Peak Oil

Putting Teeth into Sustainability
or
Mother Nature Bats Last

Martin Sereno

Cognitive Science
University of California, San Diego

(original talk, November 2004
most recent update, September 2007)
Where Oil Comes From

- raw organic material for oil (e.g., from plankton) is present in low concentrations in ‘all’ sedimentary rocks, but esp. from two warm periods 90 million and 140 million years ago

- temperature rises with depth (radioactivity, Kelvin’s mistake)

- oil is generated in rocks heated to 60-120 deg Celsius

- rocks at this temp. occur at different depths in different places

- oil is ‘cracked’ to natural gas at higher temperatures (deeper)

- abiotic oil from “crystalline basement” is negligible, if it exists

- exhausted oil fields do not refill
**Recoverable Oil**

- Oil must collect in a “trap” to be practically recoverable.
- A trap is a permeable layer capped by an impermeable one.
- Obvious traps: anticlines, domes (AKA “oil in those hills”).
- Less obvious traps found by seismic imaging: turned up edges of salt domes, buried meteorite craters (Mexico).
- Harder-to-get-at traps: shallow continental shelf (GOM).
- Essentially no oil in basaltic ocean floor or granitic basement.
Second Largest Oilfield (by current production)
Cantarell currently supplies 2% of world oil

## Recoverable Oil is Highly Localized in Space

<table>
<thead>
<tr>
<th>Country</th>
<th>Reserves</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saudi Arabia</td>
<td>261.8 Gb</td>
<td>8.8 Mb/day</td>
</tr>
<tr>
<td>Iraq</td>
<td>112.5</td>
<td>2.4</td>
</tr>
<tr>
<td>UAE</td>
<td>97.8</td>
<td>2.4</td>
</tr>
<tr>
<td>Kuwait</td>
<td>96.5</td>
<td>2.1</td>
</tr>
<tr>
<td>Iran</td>
<td>89.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Venezuela</td>
<td>77.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Russia</td>
<td>48.6</td>
<td>7.1</td>
</tr>
<tr>
<td>US</td>
<td>30.4</td>
<td>7.7</td>
</tr>
<tr>
<td>Libya</td>
<td>29.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Mexico</td>
<td>26.9</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**Crude oil: beginning of 2002**
Oil Production & Consumption % of Global Top 20 Nations by Production

Source: The CIA World Factbook

www.MarkTAW.com
Conventional Energy Wisdom:
Middle East Oil Is Limitless

- All long-term oil supply/demand models assume Middle East oil can grow as fast as oil demand rises.
- Middle East oil will also be "cheap".
- If more is needed, drill anywhere.

Source: The CIA World Factbook
www.MARKTAW.COM
Significant traps are extremely localized in space

oil = red
largest: Ghawar

from Matt Simmons
Persian Gulf
Close-up

from Matt Simmons
**Big Oil**

Several of the world’s largest oil fields show signs of fading, according to several studies, raising questions about the reliability of global energy supplies. An internal Pemex study suggests Mexico could see steep declines.

<table>
<thead>
<tr>
<th>Oil Field</th>
<th>Country</th>
<th>Oil Output in Millions of Barrels per Day</th>
<th>Percentage of National Oil Output</th>
<th>State of Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghawar</td>
<td>Saudi Arabia</td>
<td>4.5</td>
<td>40%</td>
<td>Possibly declining</td>
</tr>
<tr>
<td>Cantarell</td>
<td>Mexico</td>
<td>2</td>
<td>60%</td>
<td>Declining</td>
</tr>
<tr>
<td>Burgan</td>
<td>Kuwait</td>
<td>1.7</td>
<td>68%</td>
<td>Possibly declining</td>
</tr>
<tr>
<td>DaQing</td>
<td>China</td>
<td>1</td>
<td>40%</td>
<td>Possibly declining</td>
</tr>
</tbody>
</table>

Sources: Deutsche Bank; Reuters; Oil and Gas Journal
[named after Yucatan fisherman Rudecindo Cantarell, who discovered oil seep!]

