Carbon Sequestration: Science and Context

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  - Oak Ridge National Laboratory
  - Pacific Northwest National Laboratory
  - Argonne National Laboratory
  - Collaboration with Prof. Bruce McCarl (Texas A&M University)
- U.S. Department of Energy Office of Science

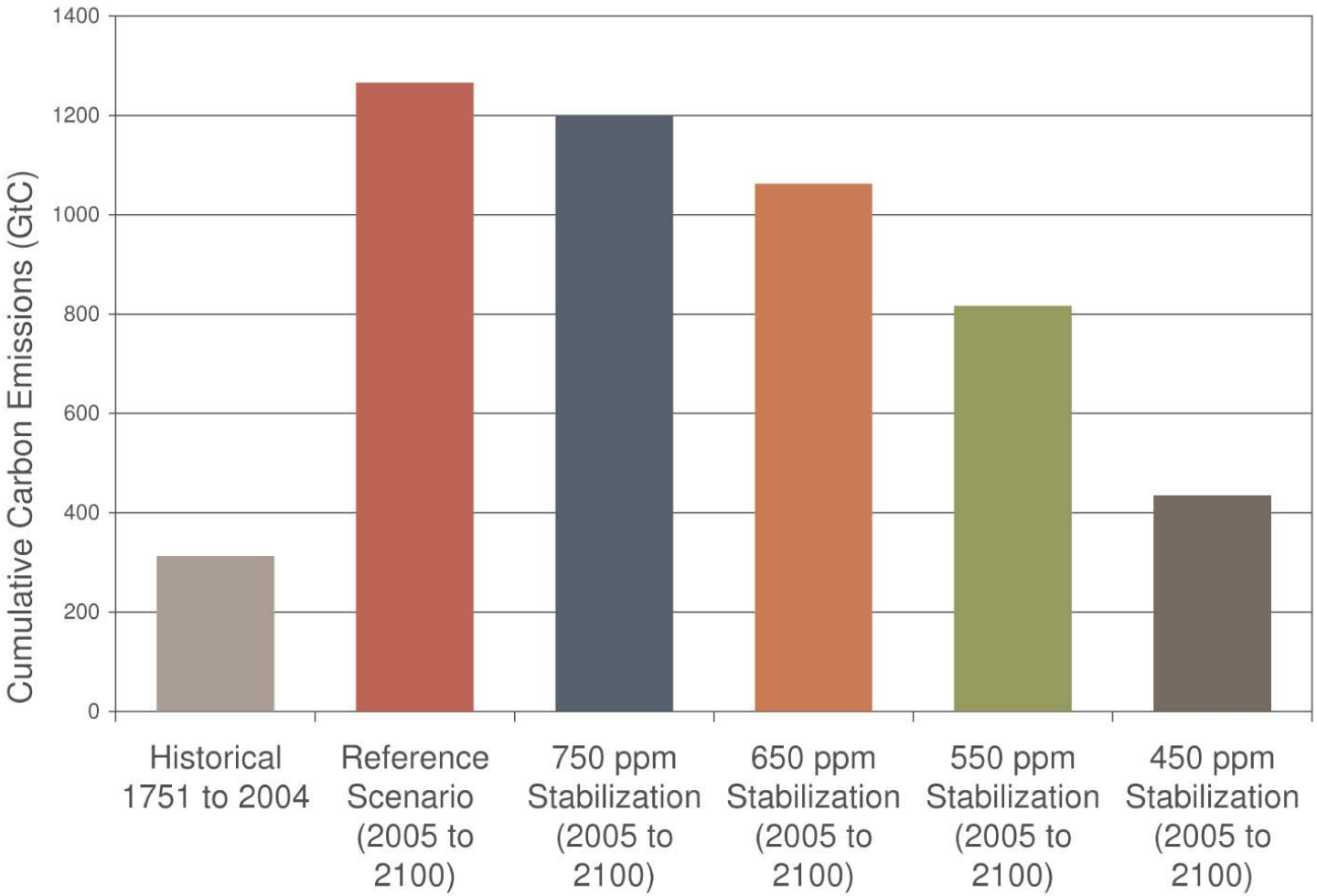
Overview

- Big Picture
  - United Nations Framework Convention on Climate Change (UNFCCC)
  - Types of greenhouse gas mitigation options
- Geologic Sequestration
- Terrestrial Sequestration
  - Why should we care about carbon in soils and plants?
  - What activities can increase the amount of stored carbon?
- Biofuels and Terrestrial Sequestration
- Economic Comparison of Mitigation Options

