Carbon cycle of North America and research needs for enhancing CO_2 removal

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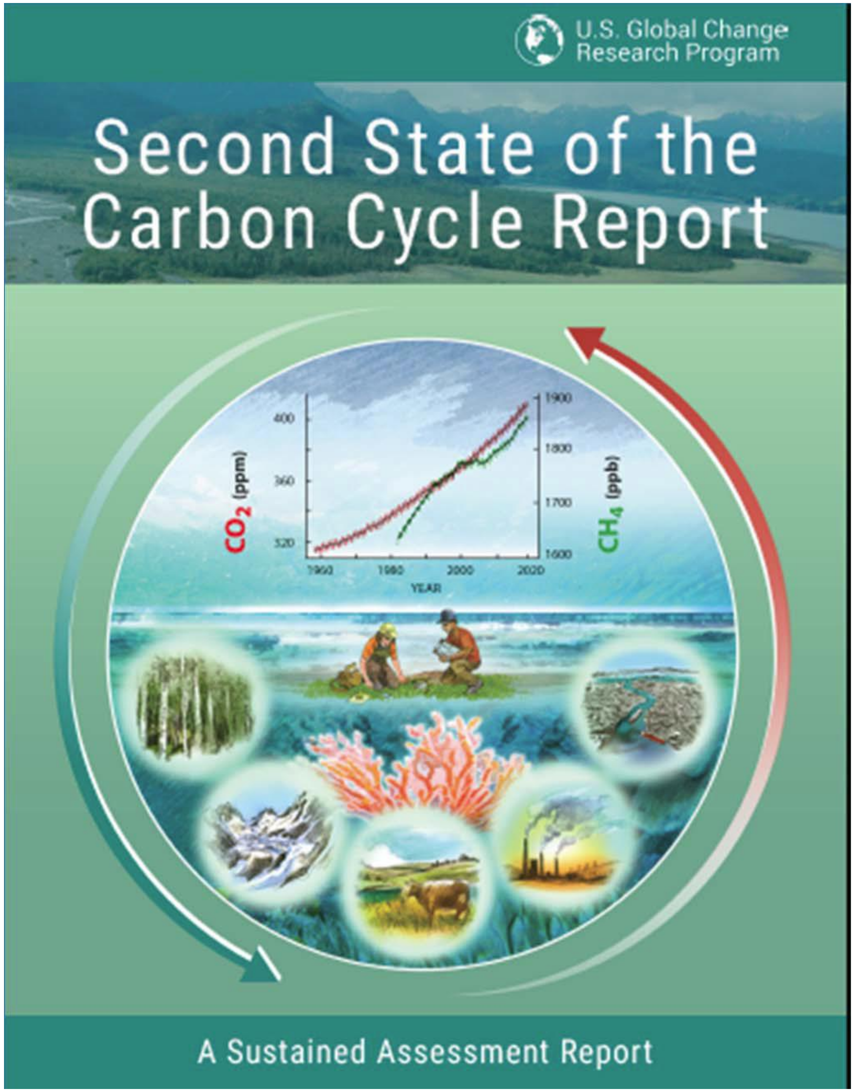
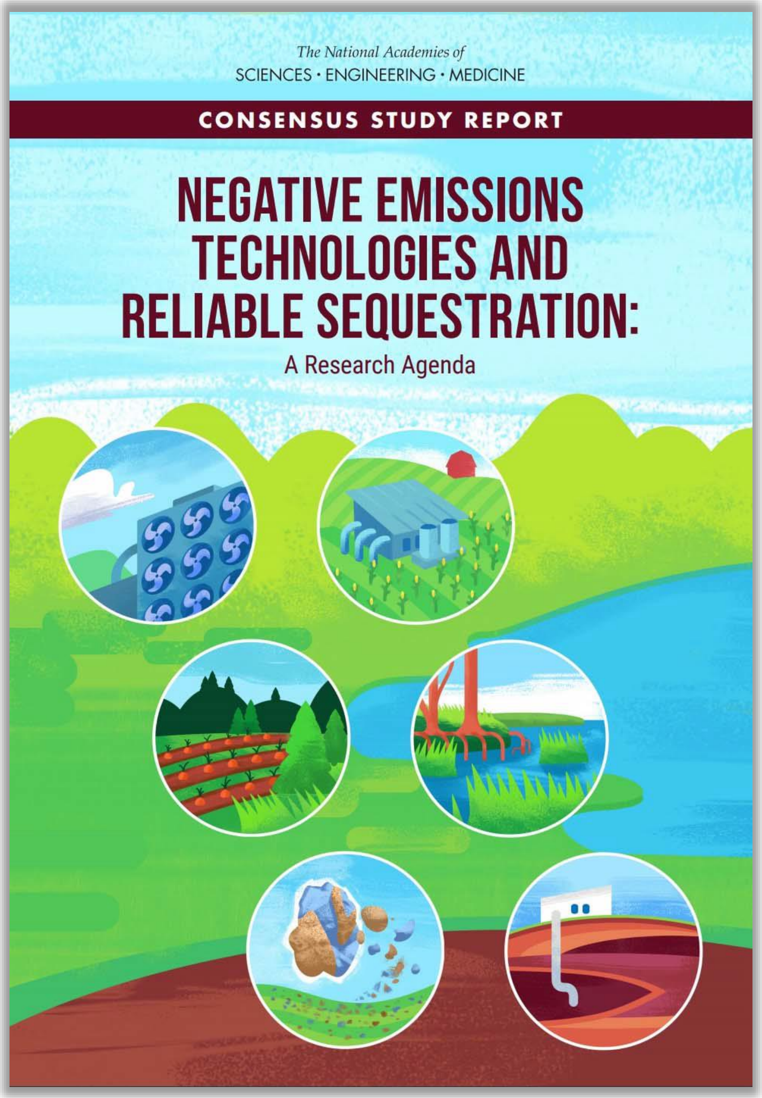
Two reports


U.S. Global Change
Research Program
Second State of the
Carbon Cycle Report
A Sustained Assessment Report


The National Academies of
SCIENCES · ENGINEERING · MEDICINE
CONSENSUS STUDY REPORT
NEGATIVE EMISSIONS TECHNOLOGIES AND RELIABLE SEQUESTRATION:
A Research Agenda

Many authors

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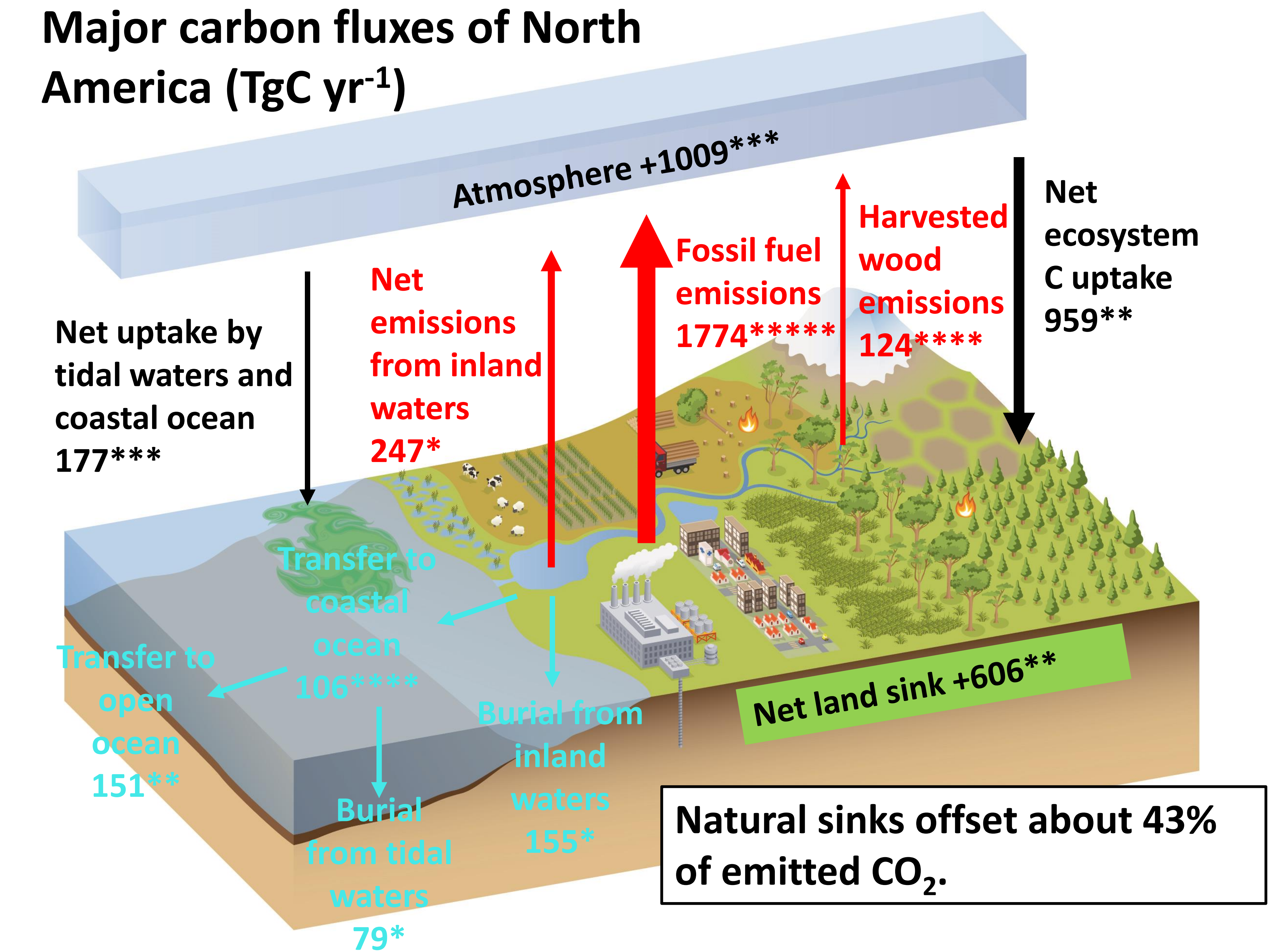
Topic overview

- The North American carbon budget and future projections
- Consequences of changes to the carbon budget
- Information about anthropogenic drivers
- Implications for policy and carbon management
- Research needs

What’s new since SOCCR-1?

