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Carbon, Climate, and Earth Stewardship: Prophetic Teachings of the Biosphere

Calvin B. DeWitt
Nelson Institute - University of Wisconsin-Madison, Madison, WI 53706
(E-mail: cbdewitt@wisc.edu)

Abstract: Human civilization from the agricultural revolution, beginning some 10,000 years ago, and urban development beginning about 5,000 years ago, was supported throughout by a reliable and hospitable climate. Now, however, this hospitability is being compromised, requiring intensified and persistent work and dedication toward its restoration – particularly by institutions, governments, and enterprises and those who scientifically and ethically create, shape, lead, reform, and maintain them. *The present* must be described with exceptional truthfulness and accuracy, with diligence toward full understanding and restoration of Earth's climate system of self-control. Knowledge of this system must be freely accessible and comprehended by all, uncluttered by false representations and misinformation, informative of relationships of cause and effect, and embracing the entire system, with consequences of human actions expressed and addressed temporally and spatially. Central to this is bringing the human use of carbon fully within the bounds of the hospitable climate control system of the biospheric economy and our common home.

Key Words: Carbon, Atmospheric Chemistry, Climate Change, Climate Economics, Biosphere, Biospheric Economy, Fitness of the Environment, Regulation, "Earth Stewardship and *Laudato Si"* – this last being a key phrase for entry on Google search.

> The business of prophecy is not foretelling the future; rather it is *describing the present* with exceptional truthfulness and accuracy
>
> – David Ehrenfeld (p. 9) (1)

INTRODUCTION

Scientific discovery in the 20th century brought worldwide attention to the consequences of adverse human actions on the biosphere and its ecosystems at local, regional, and global levels. In response to the challenge these present, a widespread effort was made in America during the decade of the 1970s that brought the U.S. Congress to develop comprehensive legislation to address these assaults on creation, accompanied and followed by similar legislation throughout much of the world. From this, people worldwide are coming to understand the reality that we all live in the biosphere---the vital system that sustains all of our lives and livelihood---and most significantly, that we are adversely affecting it in many ways, including the destabilization of Earth's climate control system. Like it or not, this has extended our stewardship, bringing us to realize our new status and responsibility as stewards of the biosphere [2]. This unsettling realization brings challenges to everyone, to our institutions, and to our developing global human civilization. This is the reality of the present.

DESCRIBING THE PRESENT

As we and human society come to understand our new setting and status, we are finding it extremely difficult to describe the present. First, we realize that this requires an immense effort and is challenged by inexperience in describing our global reality – the habitable common home

into which we, unthinkingly, have been born. We have taken this integrated and sustained system *for granted* – simply as a given to us and all life. Never have we thought it would "bite back" – in view of its long history of continued hospitability to us and all of life. An integrative understanding of the intricacies and operating scope of this remarkably integrated life-support system has been so beyond our grasp that many people today don't really want to know how it works as a wholly integrated system. We would like to have the freedom and the security it gives but without the need for integrated knowledge of its workings. Not that we are lazy about learning and knowing, but because we never expected we would ever have to know this system comprehensively. However, even as we might rather not want to know, we do not like the looks of what we are coming to see. Biospheric changes over only a decade or two contrast strongly with formerly steady and predictable features and futures. We may be reluctant to speak about it, for fear of being called alarmist, but we are coming to find it necessary to describe the present. In this we find ourselves discovering that life is largely atmospheric –with major constituents, carbon, hydrogen, oxygen, and nitrogen, always being reciprocally exchanged with the atmosphere [3]. I am hoping in this realization that religious people are coming to view this in the context of atmospheric providence for which we should respond with gratitude, care, and keeping.

ELEMENTAL & OXIDIZED CARBON

Among atmospheric constituents, carbon dioxide provides the molecular backbone of all living things. Physiologically captured from the air, its carbon is incorporated as the basic structural component of every living organism, and is subsequently sequestered in biomass, detritus, soil, peat, coal, bitumen, oil, and gaseous hydrocarbons. Returning sooner or later to the atmosphere by respiration, oxidation, and combustion principally as carbon dioxide, its atmospheric concentrations have been maintained at 0.28 percent – (280 ppm) over the course of recorded human history – a period of some 10,000 years, rising dramatically above this level only in recent decades and centuries. The trophic importance of this gas can be appreciated by considering that its removal would mean that photosynthesis would end, all green plants would perish, and very soon also every living being. But for some 10,000 years, it has been right on the mark. Not too much, not too little; always kept at or very near 2.8 hundredths of one percent (280 ppm).

