Energy From Agriculture:
New Technologies, Innovative Programs & Success Stories

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The Future of Biorefining Agricultural Biomass

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USDA's Office of Energy Policy and New Uses
NRCS
Rural Development

Motivation for Biorefineries

- Environmental quality
  - Local and regional (smog, acid rain, waste disposal)
  - Global climate change
- Excess agricultural production
  - Especially in U.S., but many countries are becoming self sufficient in food production
- National security
  - Reduced reliance on foreign cartels
- Rural development
  - Rural economies are not thriving in many parts of the world

Courtesy USDA NRCS

Biorefineries Turn Biomass into Multiple Products

Plant Science
– Genomics
– Enzymes
– Metabolism
– Composition

Production
– Trees
– Grasses
– Agricultural Crops
– Agricultural Residues
– Animal Wastes
– Municipal Solid Waste

Processing
– Acid/Enzymatic hydrolysis
– Fermentation
– Bioconversion
– Chemical Conversion
– Gasification
– Combustion
– Co-firing

End-Uses
Chemicals
– Plastics
– Functional Monomers
– Solvents
– Chemical Intermediates
– Phenolics
– Adhesives
– Hydraulic Fluids
– Paints
– Dyes, Pigments, and Ink
– Detergents
– Paper
– Fiber boards
– Solvents
– Adhesives
– Plastic filler
– Abrasives

Transportation Fuels

Electric Power

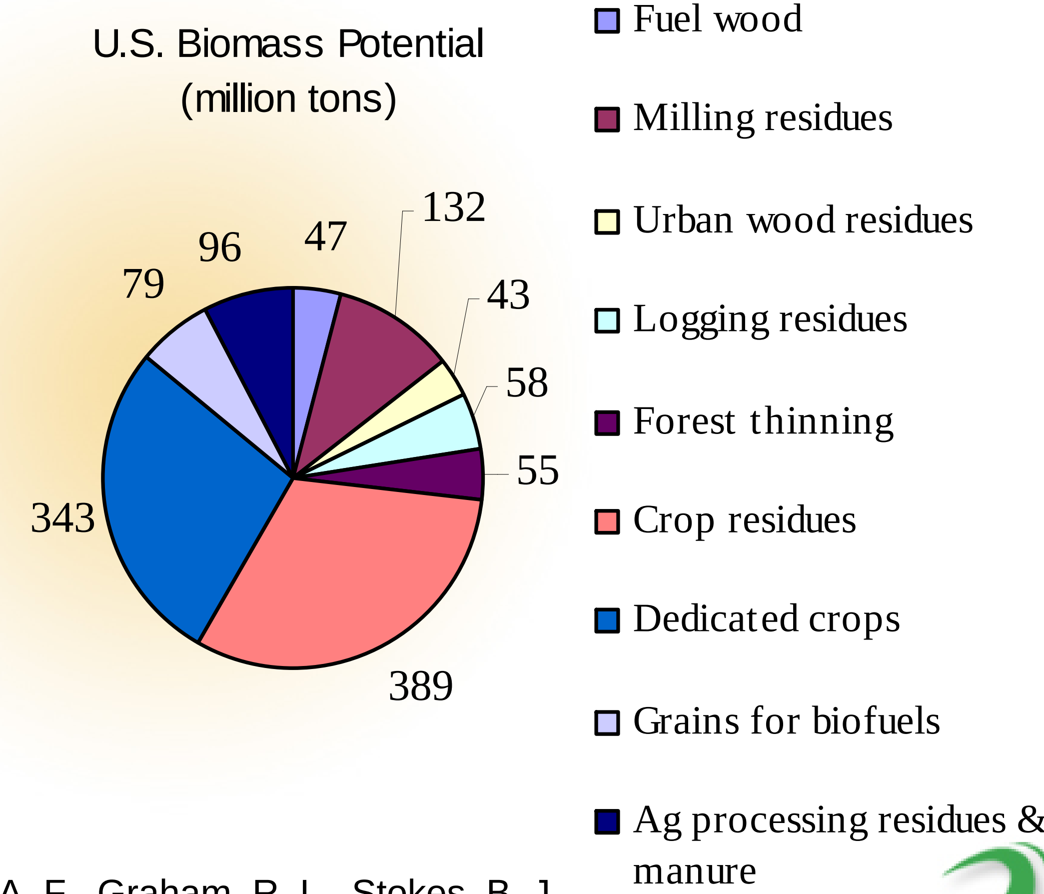
Factors Influencing the Emergence of Biorefineries

- Amount of biomass that can be produced
- Kinds of products that can be manufactured
- Kinds of conversion processes employed
- Energy balance for biobased fuels
- Optimal size of biorefineries

How Much Biomass Could Be Produced?

Total potential in U.S. is in excess of 1 billion tons (about 21 Quads)

- Could supply 21% of U.S. energy demand, or
- 33% of U.S. transportation fuel



Perlack, R. D., Wright, L. L., Turhollow, A. F., Graham, R. L., Stokes, B. J., and Erbach, D. C. (2005) Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, Department of Energy Technical Report GO-102995-2135, April.

