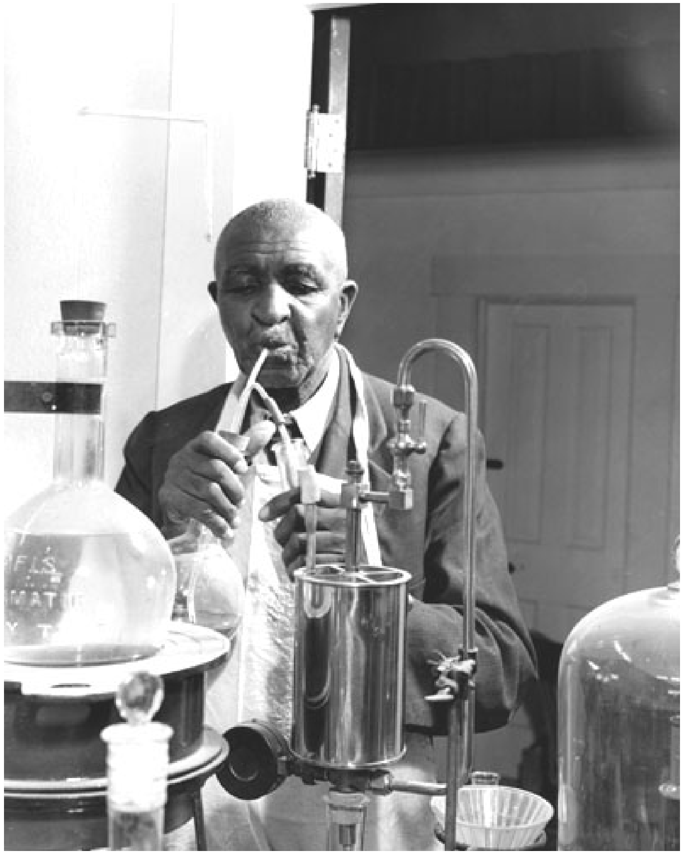
The Evolving Paradigm of Agriculture as a Provider of Energy and Chemicals

Dr. Larry P. Walker
Professor
Department of Biological and Environmental Engineering
Cornell University

Cornell University

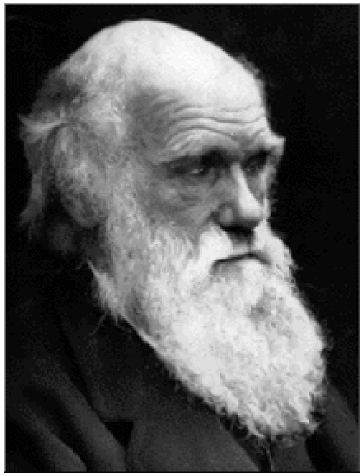
Father of Biobased Industry



"I believe the Great Creator has put ores and oil on this earth to give us a breathing spell.....As we exhaust them, we must be prepared to fall back on our farms, which are God's true storehouse and can never be exhausted. For we can learn to synthesize materials for every human need from the things that grow."

Dr. George Washington Carver
(1864-1943)

Historical Perspective



Charles Robert Darwin (1809 –1882) "On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life" (1859)

Scientific Discovery

National Security and Stability: American Civil War (1860-1865)

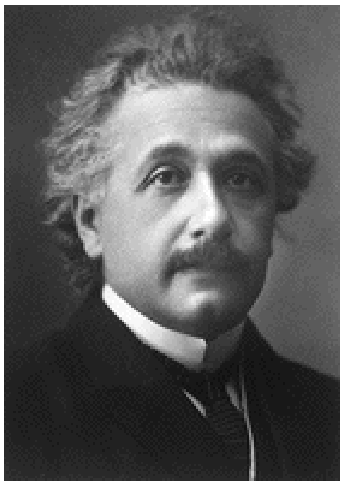
International Search for Oil Began 1859 – Energy Security

Economic Development

Cyrus Hall McCormick
(1809 – 1884)

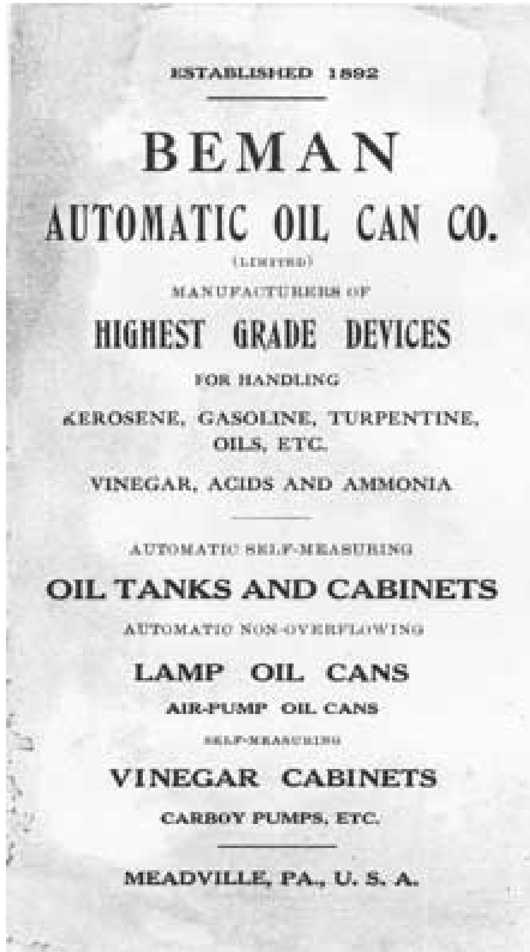
Improvement in Machines for Reaping Small Grain
Mechanical Reaper
Patent Number(s) Patented June 21, 1834

Entry into the 20th Century



Albert Einstein
(1879 – 1955)

Special Theory of Relativity (1905)



ESTABLISHED 1892

BEMAN

AUTOMATIC OIL CAN CO.

(LIMITED)

MANUFACTURERS OF

HIGHEST GRADE DEVICES

FOR HANDLING

KEROSENE, GASOLINE, TURPENTINE, OILS, ETC.

VINEGAR, ACIDS AND AMMONIA

AUTOMATIC SELF-MEASURING

OIL TANKS AND CABINETS

AUTOMATIC NON-OVERFLOWING

LAMP OIL CANS

AIR-PUMP OIL CANS

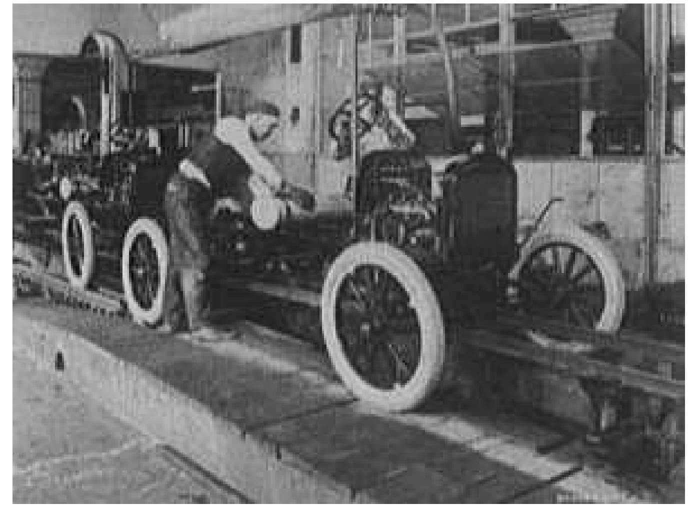
SELF-MEASURING

VINEGAR CABINETS

CARBOY PUMPS, ETC.

