

A journey in Industrial Ecology with Bob Ayres



**Material flow analysis:
from chemical
substances to urban
metabolism**

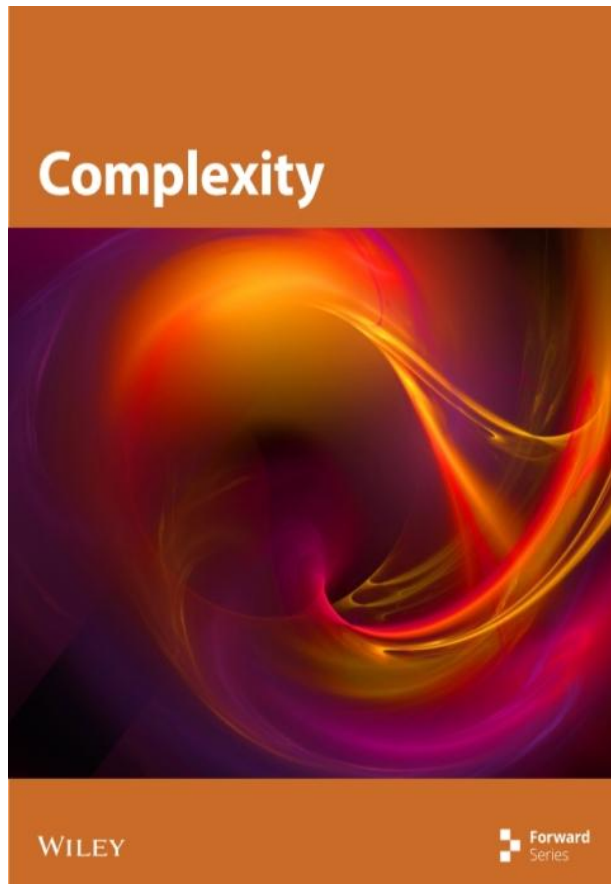
**Gara Villalba
Autonomous University of
Barcelona**



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Action-Oriented Industrial Ecology Science

May 26 - 31, 2024

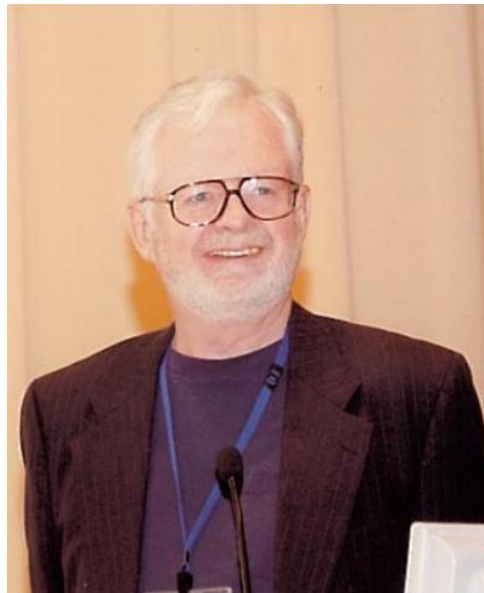


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System Complexity Versus Environmental Sustainability: Theory and Policy

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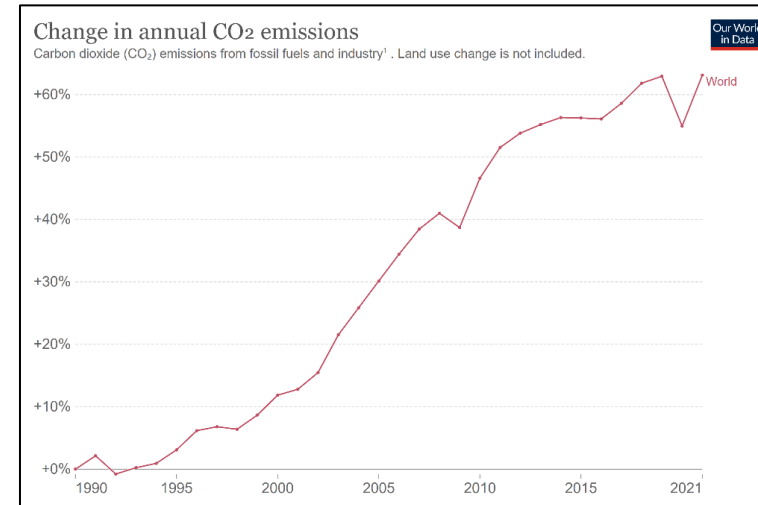
Robert Ayres



