Highlights of 30 Years Involvement in Energy Crop Development and Resource Analysis

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Outline

- Brief Energy Crop R&D History
- Energy Crop Production Technology
- Lessons Learned from Implementation Efforts
- Potential Energy Crop Supplies (Analysis Results)
- Biomass Supply Vision
- Examples of recent Private Sector contributions to improving bioenergy crop supply potential.

ORNL Managed DOE's Bioenergy Feedstock Research from 1978 to 2002

Crop development with Universities and USDA

~$100 Million DOE Investment

Molecular Genetics

Environmental Studies

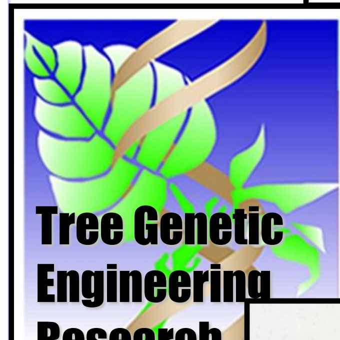
Economic Analysis

Project Support

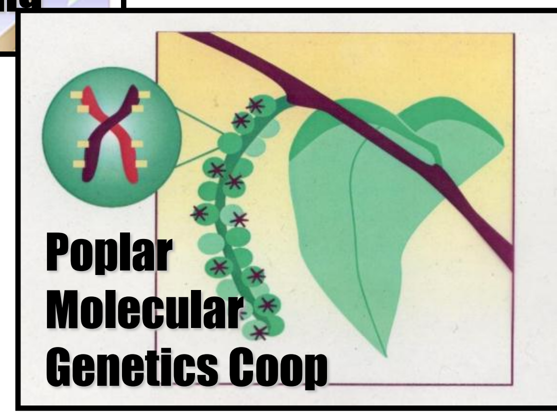
ORNL R,D&D

Minnesota Hybrid Poplar Research Cooperative

Willow Farmers Coop

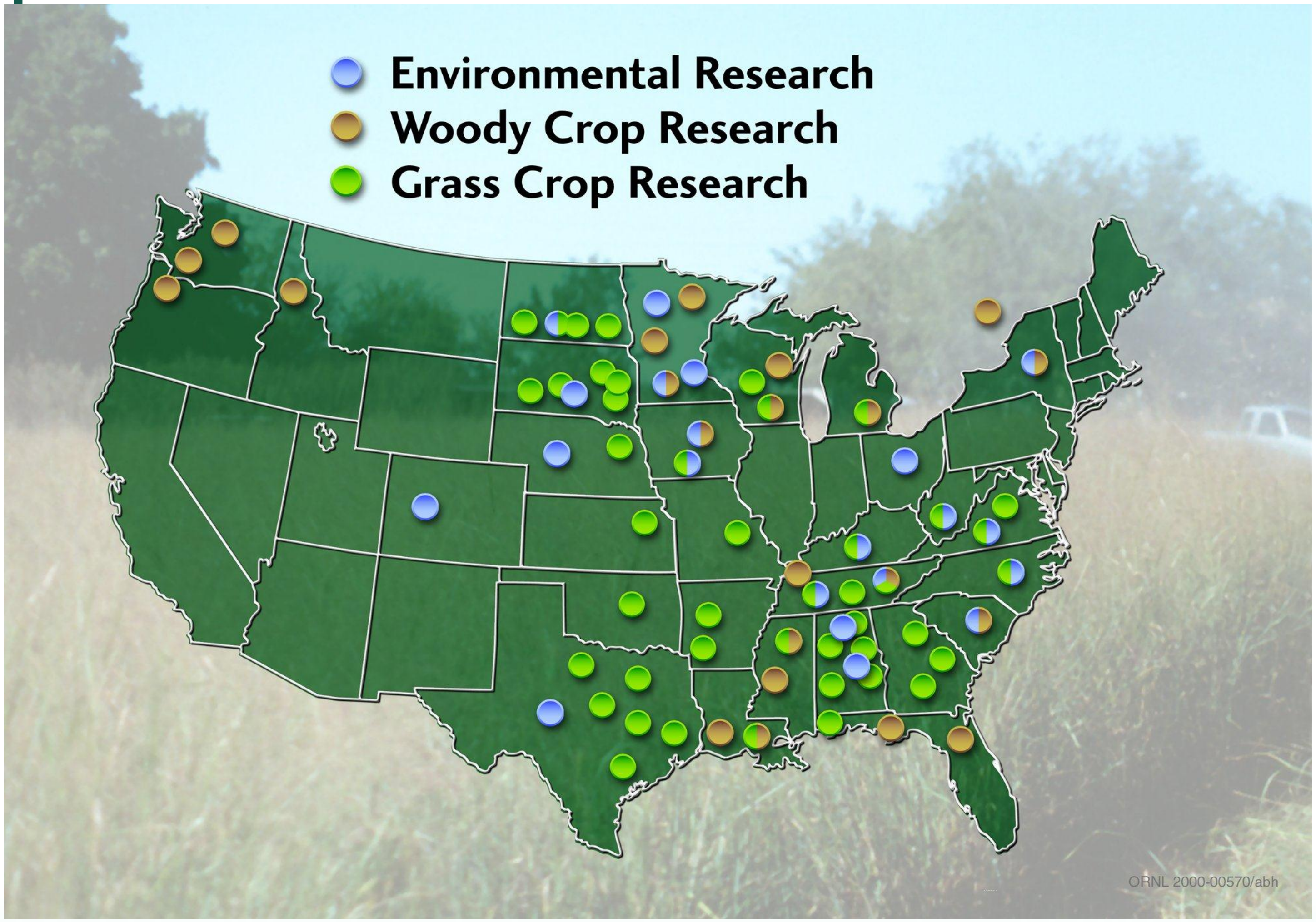


Prairie Lands BioProducts, Inc.

