# Energy and the Economy

## A Primer

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# Main Thesis and Overview

From First Principles

- All physical and mental work is explained by the laws of physics – specifically the Laws of Thermodynamics (as applied to systems far from equilibrium)
- In particular, all work depends on energy flowing from a high potential source through the work process to a low potential sink
- All economic activity depends on physical and mental work; the economy is a special case of a general energy flow system

# Outline of the Primer

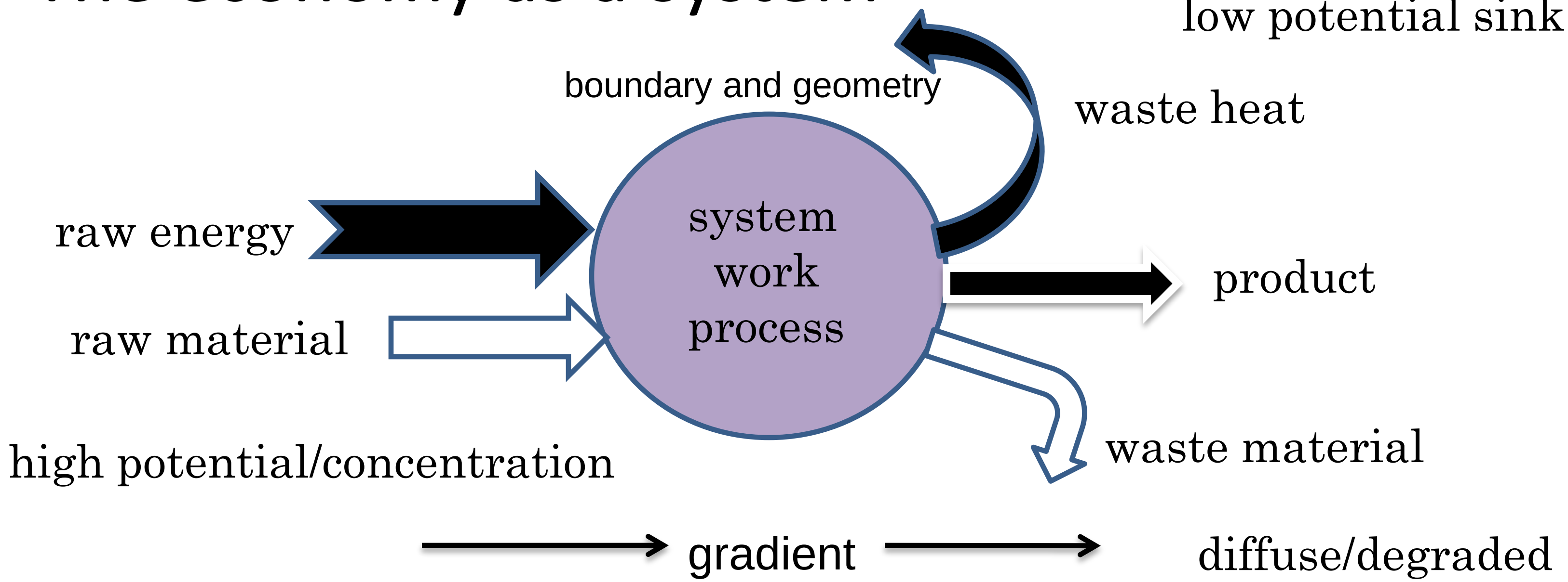
- The Macro-Macro View – Fundamental principles of energy flow and work
- Applied to economic work
- A systems analysis
- Critical features of the economic system in terms of energy flow and work
- Challenges we face

# The Economy as an Energy System

- Capturing and converting ‘raw’ energy into ‘usable’ energy
- Channeling energy flow through work processes
- Producing ***desired*** goods and services
- Producing ***useful*** goods and services
- Energy savings, investment, maintenance, development, and growth
- The economy as a super-biological/ecological system