MEADVILLE, PA., U. S. A.

Beginning of the Hydrocarbon Economy



The Beginning of the Auto Age

Mechanization of Agriculture

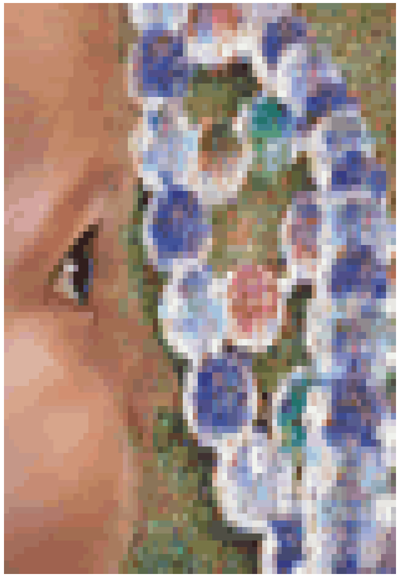
Entry into a 21st Century

War on Terror

Climate Change

Transgenic Corn

Global Economic
Competitiveness



Human Genome Project

The Big Question

How do we meet the energy and materials needs of a sustainable global community?

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Multiple Solutions!

ENERGY CONSERVATION

OIL

PHOTOVOLTAIC

WIND

NUCLEAR

COAL

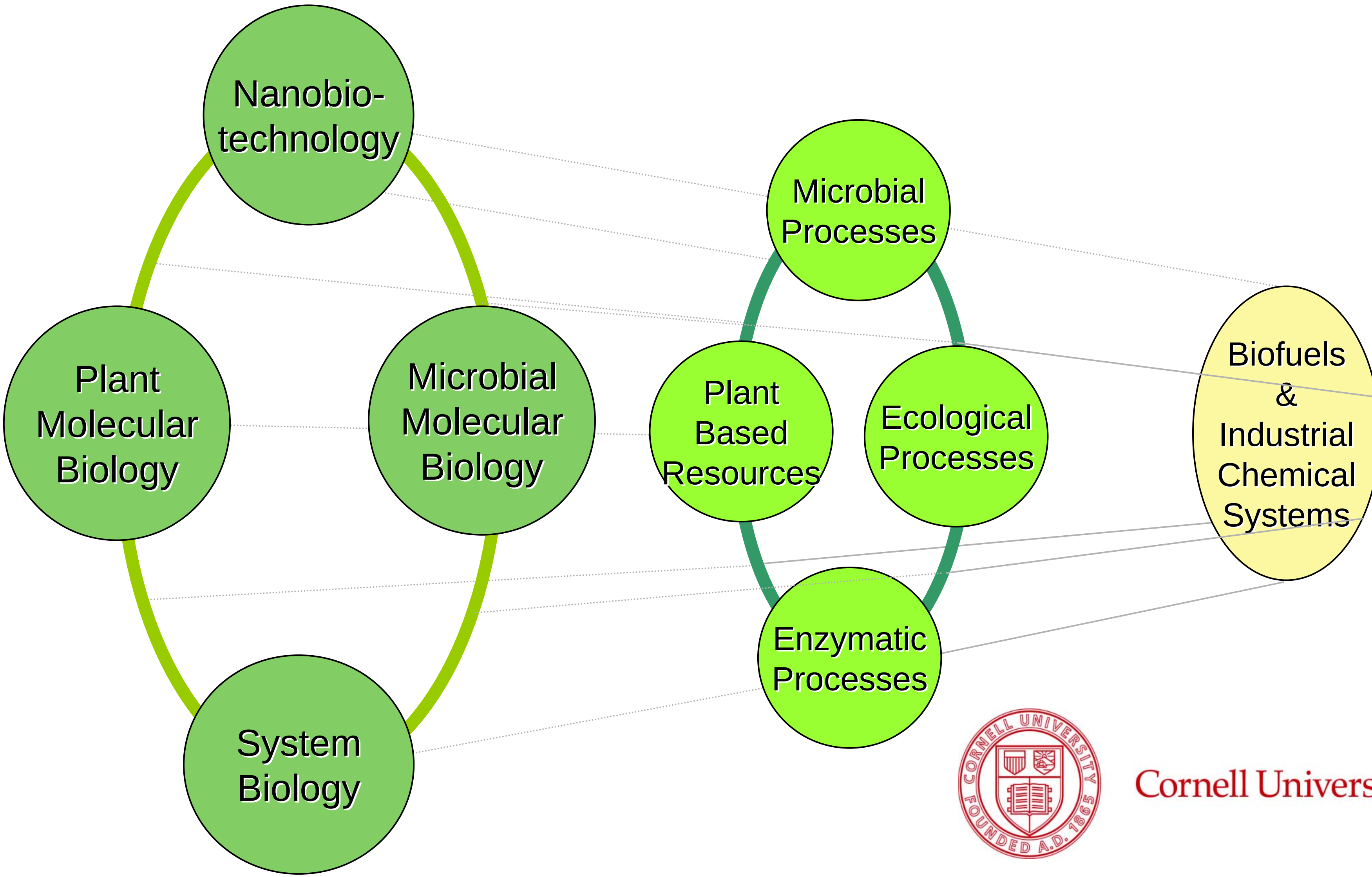
BIOMASS

Biomass is the only renewable that directly reduces our dependency on liquid fuels.

Good Science and Engineering

- genomics
- proteomics
- protein engineering
- system biology
- molecular modeling
- nanobiotechnology
- advanced materials
- advanced bioreactors
- more sophisticated control systems
- advance systems engineering tools

Integrating Knowledge and Methods from Basic and Applied Sciences for a Mission



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Elements of Industrial Ecology Design

- Integrate an entire industrial process to determine maximal beneficial use of resources
- Optimize the utilization of the resource
- Minimize waste generation during obtaining and processing of the resource
- Minimize waste during manufacturing

R. A. Frosch

Elements of Industrial Ecology Design

- Maximize destruction or reuse of waste resulting from manufacturing
- Maximize the ultimate recycling or disposal of the product,
- Minimize consumption of energy throughout the process, and,
- In all parts, environmental impact must be considered.

R. A. Frosch.

Cornell University

Principle of Ecosystems Design

An ecosystem model implies an evolutionary process as a major organizing principle:

- Components come into existence at different times and are therefore in different stages of their evolutionary history.
- New components coexists with mature products and with other on their way to extinction.

Number of tractors on farms exceeds the number horses and mules for the first time in 1954

Principle of Ecosystems Design

An ecosystem model assumes that the system is not the results of centralized planning or any systematic design process:

- **Ecosystem modeling simulate the present state of an ongoing opportunistic process.**
- **Evolutionary processes do not necessarily produce optimum outcomes –they produce satisfactory outcomes.**


All Biomass is Local:
Markets within
300 mile radius
MAPQUEST
0
100mi
100km
Canada
Montreal
Maine
Montpelier
Augusta
Concord
Boston
Providence
Hartford
Albany
Syracuse
Rochester
New York
Buffalo
Toronto
London
Flint
Detroit
Lake Erie
Erie
Cleveland
United States of America
Pittsburgh
Ohio
Pennsylvania
New York City
Trenton
Philadelphia
Baltimore
Annapolis
West Virginia
Virginia
Washington DC
North Atlantic Ocean
Cincinnati
Kentucky

Principle of Ecosystems Design

- Research is needed to determine the best species poly-culture development of biofuel feedstocks.

