Food, Fuel, and Plant Nutrient Use in the Future
CAST Issue Paper 51, March 2013

Presenters:
David Zilberman (Chair)
– Department of Agricultural and Resource Economics
– University of California, Berkeley

Bruce E. Dale
– Department of Chemical Engineering and Materials Science
– Michigan State University, East Lansing
Task Force Members

Authors:

David Zilberman (Chair)
– University of California, Berkeley

Bruce E. Dale
– Michigan State University, East Lansing

Paul E. Fixen
– International Plant Nutrition Institute, Brookings, South Dakota

John L. Havlin
– Department of Soil Sciences, North Carolina State University, Raleigh
Task Force Members

Reviewers and CAST Liaison:

Chris van Kessel
–University of California, Davis

Peter Scharf
–University of Missouri, Columbia

Harry Vroomen
–The Fertilizer Institute, Washington, D.C.

Todd Peterson
–WinField, a Land O’Lakes Company, Johnston, Iowa
Challenges Facing U.S. and Global Agriculture

• Feeding growing population (9-10 billion in 2050 with growing income)
• Providing sustainable fuels and chemicals
• Contributing to positive U.S. balance of trade and energy independence
• Increasing agricultural production within a constrained footprint (in terms of land, GHG emissions, water, among others)
• Overcoming emerging constraints on nutrient availability
Objectives of Study

• Quantify trends that govern the evolution of agriculture and the national and global implications for agricultural production, land use, and resource utilization

• Understand and quantify the factors affecting fertilizer and nutrient requirements and availability

• Identify the challenges to agricultural production systems and their implication for research, technological progress, and policy
The Educational-Industrial Complex is a Foundation for Agricultural Growth

- The unique system of public-private partnership in the U.S. has been an engine of growth for agriculture and other sectors
- Publicly funded research supported the creation of basic knowledge transferred to the private sector
  - It fed the growth of the life science, agribusiness, and agricultural sectors
  - Resulted in increased productivity and sustainability, but much more progress is needed
- The agricultural bioeconomy sectors point to the potential
Agricultural Biotechnology has Already Made a Major Difference

- Emerged in the early 1990s, taking advantage of the discovery of the genome

<table>
<thead>
<tr>
<th>Crop</th>
<th>Global Production Share (2010)</th>
<th>Increased Supply</th>
<th>Reduced Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>25%</td>
<td>6-15%</td>
<td>10-16%</td>
</tr>
<tr>
<td>Soybean</td>
<td>81%</td>
<td>12-32%</td>
<td>15-22%</td>
</tr>
<tr>
<td>Cotton</td>
<td>64%</td>
<td>18-37%</td>
<td>15-40%</td>
</tr>
</tbody>
</table>

- Reduced GHG emissions and toxic chemical use
- Impact on prices and supply will be much greater with expanded adoption
- Potential is much larger with sound research and regulation
Biofuels Are a Work in Progress

• Corn and sugarcane ethanol are economically viable
• Corn ethanol contributes to balance of trade, energy security, farm income, and higher food prices
• Learning occurs
  – Cost of corn ethanol decreased 70% from 1980 to 2000
  – Cost of sugarcane ethanol decreased 70% from 1976 to 2005
• There are limitations on first-generation biofuels, but second-generation biofuels from straw and grasses will figure in the U.S. agricultural future
If we only had a brain:
Resolving the apparent food vs. fuel conflict by using our heads
Biofuels: A crime against humanity?

• “[I]t's a crime against humanity to convert agricultural productive soil into soil...which will be burned into biofuel."
  – Jean Ziegler, UN Special Rapporteur, 2007
Power Consumption and GDP (World Regions)

GDP per Capita, PPP (current international $ per person)

Per Capita Primary Power Consumption (kilowatt per person)

- North America
- Europe & Central Asia
- Latin America & Caribbean
- World Average
- East Asia & Pacific
- Middle East & North Africa
- Sub-Saharan Africa

GDP = 5,121*PC
R² = 0.926

Average of Each Income Level
- High
- Upper Middle
- Middle
- Lower Middle
- Low
Renewable Power Is Critical for Human Well-being

• Rate of energy use (power consumption) strongly affects (determines?) national wealth, life expectancy, and education levels
• All rich societies use a lot of energy (~33% oil)
• “Energy efficiency” helps but is not an answer in itself
• Fossil energy use makes us rich today—what energy sources will make our grandkids rich?
• How will the billions of poor people in the world ever access enough fossil energy to develop their human potential?
• Of all forms of energy, liquid fuels are the most valuable and most problematic in terms of supply, price, and price volatility
• “Peak oil” has already arrived--2005 by my rear-view mirror
• Only large-scale, low-cost, low-carbon energy sources can reduce GHGs and provide energy security and long-term wealth
• Thus cellulosic (and other sustainable) biofuels are not optional—we must have them
• How can we develop sustainable biofuel pathways?
“The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race...”

