Can Large-Scale Biofuels Provide
A Real and Sustainable Solution to Reducing Petroleum Dependence?

A Comprehensive Systems Approach to Understanding Large-Scale Biofuels Deployment in the US

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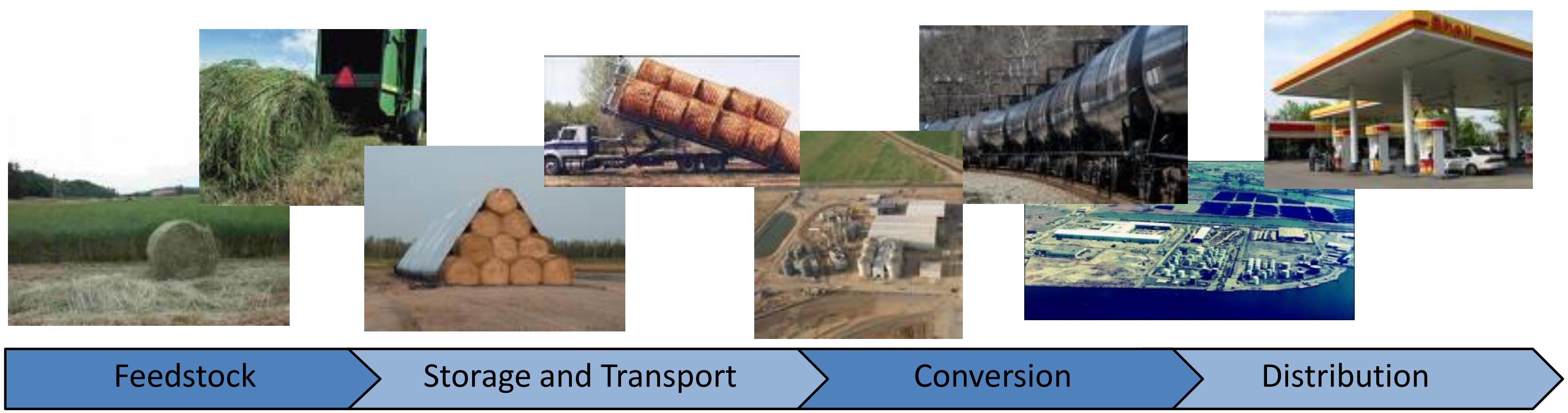
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

This project was a collaboration between General Motors and Sandia National Laboratories

Joint project conducted by GM and Sandia National Laboratories is the first true value-chain approach to future large-scale biofuels

- Purpose: Assess feasibility, implications, limitations, and enablers of producing 90 billion gallons ethanol (~60 billion gallons of gasoline-equivalent) per year by 2030
  - Ethanol used to illustrate biofuel potential without ruling out alternatives

- Scope: Focus on ethanol production from residues and energy crops for 2006 to 2030; corn ethanol capped at 15B gallons per year under 2007 Energy Independence and Security Act (EISA); cellulosic ethanol production accelerated beyond EISA to enable 90B gallons total production.



What questions did we seek to answer?

- Are biofuels an economically and environmentally sustainable solution at large scale?