- Explore using manure to meet nutrient requirements for crops that could be suitable for biofuel

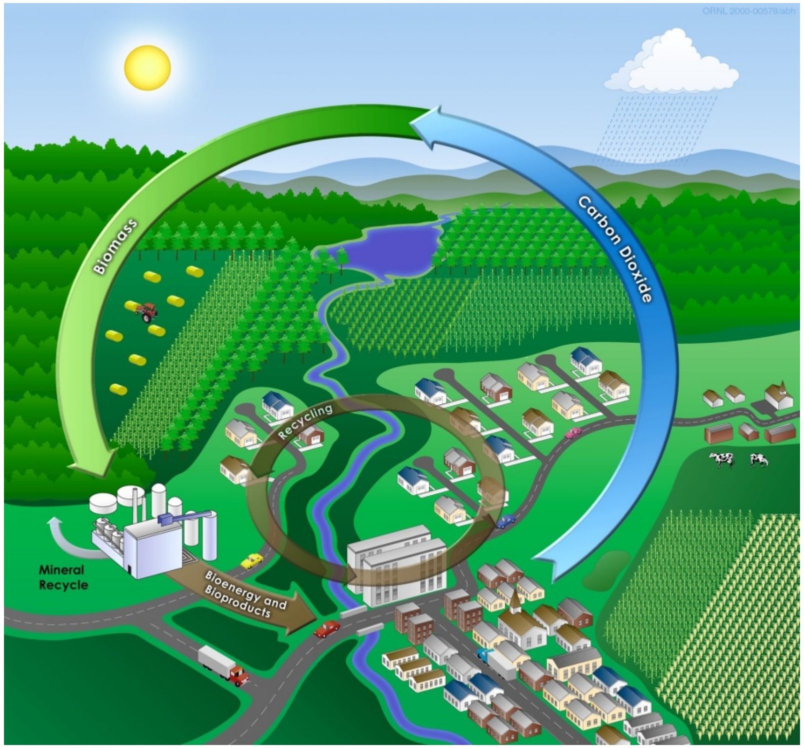
Major Subsystems of Sustainable Agricultural Based Energy System

BIOMASS PRODUCTION

FEEDSTOCK LOGISTICS

CONVERSION TECHNOLOGY

Innovative in How We Network Transformation Processes



How do we integrate structural and dynamic aspects of natural ecology in our design of industrial ecology?

What is a system?

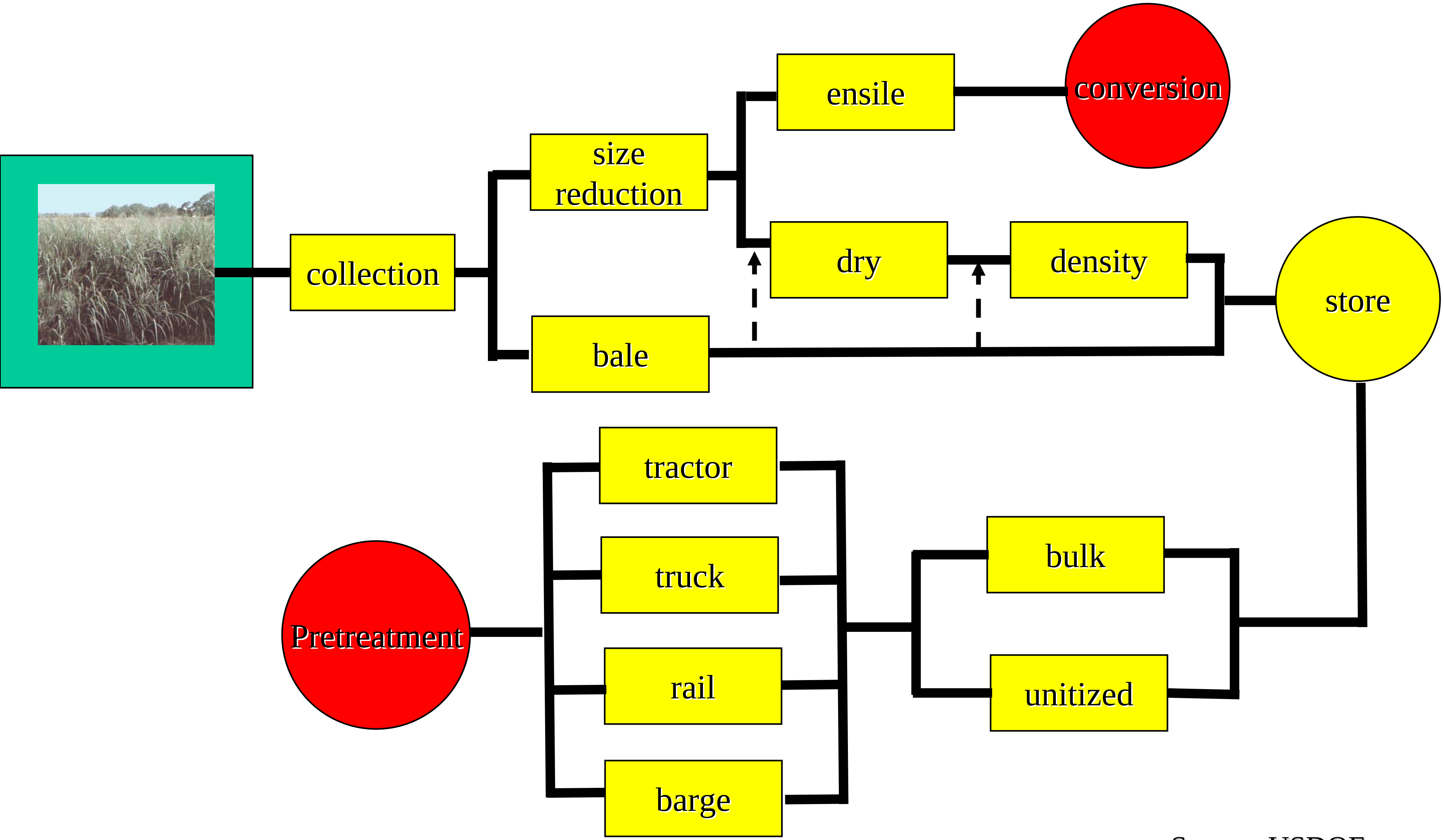
"A system is an assemblage or combination of elements or parts forming a complex or unitary whole, such as a river system or a transportation system…"

