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The carbon economy – rebuilding the building blocks of economics and science

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Over 500 astronauts have had the privilege of observing Earth from space, and some have reported what must be acknowledged as a new "worldview" of human existence in its physical environment. Fresh application of what we know in science to the overview of human activity gives revolutionary insights. The Earth's ecosystems existed before and without humans. The water cycle and carbon cycle operate naturally. White (2014) has observed that the astronauts' "Overview Effect" of the dynamic natural exchanges is humbling and mind changing. It raises the thought that it is merely the human-generated activity observed as an extra overlay which can be subjected to economic analysis.

A modern Copernican view of economics is that not man and money are the center of the world, but that the textbook macroeconomic cycle of goods and services produced and consumed is a mere cog in the global carbon cycle. Modern science can now view the planet as a materially finite complex set of ecosystems, take stock of the key elements – carbon, oxygen and hydrogen – and garner a pragmatic picture of wellbeing. Much clearer and a quite different perspective from the self-centered presumption set out in *The Wealth of Nations*.

Money is a moving measuring stick

There is a rising crescendo of disbelief among commentators from many fields on the value of National Accounts and the failures of economics to reflect or encourage what is good for wellbeing.[1] The "P" for "Production" in the GDP originally assumed that goods and services would be paid for by consumers who had done their own productive work elsewhere in the macroeconomic cycle. But now that circle has gone pear-shaped into a pyramid of debt. Stimulus favors the rich. $5 in Harlem has to go further than $5 in The Hamptons.

The concept of the flows of economic produce, measured in money (Quesnay, 1758) preceded science's discovery of atoms (Dalton, 1802), entropy (Carnot, 1824) physical work (Coriolis, 1826), and the quantification of energy (Joule, 1848). Because of the precedence of economics over science, money has become the default object of attention, with strategies of manipulating money rather than producing and consuming goods and services. Now economic decisions are made that are unhinged from the material world they are supposed to represent. Analogous to Plato's cave allegory, money is the mere (distorted and enlarged) shadow of actual reality. And as material reality depreciates, the shadows cast are being made bigger and given hyperbolic interpretations by financial gurus scanning the swirls of indicators for positive signs.

It is crucial to correcting current misunderstandings to expose the physical reality – to set it out in the open. In line with Plato's prediction, accountants will fail to recognize real

[1] http://www.thesolutionsjournal.com/node/237446.

commodities without the shadows they projected, but scientists can assess the real state of the physical economy in the context of the Earth's natural operating systems.

Carbon economy and carbon cycle

Human activity takes place in a space that is oddly shaped and seemed beyond relevance, if not comprehension to the early economists. The planet's biosphere is a volume comparable in shape to an apple skin – a layer limited to some kilometers above and below sea level – and for all practical purposes of economic analysis has no imports of goods or exports of waste. Oxygen and hydrogen are by far the main 2 elements and carbon holds to key to life and economy, trading its bonds with hydrogen for new bonds with oxygen, driving metabolism and motion and economic production.

To simulate what we know of land, sea and air, an aquarium-style prism serves well, simply acknowledging it is not to scale, and does not feature the circulation of sea and air around the globe. This is the model adopted by the UN Intergovernmental Panel on Climate Change.[2] The UNIPCC measures flows of carbon. The 2 main natural flows are the ocean-atmosphere gas exchange and the photosynthesis / respiration on land.

This natural carbon cycle is harnessed by humans to drive their circular economy of production and consumption. There is an insightful way set out by Yang and Zhang (2016), not using carbon atoms, but carbon's chemical bond exchange from hydrogen to oxygen. There is a realization that the circulatory systems of Earth can be harnessed and the human economy has been a small spinoff, with for many thousands of years up to 1750, the carbon bond trading by humans mainly only from organic carbon – carbohydrates, proteins and various forms of biomass. The industrial revolution seemed to introduce totally new technologies but the driving force of economic activity remained the carbon for oxygen trade. Adopting this perspective, the global carbon cycle and the circular flow of what economists think of as production and consumption can be fitted on the same page with the same units. The global economy exchanges carbon for oxygen and can be accounted on a yearly basis. A summary, lumping land and ocean transactions together, is presented in Figure 1.

