

On Energy, Life, and Economics



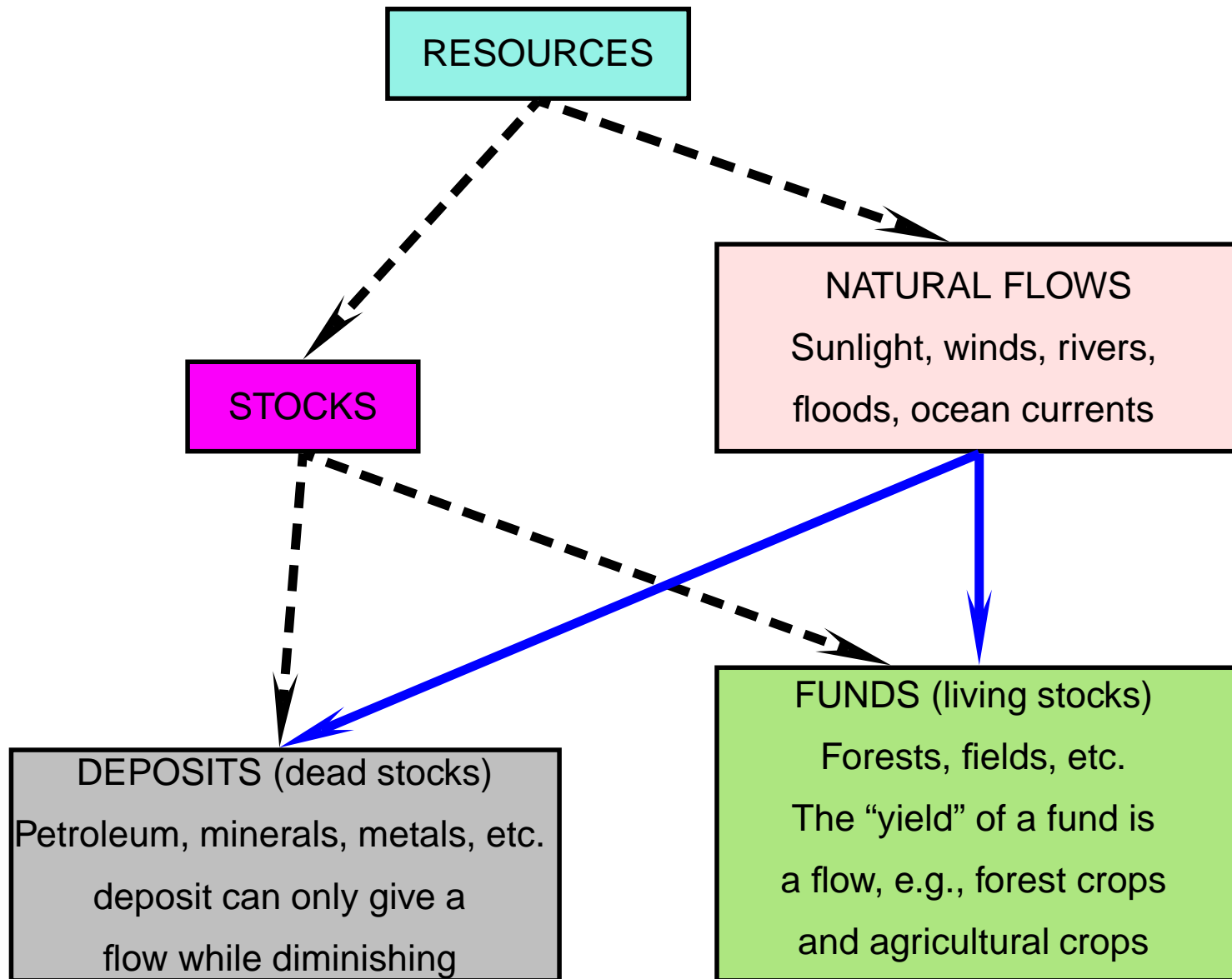
Tad Patzek, Civil & Environmental Engineering, U.C. Berkeley

Sept. 8, 2005, Ag Biotech & Midwest Rural Development Conference

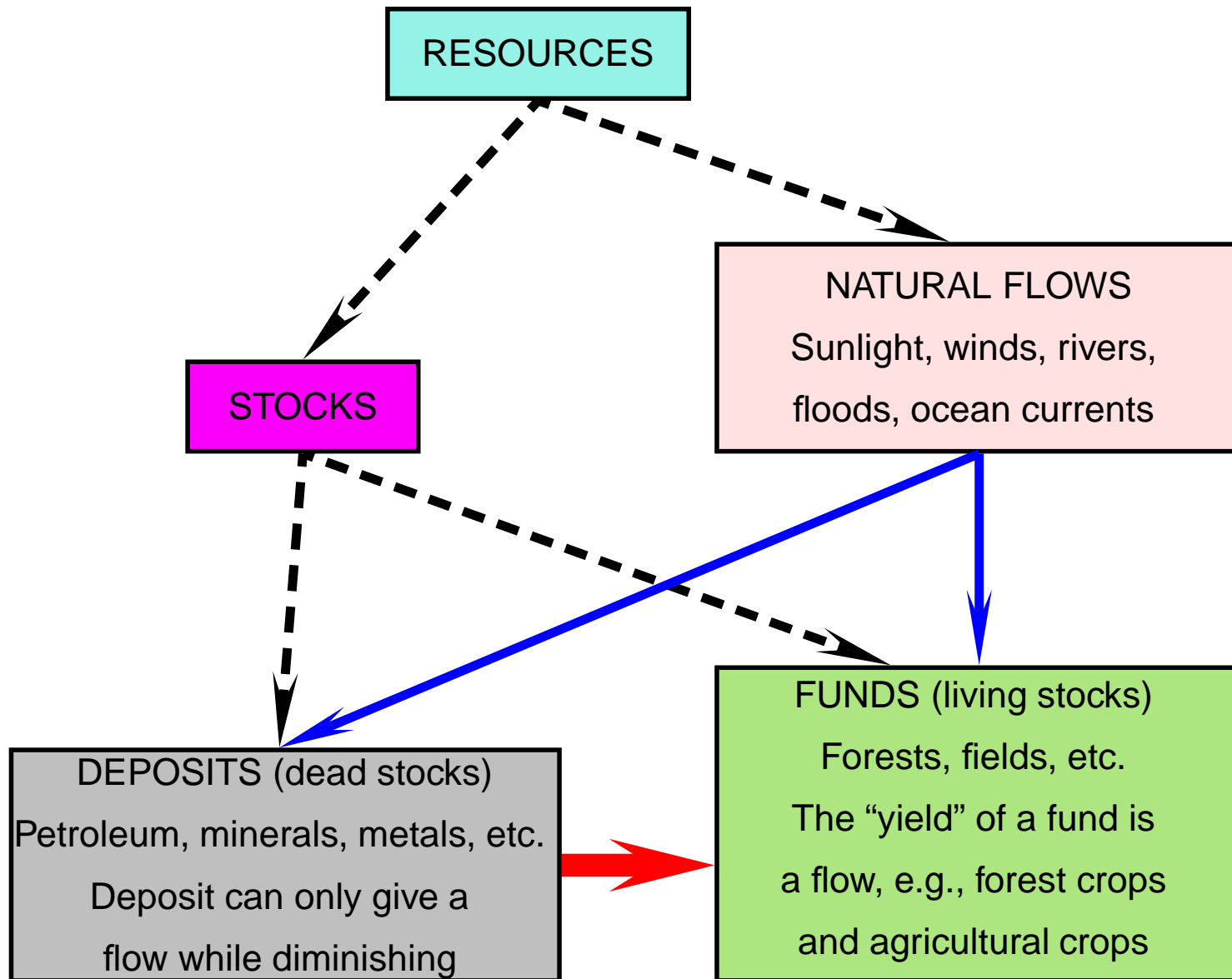
Net **Free** Energy Analysis...