Jeroen van den Bergh

Disappointing impact of environmental policies

- Although we have implemented many policies to respond to global warming ... we don't observe steady emissions reduction on a global scale



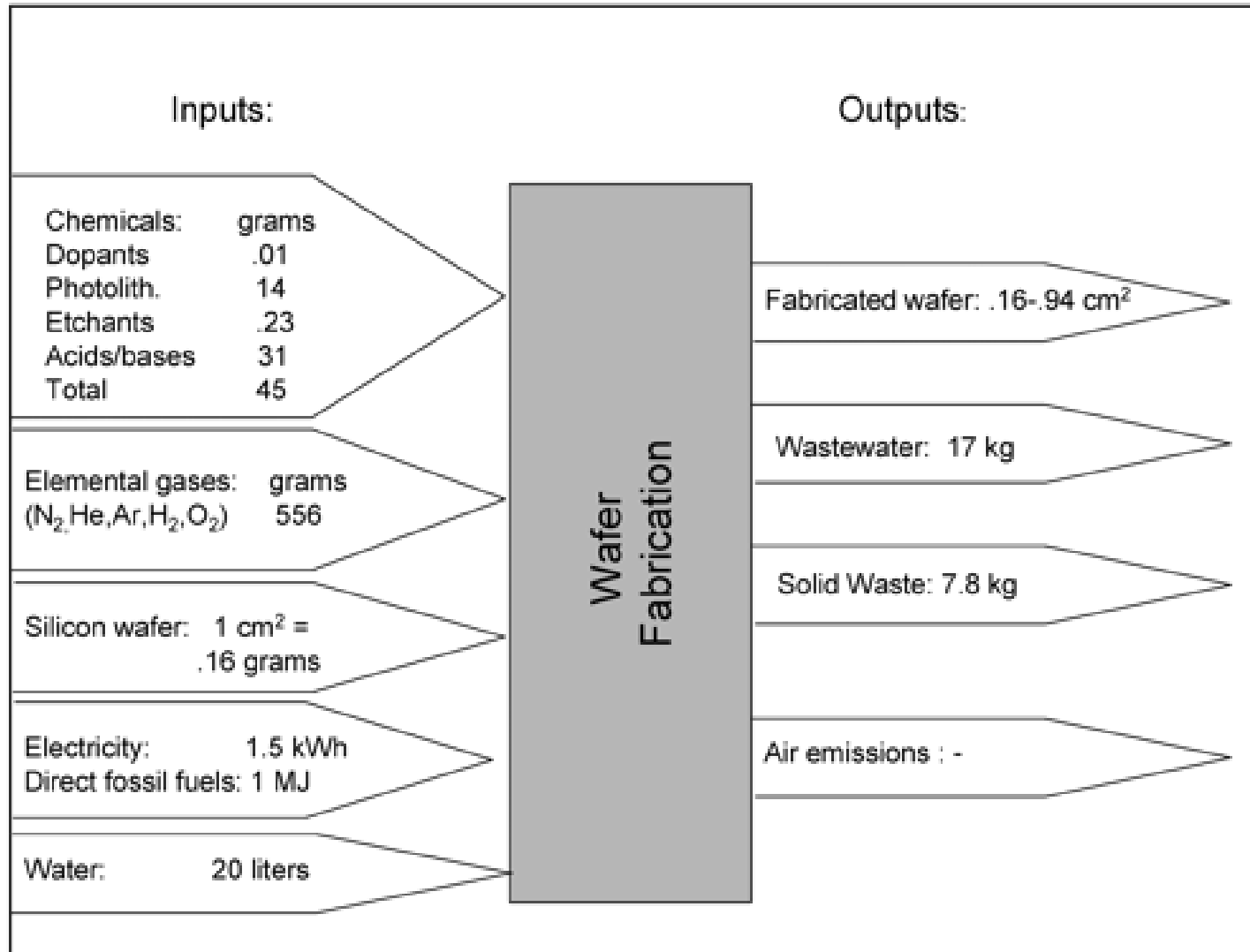
- Of course, policies could be more effective and stringent Source: Our World in Data (2023)
- But, in addition, systemic, indirect effects frustrate effectiveness: *rebound, leakage, environmental impact shifting, green paradox (oil market responses)*
- This may be partly due **complexity increases** triggered by “environmental and climate solutions”