And specifically …

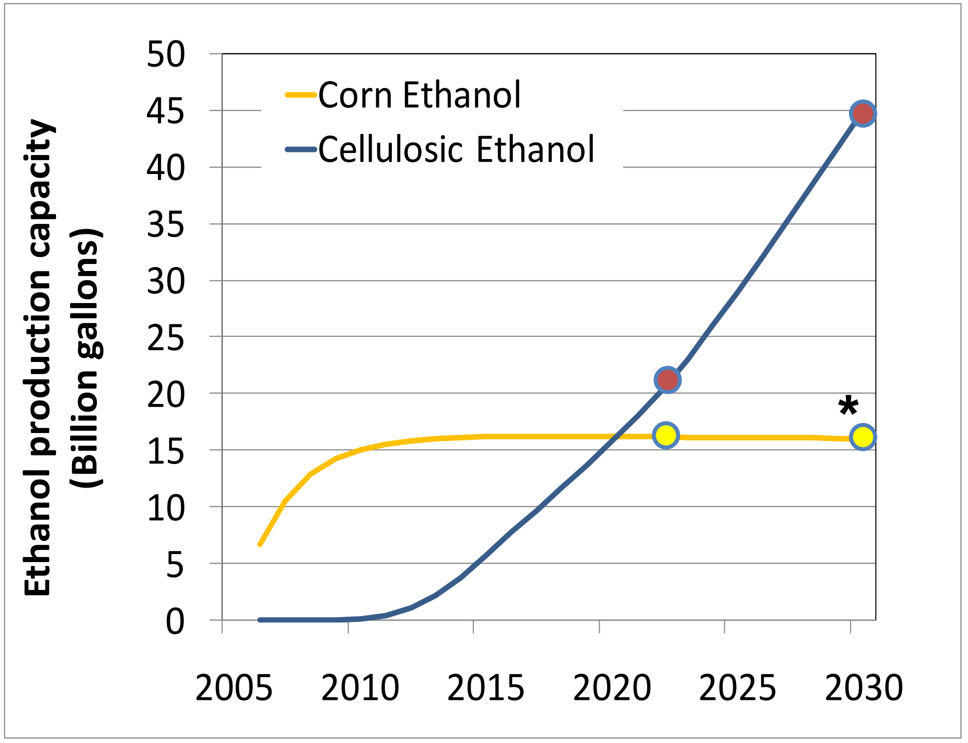
- What key enablers would be required?
- What technology levels could get us beyond the tipping point?
- What capital investment is needed across the supply chain?
- What barriers/roadblocks need to be overcome?
- Are there unintended consequences we can proactively foresee?
- Could policy drivers mitigate risk and accelerate biofuels development and use?

What is "Large-Scale?" Selecting Target Production Levels

- Study targeted 90B gallons = 60B gallons gasoline equivalent
  - 2006 EIA projections of 2030 demand: 180B gal of gasoline – displacement 1/3rd
- 90B gallons *can* be reached with enduring government commitment

Today's Focus: RFS2

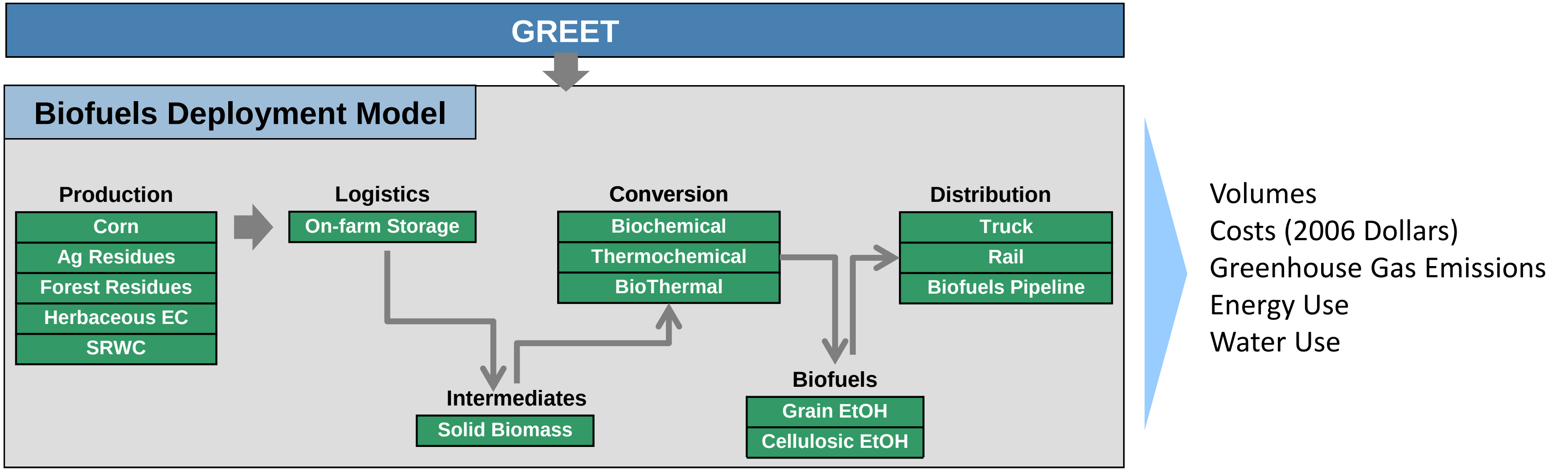
- Part 1: RFS (EISA 2007) to 2022
  - Produce 36B gal total by 2022
  - 15B gal from corn ethanol
  - 21B gal from advanced biofuels (assumed here: cellulosic ethanol)
- Part 2: beyond 2022 to 2030
  - Continue ramp up to 60B gal
  - 45B gal advanced biofuels (assumed here: cellulosic ethanol)
  - ** Corn ethanol production does not incorporate yield improvements, fractionation, new enzymes, etc.)*



