Assessing the Global Technical Potential for C Sequestration by Biomass Carbonization

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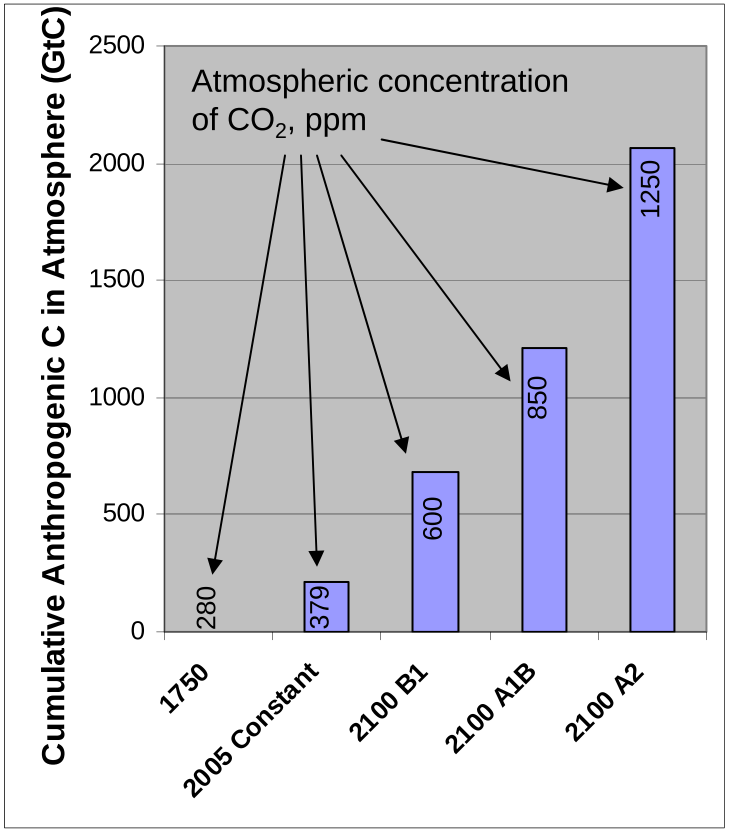
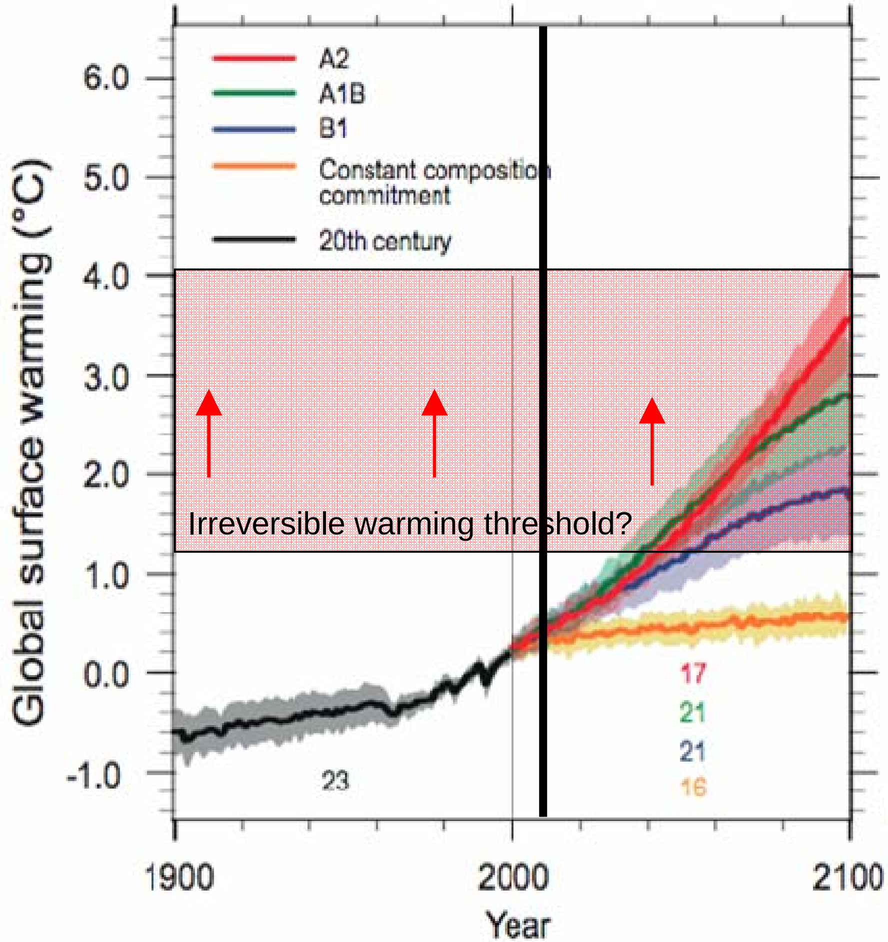
Outline

- Motivation and Overview of Terrestrial Options
- Biomass Carbonization
  - Concept
  - Feasibility
  - Scenarios
- Summary