Framework Convention on Climate Change

- 1992 United Nations Framework Convention on Climate Change (UNFCCC)
  - Objective: achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"
  - UNFCCC process has not yet specified a particular target concentration
- Carbon dioxide is the most important greenhouse gas
  - Pre-industrial concentration was approximately 280 ppm
  - 2007 concentration is approximately 385 ppm
- Carbon budgets
  - Each target for CO_2 concentration implies a cumulative carbon emissions budget over the next century
  - The following slide displays cumulative global carbon emissions budgets that correspond to CO_2 concentration limits of 750, 650, 550, and 450 ppm

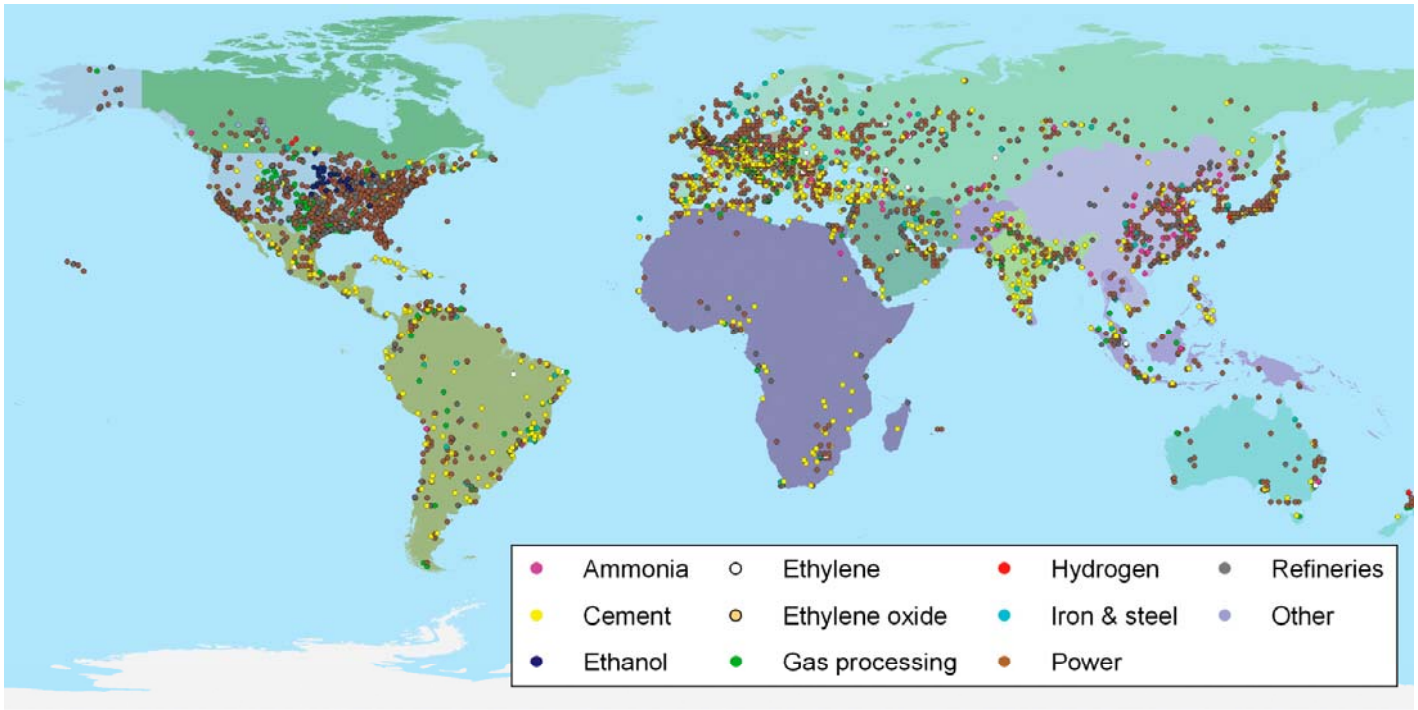
Global Carbon Emissions Budgets



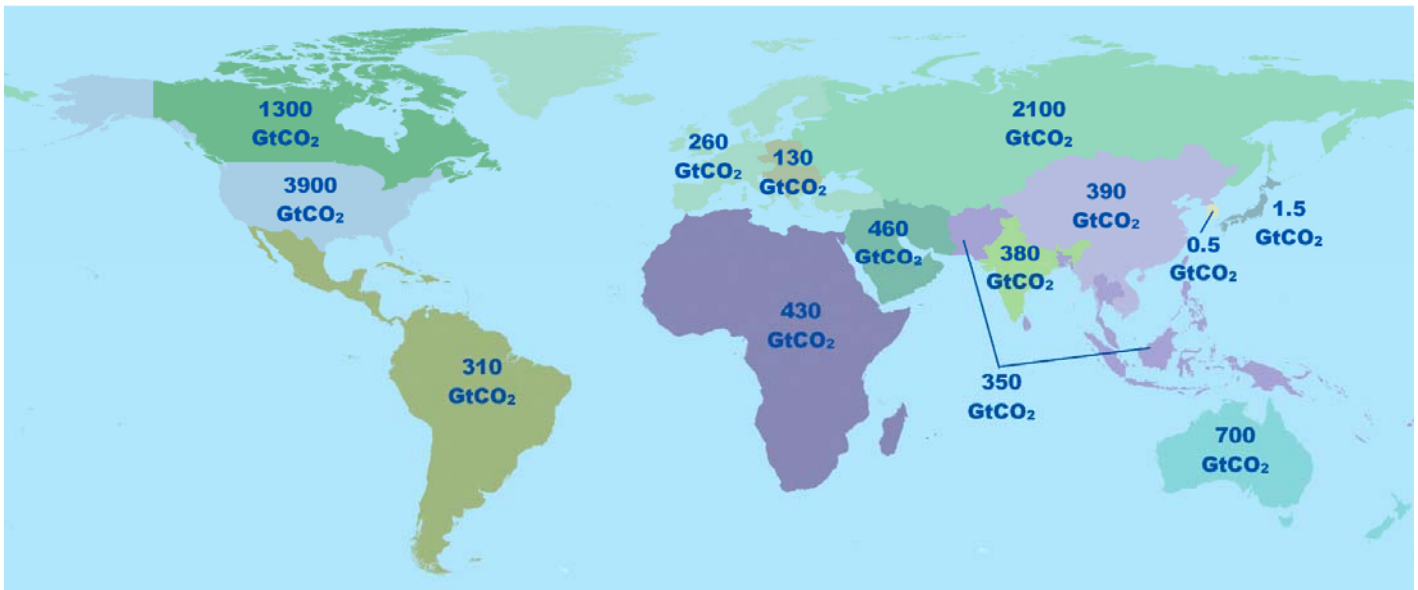
Source: Global Energy Technology Strategy, p. 27

Types of Greenhouse Gas Mitigation Options

- Energy efficiency
- Fuel switching
- Carbon dioxide capture and storage (CCS)
- Non-CO_2 GHG emissions reduction
  - Methane (CH_4)
  - Nitrous Oxide (N_2O)
  - Fluorinated gases (F-gases)
- Terrestrial mitigation options
  - Afforestation
  - Forest Management
  - Biofuels
  - Soil sequestration
    - Reduced tillage of crops
    - Conversion of land from cultivation to tall grasses
    - Application of biochar to soils
- Mitigation options vary by scale, cost, and timing



