Fossil-Fuels Energy

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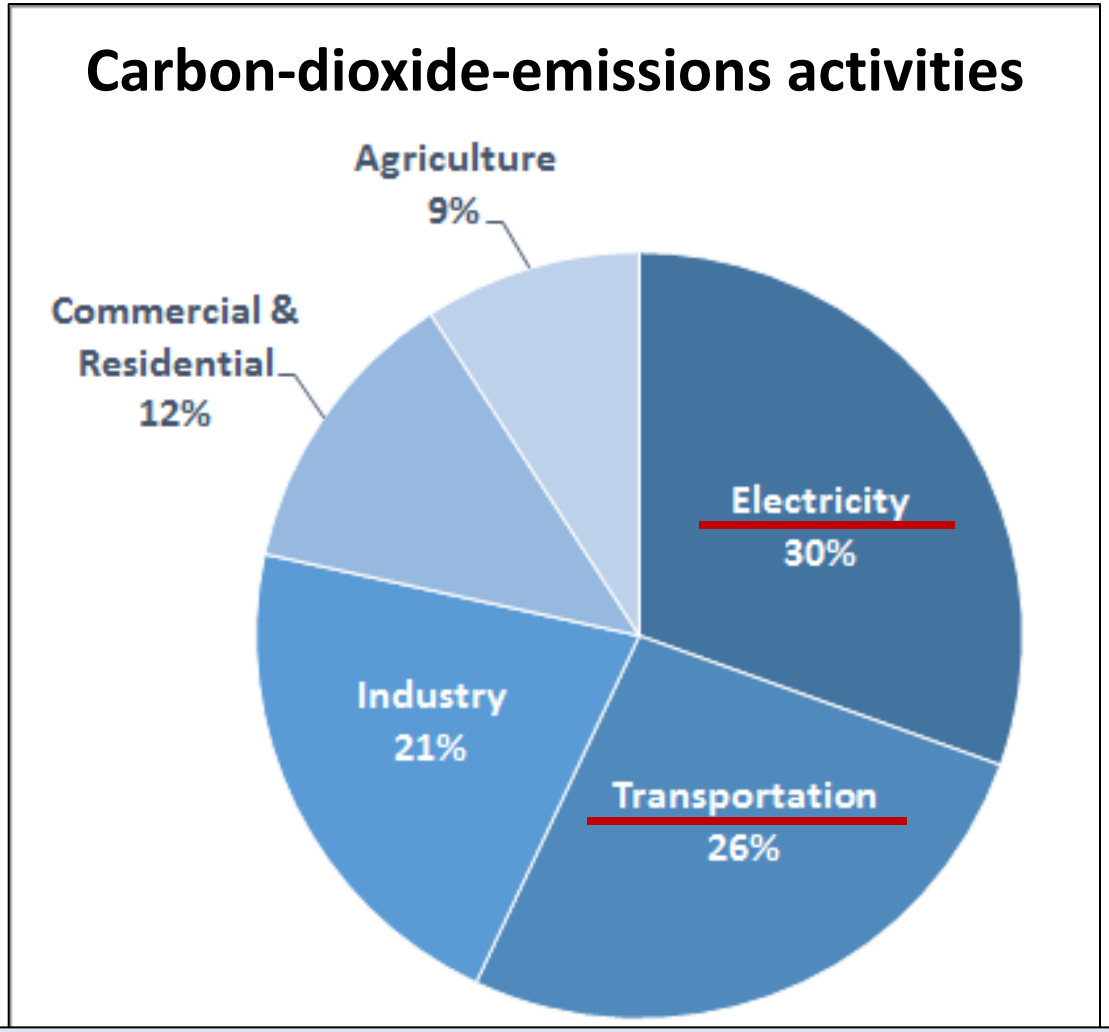
http://tinyurl.com/FossilFuelsEnergy

Agenda

- Global Warming due to Fossil-Fuels burning
- Nonrenewable-Resources Depletion Theory
- Crude-Oil Extraction
- Natural-Gas Extraction
- Coal Extraction
- Uranium Extraction
- Long-Term Future for the Earth
- Renewable Energy (next semester)
  tinyurl.com/SustainableEnergyRoper

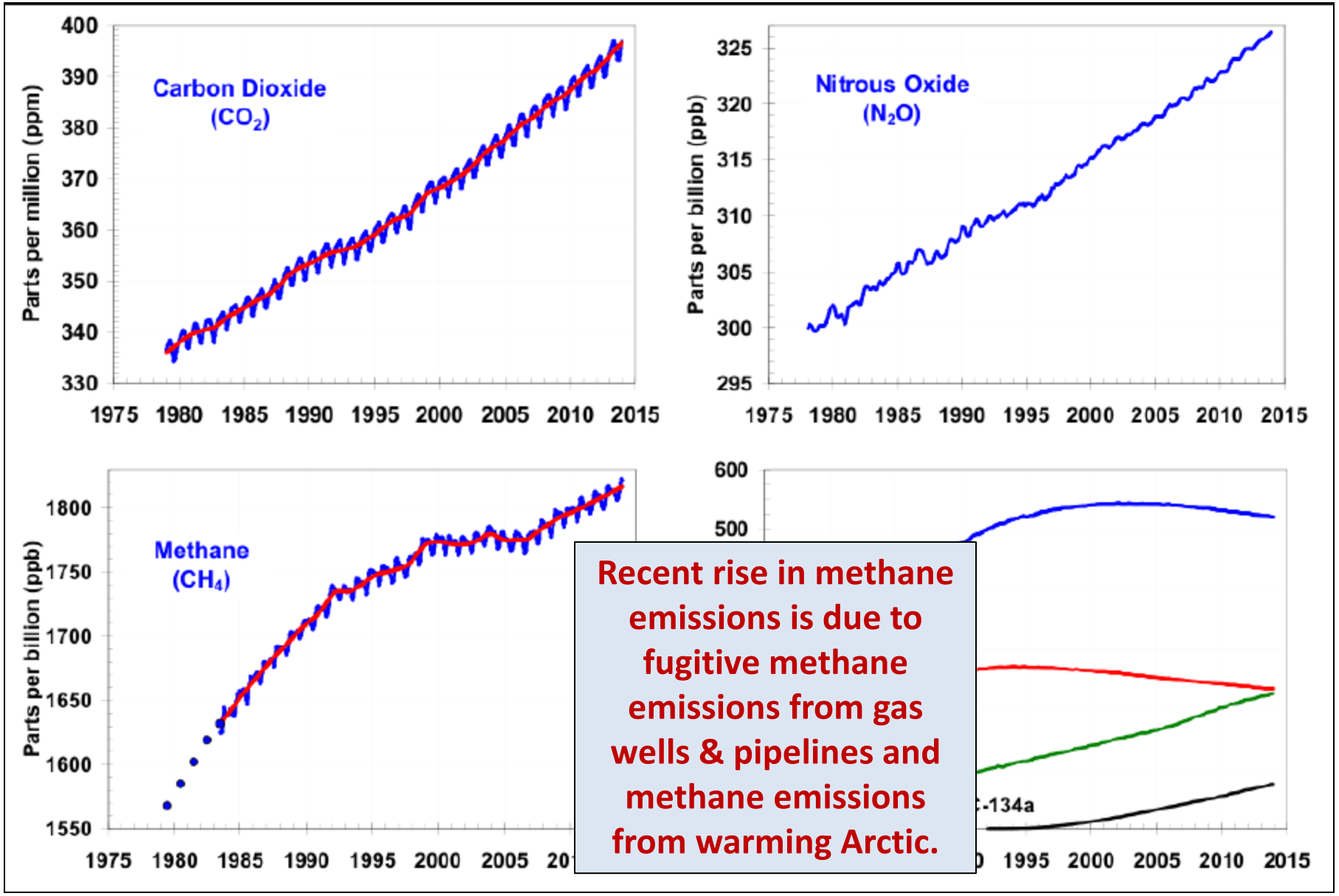
Causes of Global Warming

Too many people is basic cause!

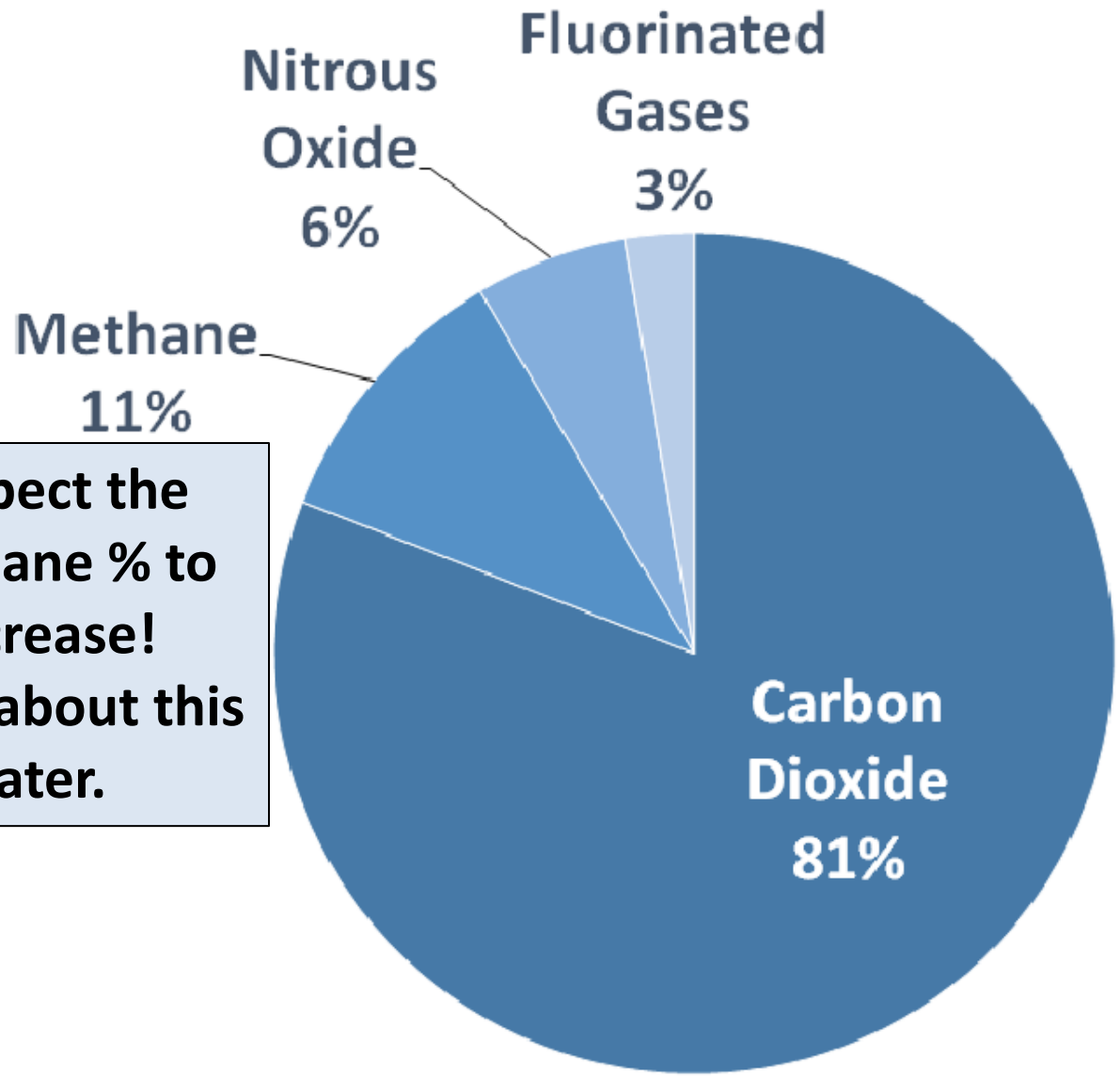


We need renewable electrical energy & electric transport!

Greenhouse Gases (GHG)



U.S. Greenhouse Gas Emissions in 2014



I expect the methane % to increase! More about this later.

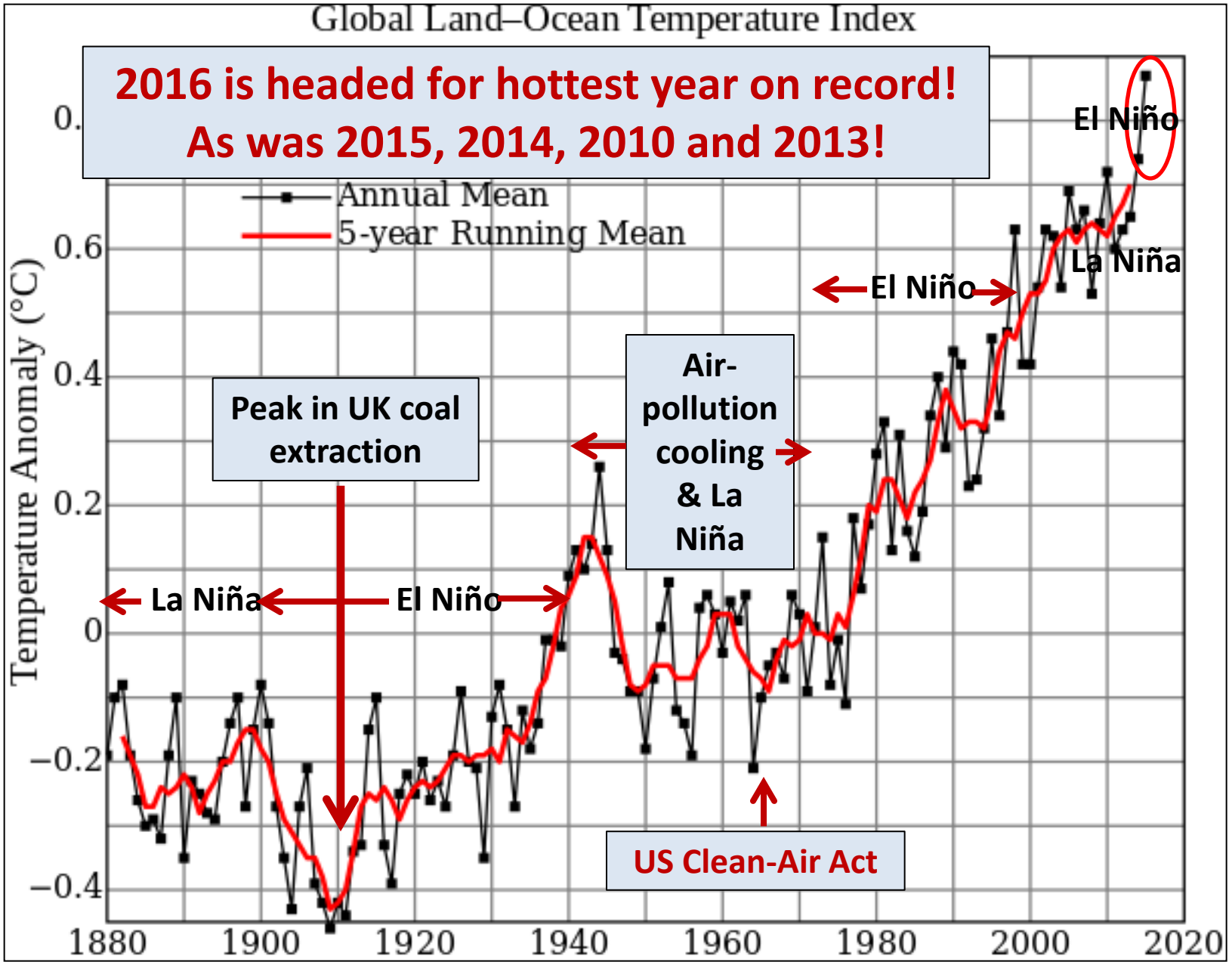
Effects of Global Warming

- Severe **droughts** due to high evaporation
- Severe **floods** due to huge downpours
- Increasing **forest fires** due to droughts
- Severe **destructive storms** (e.g., hurricanes, tornados, high winds, huge snows)
- Rising sea levels
- Acidification of oceans
- Food and water shortages
- Human migrations and survival wars (E.g. Syria!)
- Ecosystems shifting northward and upward
- Species extinction
- **Feedbacks leading to increased Global Warming**

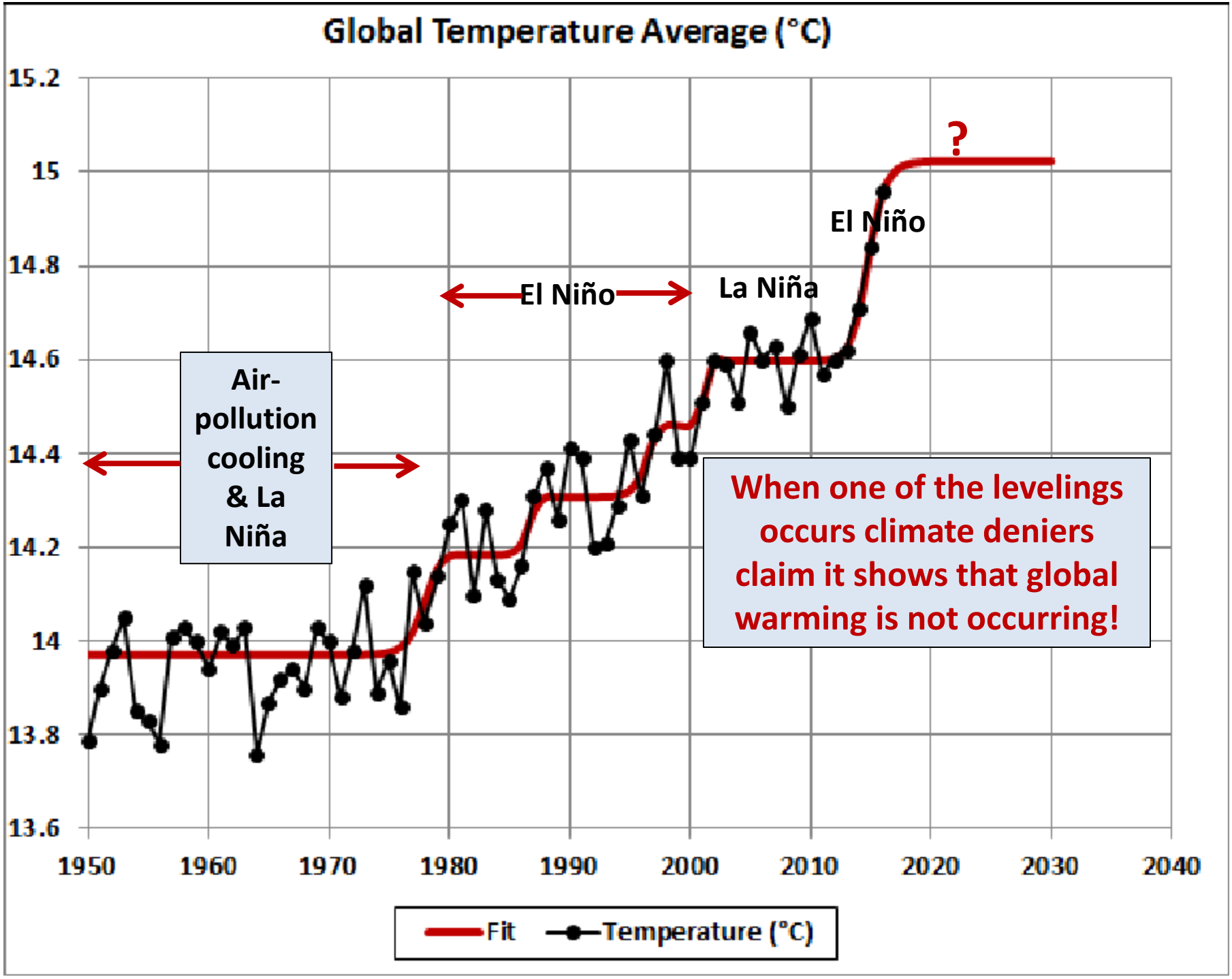
Dangerous Global Warming Feedbacks

- **High temperature** increases moisture in the air, a powerful greenhouse gas. It doubles the temperature increase of CO_2.
- **Forest fires** due to **droughts** stop trees' intake of carbon dioxide and add heat to the atmosphere. (Smoke can cause a short-term cooling effect.)
- **Sea ice melting** increases sea area and, thus, solar absorption by a factor of ~6.
- **Sea ice melting** increases sea waves that break up ice causing it to melt faster.
- **Rising sea level** increases water surface to absorb solar energy more than covered land by a factor of ~3.
- Rising **Arctic temperature** causes **tundra** to release **bound carbon dioxide and methane** into the air.
- Rising **ocean temperature** causes **bottom methane structures** to release methane into the air. (More later)

El Niño increases global warming & La Niña decreases global warming.

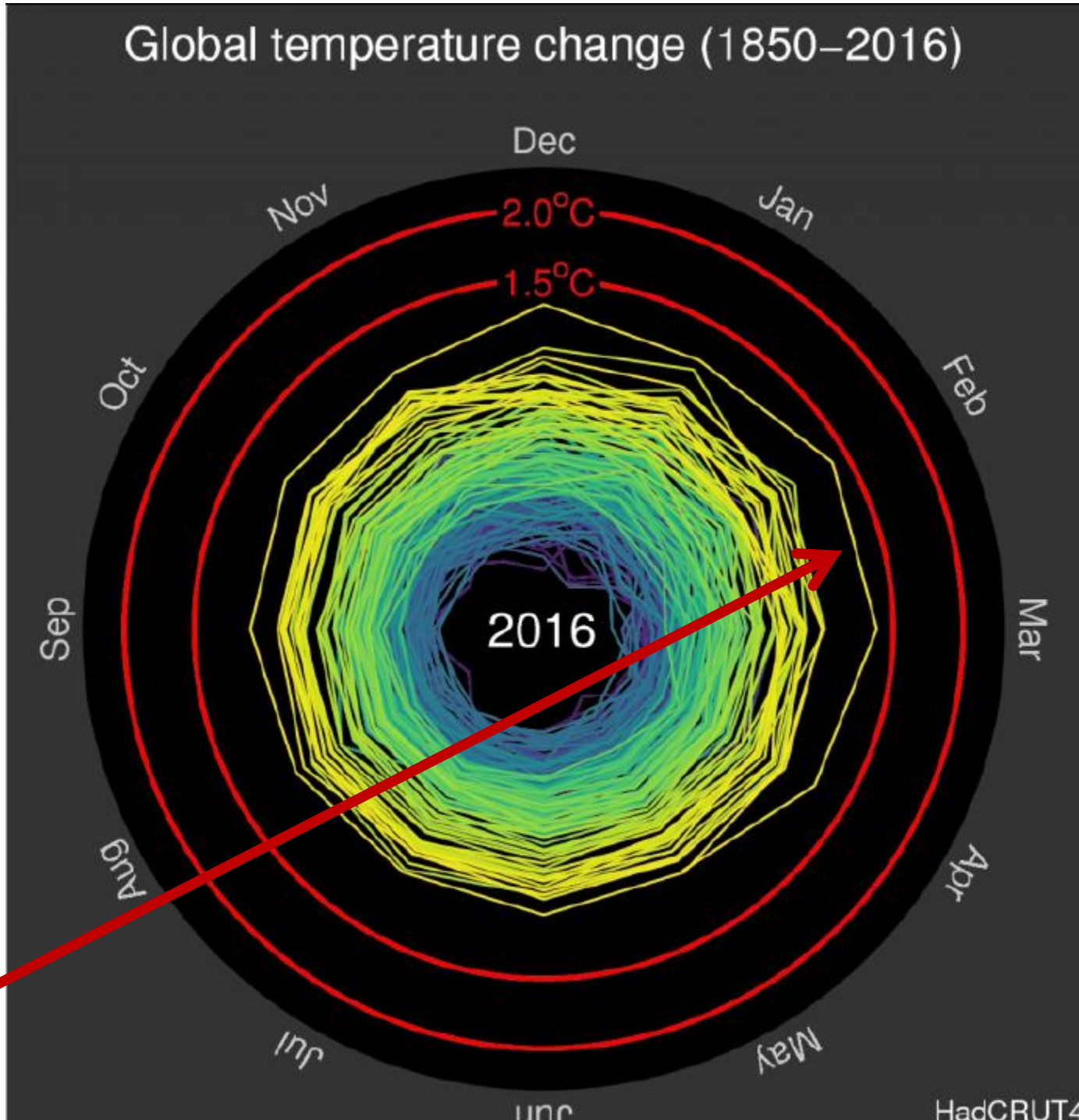


https://en.wikipedia.org/wiki/Effects_of_global_warming

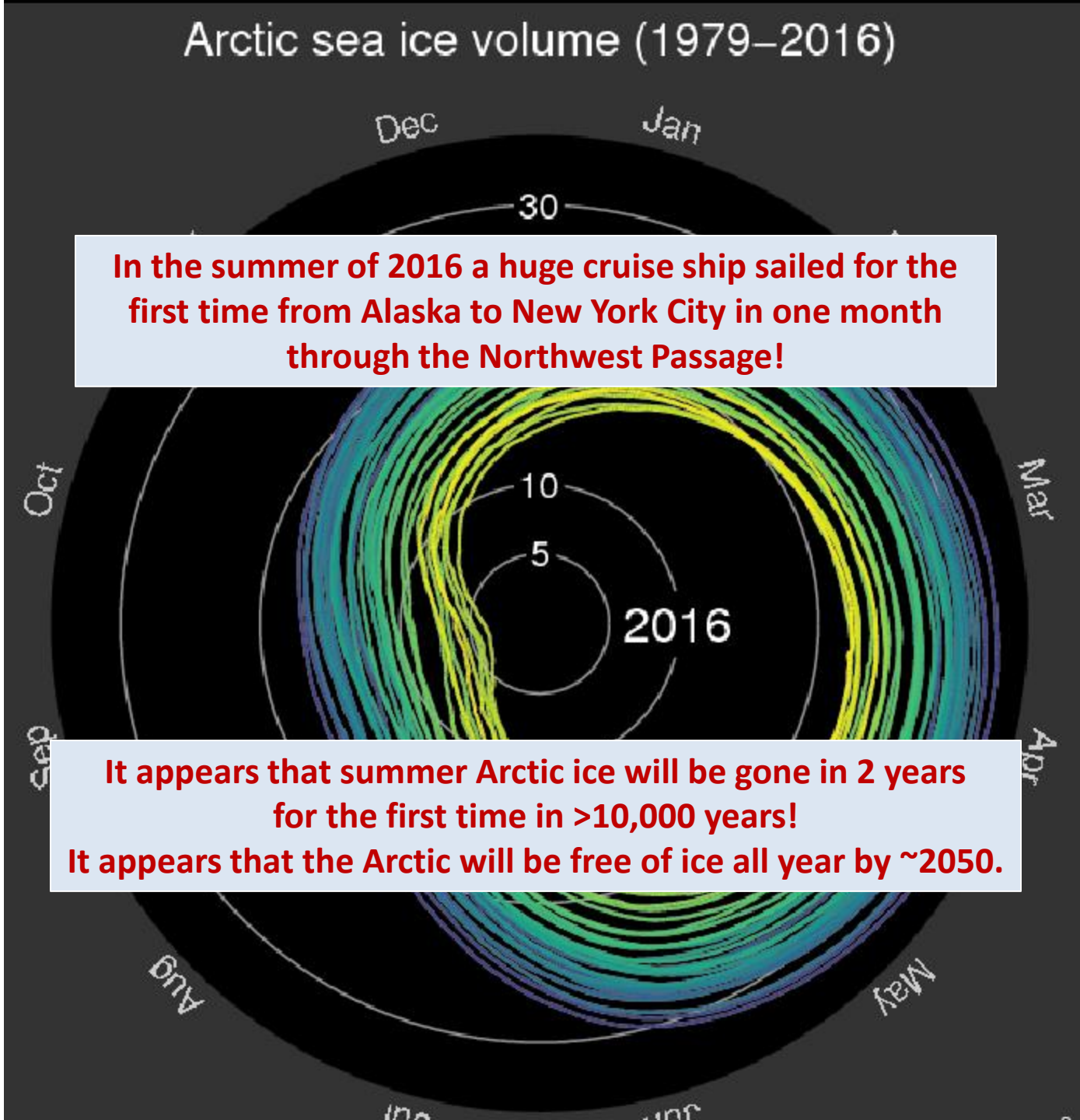

Global Temperature Average (°C)
15.2
15
14.8
14.6
14.4
14.2
14
13.8
13.6
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
?
El Niño
El Niño
La Niña
Air-pollution cooling & La Niña
When one of the levelings occurs climate deniers claim it shows that global warming is not occurring!
Fit
Temperature (°C)

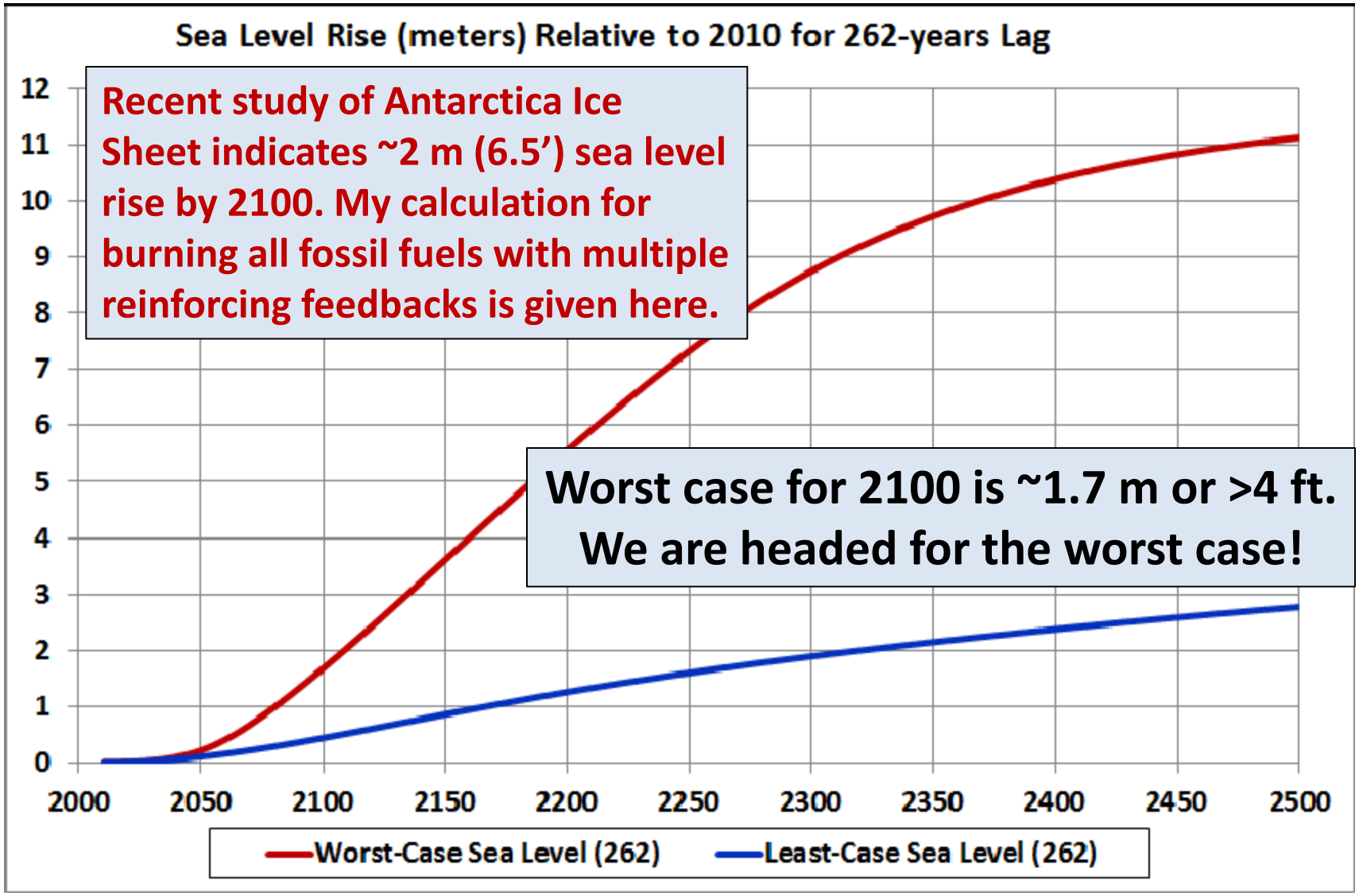
Colors represent time: Purple for early years, through blue, green to yellow for most recent years.