- Everything I will say here is based on my *Critical Reviews in Plant Sciences*, **23(6):519-567**, 2004 paper **Thermodynamics of the Corn-Ethanol Biofuel Cycle**
- I have followed the detailed recommendations of the International Federation of Institutes for Advanced Study
 - *Energy Analysis Workshop on Methodology and Conventions*, 25-30 August 1974, The Nobel House, Stockholm, Sweden, and
 - *Workshop on Energy Analysis and Economics*, 22-27 June 1975, Lidingö, Sweden

Resource Classification

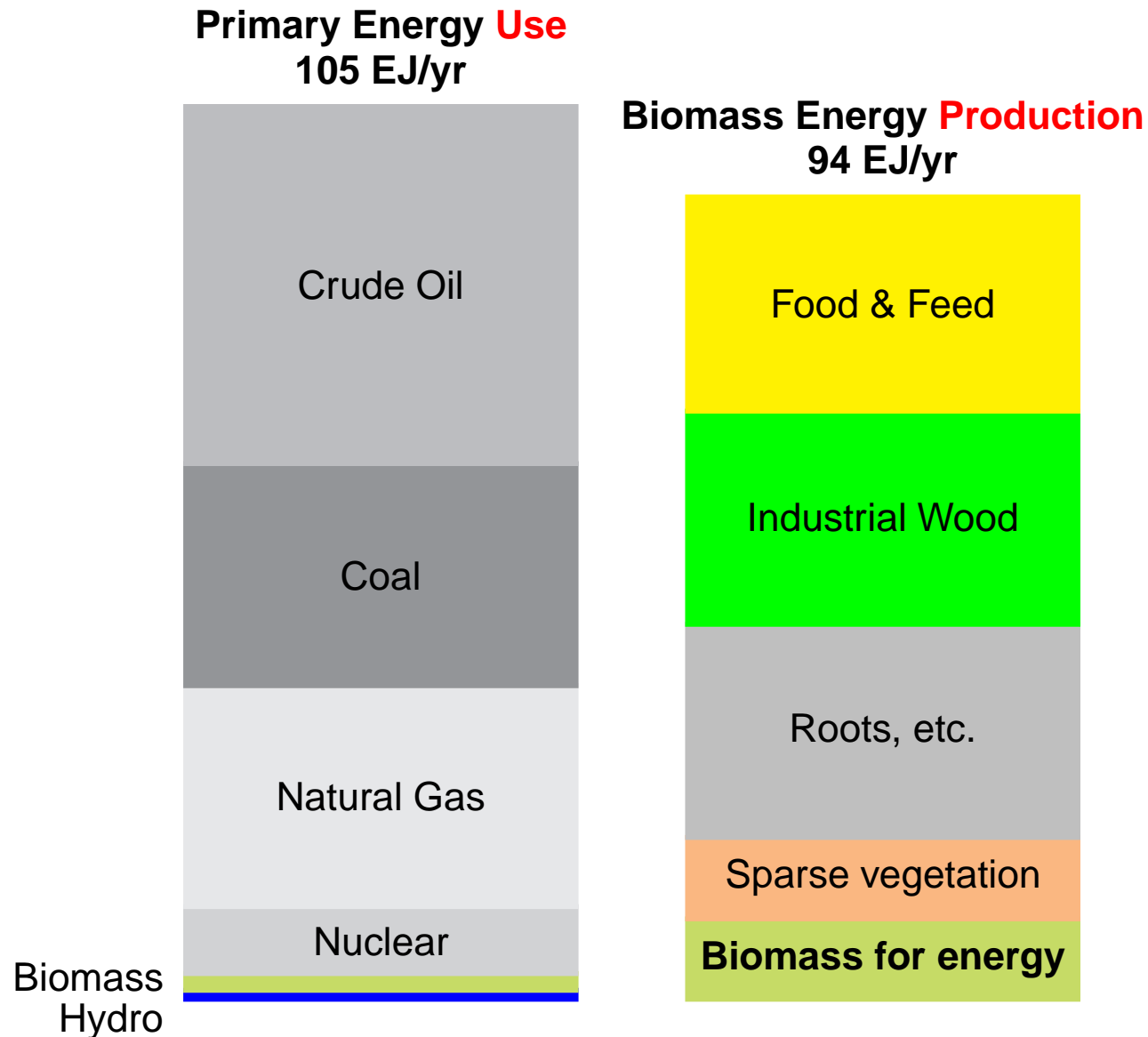


Resource Classification



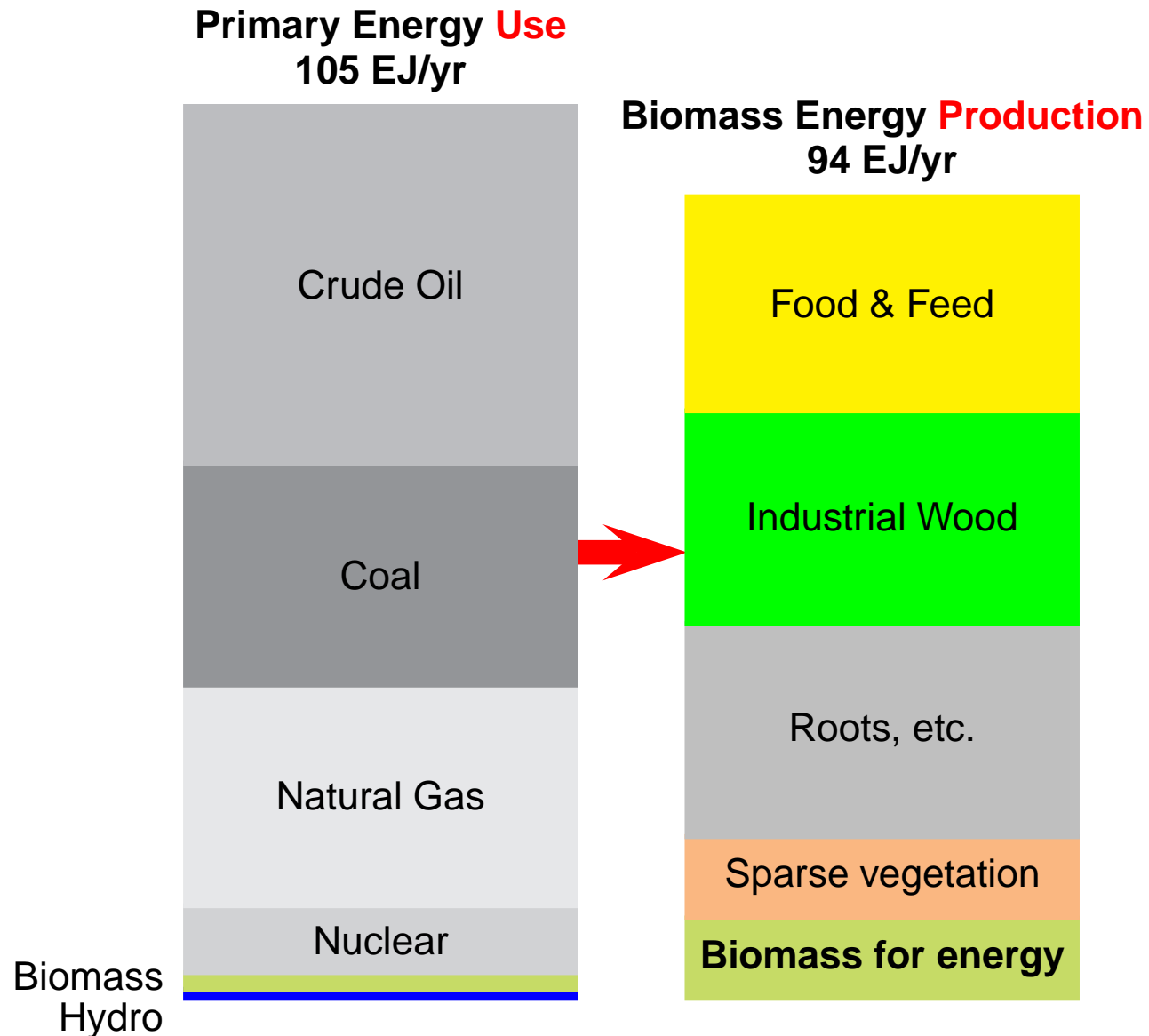
Sources: Eugene Odum, 1998

We Burn More Than Plants Produce



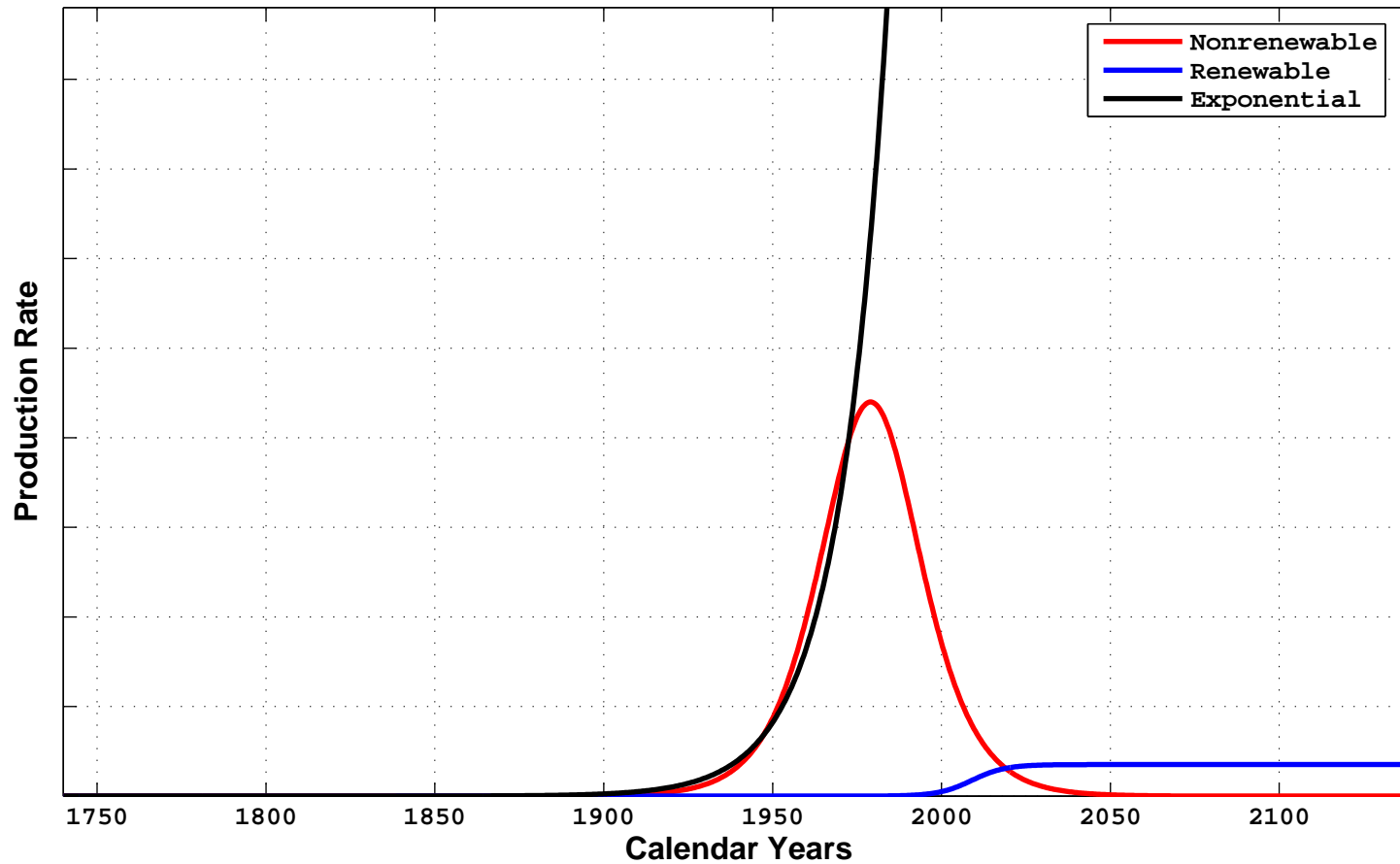
Sources: Good & Bell, 1980; Patzek, 2005

