CIVILIZATION FAR FROM EQUILIBIRUM:
Energy, complexity, and human survival

Equinox Summit, Energy 2030
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Perimeter Institute, Waterloo, Ontario

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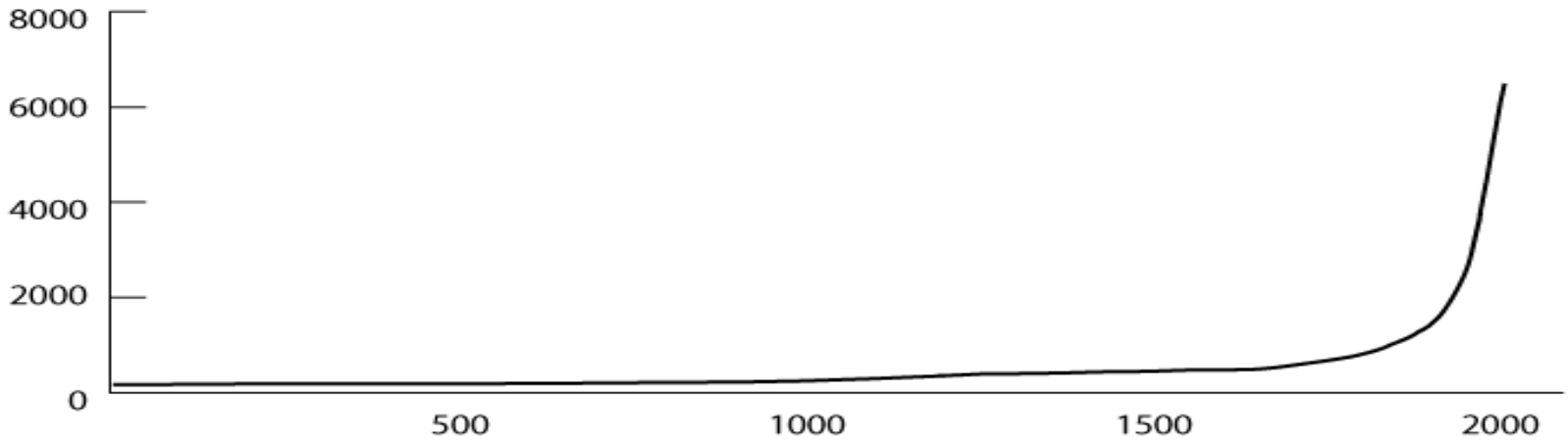
World population has quadrupled since 1900

Millions of people



Source: U.S. Census Bureau, "Historical Estimates of World Population," available from http://www.census.gov/ipc/www/worldhis.html and U.N. *World Population Prospects* 1950 - 2050 (1996 Revision).

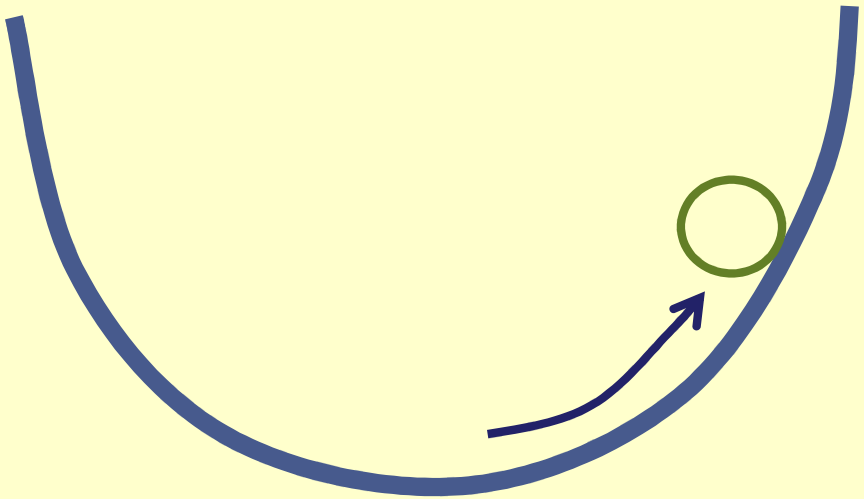
Energy should be seen as the

Master resource

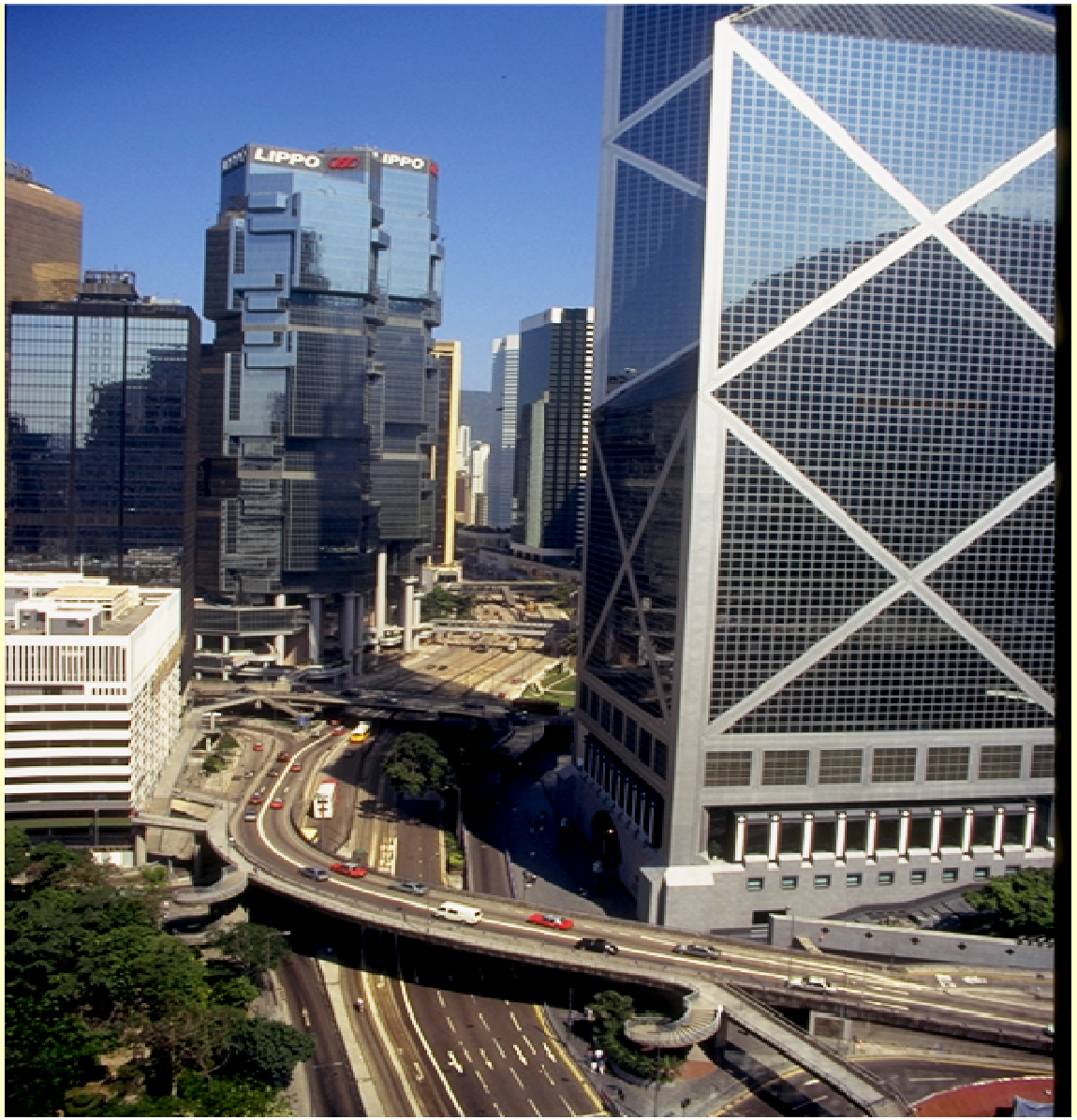
Two views of energy:

1. **Fuel**
2. **Enabler of complexity**

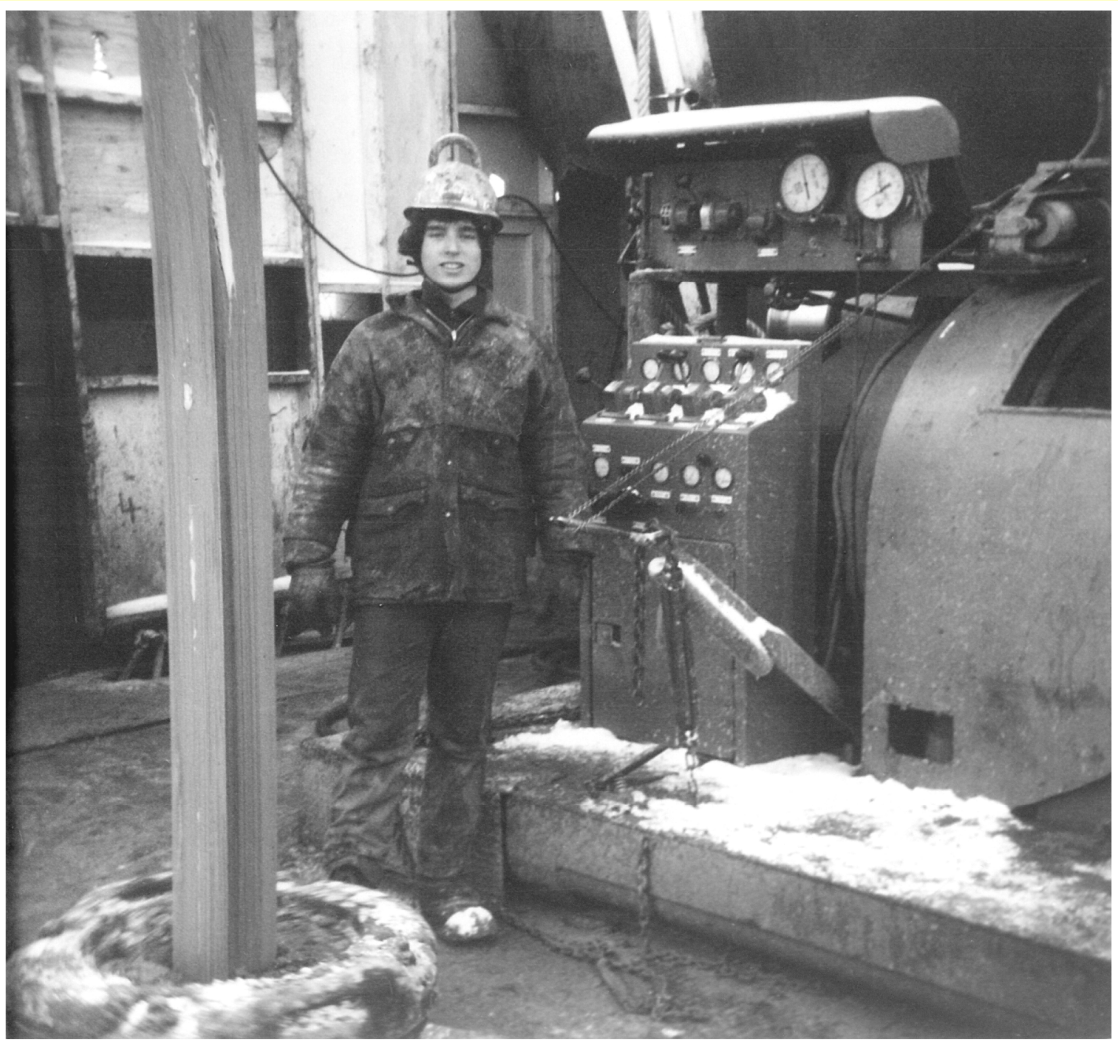
Thermodynamic Disequilibrium

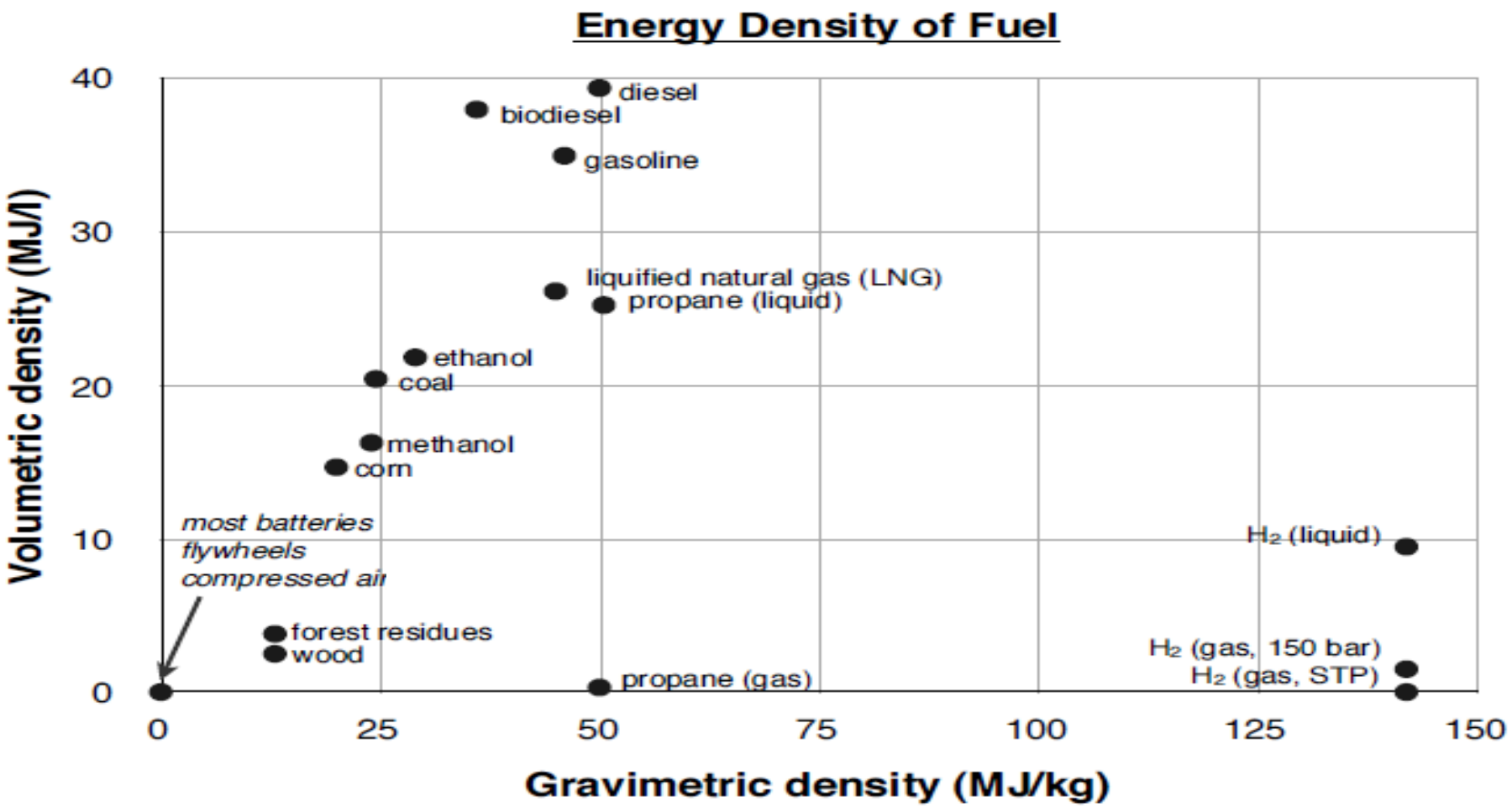


Energy and complexity

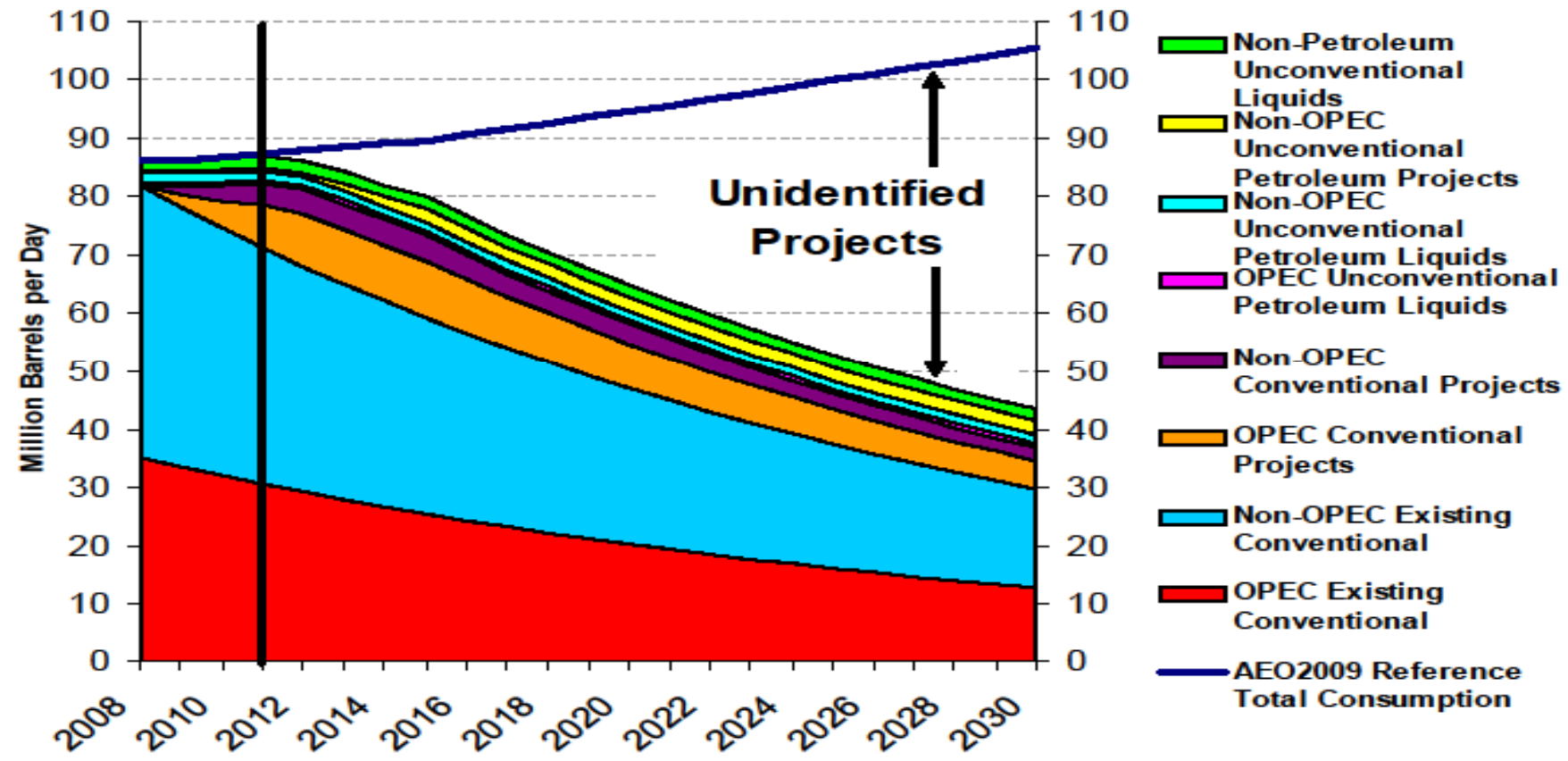


Energy and complexity




Energy Density of Fuel
Volumetric density (MJ/l)
Gravimetric density (MJ/kg)
0
10
20
30
40
0
25
50
75
100
125
150
diesel
biodiesel
gasoline
liquified natural gas (LNG)
propane (liquid)
ethanol
coal
methanol
corn
most batteries
flywheels
compressed air
forest residues
wood
propane (gas)
H2 (liquid)
H2 (gas, 150 bar)
H2 (gas, STP)

World's Liquid Fuels Supply



Source: EIA, AEO2009

How do we recognize complexity?

Many components

High connectivity

Thermodynamic openness

Nonlinearity

Emergence

What causes complexity?

In human systems
(social, economic, and technological),
complexity is introduced to solve problems

Most obviously, complexity has risen because of:

