Prospects for 2nd Generation Feedstock Technologies

Biotechnology Options for Bioenergy Crops

Richard Flavell

Ceres, Inc.

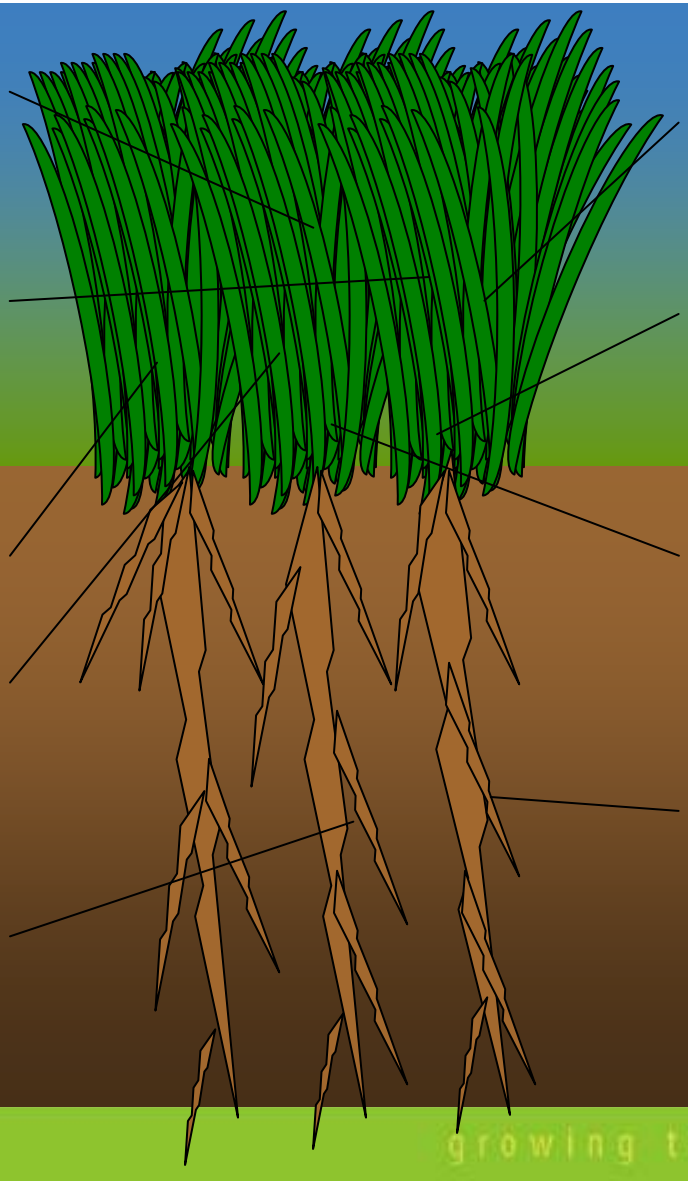
California, USA

Summary Points on Prospects

- **Prospects are excellent but…….**
  - Need to move very rapidly to have a hope of meeting targets
  - Good germplasm collections, biotechnology and strong breeding programs are essential
  - Given the commercialization pressures, improved feedstocks must be in the hands of the industry rapidly

We know what to do and how in principle—we simply need to do it, for short-term success and to build the long term, optimal business

The Perfect Second Generation Energy Crop



High biomass: increased growth rate, photosynthetic efficiency, delayed flowering

Improved composition & structure: higher fuel yield per ton

Disease and pest resistance

Optimized architecture: dense planting, no lodging, easier harvest

Salt, pH and Aluminum tolerance

Rapid and cost-effective propagation

Stand establishment: cold germination, cold growth

Perennial: multi-year crop, efficient nutrient use, high fossil energy ratio

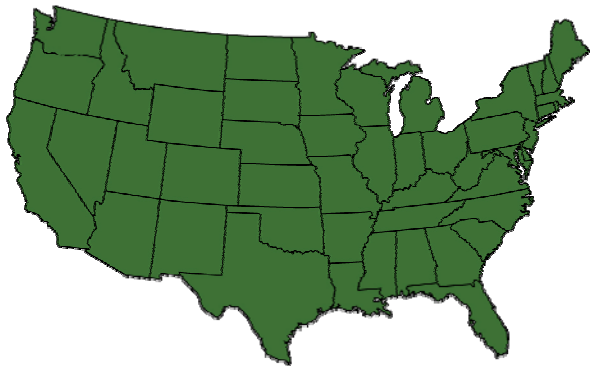
Deep roots: drought tolerance, nutrient uptake, carbon sequestration