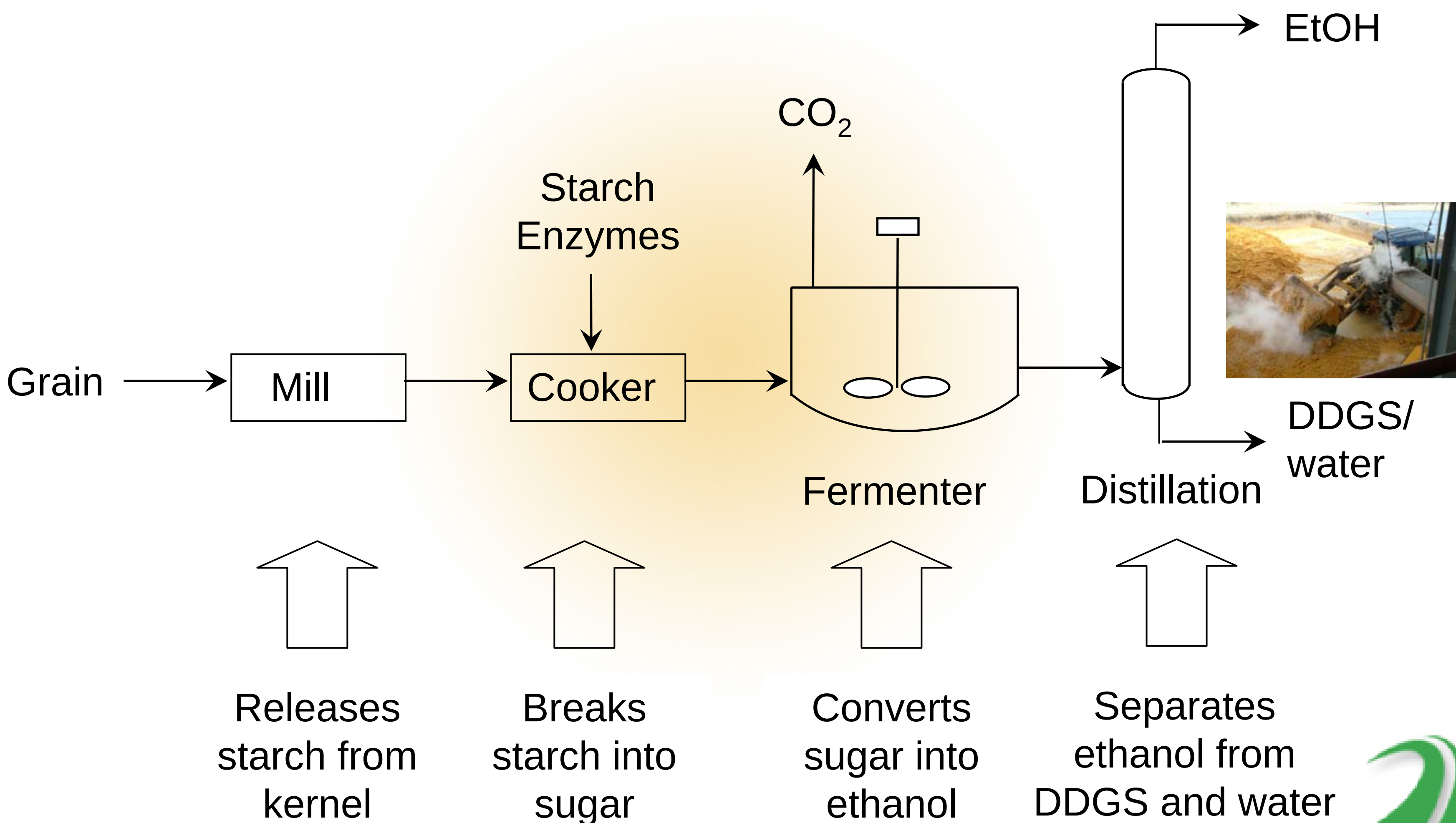
Ethanol and Biodiesel are not the Only Possible Biobased Fuels

Fuel	Specific Gravity	LHV (MJ/kg)	Octane Number	Cetane Number
Ethanol	**0.794**	**27**	**109**	**-**
Biodiesel	**0.886**	**37**	**-**	**55**
Methanol	0.796	20.1	109	-
Fischer-Tropsch Liquid	0.770	43.9	-	74.6
Hydrogen	0.07 (liq)	120	>130	-
Methane	0.42 (liq)	49.5	>120	-
Ammonia	0.68 (liq)	18.8	110	-
Dimethyl Ether	0.66 (liq)	28.9	-	>55
Gasoline	0.72-0.78	43.5	91-100	-
Diesel	0.85	45	-	37-56

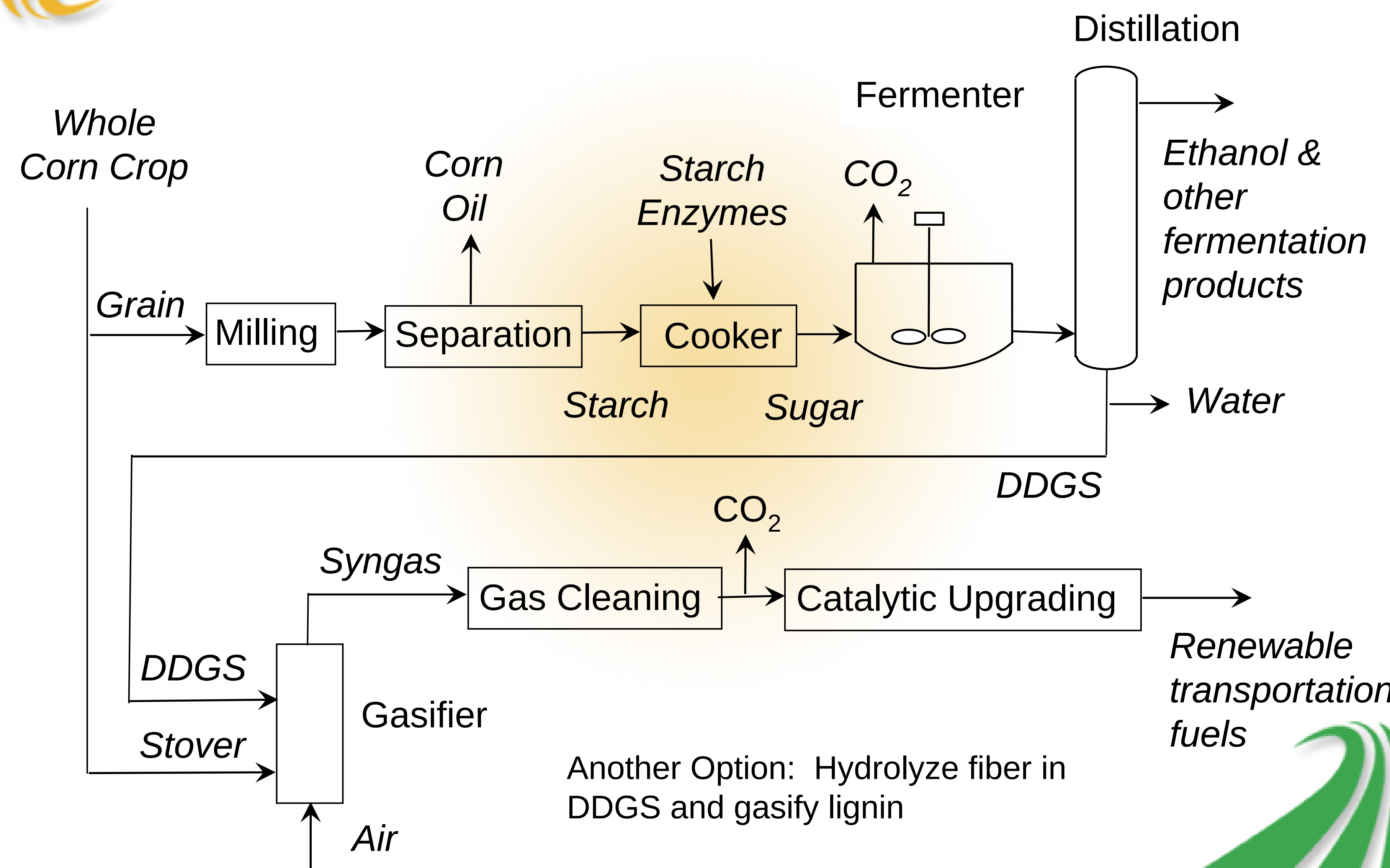
Nature of Conversions

- Traditional grain-to-ethanol plant
- Whole crop biorefinery
- Lignocellulosic biorefinery
- Thermochemical biorefinery