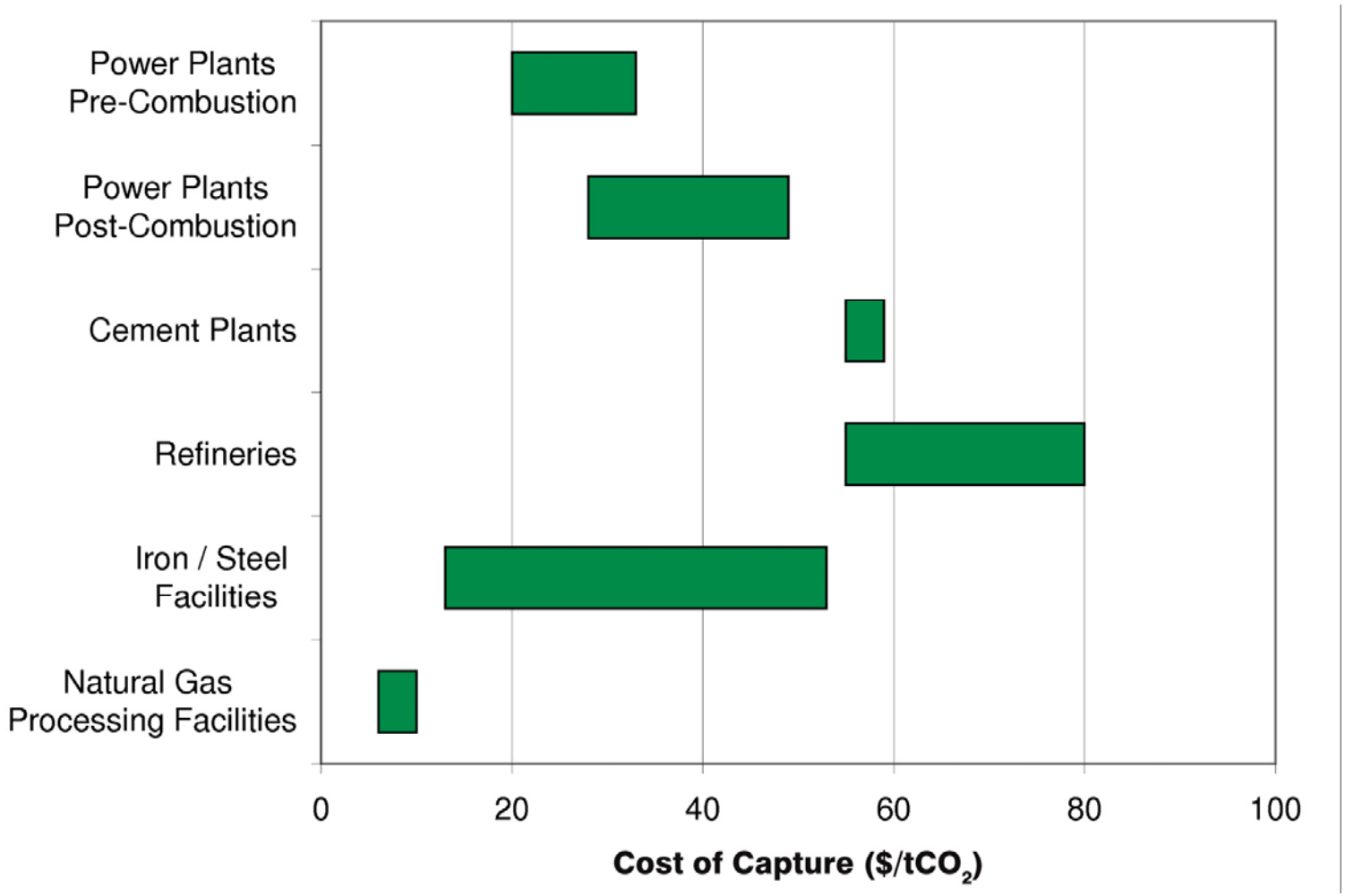
Large CO_2 point sources (accounting for about 60% of global CO_2 emissions)



Initial estimates of capacity of geologic CO_2 storage formations

Source: Global Energy Technology Strategy, p. 48

Variation in Cost of CO_2 Capture



Source: Global Energy Technology Strategy, p. 49

Why Care About Carbon in Soils and Forests?

