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Bernadette Bensaude-Vincent

Carbon, between nature and society
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Abstract:

In public media carbon is depicted as a “bad guy” threatening life and responsible for global warming by creating a greenhouse effect. However carbon dioxide is only one face of carbon, which is among the most studied elements of the periodic system. The purpose of this paper is to remind us that carbon is not reducible to its ubiquitous dioxide. The contemporary concern with its effect on climate prevents us to realize that carbon is a multifaceted element and a vital partner in the history of life and of humanity.

Author’s biographical note:

Bernadette Bensaude-Vincent is a philosopher and historian of science, emerita professor at Université Paris I Panthéon-Sorbonne. Her research topics span from the history and philosophy of chemistry to materials science and nanotechnology with a continuous interest in science and the public issues. Among her recent publications: *Carbone, ses vies, ses oeuvres* (co-authored with Sacha Loeve), Paris: Seuil, 2018; *Philosophy of Technology. Classical Readings and Contemporary Approaches*. (coedited with Sacha Loeve and Xavier Guchet) Springer, 2018 ; *Research Objects in their Technological Setting* (coedited with S.Loeve, A. Nordmann, A. Schwarz) London, Routledge, 2017 ; *Chemistry. The Impure Science*, (coauthored with Jonathan Simon), London, Imperial College, 2008.

Carbon, a familiar and abundant substance is also the most famous element in the public at large. Daily news and commercial adverts often refer to carbon taxes or carbon trading and urge for the “decarbonation” of technology. The intensive campaigns for “decarbonizing” industry or promoting “zero carbon economy” portray carbon as a ‘bad guy’ threatening life and responsible for global warming by creating a greenhouse effect. As human societies realize the impact of their technology they decide to turn CO₂ into an indicator of their footprint on the environment. Like gold and silver became money a long time ago, CO₂ recently became a general equivalent. This aerial money is supposed to help regulate the flux of carbon exchanges and provide control over the climate change and cosmic process. Carbon transformed in a universal currency is reduced to the status of a noxious gas.

This gas has been known and feared for millennia. It is mentioned by Virgil’s *Aeneid* who gave an horrifying evocation of the exhalations from a pool located in the valley of the river Asanto, in the region of Campania, Italy. Because of this place known as *la Mefite*, this gas has first been named “mephitic air”, then “pestilential vapour”, “lethal spirit”, “deadly spirit”, “sylvestre acid”, “fixed air”, “carbonic acid”, and finally carbon dioxide.

However this noxious gas is only one face of carbon, which is one of the most studied

elements of the periodic system. Carbon is so central in scientific circles that it is a star element with an impressive number of scientific awards: Carbon-14, the method for age determination in archaeology, owed the 1960 Nobel Prize in Chemistry to Willard F. Libby. The Nobel Prize in Chemistry 1996 was awarded jointly to Robert F. Curl Jr., Sir Harold W. Kroto and Richard E. Smalley for their discovery of fullerenes. The 2008 Kavli Prize in Nanoscience went to carbon nanotubes in the hands of Sumio Iijima, laureate of this Norwegian prize, and in 2010 the Nobel Prize for physics was awarded to Andre Geim and Konstantin Novoselov "for groundbreaking experiments regarding the two-dimensional material graphene".



Figure 1. *Lacus Mephiticus and its surroundings* Vincenzo Maria Santoli, *Rocæ Sancti Felicis. De Mephiti et Vallibus Anxanti, Libri Tres*, Naples, 1783. Public domain.

However impressive this collection of awards might be it does not cover all the facets and prowess of carbon. The purpose of this paper is to remind us that carbon is not reducible to its ubiquitous dioxide. The contemporary concern with its effect on climate prevents us to realize that carbon is a multifaceted element and a vital partner in the history of life and of humanity. Talking of carbon as a “partner” and of its prowess may sound like a pleasant metaphor. The personification of chemical elements is frequently used by teachers and popular writers to

