On Energy, Life, and Economics

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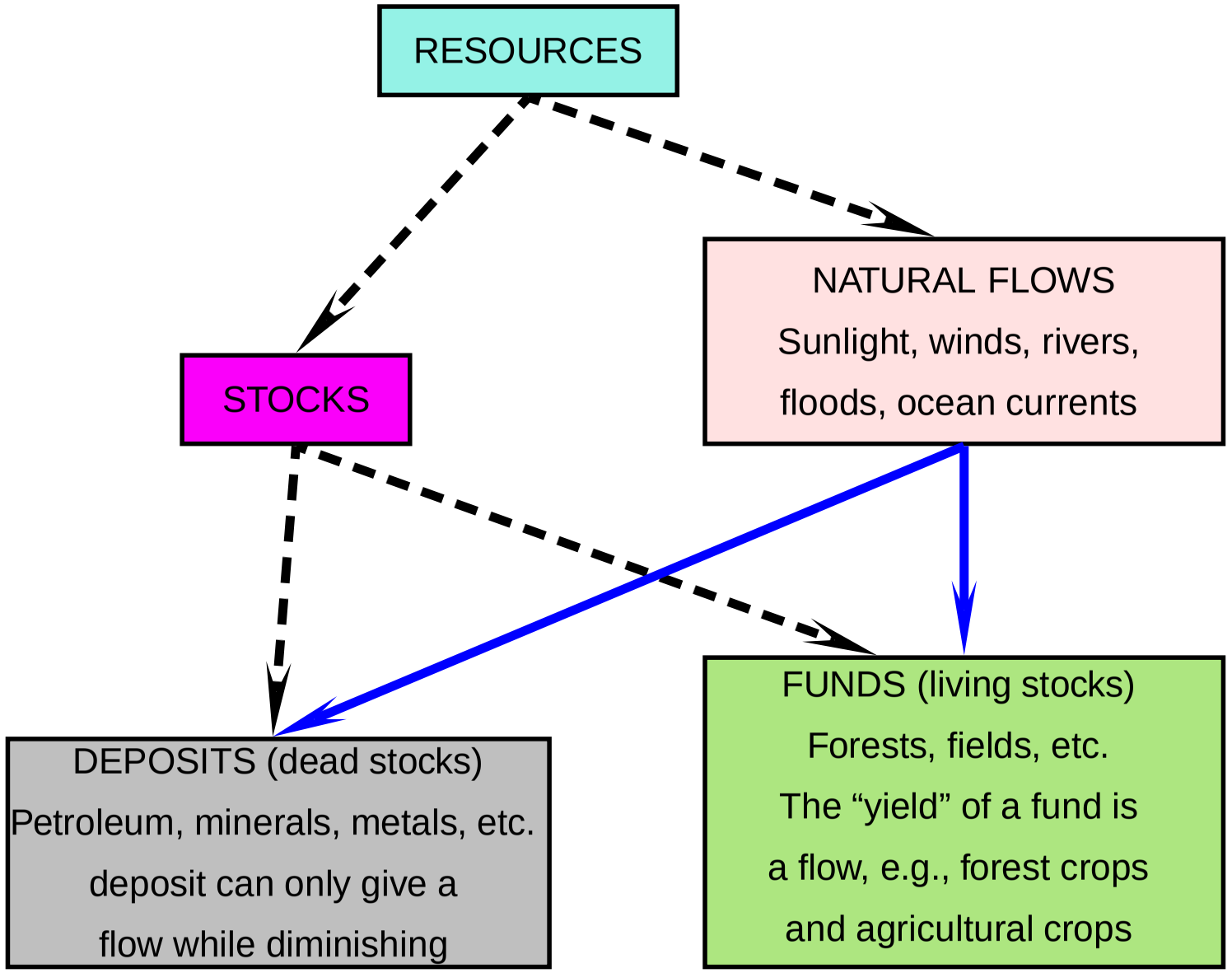
Net Free Energy Analysis. . .

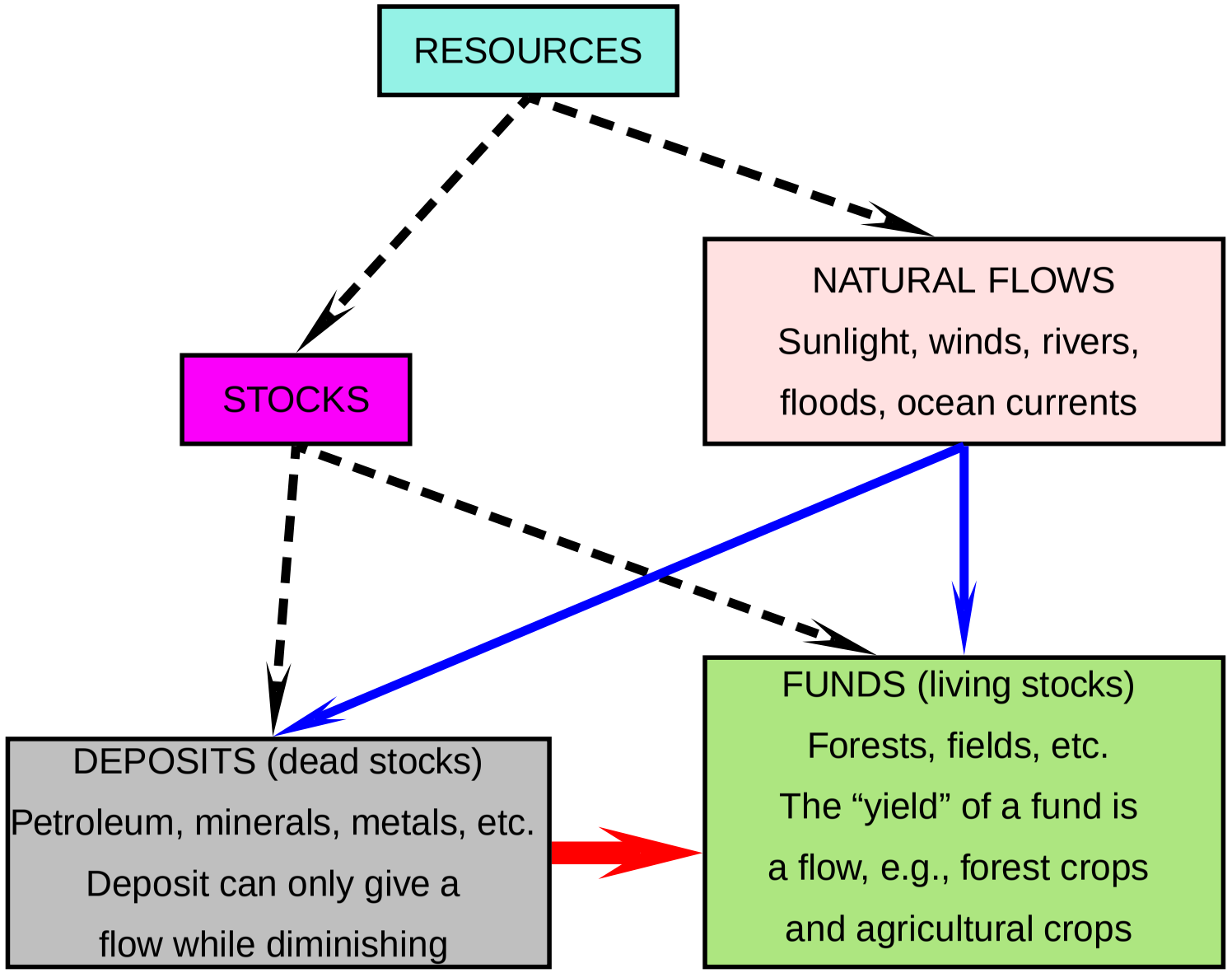
- Everything I will say here is based on my *Critical Reviews in Plant Sciences*, **23**(6):519-567, 2004 paper **Thermodynamics of the Corn-Ethanol Biofuel Cycle**
- I have followed the detailed recommendations of the International Federation of Institutes for Advanced Study
  - *Energy Analysis Workshop 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