Advances in information technology

Performance improvements at the level of system units, i.e., organizations, people, and technologies

These changes produce more complex networks with:

More nodes

A greater density of connections among nodes

Faster movement of material, energy, and information along these connections

Is rising social, economic, and technological complexity a good or bad thing?

A good thing?

Complexity often helps us solve our problems

Complexity is often a source of:

Innovation
(through novel combinations)

Adaptability
(through diversity and distributed capability)

A bad thing?

But complexity also often causes:

Opacity and extreme uncertainty

Threshold behaviour

Managerial overload

Cascading failures

Brittleness

Brittleness rises because of:

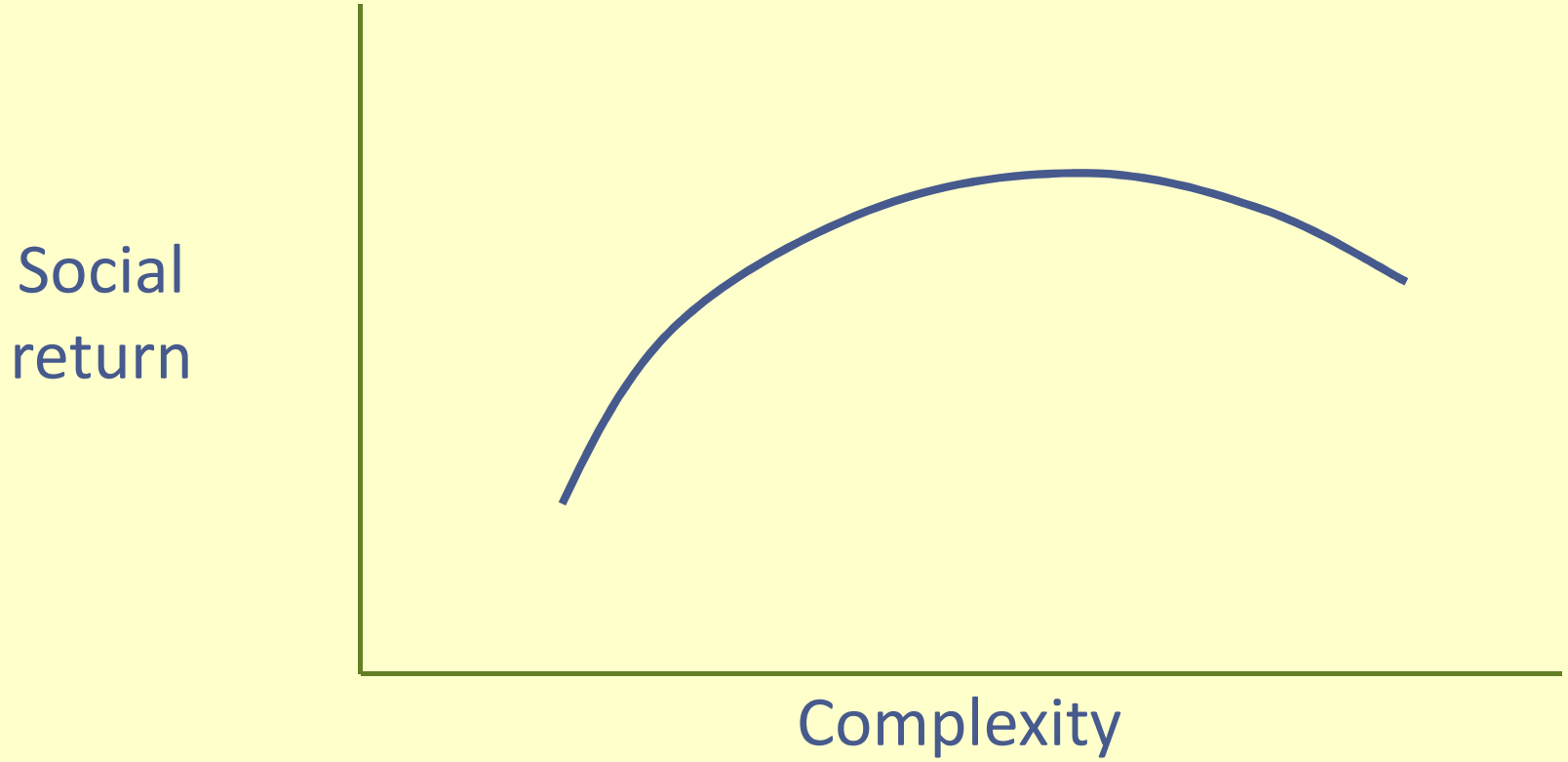
Loss of systemic capacity to exploit potential for novelty