Oceanographer Roger Revelle summarized its significance this way: "Carbon dioxide may be thought of as the most important substance in the biosphere: that part of the Earth's atmosphere, hydrosphere, and solid crust in which life exists. It has supported the existence and development of life by serving as the source of carbon, the principal element of which all living beings... are made. In past times it was a source of the free oxygen in the air and the ocean that makes animal life possible. By absorbing and backscattering the heat radiated from Earth's surface, it maintains, together with atmospheric water vapor, a sufficiently high temperature in the air and the sea to allow liquid water, and therefore life, to exist (p. 3) [4].

HOSPITABILITY IN THE BODY & BIOSPHERE

What keeps the biosphere so hospitable – to microbes, plants, animals, human beings and human society? In seeking an answer, it is helpful to ask a similar question for 'the internal environment' of the body, as did 19th-century French physiologist, Claude Bernard. His extremely important dictum, "La fixité du milieu intérieur est la condition de la vie libre" (Regulation of the internal environment is the condition for a free life.), provides an extremely important dictum that applies not only to the internal workings of all living creatures, but also provides the foundation for cybernetics and control systems in science, engineering, and society [5]. This statement about freedom is informed by the controls that regulate body temperature, blood sugar levels, alkalinity, pH, and other chemical and physiological processes with some like body temperature regulation, using a kind of *central control* and others using a more *diffuse control* that is broadly present within and throughout the system being controlled. Whether central or diffuse, "La fixité du milieu interieur" gives freedom to the body, allowing it to live without the need to think a moment-to-moment about operation and control of critical internal processes of sustainable living. In an answer to an exam question one of my university students explained it this way, "For example, there are thousands of little processes going on inside my body right now that I am not conscious of, but which are doing their best to facilitate my continued existence. If I had to consciously think about every process and control them without the help of internal regulation all my time and

energy would be spent doing that and I effectively would be a prisoner to this system of control and change, unable to live a 'free' life!" [6].

LEVEL & PRECISION OF TEMPERATURE REGULATION IN THE BODY

Regulation, be it the temperature of the body or the concentration of a gas in the atmosphere, or pH of the ocean, can be evaluated in terms of both its level and its precision. For human body temperature, the level of regulation is often placed at 37°C (98.6°F). Recent studies, however, put the level at about 36.6°C (97.9°F) and its precision is expressed as the central 95% range of 35.7 to 37.3 °C, or 1.6 Celsius degrees [7]. In contrast to endothermic mammals and birds, body temperature regulation achieved behaviorally by ectothermic animals is less precise, with intraabdominal body temperatures of the Desert Iguana, for example, having a level of 38.5°C (101.3°F) and precision, as the central 95% range, is 33.2 to 41.8 °C or 8.6 Celsius degrees [8].

ATMOSPHERIC CARBON DIOXIDE

Scientists often investigate things simply from their love to know, and this has resulted in important discoveries. It was from such research that physicist John Tyndall came to give a remarkable Friday evening lecture at the Royal Institution in 1859 [9]. He had set up a projector and screen to put a full spectrum of light on display, directing a stream of ignited oxygen and hydrogen at a cylinder of lime, calcium oxide (CaO), to produce a bright beam of the limelight. He passed this light through a prism he had fashioned from rock salt to the screen, thereby showing a spectral array with the colors of the rainbow: red, orange, yellow, green, blue, indigo, and violet. He then took a thermopile he had prepared for measuring temperature and moving it across the screen proceeded to show that light of every color warmed the screen. Next, he moved the thermopile past the red light to an area that was dark on the screen, showing that again the thermopile was heated. Clearly, radiation was still hitting the screen, but it was not visible. Calling this "dark radiation," he speculated that the aqueous and vitreous humor of the eye absorbed this light and might prevent it from passing to the retina. Upon which he brought up a cow's eye he had picked up from the local butcher and pouring its contents into a vial made of rock salt, put these eye fluids into the path of the dark radiation. Remarkably, the thermopile at the place where dark energy had been hitting the screen, was no longer warm. The dark light – what we now call infrared radiation -- had been stopped in its course by the humor of the eye.

Tyndall then told his audience how, after finding this, he had prepared a long tube through which he could project a beam of light, filling the tube with various gases. He said that he first was disappointed that nothing seemed to stop the dark radiation as had the material from the cow's eye. But gas from the spigot on his lab bench, while passing visible light fully, blocked the dark radiation completely. And carbon dioxide, while transmitting visible light fully, also blocked infrared radiation completely. With this he realized the significance of this for Earth's atmosphere, concluding that carbon dioxide would allow light from the sun to pass through the atmosphere to the earth, but would hinder infrared radiation from leaving back through the atmosphere.