Although IPCC researchers are on the right track counting carbon atoms, it is more useful to identify carbon atoms' in chemical bonds. Different fuels and different technologies use carbon atoms differently, and a more accurate picture is given by considering carbon as a catalyst and accounting for the number of bonds broken in oxygen molecules.

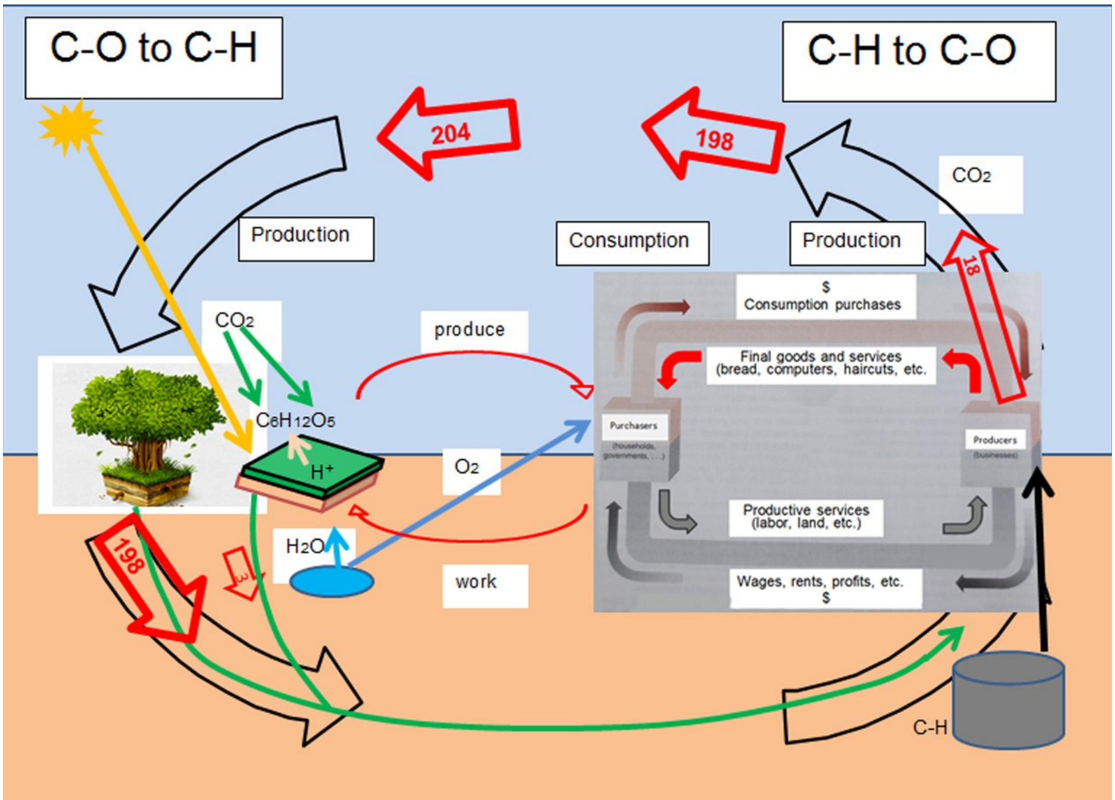
"Work" in physics and economics

It is a useful, pertinent question to inquire, what do people on Earth do? The objective, scientific answer is that they "do work". "Work" was defined in physics in 1826 by Coriolis as the force expended (by a person, animal or machine) to lift a heavy bucket up a mine shaft against the force of gravity. Work is force times distance, W=Fd. To examine the economists "circular flow of the macroeconomy" in a clear objective way, all the goods and services said to be "produced" are simply the embodiment of the work done in converting C-H bonds in foods and fossil fuels to C-O bonds. There is no other cost – not wind, hydro, solar,

[2] http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter06_FINAL.pdf.

geothermal, tidal energy are all free. The exception is nuclear energy which is excluded here for simplicity.