growing tomorrow's fuel today

Ceres Energy Crops

Ceres Energy Crops - Target Markets

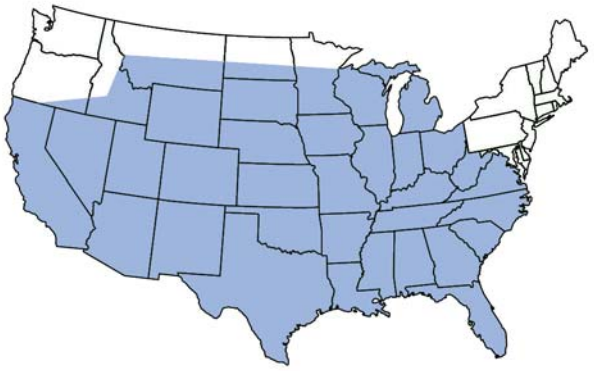
Switchgrass



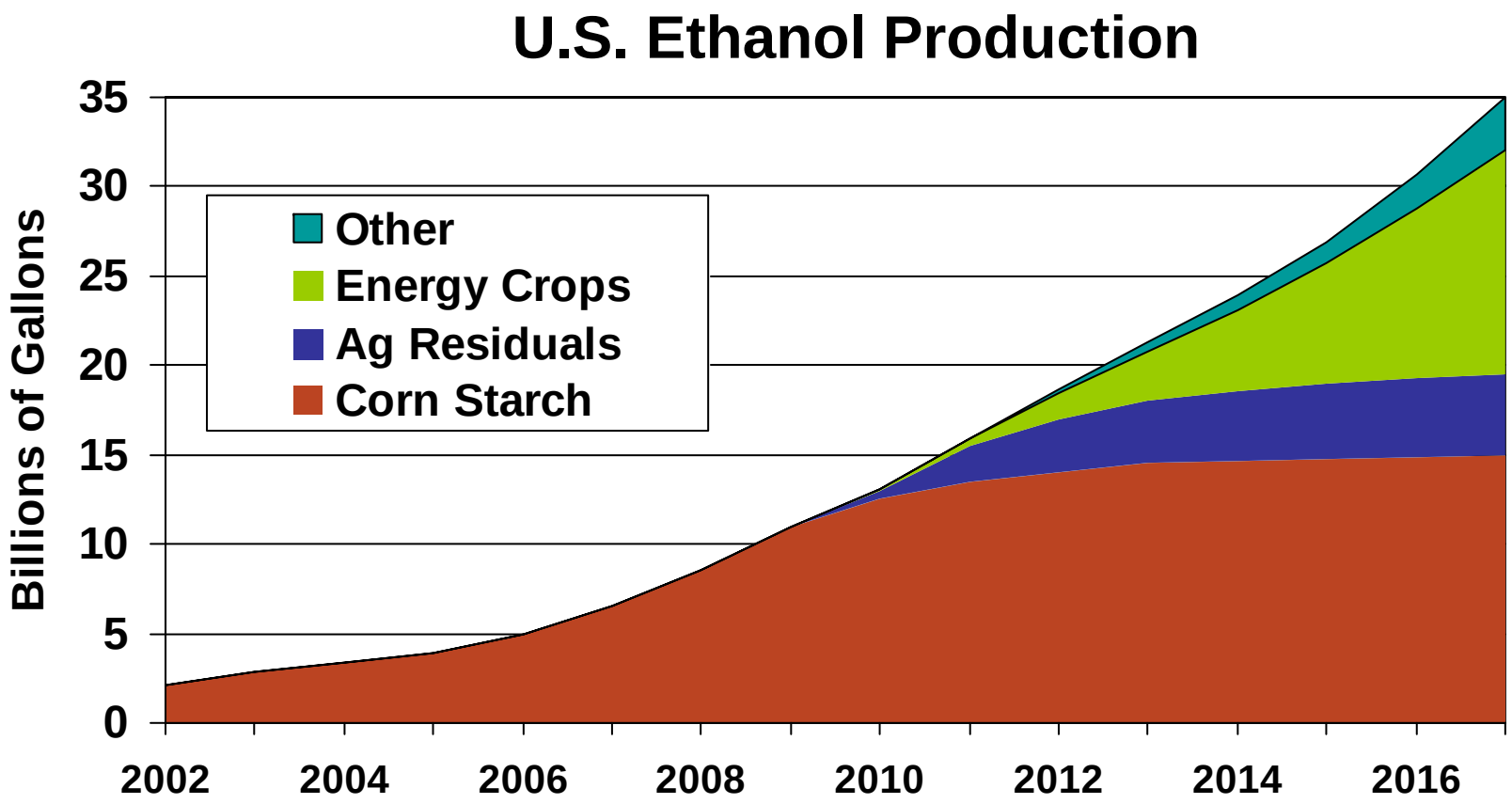
Miscanthus

Energycane

Sorghum



Achieving President Bush's 2017 RFS



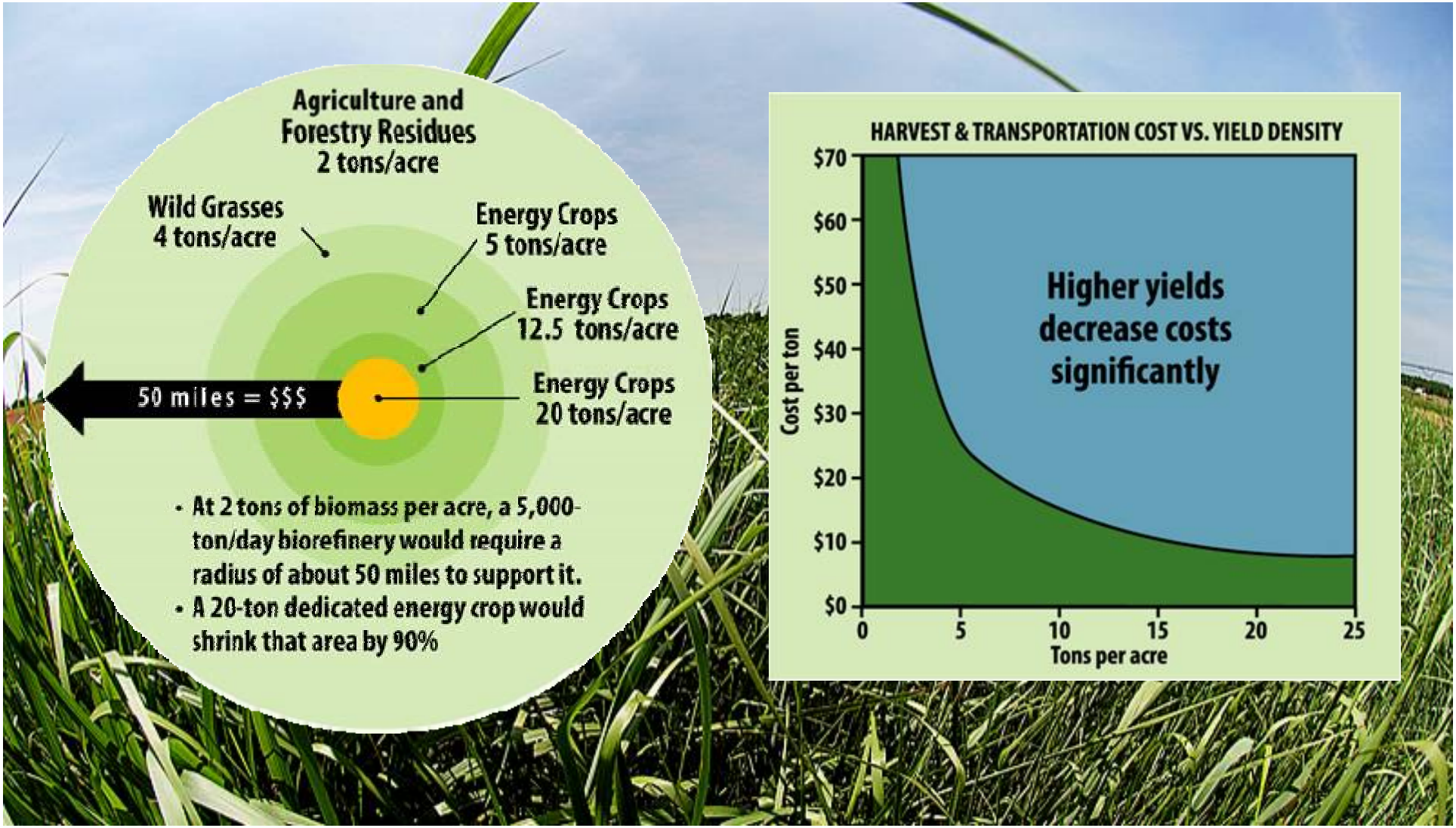
To meet President's Goal

- To provide maximum yields in 2017 need to:
  - Plant crops in 2014
  - Bulk up seed/propagules in 2011-2014