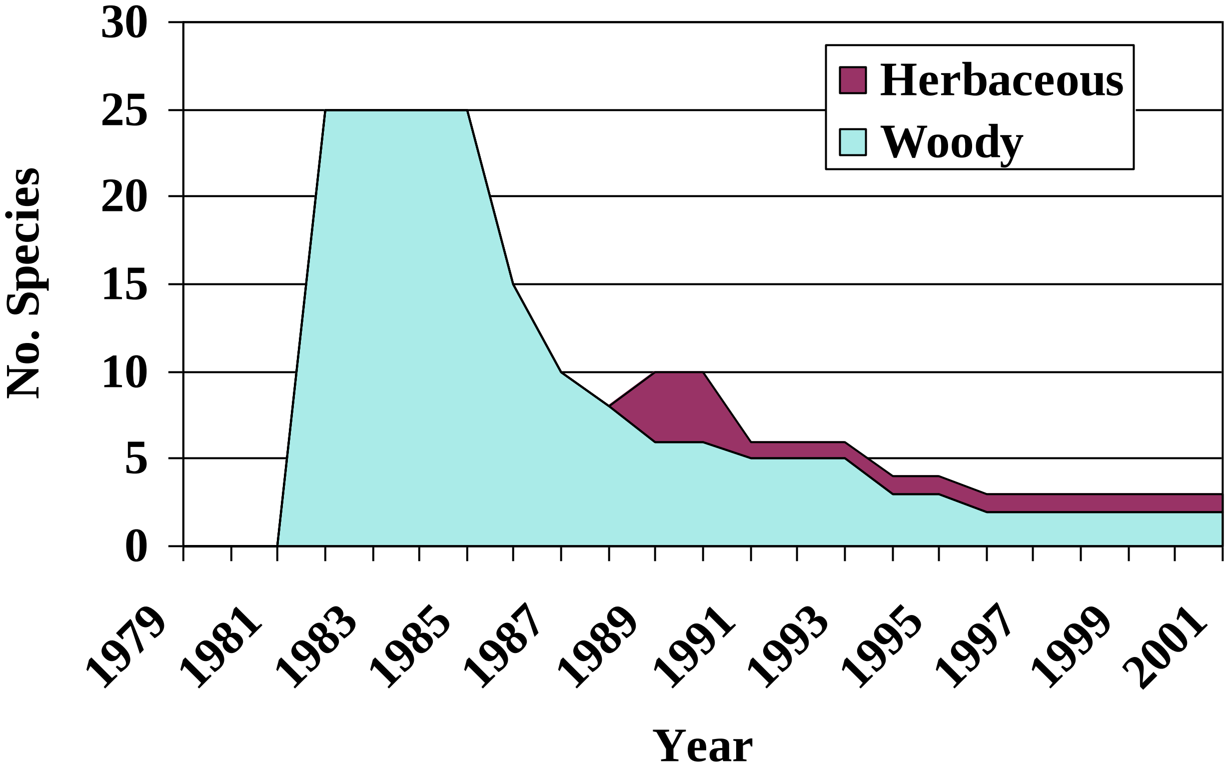


Significant Private Sector Involvement

Bioenergy Feedstock Experimental and Operational Research Sites in the U.S.



Energy Crop Species Screening, Model Selection



> 100 woody species screened
25 identified as high potential,
7 selected for development
Poplars and willows adopted commercially

35 herbaceous species screened
4 identified as high-potential,
Switchgrass selected for development as model

By late 80's woody research focused on 7 species and grass screening had begun

Woody crop management requirements were well established by late 1980's and switchgrass energy crop potential was identified.

Hybrid Poplar

Harvested at age 5 to 10

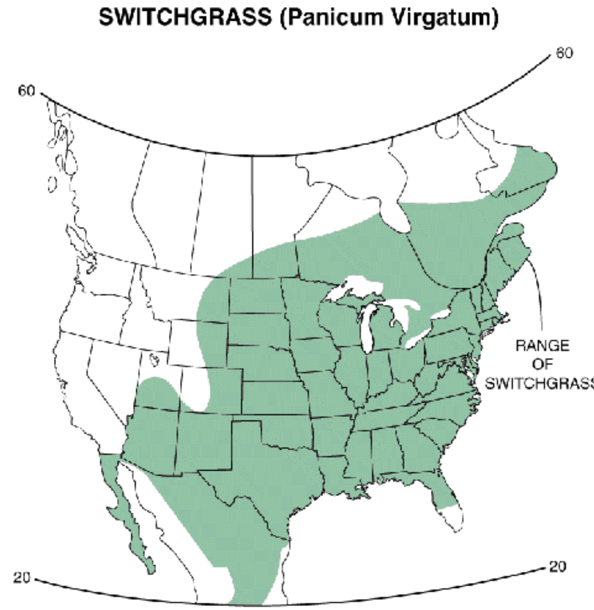
Willow coppice

Harvested at age 3 or 4

Switchgrass

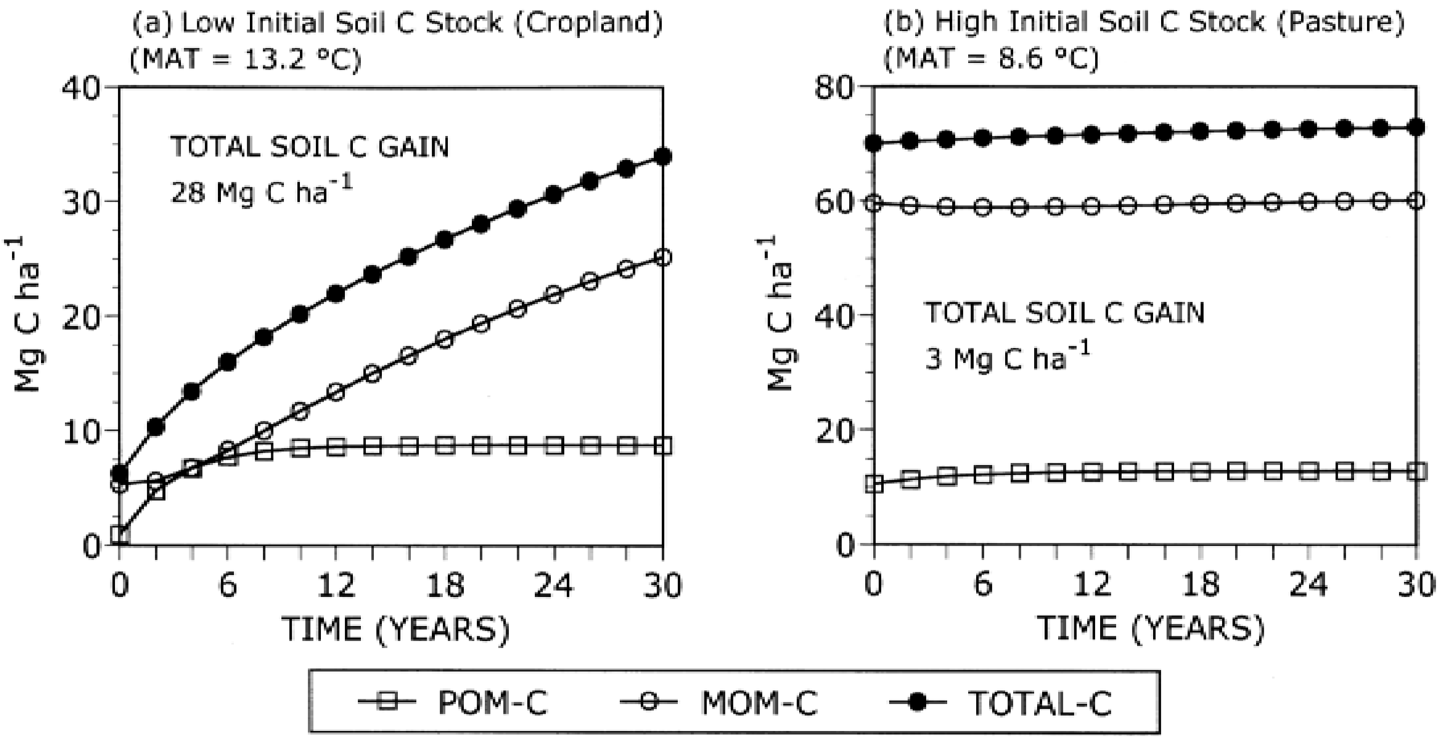
Harvested annually

Switchgrass, is produced in 10 year rotations with annual harvest, using conventional agricultural equipment, add N at ~ 10 kg/dry Mg yield/yr



Switchgrass can significantly improve soil quality and stability, and increase soil carbon in cropland soils, because of high root to top ratio

Soil carbon gain modeled
Based on actual field data
Garten (ORNL)