http://www.eia.doe.gov/emeu/cabs/Mexico/Oil.html
OIL AND GAS LIQUIDS
2004 Scenario

from ASPO, 2004
THE GROWING GAP
Regular Oil

- Past Discovery
- Future Discovery
- Production

from ASPO, 2005
Previous production plateaus preceded by price drop (demand-driven) vs. current tech bubble pop (Asian 'flu')

http://www.theoildrum.com/story/2006/4/12/204811/033#117
World Creaming Curve

Source: IEA analysis based on IHS Energy database.
Stages of production

• **Primary production** (just produce)
  – initially, oil sprays out under own pressure (e.g., 3500 psi)
  – main productive run as pressure slowly drops (2000 psi)
  – as pressure drops, dissolved gas comes out of solution

• **Secondary production** (reinstate pore pressure by injection)
  – pump water down underneath oil (Ghawar, Saudi Arabia)
  – pump nitrogen down above oil (Cantarell, Mexico)
  – pump natural gas (or CO₂) down above oil (US)

• **Tertiary production** (extreme measures)
  – underground pumps, detergents, explosions
  – inject oil-eating bacteria (repressurize with bacterial gas)

• **EROEI** (energy return on energy investment)
  – EROEI decreases with each successive stage until < 1.0
Cantarell: Primary and Secondary

Pressure

Increase in production

Production

Nitrogen injection

(update1: 2.0 million barrels/day in 2005)

(update2: Cantarell declined 10.8% in first half 2006!)

from PEMEX Outlook, Feb, 2005 (now deleted!)
http://www.pemex.com/index.cfm?action=statusfilecat&categoryfileid=2141
Plunge in Production

Declining crude-oil output at Mexico’s biggest oil field, Cantarell, is further squeezing global supply.

Source: Mexico’s Energy Ministry

Sideways Drilling – e.g., Ghawar
(increases flow by exposing longer length of borehole to oil floating on injected water)

Greatly increases flow rate from single wells
(e.g., 10,000 barrels/day vs. 300 barrels/day)

Ghawar
largest reservoir in world (looking south)
surface defined by impermeable cap (anhydrite bed)

http://www.searchanddiscovery.net/documents/2004/afifi01/index.htm
Rock permeability is spatially complex (model of 'Ain Dar and Shedgum, northern Ghawar)
Most of the World has Already Peaked

• Only producers that have not peaked are OPEC and FSU

• This is called “depletion”

• Depletion is occurring despite widespread use of secondary methods in mature fields

• Since world demand is growing, depletion means that the non-peaked countries will have to increment production both to offset depletion and to meet new demand

• Recent price increases may make companies return to previously unprofitable/abandoned fields

• Higher prices cannot make fields re-fill with easy-to-get oil, or make remaining oil with EROEI<1.0 an energy source
Natural Gas Liquids (NGL's)

- Don't confuse these with "liquified natural gas" (LNG), which is cooled, compressed methane.
- "Natural gas liquids" (NGL's) are short chain hydrocarbons (e.g., pentane) extracted from deep, hot (e.g., 180 deg C) natural gas wells with (75% the energy density of crude).
- NGL's are gases in situ but some condense to liquids when brought to the surface and cooled.
- NGL's and "condensates" are divided into immediately separated "lease condensates" (e.g., pentane) and later stage "natural gas plant liquids" (e.g., propane, butane).
- 75% of US 'oil' production is now "natural gas liquids"!
- Finally, "all liquids" adds together crude oil, NGL's, and "other liquids" (mainly ethanol, and a little biodiesel).
Past/Predicted Production, North Sea
(already discovered sites)

Peter Haile, UK Dept Trade & Industry
Past/Predicted Discovery and Production
FSU (former Soviet Union)

- Soviet Union collapse
- 80's oil price crash
- History
Reserve Estimates Unreliable, Semi-Secret