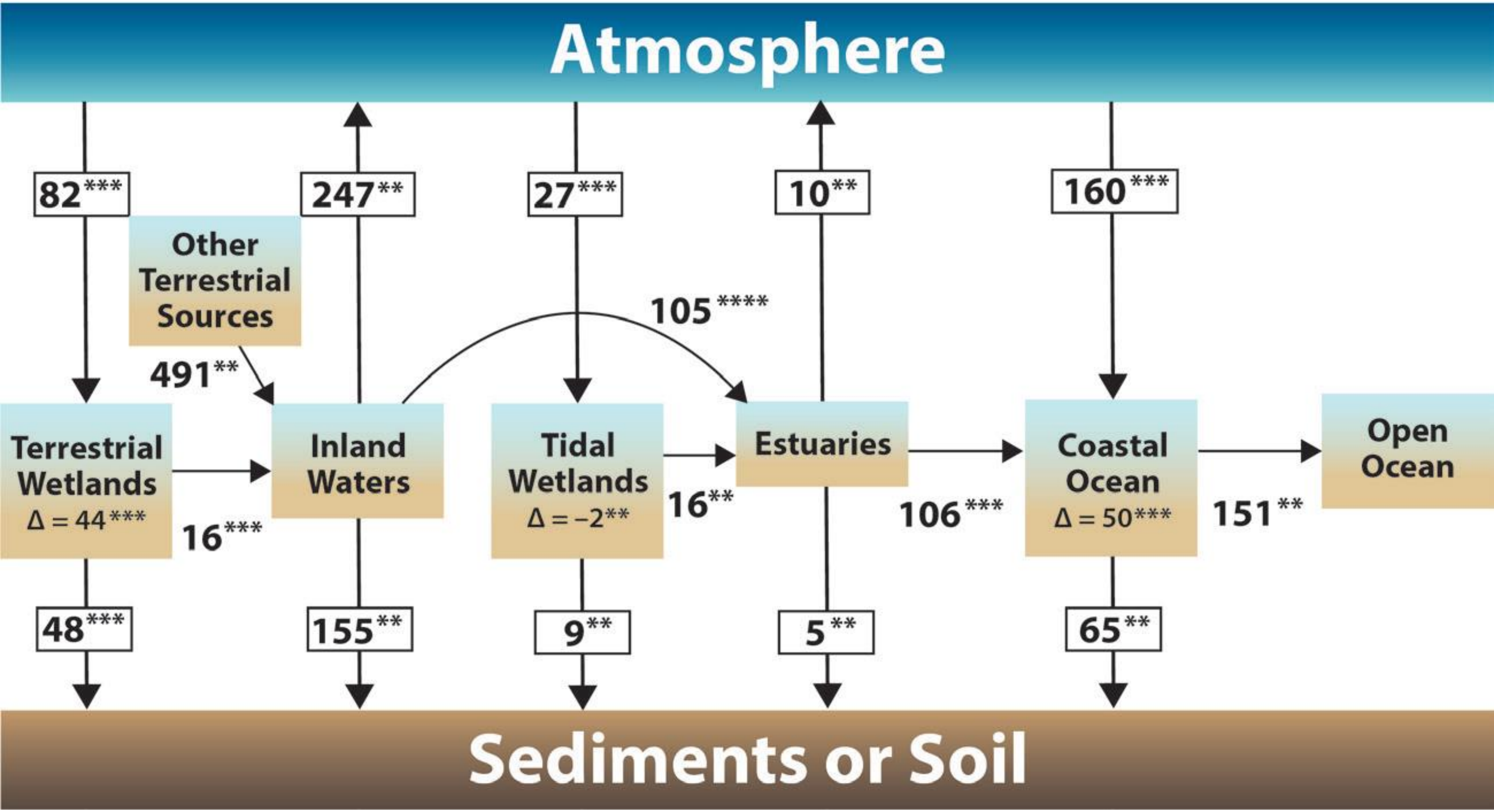
- More detail about soil carbon
- Highlight arctic and boreal ecosystems
- Highlight tribal lands
- Greater emphasis on aquatic systems
- Greater emphasis on the role of societal drivers and decision making
- More information on methane

Geographic domain of SOCCR-2

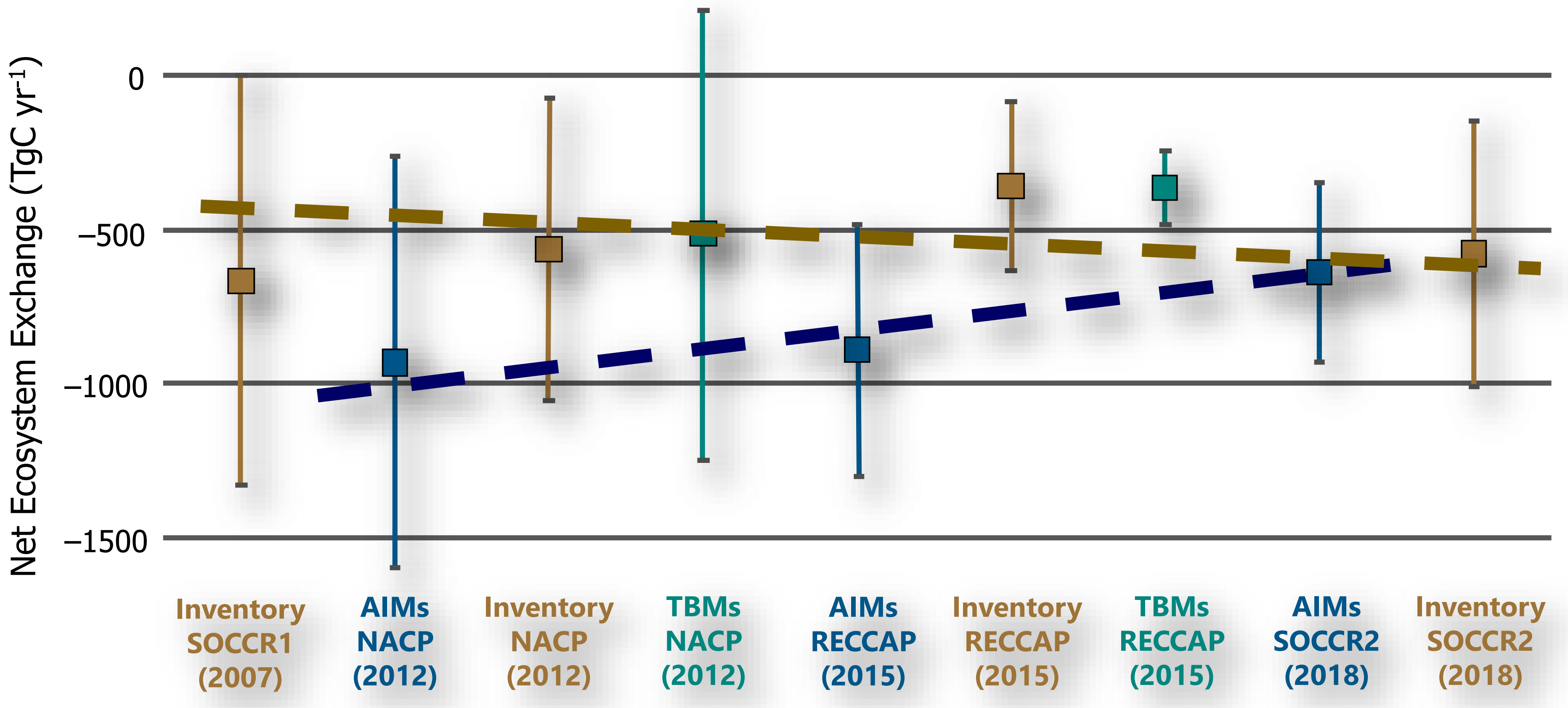


Major carbon fluxes of North America (TgC yr^{-1})
Atmosphere +1009***
Net uptake by tidal waters and coastal ocean 177***
Net emissions from inland waters 247*
Fossil fuel emissions 1774*****
Harvested wood emissions 124****
Net ecosystem C uptake 959**
Transfer to coastal ocean 106****
Transfer to open ocean 151**
Burial from tidal waters 79*
Burial from inland waters 155*
Net land sink +606**
Natural sinks offset about 43% of emitted CO_2.

