Long-term Outlook for Biofuel Production and Technologies

[What has to be done in practice]

Richard Flavell

Ceres, California, USA

Long Term Outlook

- Promising:
  - World wide concerns
  - Government initiatives (esp US)
  - Oil companies creating operating divisions
  - Growing public and private investment
  - Many solutions, local adaptations
  - Technologies not especially difficult
  - Large research initiatives, public and private
  - Power of plant breeding with biotechnology
  - Large efficiency gains envisaged

  But Scale envisaged is a big challenge, everywhere

Major Drivers For Production and Technological Successes

- Increasing prices of oils, gas etc and things tied to these prices
- Decline of “easy to get” oil and rising demands
- Security of supply— “home grown” is attractive
- Greenhouse gas increases and global warming

Large-scale Energy from Plant Feedstocks

- Oils from oil seed rape, soybean, palm oil, jatropha etc DIESEL TODAY
- Biomass for electricity production by combustion-TODAY
- Ethanol for fuels from conversion to sugar and then fermentation.- TODAY FROM STARCH AND SUGAR(CANE)—First Generation
- Hydrocarbons for transportation fuel and chemicals from all “feedstocks” from gasification, thermochemical etc Second Generation
- Ethanol etc for transportation fuel from lignocellulose — Second Generation

Land Fuel Yields for Crops

- Given finite land resources and competing land uses land fuel yield is critical

- Current US production figures:
  - US Corn kernals (average 85GJ/ha)
  - US soy oil (average 18GJ/ha)
  - US switchgrass lignocellulose, dedicated energy crop, (average 135GJ/ha)

Potential increase for dedicated energy crops is substantial as they have not been bred for biomass

Ethanol from corn v lignocellulose

- First generation technology of conversion of carbohydrates (starch) to ethanol is proven technology and “cheap”
  - Fuel from starch is energetically inefficient and undesirable long term
- Second generation fuel from lignocellulose has much better energy balance, better GHG mitigation, can improve soil fertility, water quality and wildlife habitats
  - There is broad agreement that this is what needs to be developed
  - Second generation technologies are not cost- effective today

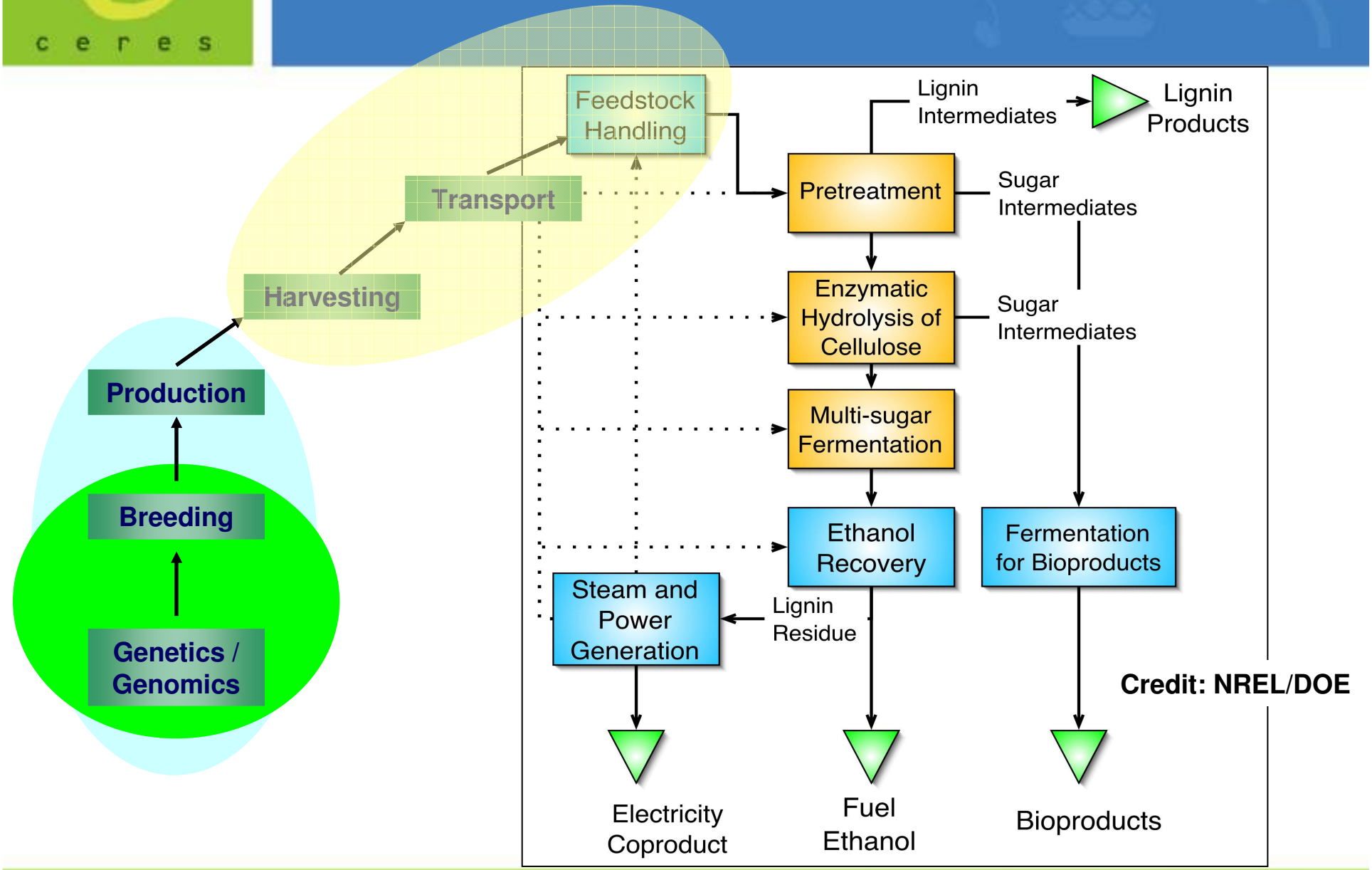
Outline of Contribution

- The technical and value chain
- Diverse global scenarios
- Current and future needs for success
- R+D Opportunities and needs to reduce costs
- Projections for cellulosic ethanol production in USA
- Feedstock improvement opportunities via "modern" breeding programs
- Essential Factors for success
- Conclusions