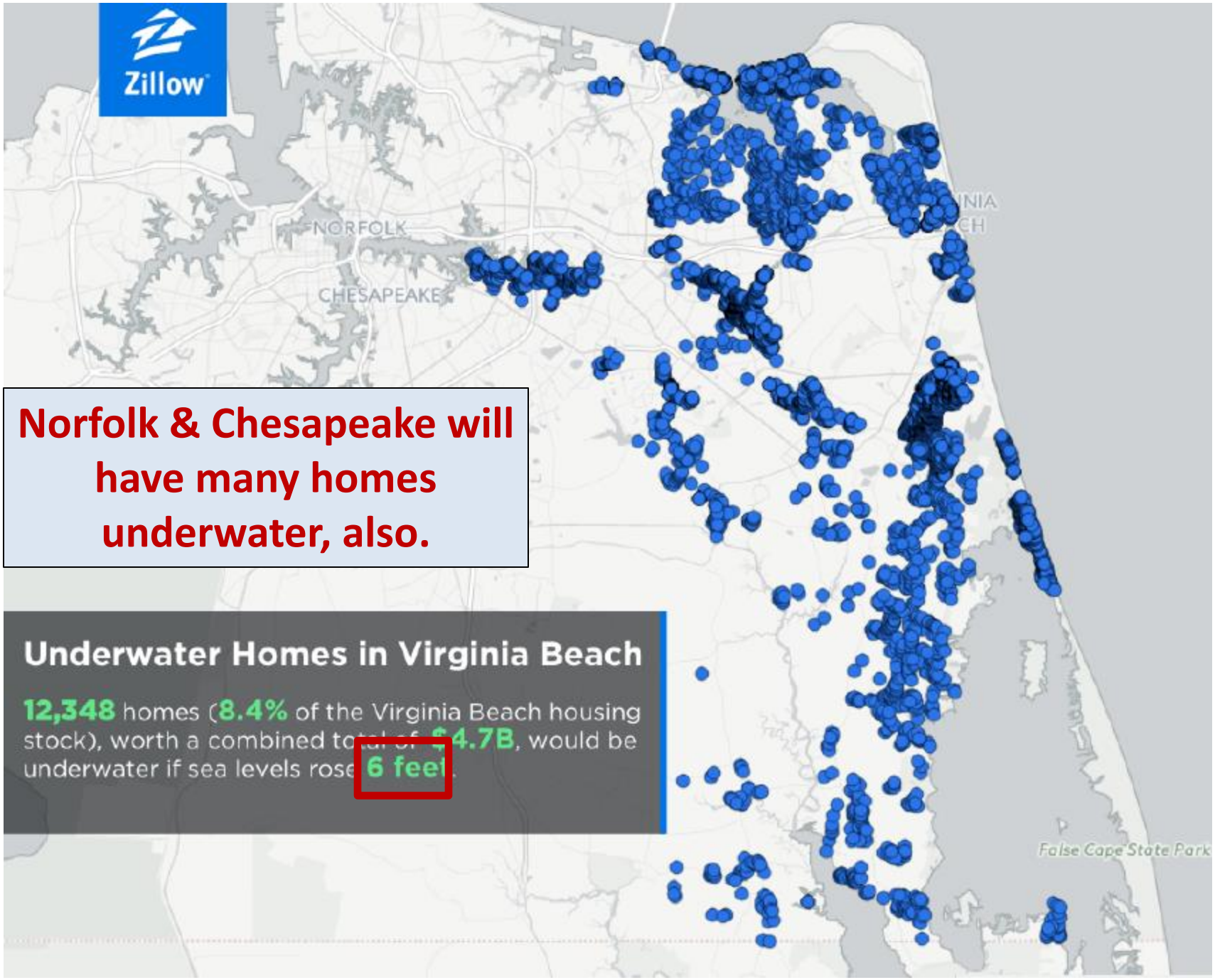
2.0°C above pre-industrial global temperature is the threshold set by the international community. Most climatologists say it should be 1.5°C. 2016 is hottest!!



Colors represent time: Purple for early years, through blue, green to yellow for most recent years.




Sea Level Rise (meters) Relative to 2010 for 262-years Lag
Recent study of Antarctica Ice Sheet indicates ~2 m (6.5') sea level rise by 2100. My calculation for burning all fossil fuels with multiple reinforcing feedbacks is given here.
Worst case for 2100 is ~1.7 m or >4 ft.
We are headed for the worst case!
12
11
10
9
8
7
6
5
4
3
2
1
0
2000
2050
2100
2150
2200
2250
2300
2350
2400
2450
2500
Worst-Case Sea Level (262)
Least-Case Sea Level (262)

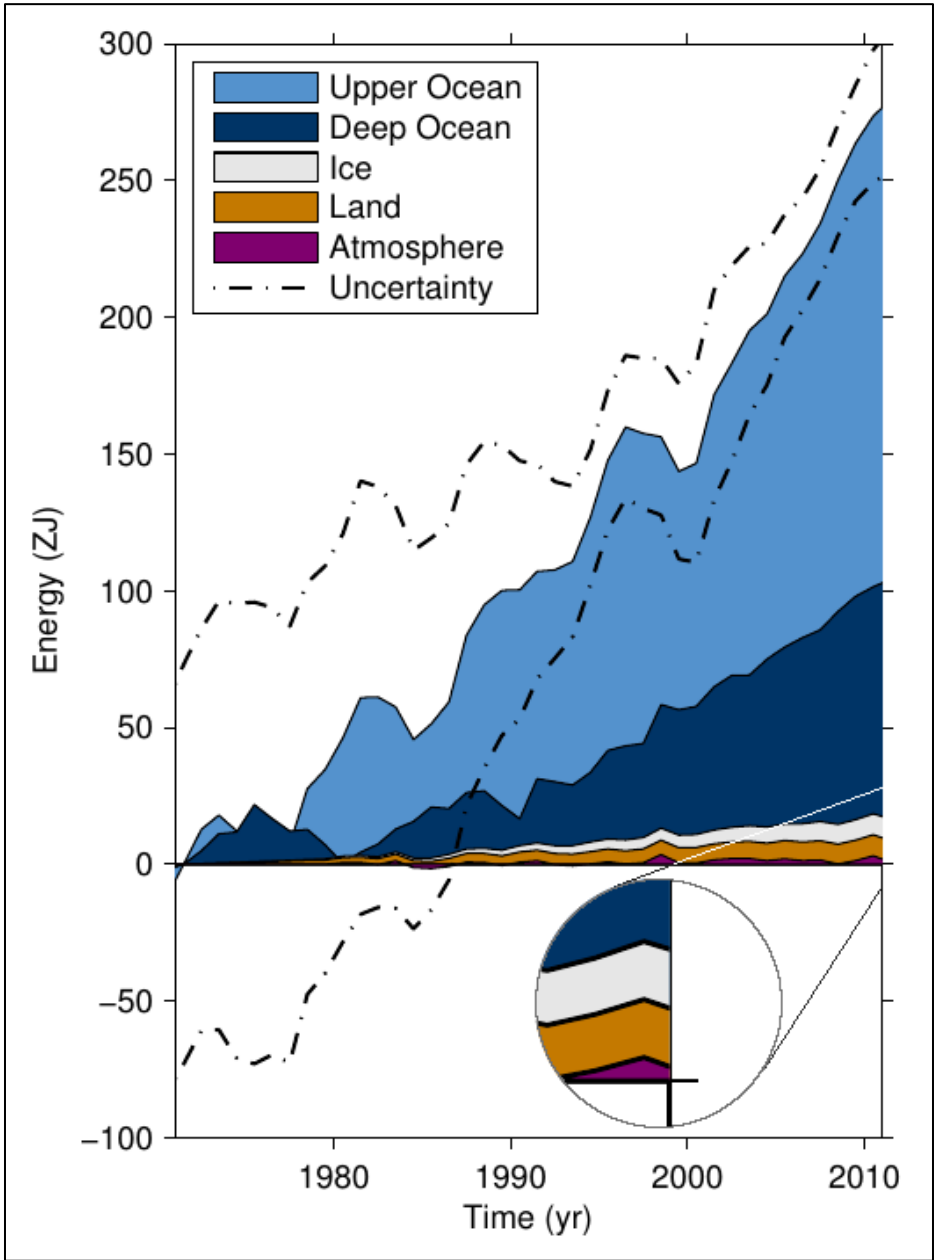

Zillow
NORFOLK
CHESAPEAKE
Norfolk & Chesapeake will have many homes underwater, also.
Underwater Homes in Virginia Beach
12,348 homes (8.4% of the Virginia Beach housing stock), worth a combined total of $4.7B, would be underwater if sea levels rose 6 feet.
False Cape State Park

Where is the Heat Energy Stored?

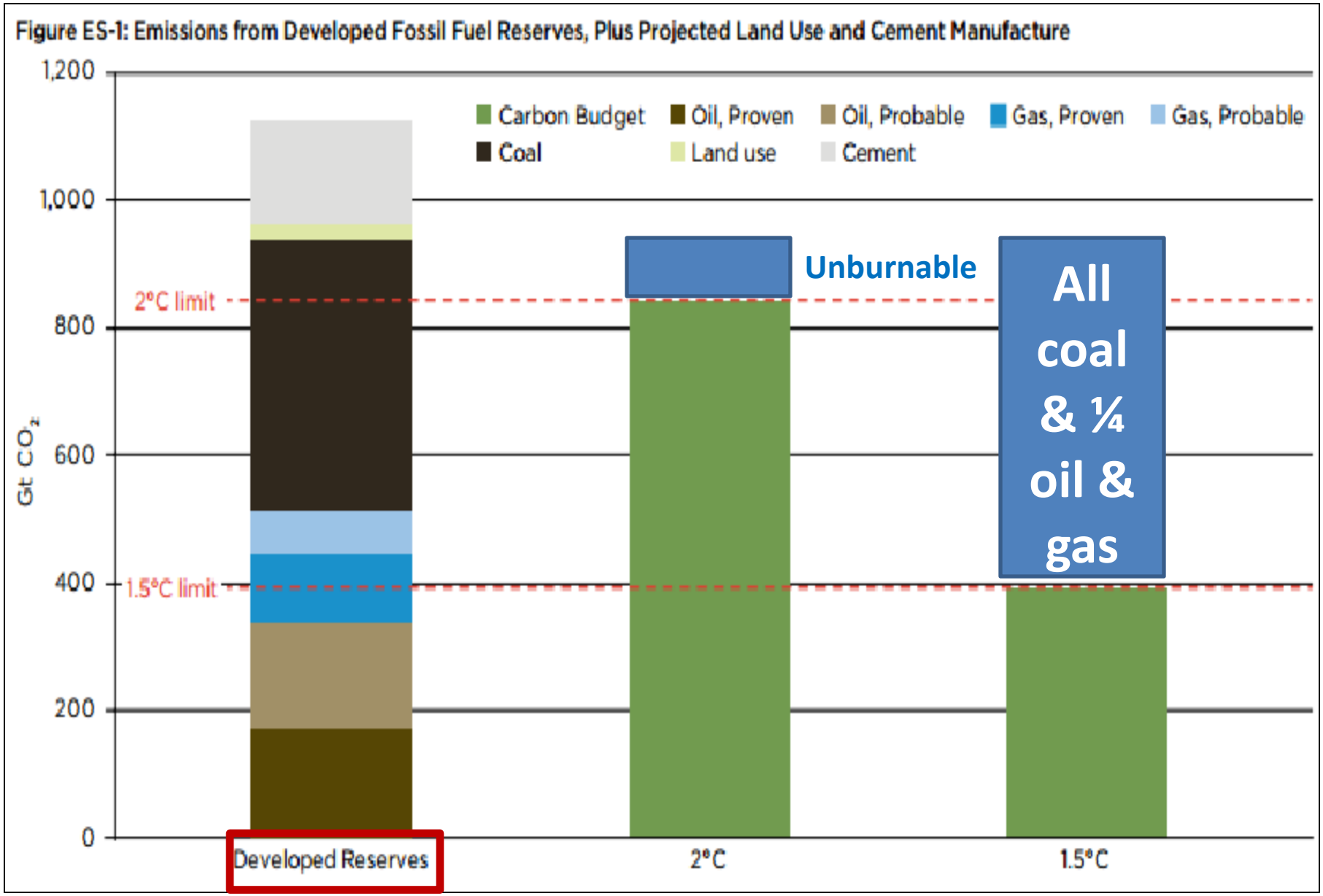
[Climate Change 2013: The Physical Science Basis]

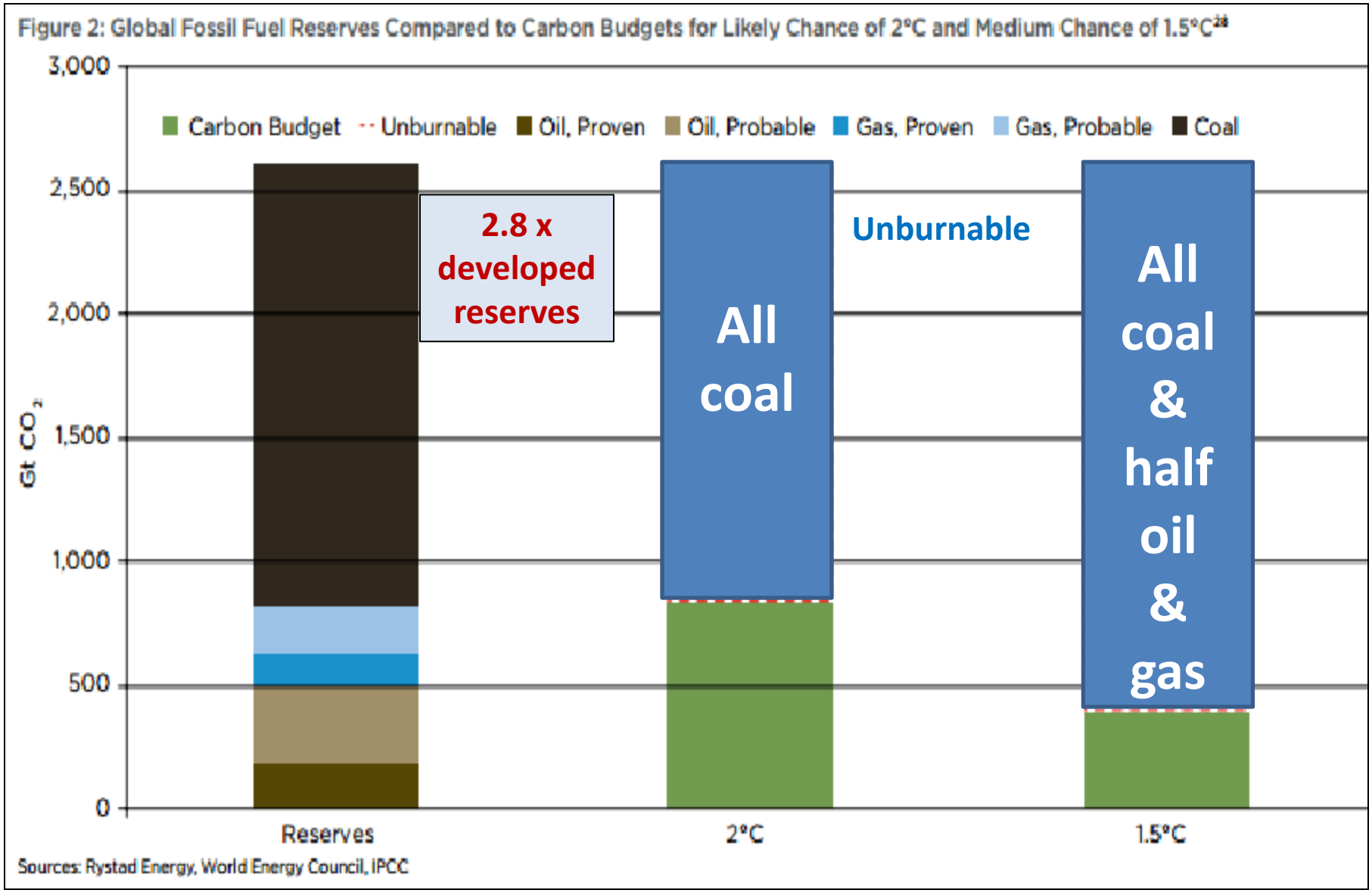
Most global-warming heat energy is stored in the oceans. It will be released slowly into the atmosphere after greenhouse gases in atmosphere are reduced,

causing continuing atmosphere warming for hundreds of years.



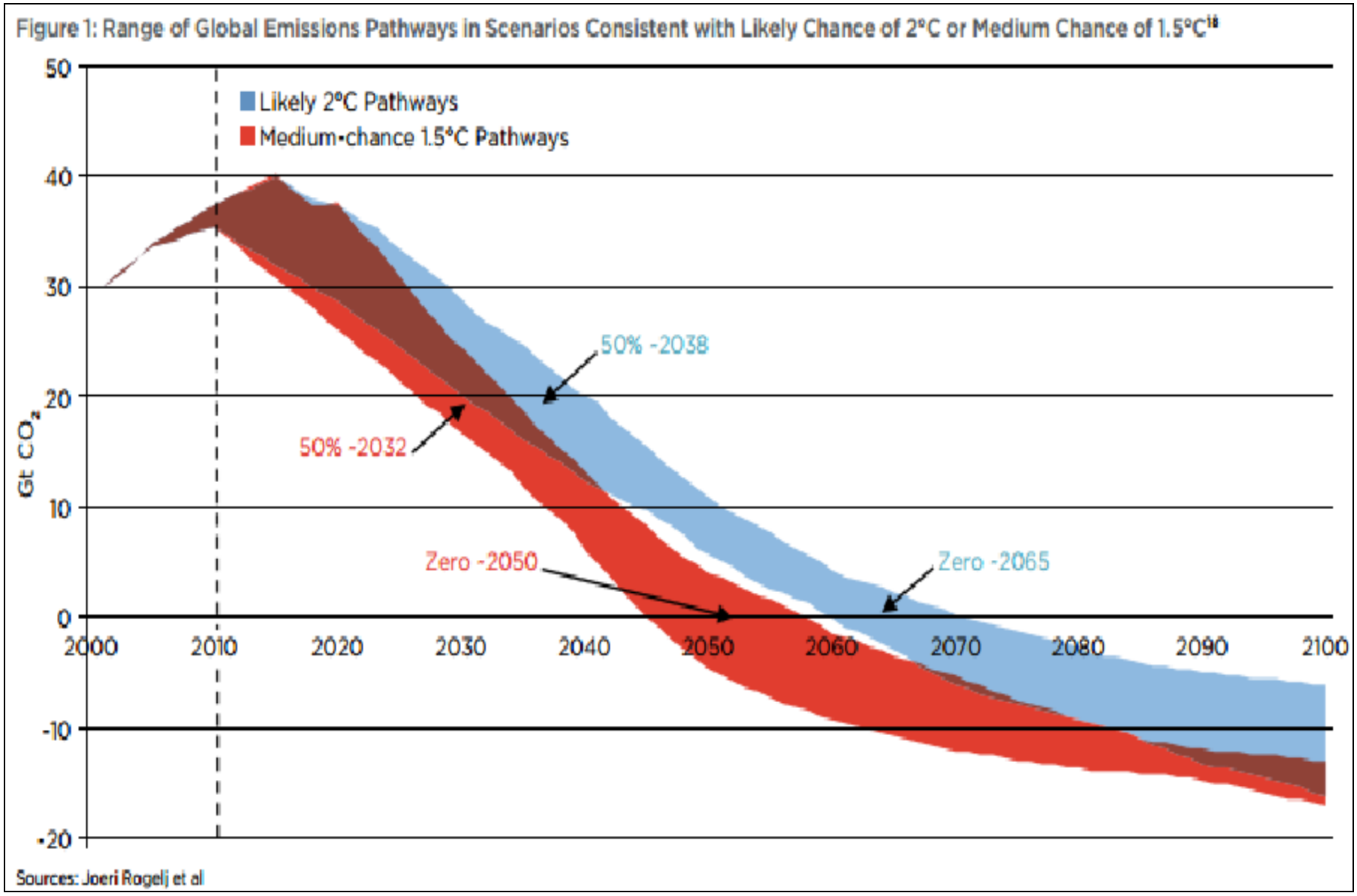
“The Sky’s Limit” Study of Fossil-Fuels Emissions





Probable Reserves

Global Emissions Pathways to Achieve 1.5°C or 2°C



Petroleum Extraction for Materials

- DO NOT burn it!
- All extraction releases methane, a powerful GHG. So, extract the petroleum that releases the least methane.
- Extract the petroleum that does the least damage to the environment.
- Maximize recycling materials (e.g., plastic) made from petroleum.

Finite-Resources Depletion Theory

- It is important to know how much **crude oil**, **natural gas** and **coal** can be extracted in the future for the United States and the world.
- We need to know because of:
  - Their cause of global warming
  - Of how fast we must bring on renewable energy
  - Their use in making useful materials.
- We need to use finite-resources depletion theory to get that knowledge.

Finite-Resources Depletion Theory

- Collect U.S. and global **yearly extraction data** (Energy Information Agency EIA & others).
- Get estimates of U.S. and **global reserves versus years** (EIA). Project to future reserves and add some.
- Use a peaking function that allows **asymmetry** (**Verhulst function** with 4 parameters).
- Fit the extraction data by varying parameters in the peaking function such that the **area under the depletion curve is equal to the amount already extracted plus the estimated remaining reserves or more**.
- M. King Hubbert first used this procedure in 1956 to accurately predict a peak in year 1970 for conventional crude-oil extraction in the U.S. He used a **symmetric peaked function, the logistic function,** the Verhulst function when there is symmetry.

Importance of a Peaked Depletion Curve

- Reaching a peak unaware for a vital non-renewable resource can cause societal disruption.
- Because of the exponential rise in extraction, the year of the peak does not change much for larger reserves. (Example later)
- Knowing peak year enables plans for imports and substitutes. (Example later)
- If importing a non-renewable resource, peak extraction years for other countries are important.
- If someone mentions availability at “current extraction rate”, insist on year of the peak.