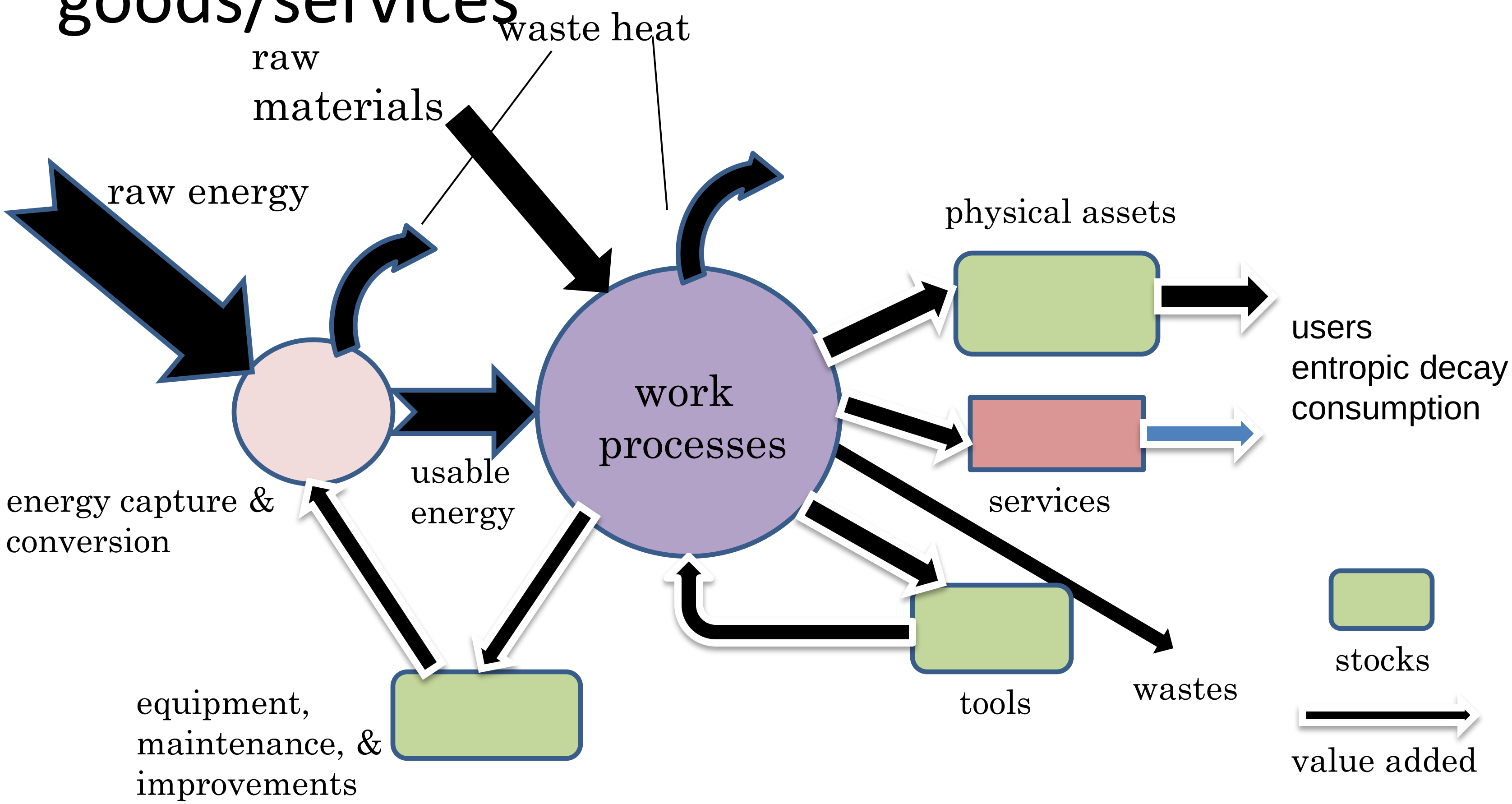
# The Macro-Macro View – Fundamental Principles

- Energy flow in systems
- Work and products
- Energy laws and consequences
- The economy as a system