Figure 1 The "circular flow of the macroeconomy" (Samuelson's canonical textbook 2009) fitted into the global carbon cycle. The numbers refer to estimate for 2014 of oxygen-oxygen bonds broken to form carbon-oxygen bonds, times 10^{38}.



It is a reflection of 18th century perspectives that wind, hydro- and solar power are classed as "energy" inputs to economic processes. It is solely the man-made material and man-derived abstract technology that is the cost of harnessing the forces of natural ecosystems. Even hydrocarbons and carbohydrates have an *in situ* status in a reference system where they can be regarded as free. It is the work done in transforming them to fuel and food that can be regarded as costs.

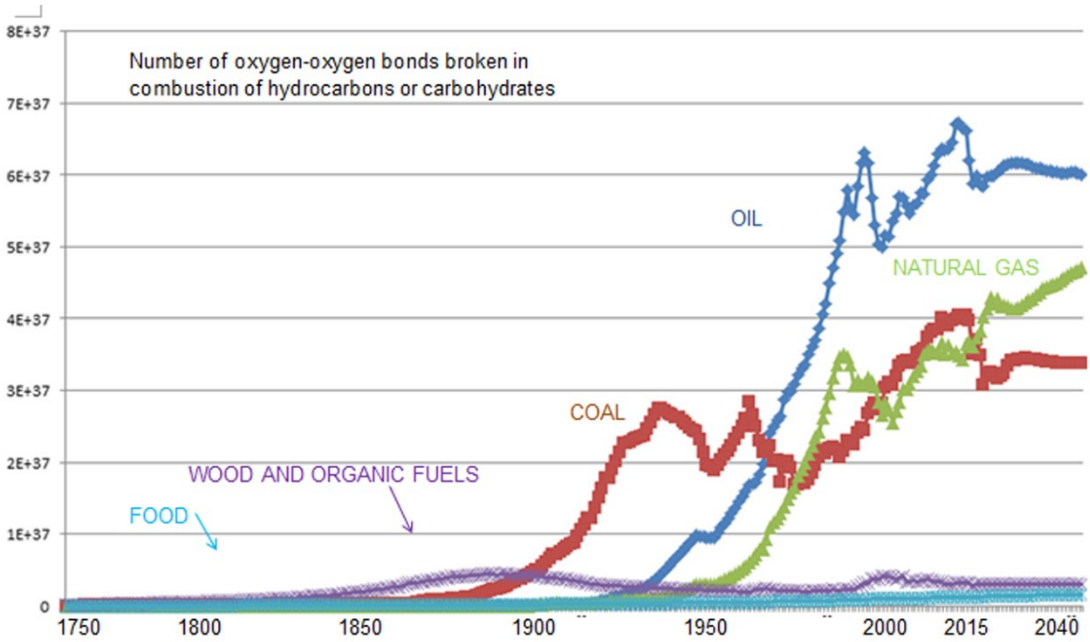
Viewed historically the aggregation of forces at work is the only input to an economic process. Building on the original classic example of the relative cost of hunting a deer or beaver, the cost of the hunting tool is also in work done making it. What economists consider to be capital equipment Costanza (1980) showed can also be recognized as accumulated embodied work done – work done not only by human labor but also done by chemical reactions. From the cost of producing individual materials (Cole and Kernan, 1996) to global production (Gutowski et al., 2013) whole cities and national economies have risen up out of raw materials by work done on them. In 1843 Joule introduced the "mechanical equivalent of heat" but in modern science "heat" is a sensation and temperature measures the work done on molecules (of mercury or some standard substance) set between benchmarks chosen by humans. When we cook with gas, or refine iron ore in blast furnaces, at the scale of molecules, work is being done.