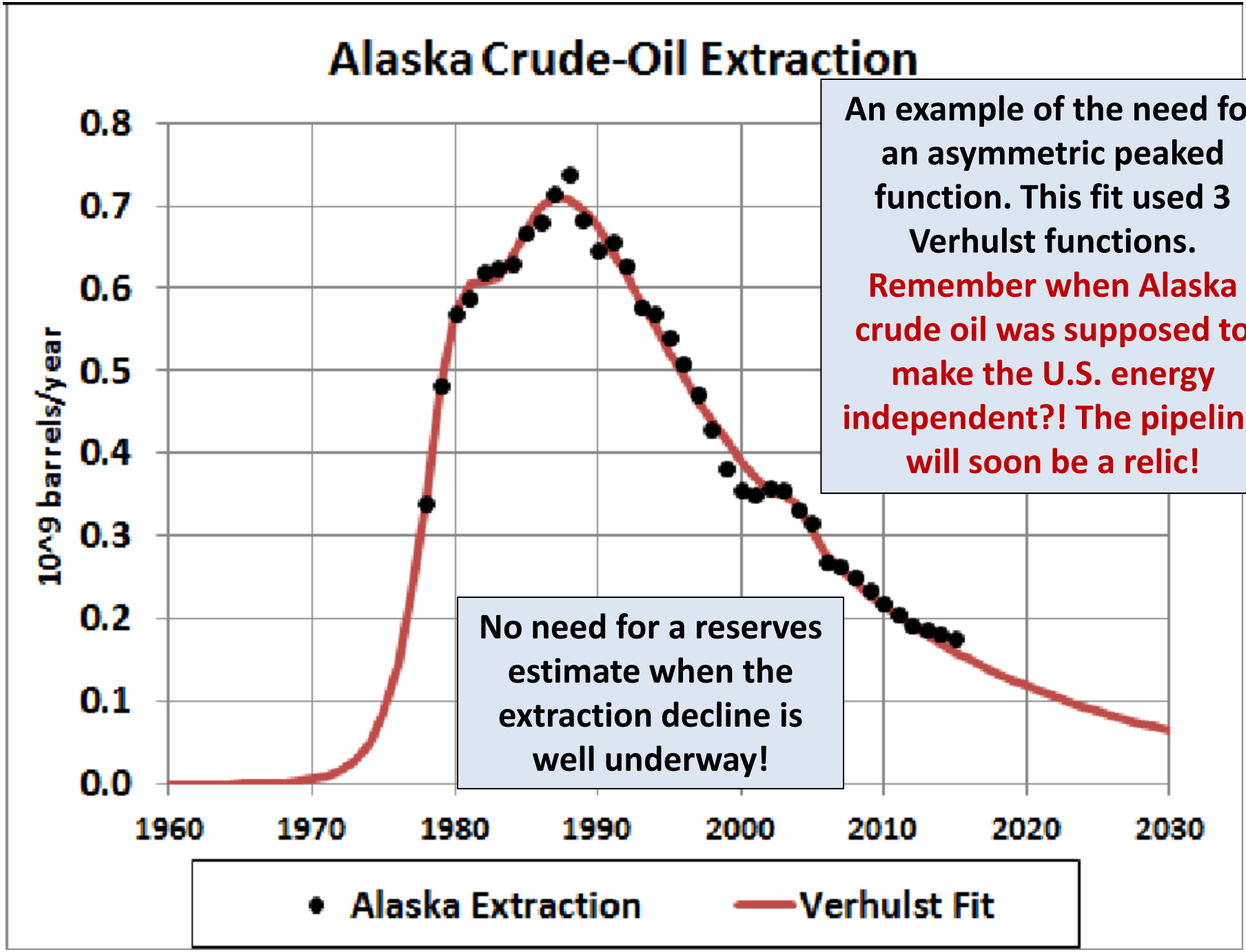
For Those Who Like Equations

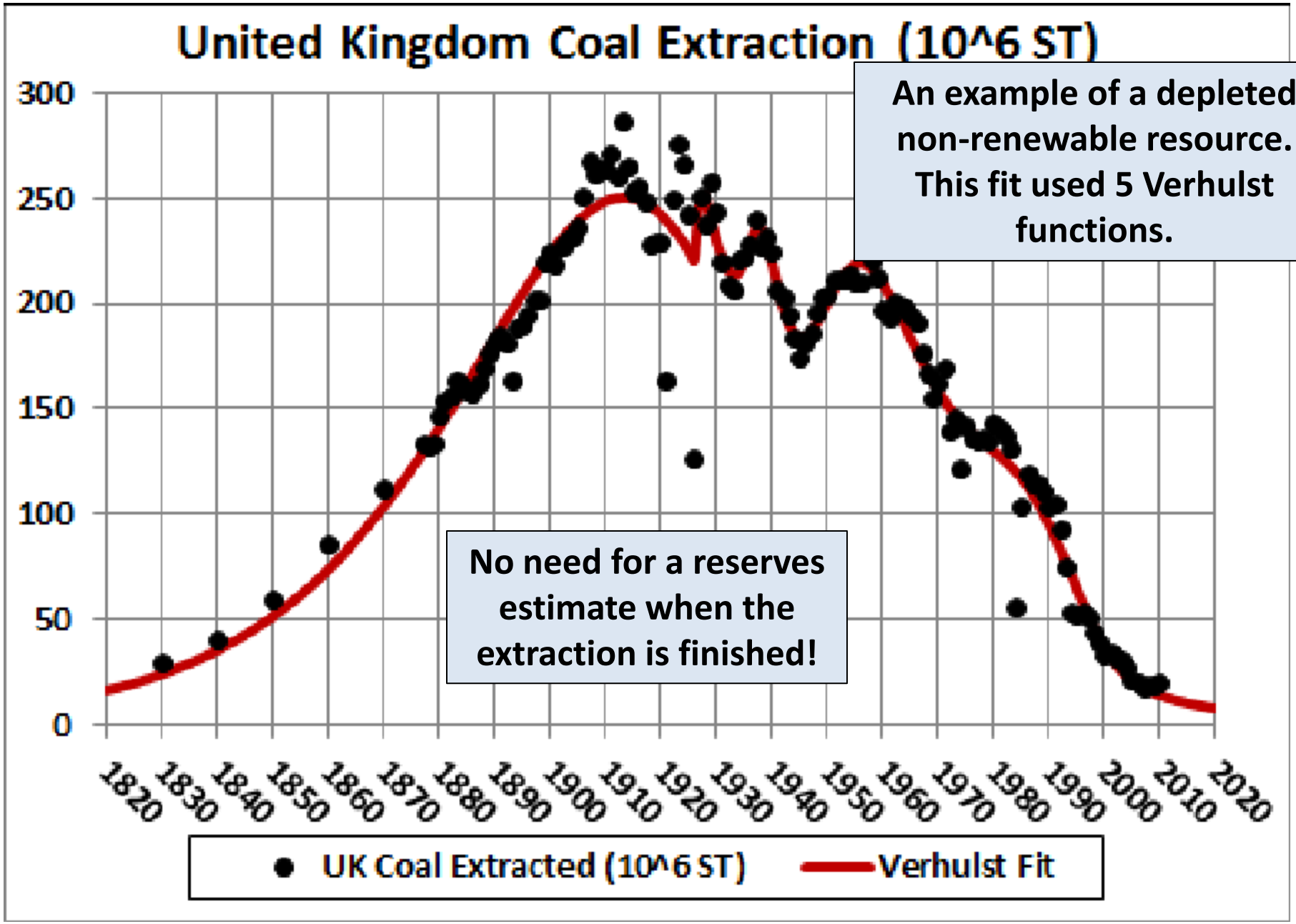
The Verhulst Function for Extraction Rate

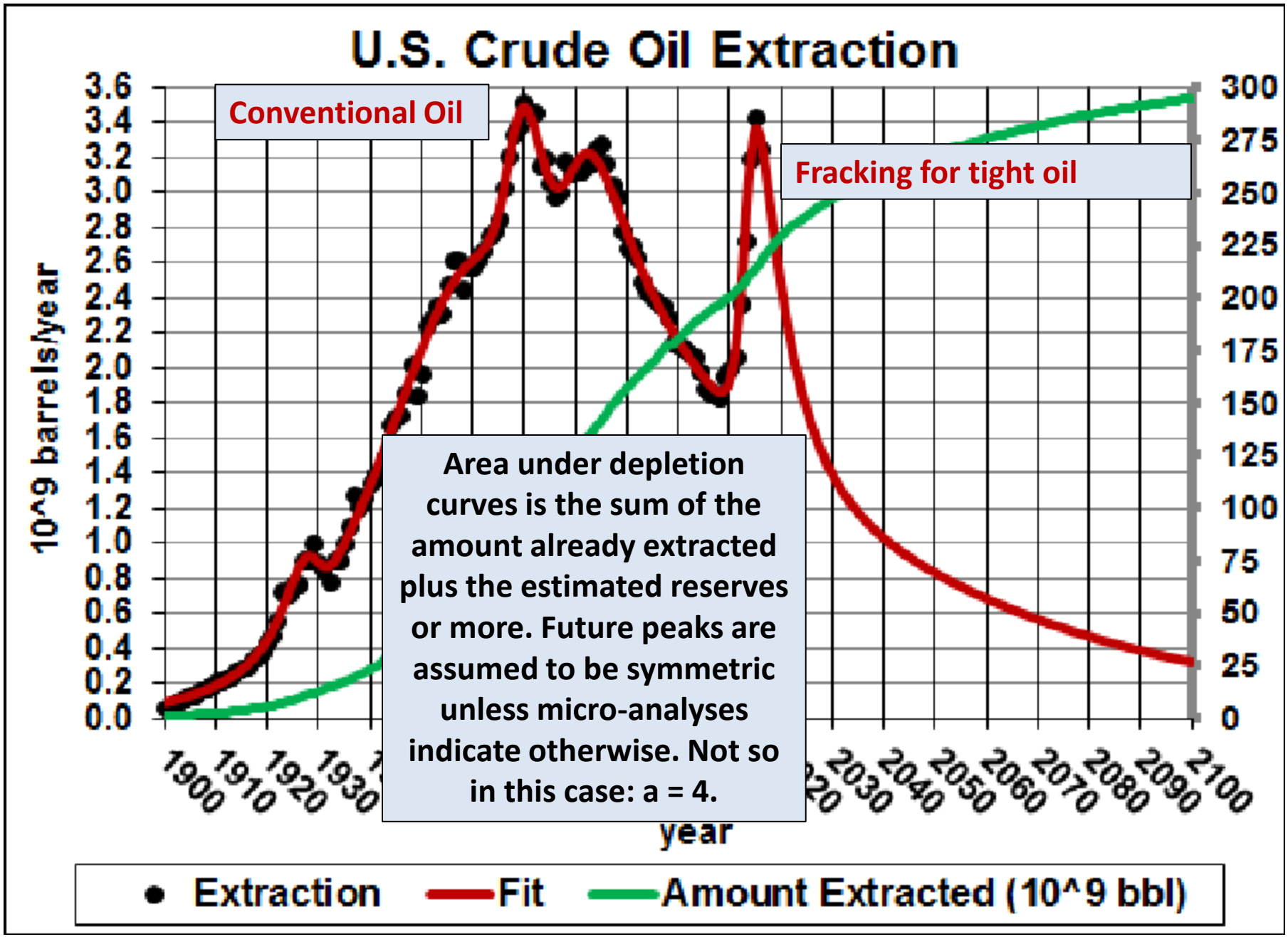
$$P(t) = \frac{Q}{a\tau} \frac{\left(2^n - 1\right)\exp\left(\frac{t-h}{\tau}\right)}{\left[1+\left(2^n - 1\right)\exp\left(\frac{t-h}{\tau}\right)\right]^{\frac{a+1}{a}}}$$

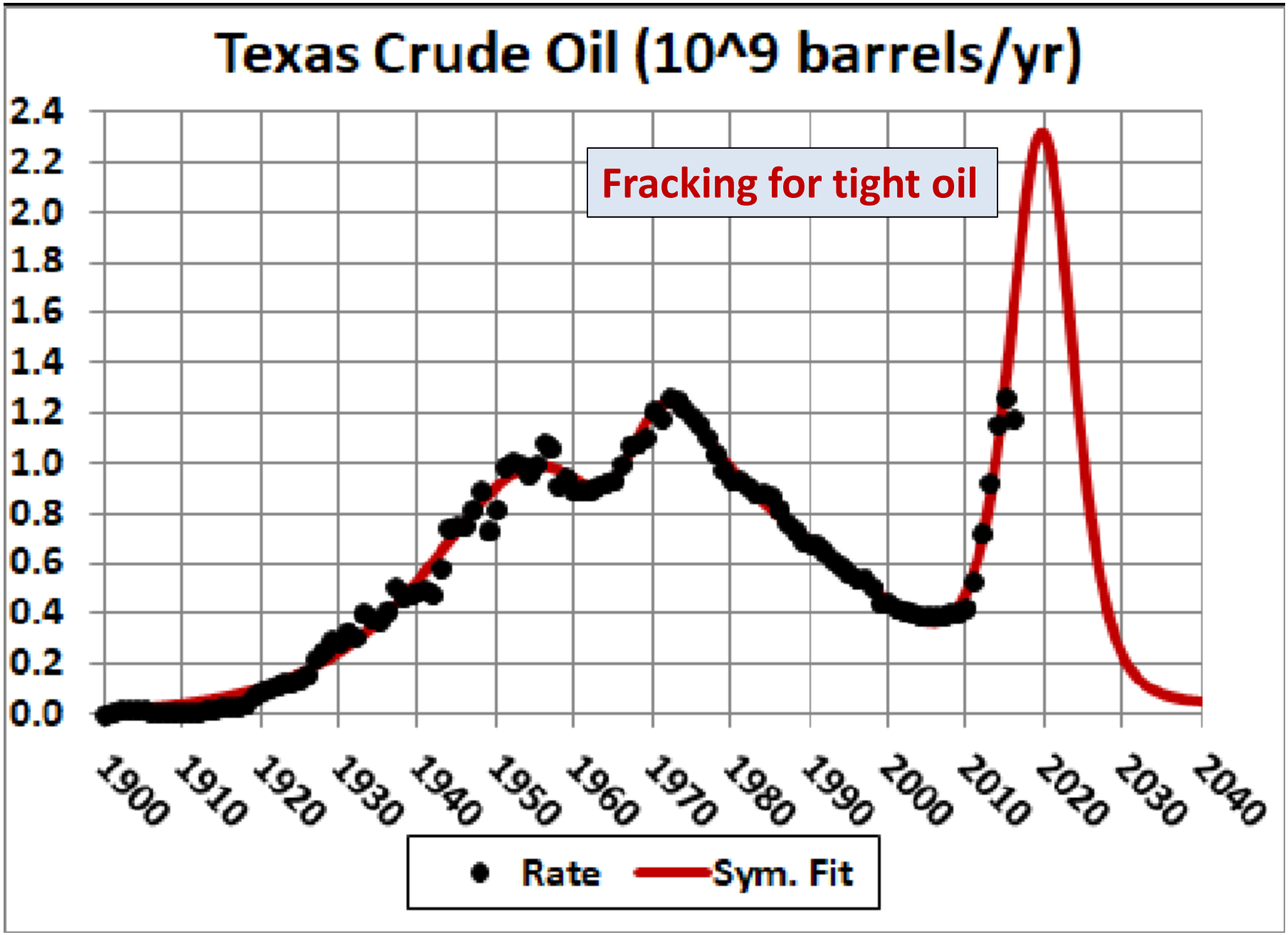
- **Q = amount to be extracted.**
- **τ = rising exponential time constant.**
- **a = asymmetry parameter. (a = 1 = symmetric case.)**
- **aτ = declining exponential time constant.**
- **h = half-way year and peak for symmetric case.**

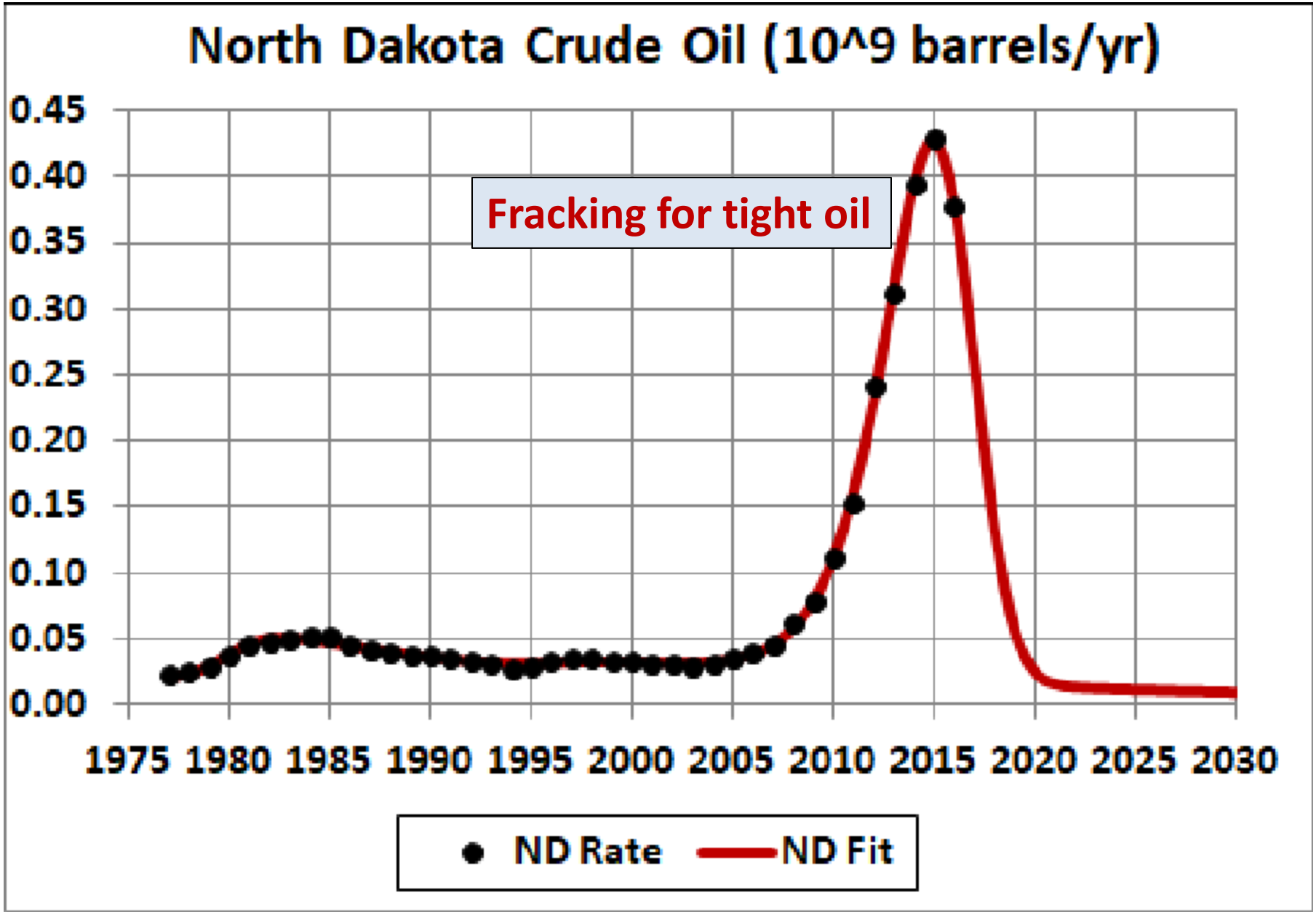
$$t_{peak} = h + \tau \ln\left(\frac{a}{2^a - 1}\right)$$


Alaska Crude-Oil Extraction
10^9 barrels/year
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1960
1970
1980
1990
2000
2010
2020
2030
Alaska Extraction
Verhulst Fit
An example of the need for an asymmetric peaked function. This fit used 3 Verhulst functions.
Remember when Alaska crude oil was supposed to make the U.S. energy independent?! The pipeline will soon be a relic!
No need for a reserves estimate when the extraction decline is well underway!

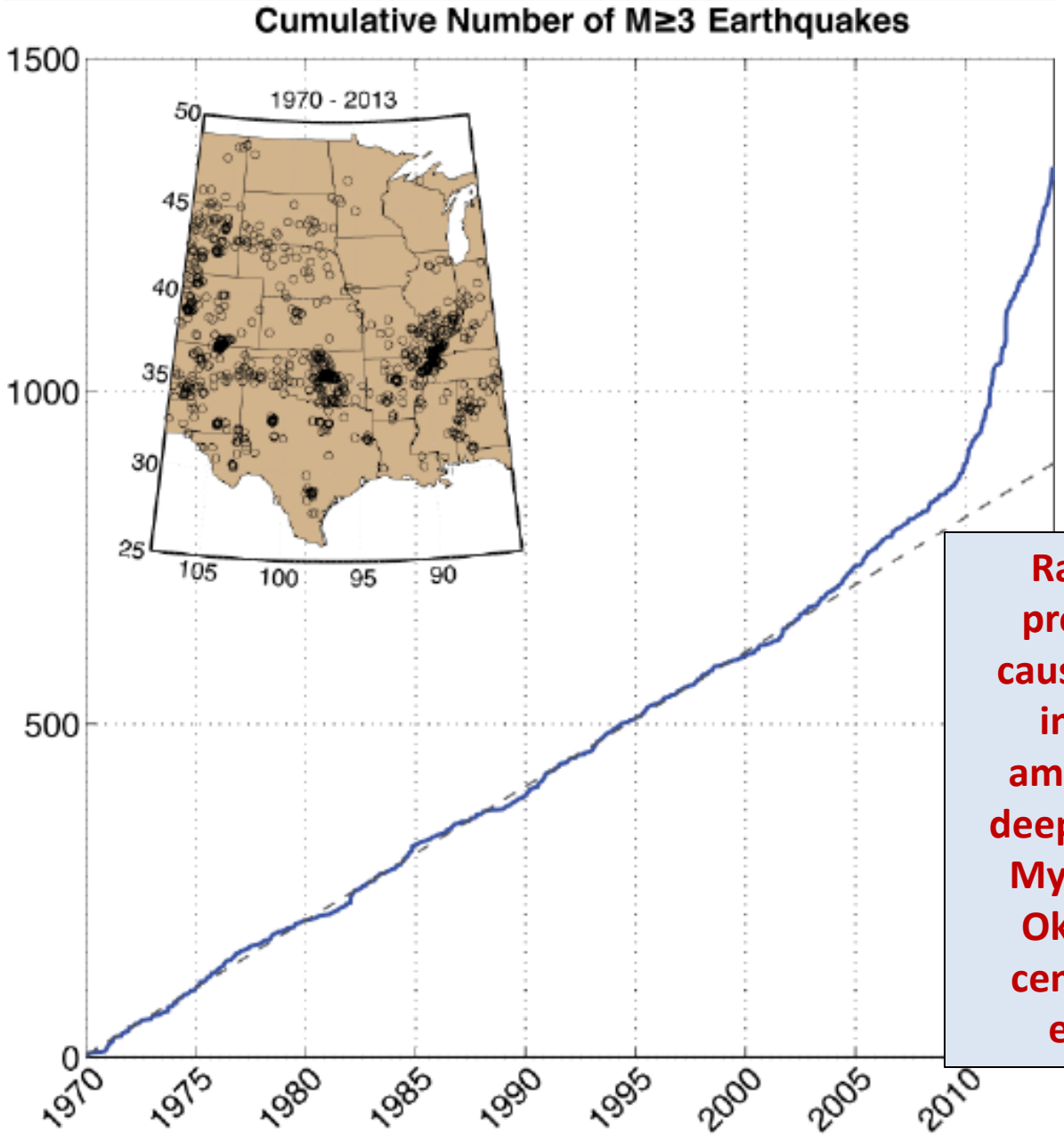

United Kingdom Coal Extraction (10^6 ST)
An example of a depleted non-renewable resource. This fit used 5 Verhulst functions.
No need for a reserves estimate when the extraction is finished!
300
250
200
150
100
50
0
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
UK Coal Extracted (10^6 ST)
Verhulst Fit


U.S. Crude Oil Extraction
Conventional Oil
Fracking for tight oil
Area under depletion curves is the sum of the amount already extracted plus the estimated reserves or more. Future peaks are assumed to be symmetric unless micro-analyses indicate otherwise. Not so in this case: a = 4.
10^9 barrels/year
year
Extraction
Fit
Amount Extracted (10^9 bbl)

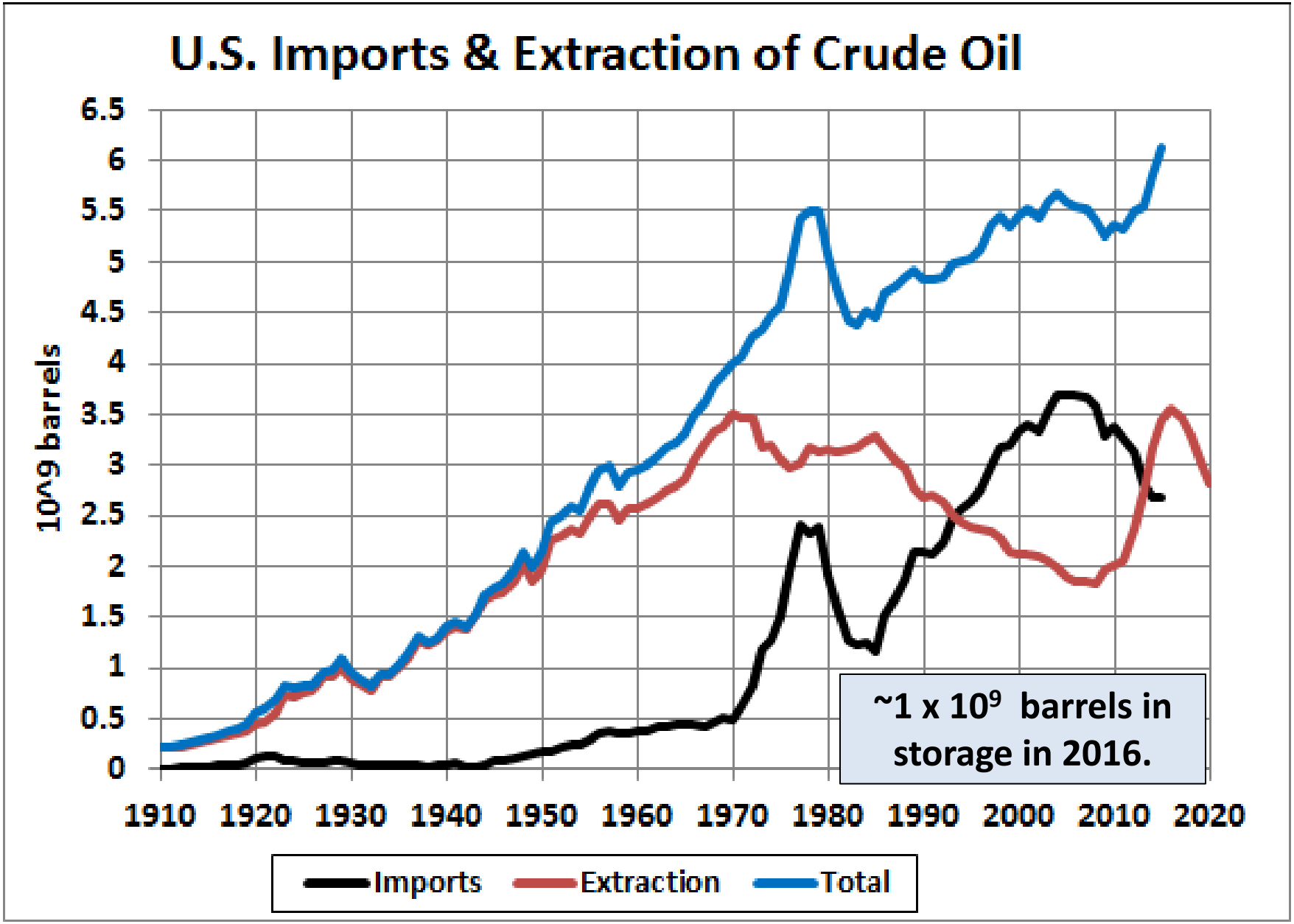

Texas Crude Oil (10^9 barrels/yr)
Fracking for tight oil
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
Rate
Sym. Fit

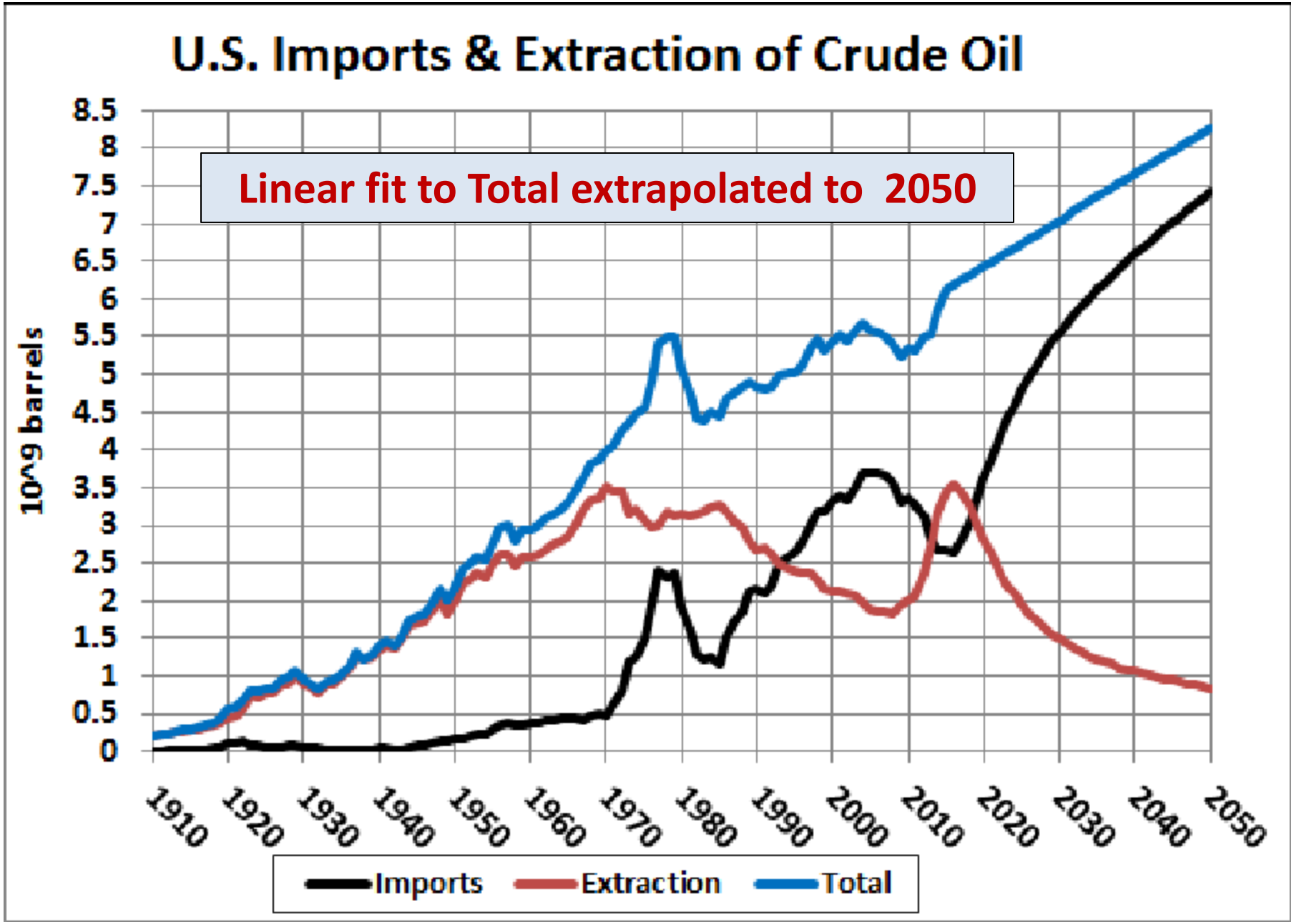

North Dakota Crude Oil (10^9 barrels/yr)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Fracking for tight oil
1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
ND Rate
ND Fit

