Changes, Sustainability, Food, Energy: Topics in Agriculture

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http://www.purdue.edu/lorre/
Agriculture

“the science, art, and business of cultivating the soil, producing crops, and raising livestock; farming.”

The American Heritage Dictionary, 1982

“the science, art, or practice of cultivating the soil, producing crops, and raising livestock and in varying degrees the preparation and marketing of the resulting products: FARMING.”

Merriam Webster on-line, m-w.com, 2012
Agriculture

Input

Sun

Fertilizer
Seed
Pesticides
Dryer Fuel
Machinery Repair
Hauling
Insurance
Other

Water

Output

Grain
Biomass (above ground)
Biomass (below ground)
US Agricultural Productivity

- **Output**
- **Input**
- **Total Factor Productivity**

Indices 1948 = 1

Source: USDA ERS
US Input/Output Ratios since 1950: fertilizers and pesticides are important

Agricultural Inputs per Unit of Output

Index (1 = 1975 Value)

Source: USDA ERS
Increase in Genetically Engineered Crops

US Percent of planted acres

1996 2000 2005 2010

Fernandez-Cornejo, USDA, ERS, July 1, 2011
Natural source was guano (bird droppings) source along coast of Chile 220 miles long x 5 feet deep (ca 1900).

Natural source had limited capacity

Synthetic routes attempted:
Priestly and Cavendish passed electric sparks through air to form nitrates

other attempts resulted in calcium cyanimide, NOX, aluminum nitride (expensive)

By 1913 Habor / Bosch developed commercial high-pressure synthesis of ammonia using recycle (conversion at 8% per pass)

from Modak, Resonance, 2002
Fertilizer: Ammonia Synthesis

\[
\frac{1}{2} \text{N}_2 + \frac{3}{2} \text{H}_2 \rightleftharpoons \text{NH}_3 \quad ; \quad \Delta H_{298K} = -45.7 \text{ kJ/mol}
\]

Feedstocks:
- \( \text{N}_2 \) from air,
- \( \text{H}_2 \) from natural gas, naptha or heavy oil

Energetics (high pressure, temperatures, recycle require energy)
- Exothermic
- Rate favored by high temperature (1000 to 3000 \( ^\circ \text{C} \))
- Equilibrium favored by low temperature and high pressure

Role of Catalysis (Haber chemistry; process by Bosch; BASF)
- 1909 Os, reaction at 600 \( ^\circ \text{C} \), 175 atm (80 g \( \text{NH}_3 \))
- 1913 Fe / \( \text{Al}_2\text{O}_3 \) / K catalyst, 400 – 700 \( ^\circ \text{C} \), 300 atm (30 tons \( \text{NH}_3 \))
- Other catalysts / processes developed (plants at 1500 tons / day)

from Modak, Resonance, 2002
Ammonia Production (2010)
est. 80% used for fertilizing crops.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Total Produced</td>
<td>131 million metric tons (32% from China)</td>
</tr>
<tr>
<td>US total consumed</td>
<td>14.7 million metric tons</td>
</tr>
<tr>
<td>Produced in US</td>
<td>8.3 million metric tons</td>
</tr>
<tr>
<td>Imported</td>
<td>6.4</td>
</tr>
<tr>
<td>Price</td>
<td>$390 / ton</td>
</tr>
</tbody>
</table>

43% imported \(^1\)

Currently depends on natural gas, a non renewable resource.

\(^1\)U.S. Geological Survey, Mineral Commodity Summaries, January 2011
Companies and Customer

Seed Producers
- Dow Agrosciences
- Monsanto
- Dupont
- Syngenta
- Bayer

GMO Crops
- Soybeans
- Maize
- Sugar Beet
- Potato
- Cotton

(Biotech)
Chemical Enterprise

Agriculture

Industry websites; GMO Compass, Genius GmbH, 2008
### Energy Consumed in Agriculture

**US Energy Consumed and CO₂ emitted (snapshot, 2005)**

<table>
<thead>
<tr>
<th>Sector</th>
<th>Energy, quads</th>
<th>CO₂, Tg emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>1 +</td>
<td>69</td>
</tr>
<tr>
<td>All Sectors</td>
<td>95</td>
<td>5874</td>
</tr>
<tr>
<td>Total US</td>
<td>96</td>
<td>5943</td>
</tr>
</tbody>
</table>