We Burn More Than Plants Produce

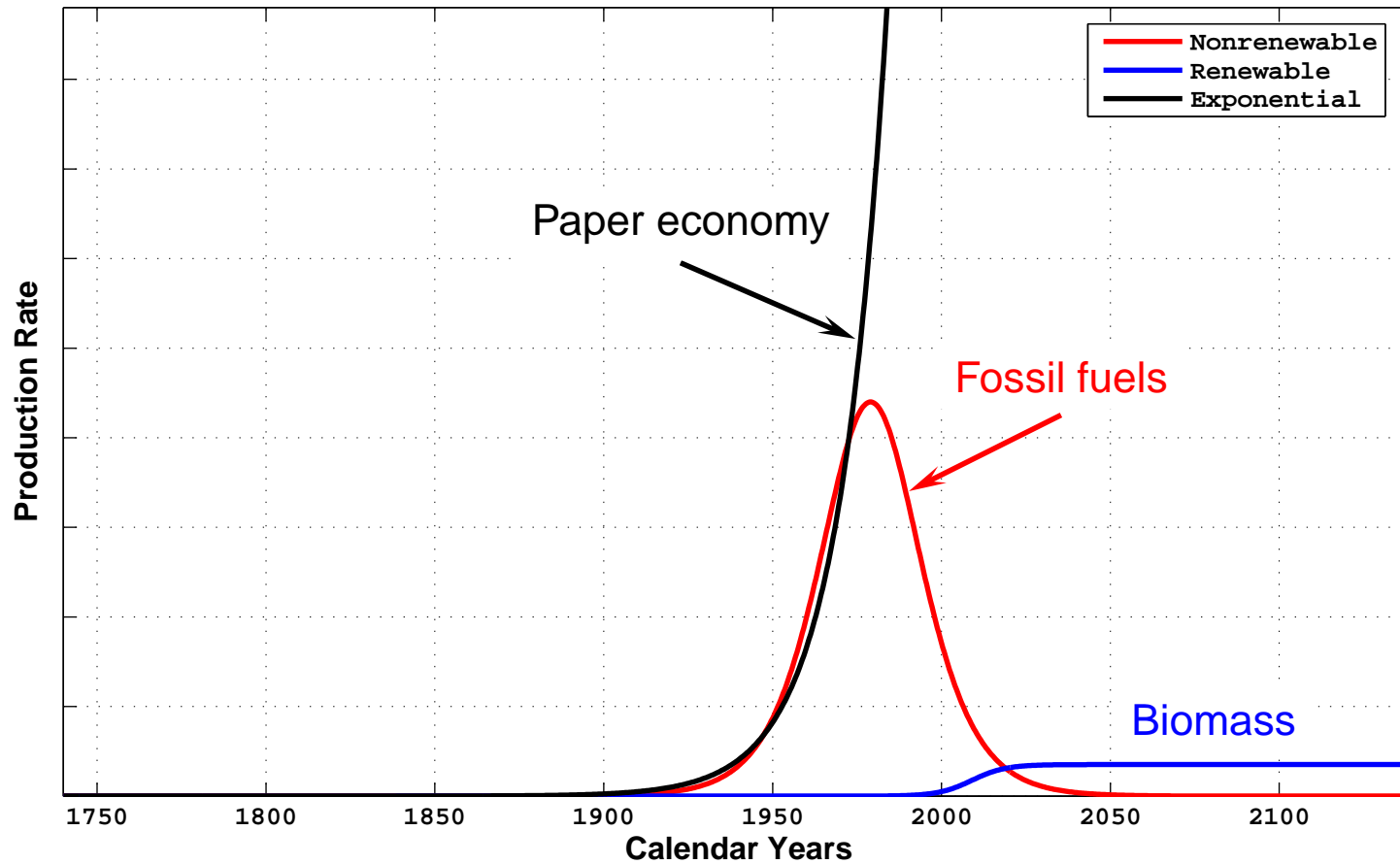


Sources: Good & Bell, 1980; Patzek, 2005

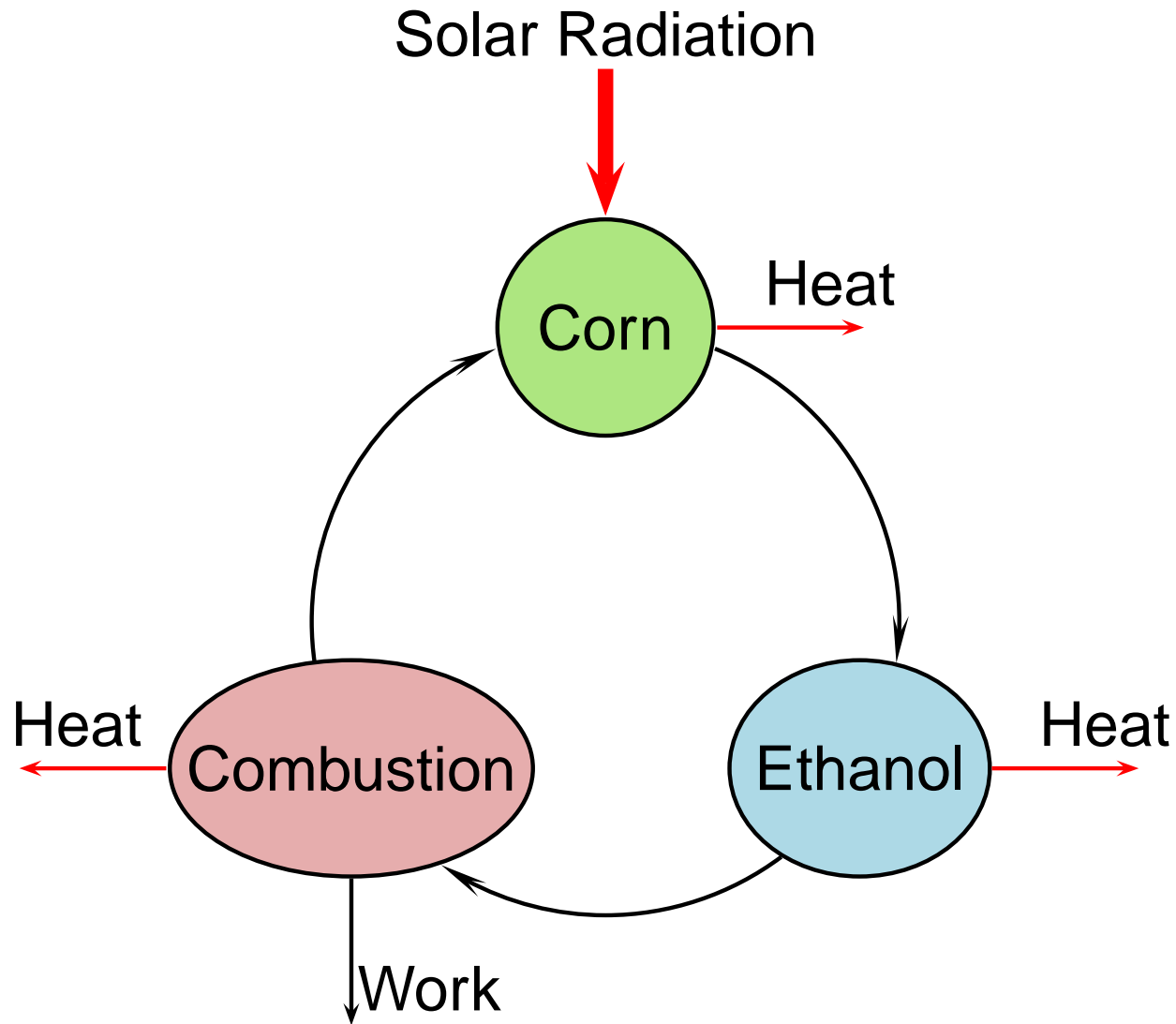
Different Types of Growth