Sources: Eugene Odum, 1998

Resource Classification



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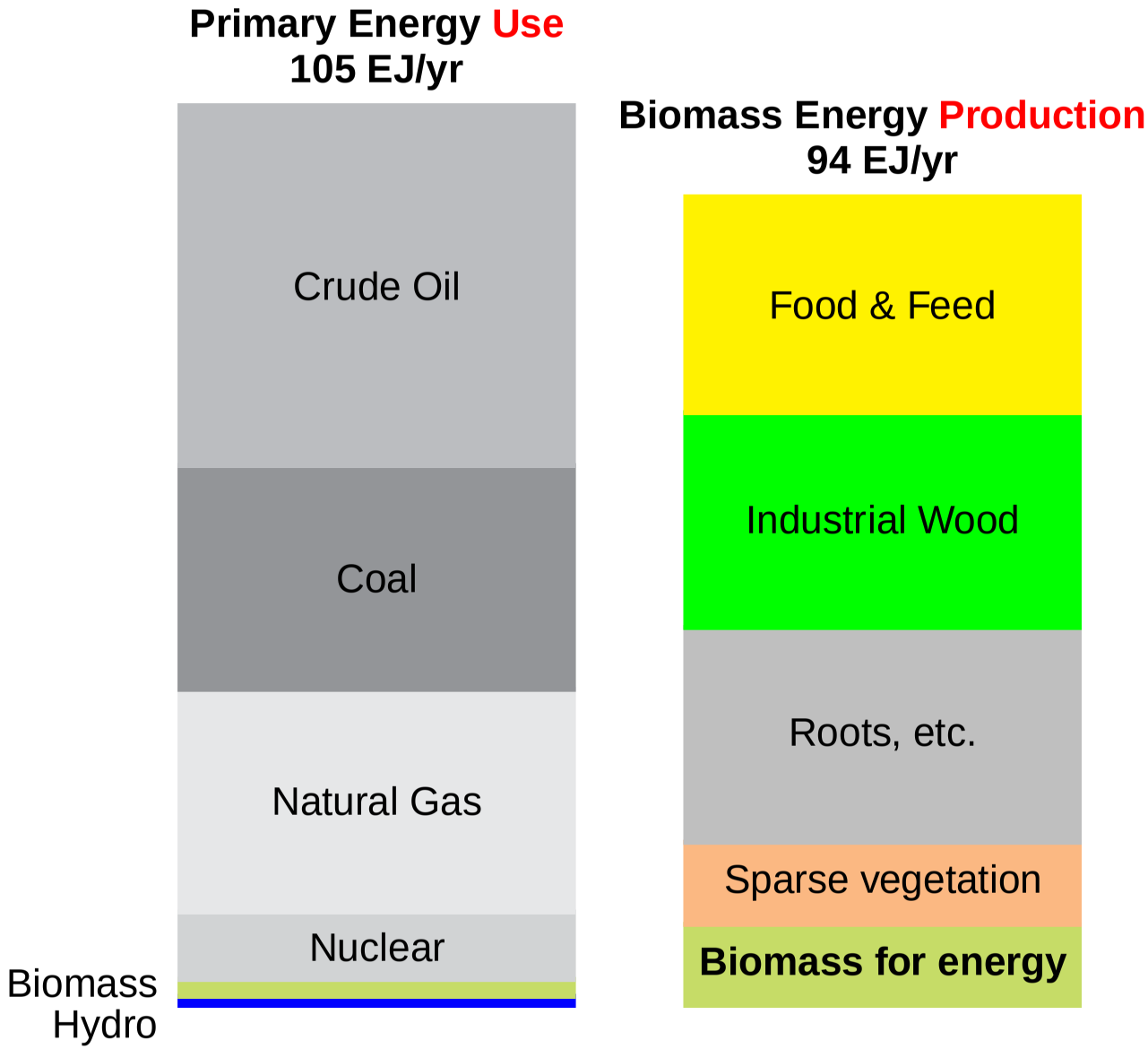
We Burn More Than Plants Produce



Sources: Good & Bell, 1980; Patzek, 2005

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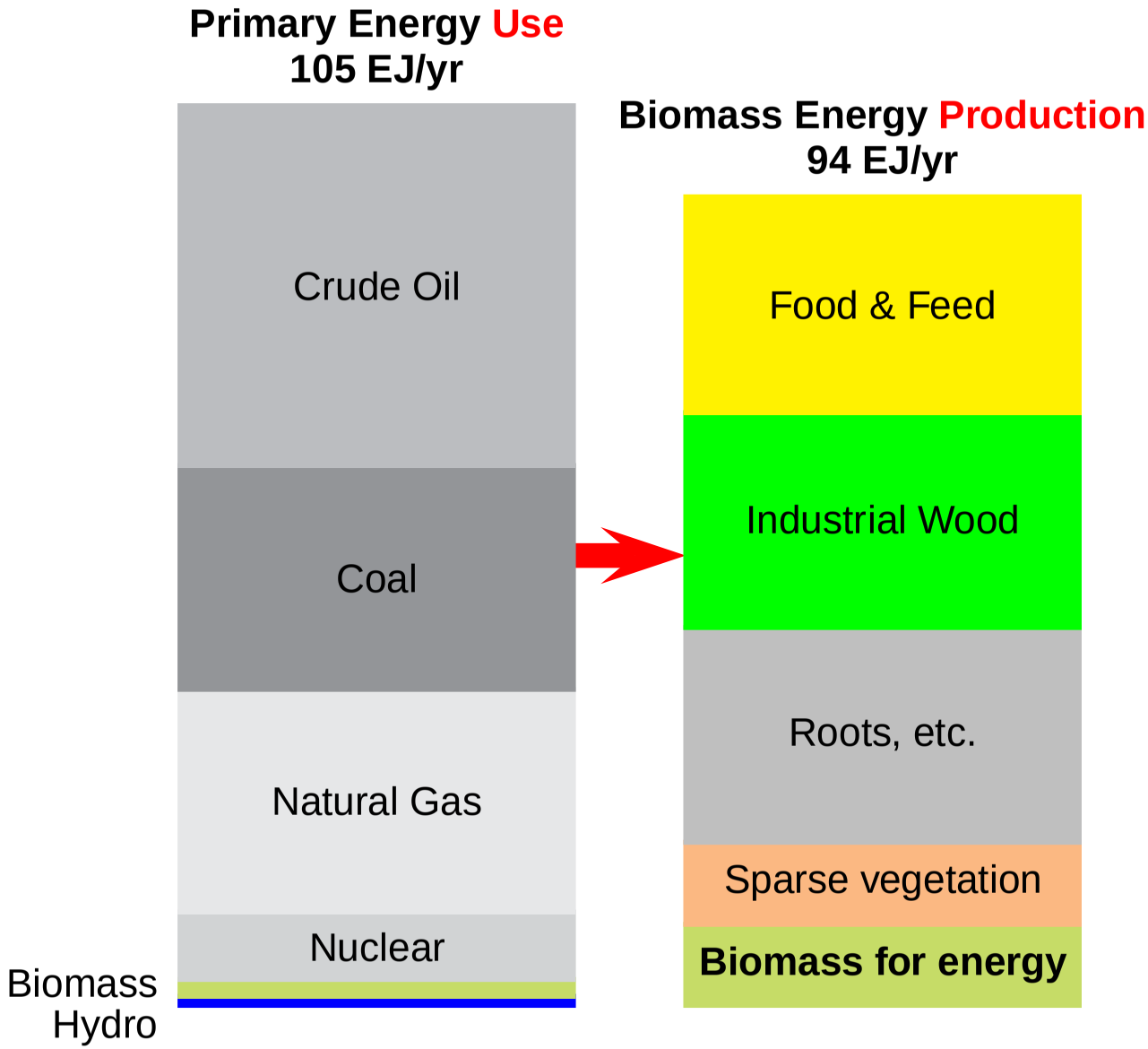