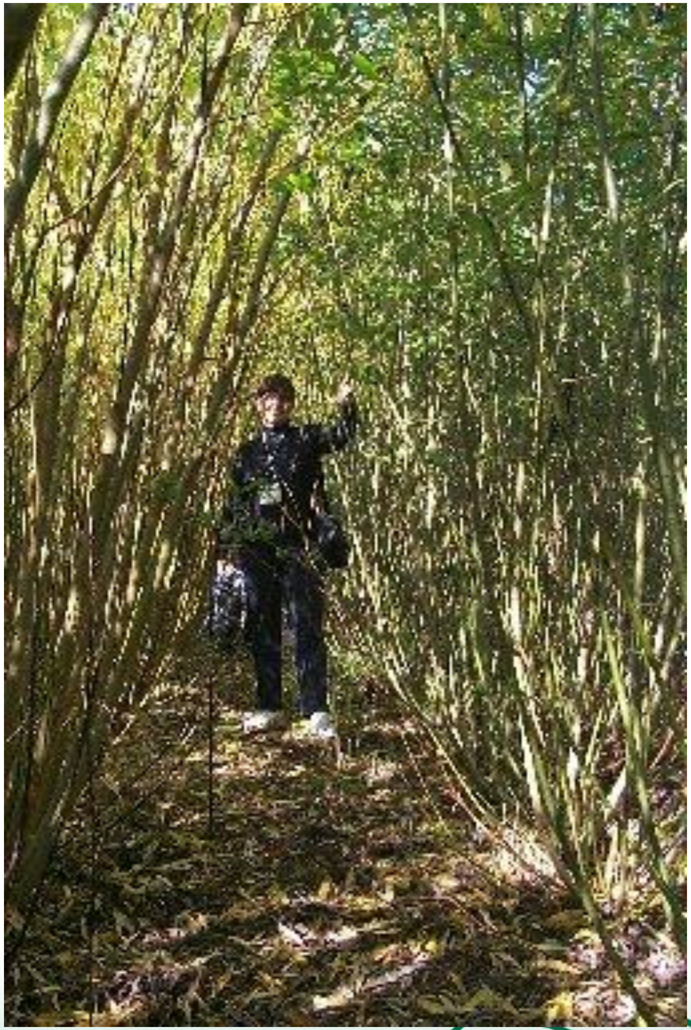
Bioenergy Crops--Willow

Status as of ~ yr 2000

- **Hybrids of *Salix spp. – mostly from Europe***
- **Produced in tight, double-spaced rows with coppice regrowth**
- **Harvested every 3 years**
- **Currently limited to Northeast and North Central Regions**
- **BFDP sponsored R&D 1990-2002 Breeding, Yield trials, Sustainable Management, Harvesting, Operational trials, Molecular genetics**
- **Farmers involved in project**

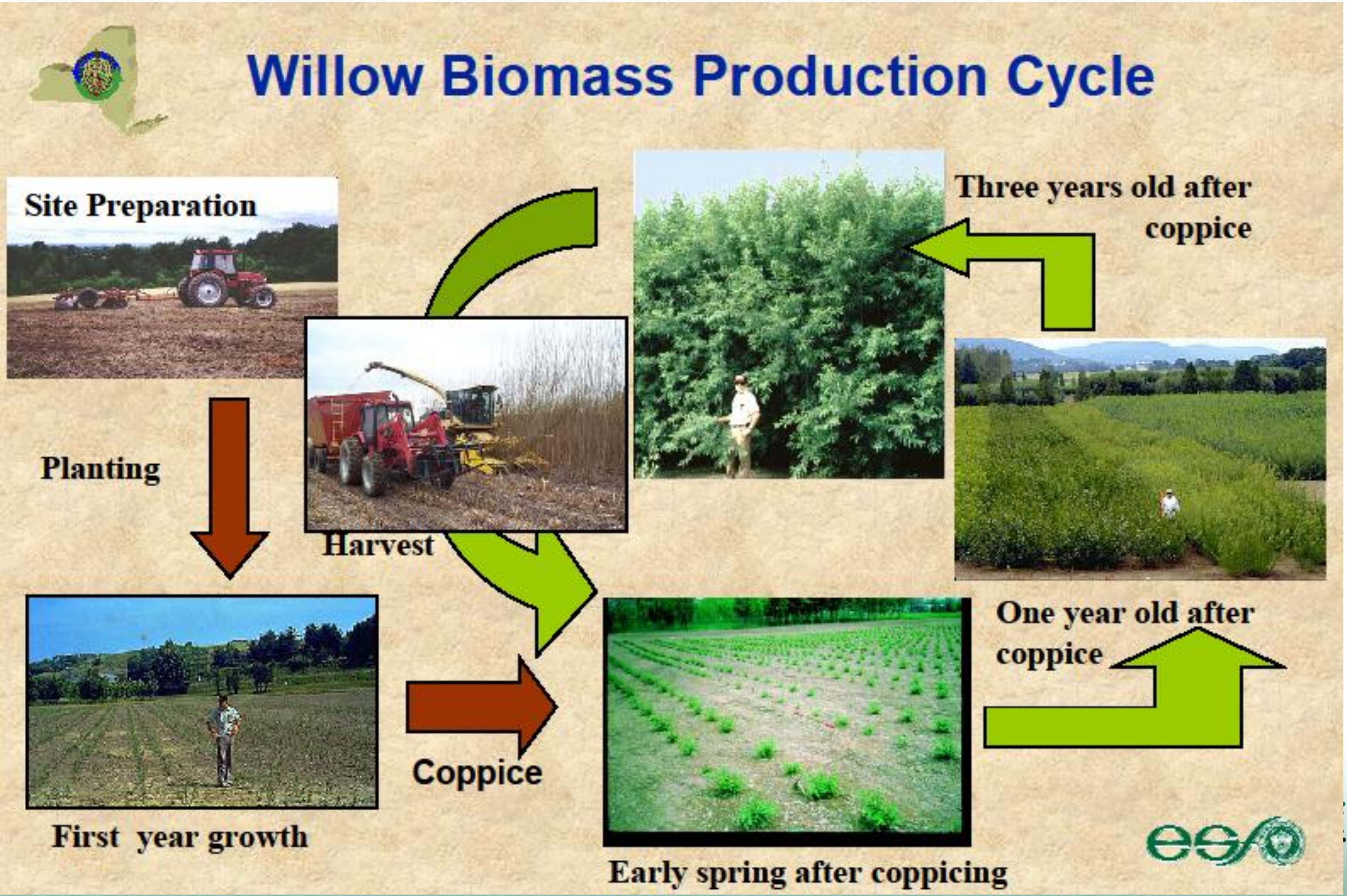
Willow is produced on cropland at ½ to 1 m spacings, harvested in 3 years, using special harvest equipment,

Species trials – double spaced rows



Willow ready for harvest

Coppice willow crops are planted at very high density and harvested in 3 years



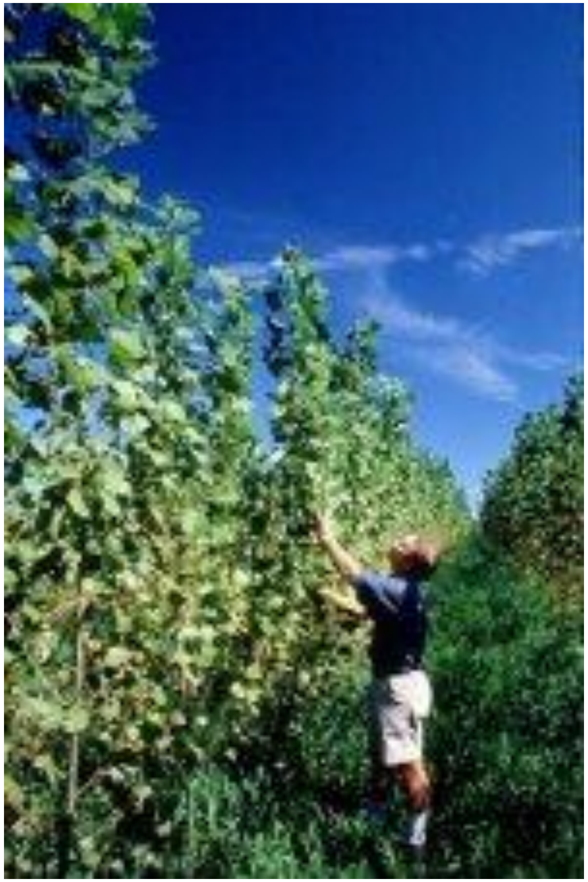
Challenges of coppice willow SRWC systems.