The Technical Chain

- The Technical and Value Chain

The Conversion Process Value Chain



Great Diversity in Global Scenarios

- Technical and economic scenarios depend on:
  - Which societies and labor costs
  - Which environments, including climate and water
  - Which technical processes
  - What scale
  - What investment
  - Activities of the global energy/oil companies
  - What plants used to grow biomass
  - Rate of yield improvements
  - Environmental taxes and Subsidies
  - Infrastucture to facilitate large-scale efficient agriculture, harvesting and transport.

Urgent Needs

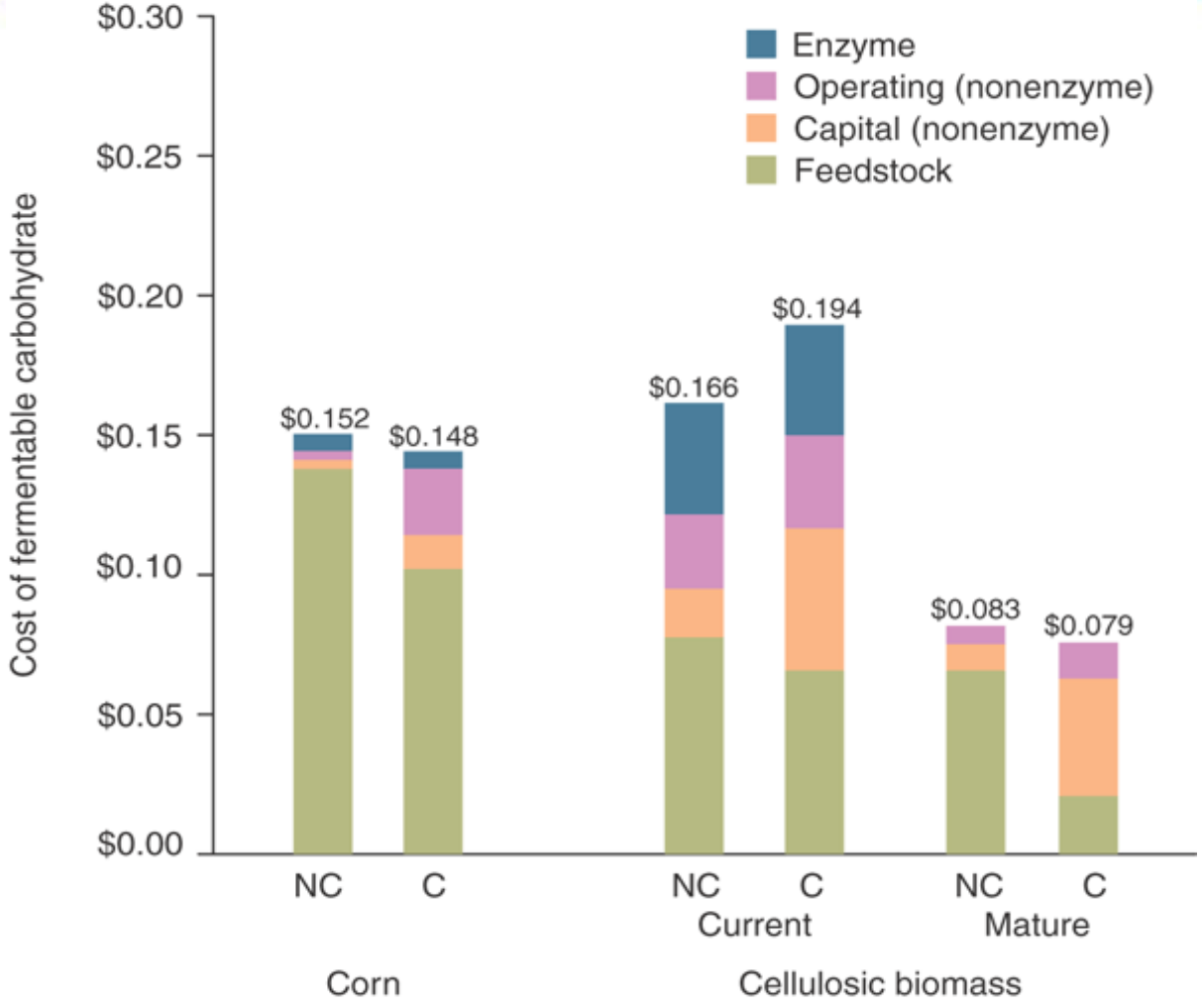
- Set targets and stimulate investment based on right criteria for:
  - Conversion to biofuels and distribution to societies
  - Feedstock choices
  - Feedstock development
  - Sustainability of supply
  - Environmental sustainability
  - Reduction of costs
  - Food v fuel v greenhouse gases v sustainability of all