Declining redundancy of critical system components
Increased risk of cascading failure

Plus (in contemporary world):

Enormous *energy* requirements to maintain system under *rising stress* far from equilibrium

Joseph Tainter:
Complexity's declining marginal social return



Joseph Tainter, *The Collapse of Complex Societies* (Cambridge: Cambridge University Press, 1988)

Tainter's argument:

Societies become inexorably more complex as they try to solve their problems

Complexity costs energy

Complexity produces diminishing returns

Marginal social return of complexity

=

$$\frac{\text{Benefit derived from marginal increment of complexity}}{\text{Cost of this complexity}}$$

Tainter is actually making two critical arguments about changing marginal social return to complexity:

1. **The benefit derived from the marginal increase in complexity is dropping**
2. **The cost per unit of energy is rising (because of declining EROI)**

Producing energy costs energy

This principle is best understood through the concept of

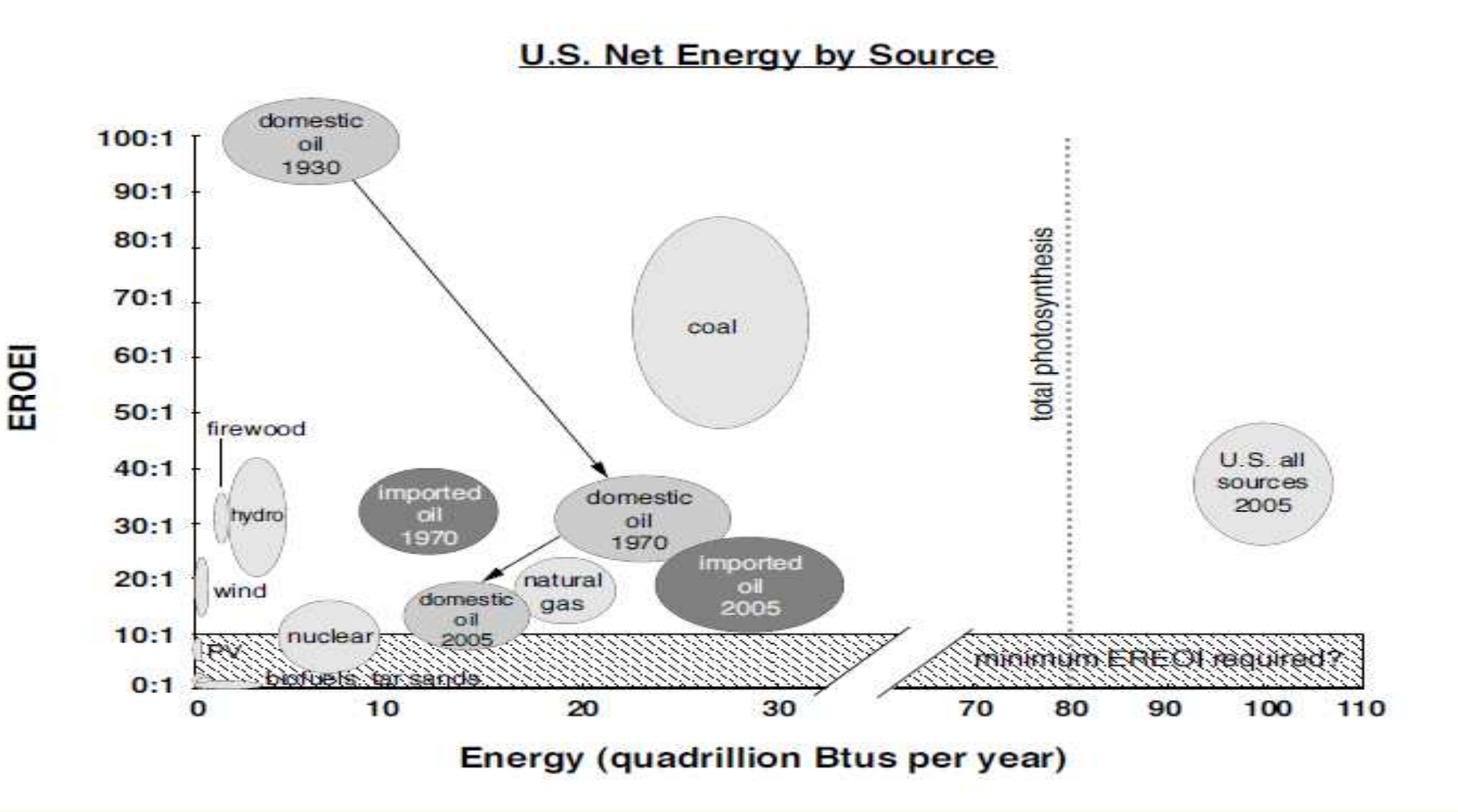
Energy Return on Investment (EROI)

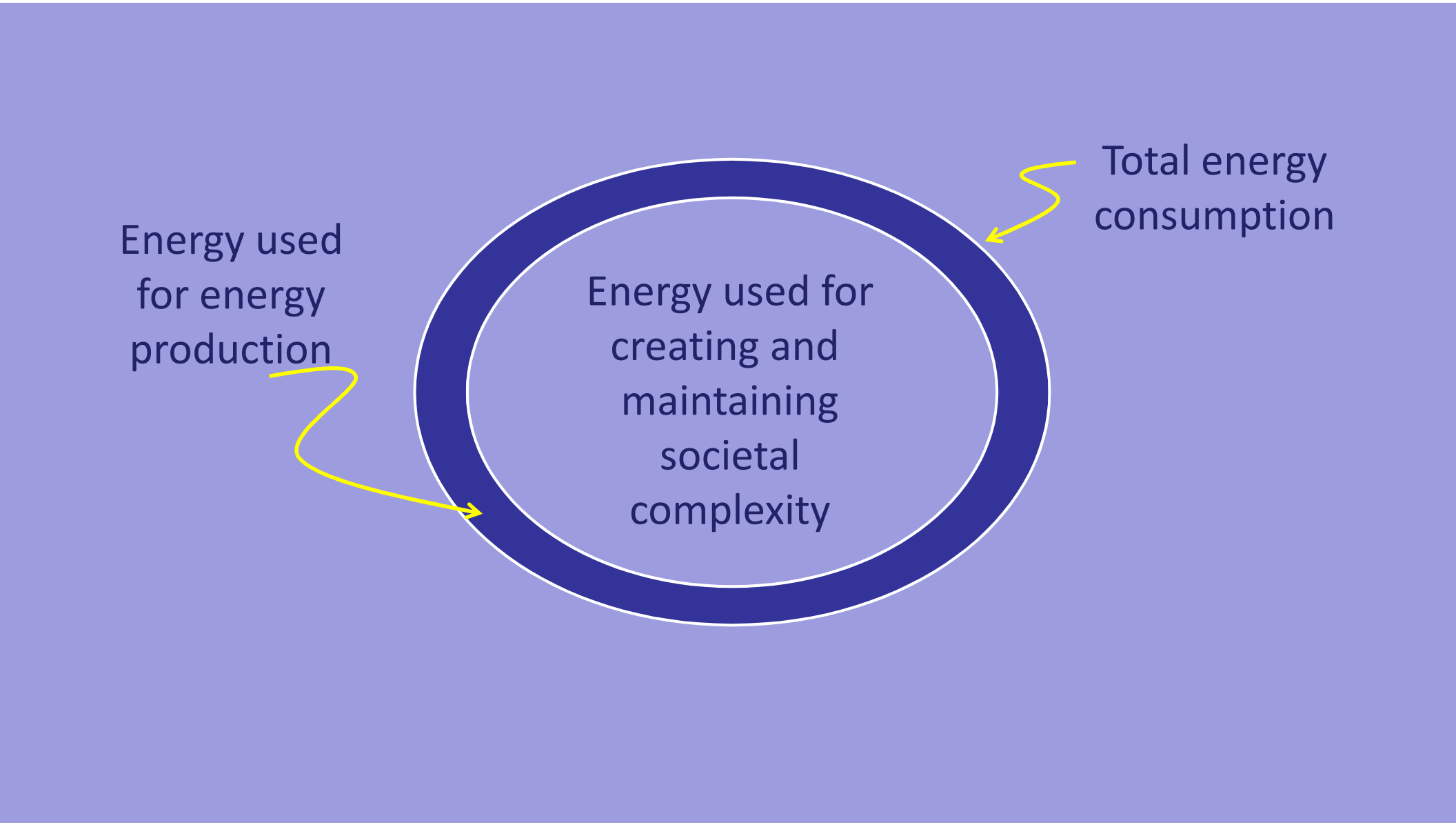
We're entering a transition from a regime of