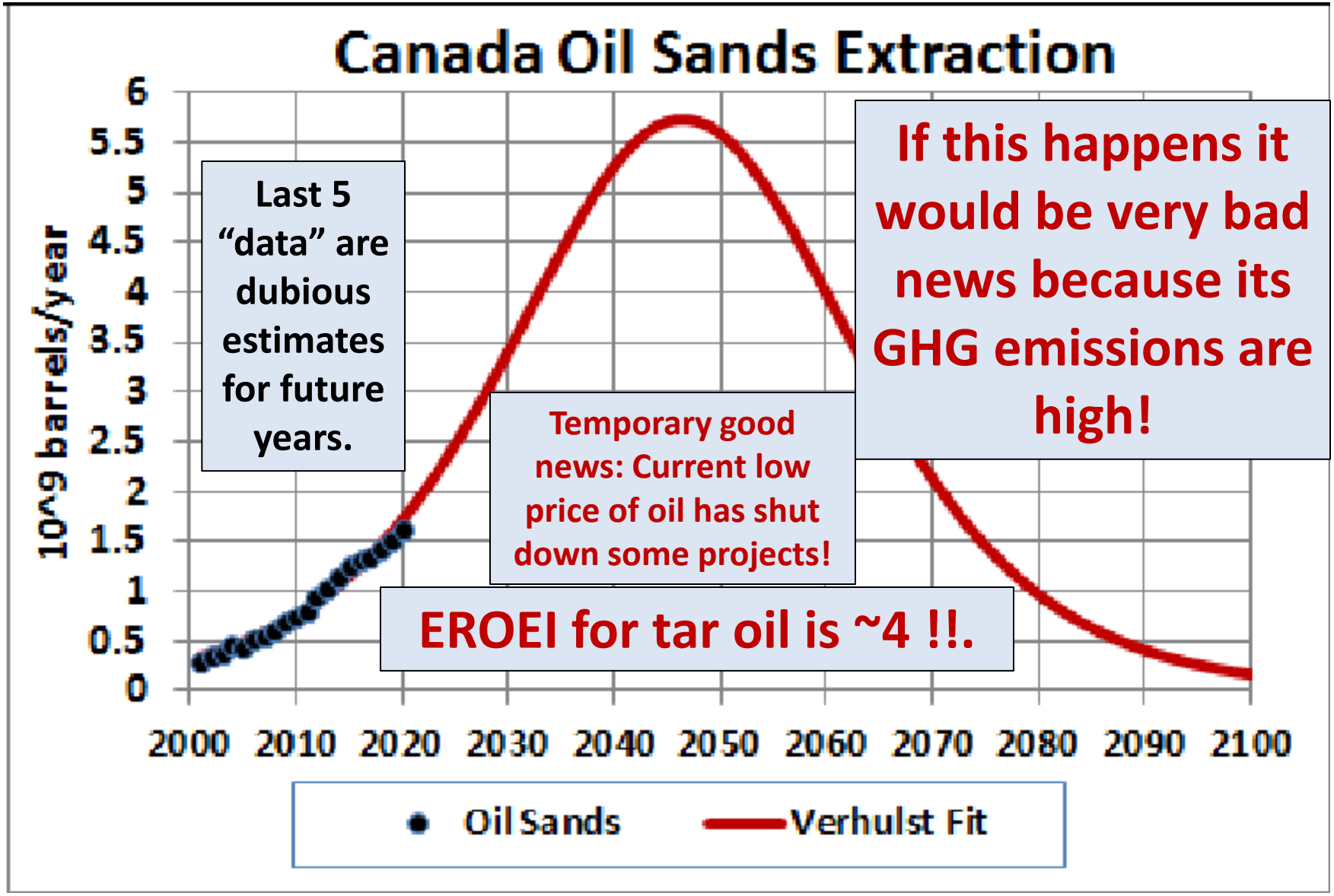
U.S. Earthquakes Related to Fracking

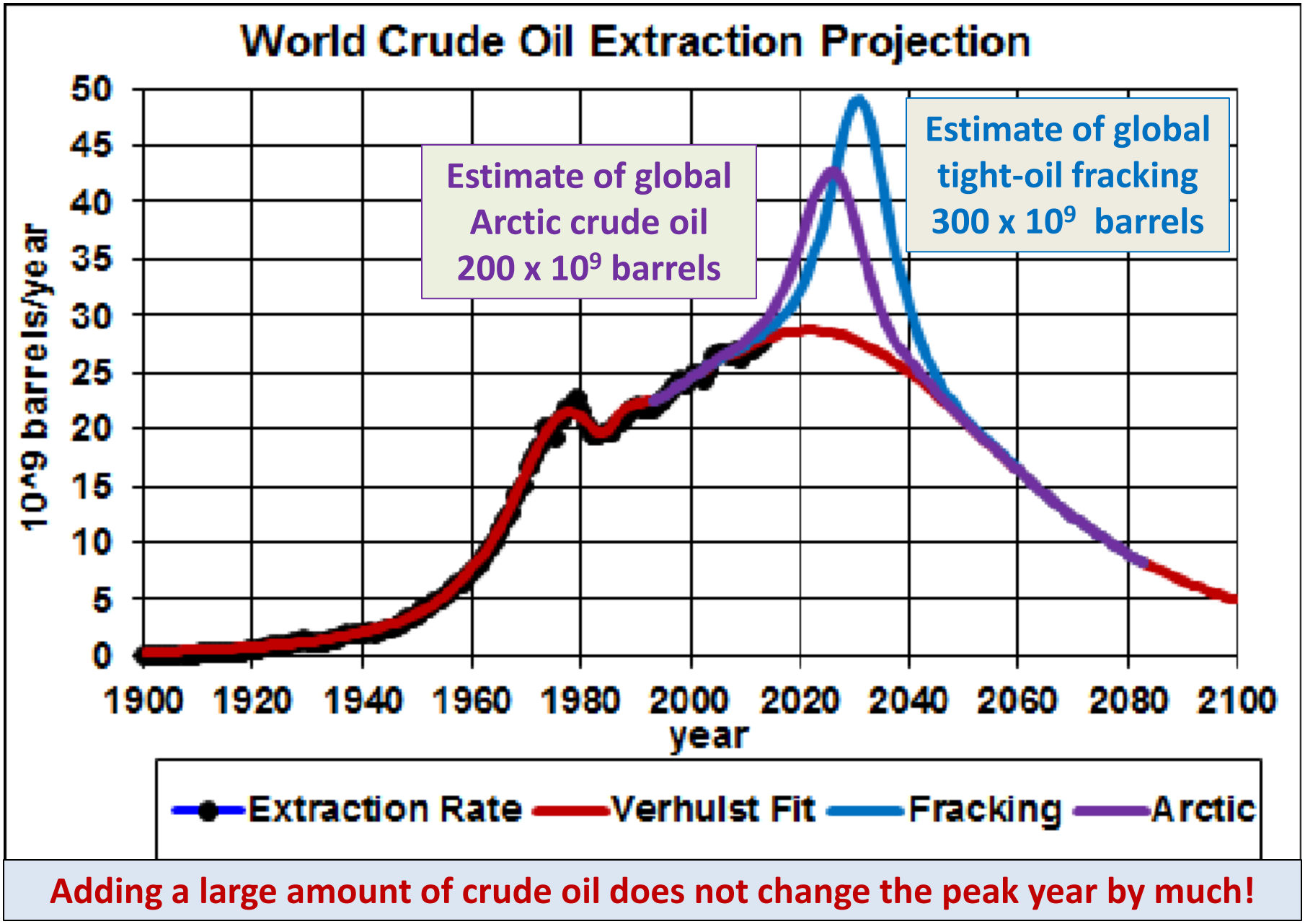


Rapid increase, probably mostly caused by fracking, inserting huge amounts of water deep into the Earth. My home state of Oklahoma is the center of fracking earthquakes!

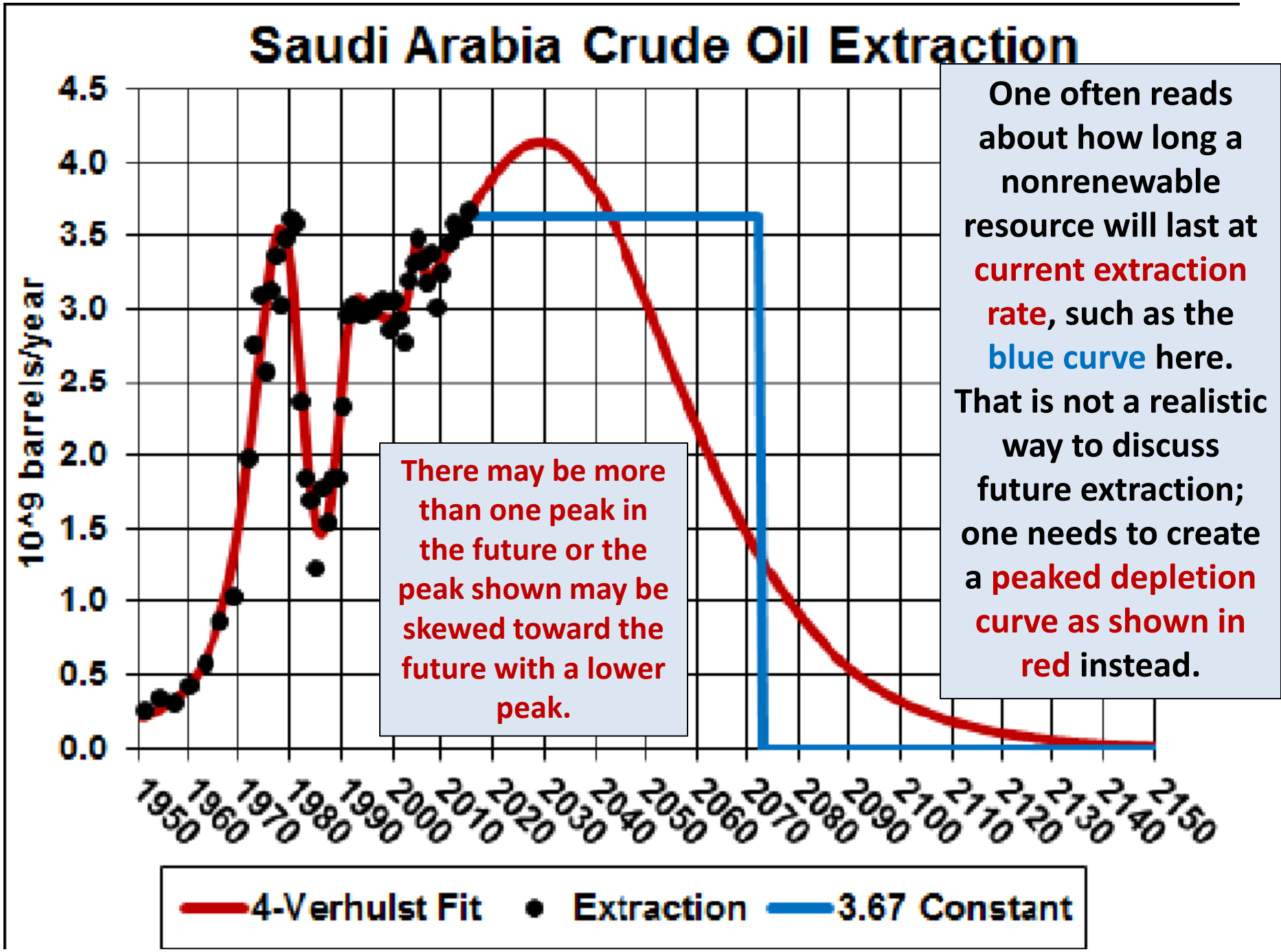

U.S. Imports & Extraction of Crude Oil
10^9 barrels
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
~1 x 10^9 barrels in storage in 2016.
Imports
Extraction
Total


U.S. Imports & Extraction of Crude Oil
Linear fit to Total extrapolated to 2050
10^9 barrels
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Imports
Extraction
Total

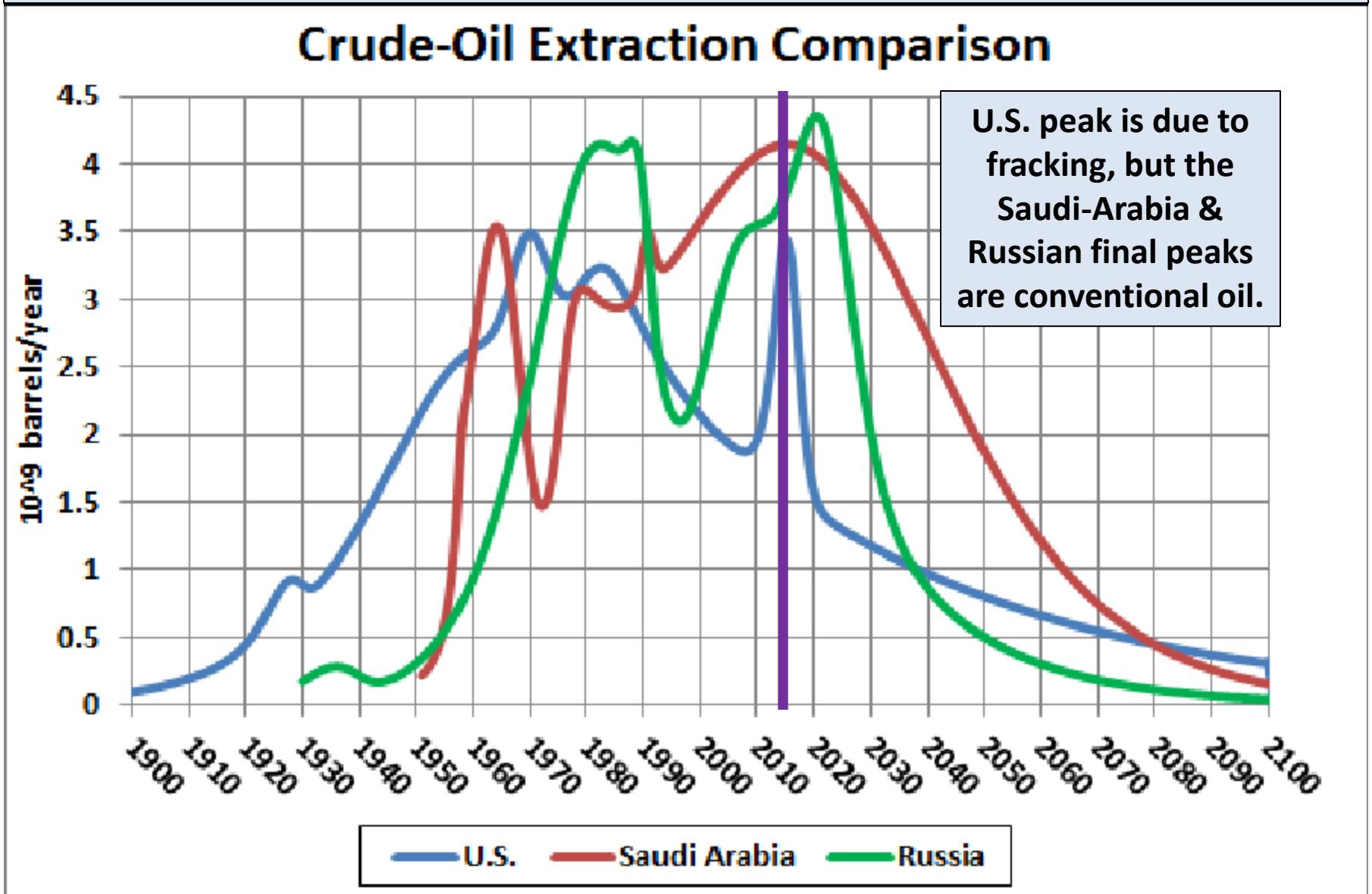

Canada Oil Sands Extraction
10^9 barrels/year
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Last 5 "data" are dubious estimates for future years.
Temporary good news: Current low price of oil has shut down some projects!
If this happens it would be very bad news because its GHG emissions are high!
EROEI for tar oil is ~4 !!.
Oil Sands
Verhulst Fit



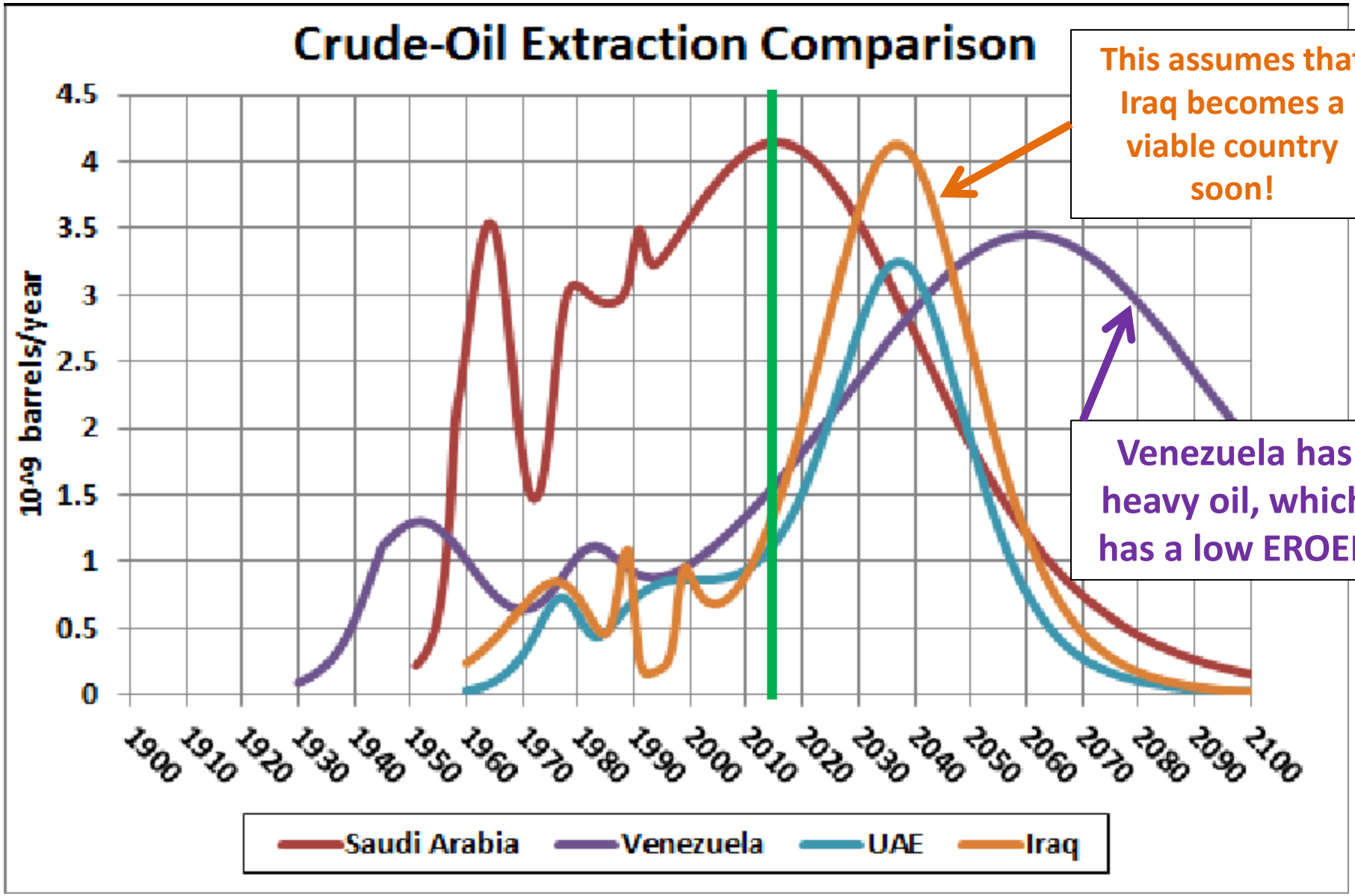
Adding a large amount of crude oil does not change the peak year by much!


Saudi Arabia Crude Oil Extraction
10^9 barrels/year
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
2110
2120
2130
2140
2150
There may be more than one peak in the future or the peak shown may be skewed toward the future with a lower peak.
One often reads about how long a nonrenewable resource will last at current extraction rate, such as the blue curve here. That is not a realistic way to discuss future extraction; one needs to create a peaked depletion curve as shown in red instead.
4-Verhulst Fit
Extraction
3.67 Constant

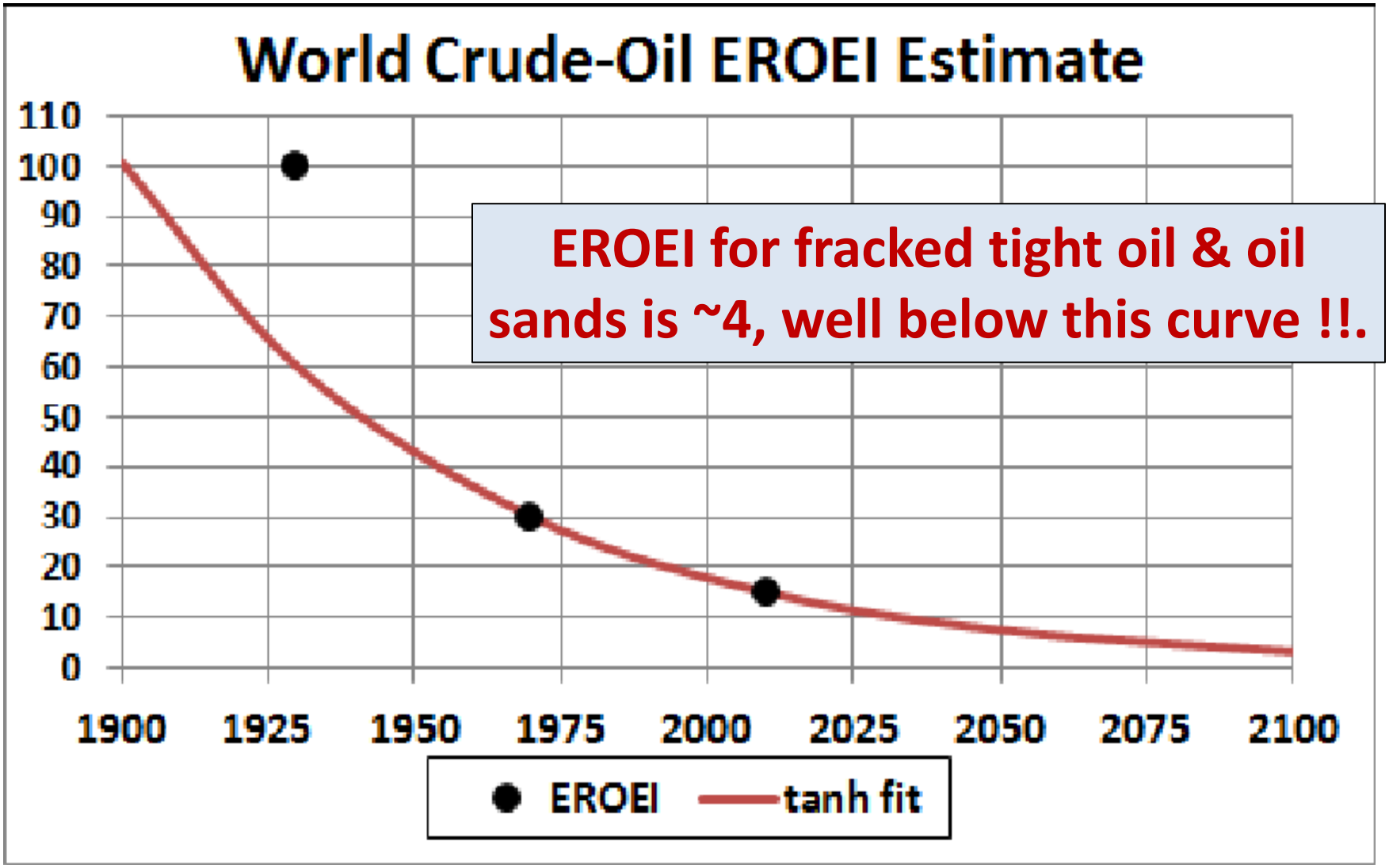
It is not true that the U.S. exceeds Saudi Arabia in extraction of CRUDE OIL!



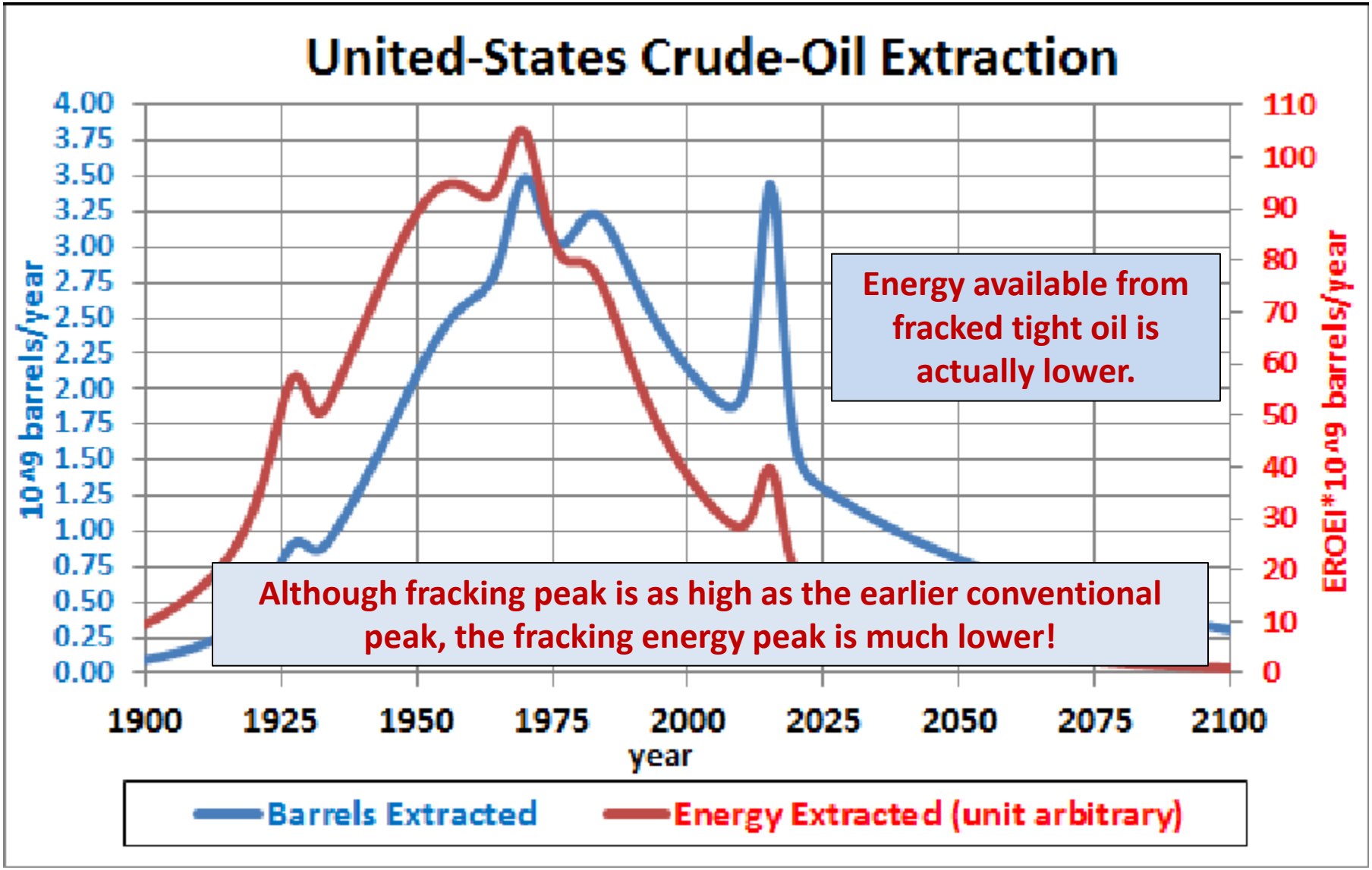
Future crude-oil-extraction competitors to Saudi Arabia