- High density plantings = high establishment costs but very short rotation = relatively immediate payment
- Specialized harvesting equipment is required. Harvest equipment developments (2008-2012) have substantially reduced costs
- Coppice willow must be harvested during the dormant season to assure that re-growth will occur.
- Winter-only harvest = long storage and/or need for alternative feedstocks for portion of year
- Coppice systems assume up to 10 harvest cycles before replanting – great for soil building, but does not facilitate quickly taking advantage of genetic improvements

Bioenergy Crops--Hybrid Poplar

Status in about yr 2000

- Hybrids are more productive than pure cottonwood species.
- Recommended spacings ranged from 2.5 to 4 m to with harvest at 6-10 years depending on region
- Harvest with conventional agricultural and forestry equipment
- Continuous breeding for yield and disease resistance required
- BFDP sponsored R&D in 1990-2002 Breeding, Yield testing, Host-pathogen interactions, Soil Carbon, Molecular genetics, Genetic transformation, Sustainable management, Harvesting, Operational Trials

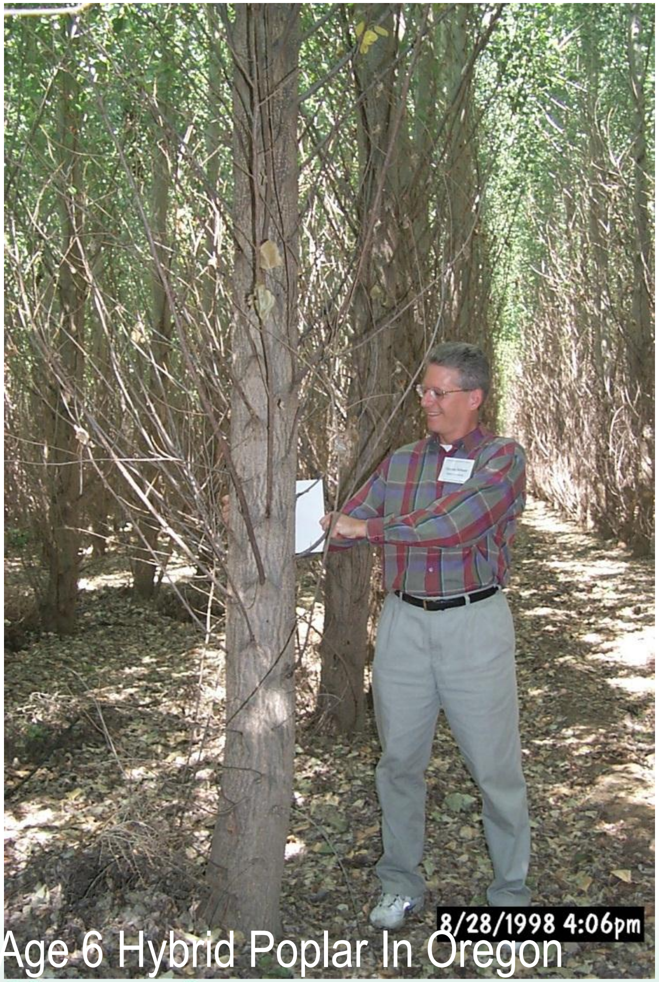


2^{nd} yr growth in PNW

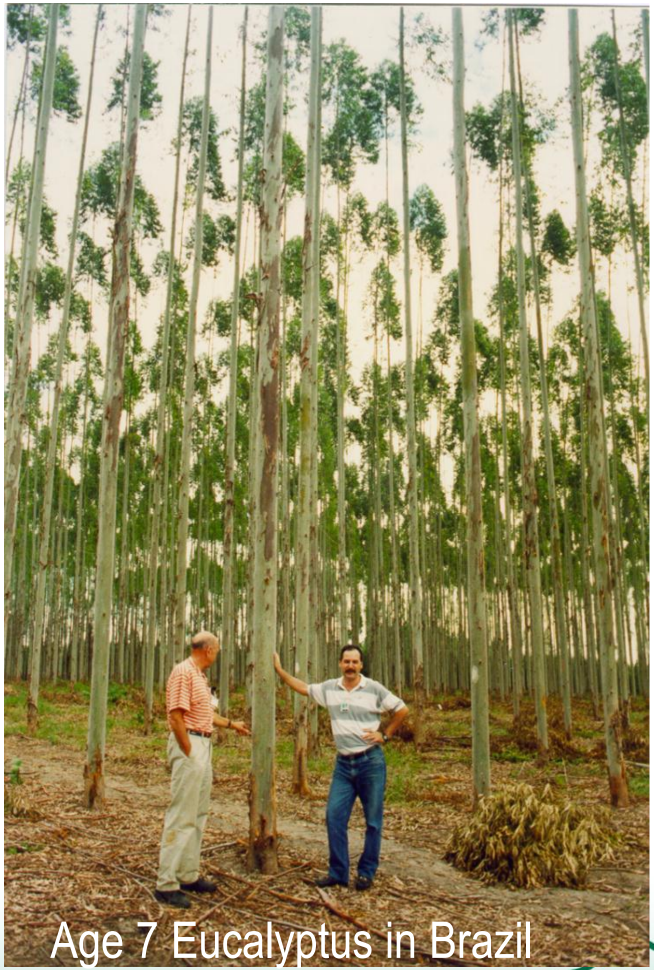
In early 1980's hybrid poplars tested in high density plantings, later abandoned due largely to lack of harvesting technology, cutting costs.

Hybrid poplar in Pacific Northwest at Age 4 planted at 2.0 x 2.0 meters

Very rapid tree growth (~15-25 Mg/ha/year) is obtainable where plenty of sunlight, water and space are available
Challenge is obtaining similar growth at tight spacings or under poorer growing conditions

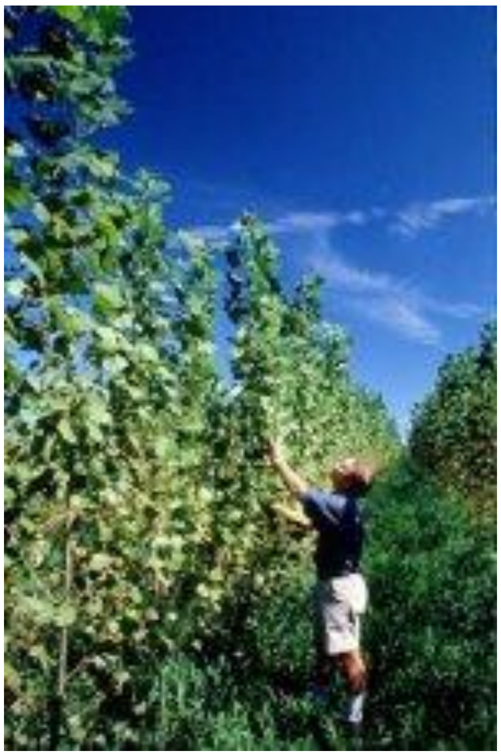


Age 6 Hybrid Poplar In Oregon



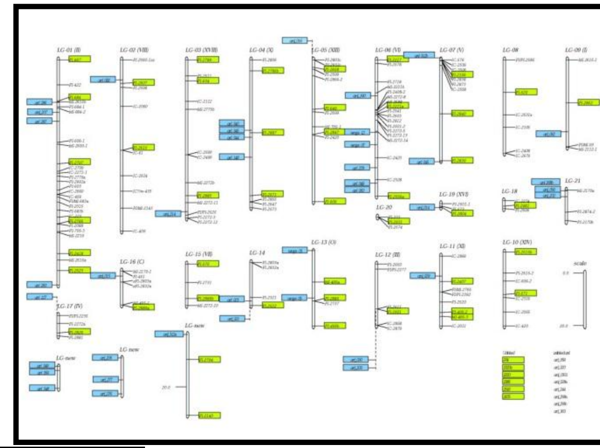
Age 7 Eucalyptus in Brazil

Poplars are produced for fiber on cropland soils at 3-4m spacing in 6-10 yr rotations, weed control is critical, currently harvested with forestry equipment



Early 2nd yr poplar growth

Weed control effects



First hardwood linkage map was a poplar hybrid, complete genome now nearly done.