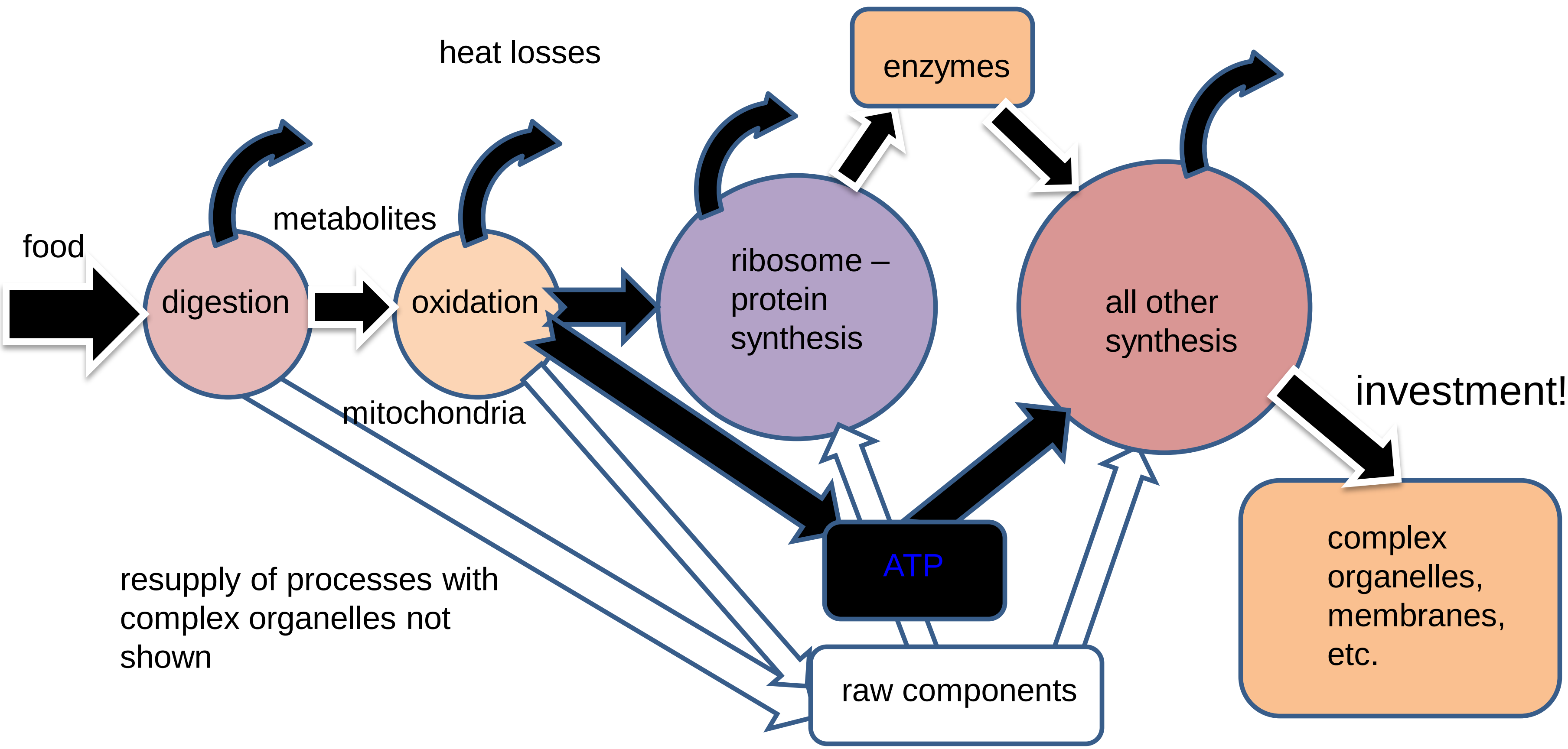
# A More Refined View

- The Economy: Energy, work, and goods/services



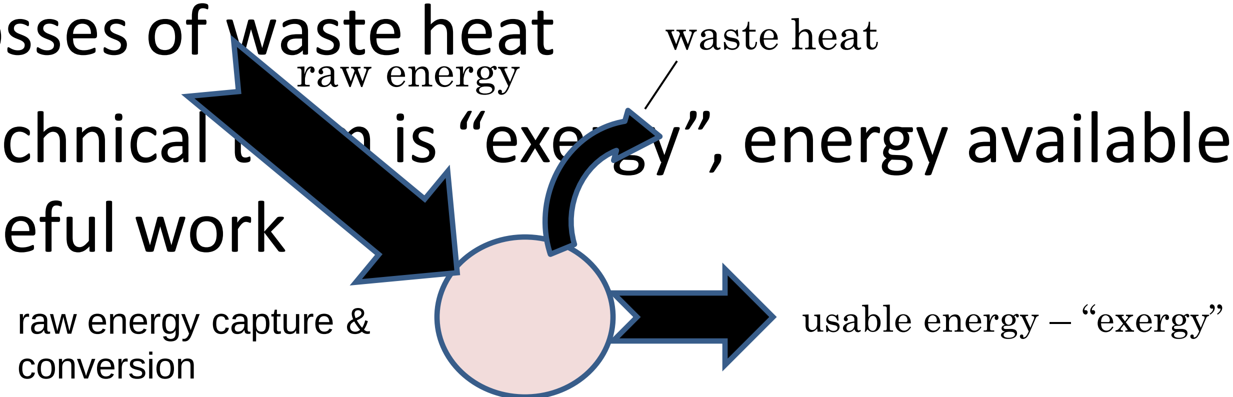
# A Biological Analog

- Cell metabolism and structural component synthesis



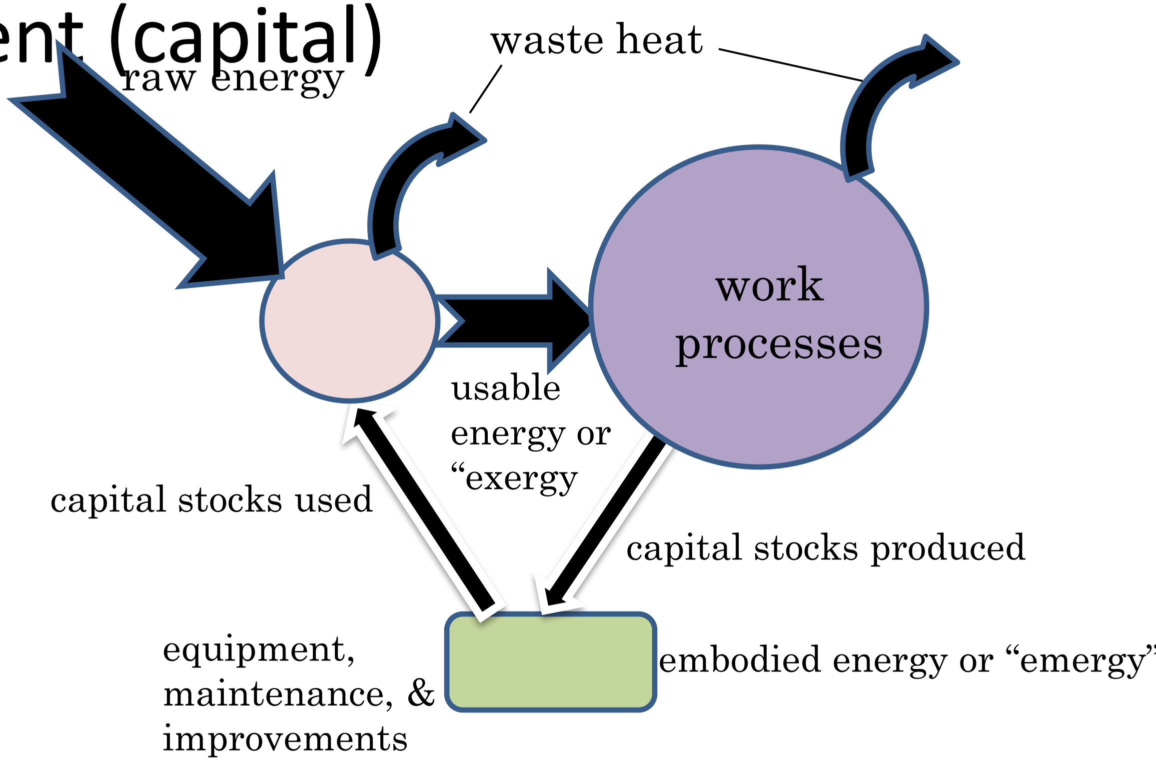
# Energy Capture and Conversion

- Raw energy from a high potential source
- Captured by physical process, e.g. photosynthesis or mining coal
- Converted into a “usable” form, e.g. electricity
  - Usability defined by the nature of the work process
  - Losses of waste heat
  - Technical term is “exergy”, energy available to do useful work



# Energy Investment

- Work needs to be done to construct, repair (entropic losses not shown), maintain, and improve energy capture/conversion equipment (capital)