Blanchard and Farbrycky

System Engineering and Analysis

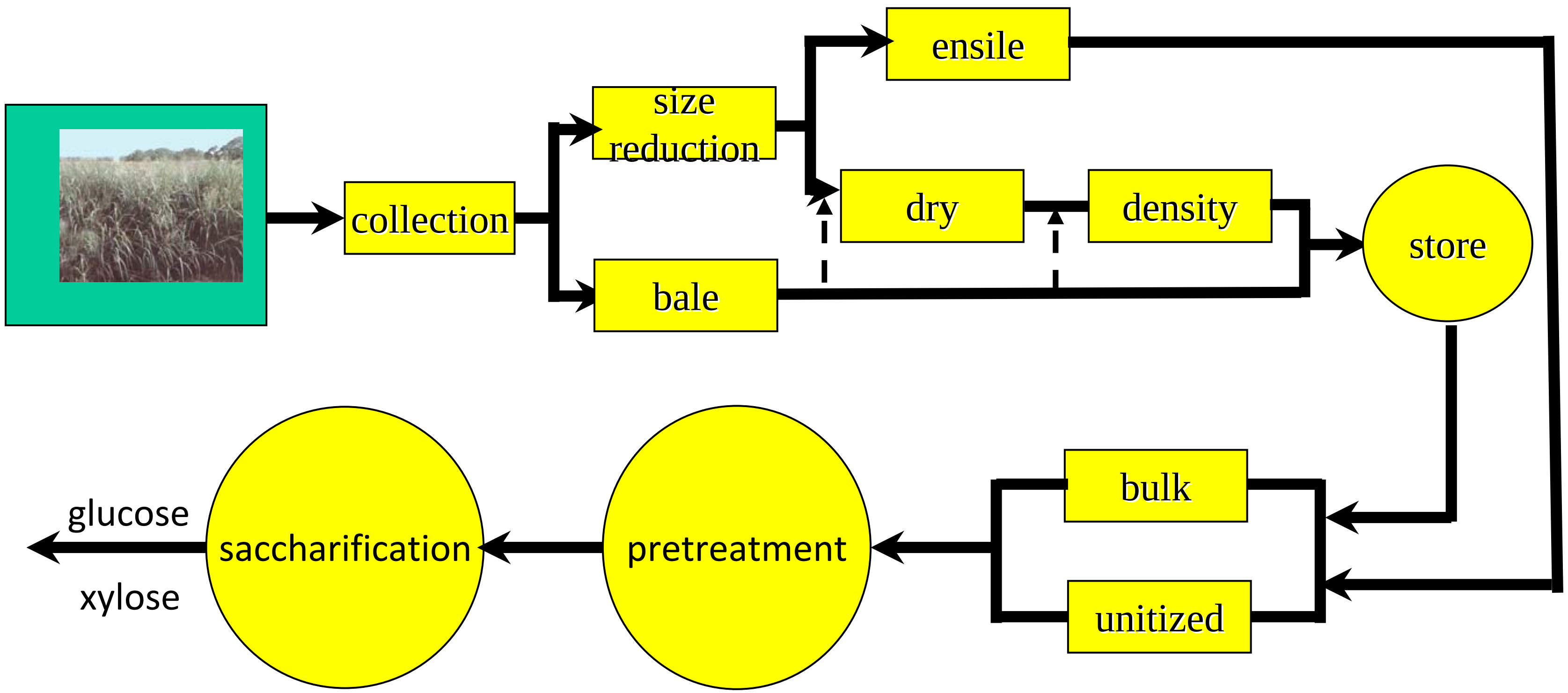
1998

Feedstock Supply System



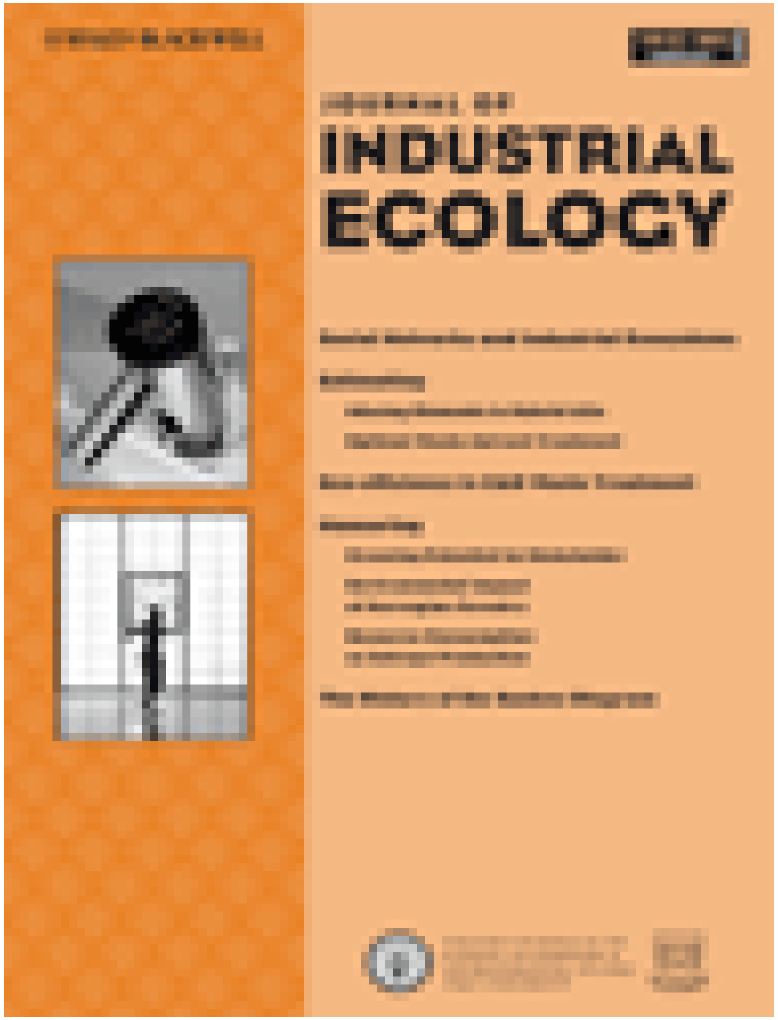
Source: USDOE

Alternative Subsystem Definition and Configuration



Two Approaches Ecosystems Modeling

- Structural studies or "systems ecology" – concentrations on the flow of material and energy.
- Dynamic studies or "population ecology" – time varying behavior of components.



INDUSTRIAL ECOLOGY

USDA Multidisciplinary Graduate Education and Training Program (MGET)

Core Course Work:

1. Sustainable Development Seminar
2. The Science and Engineering Challenges to the Development of Sustainable Bio-based Industries
3. Biomass Conversion for Energy and Chemicals, and
4. Industrial Ecology of Bio-based Industries

Engineering Industrial Ecologies

"…as a dominating species on the surface of the earth, man must learn how to engineer the developments in industry, agriculture, and human habitats as components of an industrial ecosystem. In this greatest and most challenging of engineering efforts we must be concern with feasible alternative ecosystem goals and how to direct landscape development toward these goals, rather than with projections of present trends."

Koenig, Cooper and Falvey,1972
Engineering for Ecological, Sociological and Economic Compatibility

Input-output Modeling Of Systems: Goals

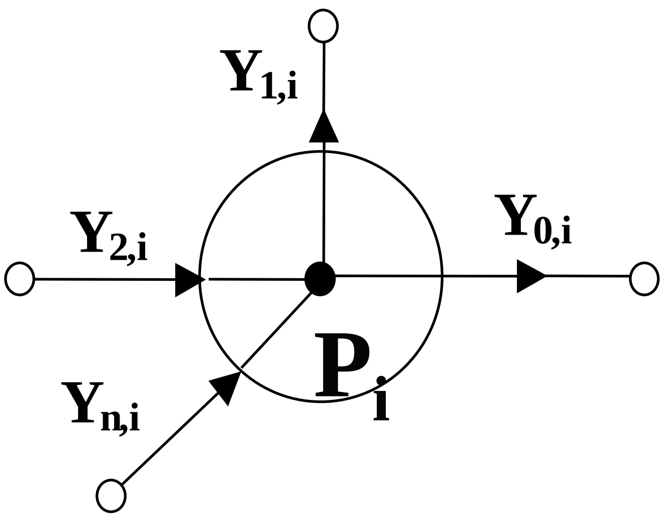
- To identify generic processes found in man-made and natural systems.
- To develop simple material flow models for generic processes.
- To define how basic processes are connected together to form a system.
- To develop and implement algorithms for calculating material flows.

