# Non-$CO_2$ GHG Emissions and Mitigation

**Francisco de la Chesnaye**
Non-$Co_2$ Gas and Sequestration Branch
US Environmental Protection Agency

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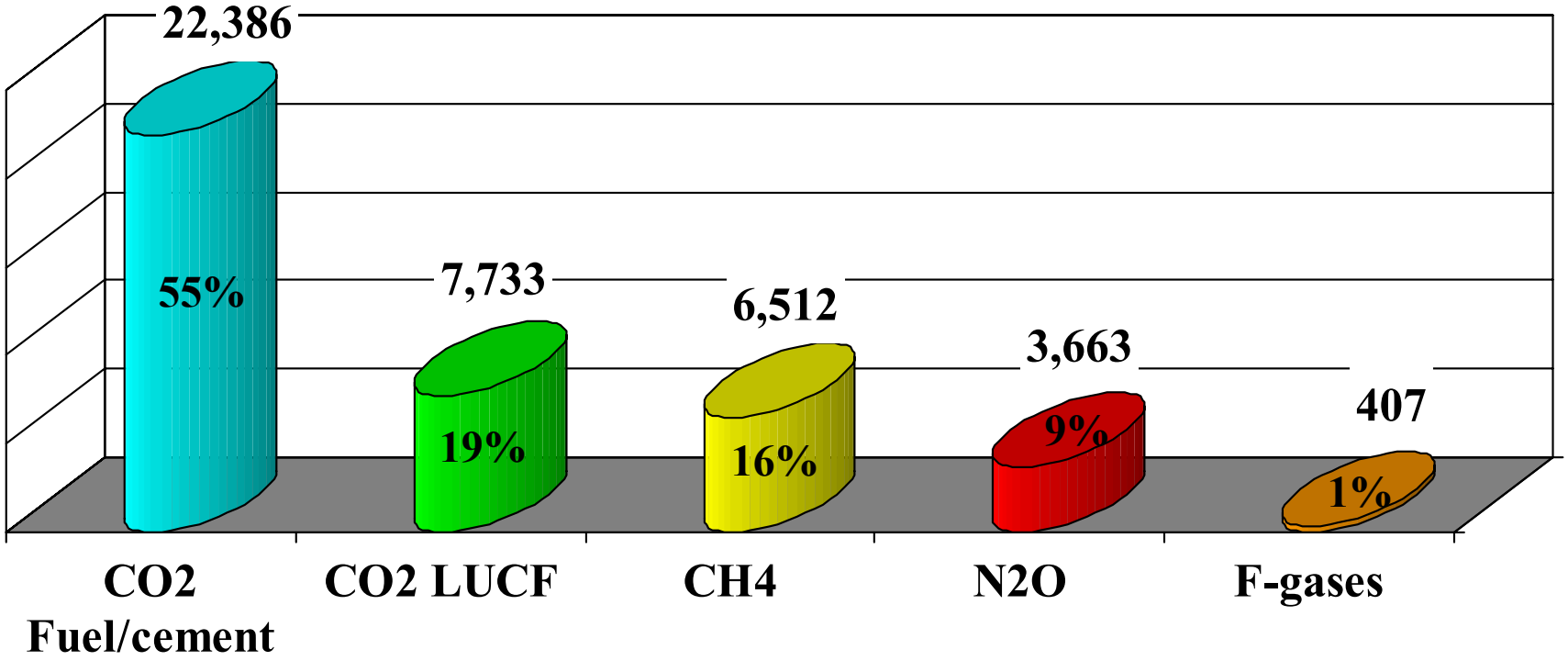
# 2000 Global Net GHG Emissions




**Total 40,702 $MtCO_2Eq$**
**(11,101 MTCE)**

Source: EPA memo for President's June 11, 2001 Statement

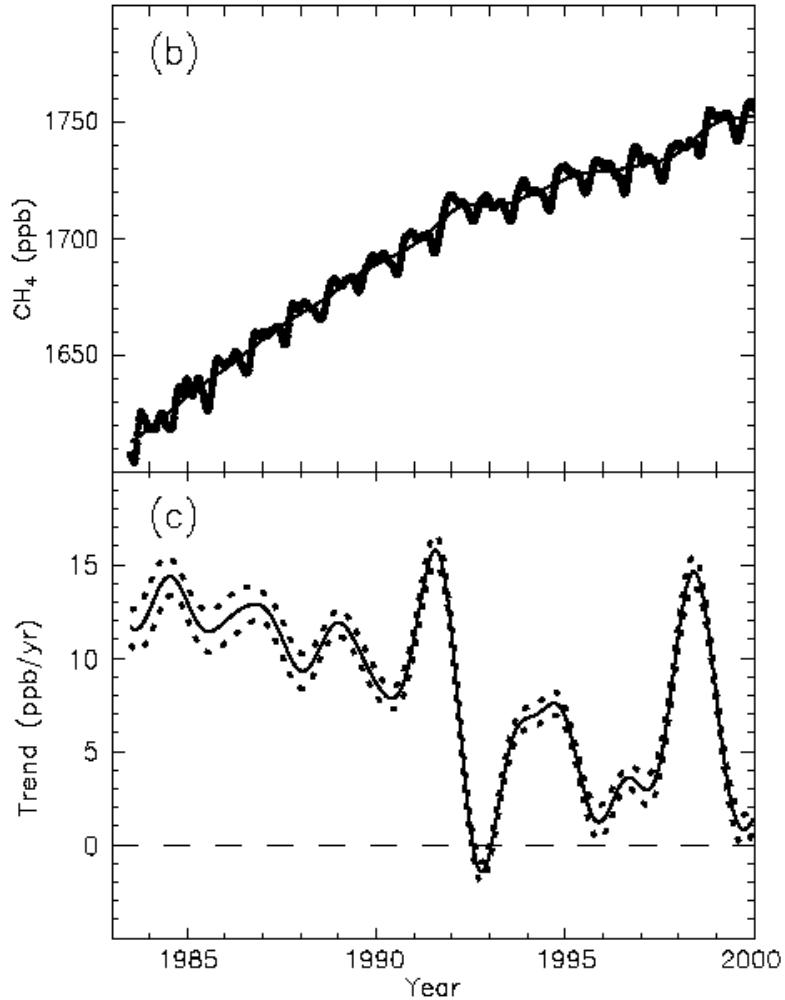
# Sources of Non-$CO_2$ Gases

- Methane -- landfills, natural gas systems, coal mining, livestock manure, ruminant livestock; 100-yr Global Warming Potential (GWP) = 21
- $N_20$ -- agricultural soils, autos, industrial (adipic & nitric acid production); GWP = 310
- Fluorinated (HGWP) Gases; GWPs range tens - thousands
  - HFC -- CFC substitutes: refrigeration, A/C, foams, solvents, fire extinguishing, aerosols
  - $SF_6$ -- electricity generation, magnesium
  - PFCs -- aluminum and semiconductors
  - HFC-23 -- HCFC-22 production

# Methane ($CH_4$): History

**(1) $CH_4$ abundance has risen with industrialization**
Atmospheric Concentration:
700 => 1750 ppb
Radiative Forcing
increase:+0.55 $W/m^2$

**(1) $CH_4$ abundance over past two decades** has shown
* Trend: Flattening
* Large interannual variability
* several possible causes



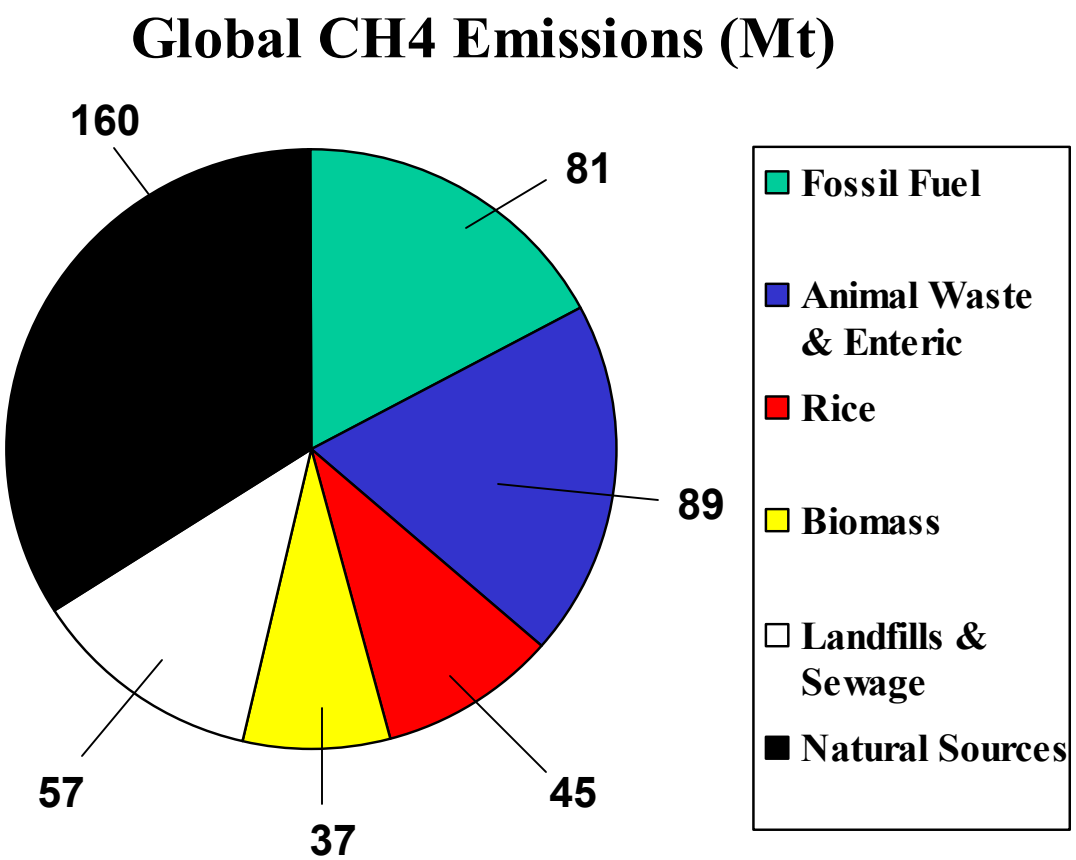
# $CH_4$ – The Budget

## Direct Sources of CH4

- Natural & Anthropogenic
- Bottom-up
  - – With lower rice, does it balance?