Carbon budget of North American aquatic ecosystems

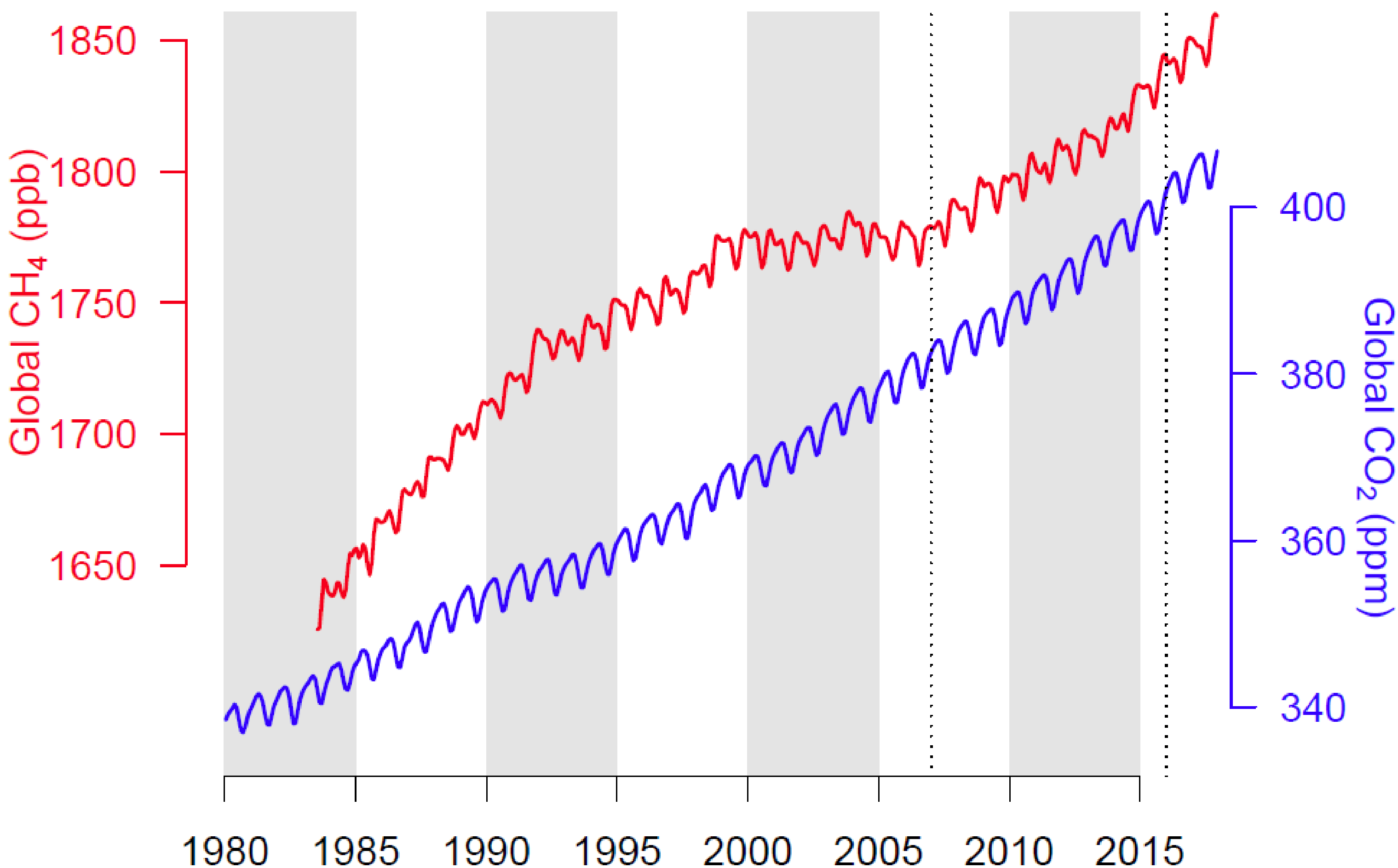


Estimates of North American Land-Atmosphere CO_2 Exchange.



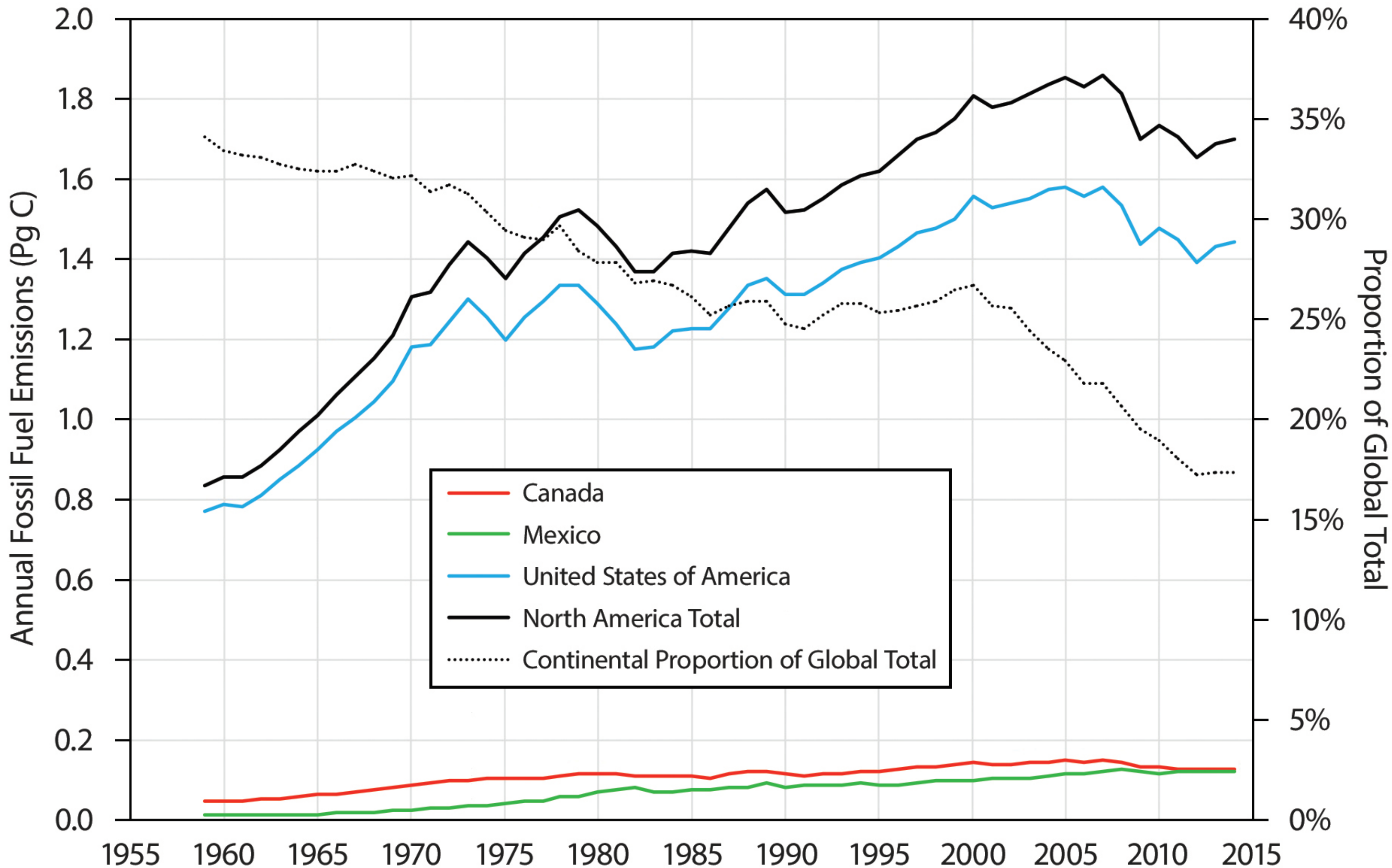
Recent changes in global concentrations of methane and carbon dioxide

Relatively stable North American CH_4 emissions despite increases in natural gas extraction and use.



