Building a Sustainable Energy Future

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Acknowledgements

Many fellow students of Sustainable Energy issues, too numerous to acknowledge.
Some original material mixed with work of others.

Most Important Themes of this Discussion

1. Population, Peak Energy, EROEI, Entropy, GDP
2. Energy and HDI
3. Re-definition good life

Four Distinct Sustainability Challenges

Problem	Imminence	Impact
I Global Warming	Approaching (5 to 10 years)	GRADUAL over 10 – 100+ years
II Peak Production Total Energy	Approaching (10 to 15 years)	DISASTROUS
III Peak Production Portable Energy	Now (-3 to 5 years)	CATASTROPIC
IV Peak Other Materials (bees, grains, species, top soil, fertile land, H_2O, Cu, P, U, Au)	Now (-25 to present)	COLLAPSE Can be exacerbated by I - III

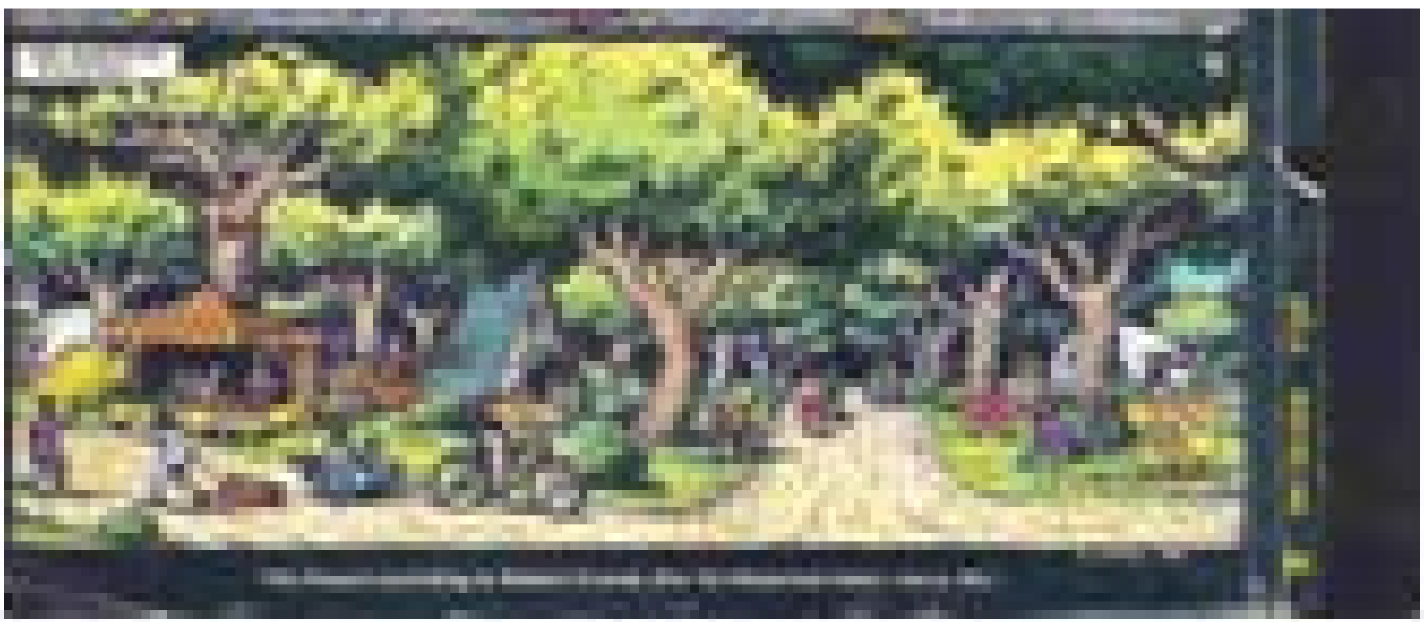
Least Important

Most Important

Challenges lead to Opportunities

A Positive Perspective

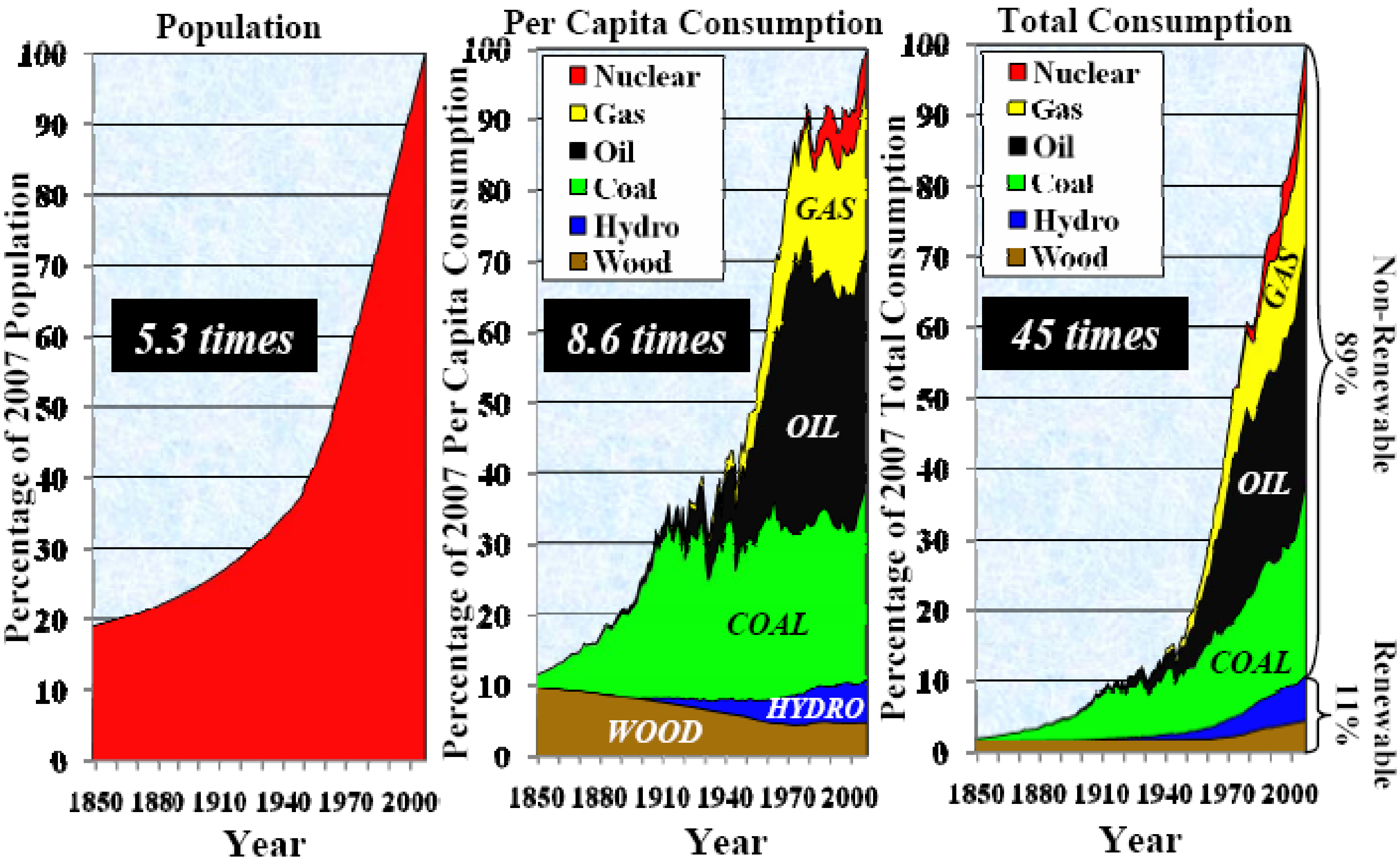
- Every challenge can be used to create a transformative change
- This Challenge is no different
- We can pro-actively address it and create a far healthier, sustainable, egalitarian society



Total Energy Consumption

- Total Energy Consumption = Population × (Per Capita Energy Consumption)

World Population, Per Capita Energy consumption and Total Energy Consumption



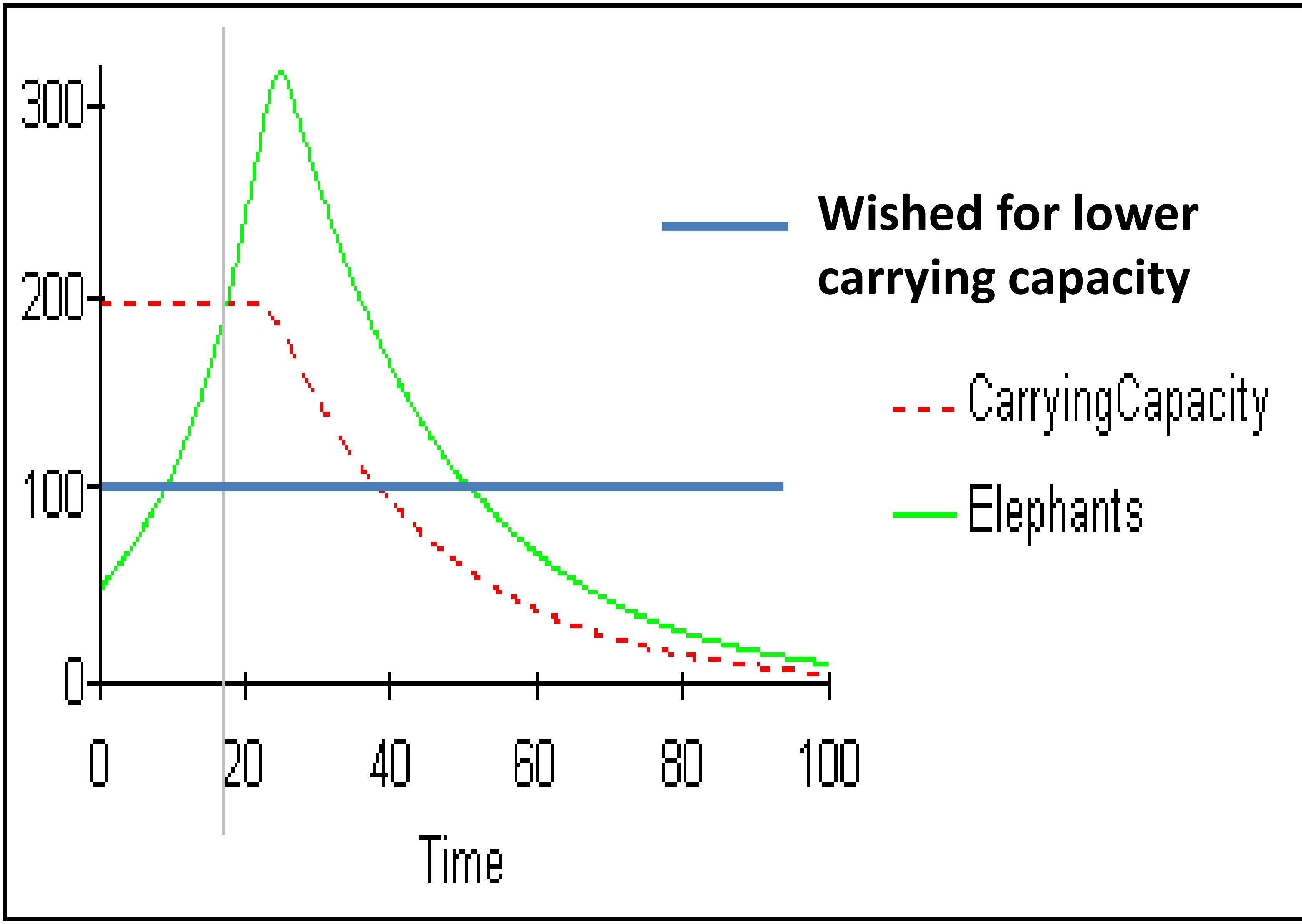
(data from Arnulf Grubler, 1998; BP Statistical Review of World Energy, 2008; U.S. Bureau of Census, 2008)

http://www.aspo-usa.org/aspousa4/proceedings/Hughes_David_Coal_ASPOUSA2008.pdf

Population, Second Law of Thermodynamics and Carrying Capacity

- Entropy or Disorder S scales with the **system size**. In any activity or process **$\Delta S > 0$** by 2nd law.
- **More population** means more materials under human consumption implies **larger ΔS**.
- **Larger ΔS** means more **destruction of carrying capacity** or environmental destruction.

Systems Analysis Model Future of Population



Fixed GDP model: Elephants do not build houses, watch television or own cars, they just eat, sleep, mate, reproduce

Energy Consumption and Population

- Total Energy Consumption = **Population** × (Per Capita Energy Consumption)

- **Increasing** only **Population continuously** on a finite earth even if we keep **GDP fixed** is **IMPOSSIBLE**

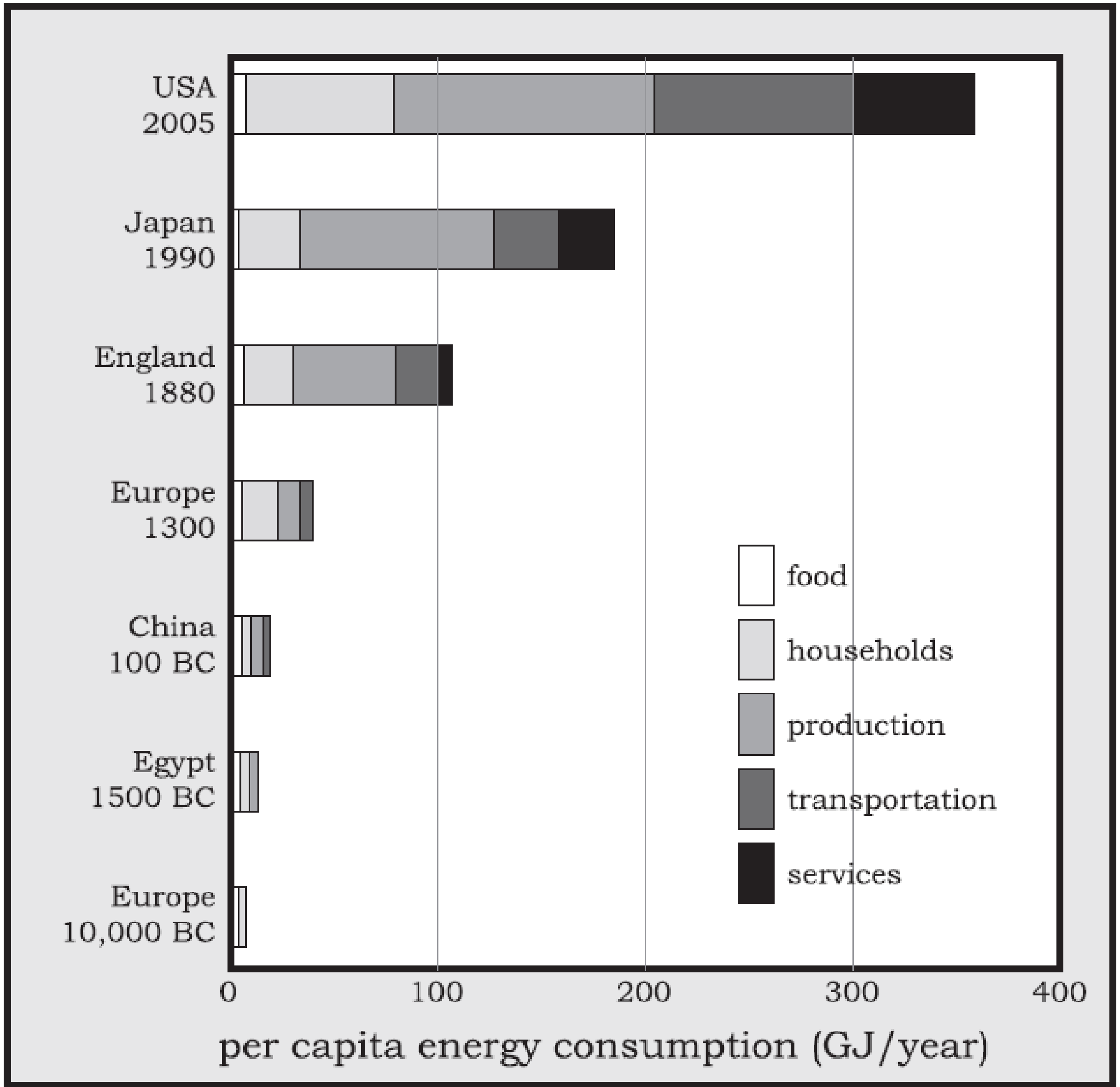
GDP and Energy Consumption

- Total Energy Consumption = Population × (Per Capita Energy Consumption)

