A Roadmap for Meeting the Aspirations of Article 4.1, the Core of the Paris Agreement by Ted Redelmeier, founder, Carbon Neutral Commons, ted@carbonNeutralCommons.org

Alternatively: "the Optimal Mechanism for the Creation of a World Carbon-Neutral Energy Economy"

Working Hypothesis: The gasification of residual biomass can produce permanent carbon sinks

Principle: We, each human, should be responsible for cleaning up after ourselves.

Law: Every economic agent, good and service must be truly net carbon neutral.

Greatest Challenge: The ability of international institutions to provide the global governance sufficient for the provision of recalcitrant carbon, a global public good.

Introduction

The core of the Paris Agreement is to be found in Article 4.1, "… to achieve a balance between anthropogenic emissions by sources, and removals by sinks, of greenhouse gases… on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty".

The Paris Agreement is aspirational. It is a remarkable collective statement of good will, but makes little effort to describe a means by which these aspirations can be realized.

This idea is organized as follows:

1. It characterizes relevant carbon flows to make precise the concepts of emissions and sinks.
2. It states the necessary and sufficient conditions for balance between anthropogenic emissions by sources and removals by sinks of atmospheric carbon.
3. It introduces gasification, a technology that can permanently sequester carbon.
4. It develops a truly carbon neutral energy market.
5. Principle, Law, Characteristics of a truly carbon neutral energy market
6. [char as biochar] or biochar
7. It discusses equity and sustainability.
8. It discusses poverty alleviation.
9. Greatest Challenge
10. Two final thoughts

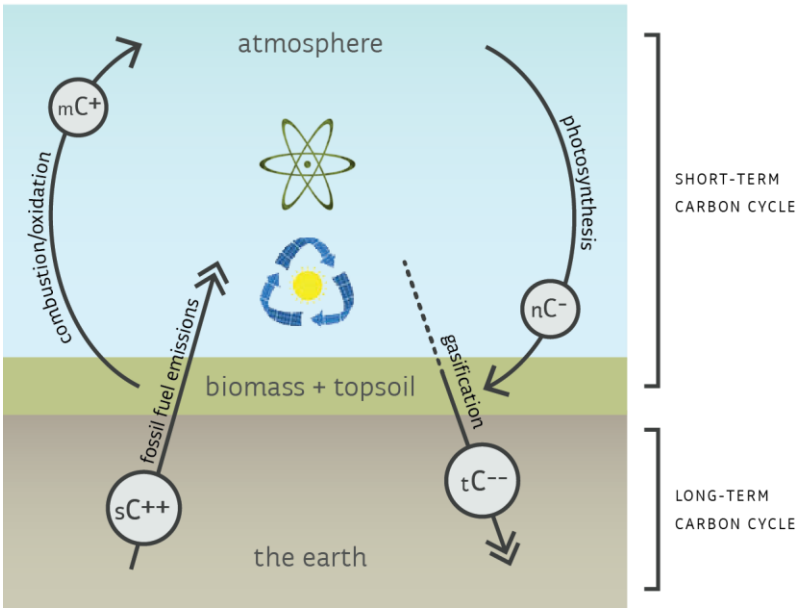
1. Photosynthesis is said to be Carbon Negative [C-] because it transfers carbon from the atmosphere to biomass. Oxidation or combustion of biomass is Carbon Positive [C+] because it transfers carbon from biomass to the atmosphere. These are both contained in the short-term carbon cycle.

   Consumption of fossil fuels is said to be Carbon Positive Positive [C++] because it transfers carbon from the long-term carbon cycle to the short-term carbon cycle, and in particular, into the atmosphere.

In the language of the Paris Agreement, the current [C+] and [C++] flows of carbon are emissions, and [C-] is a sink. Unlike the Paris Agreement, this idea differentiates between long and short-term emissions and sinks.

A long-term sink is necessary but not sufficient to achieve balance between anthropogenic emissions and sinks of carbon. This long-term sink is permanently sequestered carbon, alternatively Carbon Negative Negative [C--].

The Relevant Carbon Flows



In the above illustration m, n, s and t are the orders of magnitude of their associated carbon flow variables: m[C+], n[C-], s[C++] and t[C--].

2. The necessary and sufficient conditions for balance between anthropogenic emissions by sources and removals by sinks are that n = m + t and s = t.

3. Gasification is the heating of a feedstock in an oxygen limited environment. It is a mature technology. The output of gasification is some combination of solids, liquids and gases.

   Gasification today is large scale coal based and produces gaseous synfuels. There are economic incentives to produce these [C++] products.

   Biomass may be gasified and optimized for the production of solid char for carbon sequestration. The carbon becomes about 3/4 [C+] and 1/4 [C--], that is 4 [C-] => 3 [C+] + 1 [C--]. This expression may be interpreted as 4 units of carbon in biomass (the product of photosynthesis), when gasified, may produce 3 units of atmospheric carbon (renewable energy) and one unit of permanently sequestered carbon. There are no economic incentives to sequester carbon, no industry to develop technology to gasify biomass and sequester carbon. In the Philippines I have been involved in the development of prototype technology for this purpose.

There may be other technologies that can produce long term sequestered carbon.

4. A market for truly carbon neutral energy may be developed by first categorizing energy in accordance with three associated carbon flows.
    a. Inherently carbon neutral energy has no associated carbon flows.
    b. Energy that comes from within the short-term carbon cycle, m[C+] and n[C-], and
    c. Energy that transfers carbon between the long and short-term carbon cycles s[C++] and t[C--].

    Truly carbon neutral energy means that collectively n = m + t and s = t. Currently m > n and s >> t = 0.