Projected Atmospheric Carbon Levels and Associated Global Warming

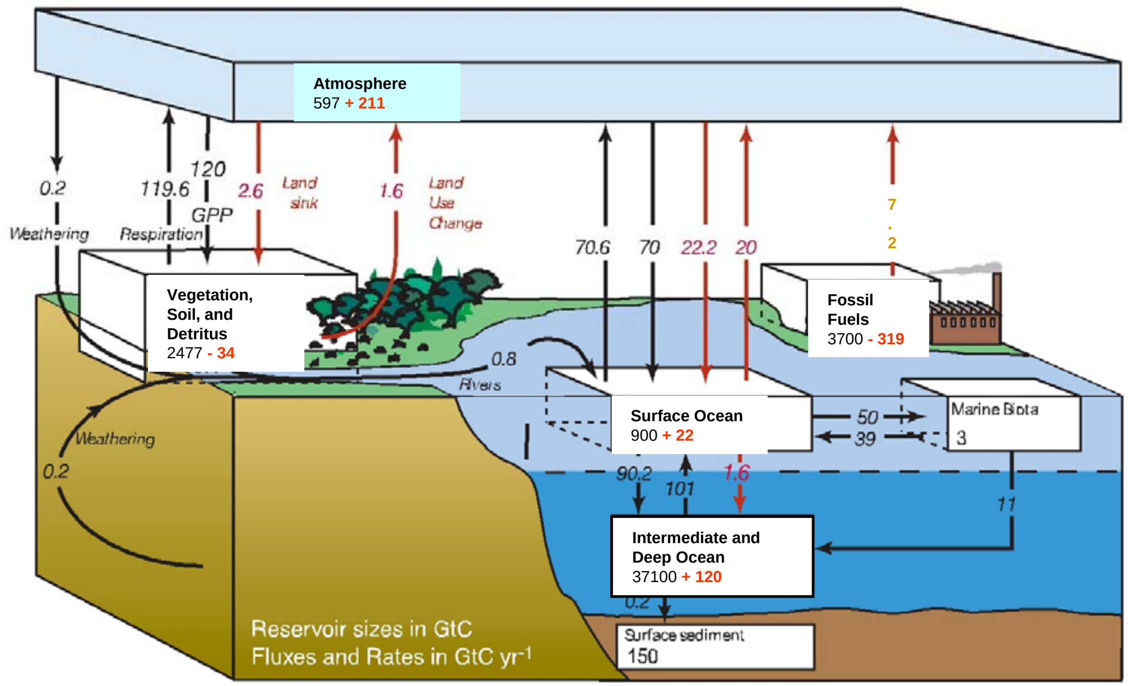




IPCC (2007) WG1-AR4, SPM, p. 14, modified to show zone where irreversible warming of Greenland ice sheet is projected to occur (ibid., p. 17)

Terrestrial Sequestration Options

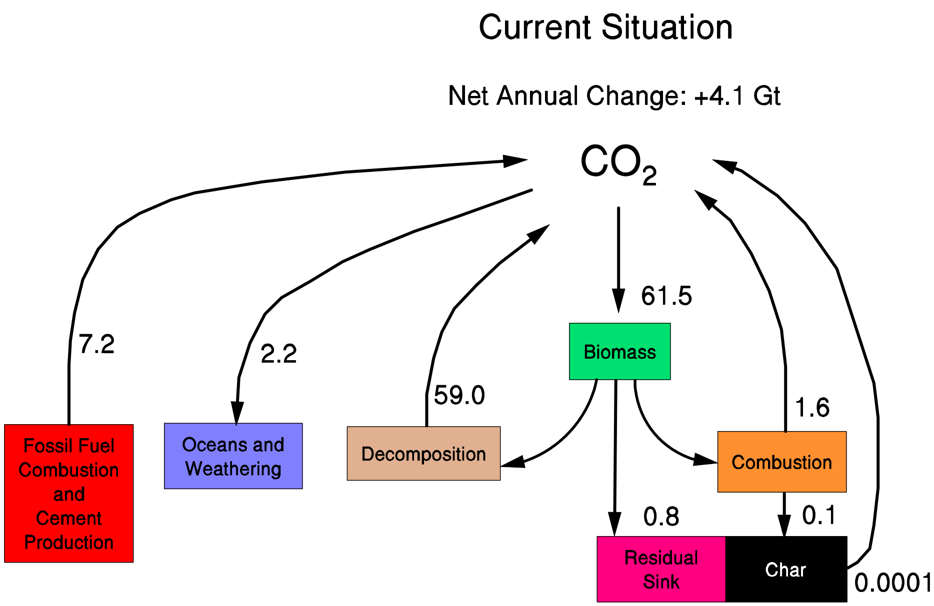
- Standing biomass (trees, crops)
  - Currently 466 Gt C
  - Near saturation
- Soil carbon
  - Currently 2011 Gt C
  - Near saturation
- Problems:
  - C Accounting
  - C Permanence
  - Only 50-100 Gt of Added Capacity Using Natural Processes

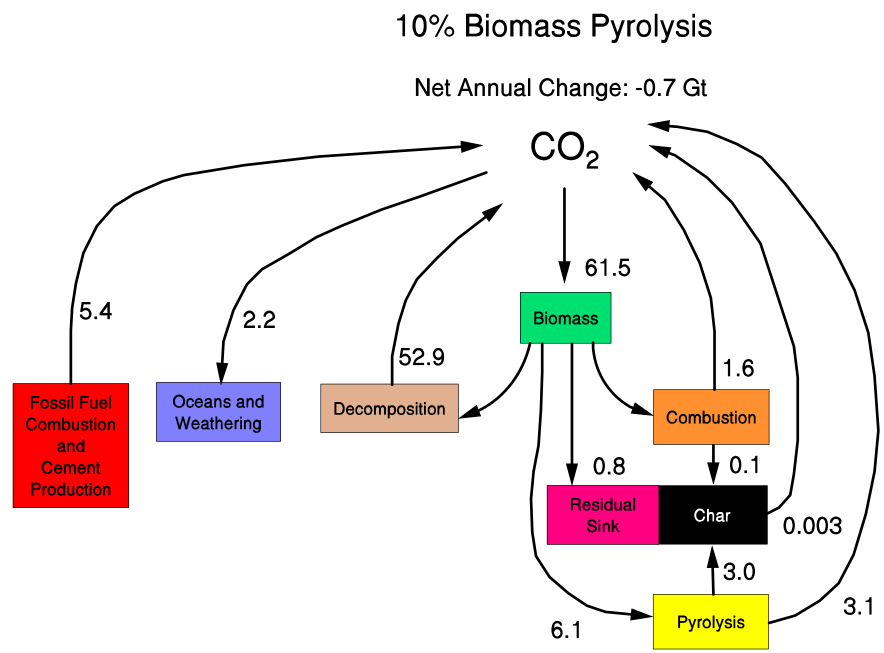


Pre-industrial values (1750)
Anthropogenic changes (2005)