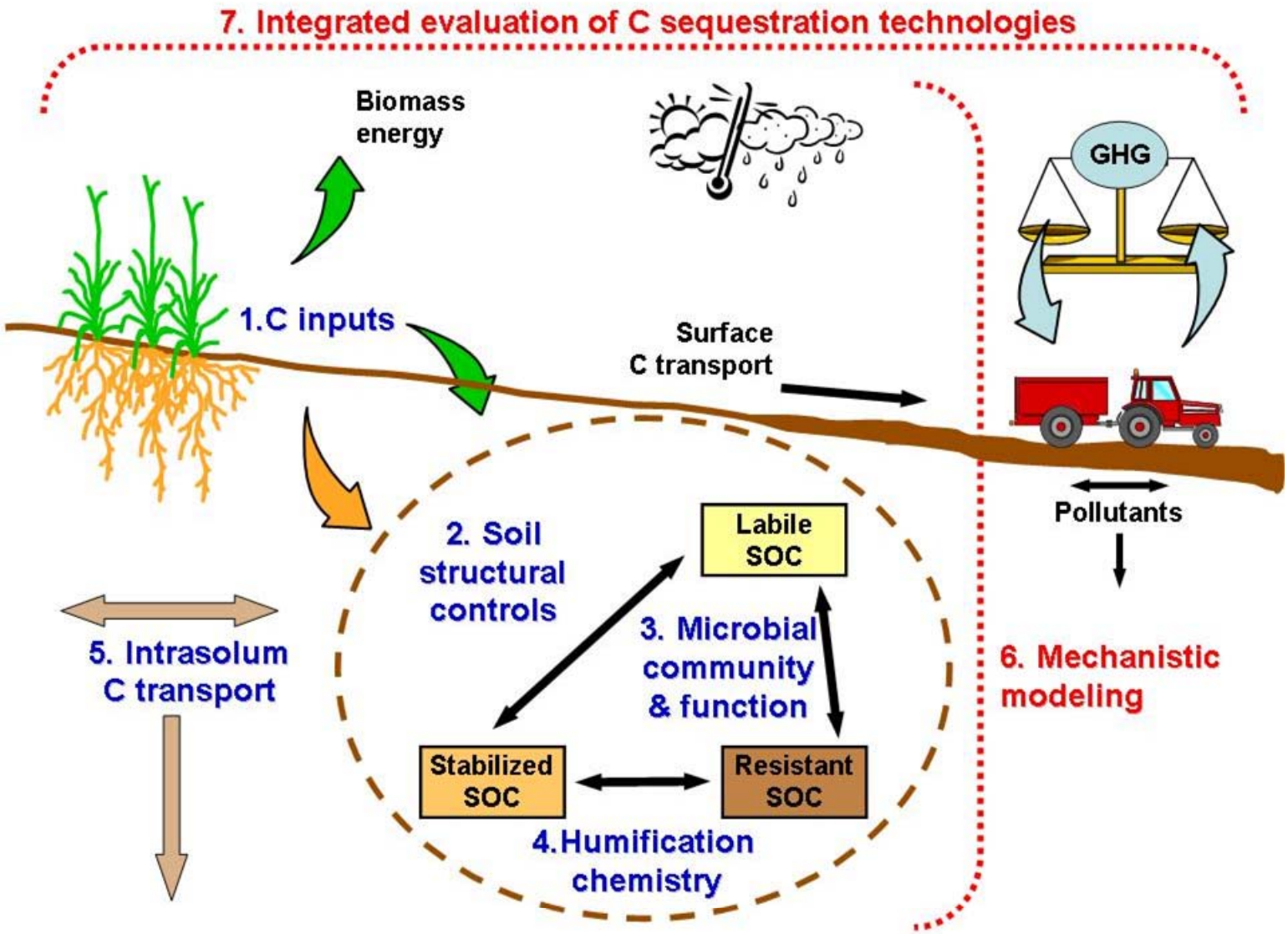
- A large amount of carbon is stored in soils and vegetation
  - Approximately 470 billion tons of carbon is stored in vegetation and 2,000 billion tons in soils (globally)
  - Compare to 775 billion tons of carbon in the atmosphere
- This stock of carbon is affected by
  - Deforestation / Afforestation
  - Cultivation of crops
  - Type of crop and management practice
- Historical loss of carbon
  - 55 billion tons from agricultural soils
  - 150 billion tons from all soils and vegetation
- Our challenge is to monitor this large stock of carbon and explore ways to enhance carbon sequestration

Source: IPCC Special Report on Land Use, Land-Use Change and Forestry

Carbon Sequestration in Terrestrial Ecosystems

- U.S. Department of Energy research consortium
  - Oak Ridge National Laboratory
  - Pacific Northwest National Laboratory
  - Argonne National Laboratory
- Research questions
  - What are the physical, biological and chemical processes controlling soil carbon input, distribution, and longevity?
  - How can these processes be exploited to enhance terrestrial carbon sequestration?
  - How do terrestrial carbon sequestration strategies relate to and influence other strategies to mitigate climate change?
  - What is the long-term potential for terrestrial carbon sequestration to mitigate climate change at a global scale?