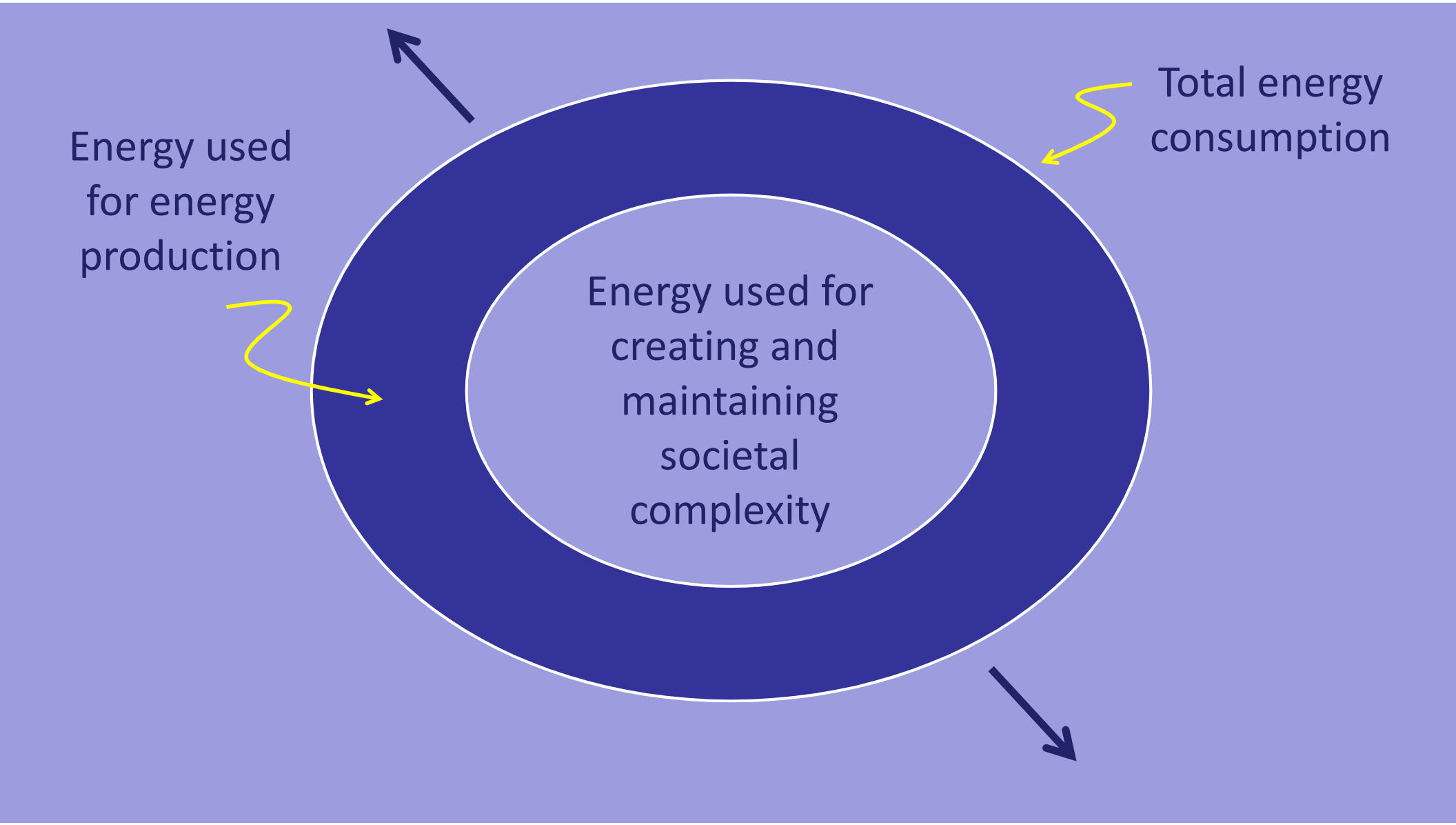
abundant high-quality, high-EROI energy

to one of

abundant mixed-quality, mixed-EROI energy


U.S. Net Energy by Source
EROEI
100:1
90:1
80:1
70:1
60:1
50:1
40:1
30:1
20:1
10:1
0:1
domestic oil 1930
coal
total photosynthesis
firewood
hydro
wind
imported oil 1970
domestic oil 1970
U.S. all sources 2005
natural gas
imported oil 2005
domestic oil 2005
nuclear
PV
biofuels, tar sands
minimum EROEI required?
0
10
20
30
70
80
90
100
110
Energy (quadrillion Btus per year)


Total energy consumption
Energy used for energy production
Energy used for creating and maintaining societal complexity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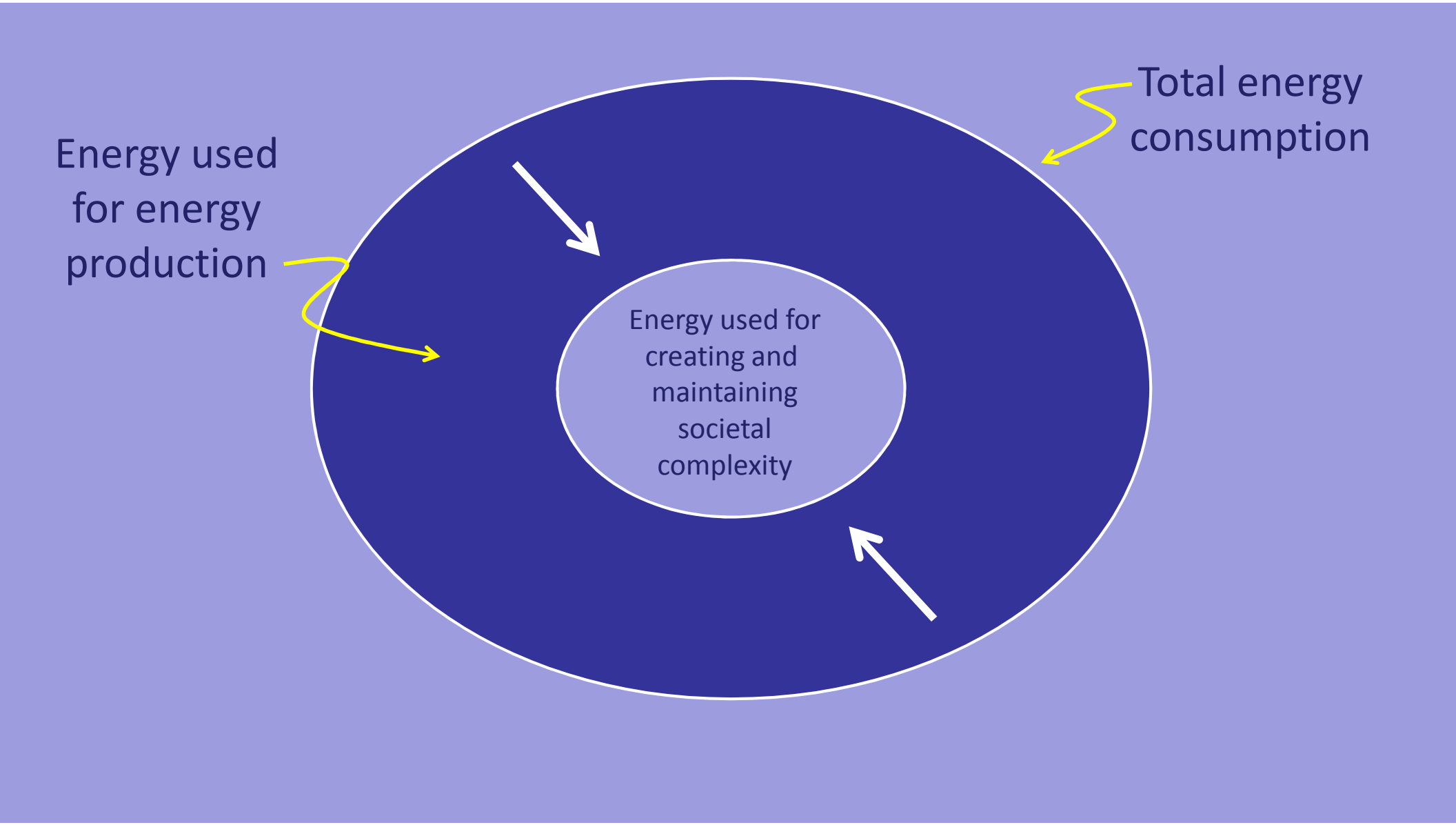
Total energy consumption
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In this new world, what should we do?