Adapted from IPCC AR4 WGI with updated inventory and flux data

Biomass Carbonization Concept





Factors to Consider

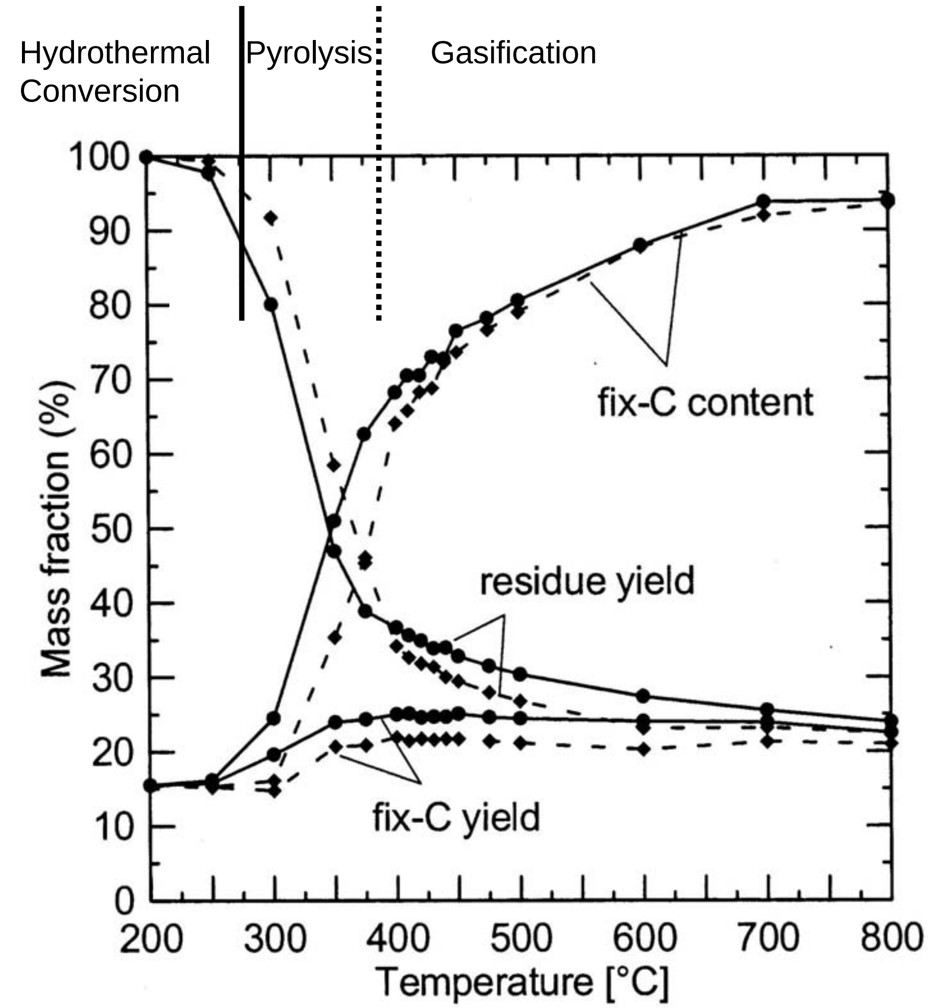
- Maximum sustainable biomass production (GtC y^{-1})
- Biomass conversion efficiency (fraction of C into char vs. used for energy and back to CO_2)
- Char storage capacity (GtC)
- Characteristic storage time (y)
- Adoption period (y)
- Carbon capture and storage efficiency (fraction of C used for energy that is recovered and sequestered)

Sustainable Biomass Production Capacity

- IPCC AR4 WG3 Ch. 4 (2007) estimates sustainable global biomass production for energy use at 250 EJ/yr
- Assuming 80% efficiency and 40 GJ/t biomass C get 7.9 Gt C/yr as global potential biomass
- Net primary production (i.e., net photosynthesis) is 61.5 Gt C/yr
- Implies global sustainable biomass capacity is about 13% of annual photosynthesis
- We will use 10% of annual photosynthesis in our scenarios

Biomass Conversion Efficiency

- Fast Pyrolysis and Gasification
- Slow Pyrolysis
- Hydrothermal Conversion



Adapted from Antal and Gronli, 2003 Ind. Eng. Chem. Res. 42:1619

Comparison of Carbonization Methods

Carbonization Method	Products	Net Energy Released, GJ/t C	Fossil C (Coal) Offset Efficiency	Solid C Production Efficiency
Fast Pyrolysis	CH_4, CO_2, Bio-Oils, H_2O, Char	22.0	0.65	0.15
Slow Pyrolysis	Char, tars, CH_4, CO_2, H_2O	17.7	0.53	0.5
Hydrothermal Conversion	“lignite”, H_2O	5.5	0.16	1.0

Land Capacity for Char Storage

- Assumptions:
  - 70.8 Mkm^2 land usable of 130.6 Mkm^2 total (data from Eswaran et al. 1999. Am.J.Altern.Agric. 14:129; see also USDA/NRCS website)
  - Bulk density of 1.3 t/m^3
  - 1 to 5% C added to top 15-50 cm of soil

	Incorporation Depth		
Amount of char C added	15 cm	30 cm	50 cm
	--------------------	Gt C	----------------
1 wt%	140	280	470
2.5 wt%	350	700	1200
5 wt%	700	1400	2300

Characteristic Storage Time ($t_{1/2}$)

- Function of:
  - Char process (highest heat treatment temperature, . . .)
  - Soil conditions (T, p_{O2}, H_2O, . . .)
- Some estimates of $t_{1/2}$:
  - Soil “organic” matter (5-20 yr)
  - Pyrolytic biochar [60-900 yr as f(T), Lehmann et al., 2008]
  - Hydrothermally converted carbon (40-500 yr?, Antonietti)
  - Bituminous coal (abiotic oxidation, 130 yr, calc. from Chang and Berner, 1998, 1999)
- Assume pseudo-first-order decay to simplify estimate

Adoption Period and CCS Efficiency

- All estimates will assume
  - 30 year adoption period
  - Either 0% or 90% C capture and storage efficiency for pyrolysis processes

100-Year Scenarios

	Constant		Varied
Biomass Carbonization Adoption Period, yr	30	Fraction of Biomass C Carbonized	1
Maximum Biomass Carbonized, % of NPP	10	Fossil C Offset Efficiency (Coal)	0.16
Adoption Rate Factor	3.850	Char Half-Life, yr	510

Slow Pyrolysis Scenario—Annual Data

Biomass Carbonization Adoption Period, yr	30	Fraction of Biomass C Carbonized	0.50
Maximum Biomass Carbonized, % of NPP	10	Fossil C Offset Efficiency (Coal)	0.53
Adoption Rate Factor	3.850	Char Half-Life, yr	80

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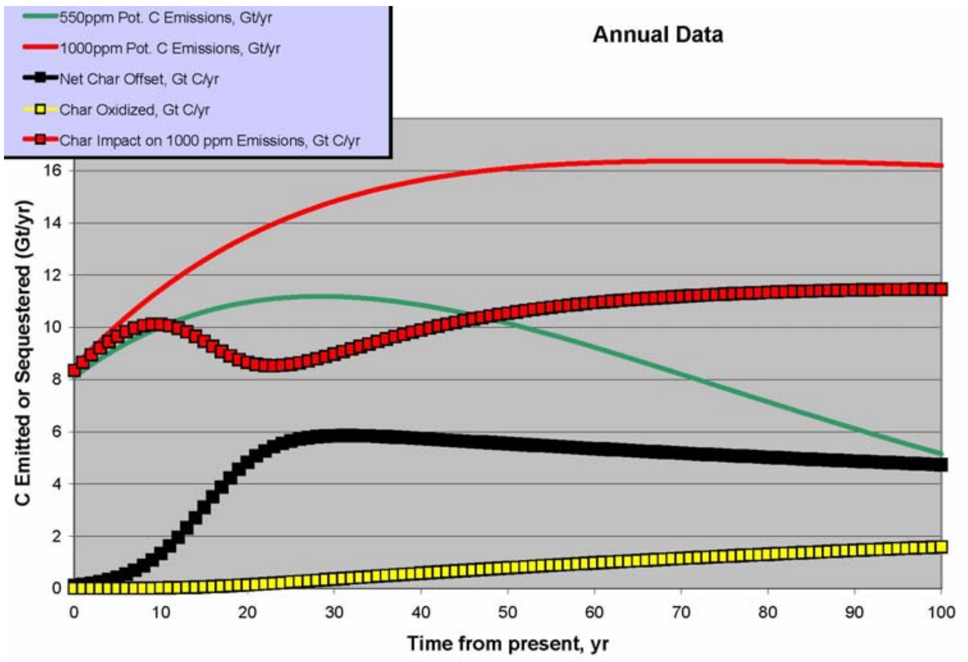