CSiTE Research Themes

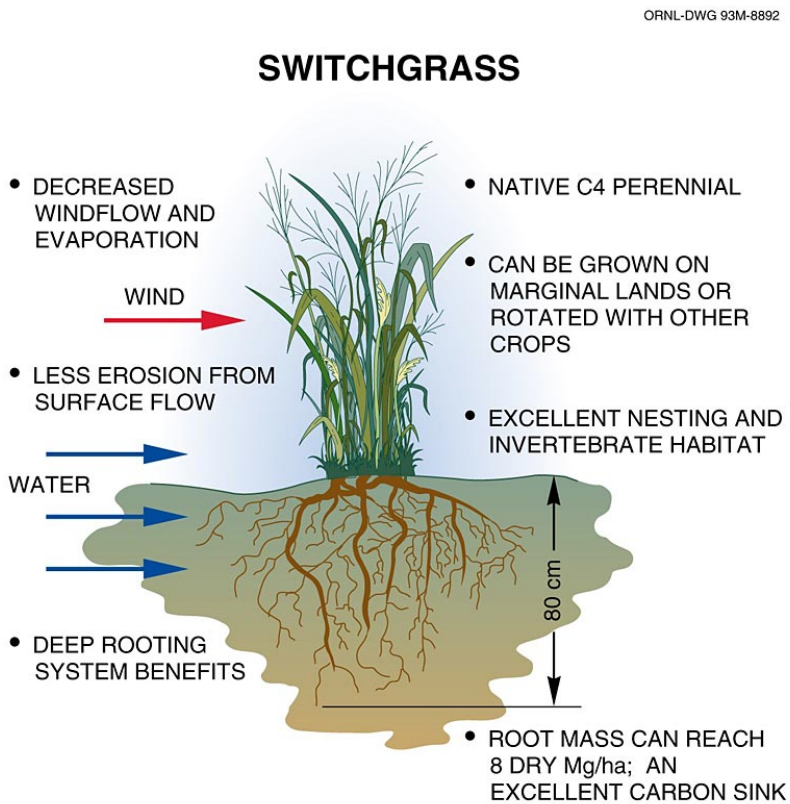


Source: CSiTE Five-Year Science Plan (http://csite.ornl.gov/)

Carbon Sequestration in Terrestrial Ecosystems

- What activities can increase the amount of carbon in soils?
  - Low or no-till crop management
  - Convert cultivated land to tall prairie grasses
  - Direct application to soils (bio-char)
- Field studies include
  - Fermi Lab, Illinois
    - Land formerly under cultivation (corn)
    - Currently planted with tall prairie grasses
    - How quickly and to what extent can tall grasses restore carbon in soil?
  - Milan, Tennessee
    - Switchgrass plots
    - Experiments across switchgrass varieties and quantity of applied fertilizer (biochar experiments planned)
    - Measurements of crop yield, carbon in soil, emissions of nitrous oxide