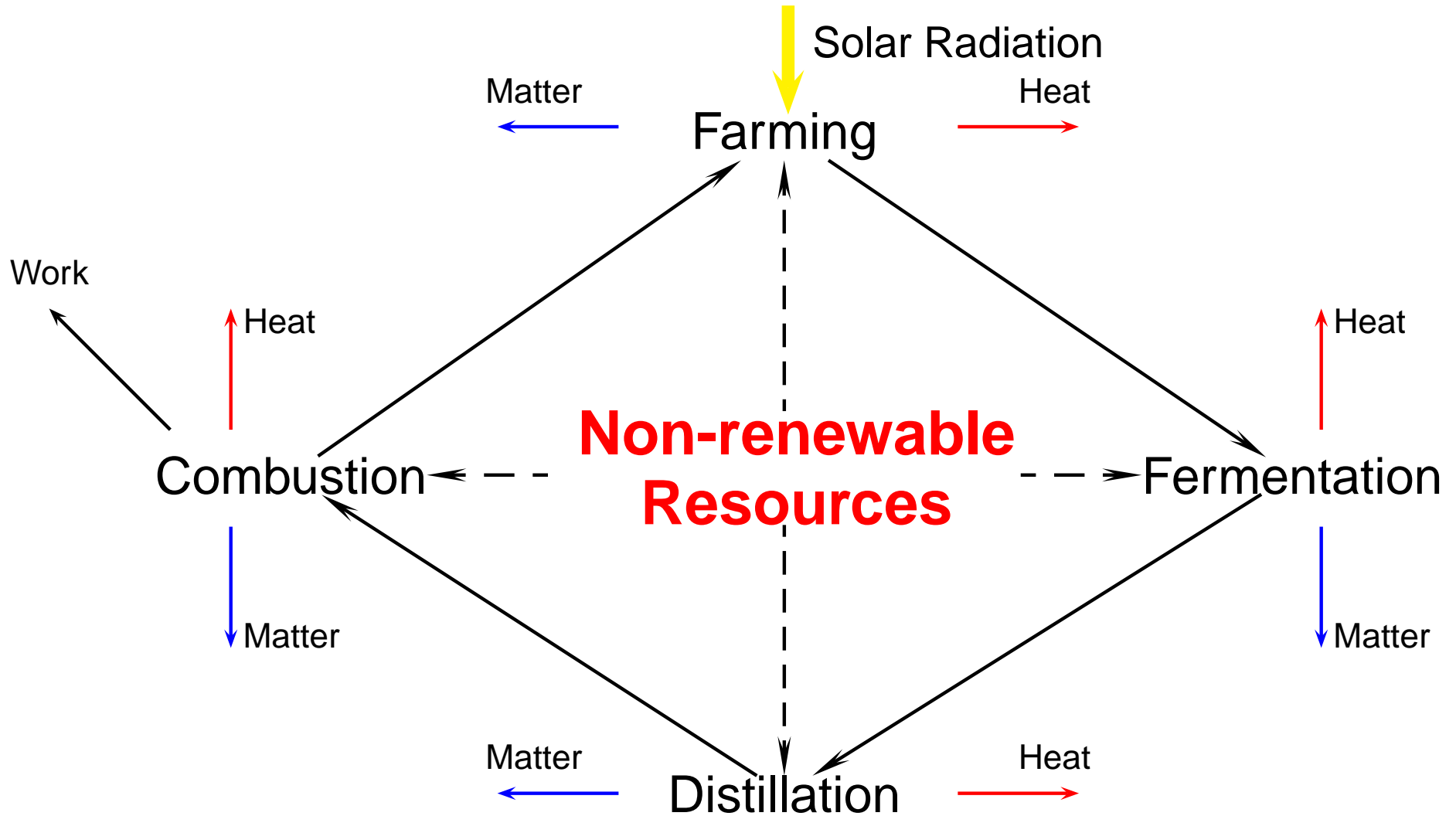
Different Types of Growth



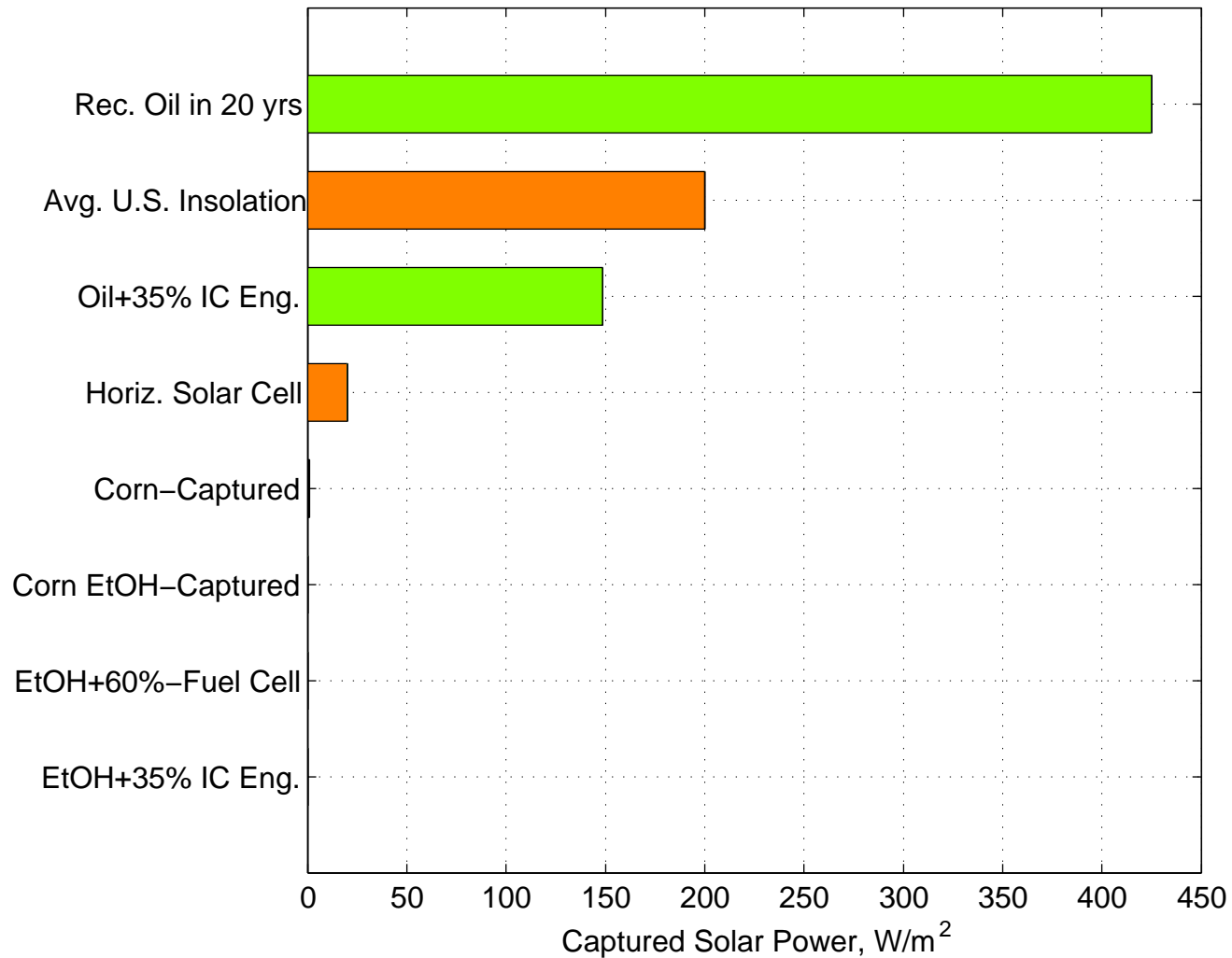
Ideal Corn-Ethanol Cycle...



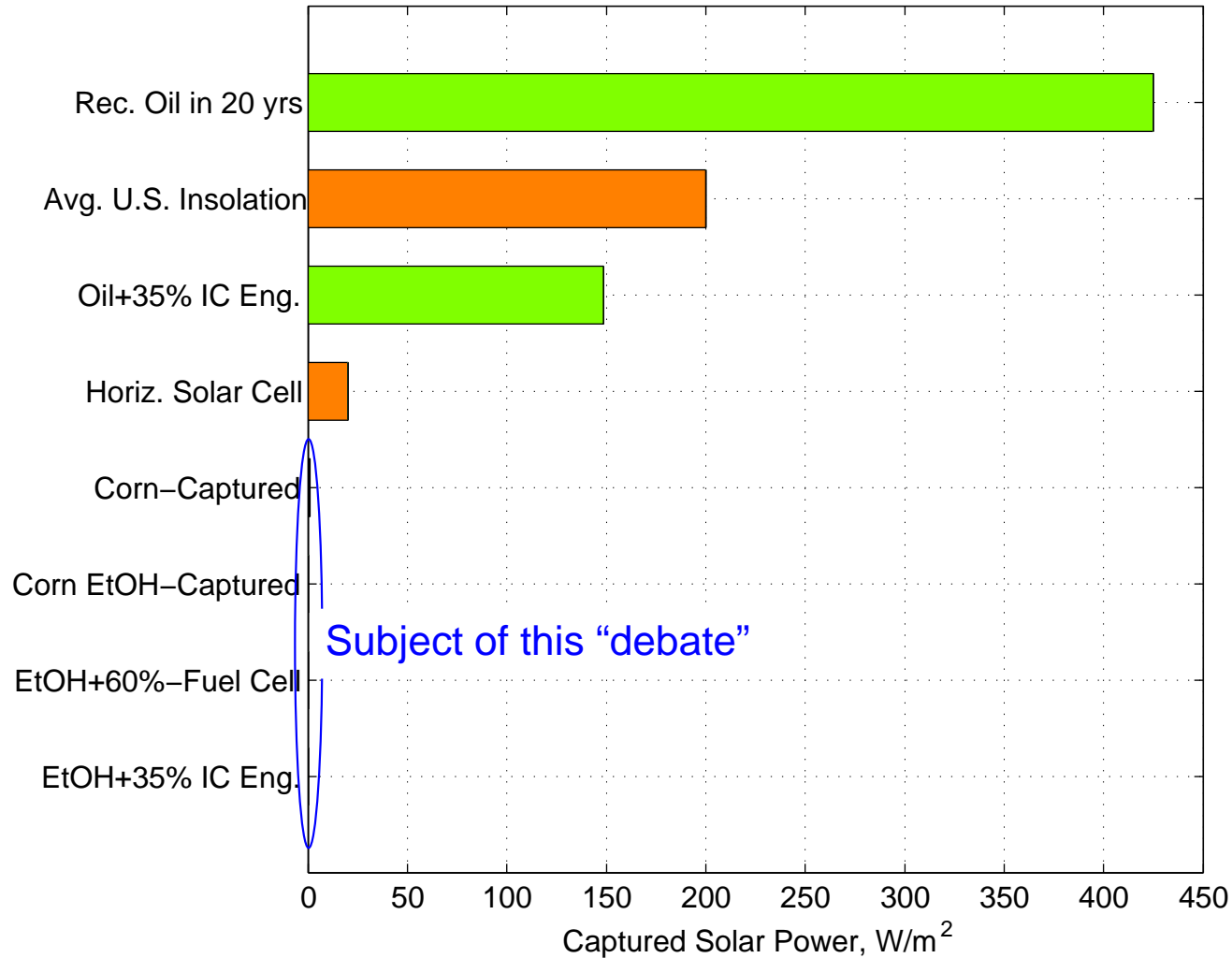
Real Corn-Ethanol Cycle...