*+Does not include fertilizer, pesticide inputs*

**Fuel vs Food Debate?**

US agriculture and Forestry Greenhouse Gas Inventory, 1990-2005, USDA
Oil Prices are Uncertain

$ / Bbl – EIA International Energy Outlook

![Chart showing oil price projections from 1990 to 2040](image-url)
Oil Prices Fluctuate

http://www.macrotrends.net/1369/crude-oil-price-history-chart
Correlation of CPI to Oil Prices

http://www.macrotrends.net/1373/oil-prices-vs-the-cpi-historical-chart
US Oil Production Renaissance

Source: EIA, Annual Energy Outlook 2014 Early Release
Energy Consumption in other Countries is Increasing (in Quadrillion Btu)
What about population growth?

16 Billion
10 Billion
6.5 Billion
Heilig, Strategic Implications of Demographic Change in Asia, vs. Naval War College, May 25, 2012.
Human Development Index Versus Per Capita Primary Energy Consumption (EIA 2014; UNDP 2014)

Souza et al., Sao Paulo, 2015
Human Impact Factors

\[ I = P \times A \times T \]

Human Impact
Population
Affluence
Technology

\[ P(\text{width}) \times A(\text{height}) \times T(\text{length}) = \text{the dimensions of three boxes representing the human impact on the planet in 1900, 1950, and 2011.} \]

The box represents human impact, which had been growing steadily since the industrial revolution. It started to grow exponentially after World War II, a phase some scientists now call the “great acceleration.”

Population
Worldwide
7 billion

Affluence
World GDP*
$55 trillion

Technology
Patent applications
1.9 million

Dimick, National Geographic, 2014
Heilig, Strategic Implications of Demographic Change in Asia, vs. Naval War College, May 25, 2012.
Sustainability

Use of Natural Resources
Natural Environment/Ecosystem
Tipping Point
  Global epidemic
  Energy
  Water
  Crop Failure
  Climate Change
  War

background from: DC12 currentpopulationtrads, 2010
10 Months: 20,000 Cases of Ebola

Dorit, Am Scientist, 103, 259 (July-August, 2015)
Global CO$_2$ Emissions are Increasing

Data Source: R. F. Keeling, et al. Scripps Institution of Oceanography

Scripps Institute: http://www.climatecentral.org/gallery/graphics/keeling_curve
Papal Draft Blames Most Global Warming on Human Activity

Draft of encyclical calls reducing carbon emissions an ‘urgent’ matter

The pope wrote that there is an “urgent and compelling” need for policies that reduce carbon emissions, among other ways, by “replacing fossil fuels and developing sources of renewable energy.”

WSJ, June 15, 2015
Highlights: Current Annual Energy Use

Global  550 EJ  Total
Biomass  62 EJ
Combustion  40
Liquid Fuels⁺  4.2

⁺of Liquid fuels:
100 billion L (Ethanol and biodiesel)
US > Brazil > China > EU, Canada

Souza et al., Sao Paulo, 2015
Current Feedstocks and Biofuels

Liquid biofuels

- Conventional Ethanol
  - Maize
    - Up to 3,900 L/ha
    - GHG emissions 35-52% lower than gasoline
  - Sugarcane
    - Up to 7,200 L/ha
    - GHG emissions 80% lower than gasoline

- Biodiesel
  - Rapeseed
    - Up to 5,700 L/ha
    - GHG emissions 29-65%
    - Lower than diesel
  - Soybean
  - Oil Palm
    - Oil Palm
    - Waste cooking oil
    - Waste animal fats
    - Rapeseed
    - Soy
    - Camelina
    - GHG emissions 45-70%
    - Lower than diesel