Current Technology: Grain-to-Ethanol Plant

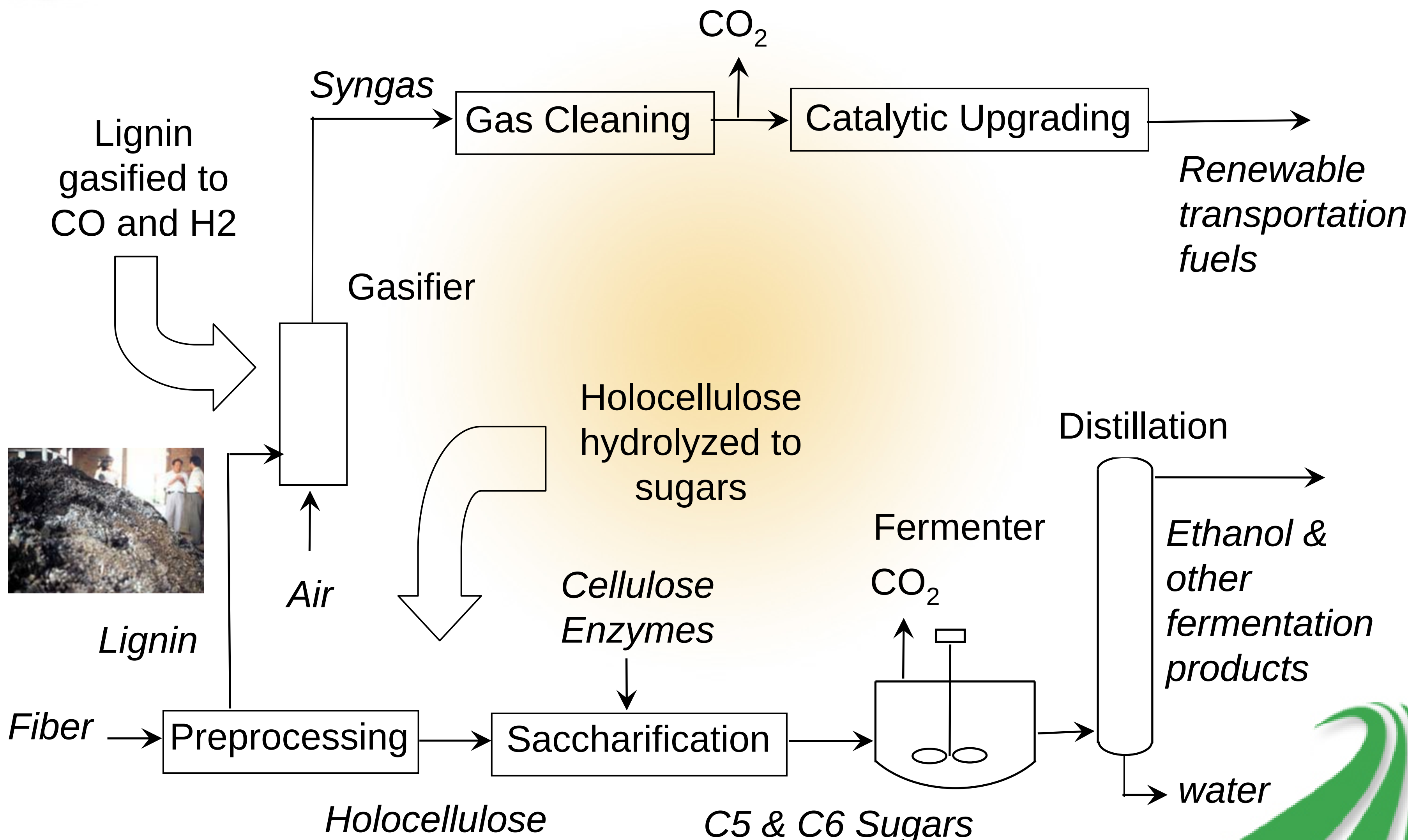


Whole Crop Biorefinery

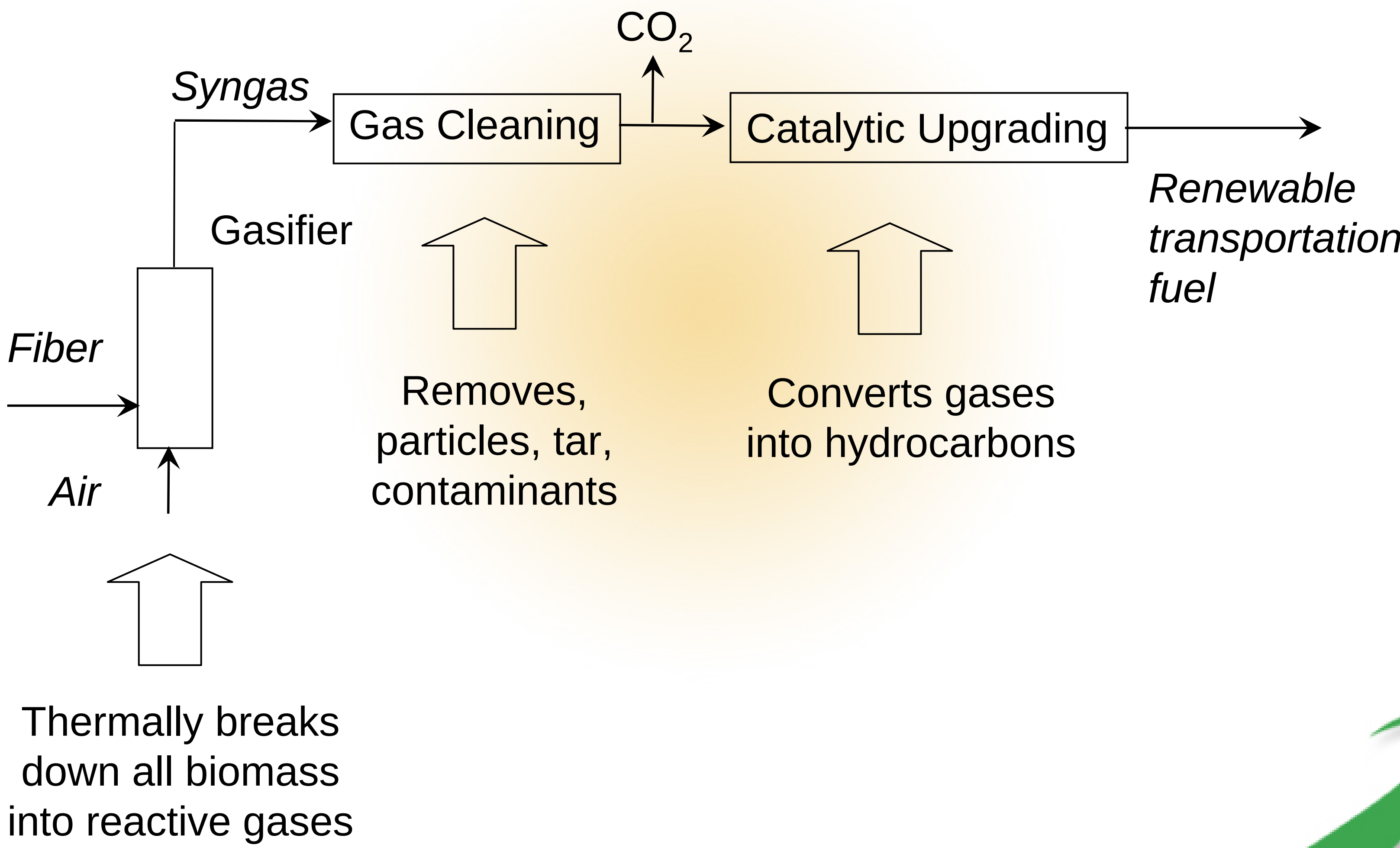


Another Option: Hydrolyze fiber in DDGS and gasify lignin