make to render the rules of chemical bonds more tangible and easily memorized. For instance, Sam Kean in his bestseller *The Disappearing Spoon* presents the periodic table as “both a scientific accomplishment and a storybook”, displaying contrasting characters such as “aggressive oxygen (who) can dictate its own terms and bully other atoms” and “poor friendly carbon” who has “low standards for forming bonds” because it needs four additional electrons on its first shell to make eight and comply with the octet rule.¹ However in this paper, the anthropomorphic metaphor is more than a rhetorical or didactic device. It is meant to emphasize the role of carbon as a key mediator in the relationship between humans and nature. Primo Levi’s famous novel *The Periodic Table* magnificently demonstrated the entanglement of materials and human destinies. In addition to the autobiographical anecdotes displaying various kinds of partnership between individual materials and individual chemists, Levi’s final chapter devoted to carbon develops broader views about the links between humans and materials: “So it happens [...], Levi wrote, that every element says something to someone (something different to each) like the mountains valleys or beaches visited in youth. One must perhaps make an exception for carbon, because it says everything to everyone, that it is not specific”.² So what can carbon tell to everyone?

The carbon riddle

Carbon challenged chemists first. The identification of carbon as an element already results from the solution of a riddle. How to believe that diamond, coal and graphite are one and the same substance when they have quite different appearances, physical properties, and economic values. Diamond is hard and translucent, graphite friable, fragile and opaque; diamond is abrasive, graphite lubricant; diamond is an electrical insulator and thermal conductor, graphite an electrical conductor and a thermal insulator. Since Antiquity, diamond has been considered as the hardest stone. The word, deriving from Greek *ἀδαμάσ* – *a* (“not”) + *daman* (“to tame”) – clearly indicates that diamond is named after its remarkable property of resistance to all attempts to break it as well as the erosion of time: it is an “everlasting stone”, which, literally, “cannot be tamed”. Diamond is adamant, refusing to be persuaded to change, or to resign. Accordingly, it became the symbol of unbreakable engagement between two persons. “Diamonds are forever”. What could it have in common

¹ Sam Kean, *The Disappearing Spoon and other true tales of madness, love, and the history of the world from the periodic table of elements*, New York : Back Bay Books, 2010, quotes from p. 5 and p. 34-35.

² Primo Levi, *Il Sistema periodico*, 1975, Eng transl by Raymond Rosenthal, New York : Schocken Books, 1984, on p. 228.

with the black substance which is used for writing and drawing because it leaves a dark mark on a sheet of paper? In contrast to diamond, graphite (derived from the Greek *graphein-* to write) is so brittle and soft that it had to be inserted into a hollowed wooden stick to be used. What could diamond and graphite share with the coal extracted by tons from mines all over Europe and in the colonies in order to provide fuel for the Industrial revolution?

It took a long time and many generations of chemists to connect these various bodies and treat them as allotropic forms of one and the same element. It is over simplistic to assume that one crucial experiment solved the riddle. Chemical textbooks often claim that Antoine-Laurent Lavoisier's 1772 experiment of the combustion of diamond proved that diamond is carbon. To be sure between 1770 and 1773 Lavoisier conducted a series of experiments with Pierre-Joseph Macquer.³ They used a porcelain furnace and a lens to concentrate the rays of the sun on a diamond in order to burn it. They concluded that diamond burned in air like common charcoal but their experiment did not establish the "true nature" of diamond. By the end of the eighteenth-century the riddle continued to puzzle chemists when they compared the chemical behaviour of diamond and charcoal. Louis-Bernard Guyton de Morveau suggested that diamond was pure carbon while charcoal was presumably a compound of carbon and oxygen. The term 'carbon' was included in the *Méthode de nomenclature chimique* published in 1787 but it was not the "birth date" of element carbon. In fact carbon was presented as the "pure principle" of charcoal. Carbon, diamond and charcoal only differed by their level of purification. And they had no link whatsoever with graphite which was considered as "plumbagol" or "blacklead". The reason is that graphite became a substitute for the lead formally used for writing in the pencils patented by Nicolas Jacques Conté in 1795. Less surprising was the term "blacklead" used to denote the residue of the distillation of animal or vegetable matter in a limited supply of air, which has been used by prehistoric humans to draw the pictograms of cave paintings some 30 000 years ago. The view that charcoal, diamond, graphite and black carbon were allotropes of carbon only prevailed in the 1840s when the Swedish scientist Jakob Berzelius introduced the notion of allotropy (i.e. other tropism or behaviour) along with 'isomery' (i.e. same parts). However Berzelius provided no explanation for the striking differences of behaviours between carbon allotropes. Only when Avogadro's hypothesis was accepted in the 1860s it became clear that the same element could exist as polyatomic molecules with different structures: crystalline structure (graphite and