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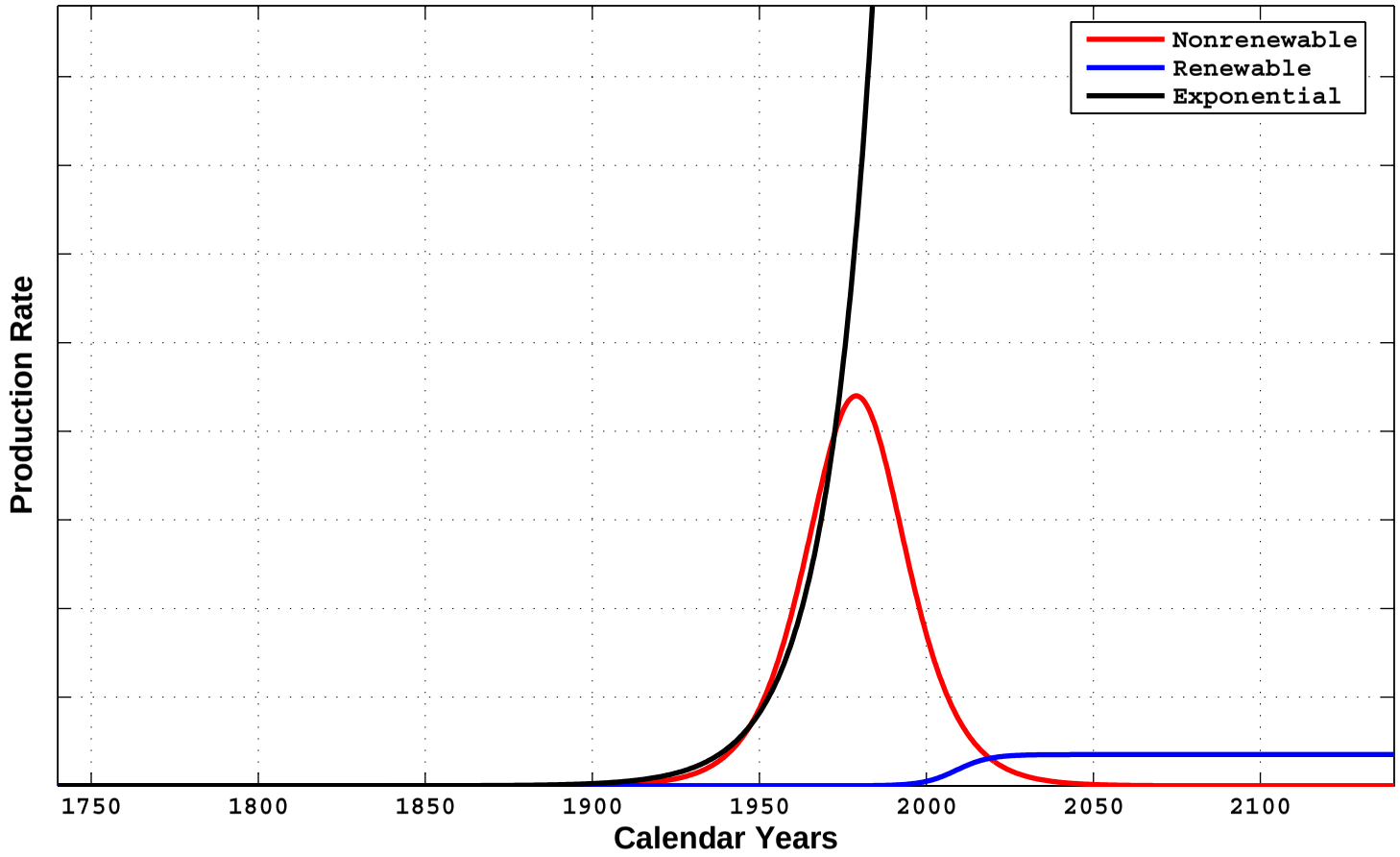
Different Types of Growth