R+D Strategies Required

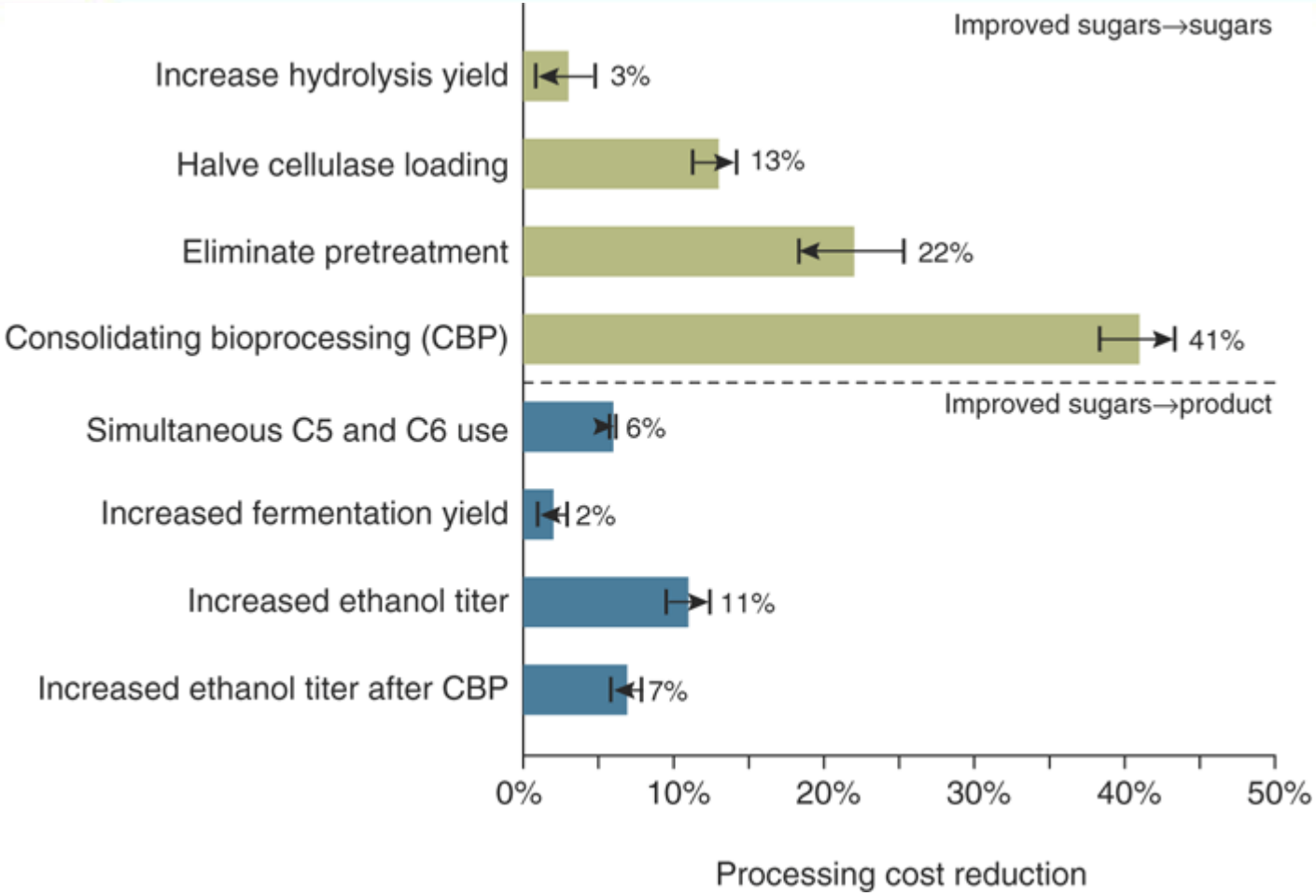
- Bring together governments, private sectors and mobilize manpower, investments, innovation and technology deployment locally and globally
- Meld aspects of biology, process engineering, crop production, land use and distribution of fuel products to:
  - Make chain cost effective
  - Make it scale to meet needs
  - Make it economically/environmentally sustainable for the private sector
  - Manage the agriculture/biofuel feedstock interactions
  - Manage short-term human needs versus sustainable solutions
  - Manage Food v Fuel v Greenhouse gases

In all scenarios

Costs of ethanol production- Feedstock Choices



Reductions in processing costs for various technological advances



US Developments, As An Example

- US example chosen because R+D investment most advanced in first generation (corn-based) and second generation (R+D phase)

State Of The Union Addresses

January 2006

"America is ***addicted to oil***, which is often imported from unstable parts of the world"…

…"We will also fund additional research in cutting-edge ***methods of producing ethanol, not just from corn but from wood chips, stalks or switchgrass***"

…"Our goal is to make this new kind of ethanol practical and ***competitive within six years***"

January 2007

*"…we must increase the supply of alternative fuels, by setting a mandatory fuels standard to require **35 billion gallons** of renewable and alternative fuels in 2017 -- and that is nearly five times the current target."*