Crude-Oil Energy Return on Energy Invested

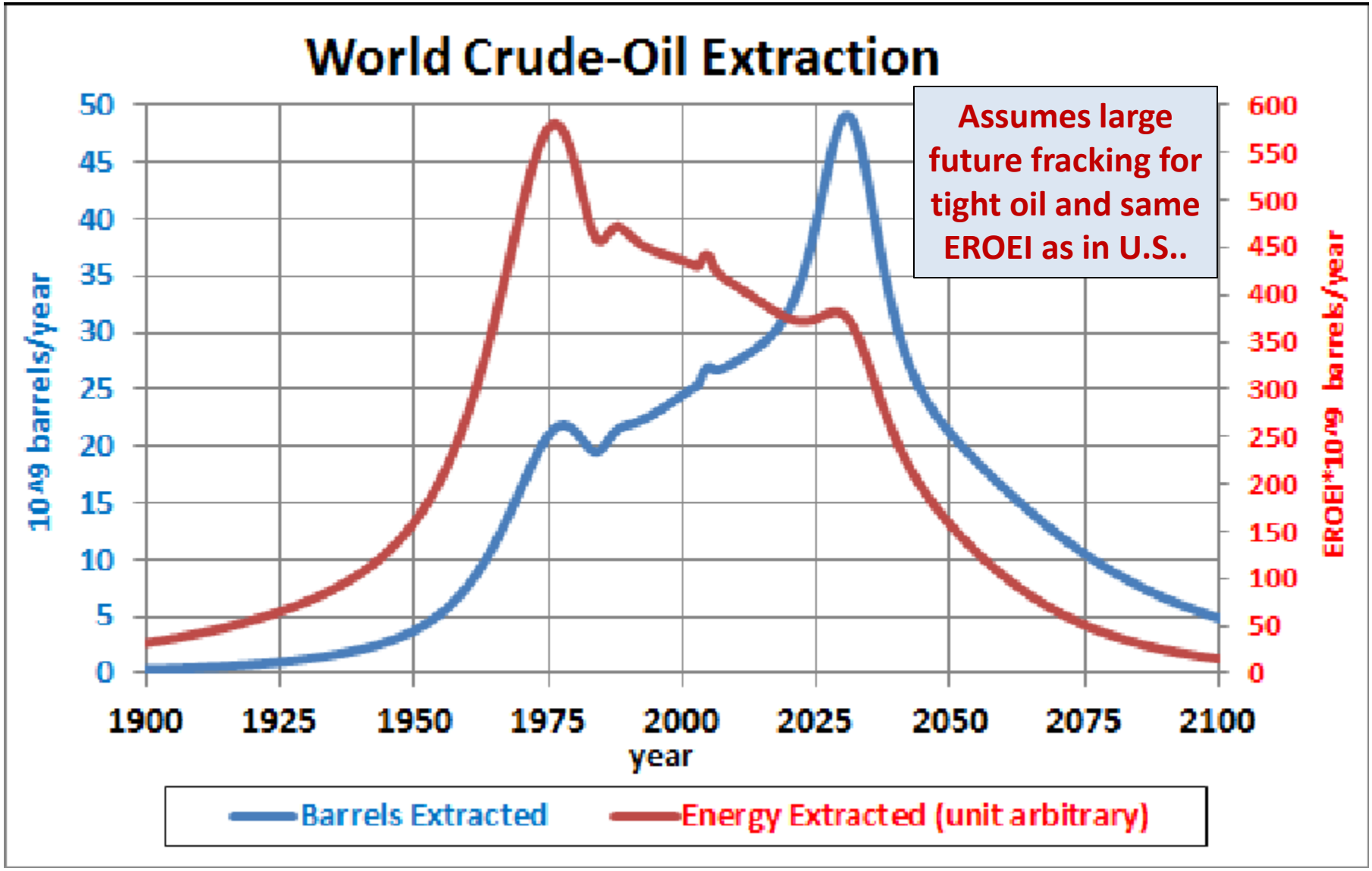


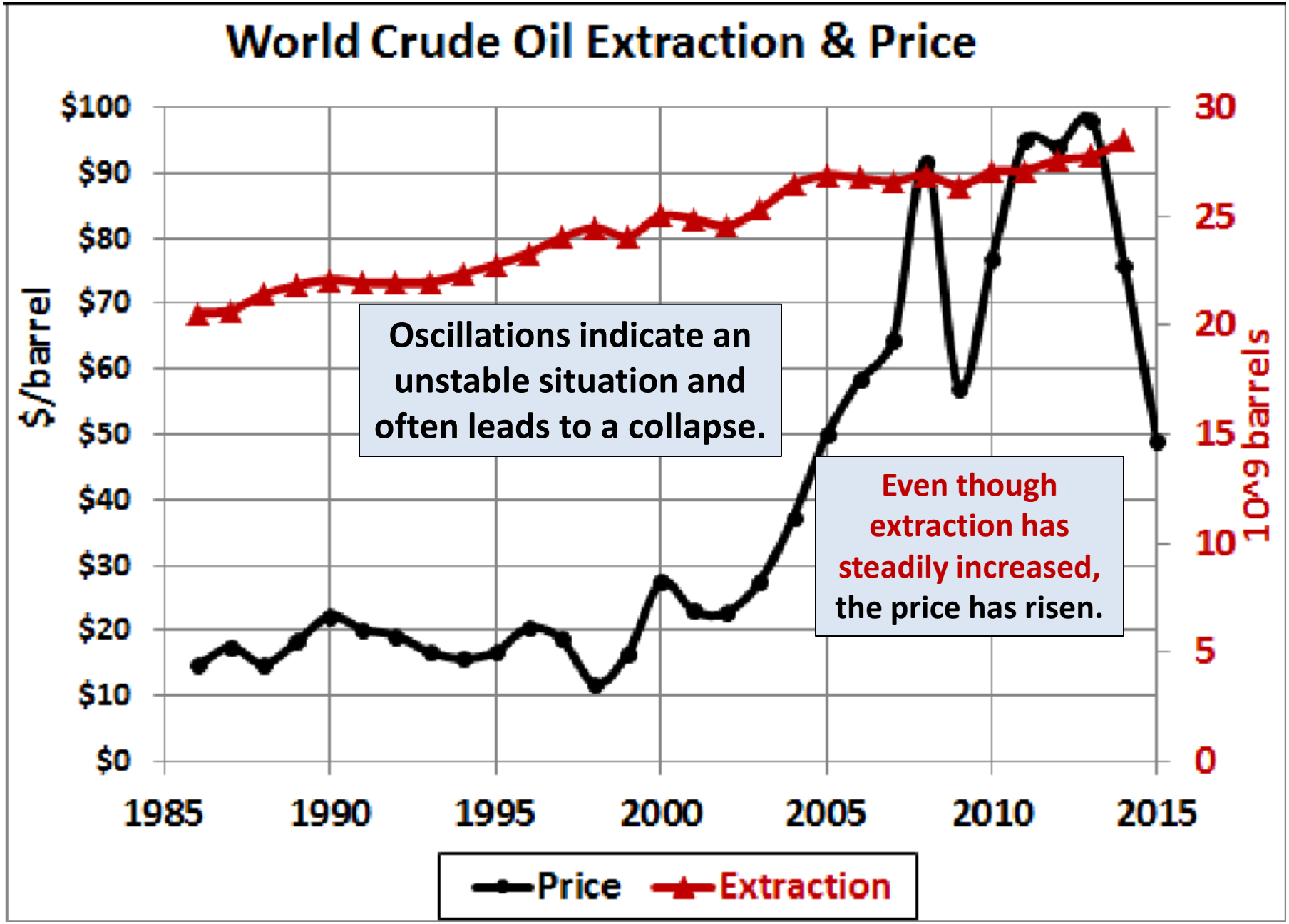
Crude-Oil Energy Return on Energy Invested

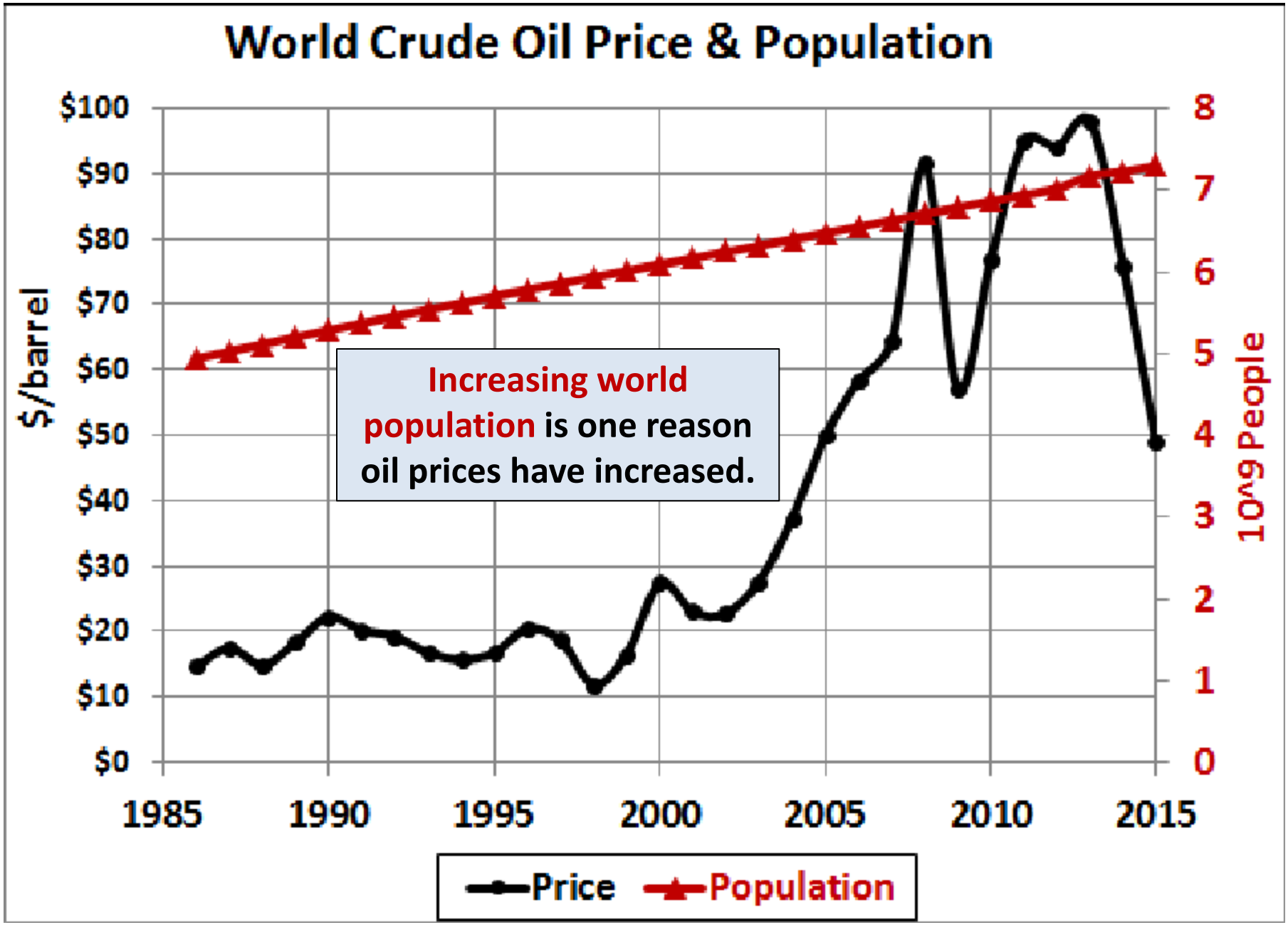


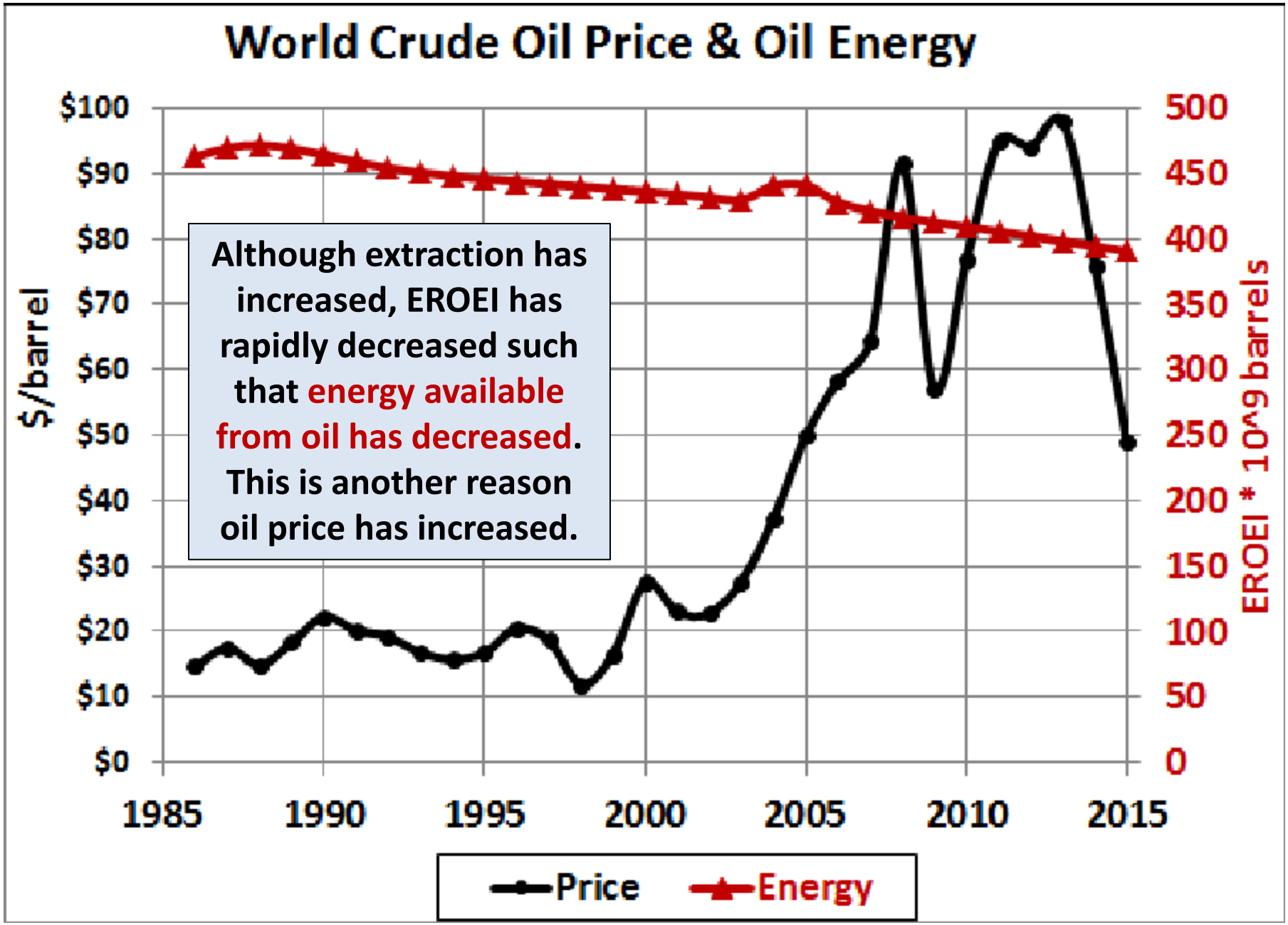
As the energy/barrel goes down with time, the amount of pollution and carbon emissions per barrel will go up, perhaps not as fast.

Energy returned for the estimated large tight-oil peak at ~2030 is much less than the energy returned for the energy peak in about 1975!



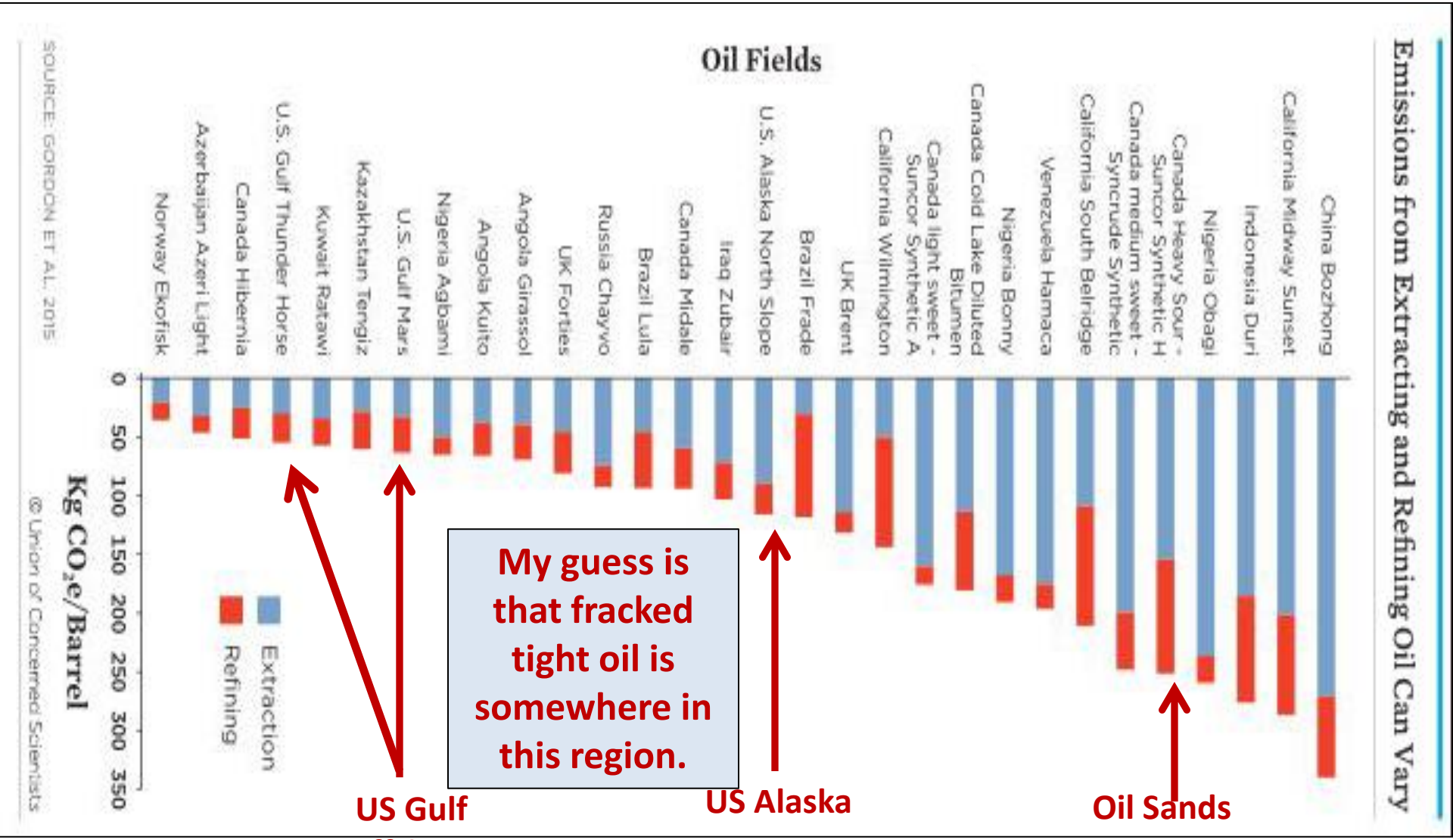

World Crude Oil Extraction & Price
$/barrel
$100
$90
$80
$70
$60
$50
$40
$30
$20
$10
$0
10^9 barrels
30
25
20
15
10
5
0
1985
1990
1995
2000
2005
2010
2015
Oscillations indicate an unstable situation and often leads to a collapse.
Even though extraction has steadily increased, the price has risen.
Price
Extraction


World Crude Oil Price & Population
$/barrel
$100
$90
$80
$70
$60
$50
$40
$30
$20
$10
$0
8
7
6
5
4
3
2
1
0
10^9 People
1985
1990
1995
2000
2005
2010
2015
Increasing world population is one reason oil prices have increased.
Price
Population

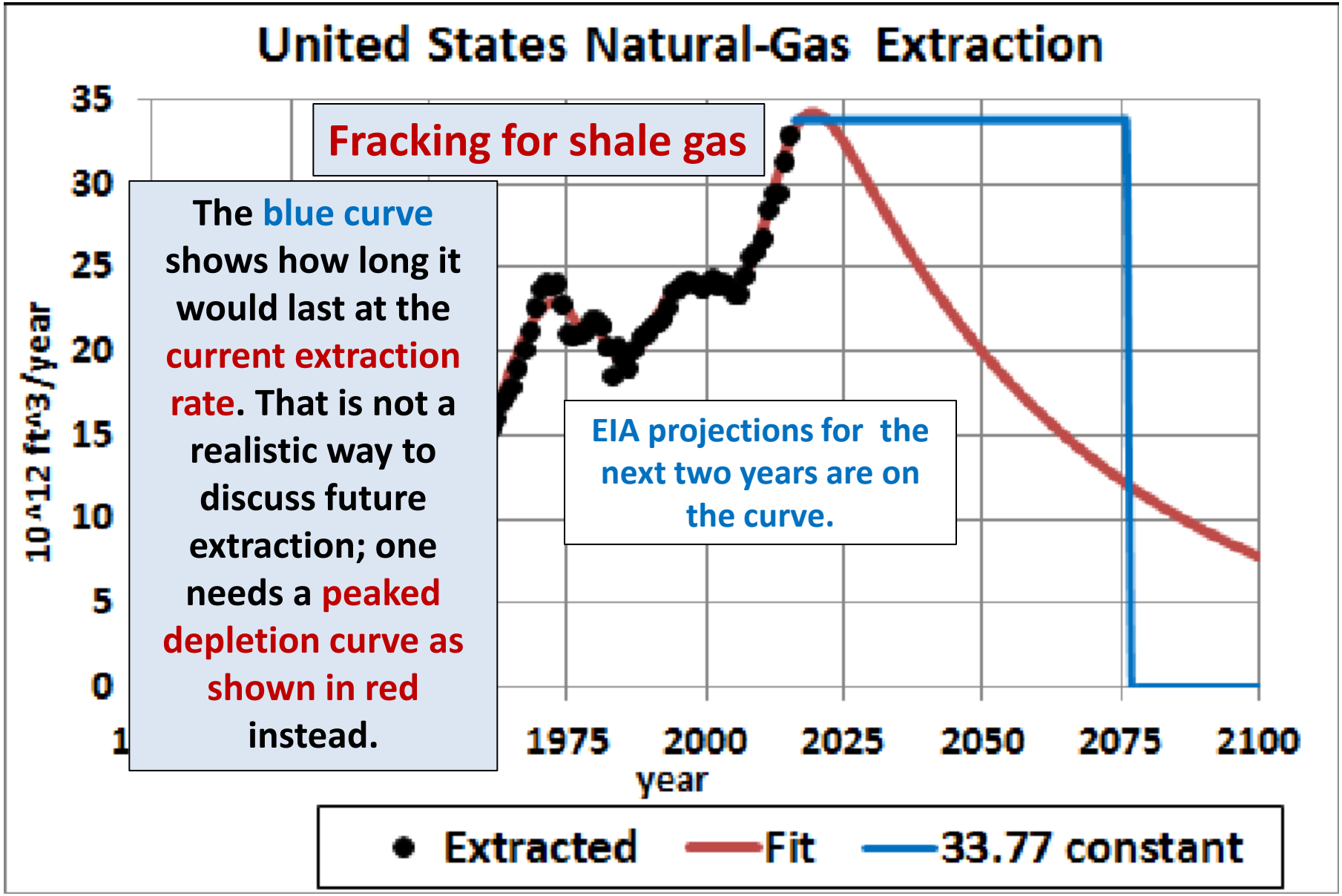


The rapid rise in price is due to increasing population and decreasing EROEI.

GHG Emissions from Extracting & Refining Oil



How about Using Natural Gas for Transport Fuel and Creating Electricity?



http://www.roperld.com/science/minerals/USGasBoom_Bust.htm

Drilling Deeper by J. David Hughes

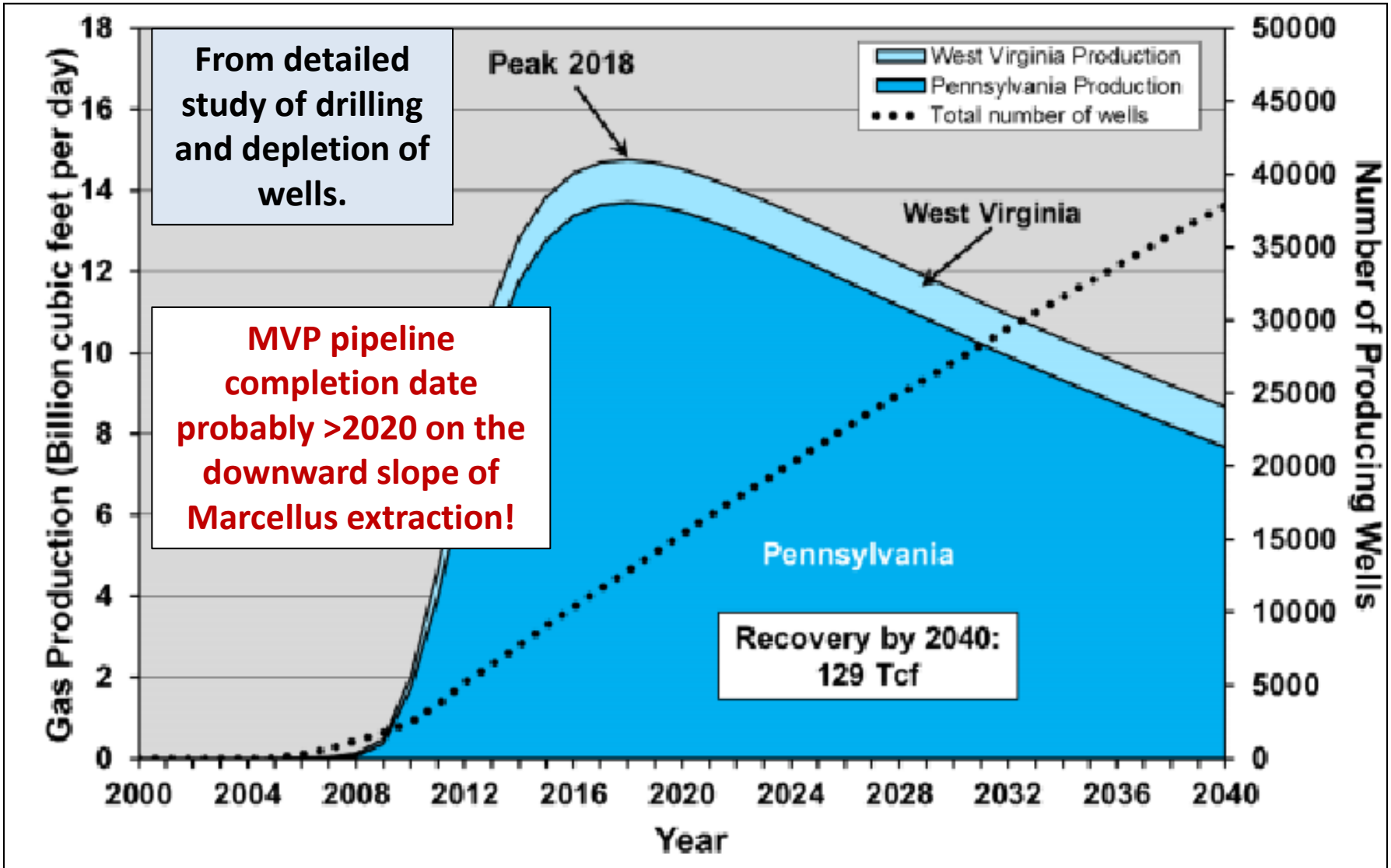
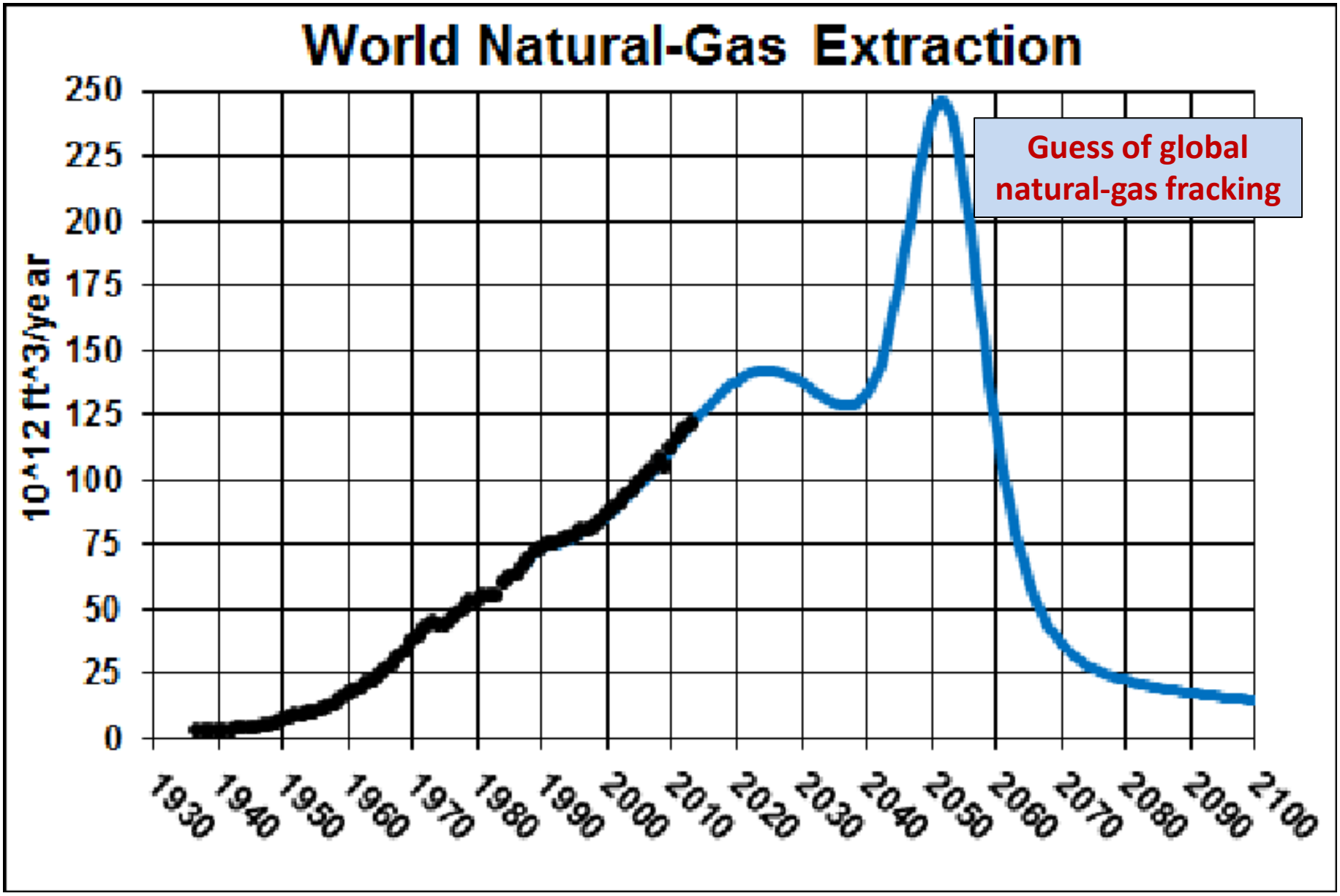
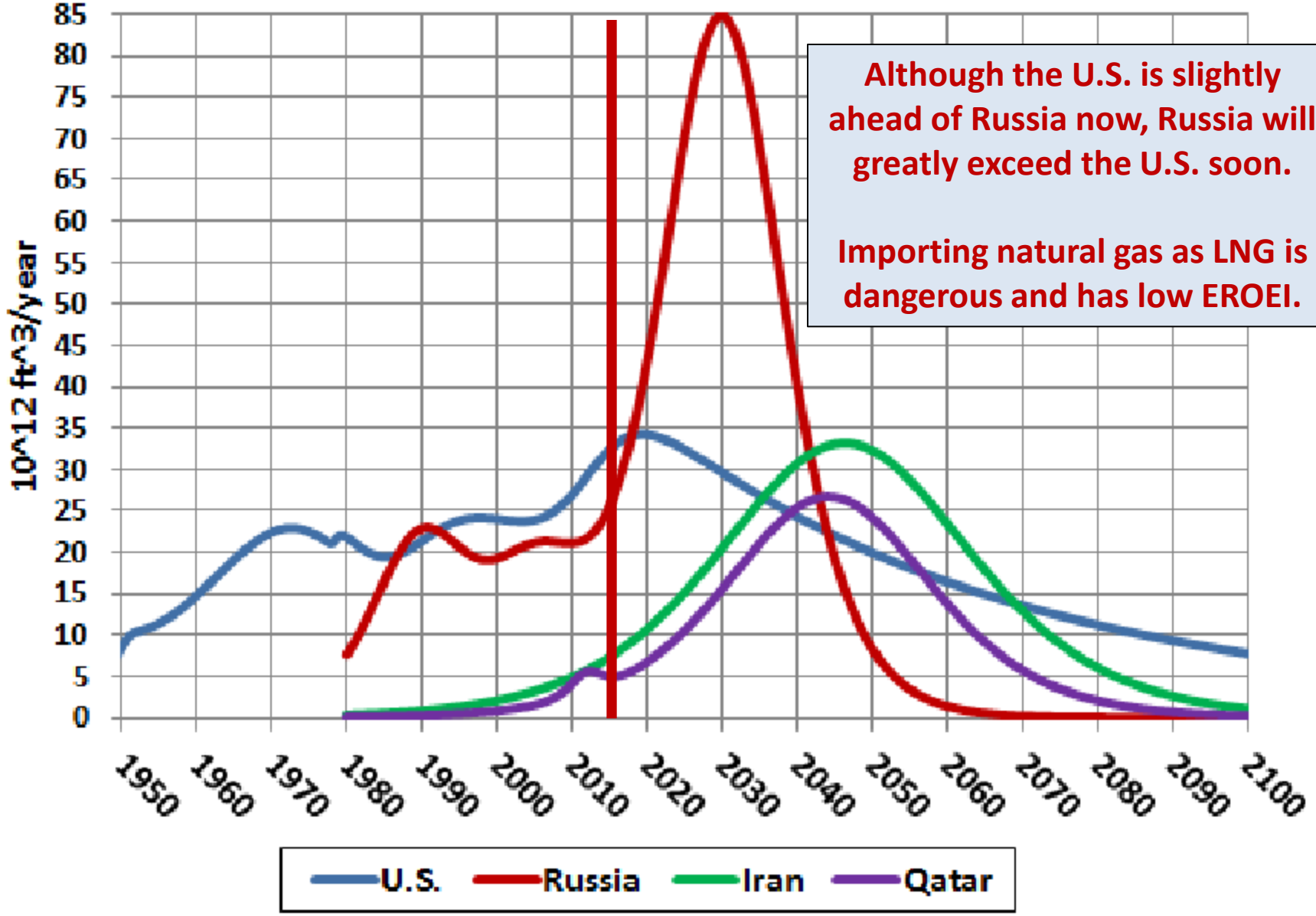


Figure 3-99. "Most Likely Rate" scenario of Marcellus gas production including both Pennsylvania and West Virginia.


