The Energy Sustainability Dilemma:
Powering the Future in a Finite World

Cornell University
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Points to be covered:

- The "ENERGY SUSTAINABILITY DILEMMA" defined:

- ***History*** *- where have we been*
- ***Forecasts*** *- where are we going and how likely is it that we'll get there*

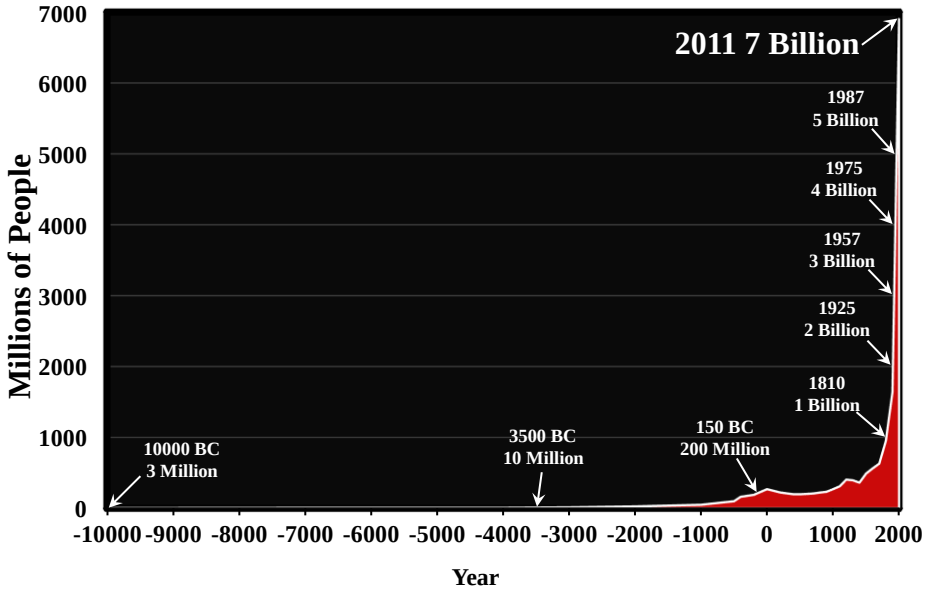
- Availability and deliverability of the nonrenewable fuels (*OIL, GAS, COAL, URANIUM*) that are the energy-dense elixers of our modern society

- *ELECTRICITY* – some issues in keeping the lights on

- Implications of *POPULATION GROWTH* and *ASPIRATIONS* of future energy consumption

- Going forward in an Energy Constrained World

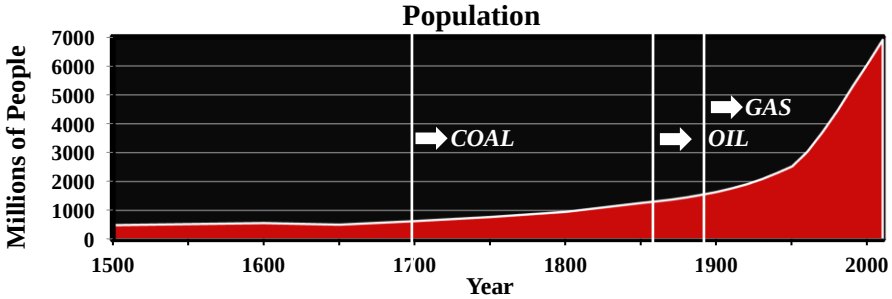
The Phenomenal Reproductive Success of the Human Race
10000 BC – 2011 AD



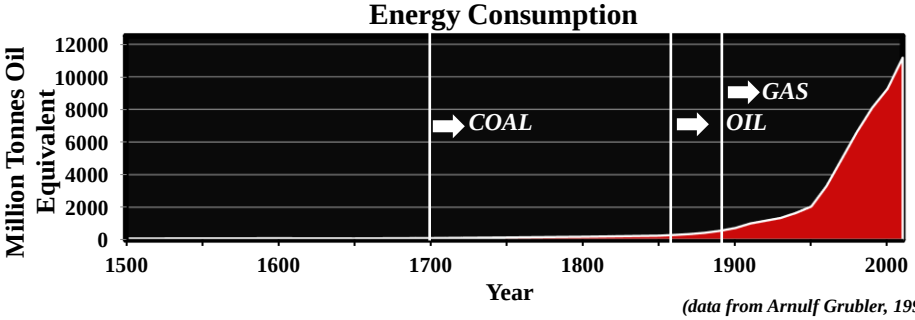
(data as cited from U.S. Bureau of Census from various authors)

Population versus Energy Consumption, 1500-2010

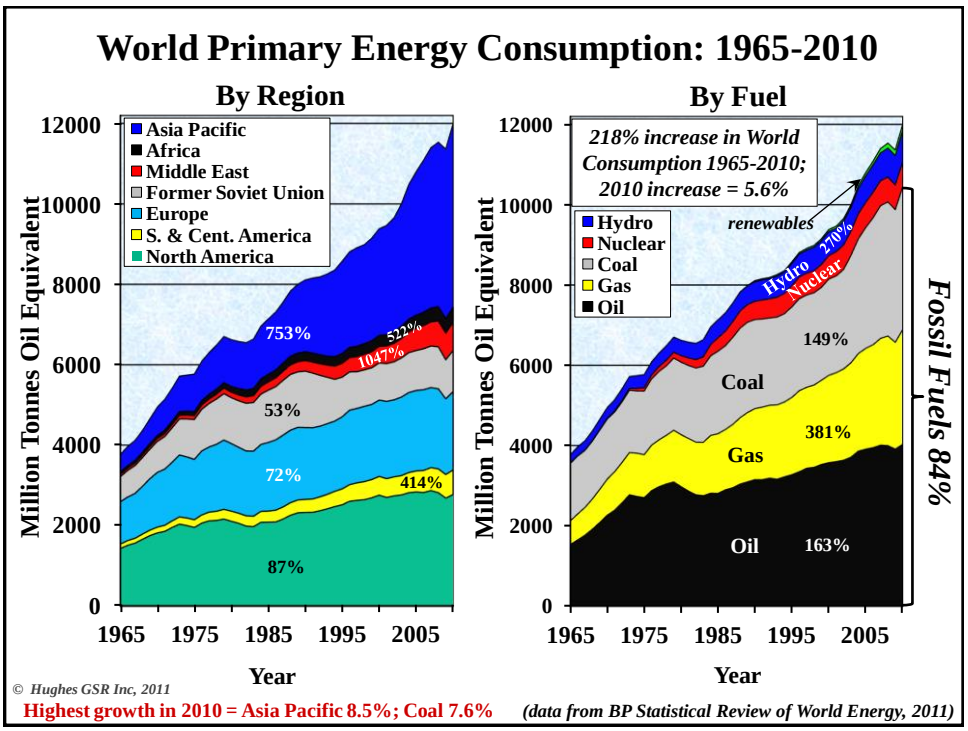
Population

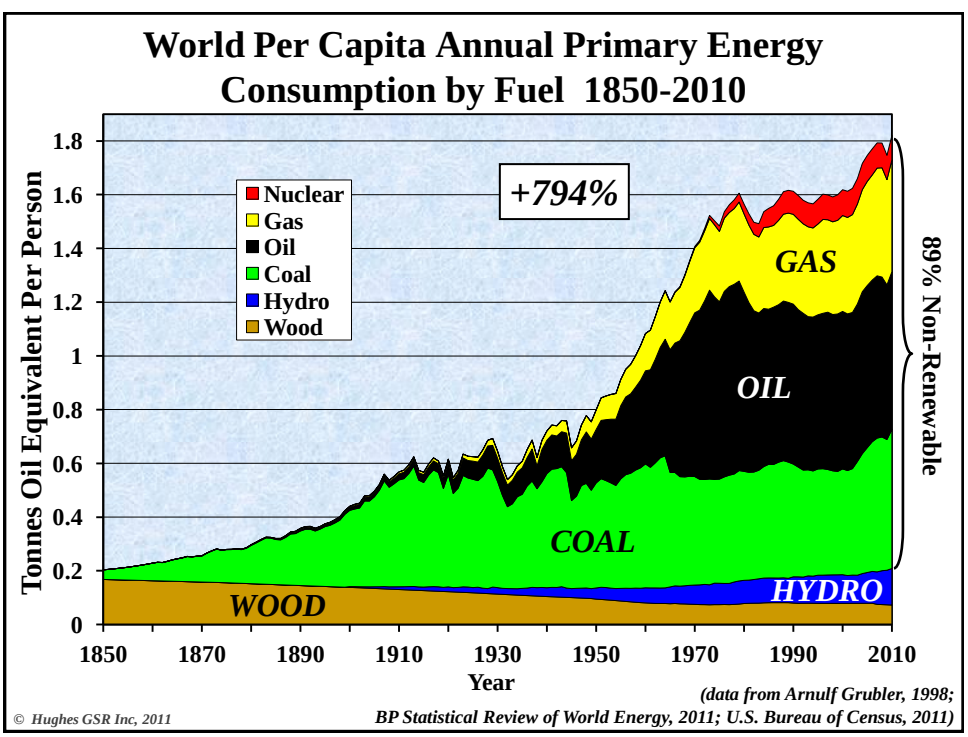


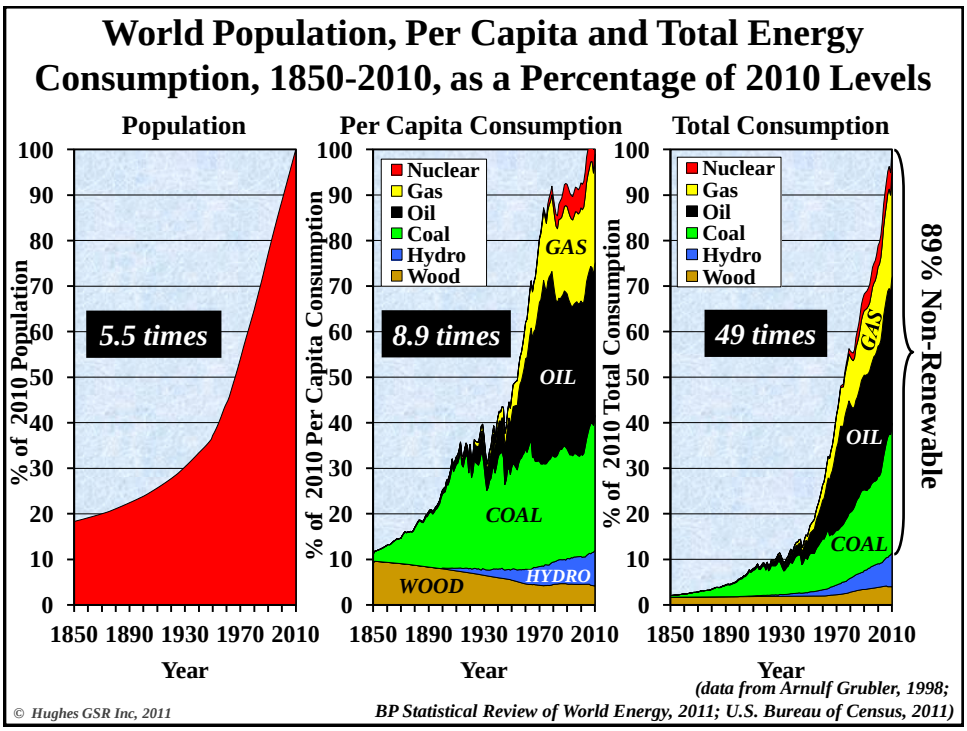
Energy Consumption

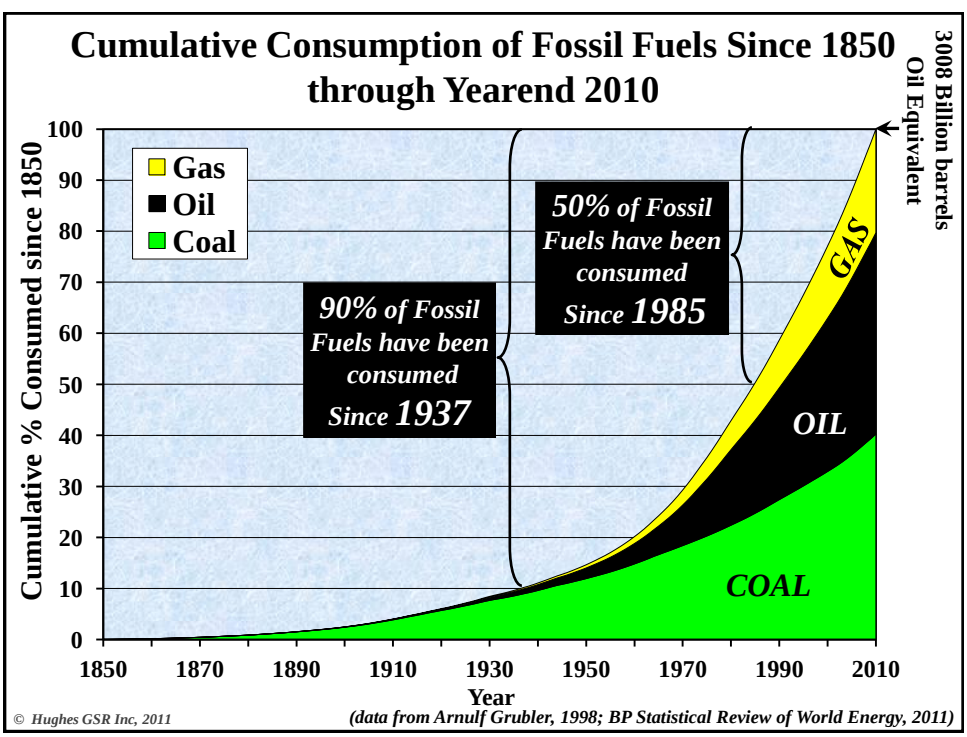


(data from Arnulf Grubler, 1998;
BP Statistical Review of World Energy, 2010; U.S. Bureau of Census, 2010)

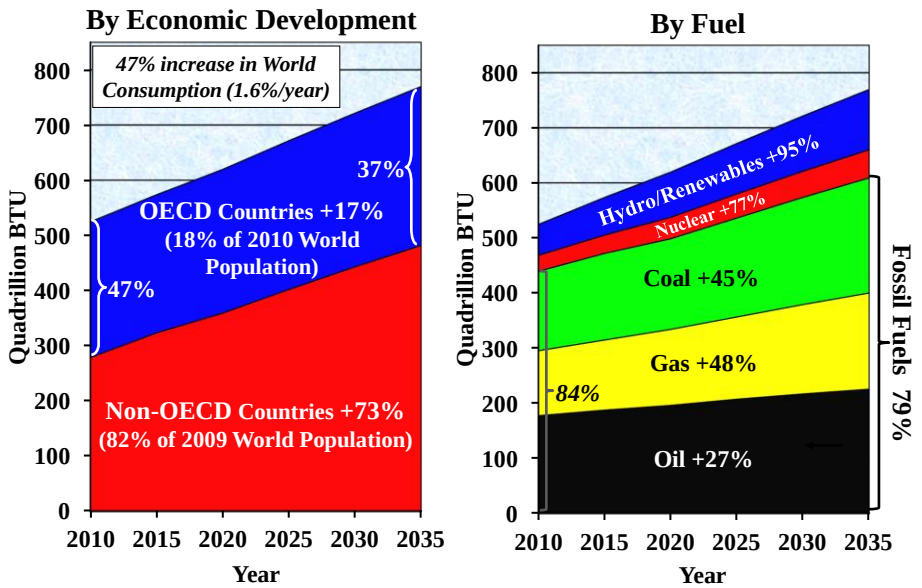

World Primary Energy Consumption: 1965-2010
By Region
By Fuel
Million Tonnes Oil Equivalent
Year
Asia Pacific
Africa
Middle East
Former Soviet Union
Europe
S. & Cent. America
North America
753%
522%
1047%
53%
72%
414%
87%
218% increase in World Consumption 1965-2010; 2010 increase = 5.6%
Hydro
Nuclear
Coal
Gas
Oil
renewables
270%
149%
381%
163%
Fossil Fuels 84%
© Hughes GSR Inc, 2011
Highest growth in 2010 = Asia Pacific 8.5%; Coal 7.6%
(data from BP Statistical Review of World Energy, 2011)


World Per Capita Annual Primary Energy Consumption by Fuel 1850-2010
Tonnes Oil Equivalent Per Person
Year
Nuclear
Gas
Oil
Coal
Hydro
Wood
+794%
GAS
OIL
COAL
HYDRO
WOOD
89% Non-Renewable
© Hughes GSR Inc, 2011
(data from Arnulf Grubler, 1998;
BP Statistical Review of World Energy, 2011; U.S. Bureau of Census, 2011)


World Population, Per Capita and Total Energy Consumption, 1850-2010, as a Percentage of 2010 Levels
Population
Per Capita Consumption
Total Consumption
% of 2010 Population
% of 2010 Per Capita Consumption
% of 2010 Total Consumption
Nuclear
Gas
Oil
Coal
Hydro
Wood
5.5 times
8.9 times
49 times
GAS
OIL
COAL
HYDRO
WOOD
89% Non-Renewable
1850 1890 1930 1970 2010
Year
(data from Arnulf Grubler, 1998;
BP Statistical Review of World Energy, 2011; U.S. Bureau of Census, 2011)
© Hughes GSR Inc, 2011

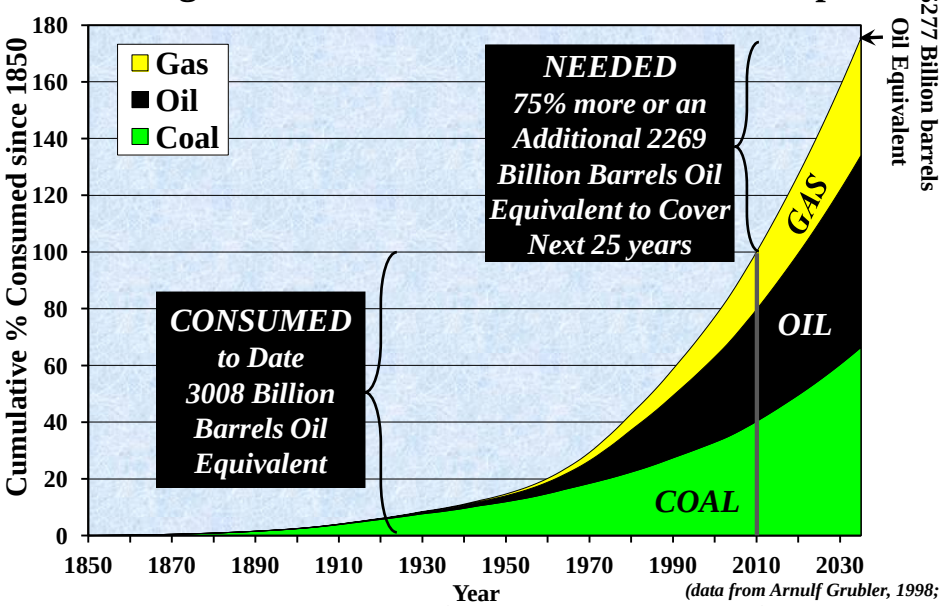

Cumulative Consumption of Fossil Fuels Since 1850 through Yearend 2010
Cumulative % Consumed since 1850
Gas
Oil
Coal
90% of Fossil Fuels have been consumed Since 1937
50% of Fossil Fuels have been consumed Since 1985
GAS
OIL
COAL
3008 Billion barrels Oil Equivalent
1850 1870 1890 1910 1930 1950 1970 1990 2010
Year
(data from Arnulf Grubler, 1998; BP Statistical Review of World Energy, 2011)
© Hughes GSR Inc, 2011

Forecast Growth In World Energy Consumption, 2010-2035 (EIA, 2011, Reference Economic Case)

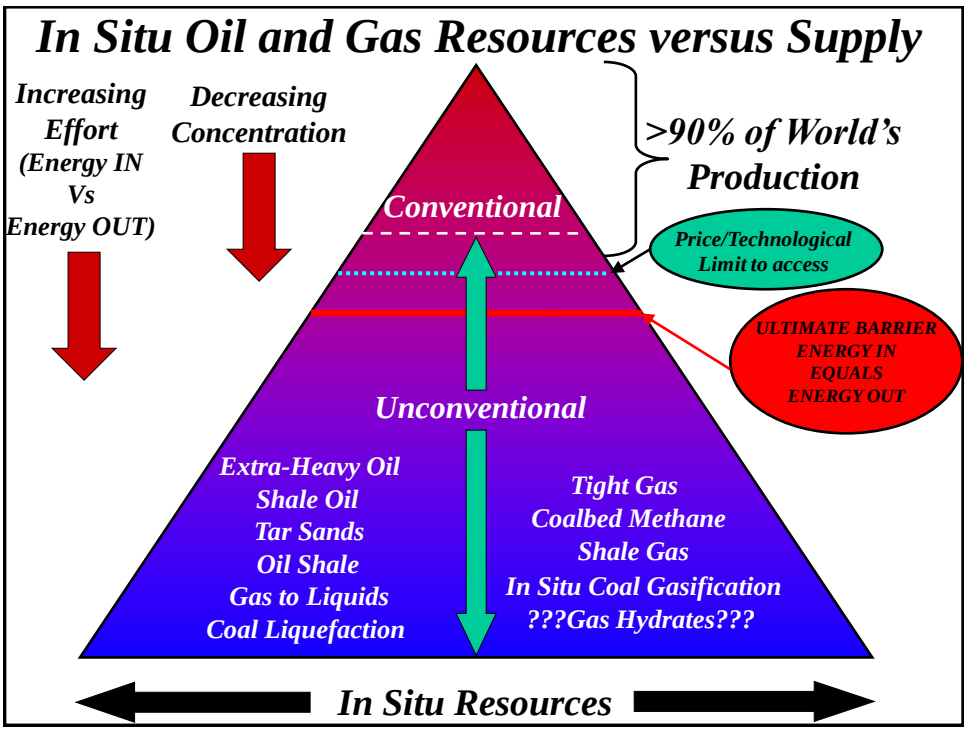


(data from Energy Information Administration International Energy Outlook, 2011)

Projected Consumption of Fossil Fuels Through 2035 as a Percentage of Yearend 2010 Cumulative Consumption



(data from Arnulf Grubler, 1998; BP Statistical Review of World Energy, 2011; EIA IEO 2011 Reference case projection)



Beware of Scale:

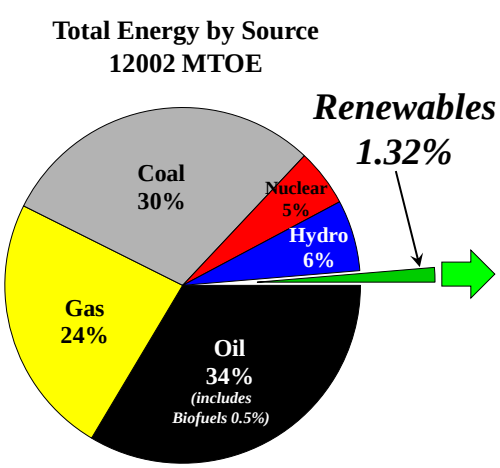
- The 84% of Primary Energy provided by Hydrocarbons is *A LOT*

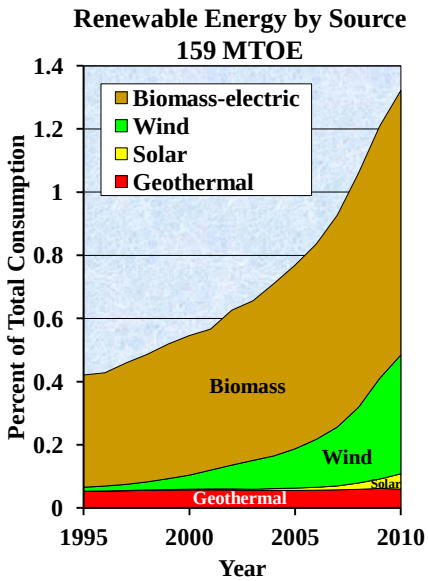
-Less than 2% of Primary Energy Consumption is now provided by non-hydropower renewables

-There are no scalable alternatives to hydrocarbons at the *RATES OF ENERGY THROUGHPUT* we enjoy at this point in time

-Unconventional hydrocarbon production is *DIFFICULT TO SCALE* compared to the cheap hydrocarbons of yesteryear

Global Primary Energy Consumption by Source in 2010
A Comparison to Total Non-Hydro Renewable* Energy





**excluding biomass burned for non-electric uses*

(data from BP Statistical Review of World Energy, 2011)

Summary

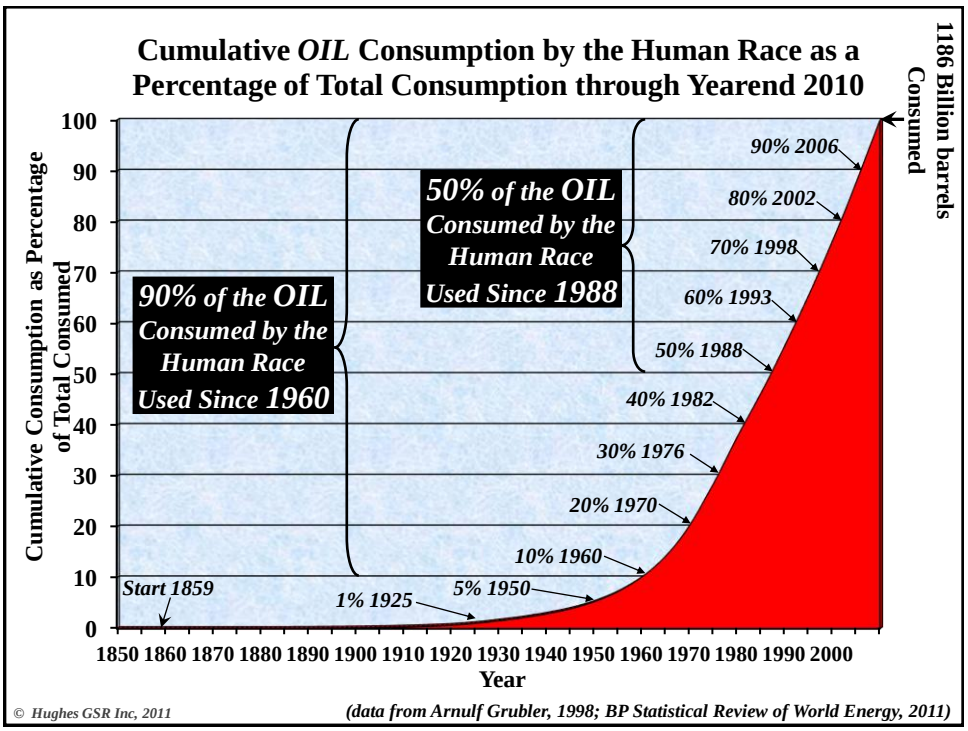
- Hydrocarbons provided 84% of the world's primary energy in 2010