Input-output Modeling Of Systems: Generic Processes[1]

- Material transformation
- Material transport
- Material storage

[1]Koening, H. E. & R. L. Tummala. 1972. Principles of ecosystem design and management. Trans. IEEE Sys., Man Cybernetics, Vol. Smc-2 (4): 449-459.

Material Transformation Processes

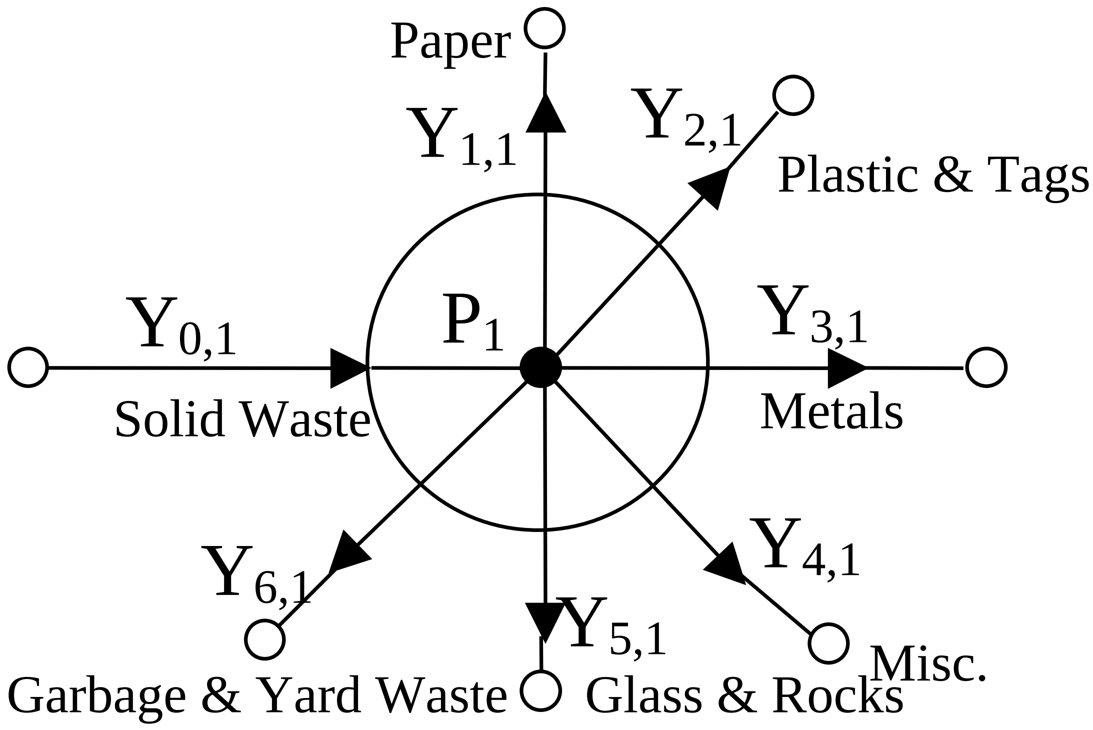


Graphical Model

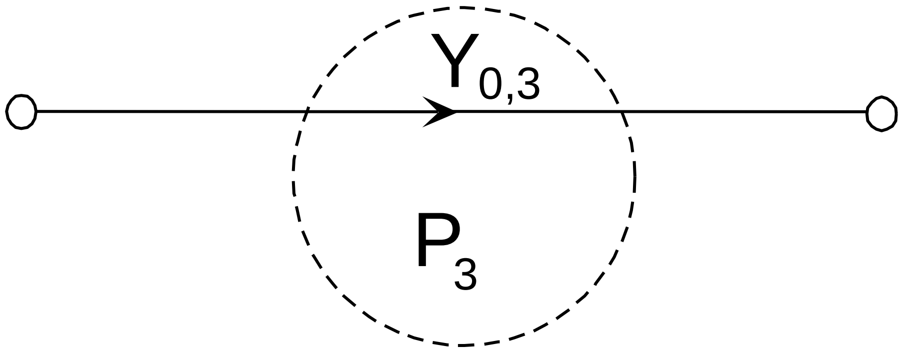
$$\begin{bmatrix} Y_{1,i} \\ Y_{2,i} \\ \vdots \\ Y_{n,i} \end{bmatrix} = \begin{bmatrix} k_{1,i} \\ k_{2,i} \\ \vdots \\ k_{n,i} \end{bmatrix} Y_{0,i} \qquad (1)$$

Mathematical Model

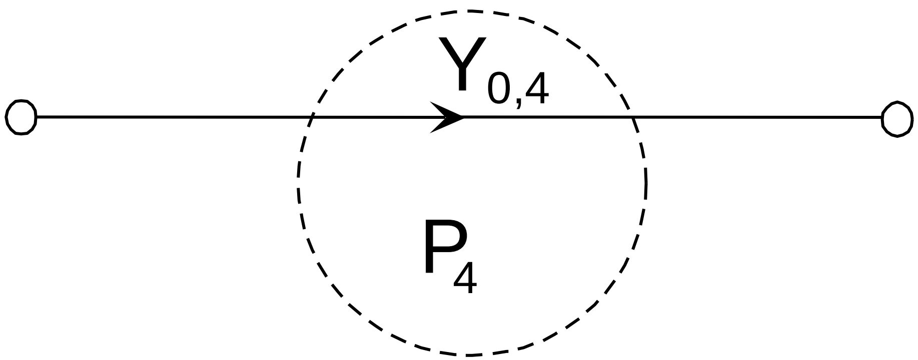
Example of Material Transformation Processes: Solid Waste Recycling.



Example of Material Transport Processes:

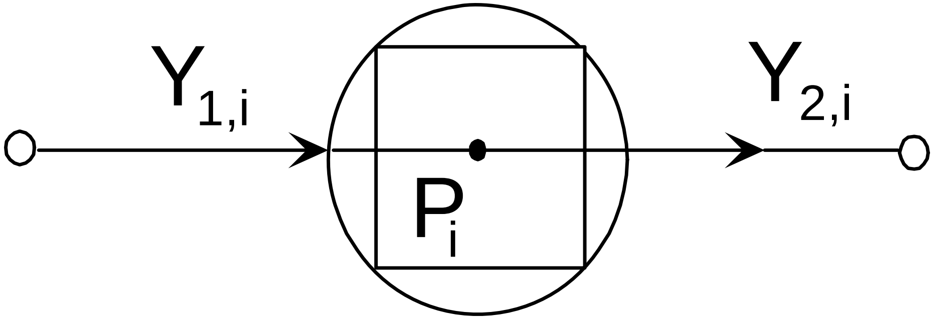


a conveyor

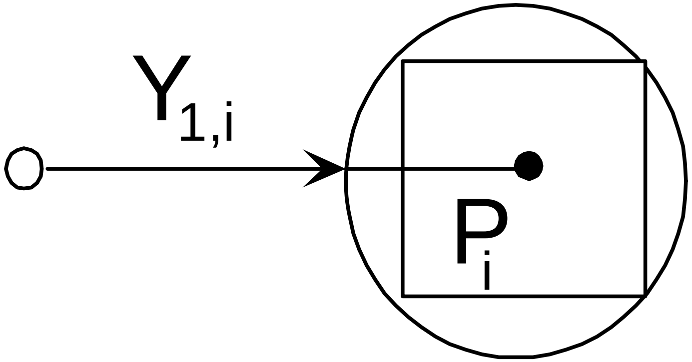


a fleet of trucks

Material Storage Processes:



$$\frac{d\psi_i}{dt} = Y_{1,i} - Y_{2,i} \quad (4)$$



$$\frac{d\psi_i}{dt} = Y_{1,i} \quad (5)$$

Societal Costs

We can define a cost vector that essentially represent the cost in nonrenewable resources:

$$x_{j,i}^{l=1} = \text{Labor}$$

$$x_{j,i}^{l=2} = \text{Solar Energy (Land)}$$

$$x_{j,i}^{l=3} = \text{Physical Energy}$$

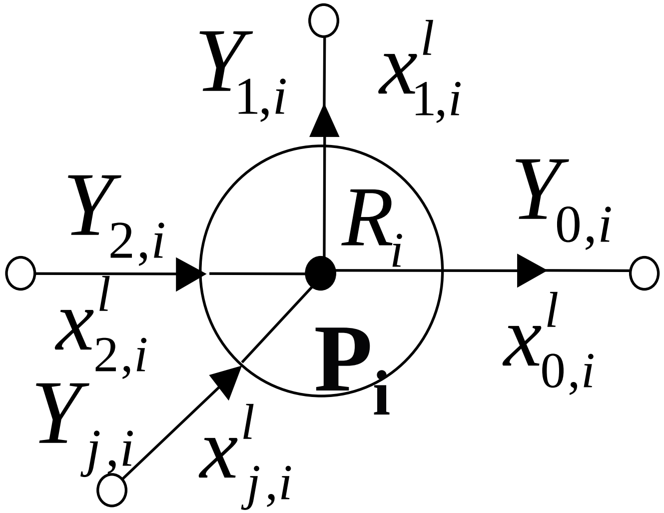
$$x_{j,i}^{l=4} = \text{Monetry}$$

where i = process number,

j = the flow associated with process "i",

l = costs.

Material Transformation Processes



Graphical Model

The cost equation for the stimulus variable is define as:

$$x^l_{j,i} = -\sum_{j=1}^{n}\left(k_{j,i}x^l_{j,i}\right) - f_i^l\left(Y_{o,i}\right) \quad (3)$$

where

i = the process number,

j = the flow associated with process “i”,

l = costs.

Material Transformation Processes

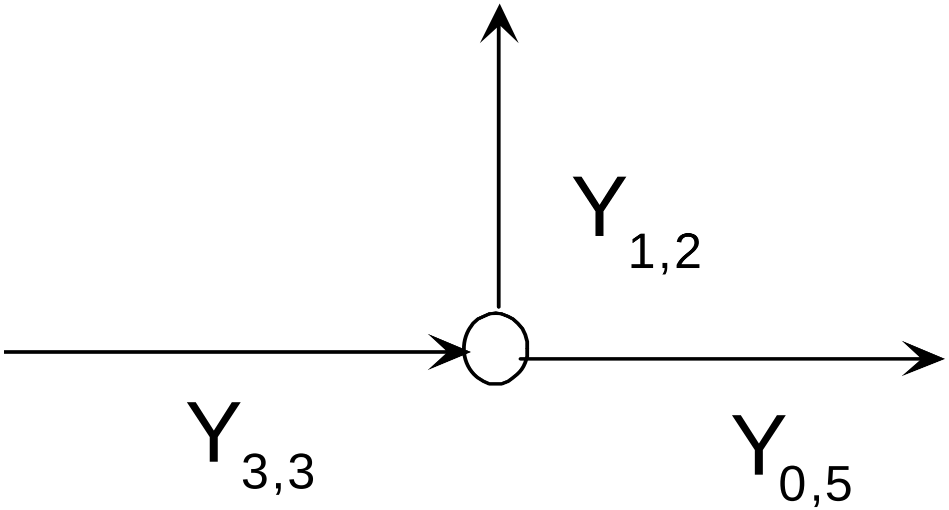
Dissecting equation 3:

$$x^{l}_{j,i} = -\sum_{j=1}^{n}\left(k_{j,i}x^{l}_{j,i}\right) - f^{l}_{i}\left(Y_{o,i}\right) \qquad (3)$$

Represents the costs involved in making input available to the process and to move the outputs from the process

Represents the costs per unit of output required to carry out the material transformation process.

Example of Nodes Connection



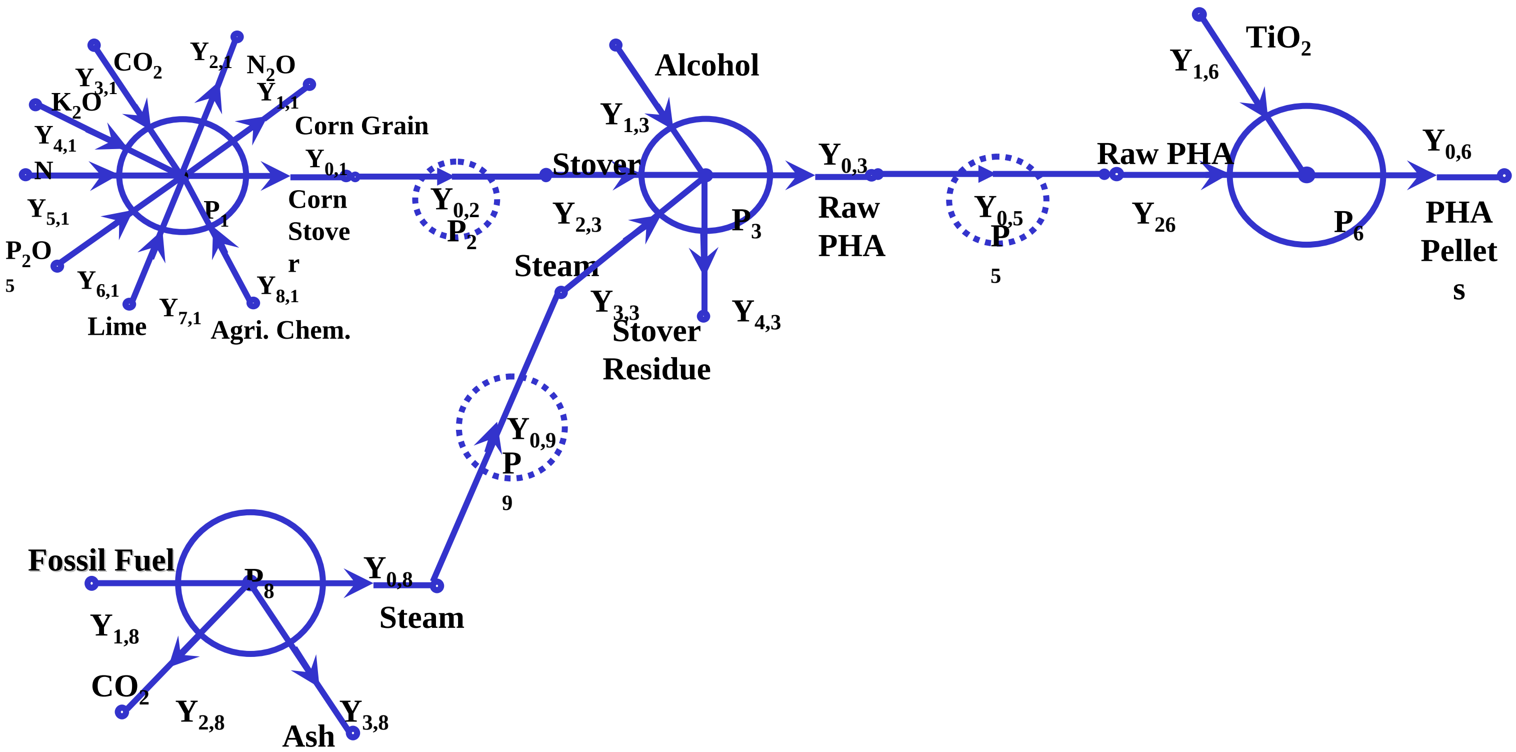
The constraint for this node is

$$Y_{3,3} + Y_{1,2} + Y_{0,5} = 0 \qquad (7)$$

Source of Study

Kurdikar, D., Fournet, L., Slater, S.C., and Paster, M, Gruys, K. K., Gerngross, T. U., & Coulon, R. 2001. Greenhhouse Gas Profile of a Plastic Material Derived from a Genetically Modified Plant. Journal of Industrial Ecology, 4(3): 107-122.