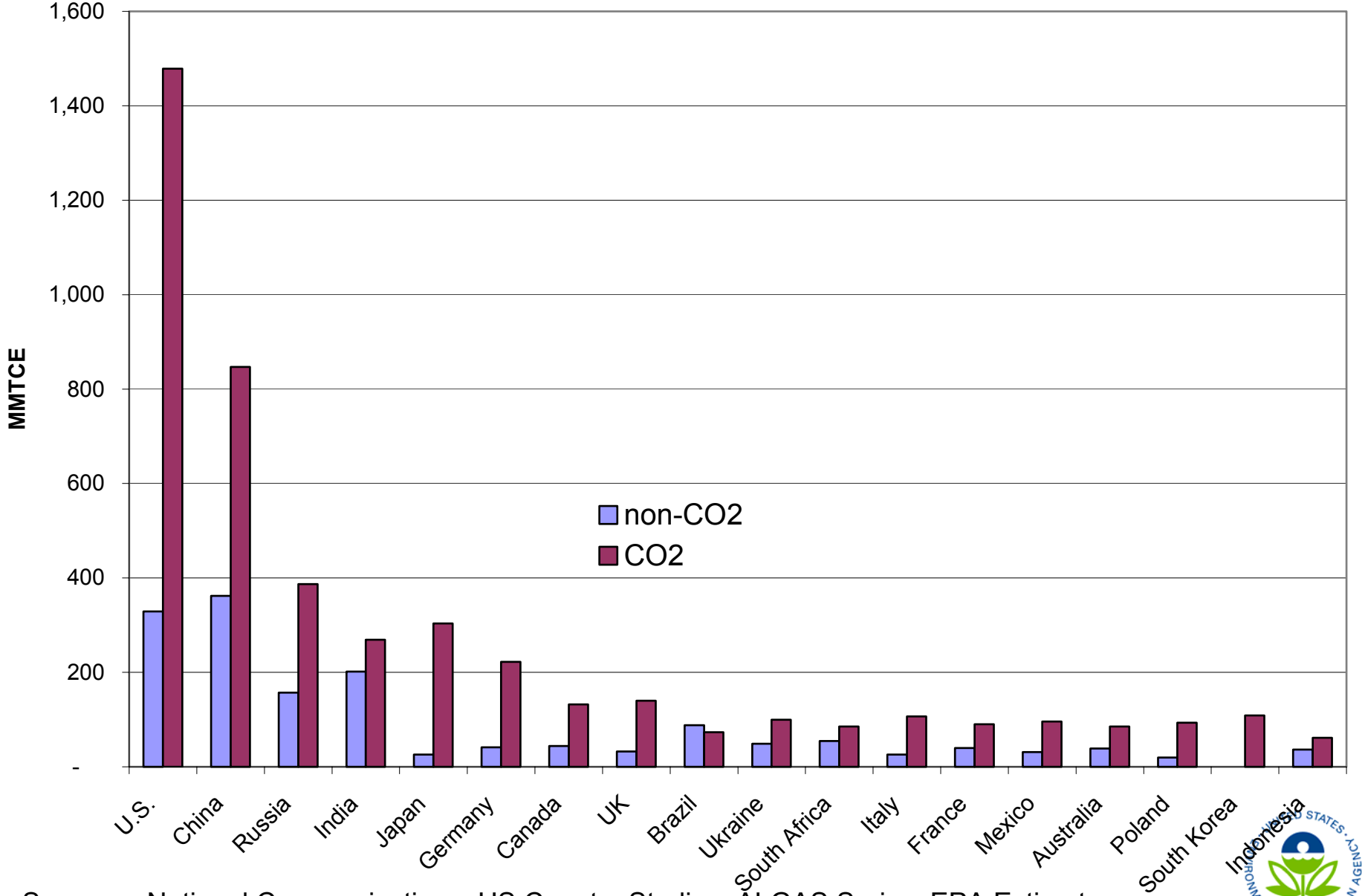
## Sinks for CH4

- Lifetime (OH loss) well calibrated: 8.4 yr
- Emissions of CO, VOC impact lifetime
  - => effective sources




Source: IPCC SRES - emissions represent mid-point of range.

# 1997 GHG Emissions of top 20 countries




Source: National Communications, US Country Studies, ALGAS Series, EPA Estimates

**Global 2000 Emissions of $CO_2$, $CH_4$, $N_2O$, High GWP gases (Mt $CO_2$ Eq.)**

| | Total | Percent | Annex 1 | Percent | Non-Annex 1 | Percent |
|---|---|---|---|---|---|---|
| $CO_2$ - Fuel and cement | 22,340 | 55% | 13,145 | 75% | 9,195 | 40% |
| $CO_2$ - LUCF (net) | 7,712 | 19% | 67 | 0.4% | 7,645 | 33% |
| CH4 | 6,701 | 16% | 2,417 | 14% | 4,284 | 19% |
| N2O | 3,503 | 9% | 1,559 | 9% | 1,944 | 8% |
| High GWP gases | 447 | 1% | 360 | 2% | 87 | 0.4% |
| **Total** | **40,702** | | **17,547** | | **23,155** | |
| | | | **% of total** | **43%** | **% of total** | **57%** |

# Total Reference Emissions of $CH_4$, $N_2O$, and F-gases in MMTCE

| Region | 2000 | 2010 | % change |
|---|---|---|---|
| China | 408 | 499 | 22% |
| US | 322 | 389 | 21% |
| CIS | 264 | 294 | 11% |
| India | 235 | 274 | 16% |
| OECD-EU | 209 | 231 | 10% |
| OPEC | 137 | 179 | 31% |
| Brazil | 130 | 162 | 24% |
| E.Europe | 65 | 77 | 18% |
| Mexico | 50 | 60 | 21% |
| ANZ | 51 | 59 | 15% |
| Canada | 43 | 51 | 18% |
| Japan | 129 | 41 | -68% |
| South Korea | 28 | 40 | 45% |
| Turkey* | 24 | 32 | 31% |
| | | | |
| Non-Annex 1* | 1,306 | 1,596 | 22% |
| Annex 1 | 1,007 | 1,163 | 15% |
| Global* | 2,314 | 2,759 | 19% |

* 2010 data does not include F-gases

# Priority GHGs & sectors

**U.S. Non-$CO_2$ Greenhouse Gas Emissions for 2000 (MMTCE)**

| Sectors | $CH_4$ | $N_2O$ | HFCs | PFCs | $SF_6$ | Total | Sector as % of Total |
|---|---|---|---|---|---|---|---|
| Energy | 58 | 20 | - | - | - | 78 | 25% |
| Industry | 0 | 8 | 22 | 5 | 5 | 41 | 13% |
| Agriculture | 46 | 86 | - | - | - | 132 | 42% |
| Waste | 63 | 2 | - | - | - | 66 | 21% |
| Total | 168 | 116 | 22 | 5 | 5 | 317 | |
| Gas as % of non $CO_2$ total | 53% | 37% | 7% | 2% | 2% | | |
| Gas as % of total GHGs | 9% | 6% | 1% | 0% | 0% | 1,909 | |

EPA (2002). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000

# Non-$CO_2$ GHG Network

- Co-sponsors
  - US Environmental Protection Agency (EPA)
  - European Commission DG Environment (EC)
  - IEA Greenhouse Gas R&D Programme (IEA GHG)

EC DG EV

# Purpose of the network

- Provides a forum for
  - Researchers and policy advisers
  - Involved in non-$CO_2$ greenhouse gas analysis
- Policy-related issues
- Informal
- Exchange of information
  - Share and compare
    - Data
    - Mitigation and abatement analyses
    - Economic modelling

## EMF 21 Participating Teams

**Non-$CO_2$ GHG Experts**
Paul Freund and John Gale, IEA Greenhouse Gas R&D Programme
**Methane & $N_2O$**
Ann Gardiner, Judith Bates, AEA Technology
Casey Delhotal, Dina Kruger, Elizabeth Scheehle, USEPA
Chris Hendriks, Niklas Hoehne, Ecofys
**Fluorinated (HGWP) Gases**
Jochen Harnish, Ecofys, Germany
Deborah Ottinger and Dave Godwin, USEPA

**Sinks (Terrestrial Sequestration)**
Roger Sedjo, RFF and Brent Sohngen, Ohio State Univ
Bruce McCarl, Texas A&M
Ken Andrasko, USEPA & Jayant Sathaye, LBNL

# Methane Source and Abatement Technologies

| Methane Source (global %) | Abatement Tech ($ - costed) |
|---|---|
| Ruminant Livestock (21%) | Nutrition & Health; Production Enhancing Agents; |
| Rice Paddies (11%) | Change in growing practices |
| Natural Gas and Oil Systems (10%) | $ - Maintenance, practices, technologies |
| Biomass Burning (7%) | NA |
| Landfills (7%) | $ - Capture use for electricity gen or direct gas use, flares |
| Coal Mining (6%) | $ - Degasification, pipeline injection, Catalytic oxidation, flares |
| Domestic Sewage (5%) | Aerobic treatments |
| Livestock Manure Management (5%) | $ - Digester capture and use for electricity gen |

**Futute technologies:** New catalytic oxidation; Fuel cells; micro-turbines; Methane inhibitors

# Technology Sets

- The decision of whether a given option is applicable to a particular region or country was based on the following three factors:
  - environmental conditions in that region;
  - region-specific infrastructure and technology; and
  - a list of options identified in a corresponding National Communication.

