Can We Outlive Our Way of Life?

Forest Fire, Central Borneo (Kalimantan), Indonesia, Sept. 17, 2006

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August 9, 2007, Redwood City, CA
Forest Fire, Central Borneo

Red is forest. Sources: www.pandhitopanji-f.org/.../imagegallery.htm, ESA
Borneo Forest Fires

CO$_2$ From SE Asia Forest Fires

Borneo Forest Fires: Result
Indonesian Oil Palm Plantations

Source: Area of Indonesian oil palm plantations is from www.fao.org/forestry/index.jsp
Cumulative CO$_2$ from Indonesia Fires

Global Impact of Indonesia Fires

NASA's Earth Probe Total Ozone Mapping Spectrometer (TOMS), October 22, 1997
Amazon Deforestation

Source: Greenpeace: 4000 acres (Gleba do Pacoval area 60 miles SE of Santarem) illegally logged to clear land for soya plantations
Amazon Deforestation: Result

Source: Greenpeace: New soybean fields
Cumulative CO$_2$ from Amazon Fires

Sources: Brazilian National Institute for Space Research (INPE); ORNL; J. Germer and J. Sauerborn, ENVI102, Table 3
An Indefensible Proposition

Converting cellulosic biomass to ethanol involves a **negative energy return** - that is, the magnitude of energy required for biomass production and conversion is greater than the magnitude of energy displaced by the ethanol produced.

- There is **no** scalable “cellulosic ethanol” technology, so there is **no** “energy return,” positive or negative.
- Existing Iogen pilot plant is only 20%-efficient, very “negative”.
- There are **no** large-scale “biowastes” or “biomass surplus” to make cellulosic ethanol.
Cellulosic Ethanol Efficiency

Sources: Iogen, DOE, Patzek, 2007
Indefensible Assumptions

- Fossil fuels we use to produce anything are the only relevant limiting factor.
- All other factors are limitless and irrelevant:
  - The Earth provides us with an infinite and instantaneous supply of pure air, fertile soil and clean water full of nutrients.
  - She can regenerate all soil we destroy, and purify all water and air we pollute.
  - Forever, she can feed 7–12 billion people, 1 billion cows, and all other non-human living consumers of plant and animal matter, . . .
  - . . . and – now – 1 billion cars and trucks (620 million produced since 1961).
A Defensible Proposition

- Every large ecosystem on Earth must approach a steady state characterized by zero net ecosystem productivity (NEP).
- When humans are not a natural part of an ecosystem, large-scale biomass harvesting by the humans leads to an eventual breakdown of that ecosystem.
- Remedial actions (waste cleanup, erosion management, and applications of nutrients) are necessary to slow down — but never stop — the ecosystem deterioration.
- All these actions require massive inputs of fossil energy and are unsustainable.
Ecosystems are characterized by:

- **Gross Primary Production** ($GPP$) = amount of CO$_2$ converted by plant photosynthesis to biomass
- **Respiration** = biomass plants, $R_a$, and animals, $R_h$, consume to live
- **Net Primary Production**, $NPP$
  \[ NPP = GPP - R_a \]
- **Net Ecosystem Production**
  \[ NEP = NPP - R_h - R_{other} \]
- In natural ecosystems, $NEP \approx 0$
- Dry biomass $\times$ HHV = Energy
Facts about Ecosystem Productivity

- Autotrophic respiration = \( \sim \frac{1}{2} \) of photosynthesis (GPP)
- Heterotrophic respiration consumes up to 95% of the remainder
- On average, net ecosystem productivity (NEP) oscillates around zero
- Agricultural ecosystems must be heavily subsidized with ancient plant matter and minerals
Net Ecosystem Productivity

Source: SONGA & WOODCOCK (2003), simulation of H. J. Andrews Experimental Forest
Mass Stays on Earth, Heat Leaves

Source: Image Science & Analysis Laboratory, Johnson Space Center
Ecological Cycles = No Waste!

Sun energy

H₂O, CO₂, Nutrients

Plant Matter

"Forever"

Death & Decay

Waste heat

Other life

Waste heat
Almost All Mass is Recycled...

The recycling goes mostly above the ground
Global GPP and NPP are Known

NASA produces a regular global estimate of gross primary productivity (GPP) and annual net primary productivity (NPP) of the entire terrestrial earth surface at 1-km spatial resolution, 150 million cells, each having GPP and NPP computed individually (MOD17A2/A3 User’s Guide).