GET READY FOR A GPT TRANSITION
GPT = General Purpose Technology

Railroads

Electricity

Internal combustion engine

Personal computer

“Green” energy technologies?

HERE TO THERE

The transition won't be smooth

Prices are key

Transport solutions must accommodate fundamental energy realities

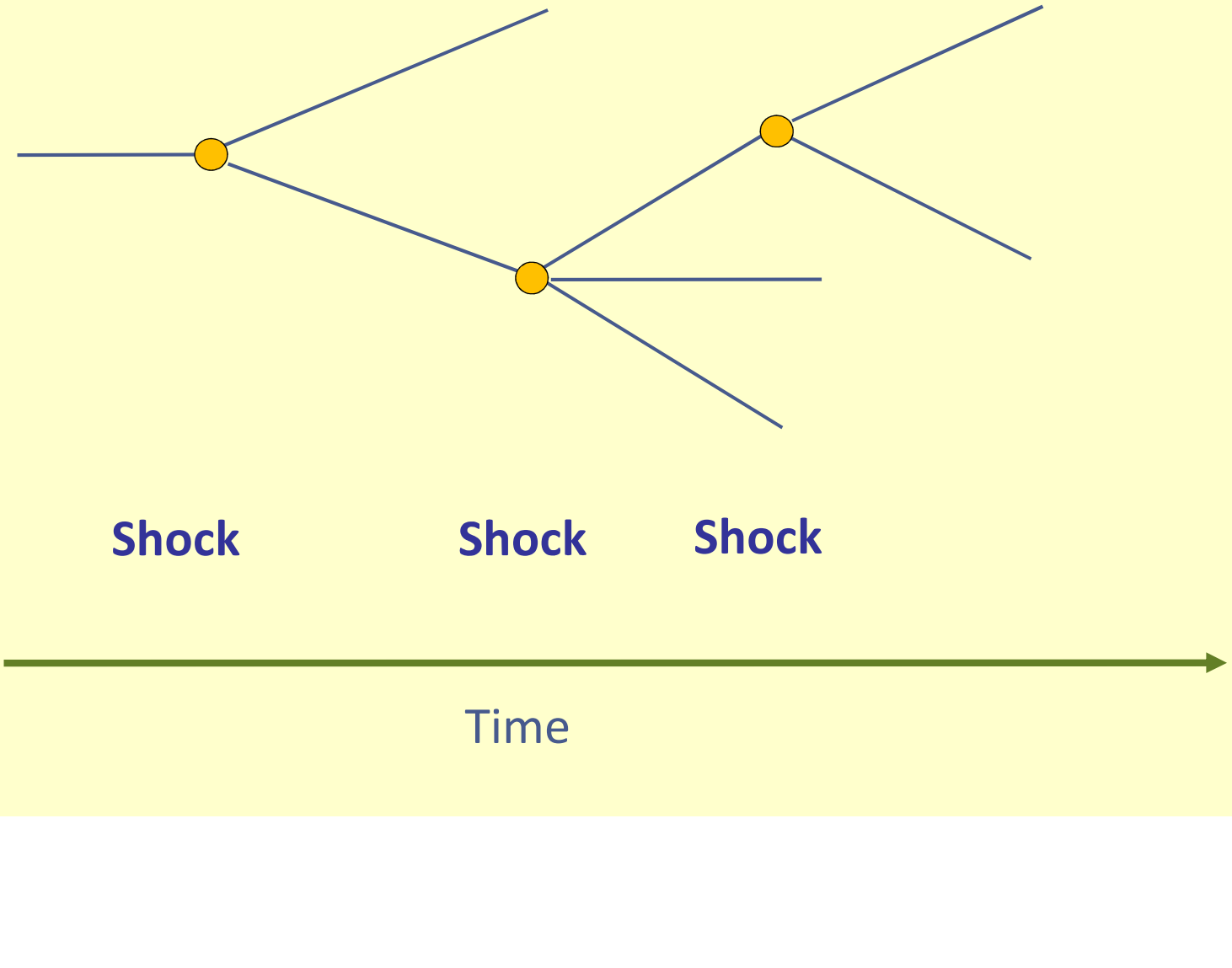
CRISIS

can create