- Per Capita Energy Consumption directly scales with Per Capita Gross Domestic Product (GDP)

- **GDP = Fixed Assets + Consumption of Products and Services + (Exports – Imports)**

Most Technology just means bigger GDP and more Energy Consumption



- From Vaclav Smil's book

GDP, Second Law of Thermodynamics and Carrying Capacity

- Entropy or **Disorder S** scales with the **system size**. In any activity or process **$\Delta S > 0$** by 2nd law.
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Energy Consumption and GDP

- Total Energy Consumption = Population x (Per Capita Energy Consumption)

- **Increasing** only **Per Capita Energy Consumption continuously** on a finite earth even if we keep **Population fixed** is **IMPOSSIBLE**

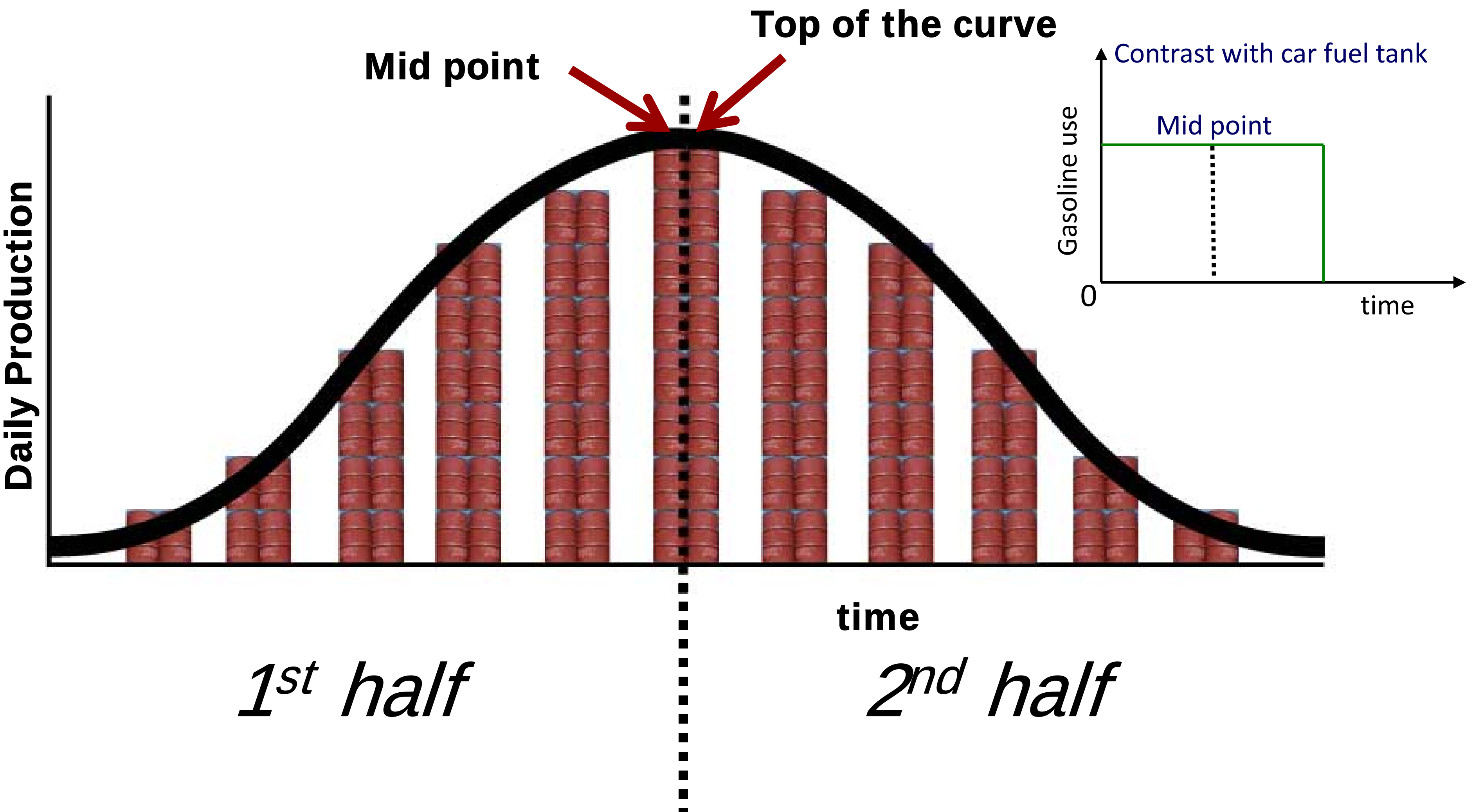
Consequences of Growth

- Total Energy Consumption = Population x (Per Capita Energy Consumption)

- **Increasing** either **Population** or Per Capita Energy Consumption or **GDP** will lead to **Chaotic destruction** of **Population** and **Orderly Civilization**

- **Can these be even kept constant?**

Peak Energy: When you plot the production of <u>an aggregate</u> of oil fields, it approximates a <u>bell curve</u>



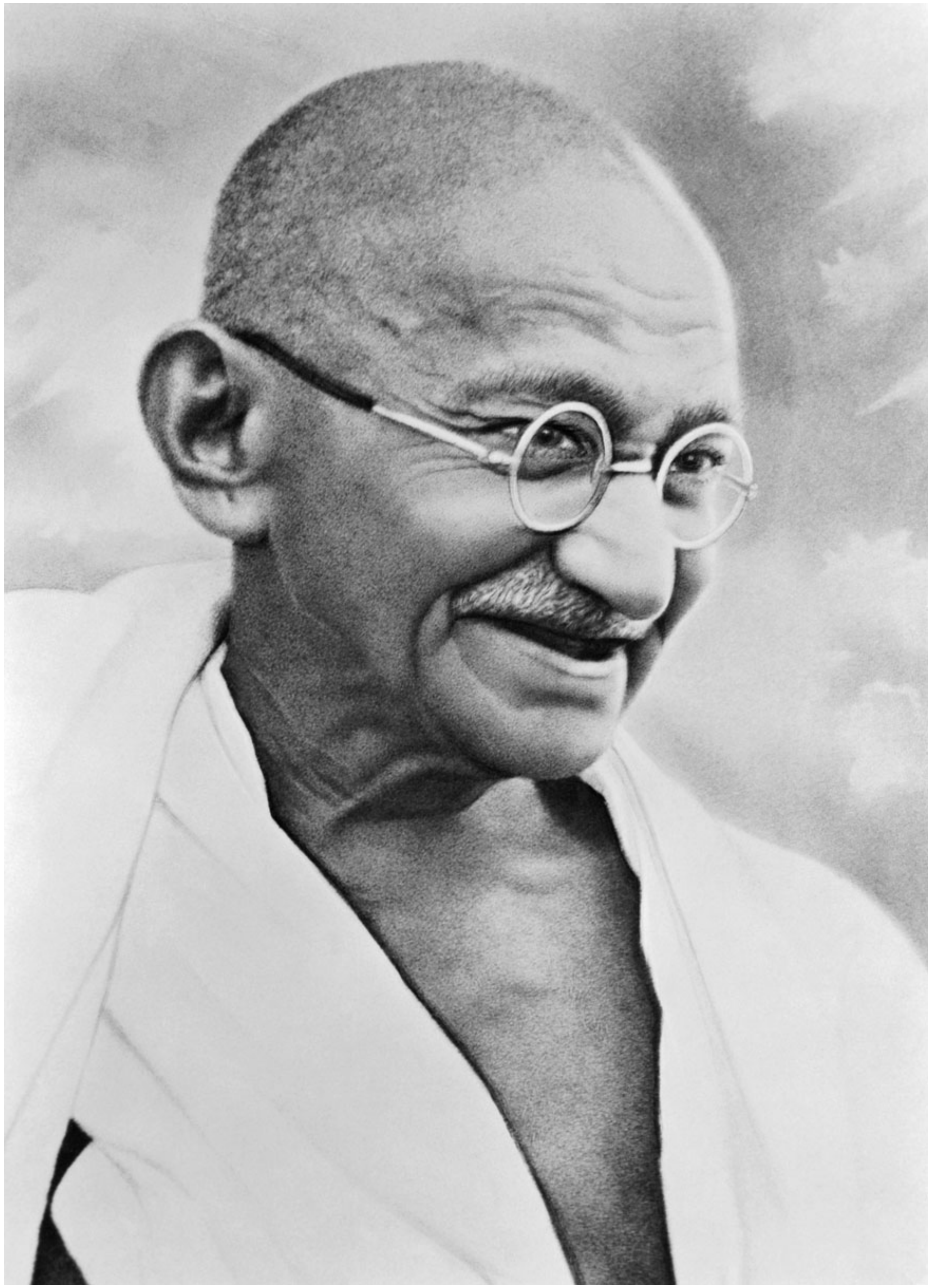
From geological peak – Production declines indefinitely forever – Applies to all minable resources – Crude Oil, Natural Gas, Coal, Uranium, Old Water, metals, other minerals

Wait a minute! I thought renewables would save us!

No, because large amount of materials sourcing is already a problem on a finite earth. Peak Materials!

We continuously increase both Population and GDP for which no amount of materials will be enough.

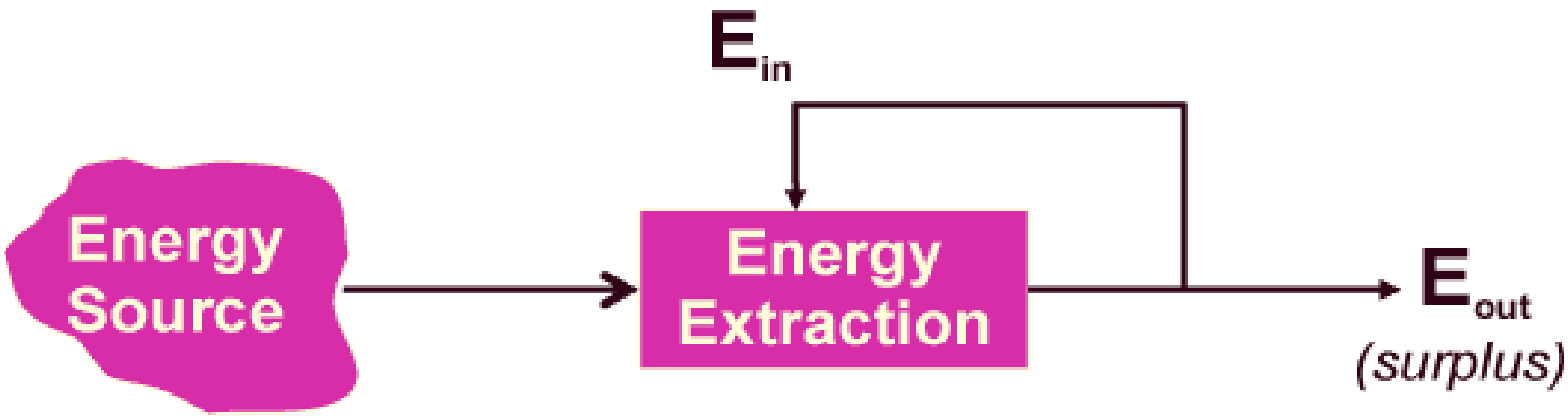
Quote from Mahatma Gandhi



Quote: “Earth provides enough to satisfy every man's need, but not one man's greed”

Now millions of us are greedy.

Energy Quality: Energy returned on Energy invested



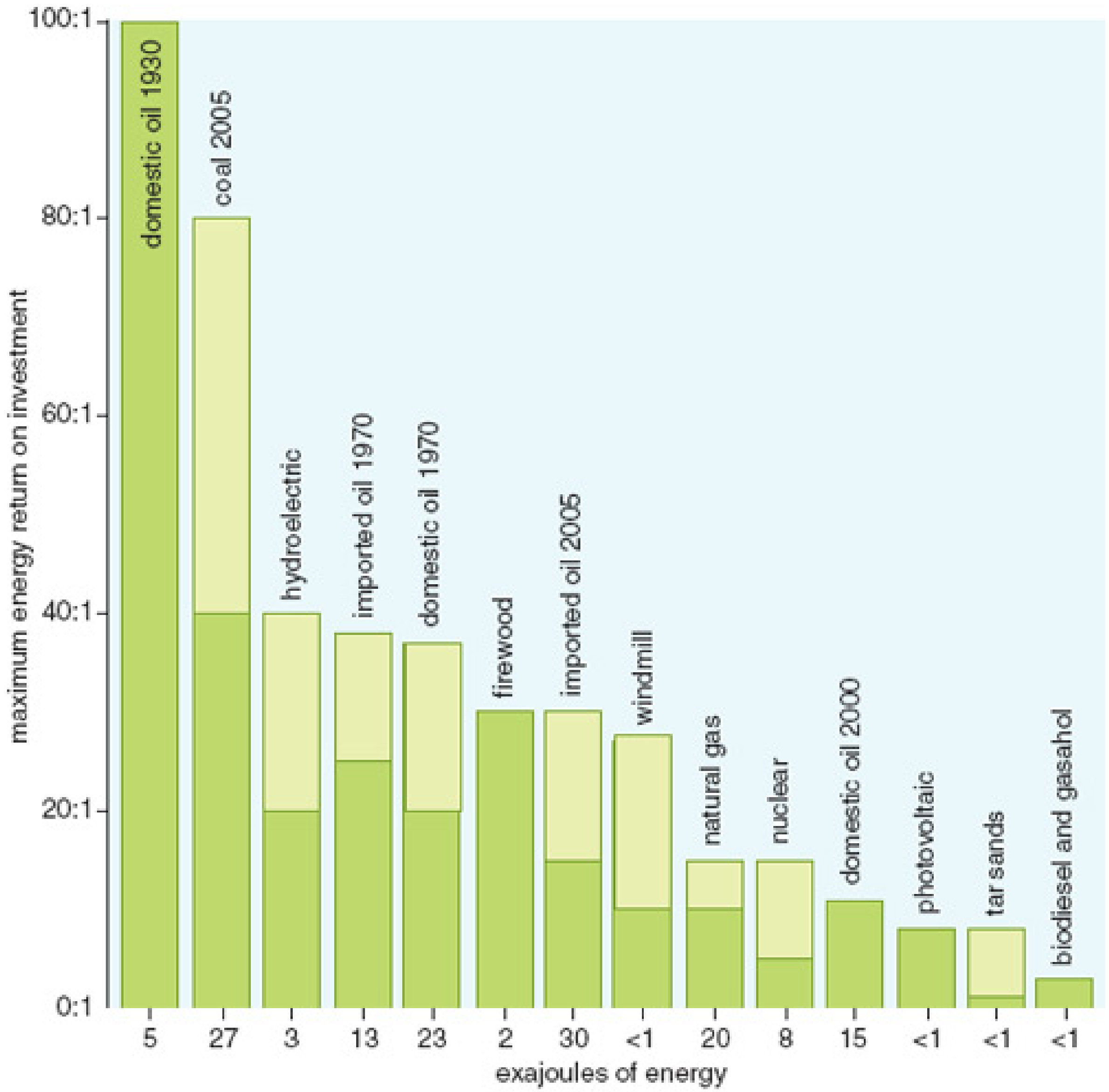
$$\text{Energy Return on Investment (EROI)} = \frac{E_{out}}{E_{in}}$$

Charles Hall, Pradeep Tharakan, John Hallock, Wei Wu and Jae-Young Ko, Advances in Energy Studies Conference, Porto Venere, Italy, September 2002

We are lowering also EROI and hence net surplus energy

http://www.eroei.com/articles/the-chain/what-is-eroei/

Renewables have lower EROI



Tom Konrad: http://www.greendump.net/the-oil-drum/managing-the-peak-fossil-fuel-transition-eroi-and-eirr

Renewables have lower energy density!