Role of increasing complexity

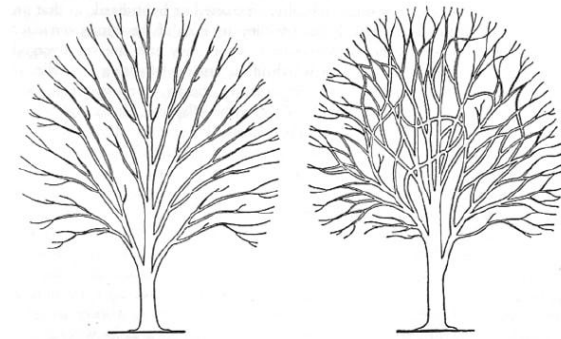
- ➔ Historian/anthropologist Joseph Tainter (2011) has argued that responses to environmental & resource problems tend to increase “cultural complexity” – economy, politics, technology & information.
- ➔ In turn, the economy requires more energy & material inputs, complicating a definite solution or even worsening the problem.
- ➔ This goes somewhat against the common view of economic history as increasing complexity going hand in hand with progress.
- ➔ Tainter suggests that future sustainability, and hence societal stability & progress, are compromised by increasing complexity.

The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor

Eric D. Williams Robert U. Ayres Miriam Heller



What makes up cultural complexity?



Kroeber (1948)

- Number/diversity of people & groupings/organisations
- Networks of interactions/communication
- Embodied/codified ideas & analytical methods (math, stats, etc.)
- Specialisation, professions & exchange/trade – inequality
- Artefacts, (intermediate/final) products & services
- Laws, norms/rules and policies – a big state
- Bureaucracies/hierarchies in private & public organisations
- (Large) geography of human activities, infrastructure & transport

Evolved/self-organized, unplanned – though influenced by individual/public goals

Why we see increases in complexity?

- Complexity grows as response to problem solving – *gradually but steadily*



- Human cultural, economic & technological history is a sequence of solving all kinds of problems & conflicts
- Complexity grows as long as it can – in nature & culture
 - *Evolutionary history*: energy/material availability => complexity ↑

Link complexity & sustainability *(inspired by Tainter)*

1. Sustainability requires hard problem-solving – research, technology, policy, politics, public resistance- **life cycle effects are very diverse!**
2. Complexity due to problem-solving does its damage slowly, subtly, unpredictably & cumulatively – *over a long period*
3. Complexity can reach diminishing returns & become ineffective.
4. Sustainability may require greater use of resources rather than less => *one must be able to afford sustainability.*

Implication: A society can be destroyed by the cost of environmental problem solving.