System Description: Fossil Fuel



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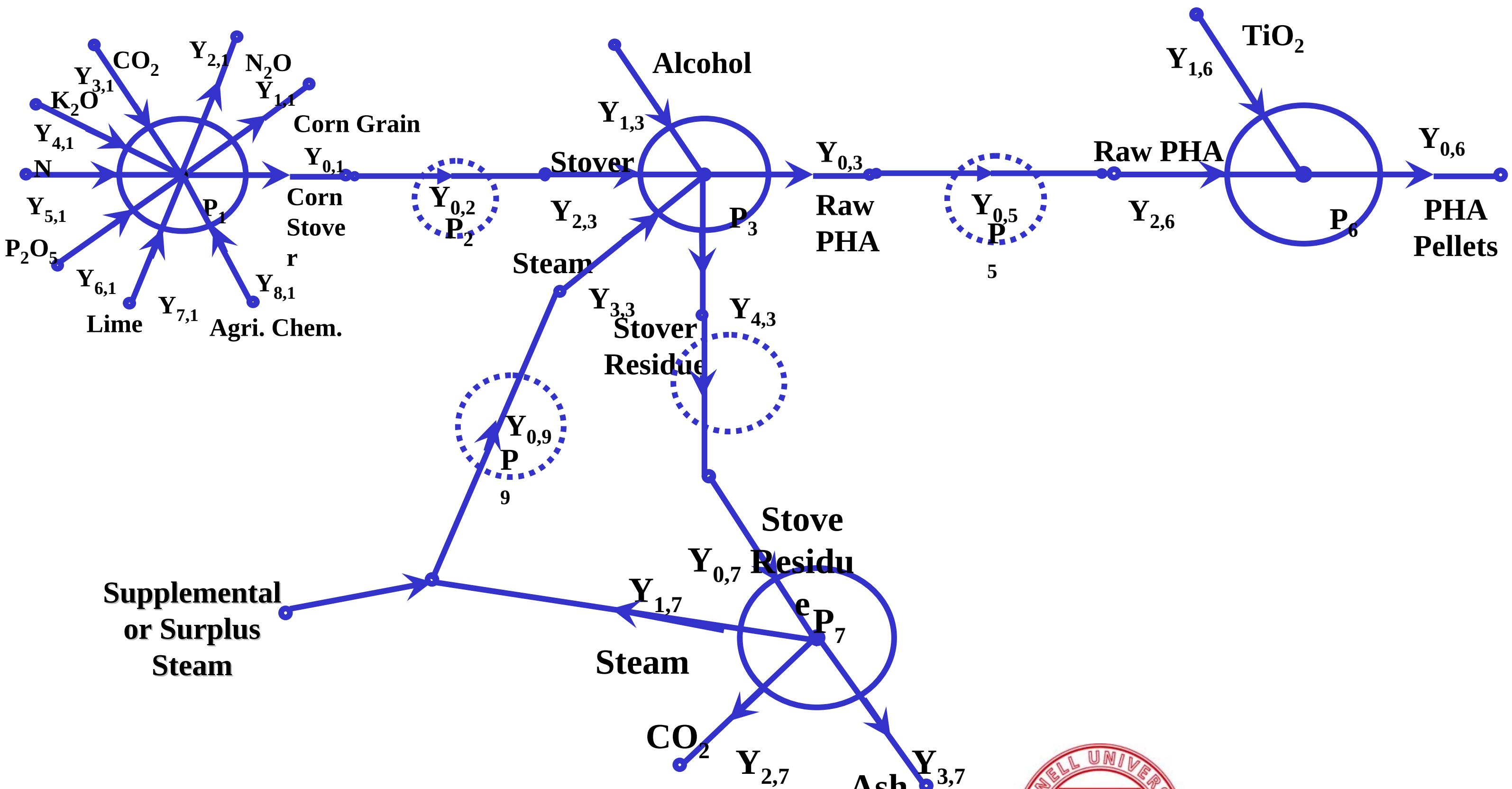
System Description: Biomass



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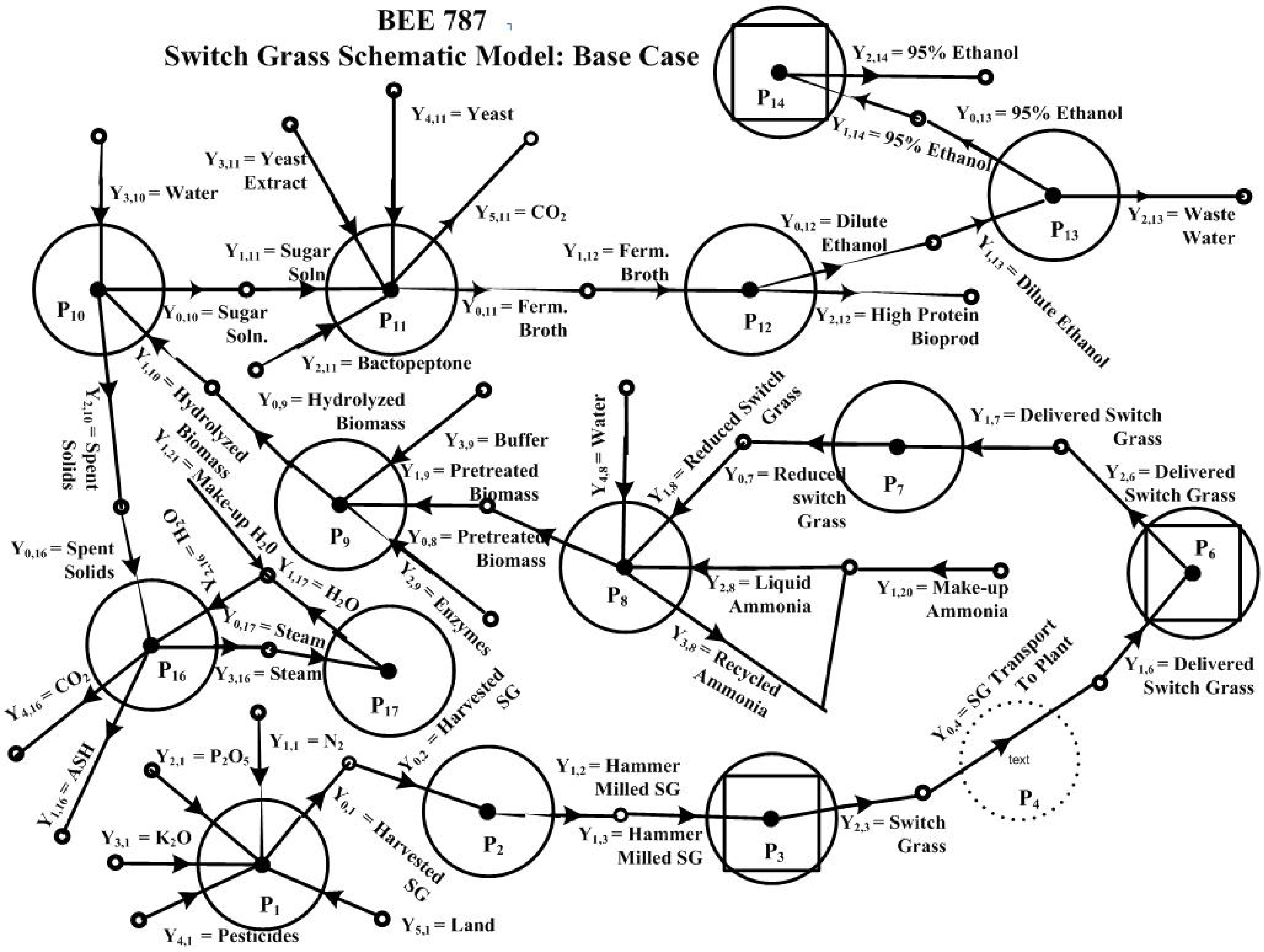
Input-Output Model of Cellulosic Ethanol Plant