To meet President's Goal

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

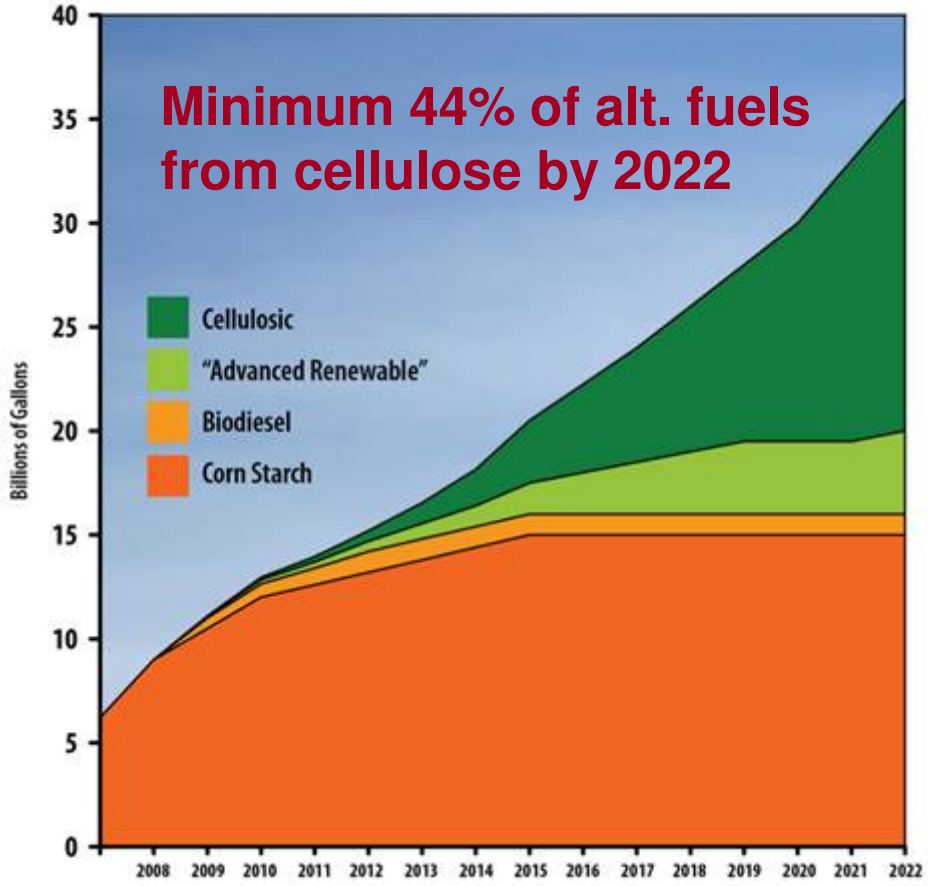
- To have improved seed in 2011 needed to start breeding in 2002-4

