Biochar and Bioenergy: What Can They Do to Help Mitigate Climate Change?

Jim Amonette

Pacific Northwest National Laboratory, Richland, WA

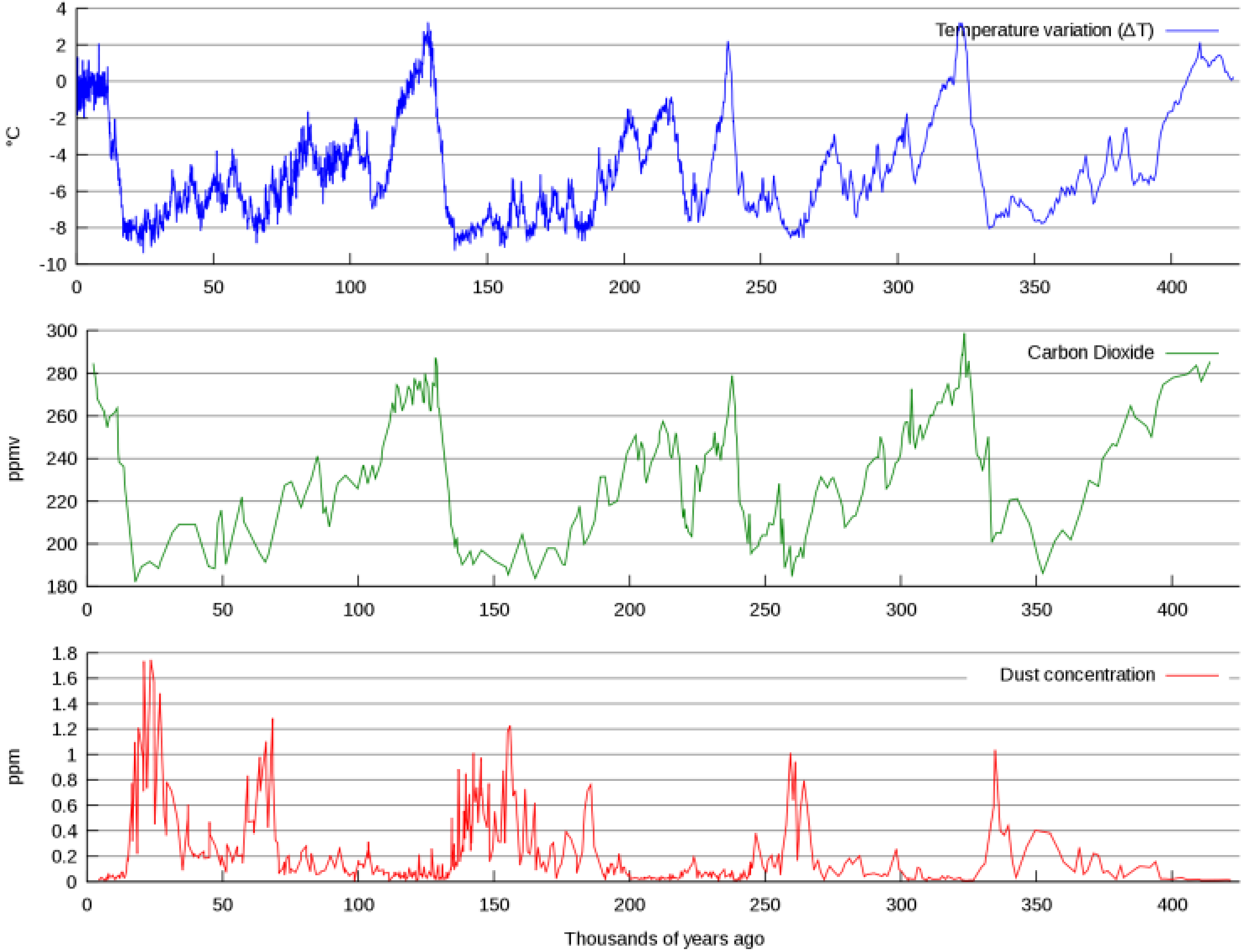
Washington State Bioenergy Research Symposium
Seattle, WA
08 November 2010

jim.amonette@pnl.gov

PNNL-SA-XXXXX

Pacific Northwest
NATIONAL LABORATORY

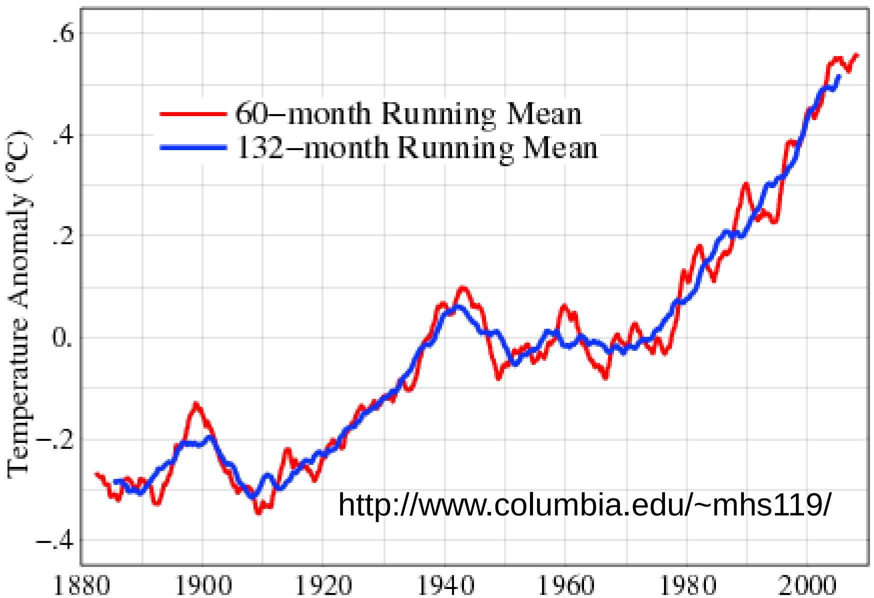
History

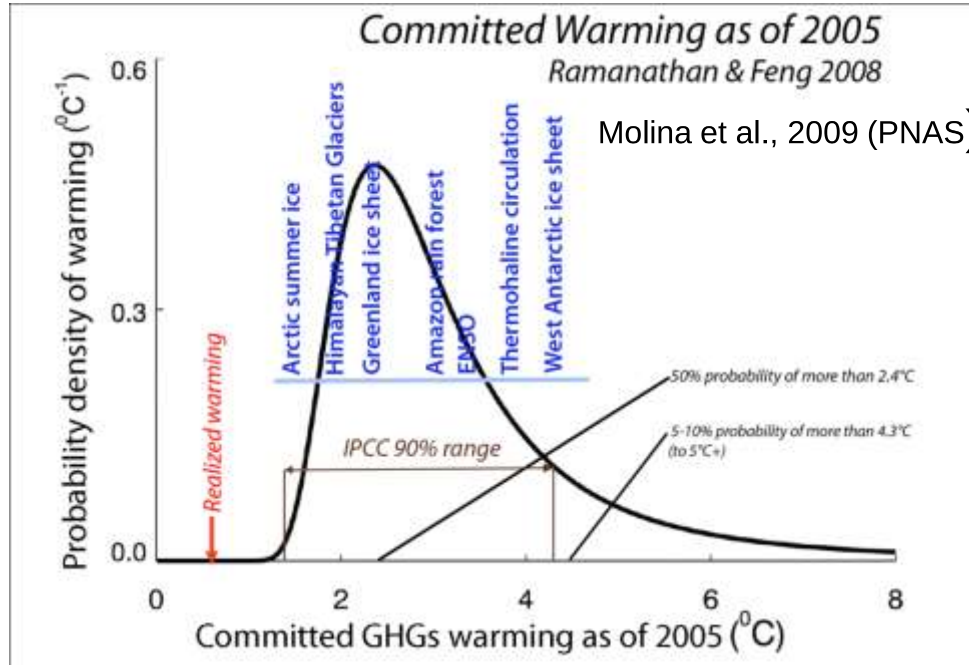


Vostok, Antarctica ice core data from Petit et al., 1999

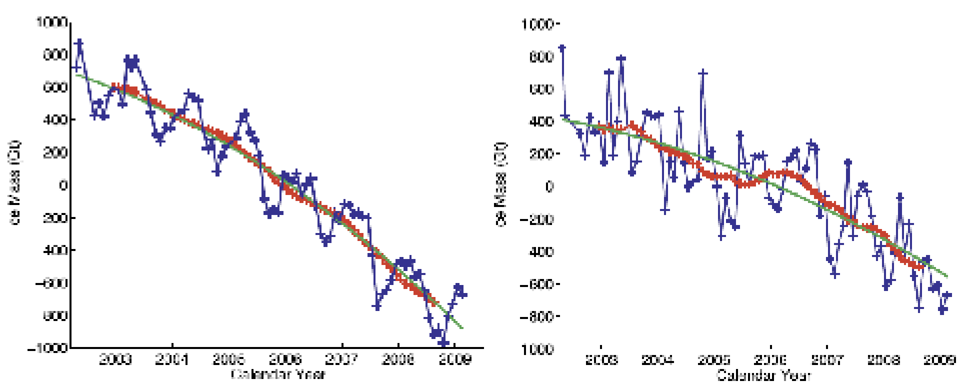
Why do we care?

Global Land–Ocean Temperature Index





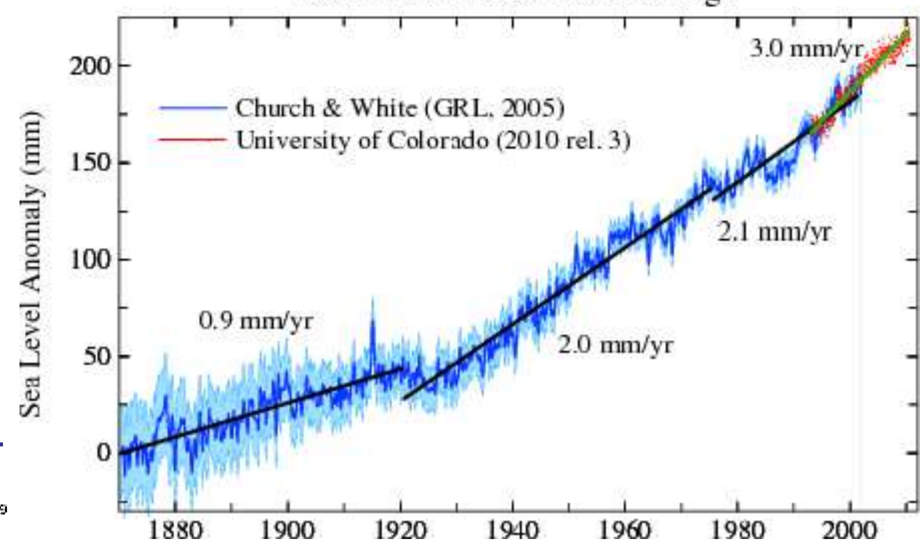
Gravity Satellite Ice Sheet Mass Measurements



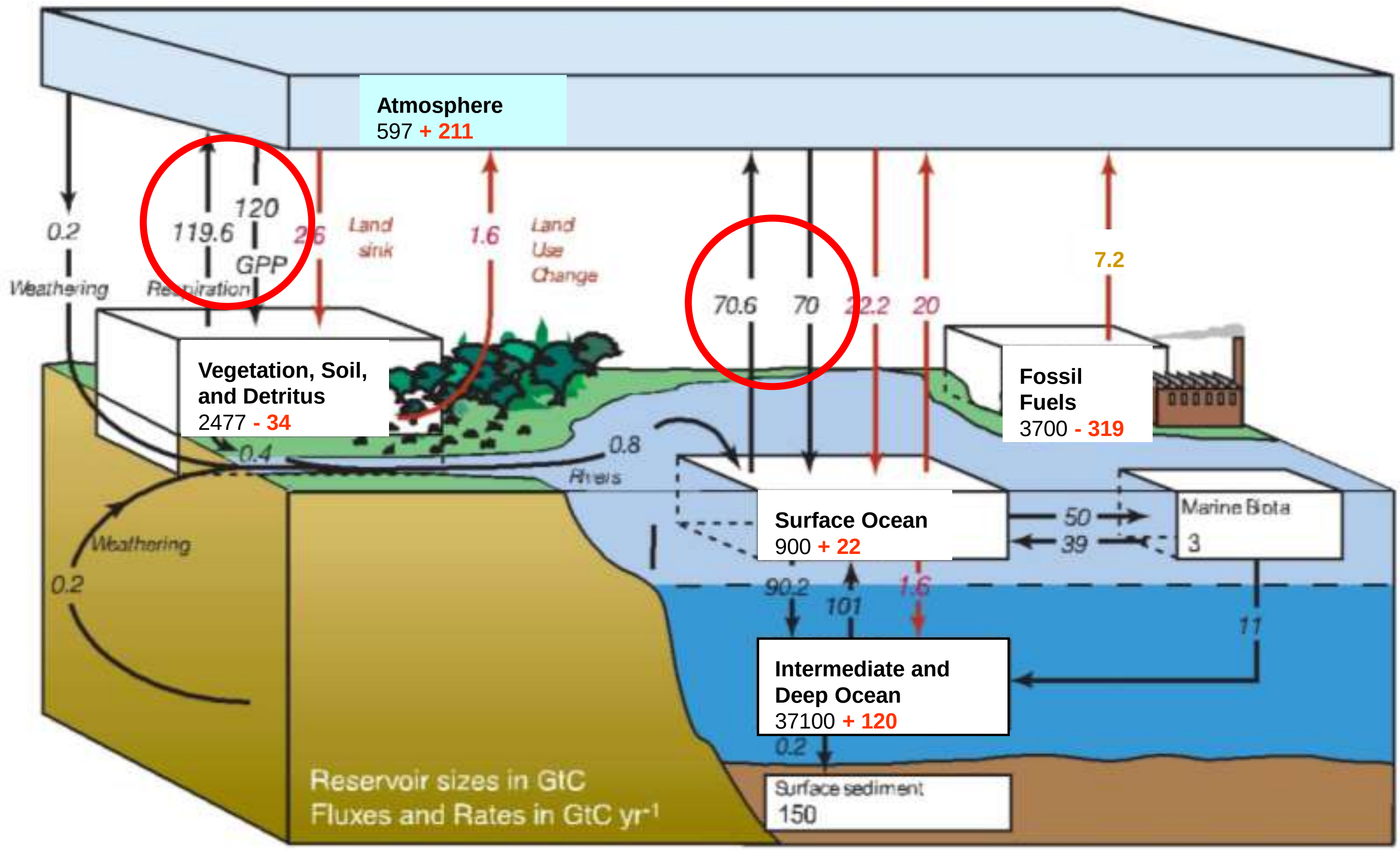
Greenland Ice Sheet

Antarctic Ice Sheet

Global Mean Sea Level Change



Solutions . . .



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

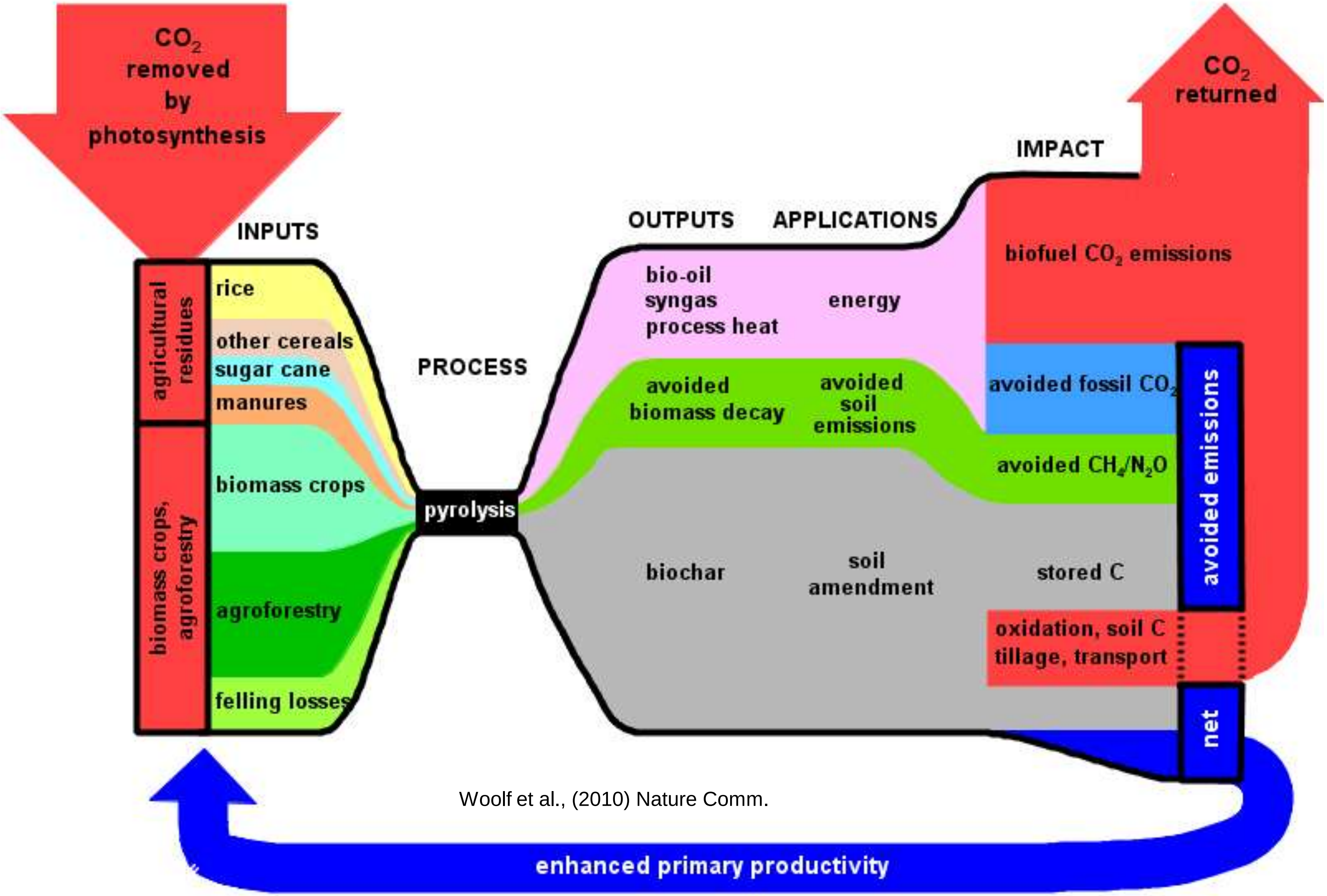
Adapted from IPCC AR4 WGI with updated inventory and flux data

How much can biomass management help?

- Key considerations include:
  - Sustainability of biomass source
  - Availability of biomass
  - Energy produced
  - Soil amendment rate
  - Impact on plant productivity
  - Impact on soil GHG emissions
- Developed a **global** model (BGRAM 1.0) to project forward 100 years assuming constant inputs
- Technical assessment only; economics of production not considered
- *Woolf, D, JE Amonette, FA Street-Perrott, J Lehmann, S Joseph (2010) "Sustainable biochar to mitigate global climate change" Nature Comms 1:56. Article is OPEN ACCESS online at www.nature.com/naturecommunications*

Pacific Northwest NATIONAL LABORATORY

Concept for Sustainable Biochar



Woolf et al., (2010) Nature Comm.

Sustainability Criteria

- Biomass primarily from agricultural/silvicultural residues
- Minimal C debt from land-use changes (10-yr maximum payback time, < 22 Mg CO_2-C_{eq} ha^{-1})
- No previously unmanaged lands converted for biochar production; abandoned croplands ok
- Modern pyrolysis technology used
  - eliminates soot, CH_4, and N_2O emissions
  - captures energy released as process heat, bio-oil, and flammable gases
  - slow pyrolysis assumed for this comparison

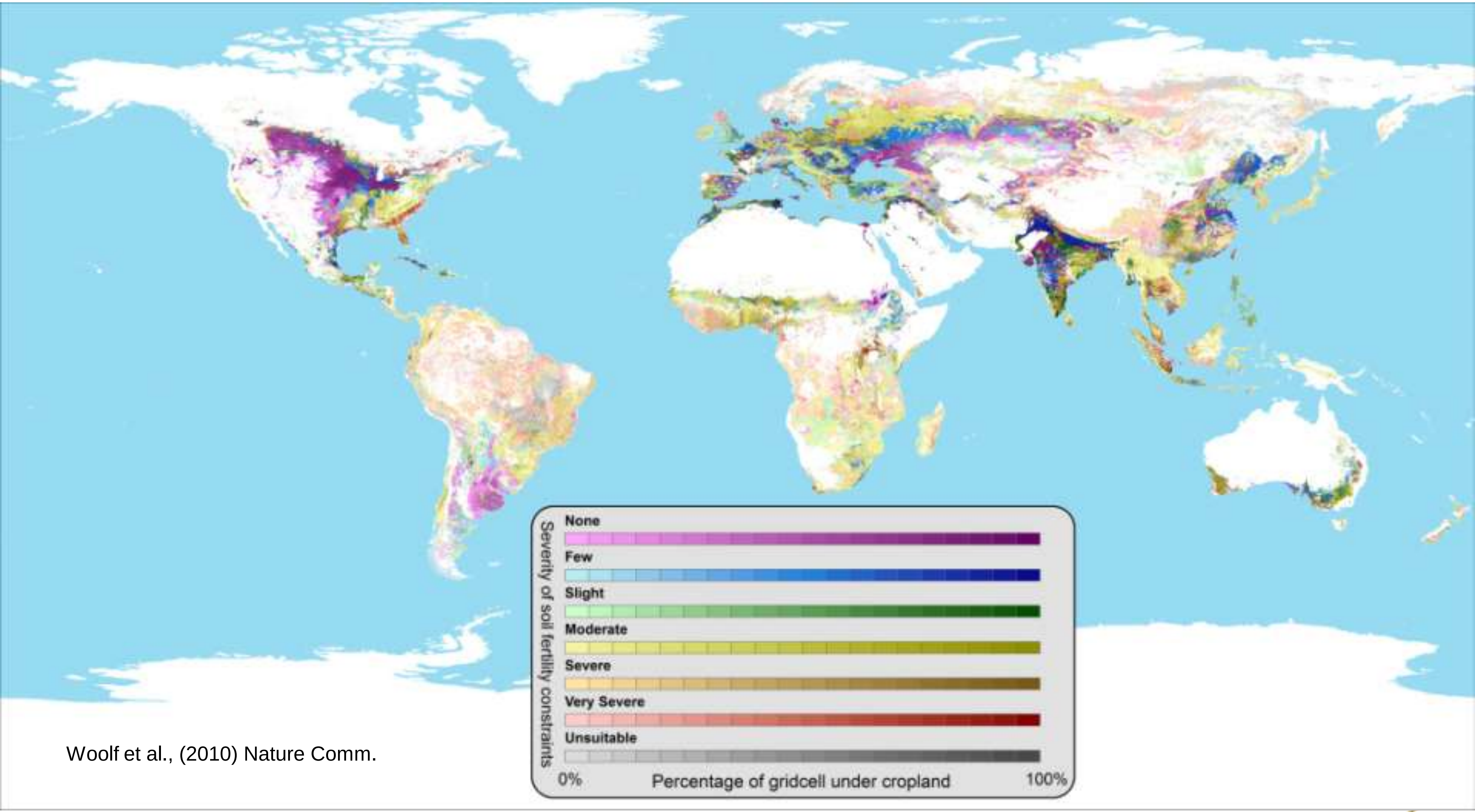
Biomass Availability Scenarios

- Alpha
  - Uses available biomass with little change to current practices
- Beta
  - Some legislation/incentives to promote sustainable land-use practices and reduced contamination of biomass streams
- Maximum Sustainable Technical Potential (MSTP)
  - Global war on climate change to avert worst-case scenario
- Scenarios do not include impacts of climate change, population growth, economics, or social customs on biomass availability
- Overall goal is to provide conservative “transparent” estimates whenever possible

Summary of Biomass Availability Scenarios

Feedstock	Biomass availability in scenario (Pg yr^{-1})					
	Alpha		Beta		MSTP	
	DM	C	DM	C	DM	C
Cereals excluding rice	0.17	0.07	0.29	0.13	0.42	0.18
Rice	0.52	0.22	0.60	0.25	0.67	0.28
Sugar cane	0.20	0.09	0.24	0.11	0.27	0.13
Manure	0.31	0.10	0.45	0.14	0.59	0.19
Biomass crops	0.63	0.30	0.94	0.60	1.25	0.60
Harvested wood	0.05	0.03	0.13	0.07	0.21	0.10
Forestry residues	0.29	0.14	0.29	0.14	0.29	0.14
Agroforestry	0.13	0.06	0.70	0.34	1.28	0.62
Green waste	0.01	0.004	0.05	0.02	0.07	0.04
Total	2.3	1.0	3.7	1.6	5.1	2.3

Fertility and Enhanced NPP



Woolf et al., (2010) Nature Comm.

Pacific Northwest NATIONAL LABORATORY

Yield Response to Biochar Amendment

- Response inversely proportional to soil fertility
- Relative biochar yields (RBY) calibrated using scant literature from both field and greenhouse studies
- Cereals responded three times more per unit biochar amendment than legumes
  - (N use efficiency?)

Crop	Field	Pot	All
	------ (RBY ha Mg-C^{-1}) ------		
Cereals	0.028	0.024	0.0220
Legumes	0.0048	0.0066	0.0066
Cowpea	0.0066	0.0077	--

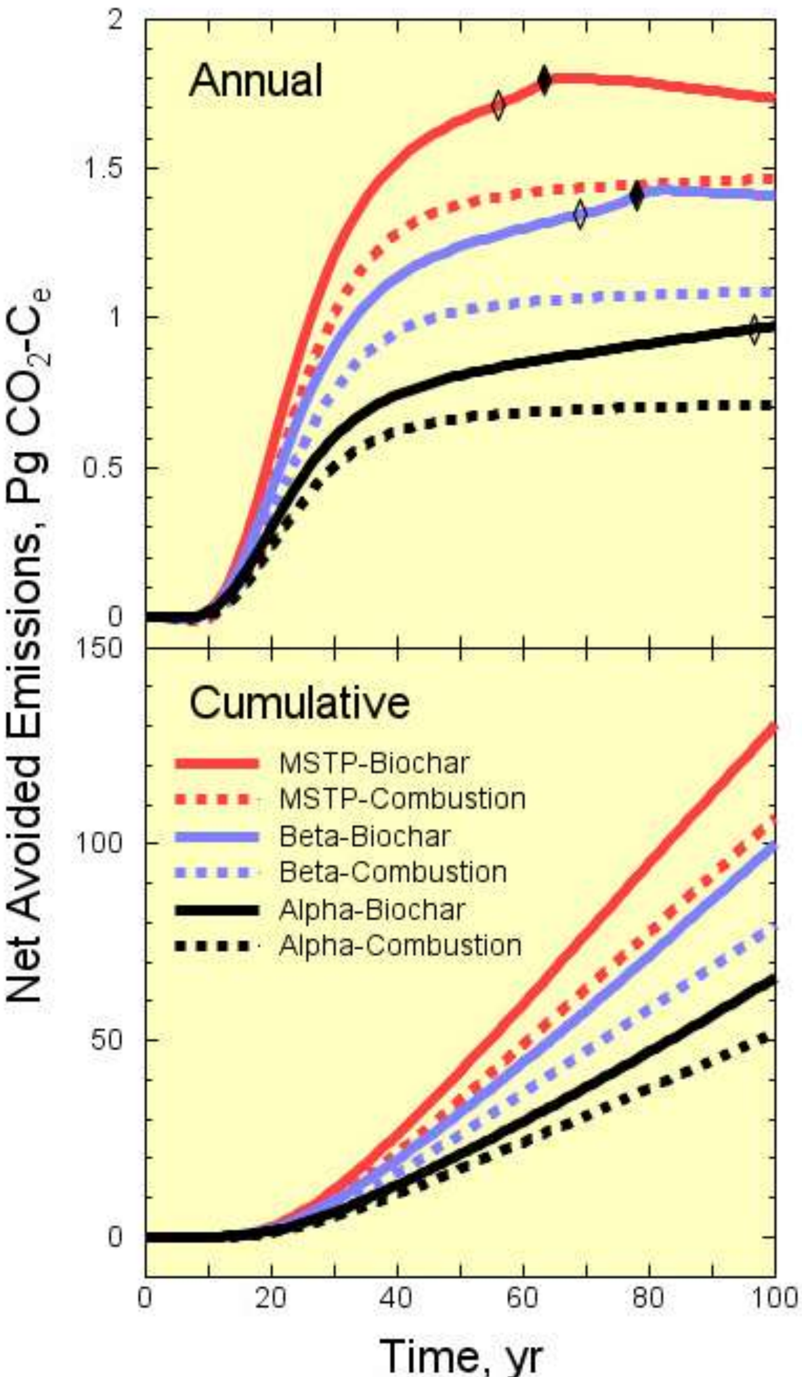
Severity of soil fertility constraint	Biomass yield response as fraction of potential maximum
None	0
Few	0.1
Slight	0.3
Moderate	0.5
Severe	0.7
Very severe	0.9
Unsuitable	1.0

Pacific Northwest NATIONAL LABORATORY

Woolf et al., (2010) Nature Comm.

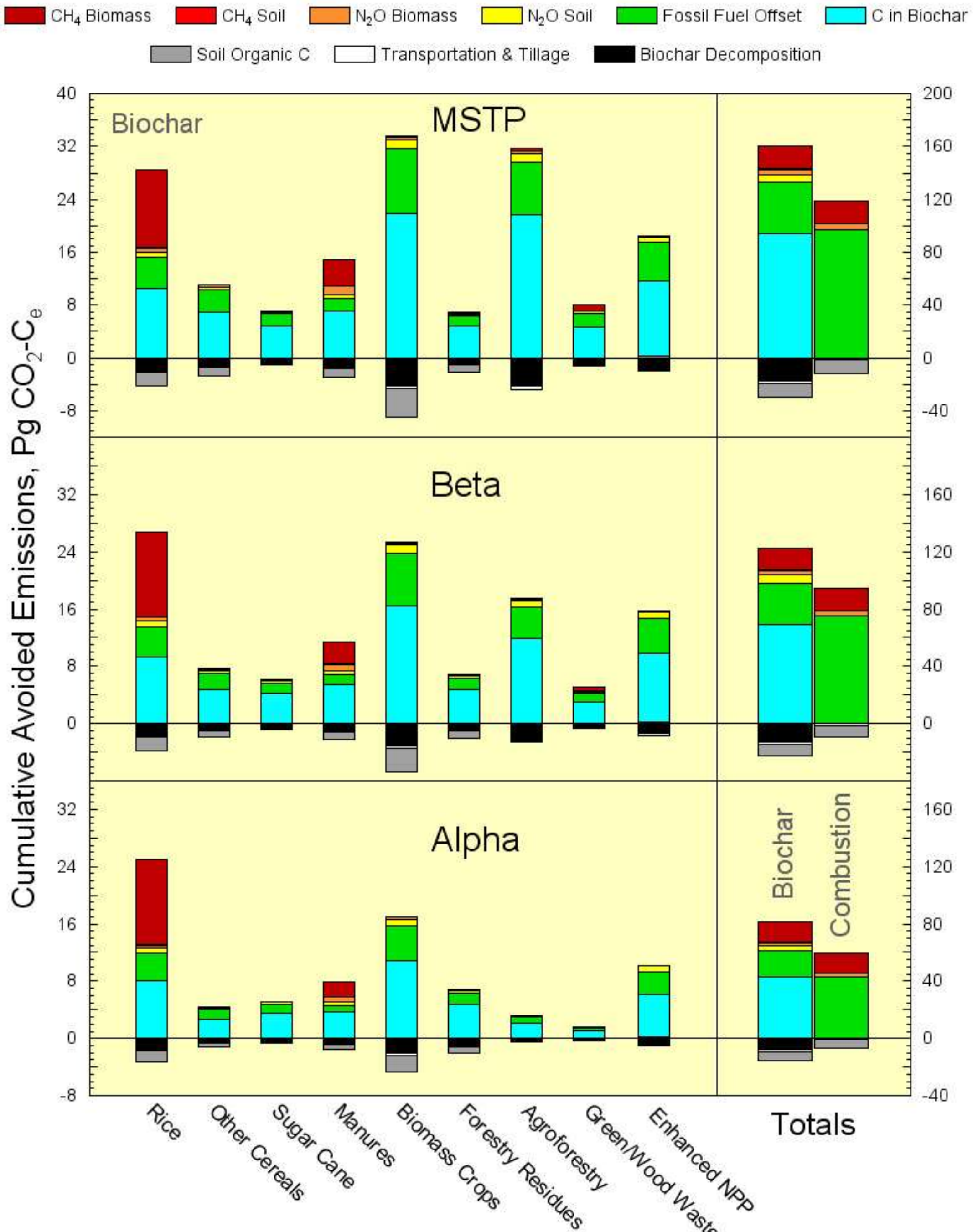
RESULTS

- Maximum avoided emissions range from about 1.0-1.8 Gt CO_2-C_{eq} yr^{-1}
- Cumulative avoided emissions for 100-years range from 66-130 Gt CO_2-C_{eq}
- After saturation of soil capacity (assuming 50 t biochar-C ha^{-1} in top 15 cm), net avoided emissions decrease due to loss of further NPP increases and GHG decreases
- Both biochar and biofuels have significant impact
- Biochar is about 22-27% more effective than biofuel combustion in combating climate change during first century of adoption



Woolf et al., (2010) Nature Comm.

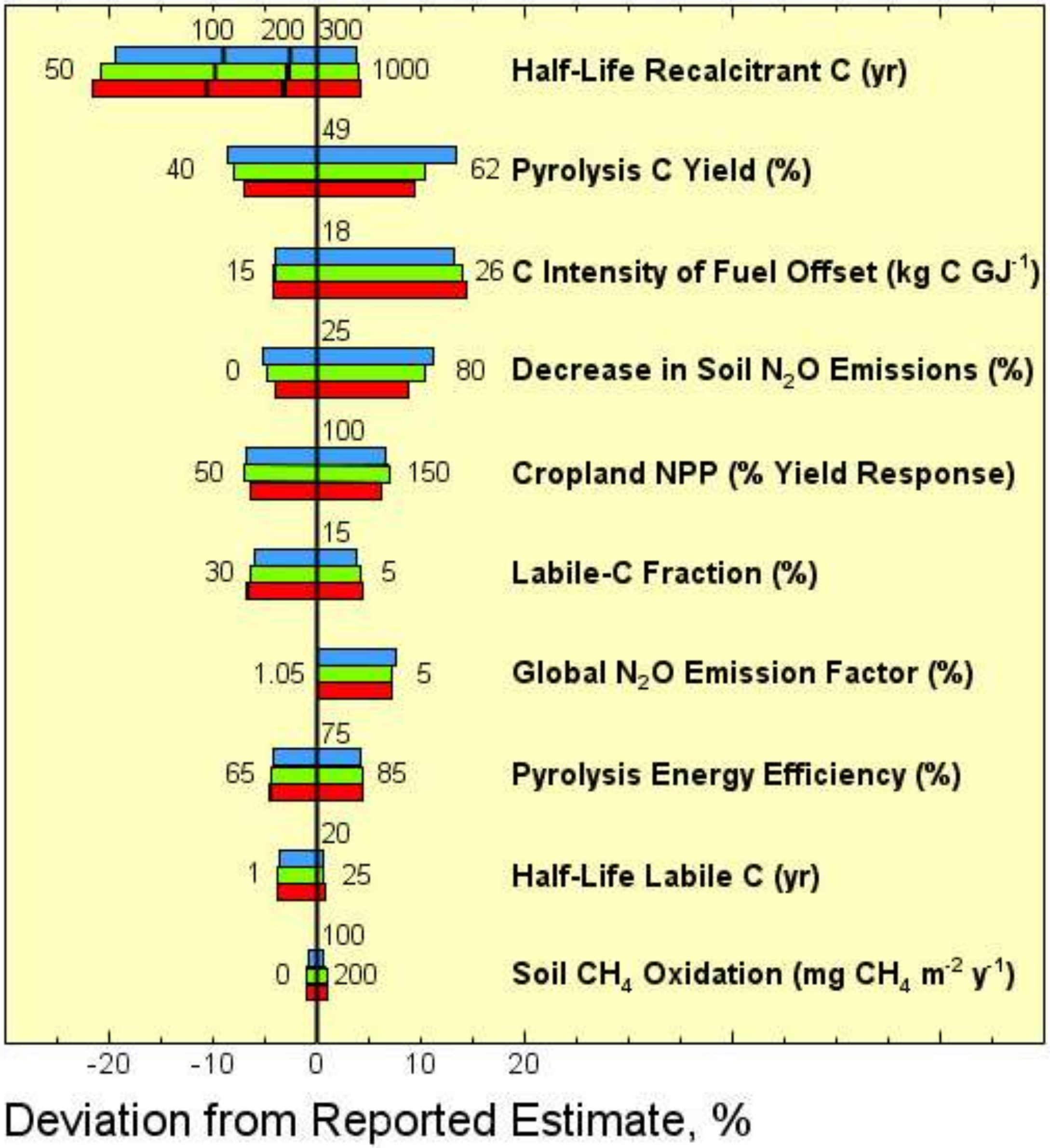
- Breakdown of results according to feedstock type and feedback from NPP increase
- Main contribution due to C storage, then fossil-C offsets and GHG offsets
- Biochar decomposition and decrease in SOC main negative impacts
- Note large impact on methane for rice and for manure
- Biomass crops (on degraded lands), agroforestry, manure, and enhanced NPP account for main differences between scenarios
- Tillage and transportation negligible



Woolf et al., (2010) Nature Comm.

Sensitivity Analysis

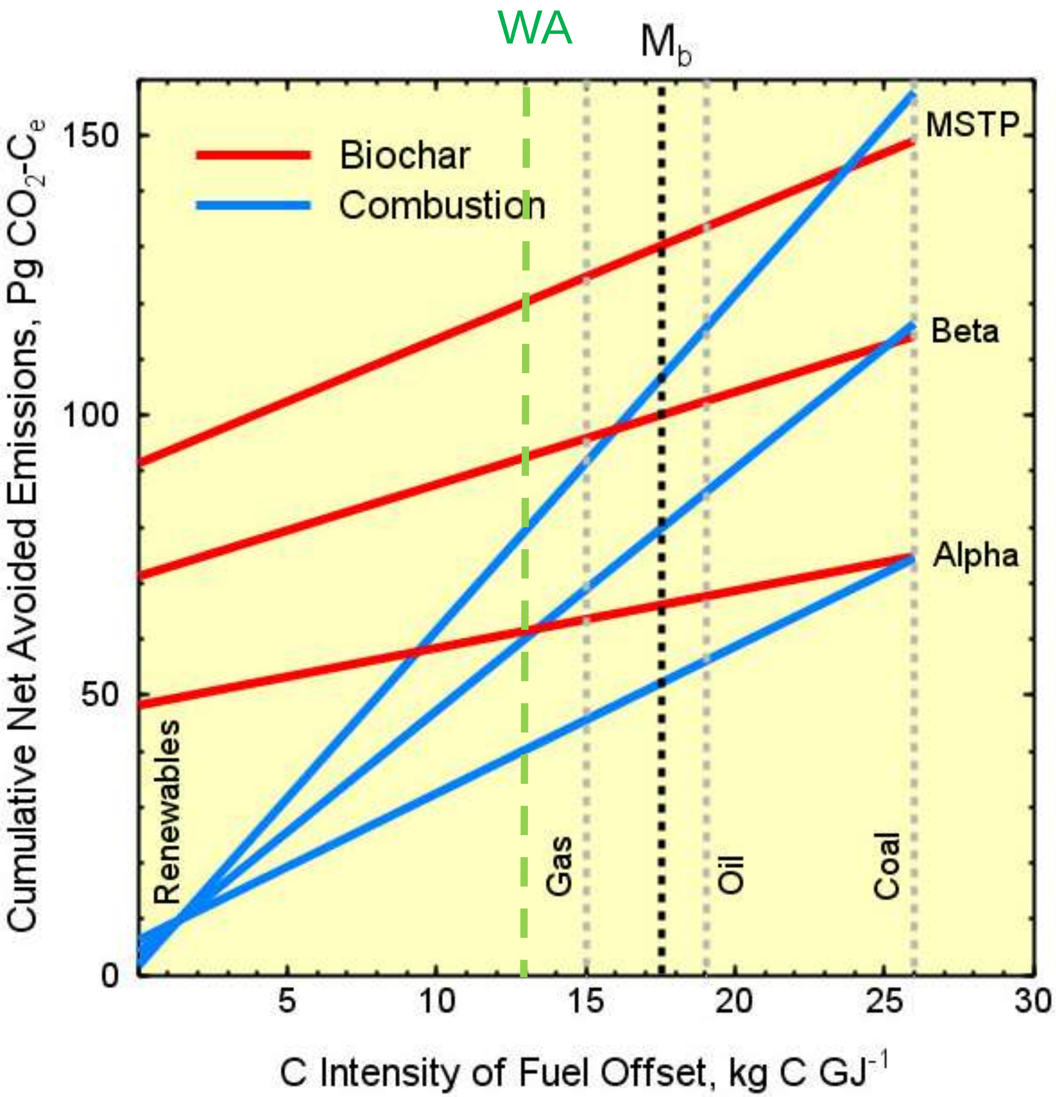
- Sensitivity analysis using Monte Carlo approach (n=1000)
- Top, middle, and bottom bars for alpha, beta, and MSTP scenarios
- Values are for parameter range
- Central values are for base case used in other figures
- Linear response in most instances except for half-life of recalcitrant C



Woolf et al., (2010) Nature Comm.

C Intensity of Fuel Being Offset

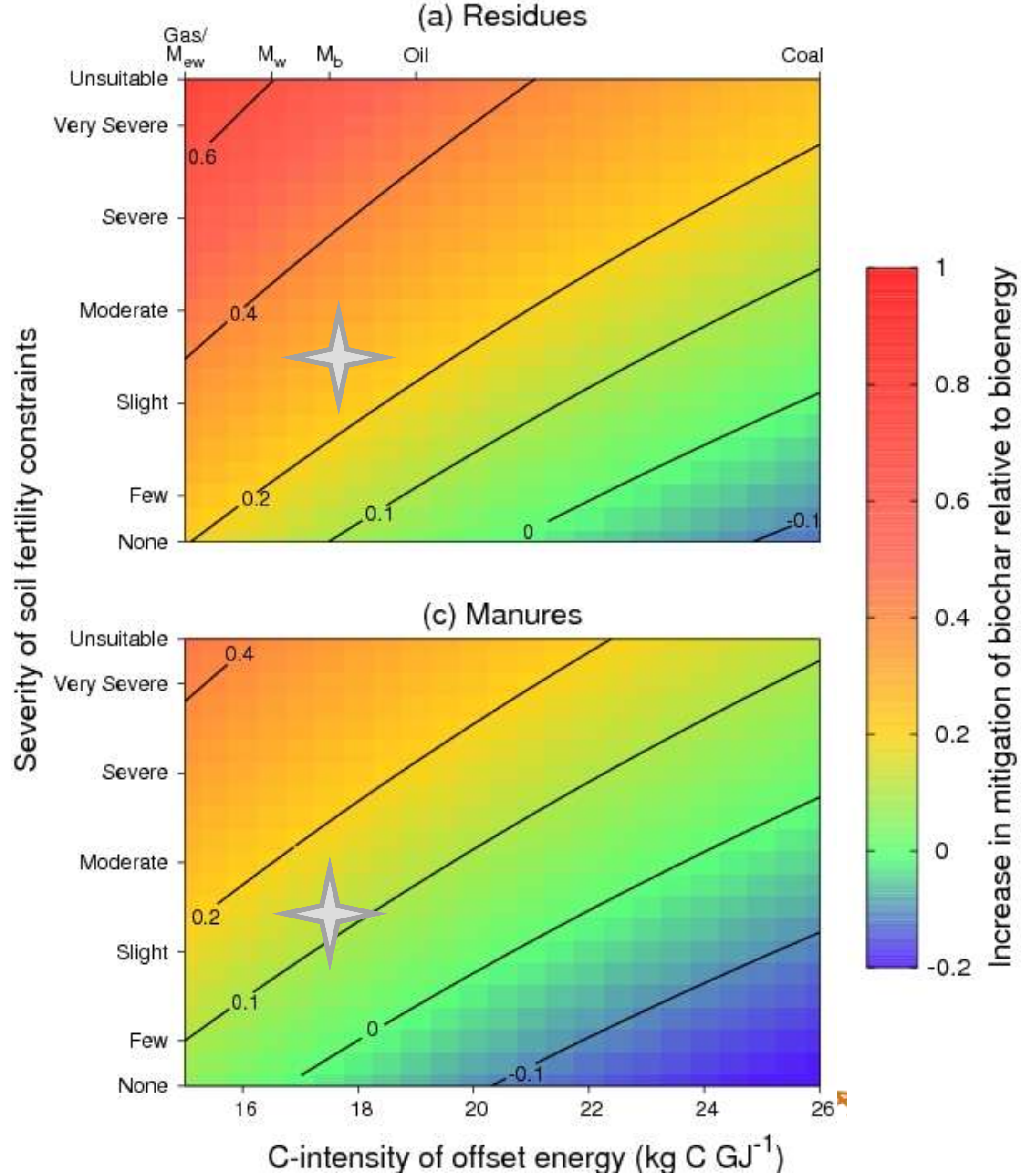
- Effect of C intensity of fuel offset on biochar and combustion mitigation potential
- As C intensity decreases, mitigation potential also decreases
- Except for the very highest C intensities (e.g., where coal is only fuel offset), biochar yields greater mitigation
- Relative benefit of biochar increases as C intensity decreases



Woolf et al., (2010) Nature Comm.

Soil Fertility & Biomass Type

- Inclusion of soil fertility factor and biomass type on relative mitigation potential of biochar and bioenergy (combustion)
- Contours indicate increase in biochar relative to bioenergy
- Star indicates baseline C-intensity and mean soil fertility
- In all cases, least fertile soils yield greater benefit from biochar than bioenergy
- Relative benefit increases as C intensity decreases

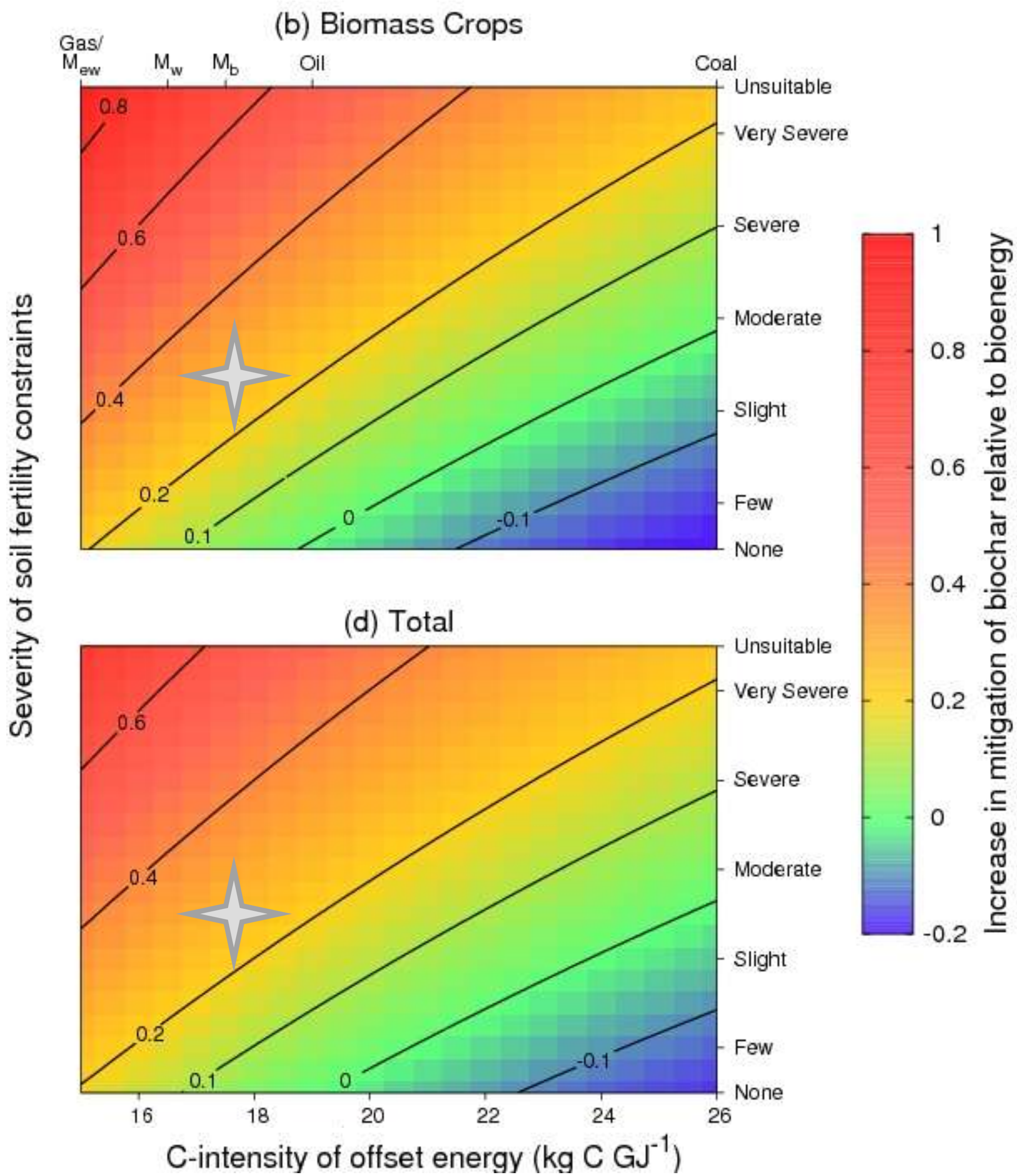


JE Amonette 08Nov2010

Woolf et al., (2010) Nature Comm.

Soil Fertility & Biomass Type

- Contours steepest for biomass crops
- Highest relative benefits (>80%) for poorest soils growing biomass crops offsetting low C-intensity fuels
- Lowest relative benefits (-19%) for most fertile soil growing biomass crops and offsetting coal
- Relative benefits of biochar and bioenergy depend highly on local conditions!



Woolf et al., (2010) Nature Comm.

Major Conclusions

- Sustainable biochar technology can offset up to 130 Gt CO_2-C_{eq} emissions during first century of adoption
- Annual offsets up to 1.8 Gt CO_2-C_{eq} are achievable
- For mean global soil fertility, C-intensity of fuel offset, and biomass type, biochar offers a 22% advantage over biomass combustion at the MSTP
- In some situations (i.e., high soil fertility plus coal offset), biomass combustion has a larger mitigation potential
- Both biochar and bioenergy yield significant offsets and local economics will likely determine which is used in a particular situation
- Recalcitrance of biochar C, yield of C during pyrolysis, and C intensity of fuel being offset are the three most important variables that affect results

Final Comment

Now is not the time for half-hearted measures.

We must take responsibility, think creatively, and act boldly if we are to meet the challenges of the Anthropocene.

Acknowledgments

Research supported in part by:

United Kingdom National Environmental Research Council (NERC) and Economic and Social Research Council (ESRC)

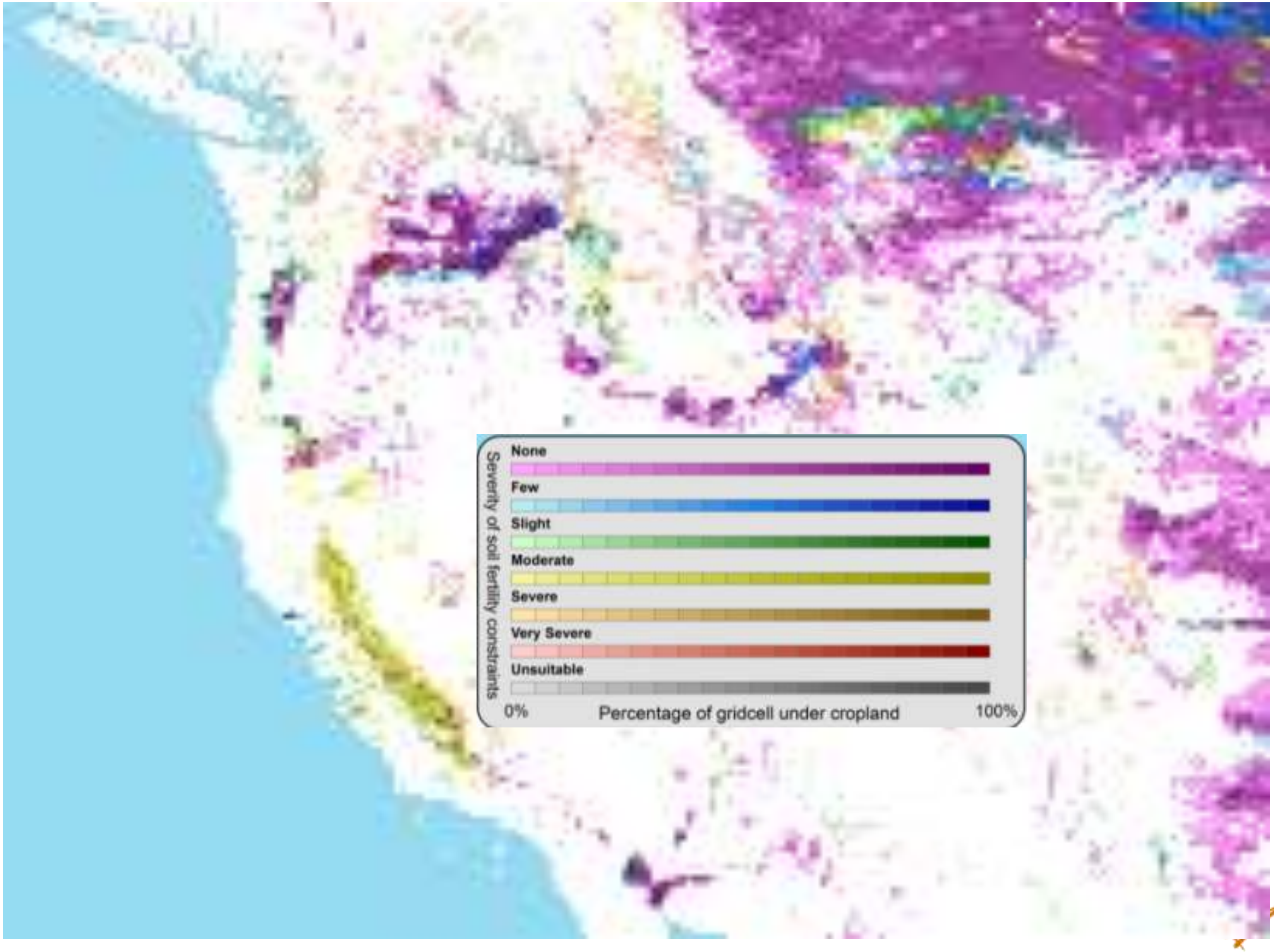
United States Department of Energy (USDOE) Office of Fossil Energy through the National Energy Technology Laboratory

USDOE Office of Biological and Environmental Research (OBER) through the Carbon Sequestration in Terrestrial Ecosystems (CSiTE) project and Mitigation Science Focus Area.

The Pacific Northwest National Laboratory is operated for the USDOE by Battelle Memorial Institute under contract DE AC06 76RL01830.

Woolf, D, JE Amonette, FA Street-Perrott, J Lehmann, S Joseph (2010) "Sustainable biochar to mitigate global climate change" Nature Comms 1:56 Article is OPEN ACCESS online at www.nature.com/naturecommunications

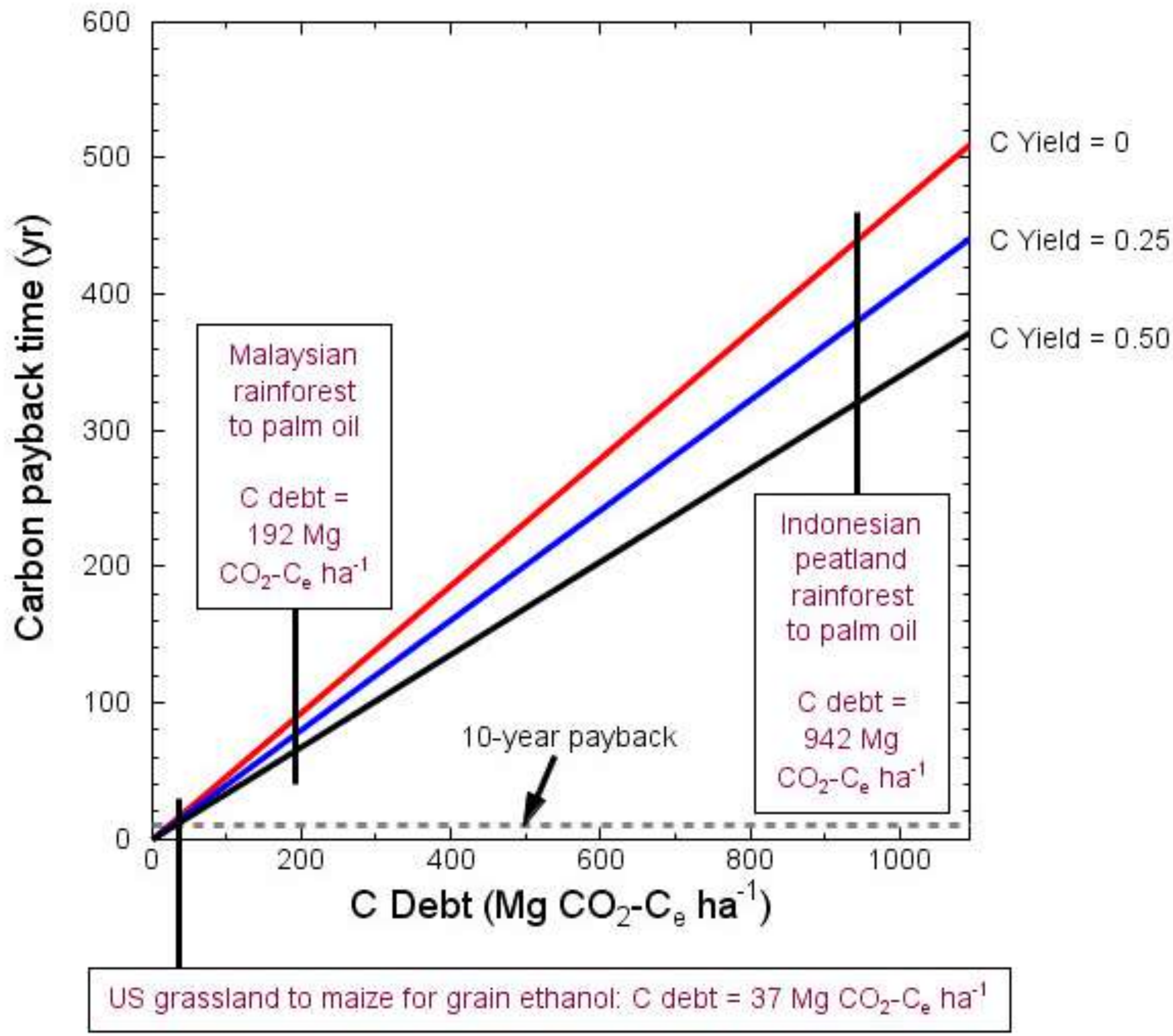

JE Amonette 08Nov2010



Pacific Northwest
NATIONAL LABORATORY

C debt and land-use change

- Even conversion of US grassland to maize production incurs a C debt with a payback period greater than ten years
- Use extreme caution when suggesting land-use changes for biomass production



Woolf et al., (2010) Nature Comm. C-debt data from Fargione et al., 2008 Science 319:1235

Excluded Feedstocks and Processes

- Slash-and-char substitution for slash-and-burn
  - Impractical to differentiate from land clearing
  - CH_4 emissions incur large C debt
- Forestry thinnings
  - Extraction difficult, nutrient losses, lack of data
- Invasive species
  - Lack of inventory data, resource depletion?
- Hydrothermal conversion
  - C half-life is on order of 40 yr
  - Chemical properties similar to lignite coal; very different from pyrolyzed biomass

Land Areas and Crop Residue Production for Each Soil Fertility Class

Soil fertility constraints	Land Area (Gha)	Cereals	Sugar Cane	Oil Crops	Pulses
None	0.31	0.52	0.11	0.10	0.008
Few	0.29	0.51	0.22	0.06	0.009
Slight	0.21	0.28	0.15	0.04	0.006
Moderate	0.32	0.33	0.39	0.10	0.007
Severe	0.18	0.16	0.14	0.05	0.004
Very Severe	0.13	0.10	0.09	0.04	0.002
Unsuitable	0.09	0.07	0.13	0.03	0.001

Woolf et al., (2010) Nature Comm.