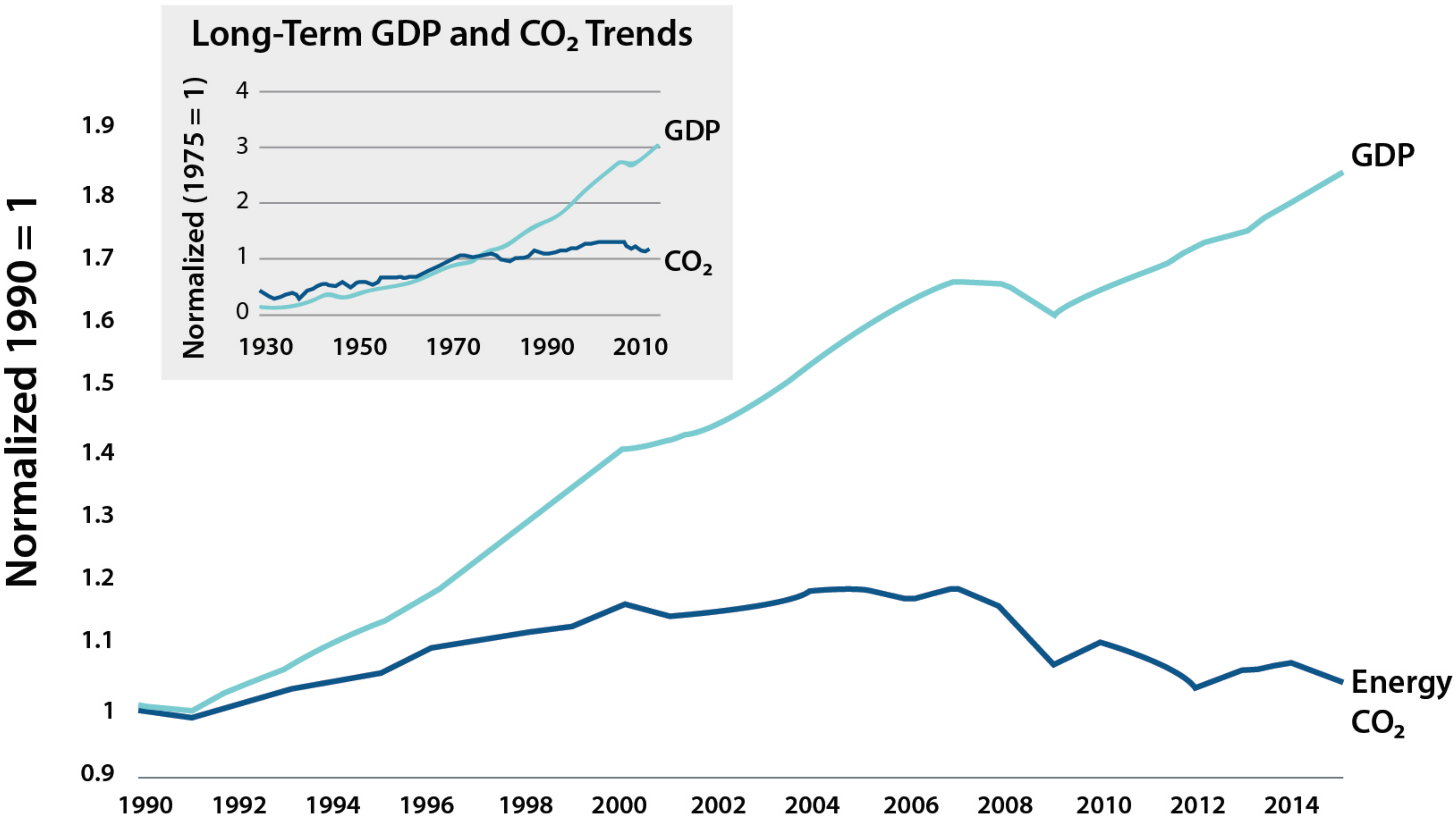
Trends in emissions from North America

Emissions from fossil fuels have declined slightly over the last decade, largely a result of decreasing reliance on coal, increasing reliance on natural gas, & increased vehicle fuel efficiency standards.



Decoupling of economic activity from carbon emissions

Continued growth in economic activity demonstrates that CO_2 emissions can be decoupled, at least partly, from economic activity.



Forests and the carbon cycle

Table 9.3. Net Emissions of Carbon Dioxide Equivalent (CO_2e)[a] for Forestlands from Net Forest Gain and Loss, Tree Growth in Urbanized Settlements, and Harvested Wood Products of Domestic Origin, by Country and Expressed in Teragrams of Carbon (Tg C) per Year

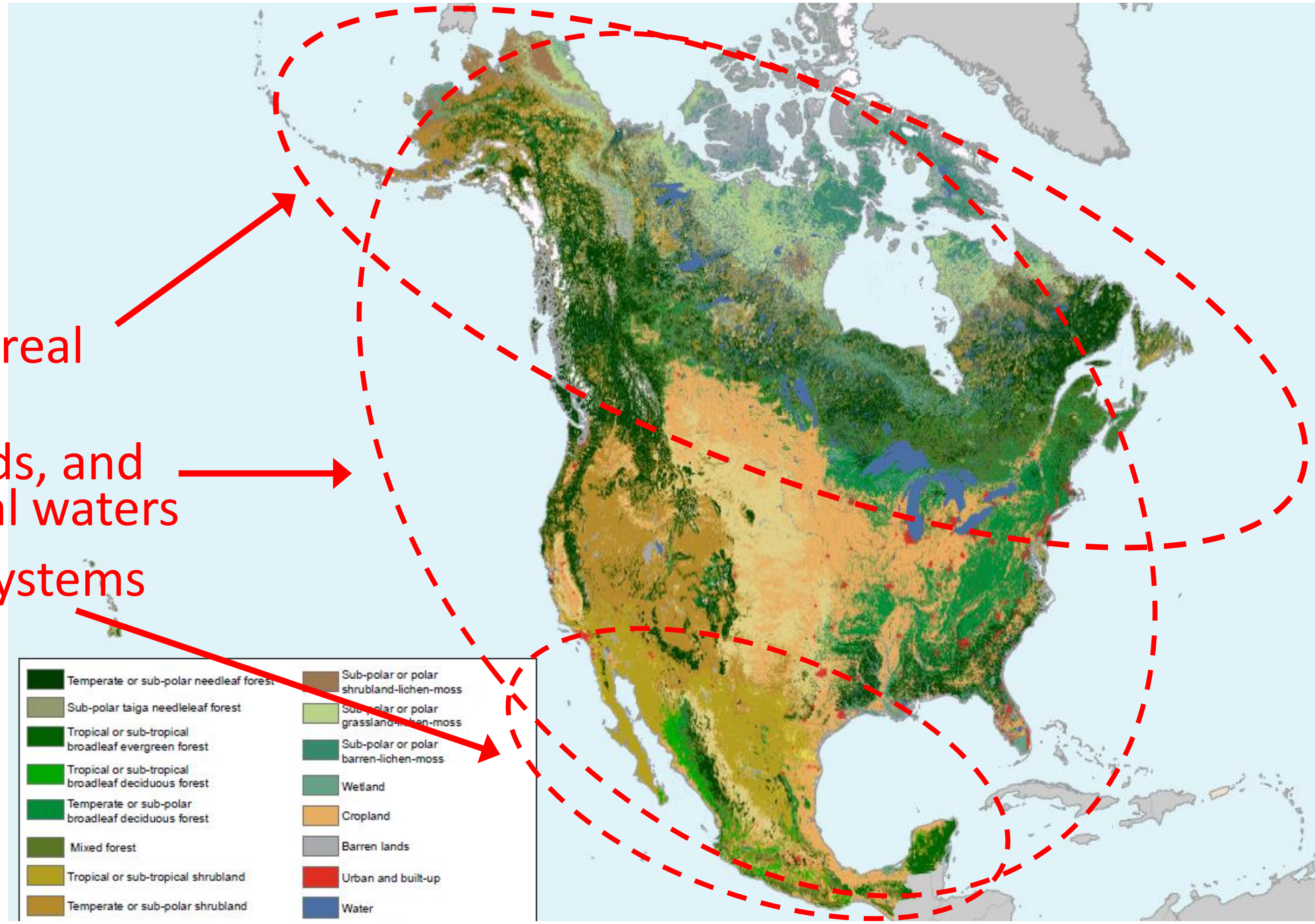
Tg C per Year	Canada[b]	United States[c]	Mexico[d]	Total[k]
1. Net Ecosystem Exchange for Forestland Remaining Forestland[e]	–18	–267	–41	–325****
Stock Change for Forestland Remaining Forestland[e] (Δ Forest C)	–27	154	ND[j]	127
2. Net Flux Due to Forest Area Gain and Loss ($A_{Loss} + A_{Gain}$)	3	0	9	11***
Emissions from Forest Area Loss[f] (A_{Loss})	3	23	12	38
Emissions from Forest Area Gain[g] (A_{Gain})	0	–23	–3	–27
3. Settlements Remaining Settlements[h] (Urban; Net Ecosystem $Production_{settled}$)	–3	–24	ND	–27***
4. Emissions from Biomass Removal and Use[i] (F_{HWP})	35	89	ND	124***
Harvest Removals of Forest Carbon (Harv)	43	113	ND	155
Stock Change for Wood Products (from Harvest Removals – 4)	8	23	ND	31
5. Forest Sector–Atmosphere Exchange (from 1 + 2 + 3 + 4; Δ Atmos. C)	16	–201	–32	–217****

The future carbon cycle of North America

- Urbanization, droughts, wildfires, and continued warming will increase emissions of greenhouse gases or reduce CO_2 removal
- Concern about capacity of land and ocean to continue to act as carbon sinks
- Warning: 5% to 15% of the carbon stored in soil pools in the circumpolar permafrost zone is vulnerable
- Potential impact of mitigation is highly uncertain despite the urgency to take action now to reduce emissions and increase CO_2 removal

Critical knowledge gaps

- Arctic and boreal ecosystems
- Soils, wetlands, and inland/coastal waters
- Tropical ecosystems



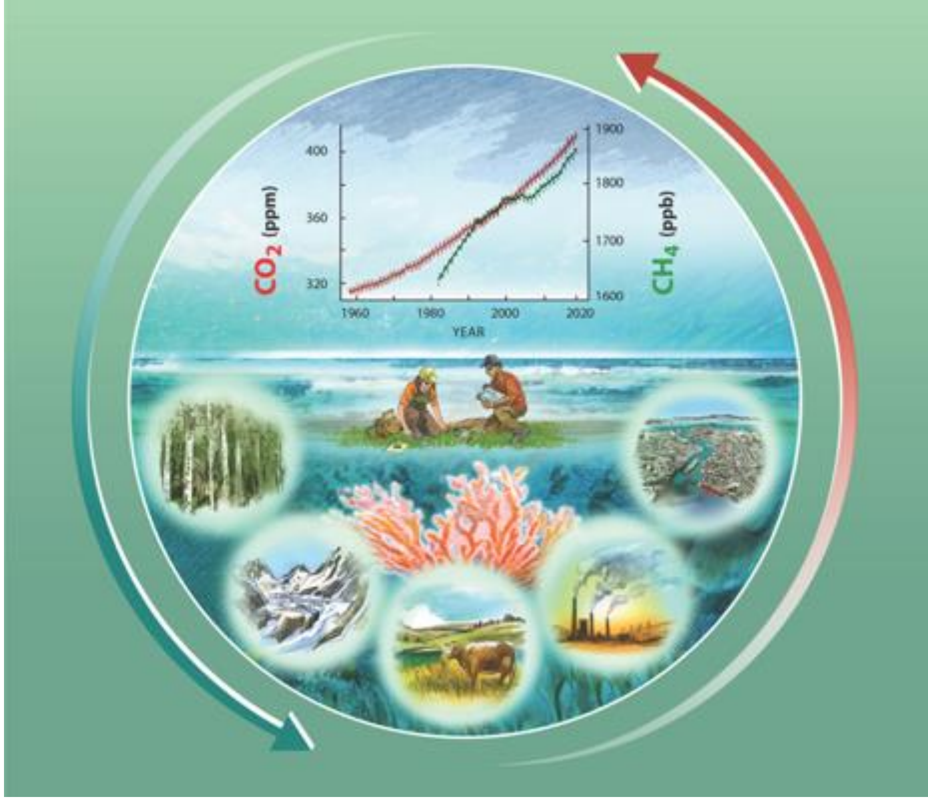
Improve understanding:

- **Impacts of human activities on the carbon cycle**
- **Feedbacks between increasing CO2 concentrations and terrestrial ecosystems**
- **Natural disturbance alterations caused by climate change**
- **Societal responses to these changes**

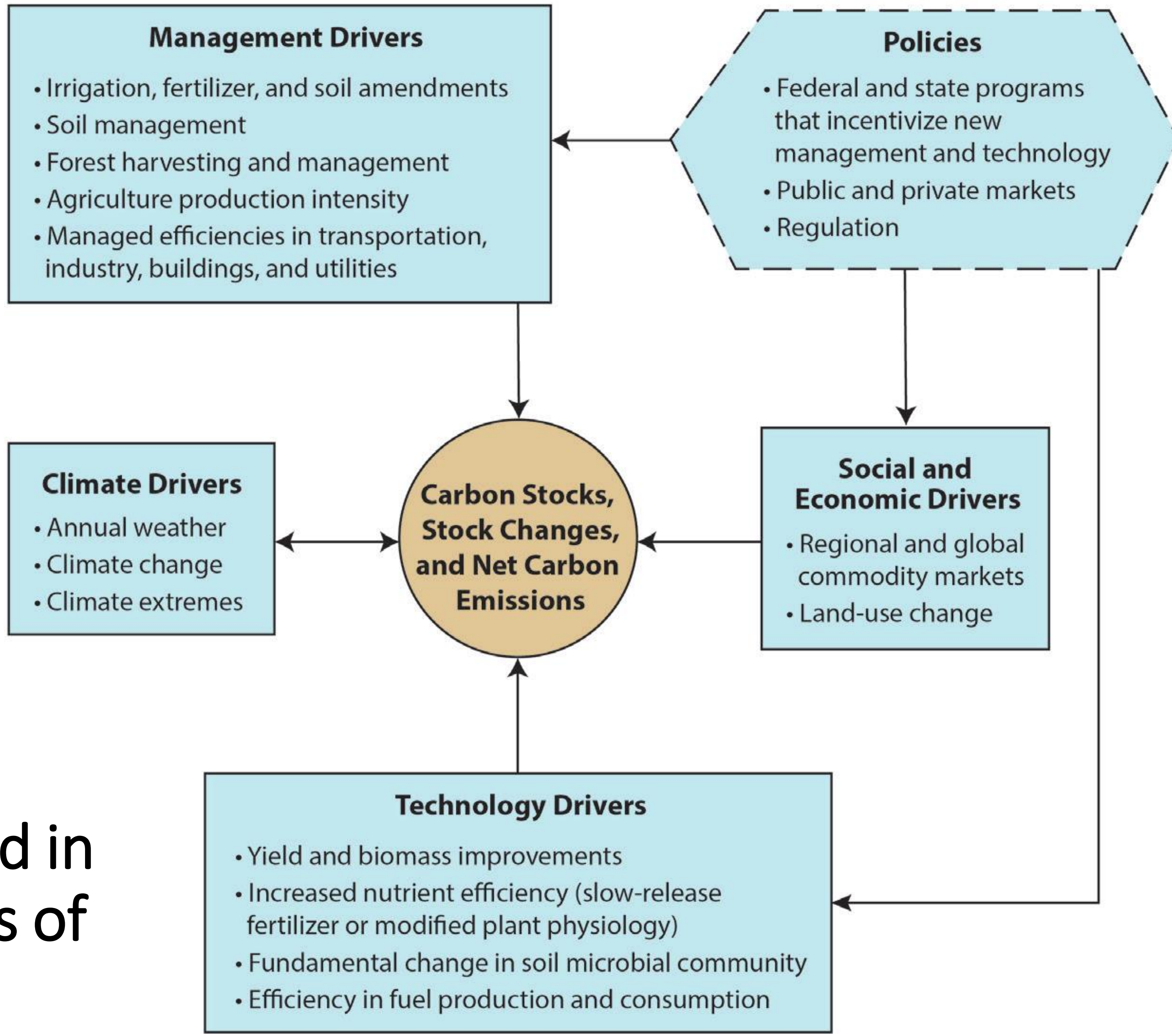
Consequences of rising atmospheric CO_2 on terrestrial and oceanic systems

- Ocean acidification already has affected some marine species and altered fundamental ecosystem processes
- Increased plant photosynthesis, growth, and water-use efficiency, though these effects are reduced when nutrients, drought, or other factors limit plant growth
- Changes in the ecosystem services that terrestrial and oceanic systems provide to humans

Pathways to reduce greenhouse gas emissions or increase carbon removals from the atmosphere



- Decrease fossil fuel use
  (largest reduction potential)
- Expand renewable energy use
- Reduce CH_4 emissions from livestock
- Increase afforestation
- Improve land management practices to remove emitted CO_2 from the atmosphere



Carbon is embedded in all aspects of society

Concluding Remarks (SOCCR-2)

- Emissions are declining from North America while economic activity is increasing
- The land and ocean sinks are persisting although the future strength may decline
- Climate-related threats to forests, soils, and waters are significant
- Potential for significant mitigation is highly uncertain

