# How Can We Avoid Dangerous Climate Change?


Edward S. Rubin
Department of Engineering and Public Policy
Department of Mechanical Engineering
Carnegie Mellon University
Pittsburgh, Pennsylvania, USA


Presentation to

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Universidad Politécnica de Valencia
Valencia, Spain

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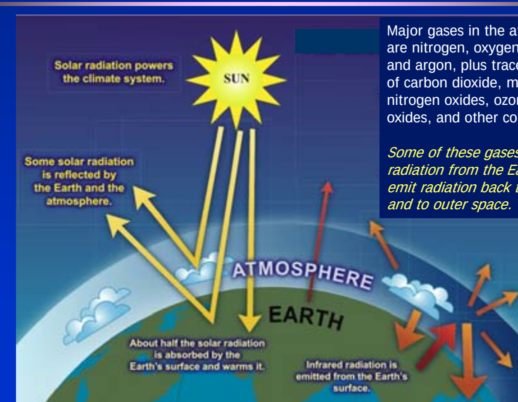
## Outline of Talk

- Fundamentals of global climate change
- Setting climate change goals
- Mitigation measures available or needed
- Costs and policy options
- Future outlook



## *Fundamentals of global climate change*

## The Global Energy Balance




Major gases in the atmosphere are nitrogen, oxygen, water, and argon, plus trace amounts of carbon dioxide, methane, nitrogen oxides, ozone, sulfur oxides, and other constituents.

*Some of these gases absorb radiation from the Earth and emit radiation back to Earth and to outer space.*

Source: adapted from IPCC, 2007

## The "Greenhouse Effect"

- Atmospheric gases that absorb long-wave infrared radiation are called greenhouse gases.
- They include $H_2O$, $CO_2$, $CH_4$ and $N_2O$, plus other gases from natural and manmade sources.
- Without natural levels of these gases the average temperature of Earth would be –19°C (instead of the actual 15°C).
- The additional 34°C of warming due to these gases is called the "greenhouse effect."



## Major Greenhouse Gases that Accumulate in the Atmosphere

| Symbol | Name | Common Sources |
|---|---|---|
| $CO_2$ | Carbon Dioxide | Fossil fuel combustion, cement production, deforestation, etc. |
| $CH_4$ | Methane | Landfills, production and distribution of natural gas & petroleum, fermentation from the digestive system of livestock, rice cultivation, fossil fuel combustion, etc. |
| $N_2O$ | Nitrous Oxide | Fertilizers, nylon production, manure, fossil fuel combustion etc. |
| HFC's | Hydrofluorocarbons | Refrigeration gases, aluminum smelting, semiconductor manufacturing, etc. |
| PFC's | Perflourocarbons | Aluminum production, semiconductor industry, etc. |
| $SF_6$ | Sulfur Hexafluoride | Electrical transmissions and distribution systems, circuit breakers, magnesium production, etc. |

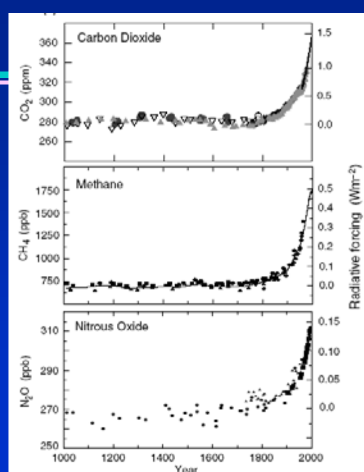
Source: USEPA, 2007

***Unlike "conventional" air pollutants, GHGs—once emitted—are not easily removed. Most remain in the atmosphere for centuries***



## Atmospheric GHG Levels

- Greenhouse gas (GHG) concentrations in the atmosphere have been increasing rapidly since the industrial age began
- These increases are a result of emissions from human activities