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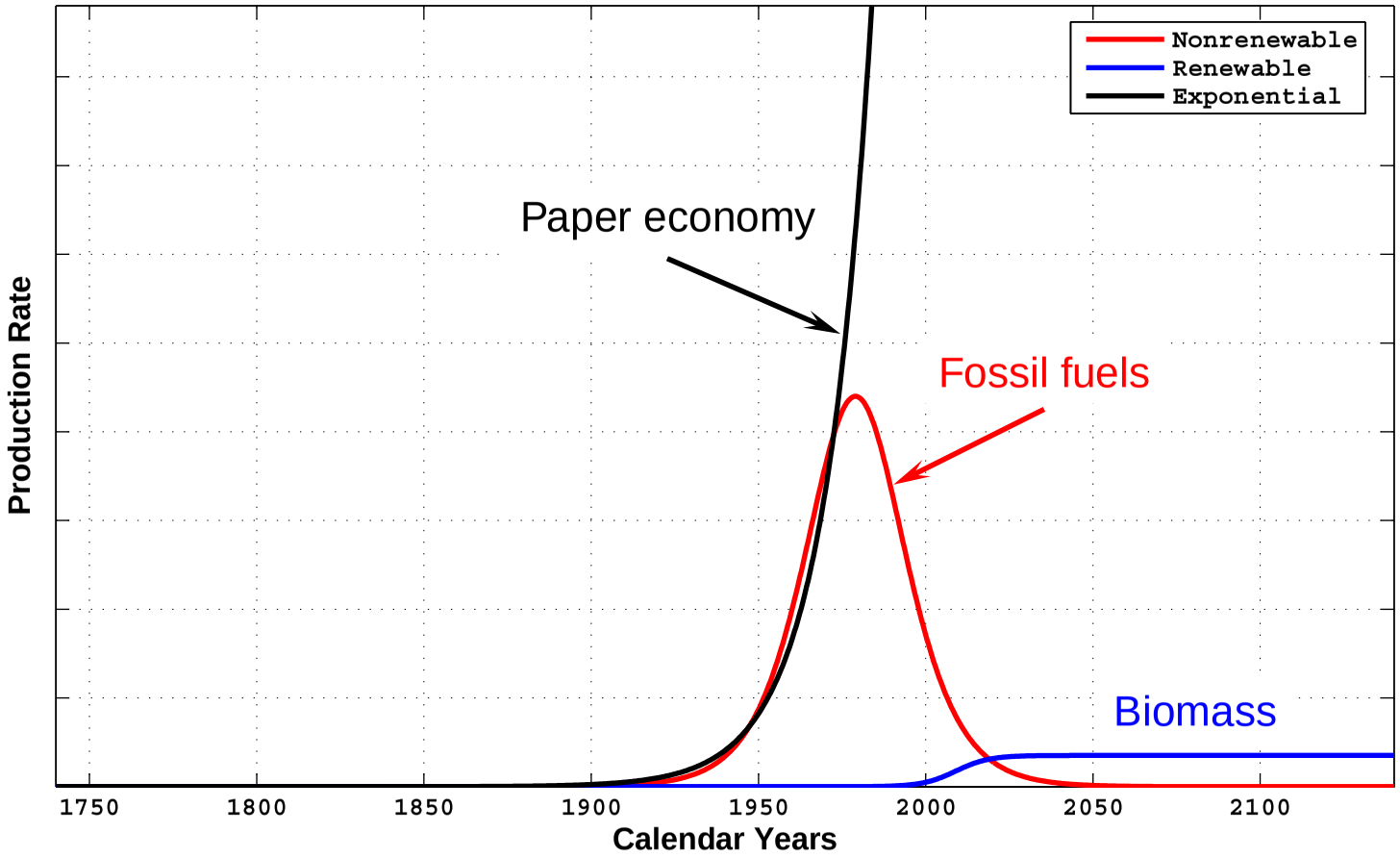
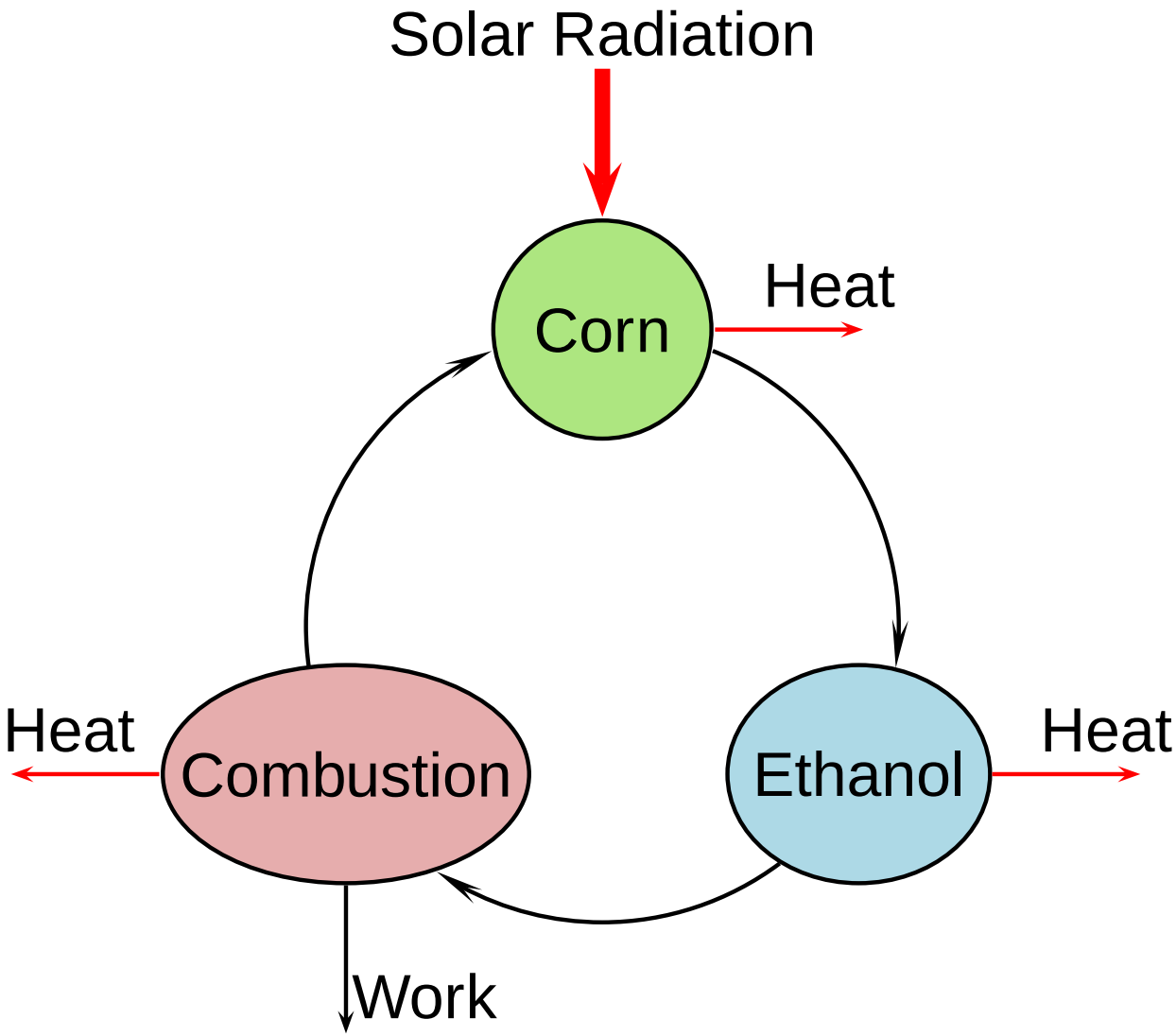
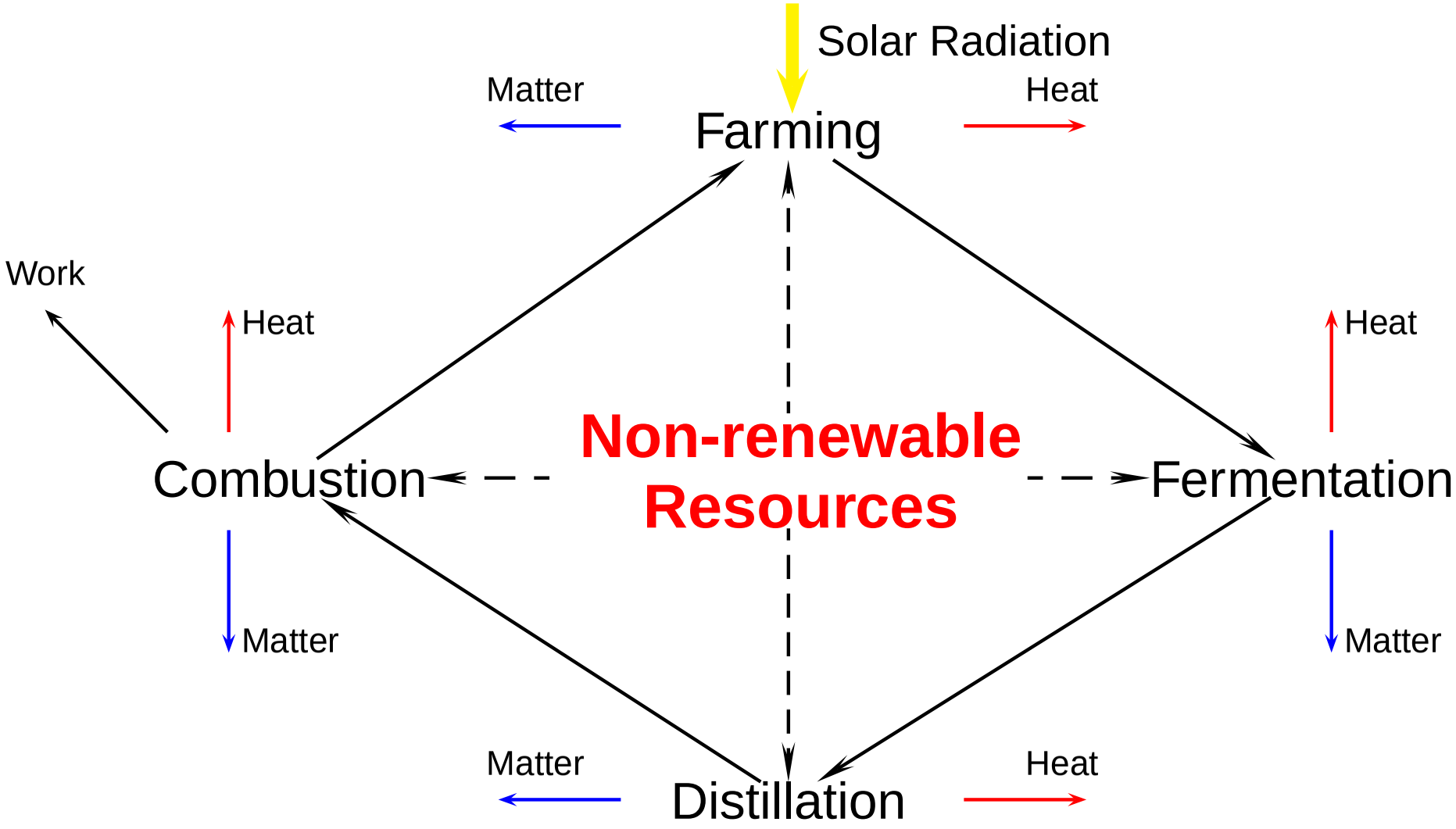


