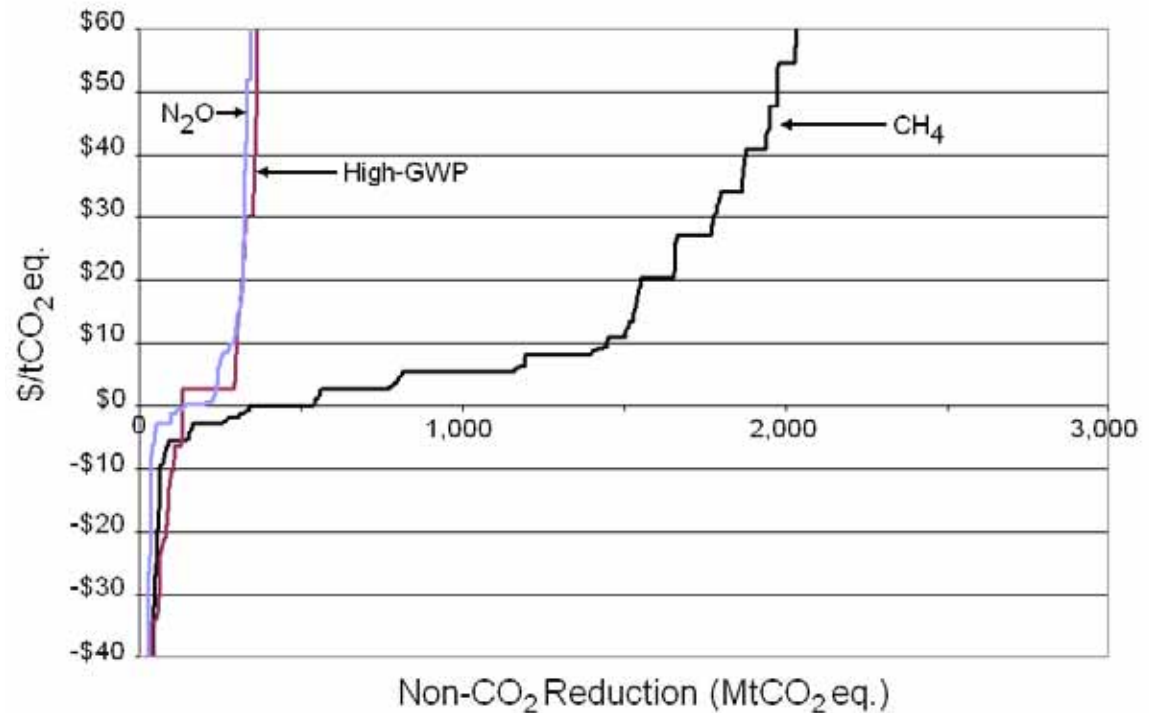
Source	Key Technologies
Industrial Sources	Adipic acid (catalysts, thermal destruction) Nitric acid (non-selective catalytic reduction)
Transportation	Non-combustion vehicle alternatives (i.e., electric cars, fuel cell vehicles), Reduce existing vehicle use (public transportation, fuel efficiency)
Agriculture Soil Management	Precision agriculture, cropping system models, control release fertilizers, soil conservation practices



