

Entropy, Complexity and Sustainable Development and Sustainable Agriculture

L. David Roper
roperld@vt.edu

tinyurl.com/SustainDevelop

Sustainability

- Definition: Meeting the needs of present humans without compromising the ability of future generations to meet their needs.
- Not possible in an isolated system, decay will occur.
- For a sustainable Earth, energy and materials from outside the Earth have to be used.
- Getting energy from the Sun is much easier than getting materials from the moon or asteroids. That is why **solar/wind energy is necessary** to have sustainable development and sustainable agriculture!

What is Entropy?

- Entropy is a measure of the disorder that exists in a defined system. Higher entropy means higher disorder.
- The entropy of a closed system (isolated such that no matter/energy enters or leaves the system) always increases. This is the [Second Law of Thermodynamics](#).
- The entropy (disorder) of the universe (the ultimate closed system) always increases.

What is Entropy?

- The entropy of an **open system** (a system that exchanges matter/energy with its environment) can increase or decrease, but if it decreases, the entropy of its total environment must increase such that the entropy of the universe increases.
- To decrease the entropy of a system, it must be open. This is how **biological systems** decrease their entropy (increase their order); they do so by increasing the entropy of the Sun and their environment. They are open to "external" systems.
- To keep the increase of entropy of a system on Earth to a low value, make the system as open as possible, **ultimately including the Sun.**

How Humans Increase Earth's Entropy

- Materials taken from the Earth to make inanimate items and eventually scattered all over the Earth.
- Materials taken from the Earth and used to produce energy that turns into heat.
- Converting one form of energy to another. For example converting mechanical energy of steam created by burning coal into electrical energy.

Minimize Earth Surface Entropy Increase

- Increase energy efficiency of all processes.
- Reduce consumption of earth resources.
- Reuse and recycle materials.
- Use geothermal energy increasing entropy inside instead of on the Earth's surface.
- Best of all, use solar energy instead of energy from burning fossil fuels or other organic material. Wind energy is a special case of solar energy.

Components of Solar Decreasing Entropy on Earth?

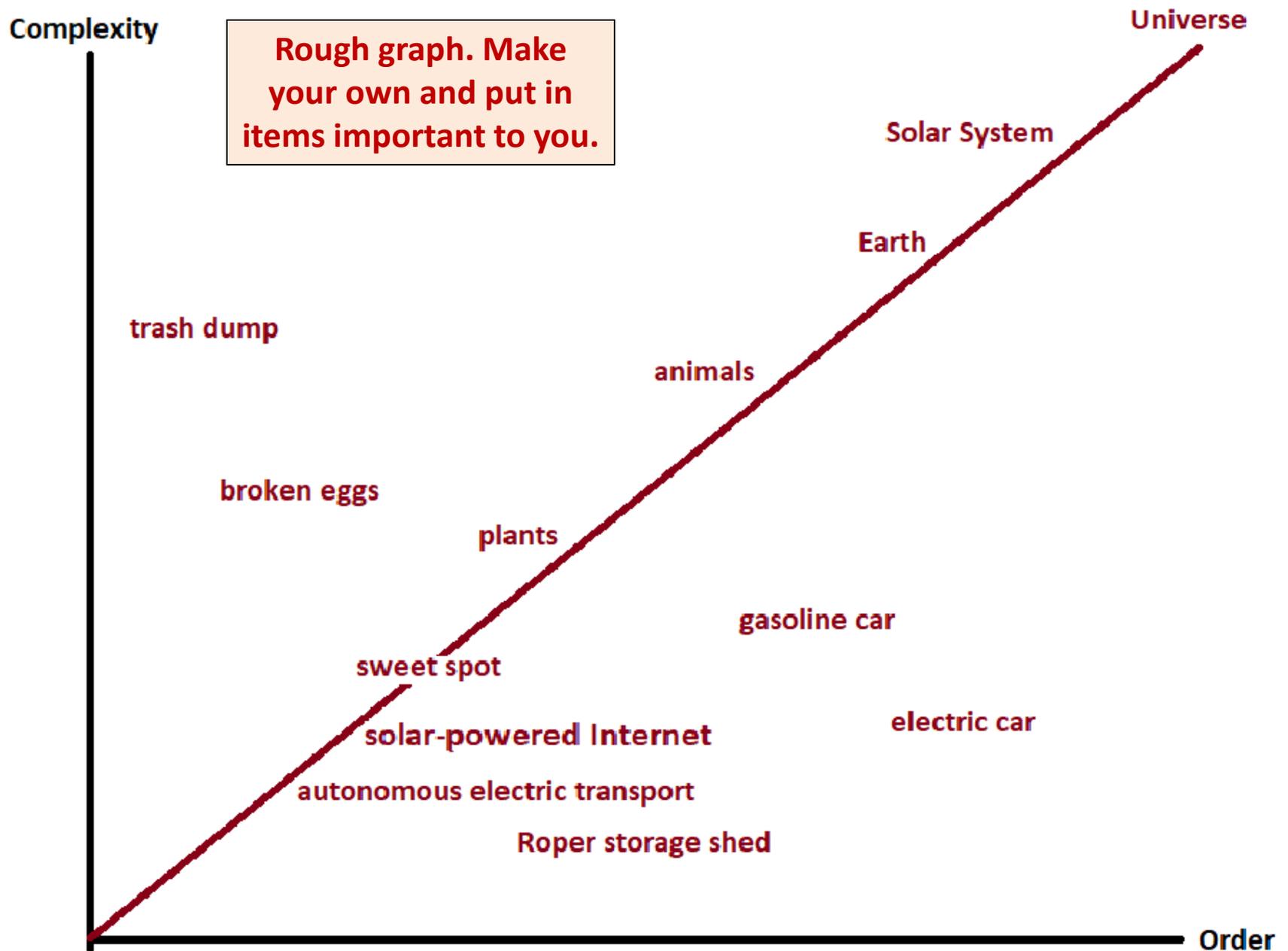
- **Electromagnetic radiation** from the Sun (optical, infrared, ultraviolet, radio, etc.)
- **Winds** due to temperature differences on the Earth caused by the Sun and to rotation of Earth.
- **Water movement** due to evaporation into the atmosphere and condensation from clouds.
- **Plants and trees** due to photosynthesis, but also increases entropy of Earth by taking nutrients from the soil and air.