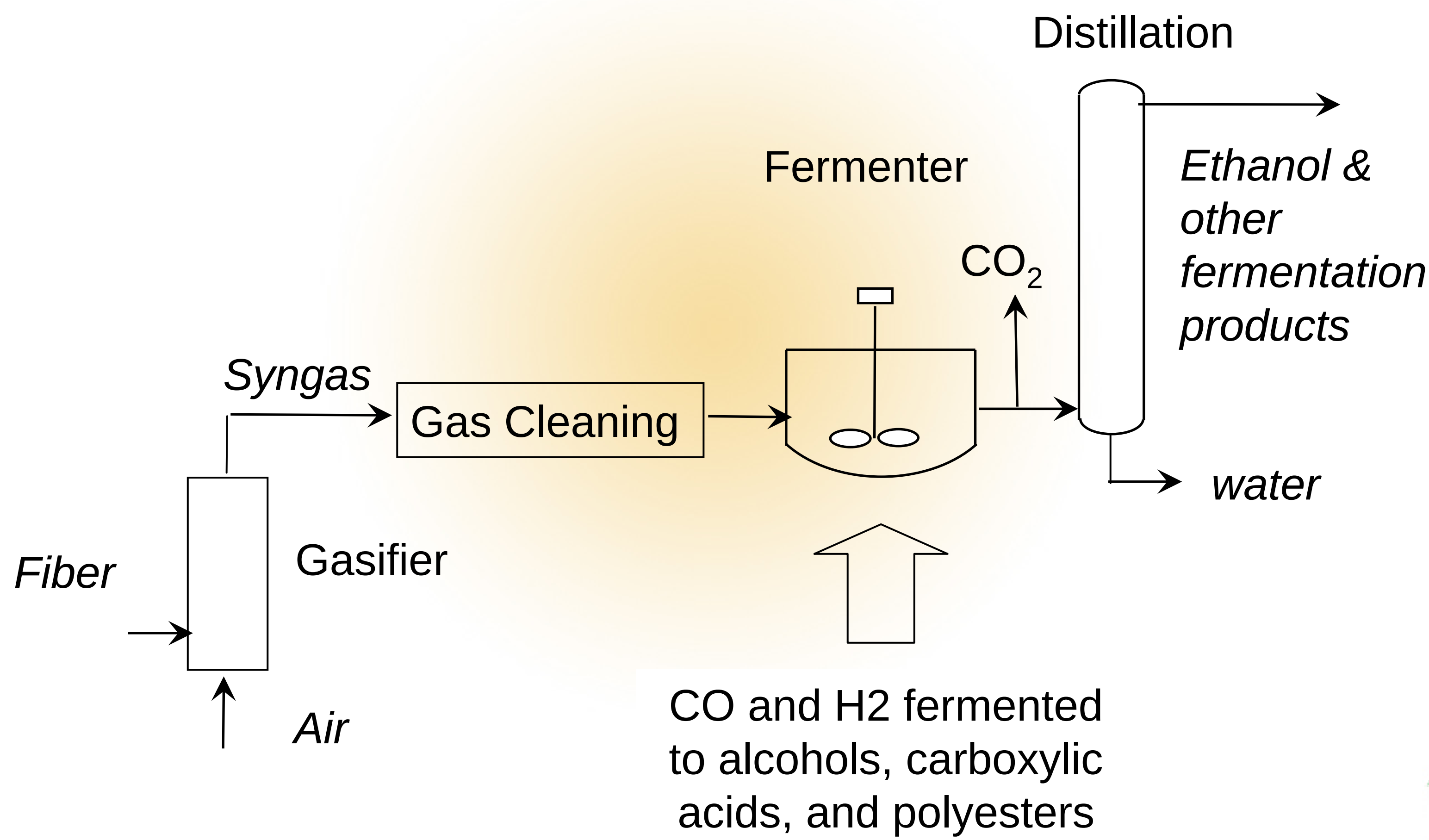
Lignocellulosic Biorefinery



Thermochemical Biorefinery

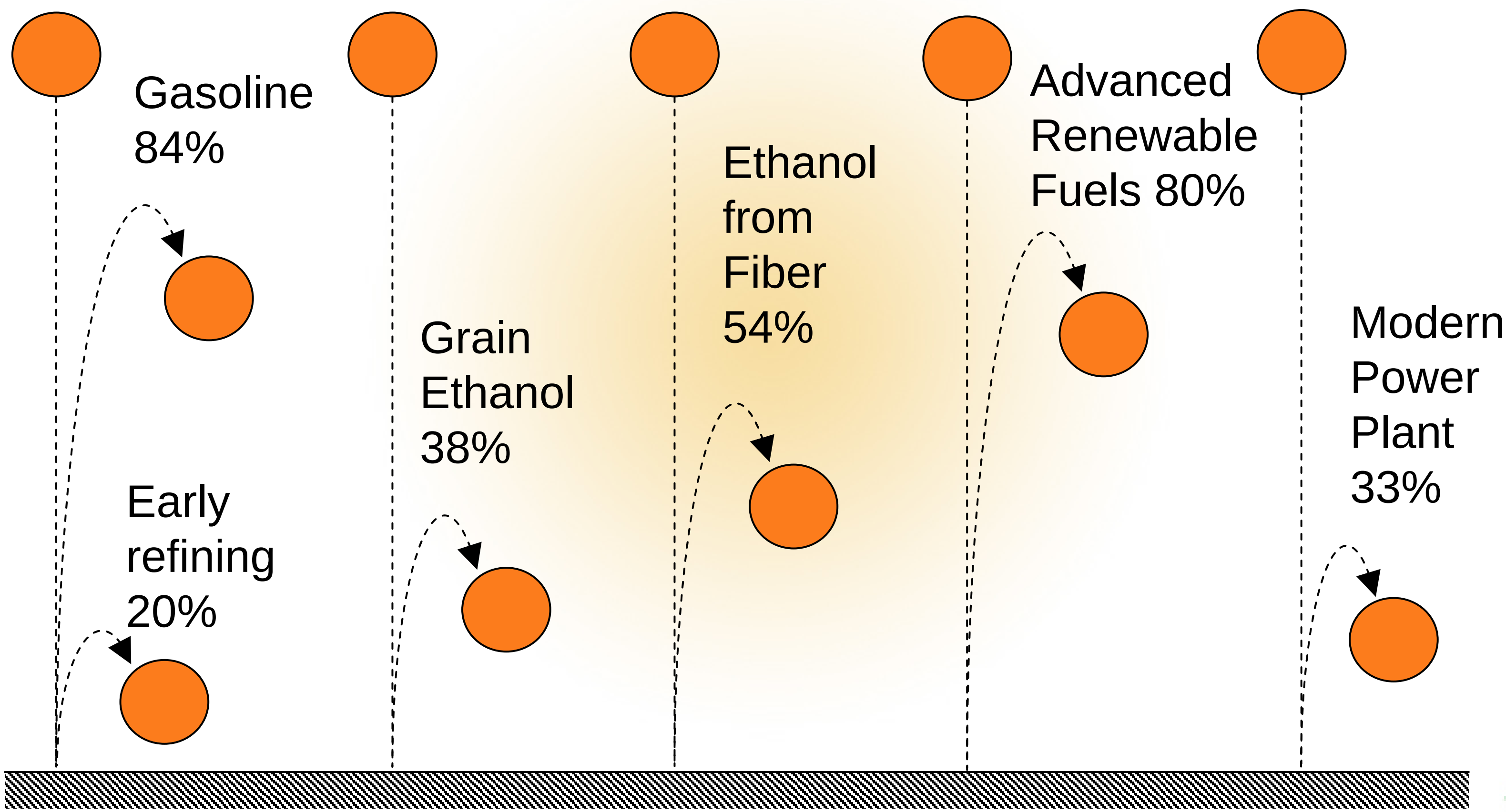


Syngas Fermentation Biorefinery