Global Mitigation Potential – by GHG

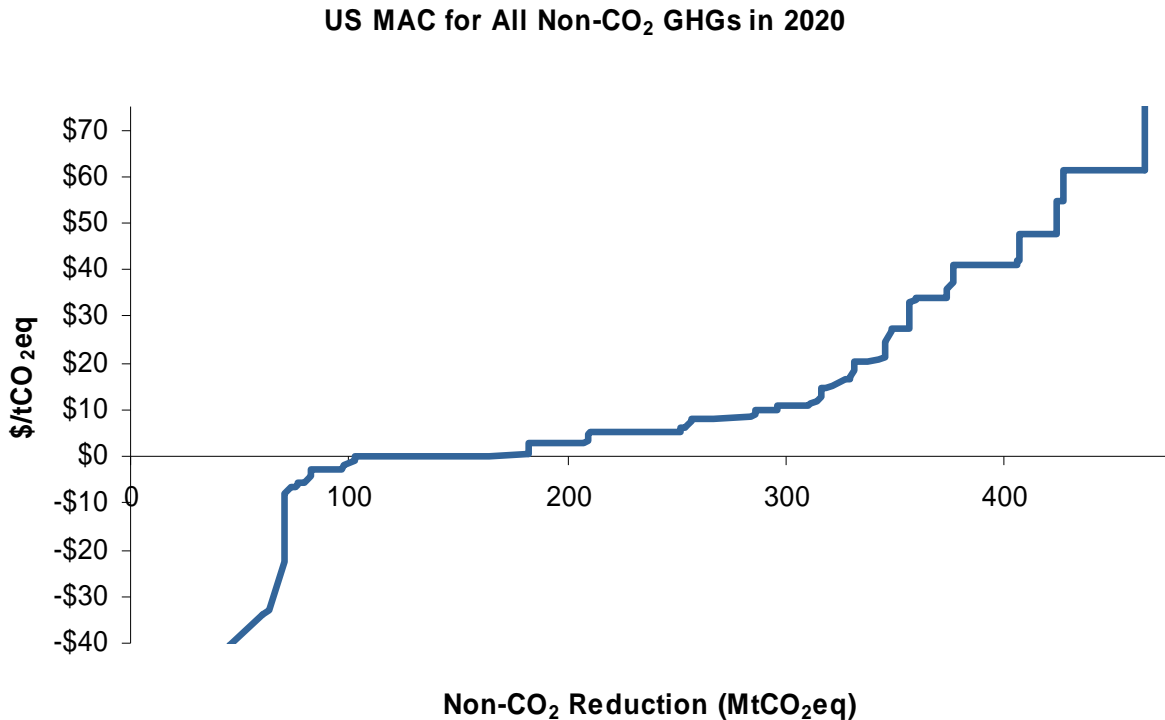
Methane mitigation has the largest potential across all the non-CO₂ greenhouse gases

- Worldwide, the potential for cost-effective non-CO₂ greenhouse gas abatement is significant (> 500 MtCO₂eq).
- At a cost-effective level, the potential for methane mitigation is the greatest
- At a breakeven price of \$30/tCO₂eq, reduction potential reaches nearly 1,800 MtCO₂eq
- While less than that of methane, nitrous oxide and high-GWP gases exhibit significant cost-effective mitigation potential.



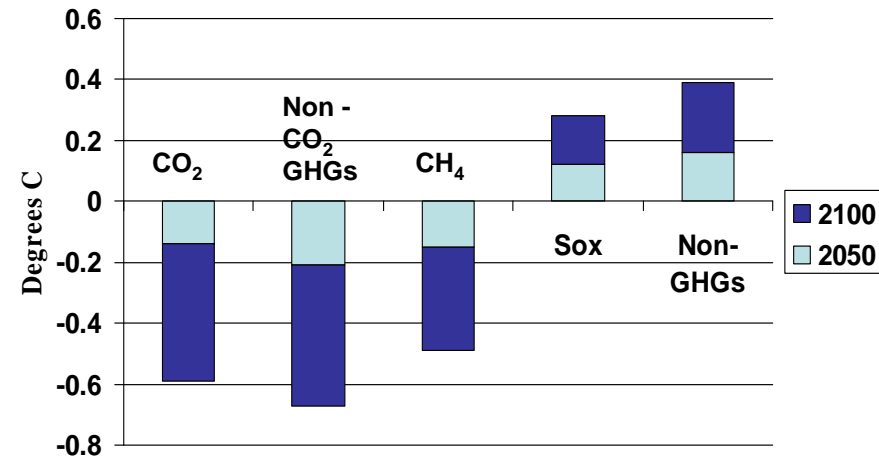
US Mitigation Potential – by GHG

- Across all Non-CO₂ greenhouse gases US cost-effective non-CO₂ greenhouse gas abatement is ~100MtCO₂eq
- At a breakeven price of \$30/tCO₂eq, reduction potential reaches nearly 350 MtCO₂eq
- Reduction potential reaches approximately 420 MtCO₂eq at a breakeven price of \$55/tCO₂eq



Non-CO2 Reductions Offer Important Climate and Economic Benefits

- Near-term Climate Benefits
 - *“Looking to likely emissions over the next half century, it is also the case that feasible reductions in emissions of methane and other non-CO₂ gases can make a contribution to slowing global warming that is as large or even larger than similar reductions in CO₂ emissions.” - MIT, 2003*
- Mitigation cost are lower than for energy-related CO₂
- Sources of “other gases” are much more diverse – not just energy and land use
- The result – a large portfolio of mitigation options and the potential for reduced costs for a given climate policy objective