# Technical Characteristics

**Table V: Technical characteristics of abatement options.**

| Characteristics of Abatement Options | Unit | Definition |
|---|---|---|
| Applicability (A) | % | The percentage of the total emissions from a particular emission source (e.g., underground coal mining) to which a given option can be potentially applied. Applicability is option- and region-specific. |
| Technical Effectiveness of Abatement Option (E) | % | The percentage of emissions that can be abated by a given option relative to the total emissions to which this option can be applied. Technical effectiveness is option-specific. |
| Option Lifetime (L) | Years | The average technical lifetime of an option. |
| Abatement Potential (P) | % | The percentage of emissions that can be reduced at the national or regional level by a given option. |
| Emission Reduction (ER) | MMTCE | The absolute amount of emissions reduced by an option in a given year expressed in million metric tons of carbon equivalent (MMTCE); ER is estimated for each region and source by multiplying the total baseline emissions in a selected year by the abatement potential P. |

# Economic Characteristics

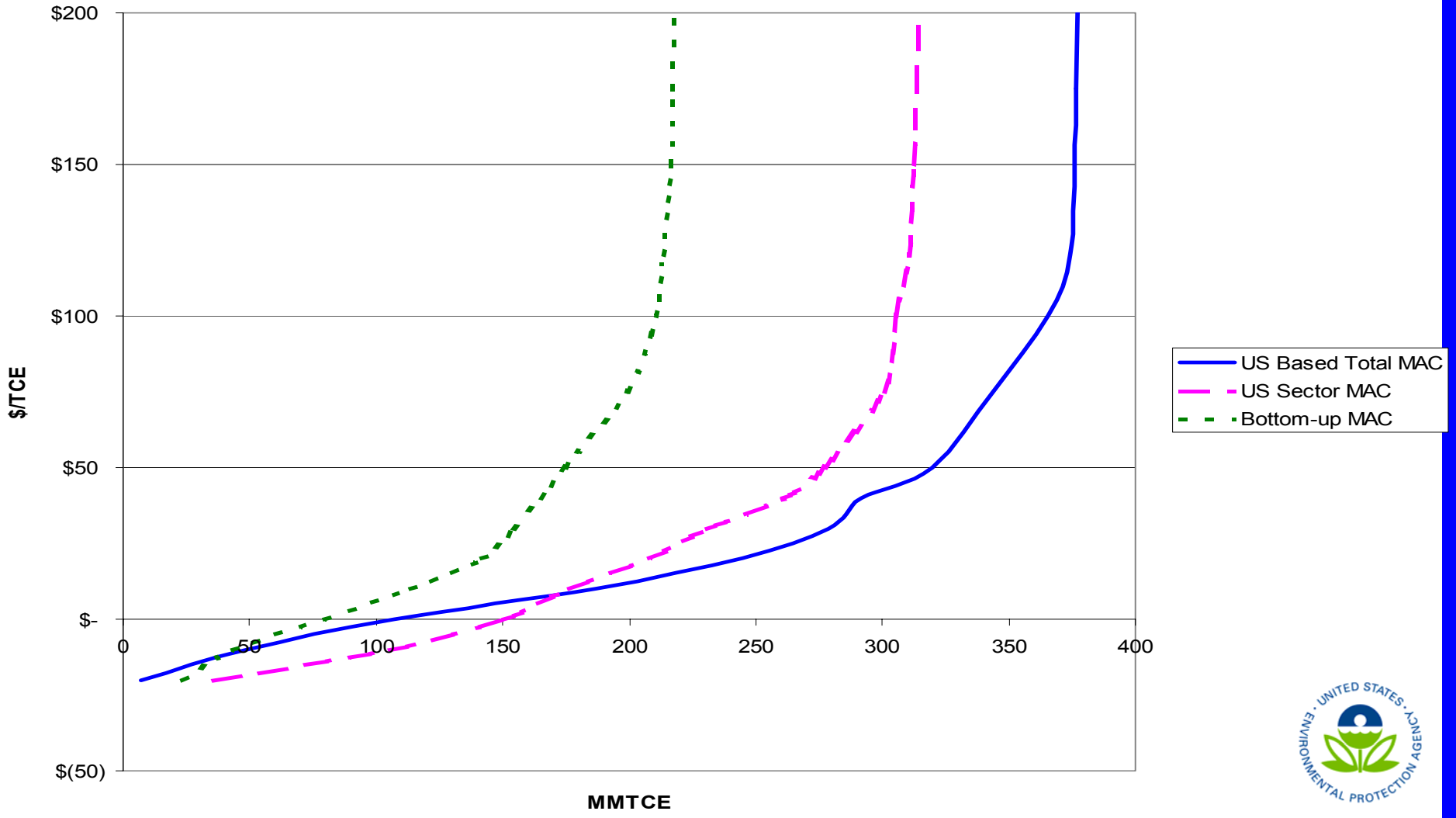
**Table VII: Economic characteristics of abatement options.**

| Characteristics of Abatement Options | Unit | Definition |
|---|---|---|
| Fixed Cost (F) | $/TCE | The total fixed capital cost of an abatement option divided by the present value of emission reduction (ER) over the option lifetime (L) and measured in 1996 $US per metric ton of abated emission expressed in carbon equivalent units (using $CH_4$ GWP = 21). |
| Recurring Cost (R) | $/TCE | The present value of variable capital and/or operation and maintenance cost divided by the present value of emission reduction (ER) over the option lifetime (L) and measured in 1996 $US per metric ton of abated emission expressed in carbon equivalent units. |
| Depreciation Tax Credit (TB) | $/TCE | The present value of tax break due to the fixed capital depreciation over the depreciation period divided by the present value of emission reduction (ER) over the option lifetime (L) and measured in 1996 $US per metric ton of abated emission expressed in carbon equivalent units. The tax credit is zero when the tax rate is zero. |
| Cost Offset (O) | $/TCE | The present value of selling methane or using it for electricity generation (as a benefit) divided by the present value of the value of emission reductions (ER) over the option lifetime (L) and measured in 1996 $US per metric ton of abated emission expressed in carbon equivalent units. |
| Net Cost (NC) | $/TCE | The average net specific cost of an abatement option measured in 1996 $US per metric ton of abated emission expressed in carbon equivalent units and equal to F + R – O – TB. |

# Non-$CO_2$ GHG & sequestration data requirements

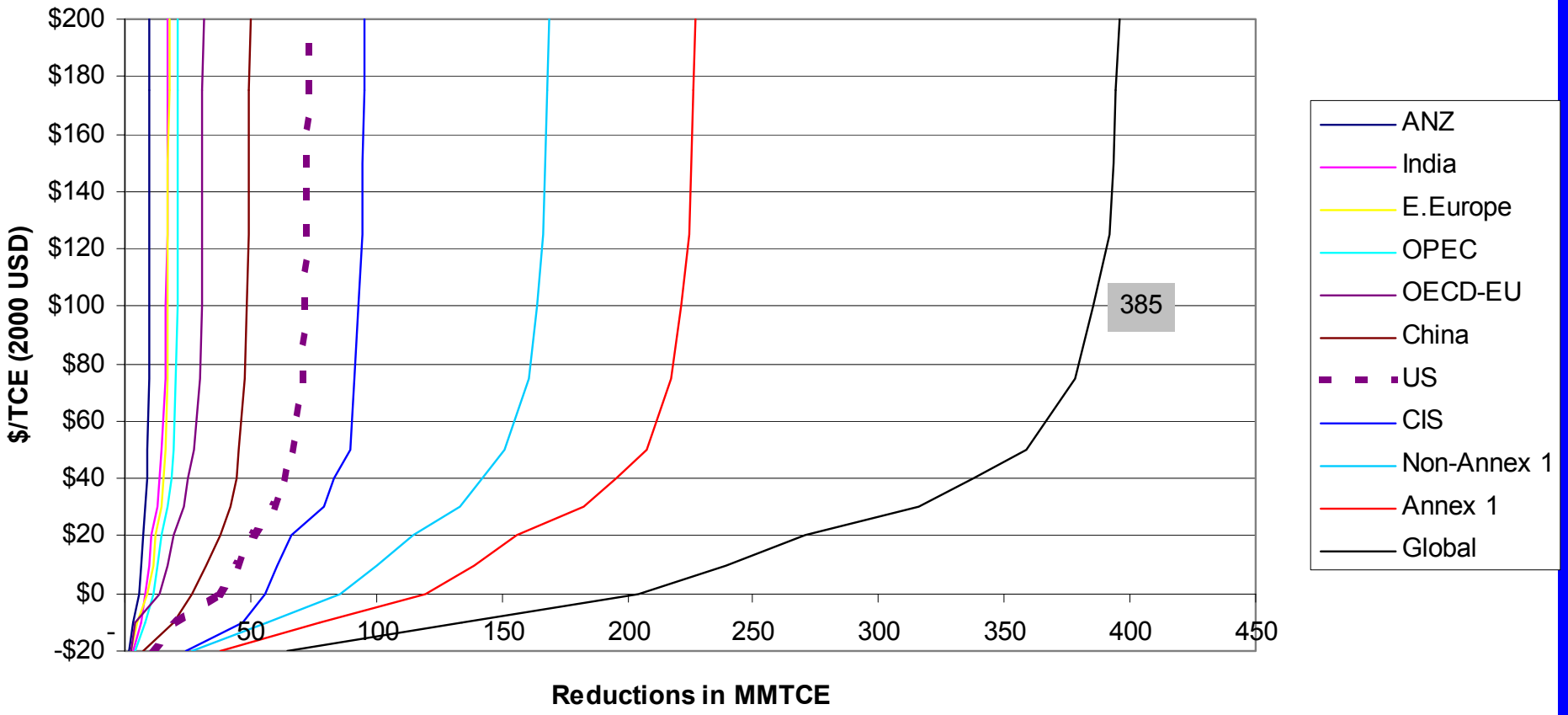
- Global, consistent non-CO2 GHG emission baselines for 2000 and projections 2020 by region. And key emissions drivers.
- Comparable marginal abatement curves
  - by region, by gas, and by sector
  - sensitivities to energy, material prices
  - in MMTCE w/ 100-yr GWP & gas specific units
  - Various discount and tax rates
- Assessment of how marginal abatement curves vary over time, from 2010 to 2100 by decade.