- Several major oil companies recently downgraded reserves.
- OPEC countries all doubled reserves estimates in mid 80’s.
- OPEC reserves have remained unchanged after strong 90’s production despite absence of new discoveries.
- Secondary production can end with sharp drops (sharp late 1990’s North Sea peak versus shallower US peak) when water reaches borehole, or sidesteps left-behind oil.
- In newer fields, primary and secondary production are being done sooner (e.g., Cantarell), or from beginning.
- Kuwait halved stated reserves in 2006 (~100 Gb to ~50 Gb).
World Reserves Estimates Through Time

Large reserves increase during 80s oil price crash

Middle East Production: ~130 Gb

Reserves unchanged after massive production

Ghawar
Largest Oilfield (~5% world production)

(from reference on next slide)
Oil column thickness (orig: 1300 feet)
- blue: 0-30 feet
- green: more than 120 feet
- red: boreholes (most now used for water injection)

Shiv Dasgupta, “Reservoir monitoring with permanent borehole sensors: Ghawar Arab D reservoir”, 74th SEG Conference, 2004

http://abstracts.seg.org/ease/techprog/downloadpaper?paper_id=817&assigned_num=762
Ghawar Anhydrite Cap
looking north
(vertically exaggerated)

http://lpsc.in2p3.fr/gpr/Dautreppe/Laherrere/Image78.jpg
possible location of traverse on 3D reconstruction
Ghawar Boreholes

blue: oil
brown: water inj

(approx. overlay)

Depletion of North ‘Ain Dar

http://www.theoildrum.com/node/2441 from Stuart Stanifold
Ghawar Field Oil Saturation Plot, 2002
(presumably just under anhydrite cap)

[blue is now oil, not water]

‘Ain Dar

North

Courtesy of Saudi Aramco

http://www.appro.com/company/0706_Appro_Eprint_A.pdf
Ghawar Depletion by Region

North Ain Dar
Area: 149.5 miles²
Swept Area: 120.75 miles²
Un-swept Area: 28.75 miles²
Area of Oil: 23 miles²
Area of Gas Cap: 5.75 miles²
Initial Reserves: 12.1 billion bbls
2004 Reserves: 1.5 billion bbls
% Depletion: 88

South Ain Dar
Area: 120 miles²
Swept Area: 79.5 miles²
Un-swept Area: 40.5 miles²
Area of Oil: 25.5 miles²
Area of Gas Cap: 15 miles²
Initial Reserves: 9.7 billion bbls
2004 Reserves: 1.7 billion bbls
% Depletion: 83

Base Case Scenario
2004 Whole Field
Reserves:
34.3 billion bbls

Ghawar Base Case Production Model

Shedgum
Area: 163.5 miles²
Swept Area: 70.5 miles²
Un-swept Area: 93 miles²
Initial Reserves: 11.3 billion bbls
2004 Reserves: 5.4 billion bbls
% Depletion: 55

Uthmaniyah
Area: 461.75 miles²
Swept Area: 327.5 miles²
Un-swept Area: 134.25 miles²
Initial Reserves: 29.3 billion bbls
2004 Reserves: 6.5 billion bbls
% Depletion: 78

Hawiyah
Area: 293.75 miles²
Swept Area: 56 miles²
Un-swept Area: 237.75 miles²
Initial Reserves: 13.8 billion bbls
2004 Reserves: 11.1 billion bbls
% Depletion: 19

Haradh
Area: 436 miles²
Swept Area: 161.75 miles²
Un-swept Area: 274.25 miles²
Initial Reserves: 14.4 billion bbls
2004 Reserves: 8.4 billion bbls
% Depletion: 42

Measurement of Areas
SHEDGUM
5X5 mile square grid

http://europe.theoildrum.com/node/2507
http://europe.theoildrum.com/node/2494
Prudoe Bay, Alaska – Production/Reserves

largest North American oil field (discovered 1968) ‘reserves’ increase but production continues to drop

Blue is reported reserves in billion barrels

Green is production in hundred thousands barrels per day.
Demand is Growing

- for example: USA, China, India
- a bicycle is a 100-watt device
- a car is a 100,000-watt device
China Imports Up (from 0)  
UK exports Down (to 0)  
since 1996  
(same x and y scales)
US: 97 quads/year
(1 quad = $10^{15}$ BTUs = 172 million barrels)