Essay on the Principle of Population

Thomas Robert Malthus
1766 - 1834
Energy Consumption Strongly Affects Human Well-being and Life Expectancy

Human Development Index (HDI)

- Health
- Education
- Living Standards

Dimensions

Per Capita Primary Power Consumption (kilowatt per person)

Brazil
Mainland China
India
Tanzania

Germany
U.S.
Norway
Iceland

HDI = 0.217*\log(\text{PC}) + 0.637

R^2 = 0.818
Some Basic Energy Facts: *Why Liquid Fuels Are So Important*

- **Services** we need from energy (current primary sources of these services)
  - **Heat** (natural gas, coal)
  - **Light/electricity** (coal, natural gas, hydro/nuclear)
  - **Mobility** (liquid fuels from oil—96%, some ethanol and CNG)—most commerce
Some Basic Energy Facts: Why Liquid Fuels Are So Important

- All energy services (all BTU, ergs, GJ) are not created equal—we value mobility (= oil) above all other energy carriers
- Electricity/batteries can never provide more than about half of mobility needs—and they cannot support commerce at all
- Commerce moves by trucks, ocean shipping, rail, and jet aircraft
- Economic chaos results when liquid fuel demand exceeds supply
- Liquid fuels, not “energy,” is the key economic security issue—and right now liquid fuels means refined oil products
- The only potentially sustainable, very large-scale source of renewable liquid fuels is cellulosic biomass—nonfood plant matter (grasses, straw, wood chips, some parts of municipal wastes, etc.)
Worldwide Crude Oil Production – Subdivided into World Regions and Top 10 Producers in 2010

Peak Oil
- Asia - Other
- China (5)
- Africa
- Middle East - Other
  - Kuwait (9)
  - United Arab Emirates (8)
  - Iran (4)
- Saudi Arabia (2)
- Europe/Eurasia - Other
- U.S.S.R. (before 1985)
- Russian Federation (after 1985) (1)
- S. America/Caribbean - Other
  - Venezuela (10)
  - Mexico (7)
  - Canada (6)
- United States (3)
Land-Efficient Animal Feeds Enable Large Environmental and Energy Benefits

• Most human use of land for agriculture is to produce animal feeds—not food directly
• By “redesigning” agricultural systems, we can achieve large environmental and energy benefits
• Use land more efficiently (and more sustainably) to produce food, feed, fuel, and large environmental services
• By producing the same amount of food/feed on existing land, we avoid the indirect land use change (iLUC) issue
• And, oh, by the way, we don’t “grow food”!
• (About 85% of our land used in agriculture is for animal feed)
Nutritional Requirements: Livestock vs. Human

Nutritional Requirement of the Entire U.S. Population

Protein 5.1 Tg/yr
Calories 238 trillion kcal/yr

U.S. livestock consumes 11.4 X and 4.8 X the amount of protein and calories that would fulfill the nutritional requirements of the U.S. population.

Dairy Cattle: 190
Beef Cattle: 558
Pigs: 153
Laying chickens: 50
Poultry: 178

All data from 2010/2011. Livestock population data from USDA-NASS, human nutrition from USDA/USDHHS, U.S. population data from U.S. Census Bureau and animal nutrition from Dale et al., “Protein feeds coproduction in biomass conversion to fuels and chemicals”.
Double Cropping

- Grow crops (grasses) over winter and spring on corn or soy land while still growing corn/soy
  - Does **NOT** require new land
  - Increases sustainable corn stover harvest rate
  - Biomass can be used for biofuels, protein, animal feed, etc.
Current vs Possible Land Use

- Total plant matter produced increases by 2.5-fold on same land area
  - Displaces 50% of U.S. gasoline and 5% of U.S. electricity
  - Reduces U.S. GHGs by more than 10% and nitrate losses by 75%
  - Food and feed production remain the same—no iLUC
Some Thoughts on the Sustainability Transition

• We are in a time of profound transition in how the world will be fueled and fed—we cannot continue forever along our current pathways, we must change and the sooner the better.

• The changes required will be far reaching, profound, revolutionary, upsetting, painful, exciting...pick your adjective.

• Liquid fuels from plant matter (biofuels) are an essential part of the sustainability transition—this will cause a huge impact on the economic, physical, and social “landscapes”.

• We should be seeking large, complementary, beneficial changes: we need food (feed) and fuel and sustainability and rural economic development and better social outcomes.

• This will not happen by accident—we must envision (use our heads) and design (do the research) sustainable biofuel systems to achieve multiple objectives...then implement these systems.
We Can Meet the Challenges

• By
  – Redesigning agricultural production systems
  – Improving crop varieties
  – Recycling nutrients
  – Adopting advanced processing technologies

• The U.S. can help meet growing food and energy demand and overcome the nutrient scarcity and other environmental challenges

• It requires continuous commitment to agricultural and life science research and sound regulation
Questions/Discussion

For a free download of Issue Paper 51, visit the CAST website @ www.cast-science.org

CAST® Issue Paper
Number 51
March 2013

Food, Fuel, and Plant Nutrient Use in the Future

Predictions of a world population of nine billion by 2050 necessitate careful stewardship of current food, fuel, and plant assets: a major part of this challenge involves managing what is beneath the surface. (Photo by Colette Kessler, USDA Natural Resources Conservation Service.)

ABSTRACT

Current conditions and future trends show that adequate food production will require increases in the use of fertilizer nutrients. With a growing population, dwindling arable land, and an increased demand for biofuels, the world cannot count on an expansion of harvested area to fill the demands. Scientists and food producers need to look at the way land is currently used to feed the world’s growing population and look into the best practices for how to move forward.

To meet global food demand, the use of genetics to improve crop productivity, promote soil conservation and management, and use nutrients efficiently is necessary. The key to these endeavors lies in supporting research and development in these areas.

This paper looks at the background leading to the current situation and addresses the resulting requirements as world food production develops during the next 40 years. Because of various circumstances, grain production will need to increase by approximately 50% during the next four decades. Current US growth rates in cereal yields should meet 2050 demands, but greater cereal yields per unit land area require increases in fertilizer nutrient use, advances in genetics, and improved soil and crop management technologies.

Other topics in this paper include issues dealing with cellulose biofuel production. According to projections, land availability is not a constraint to biofuel production, and the United States has the capabilities to decrease...