Impact of a 50% reduction from BAU in 2050, maintained to 2100

Efforts to Reduce Emissions of Non-CO2 Gases in the United States

Public-private partnership programs target major sources

- Landfill Methane Outreach Program
- Coal Mine Methane Outreach Program
- Natural Gas STAR
- AgSTAR
- VAIP (Aluminum)
- Semiconductor Partnership
- Utility SF6 Partnership
- Magnesium Partnership
- HFC-23 Reduction Partnership
- HFCs in Mobile Air Conditioning
- ODS partnerships (GreenChill, RAD)

Avoid High GWP Emissions by stratospheric ozone regulation

- Refrigerants (no venting, mandatory recovery and recycling, leak-repair if exceed emission limits)
- ODS Substitutes “SNAP” Program (Ban or limit use where more environmentally friendly substitutes exist)

Reduce methane emissions as a co-benefit of air quality regulation

- Landfills and Oil and Gas Sector – HAPs, VOCs

High Global Warming Potential Programs

Sectors: Aluminum, Magnesium, Semiconductors, Electric Power, Mobile Air Conditioning, and HFC and HCFC producers



EPA Partnership Goals:

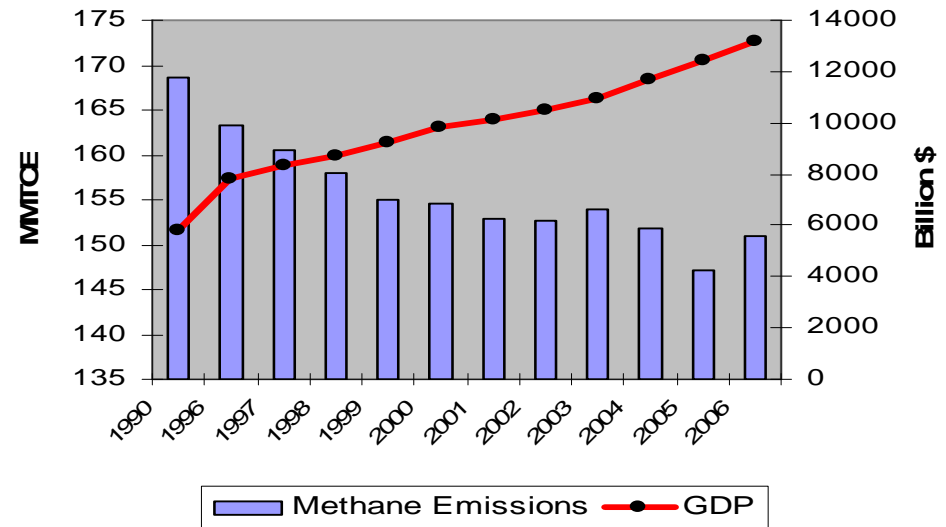
- ✓ Mobile Air Conditioning Partnership
- ✓ - **Reduce HFCs 50%** and improve fuel-efficiency by 30%
- ✓ PFC Reduction Partnership for the Semiconductor Industry
- ✓ - **Reduce PFCs 10%** below 1995 by end of 2010
- ✓ Voluntary Aluminum Industrial Partnership
- ✓ - **Reduce direct carbon intensity** by 53% below 1990 levels by 2010
- ✓ SF₆ Emissions Reduction Partnership for the Magnesium Industry
- ✓ - **Phase out SF₆** by end of 2010

Emissions of HFCs, PFCs, and SF₆ from “industrial sources” are 40% below 1990 levels, primarily due to EPA-industry partnership programs.

US Methane Partnerships

- Natural Gas STAR
 - over 100 companies (57% of industry) in program
 - Since 1993, companies have reported reductions of 63 MMTCE, valued at over \$4.2 billion USD.
- Coalbed Methane Outreach Program
 - 86% of mine degasification CH₄ is used (up from 25% in 1993)
 - industry effort to demonstrate use for ventilation air methane
- Landfill Methane Outreach Program
 - Over 445 US projects -- tripled since 1994
 - Strong corporate interest in use of landfill gas
- AgSTAR
 - Since 1994, the number of biogas recovery systems has doubled; over 180 projects - generating about 300 million kWh per year.