50,000 hectares commercial

Hybrid poplar 4-6 yr culture is possible with development of better equipment options .

Planting options

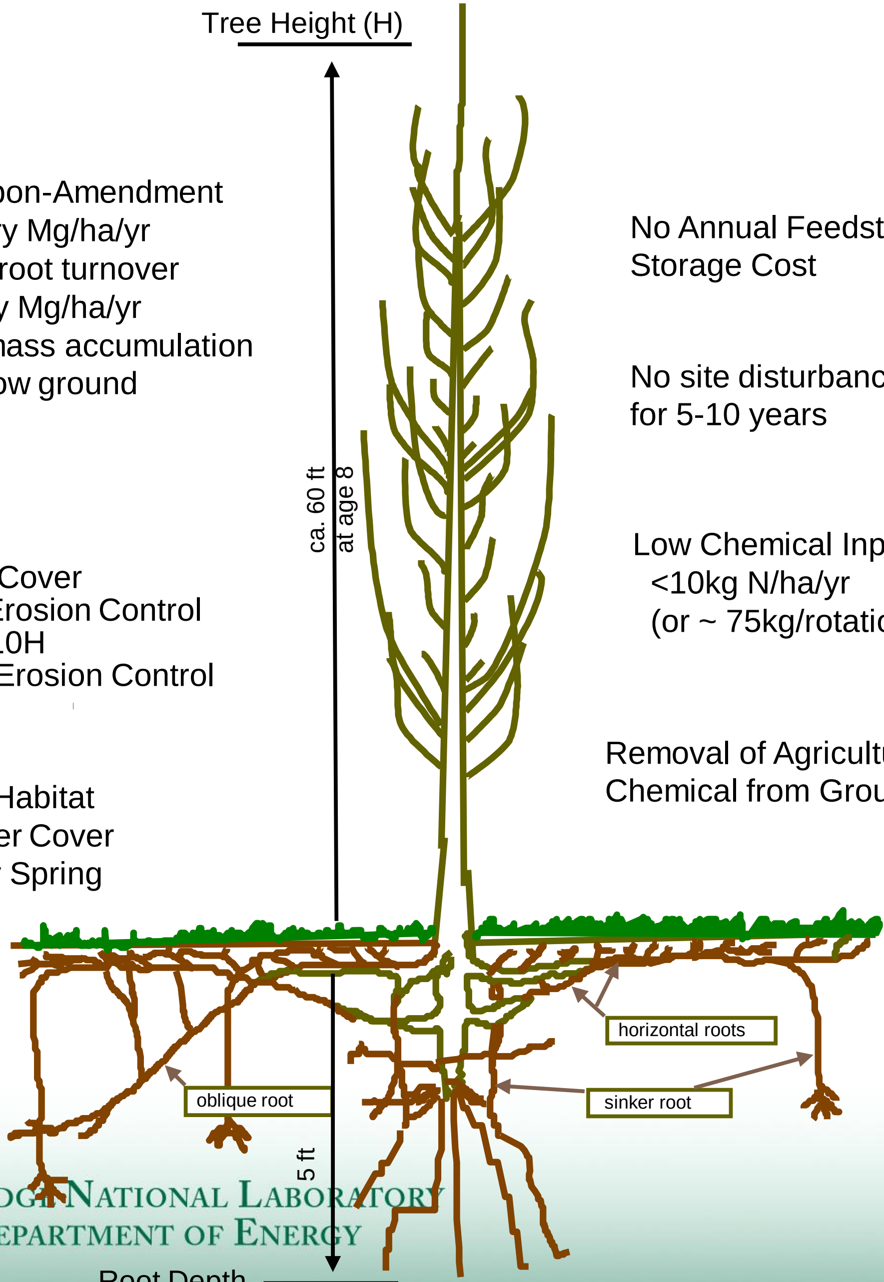
Cutting production in stool beds

1st yr poplar growth in MN

Age 5 poplar in MN

New harvester under development will greatly reduce costs – on flat lands

ATTRIBUTES OF POPULUS



Soil Carbon-Amendment
~ 1.4 dry Mg/ha/yr fine root turnover
~2.5 dry Mg/ha/yr biomass accumulation below ground

Perennial Cover
- Wind Erosion Control up to 10H
- Water Erosion Control

Wildlife Habitat
- Winter Cover
- Early Spring

No Annual Feedstock Storage Cost

No site disturbance for 5-10 years

Low Chemical Input
<10kg N/ha/yr
(or ~ 75kg/rotation)

Removal of Agricultural Chemical from Ground Water

Life History

Fast-growing perennials
Nine native species and numerous hybrid clones

Cultural Practices

Short rotation forestry on agricultural land

Productivity Potential

10 to 25 dry Mg/ha/yr

Native Range of All North American *Populus*

Pines largely ignored as bioenergy crops until recently.

Loblolly pine can be a short-rotation crop

2.5-year-old loblolly pine at 4840 trees per acre, in Robeson Co., NC. Closely-spaced planting regimes such as this can be used to produce both feedstocks for biofuels and traditional forest products on a 20- to 30-year rotation, providing added value to landowners

From:

NC State University McKeand et al. 2008 present-ation

Loblolly pine can be a dedicated energy crop with harvest at 8-16 yrs

Site preparation and planting

Replant

Seedling production

Fertili-
zation
and
weed
control

Harvest

Challenges associated with short rotation woody crops single-stem systems

- Single stem SRWC production requires forestry size equipment - thus planting and harvesting will not likely be performed by farmers.
- Farmers may only participate by leasing the land – current tendency is to lease their worst cropland.
- Most hardwoods require marginally good to good cropland , pines can be planted on lower quality land but still require intensive management for excellent growth
- SRWC will be most profitable where large parcels and relatively contiguous land with low slope is available (reduces equipment and transport costs)

Selection of appropriate energy crops involves consideration of several factors

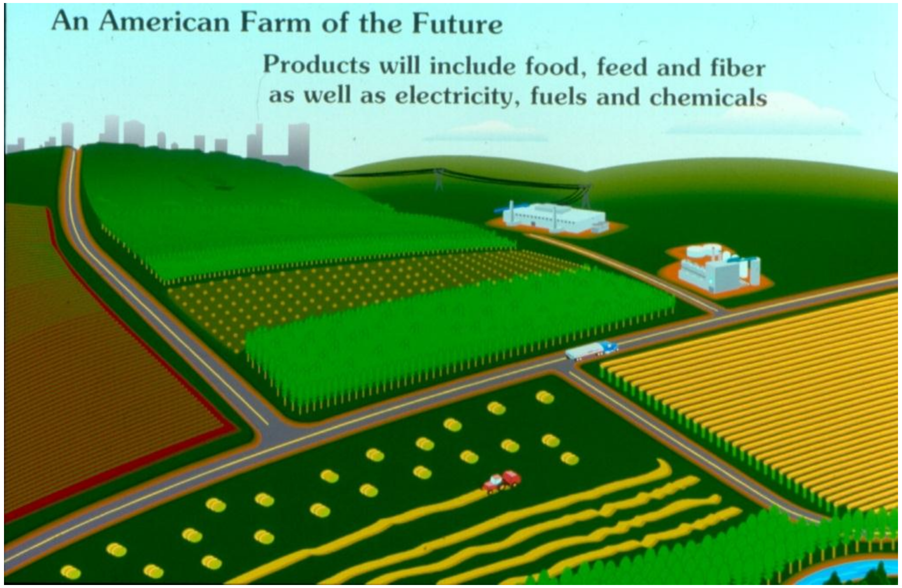
- Feedstock quality requirements for planned energy conversion technology
- Land base available near the conversion facility (25-50 mile range)
- Biological suitability of crops for the type land base available
- Availability of research information and/or experienced crop producers
- Technology for growing and harvesting the crop sustainably on the available land base.