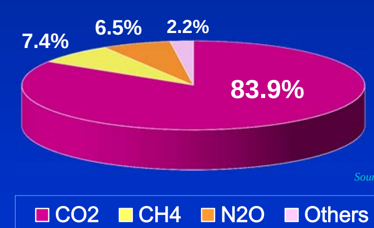

Source: IPCC, 2001



## $CO_2$ from Energy Use is the Dominant Greenhouse Gas

*U.S. Greenhouse Gas Emissions*

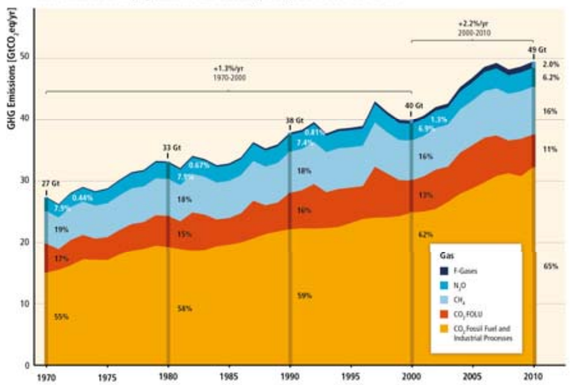
*weighted by 100-yr Global Warming Potential (GWP)*




Source: USEPA, 2007

*Combined emissions commonly expressed as equivalent $CO_2$*

## Global GHG emissions growth has accelerated despite reduction efforts




***~85% of world energy is from fossil fuels***

**Energy used for electricity generation and transportation are the major $CO_2$ emission sources**

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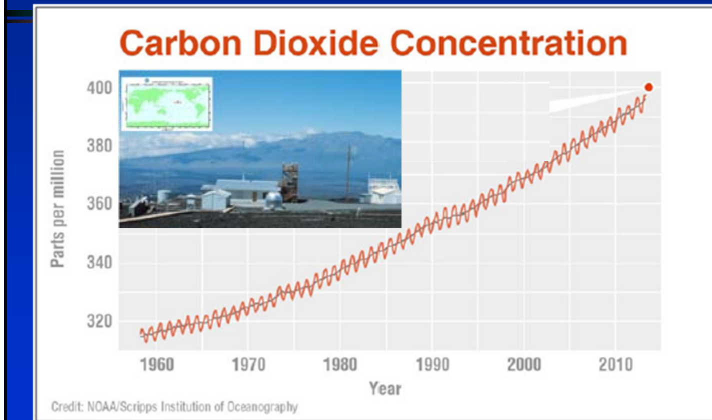
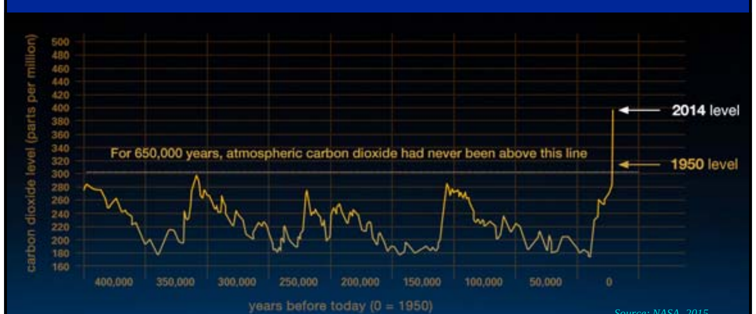
## The Mauna Loa $CO_2$ Record






## $CO_2$ Record from Ice Cores




*Ice core records also show that historical temperature changes closely track changes in $CO_2$ concentration*



## Current $CO_2$ Concentrations are at Historical High Level

SCIENTIFIC AMERICAN™

: http://www.scientificamerican.com/article/co2-levels-for-february-eclipsed-prehistoric-highs/

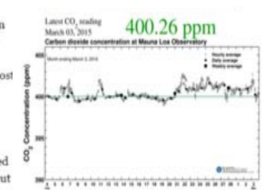
**CO2 Levels for February Eclipsed Prehistoric Highs**

Global warming is headed back to the future as the CO2 level reaches a new high

March 5, 2015 | By David Biello |

February is one of the first months since before months had names to boast carbon dioxide concentrations at 400 parts per million." Such CO2 concentrations in the atmosphere have likely not been seen since at least the end of the Oligocene 23 million years ago, an 11-million-year-long epoch of gradual climate cooling that most likely saw CO2 concentrations drop from more than 1,000 ppm. Those of us alive today breathe air never tasted by any of our ancestors in the entire *Homo* genus.