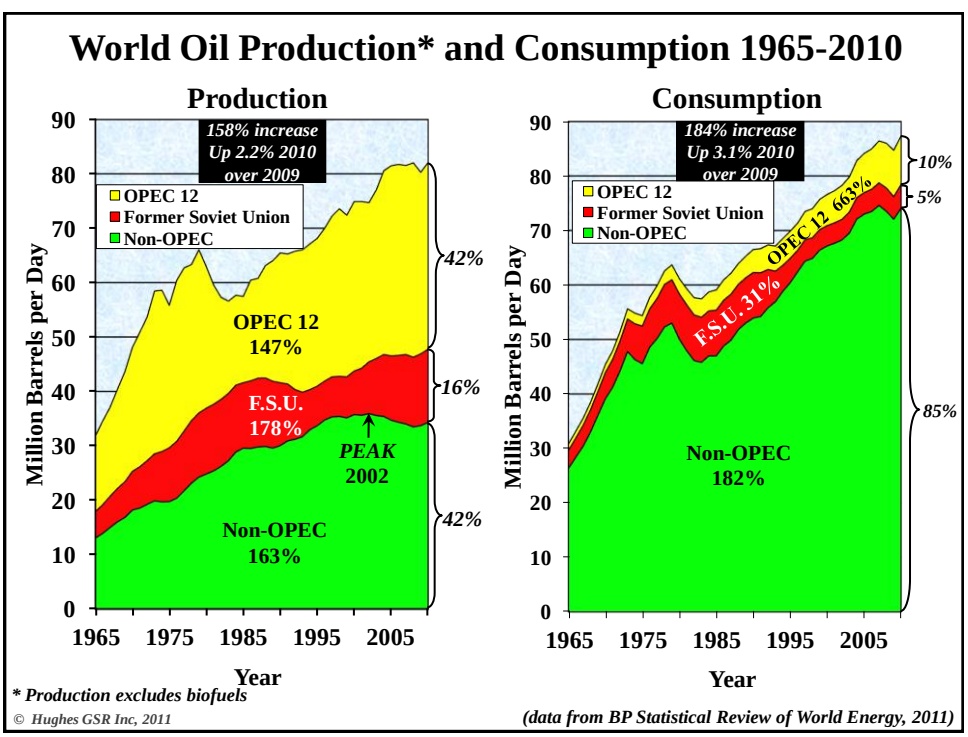
- Forecasts suggest that 79% of a greatly expanded energy demand will continue to be provided by hydrocarbons in 2035

- Most of the balance of energy supply will be provided by large hydro and nuclear – sources with their own environmental problems

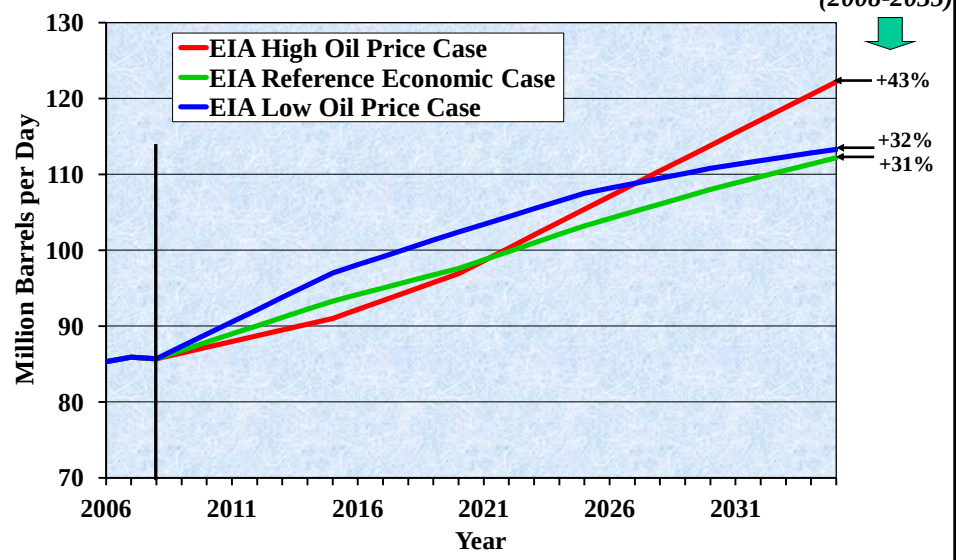
- The Question is: *IS THIS SUSTAINABLE?*

…… Lets look in more detail at oil, gas and coal


Cumulative *OIL* Consumption by the Human Race as a Percentage of Total Consumption through Yearend 2010
1186 Billion barrels Consumed
Cumulative Consumption as Percentage of Total Consumed
90% of the OIL Consumed by the Human Race Used Since 1960
50% of the OIL Consumed by the Human Race Used Since 1988
90% 2006
80% 2002
70% 1998
60% 1993
50% 1988
40% 1982
30% 1976
20% 1970
10% 1960
5% 1950
1% 1925
Start 1859
100 90 80 70 60 50 40 30 20 10 0
1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
Year
© Hughes GSR Inc, 2011
(data from Arnulf Grubler, 1998; BP Statistical Review of World Energy, 2011)

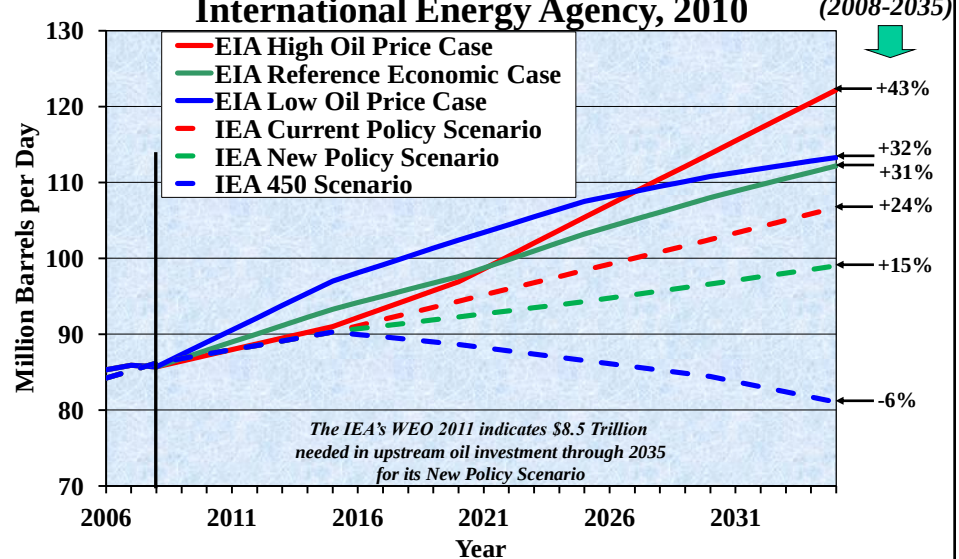

World Oil Production* and Consumption 1965-2010
Production
158% increase Up 2.2% 2010 over 2009
OPEC 12
Former Soviet Union
Non-OPEC
OPEC 12 147%
F.S.U. 178%
PEAK 2002
Non-OPEC 163%
42%
16%
42%
Million Barrels per Day
90 80 70 60 50 40 30 20 10 0
1965 1975 1985 1995 2005
Year
Consumption
184% increase Up 3.1% 2010 over 2009
OPEC 12
Former Soviet Union
Non-OPEC
OPEC 12 663%
F.S.U. 31%
Non-OPEC 182%
10%
5%
85%
Million Barrels per Day
90 80 70 60 50 40 30 20 10 0
1965 1975 1985 1995 2005
Year
* Production excludes biofuels
© Hughes GSR Inc, 2011
(data from BP Statistical Review of World Energy, 2011)

World Oil Consumption Forecasts, 2006-2035, Energy Information Administration, 2011



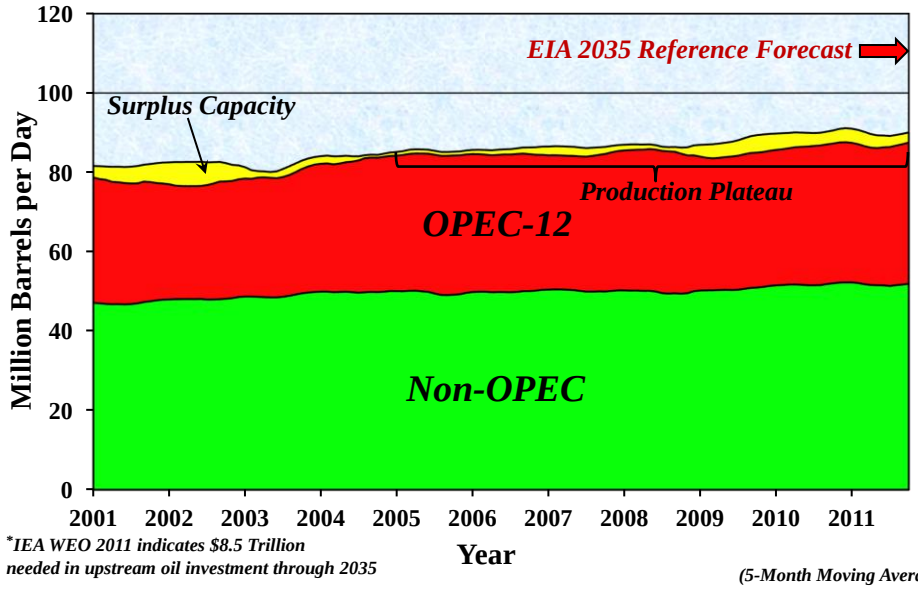
(Projections from Energy Information Administration International Energy Outlook, 2011)

World Oil Consumption Forecasts, 2006-2035, Energy Information Administration, 2011, International Energy Agency, 2010



(Projections from Energy Information Administration International Energy Outlook, 2011; and International Energy Agency World Energy Outlook, 2010)

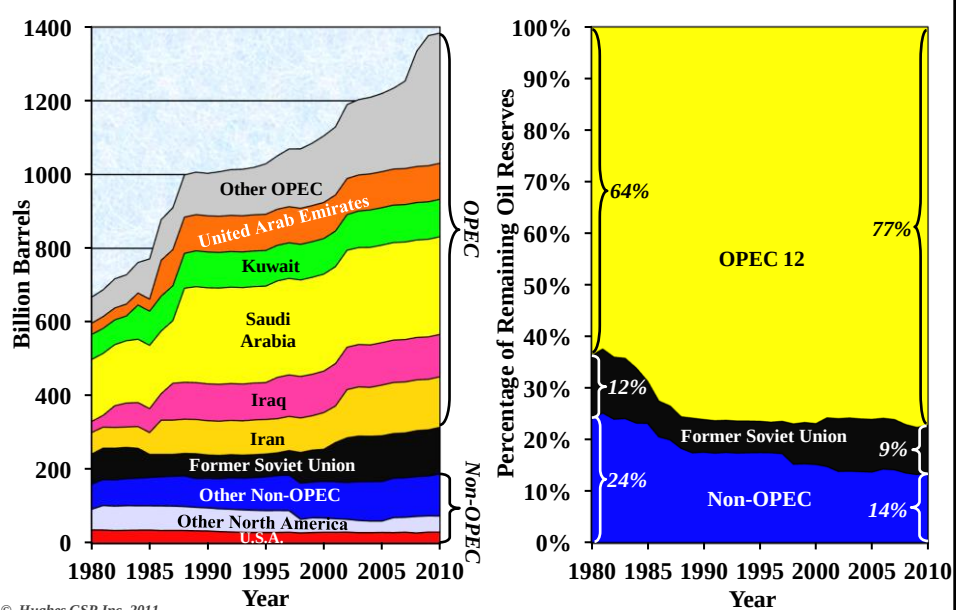
World Oil Supply – January 2001 to October 2011
Can Investment* Get Us to 112 Million barrels per Day?



*IEA WEO 2011 indicates $8.5 Trillion needed in upstream oil investment through 2035

(5-Month Moving Average including data to December 2011, from Energy Information Administration, April, 2012)

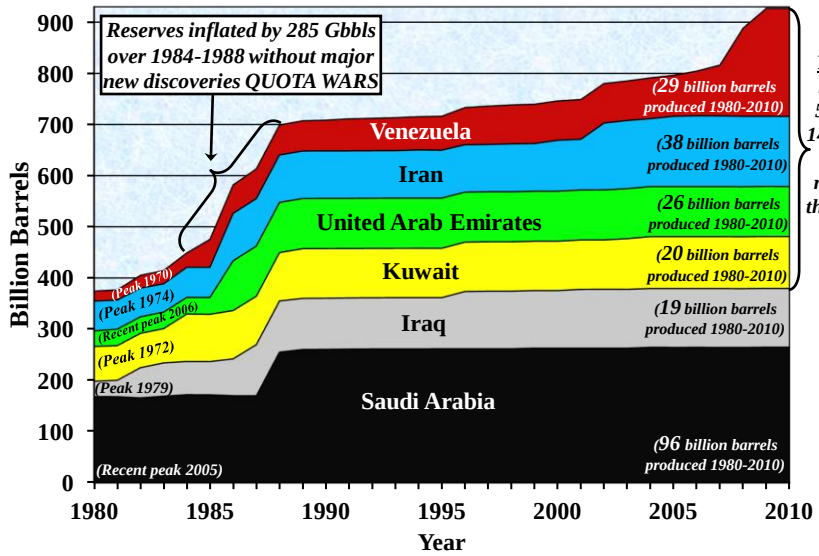
World Conventional Oil and Oil Sands* Reserves 1980-2010



* Includes Oil Sands Reserves "Under Development"

(data from BP Statistical Review of World Energy, 2011)

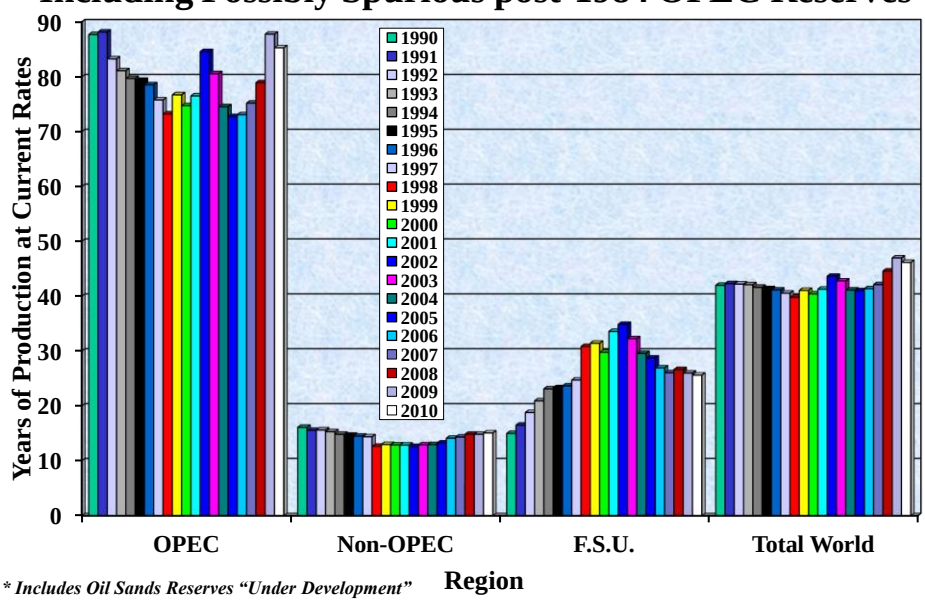
Oil Reserve Reporting in Selected OPEC Countries, 1980-2010, (87% of 2010 OPEC Reserves and 67% of World Reserves)



These Countries also Produced 228 Billion Barrels over the Period

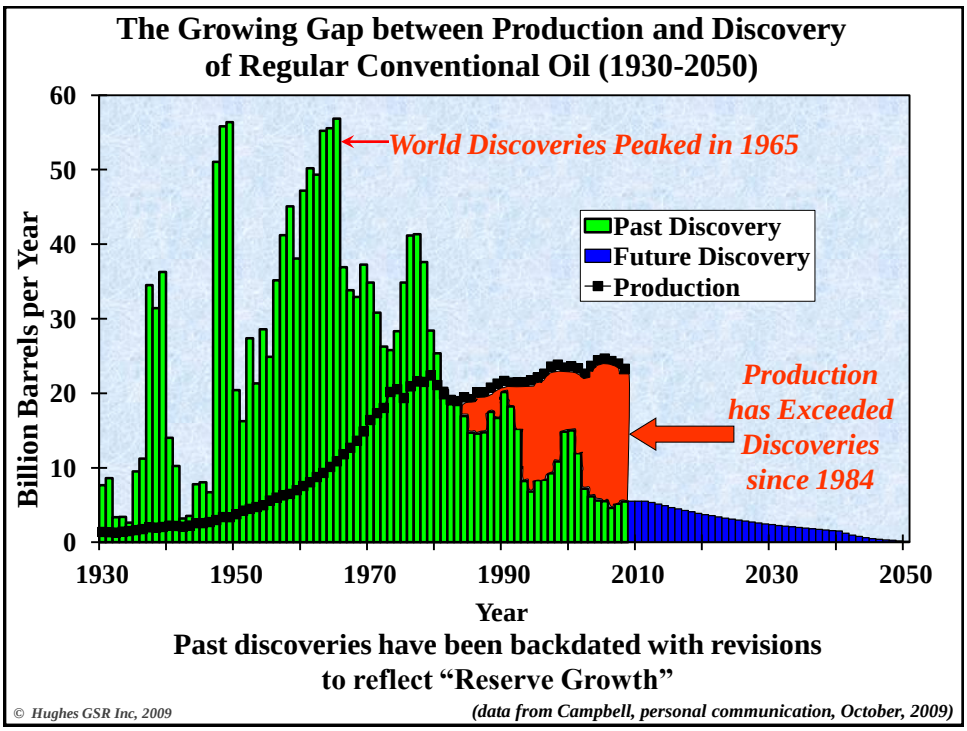
(data from BP Statistical Review of World Energy, 2011)

World Oil Reserve Lifespan in Years Including Possibly Spurious post-1984 OPEC Reserves



** Includes Oil Sands Reserves "Under Development"*

(data from BP Statistical Review of World Energy, 2011)



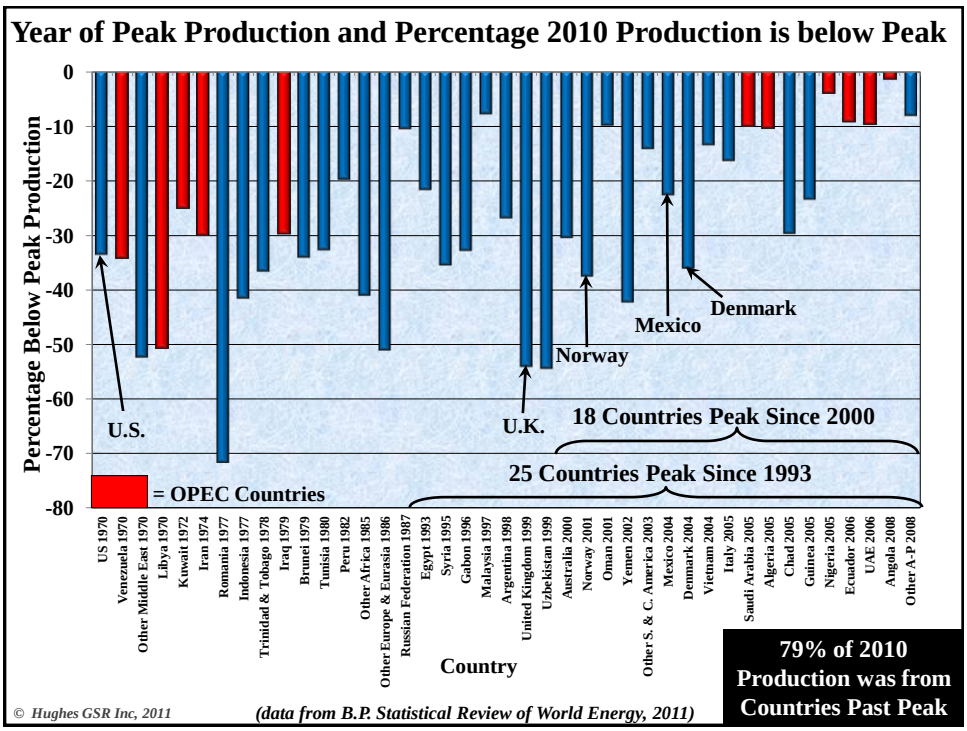
World Oil Production Peak

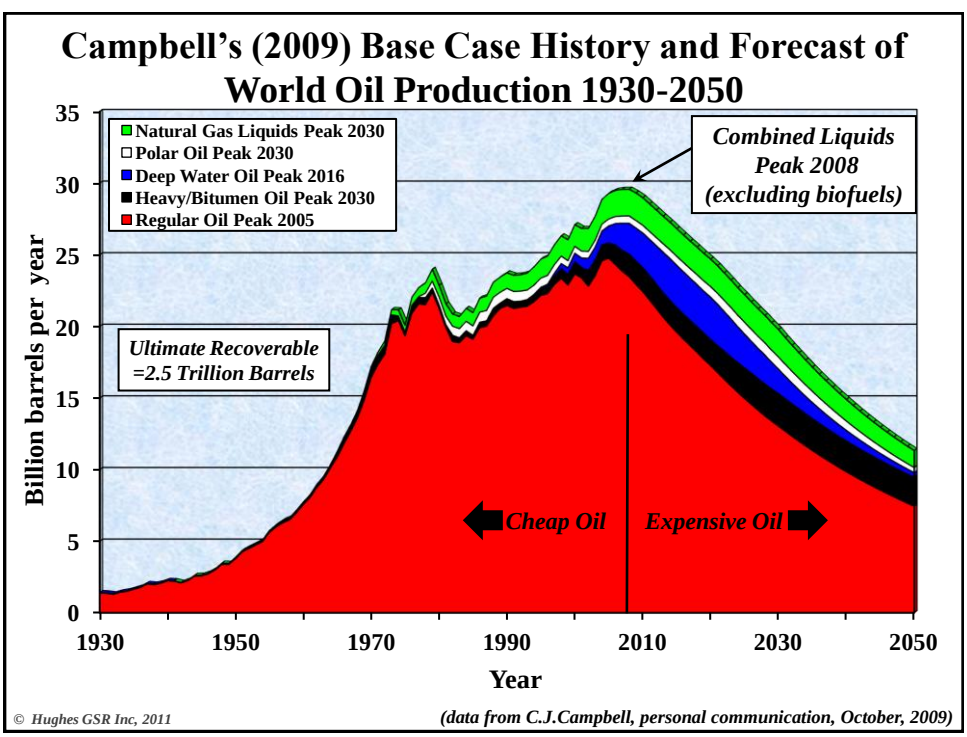
WHEN?

- Debatable, because of the variables, ***BUT IT IS HIGHLY LIKELY TO HAPPEN***

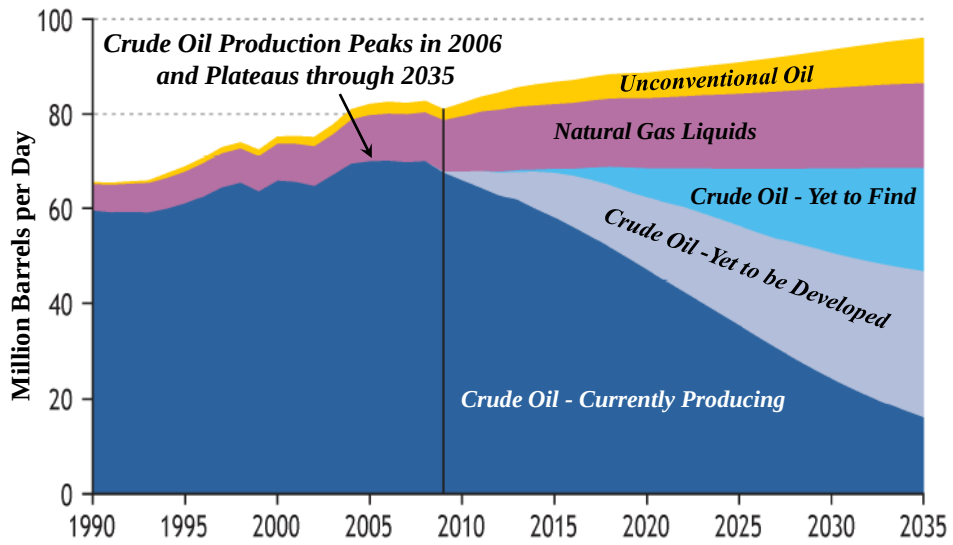
DEPENDS ON:

- **ULTIMATE RECOVERABLE RESERVES** - *a function of:*
  - **Mother Nature's Endowment** *(total discovered and undiscovered resources)*
  - **Technology and Price** *(determines economics)*
  - **Reserve Appreciation (Growth) in known pools** *(through more drilling, better technology and higher prices)*
- **RATE OF CONSUMPTION** - *a function of:*
  - **Price** *(controls economic growth and encourages/discourages conservation)*
  - **Infrastructure** *for production*
  - **Depletion rates** *of producing pools*


Year of Peak Production and Percentage 2010 Production is below Peak
Percentage Below Peak Production
0
-10
-20
-30
-40
-50
-60
-70
-80
U.S.
U.K.
Norway
Mexico
Denmark
18 Countries Peak Since 2000
25 Countries Peak Since 1993
= OPEC Countries
US 1970
Venezuela 1970
Other Middle East 1970
Libya 1970
Kuwait 1972
Iran 1974
Romania 1977
Indonesia 1977
Trinidad & Tobago 1978
Iraq 1979
Brunei 1979
Tunisia 1980
Peru 1982
Other Africa 1985
Other Europe & Eurasia 1986
Russian Federation 1987
Egypt 1993
Syria 1995
Gabon 1996
Malaysia 1997
Argentina 1998
United Kingdom 1999
Uzbekistan 1999
Australia 2000
Norway 2001
Oman 2001
Yemen 2002
Other S. & C. America 2003
Mexico 2004
Denmark 2004
Vietnam 2004
Italy 2005
Saudi Arabia 2005
Algeria 2005
Chad 2005
Guinea 2005
Nigeria 2005
Ecuador 2006
UAE 2006
Angola 2008
Other A-P 2008
Country
79% of 2010 Production was from Countries Past Peak
© Hughes GSR Inc, 2011
(data from B.P. Statistical Review of World Energy, 2011)