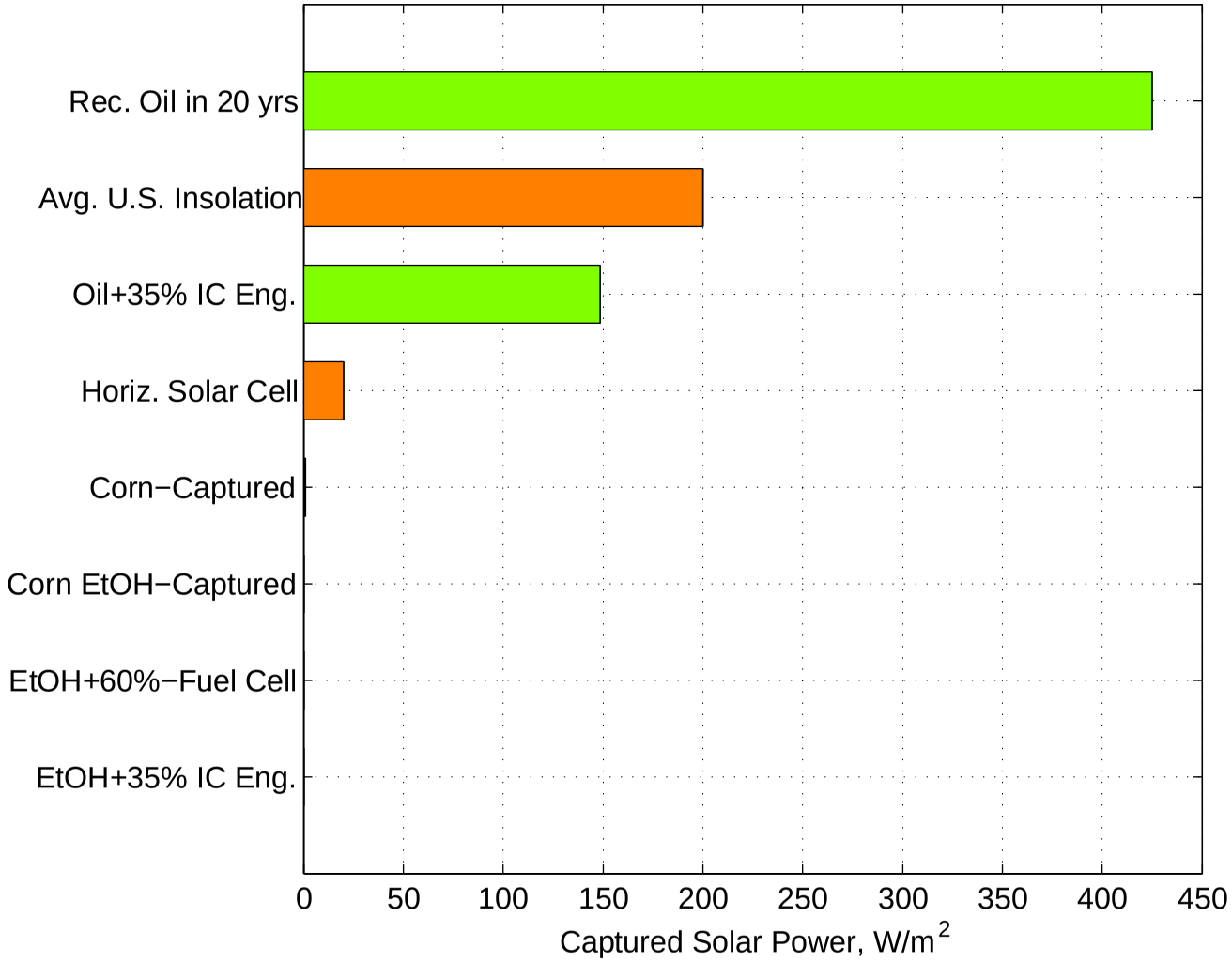
Ideal Corn-Ethanol Cycle. . .



Real Corn-Ethanol Cycle. . .