A person born in the very year that Tyndall gave this lecture, physical chemist Svante Arrhenius, brought things further in the late 1800s by calculating the effect that a doubling of atmospheric carbon dioxide would have on Earth's average surface temperature [10]. This prominent Swedish scientist used the measurements made by astronomers Samuel Langley and Frank Very of infrared rays radiated from the moon at various angles to Earth's horizon. For these measurements, they used an instrument Langley had invented, the "bolometer," that could measure temperature differences as little as 1/100,000 of a degree C. Using Langley and Very's measurements of infra¬red radiation from the moon at different heights above the earth's horizon, Arrhenius calculated the absorption of infrared radiation through different thicknesses of atmospheric carbon dioxide and water vapor. Then, from his calculations, Arrhenius computed from his knowledge of basic physics that a doubling of atmospheric carbon dioxide would raise the atmospheric temperature at Earth's surface by 5 Celsius degrees. Building upon these discoveries by Tyndall and Arrhenius, other scientists also came to realize the importance of carbon dioxide's role in maintaining a habitable Earth, among these being geologist Thomas C. Chamberlin, a professor and president of the University of Wisconsin and later chair of the Geology Department of the University of Chicago.

Chamberlin's monumental three-volume textbook, Geology, written with his colleague and former student Rollin Salisbury in 1909 [3] includes a section on Life material chiefly atmospheric where they write:

"In the building up of the organic compounds, a necessary step is the decomposition of certain inorganic compounds. The chief of these is carbon dioxide of the atmosphere and hydrosphere, the decomposition of which furnishes the carbon needed for the organic compounds. On this account carbon dioxide may be regarded as in some sense the basal material or the fundamental food of the organic kingdom, and hence it plays a radical role in the life history of Earth. Water, and the constituents of water, oxygen, and hydrogen, play a larger part quantitatively, but a less distinctive part. Nitrogen is also an essential element and usually stands next to carbon, oxygen, and hydrogen in quantity. These, it will be noted, are all atmospheric constituents, and the material of life is, therefore, dominantly atmospheric" (p. 638) [3].

Chamberlin and Salisbury developed a focus on carbon dioxide, and even though it is among the least abundant atmospheric gases, described it as the chief inorganic compound. And, on "the climatic effects of organic action" they write:

"The atmosphere blankets the earth and equalizes its temperature…[and] while the solar rays come in rather freely and heat the surface of the earth, the dark rays which the earth radiates back are measurably arrested by the carbon dioxide and vapor of water and serve to keep the air warm" (p. 642) [3].

ATMOSPHERIC CARBON DIOXIDE FOR 10,000 YEARS

During the development of human civilization, society began to change from nomadic to settled lifestyles as the agricultural revolution began some 10,000 years ago and enabled more compact human communities. Many of these communities were further enabled by increased agricultural productivity and security to develop into cities beginning about 5,000 years ago, mostly along streams and rivers that assured reliable sources of water [11]. Accompanying these 10,000 years of agricultural and societal development – and its sustained productivity of food, community security, and regularity of natural water supplies – was a reliable, sustained, and predictable climate that, if not seasonally hospitable, was successfully addressed by fabrication of adaptive clothing and seasonal food storage.

A highly significant indicator of the reliable, sustained, and predictable climate during these ten millennia is the regularity of atmospheric carbon dioxide at or near 280 ppm. With measurements of atmospheric carbon from ice cores, and continuous measurements of atmospheric carbon, begun by chemist Charles David Keeling in 1958 at the Mauna Loa Atmospheric Observatory in Hawaii, we have learned that carbon dioxide concentration for this 10,000 year period has been maintained at or near the 280 ppm level, all but for its final centuries. Data from the Law Dome, Antarctica ice core show remarkable regularity from 0 to 1600 years A.D., with its 43 records having an average concentration is 279.5 ppm (standard deviation: 2.05 ppm) and range from 276 to 284 ppm [12]. In earlier years, from 2342 to 10,123 years BP, for the seven records from the Vostoc, Antarctica ice core, the median concentration is 262.2 and range from 254.6 and 284.7 ppm. This remarkable regularly over the ten millennia course of development of human civilization indicates that atmospheric carbon dioxide has been controlled at or near 280 ppm level during this span of 10,000 years.