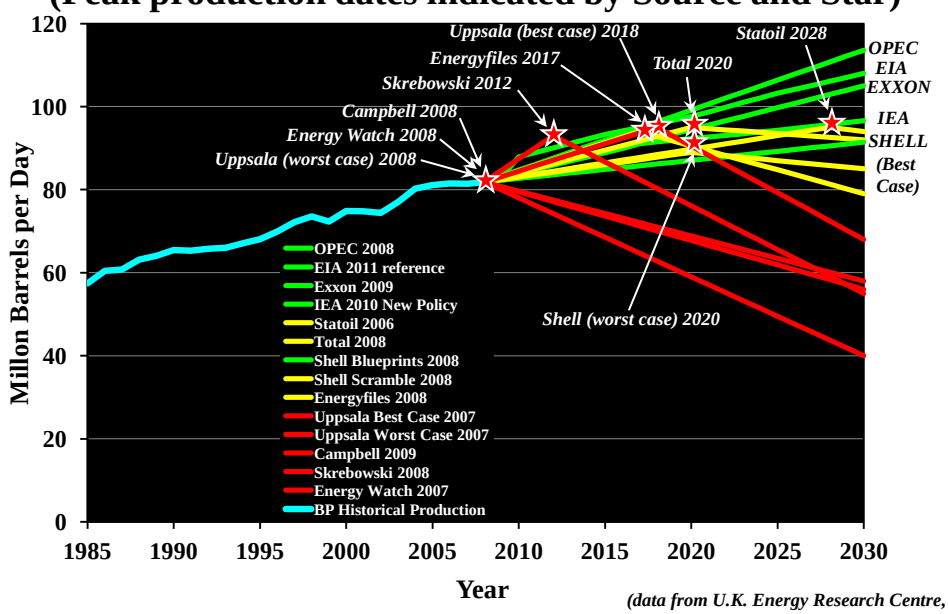

Campbell's (2009) Base Case History and Forecast of World Oil Production 1930-2050
Billion barrels per year
35
30
25
20
15
10
5
0
Natural Gas Liquids Peak 2030
Polar Oil Peak 2030
Deep Water Oil Peak 2016
Heavy/Bitumen Oil Peak 2030
Regular Oil Peak 2005
Combined Liquids Peak 2008 (excluding biofuels)
Ultimate Recoverable =2.5 Trillion Barrels
Cheap Oil
Expensive Oil
1930
1950
1970
1990
2010
2030
2050
Year
© Hughes GSR Inc, 2011
(data from C.J.Campbell, personal communication, October, 2009)

Global Liquids Production 1990-2035, IEA 2010 World Energy Outlook – New Policies Scenario



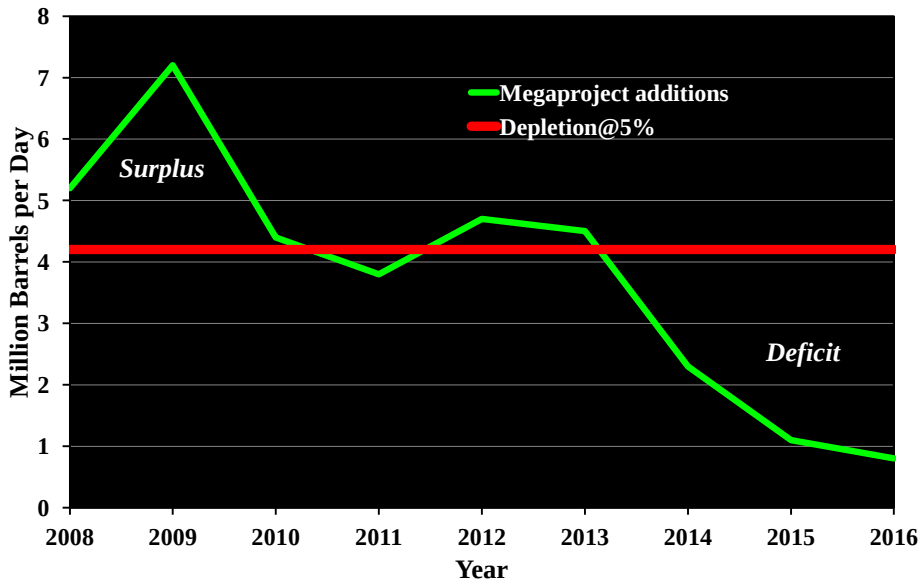
(source: International Energy Agency World Energy Outlook, 2010)

Modeled Forecasts of Liquids Production through 2030 (Peak production dates indicated by Source and Star)



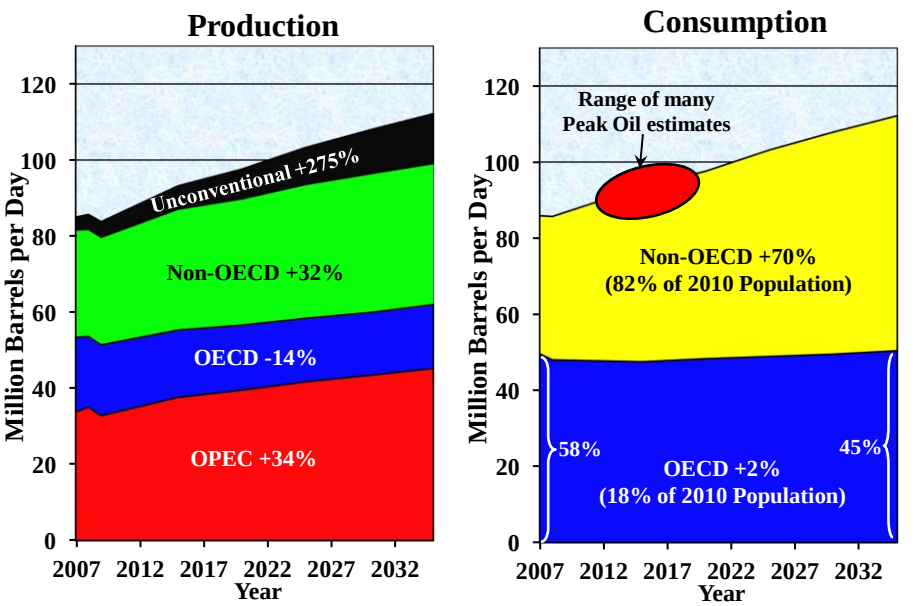
(data from U.K. Energy Research Centre, Annex 1 to Technical Report 7, October, 2009; EIA, 2010; IEA, 2010)

Global Additional Production from New Megaprojects through 2016 versus Global Oil Depletion Rate



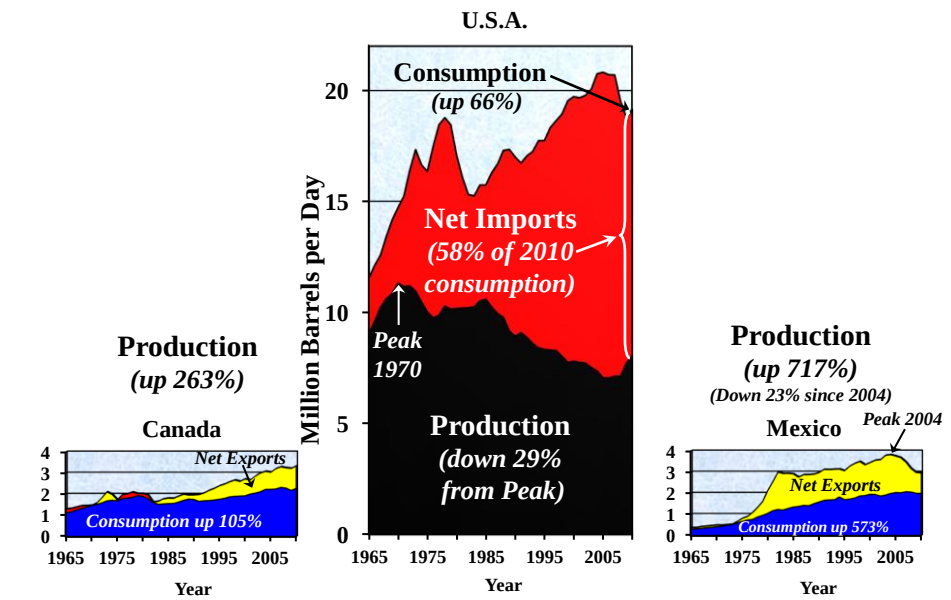
(data from U.K. Energy Research Centre, Annex 1 to Technical Report 7, October, 2009)

EIA World Oil Production and Consumption Forecast 2007-2035 (Reference Economic Case, EIA, 2011)



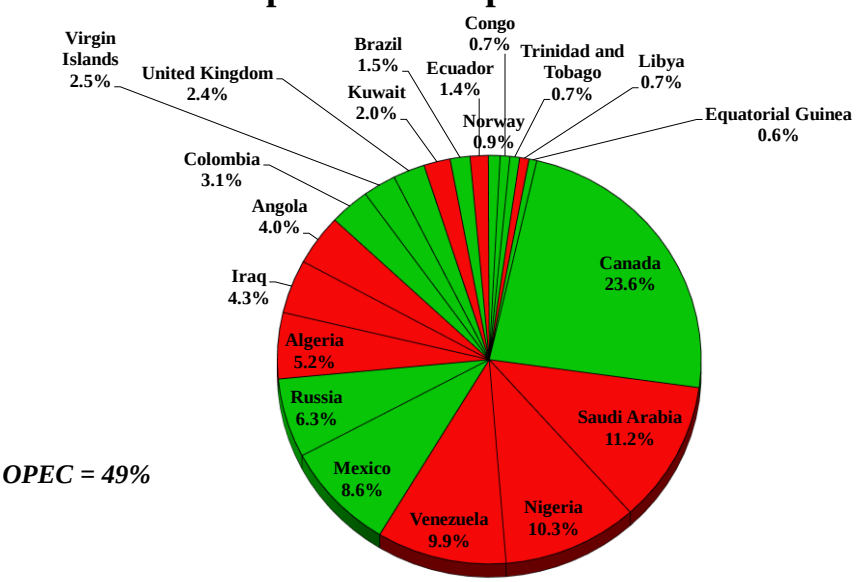
(data from Energy Information Administration International Energy Outlook, 2011)

North American Oil Consumption and Movements: 1965-2010



(data from BP Statistical Review of World Energy, 2011)

US Oil Imports from Top 20 Countries in 2010



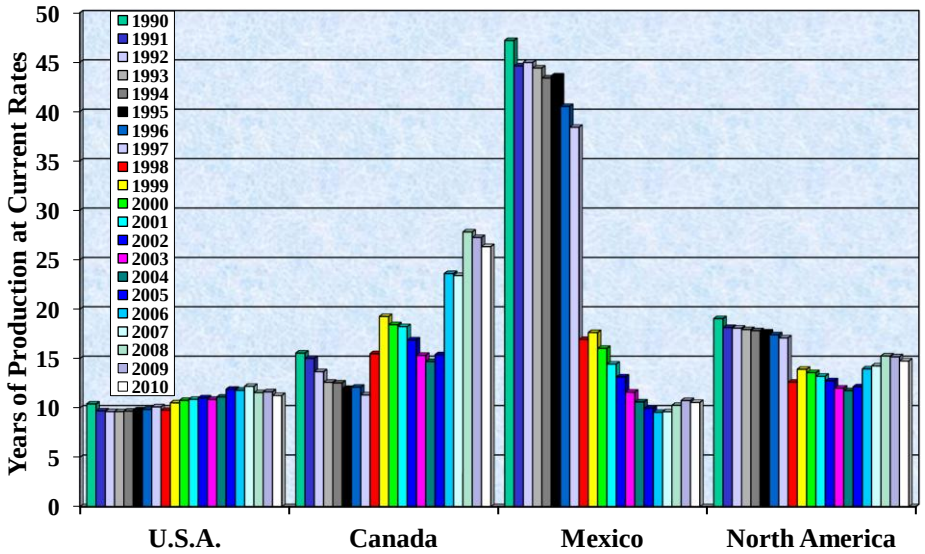
OPEC = 49%

Top 20 provided 9.8 MMbbls/day in 2010

Red = OPEC; Green = Non-OPEC

(data from EIA, 2011)

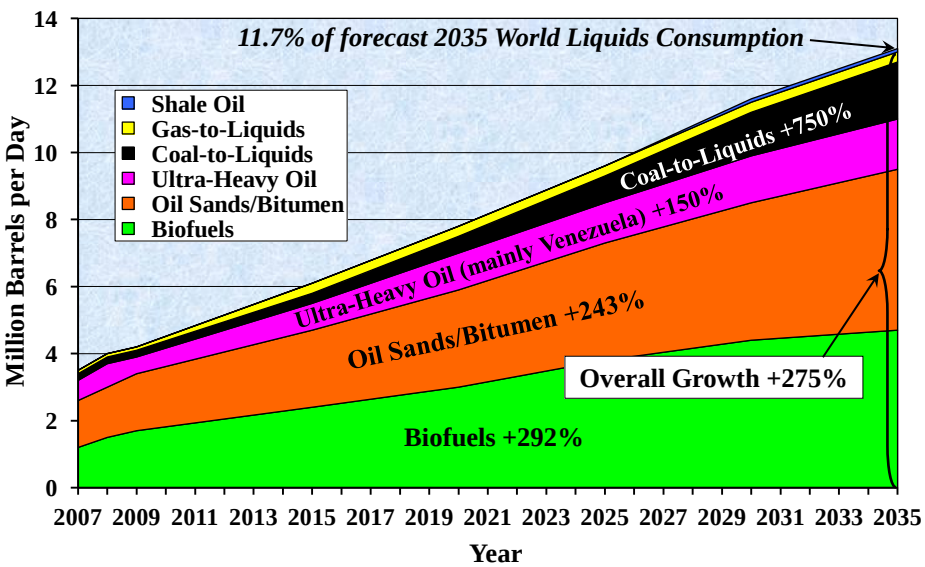
North America Oil Reserve Lifetime in Years Including Oil Sands* 1990-2010



** Includes Oil Sands Reserves "Under Development"*

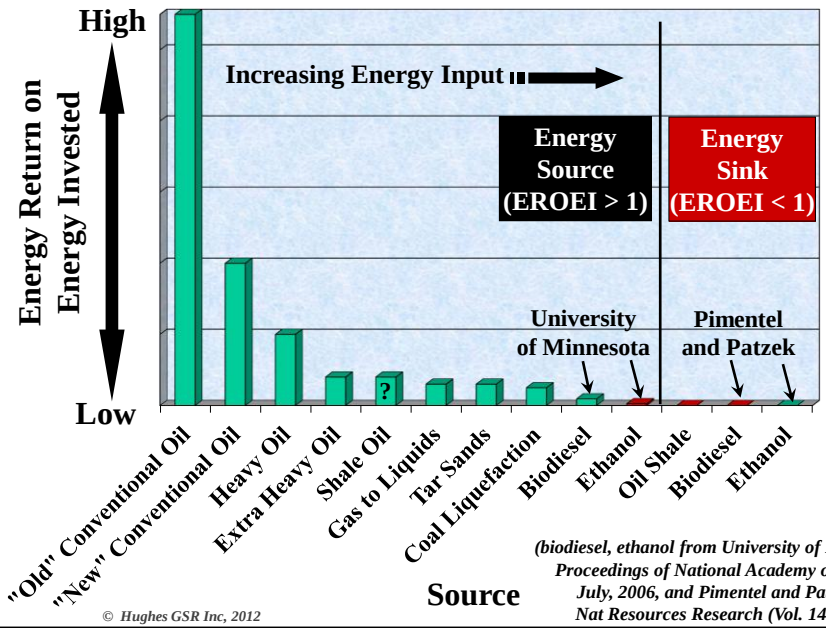
(data from BP Statistical Review of World Energy, 2011)

World Unconventional Liquids Production Forecast 2007-2035 (EIA Reference Economic Case, 2011)



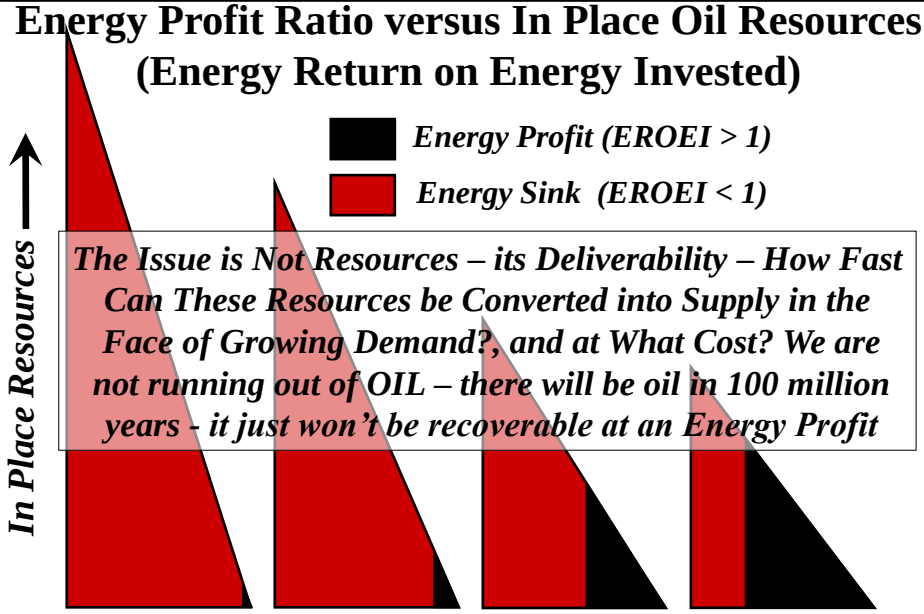
(data from Energy Information Administration, International Energy Outlook 2011)

Energy Profit Ratio for Liquid Hydrocarbons



(biodiesel, ethanol from University of Minnesota Proceedings of National Academy of Sciences July, 2006, and Pimentel and Patzek, 2005, Nat Resources Research (Vol. 14:1, 65-76))

Energy Profit Ratio versus In Place Oil Resources (Energy Return on Energy Invested)

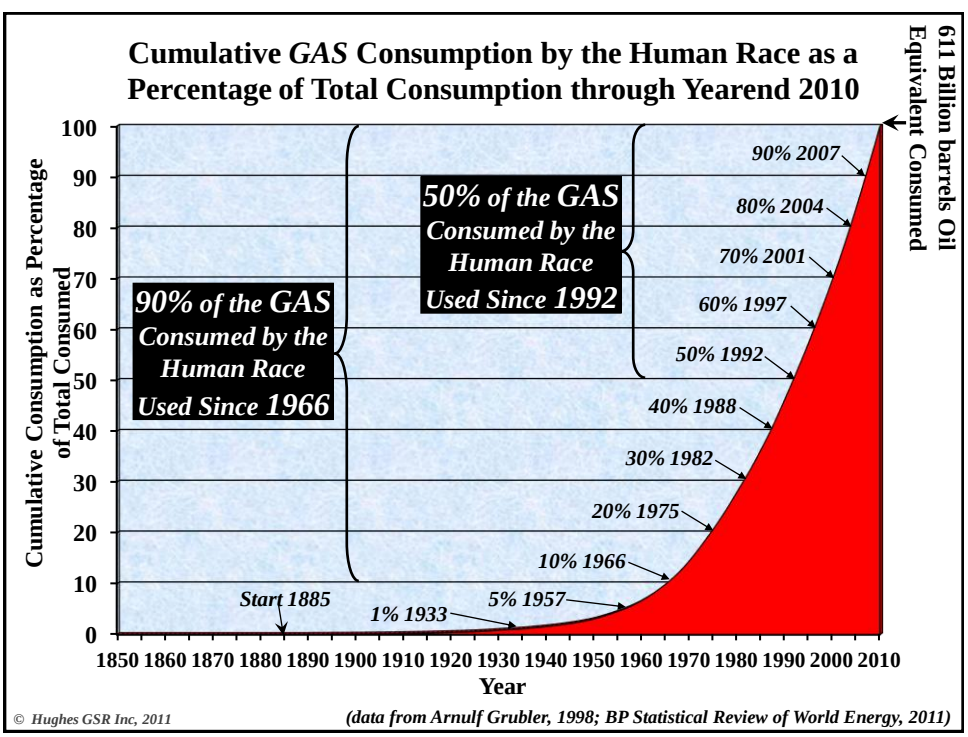


The Issue is Not Resources – its Deliverability – How Fast Can These Resources be Converted into Supply in the Face of Growing Demand?, and at What Cost? We are not running out of OIL – there will be oil in 100 million years - it just won't be recoverable at an Energy Profit

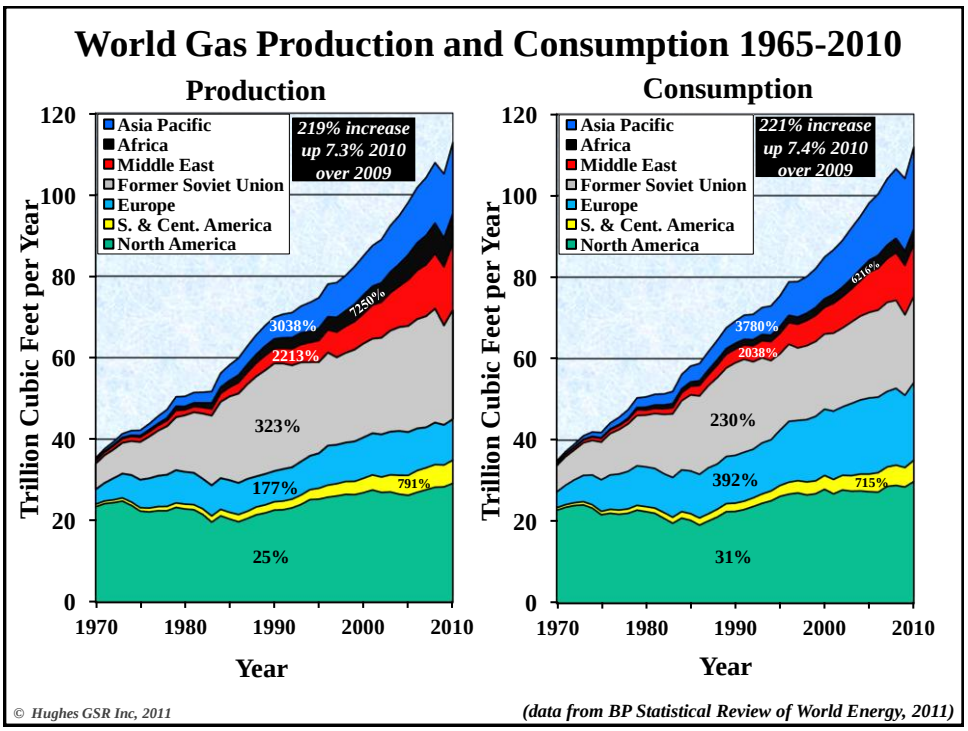
Dr. Fatih Birol, Chief Economist of the IEA, the OECD's Energy Watchdog as quoted in the Independent August 3, 2009

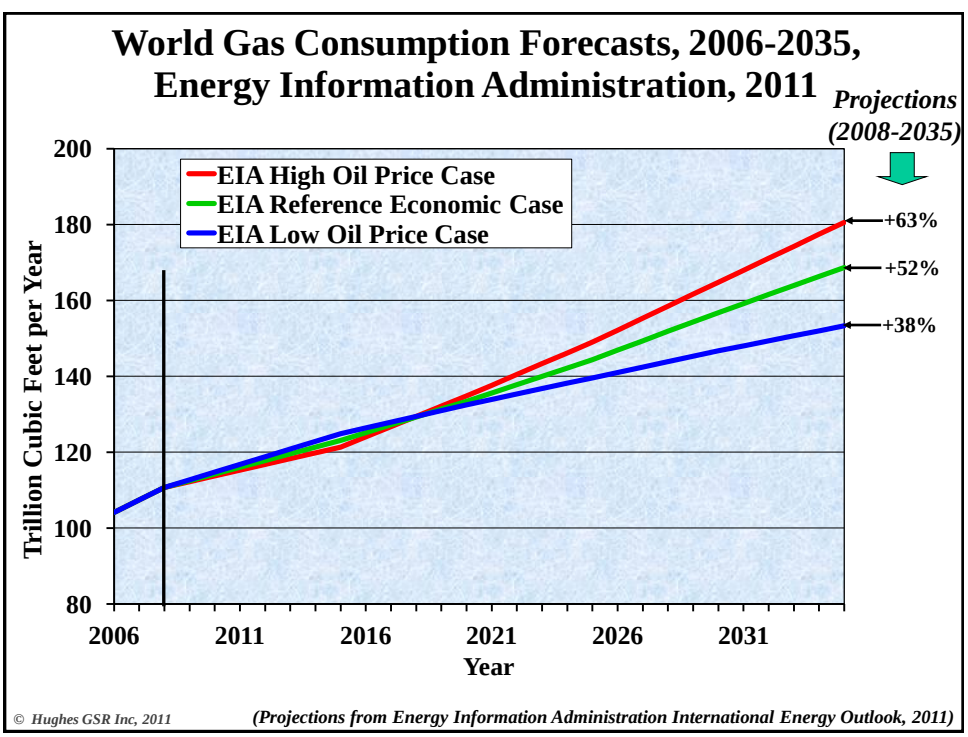
"Even if demand remained steady, the world would have to find the equivalent of four Saudi Arabias to maintain production, and six Saudi Arabias if it is to keep up with the expected increase in demand between now and 2030. It's a big challenge in terms of the geology, in terms of the investment and in terms of the geopolitics "

(from http://www.independent.co.uk/news/science/warning-oil-supplies-are-running-out-fast-766585.html

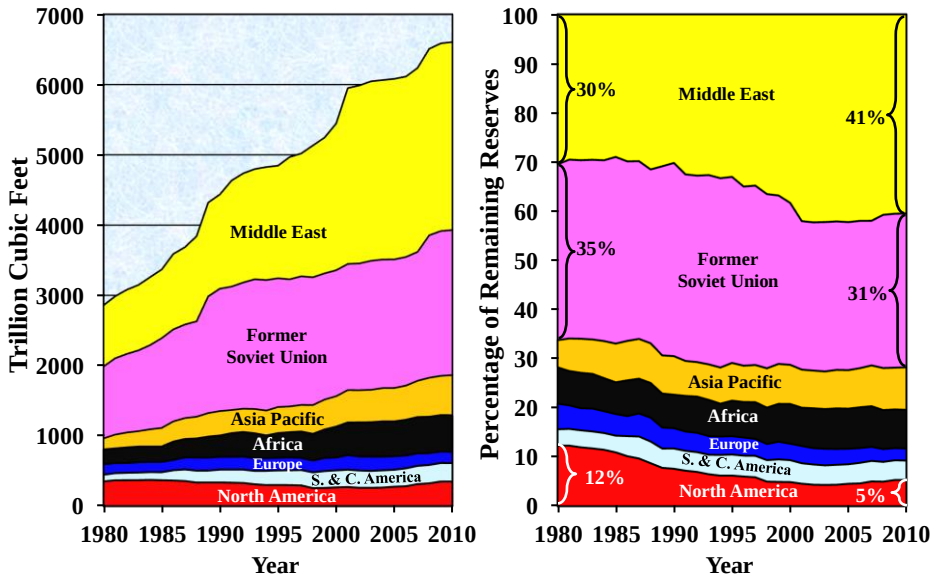


(data from Arnulf Grubler, 1998; BP Statistical Review of World Energy, 2011)