Available Free Energy…



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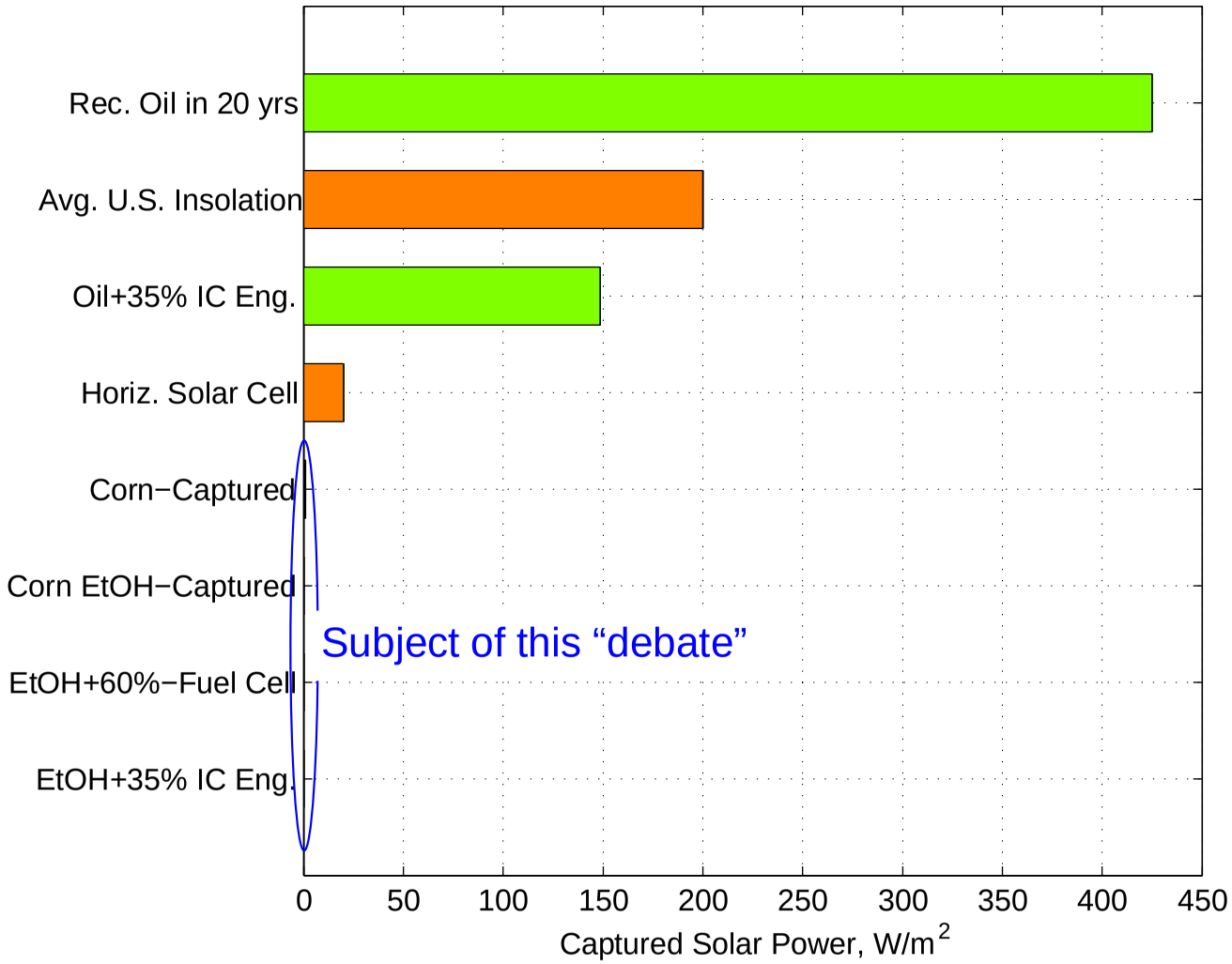
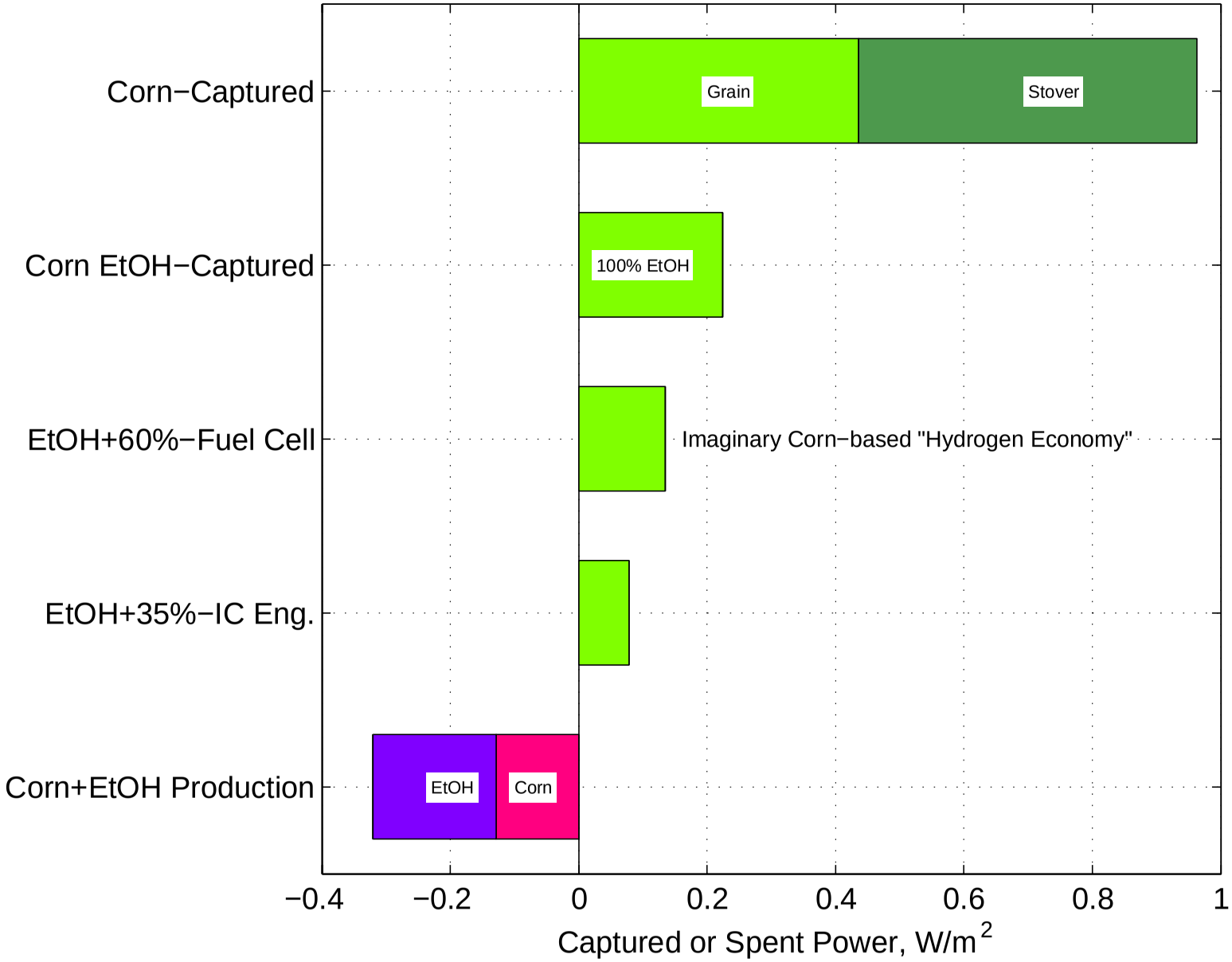