Entropy and Complexity/Diversity

- For **sustainable development/agriculture** what is needed is **low entropy (high order) and high complexity**.
- Highly complex systems can partially manage themselves; when one subsystem fails, other subsystems take up the slack. For example, human body & an organized neighborhood.
- Sometimes this involves **redundant subsystems**, such as two kidneys in humans and two computers in self-driving cars.
- Sometimes there is a “**sweet point**” at which complexity/order has a “phase change” such that it has some self management (“**emergence**”) for some finite time.

Beyond Sweet Point Features

- High complexity
- High order
- Reproducing system
- Self healing
- Rationality



A 3rd dimension is Resiliency or Longevity, complicated function of complexity and order.

Order = 1/Entropy and Resiliency = 1/Fragility.

What is Sustainable Development?

- A system involving humans is never closed. It is always connected to the environment.
- If a human-created subsystem has decreasing entropy (e.g., development), the environment to which it is connected will have increasing entropy.
- If humans are to reduce harm to the Earth's environment and, thus, have a resilient society, they must design their society to largely **use the entropy increase of the Sun**, and minimize the entropy increase of the local and Earth environments.

What is Sustainable Development and Sustainable Agriculture?

- Must have a high degree of **complexity designed using rational principles**.
- Requires much research and design effort and, initially, more administration.
- **Design with sufficient complexity/diversity** to move toward a “sweet point” for some self management that automatically adjusts to a changing environment.
- **Design for long-range local and Earth environments benefit**, not just current human benefit.

Legacy Development

- Legacy development uses low-entropy/high-complexity Earth minerals to produce low-entropy/high-complexity products, with total local and Earth entropy and complexity increasing.
- Available low-energy/high-complexity Earth minerals are **small compared to projected future needs**.
- Entropy of available Earth minerals increases with time. The “good stuff” is extracted first.
- **Eventually all minerals extracted from the Earth will be more uniformly scattered (high entropy) around the Earth.**

Reducing Wastes

- Goal: waste nothing; unachievable because of [Second Law of Thermodynamics](#).
Realistic goal: Minimize waste.
- Establish **cluster industries**, where some of the waste from an industry is used as input in another local industry. Minimizes transportation entropy increase and waste disposal.
- Require **reuse of hardy products**, such as bottles, lumber and bricks.
- **Quit manufacturing single-use items**, such as plastic bags and non-recyclable products.
- Institute **local or curbside composting of food and yard wastes**.