Laws of thermodynamics

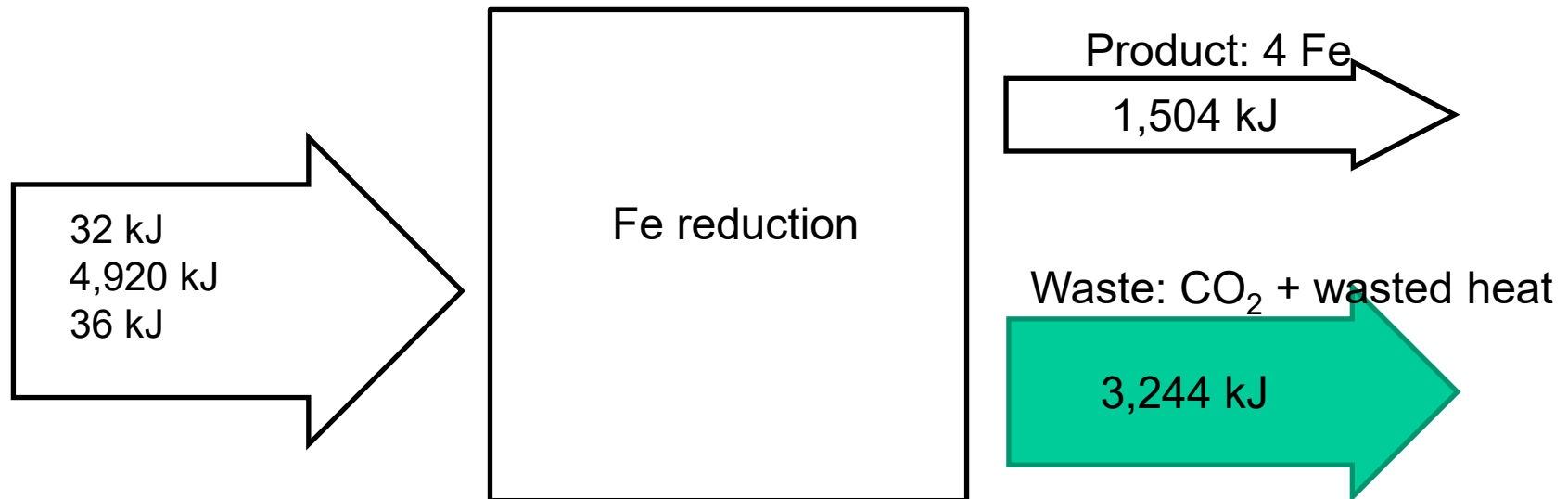
1. Energy is conserved

2. Energy is degraded

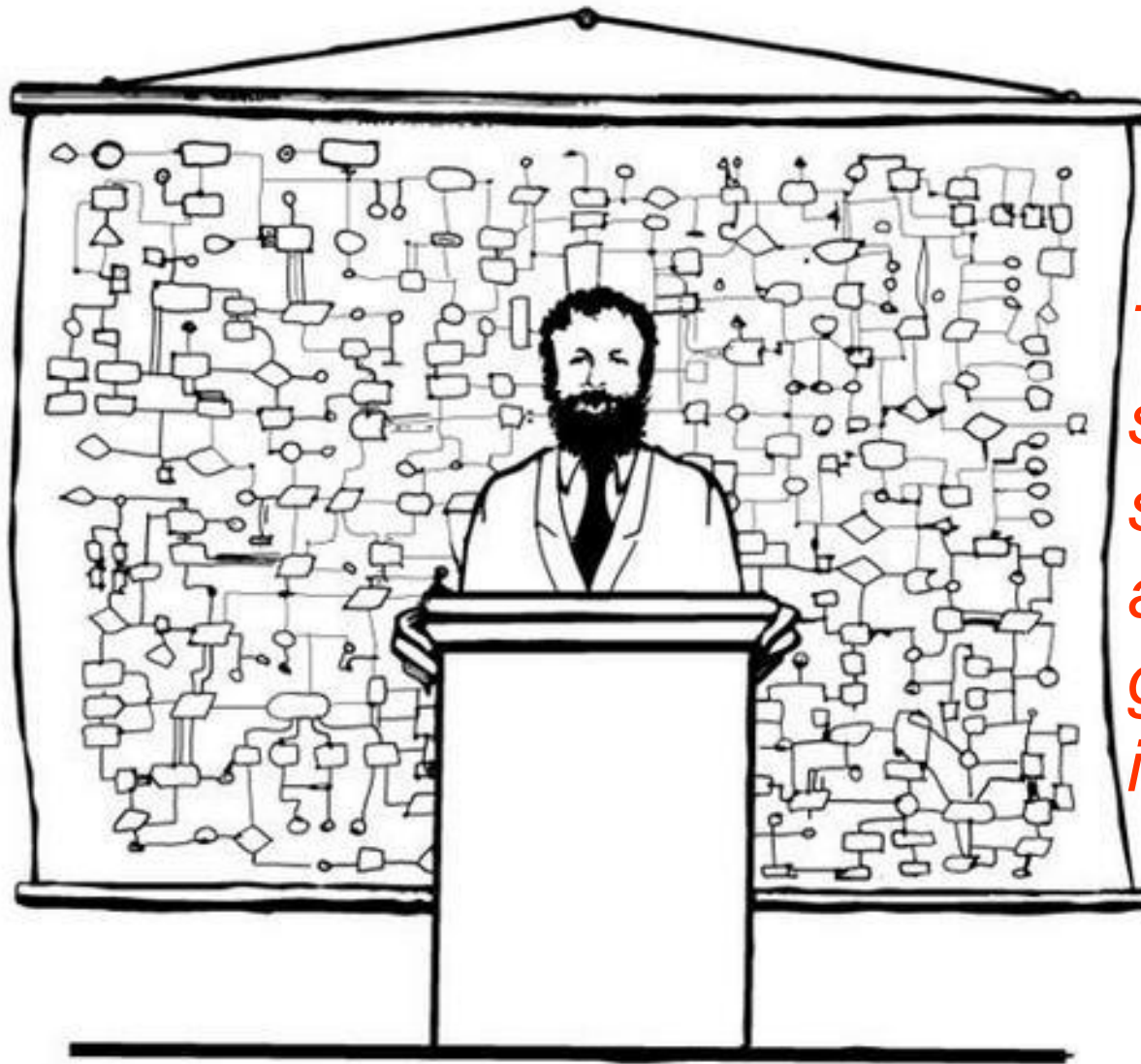
entropy increases, exergy is lost

Example cont'd

Exergy balance:



$$\text{exergy}_{\text{in}} = \text{exergy}_{\text{out}} + \text{exergy}_{\text{lost}}$$



The formation and stability of such subsystems come at a cost of exergy while generating an increase in complexity!

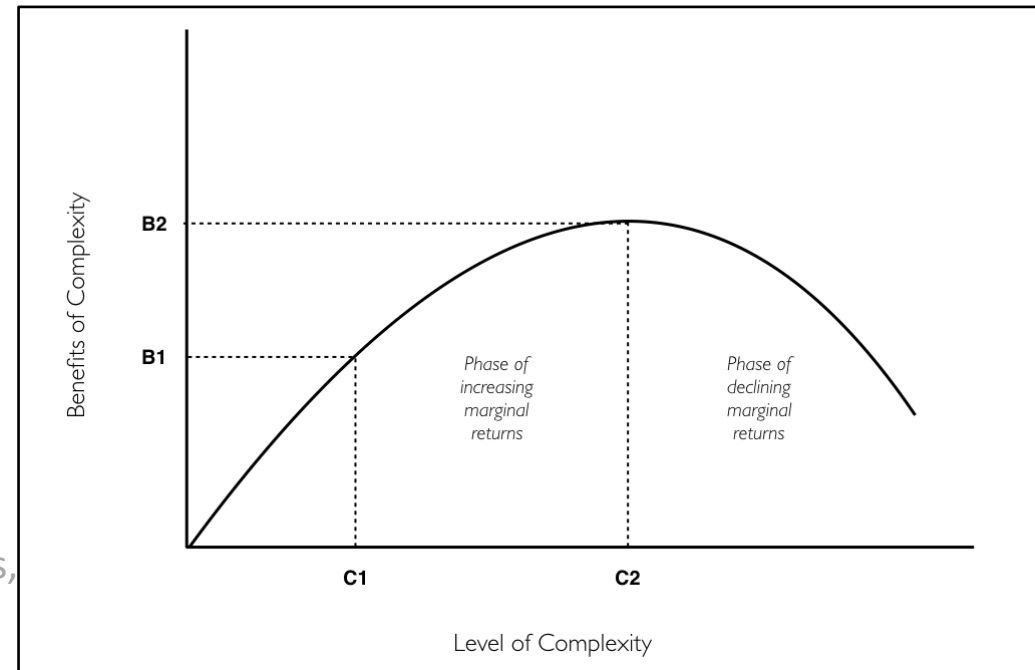
“Now that you have an overview of the system, we’re ready for a little more detail”

Source: <https://en.wikipedia.org/wiki/File:ArchitectureCartoon.png>

Historical evidence for relevance complexity?

- In “The Collapse of Complex Societies” (1988), Tainter examines the collapse of Maya & Chacoan civilizations, and Western Roman Empire.
 - **Less** social stratification, economic specialisation, centralised control, trading & production of ostentatious ‘cultural byproducts’ (monumental buildings, artworks)
- Societies collapse when investments in social complexity reach diminishing marginal returns.
- Suggests “optimal complexity”

Source: Tainter, J.A. (1988). *The Collapse of Complex Societies*. Cambridge University Press, Cambridge.