³ Christine Lehman, "What is the 'true' nature of diamond ?", *Nuncius*, 31 (2), 2016 : 361-407 ; "A la recherche de la nature du diamant : Guyton de Morveau successeur de Macquer et Lavoisier" , *Annales historiques de la révolution française*, N°1 (2016) : 81-107.

diamond), amorphous structure (carbon black), or mixed structures with various degrees of order and disorder (charcoal, soot, coke).

The riddle was solved when Mendeleev referred to the allotropic forms of carbon in order to draw a clear distinction between the abstract notion of elements and the concrete stuff of simple substances.

“A simple body is something material, a metal or a metalloid, endowed with physical and chemical properties. The idea that corresponds with the expression simple body is that of the molecule (...). By contrast, we need to reserve the name element to characterize the material particles that constitute the simple bodies and compounds and that determine the manner in which they behave in terms of their physical or chemical properties. The word element should summon up the idea of the atom”⁴.

While simple substances come into existence as concrete and physical entities at the end of a process of analysis and purification, elements are the material but invisible parts of simple and compound bodies. Carbon is a hypothetical abstract entity since it can never be isolated in stark contrast with diamond (made of pure carbon) – or anthracene (90% pure carbon).

The carbon backbone

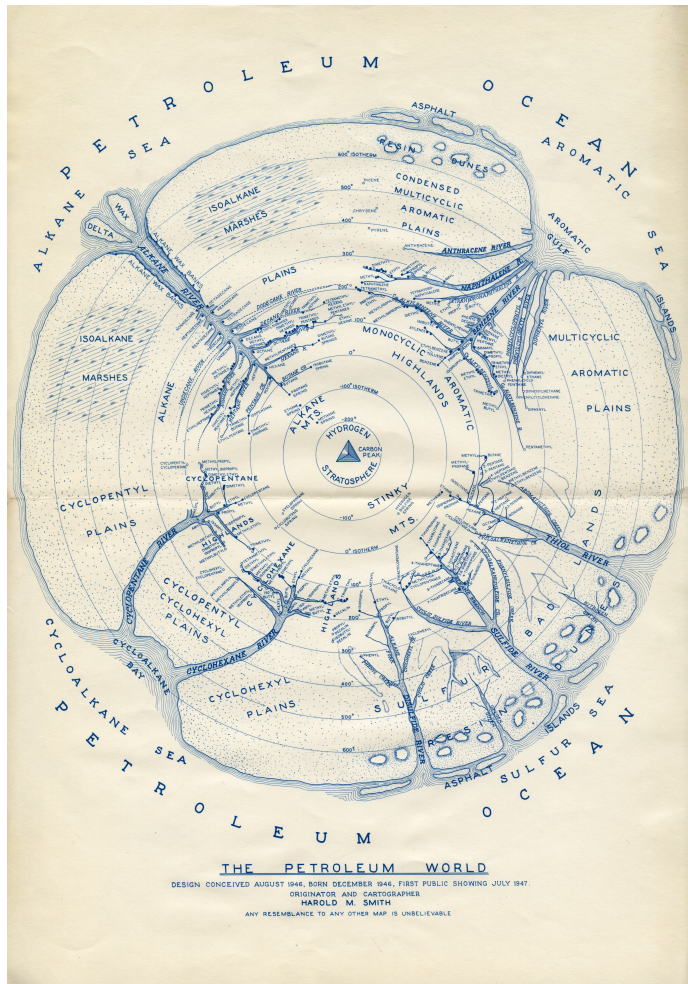
If carbon “says everything to everyone” as Primo Levi noted, it may be because of its unique atomic structure of carbon - a tetrahedron with four valence electrons - and its wide binding abilities: C–C, C=C, C≡C, C–H, etc.. Carbon is ubiquitous in nature precisely because of its wide spectrum of combinatorial dispositions. As Peter Atkins noticed “Carbon kingliness as an element stems from its mediocrity: it does most things, and it does nothing to extremes, yet by *virtue* of that moderation it dominates nature”.⁵ This anthropomorphic description of the behaviour of carbon atoms points to carbon “social mode of existence” as an individual entity whose identity is shaped by intercourse and relations with others.