No, because Energy returned on Energy Invested (EROEI) of renewables is low as just seen

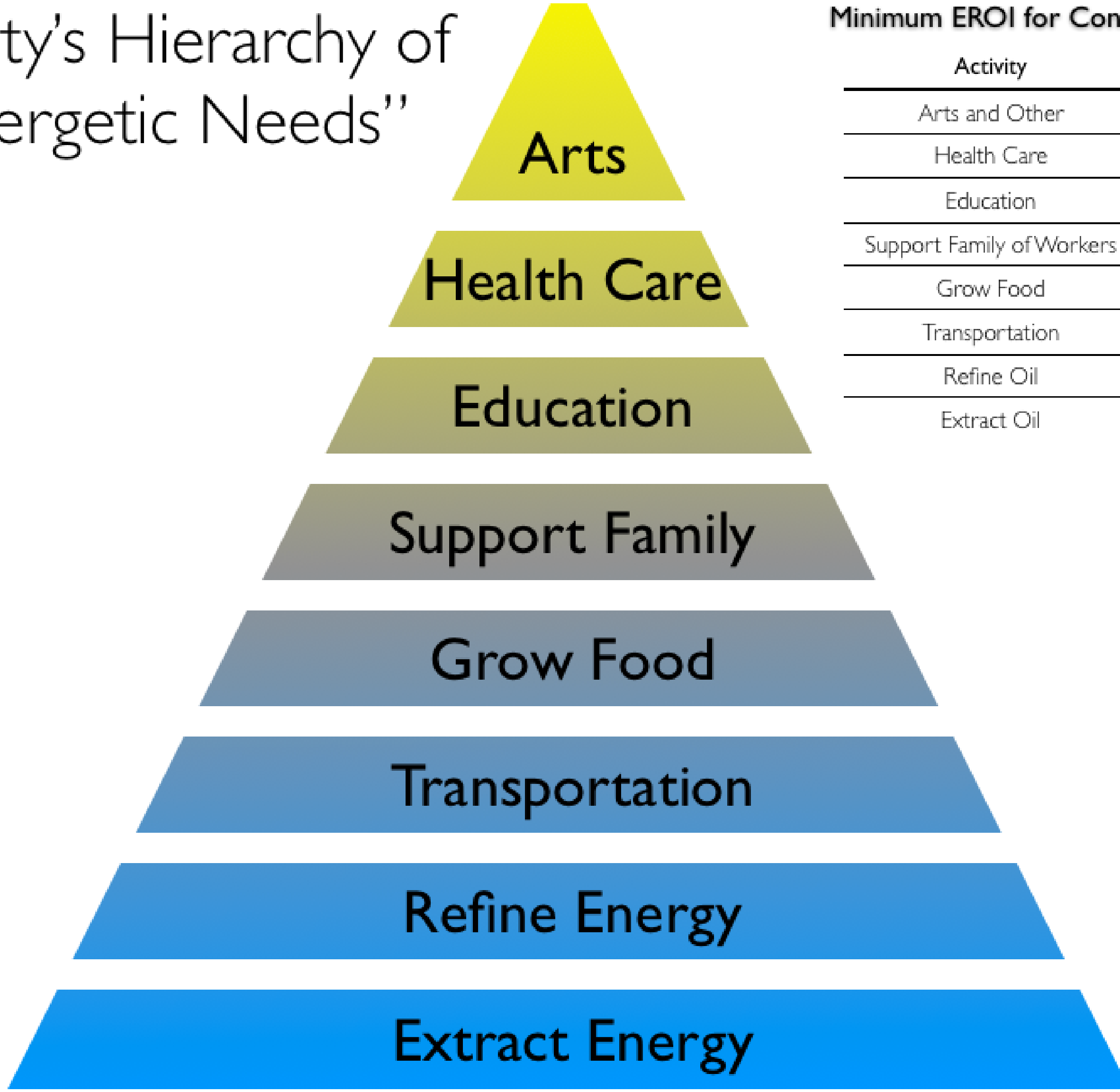
Even more so, as more materials peak, EROEI for renewables goes lower!

To Maintain Order We Need Energy

- $\Delta F = \Delta U - T\Delta S$; natural systems want to minimize ΔF
- If we want to oppose this trend we need constant input of energy $\Delta Q = \Delta U + \Delta W$
- **Life (Population) and material richness (high GDP/capita) is impossible without energy**
- **Steady GDP with decreasing energy is an oxymoron or nonsense**

Low EROEI and Culture

Society's Hierarchy of
"Energetic Needs"



Minimum EROI for Conventional Sweet Crude Oi

Activity	Minimum EROI Required
Arts and Other	14 : 1
Health Care	12 : 1
Education	9 or 10 : 1
Support Family of Workers	7 or 8 : 1
Grow Food	5 : 1
Transportation	3 : 1
Refine Oil	1.2 : 1
Extract Oil	1.1 : 1

Lambert and C. Hall *et al.*, 2012

Energy Efficiency and Embodied Energy

MATERIAL	EMBODIED ENERGY MJ/kg	EMBODIED ENERGY MJ/m3
Aggregate	0.10	150
Straw bale	0.24	31
Soil-cement	0.42	819
Stone (local)	0.79	2030
Concrete block	0.94	2350
Concrete (30 Mpa)	1.3	3180
Concrete precast	2.0	2780
Lumber	2.5	1380
Brick	2.5	5170
Cellulose insulation	3.3	112
Gypsum wallboard	6.1	5890
Particle board	8.0	4400
Aluminum (recycled)	8.1	21870
Steel (recycled)	8.9	37210
Shingles (asphalt)	9.0	4930
Plywood	10.4	5720
Mineral wool insulation	14.6	139
Glass	15.9	37550
Fiberglass insulation	30.3	970
Steel	32.0	251200
Zinc	51.0	371280
Brass	62.0	519560
PVC	70.0	93620
Copper	70.6	631164
Paint	93.3	117500
Linoleum	116	150930
Polystyrene Insulation	117	3770
Carpet (synthetic)	148	84900
Aluminum	227	515700

NOTE: Embodied energy values based on several international sources - local values may vary.

- **Increasing energy efficiency often involves using materials with higher embodied energy**
- Taken from various sources

Energy Efficiency and Embodied Energy

Item	Embodied energy (MJ/kg)[3]
Cadmium	17
Iron Raw materials	20-25
Lead	25-50
Copper	30-90
Mercury (liquid)	90-180
Nickel	180-200
Aluminum	190-230
Magnesium	270-350
Silicon (electronics-grade)	1,000-1,500
Silver	1,500
Zirconium	1,600
Platinum	190,000
Gold	310,000

- https://energyeducation.ca/encyclopedia/Embodied_energy

Energy Efficiency and Embodied Energy

Item	Embodied energy (MJ/functional unit)[4][5]
Hair dryer	79
Coffee maker	184
LCD monitor	963
Smartphone	1,000
PC tower	2,085
Washing machine	3,900
Laptop	4,500
Refrigerator	5,900
Digital copier	7,924
Cell tower	100,000

- https://energyeducation.ca/encyclopedia/Embodied_energy

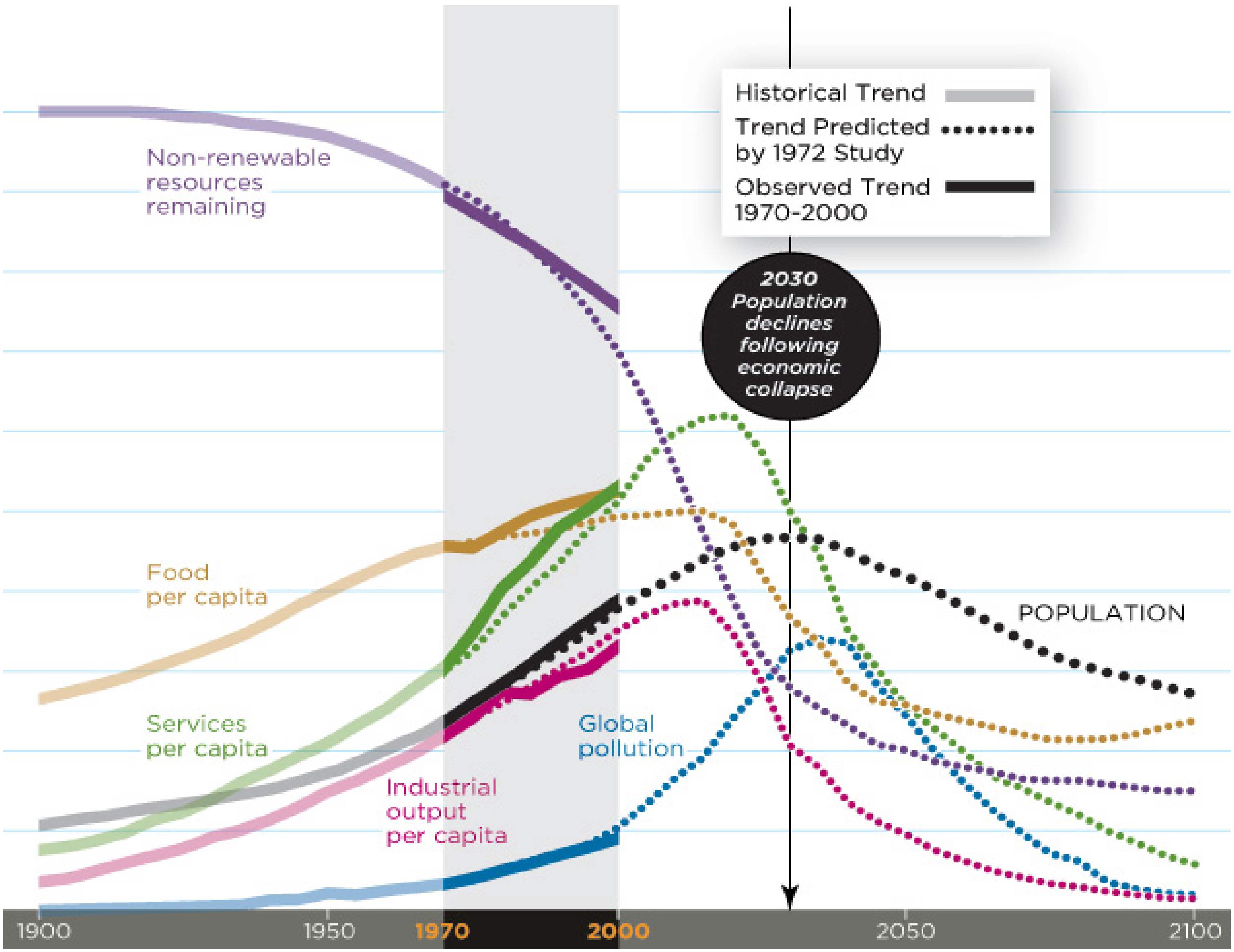
Efficiency and Renewables

- Efficiency will help just a little

- Renewables like wind, solar and geothermal energy will help but just a little

- **Population and high GDP/capita has to be reduced first**

Summation of all this data: Growth and Decline



From Alan Turner in Australia

Problem Definition

- Need to reduce Population implies decrease birth rates or increase death rate!
- Need to reduce energy consumption means reduce GDP
- GDP growth seems to improve quality of life
- GDP growth is also destructive to carrying capacity

Consequences

- Current World Economy is unsustainable even for a decade
- Current American lifestyle is unsustainable NOW
- What is the solution!

~~False Assumption~~ True Observation 1

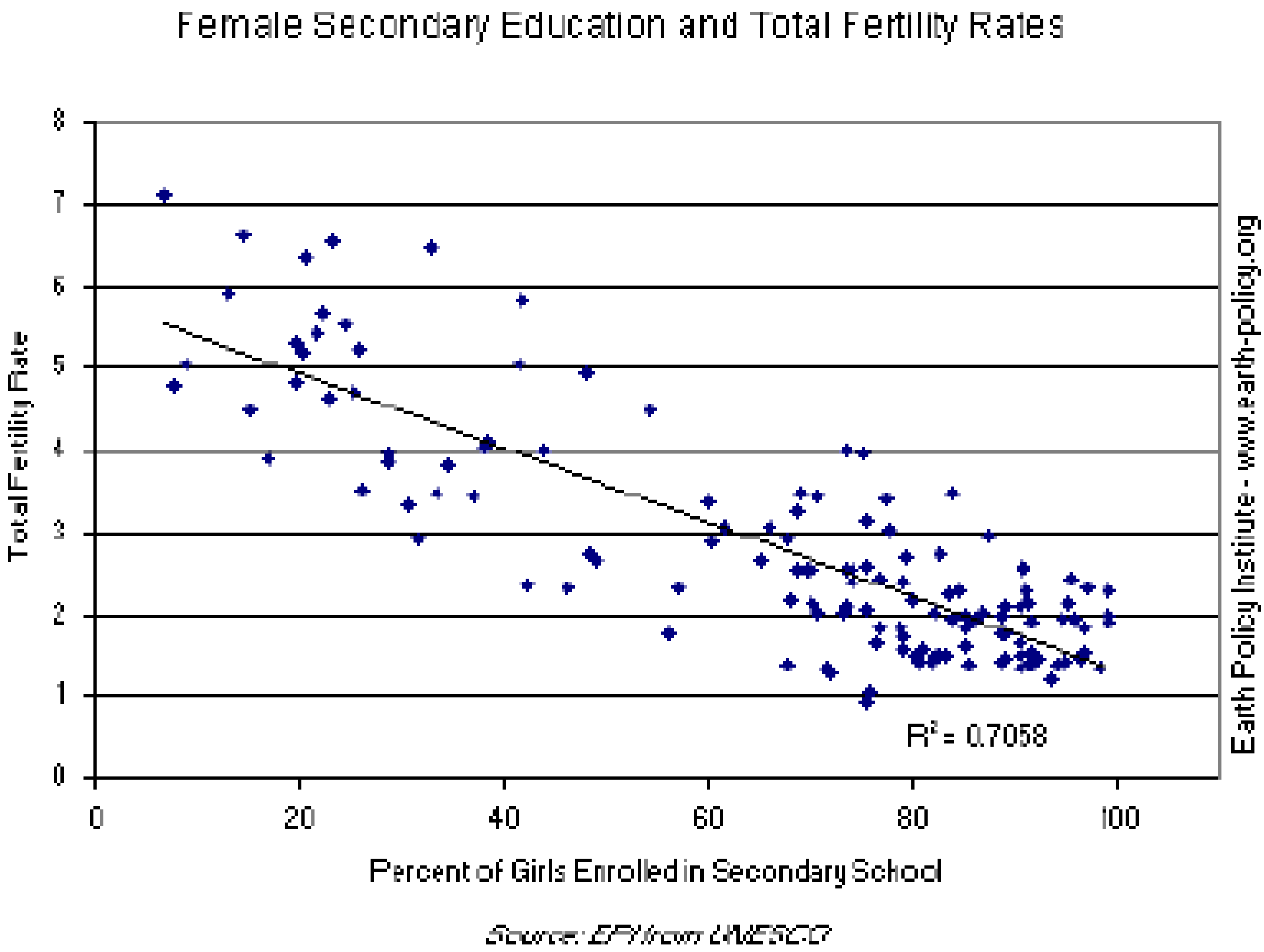
- ~~Continuous GDP growth means Human Development~~
- **Correct Observation 1: Quality of Life is related to HDI**
- Human Development Index HDI = (Life Expectancy + Years of Schooling + GDP)/3
- **Solution: Develop improved HDI and grow its value**

~~False Assumption~~ True Observation 2

- Correct Observation 2: Most GDP growth means Destruction ~~Development~~ of Carrying Capacity

- Define an Environmental Development Index and grow its value

Solution 1: More education = lower birth rates



Solution 2: All Roads Lead to ~~Rome~~ Voluntary Reduced Consumption and Efficiency!