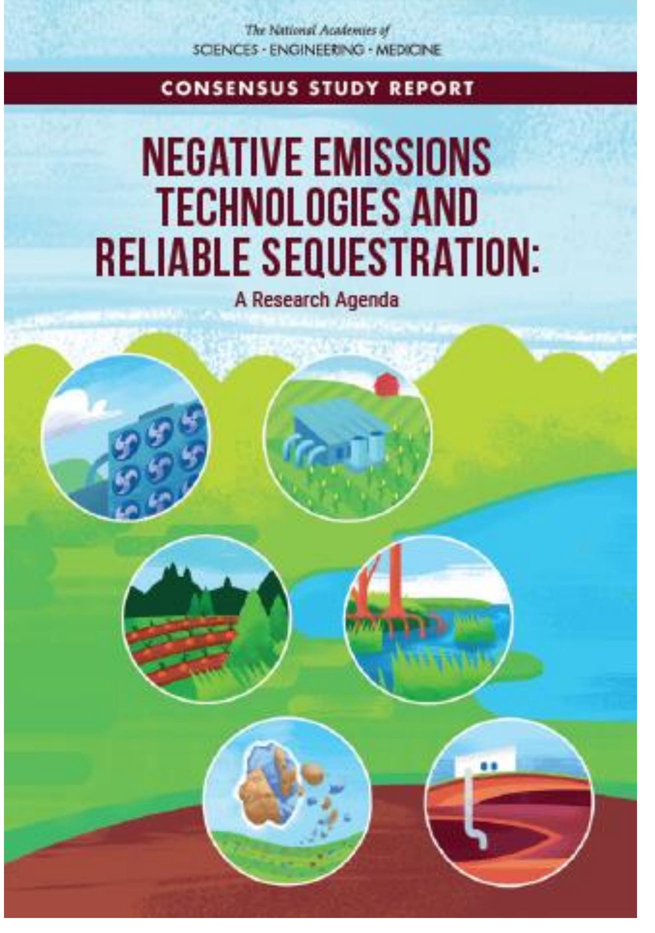
Second State of the Carbon Cycle Report

A Sustained Assessment Report

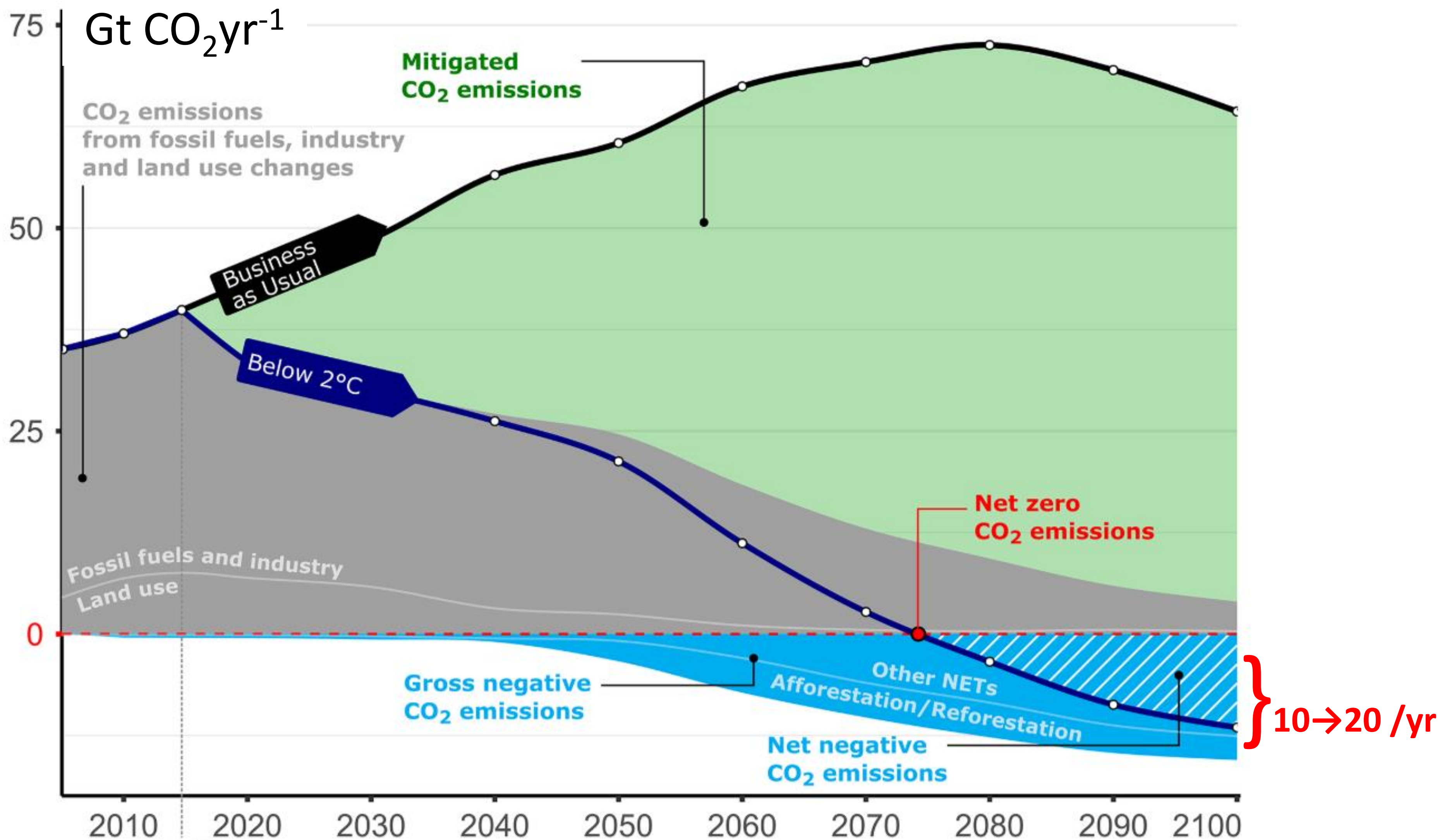
U.S. Global Change Research Program

U.S. National Academy of Sciences Study

- Assess the benefits, risks, and “sustainable scale potential” for Negative Emissions Technologies and sequestration
- Define the essential components of a research and development program, including its estimated costs and potential impact



The role of negative emissions in climate change mitigation



Fuss et al. 2018

Negative emissions technologies

Coastal blue carbon

Direct air capture

Terrestrial carbon removal and sequestration

Carbon mineralization

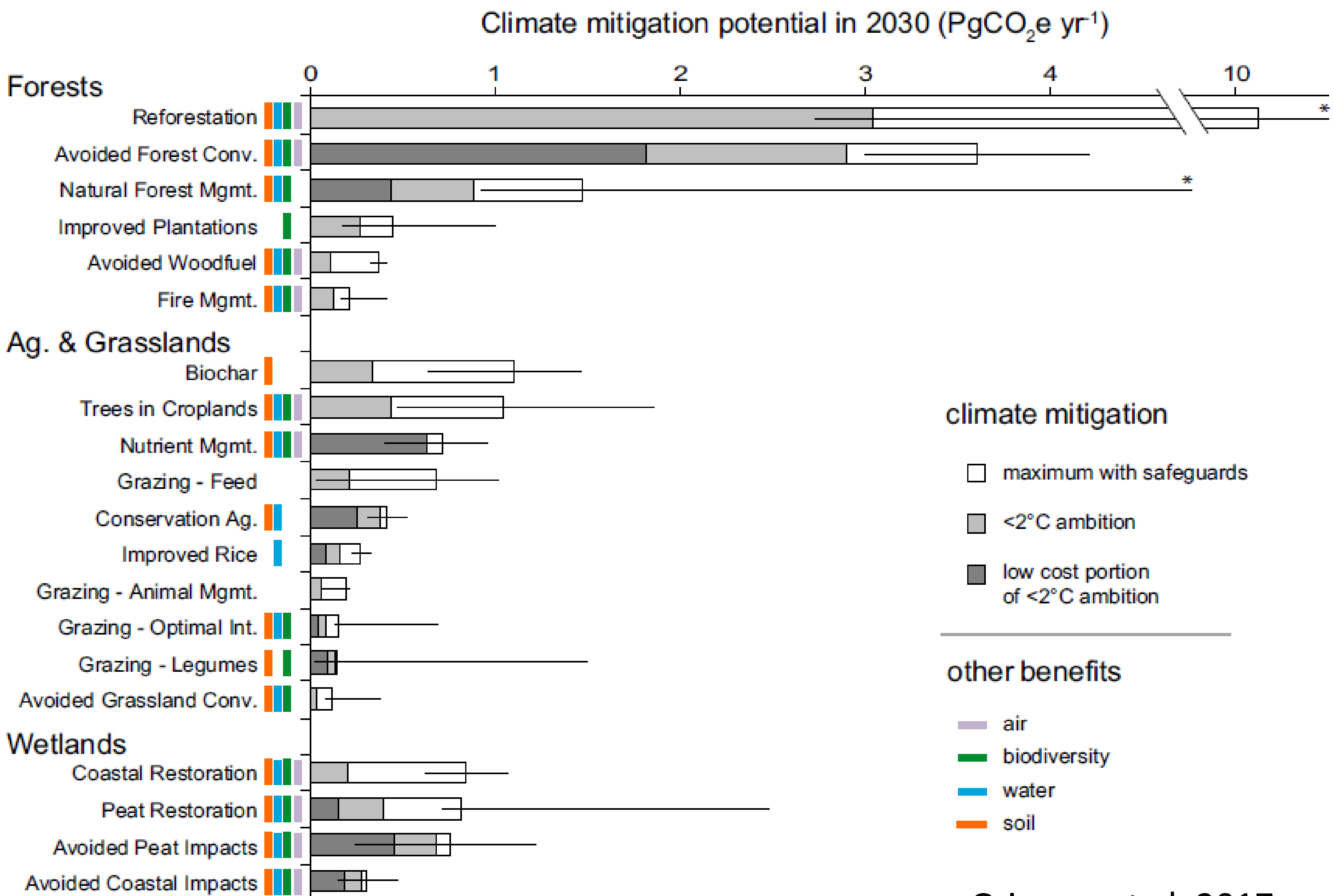
Bioenergy with carbon capture and sequestration (BECCS)

Geologic sequestration

The main negative emissions technologies and level of readiness

Carbon dioxide removal activity	Readiness
Terrestrial/coastal carbon removal and sequestration — Land use and management practices that enhance biomass and soil carbon storage.	High
Bioenergy with carbon capture and sequestration (BECCS) — Energy production using plant biomass combined with capture and sequestration of CO2 that is released.	Medium
Direct air capture and sequestration — Chemical processes that capture CO2 from ambient air and concentrate it, so that it can be injected into a storage reservoir.	Low+
Carbon mineralization —CO2 from the atmosphere forms a chemical bond with reactive minerals in rocks.	Low
Geologic sequestration — captured CO2 is injected into a geologic formation, where it remains in the pore space of the rock for a long period of time.	Low

Climate mitigation potential of 20 natural pathways



Griscom et al. 2017

Realistic global capacity to remove atmospheric CO_2 given current technology and understanding

Negative emissions technology	Estimated cost ($/t$CO_2$)	Potential rate of removal (GtCO_2/y)	Main limiting factors
Coastal blue carbon	0-20	0.13	• Land • Scientific/technical understanding
Afforestation/ Reforestation	0-20	1.0	• Land • Practical barriers
Forest management	0-20	1.5	• Demand for wood • Practical barriers
Agricultural soils	0-50	3.0	• Limited rates of carbon uptake • Practical barriers
Biomass energy with carbon capture	20-100	3.5-5.2	• Cost • Availability of biomass • Practical barriers • Fundamental understanding
Total		**9.13-10.83**	

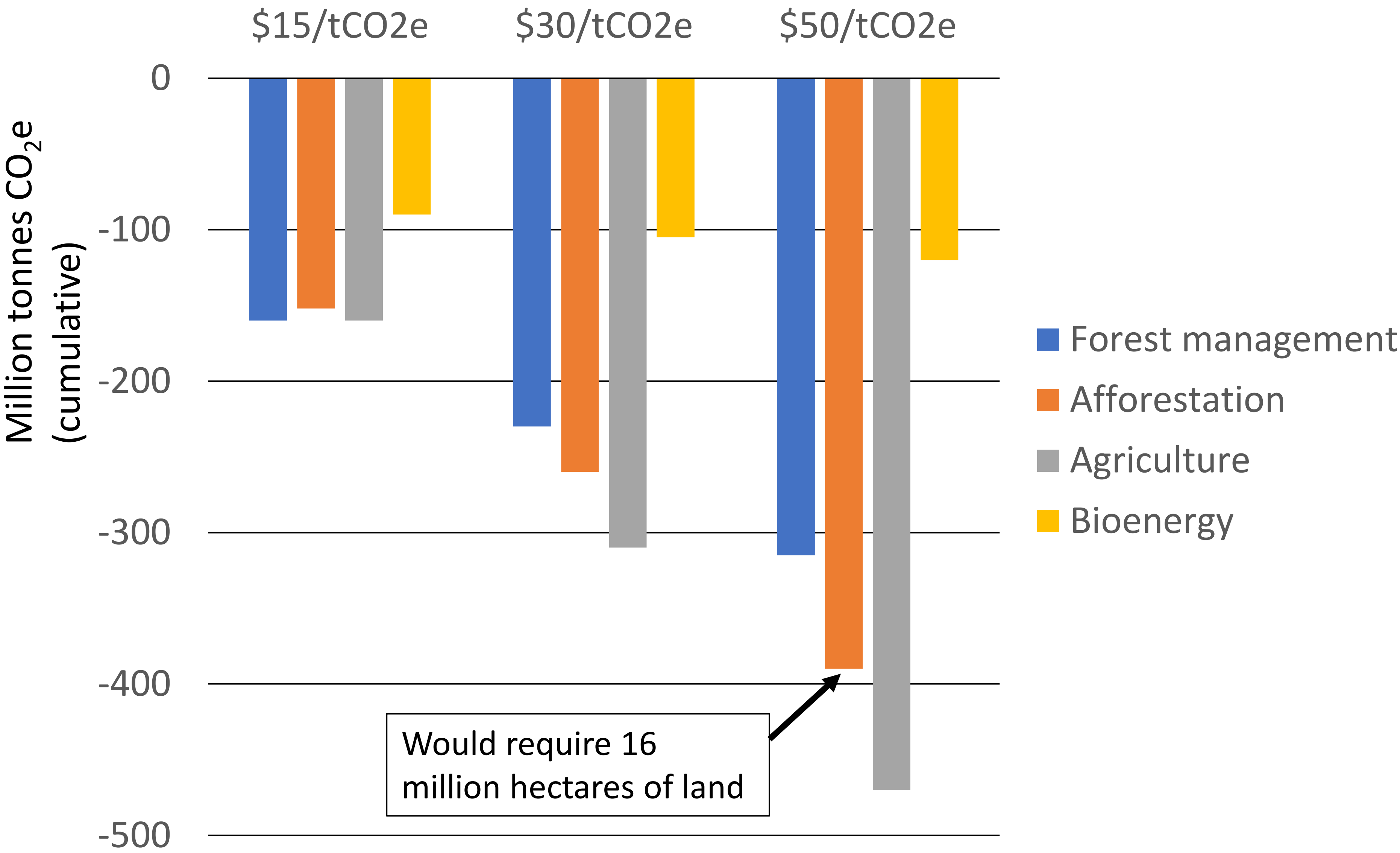
More advanced technologies needed to get 10 more