The binding capacities of carbon atoms are displayed both in nature and art. They were key to build the blocks of life — amino acids, sugars, nucleic bases— which in turn enabled the synthesis of nucleic acids DNA and RNA, the molecules carrying genetic information, of the lipid membranes that compartmentalize cells cellular, of proteins and enzymes (the actors that transform biological matter). Up to now there is no other form of life than carbonaceous life. And the million organic chemical compounds synthesized by chemical industry are also made

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⁵ Peter Atkins *Atoms, Electrons & Change*, NY Scientific American Library, 1991, p. 19

of carbon backbones, albeit less complex than those of living bodies. Because of its capacity to form an immense crowd of compounds carbon generated a chemistry of its own. Carbon chemistry alias organic chemistry, formed in the nineteenth century opened up a wide spectrum of technological applications ranging from dyes, pharmaceuticals, synthetic textiles, and plastics.



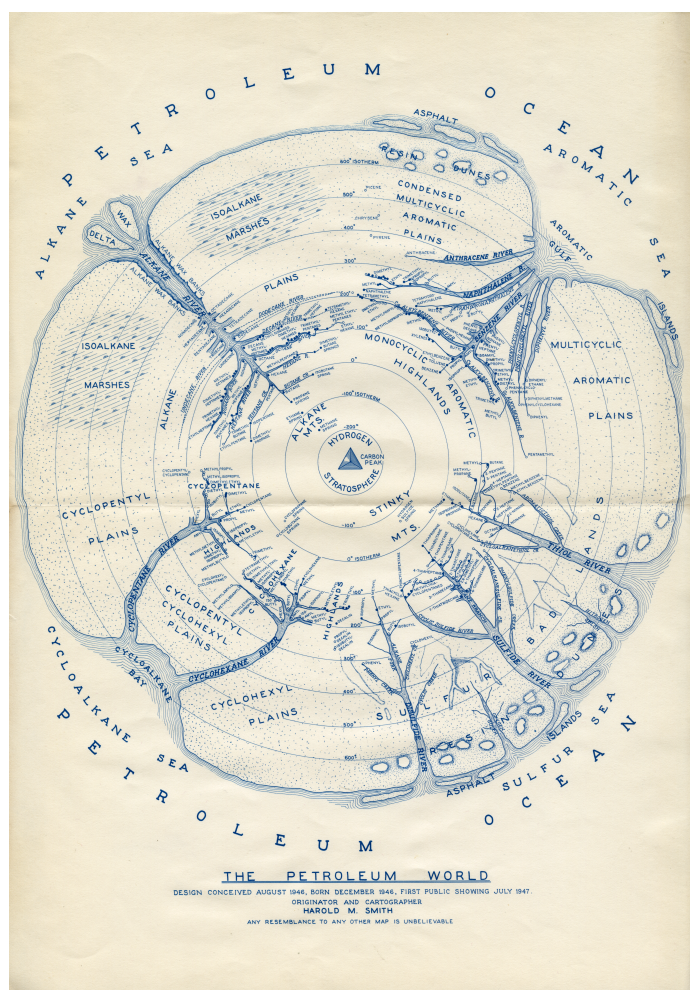


Fig 2: *The petroleum world*, 1946. Harold Smith, a researcher at Oklahoma Bureau of mines pictured the petroleum world like a medieval *mapa mundi*. The various products extracted from petroleum are rivers flowing down from the summit made of carbon and hydrogen, With permission of the Science History Institute, Philadelphia.

Whether natural or artificial, organic compounds are both the products of the structural combinatorial game allowed by carbon binding dispositions. Thus the carbon-backbone blurs the boundary between nature and artefacts, between the natural productions of life and synthetic products.

Carbohydrates or sugars are viewed as essential for life on the planet, whereas hydrocarbons are connected with pollution and climate change. Fossil fuels such as coal, petrol, and gas are the waste matter of the living world accumulated over hundreds of millions of years. They are given a second life, so to speak, when they are cracked and rearranged for making drugs, synthetic polymers and plastics, and they “die” a second death when they fuel combustion engines that release CO₂ in the atmosphere. It would therefore be more correct to urge people to reconsider the oxidation state of carbon than to pretend to decarbonise economy. Industrial societies have irreversibly dismantled tons of the carbon backbones accumulated in the earth.