Is it true that is takes more energy to produce ethanol than you get out of it?

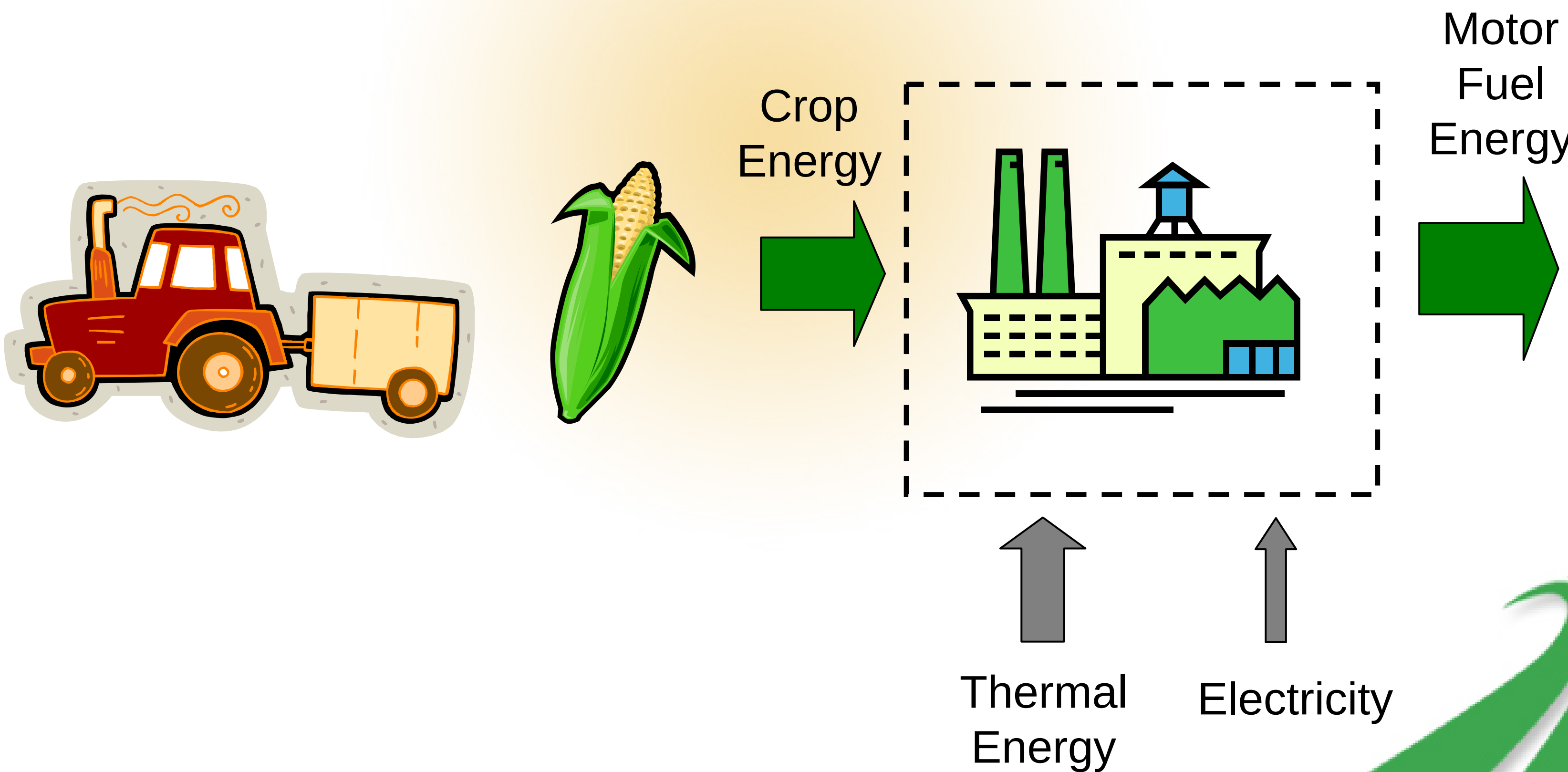
Energy Efficiency: You Can't Break Even



Source: RBAEF Project (Dartmouth) and R. Anex (ISU)