- HVO diesel
  - 6 Million metric tons
  - 0.1 EJ
  - < 0.1 Million ha of land

Souza et al., Sao Paulo, 2015
Global Land Use for Bioenergy

Total Global Land
13 Billion ha

Land Use for Bioenergy now
Traditional and Modern

< 1.3 to 60 Million ha

50-200 Million ha

Land Use for Bioenergy expansion
to produce
100-200 EJ/yr

1.5 Billion ha

Land Use for Food Crops and Arable Land

(Souza et al., Sao Paulo, 2015)
### 2007 US Land Use: 2.3 Billion Acres

18% is cropland

<table>
<thead>
<tr>
<th>Allocated Use</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest-use Land</td>
<td>30</td>
</tr>
<tr>
<td>Grassland</td>
<td>27</td>
</tr>
<tr>
<td>Cropland</td>
<td>18</td>
</tr>
<tr>
<td>Parks, National Defense Areas, Transportation</td>
<td>14</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
</tr>
<tr>
<td>Urban Areas</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>101</strong></td>
</tr>
</tbody>
</table>

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**Cropland**

Another View

Capital Expenses ("Cap Ex")
Operational Expenses ("Op Ex")

Pro-forma

Inputs = Costs (Expenses)
Outputs = Revenues

where Revenues = Demand × Price

Net Revenue = Revenue – (Discounts + Return)
Gross Profit = Revenues – Cost of Goods
Net Profit = Revenues – Expenses

from: www.investinganswers.com
For Food Crop (Corn)

<table>
<thead>
<tr>
<th>Total Revenue per acre</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain</td>
<td>640</td>
</tr>
<tr>
<td>Biomass</td>
<td>120</td>
</tr>
</tbody>
</table>

Gross Profit: 760

Operating Expenses:

Salaries: 300.
Rent*: 300.
Energy, Seed, etc.: 390.
Depreciation:
Load: 0
Equipment: 30

(720)

Margins are thin….

40 (this could easily turn into a loss)

from: www.accountingtools.com
www.extension.iastate.edu
www.cipco.net, www.agecon.purdue.edu
Why is Land not Depreciated?

1. Unlimited Life Span.
2. Scarcity
   Value increases over time
3. Depletion of Resource in Land (Mine) costs:
   Acquisition (property rights)
   Exploration (finding resource)
   Development (drilling)
   Restoration
   Depletion Expense = Base – Salvage Value
Gen 2 Second Generation (Cellulosic) Biofuels

Major sources of uncertainty for cellulosic biofuels:

- Future oil prices,
- Feedstock costs and availability by region,
- Conversion costs and efficiencies,
- Environmental impacts,
- Government policy.

*The combination of all of these uncertainties makes analysis of biofuels impacts highly uncertain.*

Current condition of the financial markets causes difficult conditions for cellulosic biofuel investment

Tyner, 2013
Gen 1 vs Gen 2

Gen 1: Ethanol from corn, wheat, sugar cane
(> 25 billion gal / yr, worldwide constrained by blend wall in US)

Sugar cane ethanol qualifies as advanced biofuel – 61% reduction of total life cycle greenhouse gas emissions (GHG)

Gen 2: Ethanol from corn stalks, sugar cane bagasse, wood, energy crops (< 20 to 40 million gals / yr in 2015)

Cellulose ethanol > 60% reduction in total life cycle GHG
Biomass (Cellulose) is Part of Agriculture

a. Agricultural residues
   Global, US Midwest

b. Wood
   Upper Midwest US, Canada (hardwoods)
   Southeast US (softwoods)
   Europe (softwoods, hardwoods)

c. Purposely grown energy crops
   Brazil
   US – still to be determined
   Africa?
Feedstocks for the Chemical Enterprise: Cornstalks

1 to 2 tons (dry basis) / acre

with permission, Shinners, 2009
Purposely Grown Switchgrass

- Warm-season perennial grass
- Low fertility requirement
- Tolerant of poor soils
- High yield (5-7 ton/acre)

Photos courtesy of Department of Agronomy, Purdue University
Biorefineries and the Chemical Enterprise

Bio(chemical) refinery:

1. Produce energy from renewable domestic raw materials (energy goal)
2. Establish robust biobased industry (economic goal)
3. Establish off-take contracts.

Biorefineries with diversified product portfolios could offer great potential for agriculture to capture added value, and a higher return on investment, while achieving energy and economic goals simultaneously.