A study of the US economy serves as a useful example. Taking 1750 as a starting point, there was no national economy – merely economic activity of villages and small regions of minimal impact. The two drivers of economic activity were food for human work and firewood for boilers in primitive industry. With the advent of the steam engine it took another 110 years before coal overtook firewood as the fuel for steam engines. Another 90 years, petroleum surpassed coal as the largest component of the American economy's appetite. Ten years later natural gas also overtook coal and even as the economy burgeoned, natural gas stayed more important than coal.

A work theory of costs

There is an amazing truth that economists were too blind to see in America's development. In the Old World, economists began in the eighteenth century with an assumption that the factors of production were land and labor. The "Labor Theory of Value" was popular. With our knowledge of science now it would have better mileage as the Work Theory of Costs. Then as mechanization was introduced, the factors were called land, labor and capital, and large machines supplanted labor's value. But with the fresh start in the New World, an original thinking observer could note that the "land" had been there for millennia, and the changes could be monitored simply by tracking the carbon processes – first in farm production and consumption, and the combustion of firewood, then with the fossil fuels. At the level of atoms, carbon-hydrogen bond attractive force being broken and releasing part of that force as oxygen bonded with carbon is a common denominator – a universal base currency. This is graphed from 1750 to 2015, with the Y axis units denoting 10^{37} carbon bond exchanges (also counted as oxygen molecules broken).

Figure 2. The US economy 1750 to 2014 and projected to 2040, driven by carbohydrates and hydrocarbons. Y axis is number of O_2 molecule bonds broken in the forming of C-H bonds



In Old World economics, fuels are a “consumable” added to the fixed cost of capital equipment. But derived from the Overview Effect experienced by astronauts observing the Earth objectively, all activity is directly or indirectly traced to the forces at work, farming, mining and building cities and infrastructure. For the short history of American development, today’s capital equipment was built from yesterday’s activities. What is there now is the result of 265 years of activity. Prigogine used the analogy of the industriousness of ants. An above-ground ant’s nest is a manifestation of the work done by the “ant economy”. In one study a population of 8 million ants built an infrastructure of their “economy” doing the “work” of lifting 40 tons of soil an average elevation of 4 meters.[3] Similarly, astronauts flying over continental USA easily appreciate the urban build-up on the east coast, the carefully tended farmlands of the midwest, and the vacant deserts beyond that.

Figure 3 A termite “economy” where the gross “product” (work done) can be estimated as the mass of soil x elevation of center of gravity.

Planning future “work”

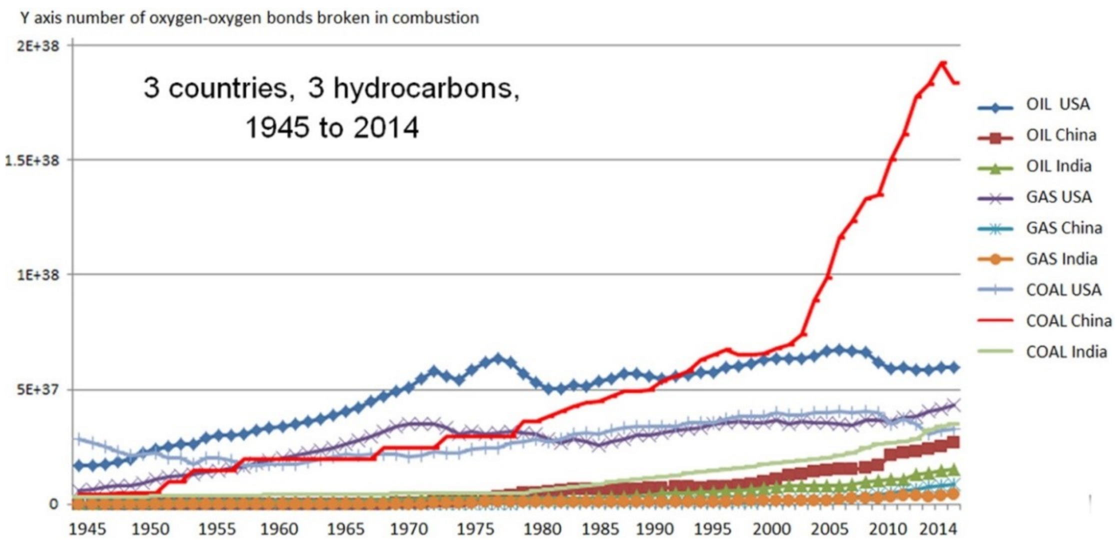
This perspective is important, not because it records history, but because it focusses sharply on questions of what is planned for the future. Using the fuels we have, what work will we do? How can we convert that to capital equipment? We can build on what we have but we cannot change the past. In fact we look at an ants nest and admire the industry that must have been employed but we also do not know if it was knocked down when half built and then rebuilt to its current size. Looking at modern America as a whole from space, we cannot know of the wasted activity of the Civil War of the eighteen sixties or the environmental damage done in the Dust Bowl of the nineteen thirties. But where America is now in development, and where it is headed is written in current and forecast fuel plans.