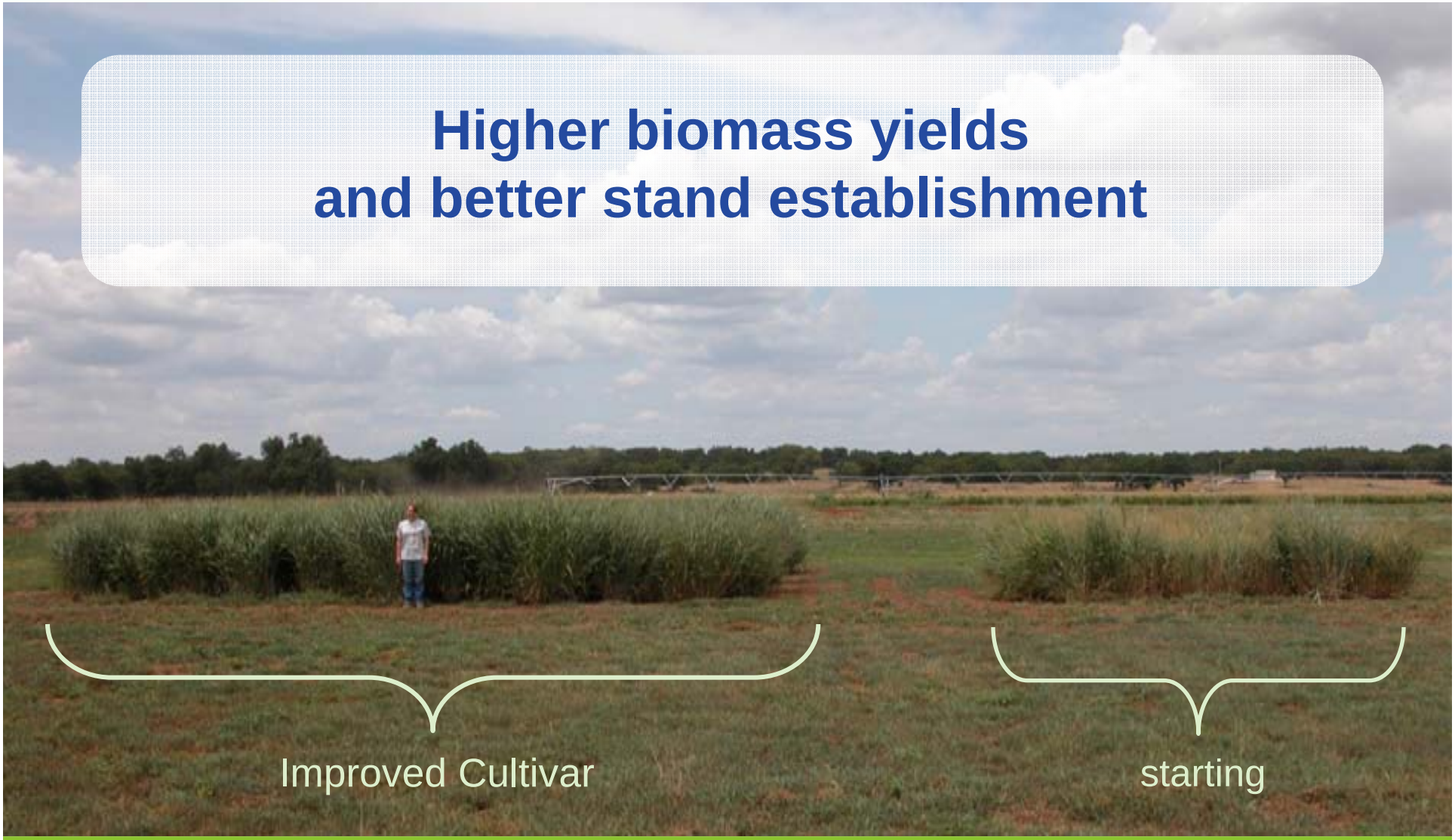
- To have improved seed in 2011 needed to start breeding in 2002-4

We are short of time. We must hurry

The Tyranny of Distance



Improved Switchgrass



Ceres 2006-07 Switchgrass Field Trial Sites

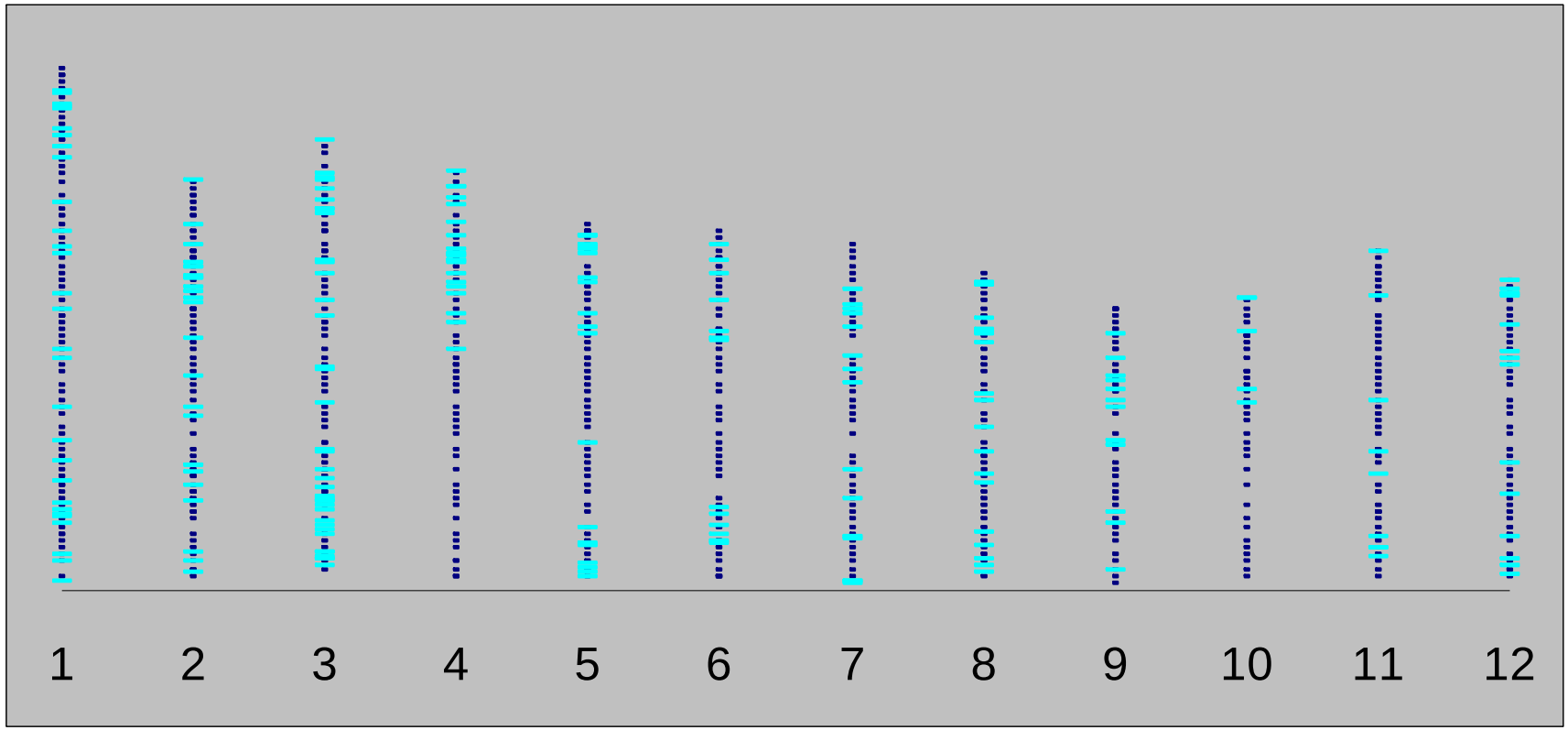
Trait Optimization is Game Changing

Parts of the Equation	Relevant Traits	Impact
Acres	▪ Stress tolerance (e.g. drought, heat, cold, salt)	▪ Growth on marginal acreage helps enable critical mass
Tons per acre	▪ Increased yield (e.g. photosynthetic efficiency)	▪ Lower production and transport costs and increased carbon sequestration
Dollars per acre	▪ Nutrient requirements (e.g. nitrogen utilization)	▪ Lower fertilizer costs and less N2O emissions
Gallons per ton	▪ Composition & structure (e.g. C5/C6, cell wall structure)	▪ Increase theoretical yield of ethanol per ton of biomass
Capital cost of refinery & variable cost per gallon	▪ Composition, structure & enzyme production (e.g. cellulases)	▪ Reduce cost of pretreatment, reduce need for and cost of enzymes, and bring actual yield closer to theoretical
Co-products	▪ Metabolic engineering & sequestration	▪ Enhance overall economics

