The Urgency of Climate Change and a New Energy Economy

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Summary and Comments on *"Earth, Environment and Energy: Fossil Fuels"* by Carlo Rubbia, presented at the Santa Fe Institute Global Sustainability Summer School, 20 July 2009

Introduction:
Since the Industrial Revolution, human growth, energy consumption, CO_2 concentration, and global mean temperature have been correlated phenomenon, and all have been growing at an exponential rate. The population boom was supported by fossil fuels, accumulated over millions of years in the Earth's crust, but exploited by humans in a few centuries. As a result, the amount of anthropogenic CO_2 released into the atmosphere grew from nearly zero to over 50 Billion tons per year and the global mean temperature has risen by 0.5°(Rubbia).

The longevity of fossil fuel resources is affected both by the discovery of new, exploitable resources (including marginal wells that are profitable at a certain price per barrel) and the current growth rate of both population and standard of living. There has been much speculation about peak oil and the future time horizon for an "end to oil" (Hubbert, Deffeyes). In fact, according to Rubbia, at present levels of consumption and known reserves, we have 45 years of oil remaining. There is a similar time horizon for natural gas (63 years) and nuclear material (54 years). Coal, which produces the most CO_2 per ton when burned (3.5 ton CO_2), also has the longest supply (230 years at present consumption levels). But the exploitation of these limited fossil fuels may be greatly shortened by the threat and effects of global warming. Which begs the question, what will be our primary energy source in the future?

Population explosion, the demographic transition, and a rise in energy consumption:
This population explosion is a huge factor in conditioning the future of man. Human population is growing at such a staggering rate that it is impossible to comprehend without a few statistical examples. Currently, every second, 21 people are born and18 die. We thus have a net gain of 3 people every second! This means that there will be 10,000 more people by the time you are done reading this summary, that every day the population increases by 220,000 people, and that nearly 90 million each year. If the total number of individuals to have ever lived is estimated at between 70 and 150 billion, as many as 6 to 10 % of all human beings who have populated the earth are alive today. This can be interpreted as the most extraordinary process affecting the evolution of the Earth and its species. It is important to note that within the 4300 million year old lifetime of our solar system, "homo sapiens" have only been around for less than one million years.

Such an expanding population demands more and more food and energy, requires a greater consumption of mineral resources and exerts increasing pressure on the environment. If these needs are met, there is a progressive reduction of the death rate followed by a rapid decrease in growth and a stabilization of population growth, as is seen in most OECD countries. This process is currently happening on a global scale and is accompanied by a general increase in economic growth and urbanization. Rubbia argues that the transition to a stable population in our modern, interconnected world will end within the 21st century.

Even as population has exploded (and the amount of energy use has increased as a result) the increases in standards of living means that each individual is using more and more energy. In the beginning of the 19^{th} century, the average power use per person was about 1kilowatt hour, about 10 times an individual's human power. Since 1850, energy usage has grown twice as fast as population, such that during the last 79 years, global population grew by 3.42 times but energy production increased by 11.7 times. By 2000, mankind consumed 14.5 terawatts per year, a pro capita amount equal to 2.3 tons of coal per person, or the amount of energy required to launch each human being into space (Rubbia).

In fact, there appears to be a huge correlation between energy usage and poverty. There are currently, 1.6 billion people (one quarter of the world's population) without electricity and 2.4 billion rely on traditional biomass as their principal energy source. Of the global population, about one half live in poverty and at least one fifth are severely under nourished. The rest live in comparative comfort and health, and Rubbia argues that the technologically advanced countries have the responsibility of helping the most needy countries.

The Long Range Consequences of Growing CO2 Emissions:

With the massive increases in energy consumption (and the current extreme rates of growth), the level of CO_2 emissions has risen dramatically. But where is this CO_2 going? Prior to anthropogenic changes, the Earth maintained a natural carbon cycle, which balanced sinks and sources of CO_2. The atmosphere contains about 750 giga-tons of CO_2 (Gt). Vegetation and soils hold about 1580 Gt, and through primary production and natural land-use changes, exchange CO_2 with the atmosphere at an essentially equal rate. The Ocean and its systems (surface water, deep ocean, sediments, marine biota, and dissolved organic carbon) hold about 6,000 Gt and also cycle CO_2 through the atmosphere at an essential balanced rate. Fossil fuels, which are normally buried sinks of CO_2, are estimated to contain 5000 Gt. We have disrupted the natural balanced carbon cycle by burning these fuels, contributing more than 30 Gt in just the past 40 years.