We are short of time. We must hurry

2007 ENERGY ACT: 36 Billion Gallons/Year

Alternative Fuel Mandates

Energy Independence and Security Act of 2007



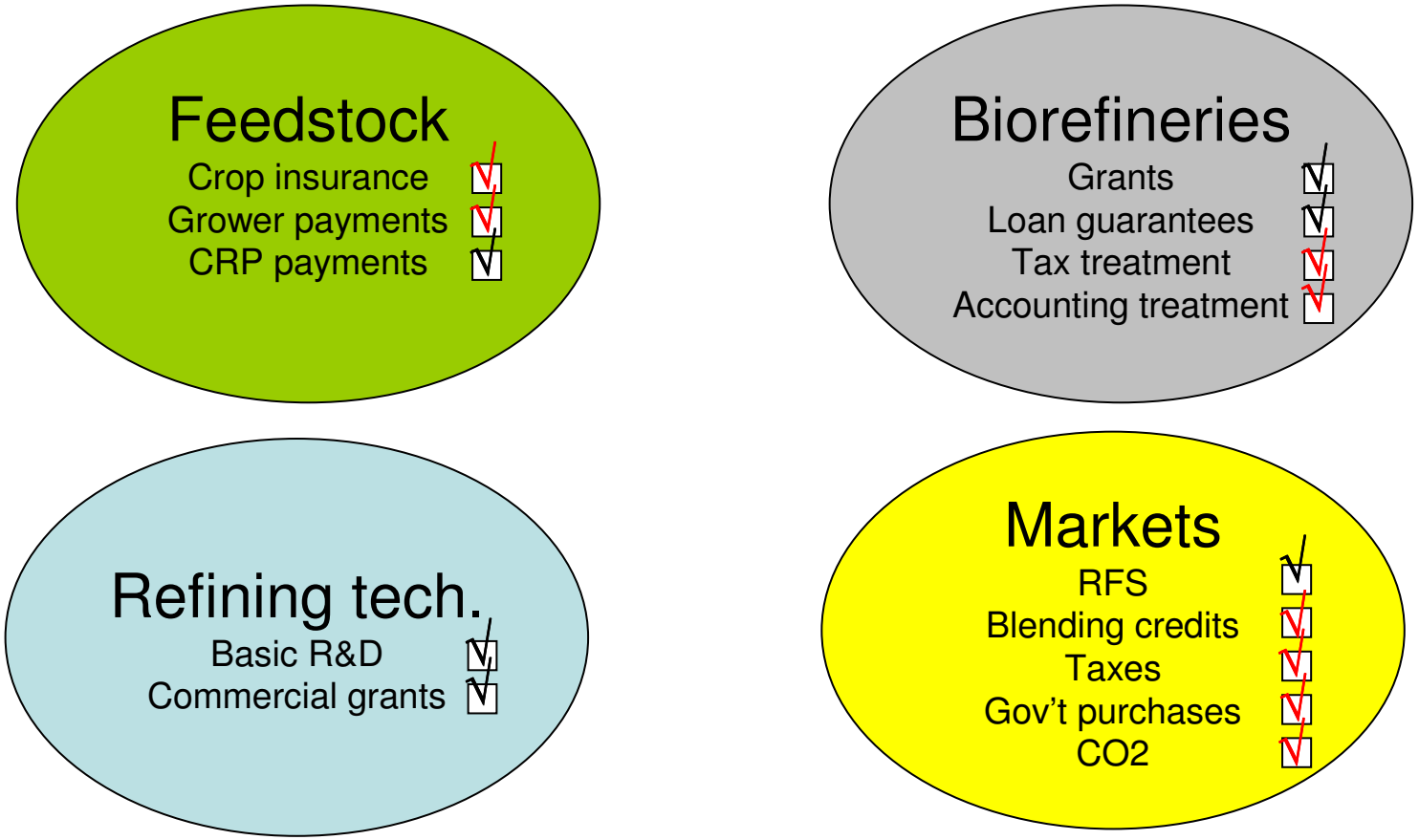
Steel in the Ground

- **$385MM in direct DOE funding for cellulosic biorefineries**
- **$4B in loan guarantees**
- **More being developed with state assistance**

U.S. Government Activities

- Feedstock - Farm Bill currently in conference
  - Payments to farmers to offset biomass crop production costs
  - Payments to biorefineries to offset feedstock purchase costs
- Biorefining technology development
  - 3 DoE centers, Livermore, Madison, Oak Ridge
  - $125M each over 5 years
- Build biorefineries
  - $4B in loan guarantees
  - $365 in direct grants for commercial scale
    - Iogen, Poet, Abengoa, Range, Alico, Bluefire
  - $200M in direct grants for 10% scale-up projects
- Mandates
  - New RFS of 36B gallons, 21B “advanced, 16B cellulosic

Government Policies – "Tilting the field"