Source: Production and end-use data from Energy Information Administration, Annual Energy Review 2002.
*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.
**OIL AND GAS LIQUIDS, 2004 SCENARIO (5,000 year view)**

**Transportation and Motors:**
- Oxen, Horses, Humans
- More Horses

**Heating:**
- Wood
- More Wood

**Population:**
- Sumer
- Crete
- Egypt
- Greece
- Rome
- Yucatan
- China
- European Renaissance

5,000 years ago ----> now

- Peak Oil
- Absolutely Enormous Numbers of Horses, Slaves
- Coal
- Europe Forests Gone
- Malthus
- Black Death
- Oil
- Cars
- Absolutely Enormous Numbers of Horses, Slaves

Population and Energy Trends:
- Wood: Heavily used for heating and transportation.
- Oxen, Horses, Humans: Used for transportation and labor.
- More Horses: Suggests an increase in demand or availability.
- More Wood: Indicates a trend towards using wood as a fuel source.
- Peak Oil: A significant point where oil resources start to decline.
Other More Optimistic Scenarios 2006
Transportation and Motors:
- Oxen, Horses, Humans

Heating:
- Wood

Population:
- Sumer
- Crete
- China
- Greece
- Rome
- Yucatan
- European Renaissance

5,000 years ago -> now

Peak Oil

ABSPO 2004, conservative scenario
(5,000 year view)

Absolutely Enormous Numbers of Horses, Slaves

Black Death

Coal

Europe Forests Gone

Malthus

Wood

Absolutely Enormous Numbers of Horses, Slaves

Coal

Europe Forests Gone

Malthus
CERA et al. 2006, most optimistic scenario (5,000 year view)

Transportation and Motors:
- Oxen, Horses, Humans
- More Horses

Heating:
- Wood
- More Wood

Population:
- Sumer
- Crete
- Egypt
- China
- Greece
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5,000 years ago → now

Peak Oil

Cars

Absolutely Enormous Numbers of Horses, Slaves

Coal

Europe Forests Gone

Malthus

Black Death

5,000 years ago

Peak Oil

CERA et al. 2006, most optimistic scenario (5,000 year view)
Oil and World Population
(since 1900)

http://canada.theoildrum.com/node/2516
from GuilderGlider

Oil and World Population
(last 2000 years)
More details about production, prediction

• business as usual (EIA, IEA, CERA)
• bottom-up (add producing, not-yet-in-production fields)
• curve-fitting (Hubbert, Deffeyes, Campbell, LaHerrere)
• country-by-country stacked graphs
• potential effect of tar sands
World Production (plus all projections)

- BP (2006)
- EIA (CO)
- EIA (NGPL)
- EIA (Other Liquids)
- Const. Barr./Cap. (CO+NGL)
- Loglets (CO+NGL)
- Deffeyes (CO)
- Laherrere (All)
- Logistic Med (CO+NGL)
- Logistic Low
- Logistic High
- Shock Model (CO+NGL)
- GBM (CO+NGL)
- ASPO-71 (CO+NGL)
- ASPO-58 (CO+NGL)
- Skrebowski (CO+NGL)
- Koppelaar (All)
- Bakhtiar (CO+NGL)
- Smith (CO+NGL)
- EIA (All)
- CERA (CO)
- CERA (All)

70's oil shock

Next Slides (2001+)

http://www.theoildrum.com/node/2143  (Jan 15, 2007)
Recent World Production (business as usual, CERA etc.)