How to optimize traits as fast as you can

- Start with well-characterized germplasm—choose the best
- Learn how to measure traits reliably and rapidly
- Make as many crosses as possible and assess as many progeny as possible
- Find “easy to measure” molecular genomic or gene expression markers for the traits using information in all crops
- Trial extensively across environments
- Add transgenes as required

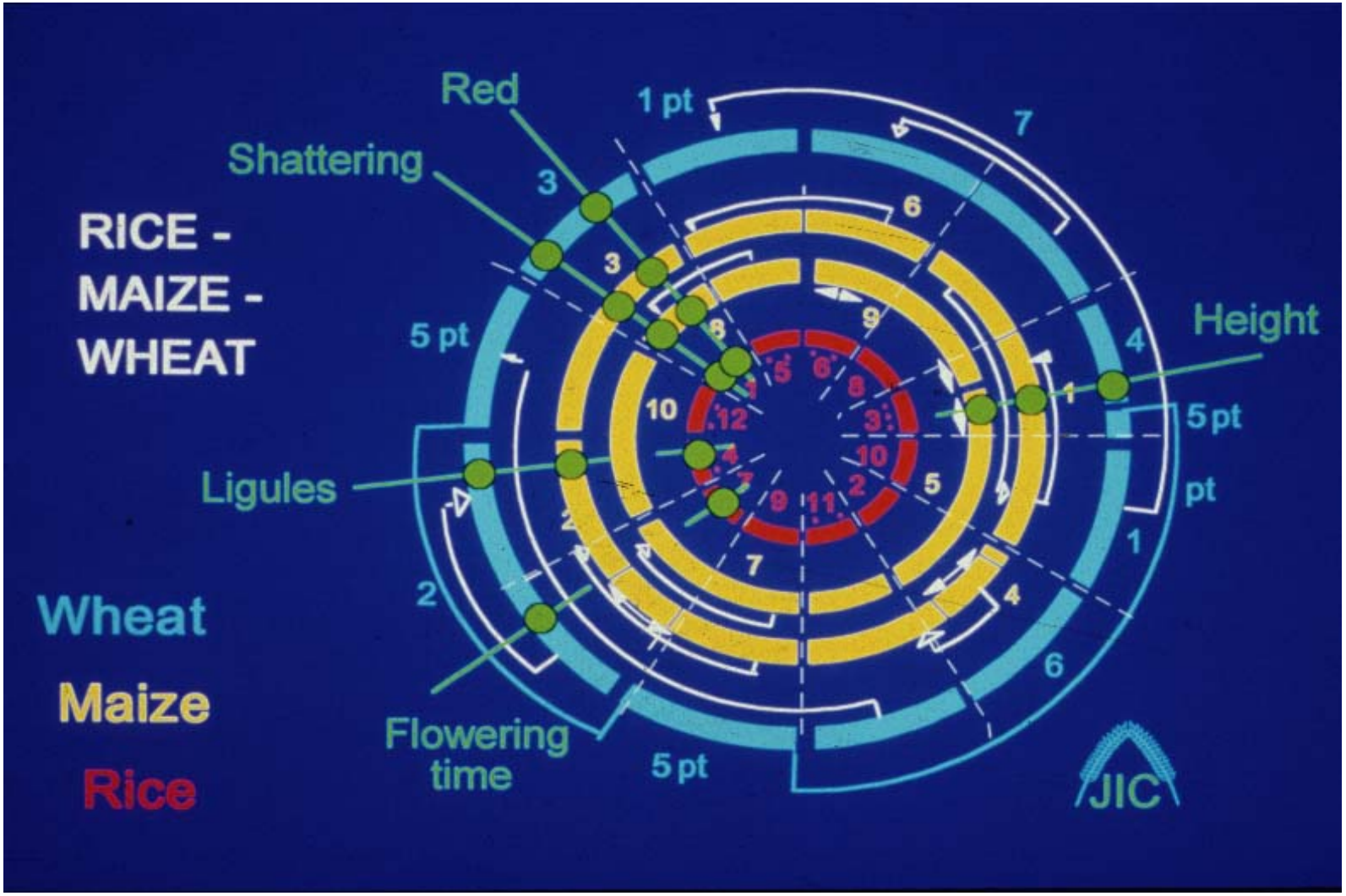
Mapping of gene-trait associations on rice chromosomes