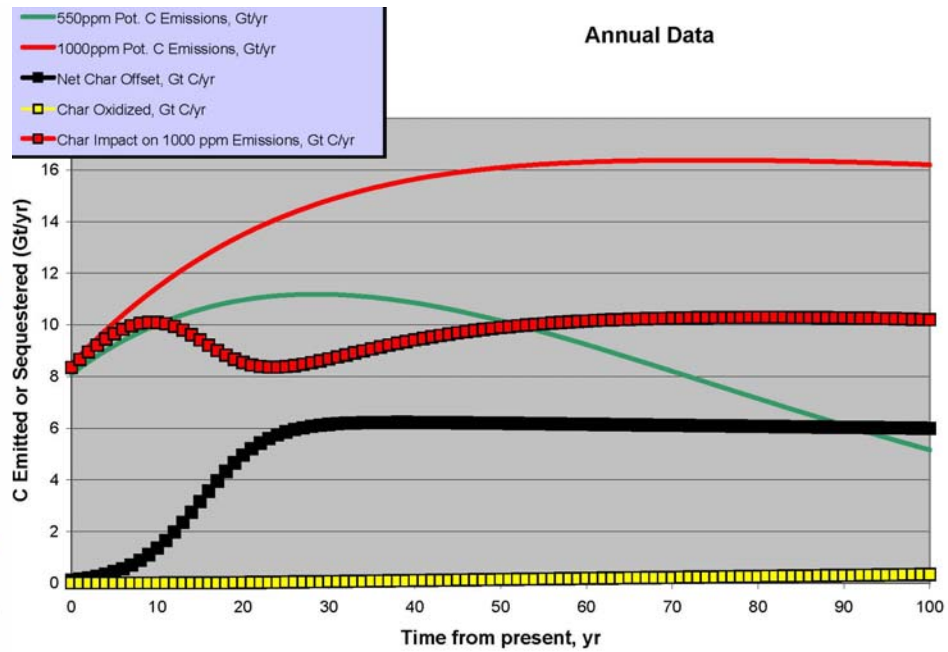

Slow Pyrolysis Scenario—Cumulative Data

Biomass Carbonization Adoption Period, yr	30	Fraction of Biomass C Carbonized	0.50
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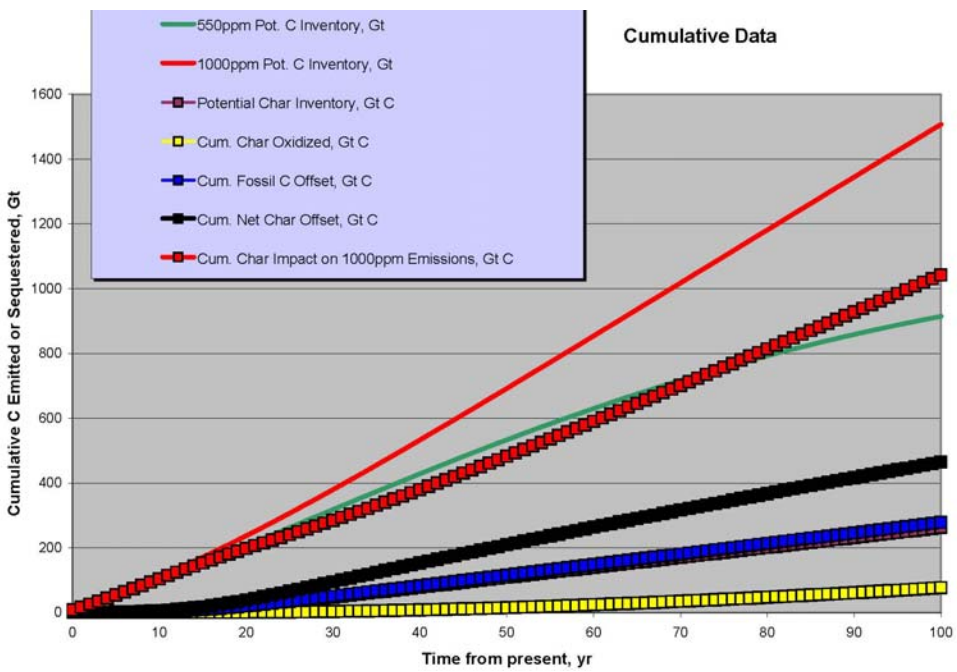
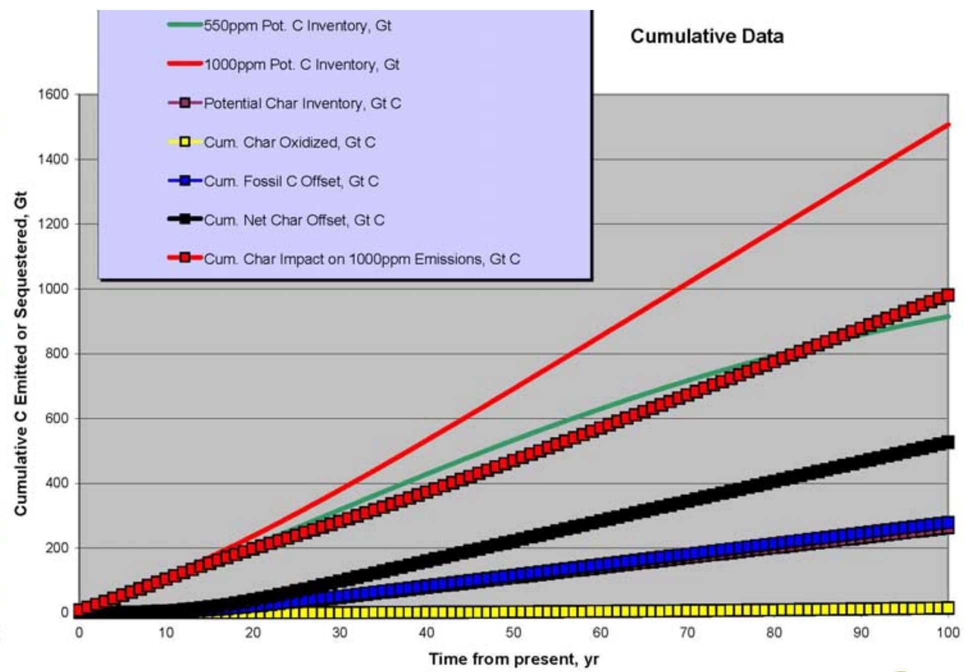
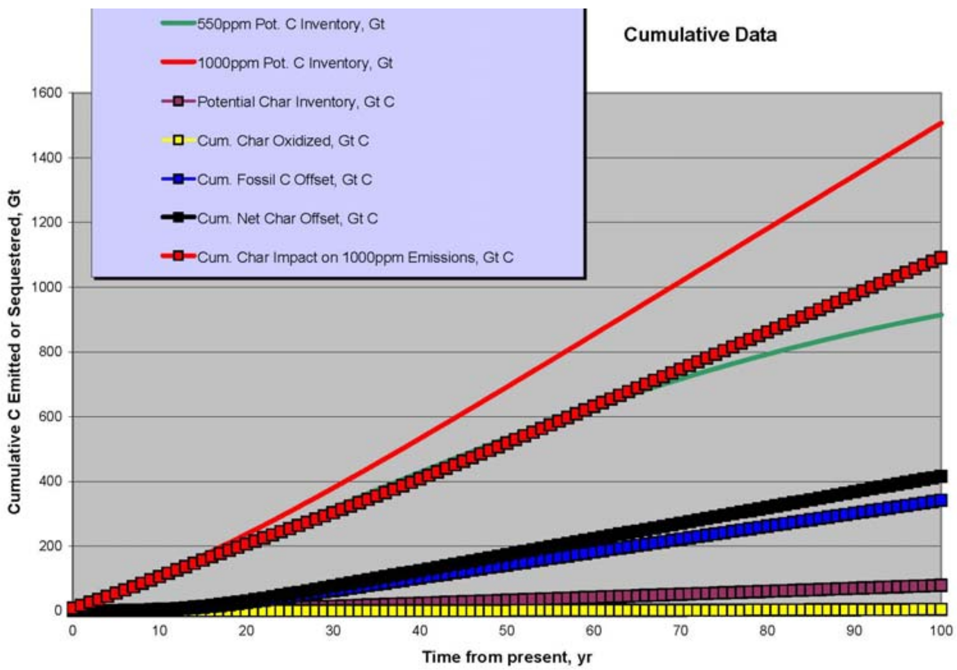