This remarkable regularity is the consequence of carbon dioxide as a principal temperature "control knob," identified as such by chemist Andrew Lacis, and colleagues in their 2010 paper, "Atmospheric CO2: Principal Control Knob Governing Earth's Temperature" [13]. Their paper was summarized by an editor of the journal *Science*, where it was published, as follows:

"The physical effect of atmospheric carbon dioxide on Earth's energy budget – that is, its 'greenhouse effect' – has been understood for more than 100 years, but its role in climate warming is still not universally accepted. Lacis et al. (p. 356) conducted a set of idealized climate model experiments in which various greenhouse gases were added to or subtracted from the atmosphere in order to illustrate their roles in controlling the temperature of the air. The findings clearly show that carbon dioxide exerts the most control on Earth's climate and that its abundance determines how much water vapor the atmosphere contains, even though the radiative effect of the water vapor is greater than that of carbon dioxide itself." (p. 471) [14].

For ten millennia, this regularity has given what physiological body temperature has given each of us: the freedom not to have to think about it. The statement by my student about physiological regulation also applies to the external environment. "La fixité du milieu extérieur est la condition de la vie libre" applied to the biosphere can be rendered:

Regulation of Earth's temperature is a necessary condition of a free life. This is a dictum we now can rightfully use to accompany the one given for our "milieu interieur" by Claude Bernard a century ago.

GREAT REGULARITIES OF EARTH'S TEMPERATURE & OCEAN NEUTRALITY

As carbon is key to the regulation of Earth's temperature, it is also key to the regulation of the chemical neutrality of the ocean. "The most striking of all the ocean's qualities is its constancy," wrote Henderson in 1913 (p.164) [15]. This chemist's discovery of this constancy, including the extraordinary property of carbonic acid in preserving chemical neutrality – familiar to every chemist as expressed in the Henderson-Hasselbalch Equation – brought him to understand the regulation of the pH of the blood, but also of the ocean and other water bodies of the Earth. In wonder, he declared for carbonic acid: "no other known substance shares this power" (p. 153) [15]. "Moreover, the chemist has discovered no means of rivaling the efficiency and delicacy of adjustment of the process… Almost wholly, through this mechanism, the oceans are always nearly neutral" (p. 153) [15]. Here there is no *central control* in contrast with vertebrate body temperature regulation, but *the diffuse control* that is broadly embedded within the system being controlled.

OVERWHELMED REGULARITIES

The data of chemist David Keeling from Mauna Loa and Antarctic ice cores show, however, that these remarkable regularities no longer exist. Atmospheric carbon dioxide is rising exponentially, increasing by 40 percent, from about 278 ppm in 1750 A.D. to 390.5 in 2011. And, widespread acidification of the ocean is underway, as the remarkable buffering system described by Henderson is being overwhelmed beyond buffering capacity, by absorbing much greater amounts of carbon dioxide as it is driven by much higher concentrations in the atmosphere. Ocean pH has decreased from 8.13 to 8.05 (nearly 0.1 pH unit, or about 28%) and is predicted to decrease further, by 0.4 pH units, by 2100 [16].

When atmospheric CO_2 concentration reached 400 ppm in 2013, physical chemist Charles Miller wrote, "Current CO_2 values are more than 100 ppm higher than at any time in the last one million years...This new record represents an increase of 85 ppm in the 55 years since chemist David Keeling began making measurements at Mauna Loa. Even more disturbing than the magnitude of this change is the fact that the rate of CO_2 accumulation in the atmosphere has also been increasing over the last few decades, meaning that future increases will happen faster." [17]. And so too for ocean acidification, as this is driven by increasing atmospheric CO_2 levels.

On October 8, 2018 the Intergovernmental Panel on Climate Change (IPCC) announced publication of their Special Report on *Global Warming of 1.5°* [18], at the invitation of the Paris Climate Accord of 2015, in which they reported that human activities, particularly increased atmospheric carbon dioxide, has resulted in about a 1 Celsius degree of global warming above pre-industrial levels (*likely* range: 0.8 to 1.2 C deg) with expected increase to 1.5 Celsius degrees between 2030 and 2052 (*high confidence*) at current rates of increase. They also reported that the ocean has absorbed about 30% of the anthropogenic carbon dioxide, resulting in ocean acidification and changes to carbonate chemistry that are unprecedented in at least 65 million years (*high confidence*), with expected impacts on a wide range of marine organisms, ecosystems, and on aquaculture and fisheries (*high confidence*).

Ocean ecosystems are changing on a large scale, with critical thresholds expected to be reached at 1.5 C degrees and above (*high confidence*). And moving to a 1.5 C degree increase will bring ecosystems such as kelp forests and coral reefs high rates of mortality and loss (*very high confidence*). As an example, multiple lines of evidence indicate that most warmer water coral reefs (70-90%) will largely disappear when global warming exceeds 1.5 C degrees (*very high confidence*). Moreover, this loss of 90% of coral reefs will remove resources and increase poverty across tropical countries worldwide. And protection of shorelines by coral reefs is at risk and will be amplified by sea level rise.