Rice chromosomes

Bright blue lines are Rice genes that are homologous to known trait genes

Predicting Traits Across Grass Genomes

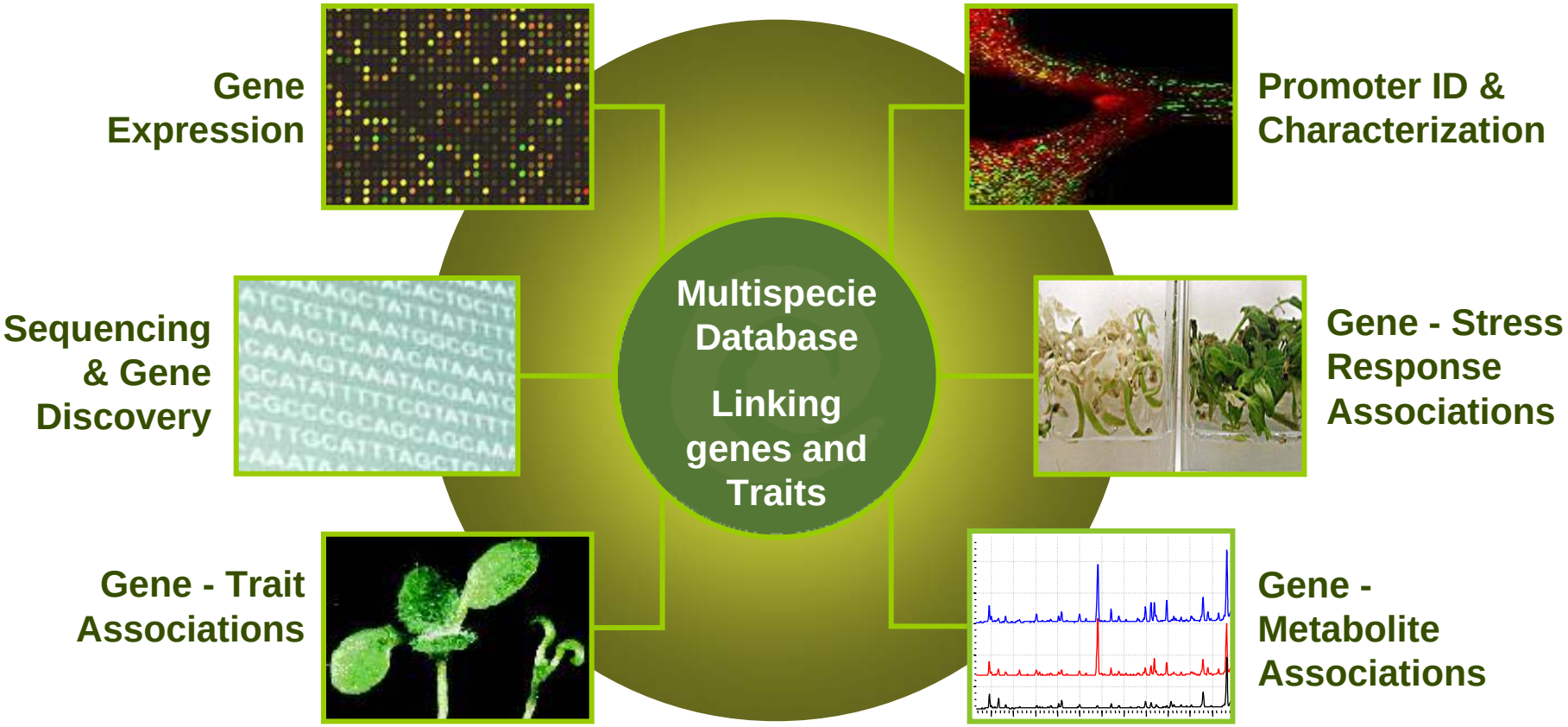


Comparative Genomics and Trait Genetics

- Rice genomes sequenced
- Sorghum genome sequenced
- Corn genome being sequenced
- Other cereal genomes extensively sequenced

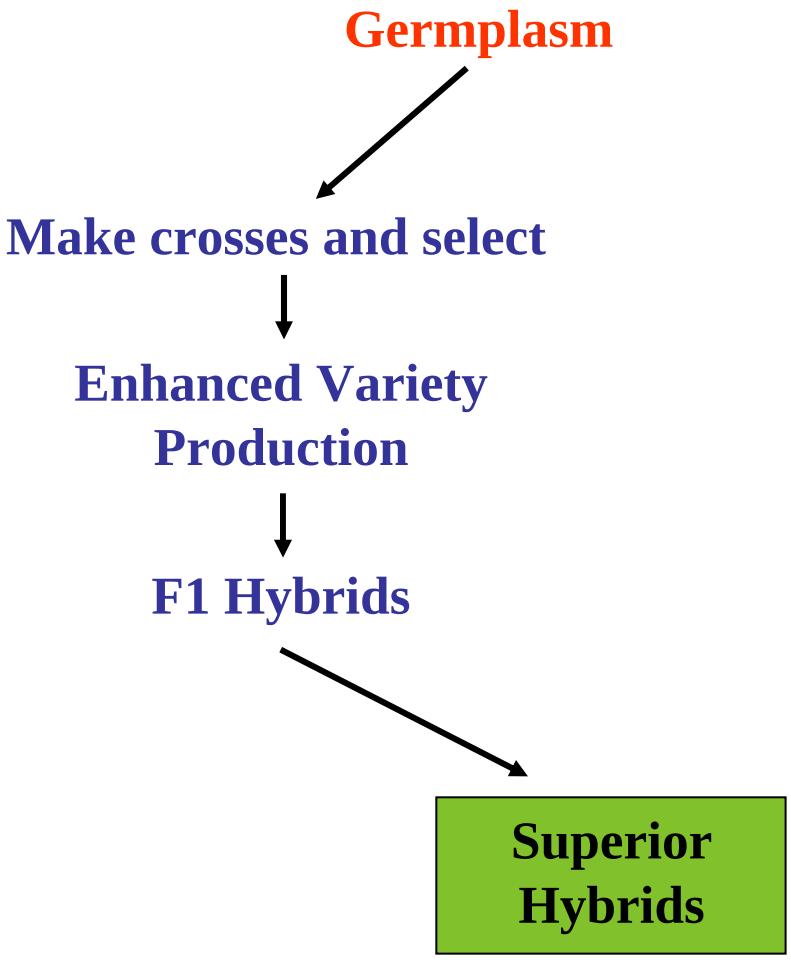
- Gene expression patterns behind traits being determined and compared

Building markers for traits using crop and model plant genomics



Integrate information from corn, sorghum, rice, wheat, barley and arabidopsis genetics and genomics to build optimal Marker Assisted Breeding breeding programs