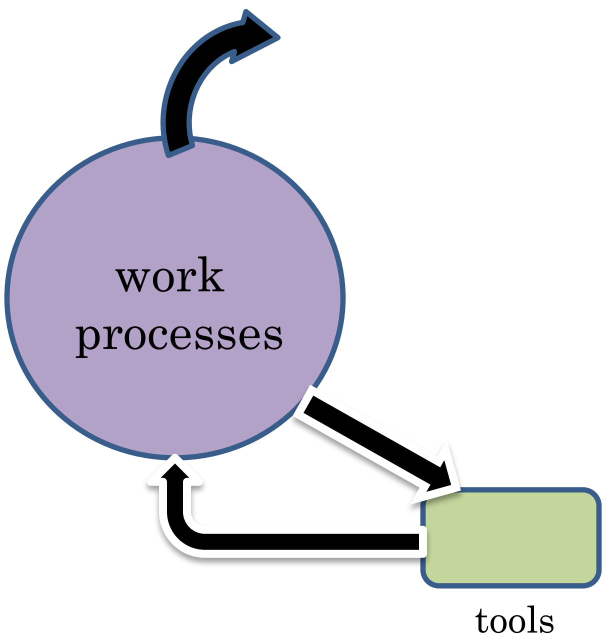


# Energy Investment (cont.)

- Some portion of the work processes of the economy must be directed toward maintaining raw energy capture and conversion equipment
- That means there is an energy feedback from the work process to the capture/conversion process in the form of equipment stocks (including repair, etc.)
- As with any capital, failure to adequately invest leads to reduction in the usable energy input to the work process
- Science and engineering work to find new resources and improve conversion efficiencies

# Tools

- Any device or procedure designed to obtain leverage in work processes
- Tool design improves with science and engineering providing greater work efficiency



# Tools (cont)

- Technology can be summarized as the set of tools mankind has discovered/invented over time
- Tool design is subject to evolution by a form of market selection
  – Users of tools recognizing a tool's inherent advantages (allowing greater productivity in a given task) will demand more of that design
  – Tool designs evolve by inventors discovering incrementally better ways (refining the tool capacity)
- Tools, like all assets are subject to entropic decay (see Investment in tools below)

# Tools (cont)

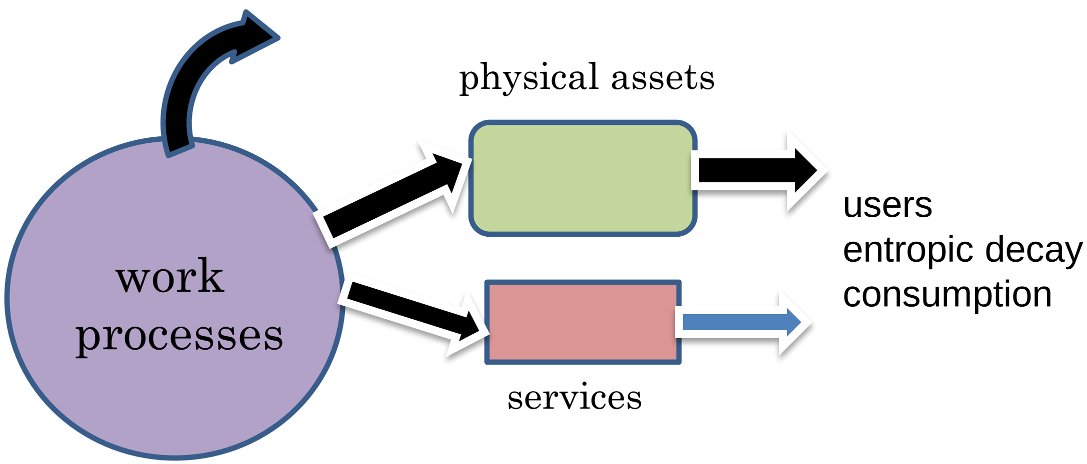
- Engineering has developed as a disciplined methodology for refining (and selecting) tool design
- Engineers obtain their knowledge of physical potentials from science
  - note some engineers do scientific thinking themselves, so we could be talking about the same person in two different roles
- Science discovers and codifies how nature works providing knowledge leverage – another kind of tool!

# Investment in Tools

- Same basic principle as energy capital investment
- Some portion of the general work processes must be devoted to the advancement of tool design for efficiency
  - Fed back into the work processes, this leads to improvements in production
- Some portion must be devoted to production of tool stock (capital) for improvement and maintenance

# Assets, Services, and Uses

- Given that the usable energy supplied to the work processes exceeds that needed to support tool and energy conversion capital, what is left over is available to supply user needs.