Biofuels and Terrestrial Sequestration

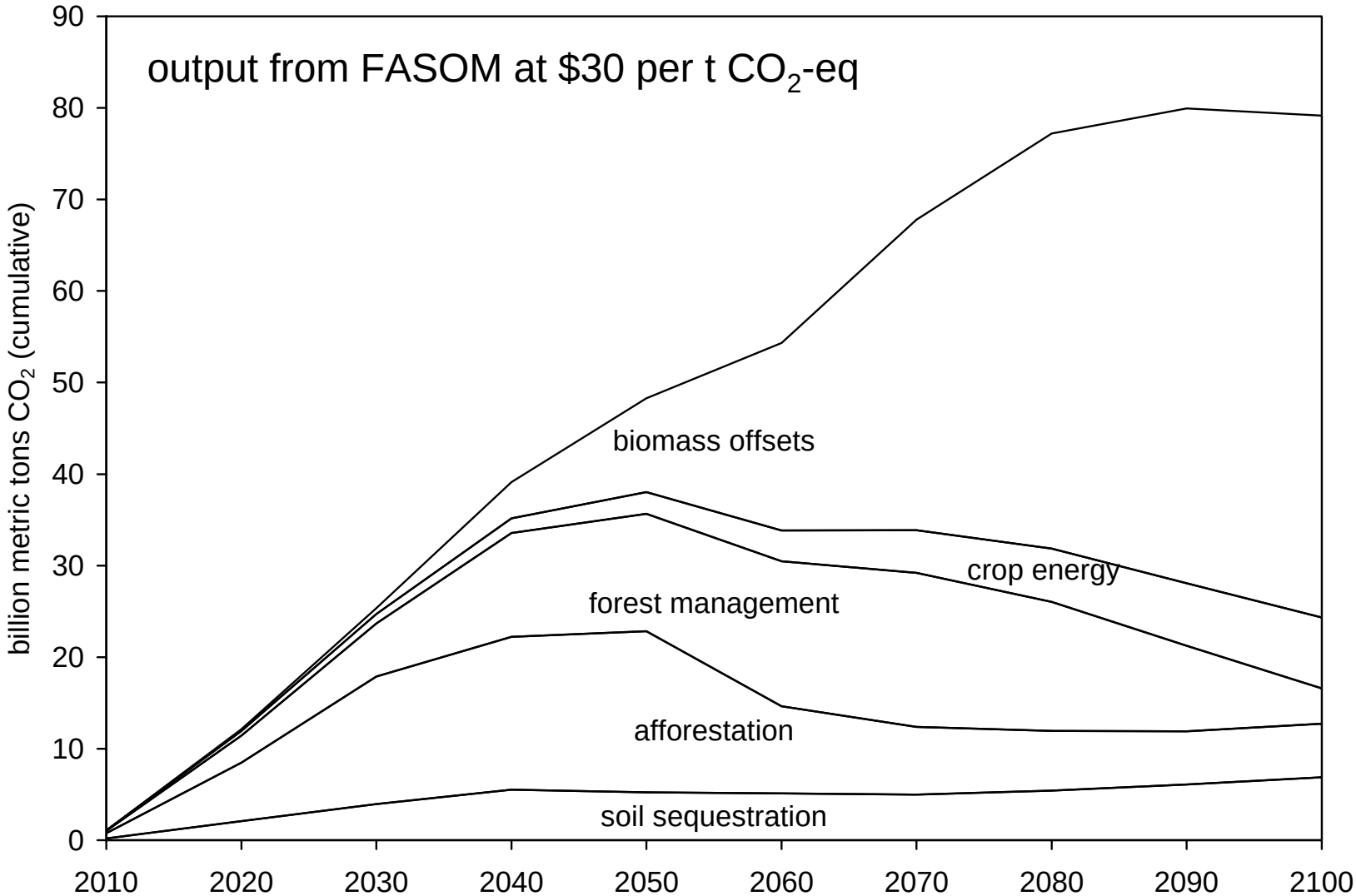


- CSiTE objective: explore carbon sequestration enhancement opportunities created by large-scale production of perennial energy crops
- Uses for switchgrass
  - Cellulosic conversion to ethanol
  - Co-fire with coal in electricity generation
  - Pyrolyze for electricity and biochar

Economic Comparison (U.S.)

- Mitigation Potential
  - Technical potential – what could be achieved if cost were not a consideration
  - Economic potential – what can be achieved at various prices for CO_2, evaluating mitigation options one at a time
  - Competitive potential – what can be achieved at various prices for CO_2, considering interactions such as competition for land
- Methodology
  - Economic models
    - Land-based mitigation options: output from the Forest and Agriculture Optimization Model (FASOM)
    - Economy-wide simulation including energy system: output from Second Generation Model (SGM)
  - Policy experiments across a range of CO_2 prices