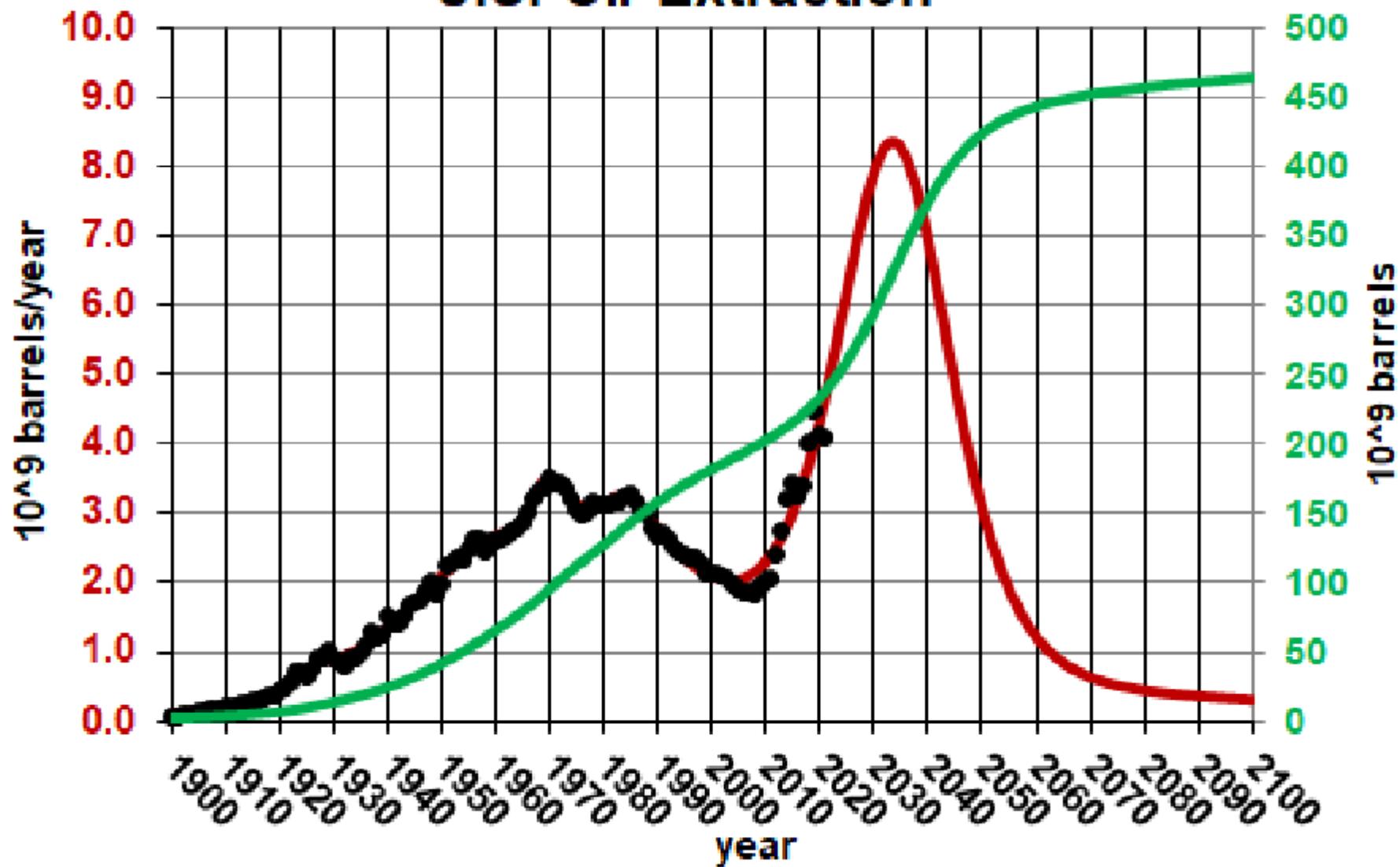
Neighbor-Sharing Composting



Two barrels are composting while one barrel is being fed material to compost.