Corn Ethanol is Inefficient



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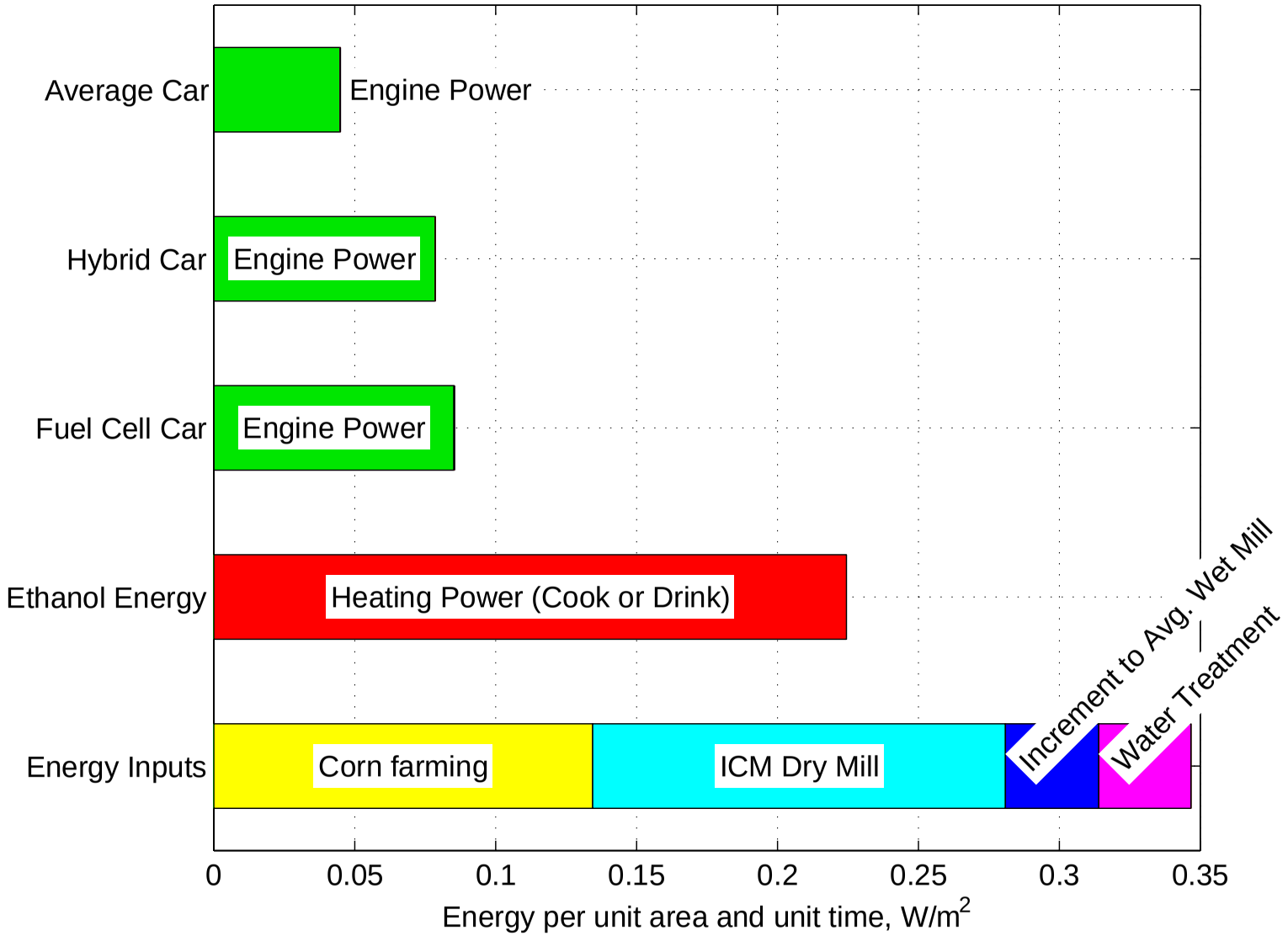
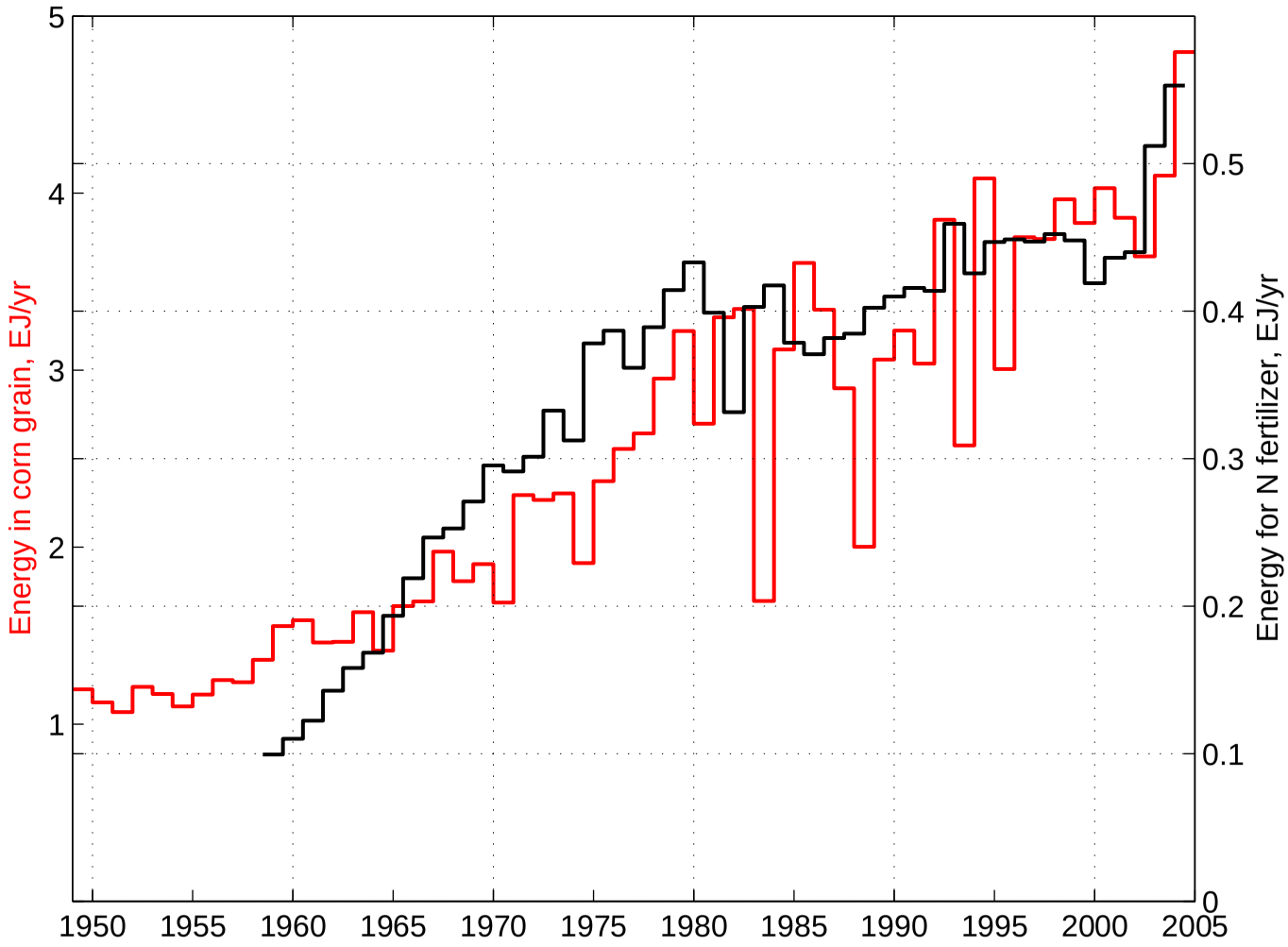