*Homo sapiens sapiens*—that's us—has subsisted for at least 200,000 years on a planet that has oscillated between 170 and 280 ppm, according to records preserved in air bubbles trapped in ice. Now our species has burned enough fossil fuels and cut down enough trees to push CO2 to 400 ppm—and soon beyond. Concentrations rise



*Setting climate change goals*

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# The Climate Policy Driver

- 1992 U.N. Framework Convention on Climate Change called for "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"

**192 countries are parties to the convention*

E.S. Rubin, Carnegie Mellon

# Implication of Stabilization

- Because of their long atmospheric lifetimes (typically measured in centuries), stabilizing current GHG *emissions* is not sufficient to stabilize atmospheric *concentrations*
- Global emissions must be reduced significantly, *no matter what stabilization target is selected!*

Analogy: To stabilize the water level in a slow-draining tub, the open faucets must be closed to match the slow drain

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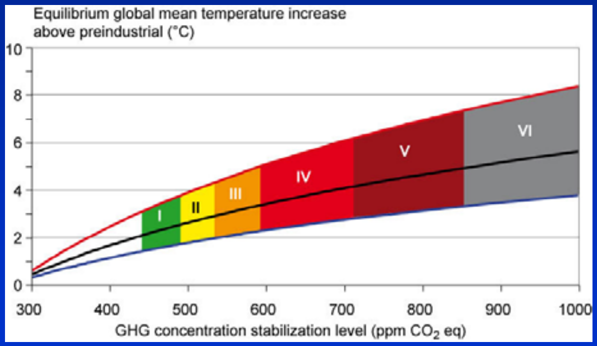
# Different stabilization goals imply different degrees of future warming…




Source: IPCC, 2007

*… and associated impacts*

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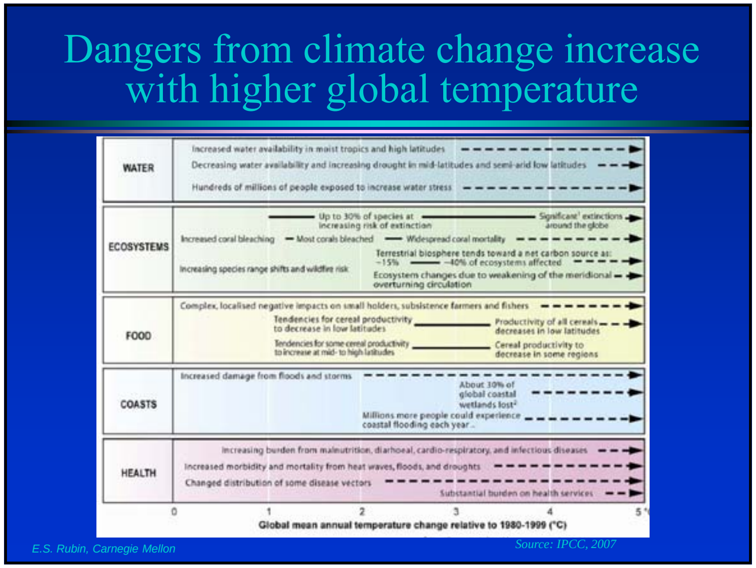
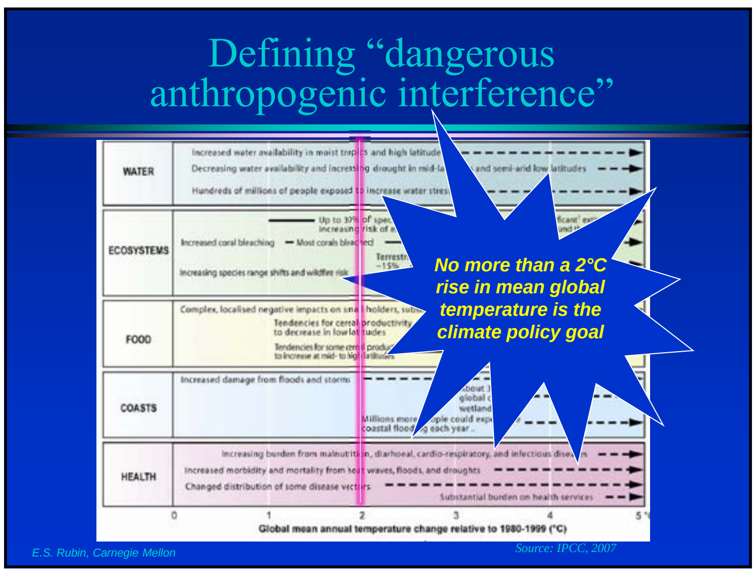
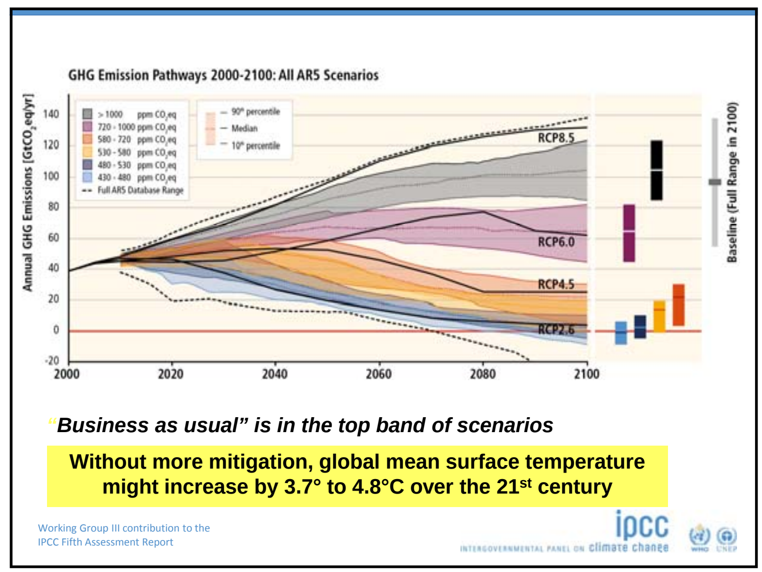