http://www.theoildrum.com/node/2143 (Jan 15, 2007)
World production crude oil + natural gas liquids

color coding -> cumulative production

graph by Khebab: http://www.theoildrum.com/story/2006/11/2/204936/516
recent data from BP: http://www.bp.com/productlanding.do?categoryId=6842&contentId=7021390
World production crude oil + natural gas liquids

color coding -> current production percent of maximum production

graph by Khebab:  http://www.theoildrum.com/story/2006/11/2/204936/516)
recent data from BP:  http://www.bp.com/productlanding.do?categoryId=6842&contentId=7021390
Production of countries that have peaked
color coding -> year of peak production

graph by Khebab: http://www.theoildrum.com/story/2006/11/2/204936/516
recent data from BP: http://www.bp.com/productlanding.do?categoryId=6842&contentId=7021390
Potential Impact of Canadian Tar Sands (high case)

graph by Khebab:  http://www.theoildrum.com/story/2006/11/2/204936/516
recent data from BP:  http://www.bp.com/productlanding.do?categoryId=6842&contentId=7021390
Basic Energy Facts Everybody Should Know

• oil and gasoline are extremely energy-dense & convenient
• a car is a **100,000 watt device** (accelerating a 130 hp car is like turning on 1,000 one hundred watt light bulbs)
• manufacturing a car uses **substantial fraction of the oil** car uses in its entire lifetime (also: 100,000 gallons of water)
• one gallon of gas (2.84 kg) contains **36 kW-hours** of energy (before losses), enough to power a small house for 1 week
• **one barrel** of oil = **one year** hard physical labor by a human (25%-efficiency gas vs. 6 hours 128 watts continuous/day)
• batteries have low energy-density (Prius NiMH battery is 0.07 kW-hours/kg – 1/45 that of 25%-efficiency-gasoline)
• solar radiation is ubiquitous but has **very** low energy density
• a “one kilowatt” photocell covers 100 sq feet and generates **3-4 kW-hours** of usable power per day (=about 1/10 gal. gasoline); must be used as generated or stored with loss
• the deployed military is 70% fossil fuel by weight
• current per capita US energy use: **250 kWh/day**
Possible Replacements – Fossil Fuel Sources

- **oil** *(currently: 40% US energy)*
- **coal** *(currently: 22% US energy)*
  - may peak 2030, then reach EROEI=1.0 before all gone
  - mercury in fish from burning coal; 2x CO₂ of oil/gas
  - coal bed methane production growing but water intensive
- **natural gas** *(currently: 23% US energy)*
  - world peak later than oil, but NorthAmerican peak passed
  - requires energy-intensive cooling/liquification to transport
- **oil/tar sands** *(currently: small portion of oil imports)*
  - two tons best sand make 1 barrel oil (14:1 weight ratio)
  - sands must be dug, heated, washed (EROEI 1.0-3.0)
- **oil shale** *(currently: 0%)*
  - EROEI worse than oil/tar sands, maybe below 1.0
- **methane hydrates** *(currently: 0%)*
  - reserves unknown, extraction methods unknown
  - may outgas on their own with arctic melting
UK Coal Production
(why Newcastle has to have coal carried to it)

From Gregson Vaux

World Coal Production
Hubbert curve using (generous) EIA reserves estimates

Expected Increased Future Demands on Coal Production
1) growth in electrical demand currently satisfied by coal (US: 53%)
2) replacing electrical generation lost to natural gas depletion (US)
3) coal-to-liquids (EROEI<1.0) to offset oil depletion (world)
4) coal gasification (EROEI<1.0) to offset gas depletion (world)

From Gregson Vaux (2005)

World Coal Production
a 2020 peak from the Energy Watch Group (2007)

Coal Mining & Burning *(curr: 22% total US energy)*

- burning coal (without carbon sequestration) generates 2X as much CO$_2$ per unit energy as burning oil or natural gas
- coal-to-liquids and coal gasification generate more CO$_2$ than burning the coal directly (EROEI<1.0 for both)
- carbon and mercury sequestration requires additional energy and will speed approach to EROEI=1.0
- a large number of new coal electric and coal-to-liquids plants are currently being commissioned and planned, most without sequestration
45,000 ton Krupp earth-mover crossing a highway in Germany en route to an open-pit coal mine.
World Gas Production

Total gas peak is later than oil (~2035) but combined gas+oil peak soon (~2010)
Depletion of US Gas Wells in the Lower 48 States (wet gas by year of start)