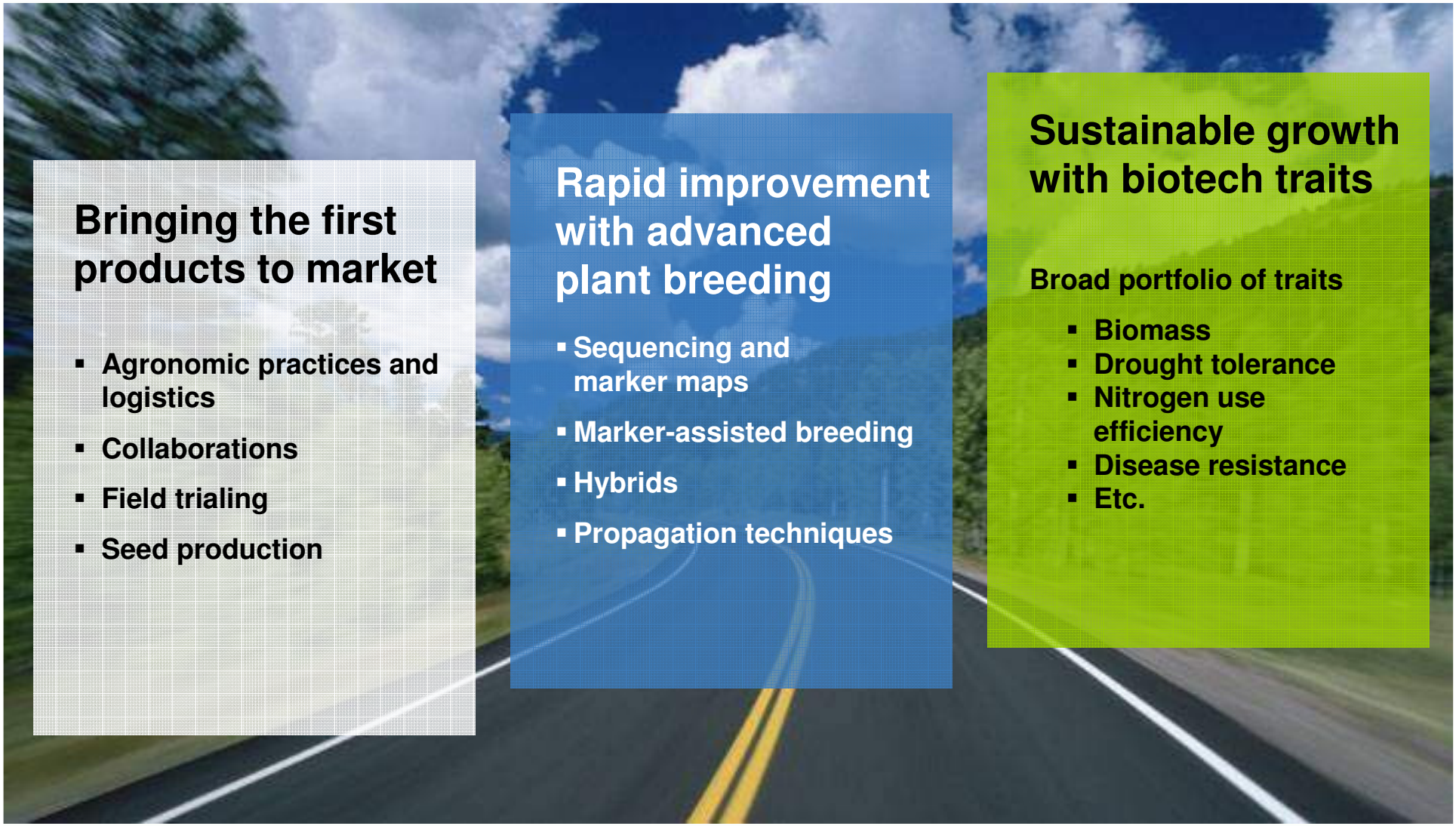


Technology curves + tilted playing field = economical by 2012

Feedstock Improvement

- Feedstock Improvement

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

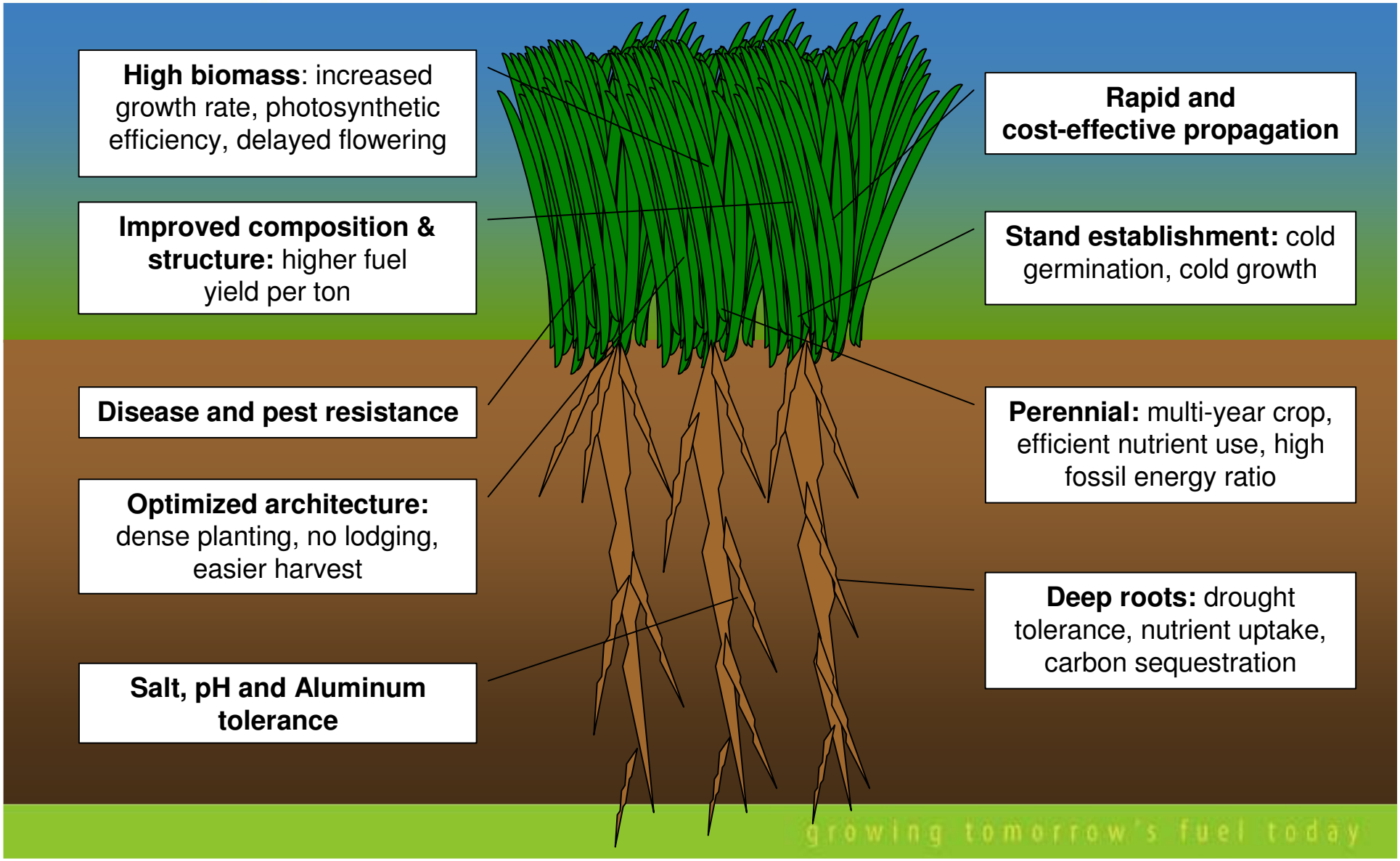
- Sequencing and marker maps
- Marker-assisted breeding
- Hybrids
- Propagation techniques