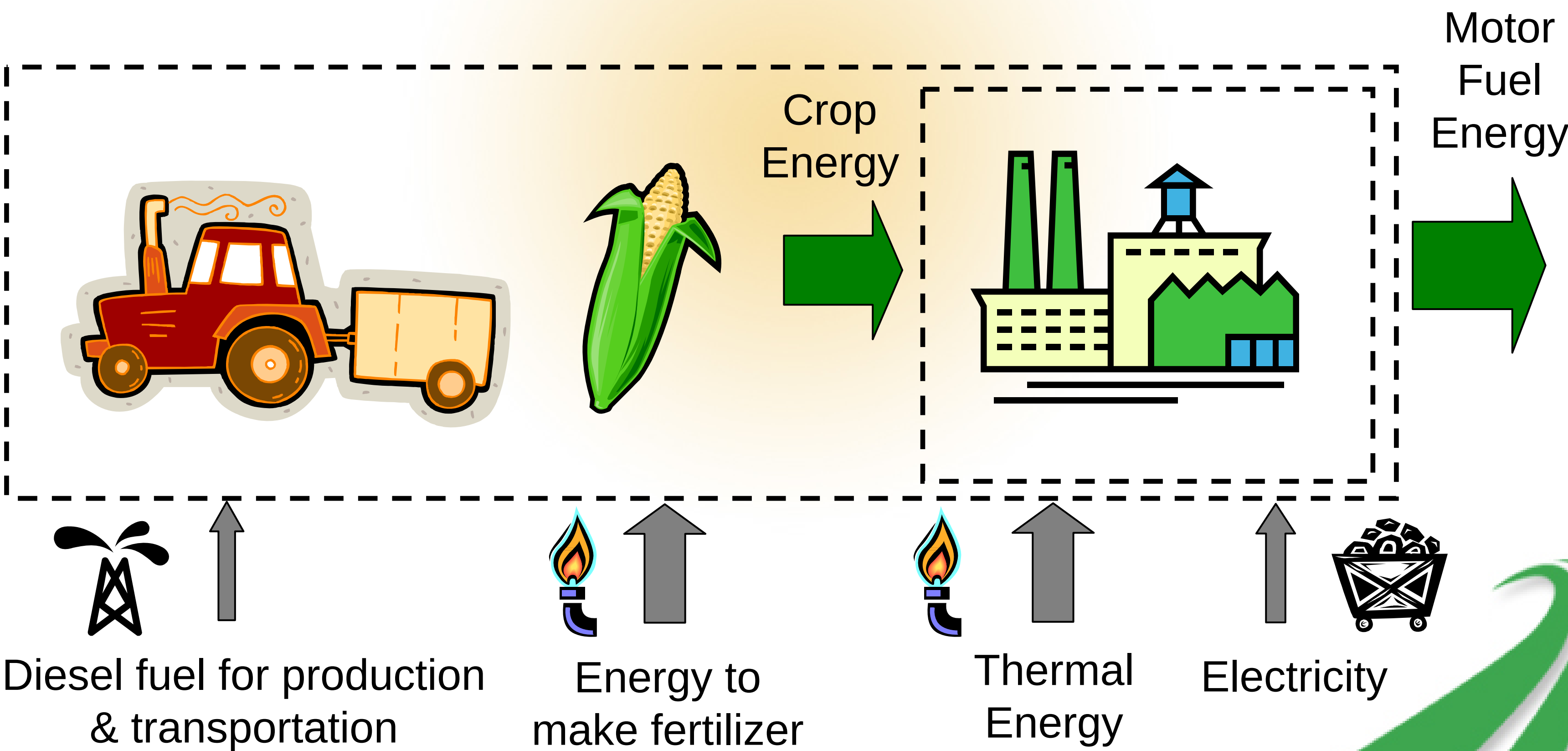
Plant Engineer's Energy Balance

$$\text{Energy Ratio} = \frac{\text{Motor Fuel Energy}}{\text{Feedstock Energy} + \text{Process Energy}} \leftarrow \text{Energy Efficiency}$$



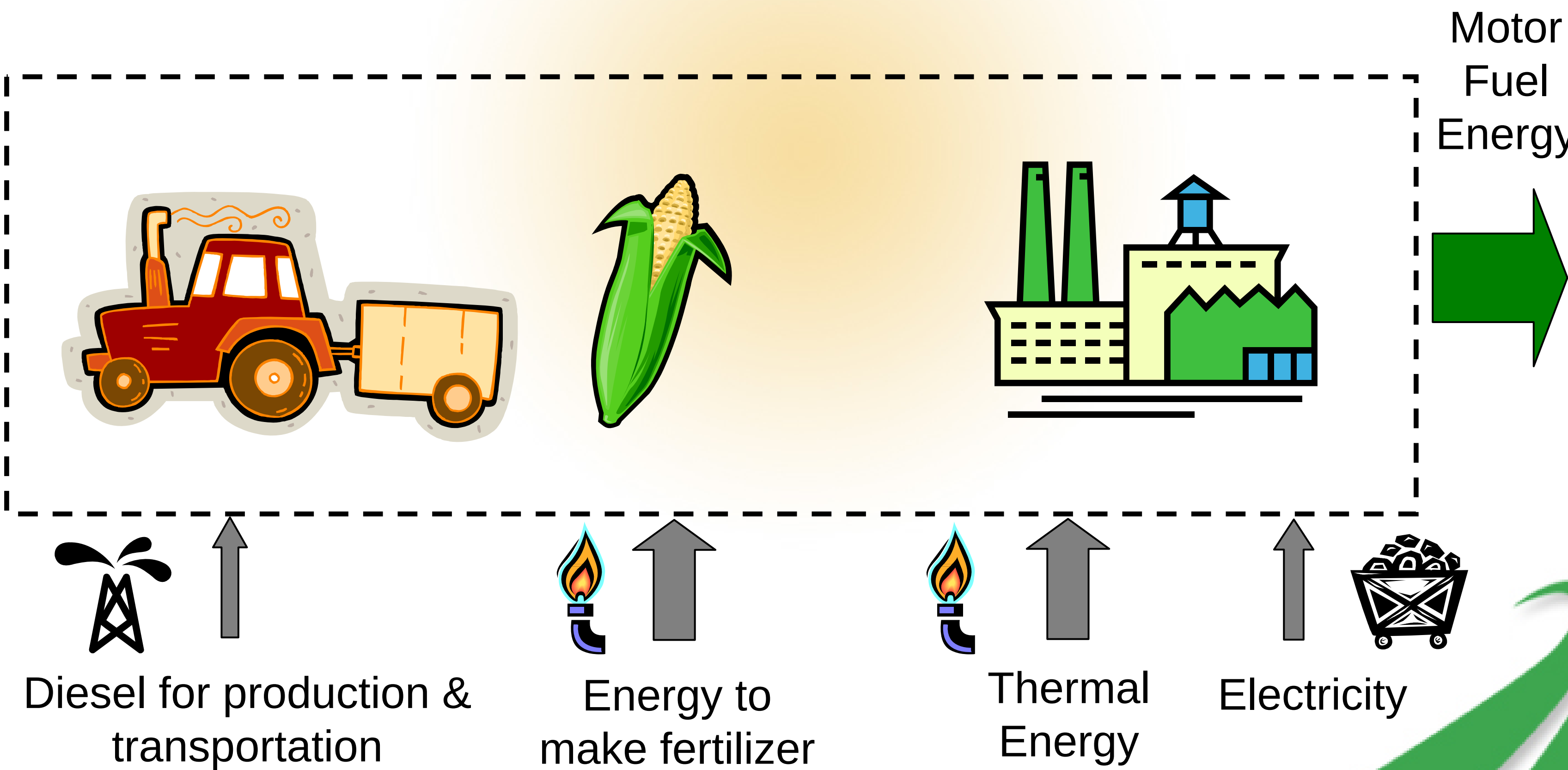
Environmentalist's Energy Balance

$$\text{Energy Ratio} = \frac{\text{Motor Fuel Energy}}{\text{Fossil Energy In}} \leftarrow \text{Greenhouse Gas Metric}$$