Solutions 3: Four types of wealth

- Human or individual capital (self-actualization, Maslow)
- Social or inter-personal capital
- Natural or ecological capital
- Material capital

Focus our values on Human, Social and Natural capital. Move away from Material capital proactively

Solutions to all 4 problems

Problem	Imminence	Impact
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IV Peak Other Materials (bees, grains, species, top soil, fertile land, H_2O, Cu, P, U, Au)	Now (-25 to present)	COLLAPSE Can be exacerbated by I - III

Least Important

↓

Most Important

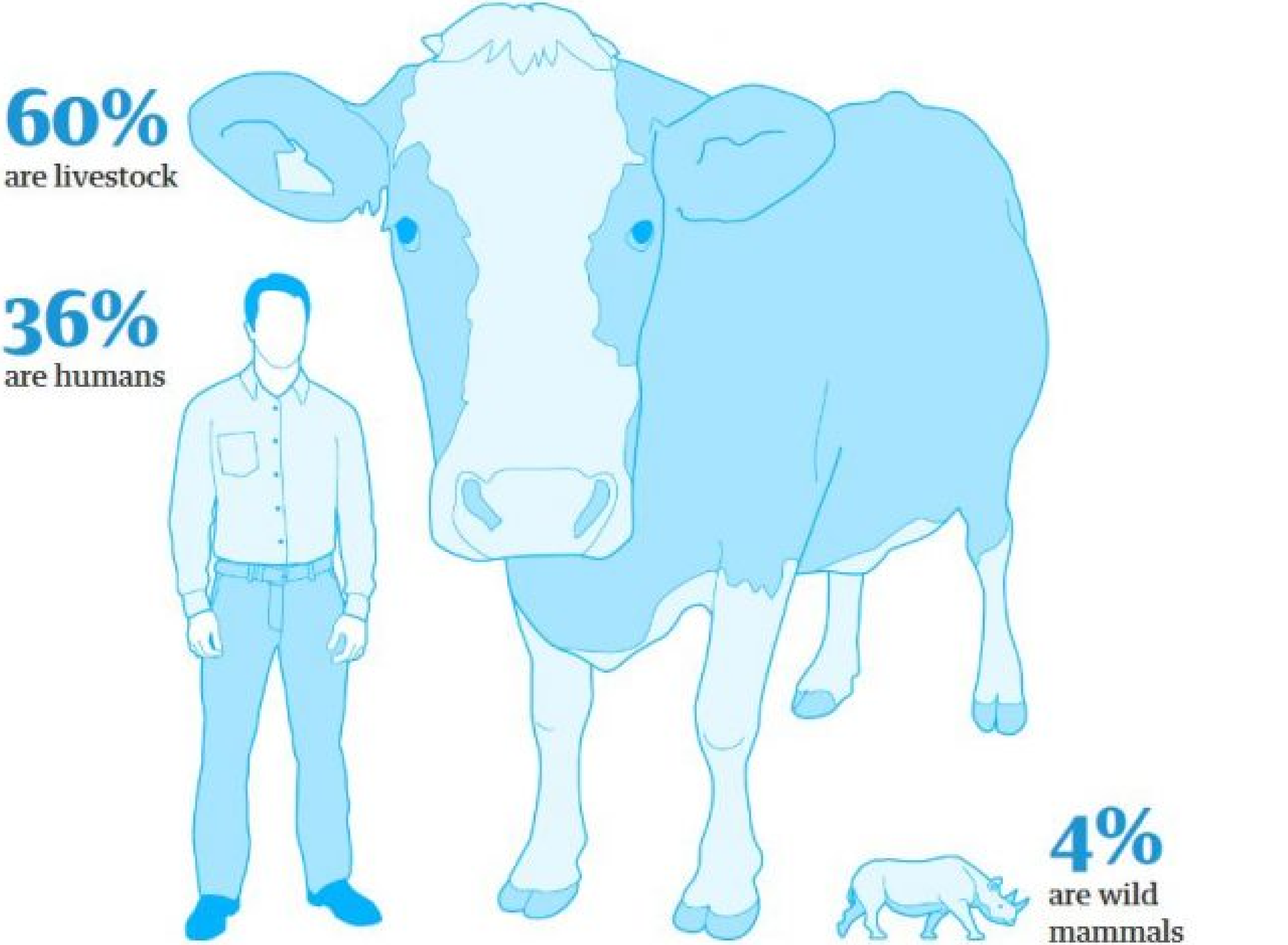
Most Important Individual Solutions I

- Have less children, lower birth rates, educate girls.
- Live in- or buy- as small a house one possibly can.
- Eat purely plant based. Do not eat animals.
- Live, work and recreate as close to home as possible.

Most Important Individual Solutions II

- Reduce, Reuse, Recycle, Renew, Redistribute
- Educate others especially children
- Change work institutions like LEC and ES
- Transform all other institutions like: Schools, Places of worship, NGOs, Sports teams etc.
- Influence elected officials

Destruction caused by Animal Agriculture



From Y. M. Bar-On *et al.*, PNAS 115, 6506 (2018).

Positives

- Less pollution, less climate change, great environment
- Whole food vegan, less illness of affluence
- More physical activity, less obesity
- Three generations of family live together so less daycare and no isolated old age
- Slower lifestyle, less stress and aging, longevity
- Greater overall quality of life for all

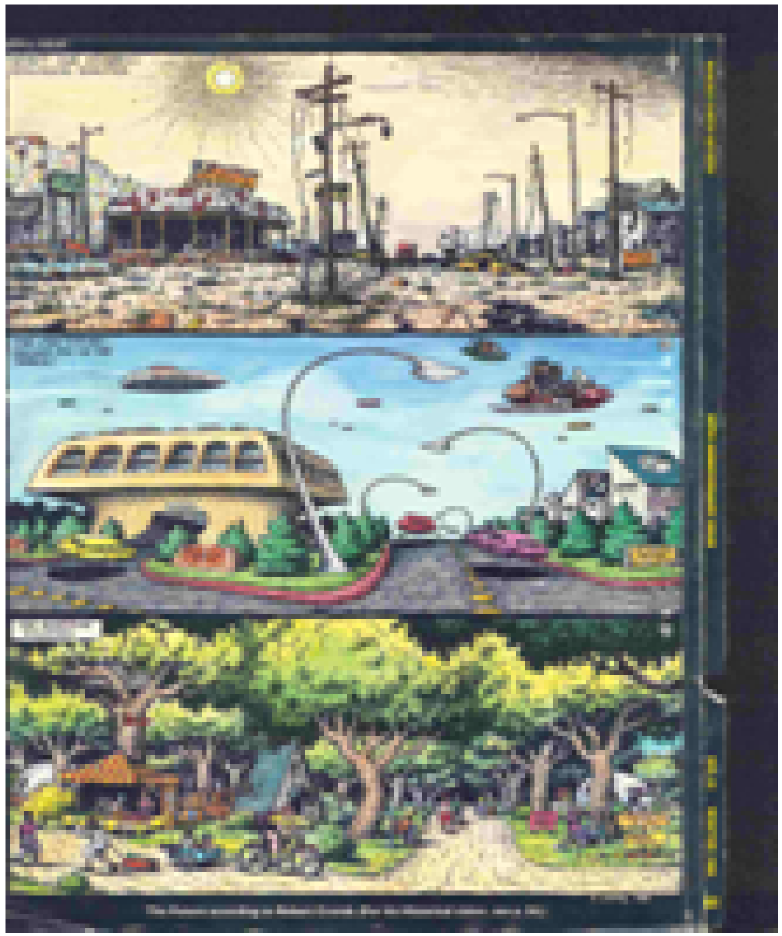
Our actions will make the future

Which Future?

Mad Max

Star Trek

The Beach



If we do nothing

Techno-fantasy led techno-fixes with no basis in reality

If we work very hard **for 50 years!**

Break for Questions

Then time for an interactive session

Promises to be completed by October 2020

- I will increase my total food calories from plants up to 50% to 100%.
- I will buy/lease a smaller car on graduation.
- I will buy/rent a smaller apartment/house/condo
- I will reduce my gas usage by 10 to 20%.
- I will reduce my cosmetic usage by 30 to 40%.
- I will reduce my textile and clothing usage by 30%.
- I will reduce my electricity consumption by 5 to 10%.
- I will reduce my paper usage by 20%.
- I will reduce my gadgets usage by 20%.
- I will reduce my travel miles by 20%
- I will reduce my use of materials or energy in hobbies by 30%
- I will take shorter showers by 30%.

Thank You

References:

- postcarbon.org
- www.resilience.org
- Book: Peak Everything by Richard Heinberg
- plantpoweredyouth.org
- nutritionfacts.org
- astro1.panet.utoledo.edu/~khare/sustainability/index.html

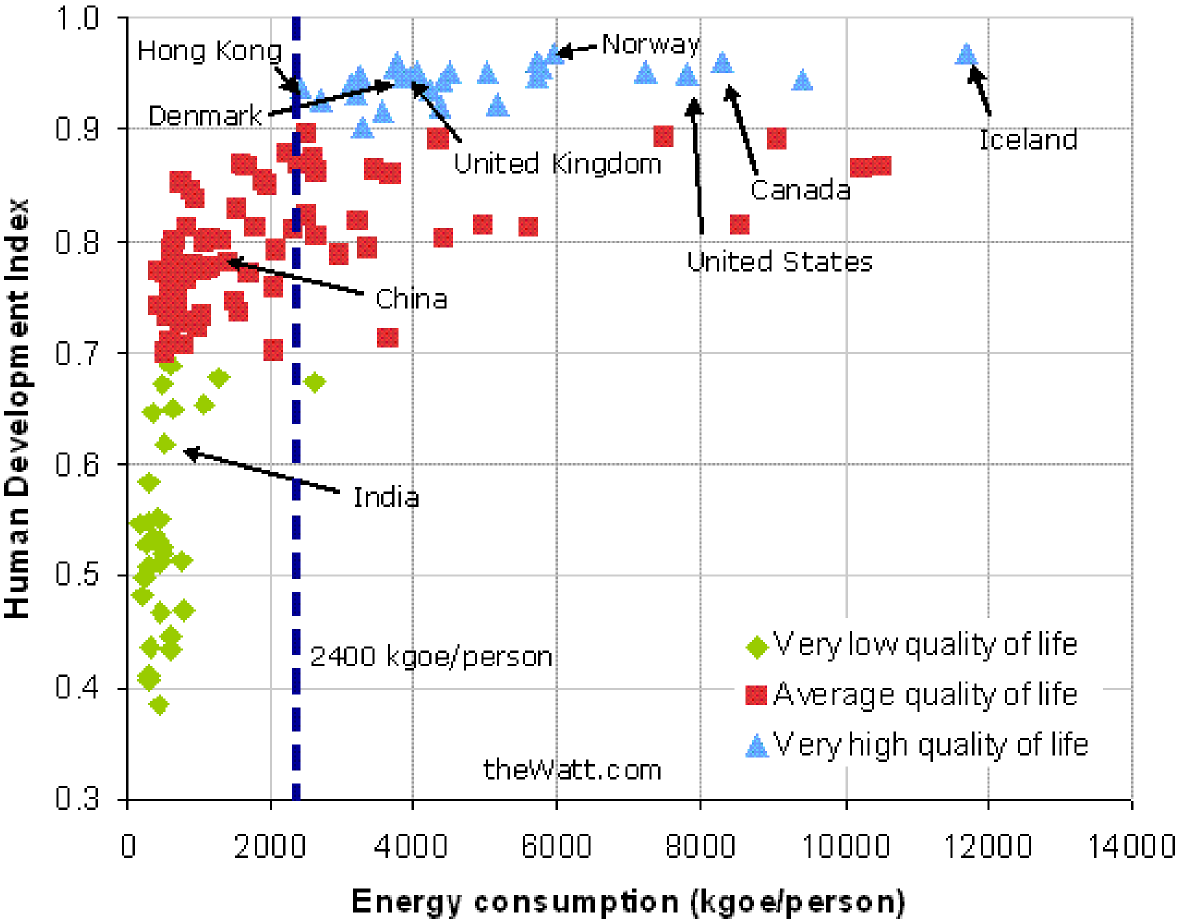
My own research

- Theory and computation
- Techniques: Quantum density functional theory, statistical mechanics, classical molecular dynamics, Monte Carlo
- Close connection with experimentalists
- Materials range from thin film to bulk materials, from metals to semiconductors, crystalline to disordered materials, and nano- to micro-length scales
- Funding: NSF, DoE, DoD, State of Ohio
- Details: See http://astro1.panet.utoledo.edu/~khare/
- Current work in hard coatings and optical properties
- 3 Ph.D. students and 1 undergraduate

Solutions: Correct definition of a good life

Less material consumption

More meaningful relationships with humans, plants, animals and location.



(Source: UNDP, 2002, WRI, 2002)

Human Development Index = Longevity + Education Level + GDP

A 10 TW-yr energy production in 2118 C.E.

- Human population of 4 billion, using 75 GJ-year/capita
- Decrease in per capita energy use by 75% for Americans
- Per capita energy use goes for rest of the world remains the same
- 20% from efficiency (10 TW becomes 8 TW)
- 40% of energy from wind (3.2 TW)
- 35% of energy from solar power, including PV, solar thermal and solar thermal electric (2.8 TW)
- 10% from hydroelectric (0.8 TW)
- 10% from geothermal (0.8 TW)
- 5% from biomass including wood, cow dung, human waste (0.4 TW)

What World Health Organization (WHO) Says

2 of 12 steps to healthy eating

- Eat a nutritious diet based on a variety of foods originating **mainly from plants, rather than animals**.
- WHO does not set particular limits for alcohol consumption because the evidence shows that the ideal solution for health is not to drink at all, therefore less is better.
- See http://www.euro.who.int/en/health-topics/disease-prevention/nutrition/a-healthy-lifestyle

What World Health Organization Says

10 more steps to healthy eating

1. Eat bread, whole grains, pasta, rice or potatoes several times per day.
2.Eat a variety of vegetables and fruits, preferably fresh and local, several times per day (at least 400g per day).
3.Maintain body weight between the recommended limits (a BMI of 18.5–25) by taking moderate to vigorous levels of physical activity, preferably daily.
4.Control fat intake (not more than 30% of daily energy) and replace most saturated fats with unsaturated fats.
5.Replace fatty meat and meat products with beans, legumes, lentils, fish, poultry or lean meat.
6.Use milk and dairy products (kefir, sour milk, yoghurt and cheese) that are low in both fat and salt.
7.Select foods that are low in sugar, and eat free sugars sparingly, limiting the frequency of sugary drinks and sweets.
8.Choose a low-salt diet. Total salt intake should not be more than one teaspoon (5g) per day, including the salt in bread and processed, cured and preserved foods. (Salt iodization should be universal where iodine deficiency is a problem)
9. Prepare food in a safe and hygienic way. Steam, bake, boil or microwave to help reduce the amount of added fat.
10.Promote exclusive breastfeeding up to 6 months, and the introduction of safe and adequate complementary foods from the age of about 6 months. Promote the continuation of breastfeeding during the first 2 years of life.