World Natural-Gas Extraction
10^12 ft^3/year
250
225
200
175
150
125
100
75
50
25
0
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Guess of global natural-gas fracking

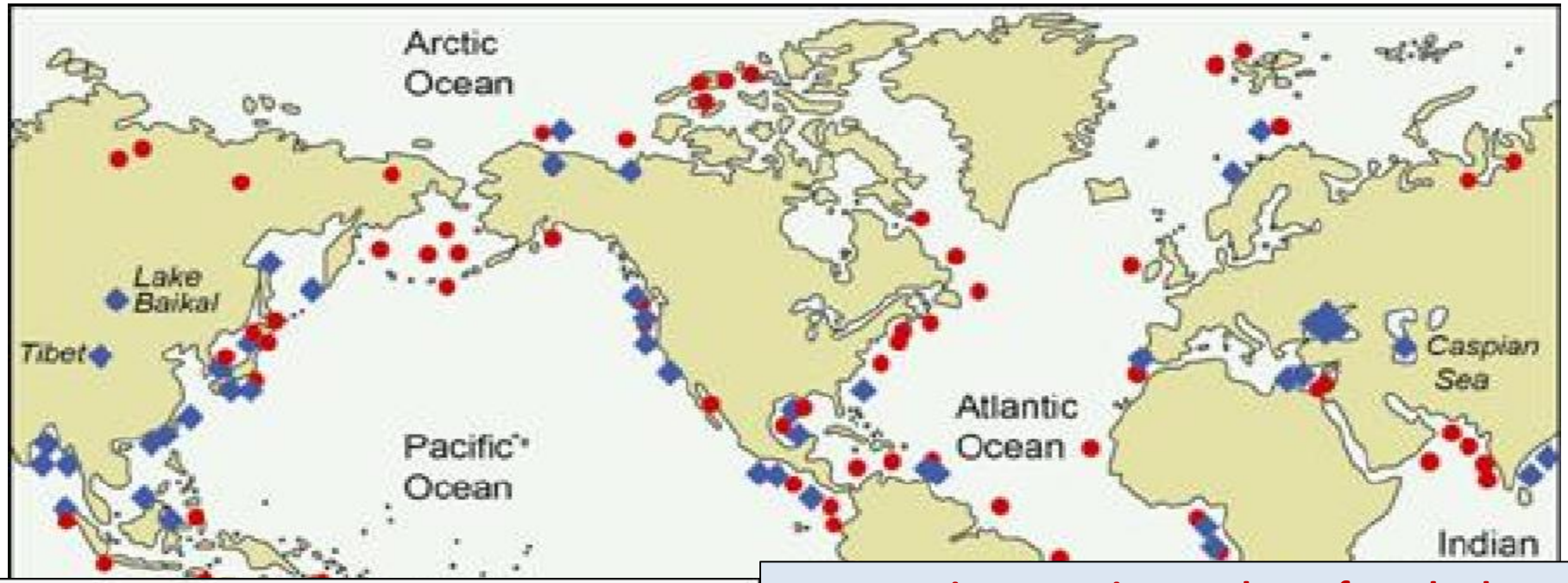
Natural-Gas Extraction Comparison

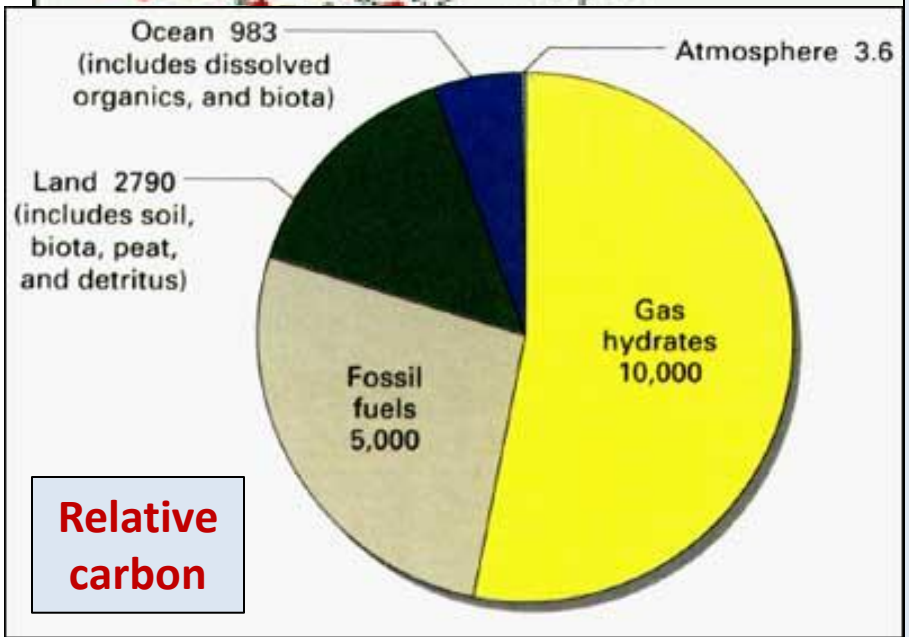


Although the U.S. is slightly ahead of Russia now, Russia will greatly exceed the U.S. soon.

Importing natural gas as LNG is dangerous and has low EROEI.

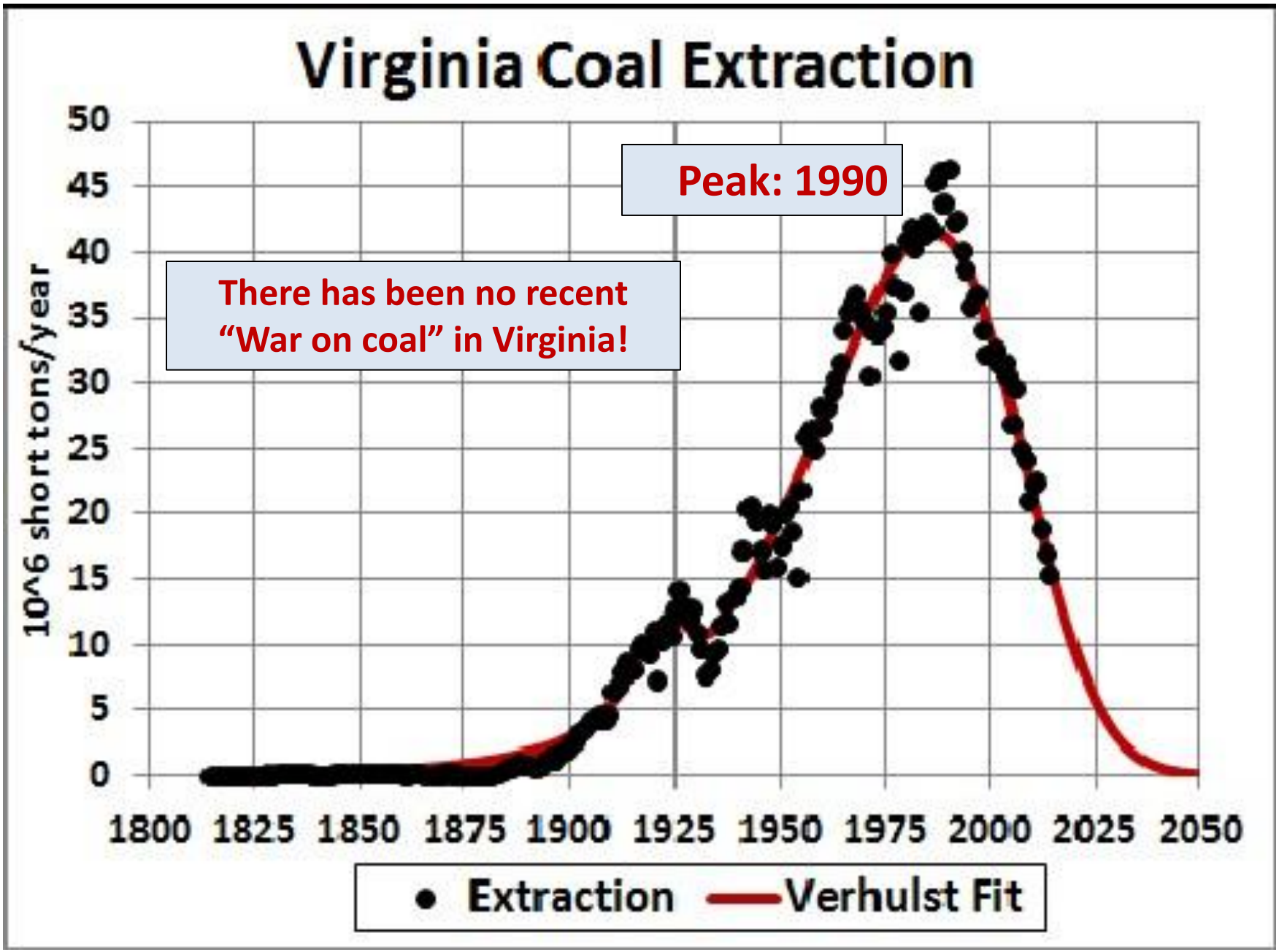
Methane Hydrates = Methane Clathrates = Fire Ice

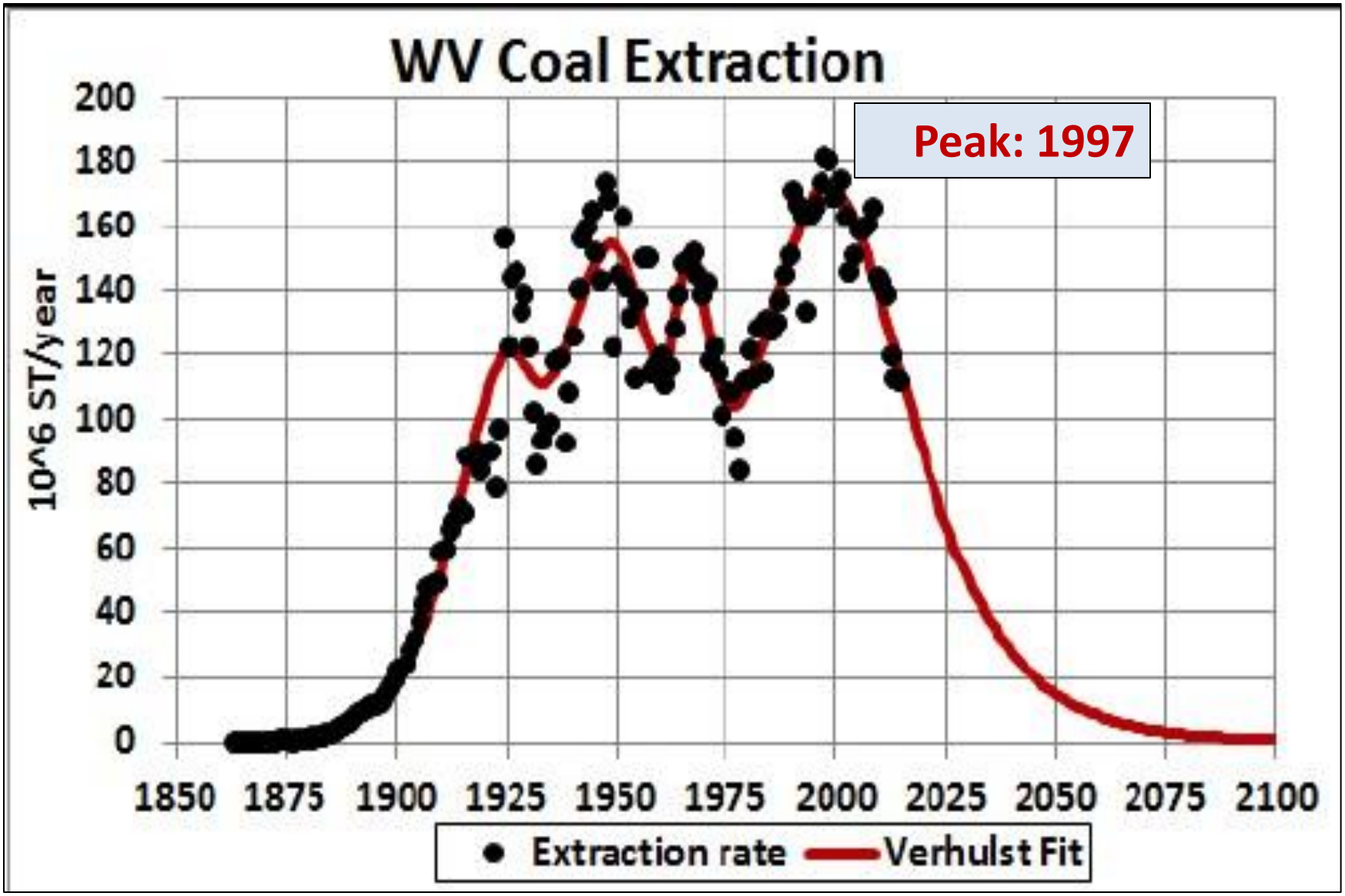




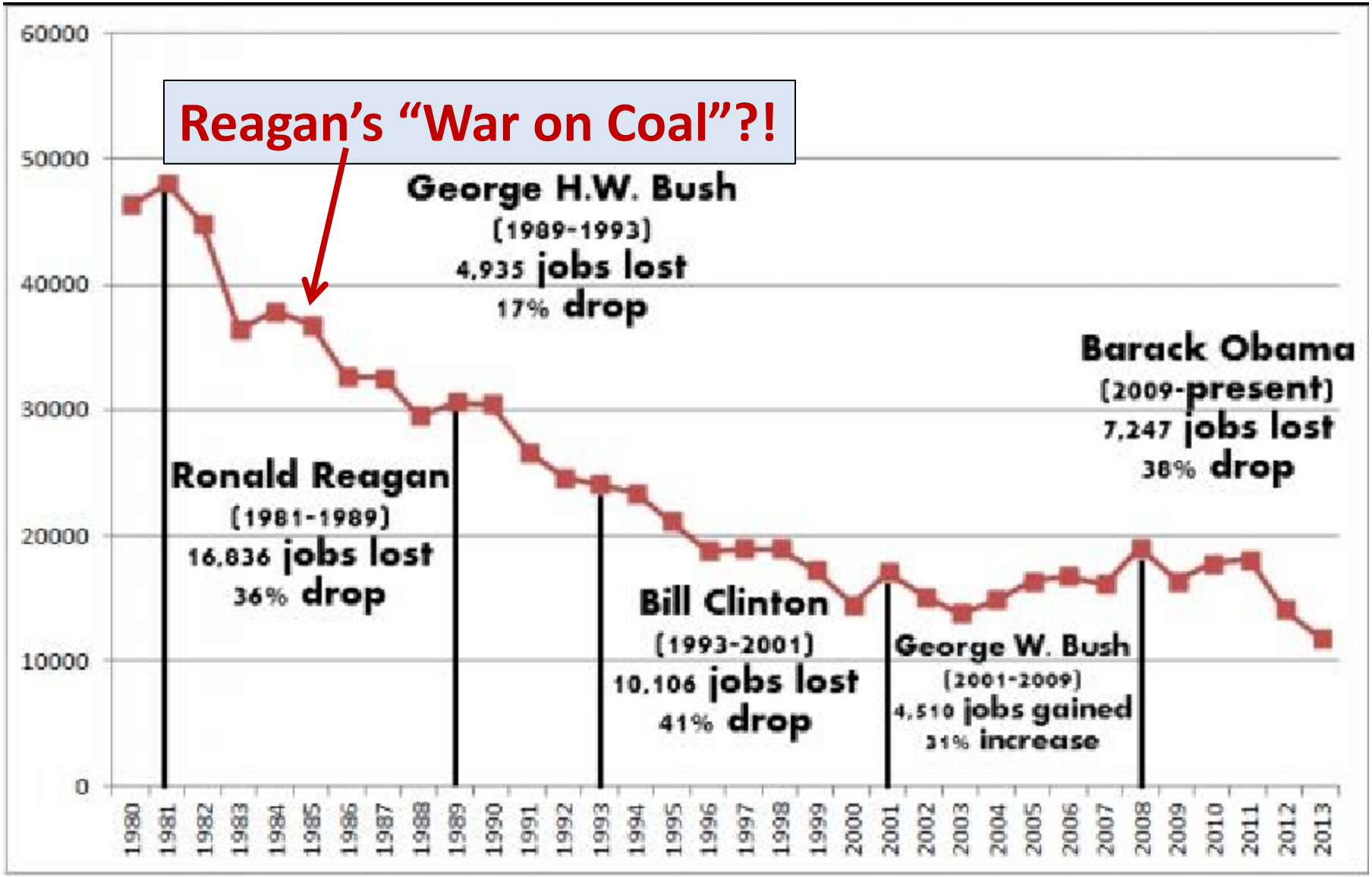
Dangers in extracting methane from hydrates:

- **Releasing huge amounts of methane into atmosphere**
- **Causing huge continental-slopes mudslides and huge tsunamis**
- **Pipelines up steep slopes to shore would be unstable.**
- **Energy cost to extract would be very high.**


Virginia Coal Extraction
Peak: 1990
There has been no recent
"War on coal" in Virginia!
10^6 short tons/year
50
45
40
35
30
25
20
15
10
5
0
1800 1825 1850 1875 1900 1925 1950 1975 2000 2025 2050
Extraction
Verhulst Fit


WV Coal Extraction
Peak: 1997
10^6 ST/year
200
180
160
140
120
100
80
60
40
20
0
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100
Extraction rate
Verhulst Fit

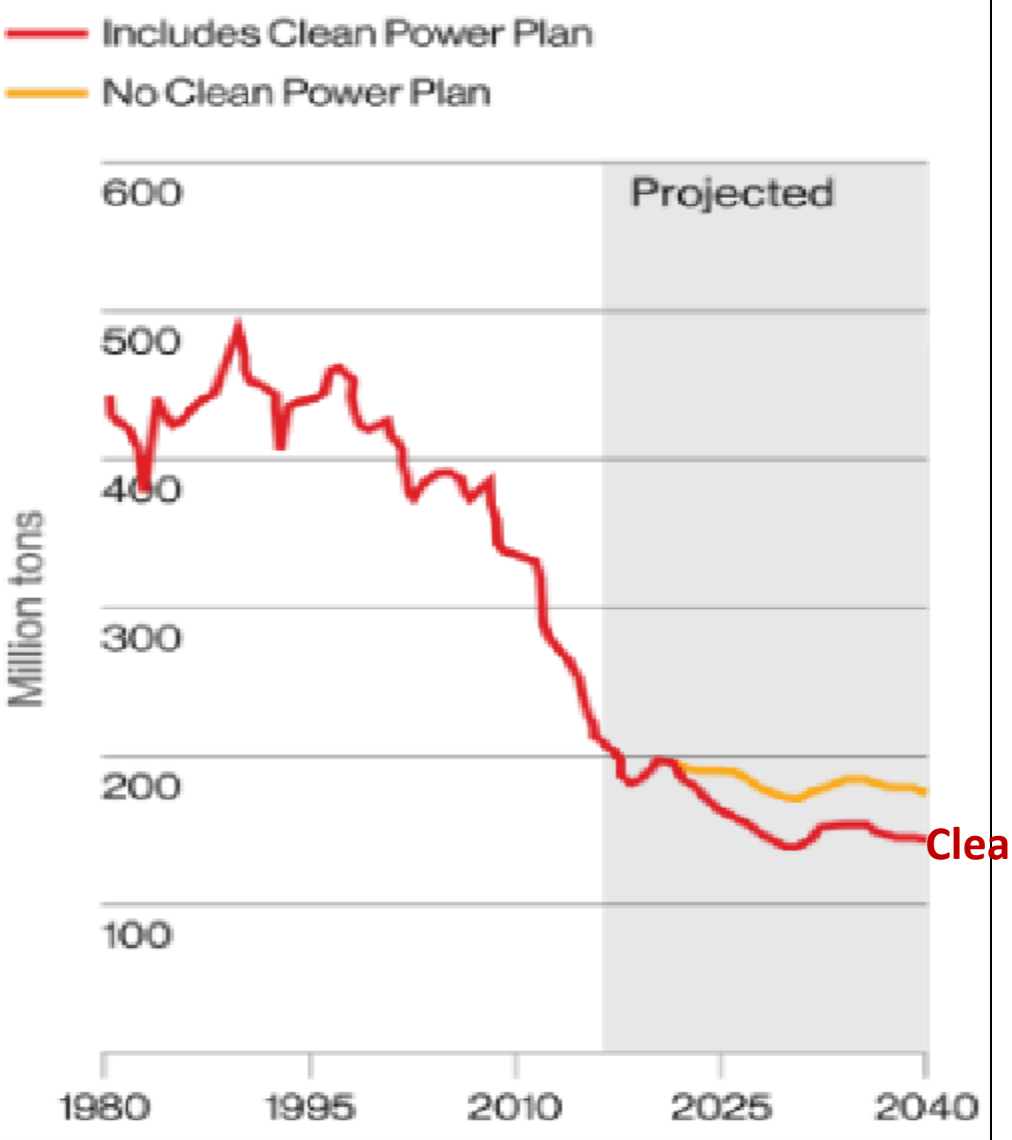
Kentucky Coal Employment

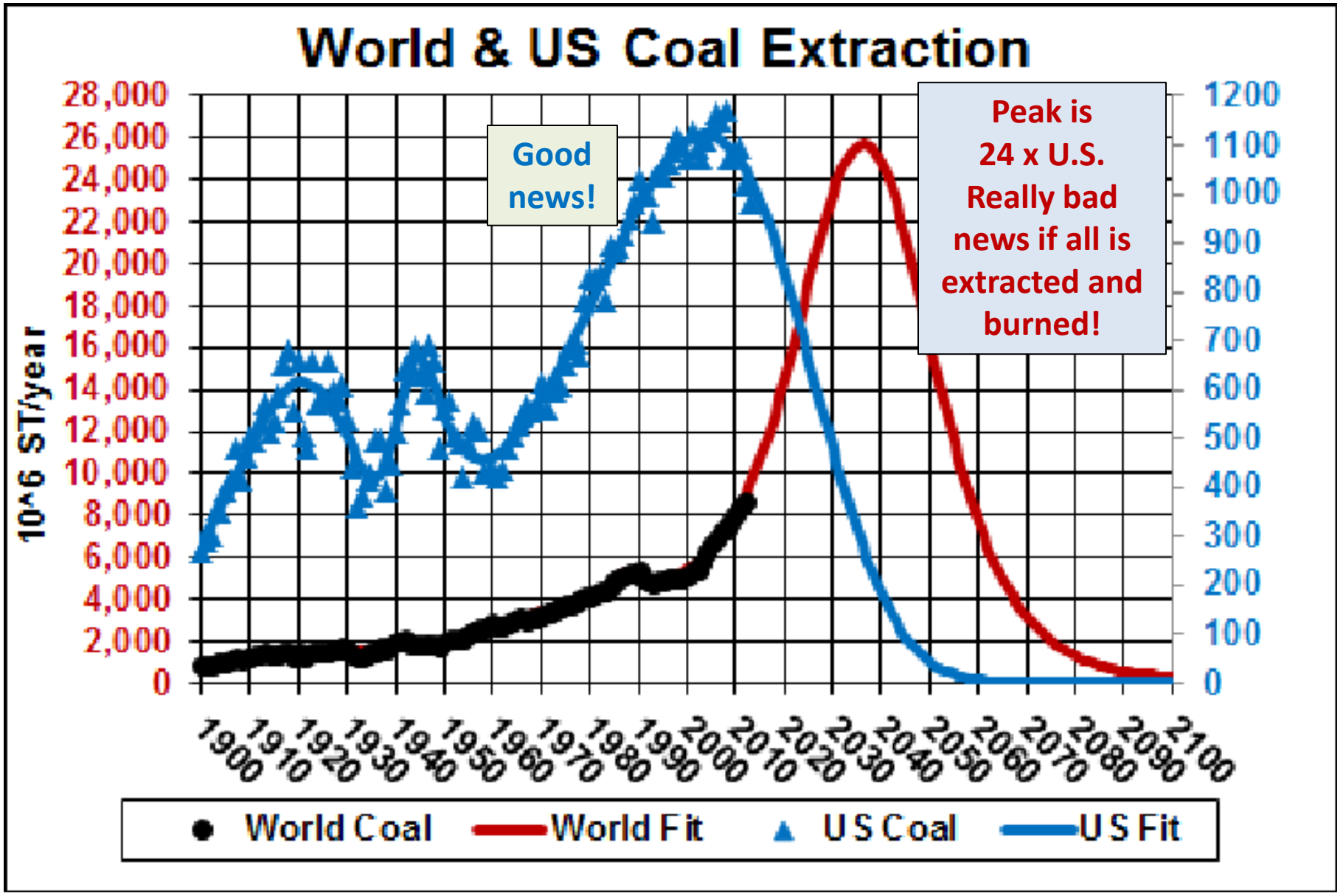


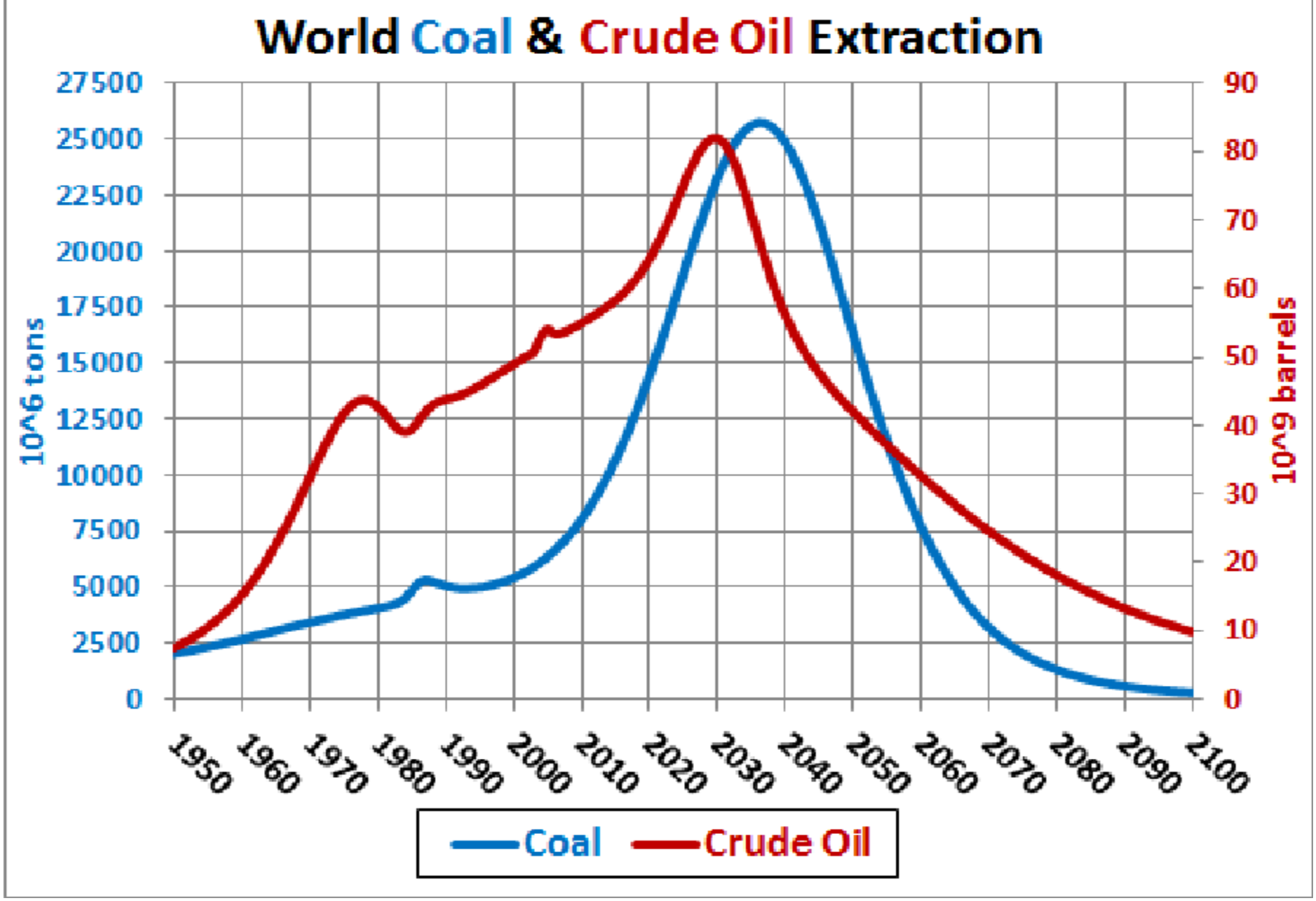
Peaked at 75,000 in 1949!