[3] http://www.swarm-intelligence.it/wordpress/giant-ant/.

The US government projects how much fuel it will need ahead from historical fact in 2015 through to the future in 2040.[4] This can be readily adjusted to also include carbohydrate foods. The reality is that in 2015 coal and gas both constituted 25% of all the carbon-hydrogen combusted. The main fuel was oil, 37%, leaving 13% for non-fossil fuel in the form of organic matter for machinery and carbohydrate foods for humans (including that indirect food for animals then directly transformed into complex C-H bonds in protein). The question then arises bluntly for policy makers, what changes can be made to optimize the mix in coming years. It transpires that despite boasting low carbon economy policies, there in the spreadsheets of the government agencies, coal in the United States will still be a major component driving the economy in 2040. Converting the official data published in BTU (British Thermal Units) coal carbon-hydrogen bonds will rise slightly in 2040. It is projected that natural gas will increase 16% in that period.

When analysis of the carbon bond exchanges is applied to other economies, immediate concerns appear that may not show up in orchestrated financial projections. India is unapologetic on its plans to boost coal fired power stations because the need for electricity has priority over pollution. Projections on China vary widely but the plans now being implemented for more coal fire power point to large increases. Officialdom hides behind the positive news that emissions per unit of GDP will decrease without laying on the same page their plans for GDP growth. The faction of economists bent on increasing consumption (of final consumer goods) will escalate coal consumption. If we just take the 3 hydrocarbons, oil, gas and coal, for 3 economies, USA, China and India, and look at the recent past, 1945 to 2014, using the unified, object currency of carbon bond exchanges with oxygen, Figure 4 shows the factual picture:

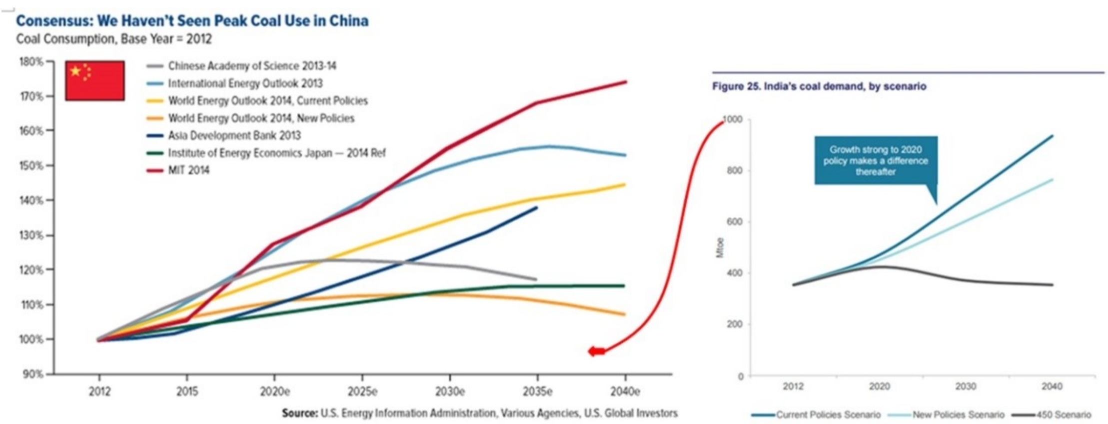
Figure 4. The US oil, gas and coal combusted, copied from Figure 2 for the period 1945 to 2014 with the addition of those 3 hydrocarbons for China and India. Starting 1950 after the establishment of PRC, Chinese coal climbs to overtake US and from 2002 increases dramatically to 2013 where 3.6 billion tons of coal released 8 billion tons of carbon atoms from their C-H bonds to break 1.8×10^{38} O-O bonds.