Changes in US Methane Emissions and Economic Growth 1990 - 2006



Methane to Markets Partnership



- Encourages development of **cost-effective** methane recovery and use opportunities in
 - coal mines
 - landfills
 - oil and gas systems and
 - agriculture (manure waste management)
- Private companies, multilateral development banks and other relevant organizations participate by joining the **Project Network – over 750 organizations now participating**
- 27 Partner Governments

Argentina
Australia
Brazil
Canada
Colombia
China
European Comm.
Ecuador
Finland**
Germany
India
Italy
Japan
Korea

Kazhakstan**
Mexico
Mongolia*
Nigeria
Pakistan*
Philippines*
Poland
Russia
Thailand*
Ukraine
United Kingdom
United States
Vietnam

* *New countries*

** *In the process of joining*



US M2M Commitment

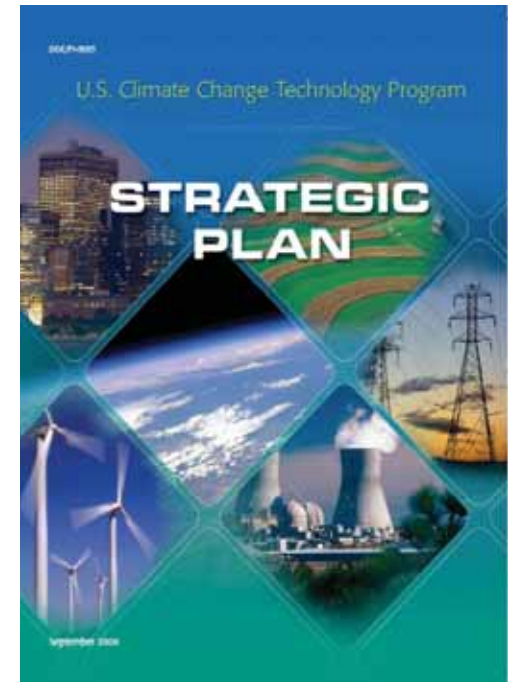


- Pledged \$53 million over five years at Partnership launch in 2004.
To date:
 - Provided over \$28 million to support a wide range of projects and activities
 - Leveraged over \$270 million in public and private sector contributions
- Providing significant support to the Partnership through the ASG and technical support in all 4 sectors
 - Providing assistance for methane recovery and use project activities in Argentina, Brazil, China, Colombia, Ecuador, India, Korea, Mexico, Nigeria, Poland, Russia, and Ukraine
- Through 2007, supporting projects that, if fully implemented, will result in estimated annual emission reductions of approximately 21 million metric tons of carbon dioxide equivalent