Tables on World and US total and Per Capita Energy Consumption

	World Energy Consumption per year	US energy Consumption per year
TW - yr	15.936	3.0346
100 Quad Btu	4.762	0.90696
10 GTon Oil Eq.	1.2002 [a]	0.2286 [c]
ExaJoules (EJ)	504.8	96.123
10 Giga Barrels of Oil	7.889	1.5708
1 Giga short ton of coal	19.051	3.6278
1 Giga metric tons of coal	17.416	3.265

	World energy consumption per capita per year	US energy consumption per capita per year
Kw-yr	2.312	9.92531
MBTU	69.09	296.639
TOE	1.741	7.47517
GJ	73.24	314.39
BOE	11.45	51.3761
Short ton of coal	2.764	11.8653
Metric ton of coal	2.488	10.6788

Solutions: Mitigation

Type of Effort	Urgency & Importance
Conservation and efficiency, personal and societal	High
Rapid deployment of existing technology, public transport, electric-transport, wind, solar-heat and photovoltaic, geothermal	High
Raising awareness by scientists and engineers of locals, media and policy makers	High
Applied engineering research	Medium term (5 – 10 years)
Fundamental research done today will have scaled impact after 20 years	Long Term (10 – 20 years)

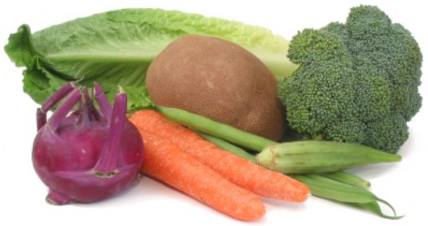
Solutions: Priorities (USA)

-Massive public education for demand reduction (target 50 to 80% per capita in 20 years)

-Reactivate electric trains, trams, trolleys, buses; Upgrade electric grid

-World War II type effort for car and truck batteries, solar, wind, geothermal, and wave energy

-World War II type effort for energy conservation in homes and buildings, lighting, CAFE standards



-Buying locally produced goods where possible, home gardens, vegan food choices

-Greater use of arable land for growing crops such as oilseed willow for wood pellets, forest generation

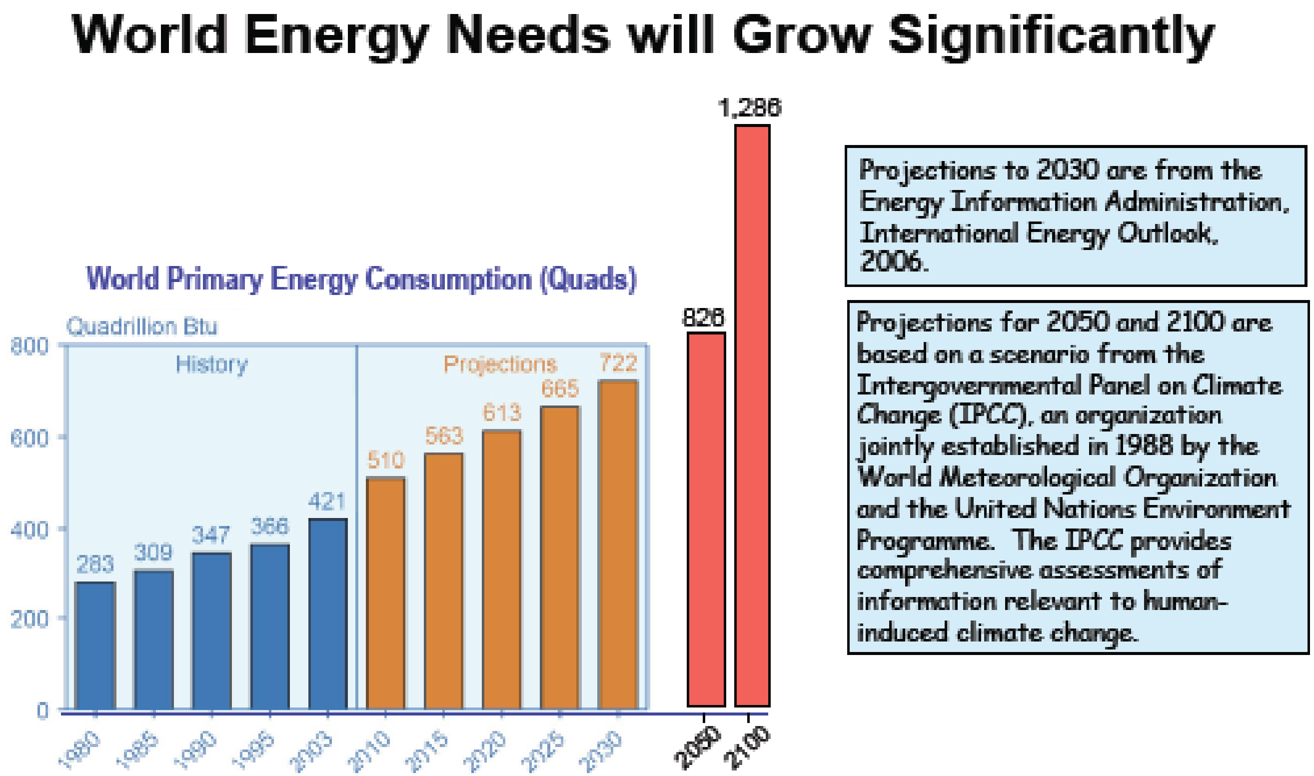
-Stop corn ethanol immediately

-Tackle population growth

Solutions: What can I do immdediately?

- Worship, Prayer, Secular Meditation
  - Brings about a relaxation neural response, good decision making, avoids panic
- Work on:
  - Getting educated yourself first
  - Reducing your liquid fuels consumption by 50% to 80%
  - Educating family, friends, co-workers, policy-makers
  - Form community support networks
  - Contacting your local, state, and federal representatives
  - Trying to reduce consumption in your line of work
  - Changing careers from energy consuming to energy producing industries
  - Participating and influencing the media
- Teach children about these issues to continue dialogue into future generations

Scale of consumption, 100 Q = 10^{20} J

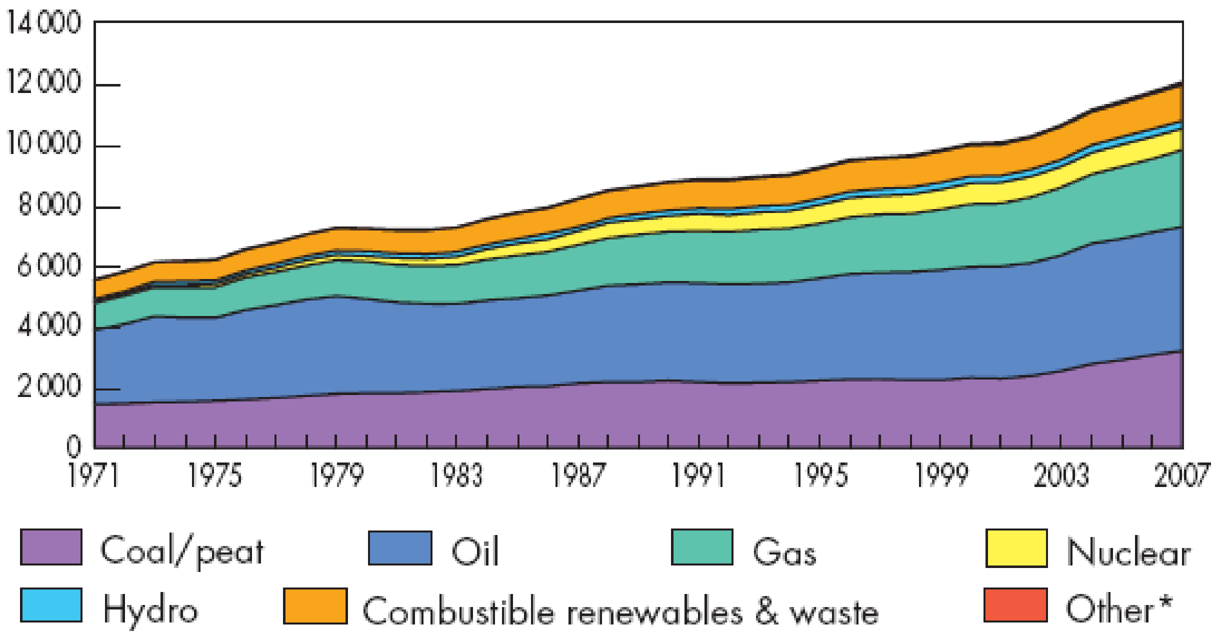


600 Quads = 6.0×10^{17} BTU = 1.86×10^{14} kW-hour = 2.12×10^{13} Watt-year = 21.2 TW-yr = 6.33×10^{20} J = 103.4 GBOE = 14.47 GTOE

1. Total Primary Energy Supply - TPES

World

Evolution from 1971 to 2007 of world total primary energy supply by fuel (Mtoe)



Key World Energy Statistics, International Energy agency , 2009

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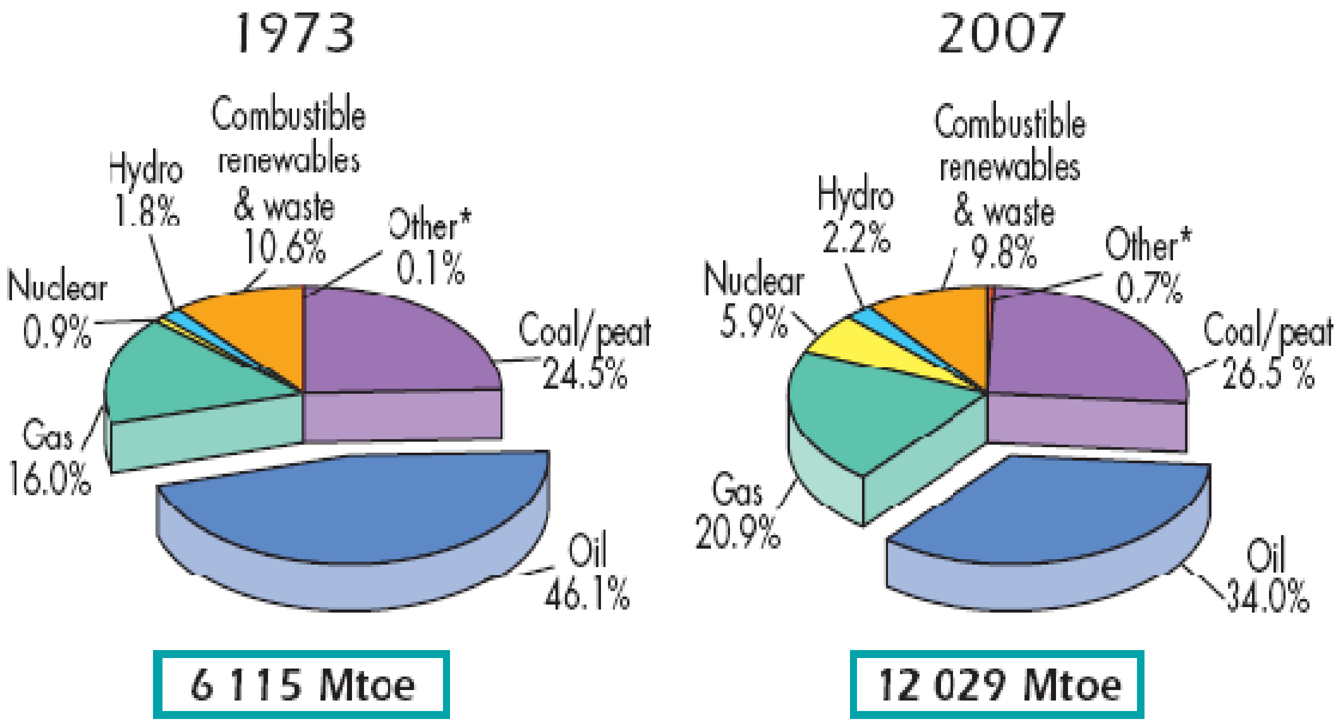
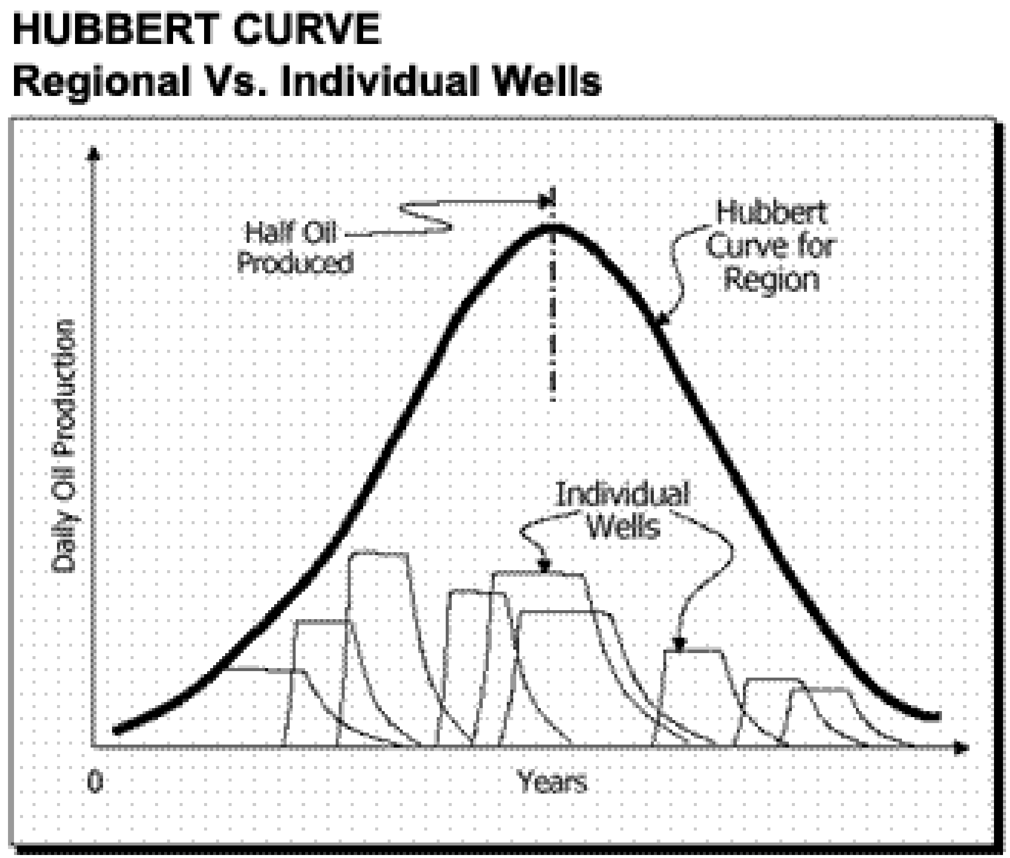
1973 and 2007 fuel shares of TPES