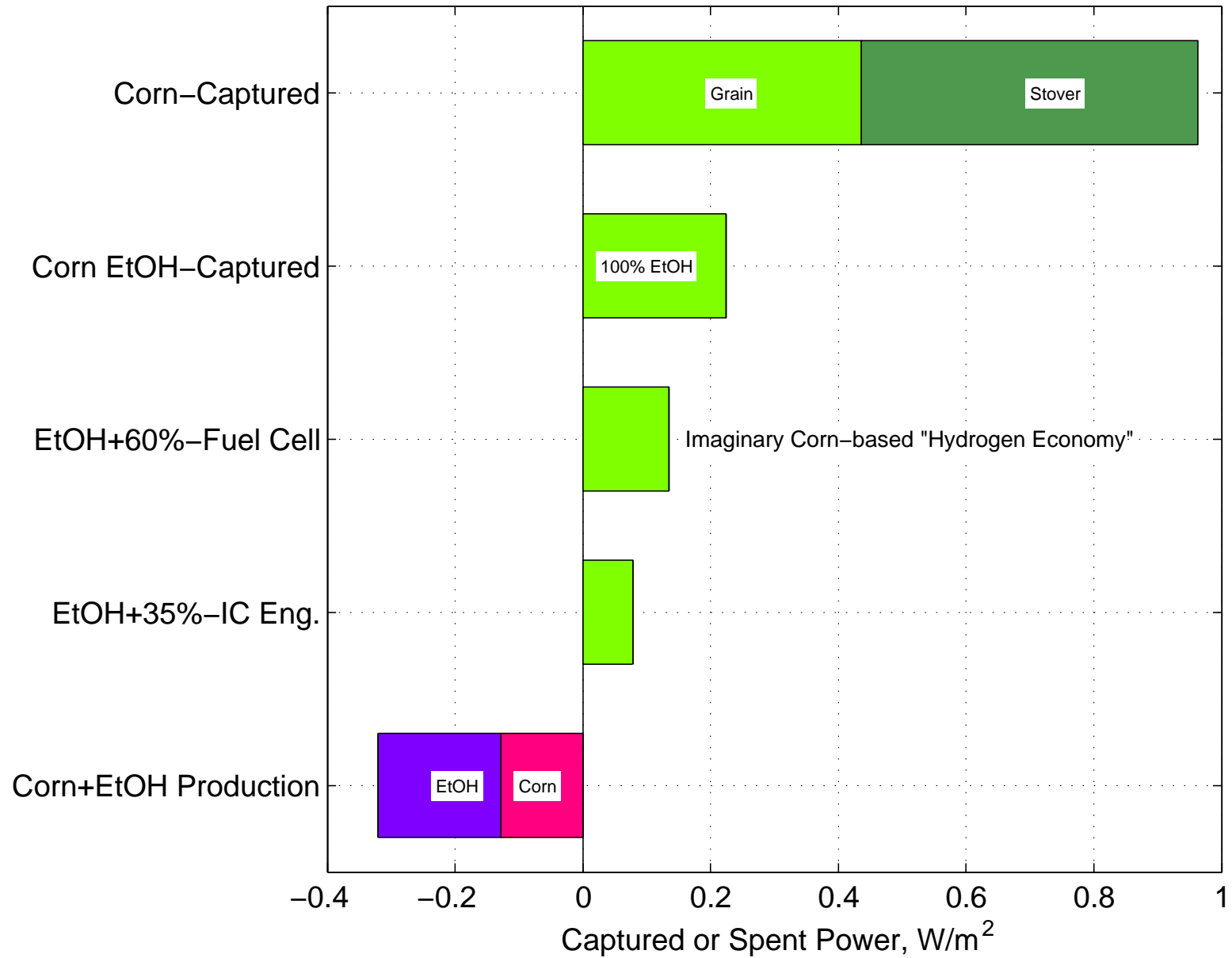
Available Free Energy...



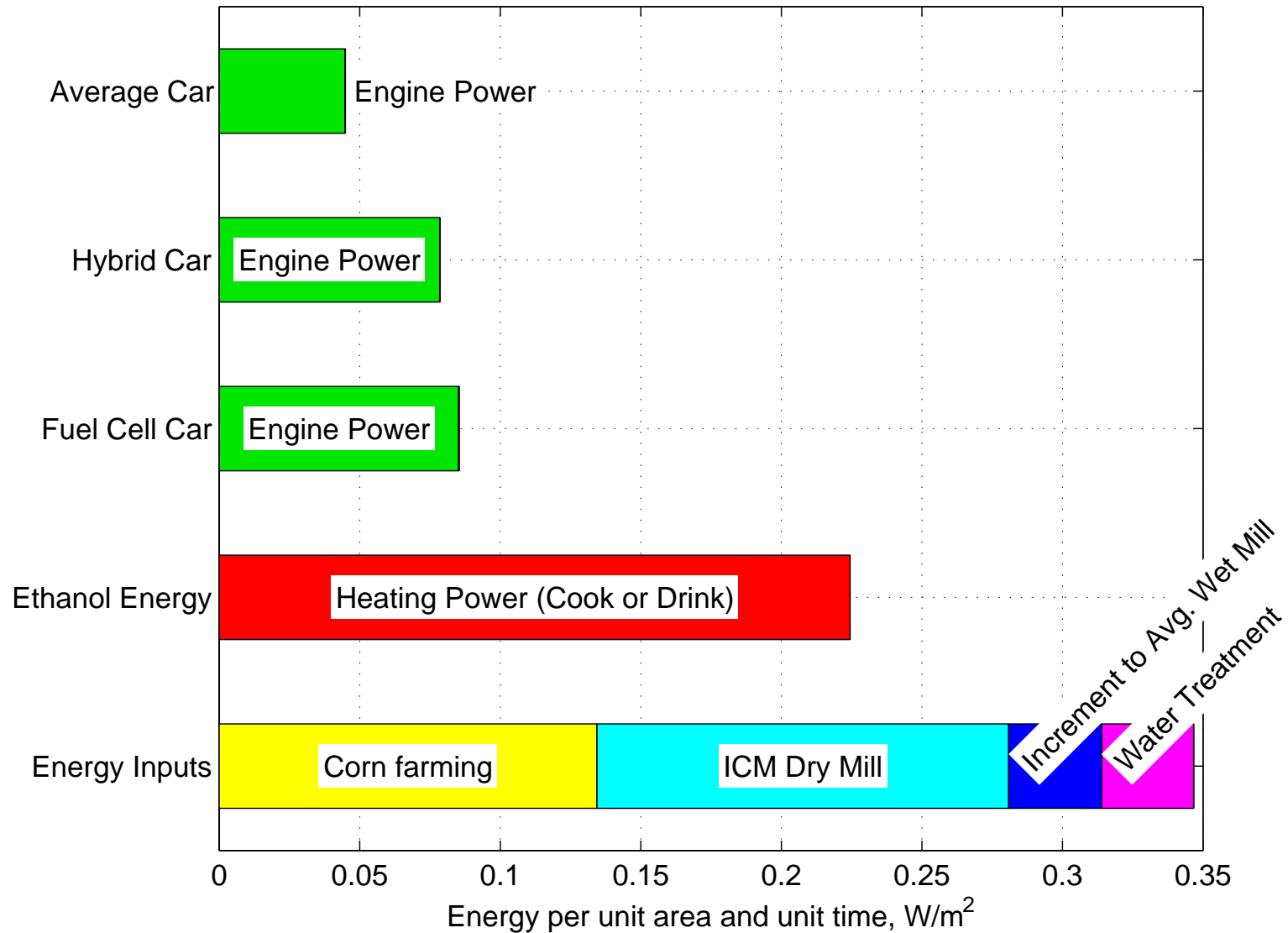
Available Free Energy...