Germplasm Development



Germplasm Development

DNA Sequencing
Molecular Biology
Bioinformatics

Molecular Markers

Germplasm

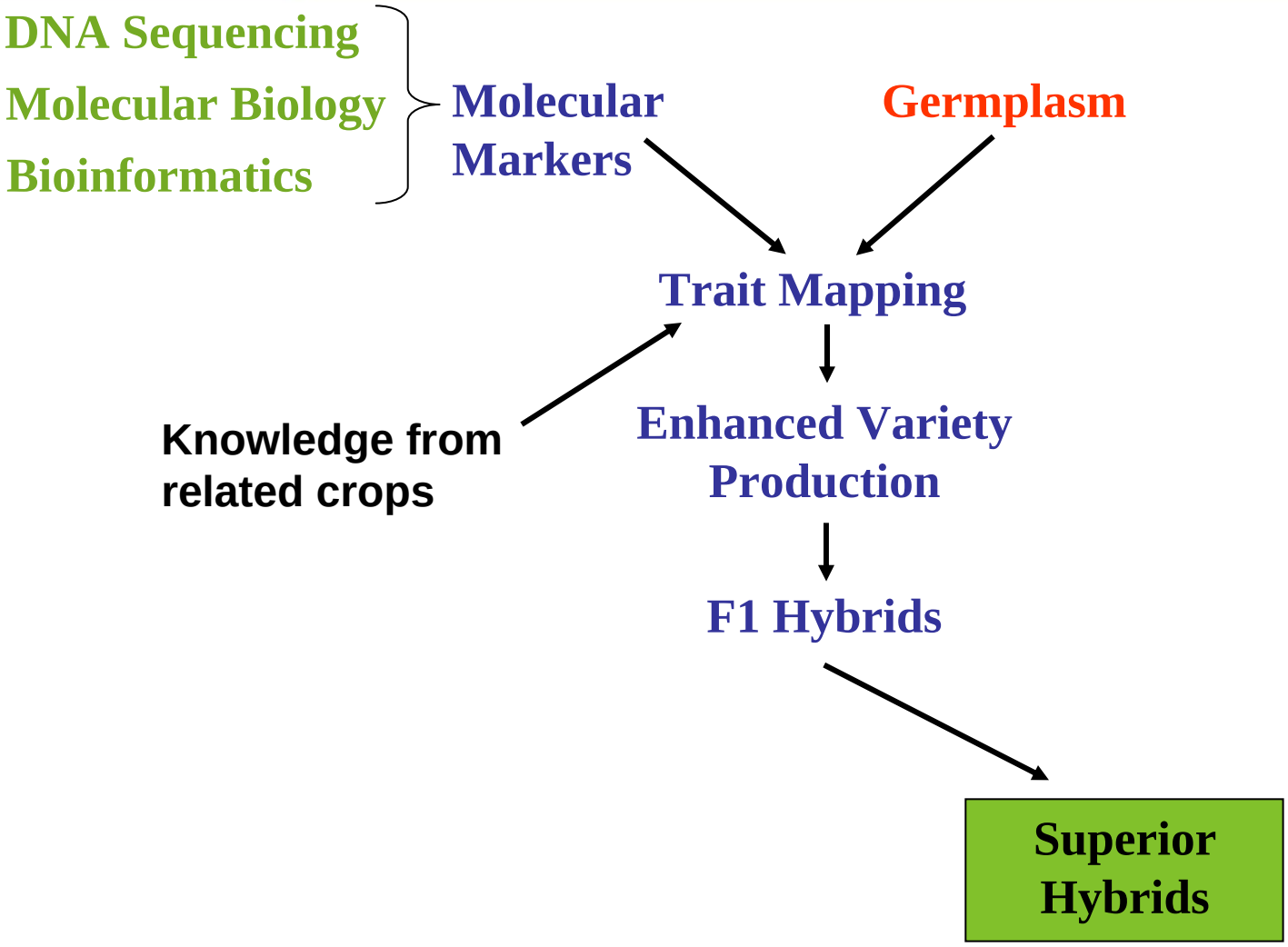
Trait Mapping

Enhanced Variety Production

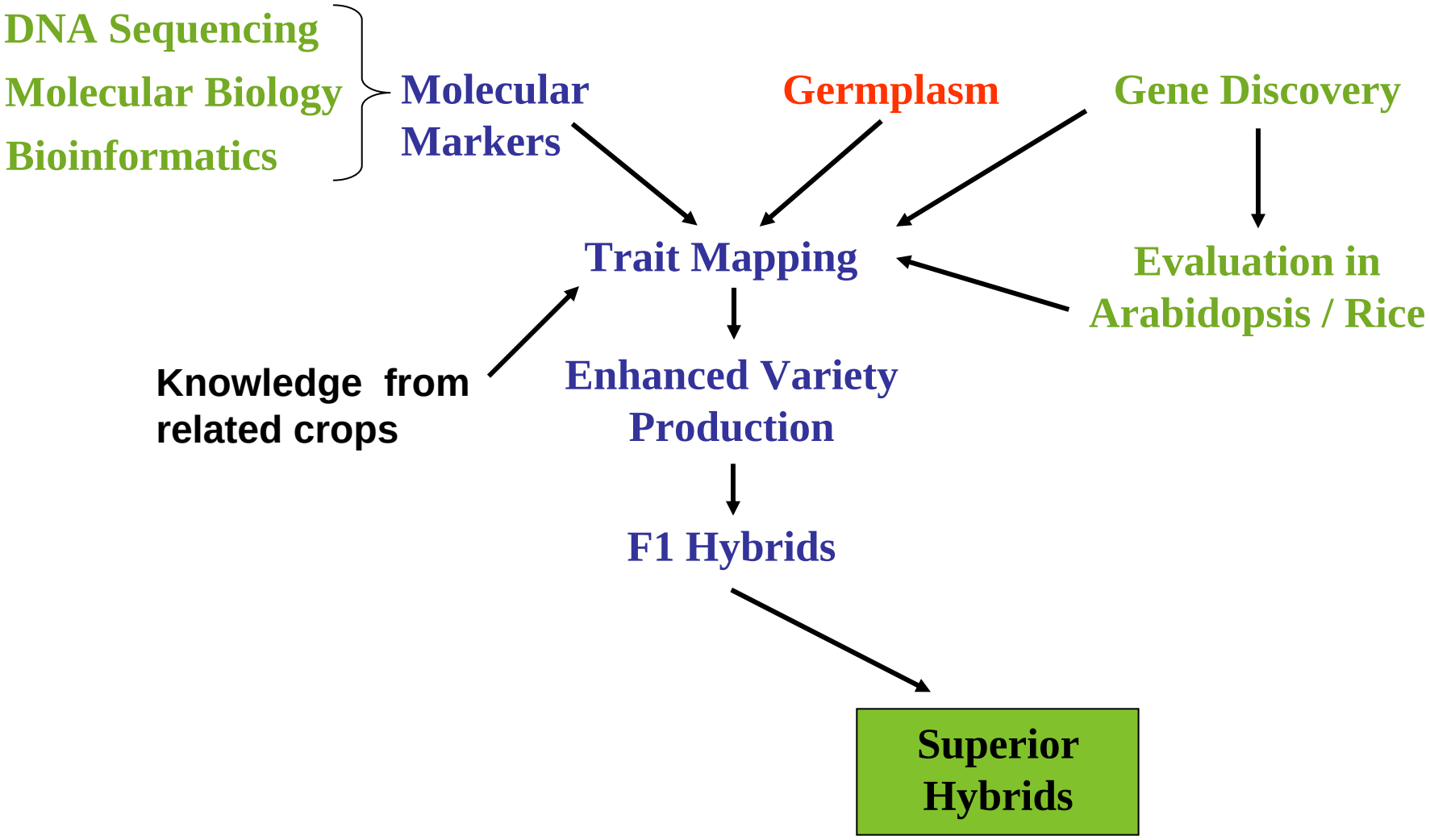
F1 Hybrids

Superior Hybrids

Germplasm Development

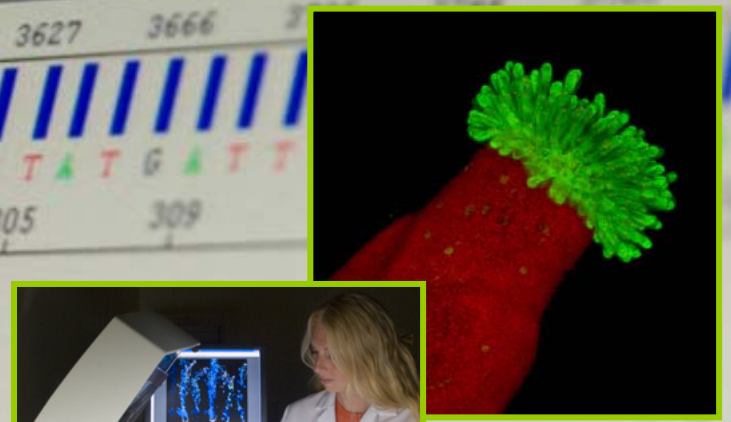


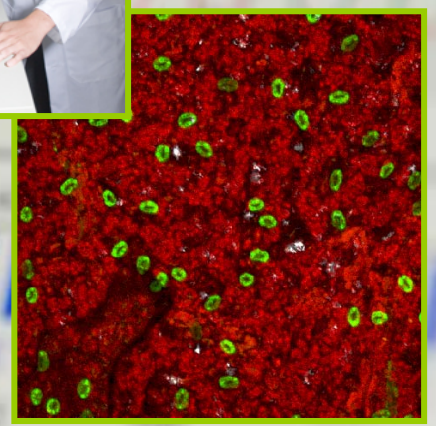
Germplasm Development



Optimize traits with transgenes

- Precisely add new traits
- Expand from single genes to **groups of genes**
- Greater control over **how**, **when** and **where traits** are expressed





