

## State of the Carbon Cycle Report- North America

[Note to reviewers: Items appearing in italics are suggestions that will be developed further through review comments and dialog among authors. Items that are not italicized reflect our current thinking about the best overall structure for the report. We welcome comments concerning all aspects of the outline.]

### Executive Summary

#### I. Introduction: What is the carbon cycle and why should we care?

- *Brief introduction to carbon cycling, concept of carbon sources and sinks, and carbon budgets*
- *Link between climate change and increasing atmospheric concentrations of carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>)*
- *Specific carbon cycle impacts other than climate: ocean pH change, terrestrial CO<sub>2</sub> fertilization, soil carbon*
- *Need for carbon cycle science to inform options for deliberate management of carbon*
- *Carbon is fundamental to life on Earth*
- *Describe the scope and organization of this report: Part I provides a summary and synthesis of the state of knowledge on the natural and managed carbon cycle and options and measures for carbon management into the future. Part II provides additional depth on the state of knowledge organized by sector or domain.*

### PART I: The Carbon Cycle in North America

#### II. How do North American carbon sources and sinks relate to the global carbon cycle?

- A. Brief overview of the natural carbon cycle and how the carbon budget is defined
- B. Fossil fuel emissions
  - *Quantify historical and present-day fossil fuel emissions*
  - *Quantify historical and present-day global use patterns of fuel types*
  - *Place North American historical and present-day emissions in a global context*
  - *Discuss energy and carbon intensity, and other concepts needed to place fossil fuel emissions in context*
- C. Accumulation of carbon in the atmosphere
  - *Historical and present-day accumulation of carbon in the atmosphere*
  - *Quantify patterns of spatial and temporal variability, global to continental scale*
  - *Explain the relative importance of the processes that control the changes in atmospheric concentrations, time scales of additions and removals.*
- D. Vegetation, soils, and land use

- *Explain conversion of forested land to agriculture, and agricultural abandonment, general implications for the carbon cycle/atmosphere.*
  - *Quantify global historical and present-day emissions*
  - *Place North American historical and present-day accumulation of carbon in vegetation and soils in a global context*
- E. Oceans and continental margins
- *Quantify historical and present-day global oceanic carbon uptake*
  - *Spatial and temporal variability, global to basin to continental margins*
  - *Discuss role of margins and coastal waters from global to North American scale*
- F. Quantitative integrated historical and current North American carbon budget in a global context
- *Assess and compare estimates from various methods*
  - *Diagrams of showing historical and present-day North American carbon budgets in context of the global budgets*

### **III. What are the primary carbon sources and sinks in North America, how are they changing and why?**

- A. Introduction and overview
- *Summary of relationship between this section and the sector focus of Part II of the report.*
  - *Review time dimension of carbon budget, current and historical ~300 yr budget*
  - *Definition of North America for this analysis*
  - *Describe treatment of CH<sub>4</sub> in this report: important because of potential climate influence, not important to carbon budget, but linked to carbon cycle at process level*
- B. Summary of carbon budget components for North America [synthesis linked to information in depth in Part II]
1. Brief overview of the natural carbon cycle and how the carbon budget is defined for North America
  2. Fossil fuel emissions
    - *Quantify fuel types used in North America, dynamics of fuel use, carbon intensity over time, seasonal variability*
    - *Summary of sectoral contributions (e.g. transportation, commercial, residential) to atmospheric carbon, quantification of economic role and emissions*
    - *Future trends*
    - *Summary of current contribution of North American fossil fuel emissions to the atmosphere*
  3. Terrestrial vegetation, soils and land use
    - *Brief history of North American land use changes and historical contributions to the atmosphere*
    - *Discuss current overall distribution of North American land in active management, continuum of land use activities*

- *Role of urbanization; settlement patterns, management trends*
  - *Distribution and dynamics of carbon in vegetation and soils across North America by ecosystem type*
  - *Future trends, vulnerabilities, uncertainties*
  - *Summary of current contributions of total vegetation/land use types in North America to the atmosphere – quantification detail; relative magnitude*
4. Aquatic carbon and land-ocean interface
    - *Transfer of carbon from land to ocean through rivers*
    - *Burial of carbon in aquatic and marine systems*
    - *Trends, changes over time, vulnerabilities, uncertainties*
    - *Summary of historical and present day contributions to the atmosphere*
  5. Coastal margins and margin-deep ocean interface
    - *Define the coastal margin of North America for purposes of this report*
    - *Explain current understanding of heterogeneity of coastal margins, uncertainty and variability of carbon fluxes, role of eutrophication*
    - *Future trends, climate interactions, vulnerability and uptake efficiency, ultimate fate of most anthropogenic CO<sub>2</sub>*
    - *Summary of contribution of coastal margins and North Atlantic and North Pacific ocean basins to the atmosphere*
- C. Knowns and uncertainties
- *How well do we know each component of the carbon budget?*
  - *How well are we likely to know each component in the near future?*
  - *Where does it matter to reduce uncertainty from a scientific perspective?*
- D. Summary: State of the North American carbon budget
1. Quantify current carbon balance of North American land and coastal margins with respect to atmospheric carbon concentrations
  2. Place current balance into historical and future perspective
  3. Potential changes in carbon sources and sinks due to factors other than carbon management
    - *Saturation of uptake*
    - *Climate change feedbacks*
    - *Land use and land management decisions, e.g. urbanization, suburban development, fire management*
    - *Surprises*

#### **IV. What are the options and measures that could significantly affect the carbon cycle?**

- A. Expectations for CO<sub>2</sub> and CH<sub>4</sub> concentrations in the atmosphere with current trajectories, by e.g. 2050 (review of best-developed scenarios, including discussion of global warming potentials)