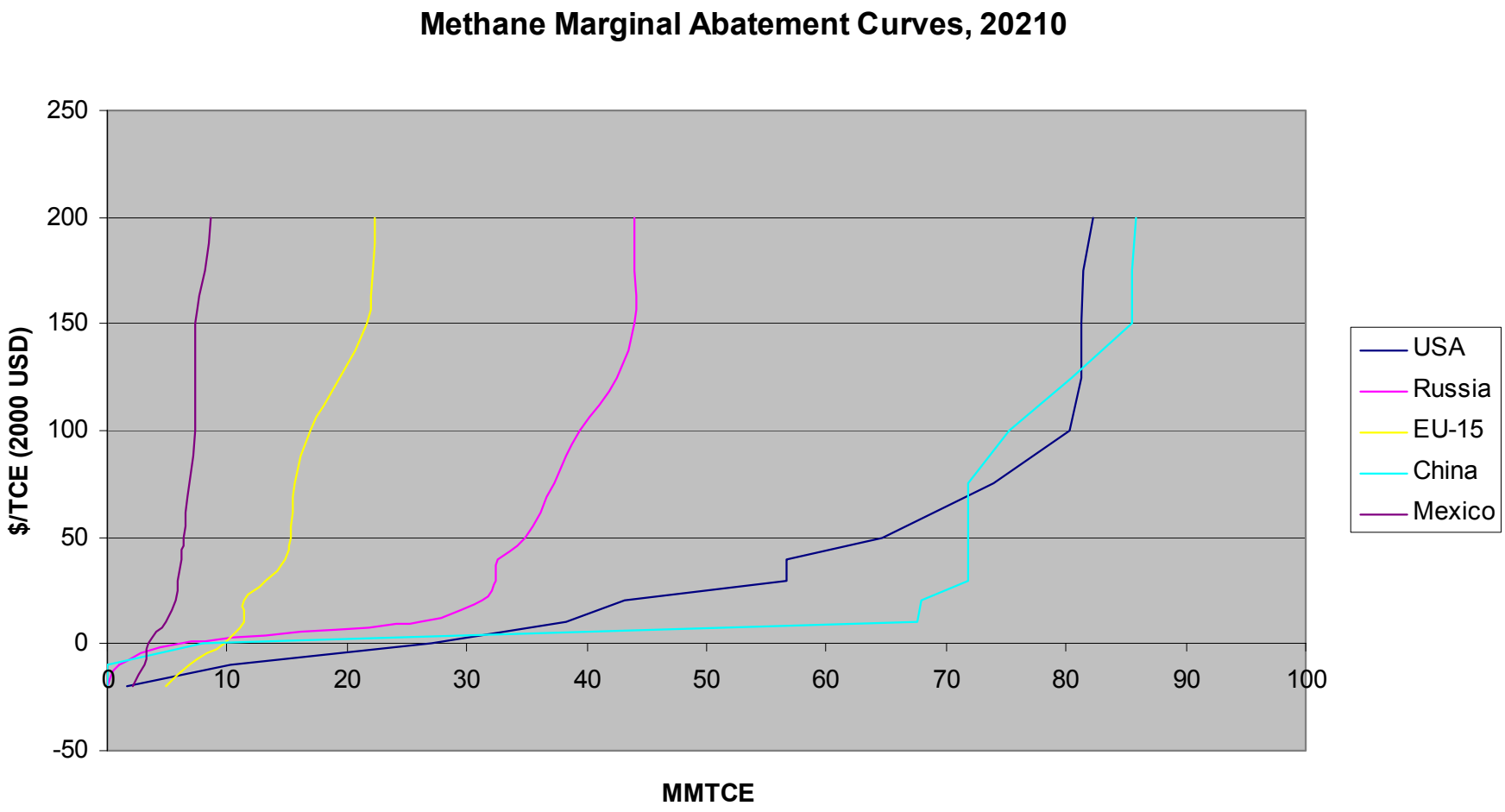
# Comparison of Three $CH_4$ MAC Estimation Approaches for 2010



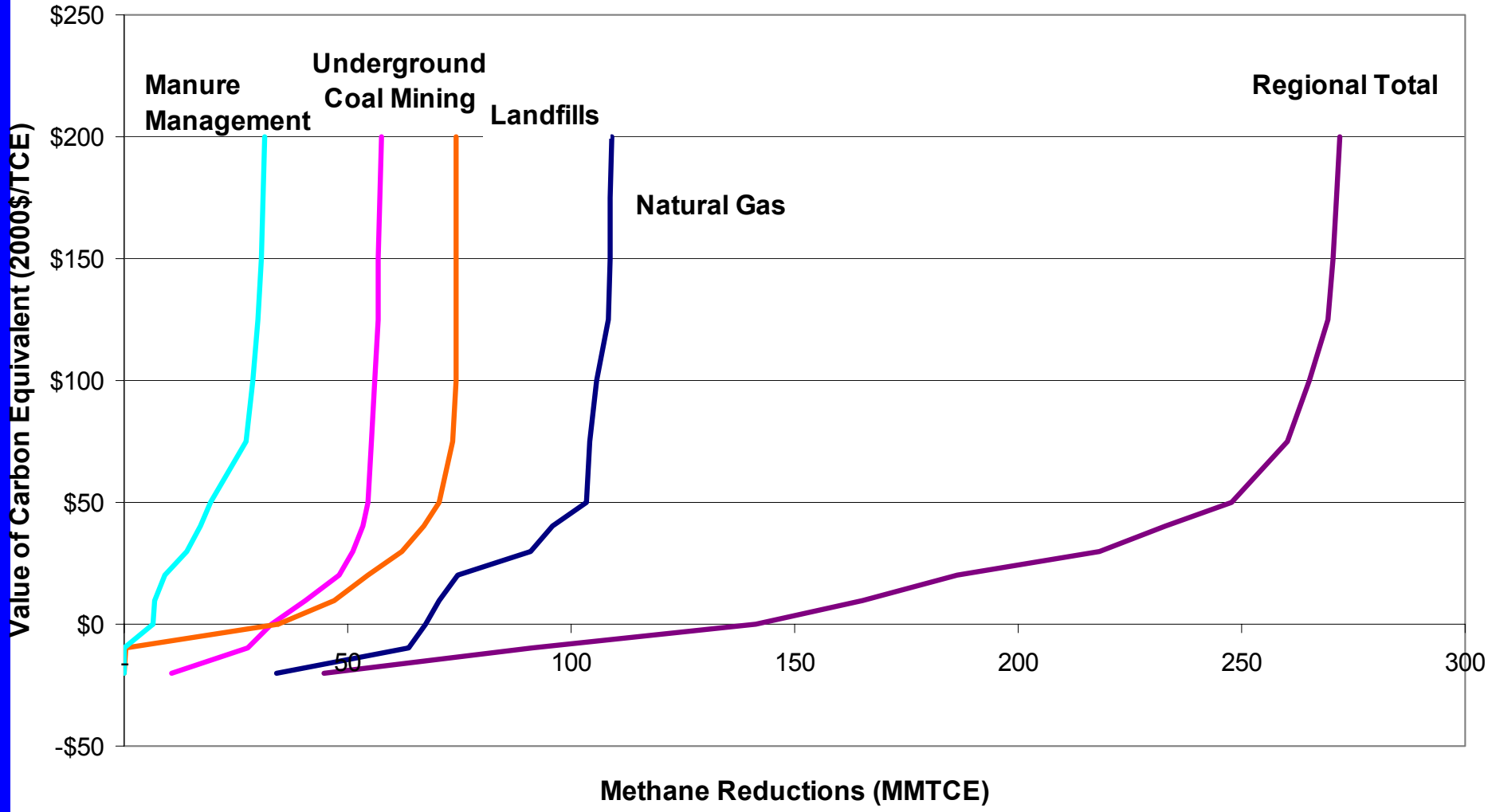
## Methane MACs for 2010

(Based on US % reductions by $/TCE)