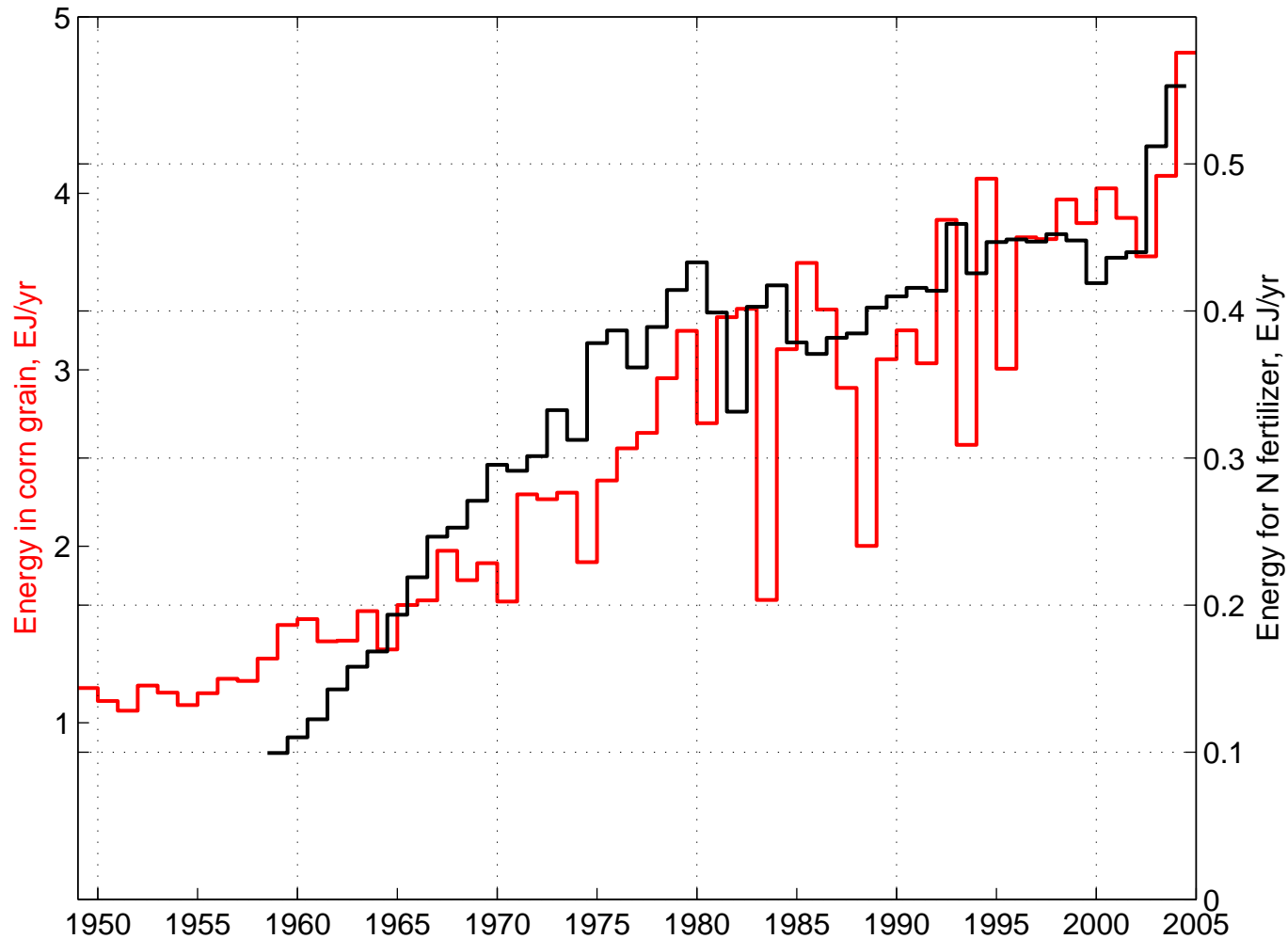
Corn Ethanol is Inefficient



Corn Ethanol is Inefficient

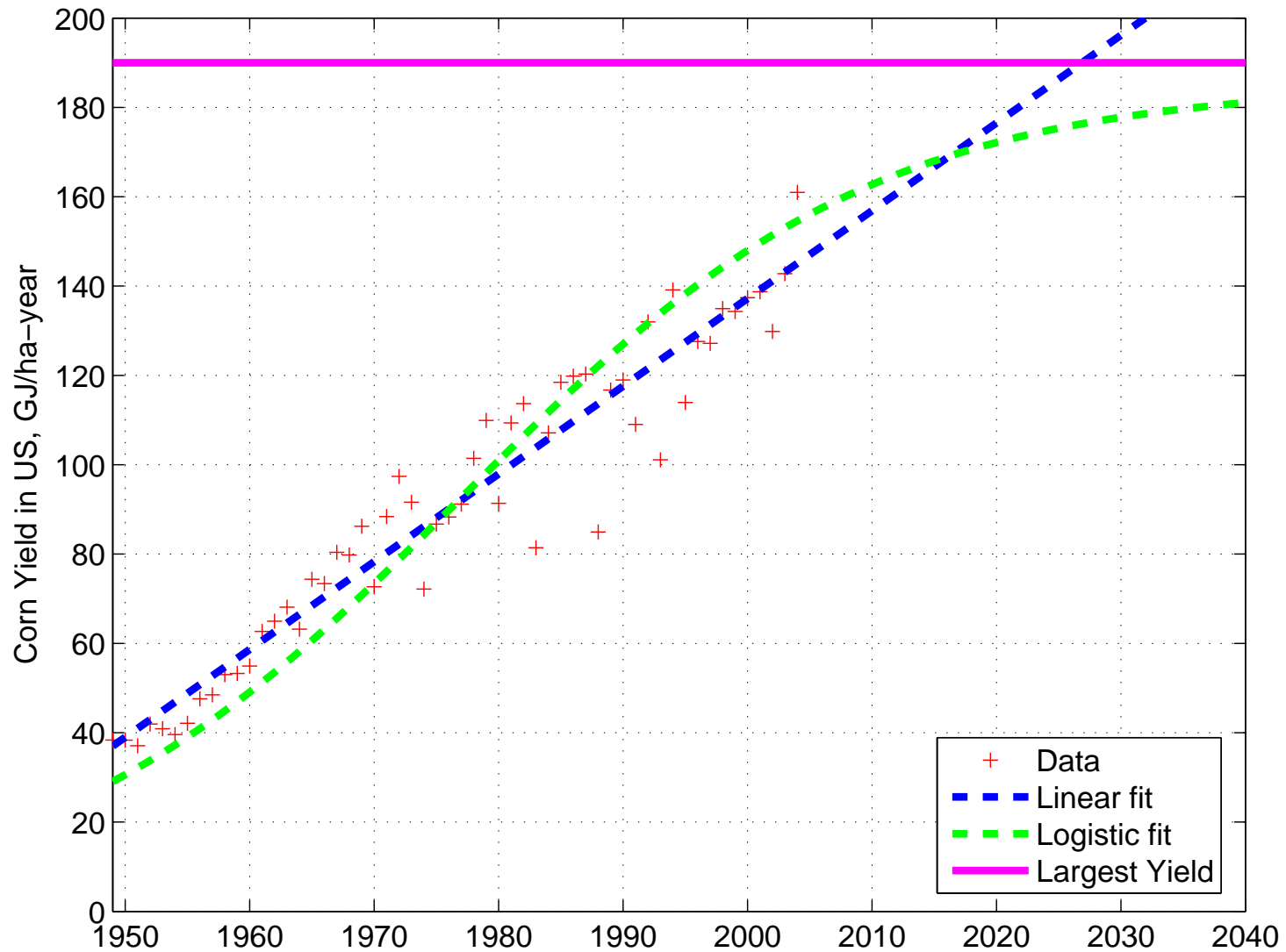


5× More Corn = 5× More Nitrogen Over the Last 50 Years...