- B. Options and measures (national, state, local, enterprise-level) that can reduce sources, potential reduction in atmospheric concentrations, and potential cost per unit of reduced concentrations or GWP

*Integrated comparison of source reduction options: potential for reducing atmospheric concentrations, and costs per unit atmospheric reduction.*

*Would cut across sectors e.g. industrial, transportation, residential options, agriculture, forestry, etc. and provide cross-sector synthesis*

- *Market instruments*
- *Technologies and practices*
- *Regulations*
- *Information and education*
- *Other*

- C. Options and measures that can enhance sinks (national, state, local, enterprise-level), potential impact and potential cost per unit impact, by sector (agriculture, forestry, other land use, injection technologies)

*Integrated comparison of sink enhancement options: potential for reducing atmospheric concentrations, and costs per unit reduction. Will provide cross-sector summary- and look at cross-sectoral opportunities:*

- *Market instruments*
- *Technologies and practices*
- *Regulations*
- *Information and education*
- *Other*

- D. Integrated comparison of sink reduction and source enhancement options, with table/chart: potential for atmospheric concentration reductions, costs per unit reduction and possible synergies and substitution effects across options

- E. Implementation issues:

- *Second order and unintended consequences (spillovers on non-carbon values)*
- *Measurement, monitoring, verification and evaluation of impact*
- *Reversibility*
- *Exogenous factors that could affect implementation (such as climate feedbacks, technological change, demographics)*

**V. How can we improve the application of scientific information to decision support for carbon management and climate decision-making?**

- *Utility: Understanding needs and decision process of decision-makers*
- *Information: Improving information and analysis*
- *Communication “plus” : Improving ability to deliver and receive information*

## **PART II – The Systems and Activities that Control the Carbon Budget in North America**

### **VI. Emissions from consuming fossil fuels and producing concrete**

- *Transportation (industry and individual)*
- *Industrial (power and manufacturing)*
- *Residential (heating and power)*
- *Commercial (heating and power)*
- *Concrete production*
- *Fugitive methane*
- *Options and measures specific to carbon management for these sectors: market instruments, technologies, regulations, information and education*

### **VII. Agriculture**

- *Quantification of amount of North American land in various types of cultivation (crop types, management regimes)*
- *Synthesis of what is known about historical and present-day carbon fluxes on agricultural land (crop type, management regime, soils)*
- *Interactive factors for agriculture; water/carbon, fertilizer/carbon, soil quality, erosion, etc.*
- *Agricultural contributions to soil carbon sequestration*
- *Agricultural sector contribution to fossil fuel emissions*
- *Agricultural product mobility—where are products consumed?*
- *Future trends: effects of climate interactions, CO<sub>2</sub> fertilization, vulnerability and saturation, multiple greenhouse gas offsets*
- *Summary of historical and present-day contributions of North America agricultural systems to the atmosphere*
- *Detailed options and measures for C management specific to agriculture*

### **VIII. Forests**

*Discussion for each forest zone (VIII A,B and C below):*

- *Quantification of amount of historical and present-day North America land in forest cultivation, forest management (e.g. National Forest), protected areas and “urban forest”.*
- *Synthesis of what is known about historical and present-day carbon fluxes from forests (species differences, plantation vs. “natural”, forest stage effect on C – i.e. new forests vs. old forests, latitudinal differences, partitioning of C into soils, leaf litter, etc.)*
- *Forest product lifetimes and mobility- where consumed, how long before returned to atmosphere*
- *Future trends, climate interactions, CO<sub>2</sub> fertilization, vulnerability and saturation*
- *Summary of historical and present-day contributions of North American forest systems to the atmosphere*

- *Detailed options and measures specific to carbon management for forested systems*

A. Boreal

B. Temperate

C. Tropical

#### **IX. Grass and Rangelands**

- *Quantification of amount of historical and present-day North America land in grasslands, amount that is currently under grazing*
- *Synthesis of what is known about historical and present-day carbon fluxes from grasslands, effect of grazing on carbon fluxes and soil carbon*
- *Summary of historical and present-day contributions of North American grass and rangeland systems to the atmosphere*
- *Detailed options and measures specific to carbon management for these sectors*

#### **X. Boreal Tundra and Peatlands (Canada and Alaska)**

- *Quantification of areal extent*
- *Synthesis of knowledge on current fluxes*
- *Future trends and vulnerabilities*
- *Summary of historical and present-day contribution of North American tundra and peatland systems to the atmosphere*
- *Detailed options and measures specific to carbon management for tundra and peatland (if applicable)*

#### **XI. Wetlands**

- *Quantification of areal extent*
- *Synthesis of knowledge on current fluxes, including carbon burial and methane contribution*
- *Future trends and vulnerabilities*
- *Summary of historical and present-day contribution of North American wetlands to the atmosphere*
- *Detailed options and measures specific to carbon management for wetlands*

#### **XII. Other land categories: Shrub lands, Arid lands, Urban ecosystems**

- *Quantification of historical and present-day amount of North America land in these other various categories*
- *Synthesis of what is known about historical and present-day fluxes in each land type (highlight special areas of new knowledge, e.g. expanding shrub lands)*

- *Trends for each; how land use and management affects each, cultural shifts towards cities and suburbs. How climate and human land use will likely impact these components.*
- *Summary of historical and present-day contribution of North American shrub lands, arid lands, and urban ecosystems to the atmosphere*
- *Detailed options and measures specific to carbon management for these categories*

### **XIII. Aquatic carbon, coastal management, ocean basins**

- *Any domain specific detail on options and measures for aquatic carbon, coastal management and ocean basins near North America that is not covered in Part I*