Image from Numerical Terradynamic Simulation Group, Missoula, Montana. Date: 12/27 – 12/31/2003
We Already Grab **Most** of NPP

Source: The Visible Earth, NASA images, 06-25-2004
Earth Has **No** Spare Capacity!

*Drawn to Scale*
An Indefensible Proposition

Ethanol produced from cellulosic biomass could make a large contribution to meeting mobility demand while honoring environmental and food production objectives.

- As formulated, this proposition contradicts a vast body of experimental and scientific evidence we have.
- Mother Nature knows of no waste and has no spare capacity.
- So-called “agricultural wastes” are our failure to close natural cycles, paid for with fossil fuels.
The fundamental unit of energy is 1 exa Joule (EJ)

\[ 1 \text{EJ} = 1,000,000,000,000,000,000,000 \text{ J} \]

is the amount of metabolized energy in food sufficient to sustain the entire U.S. population for one year @100 J/s-person = 100 W/person continuously

Currently the U.S. uses 105 EJ/year; one hundred and five times more than we need to live

If we were to metabolize this amount of energy, we would be 15 m long sperm whales, each weighing 40 tonnes. There are \( \sim 360,000 \) sperm whales worldwide and 850 times more Americans
Homo Colossus Americanus...

1 Statistical American = 1 Sperm Whale

EUGENE ODUM, Ecological Vignettes, 1998
Transportation Fuels in US

Sources: US DOE EIA, Patzek (2004)
35 Billion Gallons of Ethanol

Sources: US DOE EIA, RFA, Patzek (2007)
130 Billion Gallons of Ethanol

Primary Energy Use
- Crude Oil
- Coal
- Natural Gas
- Nuclear
- Biomass
- Hydro

NPP
- 118 EJ/yr

Biomass for agrofuels
- 1.4 or 2.8 Gt/yr

NPP
- 105 EJ/yr

Sources: NASA MODIS; NTSG Missoula, Montana; Patzek, 2007
US Population Projections

Source: www.census.gov/popest/states/tables/NST-EST2004-01.xls
Projected US Energy Use

- 270 billion gallons of ethanol per year

- World Oil Production
- US Oil Consumption

Petroleum, EJ/Year

2000 2020 2040 2060 2080 2100 2120 2140 2160 2180 2200
Capture of Solar Power…

Brief Explanation
Primary Power From the Sun...

Oil field will be depleted in 30-100 years

Captured Sun–Power, Primary W/m²

Source: T. W. Patzek & D. Pimentel, CRPS 23(6), 2004, 24(5-6), 2005
Exclude Oil...

Solar cells are up 70 - 630 times more efficient than biofuels

Source: T. W. PATZEK & D. PIMENTEL, CRPS 23(6), 2004, 24(5-6), 2005
Land Area to Drive a Car…

- Assume driving 15,000 miles/year @40 mpg in a Toyota Prius hybrid
- Alternatively, drive an all-electric car that is 2.5 times more efficient than the Prius
- Account for average energy costs of producing gasoline from crude oil (17%) and biofuels from biomass as in the slides above
- Assume energy costs of manufacturing and deploying PV panels and wind turbines, 33% and 10% of their 30-year production
Extra Area to Deliver Energy...

Additional Land Area Needed to Cover Energy Production Costs

Source: T. W. Patzek & D. Pimentel, CRPS 23(6), 2004, 24(5-6), 2005
Areas Relative to Oilfield...

Oil field area to drive the Prius is 330 square feet (30 m²)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Net Ratio</th>
<th>Gross Ratio</th>
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<tbody>
<tr>
<td>Oilfield</td>
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<tr>
<td>PV Cell</td>
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<td>Wind turbine</td>
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<td>1917</td>
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</table>
Gross Acres to Drive a Car...

Solar cells and 85%-efficient electrical car are clear winners

Source: T. W. PATZEK & D. PIMENTEL, CRPS 23(6), 2004, 24(5-6), 2005
Conclusions

Thirty million hectares (75 million acres) covered with:

**Corn** = 16 million Priuses from grain + 8 million Priuses from stover – for a while

**Sugarcane** = 47 million Priuses – for a while

**Solar cells** = 3000 million electric cars

**Wind turbines** = 270 million electric cars

We need to invest in solar cell and electricity storage technologies, *not* in biofuels