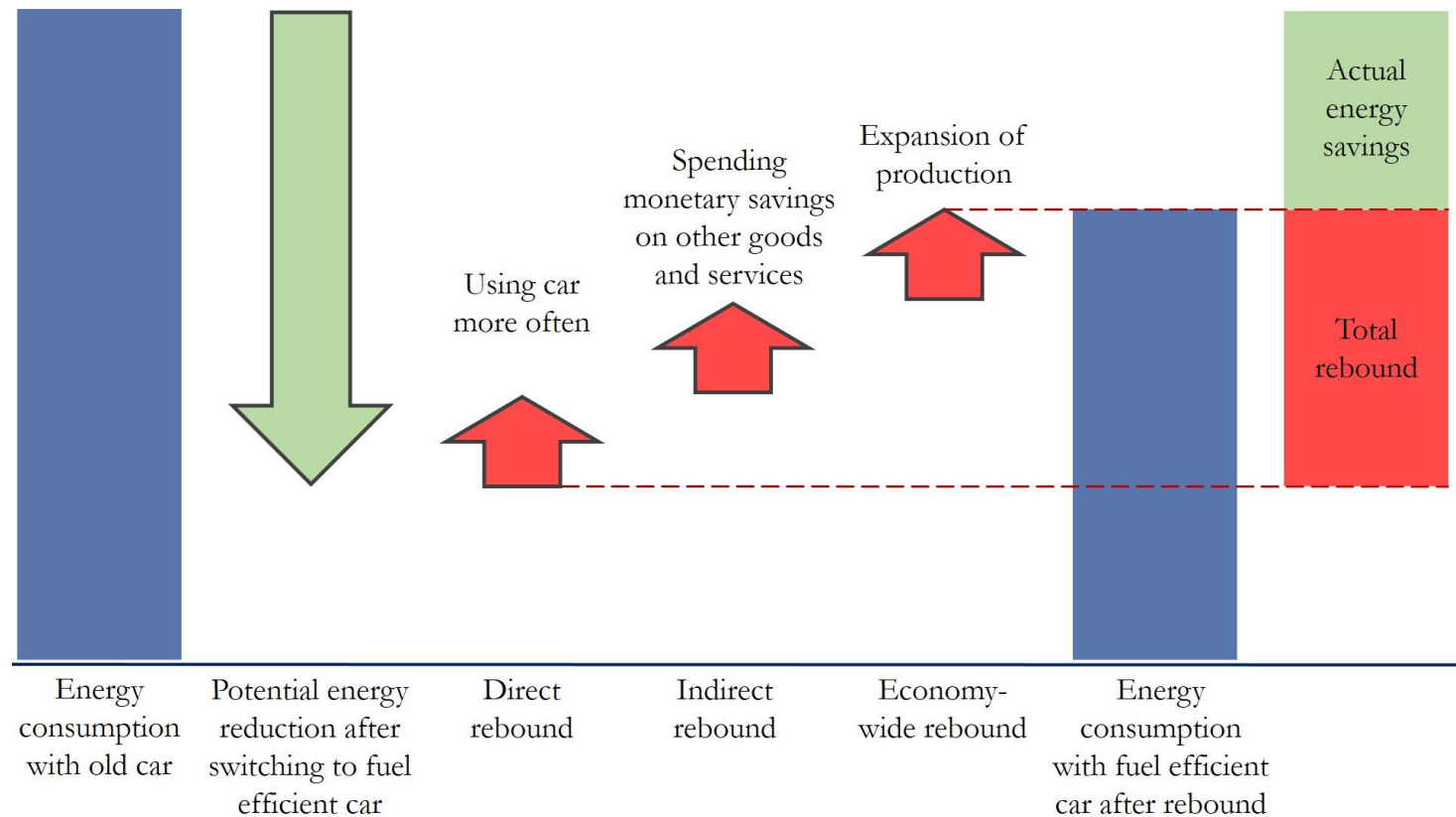


Evidence for modern economy

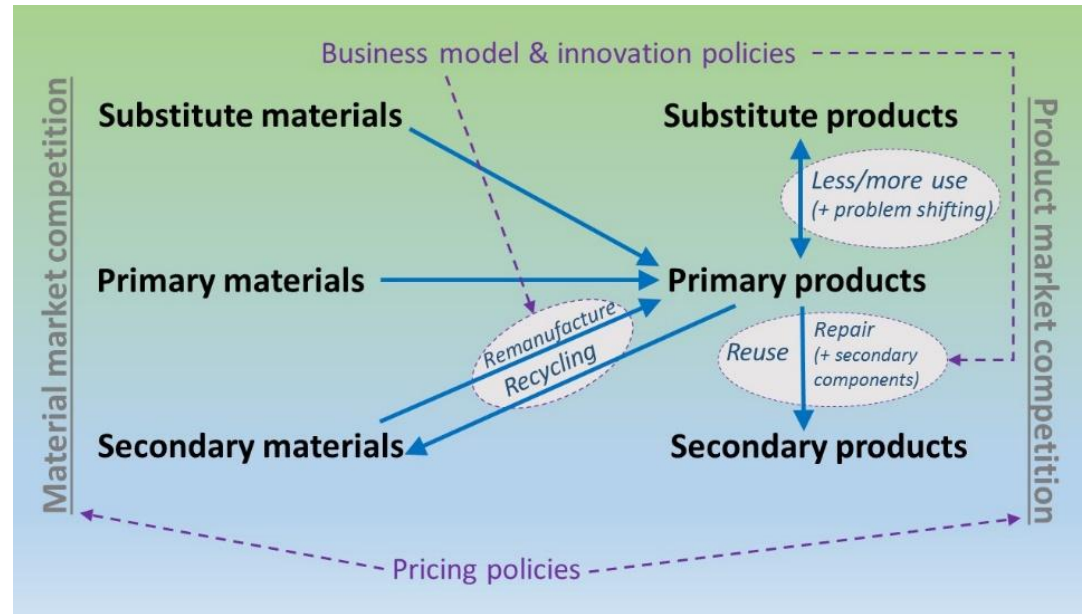
- **Solar PV, wind turbines, & hybrid vehicles** add complexity + diversity to the economy. *Variety in each w/o incentive to select env. best option*
- **Carbon capture and batteries** are add-on technologies (like end-of-pipe abatement): make existing technologies & their production system more complex => *reduce overall productivity*
- New technologies have **long and complex innovation histories** and production systems with failures & waste of energy/materials
- Much **public R&D** (universities/institutes) on env./climate issues
- Considerable **communication** about environmental problems/solutions: public & social media, publishers, air travel (UN-COP meetings)- **and we are not solving much yet!**
- **Complex of resource-intensive activities w/o definite solution so far**

Energy/carbon rebound

Potential CO₂-emission reduction of adopting an energy-efficient *technology or practice* is offset by subsequent *behavioral & systemic* responses that increase energy use



“Circular economy” may increase complexity



- ➔ Future recycling & reuse will create new loops that make production systems more complex
- ➔ Material-to-energy shifting: e.g., melting plastics or glass, collection/transport, reusing old products that are energy-intensive in use phase
- ➔ Material rebound
 - regulations prohibiting shops to provide plastic bags to customers may give rise to more plastic packaging of the products themselves, such as vegetables