Barriers to scaling up to 10 $GtCO_2$/y or more

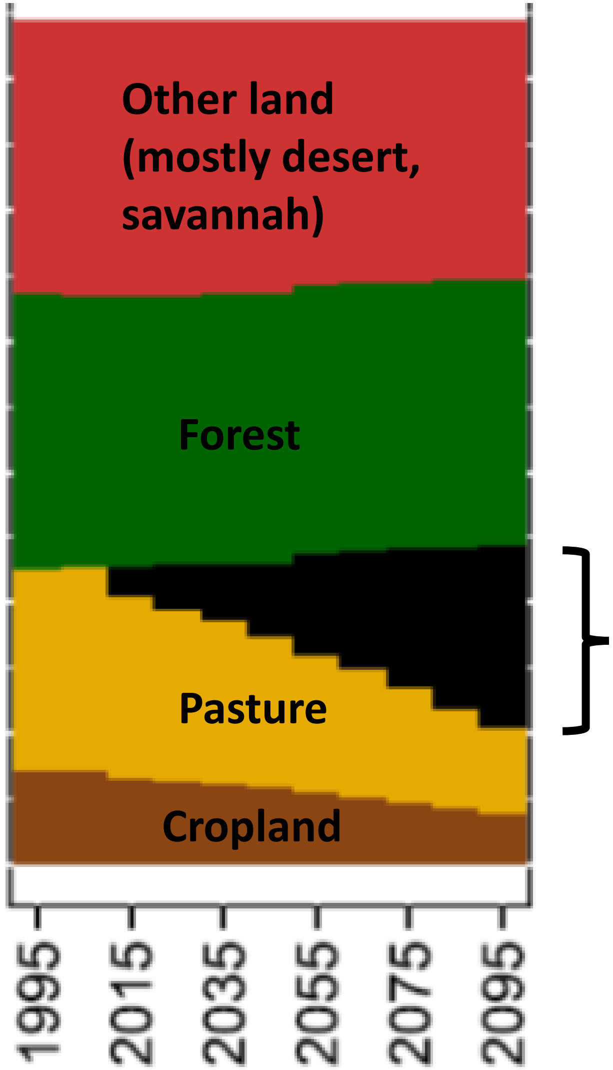
- Land constraint – global need for food
- Other environmental constraints – water availability, impacts on biodiversity
- High cost for some technologies
- Low adoption rates for changes in agricultural and forestry practices
- Permanence -- terrestrial and coastal blue carbon options are reversible
- Monitoring and verification – improvements needed, and concerns about “leakage”
- Governance – overly lax oversight
- Insufficient scientific/technical understanding

Mitigation potential of land-based CDR technologies in the United States for three carbon price scenarios.

Negative number indicates removal of CO_2 from the atmosphere.



Impact of large-scale afforestation on land use is potentially very large

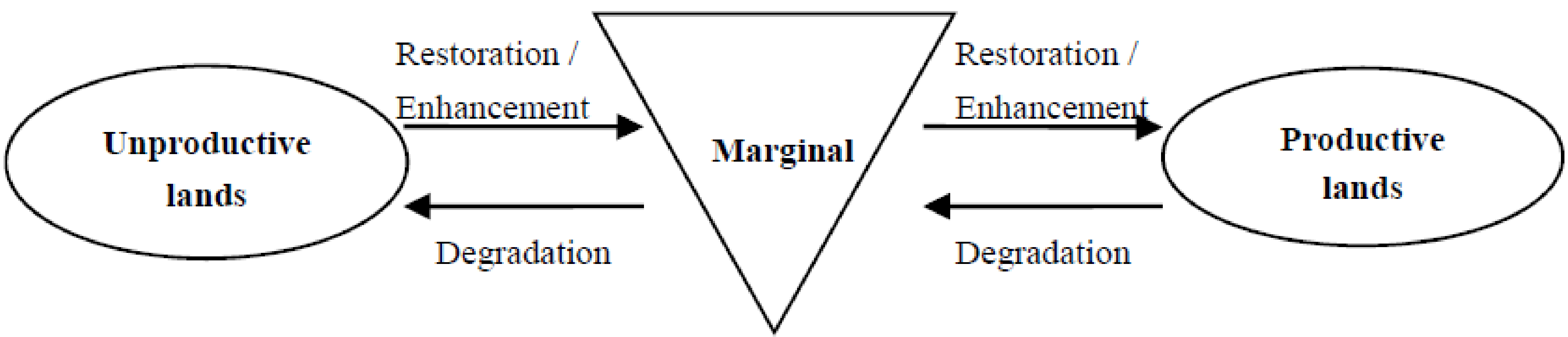


Increasing the area of forest land would have to be at the expense of land used for food production

From Humpenoder et al. 2014

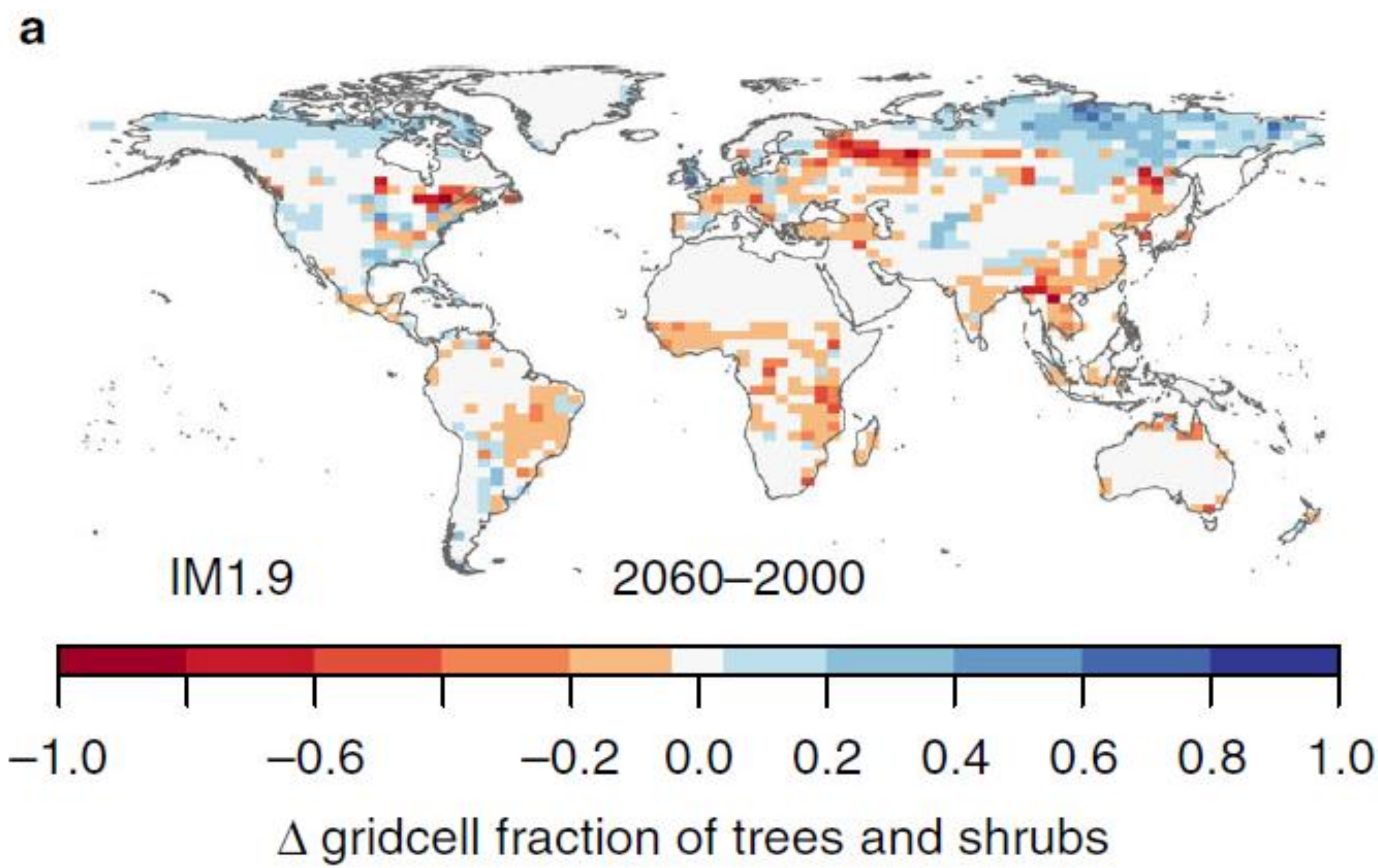
“Marginal land” is poorly defined and transitional