Cumulative Data Scenarios

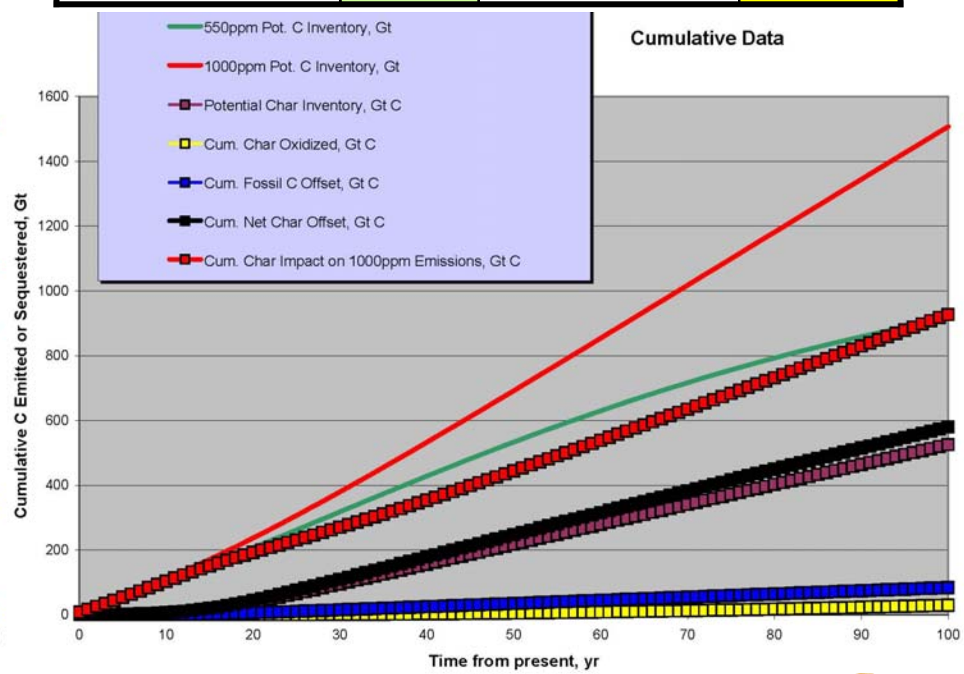
Fast Pyrolysis

Biomass Carbonization Adoption Period, yr	30	Fraction of Biomass C Carbonized	0.15
Maximum Biomass Carbonized, % of NPP	10	Fossil C Offset Efficiency (Coal)	0.65
Adoption Rate Factor	3.850	Char Half-Life, yr	500