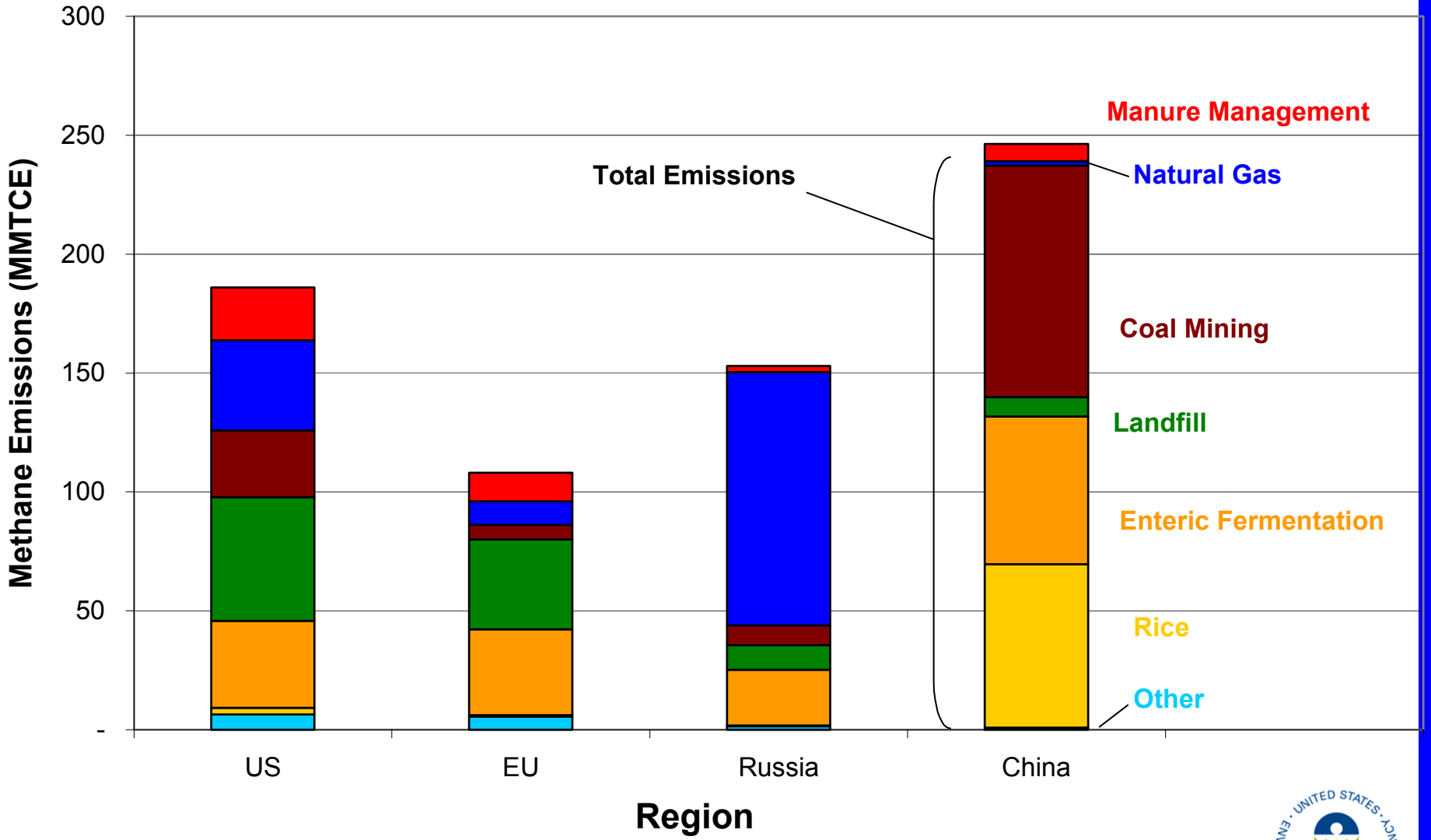

Methane Marginal Abatement Curves, 20210
250
200
150
100
50
0
-50
$/TCE (2000 USD)
0
10
20
30
40
50
60
70
80
90
100
MMTCE
USA
Russia
EU-15
China
Mexico

# U.S. Sector-Based Marginal Abatement Curves for Selected Regions
## Year 2010



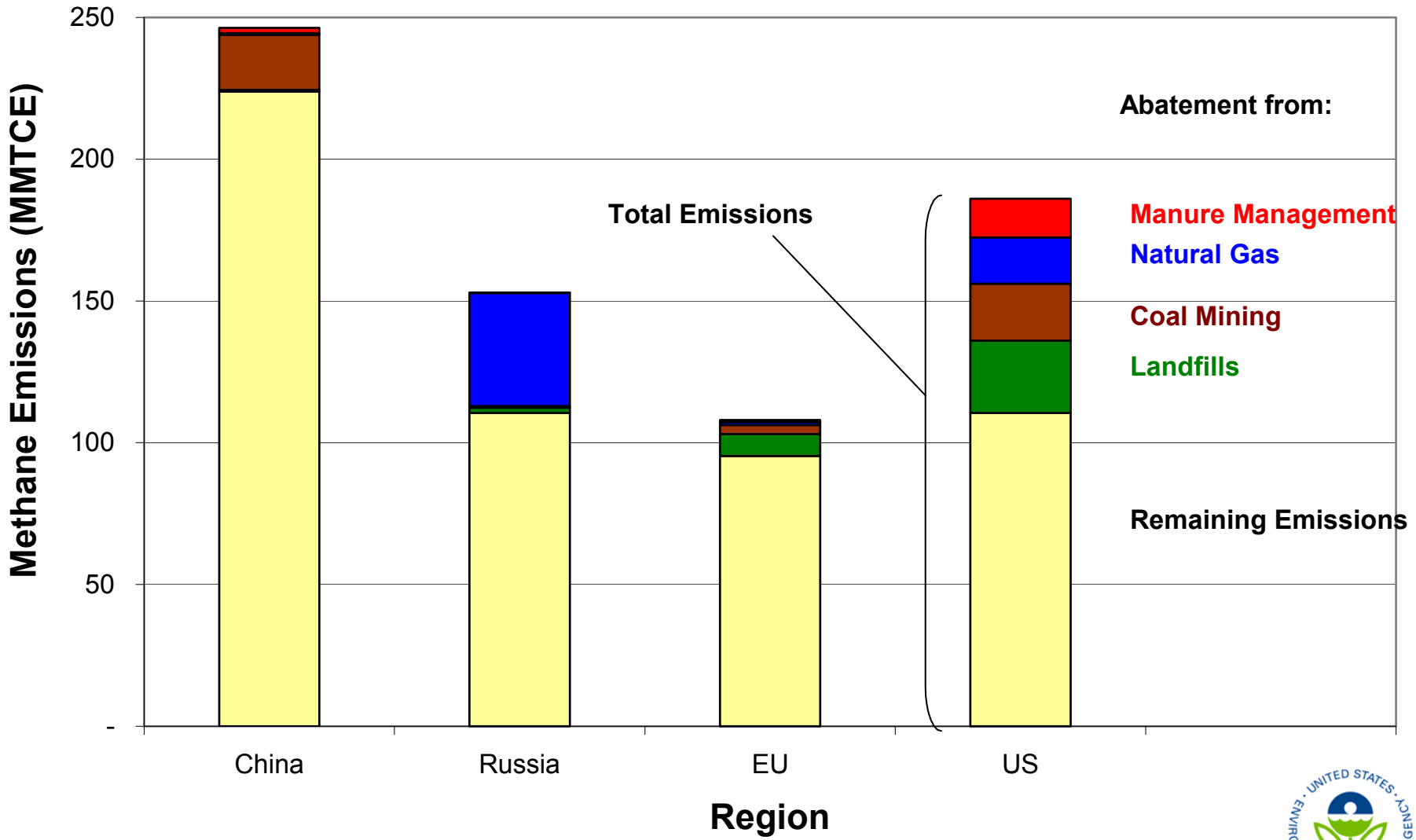

Source: USEPA, 2002

# Methane Emissions by Sector for Select Regions Based on 2010 Baseline Emissions




**Source: Compiled in EPA Reports.**

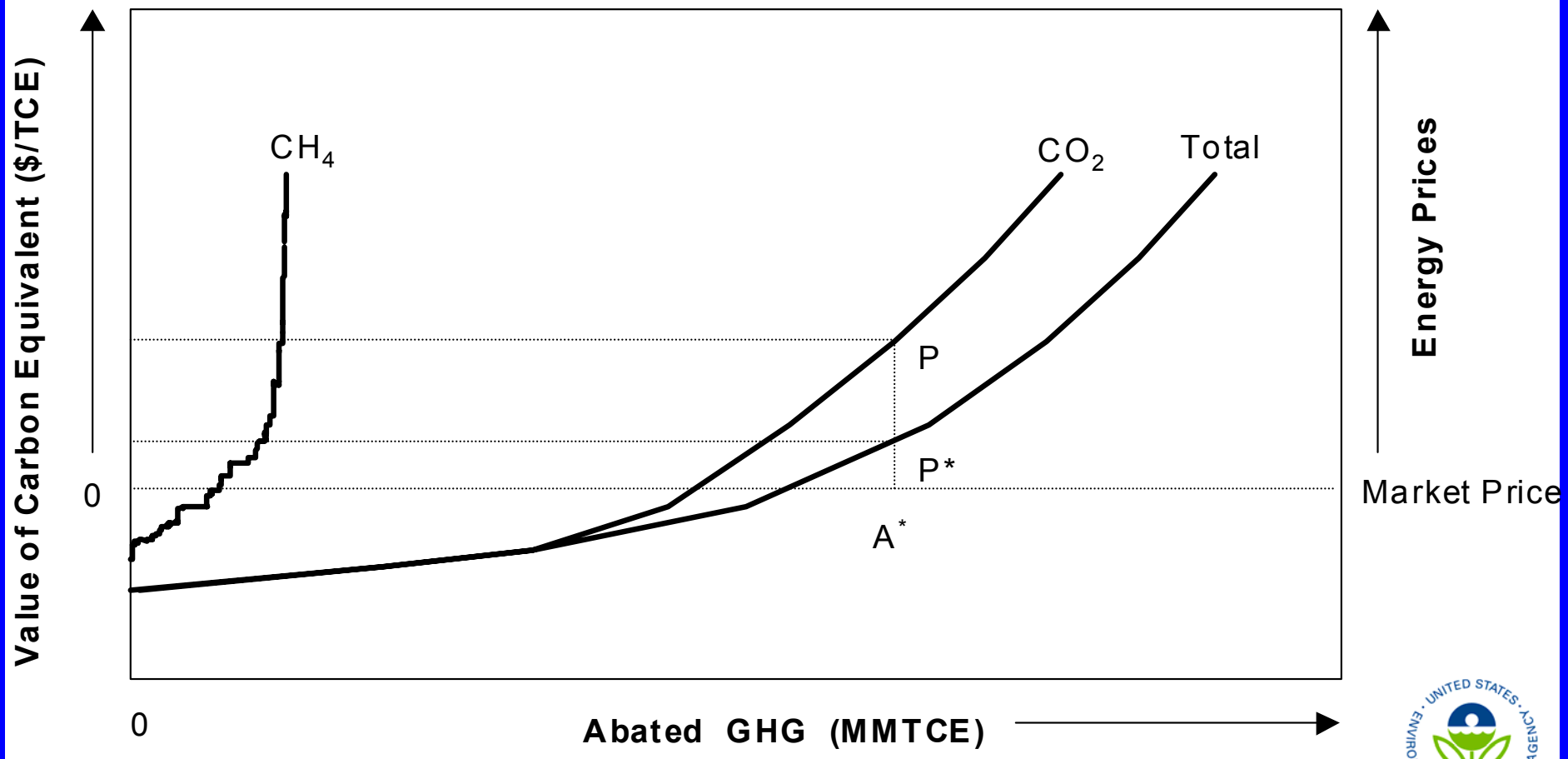
# Methane Reductions by Sector Based on 2010 Baseline Emissions and a Carbon Price of $50/TCE




Source: EPA Reports.