# Classification of Other Assets

- The distinction between tools and other assets is not easy to make
- A shelter is a kind of tool for protecting people from climate, especially in higher latitudes
- An automobile is a transportation tool
- Even entertainment devices and services can be regarded as mental tools to help refresh the mind!
- The key criteria is whether or not the asset (or service) is a net contributor to the

# Non-Tool Assets and Services

- Some tools can become non-contributors to net energy when the investment in their esthetics or “desired” features exceed s their value as a tool
- Examples: [Warning: value judgment to follow] SUVs, giant TVs, most professional and some college-level sports
- Some parts of consumable products (over-the-top packaging) do not generally make those consumables more contributory to net energy

# Other Energy Costs

- Removal of waste products
- Recycling materials
- Environmental cleanup/remediation
- Recovery from natural disasters
- Conflicts
- Governance overhead (when non-functional!)
- Inefficiencies not attended to

# What We Can Learn from Biological Systems

- Biological entities (individuals) are more stable in their constructive design and operations
  - They are adaptive within certain environmental ranges
  - They do not evolve “in place”; the phenotype has to make do
  - Generally grow to a maximum physical size but increases in biomass through reproduction
  - Governed by an elaborate hierarchical control system to assure coordination between all internal processes

# What We Can Learn from Ecological Systems

- Populations tend to be regulated in size (often with considerable variability over time) by environmental factors
- Ecological systems <u>can</u> be subject to large variation in component species but may remain relatively stable over long periods of time
- They  can also be subject to invasion by new components that can change internal dynamics

# What We Can Learn from Biological/Ecological Systems (cont.)

- Biological entities are strongly bounded, stably organized systems with relatively constrained energy flow requirements (food to biomass to wastes) – share similarities with firms
- Ecological systems are weakly bounded, generally evolving structurally. They are, however, limited by energy inflows (e.g. seasonal insolation and average temperature) – similarities with markets
- The human economy has characteristics of

# System Constraints

- Average inflow of high potential energy (with sink potential held constant)
  - If flow is increasing (i.e. source is expanding) then the system can do more work internally, growing or "reproducing"
  - If flow is constant then system can only operate in a steady state regime, even if it undergoes internal redistribution of work (e.g. evolving more efficient tools may allow development of new internal structures while the overall system dissipates heat at the same average rate over time

# System Constraints (cont.)

- Energy flow (cont.)
  - If the flow is decreasing then the system will be able to do less internal work (e.g. repairing infrastructure) while still dissipating heat. The system will contract.
- Material constraints
  - As concentrations of readily accessible raw materials decline due to consumption, more energy is needed to compensate for quality diminishment
  - Entropy applies to complex material; is only

# Challenges to the Human Economy

- Population growth unconstrained by ordinary biological factors
  - Evolution of technology has allowed humans to escape normal biological constraints
  - Discovery of ever more energy dense fuel sources created the scenario of energy inflow increasing
- Reliance on energy dense non-renewable fossil fuels
  - Modern civilization depends on fossil fuels  much more so than real-time, renewable insolation