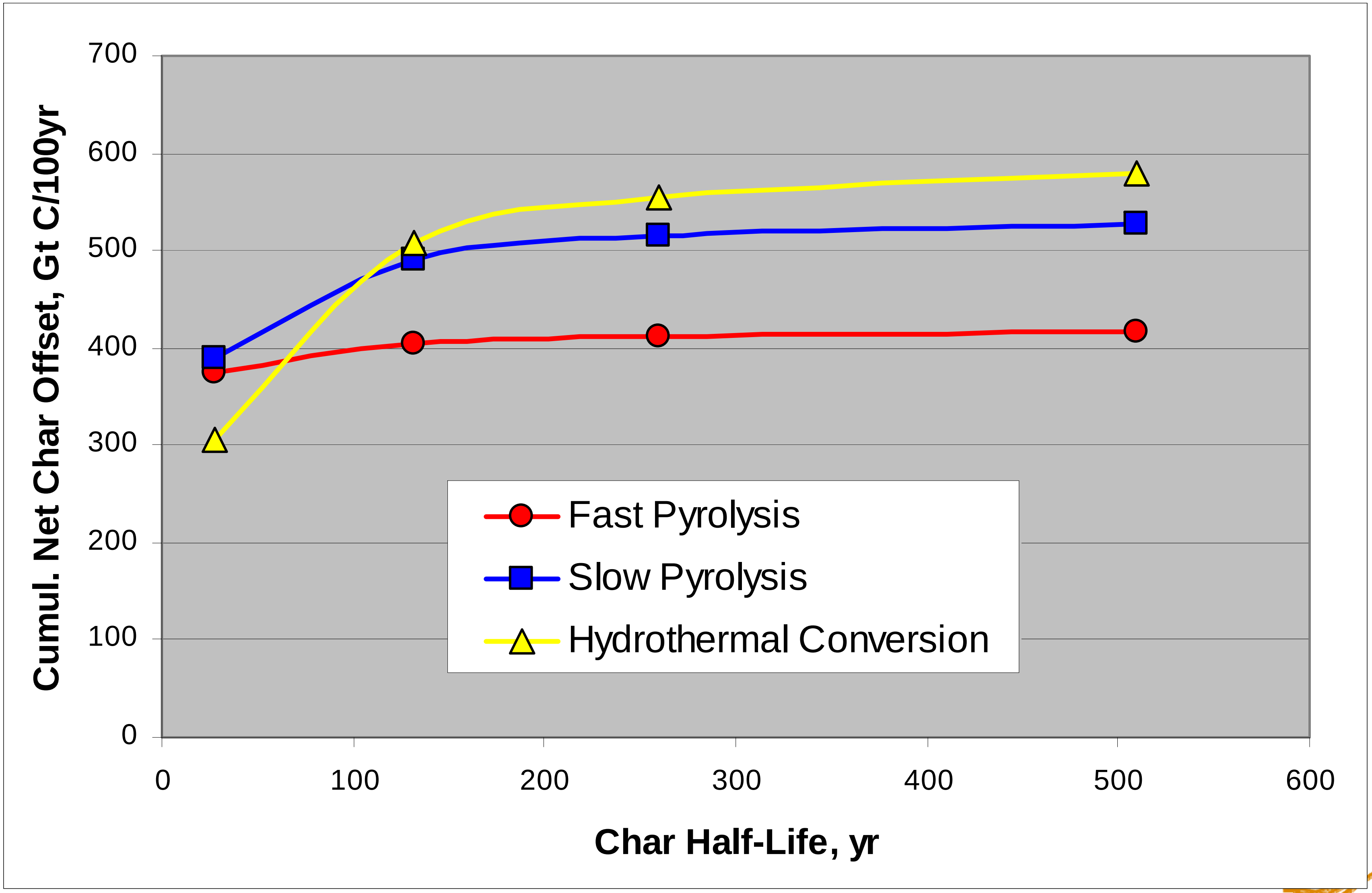


Hydrothermal Conversion

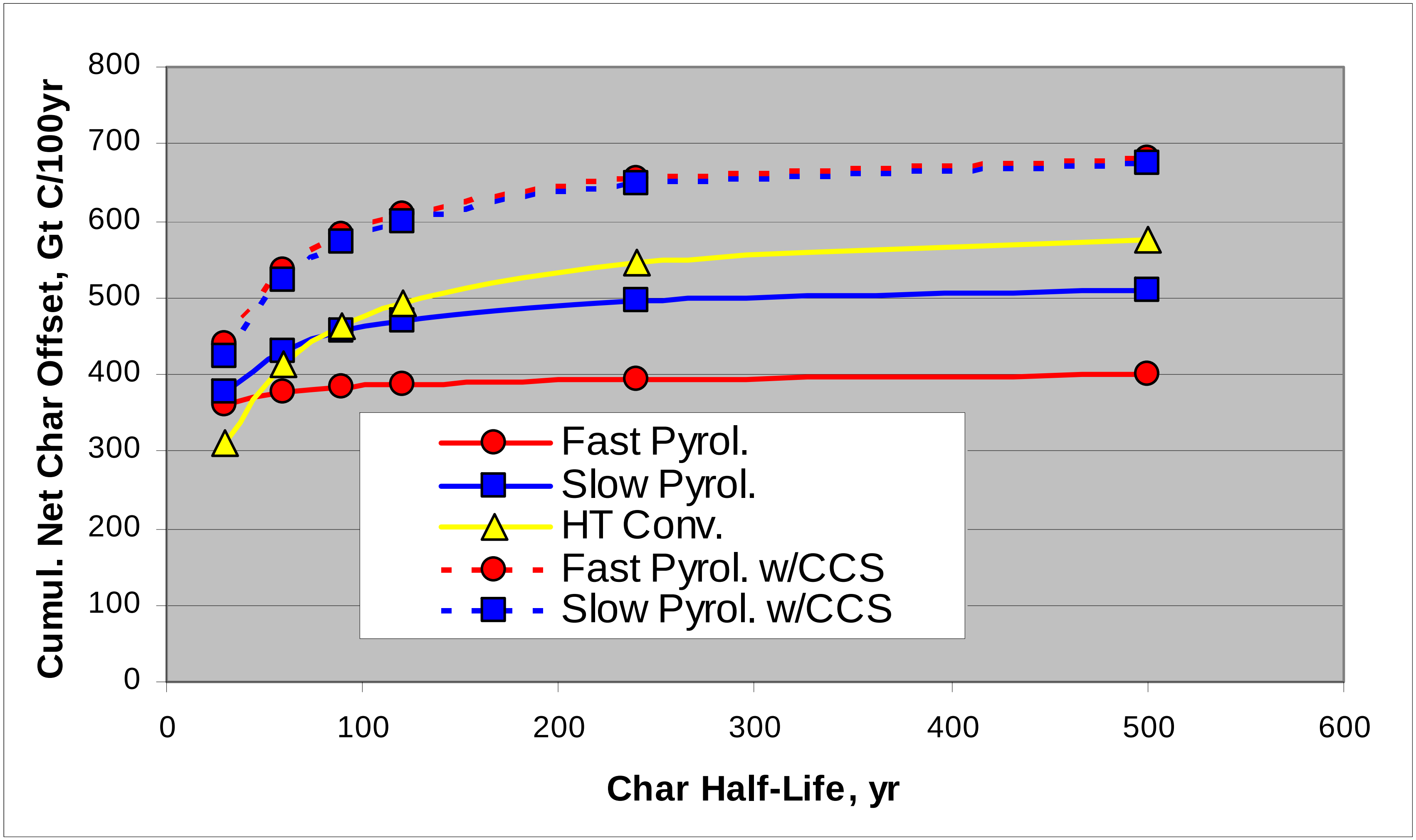
Biomass Carbonization Adoption Period, yr	30	Fraction of Biomass C Carbonized	1.00
Maximum Biomass Carbonized, % of NPP	10	Fossil C Offset Efficiency (Coal)	0.16
Adoption Rate Factor	3.850	Char Half-Life, yr	500



Net 100-yr Biomass Carbonization Impact



Impact of Carbon Capture and Storage



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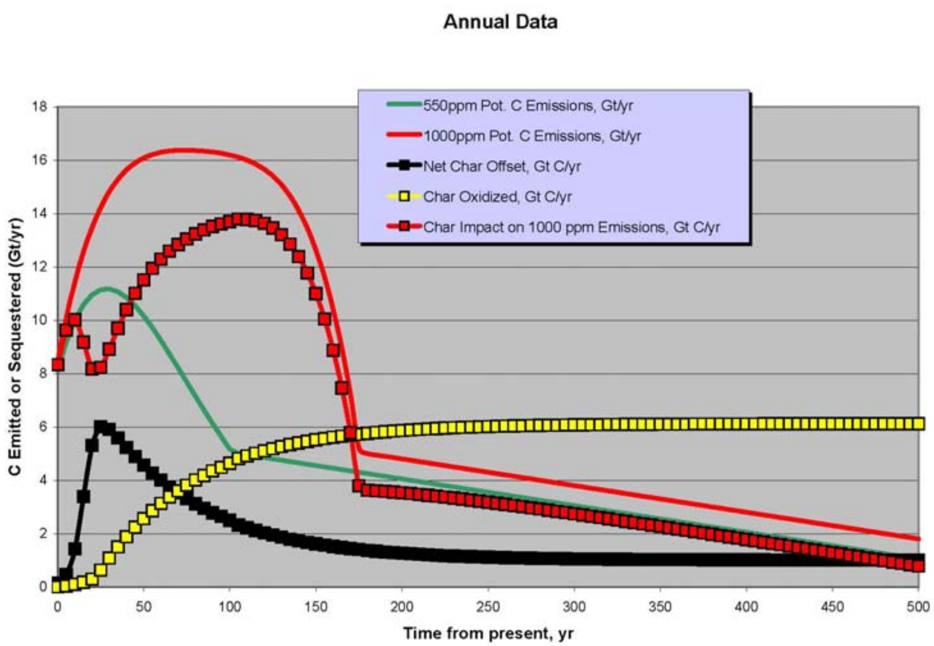
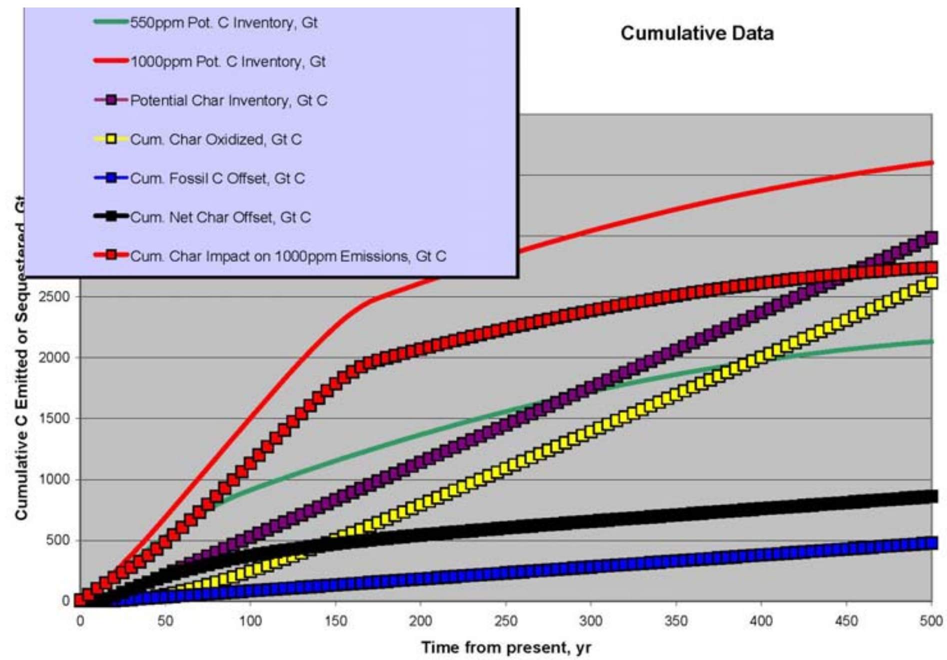
Worst Case Scenario—500 years

Hydrothermal Conversion, 40-yr $t_{1/2}$

Biomass Carbonization Adoption Period, yr	30	Fraction of Biomass C Carbonized	1.00
Maximum Biomass Carbonized, % of NPP	10	Fossil C Offset Efficiency (Coal)	0.16
Adoption Rate Factor	3.850	Char Half-Life, yr	40





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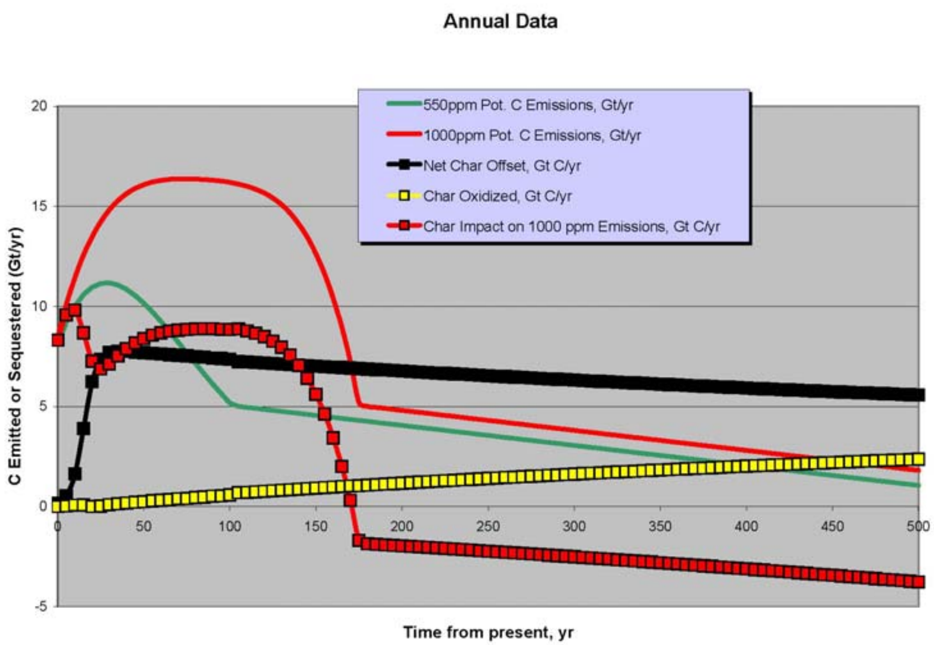
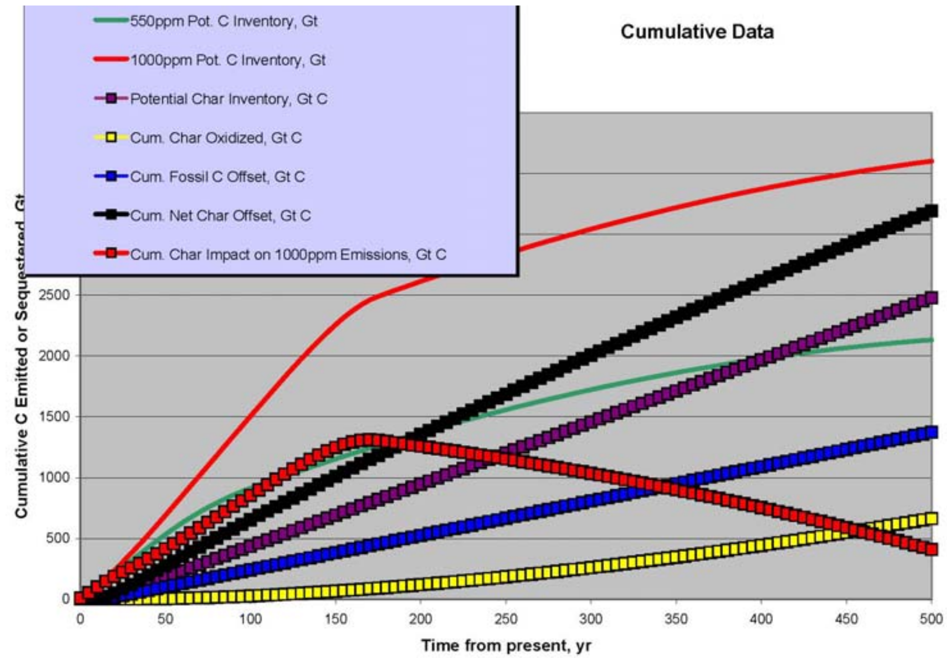
Best Case Scenario—500 years