    The following table contains the percentages of these categories in 2015 (International Energy Agency statistics) and those that would exist in a truly carbon neutral energy market.

Table 1 - Proportions of energy types in a carbon neutral economy

Category of Energy	*Primary Sources of Energy*	*Proportions in 2015 (IEA Key World Energy Statistics 2016)*		*Algebra percentages for sources of energy* [1]	*Proportions in a truly Carbon neutral energy economy, per section 6*	
Inherently carbon neutral	Nuclear, Hydro Electric, Wind, Solar	8.6 %	No carbon flow	(100 – 4s)%	70 – 80%	No carbo flow
Within the short-term carbon cycle	Gasification/Gasification of Biomass and municipal solid waste	10.3%	m > n	3s%	15 – 20%	n = m + t
Between the long and short-term carbon cycles	Oil, Coal, Natural Gas, Gasification of residual crop and forestry biomass and municipal solid waste	81.1%	s >> t = 0	s%	5 – 7%	s = t

5. Principle, Law, Characteristics of the truly carbon neutral energy market:

The single principle that each human needs to be responsible for cleaning up after him/her self must become the law that

Every economic agent, good and service must be truly net carbon neutral.

[1] Assume the relationship 4[C-] => 3[C+] + 1 [C--]. Since in balance s =t,. m = 3s, n = 4s. the quantity of fossil fuel energy is s%, the quantity of energy from the short term carbon cycle is 3s% and the quantity of inherently carbon neutral energy is (100 – 4s)%. Then 0 <= s <= 25. If s = 0, all energy will come from inherently carbon neutral energy. If s = 25, then no energy will be inherently carbon neutral, 25% fossil fuel and 75% from the short term carbon cycle. But in this case we effectively "turn the entire planet into an energy feedstock plantation. A reasonable figure (to be investigated) would suggest that s is between 5 and 7%.

Implicit subsidies exist when the values m-n and s-t are greater than zero and are measures of the negative externalities which characterize current energy markets. They no longer exist when n = m + t and s = t. The price for this will be determined by the market for [C--]. The number of atoms of carbon that this market must sequester is equal to the number of atoms of carbon in the fossil fuel market. Removal of the implicit subsidy achieves the primary aspiration of the Paris Agreement which is to balance anthropogenic emissions by sources, and removals by sinks, of carbon.

Explicit subsidy removal creates a free market for truly carbon neutral energy.

This is not a "price on carbon" which as conceived would be a command not market determined price.

The market for sequestered carbon is a necessary prerequisite for the creation of a truly carbon neutral energy market. It will match producers of physical sequestered carbon selling their net [C--] footprint to consumers with a positive [C++] footprint. It is likely one with very low barriers to entry and almost certainly a competitive market. A competitive market for a global public good!

The integrity of these markets must be inviolable.

This necessitates small, but highly functional government.

6. Production of char, the 25% of carbon that is [C--] will produce massive quantities of black matter. What will become of it? There is very substantial evidence, both long-term anecdotal and shorter-term soil science that suggests that the application of char to agricultural soil is highly beneficial. Char applied as a soil amendment is known as [char as biochar] or biochar. It should be emphasized that biochar is largely inert; it is the physical not chemical characteristics of biochar that result in these beneficial properties.

   Char will simultaneously have two distinct sources of value. [char as C--] will have a role in the global market for sequestered carbon. [char as biochar] will, I believe, have at most local markets. Its optimal use will be realized by its application to the soil from which its feedstock was grown. This will obviate the complex problem of biochar standards measurement.

7. The question of equity in the context of individual global footprints is greatly complicated when historical carbon footprints are considered. This is not given direct consideration in this idea. The universal constraint that each economic agent must satisfy n = m + t and s = t would otherwise be compromised and the matter likely become ungovernable. However, the discussion of poverty alleviation substantially addresses this.

   An internet search for "sustainable" yields about 348 million hits. I suggest that n = m + t and s = t would constructively inform any characterization of sustainable.

8. Poverty alleviation: imagine a world in which, for example, rice farming communities lead the implementation of physical sequestration of carbon, and are early producers of [C--]. These communities currently have among the lowest [C++] footprints and can become low cost

producers of [C--]. In an n = m + t and s=t economy, reasonably sized agricultural cooperatives will become important economic entities. Residual biomass will become feedstock for energy, soil restoration and carbon sequestration. Economic development and poverty alleviation must surely materialize.

There are, in the world, about 165 million hectares of rice under cultivation. The average yield is about 9 tons of biomass per year. 40% of a rice plant is milled rice, 60% residual biomass. The 5.4 tons of residual biomass has the energy equivalent of about 12 barrels of oil. 165 million hectares therefore has the energy equivalent of more than 2 billion barrels of oil. The char produced from the gasification of 5.4 tons of biomass sequesters as much carbon as the combustion of 750 litres of diesel emits.[2]

9. There is no discussion of governance or the free rider problem which are beyond the scope of this writing.

10. Two final thoughts:
    a. At the present time not one economic agent, not one good or service is truly net carbon neutral. At the point in time that the atmospheric concentration of carbon dioxide is equilibrated, every economic agent, every good and every service will be truly net carbon neutral.
    b. At the point in time that the atmospheric concentration of carbon dioxide is equilibrated there will have come into existence a commodity market for sequestered carbon. This market trades quantities of atoms of carbon. Its size will be equal to the sum of the number of atoms of carbon in the then existing markets for oil, plus natural gas, plus coal. Thus, a commodity market that today does not exist will have come into existence and become the largest commodity market in the world. And it will be a commodity market for a public good.

11. Who will help me start?

[2] The basis for these claims will be made available to the interested reader.