Dangers from climate change increase with higher global temperature
WATER
Increased water availability in moist tropics and high latitudes
Decreasing water availability and increasing drought in mid-latitudes and semi-arid low latitudes
Hundreds of millions of people exposed to increase water stress
ECOSYSTEMS
Up to 30% of species at increasing risk of extinction
Significant extinctions around the globe
Increased coral bleaching
Most corals bleached
Widespread coral mortality
Terrestrial biosphere tends toward a net carbon source as: ~15% ~40% of ecosystems affected
Increasing species range shifts and wildfire risk
Ecosystem changes due to weakening of the meridional overturning circulation
FOOD
Complex, localised negative impacts on small holders, subsistence farmers and fishers
Tendencies for cereal productivity to decrease in low latitudes
Productivity of all cereals decreases in low latitudes
Tendencies for some cereal productivity to increase at mid- to high latitudes
Cereal productivity to decrease in some regions
COASTS
Increased damage from floods and storms
About 30% of global coastal wetlands lost
Millions more people could experience coastal flooding each year
HEALTH
Increasing burden from malnutrition, diarrhoeal, cardio-respiratory, and infectious diseases
Increased morbidity and mortality from heat waves, floods, and droughts
Changed distribution of some disease vectors
Substantial burden on health services
0 1 2 3 4 5
Global mean annual temperature change relative to 1980-1999 (°C)
E.S. Rubin, Carnegie Mellon
Source: IPCC, 2007


More extreme events are expected as atmospheric concentration rises


Defining "dangerous anthropogenic interference"
No more than a 2°C rise in mean global temperature is the climate policy goal
WATER
ECOSYSTEMS
FOOD
COASTS
HEALTH
0 1 2 3 4 5
Global mean annual temperature change relative to 1980-1999 (°C)
E.S. Rubin, Carnegie Mellon
Source: IPCC, 2007