Sources: USDA, The Fertilizer Institute, Patzek 2004

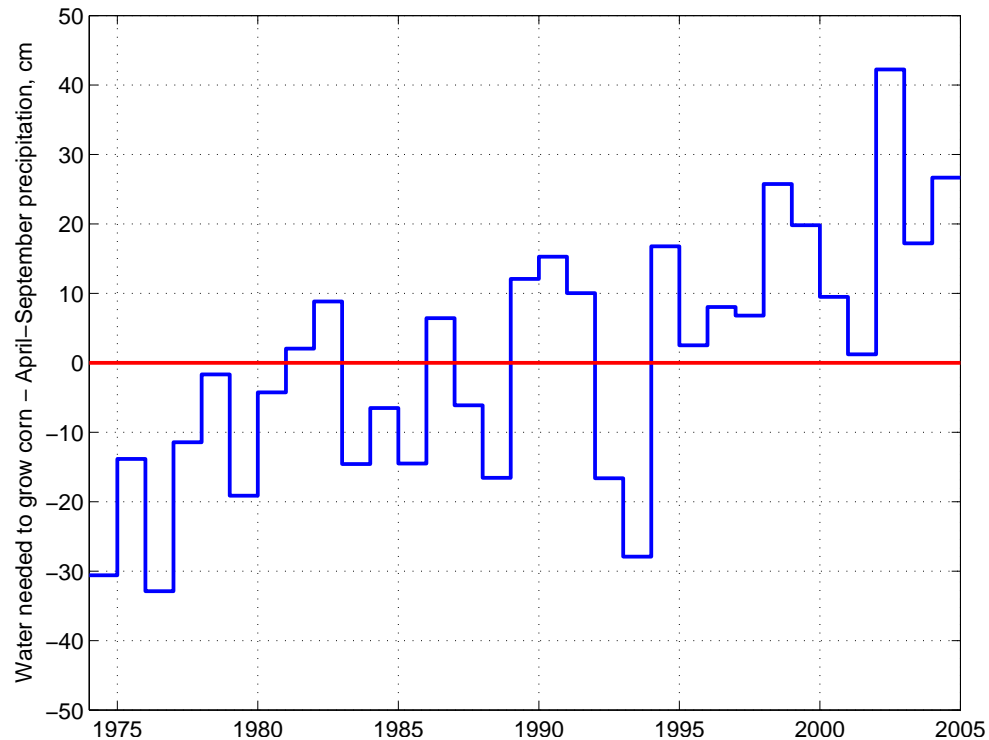
Corn Yield Trends



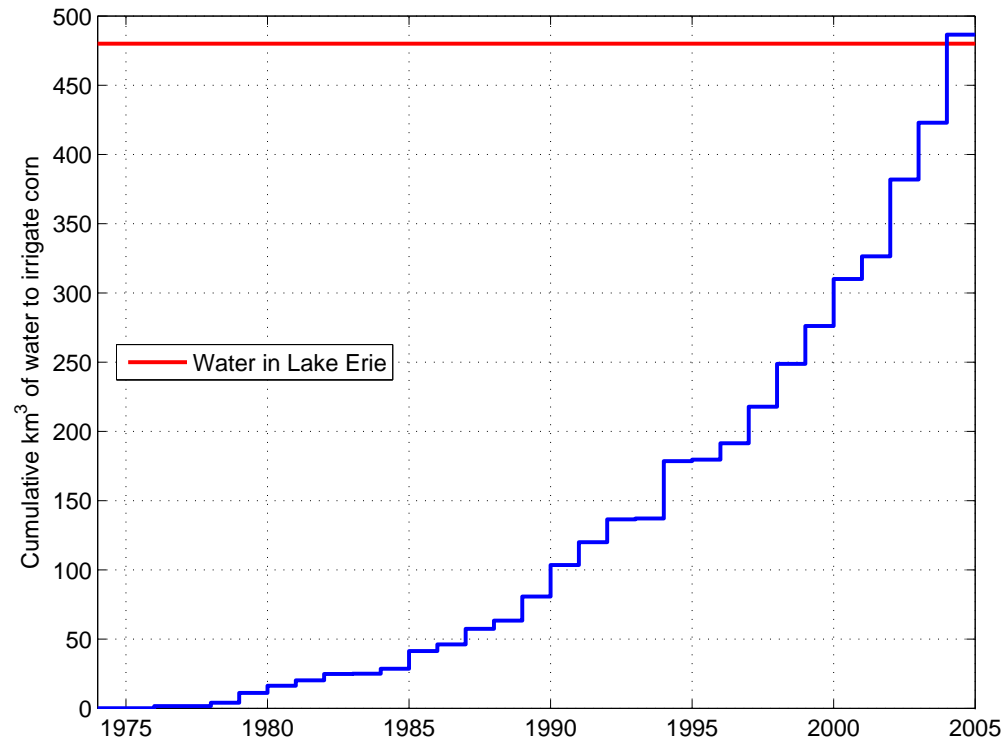
Sources: USDA, Patzek 2005

Unfulfilled Water Needs...

Minnesota



All Corn States



We will run out of local water and other environmental resources...
... long before we run out of all fossil fuels

Conclusions

- Biofuels are not the new Philosopher's Stone that turns the lovely green plants into pure, clean energy
- The claims to the contrary are pure fantasy
- A complete Second Law **free energy** analysis must be performed for all biofuel systems according to the same set of rules
- I have proposed to establish a small center at Berkeley to do just that
- The recent incomplete First Law **net-energy** analyses have been insufficient and confusing
- Conservation is the new game we will all have to learn how to play

Rebuttal

“... The world can, in effect, get along without natural resources... at some finite cost, production can be freed of dependence on exhaustible resources altogether...”

ROBERT SOLOV, Nobel Prize in Economics

Definitions

- Fossil fuel *stocks* are buried plants and animals that lived up to **200 million years** ago, and were **very slowly** transformed and concentrated by the Earth
- Ethanol and biodiesel *stocks* are products of **instantaneous** transformation of plants and animals **each year**
- Fossil fuels and contemporary fuels are **concentrates** of solar energy on two very different time scales
- The **extra** energy required to **concentrate** energy is quantified by **thermodynamics**
- Fuel value is in (1) chemical **free** energy (readiness to **oxidize**), and (2) accessibility

Confusion Reigns Supreme

- **Energy** (free or not) comes from the Greek *energeia*, or *capacity to do work*, is a **stock** or a **path-independent function of state**
- Free energy is transformed spontaneously to **heat** or **work**, which are two different **path-dependent flows**
- The First Law of thermodynamics tells us that the *increase* of energy of a system (**a stock, a function of state**) is equal to the net *inflows* of heat and work (two **different path-dependent quantities**)

Confusion Reigns Supreme

- Free energy is transformed spontaneously to **heat** and/or **work**, which are two different **flows**
- The Second Law of thermodynamics tells us how much heat (*one flow*) at what temperature is required to produce mechanical work (*another flow*)
- The mechanical work *out* corresponds to the heat *in* at **infinite** temperature; on the earth these two flows are **never** equivalent

The Second Law of thermodynamics must be used in net-energy analysis to render it complete

Confusion Reigns Supreme

- To convert free energy of a fuel (*a stock*) into mechanical work (*a flow*), we need **thermodynamic machines** (internal combustion engine, turbine, dynamo, fuel cell. . .)
- To **equate** free energy of coal (*a stock*) with its conversion to electricity (*a flow of electrons*), is a fundamental **error**
- Biofuels are not exempt from the laws of thermodynamics; they too are stocks obtained from plants
- Biofuels too are converted to work by thermodynamic machines

Dr. Dale Has Stated:

- We need the services (“qualities”) energy provides: electricity, heat & “gas in the tank”
- Burn 3 kcal of coal to get 1 kcal of electricity
 - “Net energy” is **negative 235%**
 - But electricity is higher **quality** than coal

Now you are educated enough to see that Dr. Dale confuses stocks (*free energy of gasoline and coal*) with flows (*electricity and heat*) and confuses you too

Net Energy Balances

- What I just listed are the objective **Laws of Nature**
- There is nothing Dr. Dale or I can do to change them
- By following the recommendations of the **International Federation of Institutes for Advanced Study**, I was able to perform a meaningful net free energy analysis of the corn-ethanol cycle

I challenge Dr. Dale and others to improve on my 2004 **CRPS** analysis of the thermodynamics of corn-ethanol cycle