The conversion technology dictates feedstock quality preferences and processing requirements.

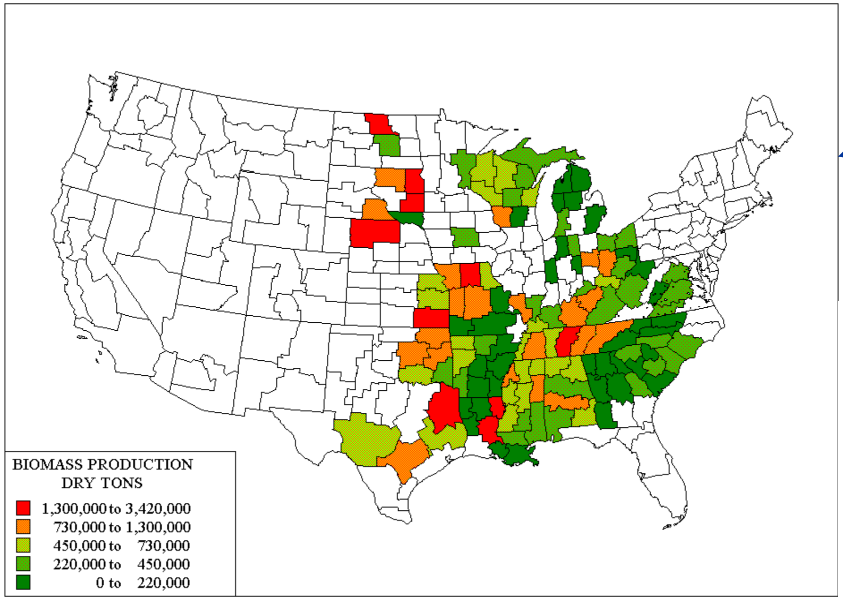
- Thermal conversion (combustion and gasification)
  - High btu, low ash, low tars, low alkali content
  - low moisture content, particle size
  - Most woods & grasses acceptable; grasses tend toward higher ash & silica
- Biochemical conversion
  - High sugars, ease of degradation
  - No extractives eg. tars
  - May eliminate suitability of pines
- But quality of a biologically suitable crop can be modified by genetic selection or transformation, crop management, and processing approaches!

Lessons learned from operational scale biomass demonstration projects and systems studies

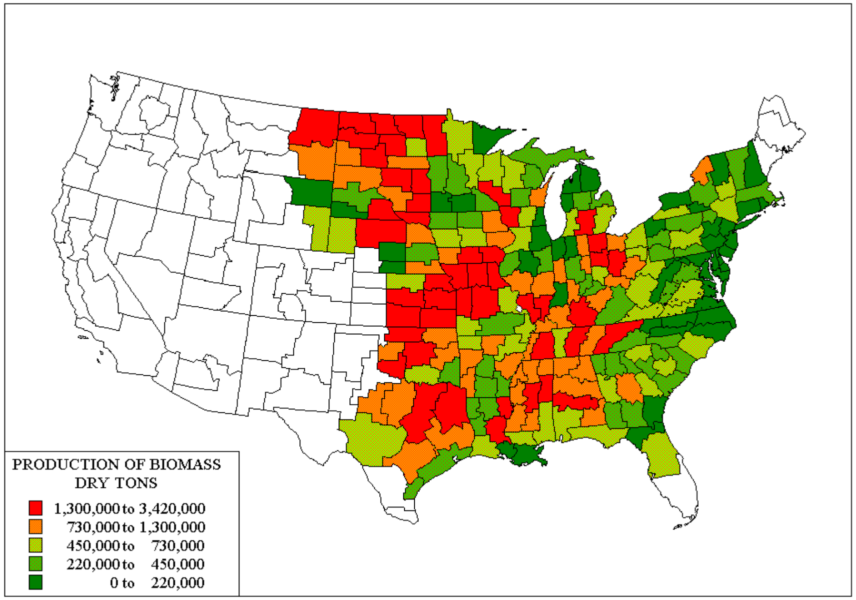
- Crop productivity is only one aspect of commercial viability
- Supply logistics issues often are major barriers
  - Harvesting requirements
  - Storage and processing needs
  - Quality requirements
- Many non-technical and institutional barriers exist
  - Policy barriers
  - Business/market development barriers
  - Fossil fuel prices
  - <u>Farmer profitability potential</u>



Areas Supporting Predicted Potential Biomass Production are a Function of Price, Production Restrictions, and Subsidies



Scenario 1: $33/dMg (farmgate) with wildlife restrictions and 75% of CRP land subsidy - 77 million dry Mg of switchgrass and poplars



Scenario 2: $44dMg (farmgate) with no restrictions and 75% of CRP land subsidy - 170 million dry Mg of mostly switchgrass

Billion ton feedstock vision

- 5% of nation's power, 20% of transport fuels, and 25% of chemicals by 2030
- Combined target is 30% of current petroleum consumption
- What are the constraints
  - Annual production must be sustainable
  - integrated feedstock supply system (reliability, quality, and consistency)
  - economic profitability for all in the feedstock supply chain
  - acceptable life-cycle environmental impact
  - net positive social impacts (production and products)