National Security Advisor’s Energy Balance

$$\text{Energy Ratio} = \frac{\text{EtOH Energy}}{\text{Petroleum Derived Fuels In}} \leftarrow \text{Dependence on Imported Oil Metric}$$

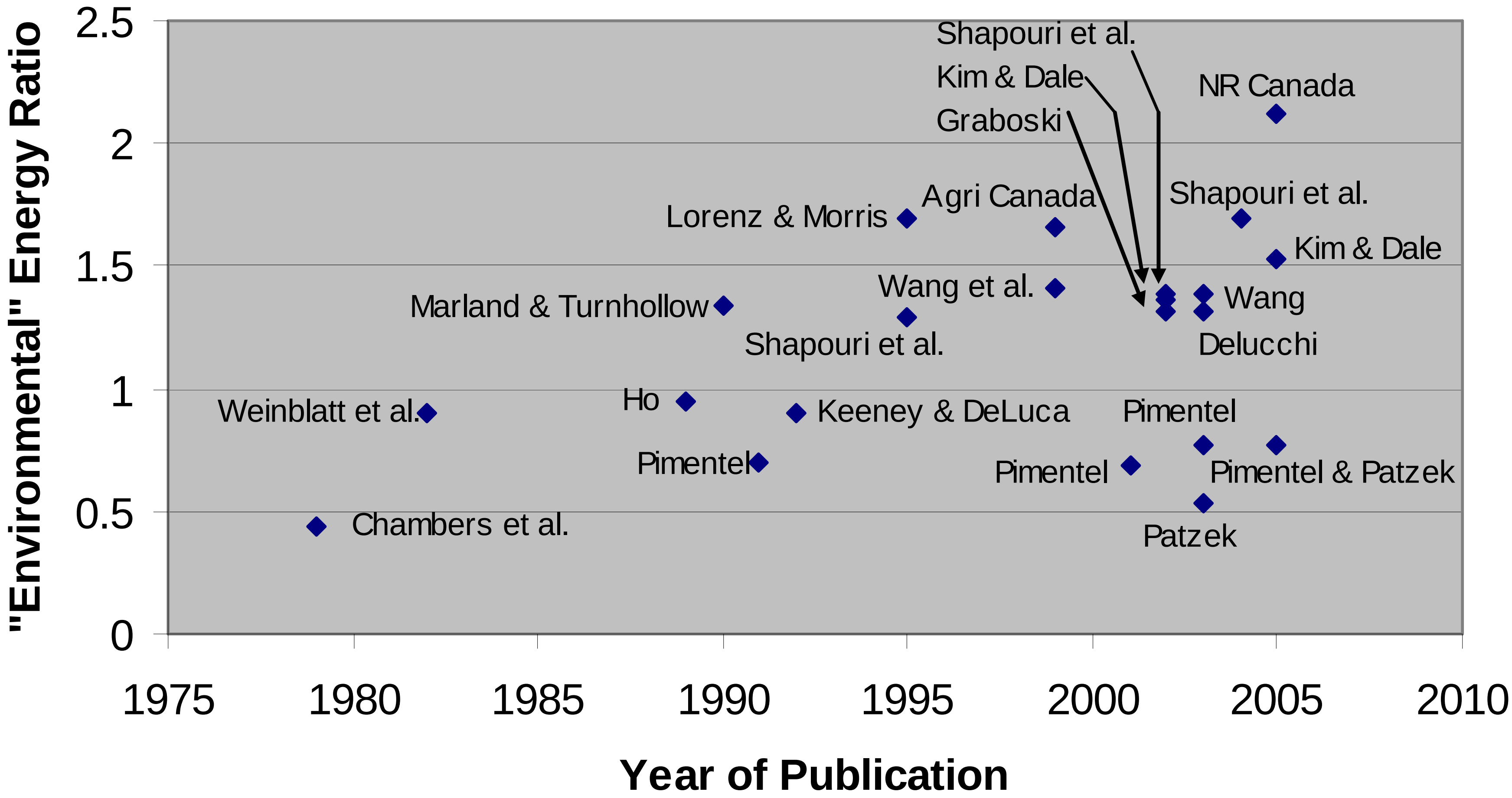


Comparison of Ethanol to Gasoline

Stakeholder	Energy Ratio	Grain EtOH	Gas-oline
Plant Engineer	$\frac{\text{Motor Fuel Energy}}{\text{Feedstock Energy} + \text{Process Energy}}$	0.38	0.84
Environmentalist	$\frac{\text{Motor Fuel Energy}}{\text{Fossil Energy In}}$	1.3*	0.81
National Security Advisor	$\frac{\text{Motor Fuel Energy}}{\text{Petroleum Derived Fuels In}}$	14	0.81

* Average of 14 *different* study groups. Range is 0.44 to 2.1. This energy ratio becomes very large (>10) as we replace fossil energy with renewable energy in the production of ethanol (or other renewable motor fuels).