World Gas Production and Consumption 1965-2010
Production
Consumption
Asia Pacific
Africa
Middle East
Former Soviet Union
Europe
S. & Cent. America
North America
219% increase up 7.3% 2010 over 2009
221% increase up 7.4% 2010 over 2009
Trillion Cubic Feet per Year
Year
3038%
2213%
323%
177%
791%
25%
3780%
2038%
230%
392%
715%
31%
0
20
40
60
80
100
120
1970
1980
1990
2000
2010
© Hughes GSR Inc, 2011
(data from BP Statistical Review of World Energy, 2011)

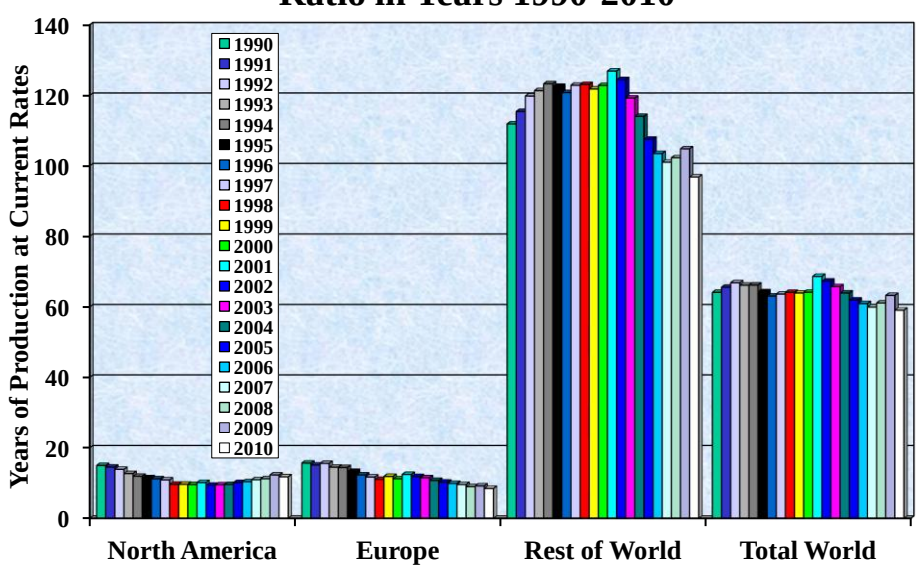

World Gas Consumption Forecasts, 2006-2035, Energy Information Administration, 2011
Projections (2008-2035)
EIA High Oil Price Case
EIA Reference Economic Case
EIA Low Oil Price Case
+63%
+52%
+38%
Trillion Cubic Feet per Year
Year
80
100
120
140
160
180
200
2006
2011
2016
2021
2026
2031
© Hughes GSR Inc, 2011
(Projections from Energy Information Administration International Energy Outlook, 2011)

World Gas Reserves: 1980-2010



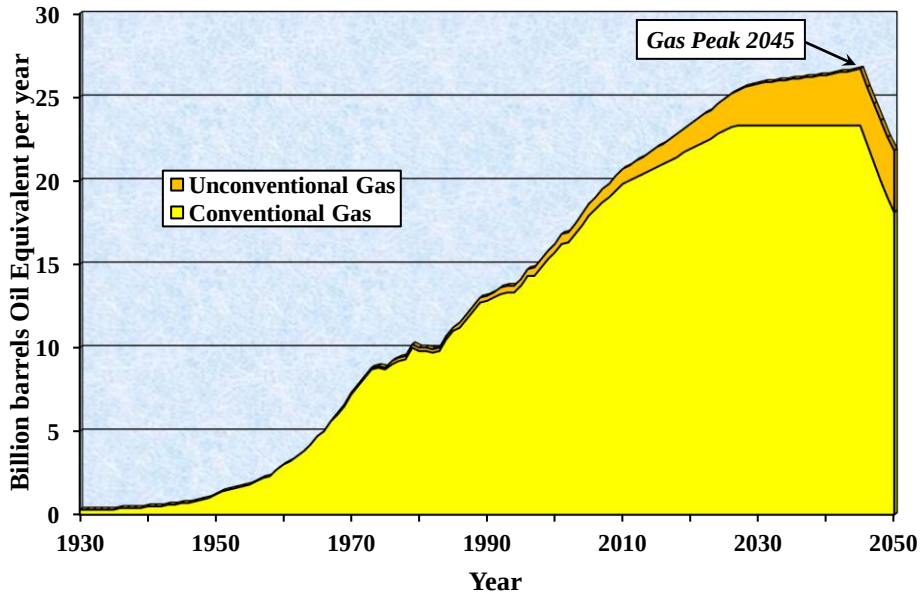
(data from BP Statistical Review of World Energy, 2011)

World Natural Gas Reserve to Production Ratio in Years 1990-2010



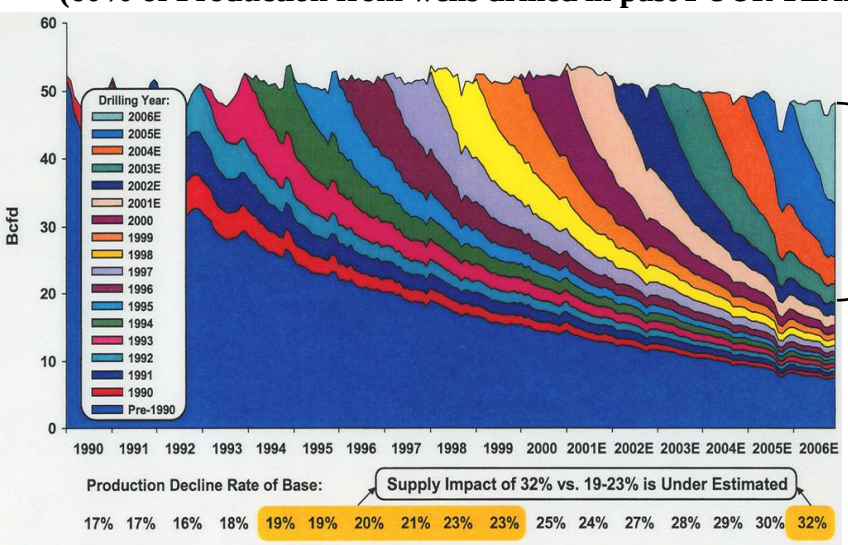
(data from BP Statistical Review of World Energy, 2011)

Campbell's (2009) Base Case History and Forecast of World Natural Gas Production 1930-2050



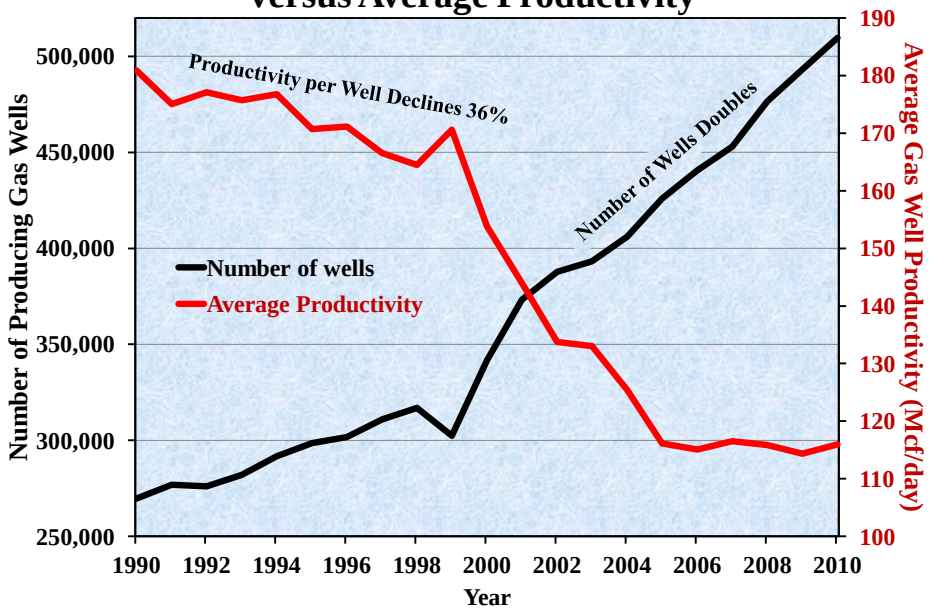
(data from C.J.Campbell, personal communication, October, 2009)

Natural Gas Production in the United States by Well Vintage at Yearend 2006 (60% of Production from wells drilled in past *FOUR YEARS*)



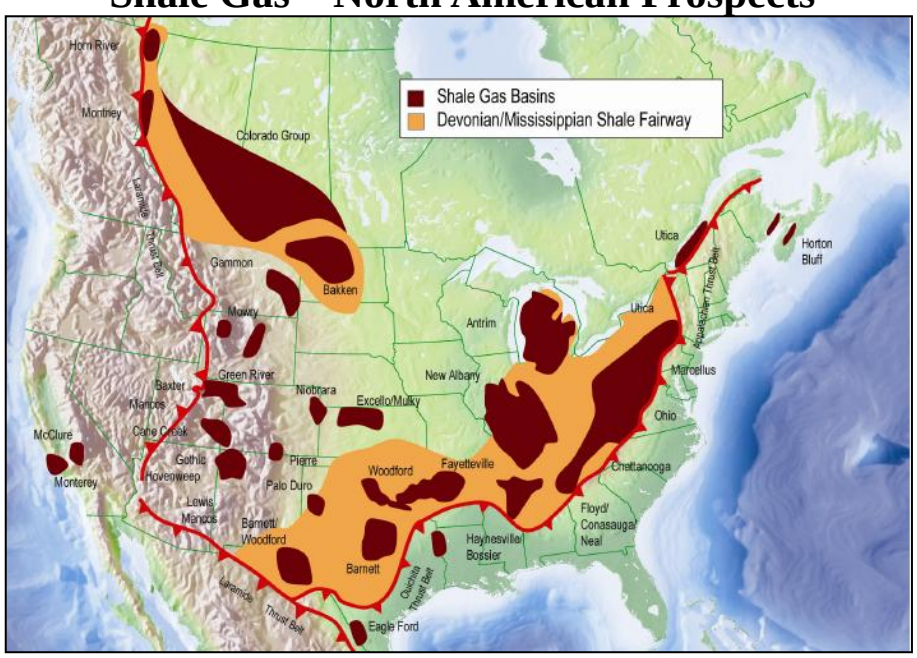
(data copyright IHS Energy, Diagram prepared and copyright by EOG Resources Inc., 2006)

Number of Operating Gas Wells in the U.S. versus Average Productivity



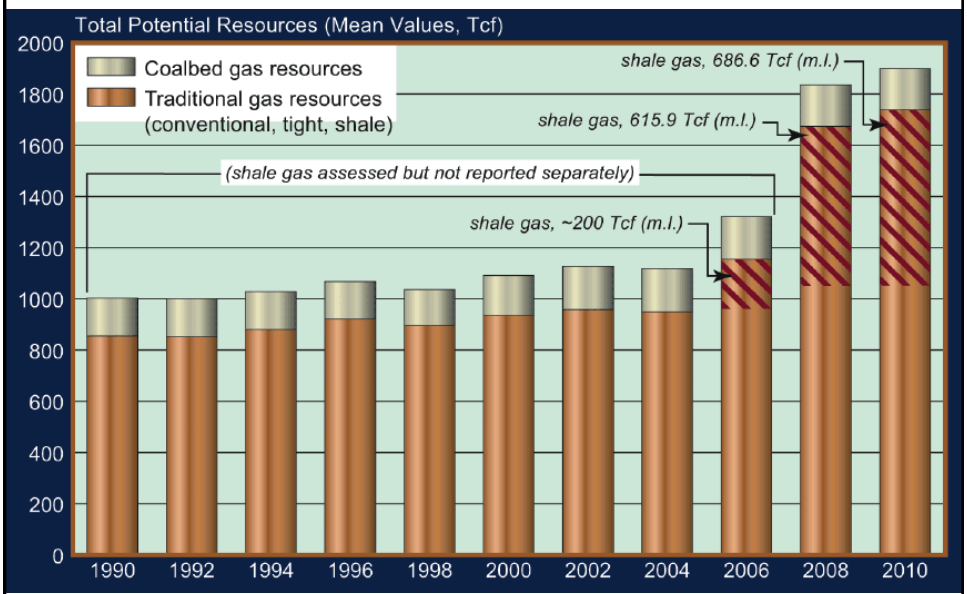
(data from EIA, 2011)

Shale Gas – North American Prospects



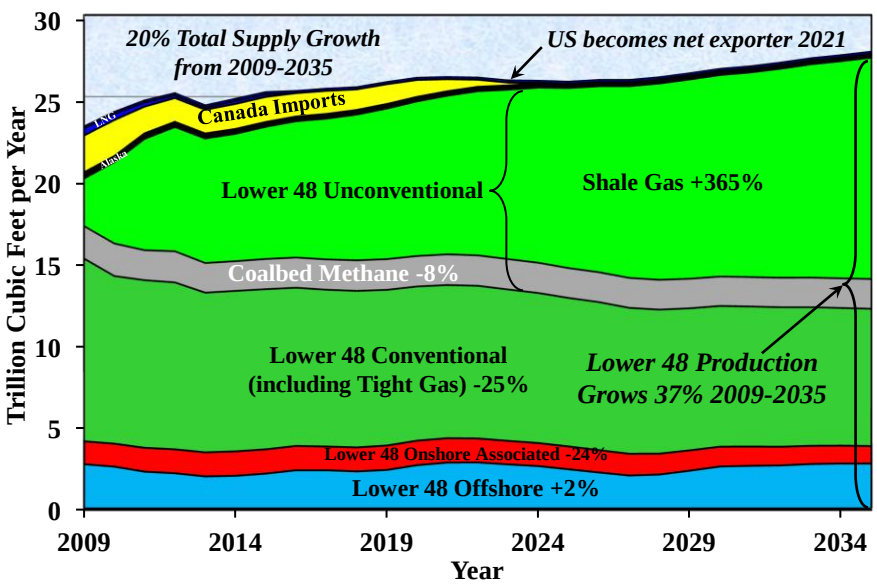
(from National Energy Board, 2009)

U.S. Potential Gas Committee 2011 Resource Estimates



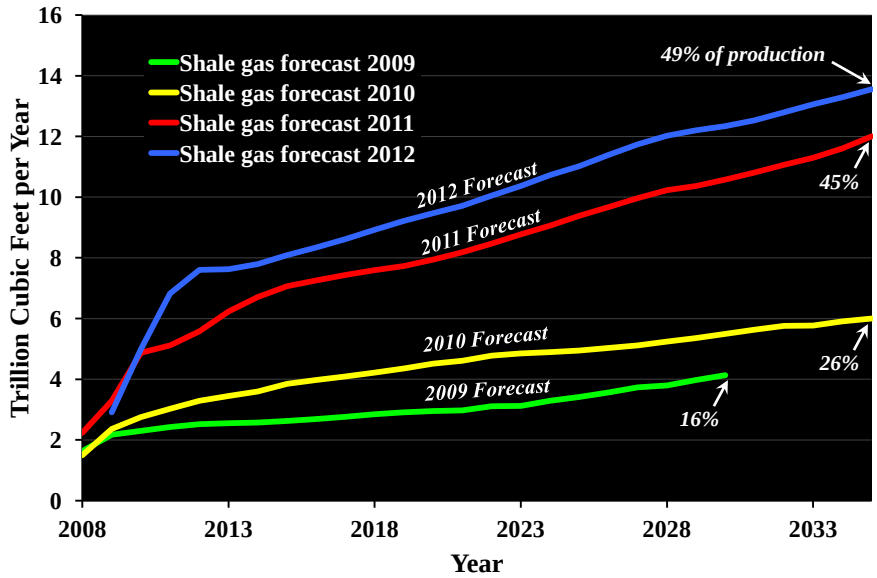
(from "Potential Supply of Natural Gas in the United States", 2011, U.S. Potential Gas Committee)

U.S. Natural Gas Supply Forecast by Source 2009-2035 (Reference Case, EIA, 2012)



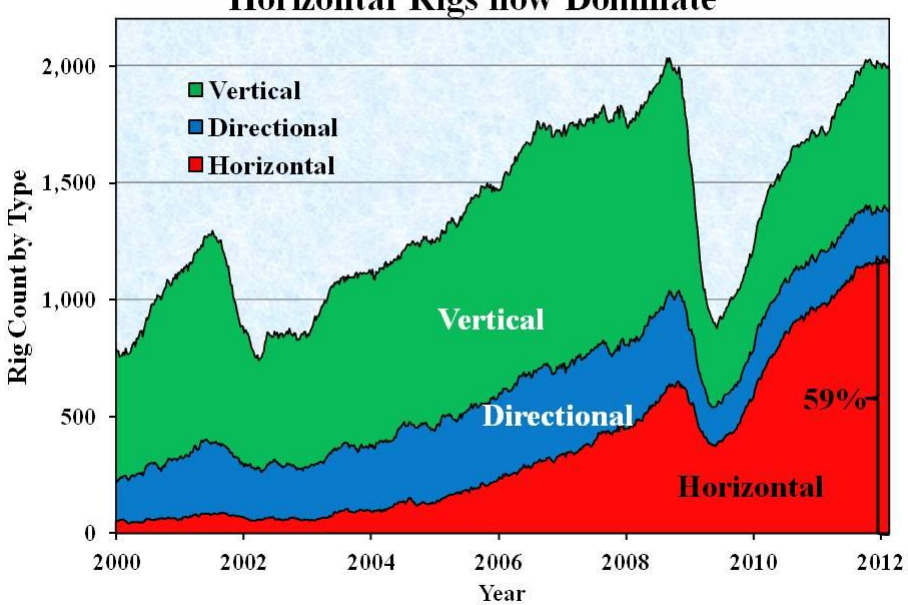
(data from Energy Information Administration Annual Energy Outlook, 2012)

EIA projections of U.S. Shale Gas Production, 2009-2012

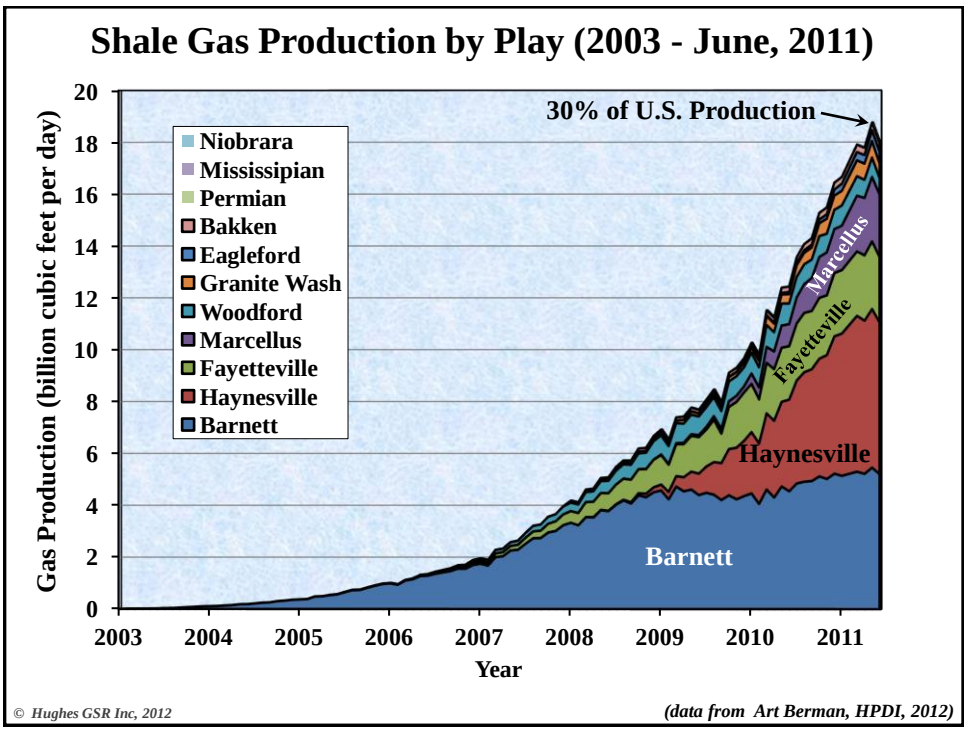


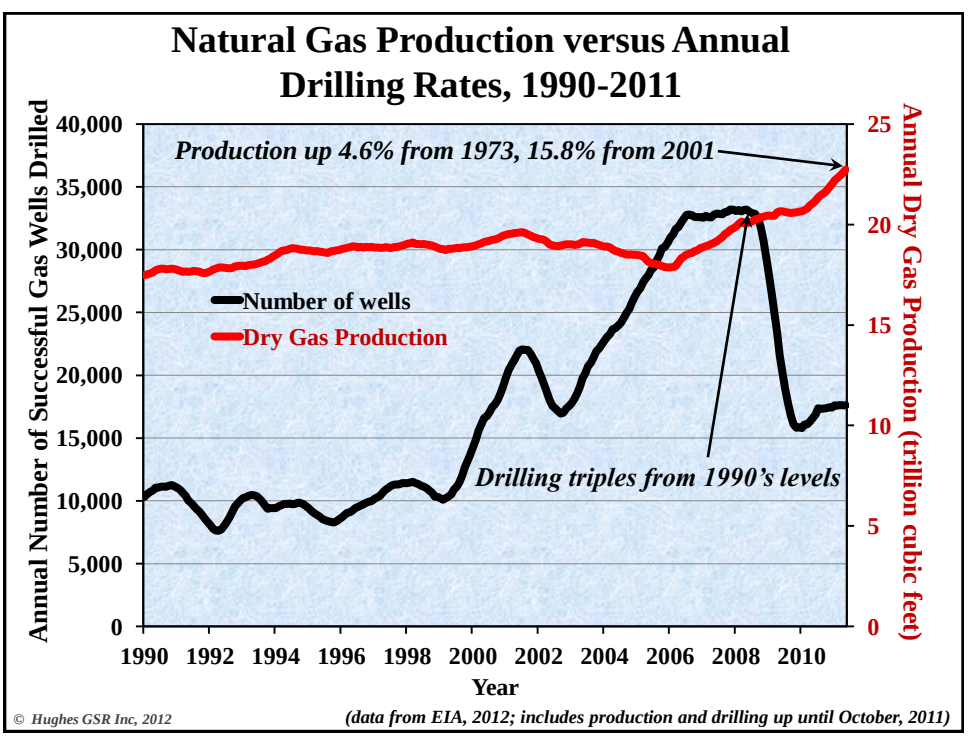
(data from Energy Information Administration Annual Energy Outlook, 2009, 2010, 2011 and 2012 reference case projections)

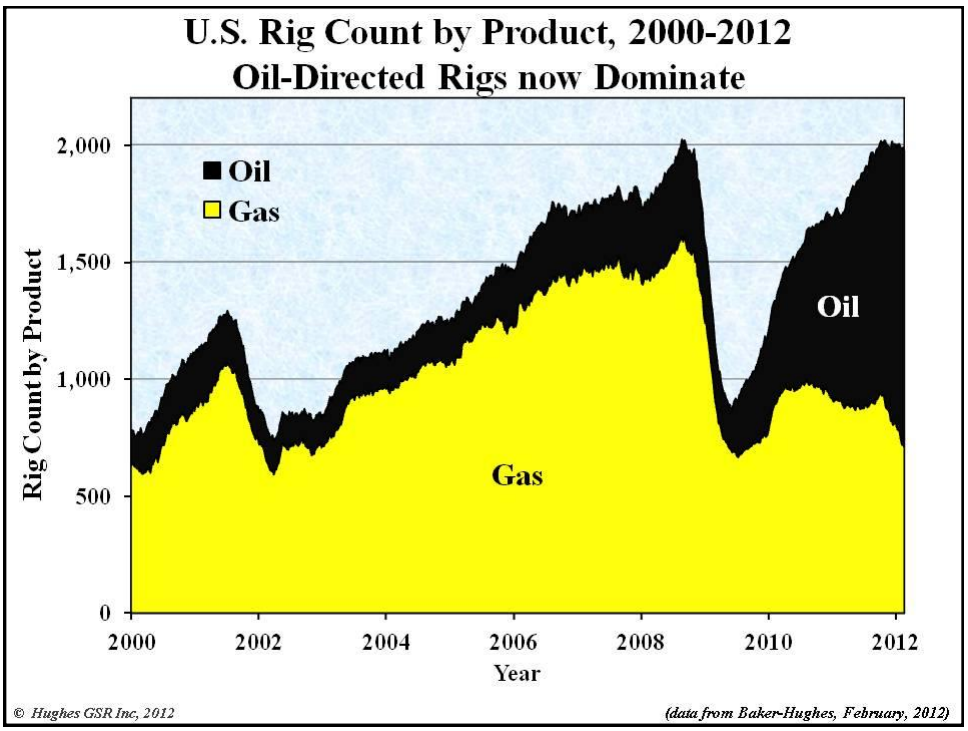
U.S. Rig Count by Type, 2000-2012
Horizontal Rigs now Dominate