Key Findings – RFS2 36B gal by 2022 ramping to 60B gal by 2030

- RFS2 (1/5th of US gasoline from biofuels) – could be achieved by successful deployment of cellulosic biofuels (in addition to corn ethanol), without displacing current crops grown
- Domestic investment for biofuels production is close to the investment required to develop new long-term domestic petroleum production
- Cellulosic biofuels can compete with oil at $90/bbl assuming:
  - Average conversion yield of 95 gallons per dry ton of biomass
  - Average conversion plant capital expenditure of $3.50 per installed gallon of nameplate capacity
  - Average farmgate feedstock cost of $40 per dry ton
- Sensitivity analyses varying these assumptions individually gave potential cost-competiveness with oil priced at $70/bbl to $120/bbl
- Policy incentives such as carbon taxes, excise tax credits, and loan guarantees for cellulosic biofuels are important to mitigate the risk of oil market volatility
- Large-scale cellulosic biofuel production can be achieved at/below current water consumption levels of petroleum fuels from on-shore oil production and refining

We built a 'Seed to Station' system dynamics model to explore the feasibility of 90 billion gallons of ethanol



Key constraints:

- Timeframe considered: 2006 to 2030
- State-level granularity

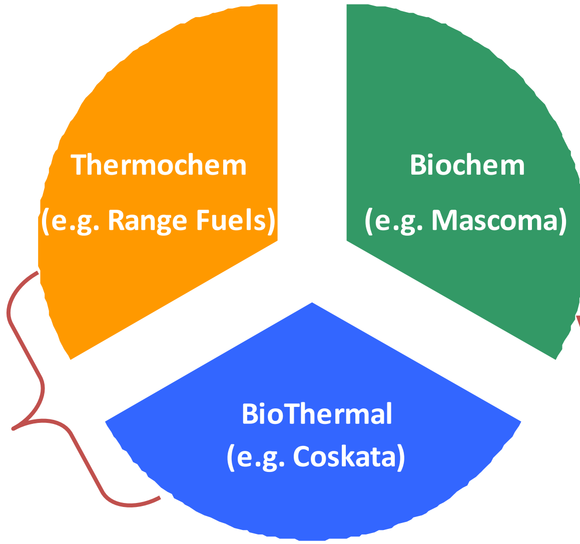
Model limitations:

- No modeling of markets
- Several real world constraints are not explicit in the model, but were analyzed separately
  - limitations on the availability of capital and distribution constraints
- Difficulty accurately assessing key costs and other values, especially for technologies that do not currently exist
  - sensitivity analyses were conducted to account for leading uncertainties

Conversion technologies are linked with specific feedstocks

For each new plant constructed, the Biofuels Deployment Model (BDM) selects a feedstock/conversion pair resulting in lowest cost of ethanol