# Illustrative MACs for Methane and Carbon Dioxide

## - benefits of multi-gas abatement strategy



# *Approaches to combine / integrate non-$CO_2$ GHG MACs with Energy Models*

1. **Quick and Simple – Off-line addition**

   MAC results in $/TCE and cumulative reductions can be added to the supply curves from an energy model results in a spreadsheet to obtain one, total GHG abatement supply curve. From this, both price and quantity results can be obtained for different emission caps, target price, or both.

2. **Inclusion of reduced form equations from MACs**

   For both the MACs and the energy model supply curves, reduced form equations can be developed. These can be used separately or added and then solved for specific energy or quantities.

3. **Endogenize non-$CO_2$ MACs or cost parameters into energy model**

   Deconstructing the non-energy MACs to their appropriate sector or sub-sector cost identities and emission reduction potentials which are then used to modify the GHG emission coefficient in the energy model's production functions

4. **Incorporate abatement and mitigation options directly into models just as those for $CO_2$ reductions**

# *Nature, 7 Oct 99:* "Multi-gas Assessment of the Kyoto Protocol."

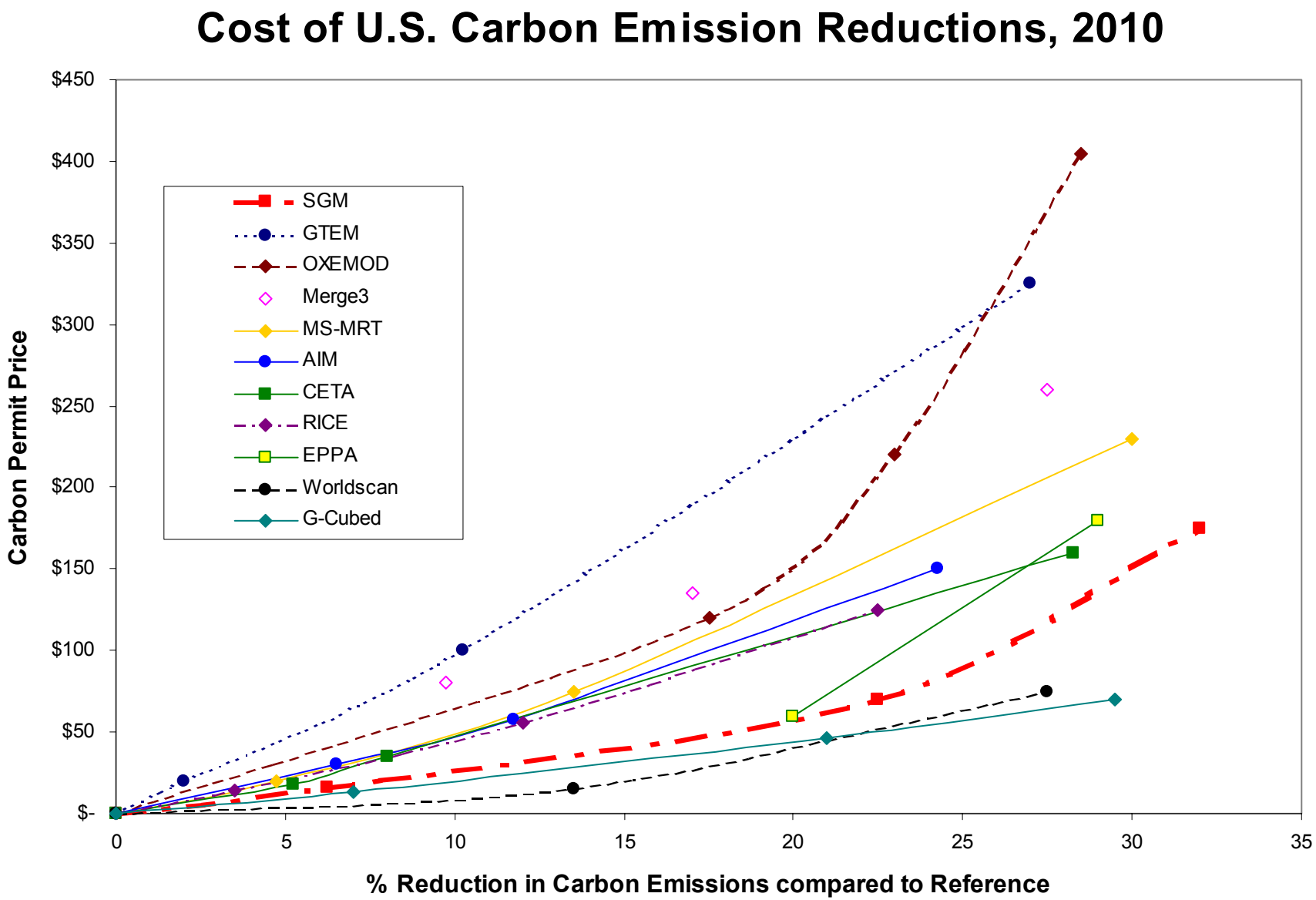
By J. Reilly, R. Prinn, J. Harnisch, J. Fitzmaurice, H. Jacoby, D. Kicklighter, P. Stone, A. Sokolov, and C. Wang at MIT

- Looked at all GHG: $CO_2$, $CH_4$ , $N_2O$ and HGWPs & sinks
- Showed that the inclusion of sinks and abatement opportunities from Non- $CO_2$ gases could reduce the cost of meeting the Kyoto Protocol by 60%
- In 2010, for Annex B as a whole, the benefit of a multi-gas approach would be about $38 billion/year
- For the U.S. alone, the benefit would be about $25 billion/year, a 40 percent reduction in costs from a $CO_2$ only control approach
- Suggests that 100-year GWPs fail to capture important time horizon and climate-chemistry effects

# Multi-gas Mitigation Analyses

- EMF 21 Multi-Gas Mitigation & Climate Change
- PNNL (H. Pitcher, S. Smith, R. Sands) & EPA Non-$CO_2$ & Sequestration Branch
  - Modeling climate change targets given multiple GHG emissions and mitigation options
  - Hansen Alternative Scenario presented at the 3rd International Symposium on Non-$CO_2$ Greenhouse Gases in Maastricht, Netherlands.

# Results of EMF 16: Cost of Kyoto



# EMF 21 Scenarios: 1) Kyoto Protocol

- Includes those countries that have ratified or are expected to ratify the Protocol by late '02 / early '03 *. Other countries should be modeled to follow their particular domestic policies, for example, the US GHG intensity policy to 2012.
- Time frame: 2008 to 2012 with policy announcements starting in 2002.
- Emission targets: As defined in Kyoto Protocol with Marrakesh Accords, the US GHG intensity policy, and others. In all cases, multi-gas mitigation is conducted.
- GWPs: As defined in Protocol.
- Country Participation: Those in Protocol with an additional 100 MMTCE from CDM. Limit sinks in CDM to 30 MMTCE.

# EMF 21 Scenarios: 2) Long-term, Cost-minimizing

(a) Achieved through $CO_2$ mitigation only, and

(b) Achieved through multi-gas mitigation.

- Climate Change Target: Hold global mean temperature change from 2000 to 2100 at 2.0ºC. (May want to also evaluate 1.5ºC and 2.5ºC).
- Time frame: 2000 to 2100. From 2002 to 2012, reference is the above Kyoto Protocol scenario.
- Emission targets: Based on meeting climate target at lowest global cost with participating countries as defined below. For models with climate modules, emission targets can be endogenously calculated. For other models, emission targets will need to be provided based on an agreed upon emission trajectories for each GHG.
- GWPs: For some models, this is endogenously calculated. For others, modeling teams will need to use 100-yr GWPs from the IPCC Second Assessment Report.

# EMF 21 Scenarios: 2) Long-term, Cost-minimizing - cont.

- Country Participation: Two options are presented here based on discussions at the May meeting:
- (i) All countries and regions starting in 2013 thereby establishing the global, least-cost trajectory to achieve the specified climate target. Any contraction in participation would show a divergence from the least-cost trajectory.
- (ii) The following sequence:
  - From 2013 to 2020, all Annex I countries set emission targets at 10% below 2000 levels through 2020, including 200 MMTCE from CDM.
  - From 2021 to 2040, Annex I continues same targets. China, India, Brazil, South Korea, and Mexico take on emission targets at 10% below 2015 levels through 2040.
  - From 2041 to 2100, all countries and regions with emission targets based on achieving the climate target on a cost-minimizing trajectory.

# EMF 21 Scenarios: 3) Decadal Rate of Change, Cost-minimizing

(a) Achieved through $CO_2$ mitigation only, and

(b) Achieved through multi-gas mitigation.

- Climate Change Target: Hold global mean decadal rate of temperature change from 2000 to 2100 at 0.2ºC. (As above, may want to also evaluate 0.15ºC and 0.25ºC).
- Time frame: same as described in # 3.
- Emission targets: same process as in # 3.
- GWPs: same process as in # 3.
- Country Participation: same options and sequences as in #3.