- The global pool of marginal land is about 1300 Mha
- This land supports about one-third of the world’s population
- Only a fraction of this total amount would be available for afforestation/reforestation and BECCS



Kang et al. 2013

Prospective loss of tree cover through 2060 from widespread deployment of BECCS



Harper et al. (2018)

Widespread deployment of BECCS needs dedicated energy crops

Productivity of selected bioenergy crops (t/ha)

Crop type/species	Southeast U.S.
Perennial grasses	7.8-21.3
Switchgrass	10.5-20.8
Miscanthus	13.0-19.3
Willow	8.5-16.8
Poplar	9.0-14.8
Other woody crops	11.2-12.3

↑ Increasing productivity and ability to develop genetic improvements

DOE 2011, 2016

Research Needs to Support Policies for Increasing CO_2 Removal by Land

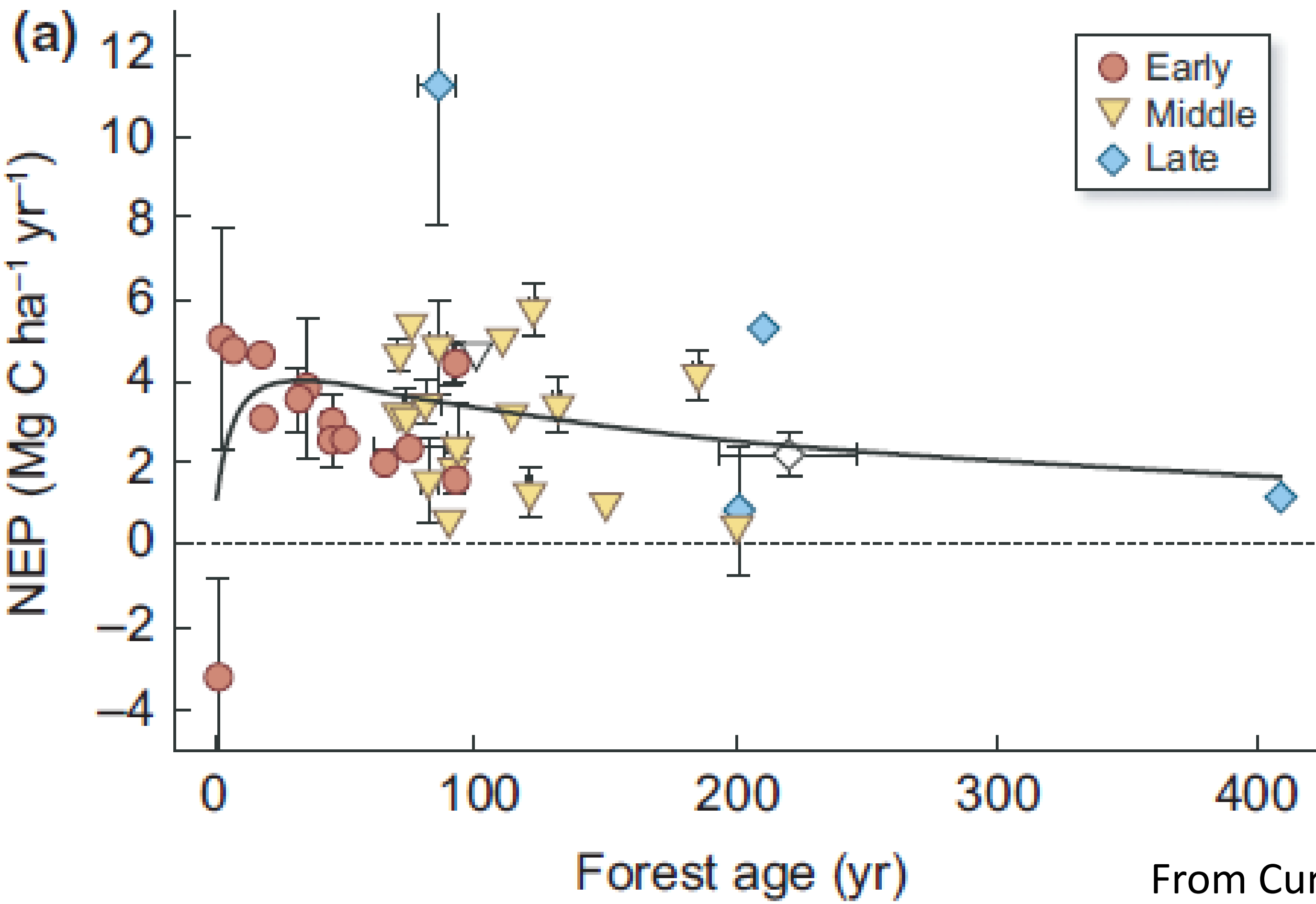
- Studies to understand ecosystem responses (particularly soils) to different factors and their interactions
- How to achieve full participation by landowners, reduce barriers to deployment
- Approaches to reduce impacts on biodiversity, water, and other land values
- Understand induced impacts such as changes in timber markets
- Monitoring, accounting:
  - ➢ Inconsistent approaches among countries
  - ➢ Soil C still a problem
  - ➢ What is the lowest cost, minimum acceptable need/approach?
- Demonstration projects

“Frontier” technologies for CO_2 removal by land

- Increasing preservation of harvested wood (0.2 to 0.8 GT CO_2/y)
  - Ensure that discarded wood products end up in landfills
  - Landfill designs for achieving the lowest possible rate of wood decomposition
- Increase wood harvest from secondary forests, coupled with increased preservation of harvested wood (0.8 to 9.3 Gt CO_2/yr)
- Cropland and Grassland Practices (1.0 to 3.0 Gt CO_2/yr)
  - Biochar Amendment
  - Deep Soil Inversion
  - High carbon input crop phenotypes

Old forests and carbon

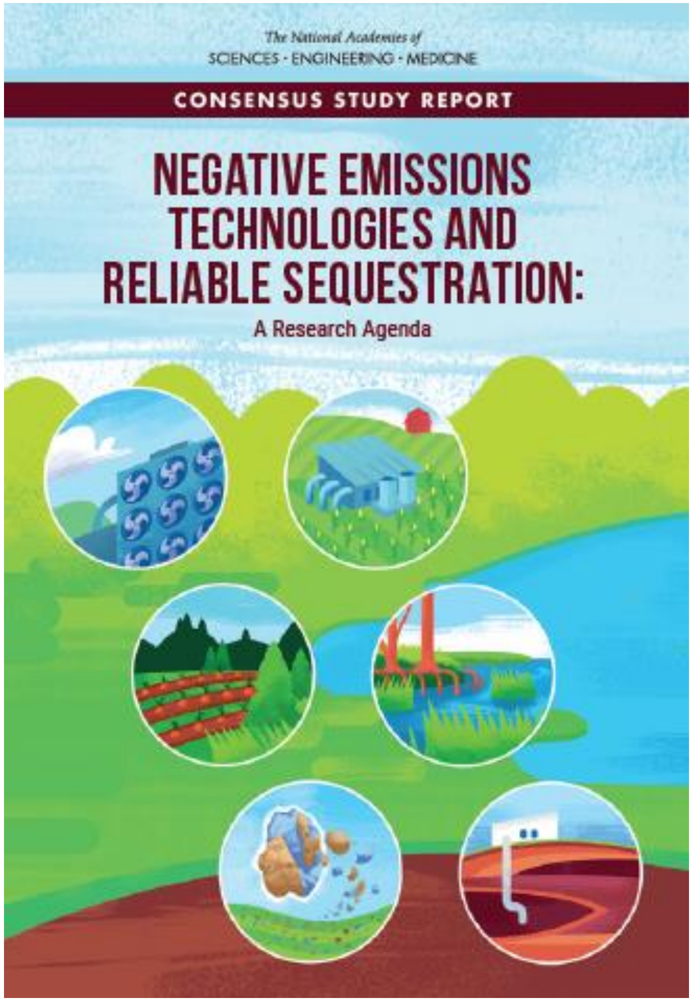
Based on a survey of published net ecosystem production (NEP) data for temperate deciduous forests, there is no evidence for a steep decline in NEP during mid-succession.



From Curtis and Gough 2018

Concluding Remarks – NAS study

- "Negative emissions" are necessary to help limit warming to 2^{o} C or less
- Realistic global capacity to remove atmospheric CO_2 with current technology is about 10 $PgCO_2$ per year, of which half is in forests and agriculture sectors, and half in BECCS
- Additional research and monitoring are needed to achieve or increase this potential
- Direct air capture and other advanced technologies are needed to reach 20 $PgCO_2$ per year of negative emissions



Thank you!!!

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- Email: rbirdsey@whrc.org
- Web site: http://whrc.org/about-whrc/who-we-are/scientific-staff/
- Link to SOCCR-2 report: https://www.carboncyclescience.us/state-carbon-cycle-report-soccr
- Link to NAS study: https://www.nap.edu/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda