Developing Carbon Capturing Crops: Vision, Strategy And Progress

Root Genomics Workshop

Plant and Animal Genome Conference

13 January 2009

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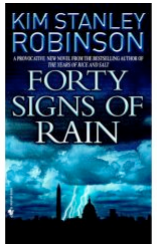

How can plant genomics contribute to mitgating global climate change?

McCarty Glacier, 30 Jul 1909* vs. 11 Aug 2004*

Kenai Fjords National Park, Alaska

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*Grant, Ulysses Sherman. 1909. McCarty Glacier:
*Molnia, Bruce F. 2004. McCarty Glacier:
From the Glacier photograph collection. Boulder, Colorado USA: National Snow and Ice Data Center/World Data Center for Glaciology. Digital media.

The Carbon Cycle
(for geneticists)

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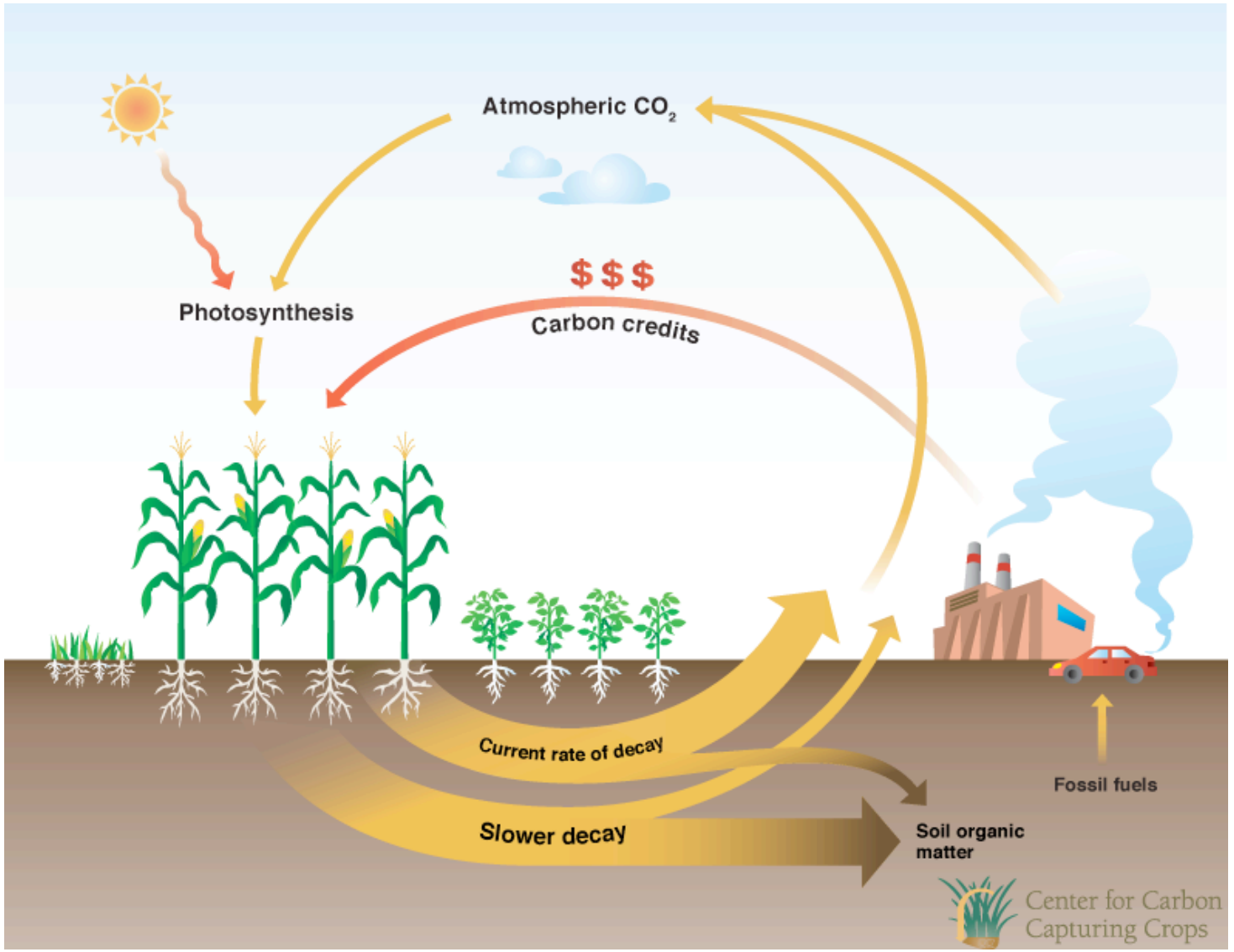

First Answer: Biofuels

The 10,000 job reductions, involving all parts of the company around the world, account for about 10 percent of Pfizer's global work force.

lar problems to some extent, and some of them are also engaged in cutbacks and reorganizations.

Big-selling drugs introduced by the in-

tions, said yesterday that the company was exploring ways to have deeper relation-

Continued on Page 6

Illustration by The New York Times

Springtime for Ethanol

A Presidential Voice Adds to a Growing Chorus of Support

By ALEXEI BARRIONUEVO

WASHINGTON — The Renewable Fuels Association, the ethanol industry's major lobbyist, works out of cramped offices that it shares with a lawyer near Capitol Hill. Pictures of ethanol plants from its 61 board members hang everywhere.

"We're about to run out of wall space," said Bob Dinneen, the association's president.

The association may only have six staff members but it is now bursting with energy, a far cry from the early days when its founder, a South Dakota farm boy who was convinced America needed to break the stranglehold of foreign oil, quit in frustration after four years.

After three decades of surviving mostly on tax subsidies, the industry is poised tonight to get its biggest endorsement from on high that it has a long-term future as a home-grown alternative to gasoline.

In his State of the Union address, President Bush is expected to call for a huge increase in the amount of ethanol that refiners mix with gasoline, probably double the current goal of 7.5 billion gallons by 2012.

While the details of the proposal are not known, 15 billion gallons of ethanol would work out to more than 10 percent of the country's current gasoline consumption, and is far beyond the current capacity of about 5.4 billion gallons.

At least half of the new ethanol would come from corn, signaling the administration's support to the Midwest farm states that have benefited the most from the recent ethanol boom.

For an industry once dominated by the will of a single powerful producer, **Archer Daniels Midland**, ethanol has come a long way, joining the oil industry and producers of major agricultural commodities as an entrenched political force in Washington. And it now enjoys a powerful role in presidential politics because of Iowa's status as one of the first states to select delegates to

Continued on Page 4

THE ENERGY CHALLENGE
Replacing Oil

A WAVE OF INTEREST IN EUROPE
Europe is experiencing a wave of interest in ventures that develop energy from less polluting or renewable sources. Page C3.

Currently most ethanol is derived from starch, but to meet the U.S. "ethanol mandate" it will be necessary to bring "lignocellulosic ethanol" technology on-line

…>3 Challenges…

NYT, 1/23/07

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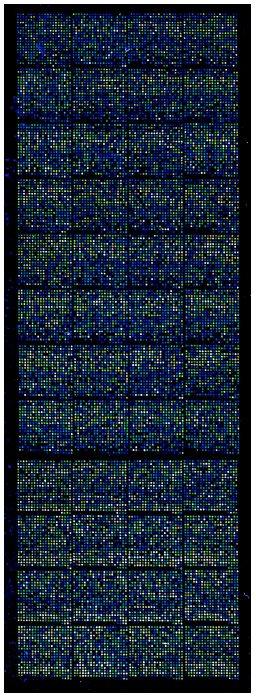
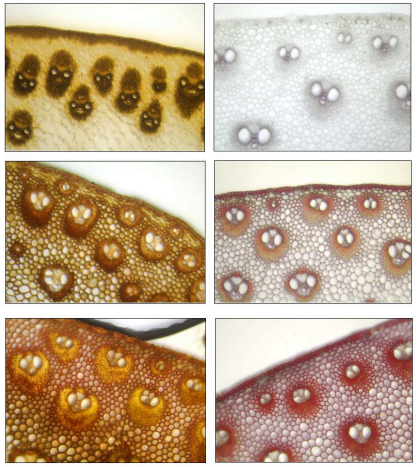
1st Challenge: Re-Engineering Plant Composition for Biofuel Production





Phenylalanine

PAL

Cinnamic acid

C4H

p-Coumaric acid

C3H ?

Caffeic acid

COMT ?

Ferulic acid

4CL

p-Coumaroyl CoA

p-Coumaroyl shikimic acid

C3H

Caffeoyl shikimic acid

CALDH

HCT

p-Coumaroyl quinic acid

Caffeoyl quinic acid

HCT

CCR

Caffeoyl CoA

CCoAOMT

Feruloyl CoA

Coniferaldehyde

CCR

p-coumaraldehyde

CAD

p-coumaryl alcohol

F5H

5-Hydroxy-coniferaldehyde

COMT

Sinapaldehyde

CAD

F5H

Coniferyl alcohol

5-Hydroxy-coniferyl alcohol

COMT

CAD

Sinapyl alcohol

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***p*-hydroxyphenyl lignin**

Guaiacyl lignin

Syringyl lignin

2nd Challenge: Carbon Debts Associated with Biofuel Production

Land Clearing and the Biofuel Carbon Debt

Joseph Fargione,[1] Jason Hill,[2,3] David Tilman,[2*] Stephen Polasky,[2,3] Peter Hawthorne[2]

Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change

Timothy Searchinger,[1*] Ralph Heimlich,[2] R. A. Houghton,[3] Fengxia Dong,[4] Amani Elobeid,[4] Jacinto Fabiosa,[4] Simla Tokgoz,[4] Dermot Hayes,[4] Tun-Hsiang Yu[4]

Science, 29 Feb 2008

Conversion of ag land to biofuel production results in add'l land being brought into production. Doing so incurs a "carbon debt" that can require 30-100 years of biofuel production to offset.

7 April 2008

Time, 7 April 2008

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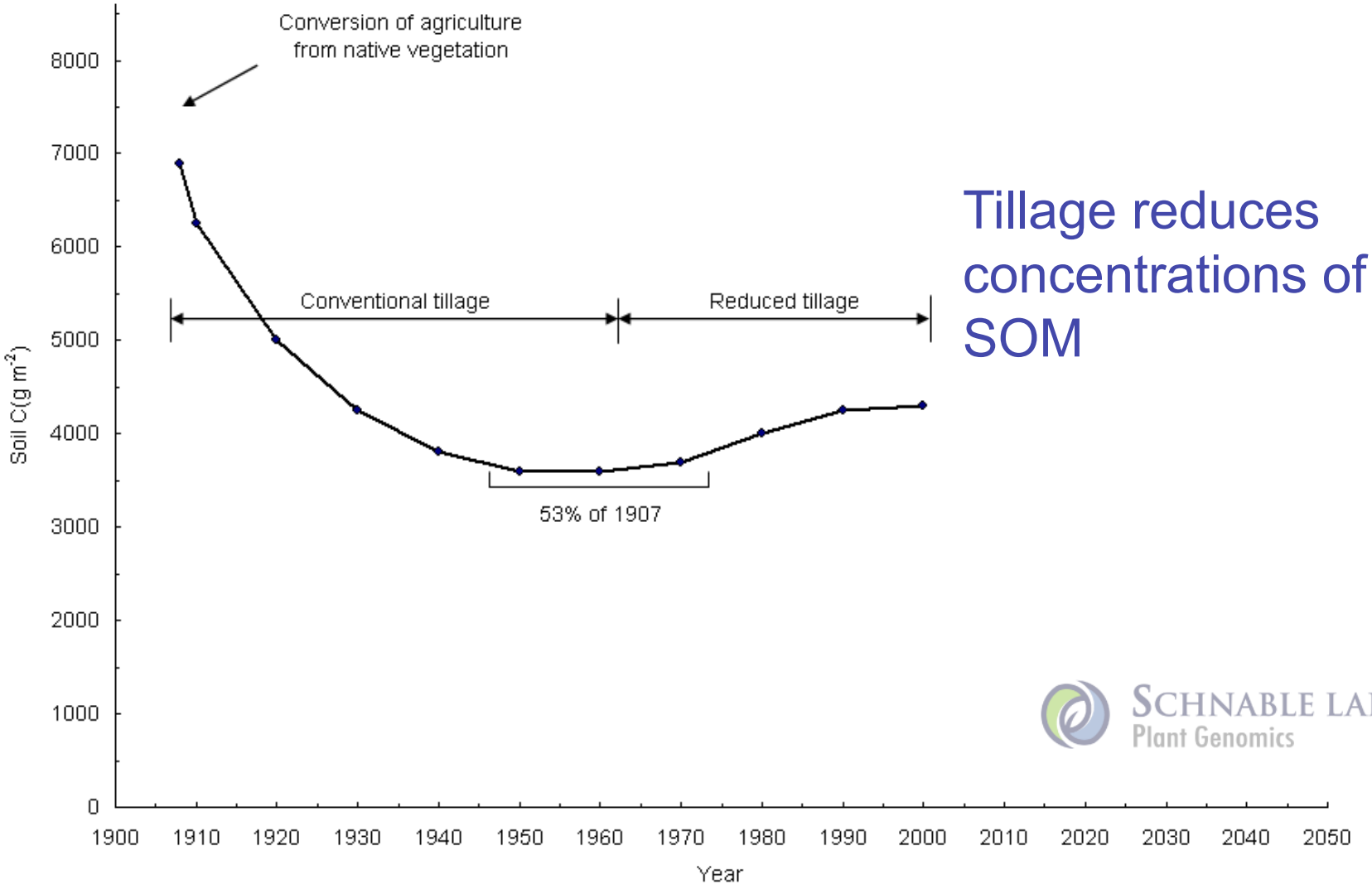
Soil Organic Matter (SOM) over Last Century



Tillage reduces concentrations of SOM

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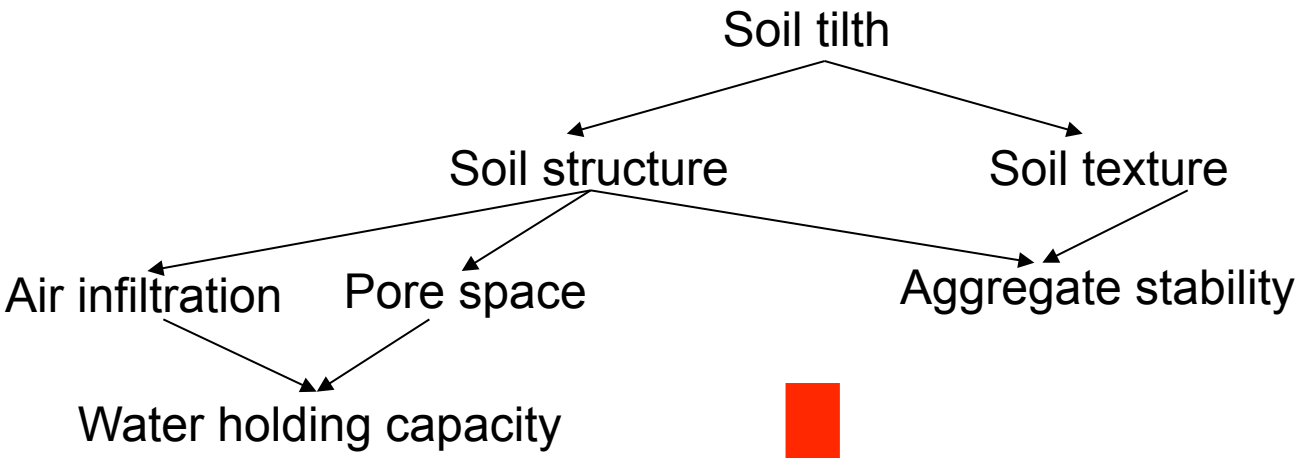
Modified from A.S. Donigian Jr. *et al*. [*EPA Report*. EPA/600/R-94-067 (1994)] and P.A. Matson *et al.* [*Science* 277:504-509 (1997)].

Soil Organic Matter is a “Good Thing”



Soil fertility

Crop production

Agricultural sustainability

Externalities:

- Improves water quality
- Reduces erosion
- Reduces nitrogen loss

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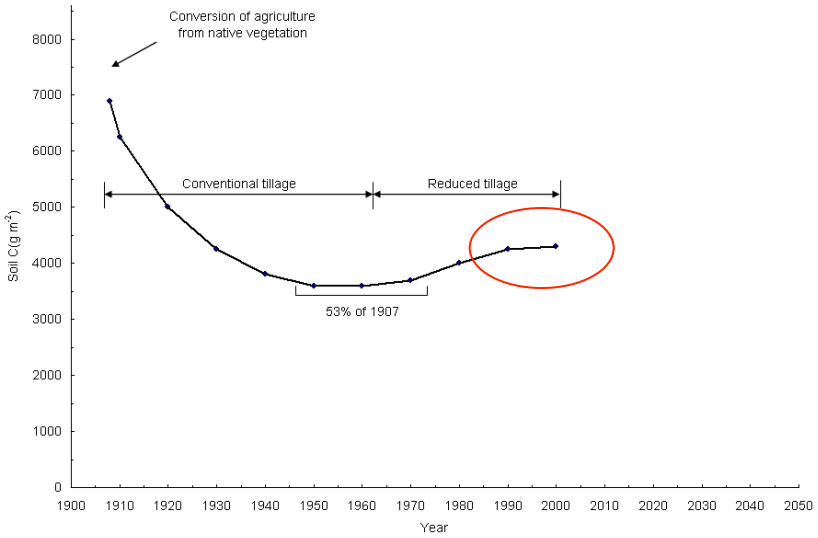
SOM has reached a new equilibrium



Based on:
Reduced tillage
Return of ~50% of biomass to the soil

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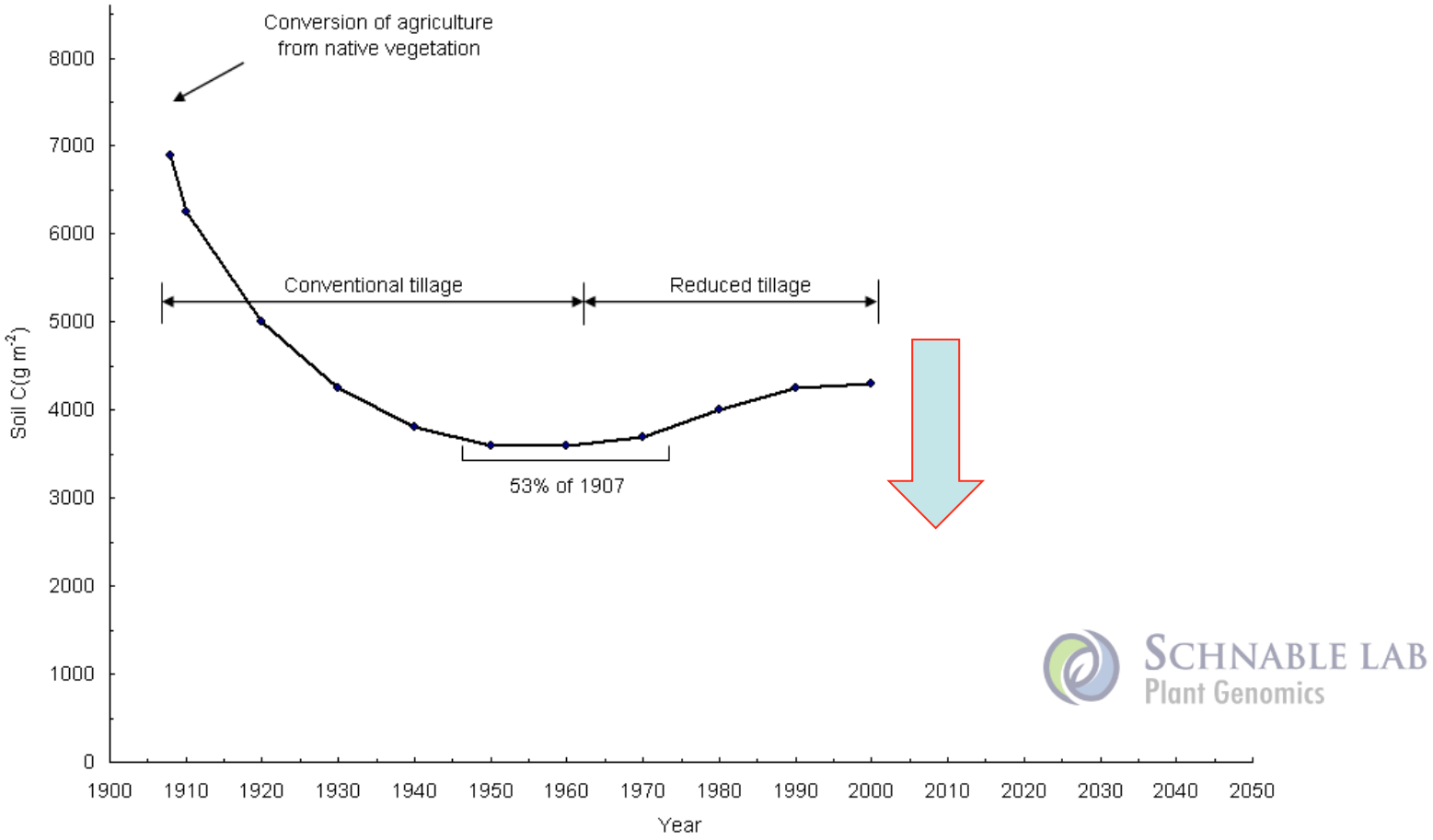
What happens if we remove "all" of above-ground biomass for biofuel production?

Leaves, husks, stalks, cobs comprise ~50% of above-ground biomass

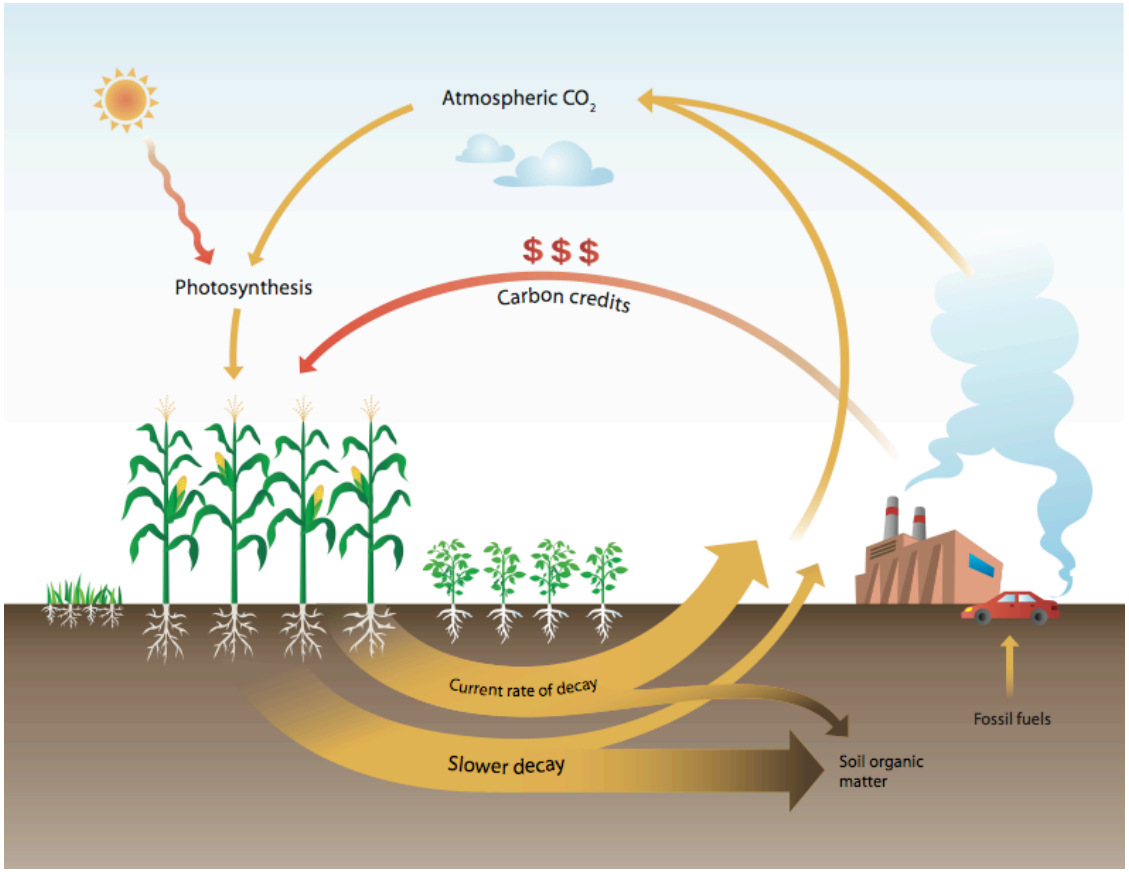
Third Challenge: Response of Soil Organic Matter to Removal of Biomass



Modified from A.S. Donigian Jr. *et al*. [*EPA Report*. EPA/600/R-94-067 (1994)] and P.A. Matson *et al.* [*Science* 277:504-509 (1997)].

Center for Carbon-Capturing Crops

Goal: to produce crops with biomass that is more "resistant" to microbial degradation



–Alter composition to reduce rate of decay, e.g., increase concentration of compounds that have long half lives in soil.

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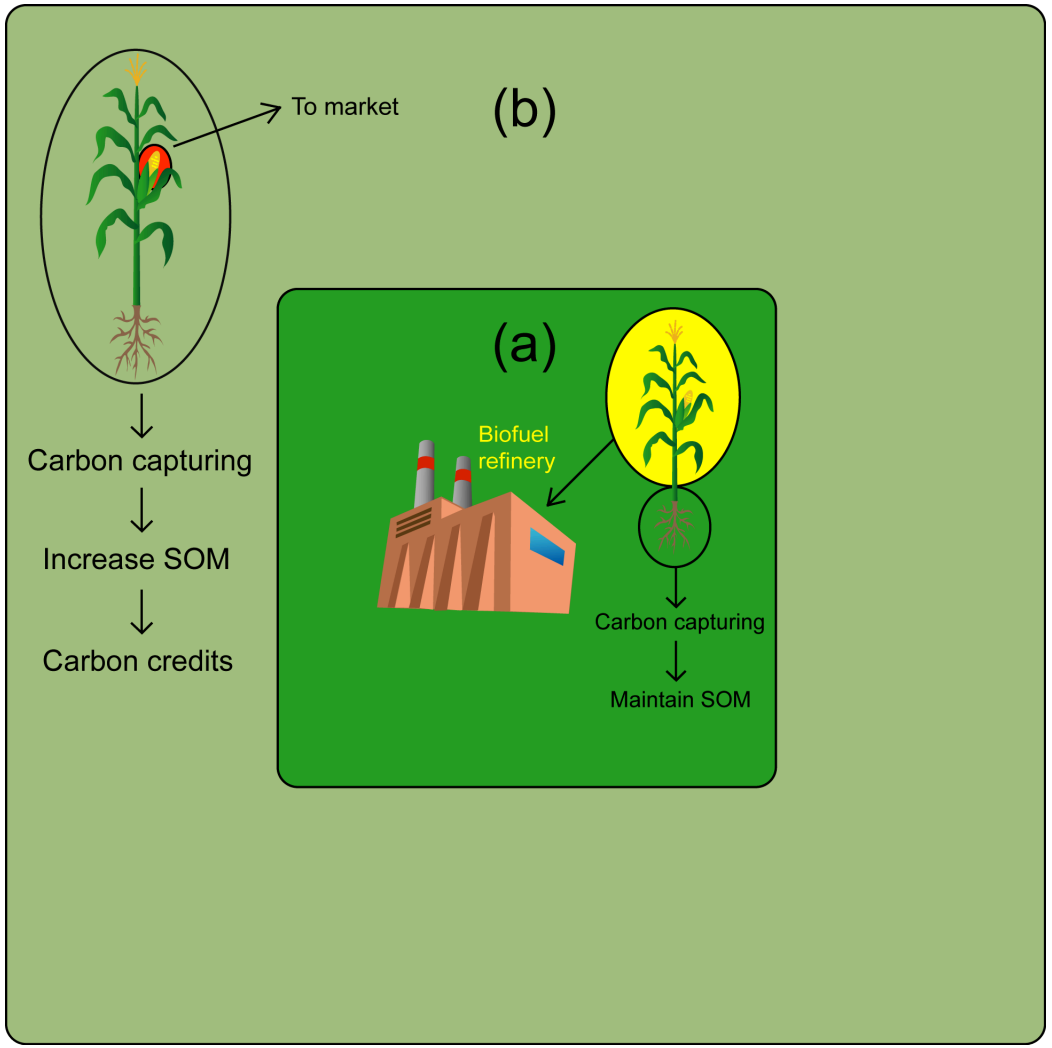
Potential Benefits of Carbon Capturing Crops

- More quickly “repay” carbon debt on newly cultivated biofuel production fields
- Help maintain soil organic matter levels under intensive biomass production systems
- Increase equilibrium amount of soil organic matter under traditional cropping systems
  - Improved water quality
  - Reduced erosion
  - Reduced nitrogen loss
- Help mitigate global climate change by sequestering atmospheric carbon in agricultural soils
- Provide additional income to the farm sector through carbon credits

Deployment Strategies

a) Land close to biorefineries = Bulk biomass production → Maintain SOM

b) Other crop land = Grain production → Increase SOM (sequester carbon; earn carbon credits)



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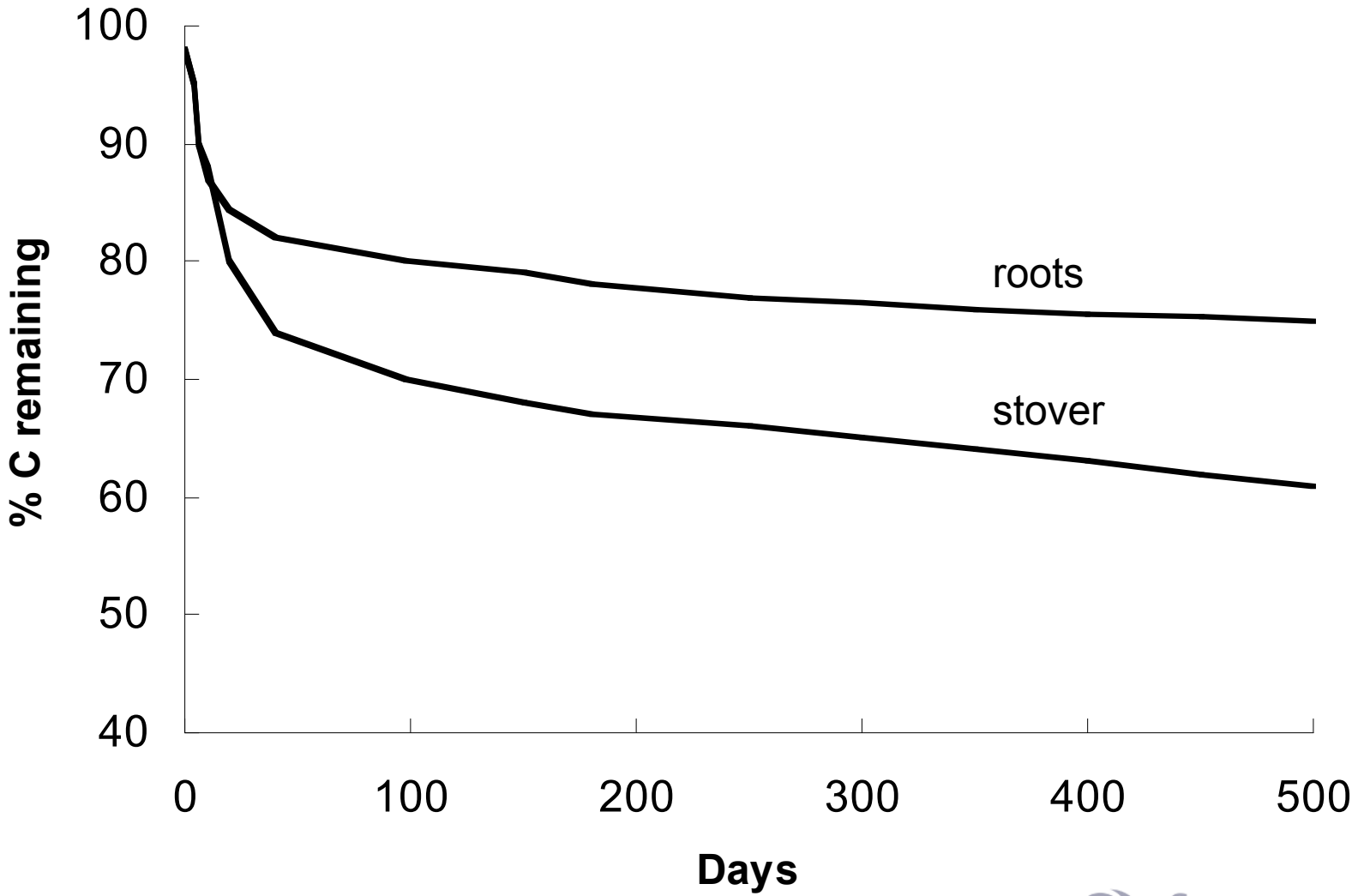
Potential Strategies

- Alter (below-ground) biomass:
  - Increase total root mass
  - Alter structure of roots to reduce rate of decay
    - Cloning root mutants (w/ Frank Hochholdinger)
  - *Alter composition to reduce rate of decay*
    - (e.g., increase concentration of compounds that have long half lives in soil; which compounds are long-lived?)

Decomposition of Maize-Derived Carbon



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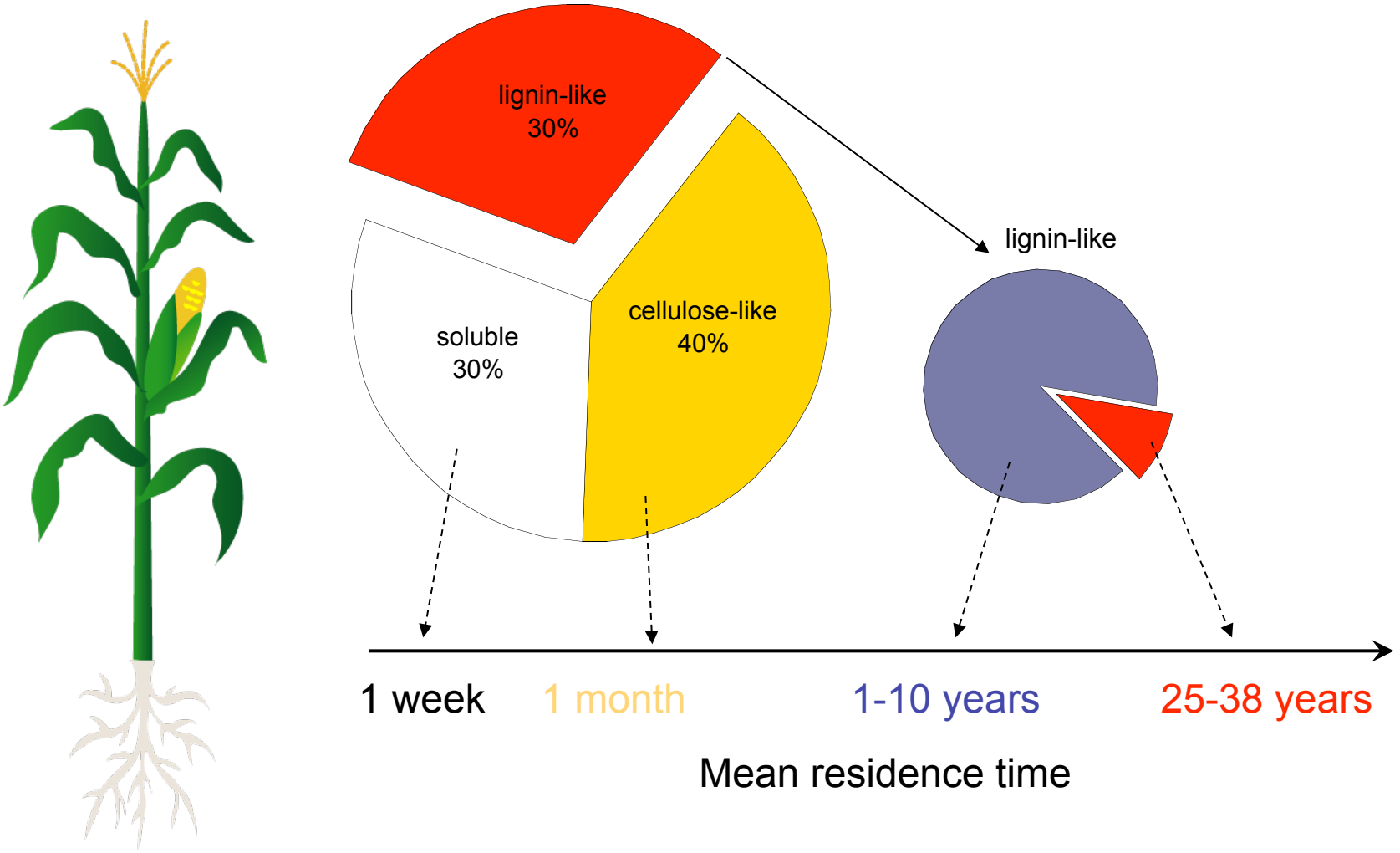
Adapted from Johnson et al., 2007. Soil Sci. Soc. Am. J. 71 (1): 155-162.

Decomposition of Biomass-Derived Carbon



Hadas et al., 1993; 2004; Heim and Schmidt 2007; Rasse et al., 2006

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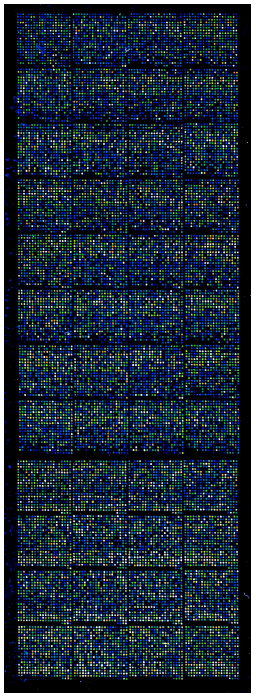
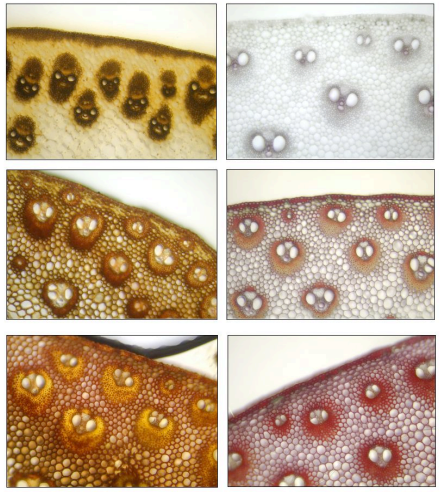
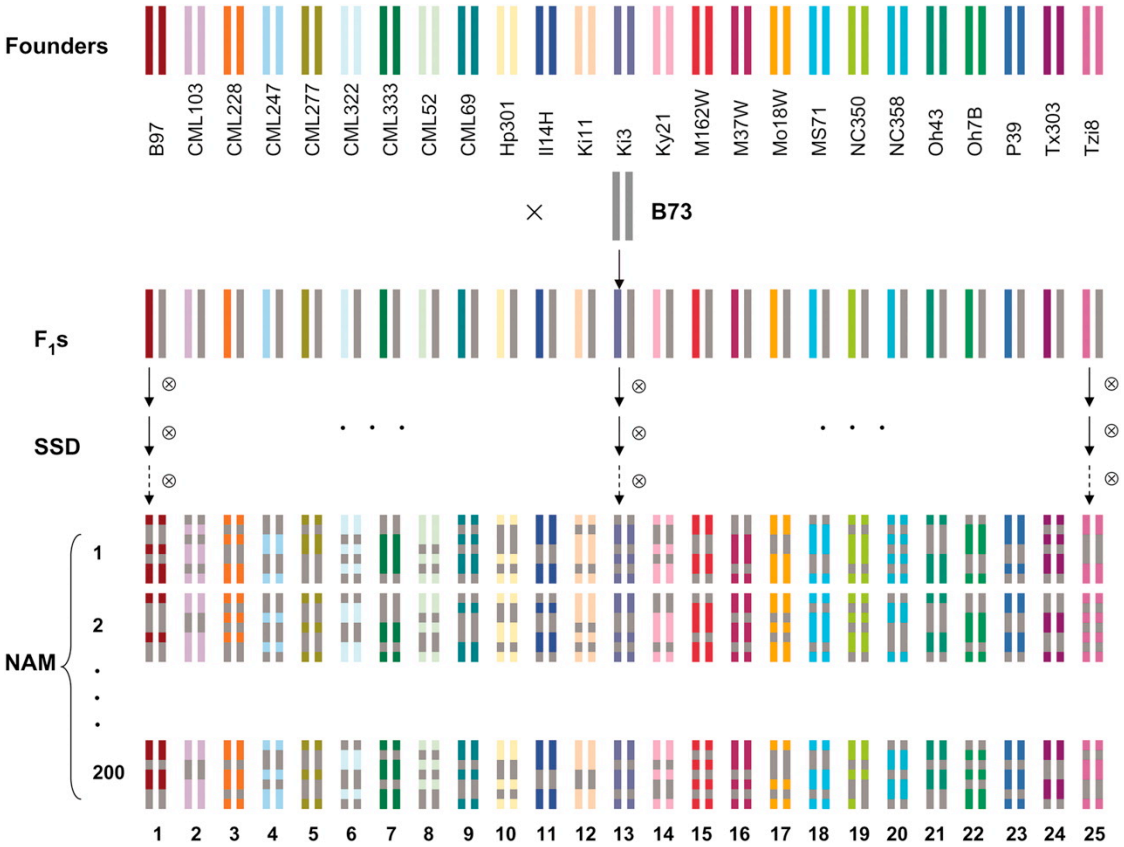
Re-Engineering Plants for Carbon Sequestration





Using the NAM Population to Elucidate the Genetic Regulation of Cell Wall Composition

Nested Association Mapping (NAM) Population: Genome reshuffling between 25 diverse founder inbreds and the common (B73) inbred parent and the resulting 5,000 immortal genotypes



Yu, J. et al. Genetics 2008;178:539-551

, … 25 diverse lines

, … 25 families

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… 200 RILs per family

Harvested 2 stalks per RIL

Genetic Control of Cell Wall Composition

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A “Grassroots” Approach to
Carbon Sequestration

QTL mapping for Carbon Capturing Trait

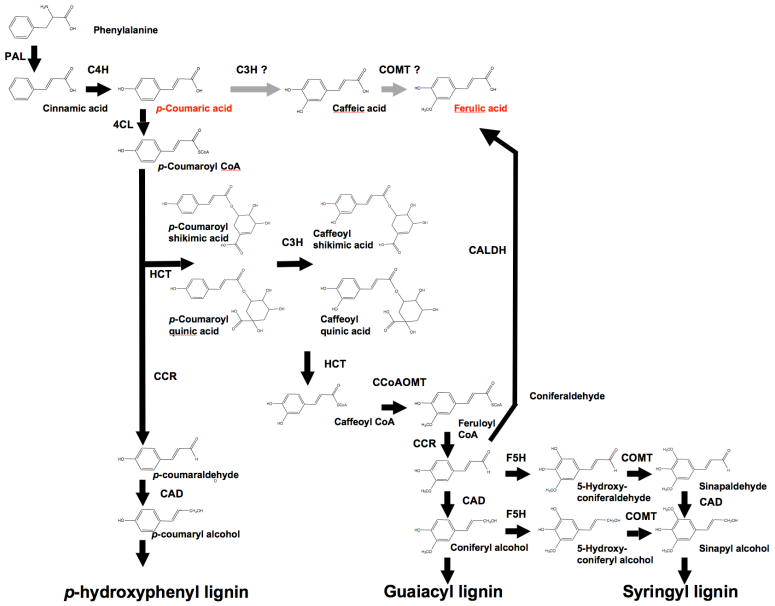
Metabolomic analyses of stover samples from IBM & NAM RILs (N=12,000)

Mapped Traits:

2 QTL for [p-coumaric acid]

2 QTL for [ferulic acid]

1 QTL for C/N%



Which other biomass constituents contribute to carbon sequestration?

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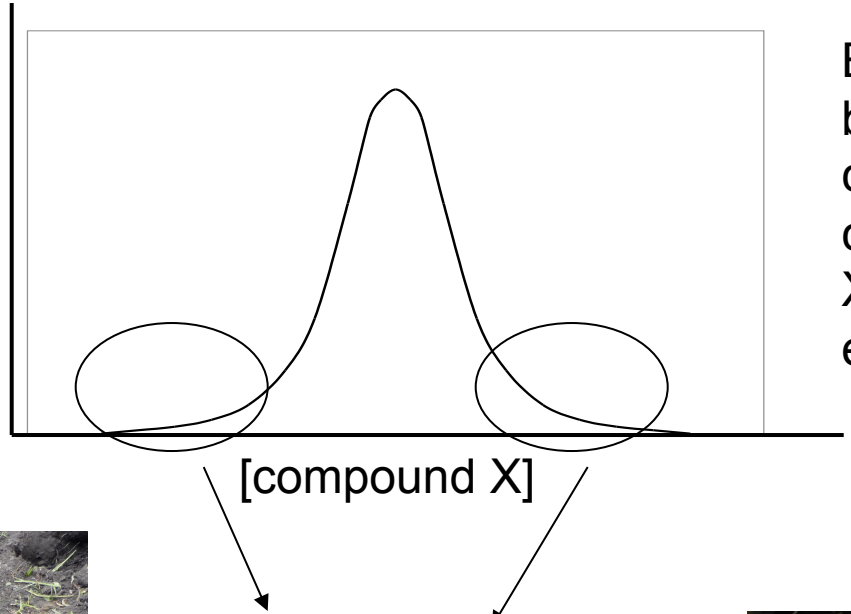
Which Biomass Constituents Have Longest Half-Lives?



Bury equal amounts of biomass from multiple RILs containing low and high concentrations of compound X. Compare rates of CO_2 emission from two pools.