Given the immense increase of CO_2 emissions, (20 billion tons per year) we must understand how long it will stay in the atmosphere, behaving as a greenhouse gas and contributing to climate change. After 1,000 years 17-33% of the fossil, or human caused, CO_2 will remain, after 10,000 years 10–15% remains, and after 100,000 years, 7% remains. This means that the mean lifetime of fossil CO_2 is about 30–35 thousand years, akin to the lifetime of plutonium. This long life allows CO_2 to play a part in the life cycles of major ice sheets, ocean methane clathrate deposits, and future glacial/interglacial periods. Even if we were to stop emitting CO_2 today, several millennia from now CO_2 concentrations would remain high enough to influence climate. Unfortunately, the time-lines that we use to discuss climate change solutions often is not beyond 300 years, unlike today's public perception of nuclear energy which is aware of the long-term waste issues. Our ignorance of the long tail of CO_2, has contributed to the fact that we are essentially changing the planet forever, even though our species has been around a relatively short period of time (D. Meadows). Ultimately, Rubbia postulates, most of the CO_2 excess will have to be carbonized in the deep oceans, although this could have negative consequences, such as ocean acidification, nutrient depletion, marine organism death, and decreasing solubility as the ocean warms (J. Russell). Climate change is already having a dramatic affect on our planet. For example, the Upsala Glacier in Patagonia, visible in 1928 as a sheet of ice, is today a large lake.

Even as renewable and non-carbon technology is introduced, the immense amount of cheap coal readily available means that there will be the tendency to burn it for a long time. Moreover, certain processes can turn coal and oil shale into liquid fuels. For example, during WWII, Germany made massive amounts of gasoline from coal to replace the wartime shortage of petroleum. It is essential, Rubbia argues, that everyone in the world must stop burning coal if we are to have any hope of curbing our emissions. Unfortunately, some of the world's biggest economies rely on coal; it provides almost 50% of USA's and Germany's electric power, 70% of India's and 80% of China's. It is also a livelihood for billions of people, and can be seen as a secure, domestic energy source. The trade-off is that it produces twice the CO_2 emissions as natural gas.
Instead, he proposes, we need new energy sources and technologies to preserve the future of mankind.

Geo-engineering: reconciling fossils and climate

Given the enormous problems we face, many have proposed large scale, earth-wide solutions to climate change. For example, some proposed projects include emitting aerosols into the stratosphere, placing giant reflectors in orbit, ozone preservation with chemicals, cloud seeding, iron fertilization of sea, growing trees on a large scale, genetically modified crops, greening the deserts with vegetation, pumping liquid CO_2 into rocks or the deep seas. Many of these ideas are unrealistic at the first sight, for instance the proposal for huge reflectors in space, and there are many unknown consequences of tampering with Earth systems at this scale. At any rate, they point to the extreme difficulty in facing the consequences of climate change, and Rubbia believes we should foster serious debate on other, innovative ideas on the planetary scale. We are all connected, and as such we need to have crazy, large, unthinkable ideas.

One idea has been the proposal of clean coal sequestration (CSS). In this process, CO_2 is injected into the earth or at the bottom of the ocean. It is a technique already used by the oil industry, but at the level of a few million tons per year. The cost is not insubstantial. Already $3.4 Billion have been spent by USA to develop this technology, and similar incentives have been given by EECC and elsewhere. The idea is far from perfect. Many sources of CO_2 are not applicable to CCS, and sequestration is does not eliminate the CO_2 forever, eventually entering the atmosphere (after 500 years, 75% still remains). Moreover, at certain concentrations, CO_2 gas is deadly (we see this naturally during some volcanic eruptions) which could create many safety concerns. The degradation processes for the sealed well and the reservoir behaviors over long timescales are very difficult to predict, and significant leaks from the pressurized CO_2 reservoir can be expected. On a small scale, CSS may be a solution, but on the orders of magnitude matching our emissions (we would need to sequester 2000 km3 of super-fluid CO_2, with each km3 equal to1.1 x 109 Tons), it may not make sense to rely on this approach.

Another possibility would be the fairly quick conversion of CO_2 into mineral carbonates. Mineral sequestration involves the reaction of CO_2 with minerals to form geologically stable carbonates, and has the potential to convert naturally occurring silicate minerals to geologically stable carbonate minerals and silica. This process emulates natural chemical transformations such as weathering of rocks to form carbonates, and there may be a way to speed it up through in situ reactions in rocks with a high concentration of Peridotite. However, this process creates 10 times the mass of the initial carbon emission, which creates a large storage problem, and the minerals used in the reaction must be initially finely crushed to a dust of micron size. The long reaction time and demanding reaction conditions contribute to process expense, and the environmental impact from mining and carbonation must be considered.