Sustainable growth with biotech traits

Broad portfolio of traits

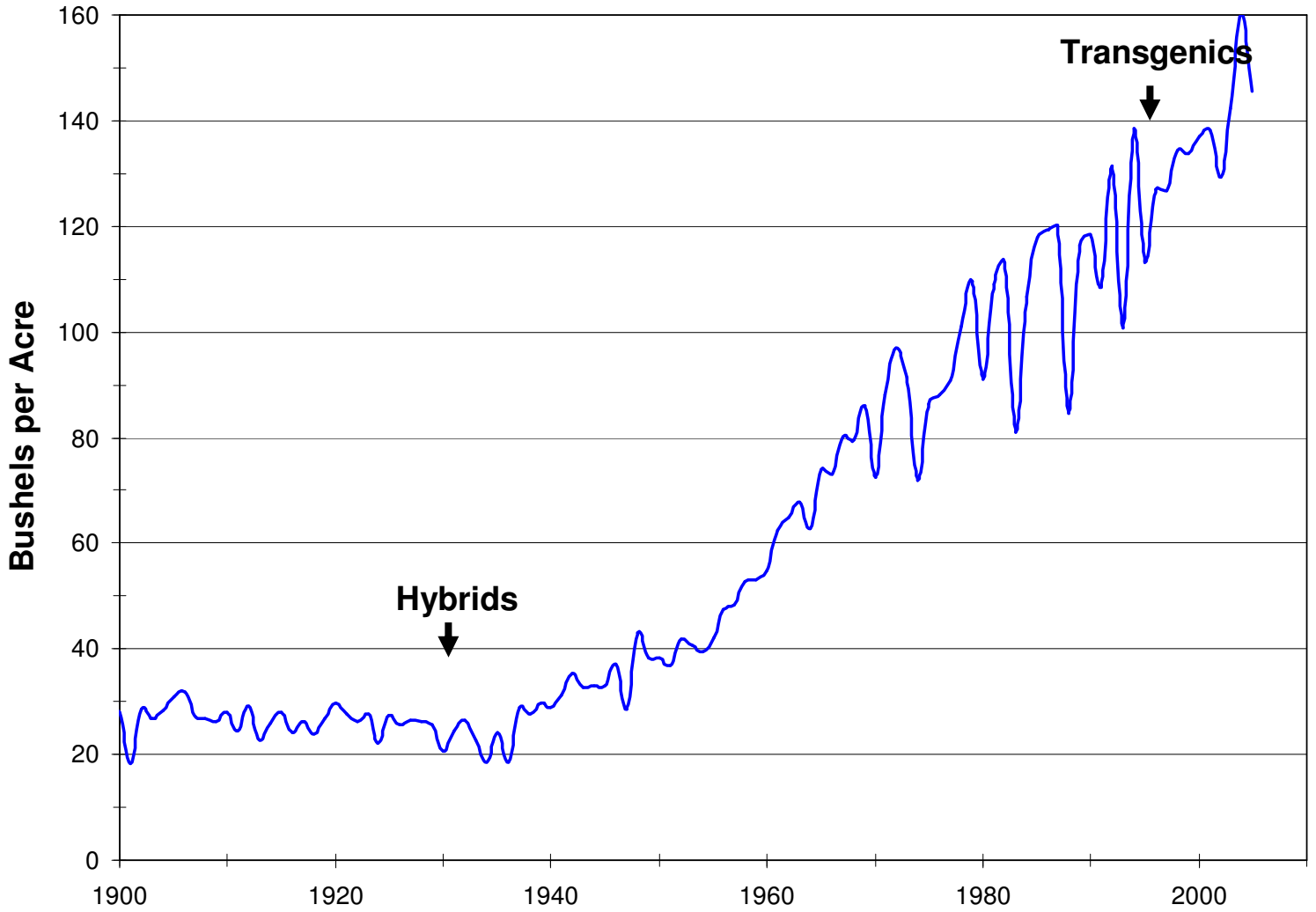
- Biomass
- Drought tolerance
- Nitrogen use efficiency
- Disease resistance
- Etc.