Drought tolerance

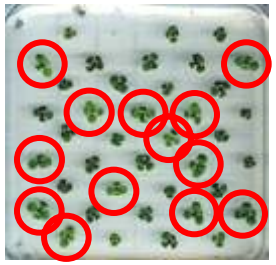
Increased yield

Heat tolerance

Drought recovery

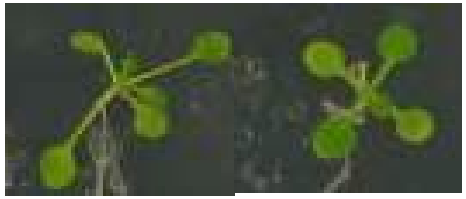
Nutrient utilization

Root growth



Cold germination

Increased biomass



Shade tolerance

Flowering time

Stature control

Salt tolerance

Example: Fewer Agronomic Inputs

Control

New Trait

Nitrogen Use Efficiency

Example: Drought Tolerance

Control

New Trait

Example: Processing Efficiency

Lignin Deposition

Ceres
Reduced Lignin

Wild Type

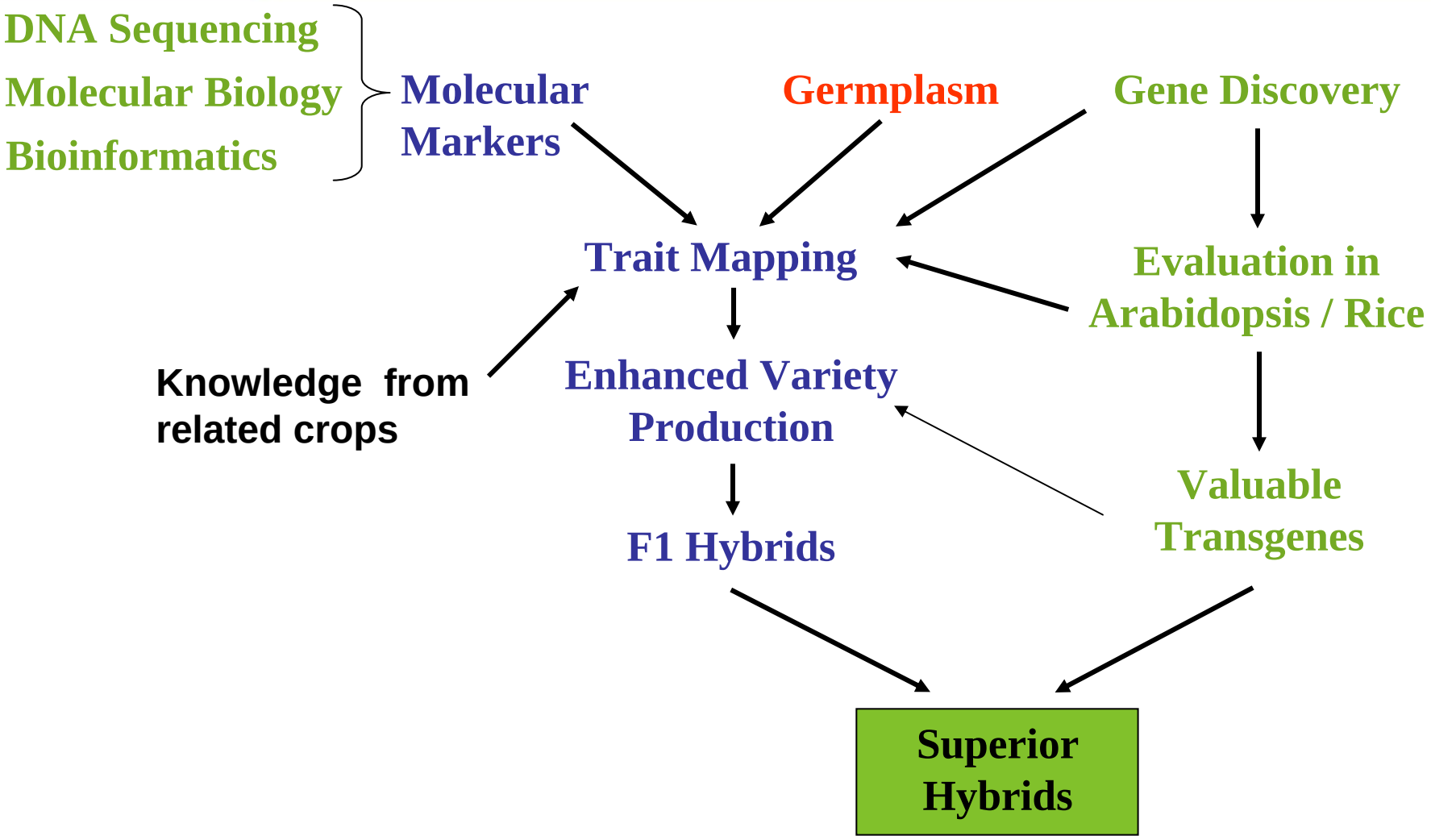
Ceres
Increased Lignin

Ceres has isolated numerous genes involved in the control of lignin production

Evaluating genes for energy crops in Rice Pipeline

- Institute of Crop Sciences
- Chinese Academy of Agricultural Sciences
- South China University of Tropical Agriculture