A "new hydrogen economy"?

Many people have proposed that we transition to a hydrogen economy (http://en.wikipedia.org/wiki/Hydrogen_economy#References). Hydrogen is indeed clean, giving only water and energy when produced. Governments and some major industries seem to be committed to develop the ''hydrogen economy'' (see for example the statements by President Bush's January 2003 State of the Union message and President Prodi's talks at the EEUU). However, hydrogen (H2) is not a natural energy source on Earth and it is currently generated in non-renewable ways from natural gas or coal. Steam methane reforming (SMR) is the most common and least expensive method of producing commercial hydrogen but the process emits large amounts of CO_2. This highly explosive gas is dangerous and costly to handle and requires high-pressure equipment and the use of special materials to transport. No infrastructure currently exists for it and the cost of building it will no doubt be prohibitive. Rubbia outlines an alternative production method with no CO_2 emissions; natural gas is heated enough to spontaneously split into H2 + carbon (called pyrolytic dissociation). The device to do this is a simple graphite tube dissociator heated at very high temperature. The natural gas is introduced at high temperatures and fast flow rates and a dense stream of black carbon particles emerges from the outlet end of the reactor. This carbon black is recovered and separated. Other benefits include the large amounts of fossil natural gas available at the point of production for a very low cost. Spontaneous, local conversion of natural gas into H2 and black carbon without CO_2 emissions could be easily performed at the side of natural gas production. CO_2 could be recovered and stored as black carbon or used as a chemical material, replacing some of the virgin conventional sources.

In order to solve the transport and storage problems associated with H2, Rubbia suggests a method that converts hydrogen and recovered CO_2 into organic methanol. Methanol is a bulk commercial chemical and an excellent fuel in its own right. It is liquid at room temperature and can be blended with gasoline or used in specially formatted "fuel-cells". Methanol can be converted to ethylene, a key material used to produce hydrocarbon fuels and their byproducts, thus giving us a possible alternative to replace oil. Perhaps most importantly, methanol can be used within our current fueling infrastructure to provide a feasible and safe way to store energy. In the future, Rubbia suggests hydrogen could be produced from concentrated solar power (CSP), eventually creating methanol from renewable sources.

Carbon sequestration is has become a primary focus for many governments trying to limit emissions (for example, http://www.netl.doe.gov/technologies/carbon_seq/index.html). Rubbia outlines a way to remove CO_2 from the atmosphere through air extraction. He finds it appealing because you can separate the CO_2 source from its disposal and as such the atmosphere acts as a temporary storage and transportation system. A solar chimney is large tower with a central updraft tube that generates a strong convective flow of air over a chemical sorbent that combines with CO_2. Behaving like "synthetic trees", these dedicated sinks could potentially work in combination with hydrogen production to make high efficiency, large scale, and environmentally attractive industries.

The "dream" of CO_2 as an asset not a liability:

The task of managing climate change will require big bold ideas. Many of our current solutions become impossible at scales that take into account our rapidly expanding population. Our current energy supply is dirty, unstable, and expensive. The future of oil is uncertain and we may not notice the physical "peak" until we are already rapidly dropping down the other side. Perhaps we will be seen as barbarians in the future for burning such a precious organic material. Rubbia argues that new types of energy sources and transport methods must be developed. He raises the question of how to make "pre-paid" sources of CO_2 useful to society rather than a bane. The methanol conversion may be a good transition technology because it can work with our existing infrastructure and technology paradigms, allowing faster diffusion of the technology while completely displacing our current technology (A. Hardagon; D. Paul).

Rubbia's approach is nearly completely technological. He has an upstream energy focus without looking at end of the pipe solutions and possible behavioral changes and efficiency (Lovins). Any concerns about safety, regulatory issues, unseen environmental impacts, national security issues, and overall life-cycles costs of his processes are dismissed, because he sees these as purely technological problems to be fixed and tweaked, not underlying issues with the system. His presentation also raises a number of political and ethical questions that cannot be easily solved by science. For example, where does the responsibility lie to fix the CO_2problem? Is it with the OECD countries that have stable populations and comparatively cleaner energy, or with the developing world that has not had time to fully industrialize? In addition, what is the appropriate time scale that we should consider when making decisions given the long life span of CO_2?

Given the urgency of addressing climate change, will we need innovation in both technology and policy.