Fast Pyrolysis w/CCS, 500-yr $t_{1/2}$

Biomass Carbonization Adoption Period, yr	30	Fraction of Biomass C Carbonized/Sequestered	0.83
Maximum Biomass Carbonized, % of NPP	10	Fossil C Offset Efficiency (Coal)	0.46
Adoption Rate Factor	3.850	Char Half-Life, yr	500





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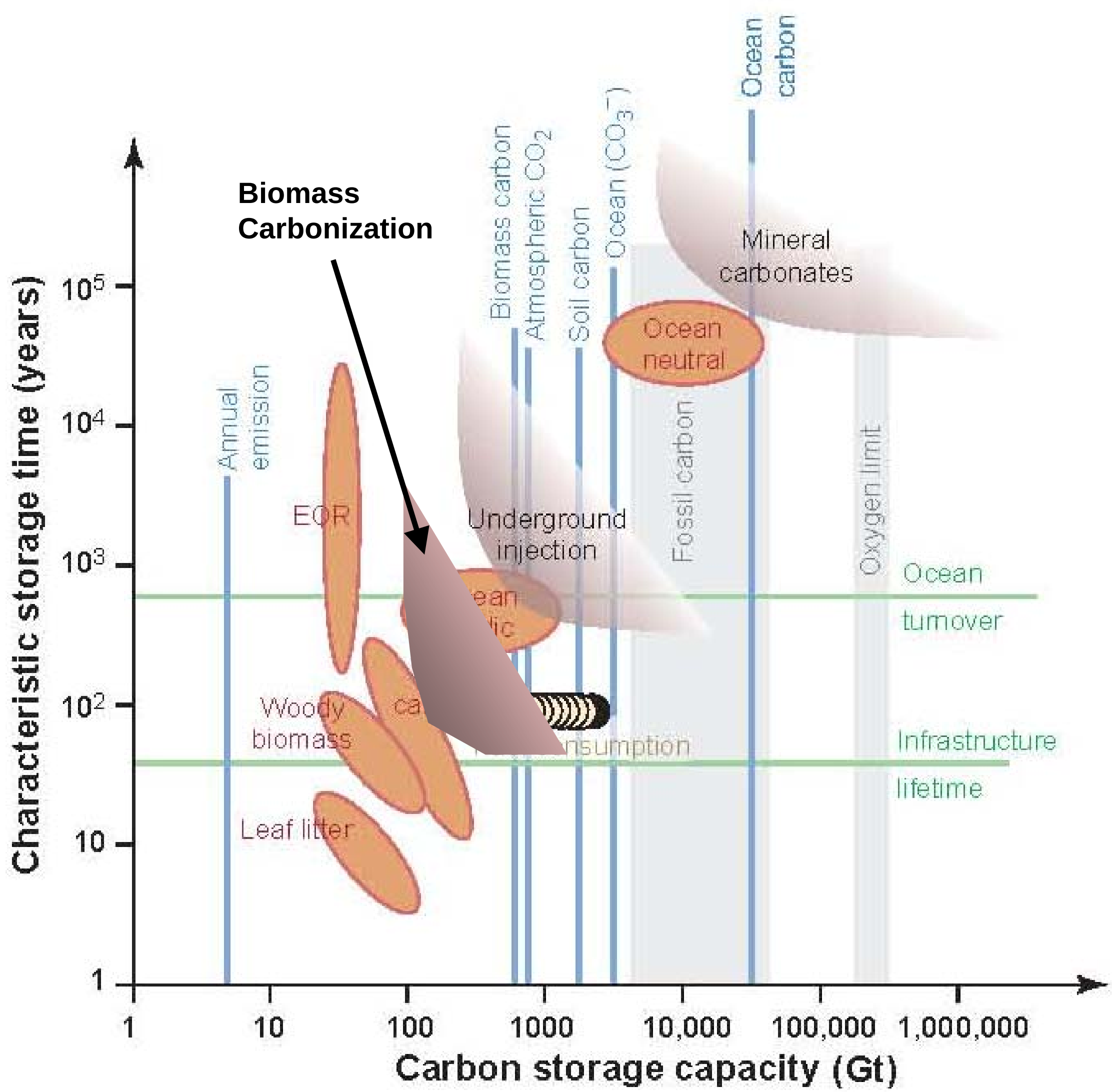
Revised C Sequestration Capacities and Longevity



(Modified) Lackner et al., 2003, Science 300:1677

Conclusions

- Biomass carbonization has large potential as a climate change mitigation option
- Estimated sequestration capacity of 300-580 Gt C over 100 years assuming land capacity is available
- Relatively simple technology, easily implemented globally in 10-30 years
- Research needs include
  - determine co-location of available land and biomass
  - add feedback of increased fertility
  - determine rate of oxidation in soils for various types of chars/lignites and different soil types
  - Impact on soil biota—possible treatment regimes prior to soil application
  - confirm initial reports of N_2O and CH_4 emission reductions
  - assess economic potential

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