Biomass
↓ Gasification
Syngas
↓ Catalysts
Ethanol



Biomass
↓ Enzymes
Sugars
↓ Microorganisms
Ethanol

Short Rotation Woody Crops

Inputs:
Acres available
Yield vs. time
Years to maturity
Costs

Forest Residue

Inputs:
Resource supply
Cost of harvest

Biomass
↓ Gasification
Syngas
↓ Microorganisms
Ethanol

Herbaceous

Inputs:
Acres available
Yield vs. time
% harvestable
Costs

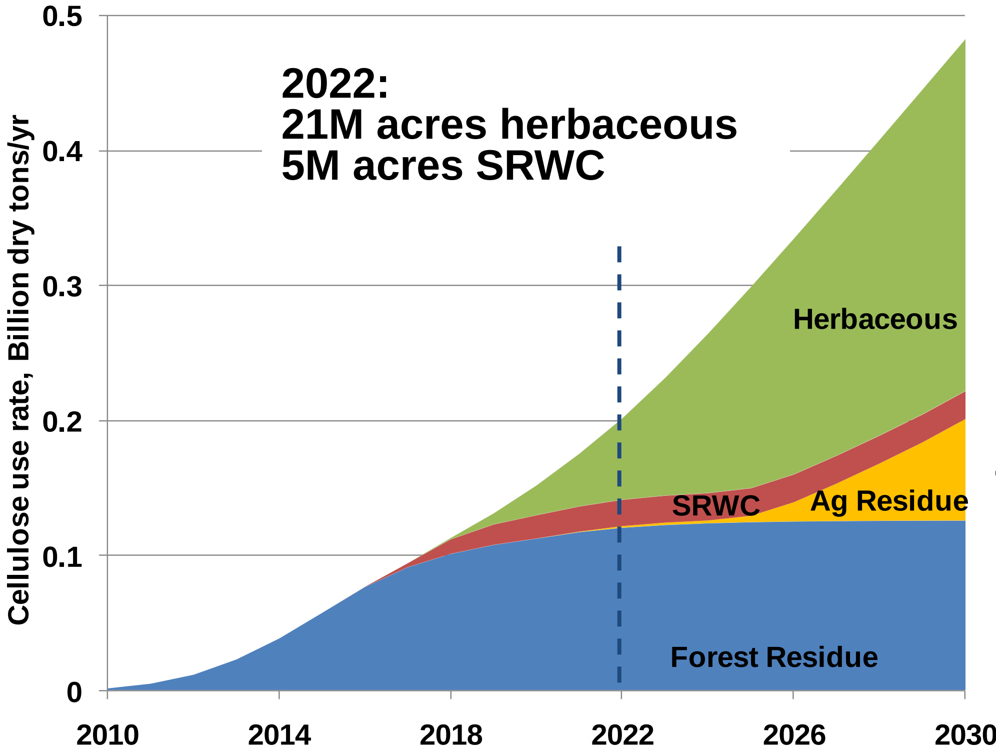
Ag Residue

Inputs:
Acres planted
Yield vs. time
% harvestable
Fertilizer makeup
Cost of harvest

Above linkages are only representative – other combinations possible

Biomass production for 60B gal can rely largely on idle land and residues using diverse feedstocks

- Feedstocks should be viewed as representative – we did not include annual crops such as sorghum, sugarcane or municipal solid waste (MSW)
- Regionally diverse feedstocks are spread across the US to nearly all states; as a whole this reduces risk due to regional weather events
- Costs and land area used per gallon of ethanol decline as new cellulosic feedstocks are developed with improved per-acre yield