Importantly, the IPCC's Figure SPM.2 illustrates graphically the impacts and risks of increasing global warming for people, economies, and ecosystems for what they call Five Reasons for Concern (RFCs) [18]. Because the remarkable regularity within Earth's climate system has thus been overwhelmed, it is vitally necessary that a clear and decisive restorative response is necessary. Earth's climate system and ocean buffering system need restoration to the self-control that has been sustaining Earth's life and human civilization for ten millennia and more.

RESPONSIBILITY FOR RESTORING & MAINTAINING THE CAPACITY FOR REGULATION

When the system that maintains biospheric temperature control is overwhelmed, by whatever its drivers, our task is much like the physician's: we must restore the conditions of health so that the thermoregulatory system can do the work it normally does, including its sustaining vibrant life. Body temperature regulatory systems teach this well: if they are pushed off track by hypothermia or hyperthermia, the physiology of the body does not accommodate to a new body temperature above or below the 36.6°C (98°F) level. Instead, its capacity to self-regulate must be restored. Work that puts the regulatory process back into full self-control is required, thereby to give the freedom and security to live a fruitful and abundant life.

SHOULD WE LIVE OUR LIVES WITH A CONTINUOUS FEVER?

We know from experience that if our body temperature is 40°C (104°F), meaning that we have a fever, it is good to bring it down to a 39°C (102.2°F) fever. But we also know that it is not good for our bodily economy to operate at this, or any, feverish temperature continually. We simply must restore the conditions that allow our body thermoregulation to operate with full health, meaning that it again operates at its normal level and precision. So too, as it may be a very worthy goal today to bring atmospheric carbon dioxide to 350 ppm, we also know that we cannot simply make this still feverish level the new norm!

The aim of restoring health – be that of our body or biosphere – is to get things back under self-control. As the goal of the physician and nurse is to restore body temperature to normal, not having it work with a marginal fever, so too with Earth's climate system. From physiology and medicine, we learn this: It is always is the greater part of the physician's task – including the Earth physician – to restore the self-regulatory processes of the system to normality; disabling the drivers that degrade its self-control.

There often will be frustration, even with colleagues, as we work to restore integrity and normality to the 'external environment' in which all living things live. Among such frustration is the experience of fellow scientist Louis Sytsma, with whom I taught at Au Sable Institute. Upon visiting a waste chemical injection well in Kalkaska County, Michigan he found another chemist in charge doing calculations on what could be injected into the deep ground beneath such that the pure waters below could be raised up to the limits that had been set for deep groundwater pollution. The limit had become the goal, even as maintaining the relative purity of deep underground formations from pollution was being sacrificed. The position of my colleague was that his profession of chemistry should call him to find and have implemented methods to maintain groundwater quality and develop ways to use the materials that were to be injected as a resource, not simply discard them without regard to consequences.

As my chemist colleague used his knowledge of chemistry to gain insight into the responsibilities of chemists, so did Walter Cannon for physiologists and medical doctors. Cannon, who coined the word *homeostasis* to describe the consequences of self-regulation, had written *The Wisdom of the Body*, a book on this subject [19]. His publisher, W. W. Norton, encouraged him to make applications from his research to society as part of his book, but Cannon refused. Only after repeated urging he reluctantly did so, but only as an epilogue in a later edition. Nearly a decade later, however, when giving his address as the outgoing president of the American Association for the Advancement of Science in 1940, he put things together, speaking on "The body physiologic and the body politic."

Physiological homeostasis would suggest, further, that stability is more important than economy… Extra blood volume, lung capacity, blood pressure, and cardiac power --much more than ordinarily required --all indicate generous preparations for meeting unusual demands, which might create disorder if they were not met. In personal and governmental practice, also, the principle of preferring security to the economy has been to some degree recognized. Life insurance and accident insurance may be paid year after year with no advantage except a sense of being protected. Fire departments are maintained, and armies and navies are kept in fighting trim at great expense, again with special regard for safety rather than economy (pp. 7-8) [20].

We can profitably do as medical doctor Walter Cannon did, to apply our understanding of the regulatory and control systems of the human body, or of chemical regulation in the body and oceans, as Lawrence J. Henderson did in chemistry [15] to the body politic. More than that, however, we can apply this understanding to the operations of Earth and its atmosphere, wisely employing limits we might set, but always aiming to go beyond setting limits to achieve normal levels of self-regulation.