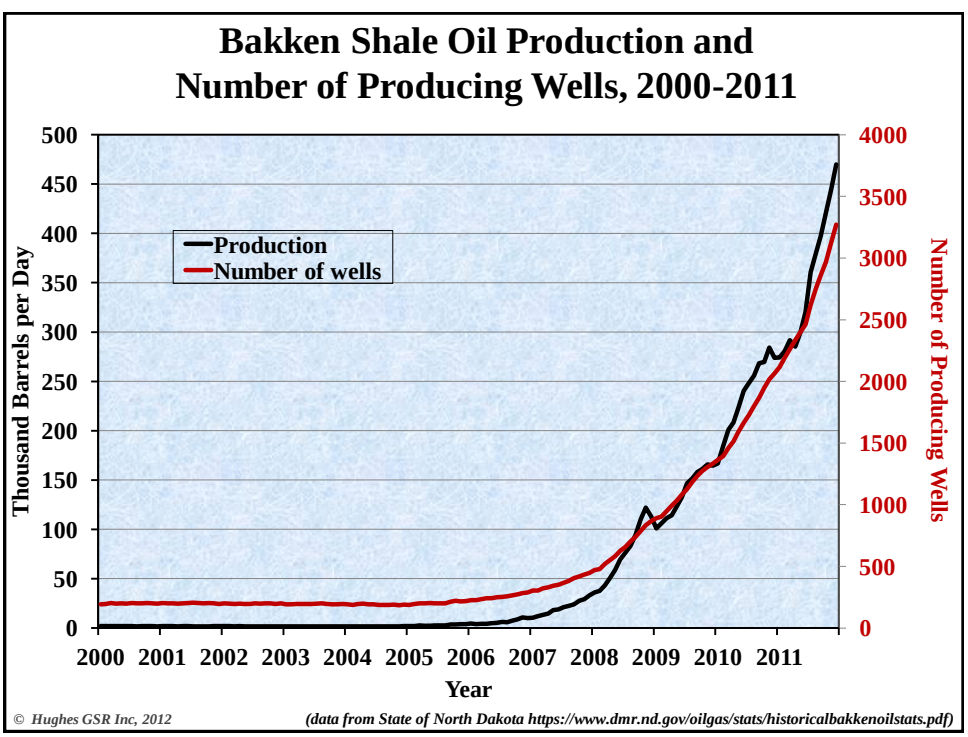


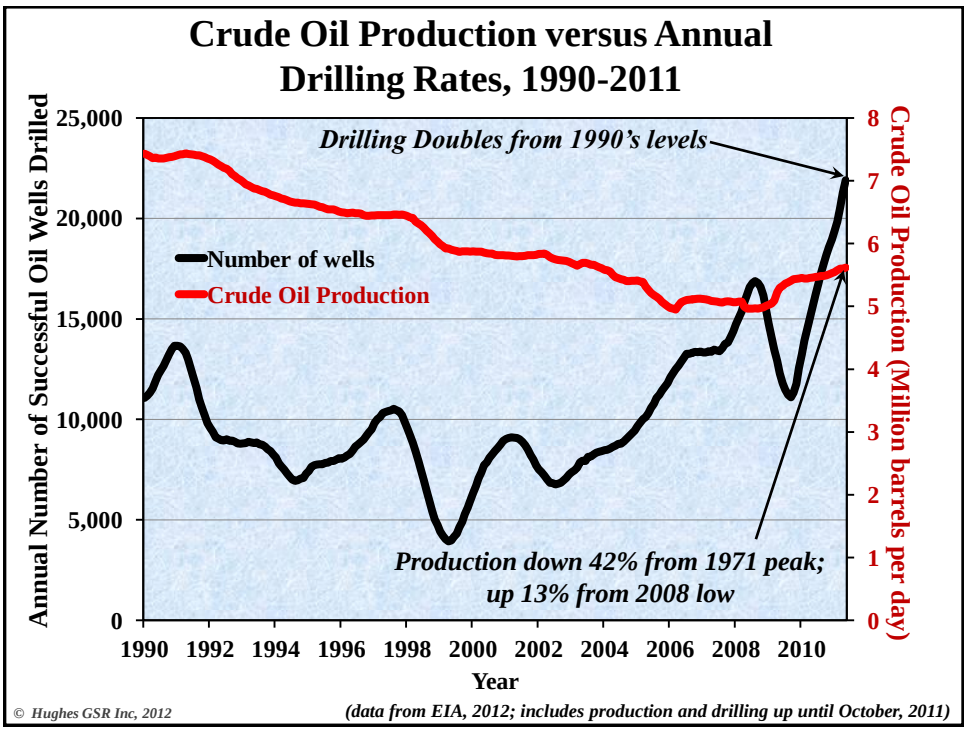
(data from Baker-Hughes, February, 2012)


Shale Gas Production by Play (2003 - June, 2011)
Gas Production (billion cubic feet per day)
Year
30% of U.S. Production
Niobrara
Mississipian
Permian
Bakken
Eagleford
Granite Wash
Woodford
Marcellus
Fayetteville
Haynesville
Barnett
Marcellus
Fayetteville
Haynesville
Barnett
0
2
4
6
8
10
12
14
16
18
20
2003
2004
2005
2006
2007
2008
2009
2010
2011
© Hughes GSR Inc, 2012
(data from Art Berman, HPDI, 2012)


Natural Gas Production versus Annual Drilling Rates, 1990-2011
Annual Number of Successful Gas Wells Drilled
Annual Dry Gas Production (trillion cubic feet)
Year
Production up 4.6% from 1973, 15.8% from 2001
Number of wells
Dry Gas Production
Drilling triples from 1990's levels
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
0
5
10
15
20
25
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
© Hughes GSR Inc, 2012
(data from EIA, 2012; includes production and drilling up until October, 2011)

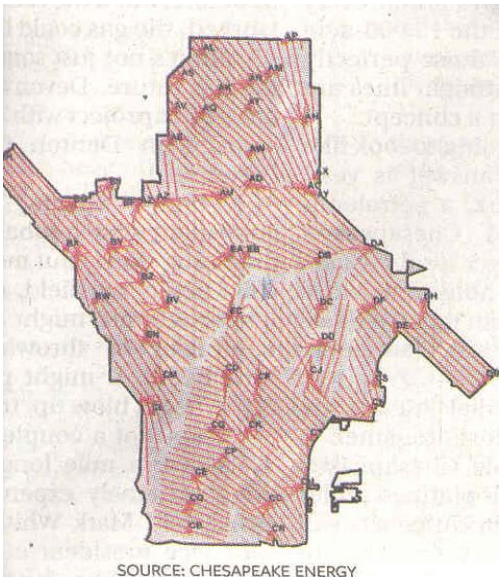

U.S. Rig Count by Product, 2000-2012
Oil-Directed Rigs now Dominate
Oil
Gas
Rig Count by Product
2,000
1,500
1,000
500
0
2000
2002
2004
2006
2008
2010
2012
Year
Oil
Gas
© Hughes GSR Inc, 2012
(data from Baker-Hughes, February, 2012)


Bakken Shale Oil Production and
Number of Producing Wells, 2000-2011
Production
Number of wells
Thousand Barrels per Day
500
450
400
350
300
250
200
150
100
50
0
Number of Producing Wells
4000
3500
3000
2500
2000
1500
1000
500
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Year
© Hughes GSR Inc, 2012
(data from State of North Dakota https://www.dmr.nd.gov/oilgas/stats/historicalbakkenoilstats.pdf)



Shale Gas Fracturing Job, Barnett Shale, Texas

Example: Dallas/Fort Worth Airport Property, Barnett Shale Play



SOURCE: CHESAPEAKE ENERGY

- 53 pads on 18,076 acres,30 square miles
- Each red dot is a pad
- Each red line is a well
- Almost complete coverage
- Patchwork, mostly ideal units
- One developer

57

(Thanks to Anthony R. Ingraffea, 2012)

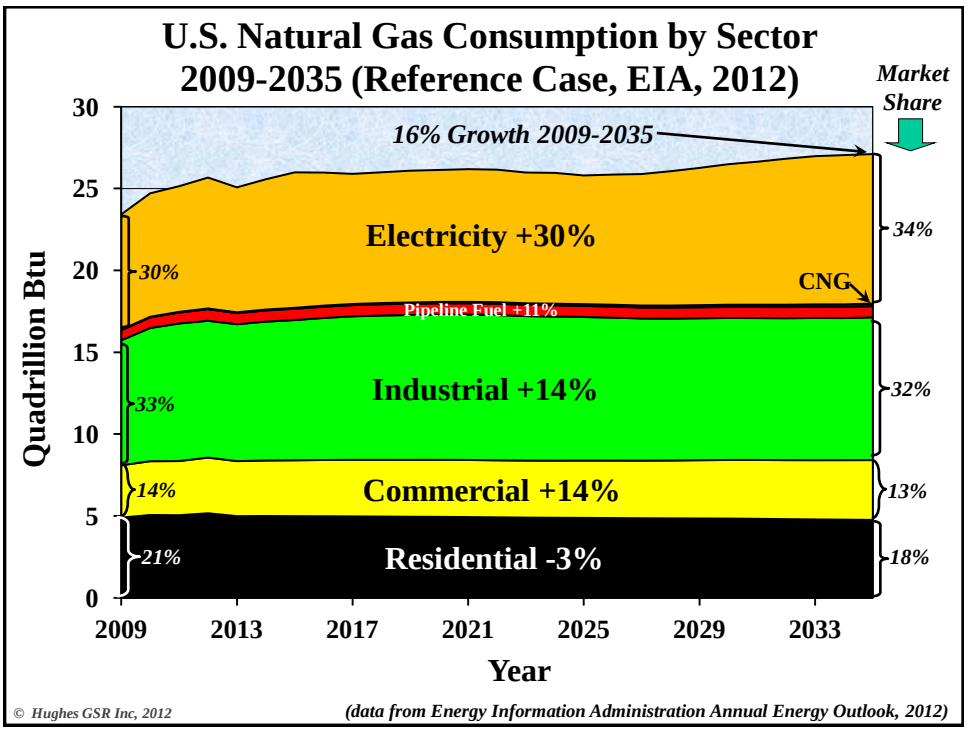
The Optimism on Shale Gas

- There is so much natural gas that there is enough available, according to one researcher, "to displace half of the coal burning power plants [in the United States] by 2020" (Pickens Plan, 2012)

- "We have the domestic natural gas necessary to fuel our trucks and fleet vehicles…" (Pickens Plan, 2012)

- Studies from prestigious energy research firms and universities have affirmed that the dream of clean, abundant, home grown energy is now reality, with the help of shale gas. (ANGA, 2012).

- "I believe U.S. natural gas producers can increase supplies by 5% per year for at least the next decade and that assumes there is no more access to public lands and waters than there is today." (Testimony to Congress, Aubrey McClendon, July 30, 2008). [63% compounded]



Arthur Berman on Shale Gas
(ASPO meeting in Washington DC, October, 2010)

"Shale plays are marginally commercial at best."

"The plays have consistently contracted to a core area that represents 10-20% of the resource that was initially claimed. The manufacturing model has failed."

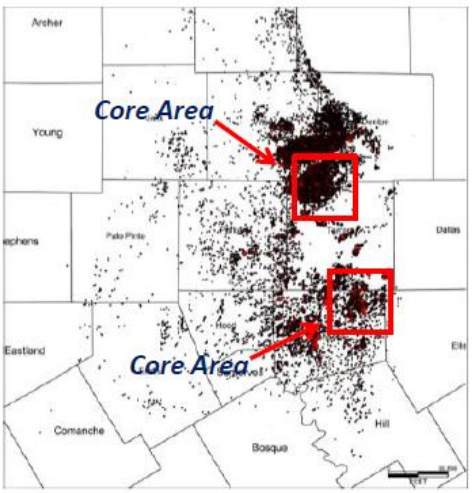
"These are not low-cost plays: the marginal cost of production for most companies is $7.50/Mcf based on SEC 10-K filings over the past 5 years."

"Reserves have been greatly over-stated and 80% of booked reserves are undeveloped."

(from Art Berman's ASPO-USA presentation in October 2010)

Shale Plays inevitably contract to core areas with higher productivity and the "rest"

The Barnett Shale core areas

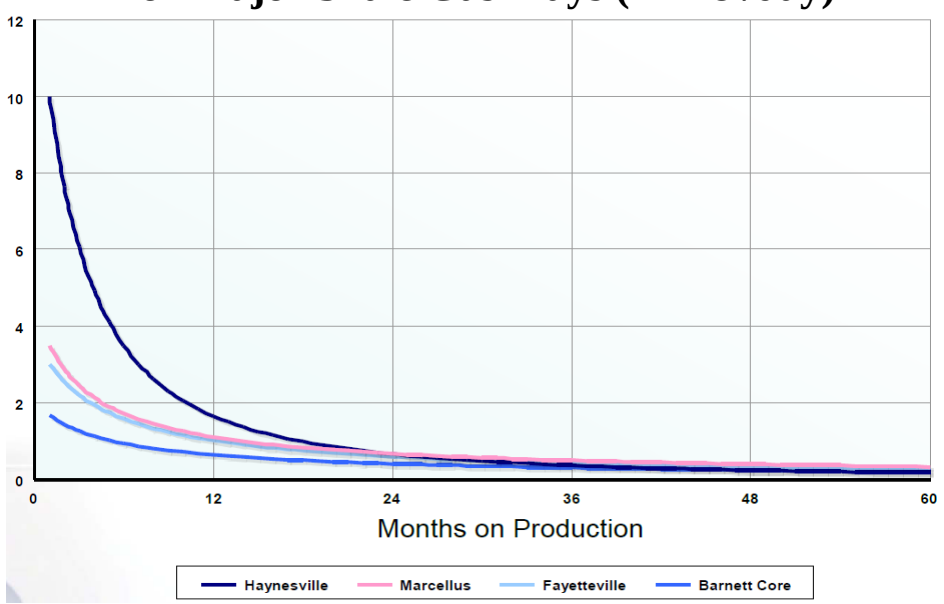


"There was a time you all were told that any of the 17 counties in the Barnett Shale play would be just as good as any other county," McClendon said. "We found out there are about two or two and a half counties where you really want to be."

--Bloomberg News October 14, 2009

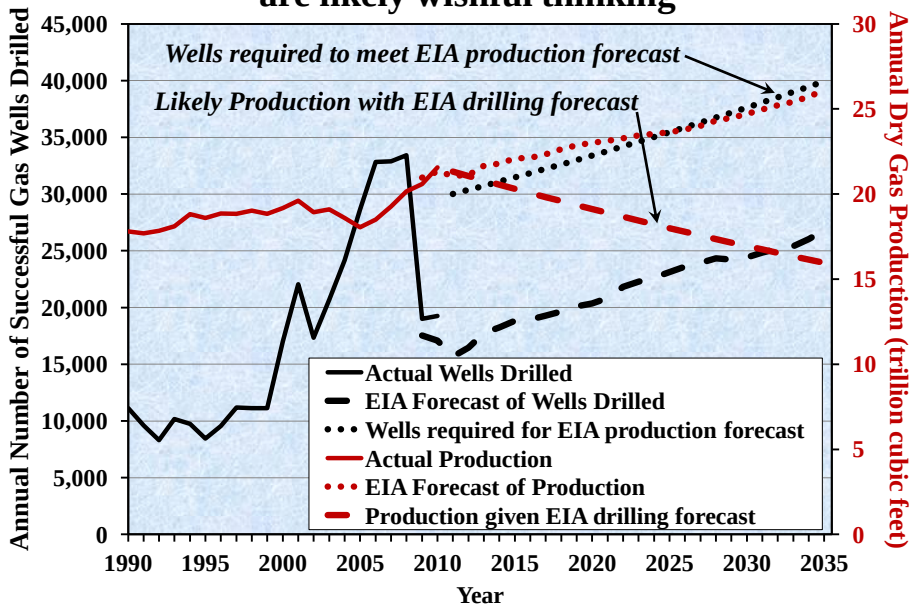
(from Art Berman's ASPO-USA presentation in October 2010)

Theoretical Production Profiles for Major Shale Gas Plays (MMcf/day)



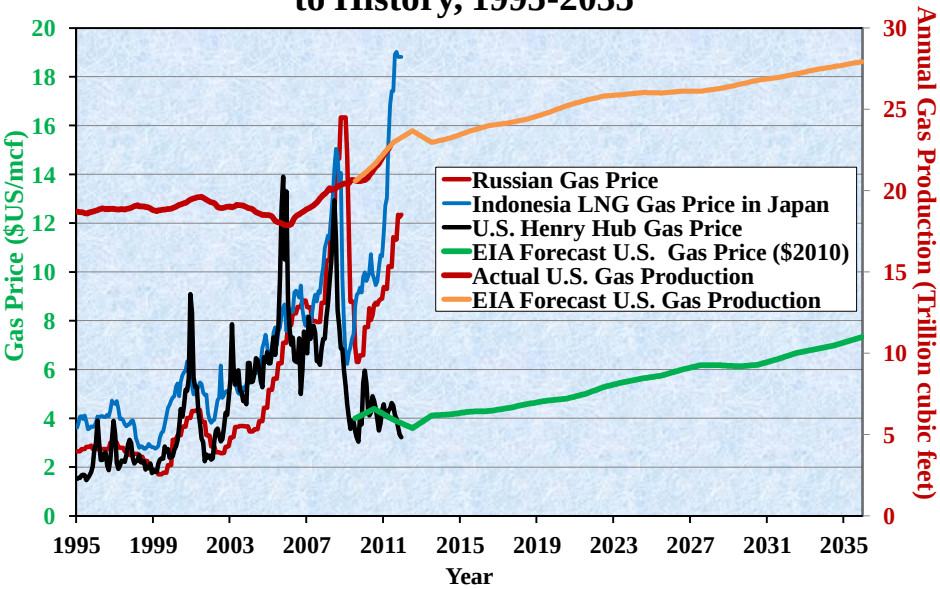
(data from Moorman, Southwest Energy, November, 2009)

The EIA's forecast of low drilling rates and high production are likely wishful thinking



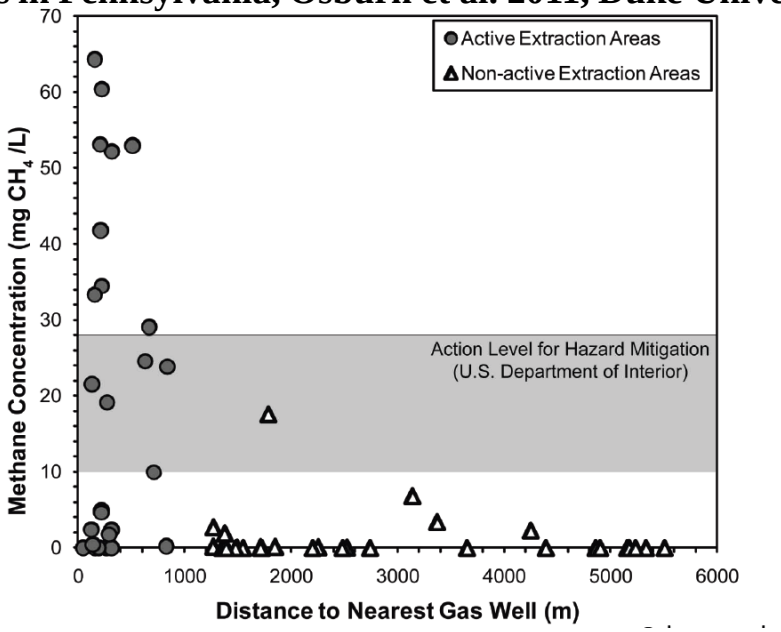
(data from EIA, 2011)

EIA projections of Gas Price and Production Compared to History, 1995-2035

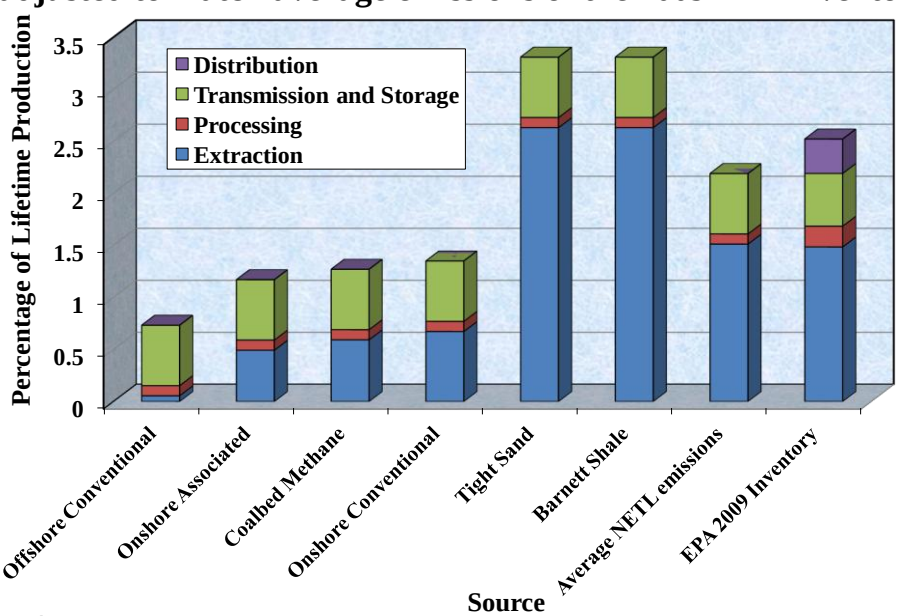


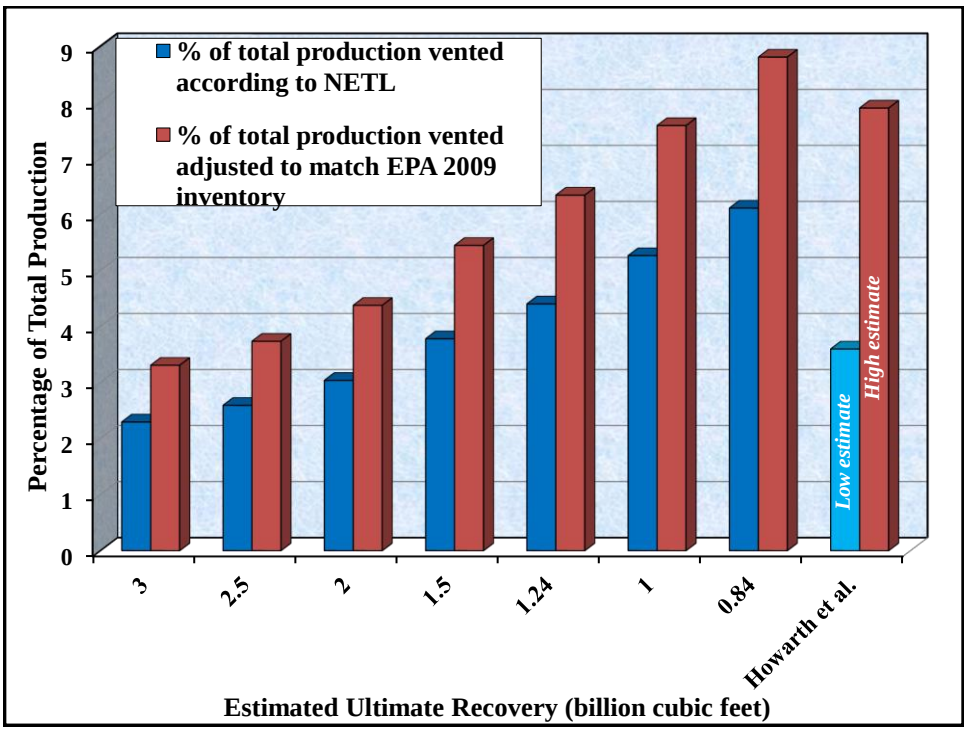
(data from International Monetary Fund 2012; EIA AEO 2012)

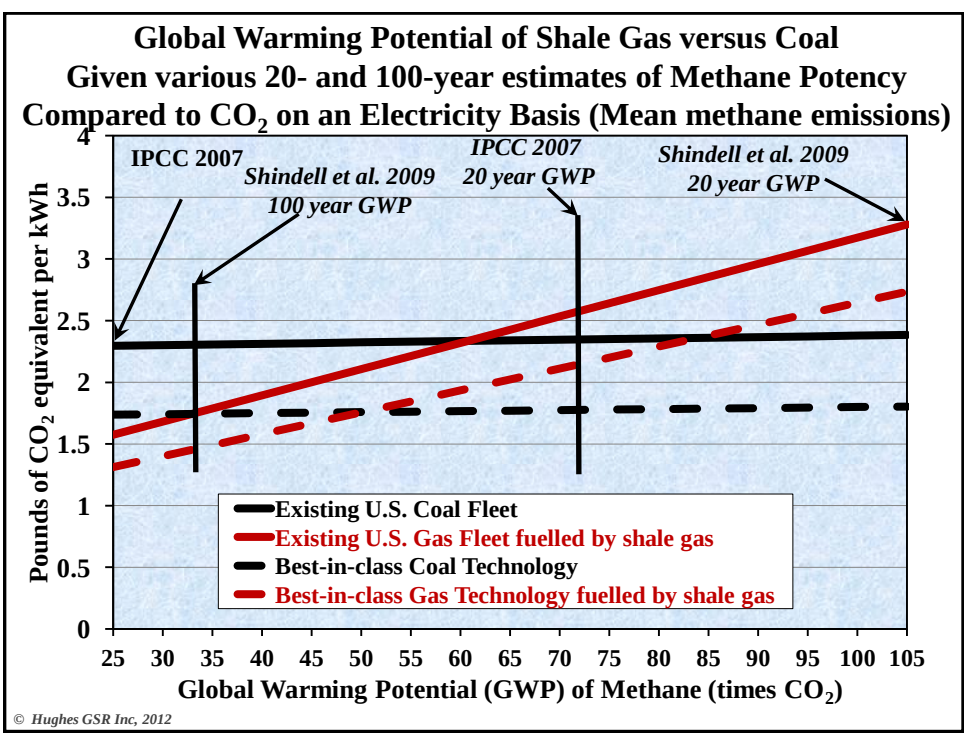
Methane Contamination within 1000 metres of Active Wells in Pennsylvania, Osburn et al. 2011, Duke University

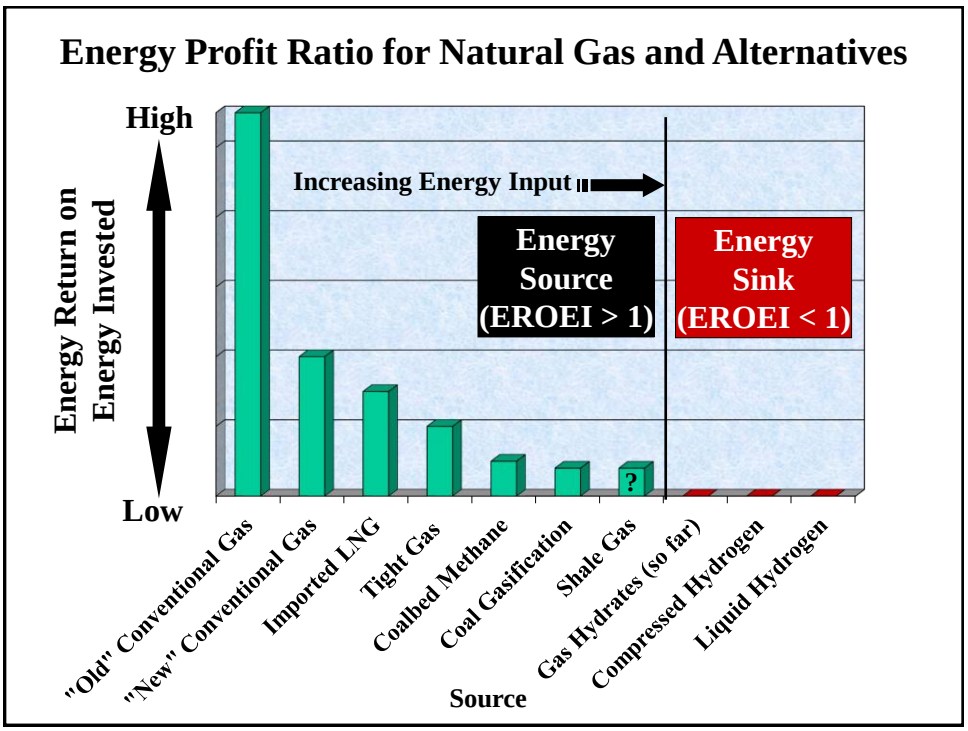


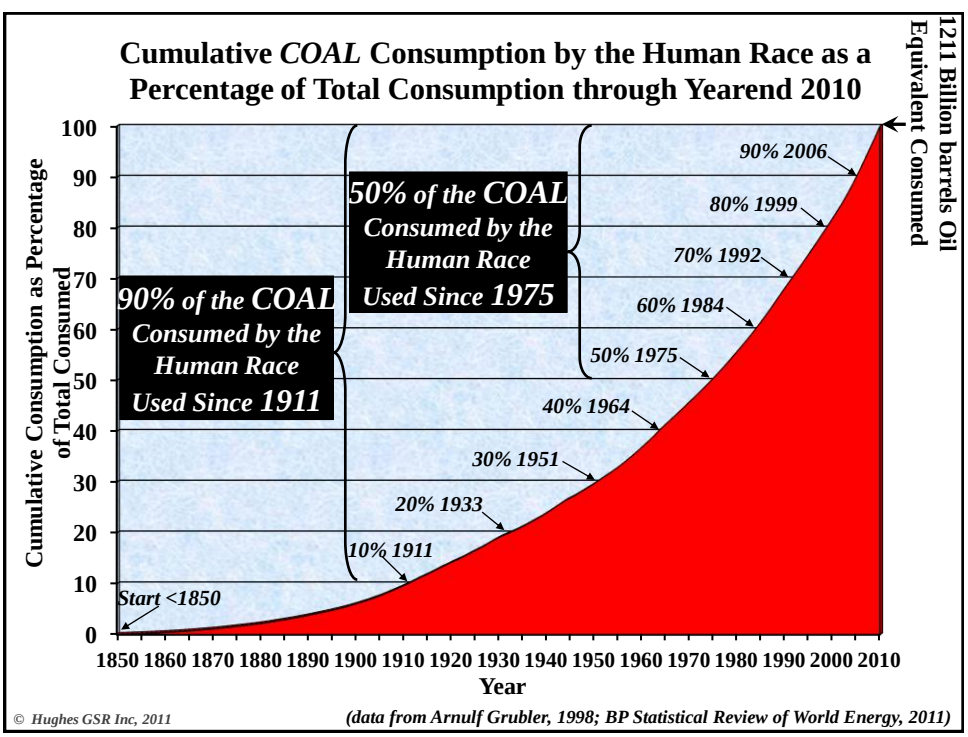
NETL (Skone, 2011) Methane Emissions by Gas Source adjusted to match average emissions of the 2009 EPA inventory