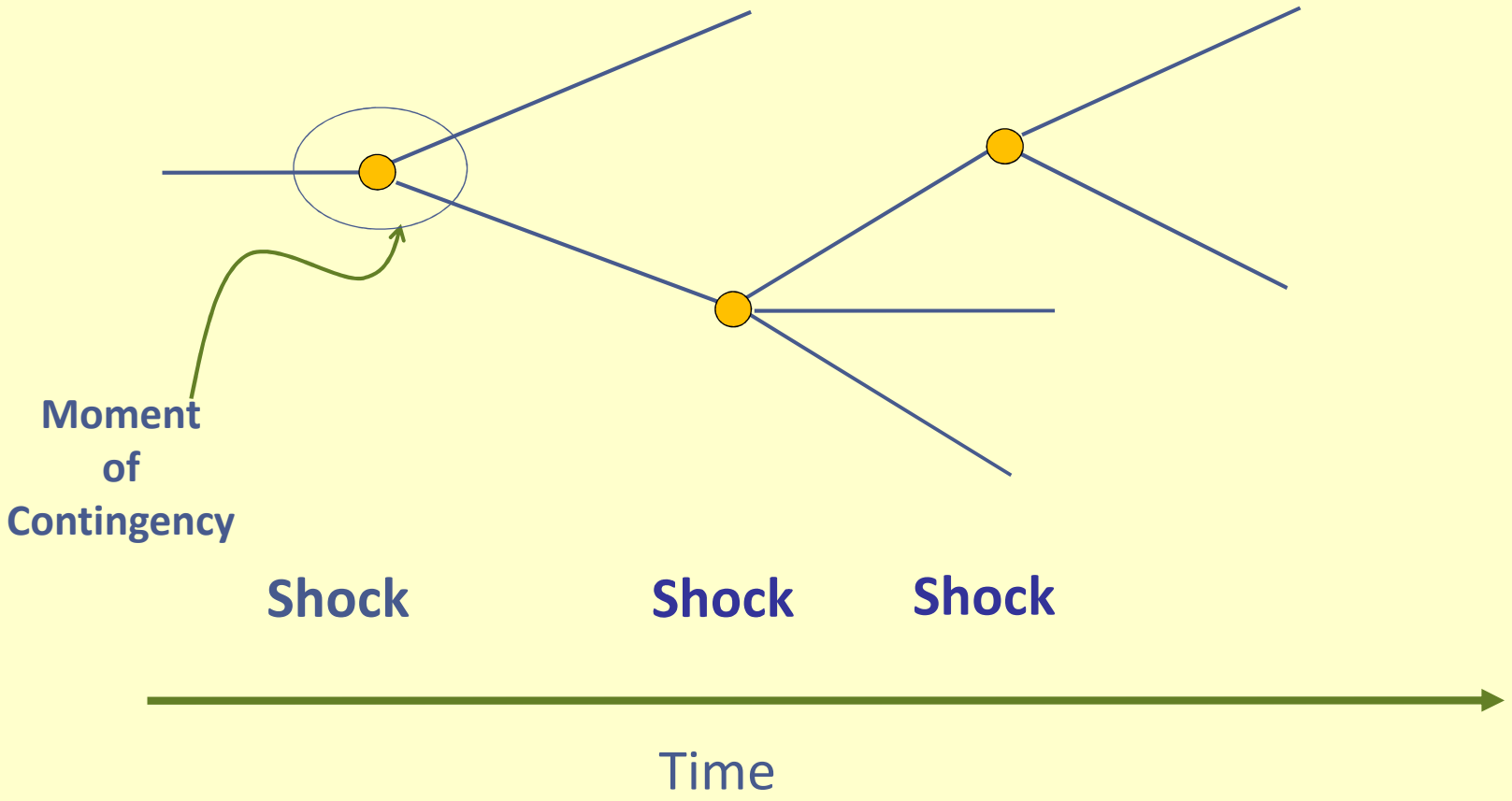
OPPORTUNITY

If we're ready to
exploit it

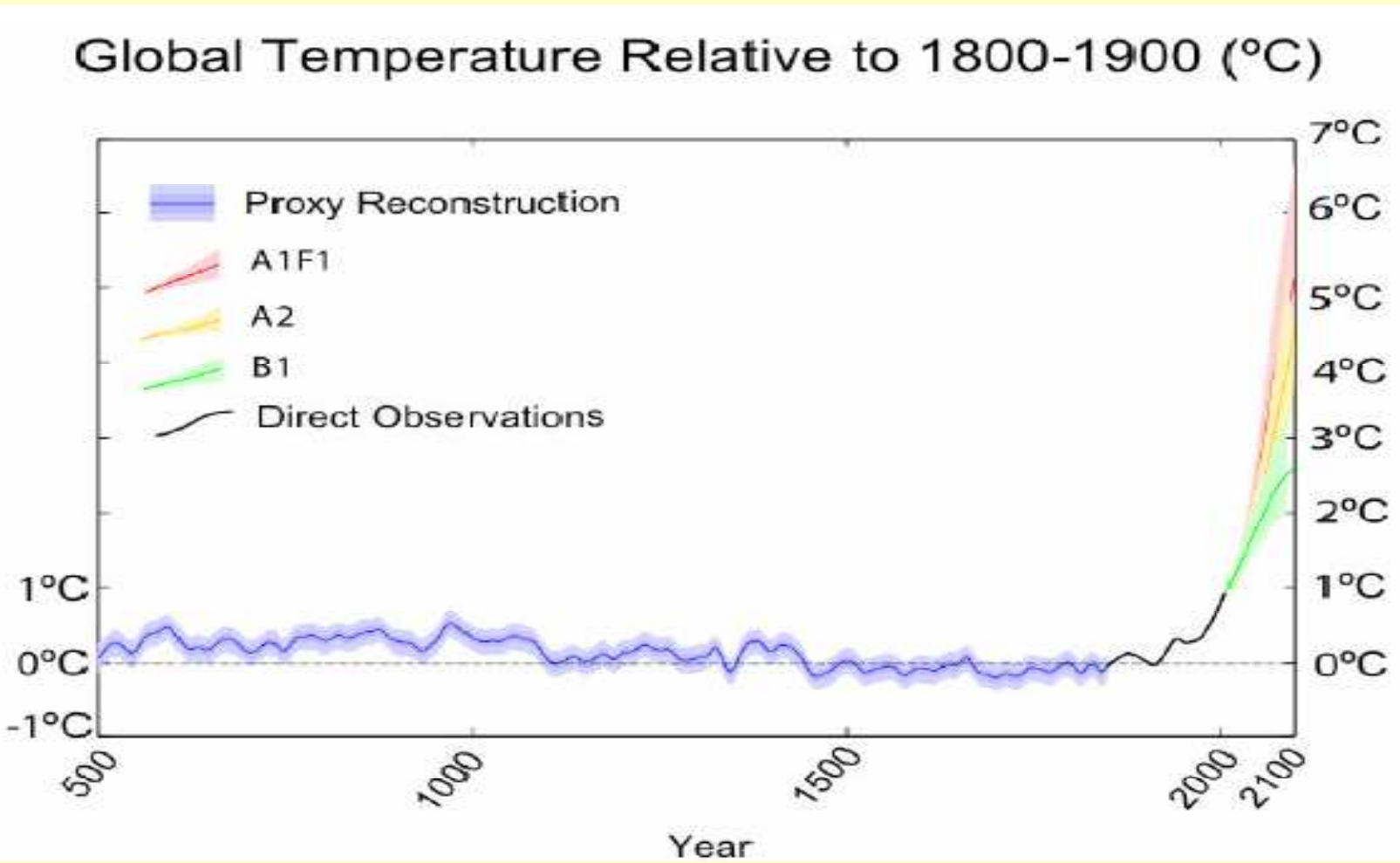
CRISIS AND CHANGE

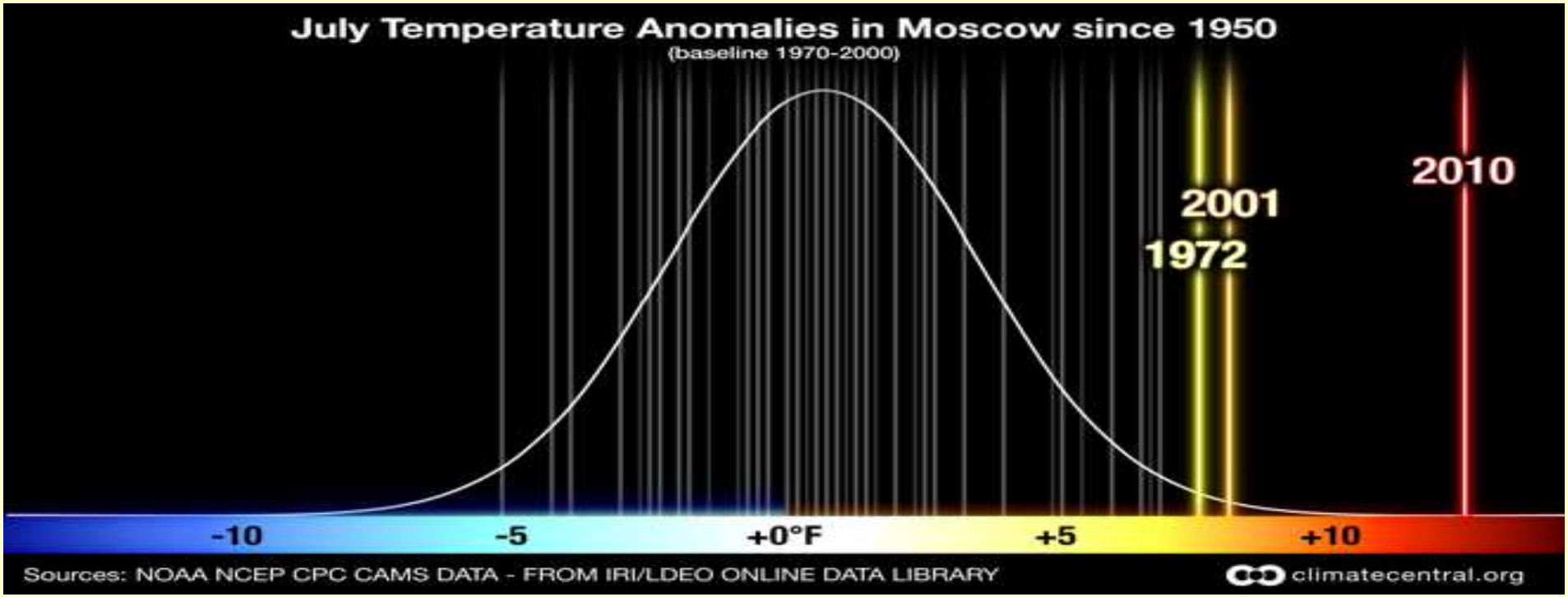


CRISIS AND CHANGE



CLIMATE SHOCK


Global Temperature Relative to 1800-1900 (°C)
Proxy Reconstruction
A1F1
A2
B1
Direct Observations
7°C
6°C
5°C
4°C
3°C
2°C
1°C
0°C
1°C
0°C
-1°C
500
1000
1500
2000
2100
Year