2030 Data:

<u>44M acres</u>
6 tons/acre
$49/ton delivered

<u>5M acres</u>
5 tons/acre
$67/ton delivered

<u>50M acres</u>
1.5 tons/acre
$49/ton delivered

<u>20M acres</u>
6 tons/acre
$40/ton delivered

44M acres is 100% of idle land plus 7% of cropland used as pasture

5M acres is 7% of forest land

49M acres

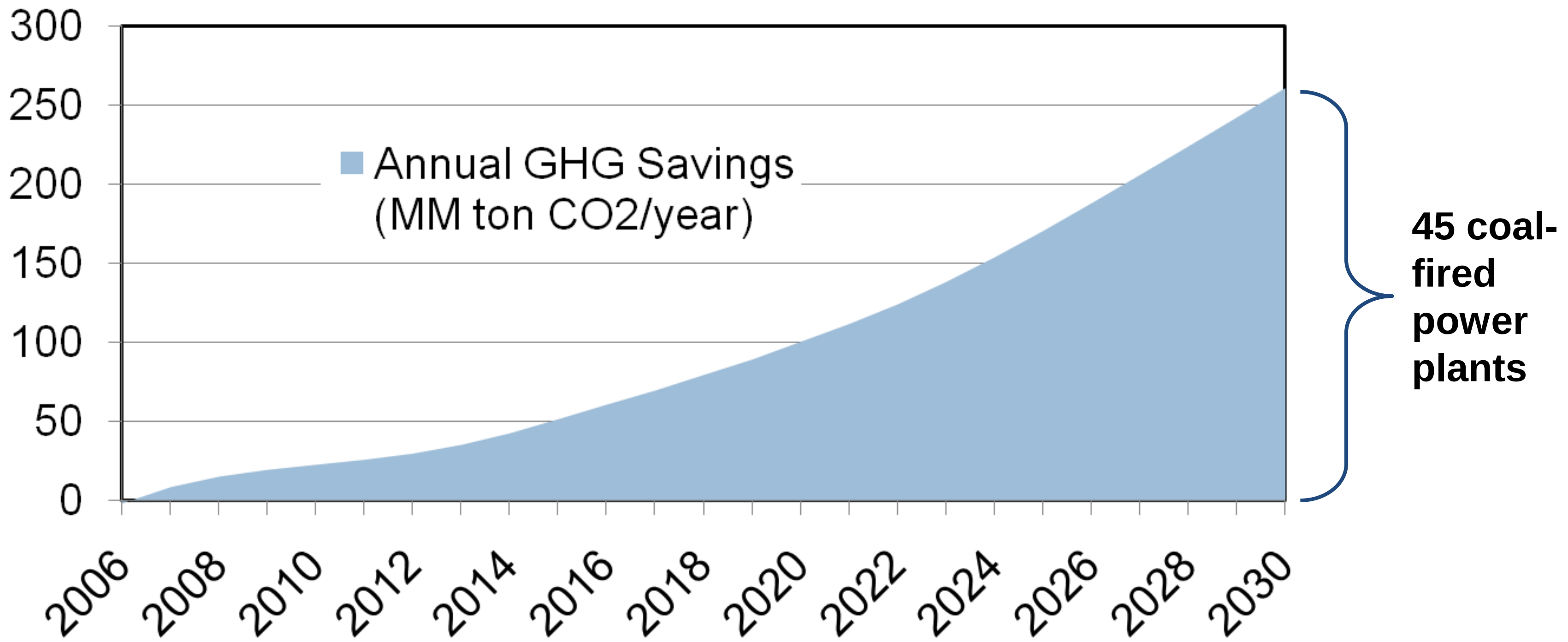
No land use change for residues

What do these CO_2 savings amount to?

- 60B gallons of ethanol by 2030 provides annual GHG savings in 2030 of 260 million tons of CO2e per year

This is equal to:

- 13% GHG emissions reduction from current fleet of light-duty gasoline vehicles
- Removal of 45 coal-fired power plants



Key findings

We did not find fundamental barriers to large-scale production of biofuels (e.g., supply chain or water constraints), assuming the technology matures as projected here