The tremendous power embedded in the carbon chains assembled by life has generated a kind of addiction of humans to the consumption of carbon backbones. This gluttony, based on the belief that they were an indefinite endless resource, contrasts with other more constructive technological uses of carbon.

Carbon creativity

Carbon atoms have a singular capacity for inventing new identities in assembling new molecules, such as fullerenes, nanotubes or graphene with unusual properties. Significantly, Richard Smalley in his Nobel Lecture “Discovering the fullerenes” insisted on “the genius” of carbon, on its amazing creativity:

“The discovery that garnered the Nobel Prize was the realization that carbon makes the truncated icosahedral molecules and larger geodesic cages, *all by itself*. Carbon has *wired within it*, as part of its birth-right ever since the beginning of the universe the genius for spontaneously assembling, into fullerenes”.⁶

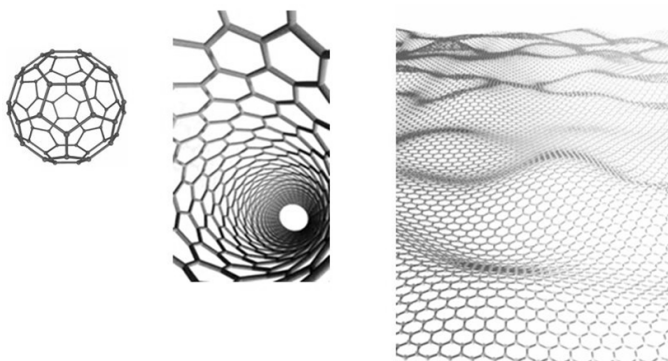


Fig 3: The three most famous nanocarbons: fullerenes discovered in 1985 by Robert F. Curl Jr., Harold W. Kroto and Richard E. Smalley ; nanotubes identified by Sumio Iijima in 1991, and freestanding graphene obtained by Andrei Geim et Konstantin Novoselov in Manchester, 2004. Public domain.

Over the past twenty-five years, in addition to the fullerenes, nanoscientists have displayed a zoo of nanocarbons: Nanotubes, nanobuds, nanotori, nanocones, nanohorns, nanoribbons. These avatars of carbon challenge all boundaries between organic and mineral, between

⁶ Richard Smalley, *Discovering the fullerenes* , Nobel Lecture, 1996, p. 90-91.
http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1996/smalley-lecture.html

crystals and glass. They exhibit planar configurations, which can be bent, folded, or rolled in tube or in cone, just as in origami art. With nanotechnology, carbon appears as an almost immaterial material, a single-layer of atoms, a pure surface. Indeed structure still matters, but it is functionalized and redefined in terms of device or machine. The combinatorial potential no longer involves crowds of molecules in chemical reactions; it rather refers to a construction game assembling single molecules of carbon. Once again after the great expectations generated by nineteenth-century synthetic chemistry, carbon looks like a cornucopia of futuristic products: new screens, better batteries, flexible electronics, ultra-fast computers, ultra-thin sensors, traps for pollutants sequestration.

In conclusion, the demonization of carbon is misleading and actively contributes to occult the innumerable affordances of carbon. The identification of all the various modes of existence of carbon with one of them is a kind of social construction of ignorance rests. The problem is not that there is too much carbon—though there is of course too much CO₂ in atmospheric air. By consuming few centuries of “buried suns” per year, we disconnect the historical time of human activities from the geological and biological times of the earth. The implementation of carbon trading, carbon taxes is a brave attempt to bridge the gulf. But it may rather increase the gulf as long as the system of compensation provides a means for indefinitely postponing effective measures of reduction of emissions by changing our life styles. It tends to dissolve the urgent issue of climate change into counterfactual and abstract speculations and also disconnects our present from the future by persuading people that they can be “carbon neutral” and consequently not indebted to future generations. Carbon is not a “bad guy” that should be “neutralized” or “sequestered”. Carbon should be rescued, because we depend on it, as do other animals and plants on which we are depending too.