U.S Climate Change Technology Program

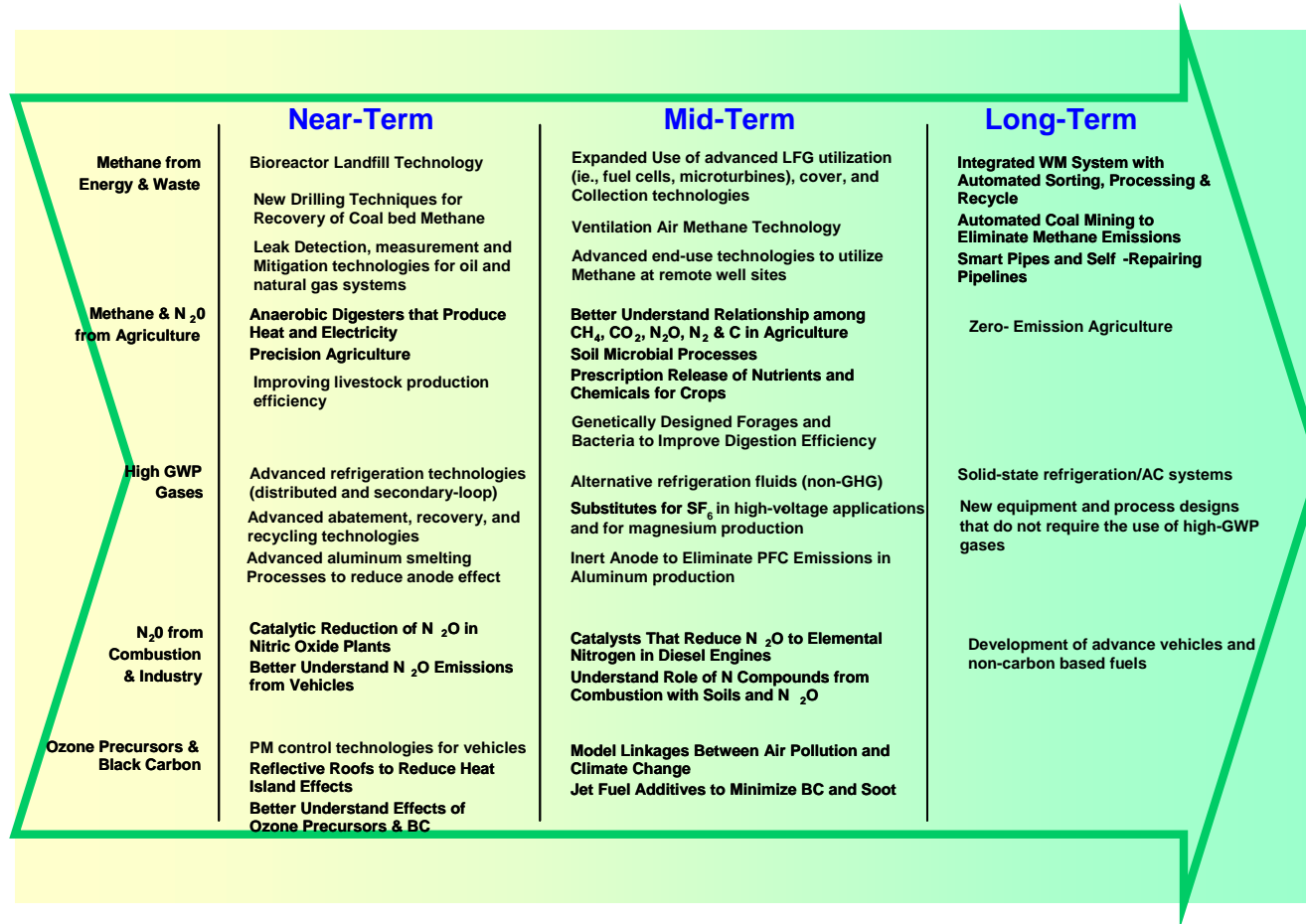
- Mission –Accelerate R&D on Adv. CC Techs
- CCTP authorized in EPAAct2005. Led by DOE.
- Scope –Ten Federal R&D Agencies
- Budget --\$4.4 Billion Requested for FY'09
- Activities –Coord. R&D Planning & Budgeting
- Goals: Four emissions-related strategic goals:
 - Reduce emissions from energy end use & infrastructure;
 - Reduce emissions from energy supply;
 - capture & sequester CO₂; and
 - **Reduce emissions from non-CO₂ gases.**
- Two cross-cutting, supporting strategic goals:
 - Improve capabilities to measure & monitor GHGs; and
 - Bolster basic science and strategic research



Current Technology Status

- For many sources, attractive technologies are commercially available or close-to-market
- R&D efforts would target incremental improvements to technologies/mitigation options or longer-term transformational change
- Examples include:
 - Methane from waste & energy
 - High GWP emissions from industry
- For other sources, basic R&D efforts are needed to better understand emission processes and options for mitigation
- Examples include
 - Methane & N₂O from agriculture
 - N₂O from combustion and industry
 - Black carbon & tropospheric ozone

Non-CO2 Technology Roadmap



Potential Research Areas for GCEP Consideration

Methane Emissions – Natural Gas

- Development of cost-effective, small-scale liquefaction and power generation technology for low-quality/stranded gas
- Advancing existing or developing new remote sensing technologies with capabilities to both detect and accurately measure leaks remotely
- Exploration of revolutionary equipment designs, such as “smart pipes or seals”

Methane Emissions – Waste Sector

- Development of cost-effective gas purification and liquefaction technology
- Improving landfill gas collection efficiencies
- Advanced, cost-effective integrated waste management and processing systems
 - Advanced source separation/waste recognition technology
 - Conversion technology to transform waste into different fuel types and product feed stocks

Potential Research Areas for GCEP Consideration

Methane and Nitrous Oxide From Agriculture

- Improve understanding of the interaction and interrelationship among methane, CO₂ and N₂O emissions in agricultural environments
- Further development of precision agriculture technologies
- “Smart materials” for prescription release of nutrients and chemicals for major crops
- Improve understanding of specific rumen microbial processes to support development of methods for making desirable engineered microbes competitive with natural rumen microbes
- Development of vaccinations that can reduce methane production in the rumen

Conclusions

- Non-CO2 GHGs offer significant opportunities for cost-effective mitigation, particularly in the near-term
- From a range of diverse sources with varied mitigation options
- Can reduce costs of meeting a given climate policy objective and offer multiple co-benefits
- Commercially available mitigation technologies and practices exist for many sources
- Barriers exist but are being addressed through Methane to Markets voluntary public-private international partnership
- For some sources, research and development is needed to develop appropriate mitigation strategies or technologies