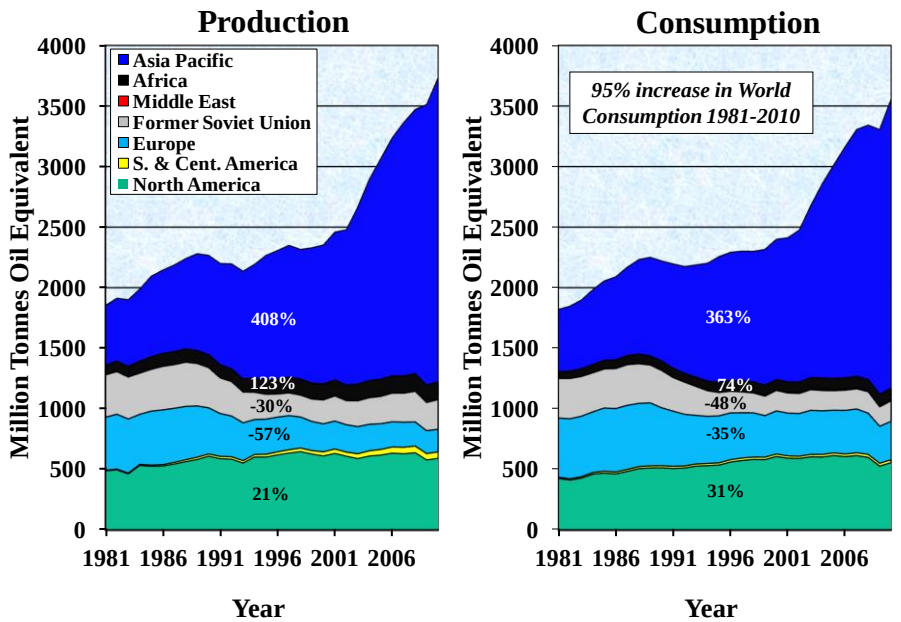

% of total production vented according to NETL
% of total production vented adjusted to match EPA 2009 inventory
Percentage of Total Production
0
1
2
3
4
5
6
7
8
9
3
2.5
2
1.5
1.24
1
0.84
Howarth et al.
Low estimate
High estimate
Estimated Ultimate Recovery (billion cubic feet)


Global Warming Potential of Shale Gas versus Coal
Given various 20- and 100-year estimates of Methane Potency
Compared to CO_2 on an Electricity Basis (Mean methane emissions)
IPCC 2007
Shindell et al. 2009
100 year GWP
IPCC 2007
20 year GWP
Shindell et al. 2009
20 year GWP
Pounds of CO_2 equivalent per kWh
0
0.5
1
1.5
2
2.5
3
3.5
4
Existing U.S. Coal Fleet
Existing U.S. Gas Fleet fuelled by shale gas
Best-in-class Coal Technology
Best-in-class Gas Technology fuelled by shale gas
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
Global Warming Potential (GWP) of Methane (times CO_2)
© Hughes GSR Inc, 2012


Energy Profit Ratio for Natural Gas and Alternatives
High
Low
Energy Return on Energy Invested
Increasing Energy Input
Energy Source (EROEI > 1)
Energy Sink (EROEI < 1)
?
"Old" Conventional Gas
"New" Conventional Gas
Imported LNG
Tight Gas
Coalbed Methane
Coal Gasification
Shale Gas
Gas Hydrates (so far)
Compressed Hydrogen
Liquid Hydrogen
Source

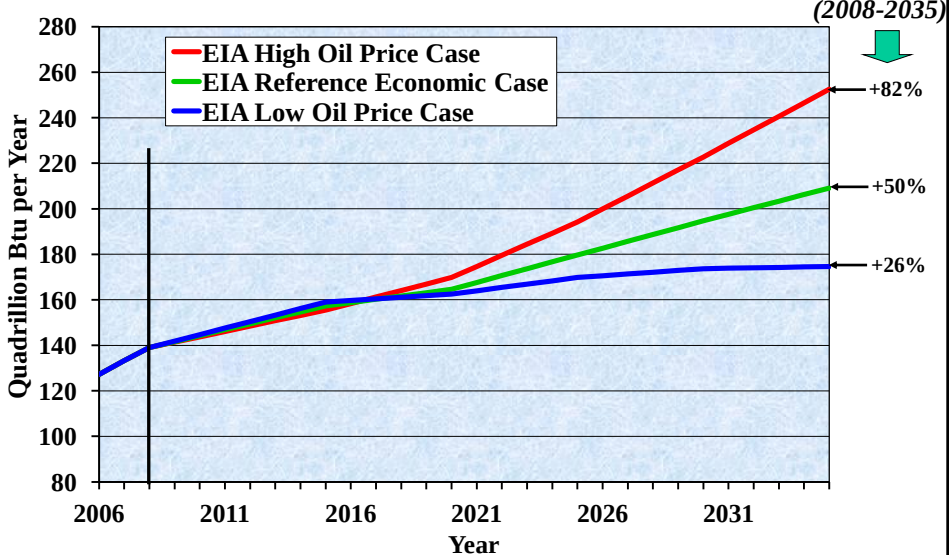

Cumulative COAL Consumption by the Human Race as a Percentage of Total Consumption through Yearend 2010
Cumulative Consumption as Percentage of Total Consumed
1211 Billion barrels Oil Equivalent Consumed
90% of the COAL Consumed by the Human Race Used Since 1911
50% of the COAL Consumed by the Human Race Used Since 1975
Start <1850
10% 1911
20% 1933
30% 1951
40% 1964
50% 1975
60% 1984
70% 1992
80% 1999
90% 2006
Year
© Hughes GSR Inc, 2011
(data from Arnulf Grubler, 1998; BP Statistical Review of World Energy, 2011)

World Coal Production and Consumption: 1981-2010



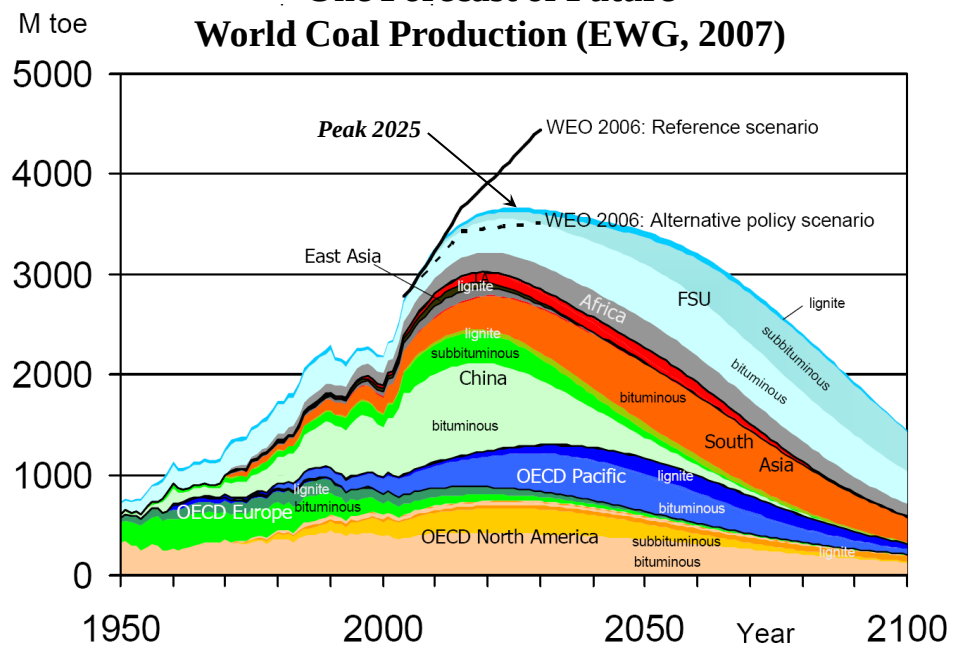
 Coal production up 44% since 2002 *(data from BP Statistical Review of World Energy, 2011)*

World Coal Consumption Forecasts 2006-2035, Energy Information Administration, 2011



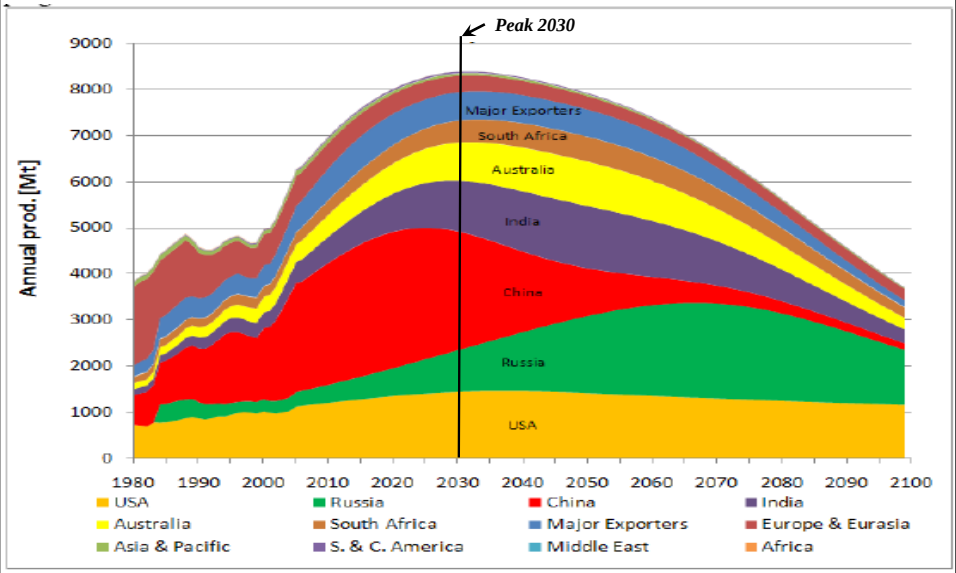
 (Projections from Energy Information Administration International Energy Outlook, 2011)

One Forecast of Future World Coal Production (EWG, 2007)



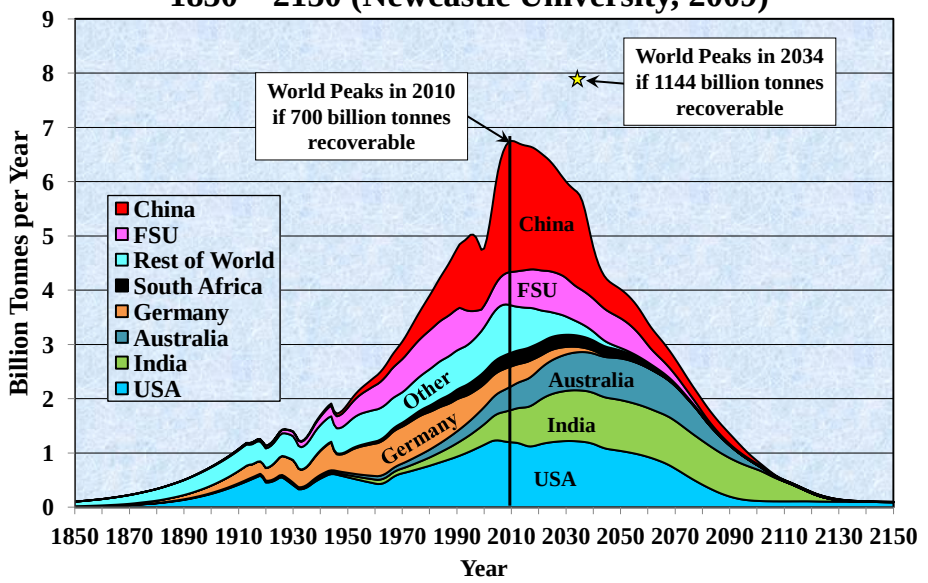
(from Energy Watch Group, March, 2007)

Uppsala Forecast of Global Peak Coal, 2008



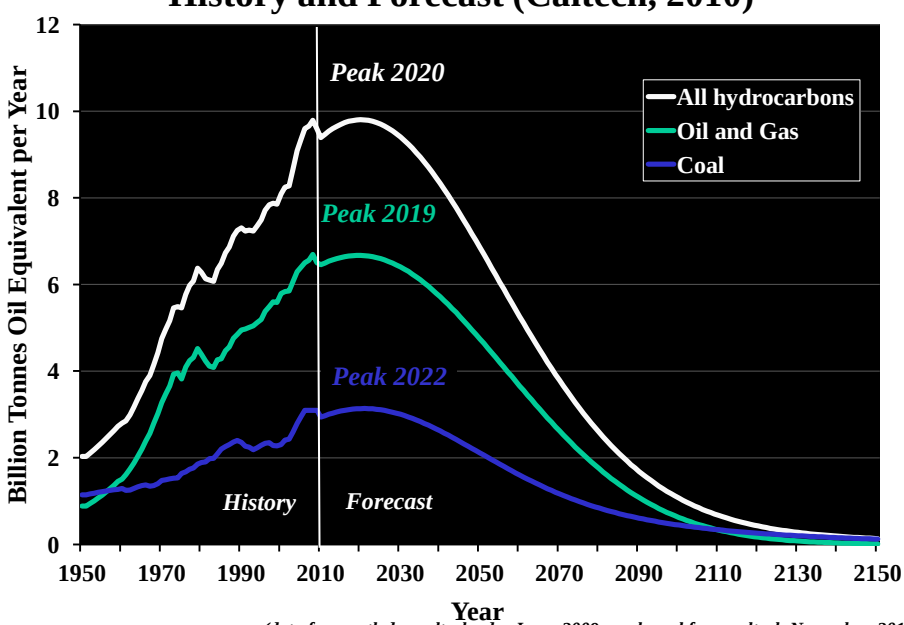
(from Hook, Zittel, Schindler, Aleklett, 2008)

Peak Coal Production Forecast using Hubbert Linearization 1850 – 2150 (Newcastle University, 2009)

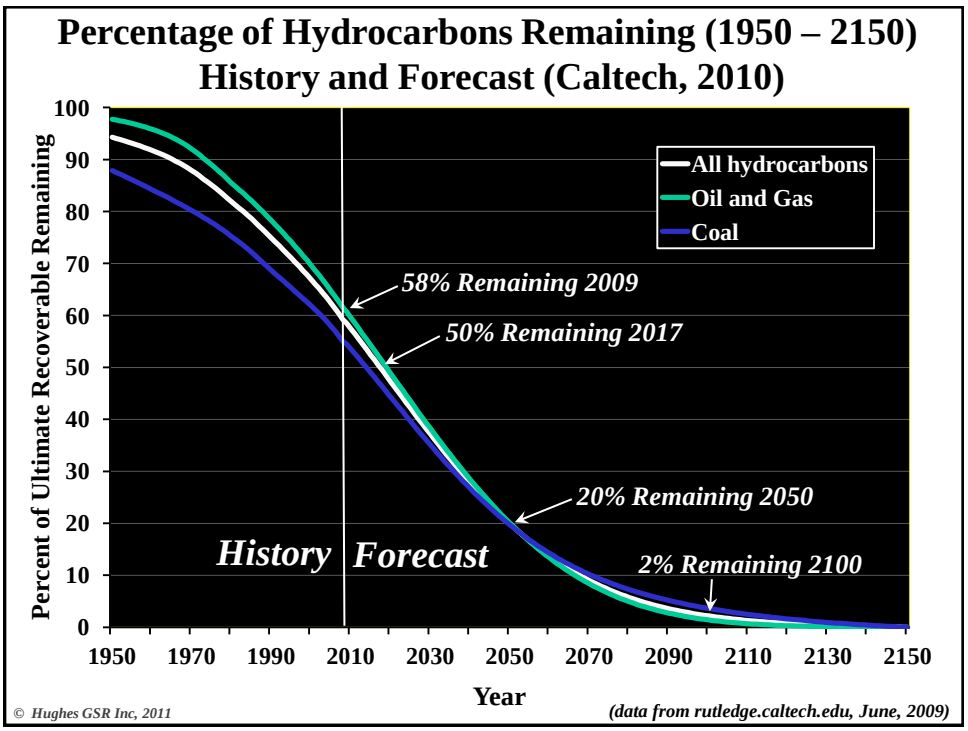


(data courtesy of S.H.Mohr and G.M.Evans "Forecasting Coal Production Until 2100", 2009)

All Hydrocarbons Production (1950-2150) History and Forecast (Caltech, 2010)

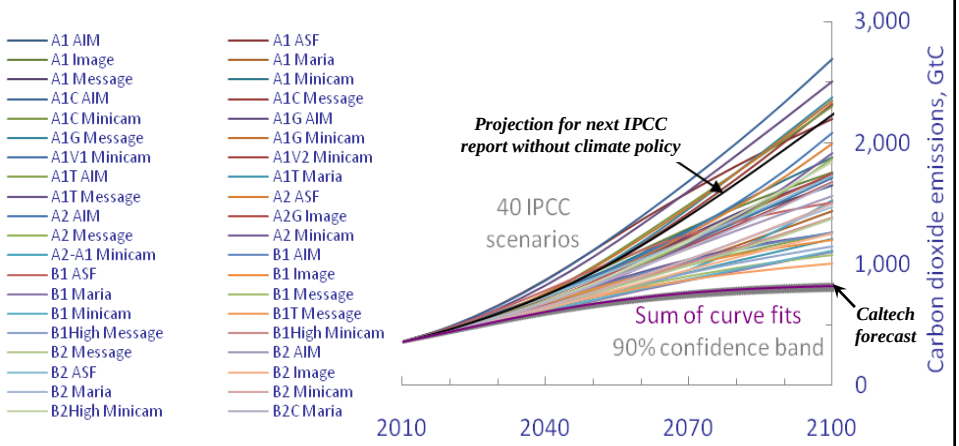


(data from rutledge.caltech.edu, June, 2009; peak coal from caltech November, 2010)



Each Windmill requires 260 tonnes of steel made from 170 tonnes of coking coal and 300 tonnes of iron ore, all mined and transported by hydrocarbons

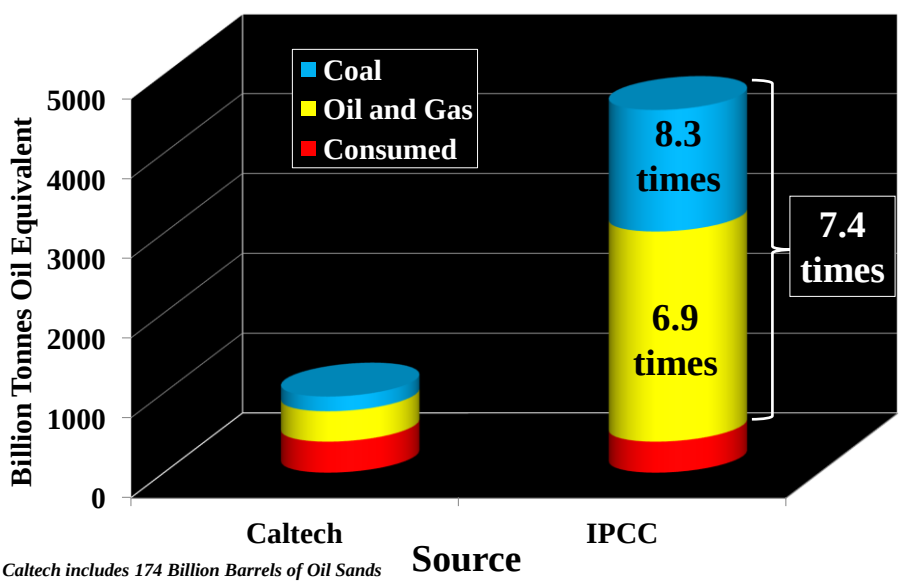
Cumulative CO_2 Emissions
Caltech (2010) compared to UN IPCC Scenarios



- Caltech's production constrained projection has lower emissions than any of the 40 IPCC scenarios
- Jean Laherrere was the first to call attention to this situation

(from rutledge.caltech.edu, November, 2010)

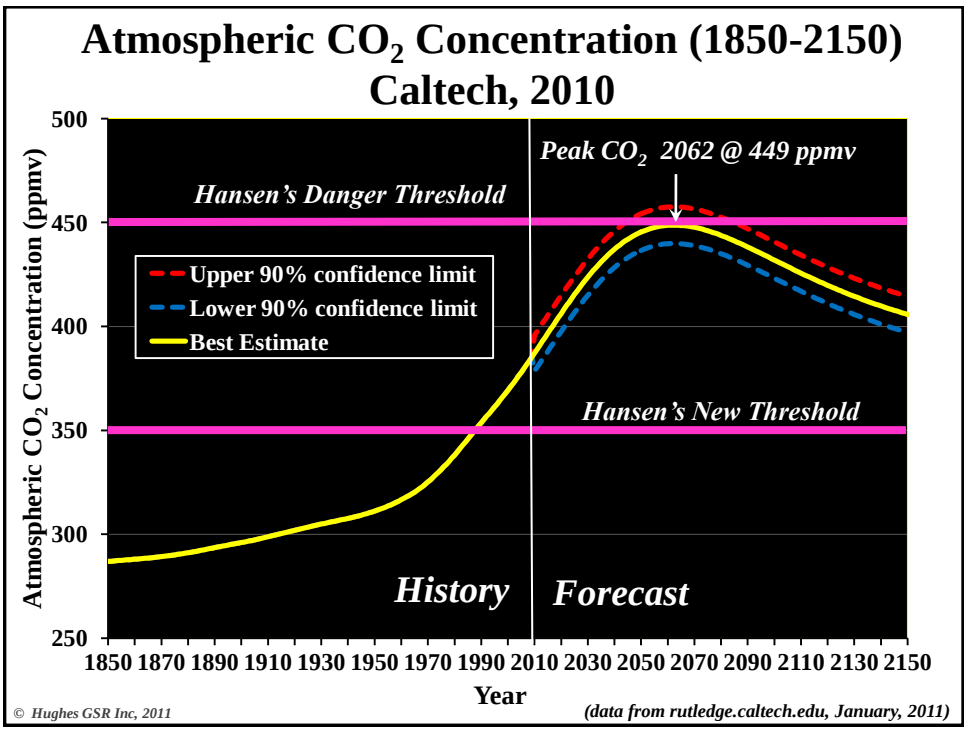
Consumed and Remaining Recoverable Hydrocarbons
Caltech (2009) vs IPCC

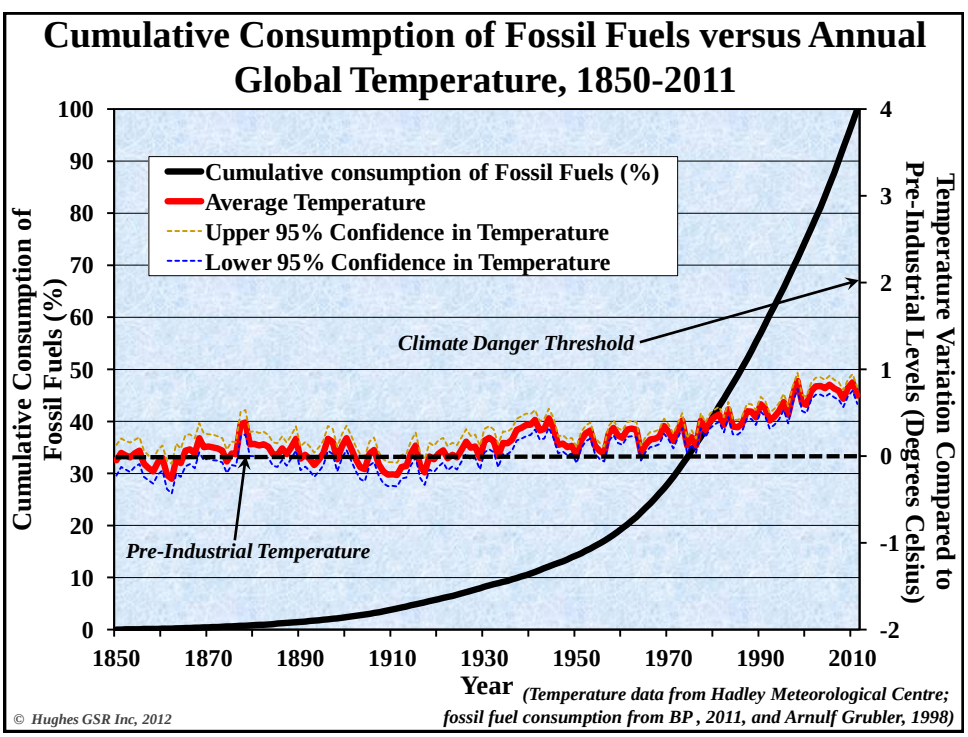


Caltech includes 174 Billion Barrels of Oil Sands

IPCC includes only maximum consumption to 2100, ultimate recoverable would be higher

(data from rutledge.caltech.edu, June, 2009)