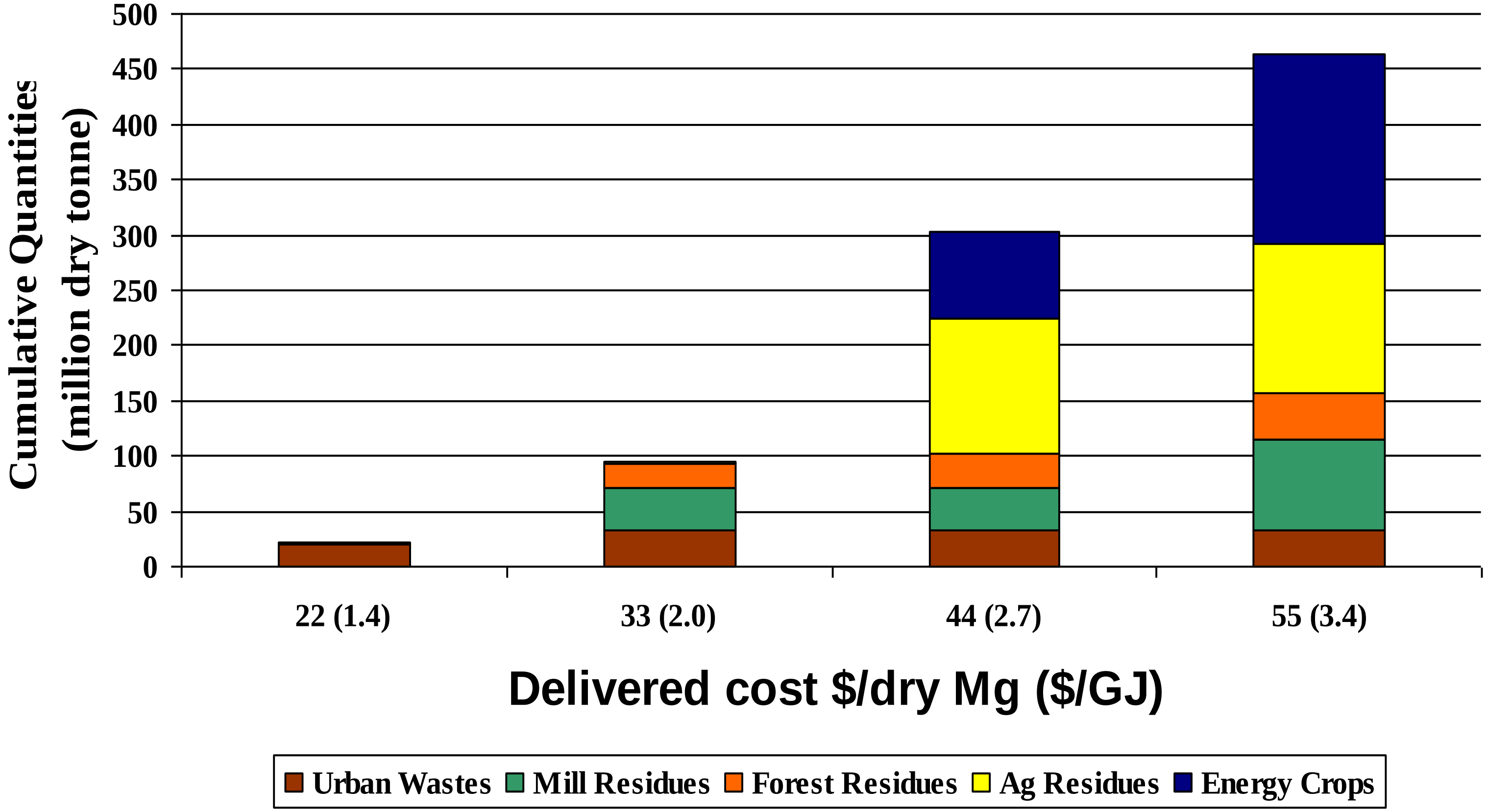
· *Biopower* - Biomass consumption in the industrial sector will increase at an annual rate of 2 percent through 2030, increasing from 2.7 quads in 2001 to 3.2 quads in 2010, 3.9 quads in 2020 and 4.8 quads in 2030. Moreover, biomass use in electric utilities will double every ten years through 2030. Biopower will meet 4 percent of total industrial and electric generator energy demand in 2010 and 5 percent in 2020.

· *Biobased Transportation Fuels* - Transportation fuels from biomass will increase significantly from 0.5 percent of U.S. transportation fuel consumption in 2001 (0.147 quads) to 4 percent of transportation fuel consumption in 2010 (1.3 quads), 10 percent in 2020 (4.0 quads), and 20 percent in 2030.

· *Biobased Products* - Production of chemicals and materials from biobased products will increase substantially from approximately 12.5 billion pounds, or 5 percent of the current production of target U.S. chemical commodities in 2001, to 12 percent in 2010, 18 percent in 2020 and 25 percent in 2030.

Figure 1. Biomass feedstock vision goals. Source: U.S. Department of Energy, *Roadmap for Agriculture Biomass Feedstock Supply in the United States*, DOE/NE-ID-11129, November 2003.

Potential Available Lignocellulosic Feedstock Quantities (ORNL, 1999)



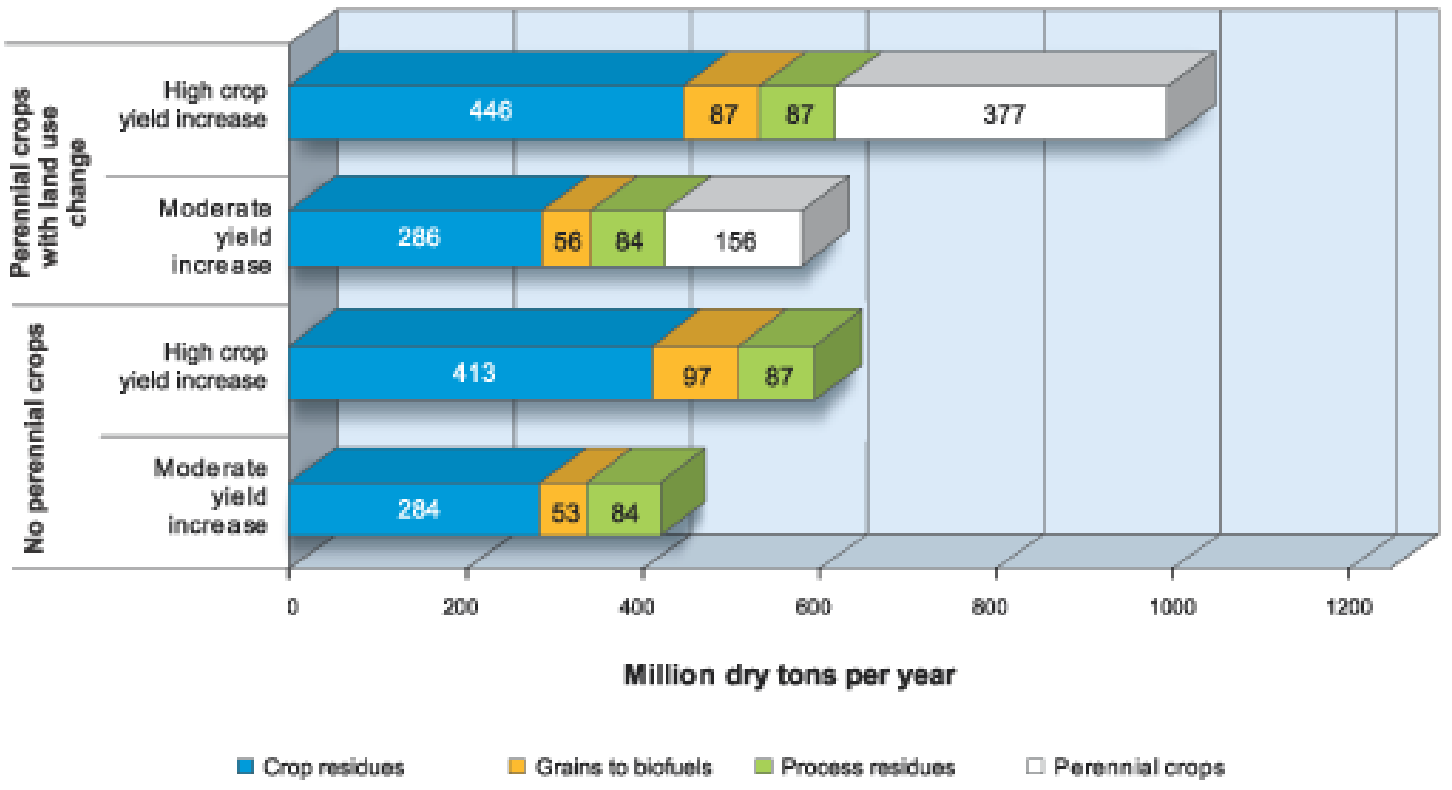
All types of biomass, plus technology advances, are needed to provide significant supplies

What if?

