PART I: OUR CONVERGING CRISES

Energy

We're starting this series with the subject of energy, and for a good reason. Energy is key to everything—it's an essential driver of the natural world and of the human world, and it will also be pivotal to the societal transformations we'll be experiencing in the 21st century and beyond. Energy is what enables us to live, and to build civilizations and thriving economies. But it's even more fundamental than that. Without energy, literally nothing can happen.

Physicists define energy as "the ability to do work." Energy exists in several forms—including thermal, radioactive decay, kinetic, mechanical, and electrical—and its form can change. The energy in sunlight is captured by green plants in photosynthesis and converted to energy that's chemically stored in the form of carbohydrates. Animals eat those plants, and some other animals eat those animals. In this way, sunlight energy gets distributed throughout the living world.

We humans get our biological energy from plant and animal foods, but we also derive energy in other ways. For example, the sunlight energy chemically stored in coal millions of years ago can be released as heat through combustion. That heat can be used to boil water, creating steam at high pressure, which can flow through turbines that spin magnets to produce an electric current. The electric current is then passed through transformers and wires into our homes, offices, and factories, where it is available to power computers, lights, and appliances.

Energy cannot be created or destroyed, and it tends to move from areas of high concentration to low concentration. Just observe what happens to the heat energy in a cup of coffee that sits for half an hour; it dissipates through the air and the table on which it's sitting.

When we drill an oil well or put up a solar panel, we're not actually creating energy. What we're really doing is getting energy that already existed as a static stock--say, in an oil deposit--or an ongoing flow--such as sunlight--to do some work for us as it's in the process of being dispersed.

Archaeologists and historians tend to categorize periods of human history based on technological or political developments, like the Iron Age or the Han Dynasty. But the truly great transformations in human history were the result of changes in the ways we harnessed energy.

First came the use of fire, starting hundreds of thousands, maybe millions of years ago. Fire not only provided warmth but also enabled us to cook food, increasing the efficiency of our internal, metabolic energy systems.

About 10,000 years ago the Agricultural Revolution began, increasing our ability to harvest energy from the land.

Then, only about 250 years ago, our expanding use of fossil fuels ushered in the Industrial Revolution.

For over 99 percent of our history as a species, we had harvested solar energy concentrated in firewood and wild or cultivated foods, and we *exerted* energy through muscle power. But during the last couple of centuries we've found ways to use ancient sunlight stored in coal, oil, and natural gas. These fuels have given us energy that's even more highly concentrated, that's easily transported, and that's available in quantities that dwarf what we used previously.
Think of it this way. If you had to push your car thirty miles, it would take you weeks of hard work. But a single gallon of gasoline, costing just a couple of dollars, will do the same work in just a few minutes.[1] That's cheap, concentrated energy.

During the past century, per capita global energy use has increased 800 percent. And we've invented an astonishing variety of machines to take advantage of all that energy—machines to heat and cool us, to transport and feed us, to enable us to process information and communicate, to extract raw materials, and to manufacture consumer products.

Agricultural machinery has largely replaced human labor. Before fossil fuels, at least three-quarters of the population had to work at farming to provide food for everyone else. In contrast, mechanized agriculture requires about one percent of all labor in industrialized countries.[2] It has freed an enormous number of people to engage in other pursuits,

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[1] Calculation: 1 gallon of gas = 120,476 BTU = 35,308 watts (source: EIA calculator). Average adult can produce 70 watt-hours of energy. Therefore one gallon of gas = 504 hours of human labor.

[2] Source for 1850 data: http://www.nytimes.com/1988/07/20/us/farm-population-lowest-since-1850-s.html. Source for 2012 data: https://fred.stlouisfed.org/series/USAPEMANA.

including manufacturing, advertising, banking, sales, marketing. The result has been the explosive growth of the middle class.

However, energy is also central to our current global sustainability predicament, due to two problems.

One is depletion, which means that over time we're exhausting the economically useful, easy-to-get fossil fuels.

The other is pollution, one of the effects of which is climate change.

We'll talk about each of those two problems in more detail later in this video series. But what's important to understand for now is that these two inevitable consequences of burning more and more coal, oil, and natural gas make it imperative that we make a transition from fossil fuels to alternative energy sources as quickly as possible.

The fossil fuel era has been transformative, but it's destined to be brief in historic terms--maybe just 300 years in all. And its last chapters are beginning to unfold right now.

What will be the energy sources of the future? Some say nuclear power—but we've had a few decades of experience with nuclear plants and they've turned out to be expensive and risky.

Realistically, our best bets are solar and wind. But these have very different characteristics from the energy sources that modern industrial society was built around. Solar panels and wind turbines produce electricity, which is high-value energy, without having to burn fuels and create pollution. But sunlight and wind are only available ***intermittently***—the sun doesn't always shine, the wind doesn't always blow.

We will have to design new energy systems and retrofit existing ones to account for the different characteristics of renewable energy. In practice this means we need to invest in a combination of three things:

- large-scale ***energy storage*** (using large batteries, for example),
- ***capacity redundancy*** (where we build much more electricity generation capacity than we actually need most of the time), and
- ***demand management*** (using energy when it's available rather than any old time).

Currently only about 20 percent of the energy we use is in the form of electricity, so we will have to adapt transportation and a wide range of industrial processes to these new energy sources. Some of these adaptations will be easy: instead of heating most of our buildings with natural gas as we do today, we could insulate our buildings better and provide heat with electric heat pumps, a technology widely used in Japan and Europe. Other adaptations will be a challenge: the best renewable energy options for airplanes and container ships will likely be very expensive substitutes for the oil-based fuels we currently use.

The extreme high heat necessary for making cement, steel, and other industrial materials and products will also probably be expensive to produce without cheap fossil fuels.

In some ways, the challenges of the transition to renewable energy are best exemplified by the electric car. We can replace vehicles that run on internal combustion engines with ones that run on electric batteries. And those batteries can be charged with renewable wind or solar energy. But, in order for us to get to a 100 percent renewable energy economy, the lithium in those batteries, along with hundreds of other raw materials, will somehow eventually have to be extracted from the ground without enormous, diesel powered excavators and trucks. Parts now made from byproducts of fossil fuels—including tires, seats, and dashboards—will have to be manufactured from some other raw materials. And millions of miles of roads and countless parking structures currently made from concrete, asphalt, and steel will need to be made or repaired using alternative materials, or with concrete and steel somehow made using only renewable energy.

The more detailed our analysis of the car and its support infrastructure gets, the more challenges to a completely renewable automotive transport system we uncover.

Moreover, because we will be substituting out our current energy sources, rather than just adding new energy supplies to existing ones, it is very likely that we won't have as much energy available at the end of the transition as we did when we started.

That has enormous implications for economic growth and globalization—implications we'll be exploring in later videos. Our future may very well be slower-paced and more localized.

Energy is at the center of our century's predicaments, and the transition away from fossil fuels to other energy sources is probably humanity's most important project for the 21st century. But, as we are about to see, it's certainly not the only challenge we should be paying attention to.