1) gas wells deplete more rapidly than oil wells
2) the rate of depletion of gas wells is increasing rapidly

from David Maul

http://www.energy.ca.gov/papers/2004-10-27_MAUL_GASOUTLOOK.PDF
Oil and Natural Gas are Critical to Current World Food Production

Fertilizer Production
(mostly from natural gas)
World agriculture productivity & fertilizer production

Jean Laherrere 2004
World grain production & consumption and population

Jean Laherrere 2003

Source: USDA
Grain Consumption is Outstripping Production

Note: Includes Coarse Grains and Wheat

http://www.fas.usda.gov/grain/circular/2006/05-06/graintoc.htm
Hydrogen is Not an Energy Source

- more energy used in making hydrogen than you get out of it
- currently made from natural gas (50% loss chemical energy)
- can be made from oil (>50% loss)
- can be made (along with CO) from coal (65% loss)
- compression to 12,000 psi uses additional energy (15% loss)
- energy density still 1/3 that of gasoline (remember Avogadro)
- tanks leak (H is tiny); unburnt hydrogen is a greenhouse gas
- 4x as much energy needed to pump hydrogen vs. natural gas
- can be stored as metal hydride, but with 70% loss of energy
- fuel cells use expensive metals and have reliability problems

Concl.: hydrogen is a bad choice, even as energy carrier
Possible Replacements – Nuclear Sources

- **nuclear fission** *(currently: 7.5% total US energy)*
  - making fuel is energy-intensive
  - 1960’s EROEI for fissionable uranium < 1.0 (because of diversion to weapons and sale as nuclear reactor fuel to other countries)
  - uranium a non-renewable resource and in scarce supply
  - breeder reactor technology still not practical after 40 yrs.

- **nuclear fusion** *(currently: 0%)*
  - current test beds demonstrating magnetically confined plasma fusion require helium for superconducting coils
  - helium comes from oil and gas wells and cannot be made now (though some could be made in a hypothetical continuously running fusion reactor)
  - a practical continuous-energy-generating fusion demo still several decades away (same prediction in 1980!)
Uranium production in France
(produces majority of its electricity from uranium)

http://www.theoildrum.com/node/2379 from Miquel Torres
World Uranium Production and Requirements
(reasonably assured + inferred reserves < 130 $/kg [4,742 kt Reserves])

http://www.theoildrum.com/node/2379

from Miquel Torres
Possible Replacements – Renewable Sources

• **hydroelectric** *(currently: 2.3% total US energy)*
  – substantially tapped out, few new sites available
• **wind** *(currently: 0.07% total energy, 3% Calif. electrical)*
  – substantial growth possible in windy areas
• **solar photovoltaic** *(currently: 0.006% total, 1% CA electr.)*
  – costly, large: 20 kWh/day syst. is $50,000 and 500 sq ft
• **solar heat-concentrating steam/Stirling systems**
  – possible replacement for centralized power generation
• **local solar passive heating**
  – solar water heating systems common in 1900 before gas
• **tides**
  – small demo systems exist
• **solar from space, wires into space, cold fusion**
  – among other possibilities, none with practical demo
Energy Scavenging/Conversion

- **biogas** (anaerobic digestion of animal manure)
  - in small scale use for decades (esp. the Netherlands)
  - recovers some fossil fuel input to growing food/animals
- **biodiesel** (chemically modify plant vegetable oil w/10% alc.)
  - better EROEI and energy density than ethanol
  - water immiscible (no distilling step)
  - biodiesel for UK would require >100% of UK arable land
  - biodiesel for developed world would require all of Africa
- **thermal depolymerization** (cook tires, animal tissue waste)
  - currently: 0.0002% (500 barrels/d vs. 20 million/d used)
  - EROEI < 1.0 (recovers 85% of energy of inputs)
  - can recover part of fossil fuel inputs to tires, chickens
- **ethanol** (from fermentation of corn, switchgrass, sugar cane)
  - must be distilled from initial raw water-ethanol mixture
  - distillation step alone uses 40% of energy in final product
  - w/farming, almost energy-neutral (EROEI 0.8–1.25)
Real energy sources must have $\text{EROEI} > 5-10$

- Crude oil (e.g., EROEI=10) means 1 unit of energy expended (e.g., from other oil) to produce 9 units of useful energy.