July Temperature Anomalies in Moscow since 1950
(baseline 1970-2000)
2010
2001
1972
-10
-5
+0°F
+5
+10
Sources: NOAA NCEP CPC CAMS DATA - FROM IRI/LDEO ONLINE DATA LIBRARY
climatecentral.org

ENERGY SHOCK

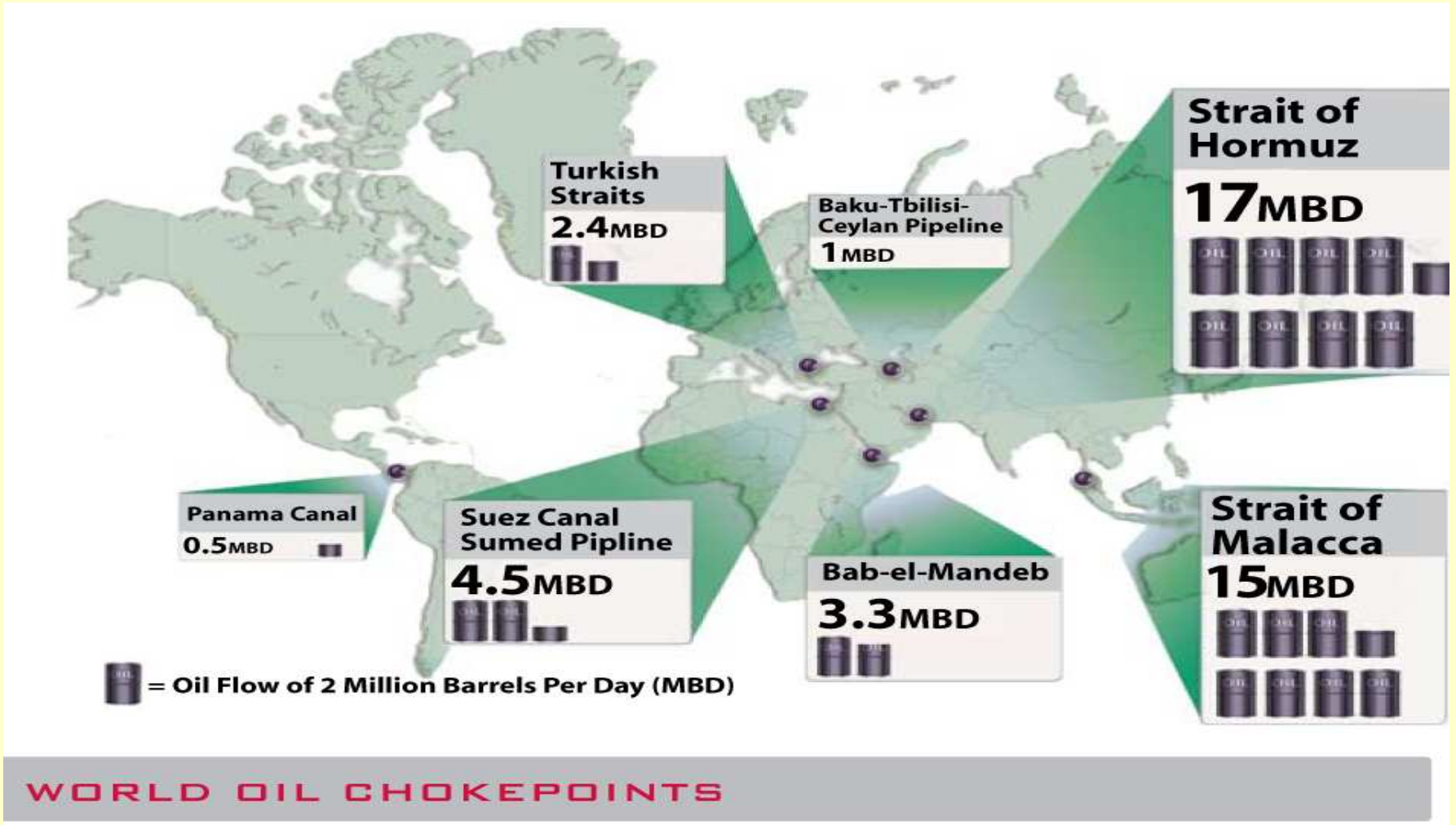
the JOE 2010

JOINT OPERATING ENVIRONMENT

READY FOR TODAY. PREPARING FOR TOMORROW.

“By 2012, surplus oil production capacity could entirely disappear, and as early as 2015 the shortfall in output could reach nearly 10 MBD.

A severe energy crunch is inevitable without a massive expansion of production and refining capacity.”



WORLD OIL CHOKEPOINTS

Liquid Fuel Emergency

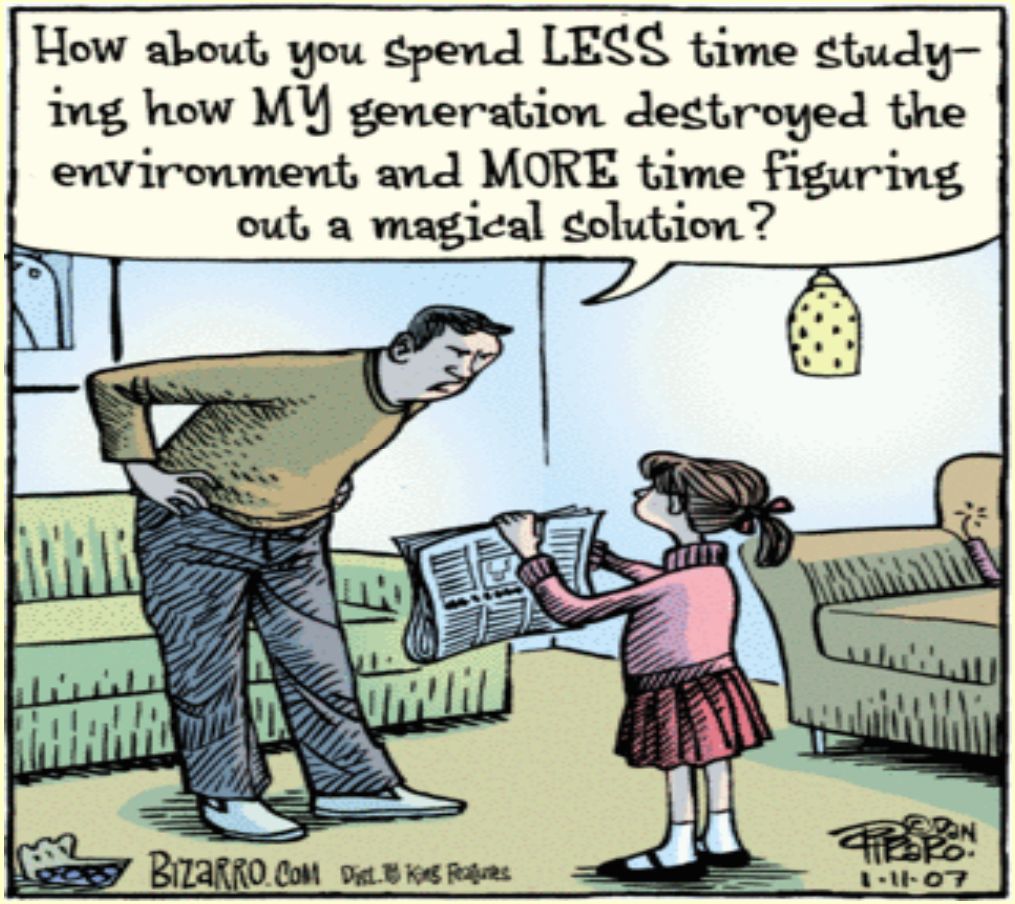
EASTERN CANADA IS VULNERABLE

Because of NAFTA obligations and pipeline configurations, eastern Canada cannot be readily supplied from western Canada

Western oil stops at Toronto, which is served from both west and east

About 90 percent of oil supply to Quebec and the Maritimes is from overseas (eastern Canada is like Japan in this regard)

Canada has no strategic reserve.


How about you spend LESS time studying how MY generation destroyed the environment and MORE time figuring out a magical solution?
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