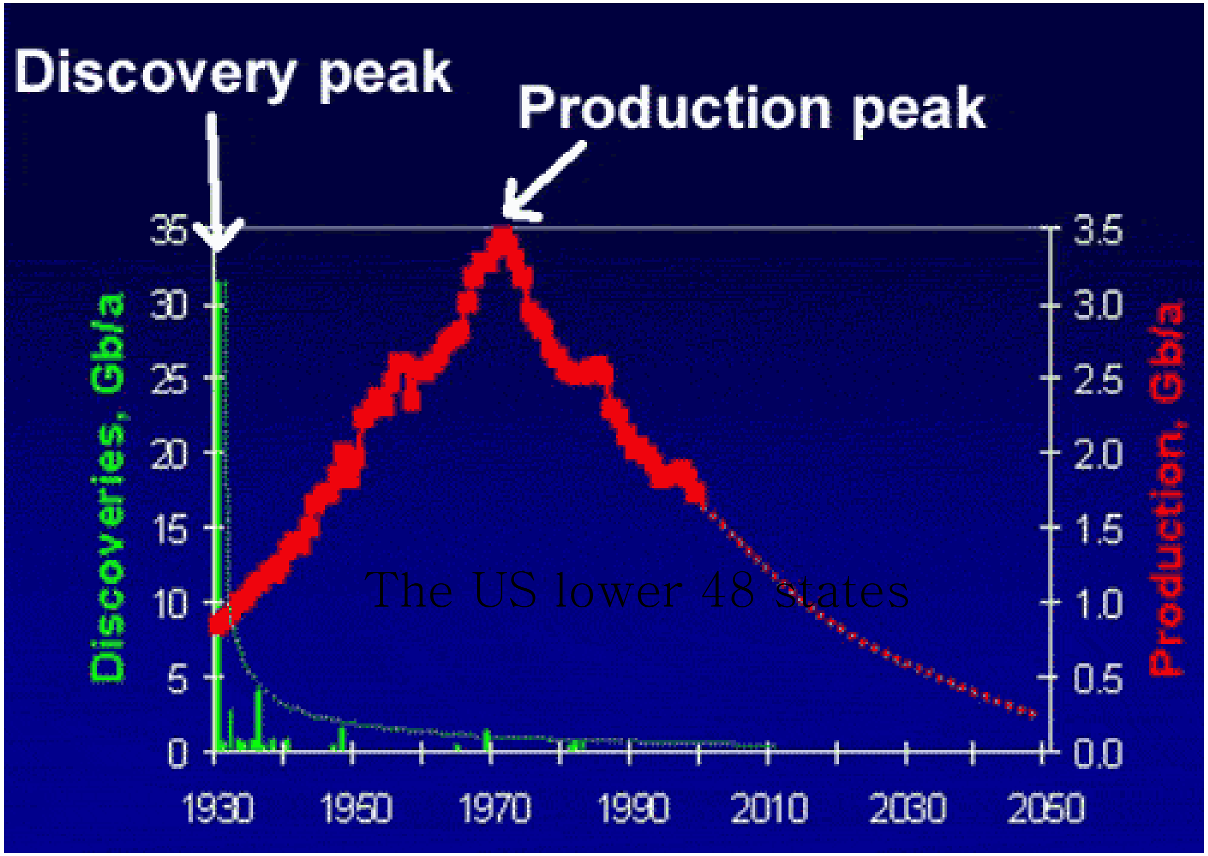


Key World Energy Statistics, International Energy agency , 2009

Different Well Discovery and Production Times ==> Peak in Production Curve

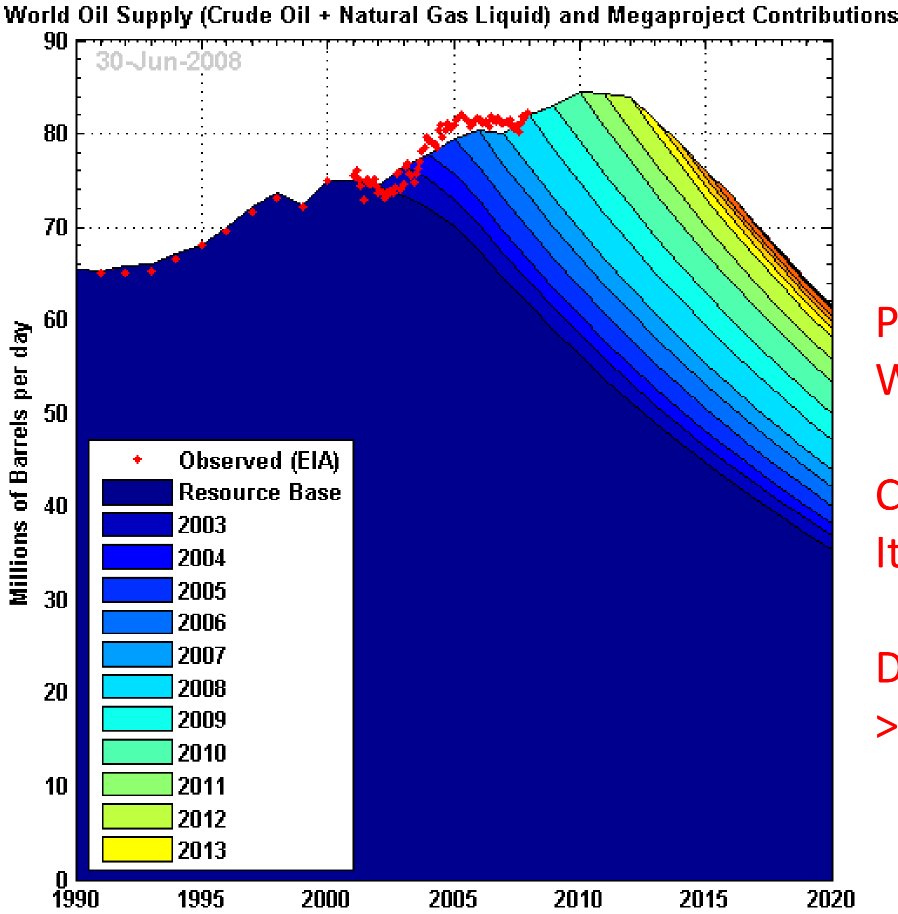


Oil *discoveries* in the US peaked
- then 40 years later *production* peaked



Adapted from Collin Campbell, University of Clausthal Conference, Dec 2000

Same Chart: Now a new projects analysis



From: Skrebowski at www.theoildrum.com, July 2008 posting and Wiki Oil Mega Projects database.

Peak oil is imminent.
Will happen in < 5 years!

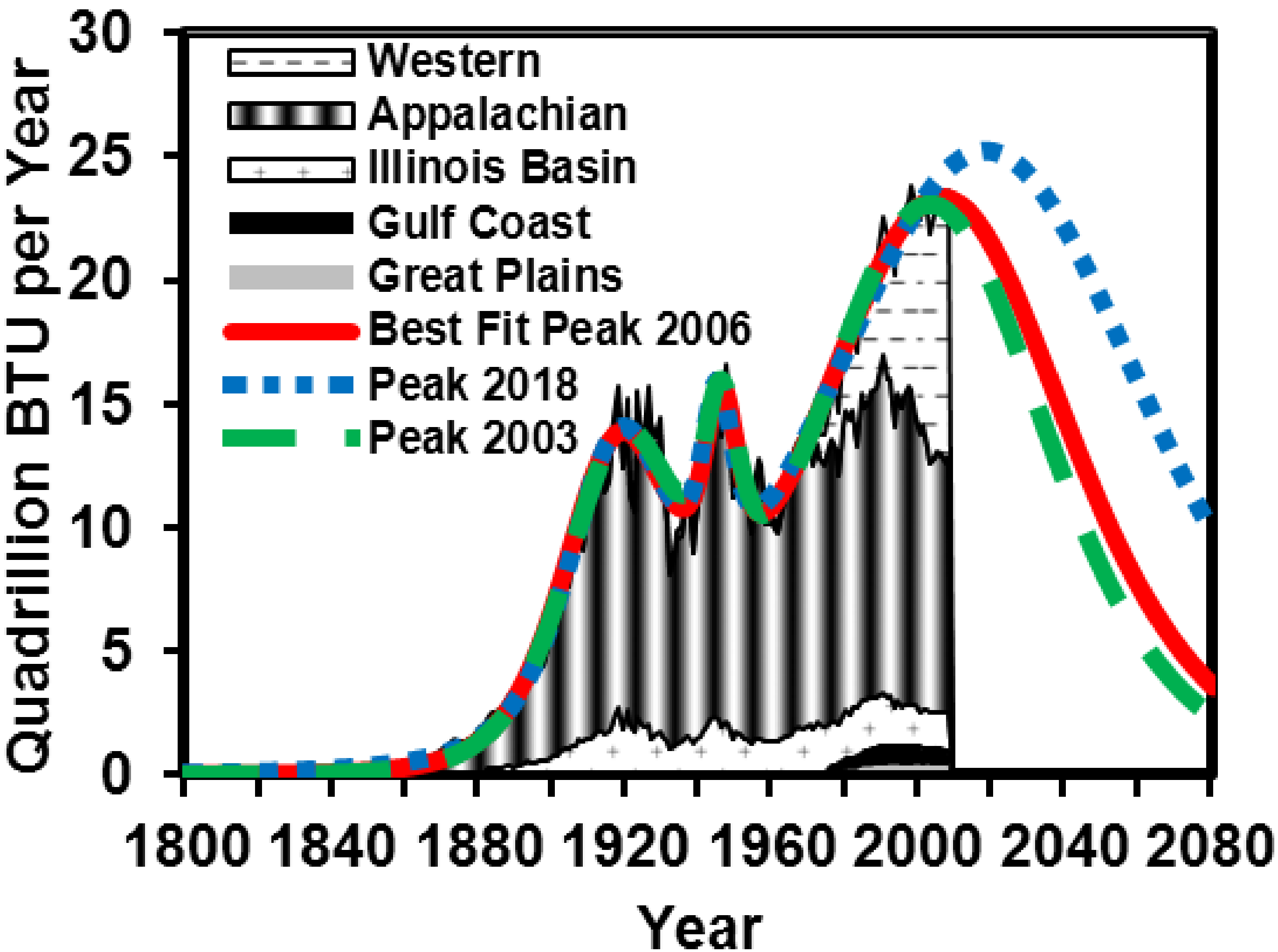
Conventional crude peaked in 2005.
It is already in the past tense!

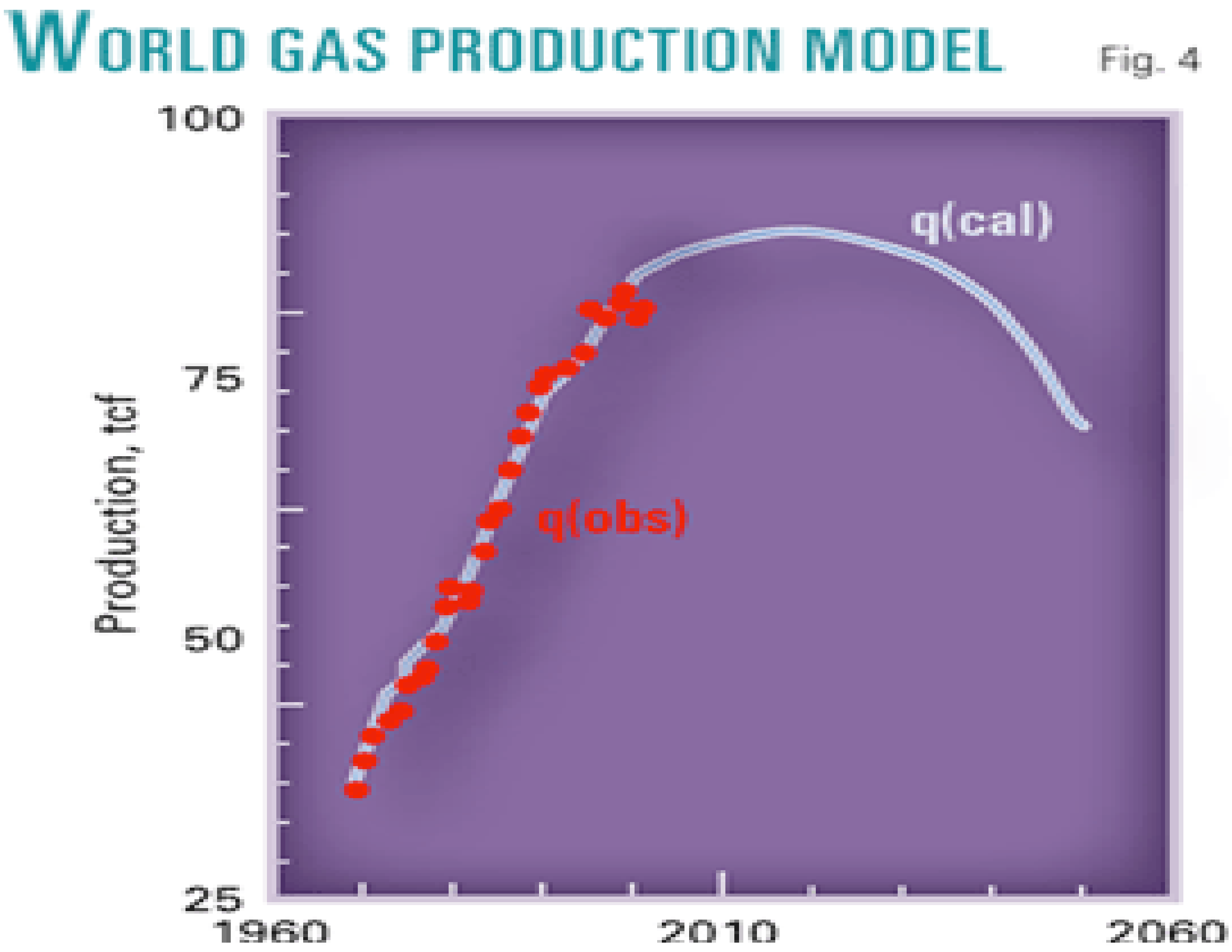
Decline after peak will be
> 2% to 5%/year!