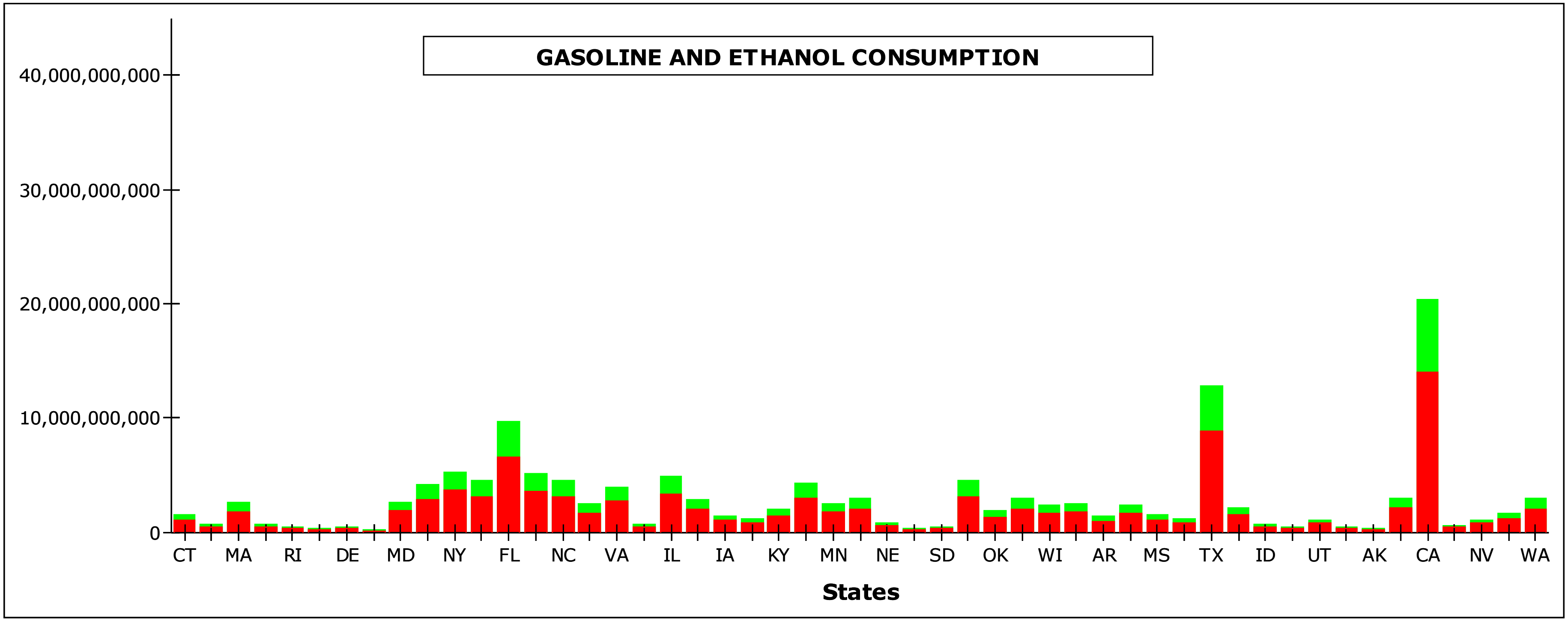
However, multiple actions could be taken to enhance the successful build-out of the cellulosic biofuels industry:

- Supportive policies, including well-planned market incentives and carbon pricing, that could minimize investment risks in light of oil price volatility and periodic economic dislocations
  - Options include greenhouse gas taxes and market incentives (e.g., \$50/ton CO_2 tax significantly reduces required incentives)
- Enhanced R&D and commercialization-associated funding, despite current declining/low oil prices
  - Conversion investments to increase conversion efficiency and decrease capital cost
  - Improved energy crop technology to reduce cost, land use, and water use
  - Decreased timeframe for technologies to reach maturity (lowers investment risk)
- Infrastructure investment to ensure the rail and road network in the US can safely support future expanded economic activity, including biofuels