GHG Emission Pathways 2000-2100: All AR5 Scenarios
Annual GHG Emissions [GtCO2eq/yr]
> 1000 ppm CO2eq
720 - 1000 ppm CO2eq
580 - 720 ppm CO2eq
530 - 580 ppm CO2eq
480 - 530 ppm CO2eq
430 - 480 ppm CO2eq
Full AR5 Database Range
90th percentile
Median
10th percentile
RCP8.5
RCP6.0
RCP4.5
RCP2.6
Baseline (Full Range in 2100)
2000 2020 2040 2060 2080 2100
"Business as usual" is in the top band of scenarios
Without more mitigation, global mean surface temperature might increase by 3.7° to 4.8°C over the 21st century
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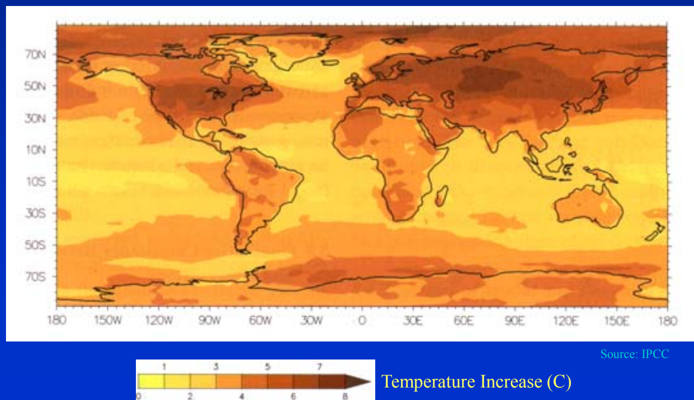
## Predicted Temperature Changes for a Doubling of Atmospheric $CO_2$ Concentration

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## Mitigating Climate Change Requires Large Emission Reductions Soon

The most recent IPCC assessments indicate a need for large reductions by 2050 to avoid serious impacts (>2ºC rise)

| **Required change in global GHG emissions from 2000 to 2050** |
|---|
| **–50% to –85%** |

Source: IPCC, 2007, 2014

*This conclusion was also affirmed in the 2010 report of the U.S. National Academies: "America's Climate Choices"*

*E.S. Rubin, Carnegie Mellon*

*What mitigation measures are currently available or needed ?*

*E.S. Rubin, Carnegie Mellon*

## Mitigation Options

*Available Today—Methods to:*

- Reduce $CO_2$ emissions from energy use
- Reduce non-$CO_2$ emissions from
  - Industrial processes
  - Agricultural activities
  - Landfills /Other sources
- Enhance natural sinks
  - Afforestation /Reforestation
  - Soil management

*Focus on $CO_2$ from energy use*

*Potential Future Options:*

- Geoengineering

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# General Strategies for Reducing $CO_2$ Emissions

**The Kaya Identity**

$$\frac{CO_2 \text{ emissions}}{\text{per year}} = \left(\frac{\text{Population}}{\text{per year}}\right) \times \left(\frac{\text{GDP}}{\text{per capita}}\right) \times \left(\frac{\text{Energy use}}{\text{per GDP}}\right) \times \left(\frac{CO_2 \text{ emissions}}{\text{per unit energy}}\right)$$

*Measures to reduce the last two terms are the focus of current analysis*



# Options to Mitigate $CO_2$ Emissions

- Reduce the demand for energy used in buildings, transportation, and industrial activities
- Improve the efficiency of energy conversion and utilization, so less energy is needed to meet demands for goods and services
- Produce and use alternative energy sources with low or no GHG emissions
- Capture and sequestration $CO_2$ at power plants and other large industrial sources to prevent its release to the atmosphere


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*What options should we pursue?*

*What will it cost?*



# Cost-Effectiveness of a Technology

*Cost-Effectiveness:*

$$\text{\$/ton } CO_2 \text{ reduced} = \frac{\text{Net Annual Cost}}{\text{Net } CO_2 \text{ Reduction}}$$

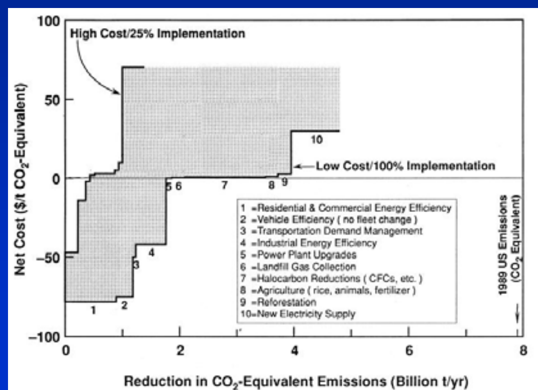
$$\text{Net Annual Cost} = (\Delta \text{ Capital Cost})(\text{CRF}) + \Delta (\text{Annual O\&M Cost})$$