The Perfect Second Generation Energy Crop



Ceres Energy Crops

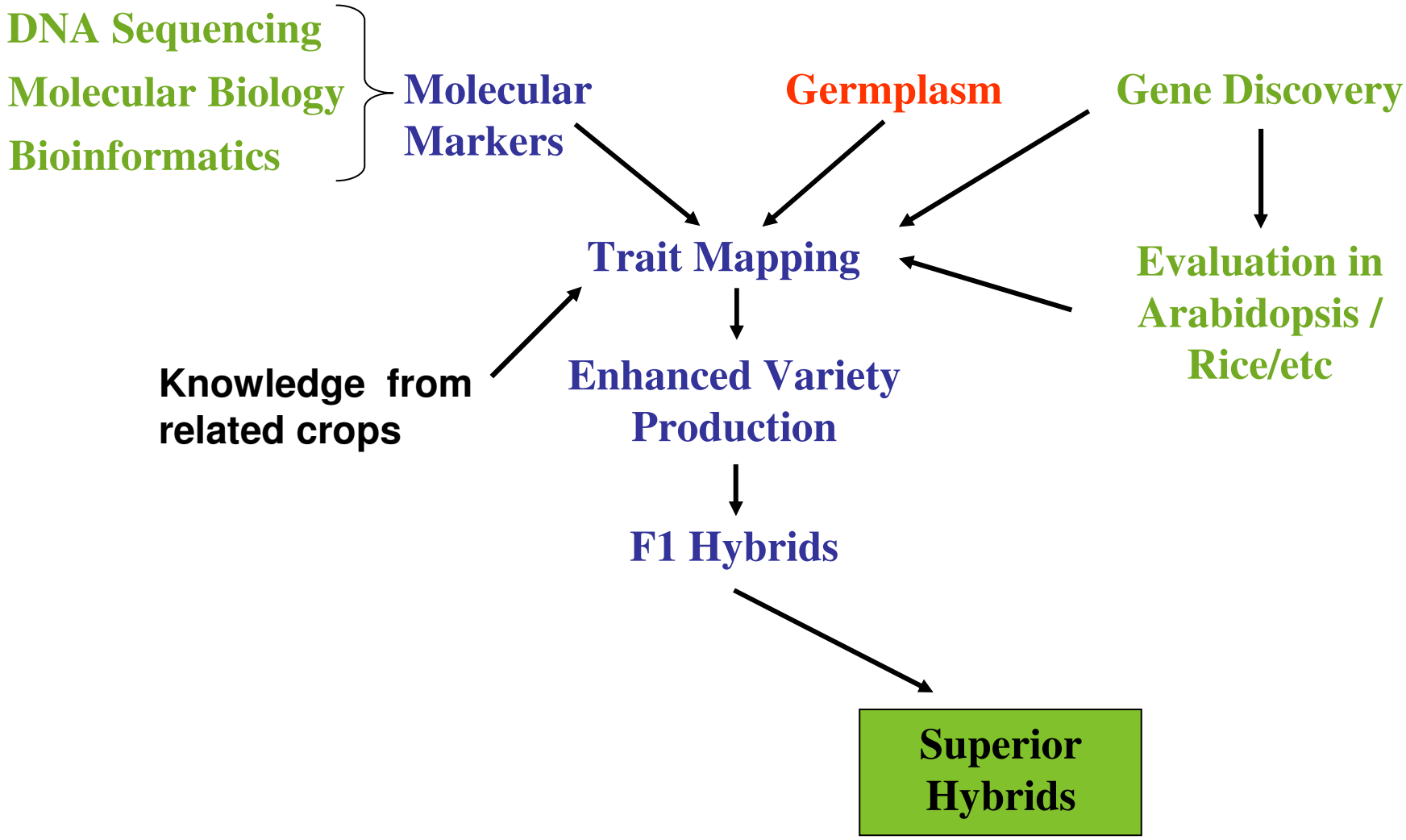
History of Corn



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

Germplasm Development



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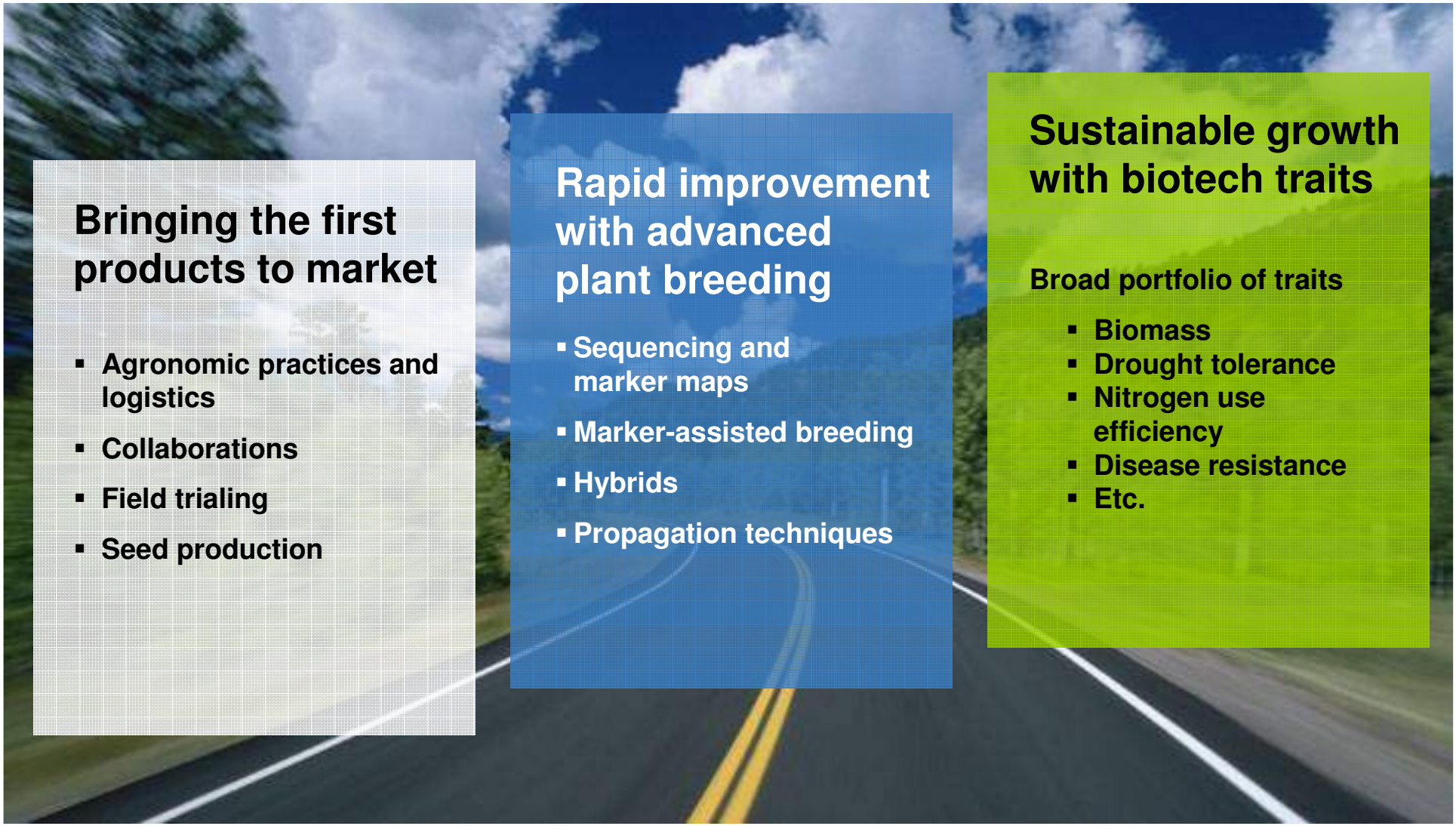

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Associated Essential Requirements

- Education of people, governments and societies
- Training
- Distribution of knowledge
- Agreements with societies
- Investment
- Links with energy companies and fuel users
- Infrastructure, harvesting systems, transport
- Global industrial strategies
- Much more efficient breeding programs for new crops
- Water and sunshine
- Disease management

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  BUT HUGE NUMBER OF CHALLENGES ASSOCIATED WiTH SCALE OF AGRICULTURE AND INVESTMENT REQUIRED

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