Modeling considerations

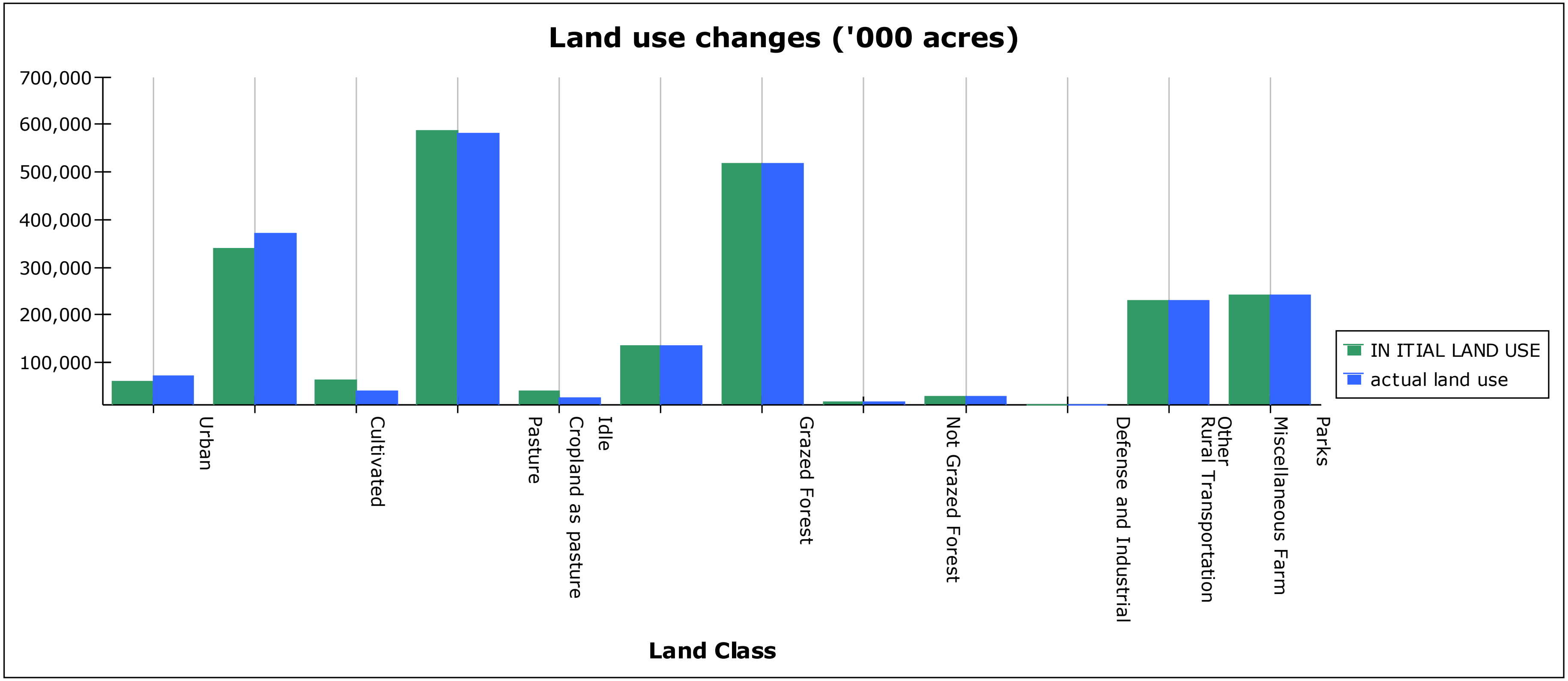
- Scope
  - Geography – USA disaggregated by state
  - Granularity – multiple technologies and feedstocks
- Constraint versus Consequence – model boundary
  - Outcomes limited by physical constraints, delays, assumptions
  - Outcomes show consequences, some not possible to achieve
- Material balance and material flow – ethanol plants
  - Use of aging chains with delay
  - Learning curves and technology costs