CONTROLLING OURSELVES

Unlike the assessment of *Man's Role in Changing the Face of the Earth* in 1956 which described increased human influence upon earth's systems, we now know six decades later that we human beings have not only achieved domination, but also are seemingly unable to control our domination, even as we find ourselves destabilizing Earth's climate regulation [21]. The greatest unsettling truth at present is that through our actions, we have so transformed the biogeographic, trophic, and climate systems that sustain us and all life that we have propelled ourselves into a new role: like it or not, our responsibility has been extended to become responsible stewards of the biosphere. Our work is not to further press and overwhelm our climate system's operations, not to presume we can take over its control and put it into our own hands. Instead, it is to discover the systems that control Earth's climate system and to bring ourselves in accord with that control.

Beyond this, we must be persistently diligent in restoring the conditions that once again allow earth's controls to operate in service to life on earth – as it has been providing for past centuries and millennia. For this, we need fully to understand the biosphere's operations as a controlled system. This return of the economy of the biosphere to its self-control requires a more comprehensive and integrative understanding of the biosphere that we have put together --integratively, with full knowledge of how its level and precision are being compromised by human drivers. In this, we need vitally to enculturate this understanding into our practices and institutions to restore and sustain a habitable earth. Simply put, we must come to rule ourselves with truth and grace.

INSTITUTIONS & THEIR ROLE

Global changes that contribute to unsustainability at all levels – including climate, weather events, degraded ecosystem services, and regional public health issues – require understanding not only of the biosphere but also of *institutions* [22]. For it is institutions that produce and can correct the various social drivers both of sustainability and unsustainability. Institutions, according to institutional economists, are the sets of rules, conventions, arrangements, and frameworks that form and shape human actions in the biosphere. They shape human relationships within the world, either in support of the way the biosphere works, contrary to it or indifferent toward it. They are the social constructs that frame human action in the world, whether that be at the level of the family, profession, church, club, community, business, economy, organizations, or government and are determined by beliefs about society and the wider world, beliefs that institutional economist and Nobel laureate Douglass C. North describes as 'internal representations' of the world (p. 49) [23]. Thus, institutions are external manifestations of our beliefs – manifestations of our internal representations of the world.

While our society becomes aware of the consequences of destabilizing the regularity of atmospheric carbon dioxide and its effects on our biosphere's climate system, including highly consequential global warming and ocean acidification, we find that our out-of-control system for atmospheric carbon dioxide regularity has not yet been sufficiently encompassed within our institutions – a conclusion that is self-evident from describing the present with exceptional truth and accuracy. A belief that all people hold in common is that our society must not degrade or destroy the habitability of our biosphere – our common home. This basic belief is deeply embedded in us and vital to each of us and to our civilization. When institutions are not adequately matched to what is necessary to sustain the biosphere, like the climate control system that has held Earth's thermostat very near 280 ppm for 10 millennia, they require reform that matches the needs for restoration of normality. Specifically institutional reform, innovation, and creation is needed immediately that (1) recognizes that the term *fossil fuels* as a very serious misnomer for what in fact is sequestered *fossil carbon with a key storage function within Earth's climate control system,* (2) recognizes that release of carbon dioxide from fossil carbon turns up the control knob of Earth's temperature control system, (3) works to put the human carbon economy back into its proper place within the larger biospheric carbon economy, and (4) recognizes that negative feedback has to be built into our economy that restores atmospheric carbon dioxide the normality it has had for 10,000 years.

CARBON, CLIMATE, & STEWARDSHIP

The distinguished historian of chemistry, Colin Russell, Fellow of the Royal Society of Chemistry, gave a series of lectures at Cambridge University that examined the prospects for restoring environmental integrity on earth. In 994 these lectures on his comprehensive historical

inquiry were published, on the present condition and prospects for the future of our planet, with special attention to the history of chemistry and the chemical industry [24]. Importantly, he concluded that science and technology are not the problems. Instead, he located the problem in what he called *the motivating springs of active degradation*: human *arrogance*, *ignorance*, *greed*, and *aggression*. Human beings know what environmental integrity means and yet they degrade the Earth. This is the human predicament.

Importantly, Russell evaluates the prospects for addressing this predicament through the postmodern organismic view of Earth but finds this countering the very science needed to restore environmental integrity. He evaluates the conventional reductionist view but finds this inadequate for addressing this human predicament and the breadth of its impact. In seeking a third way, he comes to an ancient response to this predicament, summarized by the keyword, *stewardship*. Russell's proposition is this: human beings have an instrumental stewardship function in Earth's recovery, whatever theological views they may or may not hold. At the *conceptual level*, stewardship makes the great effort to understand the complex systems of the planet and biosphere, says Russell. It recognizes that in times of environmental degradation the need for public understanding of science is greater than ever. At the *perceptual level*, stewardship leads people to value the Earth highly as a treasure held in trust. It develops empathy with nature and sympathy for those who work for environmental integrity. And at the *relational level*, stewardship elicits practical strategies for relating people to the Earth as responsible members who are obedient to the dictates of conscience [25].