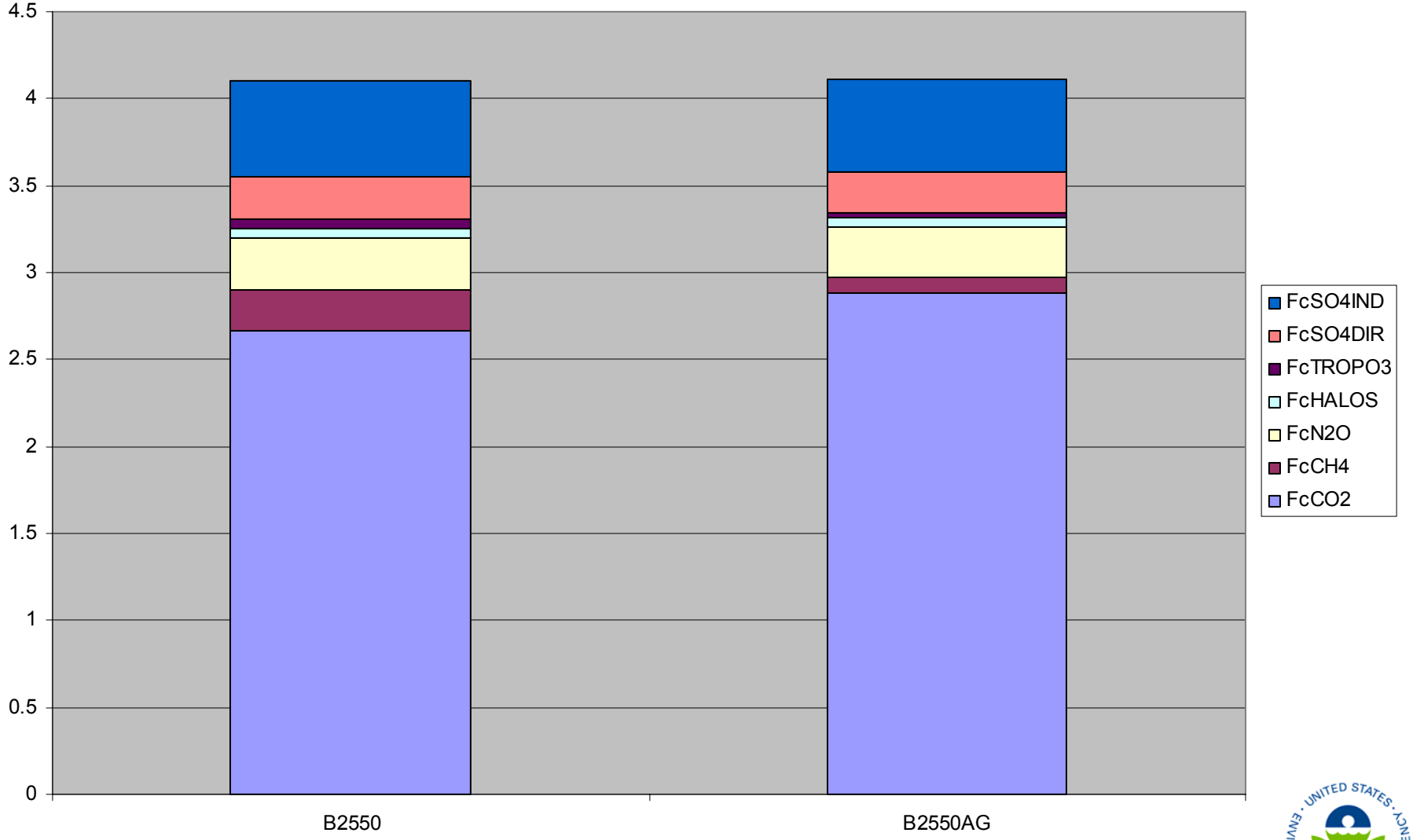
# EMF 21 Possible modeler's choice scenarios

- Longer-term GHG intensity targets including criteria for country participation and when come under targets.
- Different combination of country participation and when come under targets.
- Various levels of emissions constraints and policy regimes, e.g., trading, banking.
- Hansen Alternative Scenario
- Safety Valve approach.
- Other formulations for facilitating developing country participation which reflect potential for NCGG?
- Historic responsibility, e.g., the Brazil Proposal.

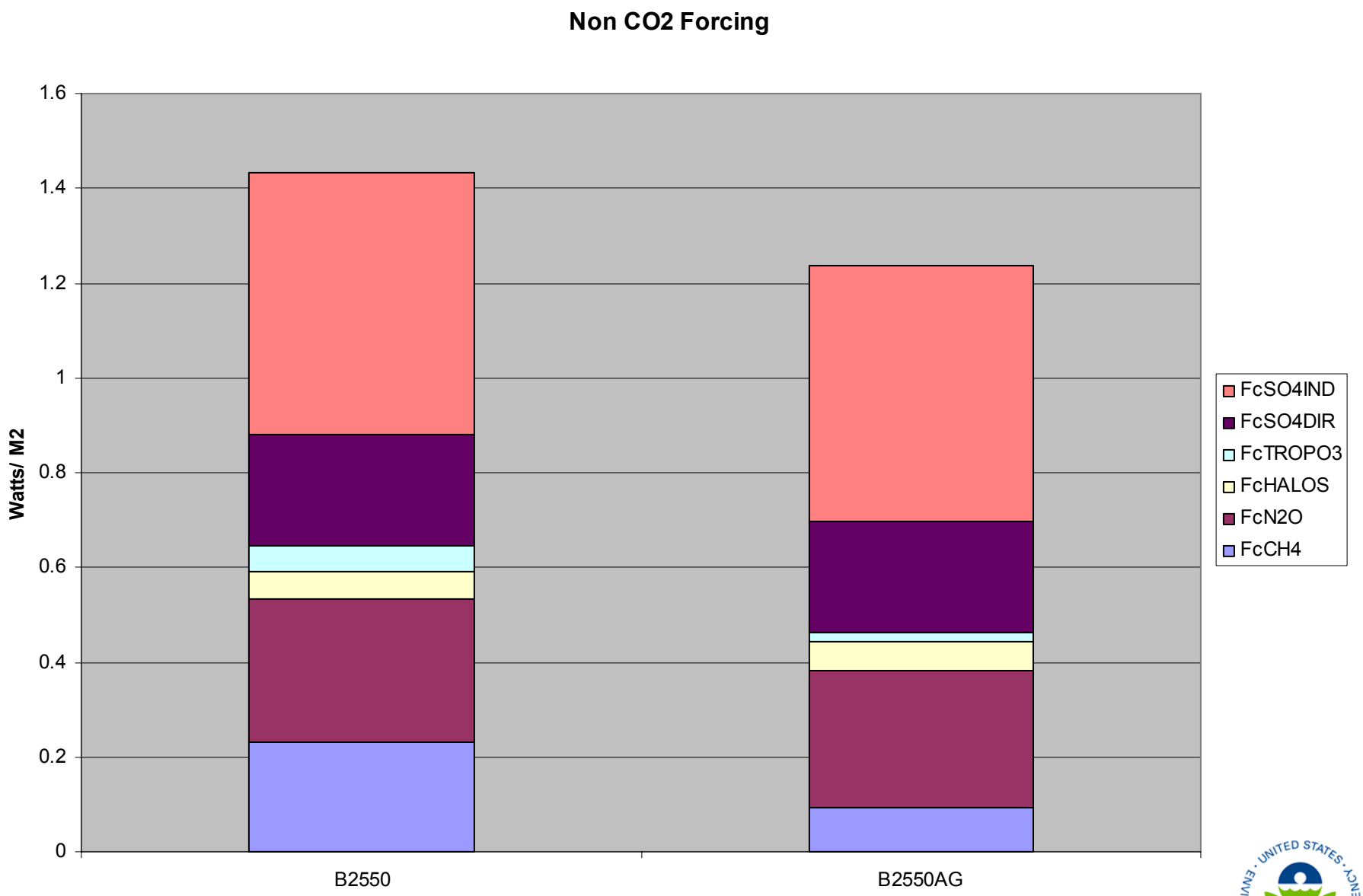
# PNNL Scenario

- Under multi-gas mitigation, achieve same forcing as achieved by 550 and 450 ppm $CO_2$ stabilization targets
- Differences in Emissions Reductions
- Evaluate forcing changes & affect on carbon prices