Bozell and Petersen, 2010
Agriculture gives back: Biochemical and Chemical Conversion

Transformation through Intermediates (sugars)

"Biochemical conversion"

main difference is in the primary catalysis system

Reduction to building blocks (CO, H₂)

"Thermochemical conversion"

David Dayton, NREL, IEA, 2007
Pretreatment Principles (step 2)

Pretreatment gives enzyme accessible substrate

Lignin

Cellulose

Amorphous Region

Crystalline Region

Hemicellulose

Mosier et al., 2005
Fermentation Scale-up: Making Mash

Untreated, 150 g / L

Pretreatment

Pretreated and Processed, Pre-fermentation

Ladisch et al, 2010 AIChE Meeting, Salt Lake City, Paper 257e, Nov 9, 2010
Technology benefit of pretreatment: enhanced yields in Steps 3 and 4

Corn Stover

Pretreatment

Sugars Formed

No Pretreatment

Glucan Hydrolysis Yield

Hydrolysis Time (hrs)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90%

15 FPU/g glucan cellulase (Spezyme CP)
+40 IU/g glucan b-glucosidase (Novozyme 188)
Biochemical Conversion of Cellulose

1. Feedstock Preparation
2. Pretreatment
3. Hydrolysis
4. Fermentation
5. Separations
6. Combustion or Gasification

- Enzymes
- Microbes (Yeast, Bacteria)

Aqueous based, microbial/protein catalysts, mild conditions

Feedstock

Catalysts

Energy

CO₂

Residue

Co-products
Sugar derived platform chemicals include

- Hydroxymethylfurfural (HMF)
- Furfural
- Levulinic acid
- γ-valerolactone

Catalytic conversion to alkanes, and to precursor molecules for use in production of polymers, lubricants, and herbicides.

Bozell and Petersen, 2010
Global Industrial Chemical Production
80 million tons of industrial chemicals / yr.
Utilizes 3 billion barrel-of-oil equivalents (crude oil, naphtha, and natural gas).

Petrochemical types:
Base chemical building blocks,
intermediate chemicals, and derived polymers

Look for oxygenated chemicals, derived from sugars with high margins

Economic Synergies between Agriculture and the Chemical Enterprise

Agriculture is market for:
- Seeds
- Fertilizers
- Pesticides / herbicides

Agriculture provides hedge for some feedstocks needed by chemical enterprise
- Oil
- Carbohydrates
- Cellulosics
- Fermentation substrates

Translation of science from discovery to commercial scale is critical: requires sustained research and development
**US Partnerships**

**Chemical enterprise** (exports of $86.9 billion, 2011).
- Possible partnerships based on
  1. discovery of new processes based on sugars
  2. research on utilization of renewable resources
  3. business models based on products from agricultural (particularly cellulosic) commodities

**US Agriculture** (net balance of trade of $43 billion, 2011; projected $24 billion in 2012)
- 1. design / grow crops for value-add chemicals
- 2. continue improvements in productivity
- 3. business models for year round supply
- 4. Industrial fermentation capacities
New (old) ways of thinking

PROTEIN METABOLISM
The liver and kidneys play important roles in what happens to that sandwich you eat.

1. **Once in the bloodstream**, the amino acids travel to the liver and other organs, such as skeletal muscles, that use them to make proteins for tissue repair or repair. Amino acids are also used to build important molecules such as enzymes and hormones.

2. **The liver** removes amino acids from the bloodstream, sending them to the kidneys. It converts the amino acids into smaller molecules, such as proteins and enzymes, that enter the bloodstream.

3. **In the bloodstream**, amino acids are converted to glucose and fatty acids, which are used for energy or stored for later use.

4. **The kidneys** filter the blood and excrete any excess water, salt, and waste products in the urine.

5. **In the small intestine**, digestion occurs. This process involves enzymes that break down the peptide molecules into amino acids. Then, two transport systems, made of carrier proteins and GLUT4, absorb the amino acids into the intestinal wall and push them out into the bloodstream.