Germplasm Development

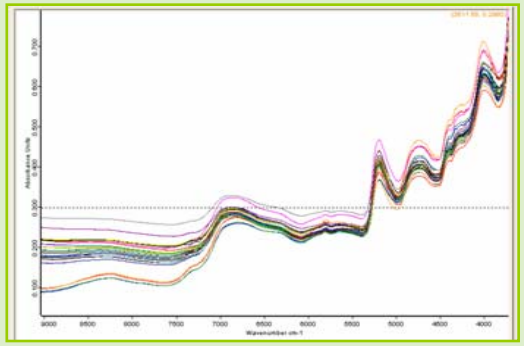


- Composition and Conversion

Rapid Composition Analysis Process

Biomass Samples

NIR Spectra



PCA Sample Selection

What used to take 1 year…

Now takes

Wet Chemistry

3 days

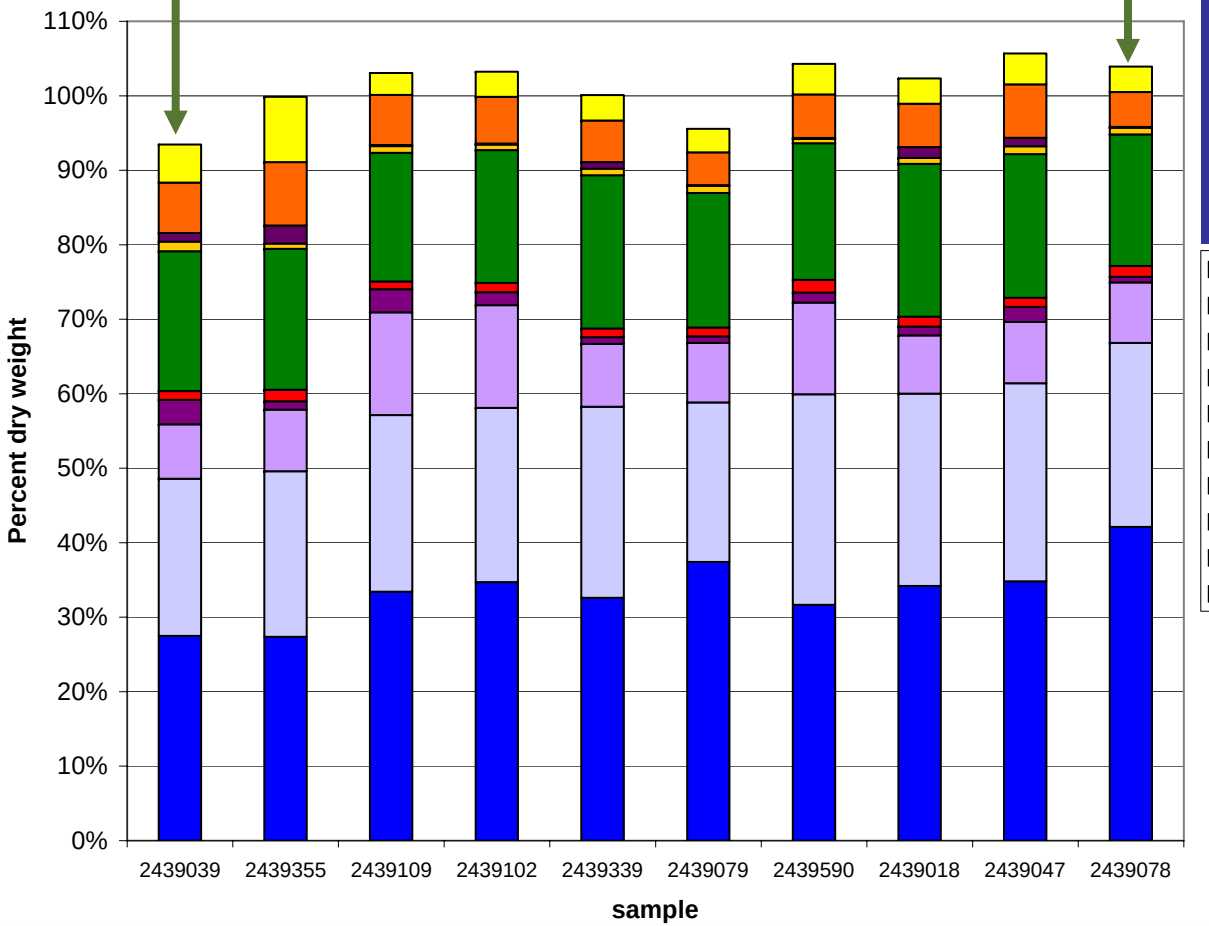
Composition Data

Plant varieties optimized for conversion to biofuels

Diversity in Biomass Composition Impacts Conversion Process Economics

85 gal/T *

117 gal/T *



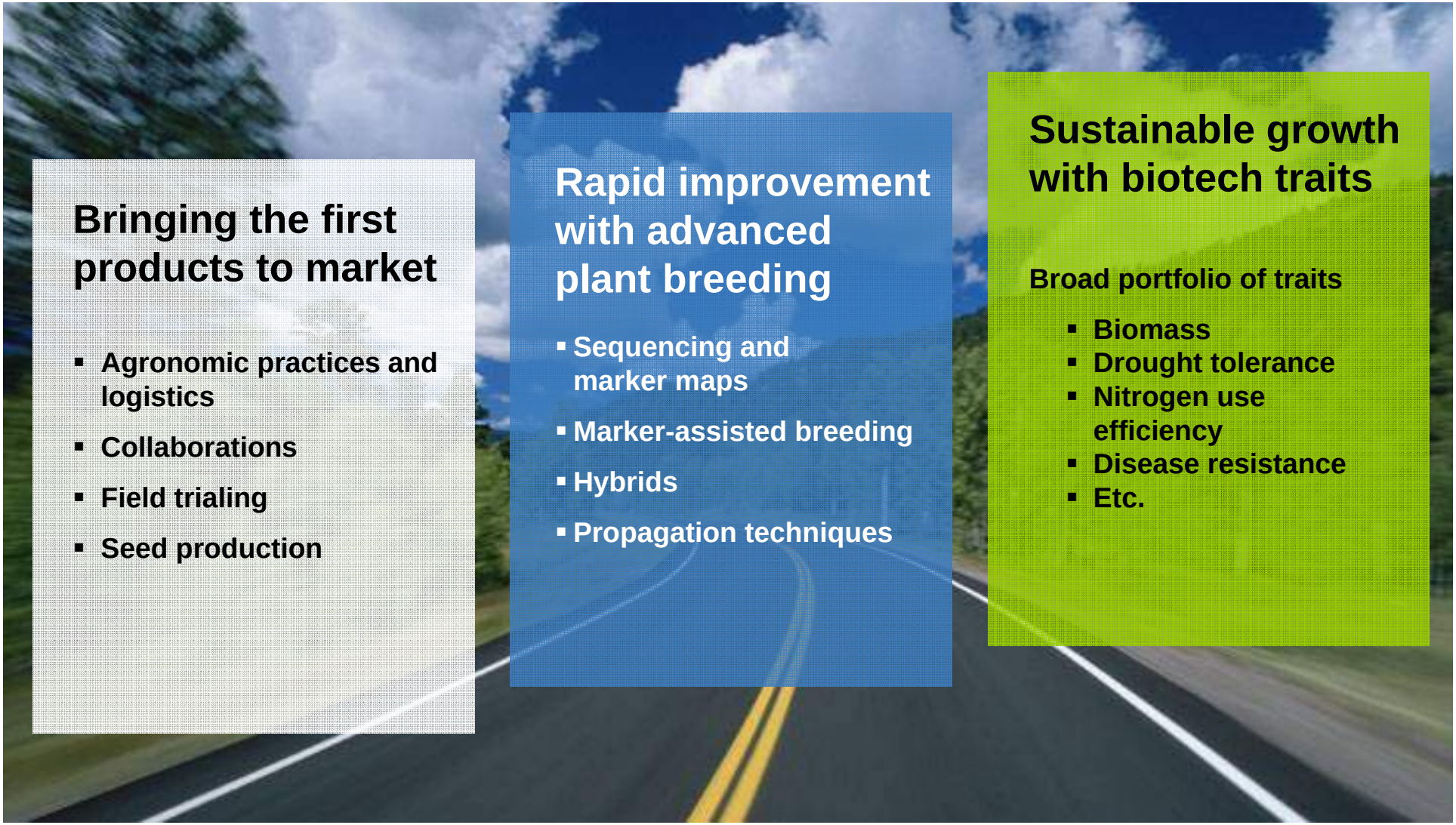
Switchgrass composition by wet chemical methods

•Theoretical ethanol yield from EERE ethanol yield calculator http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html

Composition Matters

- **Variations among feedstocks and cultivars impact:**
  - fuel yield
  - process efficiency
  - biorefinery profits
- **We can select among natural variation & make improvements with biotechnology**

The Fast-Lane Forward



Bringing the first products to market

- Agronomic practices and logistics
- Collaborations
- Field trialing
- Seed production

Rapid improvement with advanced plant breeding

- Sequencing and marker maps
- Marker-assisted breeding
- Hybrids
- Propagation techniques

Sustainable growth with biotech traits

Broad portfolio of traits

- Biomass
- Drought tolerance
- Nitrogen use efficiency
- Disease resistance
- Etc.

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Thank you

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the energy crop company™