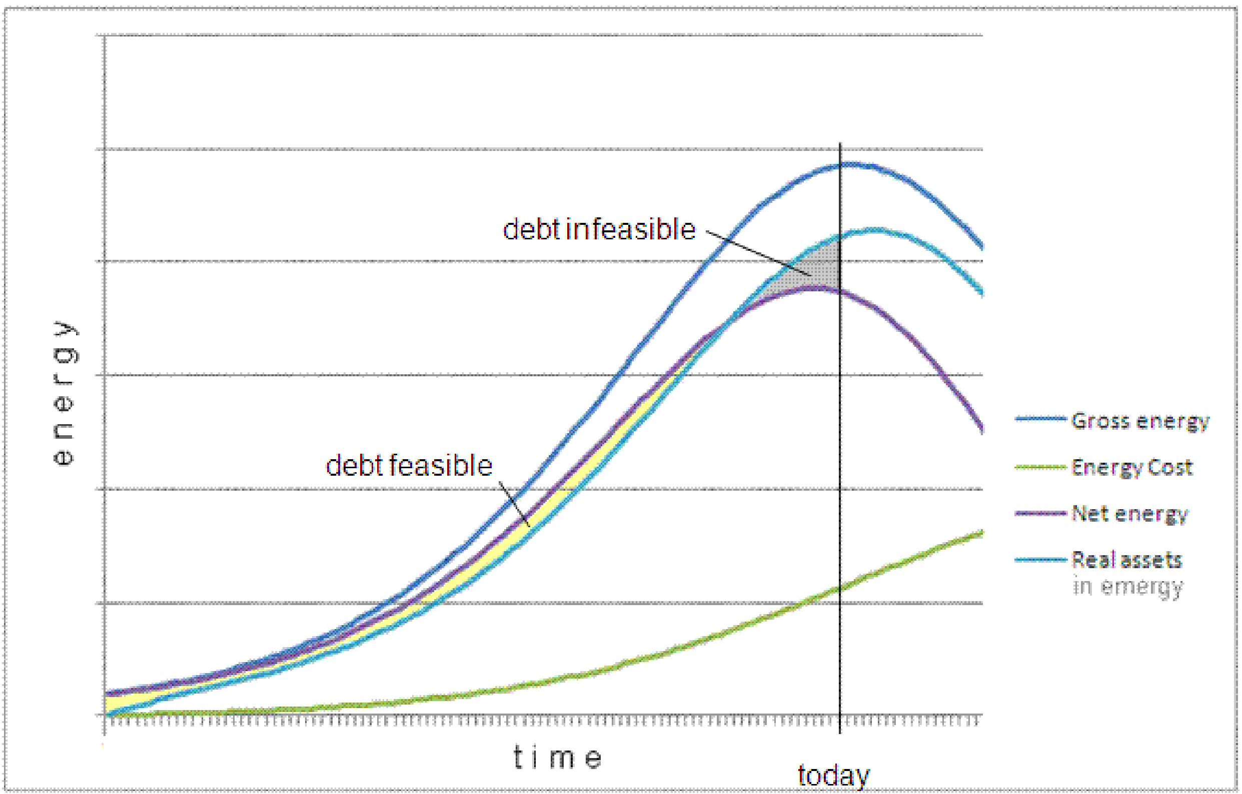
# Challenges (cont.)

- Depletion of high-grade, easily reached fossil fuels: particularly oil
  - Requires greater energy expenditures on investment in energy extraction (capture and conversion)
  - The ratio of energy return to energy invested (EROI) declines as the denominator increases
  - Net energy available to do useful work declines
  - Economy goes into contraction

# Challenges (cont.)

- Energy flow and economic activity as a function of resource depletion

Asset Production as a Function of Net Energy



# Challenges (cont.)

- As energy investment per unit of energy (exergy) returned increases it contributes to the decline in capture and conversion investment (e.g. investment in new oil exploitation becomes unprofitable)
- The increases in raw energy flow from non-renewable sources tails off and reaches a peak after which it begins to decline
- Even before the peak of production the net energy available (green line in graph) tails off

# Challenges (cont.)

- Consumable wealth production (particularly of non-essential goods and services) was supported by excess net energy prior to the point where consumption crosses net energy production.
- Prior to that point in time it was possible to “borrow” against future production; the excess could pay back principal and interest
- After that time we enter a period of accumulating deficits that cannot be paid back

# What to Expect

- Without a replacement of fossil fuel energy (high quality) by some renewable source(s) society goes into rapid and permanent decline
- The deficit is too large to allow any investment in new energy capture and conversion equipment
- Society uses up its accumulated wealth
- The population is no longer supportable at anywhere near current levels

# Conclusions

- The “true” currency of an economy is the same as that for biological and ecological systems – ENERGY
- The economy obeys the same laws as pertain to physical systems, especially the Second Law of Thermodynamics applied to far from equilibrium systems
- The decline of energy flow supported by non-renewable sources absolutely means the decline of economic work and an

# Implications

- As long as energy flow increased through history the economy could evolve and grow; energy could be borrowed from the future in the sense that current stocks could be invested in non-energy goods and services knowing that new energy would take its place
- When energy flow peaks and declines the economy goes into contraction and there is nothing left to borrow against; investment will decline
- The system will reach a new, much lower

# Questions?

- What do we do?
- How will this play out?
- What happens at the intersection of peak energy and impactful climate change?
- And endlessly more questions besides…