Bomgardner, CEN, 93(6), 11, Feb 9, 2015

SEARCHING FOR SYMBIOSIS
Microbes abound that could boost crop performance. Small startups and major agriculture firms are looking high and low to find the best.

6. **The Plant Microbiome**

   At least one beneficial microbiome, glutamates, can be incorporated into a plant's tissues to boost its ability to fix nitrogen from the atmosphere. For example:

   - **BNF (Rhizobium)**
   - **Soil bacteria**
   - **Plant-symbiotic bacteria**
   - **Plant DNA**

7. **The Plant Microbiome**

   Just as humans have a microbiome involving the gut and skin surface, plants have communities of symbiotic microbes in their tissues. Root surfaces, and root zone. Start-ups are creating designer microbes, other plant- or soil-microbes to increase yield and nutrient stress tolerance and enhance plant health and growth rates.

Bomgardner, CEN, 93(19), 11, May 10, 2015
# A New Crop

**Agriculture start-ups target diverse products for plant and animal health**

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>TECHNOLOGY</th>
<th>BENEFIT</th>
<th>AMOUNTa ($ MILLIONS)</th>
<th>DATE</th>
<th>INVESTORS INCLUDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgriMetis</td>
<td>Baltimore</td>
<td>Natural products</td>
<td>Crop protection</td>
<td>7.3 (series A)</td>
<td>February 2015</td>
</tr>
<tr>
<td>Arcadia Biosciencesb</td>
<td>Davis, Calif.</td>
<td>Biotech crops</td>
<td>Nitrogen, water efficiency</td>
<td>33.0 (series D)</td>
<td>May 2014</td>
</tr>
<tr>
<td>Azotic Technologies</td>
<td>Lancashire, England</td>
<td>Microbes</td>
<td>Nitrogen fixing</td>
<td>None yet</td>
<td></td>
</tr>
<tr>
<td>BioConsortia</td>
<td>Davis, Calif.</td>
<td>Microbe groups</td>
<td>Yield enhancement</td>
<td>15.0 (series B)</td>
<td>April 2014</td>
</tr>
<tr>
<td>Blue River Technology</td>
<td>Mountain View, Calif.</td>
<td>Robotics</td>
<td>Automated weeding</td>
<td>10.0 (series A)</td>
<td>March 2014</td>
</tr>
<tr>
<td>BotanoCap</td>
<td>Israel</td>
<td>Microencapsulation</td>
<td>Crop protection</td>
<td>4.2 (seed)</td>
<td>December 2013</td>
</tr>
<tr>
<td>Green &amp; Grow</td>
<td>Austin, Texas</td>
<td>Microbial by-products</td>
<td>Yield enhancement</td>
<td>6.0 (series B)</td>
<td>August 2014</td>
</tr>
<tr>
<td>NewLeaf Symbiotics</td>
<td>St. Louis</td>
<td>Microbes</td>
<td>Plant growth</td>
<td>17.0 (seed)</td>
<td>September 2014</td>
</tr>
<tr>
<td>NexSteppe</td>
<td>San Francisco</td>
<td>Specialty crops</td>
<td>Biomass production</td>
<td>22.0 (series C)</td>
<td>September 2014</td>
</tr>
<tr>
<td>Prevtect Microbia</td>
<td>Montreal</td>
<td>Vaccine</td>
<td>Animal health</td>
<td>4.0 (seed)</td>
<td>November 2011</td>
</tr>
<tr>
<td>Spensa Technologies</td>
<td>West Lafayette, Ind.</td>
<td>Electronic devices</td>
<td>Pest control</td>
<td>1.9 (seed)</td>
<td>October 2014</td>
</tr>
</tbody>
</table>

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**SOURCES:** Companies, CleanTech Group, Securities & Exchange Commission

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a Seed funding is the firm’s initial amount of capital raised. Series A, B, C, and D funding refer to subsequent rounds of financing that give investors equity in the company. b Filed for an initial public offering of stock.
Conclusions


Factors that impact food, energy, and chemicals production are:

1. Land
2. Seeds
3. Productivity
4. Energy
5. Technology

The chemical and energy enterprises are needed to provide production tools to agriculture, either in the field or in the plant.

Distribution of resources / population tipping point are unknowns.