…the world will peak between 2010-2015

Adapted from: Richard C. Duncan and Walter Youngquist

Peak Production of US coal
Similar trends for World coal (Reaver and Khare, Int. J. Coal Geol. 131, 90 (2014))

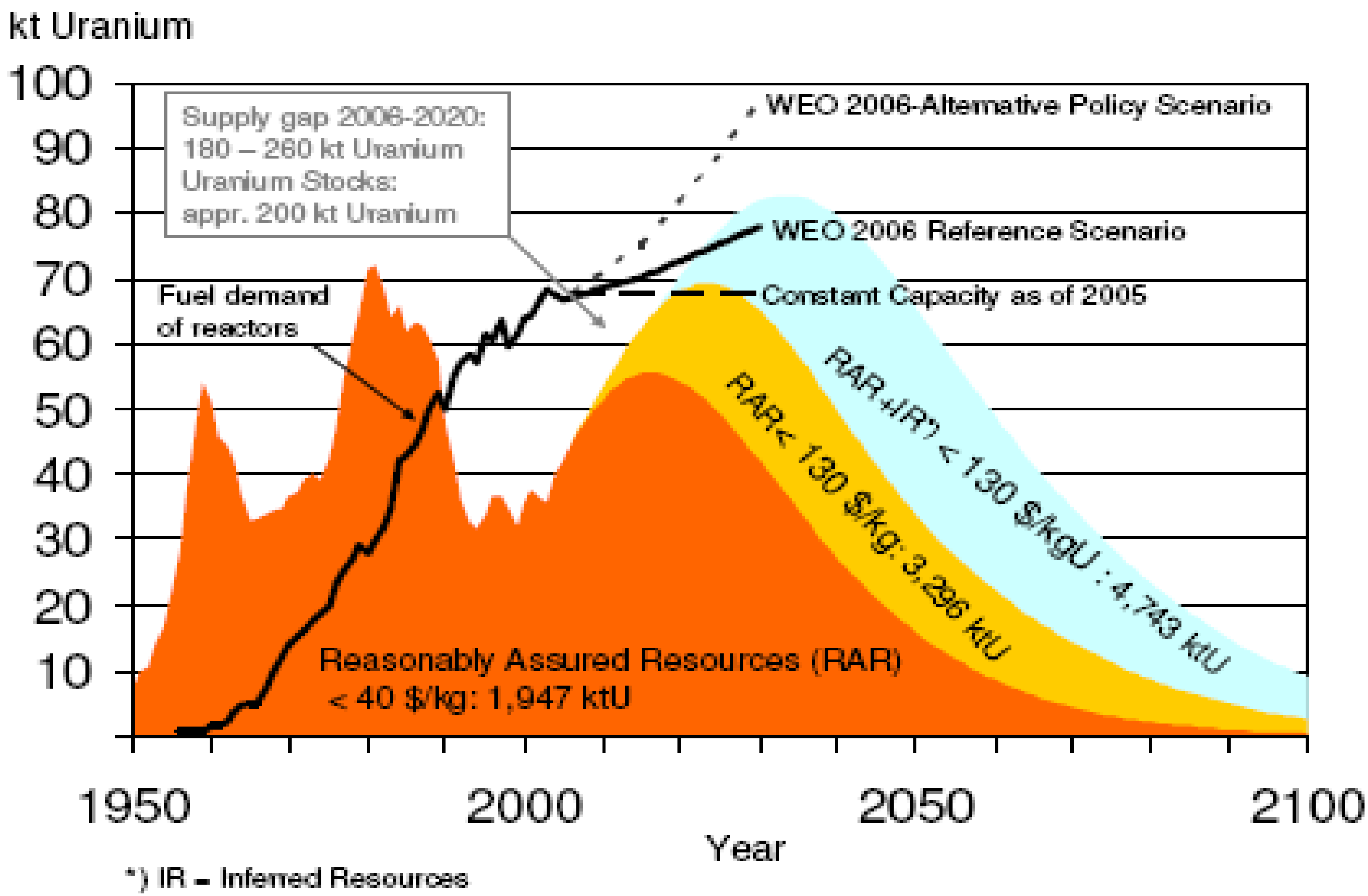




(Imam *et al.*, Oil and Gas Journal, August 2004)

Uranium Supply

The figure summarizes the present supply situation



Uranium Resources and Nuclear Energy *by Energy Watch Group, December 2006*

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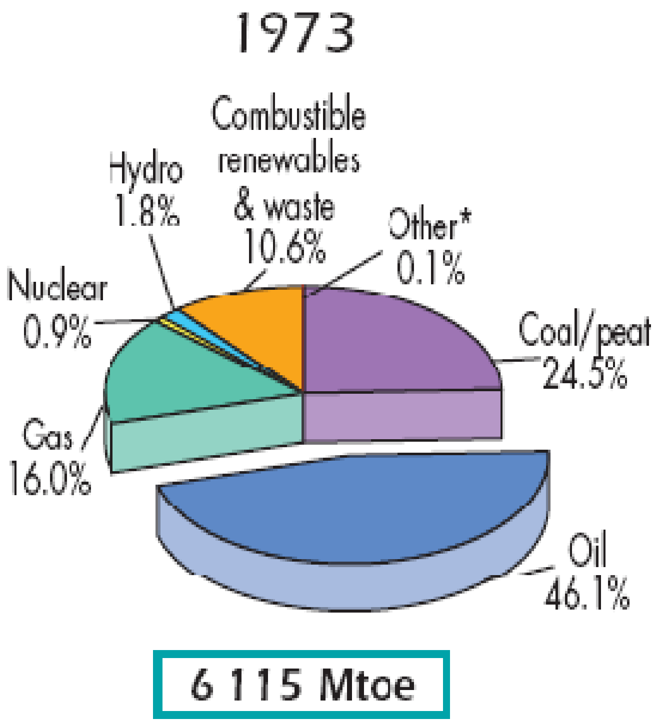
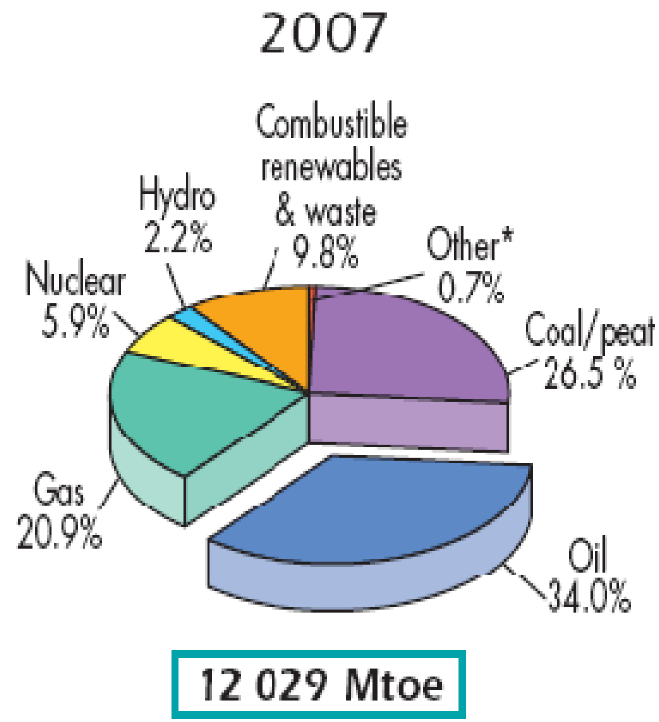
1973 and 2007 fuel shares of TPES





Key World Energy Statistics, International Energy agency , 2009

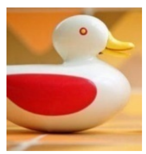
To Maintain Order We Need Energy

- $dF = dU - TdS$; natural systems want to minimize dF.
- If we want to oppose this trend we need constant input of energy $dQ = dU + dW$.
- Life and material richness is impossible without energy.
- Sustainable GDP growth with decreasing energy is an oxymoron or nonsense

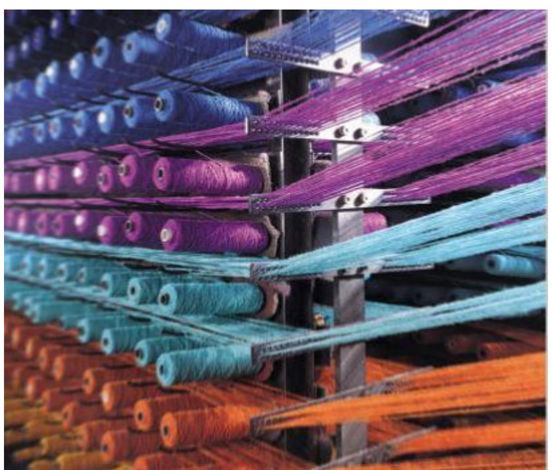
Materials from fossil fuels: Plastics, textiles, pharmaceuticals, paints, dyes, asphalt

No easy scalable substitute for oil

Easy means low EROEI




Renewable Energy and Materials: Wind

Total reserves of Neodymium = M_{Nd} $= 8 \times 10^9$ Kg

Mass of Nd required to produce 1 MW energy = m_{Nd} $= 275$ Kg

Total power produced = $\frac{M_{Nd}}{m_{Nd}} \times 10^6\, W = \frac{8 \times 10^9}{275} \times 10^6\, W$ $= 29$ TW

Total energy produced per year = 29 TW-yr × Capacity factor = 7.25 TW-yr

Renewable Energy and Materials: Cars

TOYOTA PRIUS CALCULATION :

Mass of Neodymium required for 1 car = m_{Nd} = 1 kg

Mass of Dysprosium required for 1 car = m_{Dy} = 0.1 kg

Total reserves of Neodymium = M_{Nd} = 8×10^9 kg

Present production of Dysprosium per year = M_{Dy} = 1×10^5 kg

Hence number of cars produced using Neodymium = $\frac{M_{Nd}}{m_{Nd}} = \frac{8\times10^9}{1}$ = 8 billion

But mass of Dysprosium required for this is $= 8 \times 10^9 \times 0.1 \quad = 8 \times 10^8$ kg

Table of embodied energy of consumables

Utility	$1 = 360 MJ[a]
Transportation	$1 = 37 MJ[b]
Other expenses	$1 = 252 MJ[c]
Red meat	1kg = 2131 MJ
White meat	1kg = 663 MJ
Dairy	1kg = 481 MJ
Rice	1kg = 220 MJ
Vegetables	1kg = 90 MJ
Miscellaneous food	1kg = 159 MJ

a – price of 1 kWh electric power is assumed to be $0.10.

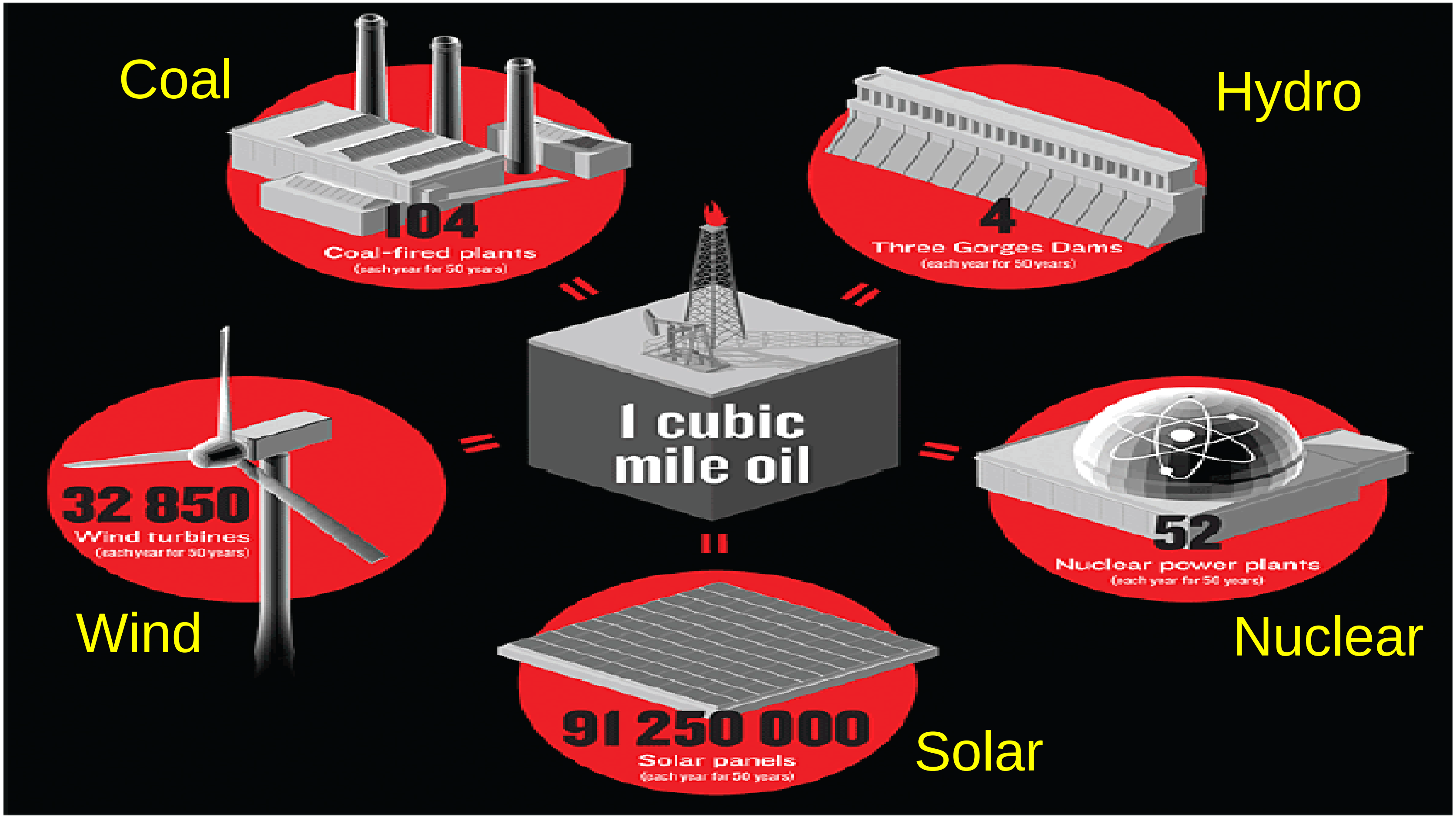
b – price and energy content of a gallon gasoline is assumed to be $4 and 149 MJ respectively.

c – It is assumed that other expenses consume a fraction (1/3) of energy from gasoline and the remaining (2/3) from utility electric power at rates of $4 for gasoline and $0.10/kWh for electric power.

Impact: Economic, Social and Cultural

- ~~Growth Economics~~ ==> Steady or Shrinking Economy
- Industries
  - Tourism ↓
  - Entertainment (movies in theaters, sports, theme parks, shopping) ↓
  - Restaurants ↓
  - Transportation (cars, trucks, oil-ships vs. electric (trains and cars), sail-ships)
  - Banking & Finance ↓
  - Law & Health Services ↓
  - Housing (Suburban long commute vs. urban walking), Education ↔
  - Farming, Solar, Wind, Geothermal, Lumbering, Energy equipment ↑
- Family Structure
  - Grandparent-Parent-Child relationship
  - Husband-Wife relationship
  - Neighbor-Neighbor relationship (less house mobility)

Per year oil consumed = 1 mile^3 = 50 years of power of each of these!!



Source: H. Goldstein and A. Sweet, IEEE Spectrum Online, Jan. 2007.

Oil has high energy per unit mass!

- 1 gallon = 37.63 kW-hr = 32408.3 Food-cal
  = 11 able-bodied young men working a full day.

- World yearly consumption
- 31 GBa/yr = 4.216 Gtoe = 5.593 TW-yr/yr

- US yearly consumption
- 7.665 GBa/yr = 1.04244 Gtoe/yr = 1.382 TW-yr/yr = 3 times the US yearly electricity consumption.