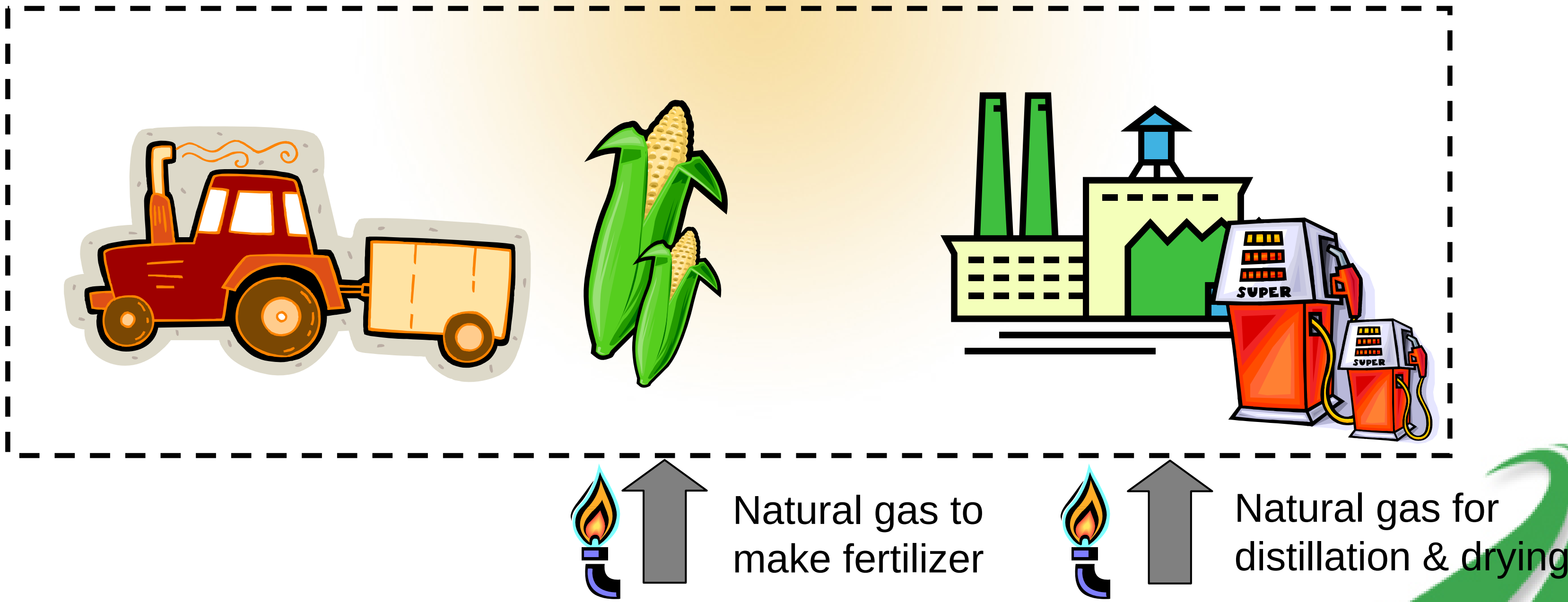
No Consensus Among Researchers on Energy Ratio for Ethanol from Corn



Adapted from Wang (2005)

Main Areas of Disagreement Among Researchers

- Yield of grain on farmland
- Amount of energy consumed to produce fertilizer
- Yield of ethanol from grain
- Amount of energy consumed within manufacturing plant



Why the Disagreements?

- No such thing as a “typical” grain ethanol plant
  - Some may have “environmental” energy ratios less than one while for other plants it is greater than one (especially newer plants)
- Concerns about long-term sustainability of grain-to-ethanol
  - Some corn production practices are detrimental to soils
  - Energy balances are marginal compared to what could be achieved with fiber-to-fuel technologies

Optimal Size of Plant

- Fossil fuel – unit product cost decreases with plant size

Unit Cost of Product = Fuel + Fuel Transportation + Plant Operations

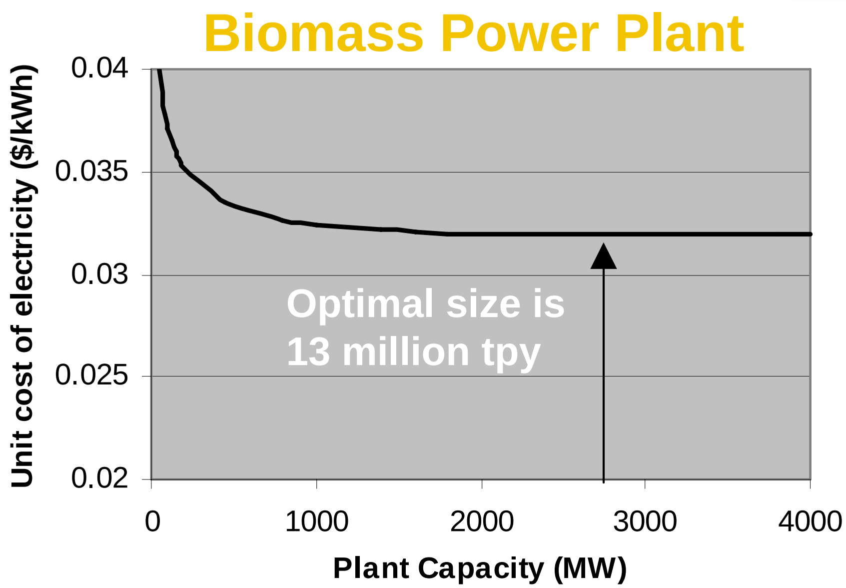
Fuel	Fuel Transportation	Plant Operations
Independent of plant size	*Independent* of plant size	***Decreases*** with plant size

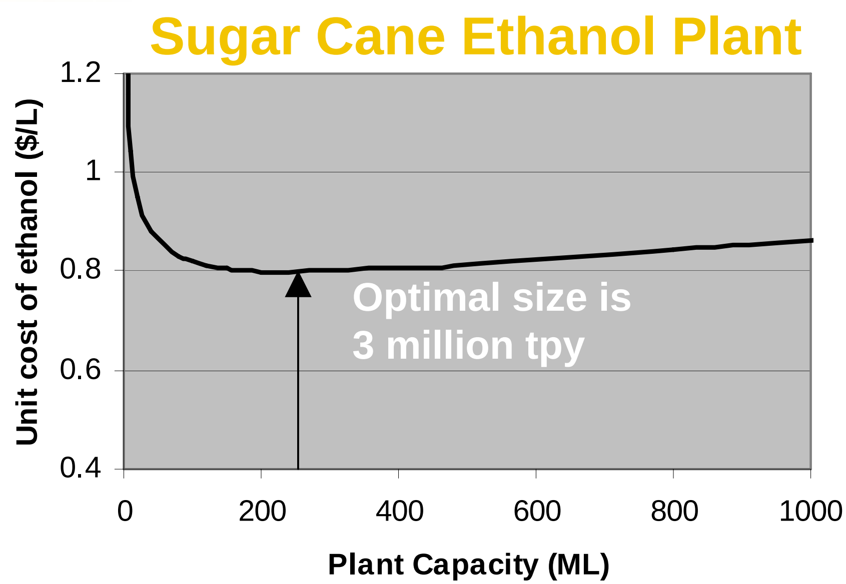
- Biomass – optimal size for least cost of unit product

Unit Cost of Product = Fuel + Fuel Transportation + Plant Operations

Fuel	Fuel Transportation	Plant Operations
Independent of plant size	***Increases*** with plant size	***Decreases*** with plant size

Optimal Size of Plant





- Optimal size for biomass power plant is much larger than for ethanol plant
- Optimization curves are relatively flat
- Depends upon ratio of biomass transportation cost to processing plant cost (not biomass cost)

Conclusions

- The U.S. has sufficient biomass to supply biorefineries
- A number of plant configurations are possible for production of biobased fuels (not just ethanol) and biobased products
- Advanced technologies can further improve energy balance for biobased fuels
- Further study is required to understand factors influencing optimal size of biorefineries