Appalachia Coal Production

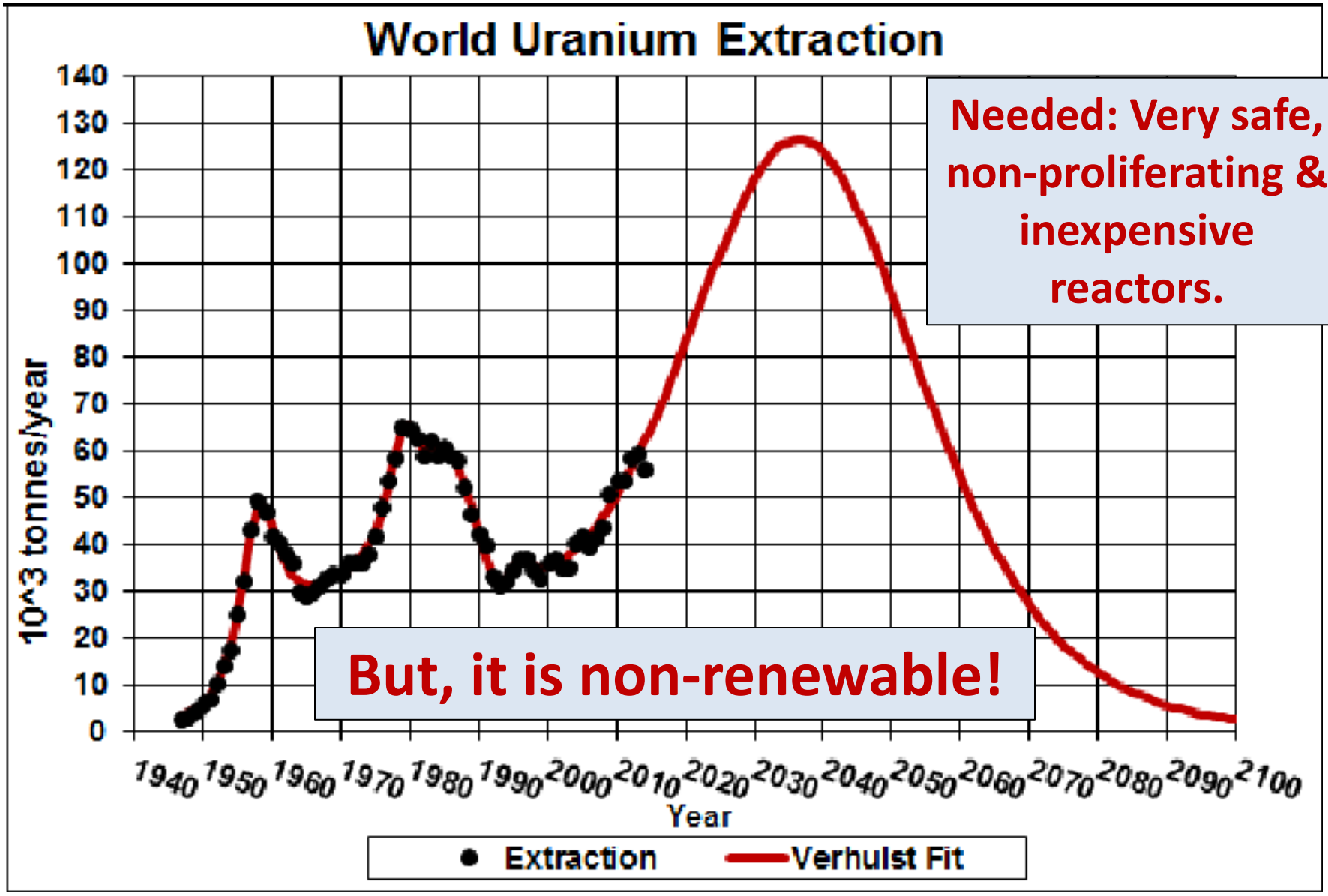
The Clean Power Plan stands to hurt coal mining somewhat, but the industry is already doomed.




World & US Coal Extraction
10^6 ST/year
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Good news!
Peak is 24 x U.S. Really bad news if all is extracted and burned!
World Coal
World Fit
US Coal
US Fit

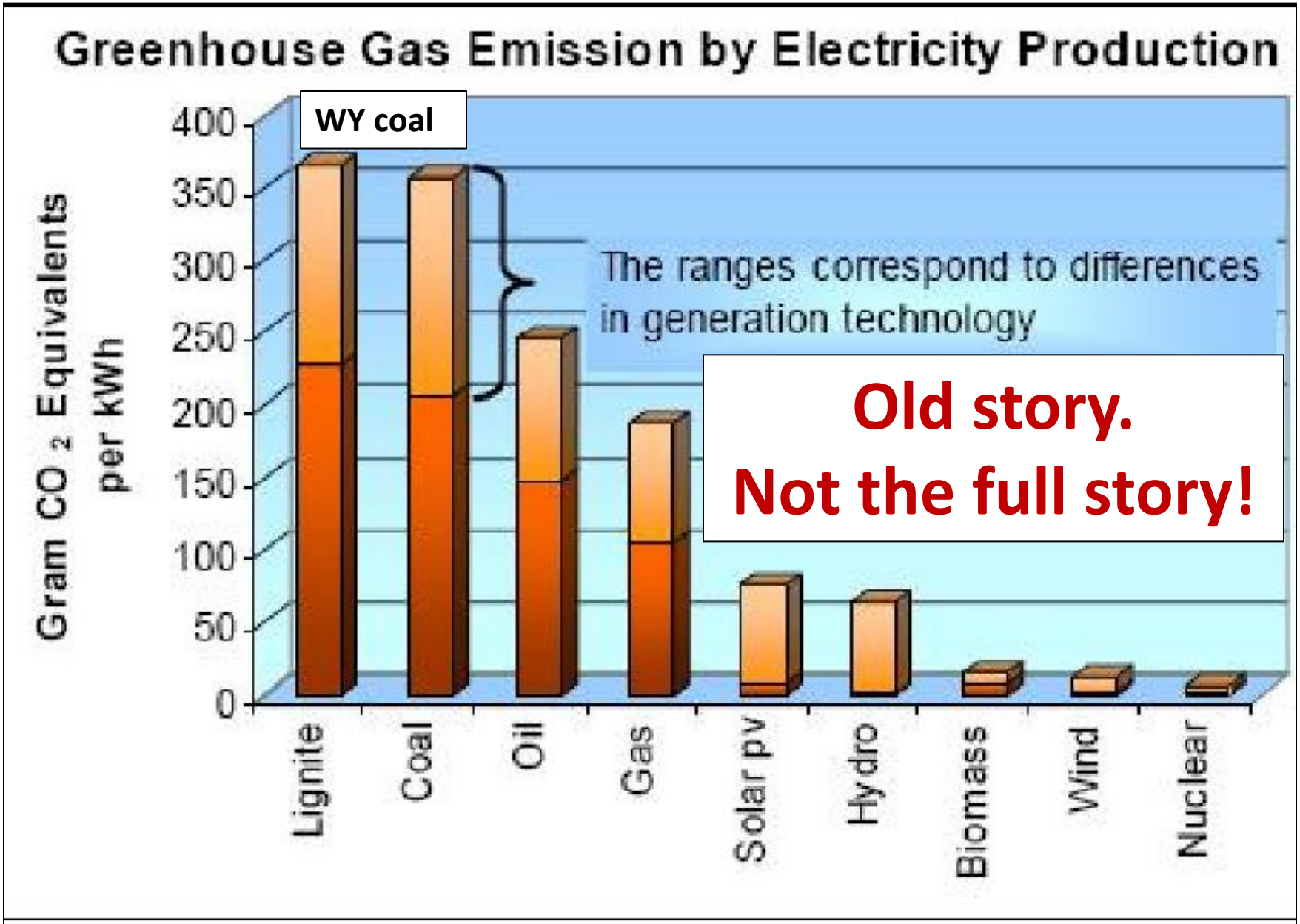


Even though coal & oil will peak 50-60 years before 2100, global warming will last hundreds of years longer!


World Uranium Extraction
Needed: Very safe, non-proliferating & inexpensive reactors.
But, it is non-renewable!
10^3 tonnes/year
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
Extraction
Verhulst Fit

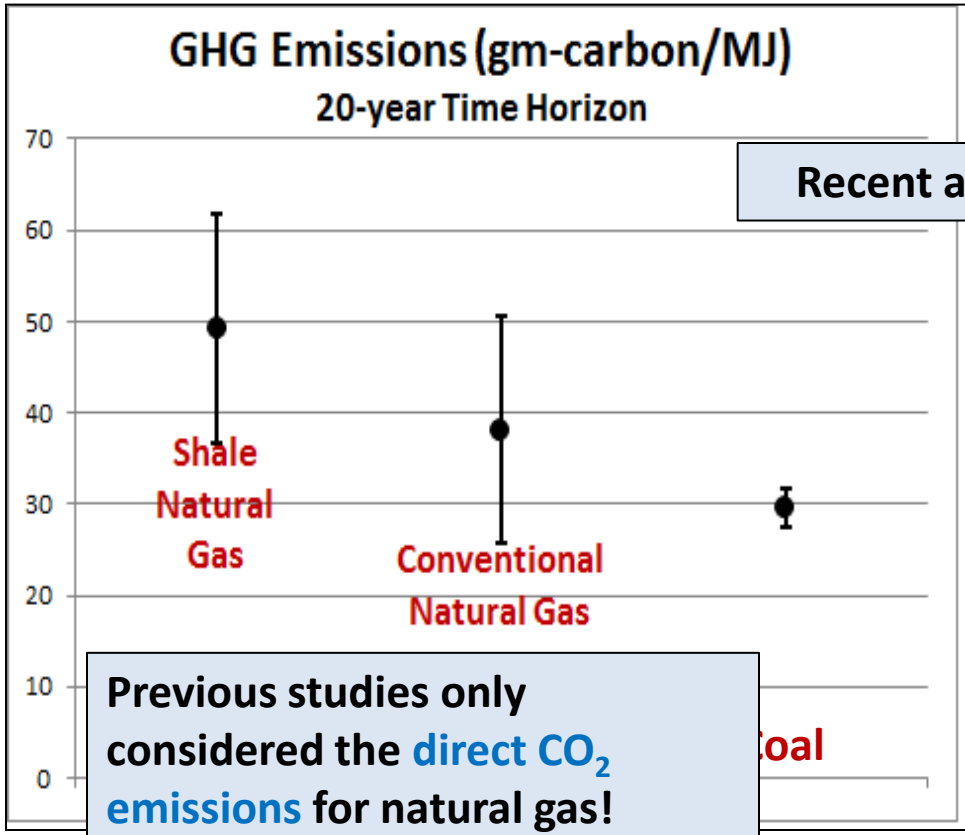
Minerals-Depletion Studies

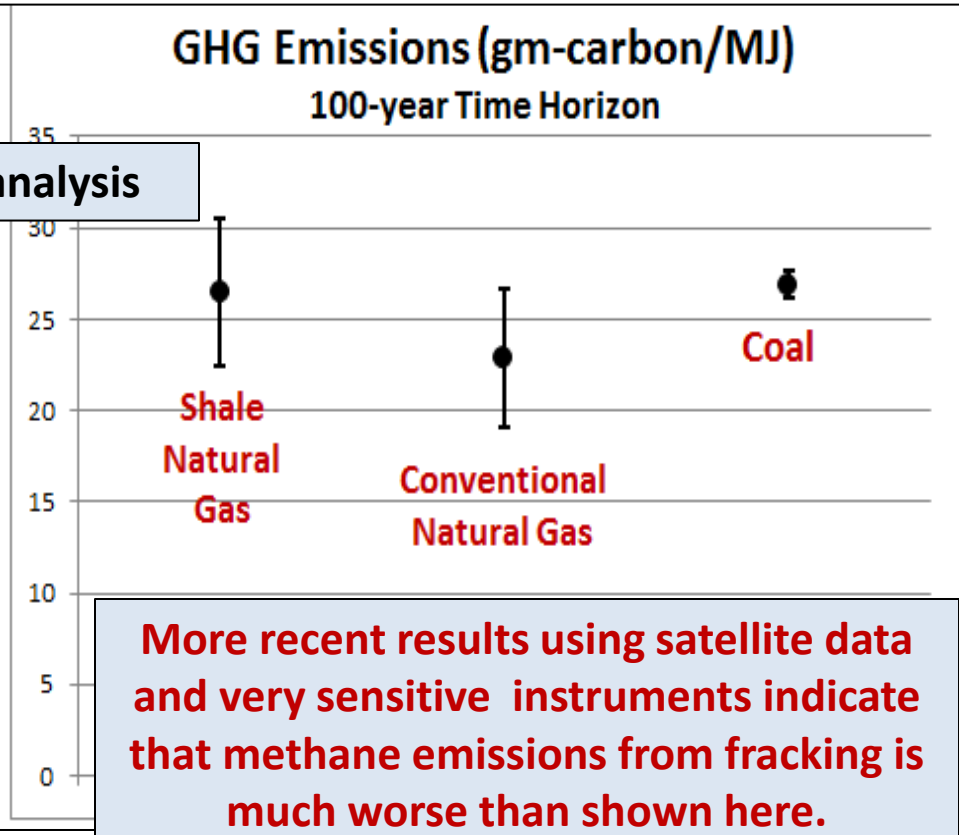
- **tinyurl.com/MineralsDepletion**
- Since the 1970s I have done studies of minerals depletion using the method described above.
- All major minerals for the world
- Crude-oil for all major countries and U.S. states
- Natural-gas for all major countries and U.S. States
- Coal for all major countries and U.S. states



Greenhouse Gas Emission by Electricity Production Method.
(Source: OECD/NEA)

CO_2 & CH_4 Emissions of Fracked Natural Gas





Recent analysis

More recent results using satellite data and very sensitive instruments indicate that methane emissions from fracking is much worse than shown here.

Previous studies only considered the direct CO_2 emissions for natural gas!

Fugitive-Emissions Conclusions:

- **Shale gas is much worse than coal over 20 years.**
- **Conventional gas is worse than coal over 20 years.**
- **Both gases are similar to coal over 100 years.**

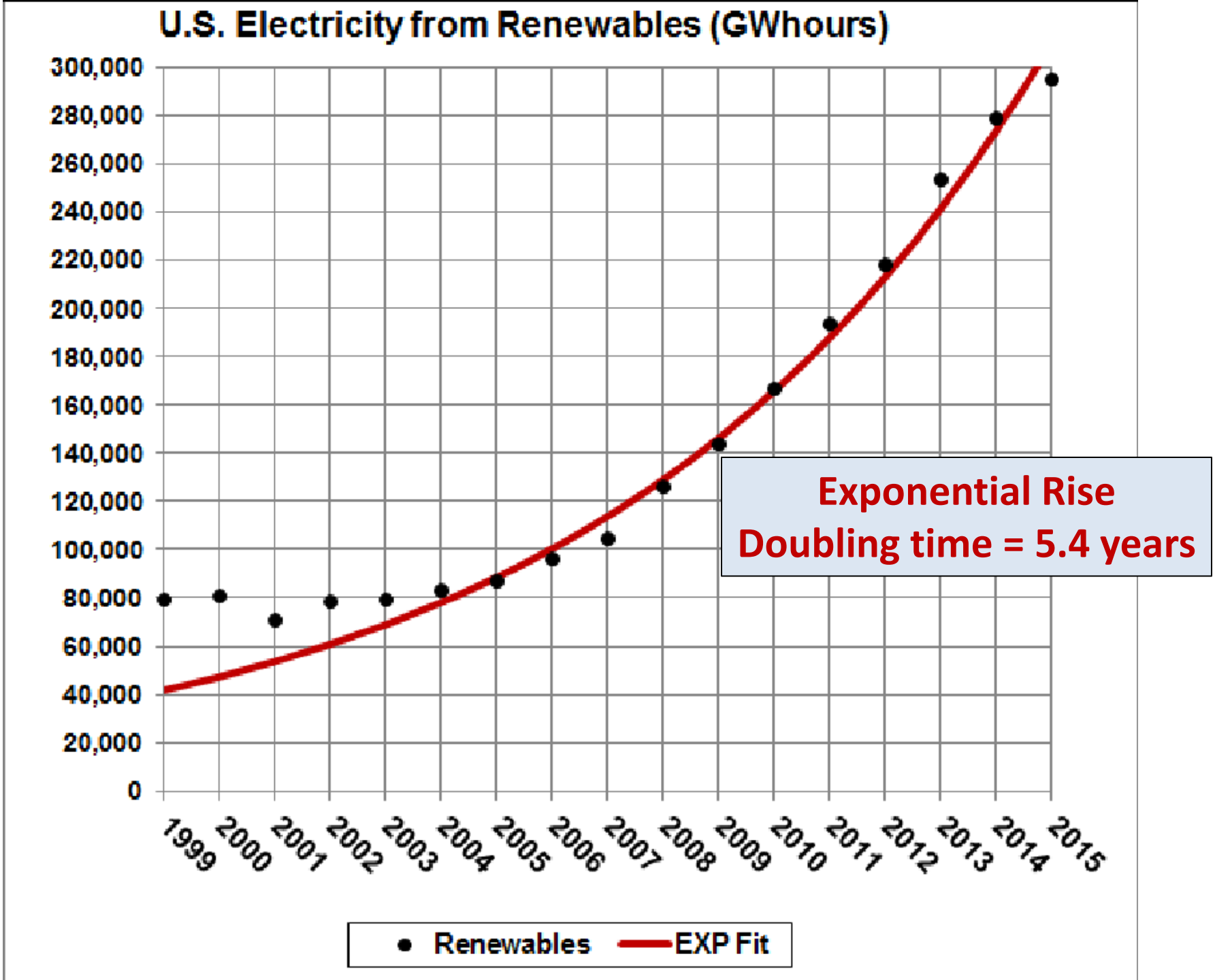
-kWh = 3.6-MJ

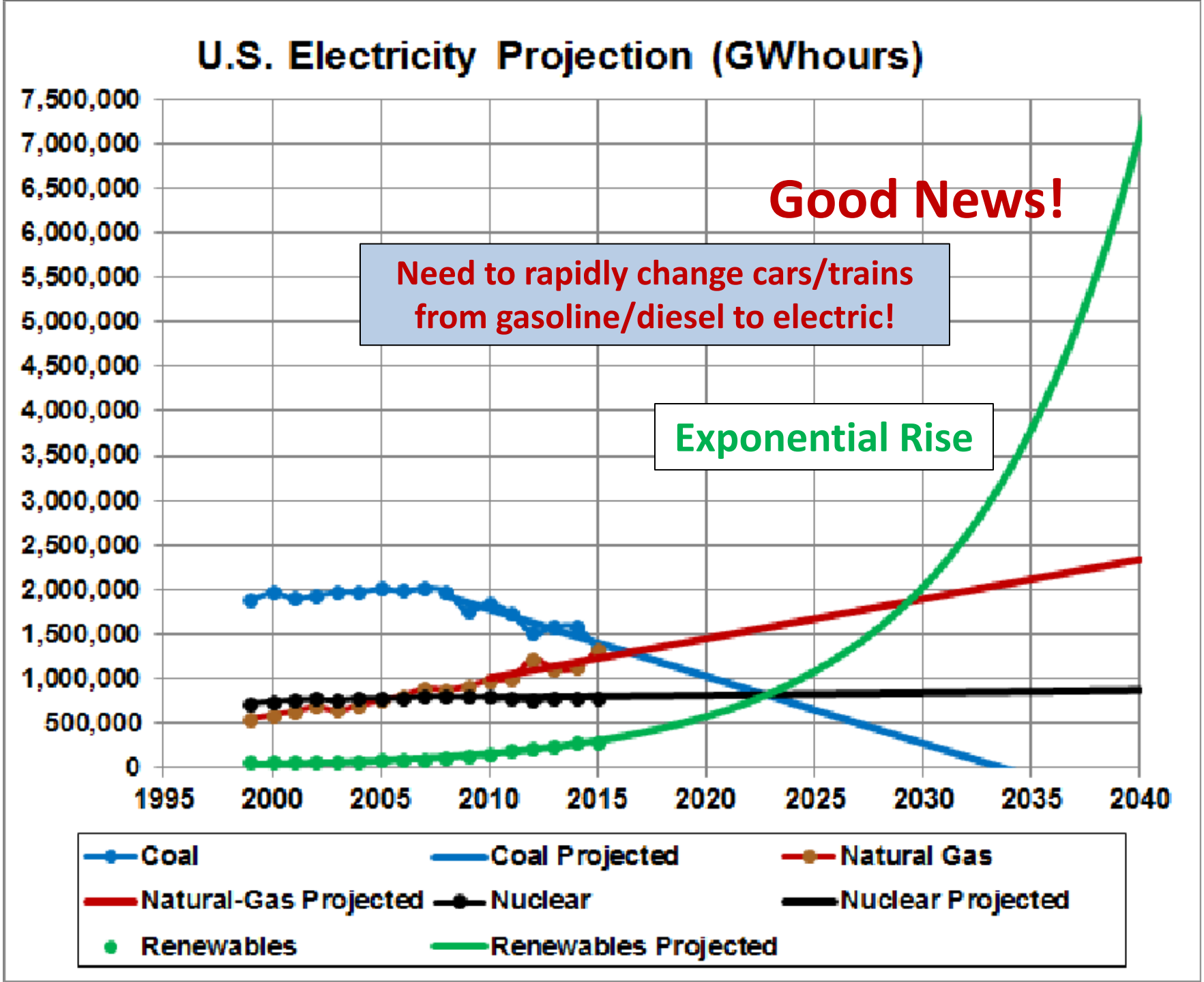
h oxygen in the atmosphere to convert

ter with a 7-years half-life, one has to

o compare methane climate forcing to

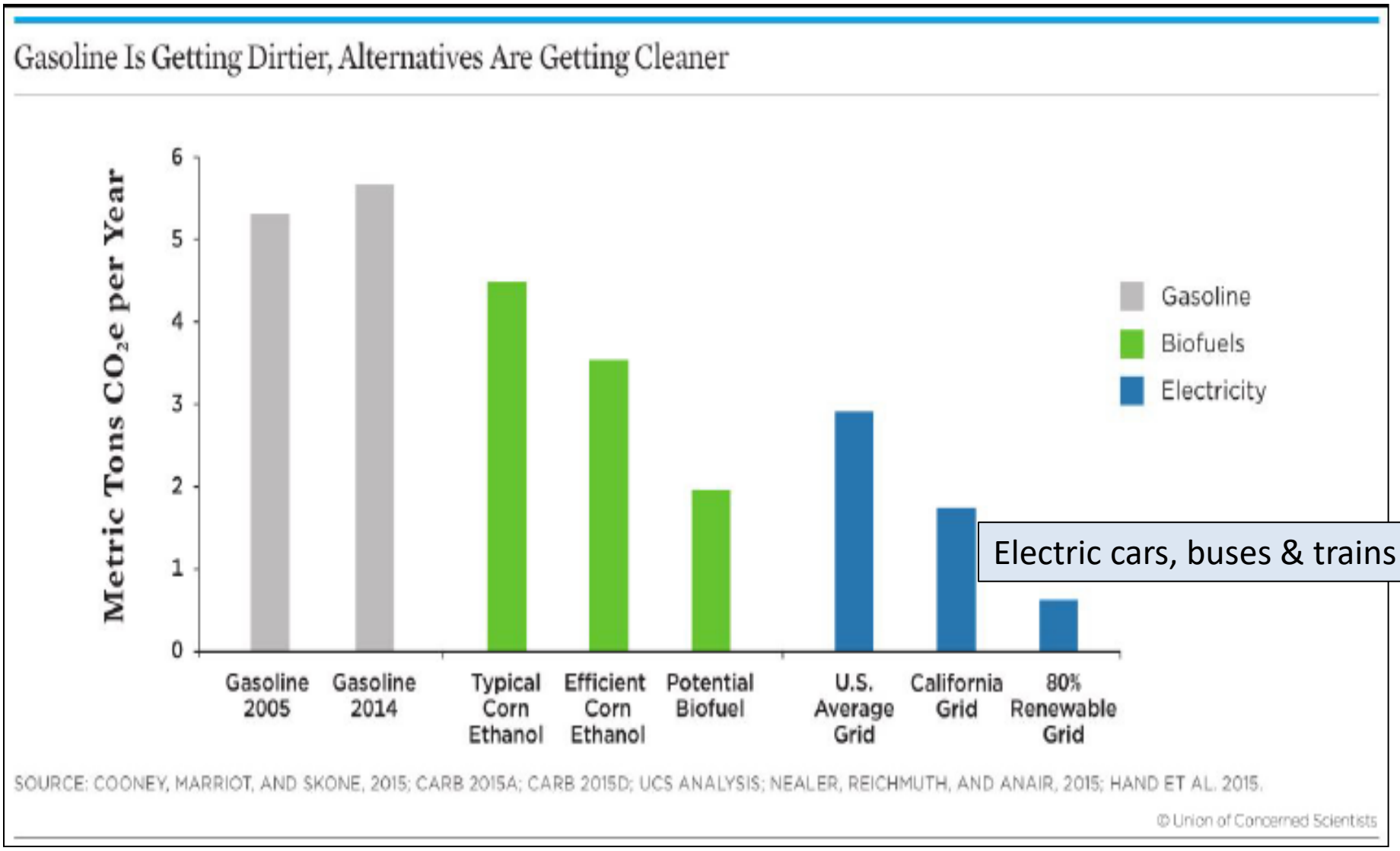
ttp://phys.org/tags/methane/ .