1 toe = 4.1868 x 10^{10} Joules; 1 Ba = 42 gallons = 0.136 toe

1 Ba = 0.136 X 4.1836 X 10^{10} J = 5.6896 GJ = 1.5805 MW-hr = 65.85 kW-day = 180.42 W-yr

Material Wealth means a type of Order

- Wealth for a mushroom is decaying matter
- Wealth for a plant is fertile soil, water, sunlight

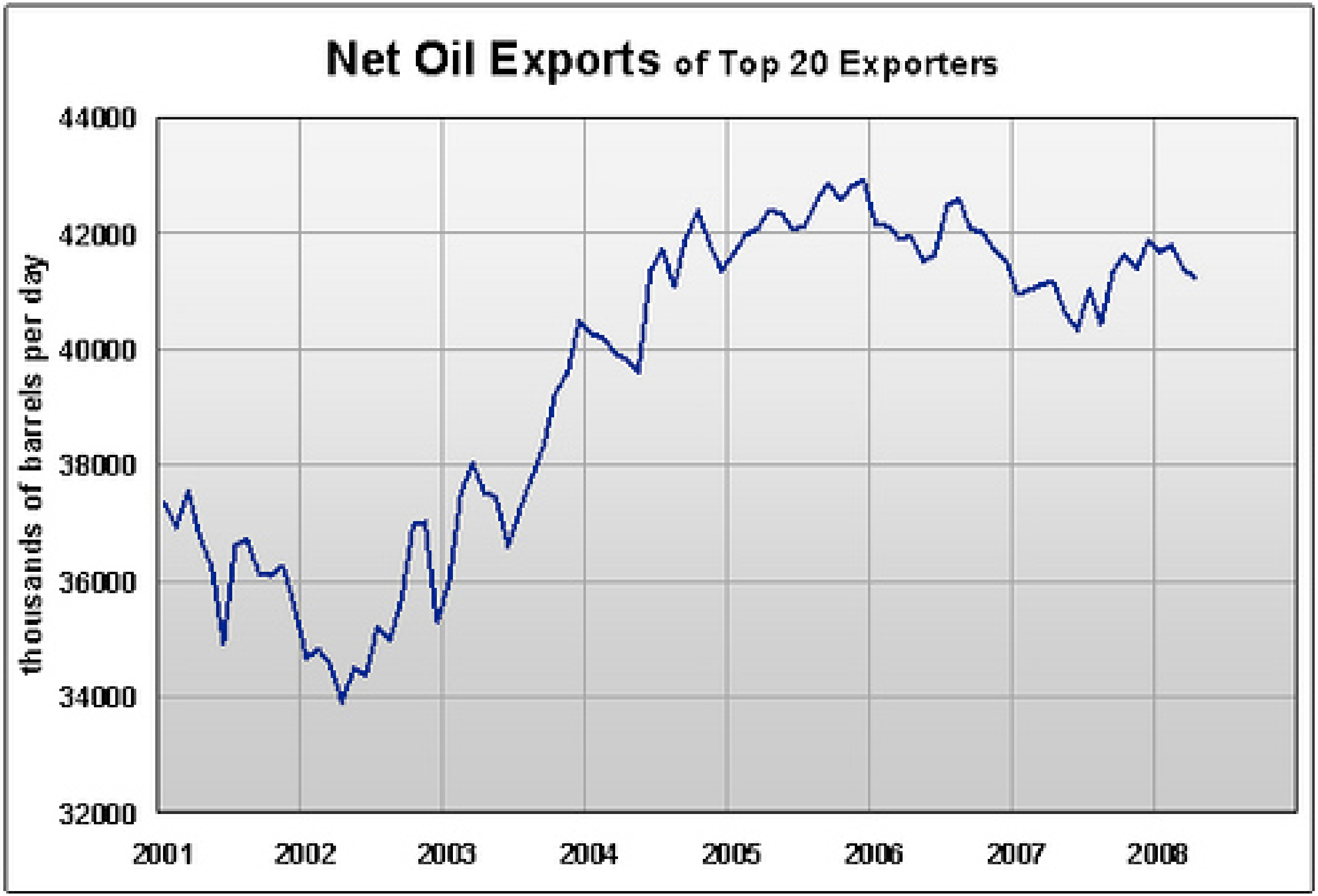
- Wealth for a deer is green grass, water
- Wealth for a lion is lots of deer, water

- Wealth for humans is a certain type of order in the nearby environment. Of course this means creating more disorder elsewhere.

To Maintain Order We Need Energy

- Increasing order means decreasing entropy in the nearby human environment
- This implies increasing useful energy flow through the economic system
- Life and material richness is impossible without energy
- Sustainable GDP growth with decreasing energy is an oxymoron or nonsense

No spare capacity AND
Net exports are decreasing!

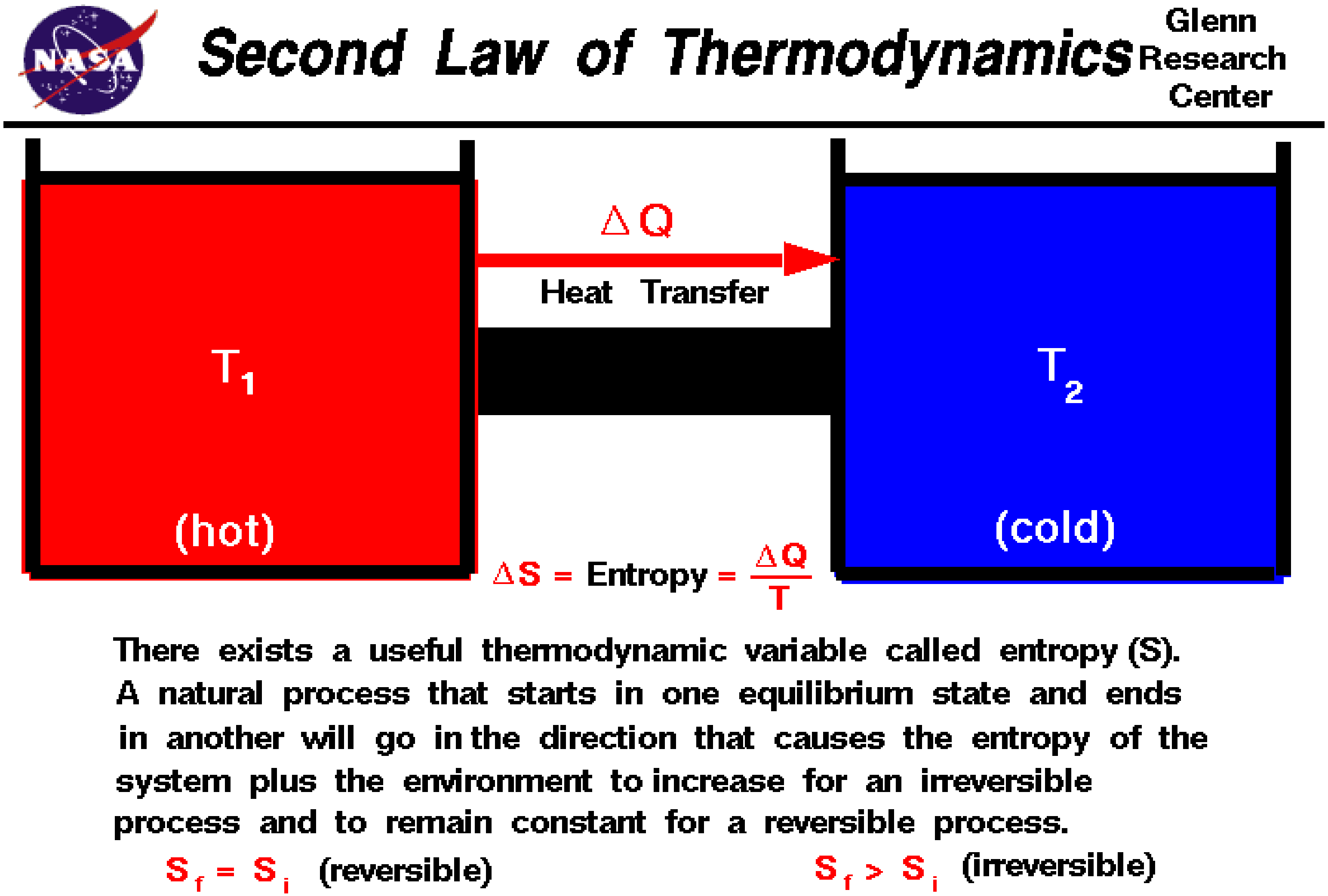


Sources: EIA, IEA, TOD

Spurious OPEC Reserve (GBOE) Revisions

Year	Abu Dhabi	Dubai	Iran	Iraq	Kuwait	Neutral Zone	Saudi Arabia	Venezuela
1980	28.0	1.4	58.0	31.0	65	6.1	163	18
1981	29.0	1.4	57.5	30.0	66	6.0	165	18
1982	30.6	1.3	57.0	29.7	65	5.9	165	20
1983	30.5	1.4	55.3	41.0	64	5.7	162	22
1984	30.4	1.4	51.0	43.0	64	5.6	166	25
1985	30.5	1.4	48.5	44.5	**90**	5.4	169	26
1986	30.0	1.4	47.9	44.1	90	5.4	169	26
1987	31.0	1.4	48.8	47.1	92	5.3	167	25
1988	**92.2**	**4.0**	**92.9**	**100**	92	5.2	167	**56**
1989	92.2	4.0	92.9	100	92	5.2	170	58
1990	92.2	4.0	92.9	100	92	5.0	**258**	59
1991	92.2	4.0	92.9	100	95	5.0	258	59
1992	92.2	4.0	92.9	100	94	5.0	258	63
1993	92.2	4.0	92.9	100	94	5.0	259	63
1994	92.2	4.3	89.3	100	94	5.0	259	65
1995	92.2	4.3	88.2	100	94	5.0	259	65
1996	92.2	4.0	93.0	112.0	94	5.0	259	65
1997	92.2	4.0	93.0	112.5	94	5.0	259	72
1998	92.2	4.0	89.7	112.5	94	5.0	259	73
1999	92.2	4.0	89.7	112.5	94	5.0	261	73
2000	92.2	4.0	89.7	112.5	94	5.0	261	77
2001	92.2	4.0	89.7	112.5	94	5.0	261	78
2002	92.2	4.0	89.7	112.5	94	5.0	261	78

Thermodynamics – Second Law



http://www.grc.nasa.gov/WWW/K-12/airplane/thermo.html

My own research

- Theory and computation
- Techniques: Quantum density functional theory, statistical mechanics, classical molecular dynamics, Monte Carlo
- Close connection with experimentalists
- Materials range from thin film to bulk materials, from metals to semiconductors, crystalline to disordered materials, and nano- to micro-length scales
- Funding: NSF, DoE, DoD, State of Ohio
- Details: See http://astro1.panet.utoledo.edu/~khare/
- Current work in hard coatings and optical properties
- 2 Ph.D. students and 1 undergraduate

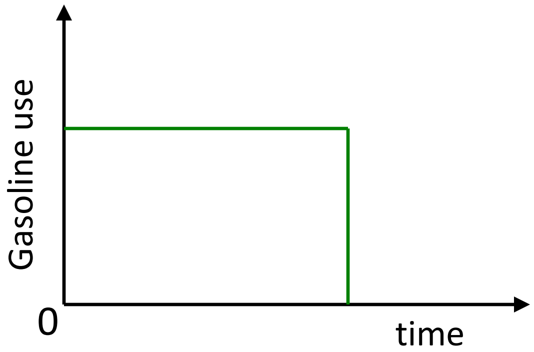
First crude oil found < 150 years ago

Before the first oil well was dug in Pennsylvania in 1859, Nature had made about two trillion barrels of oil and scattered it unevenly around the world.

By 2008 we've used up about one trillion. In other words we're near the half-way point.

"Hubbert's Peak: The Impending World Oil Shortage", Kenneth S. Deffeyes

An oil well isn't like a car's fuel tank



- With a car you can drive at full speed until the moment you run out of fuel.

Sequence of Emotional Reactions

Steps

- Surprise and Shock
- Denial of Problem
- Anger
- Bargaining “Give me some time”
- Depression
- Acceptance or Surrender
- Adaptation and Creative Action

Adapted from “On Death and Dying,” Elisabeth Kubler-Ross

Fuel Prices

Yesterday

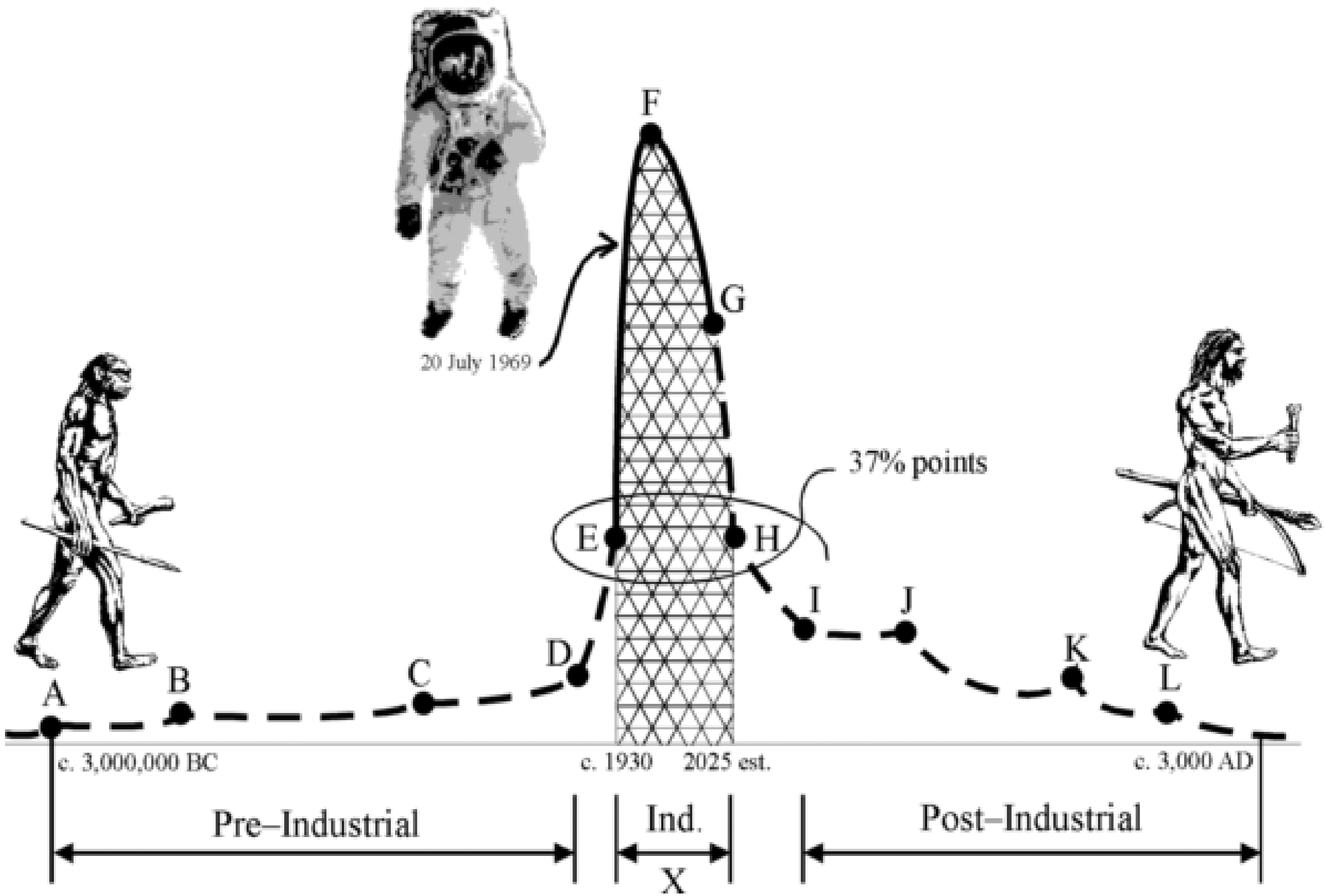
1955

Today

2012

… Tomorrow?

Industrial Civilization Lifetime about 200 years



From Olduvai Gorge