Mega-projects add complexity



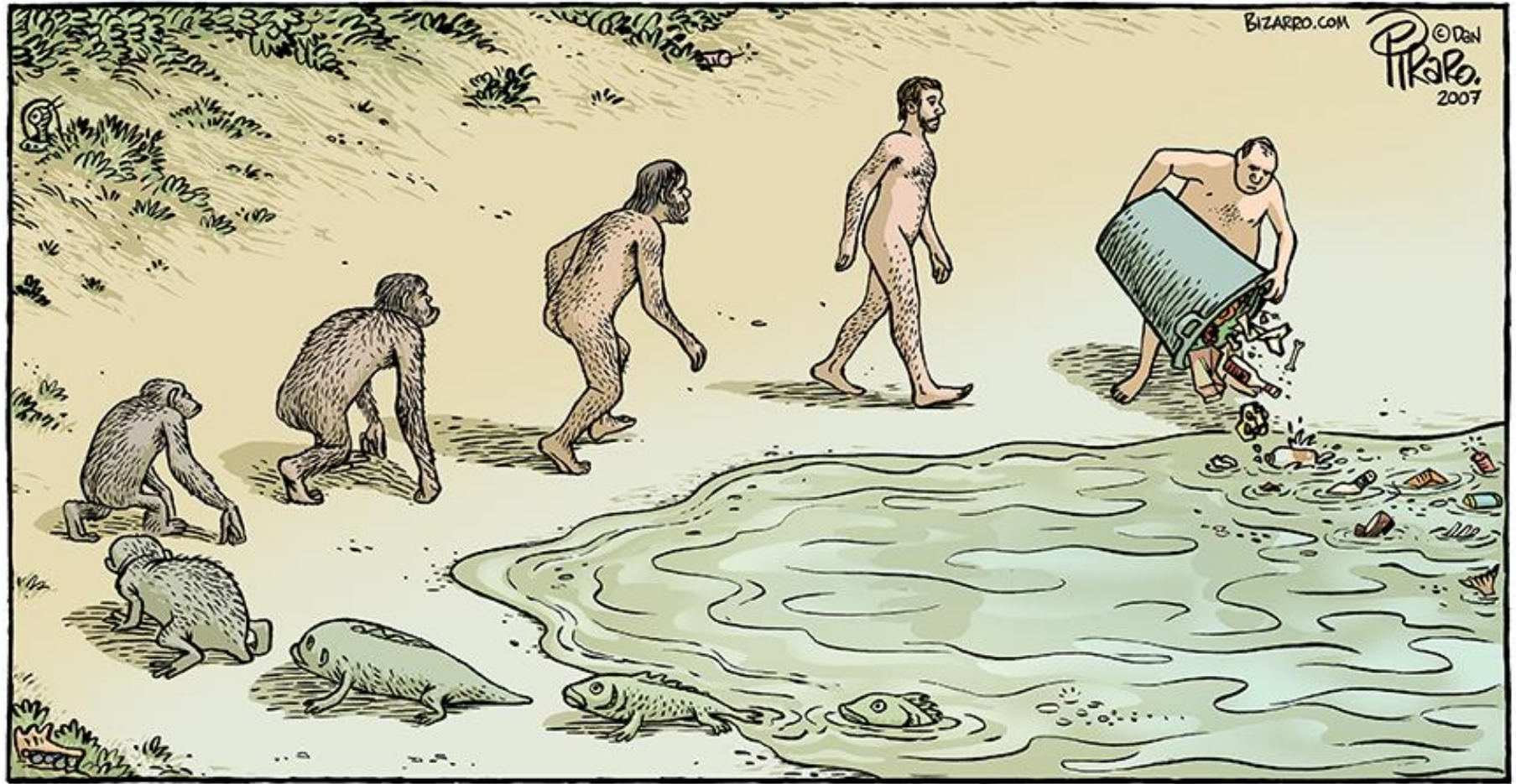
- Tend to have long innovation path & complex production system. Hence, negative impacts during long time before (uncertain) payoffs.
- Nuclear fission project ITER in Cadarache (France) is a good example. Possibly the most complex technology on the planet.
- Experimentation and learning to manage uncertainties, technical setbacks & cost escalation => inevitable waste of resources
- What implication for sustainability: *discourage mega-projects?*

Policy implications: “decomplexify”?

- **Tainter:** (1) voluntarily reduce consumption, (2) use price mechanism to control consumption, (3) ration resources, (4) reduce population.
 - Note that 2 and 3 result in a cap-and-trade system. 1 & 4 seem unrealistic.

- **Discourage increase in complexity**
 - *Planning economic complexity* probably a bad idea – nobody oversees it, bad experiences (e.g., communism)
 - *Small is beautiful, local communities and degrowth* (Tainter’s suggestion 1). Several doubts: political resistance, negative systemic effects (rebound); & lacks coordination/scale economies.
 - *Decentralized vs centralized energy solutions*: what is less complex?

Evolving complexity: *many questions, few answers*



Thank you!

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