U.S. Electricity from Renewables (GWhours)
300,000
280,000
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Exponential Rise
Doubling time = 5.4 years
Renewables
EXP Fit


U.S. Electricity Projection (GWhours)
7,500,000
7,000,000
6,500,000
6,000,000
5,500,000
5,000,000
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
Good News!
Need to rapidly change cars/trains from gasoline/diesel to electric!
Exponential Rise
Coal
Coal Projected
Natural Gas
Natural-Gas Projected
Nuclear
Nuclear Projected
Renewables
Renewables Projected

Comparative Emissions for Auto Fuels

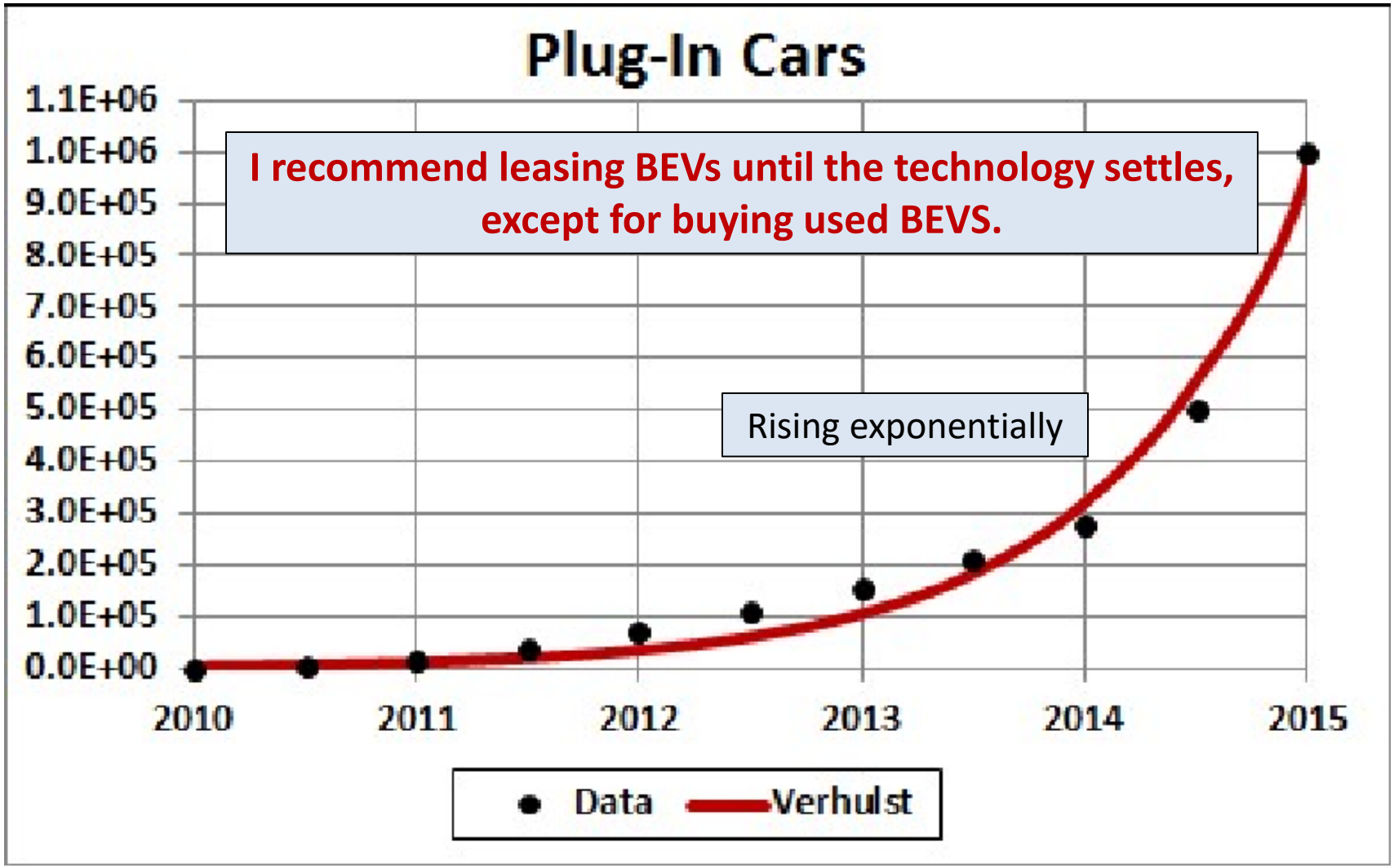
http://www.ucsusa.org/clean-vehicles/clean-fuels/transportation-fuels-future?autologin=true#.Vrq0BfkrLmE



Electric cars, buses & trains

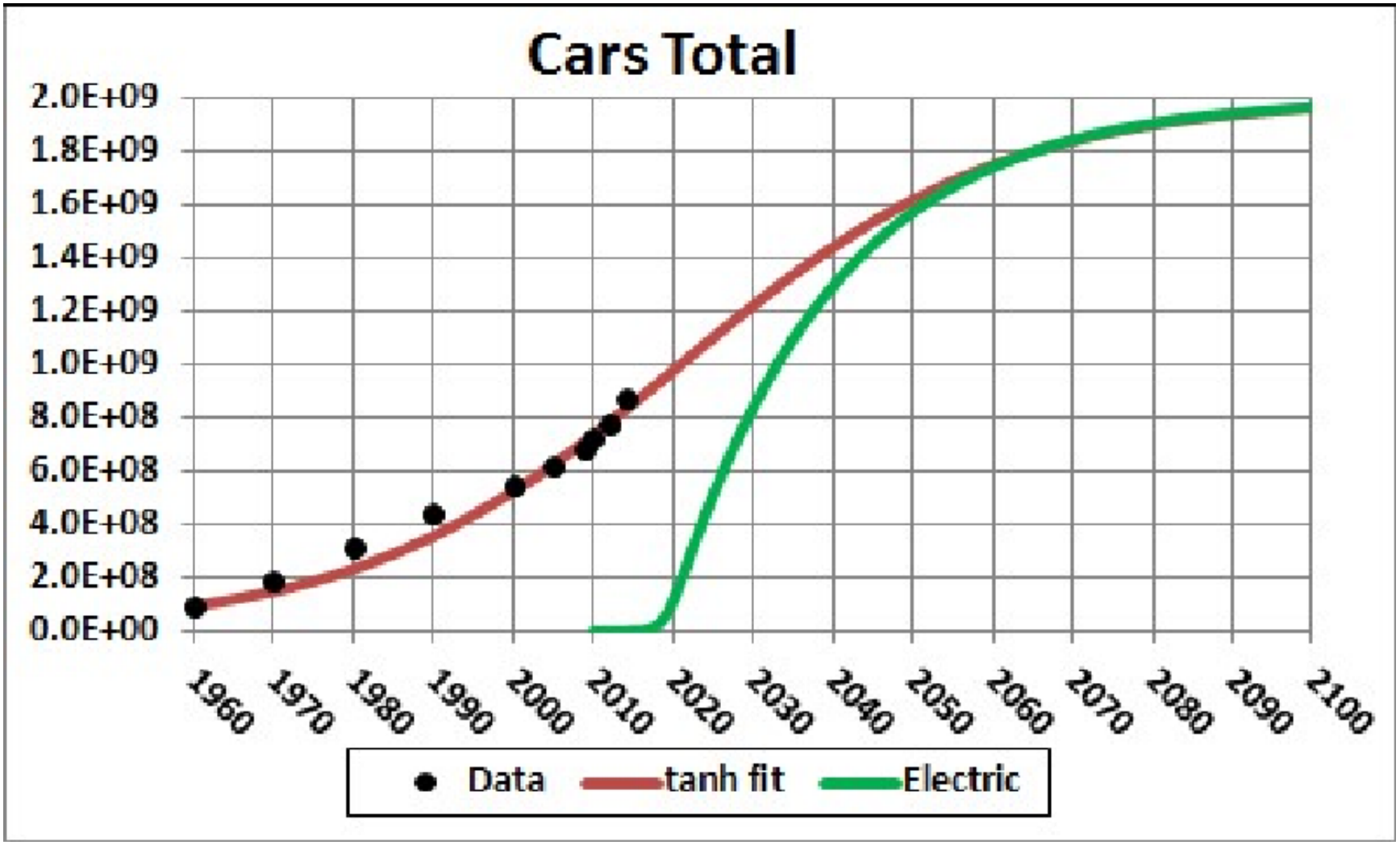
We must change to electric transportation asap with renewable energy!

Plug-In Car = BEV (Battery Electric) or PHEV (Plug-In Hybrid)



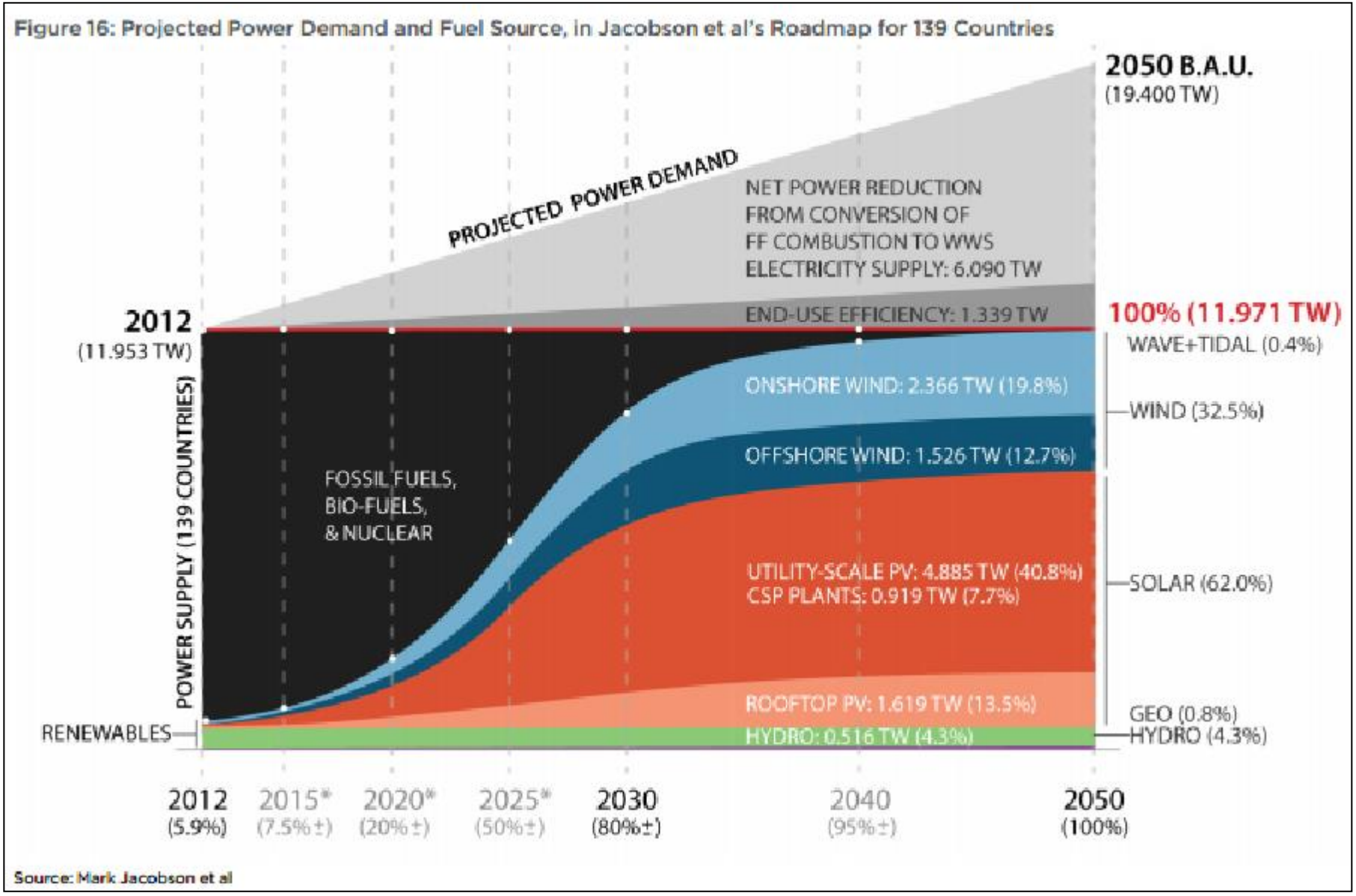
This is for the world out of ~1 x 10^9 cars.

My estimate as to when all cars will be electric (BEVs or PHEVs)



Preview of Next Semester: Sustainable Energy

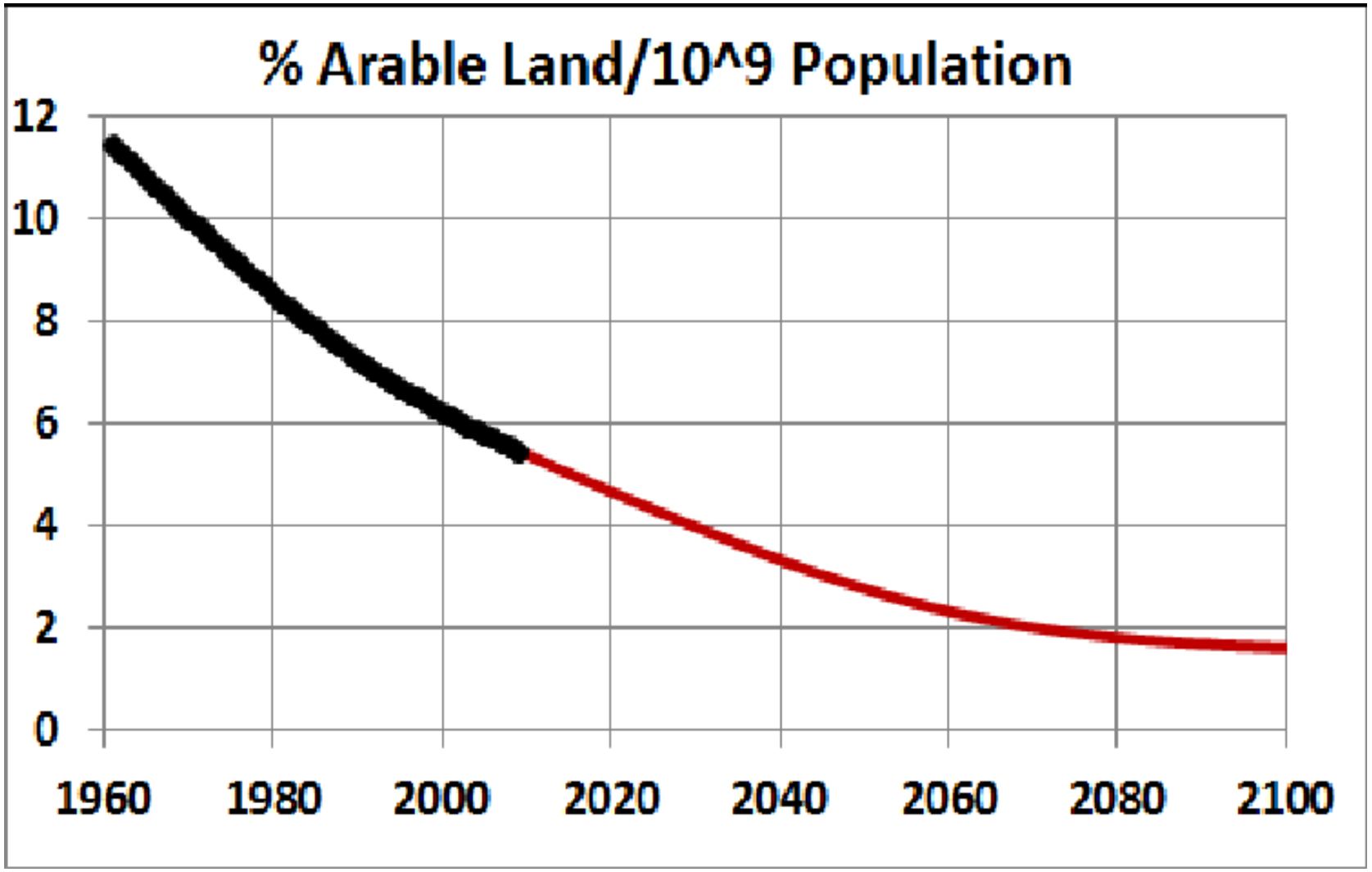
tinyurl.com/SustainableEnergyRoper

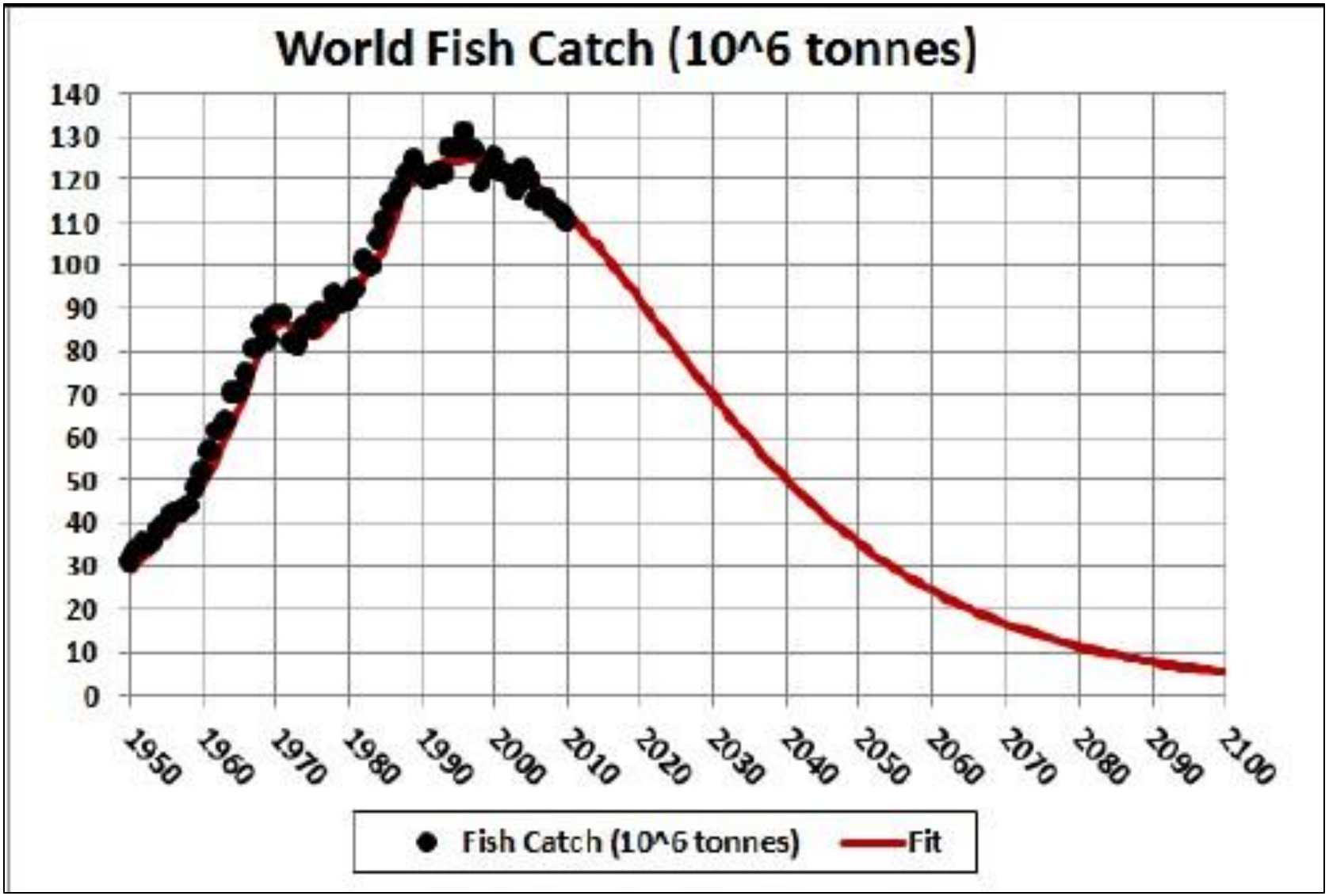


Other Troubles besides Global Warming and Decline of Fossil-Fuels Energy

Two examples are:

- Declining arable land
- Fish catch:


% Arable Land/10^9 Population
12
10
8
6
4
2
0
1960
1980
2000
2020
2040
2060
2080
2100


World Fish Catch (10^6 tonnes)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Fish Catch (10^6 tonnes)
Fit

Global Warming

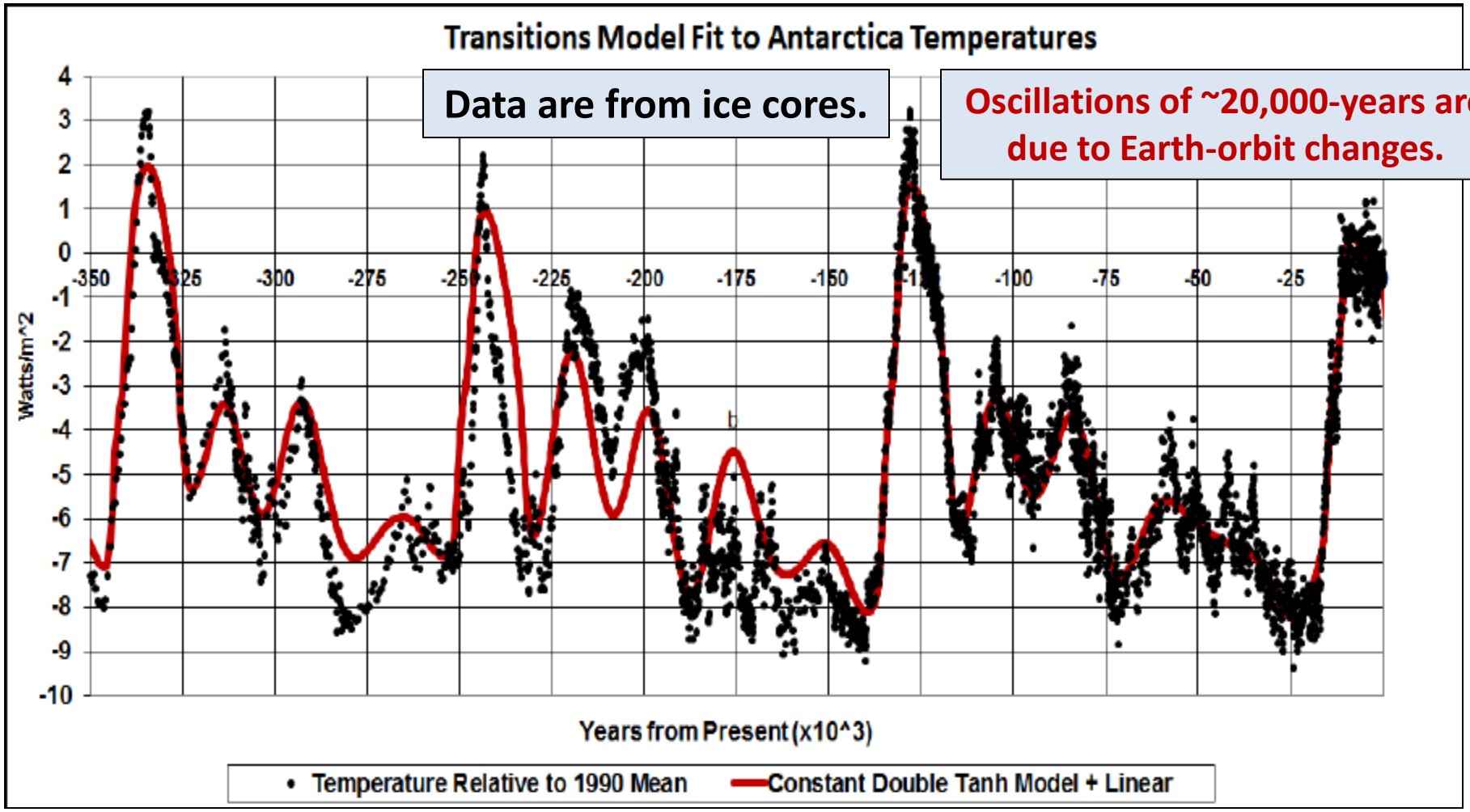
- **It is not just a scientific or political problem.** Even more it is a **moral problem**, whether you are an Agnostic, Atheist, Christian, Jew, Muslim or Secular Humanist. Many people are dying already due to Global Warming.
- It is about the Earth and the society that we are going to leave for our descendants.
- **However, the Earth would be fine without us!**

Long-Term Future for the Earth

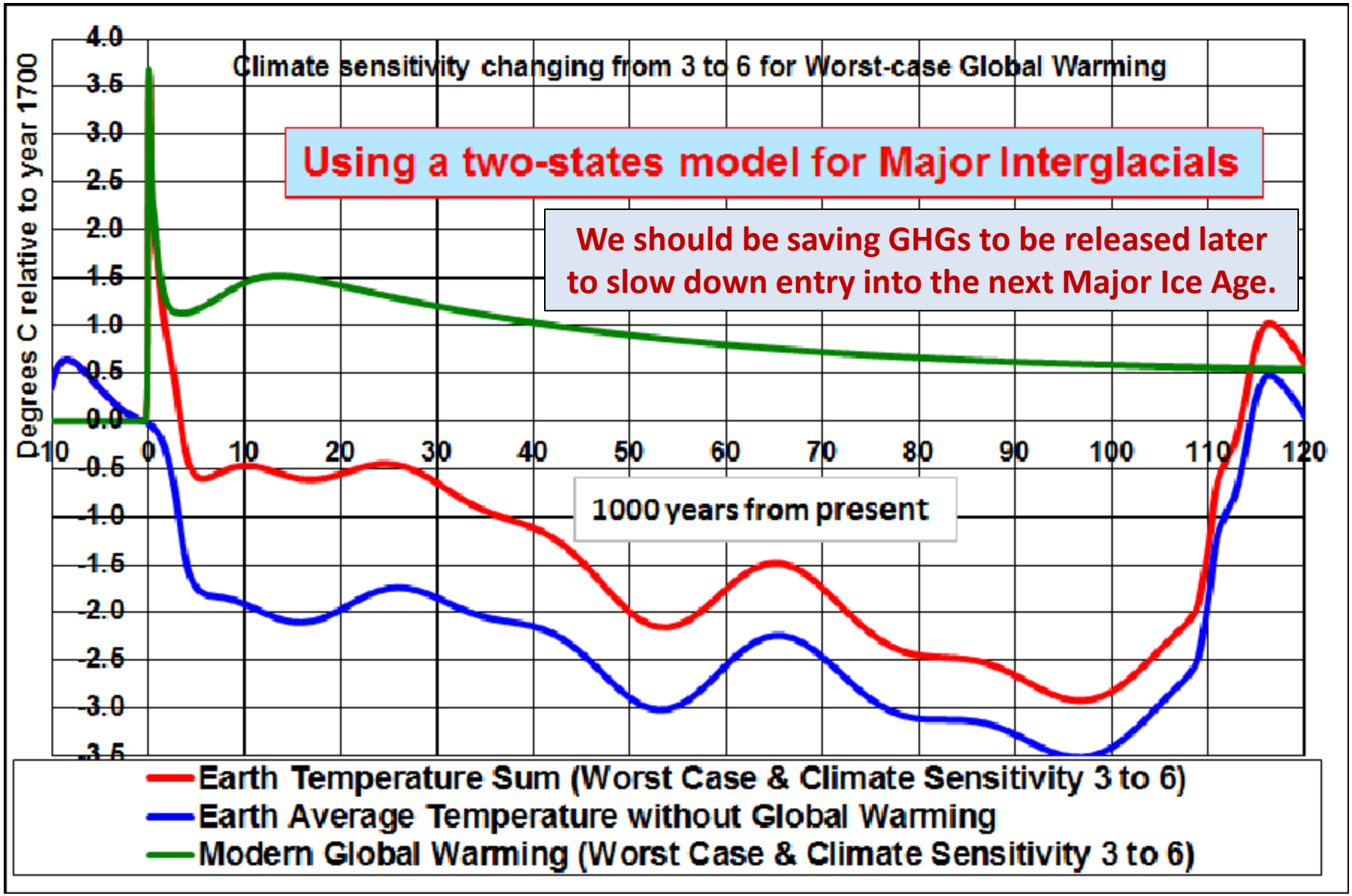
The Earth would be on a downward temperature slide into the **next ~100,000-years Major Ice Age** now if it were not for global warming, which was **started with agriculture and will end with burning fossil fuels.**

A Model Fit to the Last Three ~100,000-Years Major Ice Ages

Data from Antarctica ice cores are more accurate for last Major Ice Age.



Note the high temperature ~125,000 years ago, toward which we are heading.
The sea level then was 5-7 meters higher than today!


Climate sensitivity changing from 3 to 6 for Worst-case Global Warming
Using a two-states model for Major Interglacials
We should be saving GHGs to be released later to slow down entry into the next Major Ice Age.
Degrees C relative to year 1700
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
1000 years from present
Earth Temperature Sum (Worst Case & Climate Sensitivity 3 to 6)
Earth Average Temperature without Global Warming
Modern Global Warming (Worst Case & Climate Sensitivity 3 to 6)