[4] http://www.eia.gov/forecasts/aeo/data/browser/#/?id=1-AEO2015&cases=ref2015&sourcekey=0.

Where will China go with coal in the next 25 years? What about India? On the one hand governments want to present a responsible picture that does not threaten global environmental health. But in a different arena enterprises are boasting plans and contracts for new power stations, with output stated in gigawatts and rarely likely demand for coal. Thus there is a wide range of projections and the units of measurement vary, making comparisons of estimates confusing, and losing the concepts of scale because each report seems "important". Figure 5 reproduces 2 graphs: a publication of China coal forecasts to 2040 measured in percentage increase, and a graph from a report showing 3 scenarios for India coal for the same period, measure in tons. In fact the whole of the Indian graph would easily fit under the lines on the China graph, because India's high scenario reaches 1 billion tons in 2040, a quarter of China's 2012 consumption.

Figure 5. 2 graphs from different reports on the scenarios for coal consumption in China and India. The two graphs are not to scale and the comparison must be made in the historically factual tonnage of 2012, China 3700 million, India 650 million. In fact India's highest estimate in 2040 is "only 1000 million, way under the data in the China graph.



The use of units taken from chemistry has the advantage of unifying comparisons, and also makes the discussion "clinically clean". Dollar values are notoriously fudgable. And the physical units for fuels in mass and volume are also messy to compare. The exact characteristics of "oil" and its byproducts, and the range of energy densities in different types of coal can be used to the advantage of experienced presenters to show the scenario advantageous to themselves. The unit of accounts should not be just carbon atoms, as set out by the IPCC. For policy makers and general public, a universal, scientific, objective currency unit of carbon bonds with hydrogen broken and then joined to oxygen is a concept that needs to be accepted. It is the bond swap carbon does, oxygen for hydrogen that releases a real "stimulus package" of electromagnetic force able to do work. During the industrial revolution biologists, with Pasteur as champion, led the general public to the realization that invisible germs were real and important in managing our daily behavior. These tiny invisible bonds between carbon-hydrogen and between oxygen-oxygen are the foundations of our life blood, and if we can grasp the concept, at the magnitude of human perceptions, kilograms and liters for individual lifestyles, and the strings of 37 digits needed to express national and global accounts, we will better understand the wealth of nations and the costs involved in maintaining and conserving wellbeing.

The diagram of the Circular Flow of Macroeconomic Activity purports to report on the physical production of bread, computers haircuts, “etc.” and then lapses into their “equivalents” in purchase prices (Samuelson, 2009). The gross activity can be counted directly in the universal currency of bond exchange, O-O to O-C. This unit is universal, scientific, objective and cannot be magically created. There are challenges in defining final and intermediate production phases and what to count when. Not a simple exercise but less daunting than the tasks of the army of public servants and private accountants in the National Accounts data supply chain. A first attempt at comparing annual dollar and chemical bond exchange accounting for the USA years 1990-2017 shows how drop off in physical activity signals the Financial Crisis that appears in GDP data a year later.[5] This approach of measuring physical activity has now been applied to the Chinese economy 1991-2018 and published in the journal of China’s Ministry of Ecology and Environment (World Environment, 2020.02). The early warning of changes in GDP serves as a useful index for policy planners.

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[5] https://www.thesolutionsjournal.com/article/reckoning-gdp-counting-chemical-bond-exchanges/.