It is in this context of Russell and the keyword *stewardship* that the announcement on October 8, 2018 of the Nobel Prize in Economic Sciences awarded to William D. Nordhaus "for integrating climate change into long-run economic analysis" is particularly important. His conceptual development of the social cost of carbon (SCC) has already delivered more than $1 trillion dollars of benefits by actions of various U.S. agencies, with the SCC defined as the monetized value of the net impacts from global climate change that result from an additional ton of CO_2." [26] when motivated by the ethical motivations of responsible stewardship – as these were embedded in U.S. federal requirements that were in place that incorporated the SCC (p. 5) [27]. But it fails when the motivating springs – arrogance, ignorance, greed, and aggression – overwhelm responsible stewardship. Thus, internationally there will be free-riders who contribute little or nothing to reducing carbon dioxide but reap the benefits of the efforts of other parties. And, the benefits often will be "diffuse in space and time" (p. 29) [27], and escape most everyone's attention and concerns. In response to the problem of such free-riding and diffuse benefits, Nordhaus proposes Climate Clubs [39] which, properly designed, could harness Russell's motivating springs to drive desired outcomes. Such design would have the potential of embedding the SCC into the interacting climate and economic system to bring this system fully into accord with its operations in natural systems, with a more diffuse control. Use of Global Carbon Budgets will be helpful in this design [28]. Colin Russell's analysis, in either case, still requires an over-riding stewardship ethic.

RESOURCEFUL EARTH VS. EARTH AS TEACHER

A consultation was held at Windsor Castle on September 15-17, 2000 by the John Ray Initiative to explore the value and robustness of *stewardship* as a theological, philosophical, scientific, and pragmatic concept. Its intention was to investigate the biblical and traditional roots of stewardship, together with any implications from scientific perspectives, and to inquire whether these provide an adequate description for general use in the secular as well as religious context. The consultation was under the leadership of Sir John T. Houghton, co-chair of the first Scientific Assessments for the IPCC, and geneticist R. J. "Sam" Berry of University College London; and I was one of four speakers in four half-day sessions attended by 24 key thinkers. The arrangement was that one of us speakers would be asked after the first four lectures to give a second presentation, informed by the first two days, as a conclusion who turned out to be me and I wrote:

A worldview that perceives human life and economy within the wide embrace of Creation's economy is a necessary component of every successful culture. What UCLA geographer and biologist Jared Diamond describes for the collapse of Easter Islanders can become a metaphor for our earth. (p. 148) [29]. "When the Easter Islanders got into difficulties, there was nowhere to which they could flee, nor to which they could turn for help…" (p. 119) [30].

Successful cultures and civilizations must shape and reshape human behavior in the direction of maintaining individual, community, and environmental sustainability… They had to understand their world and its workings by direct experience and accumulated knowledge (scientia), had to gain from their experience and culture an understanding of what constituted right

living in the world (ethics), and had to put an interactive and coherent understanding of the world, and how rightly to live, into practice (praxis). Their behavior had to flow from the interactive and coherent engagement of scientia, ethics, and praxis… This is the essence of stewardship. *Stewardship dynamically shapes and reshapes human behavior in the direction of maintaining individual, community, and biospheric sustainability in accord with the way the biosphere works.* (p. 150) [29].

WINDSOR CASTLE & THE LONG WALK

Following the concluding session of the Windsor consultation on stewardship, John Houghton and I strolled along the Long Walk out from Windsor Castle, talking about what we should do next in our life's journey. We concluded that it was vital to bring together leading climate scientists and evangelical leaders at a forum to discuss global warming and our common home. About this a pioneering atmospheric physicist and author of a highly-regarded book, *Global Warming: The Complete Briefing*, a book that in its 5 editions had a chapter on Why We Should be Concerned, NRC meteorolgist and climatologist, John S. Perry, in an editorial review in the Bulletin of the American Meteorological Society, wrote:

John Houghton has drawn on the exhaustive efforts of the Intergovernmental Panel on Climate Change to produce a notably compact, impeccably concrete and authoritative, meticulously balanced, and lucidly presented guide to the complex yet vital issue of global warming. Houghton holds that we humans are thus on earth for a purpose – to serve as its stewards, not just on behalf of the future carriers of selfish genes but on behalf of God. Many avowed agnostics such as myself, will find this forthright declaration of religious belief and divine purpose a bit startling in an otherwise rigorously scientific volume. However, in a line of argument that I have no difficulty at all in supporting, Houghton demonstrates that the domains of science are simply complementary ways of looking at the truth. The former deals with how the world works and the latter with why [31].