- Ethanol at EROEI=1.2 means 5 units of energy expended (e.g., from other ethanol) to produce 1 unit of useful energy, greatly increasing overall energy usage.

The graph shows the relationship between Net Energy and EROEI. The equation $\text{Net Energy} = \text{EROEI} - 1$ is also indicated.
World primary energy mix

- oil
- coal
- gas
- biomass
- nuclear
- hydropower
- geothermy
- sun, wind & others

1/1400 of oil+gas+coal

Jean Laherrere 2004

sources: IFP&BP
World production of coal, oil, gas with forecasts (no demand constraints) from ultimates & population with UN 2003 forecasts low to medium.
Peak Everything

Fossil fuels production and forecast for an ultimate of 1300 Gtoe
Total Energy per capita peaked in 1980.
Summary of the Main Difficulties

- Total oil used since 1850 – **about 1000 billion barrels (Gb)**
- Total conventional world reserves remaining – **1000 billion barrels**
- Percent oil currently in use discovered before 1973 – **70%**
- Time left, current world usage (29 billion/year) – **33 years**
- Time left, US uses only oil still left in US fields – **3 years**
- Time left, US grabs/uses all of Iraq's oil for itself – **15 years**
- Time left, whole world uses oil at US's current rate – **6 years**
- Percent US oil used in food production (not including packaging, refrigeration, trucking, cooking) – **25%**
- Physical human work equivalent of energy used to generate US diet for 1 person, 1 day – **3 weeks**
- Oil in US strategic reserves (< 1 billion) – **1 month US use**
- Percent world oil used by non-US-ians – **75% and growing**
Suggestions

• *reduce* oil production/use now (so coming fall less steep)
• expand, electrify rail (4-6x as efficient as trucks, cars)
• plan for de-globalization, local food production, economy
• locally co-generate heat and electricity (cf. Sweden)
• utilize fossil fuel to construct renewables while we still can

• “the market” will probably not save us:
  – it won’t trump geology, it can’t change Maxwell’s equations, make hydrogen more compressible, make fusion work next year, or contract gracefully
  – it doesn’t look far enough into the future (it decided to *disinvest* in renewables from late 80's until 2004!)
  – it can fail industrial civilization/population

• there is still time: the technological-literary-demographic collapse of Rome, the Maya, etc. took centuries
Other Relevant Problems

- economic (US)
- social (US)
- climate
Money supply, M3*, & US Deficit Growth
Look Unstable

Total money, M3, doubled after 1995 (new Fed policy?)
Cumulative curr acct debt explodes to 50% of GDP
(striking mirror-image of M3)

2005 comparisons for scale (billions):
GDP US, year: 11,000
GDP Calif., year: 1,500
Total assets US: 38,000
Total debt US: 40,000
Residential debt US: 6,800
Consumer debt US: 1,700
Foreign-own assets: 8,000
daily currency trans: 1,700
GDP World, year: 43,500
opt/fut/bask/hedge: 300,000 (!)

*update, the Fed discontinued reporting M3 on March, 2006

http://www.kitcocasey.com/displayArticle.php?id=133
http://research.stlouisfed.org/fred2/series/WM3NS/

Current Account Deficit
Yearly (billions)
(note smaller vertical scale spacing than cumulative)

Current Account Deficit
Cumulative (billions)

M3 Money Supply (billions)

(same vertical scale spacing as cum.)
Incarceration Rates, Selected Countries

United States
Spain
United Kingdom
Netherlands
Australia
Canada
Austria
Italy
Germany
France
Ireland
Switzerland
Sweden
Denmark
Norway
Japan