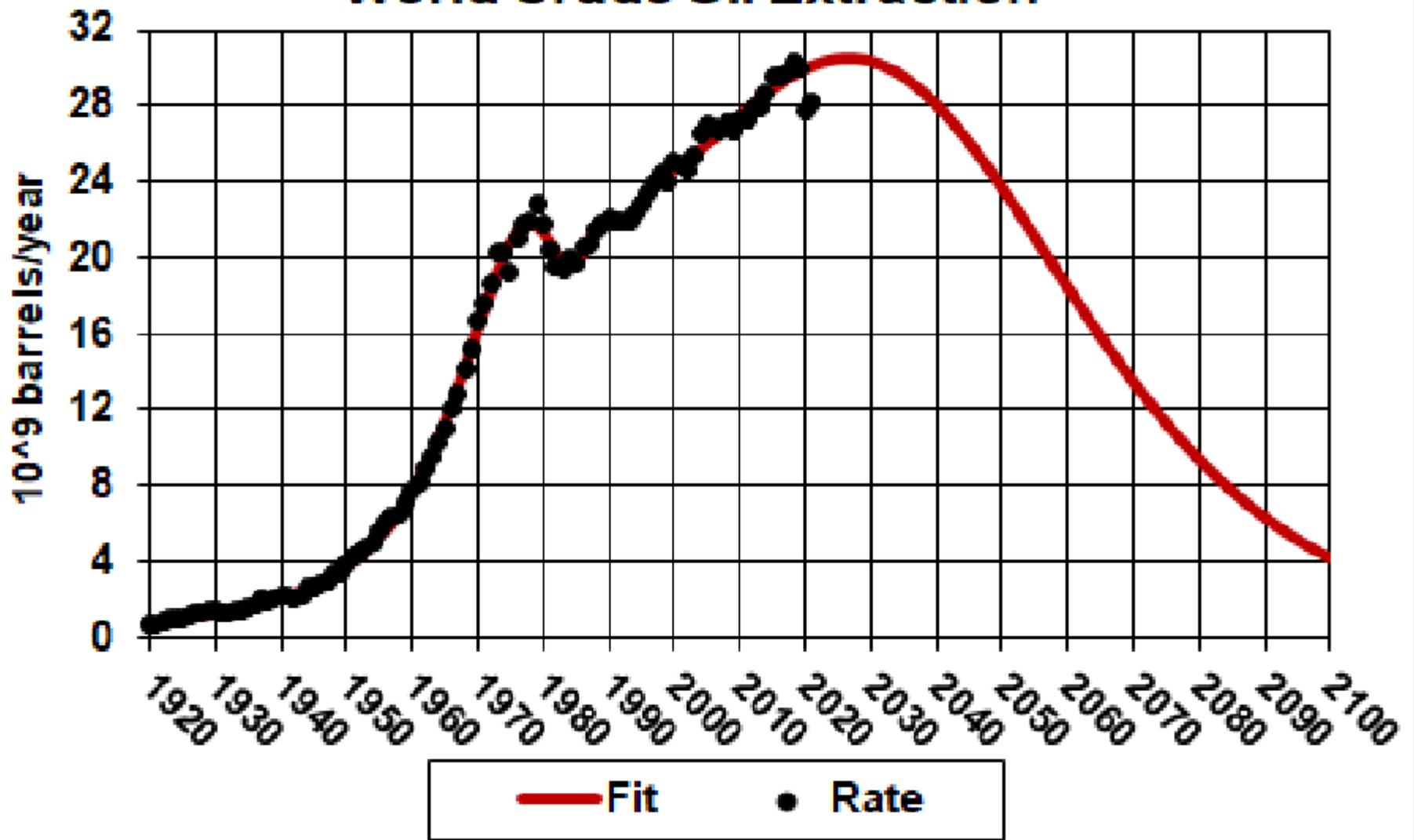
- 3 composting barrels.
- 1 **green** food digester pit for extremely cold weather.
- Small covered ground pit for drying out compost.
- Dry compost from pit is put on ground for garden use.