The Forum on Global Warming and Climate Change was held at St. Anne's College, Oxford University, July 14-17, 2002. Its some 70 leading climate scientists, policy-makers and Christian leaders from across 6 continents produced the Oxford Declaration on Climate Change [32]. It declared that activities, especially the burning of coal, oil and natural gas, are rapidly increasing the concentrations of greenhouse gases, especially carbon dioxide, in the global atmosphere… And it concluded that the Christian community has a special obligation to provide moral leadership and an example of caring service to people and all God's creation and proclaimed that human-induced climate change is a moral, ethical and religious issue and a matter of urgent and profound concern. It referenced the biblical teaching on loving your neighbor, with the new implications of this in the face of present and projected climate change (Matthew 22:37-39), on reconciliation of all things (Colossians 1:20) and on the human calling to the ministry of reconciliation (2 Corinthians 5;18-19) [33]. Finally, the Oxford forum participants called upon leaders in churches, business and government to join them in recognizing human-induced climate change as a moral and religious issue and to take necessary action to maintain the climate system as a remarkable provision in creation for sustaining all life on Earth.

OUR COMMON HOME REQUIRES A COMPELLING UNDIVIDEDNESS

Civilization, from the agricultural revolution beginning some 10,000 years ago and urban development beginning about 5,000 years ago, has had a reliable and hospitable climate. As for the past ten millennia, it can be in the future. At present, however, Earth's climate regulation system is being seriously compromised. It is this that brought Jesuit chemist and pope, Jorge Mario Bergoglio, to write, "Now, faced as we are with global environmental deterioration, I would like to enter into dialogue with all people about our common home" [34]. He had taken on the name Pope Francis, whose namesake from Assisi is his guide and inspiration and with this invitation introduced his comprehensive treatise, *Laudato Si' – On Care for Our Common Home* – a scientifically and ethically grounded treatise on climate change, biodiversity loss, ocean degradation, atmospheric pollution, and social degradation [34].

As I was finishing my review of his treatise – for *The Quarterly Review of Biology* in 2015 [35] at the invitation of its editor-in-chief, Daniel Dykhuizen – I found myself being drawn to a compelling conclusion: *Laudato Si'* is so clear-sighted in its prophetic description of the present, so integrative of science and religion and of human and natural ecology, and so vital toward caring for Earth as Our Common Home, that it clearly earns the status of *required reading* for everyone, even as it embraces everyone and everything. For chemistry, physics, biology, ecology, and all of the natural sciences, it is particularly significant as it compels *undivided perseverance* on Care for Our Common Home. So too for science and religion as I have described in "Earth Stewardship and Laudato Si': Care for

Our Common Home Compels Undividedness of Science and Religion," a blog article for the International Society for Science and Religion [36].

In this treatise, he is aiming not for mere dialogue but the dialogue that results in appropriate action that is at once swift and deliberative. Human civilization, and indeed life on Earth, has come to global crisis – specifically in the sense of *crisis* – the Greek rendition of *crisis*, meaning: "The point in the progress of a disease when an important development or change takes place which is decisive of recovery or death." *Krisis* is "the turning-point of a disease for better or worse… a state of affairs in which a decisive change for better or worse is imminent" [37]. It is with this meaning that he writes "today's problems call for a vision capable of taking into account every aspect of the global crisis" in an *integral ecology* (p. 93) [34].

All of which makes Pope Francis' *Laudato Si' – On Care for Our Common* Home required reading as a remarkably comprehensive treatise on understanding and caring for the earth system as our common home. And its title invites every person on earth to "gratefully admire the beneficent arrangement which permits the Earth to be clothed with verdure and abundant life," as astronomer Frank Washington Very presaged this in 1900 (p. 130) [38].

We have come to realize, with Francis, that "Given the scale of change, it is no longer possible to find a specific, discrete answer for each part of the problem. It is essential to seek comprehensive solutions which consider the interactions within natural systems themselves and with social systems. We are faced not with two separate crises, one environmental and the other social, but rather with one complex crisis which is both social and environmental. Strategies for a solution demand an integrated approach to combating poverty, restoring dignity to the excluded, and at the same time protecting nature." (p. 104) [34]. My "Earth Stewardship and *Laudato Si'* " [35] develops these topics and themes in a more detailed and more-comprehensive 14-page paper that is available as a free download at https://doi.org/10.1086/688096_and Pope Francis's *Laudato Si' – On Care for Our Common Home* is available as a free download at www.papalencyclicals.net/.

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