Geography example



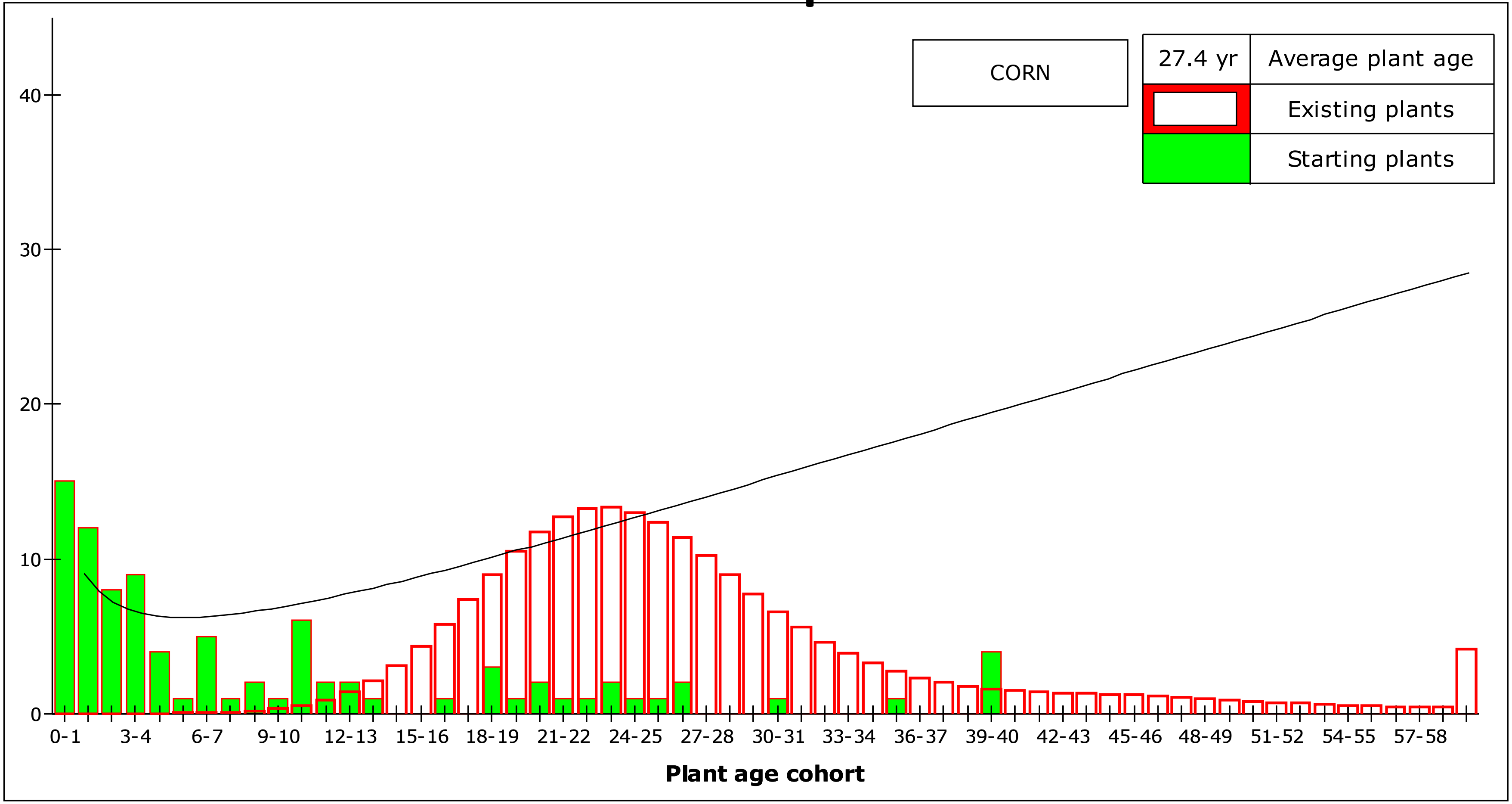
In the aggregate, totals can be misleading. Activity and decisions are local.

Constraint versus Consequence example



Balance land by class over the runtime, observe 'conservation' of acreage,
Maintain protected and probably unavailable land classes.

Material balance and material flow example



Understand the ‘fleet’ of ethanol production plants, the initial fleet, their aging, and replacement.

Summary and conclusion

- System dynamics is a strong complement to other methodologies (GIS, operations research)
- Model boundaries are based upon reasonable and defensible assumptions
- Rigor, standards and peer review pay off
- Modeling process with collaboration is rewarding professionally and in outcome – go “under the hood” with your client