Atmospheric CO_2 Concentration (1850-2150)
Caltech, 2010
Peak CO_2 2062 @ 449 ppmv
Hansen's Danger Threshold
Upper 90% confidence limit
Lower 90% confidence limit
Best Estimate
Hansen's New Threshold
History
Forecast
Atmospheric CO_2 Concentration (ppmv)
500
450
400
350
300
250
1850 1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090 2110 2130 2150
Year
© Hughes GSR Inc, 2011
(data from rutledge.caltech.edu, January, 2011)


Cumulative Consumption of Fossil Fuels versus Annual Global Temperature, 1850-2011
Cumulative consumption of Fossil Fuels (%)
Average Temperature
Upper 95% Confidence in Temperature
Lower 95% Confidence in Temperature
Climate Danger Threshold
Pre-Industrial Temperature
Cumulative Consumption of Fossil Fuels (%)
100
90
80
70
60
50
40
30
20
10
0
Temperature Variation Compared to Pre-Industrial Levels (Degrees Celsius)
4
3
2
1
0
-1
-2
1850 1870 1890 1910 1930 1950 1970 1990 2010
Year
(Temperature data from Hadley Meteorological Centre; fossil fuel consumption from BP , 2011, and Arnulf Grubler, 1998)
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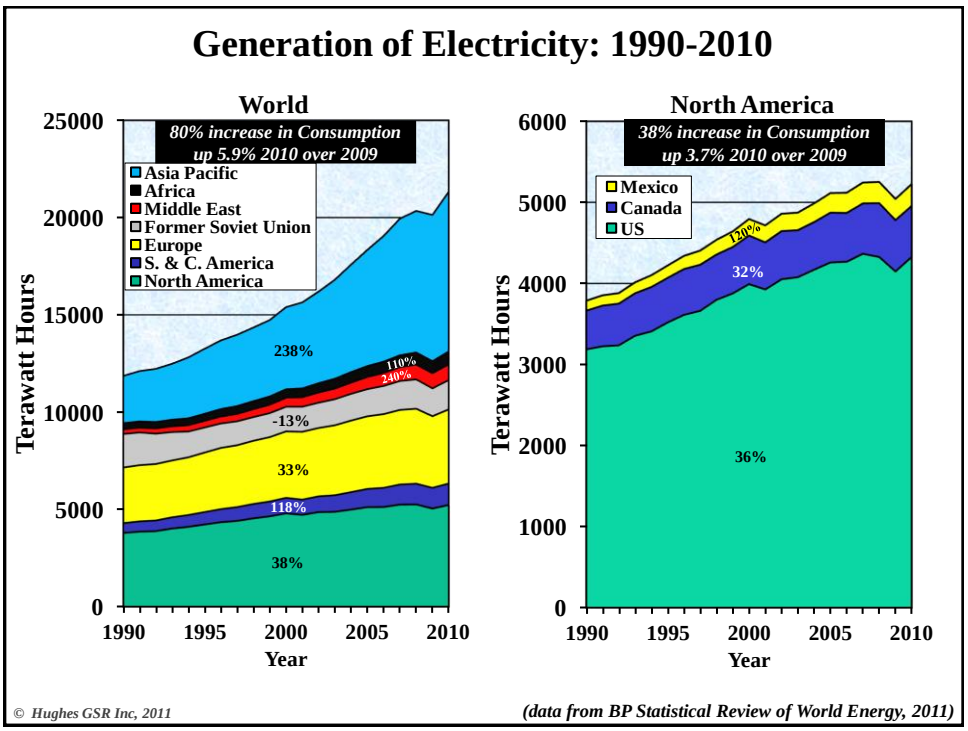
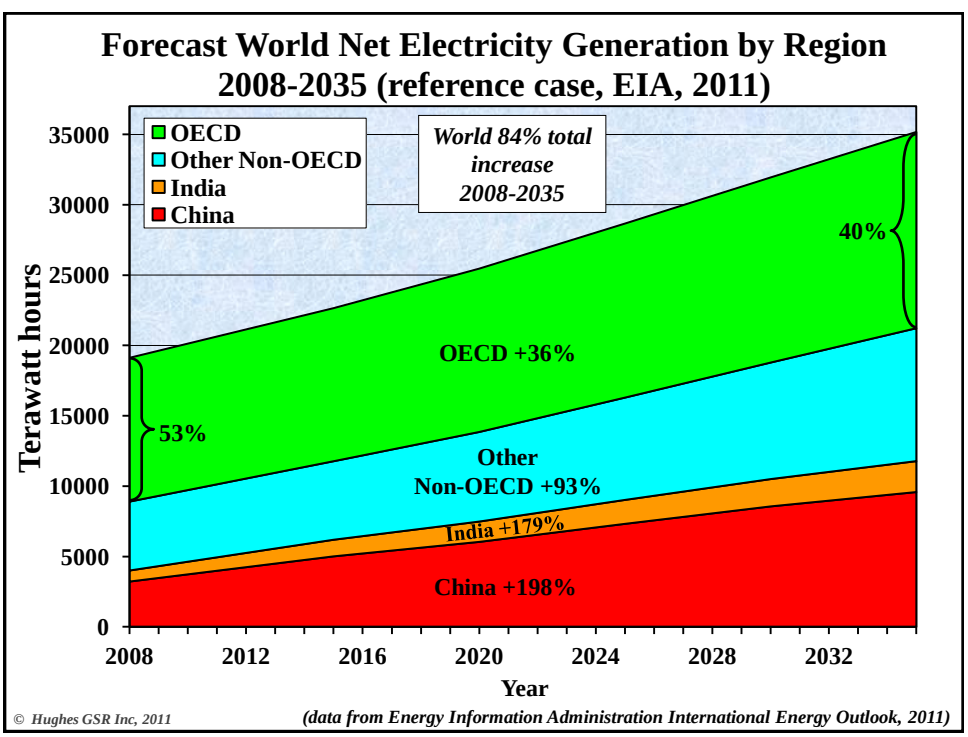
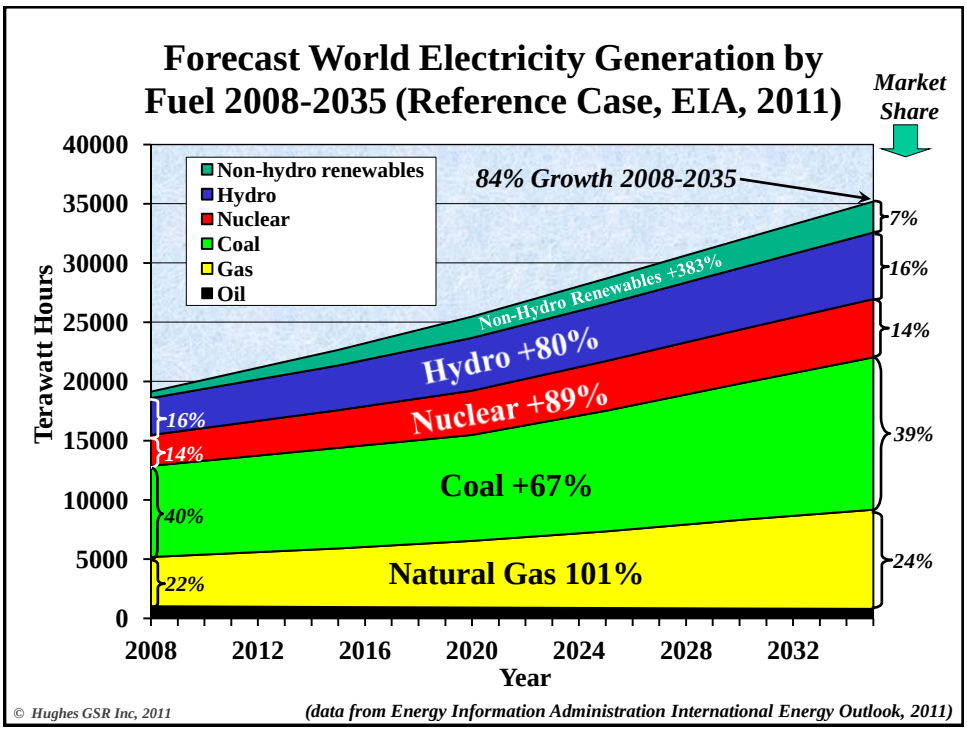
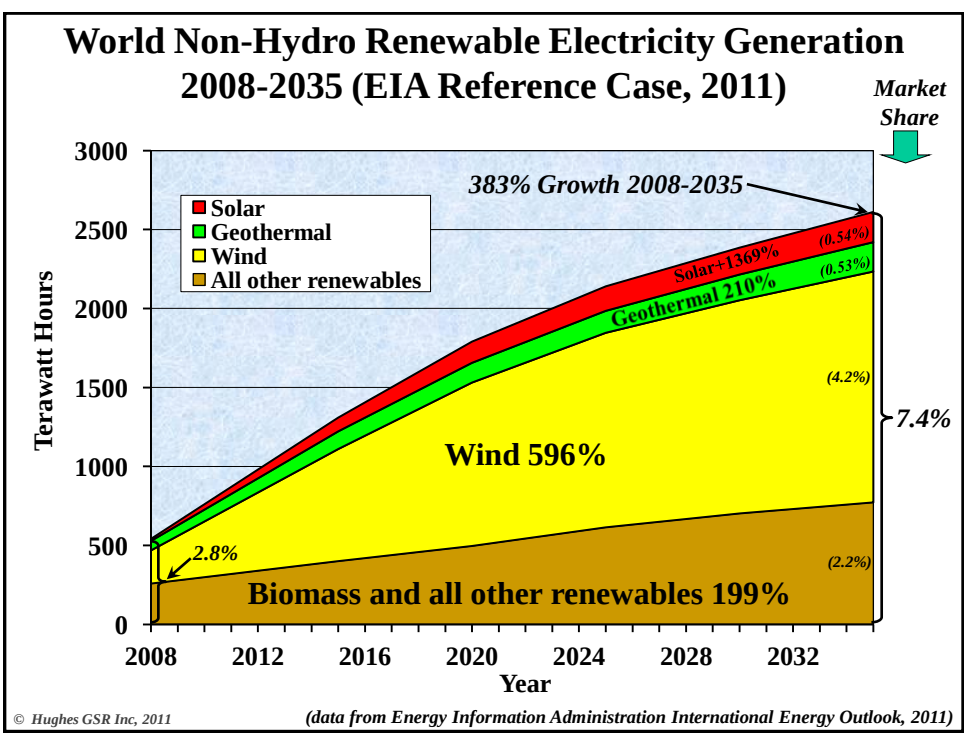
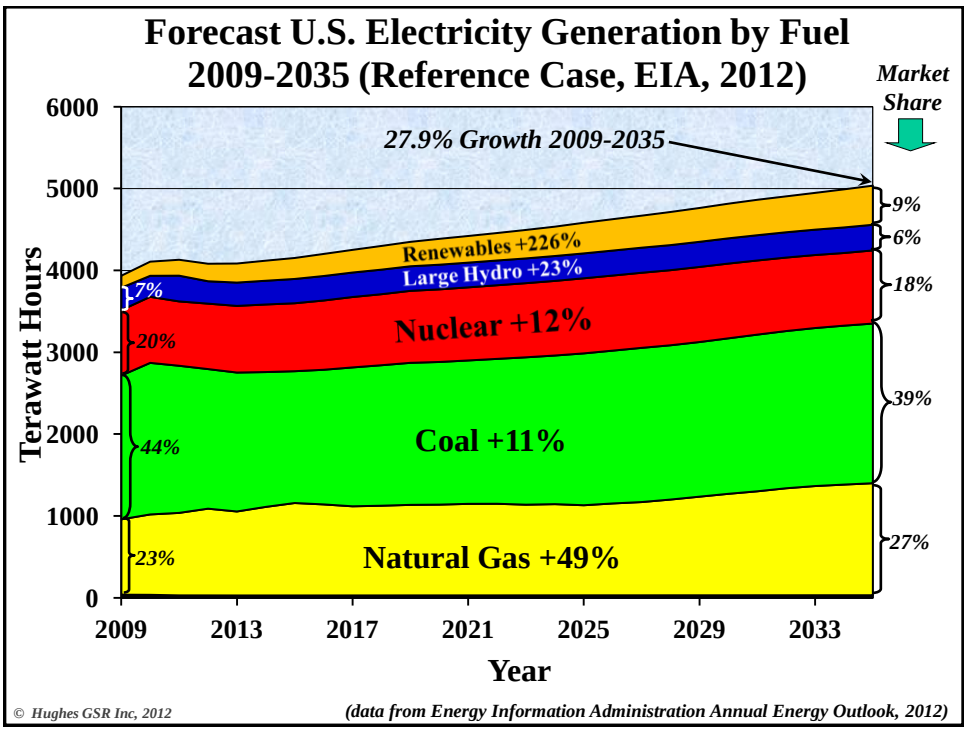
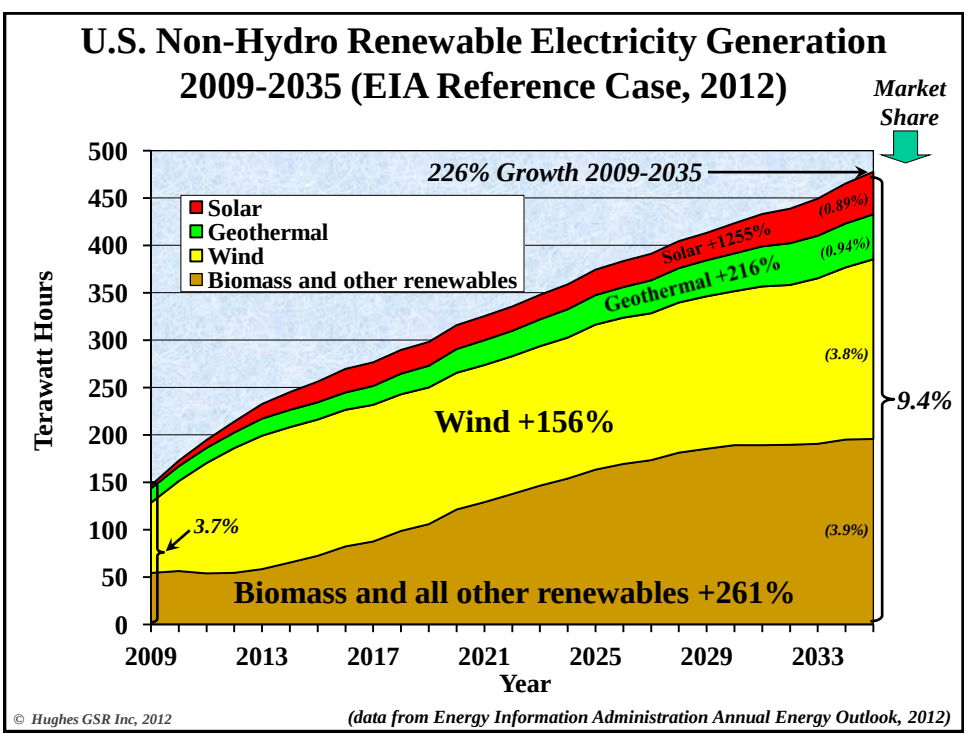

Generation of Electricity: 1990-2010
World
80% increase in Consumption
up 5.9% 2010 over 2009
Asia Pacific
Africa
Middle East
Former Soviet Union
Europe
S. & C. America
North America
238%
110%
240%
-13%
33%
118%
38%
Terawatt Hours
25000
20000
15000
10000
5000
0
1990
1995
2000
2005
2010
Year
North America
38% increase in Consumption
up 3.7% 2010 over 2009
Mexico
Canada
US
120%
32%
36%
Terawatt Hours
6000
5000
4000
3000
2000
1000
0
1990
1995
2000
2005
2010
Year
© Hughes GSR Inc, 2011
(data from BP Statistical Review of World Energy, 2011)


Forecast World Net Electricity Generation by Region
2008-2035 (reference case, EIA, 2011)
OECD
Other Non-OECD
India
China
World 84% total
increase
2008-2035
40%
OECD +36%
53%
Other
Non-OECD +93%
India +179%
China +198%
Terawatt hours
35000
30000
25000
20000
15000
10000
5000
0
2008
2012
2016
2020
2024
2028
2032
Year
© Hughes GSR Inc, 2011
(data from Energy Information Administration International Energy Outlook, 2011)

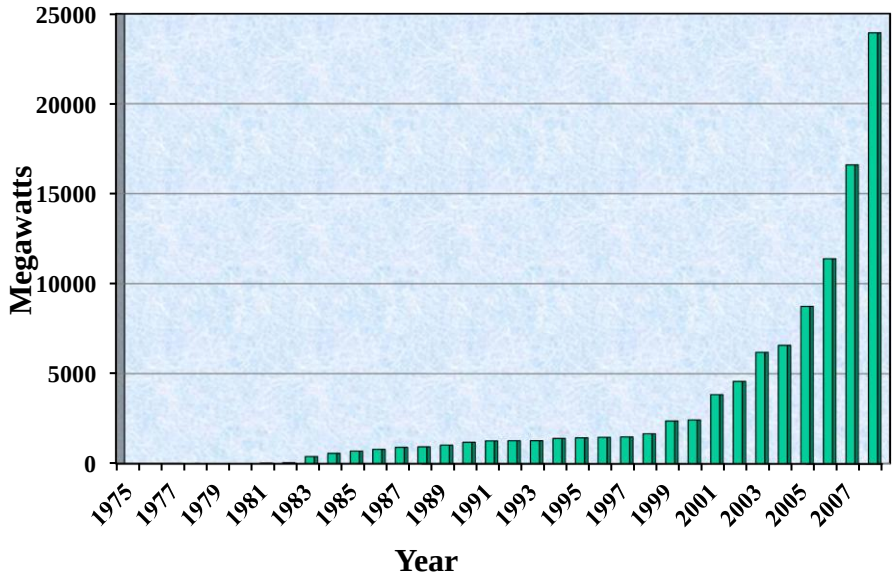

Forecast World Electricity Generation by Fuel 2008-2035 (Reference Case, EIA, 2011)
Market Share
Terawatt Hours
Year
Non-hydro renewables
Hydro
Nuclear
Coal
Gas
Oil
84% Growth 2008-2035
Non-Hydro Renewables +383%
Hydro +80%
Nuclear +89%
Coal +67%
Natural Gas 101%
16%
14%
40%
22%
7%
16%
14%
39%
24%
40000
35000
30000
25000
20000
15000
10000
5000
0
2008
2012
2016
2020
2024
2028
2032
© Hughes GSR Inc, 2011
(data from Energy Information Administration International Energy Outlook, 2011)


World Non-Hydro Renewable Electricity Generation 2008-2035 (EIA Reference Case, 2011)
Market Share
Terawatt Hours
Year
Solar
Geothermal
Wind
All other renewables
383% Growth 2008-2035
Solar+1369%
Geothermal 210%
Wind 596%
Biomass and all other renewables 199%
2.8%
(0.54%)
(0.53%)
(4.2%)
(2.2%)
7.4%
3000
2500
2000
1500
1000
500
0
2008
2012
2016
2020
2024
2028
2032
© Hughes GSR Inc, 2011
(data from Energy Information Administration International Energy Outlook, 2011)


Forecast U.S. Electricity Generation by Fuel
2009-2035 (Reference Case, EIA, 2012)
Market Share
27.9% Growth 2009-2035
Renewables +226%
Large Hydro +23%
Nuclear +12%
Coal +11%
Natural Gas +49%
7%
20%
44%
23%
9%
6%
18%
39%
27%
Terawatt Hours
Year
6000
5000
4000
3000
2000
1000
0
2009
2013
2017
2021
2025
2029
2033
© Hughes GSR Inc, 2012
(data from Energy Information Administration Annual Energy Outlook, 2012)

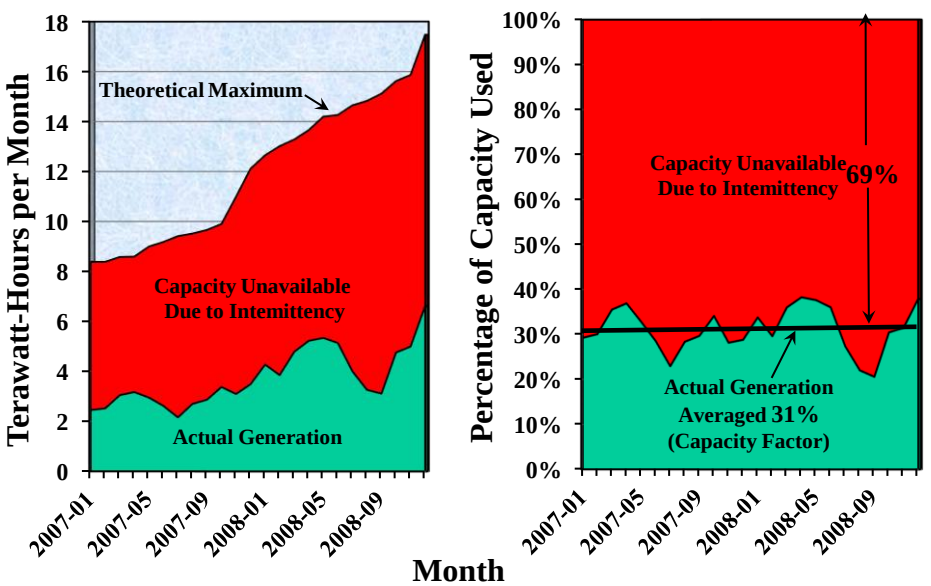

U.S. Non-Hydro Renewable Electricity Generation
2009-2035 (EIA Reference Case, 2012)
Market Share
226% Growth 2009-2035
Solar
Geothermal
Wind
Biomass and other renewables
Solar +1255%
Geothermal +216%
Wind +156%
Biomass and all other renewables +261%
3.7%
(0.89%)
(0.94%)
(3.8%)
(3.9%)
9.4%
Terawatt Hours
Year
500
450
400
350
300
250
200
150
100
50
0
2009
2013
2017
2021
2025
2029
2033
© Hughes GSR Inc, 2012
(data from Energy Information Administration Annual Energy Outlook, 2012)

Total U.S. Wind Generation Nameplate Capacity 1975-2008



(data from Energy Information Administration, 2010)

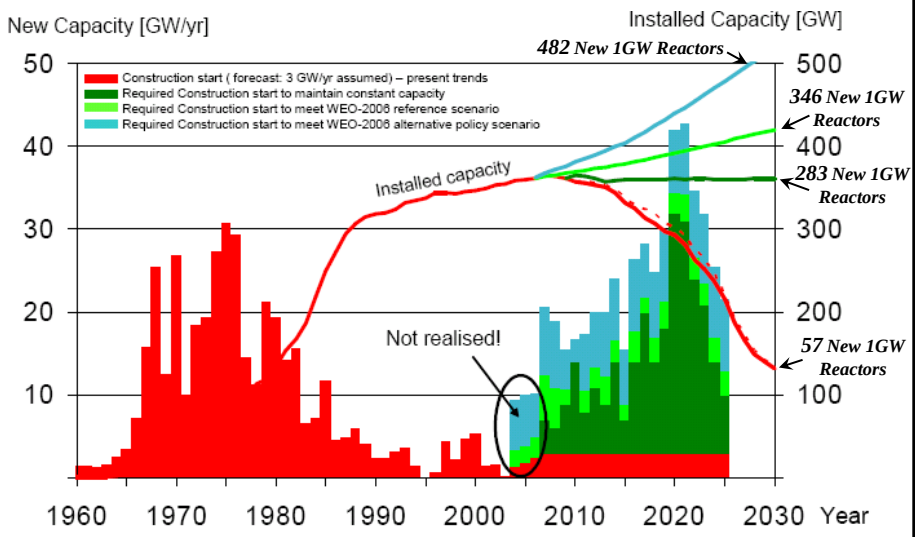
Actual Wind Generation in the U.S. Compared to Nameplate Capacity, 2007-2008



(data from Energy Information Administration, 2010)

WHAT ABOUT "NUCLEAR"?