$$\text{where, CRF} = \frac{d}{1-(1+d)^{-n}}$$

d = discount rate

n = technology life

# An Early Abatement Cost Curve for U.S.
(1992 National Academies Study)

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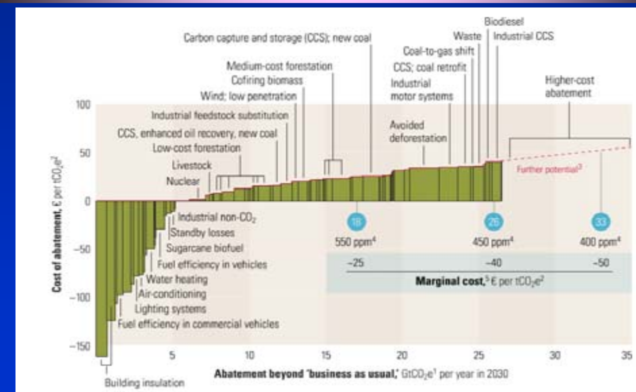
Source: Rubin, et.al, 1992

# A Recent Global Abatement Cost Curve for 2030

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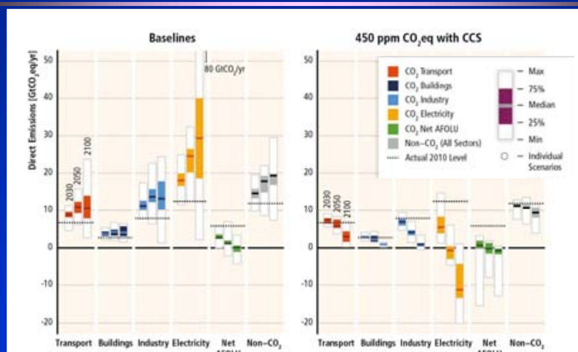
Source: McKinsey & Co., 2007

# Cost-effective strategies require a portfolio of measures to meet goals




**Mitigation requires major technological and institutional changes**

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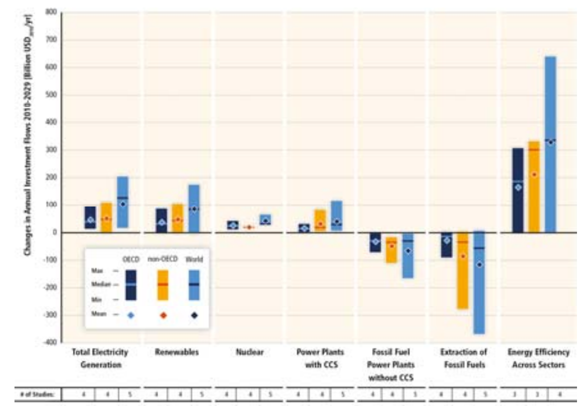
Source: IPCC AR5, WG III, 2014

## Substantial reductions in emissions would require large changes in investment patterns.

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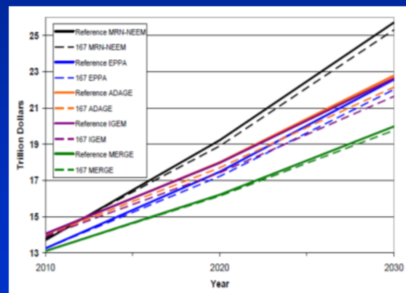
## Economic Impact

- All models project that GDP continues to grow, but at a somewhat lower rate than reference case
- The magnitude of impact on GDP is especially sensitive to the:
  - Timing of reductions
  - Availability of advanced technology
  - Availability and price of international *offsets*




*Source: NAS, 2010*

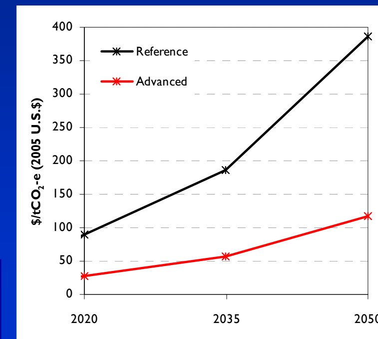


## Value of Sustained R&D

Projected price of $CO_2$ emissions under two technology scenarios:

- REFERENCE: Continue historical rates of technology improvement
- ADVANCED: Strong R&D with more rapid technological change