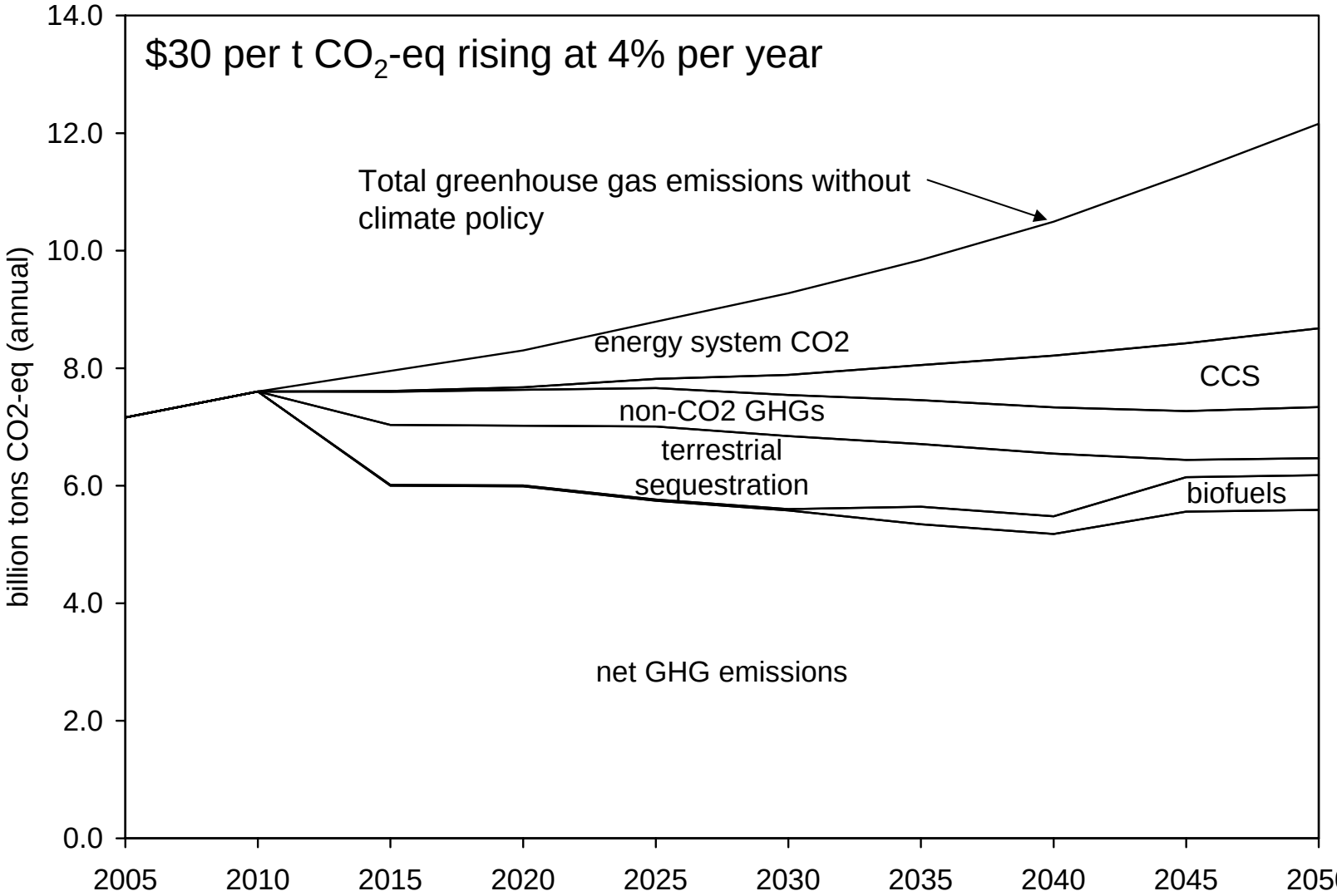
Land-Based Emissions Reductions or Offsets (U.S.)



Economy-wide Economic Analysis

- Full coverage of US economy
- Domestic mitigation only
- CO_2-eq price rises at 4% real interest rate
  - Cumulative emissions constraint from 2012-2050
  - Simulate US net greenhouse gas emissions across a range of CO_2 price scenarios
- Sources of mitigation potential
  - Energy system: Second Generation Model
  - Non-CO2 greenhouse gases: U.S. EPA
  - Terrestrial sequestration and biofuels: output from the Forest and Agriculture Optimization Model (FASOM)
- Extension of analysis (with Bruce McCarl) published in *Climatic Change*, January 2007

Simulation of U.S. Greenhouse Gas Emissions



Summary of Mitigation Options

- Energy Efficiency and Fuel Switching
  - Large component of mitigation potential
- Carbon Dioxide Capture and Storage (CCS)
  - Large potential
  - Time is needed for technology deployment and turnover of existing capital
- Non-CO2 Greenhouse Gases
  - Available early at relatively low cost
- Terrestrial Sequestration
  - Available early but reaches saturation
  - Sequestration potential affected by scale of biofuel production
  - Application of biochar avoids or delays saturation (not included in analysis)
- Biofuels
  - When and at what cost will cellulosic conversion technologies be available at large scale?
  - Competition for land with food crops and forest products
  - Pyrolysis yields biochar—carbon-*negative* energy production

Further Reading

- Edmonds et al. 2007. *Global Energy Technology Strategy*, Battelle. (http://www.pnl.gov/gtsp/)
- McCarl, B.A. and R.D. Sands. 2007. "Competitiveness of Terrestrial Greenhouse Gas Offsets: Are They a Bridge to the Future?" *Climatic Change* **80** (1-2): 109-126.
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