Benefits of Industrial Ecology Modeling Framework

- *Explicitly couples principles of ecology with system thinking.*
- *Emphasizes the importance of examining different mixed of technology and different "network" structures.*
- *Provides a very robust method for documenting how key technology coefficients and cost equations are linked to processes and evolve over time.*

Benefits of Industrial Ecology Modeling Framework

- *Can generate the material, energy and monetary flows need for life-cycle analyses, and for determining carbon footprint.*
- *Represent the middle ground of between spread-sheets and full blown Aspen modeling.*
- *Is an excellent tool for teaching undergraduate and graduate students the principles of industrial ecology.*

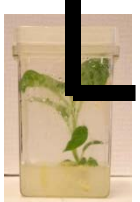
Cellulosic Ethanol Program (CEP) at Cornell University

Feedstock Biomass

Plant Breeding
Don Viands
William Pardee
Julie Hansen

Agronomics
Gary W. Fick
Russell Hahn
Les Hulcoop

Biocontrol
Donna Gibson
Gary Bergstrom

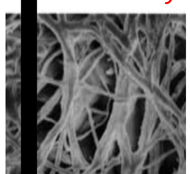


Plant genomic
Tom Brutnell
Jocelyn Rose
Stephen Kresovich

Pretreatment of lignocellulosic

Alkaline pretreatment
Jim Gossett

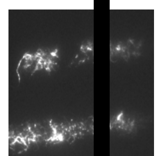
Water pretreatment
Larry Walker



Physical and biological characterization
Jim Gossett
Larry Walker

Enzyme optimization

Single cellulases
Harold Craighead
Larry Walker
David Wilson



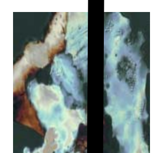
Enzymes Cocktails
David Wilson
Larry Walker

Enzyme prospecting
Stephane Corgie
Harold Craighead
Larry Walker
David Wilson

Whole organism fermentation

Ethanol tolerance
Susan Henry
Manuel Villa
Larry Walker

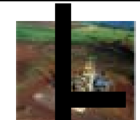
Mixed cultures bioprocess
Larry Walker
Manuel Villa
Stephane Corgie



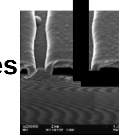
Metabolic Engineering
Susan Henry
Larry Walker
Manuel Villa
David Wilson

Microbial prospecting
Stephane Corgie
Larry Walker
Harold Craighead

Systems integration



Industrial ecology
Norm Scott
Larry Walker



Real-time nano-sensors
Harold Craighead
Larry Walker
Stephane Corgie

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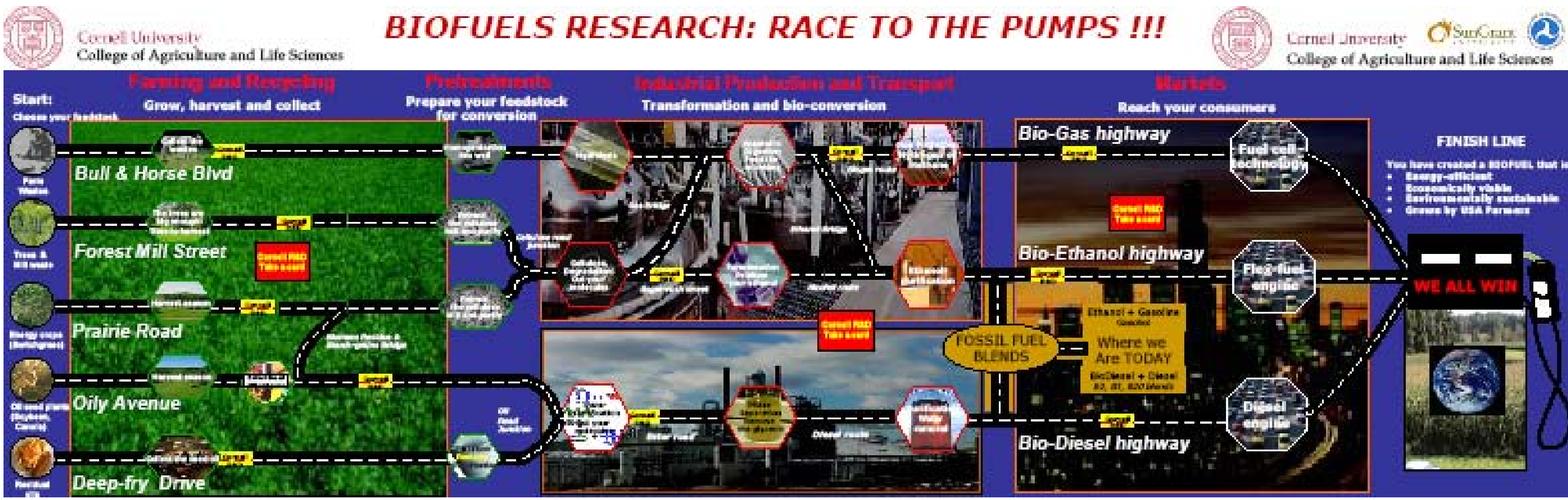
Educating the Next Generation of Scientists and Engineers

Educating the Next Generation of Scientists and Engineers



Reaching out to {
- K-12 Students
- Communities and stakeholders

Some key questions?

- What is driving the evolution of this paradigm?
- How do we manage the inherently disruptive nature of evolutionary processes?
- How do industry, government and universities work together to exploit opportunities and address challenges arising from this disruptive process?

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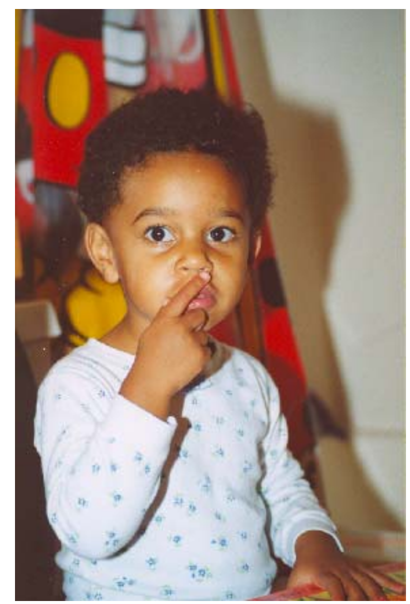
Innovative in Human Development

What a wonderful world!



"This only one world is our own to make and to keep."

Gerard Piel

Thank You for your support and interest!