U.S. Oil Extraction

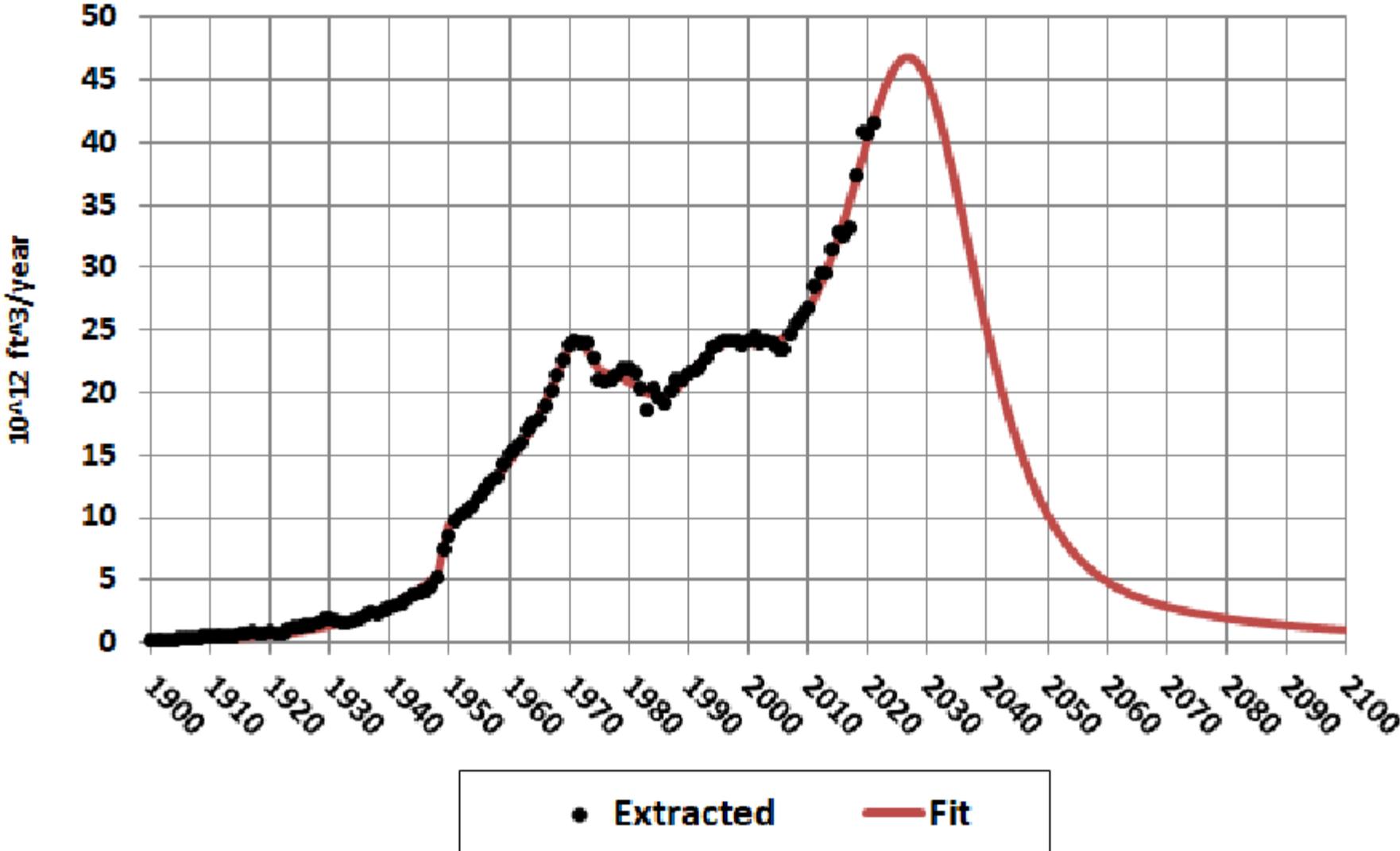


— Fit • Rate — Extracted

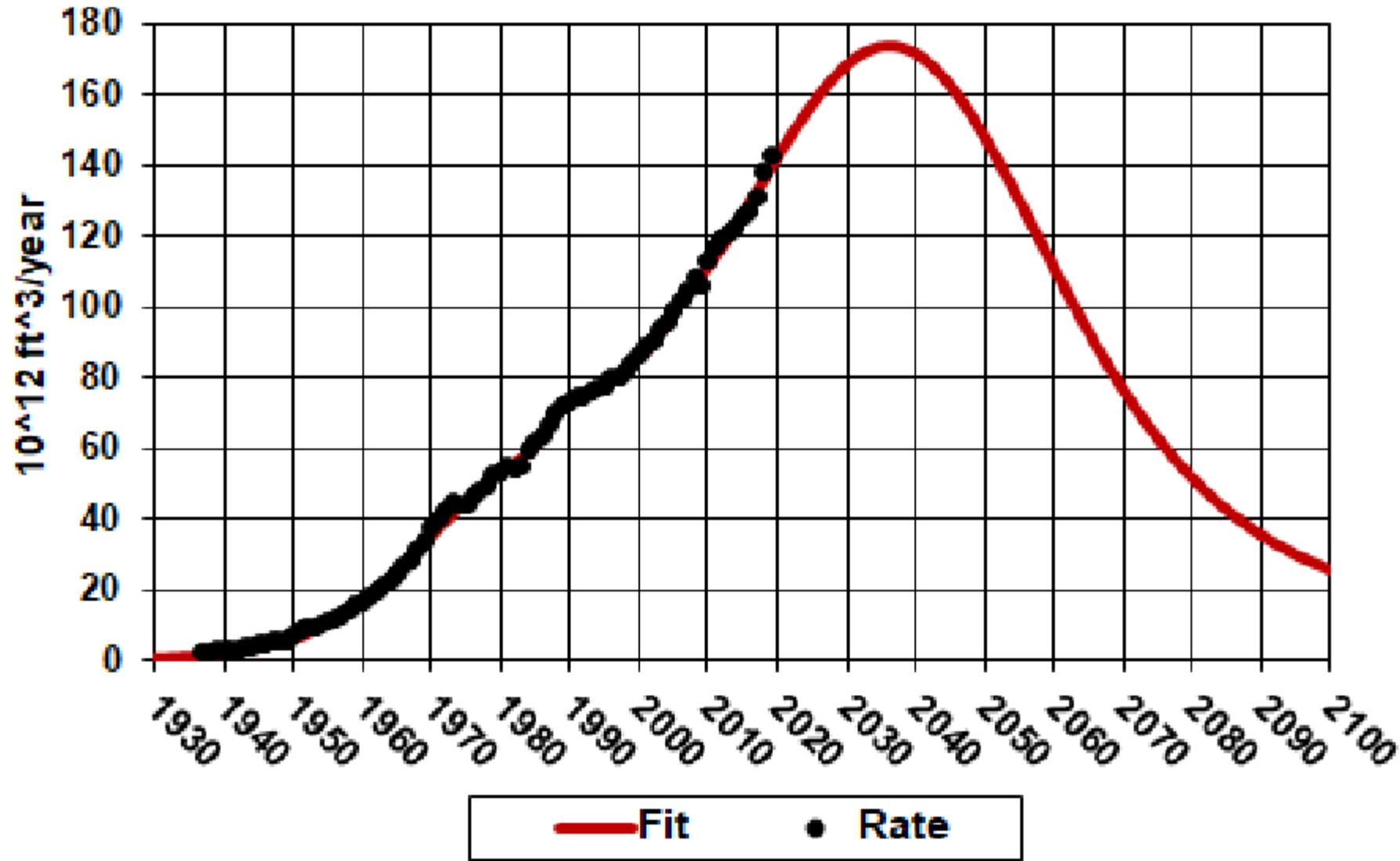
World Crude Oil Extraction



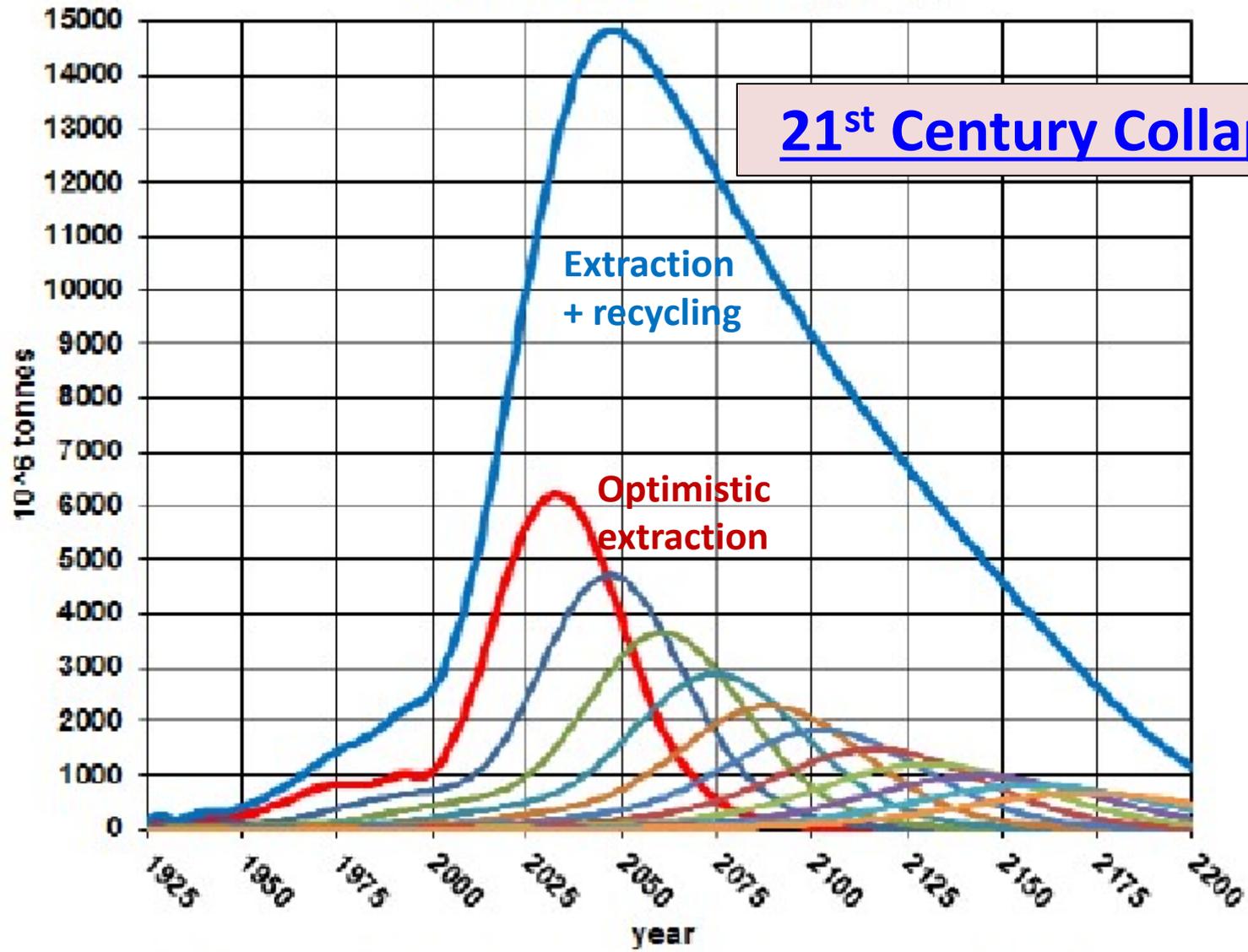
United States Natural-Gas Extraction



World Natural-Gas Extraction



World Iron-Ore Recycling



21st Century Collapse

- Average Fit
- Total with Recycling
- 1st Recycle
- 2nd Recycle
- 3rd Recycle
- 4th Recycle
- 5th Recycle
- 6th Recycle
- 7th Recycle
- 8th Recycle
- 9th Recycle
- 10th Recycle

How to Prevent Civilization Collapse

- **Quit burning fossil fuels** to keep global warming under control. Replace with **solar/wind energy and energy storage**.
- Use most of the remaining crude oil and natural gas to create the infrastructure for **distributed renewable energy and energy storage** to replace fossil fuels for energy.
- Create **community electrical microgrids** that can be made independent of national grids, when necessary for **resiliency**.
- Greatly increase **product reuse and recycling**.
- Reduce population growth by a **huge world-wide birth-control program**.

Lifespans

- Average mammal species: about 1-million years.
- Homo sapiens evolved from earlier species 300,000 to 200,000 years ago.
- Average “intelligent” civilization: ~300,000 years.
- Oldest existing nation: Greece ~5,200 years old.
- *Are Homo sapiens* evolved enough to survive weapons of mass destruction and global warming?

Optimism

- Renewable power is growing exponential around the world (70% of net additions in 2017).
- Crude-oil extraction and natural-gas extraction will peak by ~2030.
- Organic farming is growing.
- Knowledge of global warming is increasing.
- Electric cars on roads are growing exponentially and much quicker than hybrids and gasoline cars did.
- Some communities are requiring new homes to have **solar panels** on roofs and be wired for electric cars charging.
- 91% of millennials would consider purchasing an electric car.

U.S. Electricity Projection (GWhours)