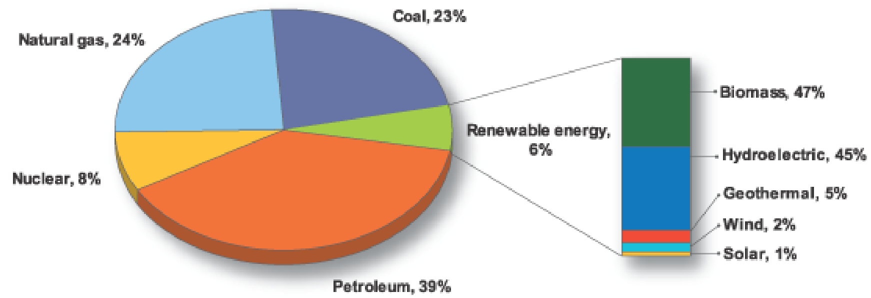
- All major crops were harvested for multiple uses (with sufficient residues left on soil for sustainability)?
- Protein for animals and cellulose for ethanol could be efficiently derived from the same crop (eg. alfalfa or switchgrass)?
- Average Switchgrass yields could be doubled and/or it could become a nitrogen fixer?
- Field harvest techniques for grasses could efficiently separate leafy parts(protein source) from stems (lignin and cellulose source)?
- Grass storage and handling issues could be solved cheaply?
- Trees could be domesticated and yields doubled?
- Tree plants could be more cheaply and quickly harvested?
- Grasses, trees and grains were more drought tolerant?

WHAT IS THE CROPLAND POTENTIAL?

- Total resource approaches 1 billion dry tons/year with energy crops [by ~ 2030]
  - Yield increase of 25 - 50% for corn and other small grains, 15 - 30% for other crops
  - Change in tillage practices
  - Residue collection equipment
  - Residues from soybeans
  - The allocation of active cropland, idle cropland, and pasture to perennial crops, yielding 4.7 – 7.4 dry tons/ac; 40 - 60 $x10^6$ acres



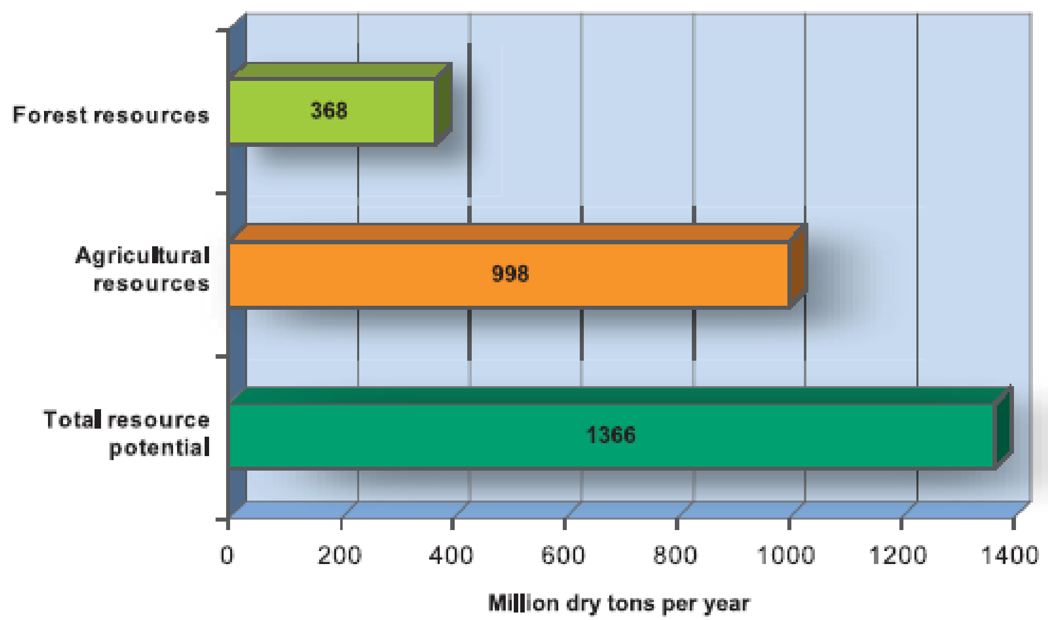
ARE THERE SUFFICIENT BIOMASS RESOURCES TO REPLACE A SIGNIFICANT FRACTION OF THE NATION'S PETROLEUM REQUIREMENTS?



Biomass Consumption	Million dry tons/year
Forest products industry	
Wood residues	44
Pulping liquors	52
Urban wood and food & other process residues	35
Fuelwood (residential/commercial & electric utilities)	35
Biofuels	18
Bioproducts	6
Total	**190**

- Forestlands and agricultural lands contribute 190 million dry tons of biomass - 3% of America's current energy consumption.

- Yes, land resources can provide a sustainable supply and still meet food, feed, and export demands
- Estimates are reasonable given trends and time for scale-up & deployment
- R&DD, policy change, stakeholder involvement required



Were the 2005 "Billion Ton" potential estimates unrealistic? I don't think so (for the future).

- Billion Ton update using economic and environmental constraints came up with a similar estimate.
- Conventional crop yields continue to increase with improved drought resistance.
- New research at universities and by private industry continues to develop higher yielding energy crops (eg. Miscanthus, and new poplar clones).
- Genomic research is resulting in many discoveries that have potential for increasing yields and drought tolerance.
- New planting and harvesting techniques are now being demonstrated for poplars, willows and grasses, with resultant cost reduction.

Examples of private industry developments include:

- ***Energy Performance Systems*** **had developed a 6 row injection planter for trees propagated by cuttings and a row tree continuous harvester design for handling whole trees.**
- ***Biosystems Engineering*** **has developed a very robust continuous harvester/chipper that can handle trees up to 8 inches dbh.**
- ***New Energy Farms*** **has developed "specially created planting propagules" that can be planted mechanically like seeds.**
  - **Reduces planting costs for Miscanthus by 50%**
  - **Planting materials are easier to handle**
  - **New cultivars can be bulked up to market volumes much faster**
- ***Arbor Gen*** **is testing high yielding eucalyptus species & varieties with improved frost tolerance for southern U.S. and testing many hybrid poplar clones for the southeastern US.**

Energy crop establishment

CEEDS™

CROP EXPANSION ENCAPSULATION & DRILLING SYSTEM

Aims

To make perennial energy crop establishment as simple as drilling a row crop, scalable, low cost and maximize the yield potential of a cultivar.

Energy crop establishment

CEEDS – Key points

- Reverse engineered a seed for veg crops (plus non rhizome option)
- Micronized, highly vigorous vegetative tissue (different types)
- Reduced the establishment price to circa $600-700 acre (Planted)
- Fully scalable, reduced planting weight from 1.5t to 250 Kg Ha (MxG)
- Shipping logistics 5x better than current vegetative tissue
- Fully automatic planting, min till for lower cost
- Combined with agronomy, more effect than breeding (up to 50%)
- Applied to a range of crops, Miscanthus to Sugar Cane

Image shows left rhizome plant establishment right CEEDS establishment after 60 days (Miscanthus)

UT-BATTELLE

Image shows from left to right, CEEDS, plug plant and rhizome after 60 days (Miscanthus). Yellow boxes highlight original propagule size.

UT-BATTELLE

Energy crop management

BiomassDirect©

Created by New Energy Farms and Muddy Boots Software®

Aims

To make it easy for end users to directly aggregate energy crop biomass from farmers directly, without intermediaries.

Energy crop mnageme

BiomassDirect©

Created by New Energy Farms and Muddy Boots Software®

Key points:

- When energy crops are scaled, growers and end users need assistance, current row crop support (on farm) is not cost effective as there is no annual sale.

- Farmers get extension advice specific for their crops, with the ability to trade direct to end users, aim is also to focus on good agronomy, increasing yield easier than breeding.

- End users get direct low cost sourcing of biomass with full sustainability reporting (accurate to field level) and benefits of logistics and yield forecasting.

- Breeders / developers get secure routes for generating per acre/per tonne royalty payments plus access to developmental tools (yield prediction etc)

Managing our lands for energy, food and fiber