Percent US citizens in jail was approx. constant from 1920 to 1980

Prison planet begins 1980 in US

Corporate planet

Corporate dominance, anti-correlation of corporate profits, workers' earnings begins 1980 in US

US: number of persons under correctional supervision

Percent US citizens in jail was approx. constant from 1920 to 1980

US: real corporate profits and real weekly workers' earnings

Profits and wages anti-correlated

Profits and wages move together

Source: Sanders Research Associates & EcoWin
We are Performing a One-Time Experiment on Our Atmosphere

We are experimenting with CO₂ in our atmosphere, equivalent to the difference between the last glacial and interglacial periods. The CO₂ levels have increased dramatically in recent years, particularly in 2004 and 2005, which is almost double the average of the period from 1970 to 2000. This may be due to positive feedback processes, such as:

- Albedo reduction from ice melting
- Warming-induced decomposition

Sources: Jean-Marc Barnola et al., CD Keeling
Temperature has been strongly correlated with CO$_2$ for the last 650,000 years.
Measured warming this millennium (via proxies) matches model predictions

Glaciers across the entire planet have begun a rapid retreat in the second half of the 20th century

http://www.sciencemag.org/cgi/content/full/297/5586/1481
http://www.worldviewofglobalwarming.org/pages/glaciers.html
Global warming – 5 key points

• previous glacial-interglacial climate 'flips' triggered by small variations in 'forcing' (e.g., periodic orbital wobble) that vary seasonal distribution (vs. amount) of radiation

• over the past million years, CO\textsubscript{2} increases follow temperature increases by an average of 700 years during the initial stages of warming observed at glacial-interglacial transitions

• initial CO\textsubscript{2} increases then amplify warming over the full 5000 years of the cold-warm climate flip

• polar ice covers didn't melt in previous warm periods, but they are melting now, esp. northern

• humans are now in control of climate -- warming caused by anthropogenic CO\textsubscript{2} (and CH\textsubscript{4}) is a new regime
Global Temperature – 0.15 million years

(more recent to left in this and next 3 slides)
Global Temperature – 5.5 million years

\[ \delta^{18}O \text{ Benthic Carbonate (per mil)} \]

Equivalent Vostok \( \Delta T \) (°C)

100 kyr cycle

41 kyr cycle

Five Million Years of Climate Change From Sediment Cores

Millions of Years Ago
Global Temperature – 60 million years

65 Million Years of Climate Change

Benthic δ¹⁸O (per mil)

Rapid Glacial Cycles
Antarctic Reglaciation
Antarctic Thawing
Antarctic Glaciation

Eocene Optimum
PETM

Polar Ocean Equivalent ΔT (°C)

 Millions of Years Ago
Global Temperature – 500 million years

δ18O (parts per thousand)

HOT

COLD

Prev. Slide

Glacial Periods

N Pg K J Tr P C D S O Cm

Millions of Years Ago
The North Atlantic 'heat conveyor' appears to have slowed by 30%.

Cold fresh water from melting northern ice reduces northern descending return currents of cooled salty water, which results in more warm northeasterly water taking a subtropical shortcut back to the equator.

This effect will ride on top of overall global warming, probably only serving as a moderating influence on heating at higher latitudes.

Update (Sep’07): more complete data shows that older data is too sparse to make reliable predictions (currently collected data is better).
Speculations (June 2005)

• US continues military actions, base-building near mideast oil
• oil price increases initially lead to stagnation plus inflation
• oil production peaks (2008) as Ghawar, Cantarell decline
• coal use for power/synfuels increases sharply to 2030 peak
• fossil methane use increases (outside US) to 2030 peak
• new US nuclear plants commissioned, begin online by 2015
• local co-generation of heat/electricity prevented by NIMBY
• wind and solar increase 100x (to 7% of 2005 oil+gas+coal)
• large CO₂ increase, warming from extra coal use by 2030
• magnetically-confined fusion fails to ever come online
• slow collapse of global industrial civilization begins 2030
• population/technology/military contraction complete by 2100
Speculations (August 2007)

• same as June '05, except now clear Canterell peaked 2004