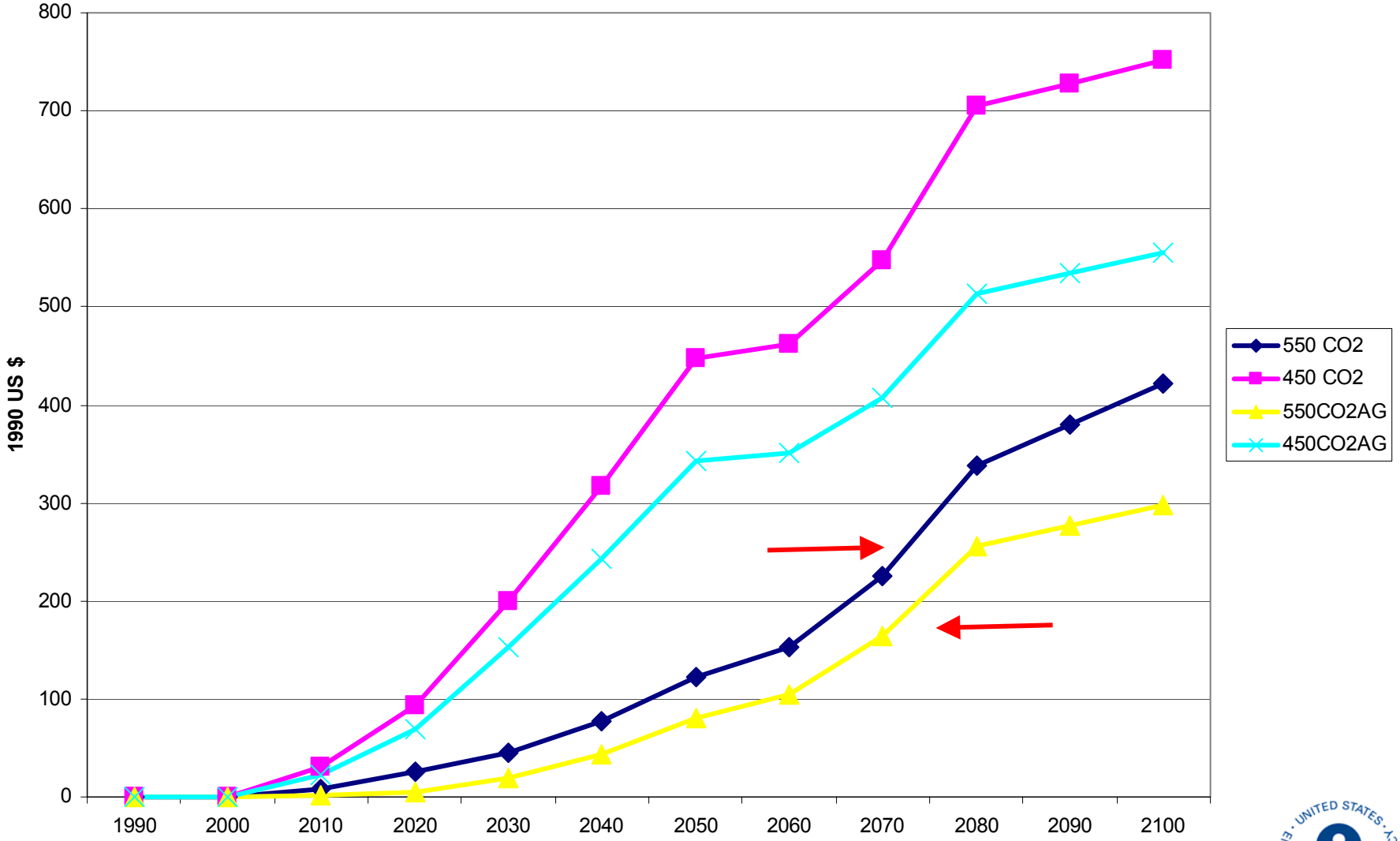
## Forcing for CO2 and All Gas 550 Control Cases




Source: Hugh Pitcher, PNNL


Non CO2 Forcing
Watts/ M2
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
B2550
B2550AG
FcSO4IND
FcSO4DIR
FcTROPO3
FcHALOS
FcN2O
FcCH4

## Impact of All Gas controls on Shadow price of carbon



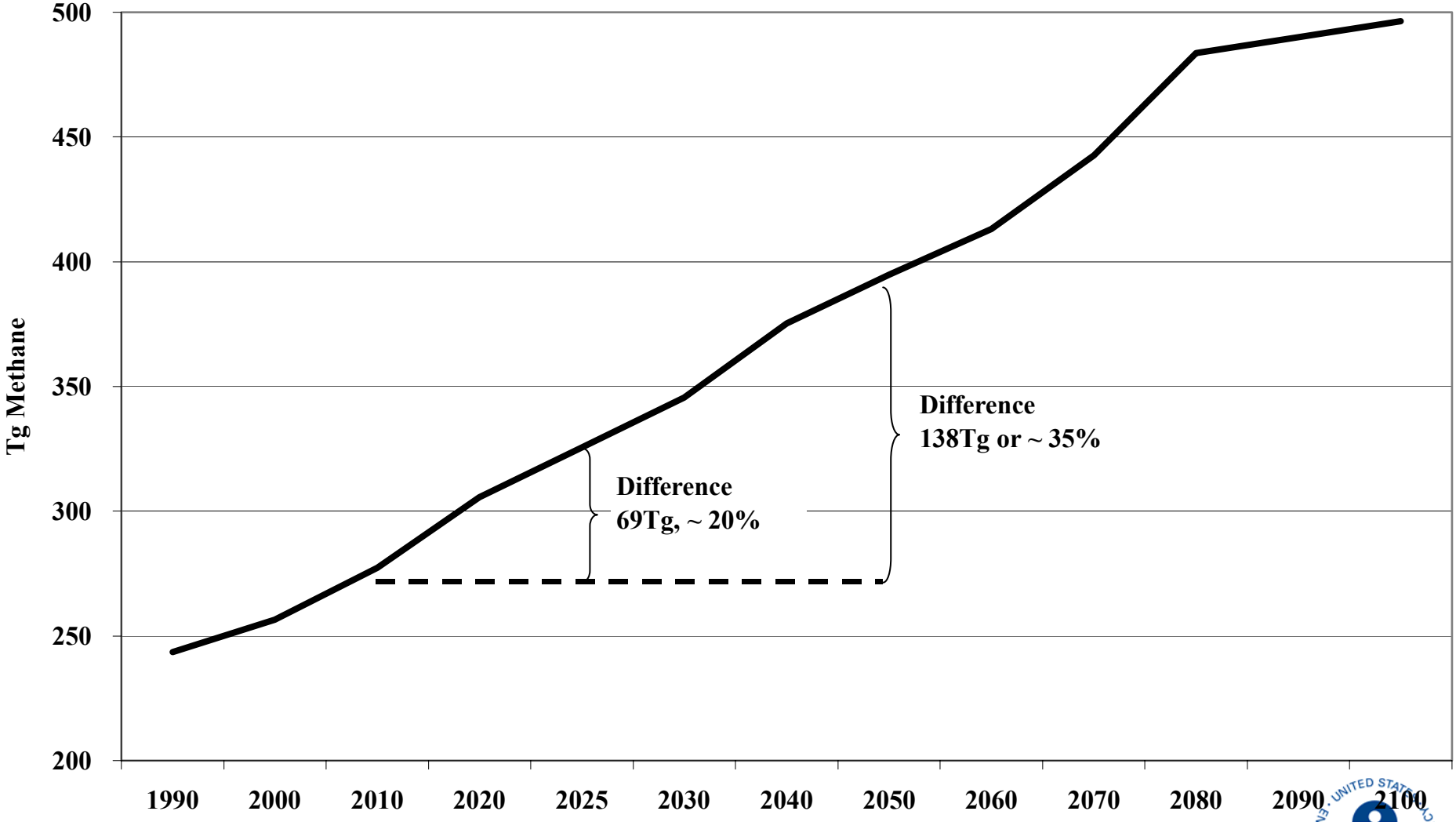
# Hansen Alternative Scenario

- Assessed the feasibility of stabilizing global methane emissions over the period 2000 to 2050.
- Methane emission projections from PNNL's MiniCAM, PE Energy /Agriculture model.
- Applied recent USEPA estimates of methane mitigation costs in key countries and regions

# Motivation

- Dr. James Hansen's "alternative strategy":
  - Hold the increase in anthropogenic radiative forcing over 2000-2050 period to 1 Watt/meter$^2$
  - Net increase of NCGG & aerosols forcing to 0 Watt/meter$^2$ and that of the $CO_2$ forcing at 1 Watt/meter$^2$

# Global Methane Emissions & Stabilization at 2000 Levels




Source: Courtesy H. Pitcher MiniCAM B2 run

## Selected Region Baseline Methane Emissions and Reductions[1] for 2010

| Source | Reference Baseline 2010 (MMTCE) | Reductions at $150/TCE (MMTCE) | % of Baseline |
|---|---|---|---|
| Natural Gas | 216 | 109 | 50% |
| Underground Coal Mining [2] | 88 | 57 | 65% |
| Landfills | 159 | 74 | 47% |
| Livestock Manure Management [3] | 44 | 31 | 69% |
| 13 Regional Total | 507 | 270 | 53% |
| Global Total [4] for above sources | 725 | Coverage as % of Global | 70% |
| Global Total [5] for all sources | 1,588 | Coverage as % of Global | 32% |

Notes: Regions include: Australia / New Zealand, Brazil, Canada, China, Eastern Europe, European Union, India, Japan, Mexico, Russia, South Korea, Ukraine and the US.

[1] Reductions based on applying US sector-based MACs to each region's sectors and adding up.

[2] Underground coal mining excludes surface mining emissions.

[3] Manure management includes swine and cattle, but excludes "other" for US only.

[4] & [5] Global methane estimates from MiniCAM runs courtesy H. Pitcher, PNNL. Global Total all sources adds enteric fermentation, rice production, biomass burning, domestic sewage to the 4 previous sources.

# Hansen Alternative Scenario Conclusion

- Stabilization could nearly be achieved in 2025 based on the emission reduction potential associated with four major methane sources: landfills, coal mines, natural gas and oil systems, and manure management systems
- Maintaining stabilization through 2050 will necessitate emission reductions across a wider array of sources, particularly ruminant livestock and rice production.

# Additional issues for Multi-gas Mitigation

- Review of non-$CO_2$ and sinks methodologies and data
- How to treat other forcing agents,eg, SOx and BC
- Should target be Radiative Forcing or Temp change, Climate Sensitivity?
- Transactions Costs
- How to handle negative costs
- Study Sub-groups, eg., sinks, international trade & banking, allocation, other forcing agents
- Other climate variables reported, eg, precipitation, sea level raise

# Conclusions

- Non-$CO_2$ GHGs are too important to ignore
- Given the nature of the sources, specialized expertise and focused attention is required
- To date, opportunities to exchange among experts across sectors & countries have been limited
- Many countries are developing non-$CO_2$ GHG expertise

# Contact Information


## Francisco de la Chesnaye

**Tel: 202-564-0172**

**E-mail: delachesnaye.francisco@epa.gov**

**U.S. Environmental Protection Agency**

**Office of Air and Radiation, Non-$CO_2$ Gases & Sequestration Branch**

**1200 Pennsylvania Ave., NW (6202 J)**

**Washington, DC 20460**

**Fax: 202-565-2134**

**www.epa.gov/ghginfo/**