Generation Capacity at Current Construction Levels and Levels Required to Maintain and/or Increase Nuclear Capacity by 2025



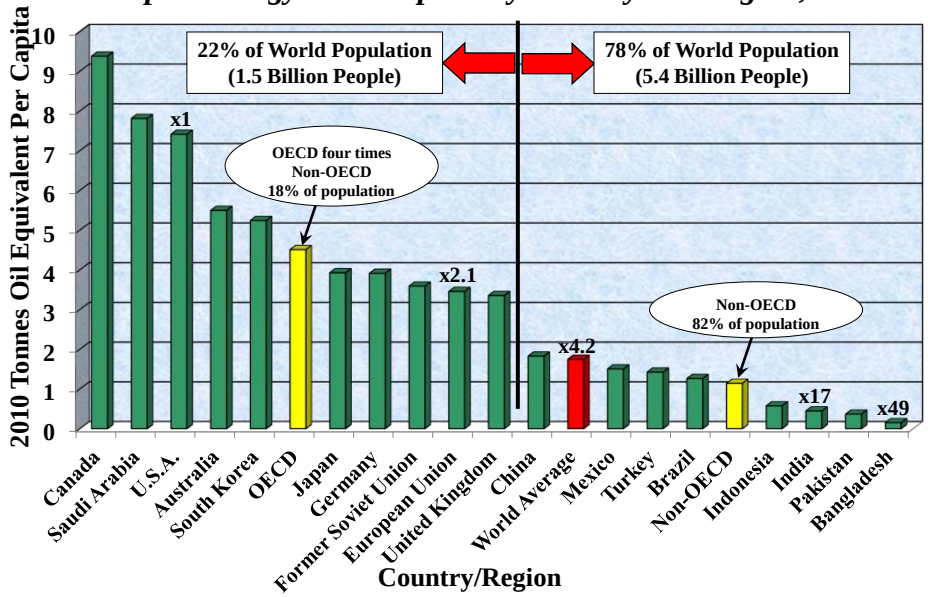
(adapted from Energy Watch Group, Paper EWG Series No. 1/2006, (2006); data from IAEA, (2006))

The Last Piece of the Energy Sustainability Puzzle:

POPULATION GROWTH and ASPIRATIONS OF GROWTH IN ENERGY CONSUMPTION IN THE DEVELOPING WORLD

There is a Great Inequity in Energy Consumption Worldwide

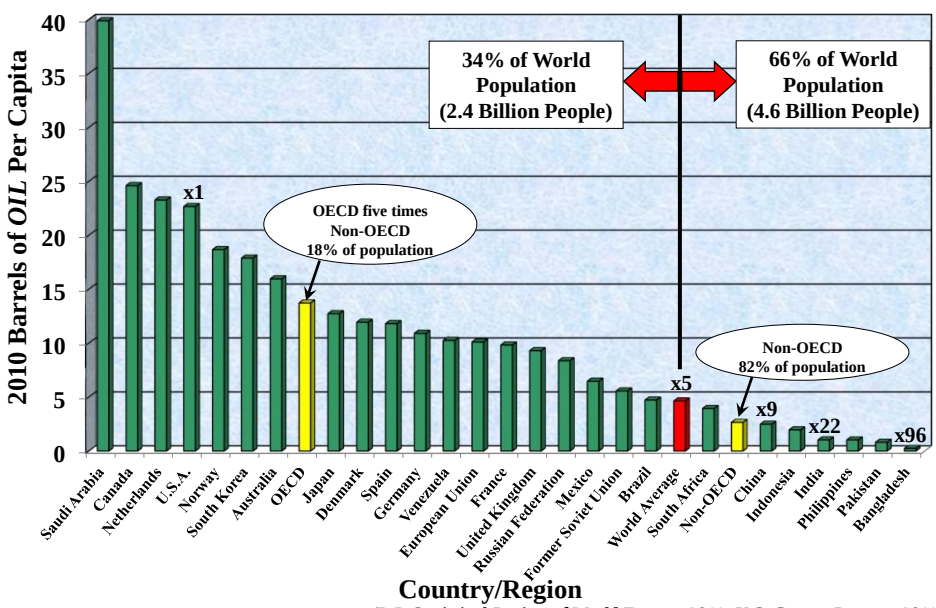
Per Capita Energy Consumption by Country and Region, 2010



(B.P. Statistical Review of World Energy, 2011; U.S. Census Bureau, 2011)

There is a Great Inequity in Energy Consumption Worldwide

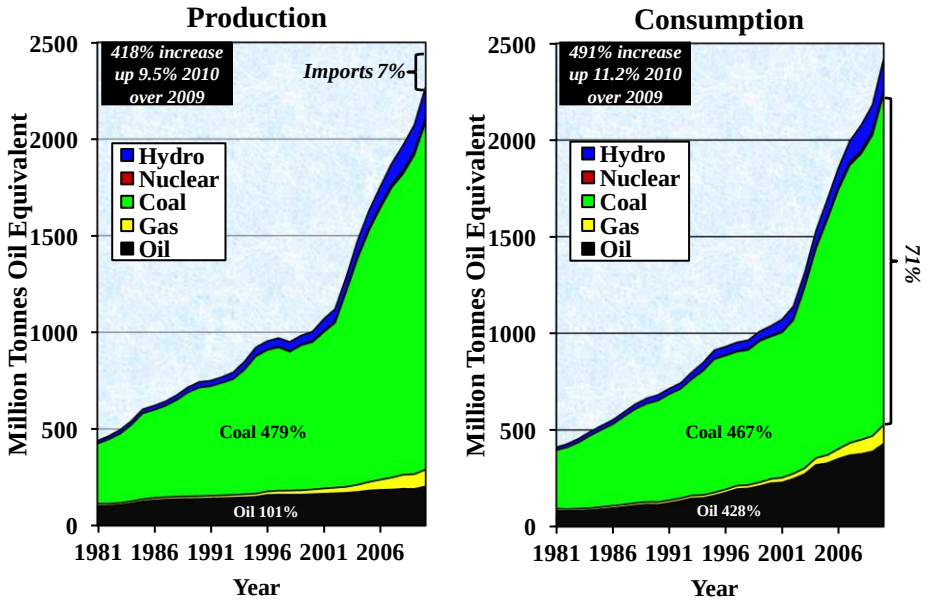
Per Capita OIL Consumption by Country and Region, 2010



(B.P. Statistical Review of World Energy, 2011; U.S. Census Bureau, 2011)

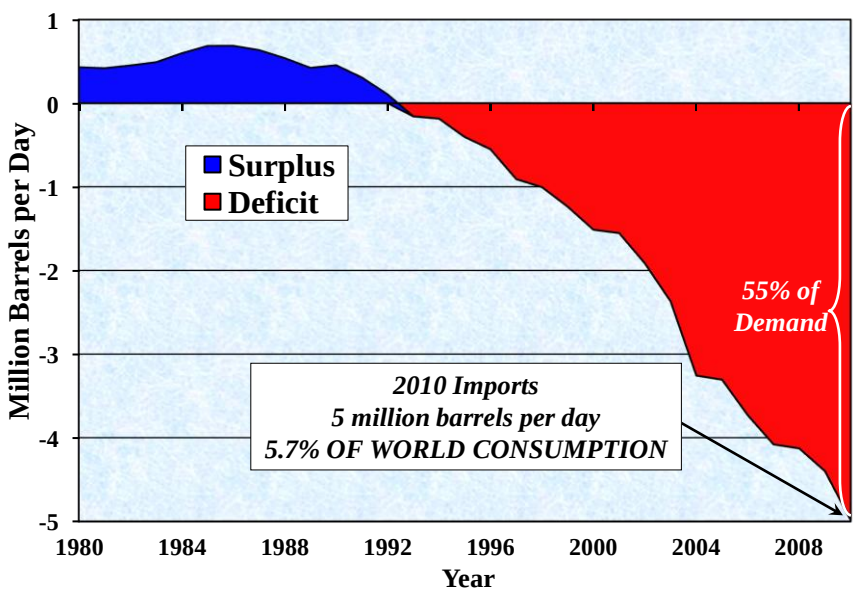
CHINA: The World's Number 1 Consumer of Energy

Primary Energy Production and Consumption by Fuel: 1981-2010



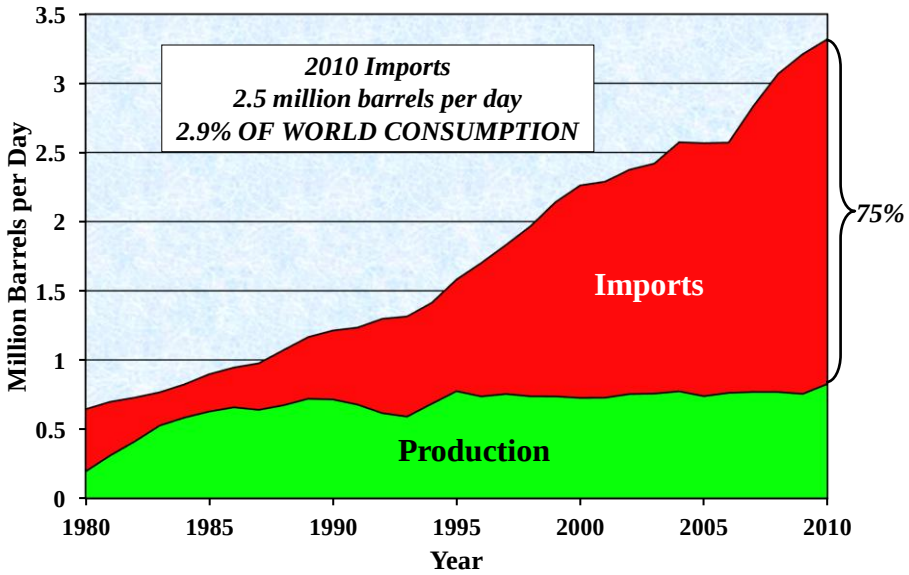
(data from BP Statistical Review of World Energy, 2011)

CHINA's Oil Production Surplus and Deficit 1980-2010



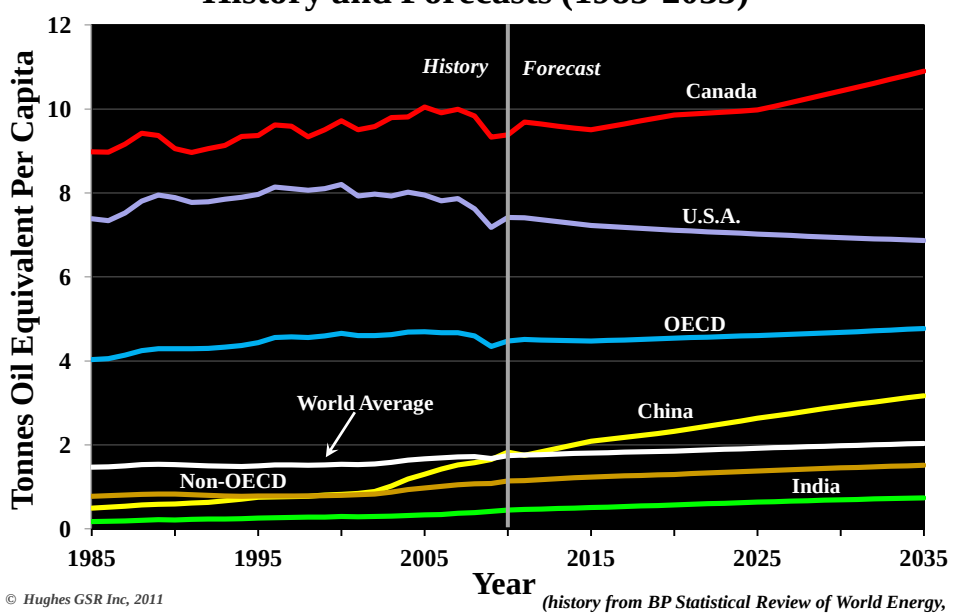
(data from BP Statistical Review of World Energy, 2011)

INDIA's Oil Production and Imports 1980-2010

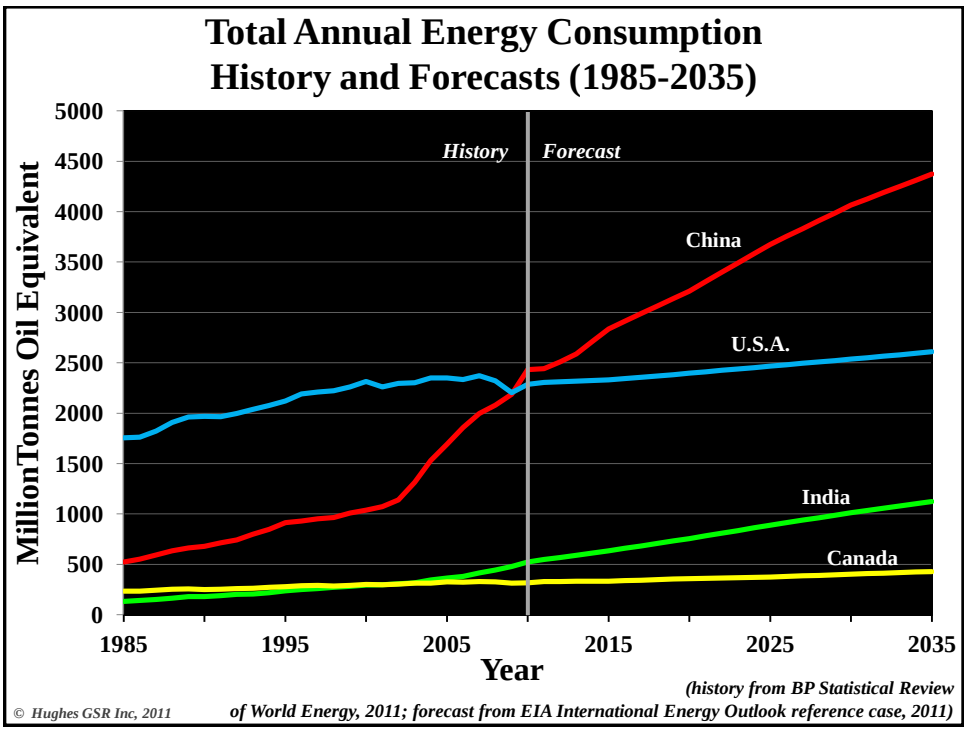


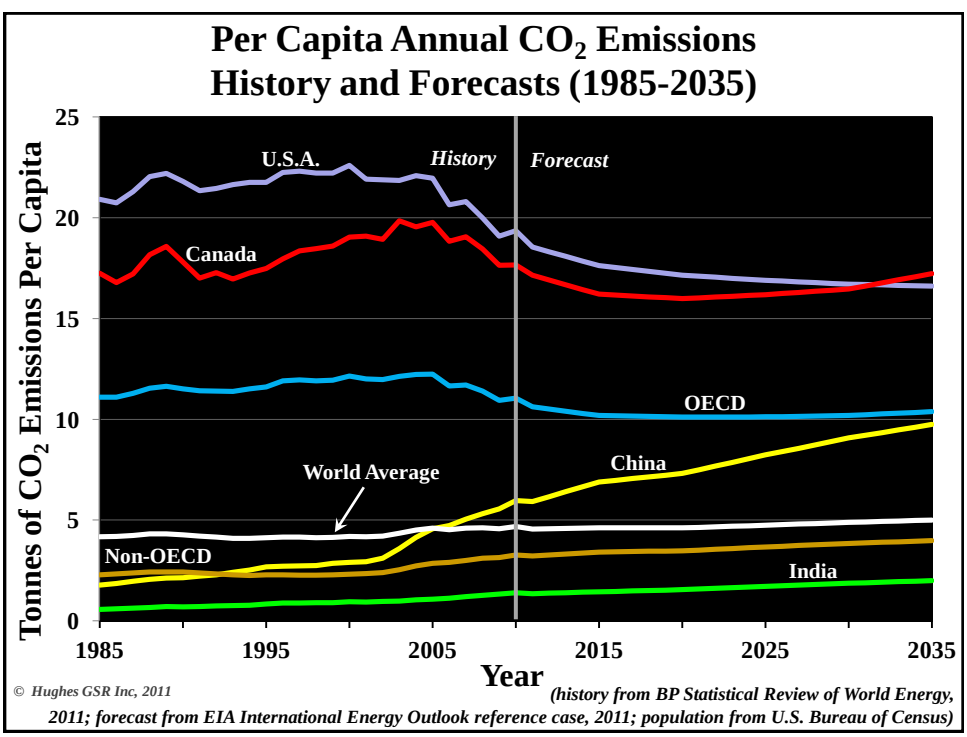
(data from BP Statistical Review of World Energy, 2011)

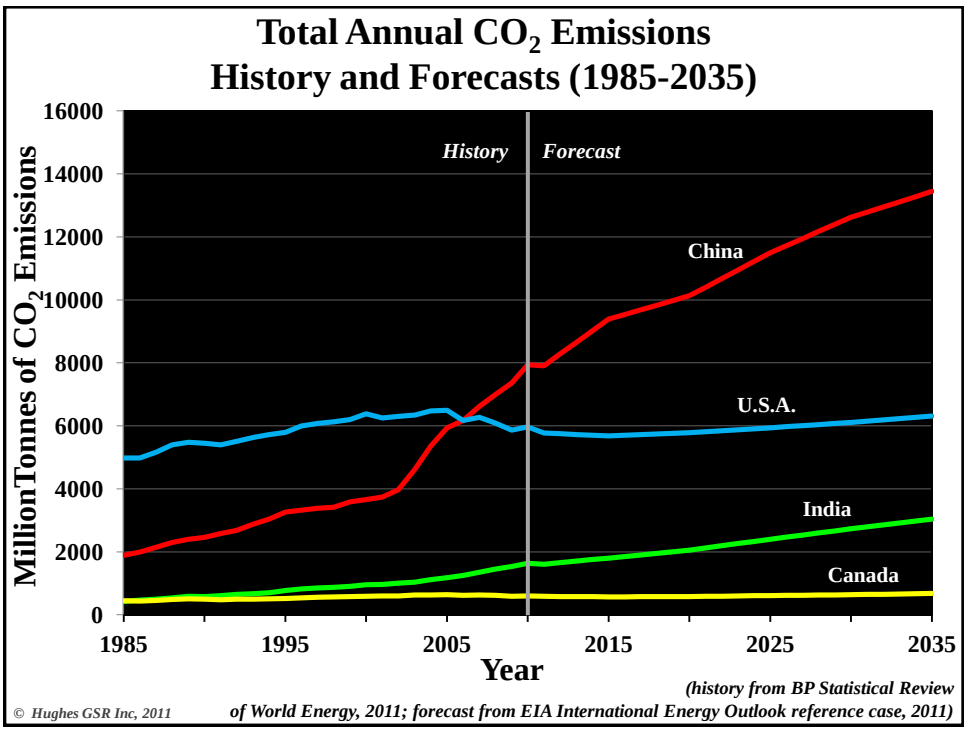
Per Capita Annual Energy Consumption History and Forecasts (1985-2035)

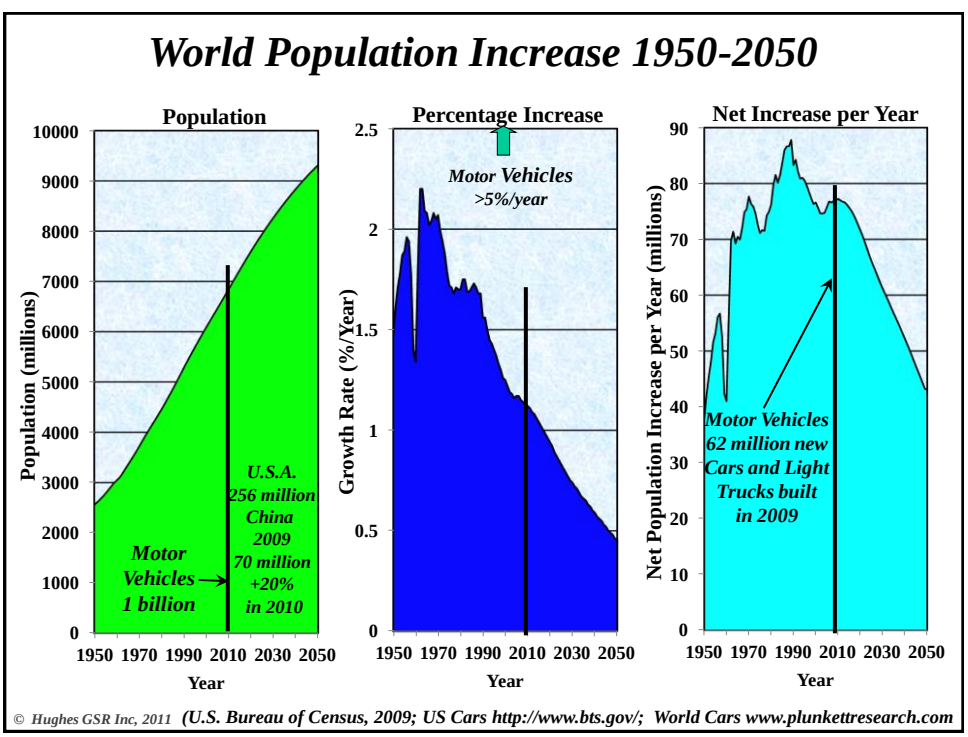


(history from BP Statistical Review of World Energy, 2011; forecast from EIA International Energy Outlook reference case, 2011; population from U.S. Bureau of Census)

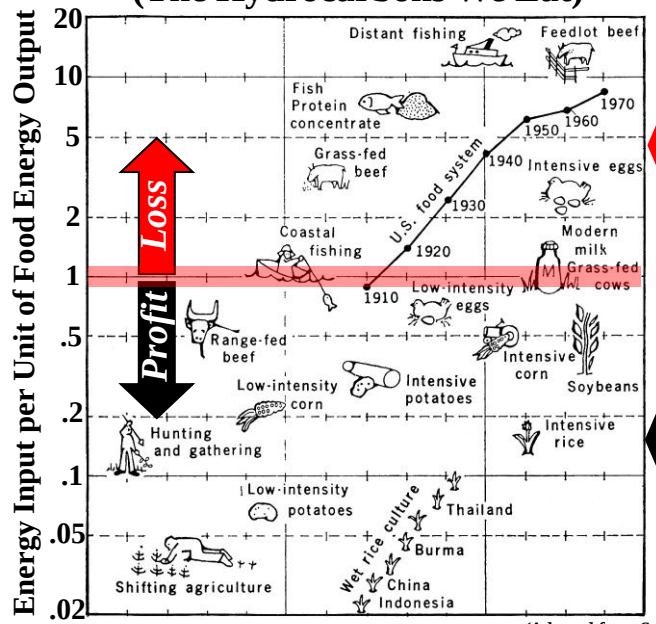

Total Annual Energy Consumption
History and Forecasts (1985-2035)
MillionTonnes Oil Equivalent
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
History
Forecast
China
U.S.A.
India
Canada
1985
1995
2005
2015
2025
2035
Year
© Hughes GSR Inc, 2011
(history from BP Statistical Review of World Energy, 2011; forecast from EIA International Energy Outlook reference case, 2011)


Per Capita Annual CO_2 Emissions
History and Forecasts (1985-2035)
Tonnes of CO_2 Emissions Per Capita
25
20
15
10
5
0
U.S.A.
History
Forecast
Canada
OECD
World Average
China
Non-OECD
India
1985
1995
2005
2015
2025
2035
Year
© Hughes GSR Inc, 2011
(history from BP Statistical Review of World Energy, 2011; forecast from EIA International Energy Outlook reference case, 2011; population from U.S. Bureau of Census)


Total Annual CO_2 Emissions
History and Forecasts (1985-2035)
Million Tonnes of CO_2 Emissions
16000
14000
12000
10000
8000
6000
4000
2000
0
History
Forecast
China
U.S.A.
India
Canada
1985
1995
2005
2015
2025
2035
Year
(history from BP Statistical Review
of World Energy, 2011; forecast from EIA International Energy Outlook reference case, 2011)
© Hughes GSR Inc, 2011

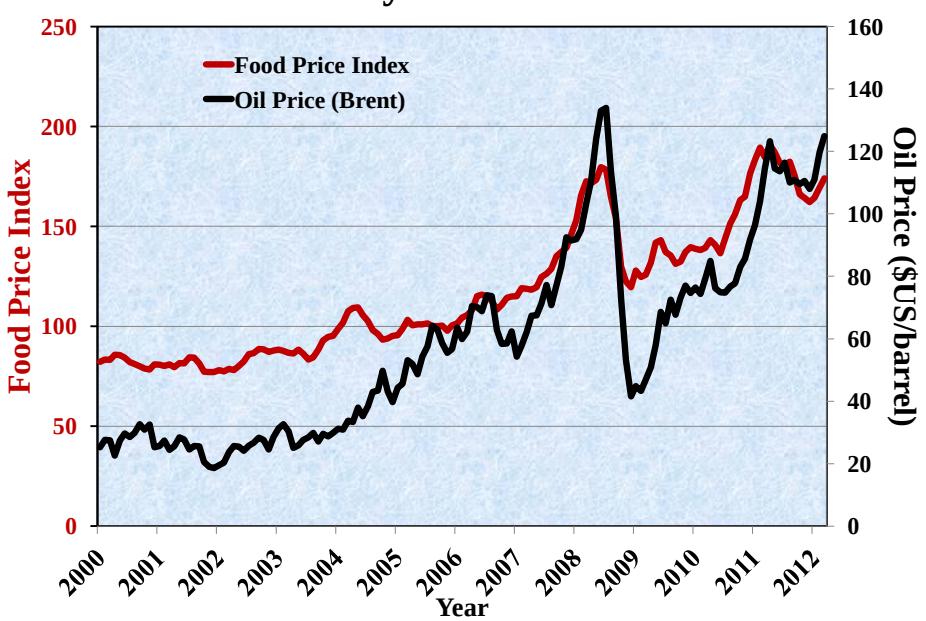

World Population Increase 1950-2050
Population
Population (millions)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Motor Vehicles 1 billion
U.S.A. 256 million
China 2009 70 million +20% in 2010
1950 1970 1990 2010 2030 2050
Year
Percentage Increase
Growth Rate (%/Year)
2.5
2
1.5
1
0.5
0
Motor Vehicles >5%/year
1950 1970 1990 2010 2030 2050
Year
Net Increase per Year
Net Population Increase per Year (millions)
90
80
70
60
50
40
30
20
10
0
Motor Vehicles 62 million new Cars and Light Trucks built in 2009
1950 1970 1990 2010 2030 2050
Year
© Hughes GSR Inc, 2011
(U.S. Bureau of Census, 2009; US Cars http://www.bts.gov/; World Cars www.plunkettresearch.com

Trends in Energy Investment for Food Production (The Hydrocarbons We Eat)



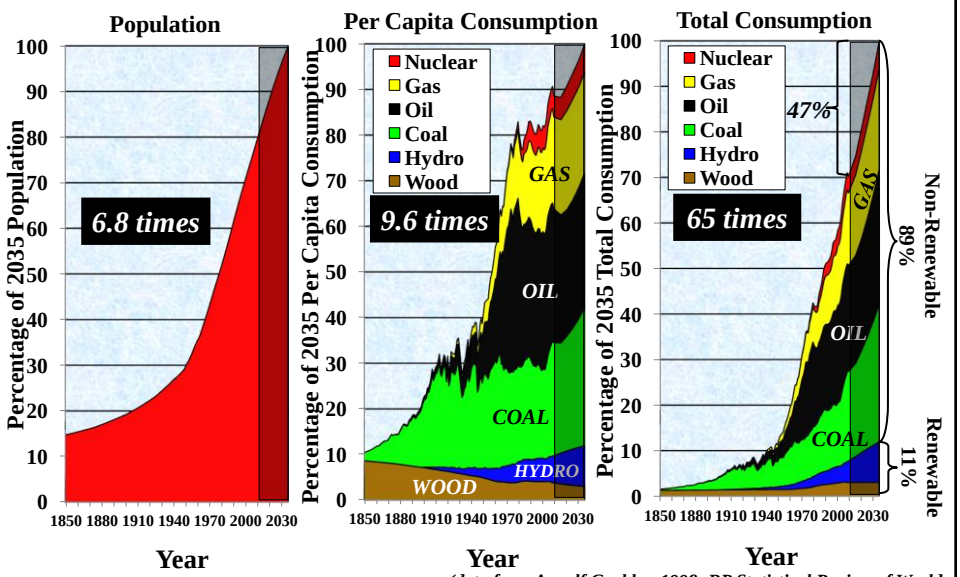
(Adapted from Science, April 19, 1974)

Food Commodity Price Index vs Oil Price



(International Monetary Fund, 2012)

World Population, Per Capita and Primary Energy Consumption, 1850-2035, as a Percentage of 2035 Levels



(data from Arnulf Grubler, 1998; BP Statistical Review of World Energy, 2010; U.S. Bureau of Census, 2010); EIA IEO, Reference Case, 2010)

"Anyone who believes *EXPONENTIAL GROWTH* can go on forever in a finite world is either a madman or an economist"

(Economist Kenneth Boulding, early '70's)

"The term *'SUSTAINABLE GROWTH'* is an Oxymoron"

(Albert A. Bartlett, 2000)

Summary and Implications

- **Achieving a sustainable energy system is likely to be the defining issue of our time as the economic growth paradigm abuts physical limits to growth.**
- **In an era of constrained energy the correlation of economic growth with energy supply and price will set the stage for economic and geopolitical volatility and intense competition for energy resources.**
- **The Climate Change dialogue for the most part excludes any consideration of resource limitations on growth, and hence leads us down some counter productive pathways, although initiatives on conservation, efficiency and renewables fortuitiously also address the energy question.**
- **Hydrocarbons represent an extremely convenient, dense form of non-renewable energy for which there are *NO SCALABLE ALTERNATIVES*. They will be needed for the development of infrastructure for the next paradigm of more sustainable human development.**
- **A sustainable energy future is not out of reach but will be hugely challenging – the U.S. and Canada have no real energy strategy – this must be a high priority for the future.**