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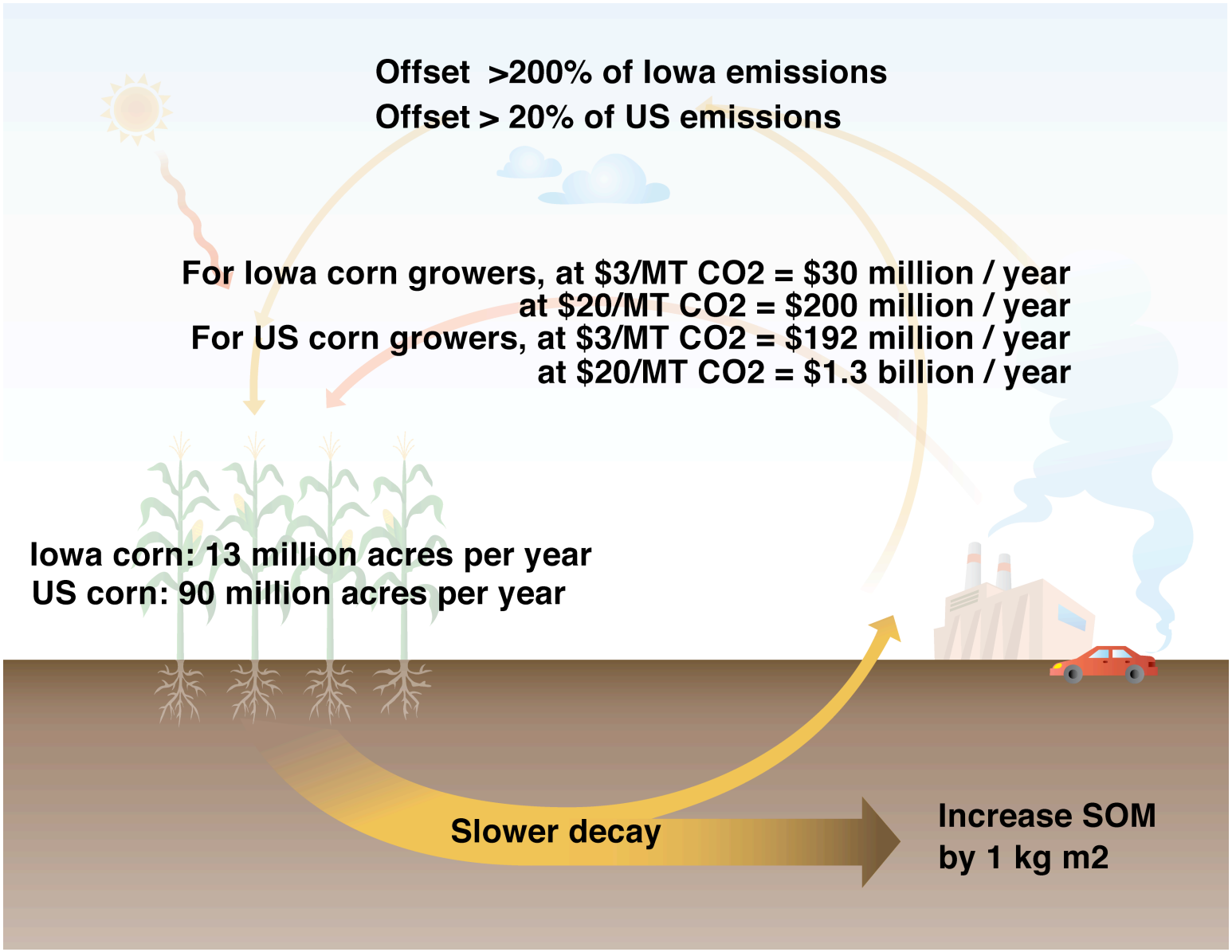
Offset >200% of Iowa emissions

Offset > 20% of US emissions

For Iowa corn growers, at $3/MT CO2 = $30 million / year
at $20/MT CO2 = $200 million / year
For US corn growers, at $3/MT CO2 = $192 million / year
at $20/MT CO2 = $1.3 billion / year



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Apply what is learned from maize to dedicated biofuel crops…

Switchgrass

Miscanthus

M. sinensis *M. sacchariflorus* *Miscanthus x giganteus*

Photos courtesy of Ted Crosbie

… and to pasture and hay crops, turfgrass, forest crops…

Acknowledgements

http://c2c2.iastate.edu/

Ramesh Nair

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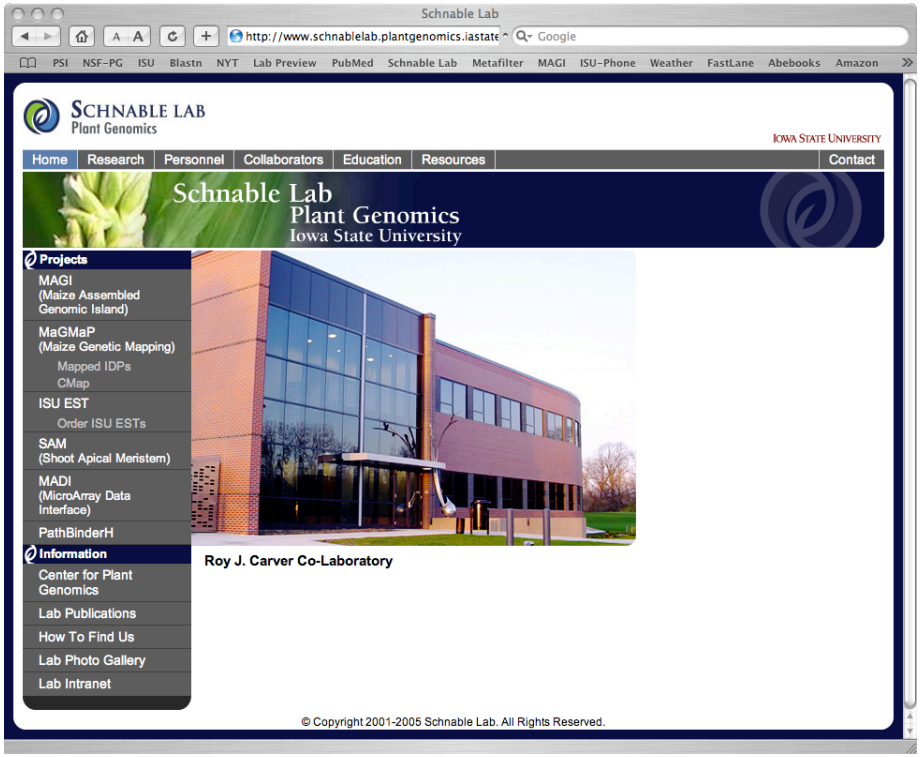
Thanks to the Panzea group for sharing the NAM pop'l and to Torbert Rochefort (Univ of IL) and Candy Gardner & Paul Scott (USDA/ISU) for logistical support

For more details and discussion, please visit Poster 321

Sarah Hargreaves



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