***An early start and a strong R&D program could reduce total costs significantly***




*Source: Kyle et al. 2009*



## Policy options that can foster technology change and innovation

| "Technology Policy" Options | | | Regulatory Policy Options |
|---|---|---|---|
| **Direct Gov't Funding of Knowledge Generation** | **Direct or Indirect Support for Commercialization and Production** | **Knowledge Diffusion and Learning** | **Economy-wide, Sector-wide, or Technology- Specific Regs and Standards** |
| • R&D contracts with private firms (fully funded or cost-shared)<br>• Intramural R&D in government laboratories<br>• R&D contracts with consortia or collaborations | • R&D tax credits<br>• Patents<br>• Production subsidies or tax credit for firms bringing new technologies to market<br>• Tax credits, rebates, or payments for purchasers/users of new technologies<br>• Gov't procurement of new or advanced technologies<br>• Demonstration projects<br>• Loan guarantees<br>• Monetary prizes | • Education and training<br>• Codification and diffusion of technical knowledge (e.g., via interpretation and validation of R&D results; screening; support for databases)<br>• Technical standards<br>• Technology/Industry extension program<br>• Publicity, persuasion and consumer information | • Emissions tax<br>• Cap-and-trade program<br>• Performance standards (for emission rates, efficiency, or other measures of performance)<br>• Fuels tax<br>• Portfolio standards |

Source: NRC, 2010



## *Future Outlook*

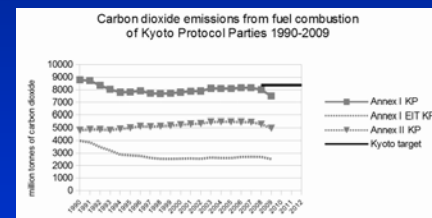
## Still No Universal Consensus on Key Issues

- Importance and urgency of addressing climate change
- Role of developed vs. developing nations
- Best or preferred policy measure(s)
- Cost of mitigation and distribution of costs across society and regions
- Availability and/or acceptability of some mitigation options (at largre scale)



## Many Initial Steps Taken Worldwide to Reduce Emissions

- 1997 Kyoto Protocol initiated planning and actions in the EU and elsewhere for commitments by 2008-2012.




- Negotiations now underway to seek binding agreements from all the nations at the UNFCC Conference of Parties (COP 21) in Paris, December 2015.

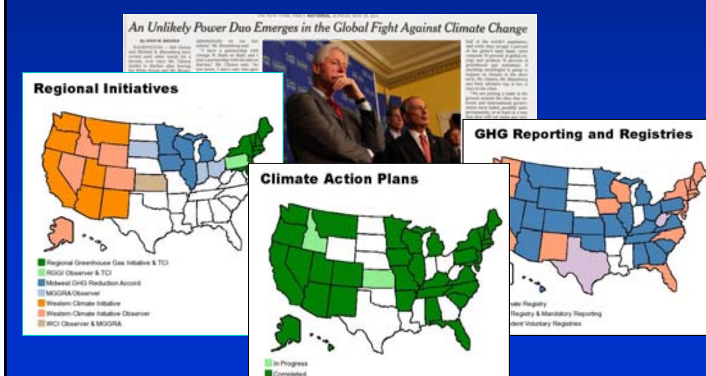


## Other Recent Developments

- In the U.S., the Obama Administration has taken administrative actions to reduce GHG emissions under existing laws in the absence of new national legislation
  - Fuel economy standards for new vehicles to average 54.5 miles per gallon (4.3 liters/100 km) by 2025
  - $CO_2$ emission standards for new coal plants (~50% reduction) + $CO_2$ limits for existing power plants (30% reduction by 2030)
- Bi-lateral agreement with China to reduce national GHG emissions by 2030



## Also many regional, state, local and private initiatives underway






Source: Pew Climate Center, 2011

# Y aqui en Valencia . . .




# What Will the Future Bring ?

- *The climate change problem is not going away !*
- Strong policy drivers are needed to create markets for effective mitigation measures
- Adaptation measures will be increasingly needed in the absence of mitigation measures
- **WATCH THIS SPACE FOR UPDATES**




*Gracias*

*rubin@cmu.edu*