Source: Patzek, 2004

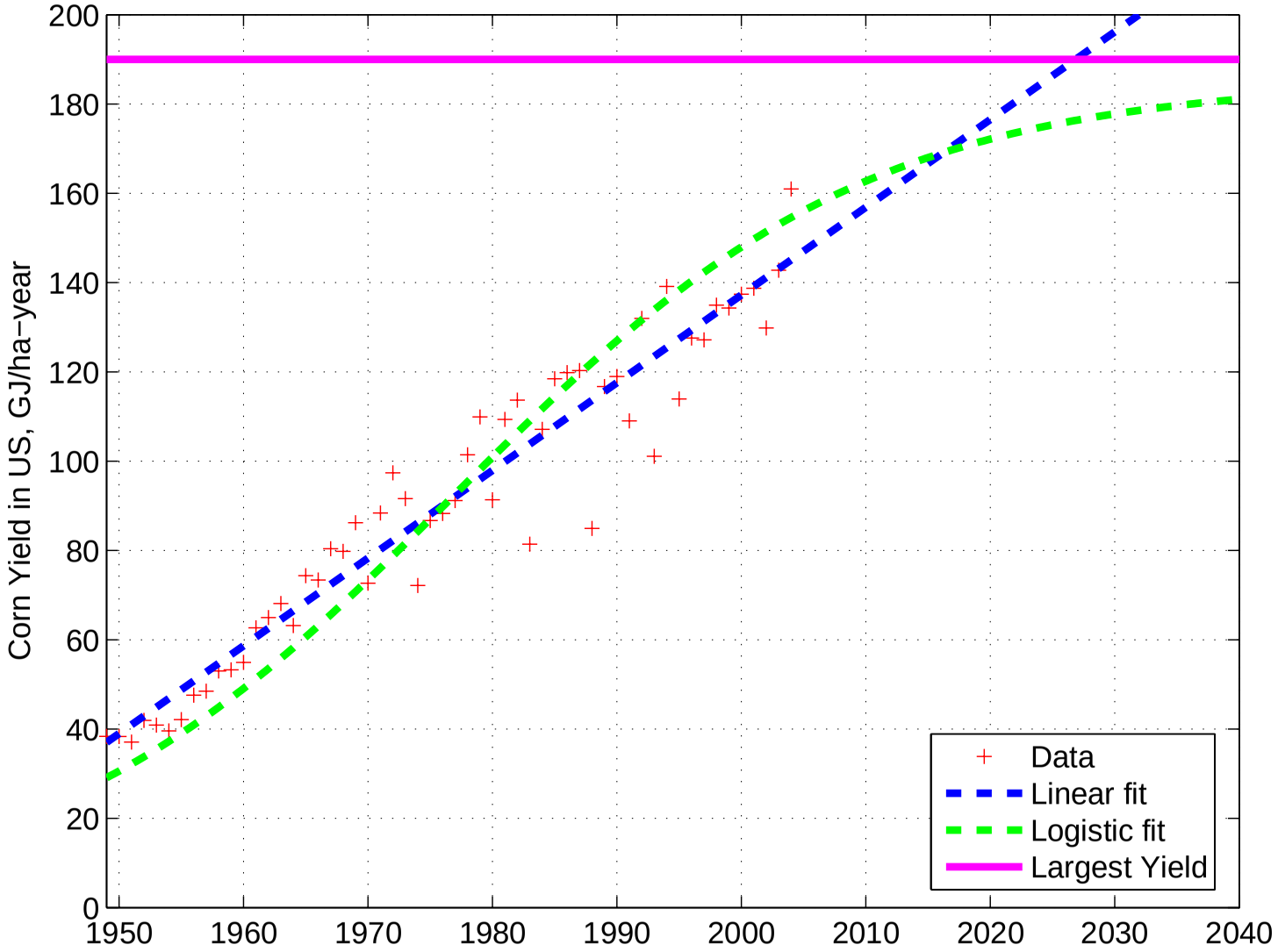
5×More Corn = 5×More Nitrogen

Over the Last 50 Years. . .



Sources: USDA, The Fertilizer Institute, Patzek 2004

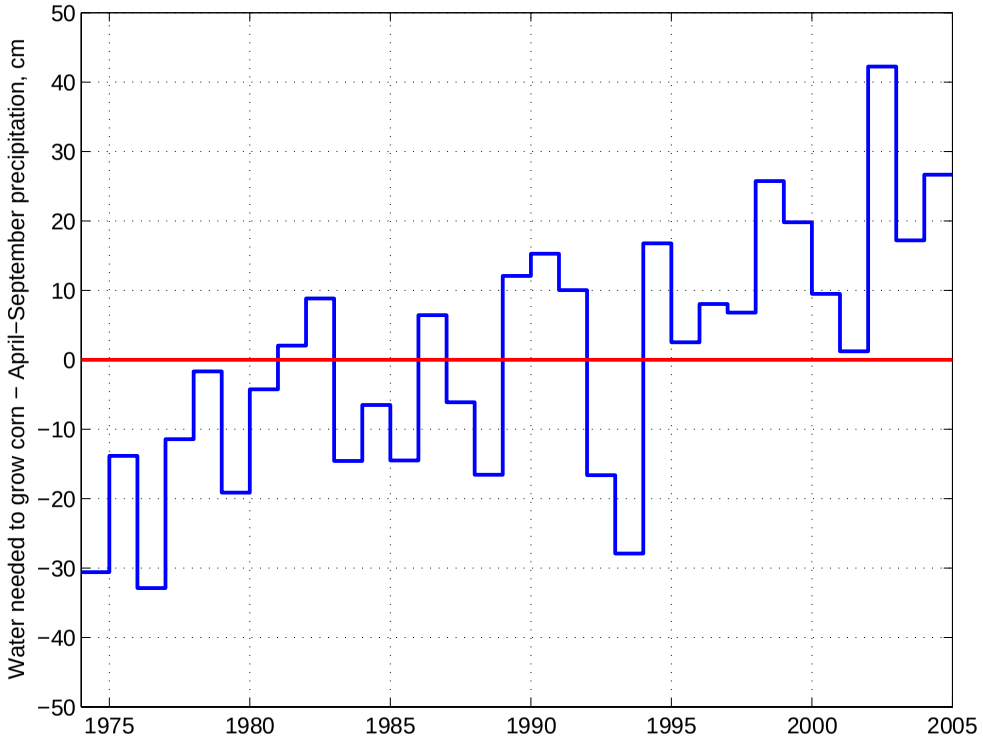
Corn Yield Trends



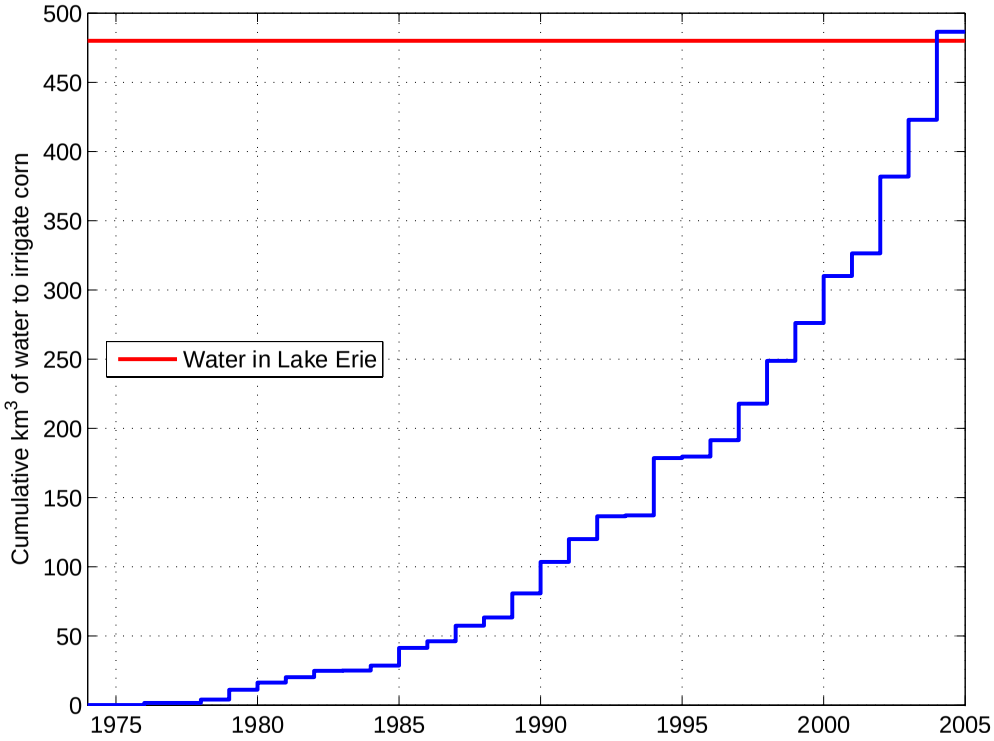
Sources: USDA, Patzek 2005

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 thermo-dynamics; 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