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Review

Review of the twenty-three year evolution of the first university course in green chemistry: teaching future leaders how to create sustainable societies

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ABSTRACT

In 1992, it was clear that the challenge of transforming tertiary chemistry education to assist with leadership development for what is now called "sustainability" held important potential. There were no appropriately focused university courses. Green chemistry had not been named. So a course for upper level undergraduates and graduates, now entitled *Chemistry and Sustainability* (*C&S*), was launched to build both professorial and student competence for advancing the relationship between commercial chemistry and health and the environment. *C&S* has undergone iterative development ever since to better educate students in sustainability leadership. This contribution reviews the insights that clarified into what is important for tertiary education to address in chemical sustainability. The reviewed *C&S* concepts, methods, tools, and assessments include: 1) the strategic thinking, 2) three early sets of principles evaluated for relative steering power toward the most hazardous chemical sustainability challenges, 3) the syllabus and objectives, 4), the presentation style, 5) the thematic content highlighting; (i) the organizational tool for green science technical challenges called the *C&S Bookcase*, (ii) the conceptual-analytical tool for identifying future-safe technologies called the *Technology-Sustainability Compass* (TSC), and (iii) the ethical code developed to provide students with a theoretical foundation for sustainability path-finding called the *Code of Sustainability Ethics for Leaders* (COSEL), 6) the interdisciplinary content meshing technical chemical education with (i) the pursuit of transgenerational justice developed from the ethics of Hans Jonas, (ii) the history of chemical pollution, (iii) the impact of toxic elements, persistent molecular pollutants and endocrine disruptors on health and the environment, and (iv) strategic leadership for sustainability, 7) the use of stellar internet resources on the health and environmental content of energy and chemicals to emphasize immediacy, relevancy and importance, 8) the homework assignments, and 9) the 2014–15 student course analyses. This review is intended to deliver cognition grenades to vaporize clouds of obscurity shielding fortresses of unsustainability in the chemical enterprise—the most demanding sustainability challenges today are cultural strongholds that must be breached and not technical rivers that must be forded. The key *C&S* transformative insight is that cultural blockades against the rational advancement of sustainability within the chemical and allied enterprises, the resulting impacts, and the strategies for breaking free should be emphasized with the relevant technical content in the quest for competence in educating leaders for a sustainable world. This long review is a concatenation of four thematic reviews, so integrated to help interested teachers design related courses.

1. Introduction

1.1. The epic question of sustainability

A civilization that does not conceive of itself as a living entity embodying a past from which it can learn, a present in which it chooses to act for the common good, and a future of which the

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open-ended good is its dominant strategic objective is doomed to drift helmless toward self destruction. Is our global civilization so doomed? Or will we answer affirmatively the most Epic Question our species has ever had to confront: *"Is a large technologically powerful human population sustainable on the earth?"* (Collins, 1997).

This question does not have a contemporary yes-or-no answer. Instead, it challenges leaders everywhere to move the world toward "Yes". How can leaders judge whether any course of development, ethical, educational, legislative, economic, technological, environmental, social, etc., is heading their jurisdictions toward "Yes"? And how should leadership performance be assessed? Future-oriented ethics is the best rudder for holding a course toward sustainability, and science is the best compass for avoiding negative impacts of development decisions on the functioning ecosystems on which all life depends. Therefore, the foul winds of unsustainability wane and the fair breezes of sustainability freshen according to the leader's fealty to the future good and commitment to be guided by science.

On Wikipedia: a tool for interdisciplinary communication

The use of online encyclopedias is often frowned upon in academic scholarship. However, if cross-disciplinary activity is to be the core of sustainability competency, then isn't every mechanism that helps scholars to learn quickly about other fields worthy of support? By using resources such a Wikipedia critically, scholars in one field can quickly assess what is going on another as an entry point for facilitating collaborations. Wikipedia entries evolve. While Wikipedia citations could undermine scholarly purposes by unpredictable future changes, for the rapidly evolving fields that matter most to sustainability, updating offers the advantage of contemporaneity. In recognition of the utility of Wikipedia in developing *C&S*, it will be judiciously cited from herein.

An Everest of scientific data is telling us that our civilization is not sustainable and that many perils are technological in origin. The list of calamities includes, *inter alia*: the human population has outgrown the planetary capacity; atmospheric carbon dioxide levels keep rising to render permanent environmental and societal disruption ever more inevitable; the oceans are being poisoned, killed, heated, filled and acidified; biodiversity is being devastated; the familiar hydrological cycle is collapsing; the low dose adverse effects of some everyday chemicals threaten to degrade the nature of life itself; and novel farming practices and regional societal instabilities have created favorable evolutionary conditions for superbugs.

How did our species arrive at environmental chaos that will surely doom its future absent rapid, radical change? The scholarship and process of perfecting *C&S* has educed a simple answer: the ethical foundations of human decisions today are mostly not future-oriented at a time when human power has escalated through science and technology to future-lethal potency—all prior ethics are inadequate for securing sustainable development (Jonas, 1984).

The absence of an ethic of love and responsibility for the future has resulted in our *carpe diem* existence with an almost civilization-wide impotency to make sleepwalkers of ordinary people and permit present-obsessed, economically and not scientifically impelled power to coerce the world to the edge of the precipice. The crises of sustainability are, first and foremost, crises of leadership. Competent leaders steer their dominions away from future-unsafe toward future-safe technologies. For example, by steadfastly reorienting their energy economies away from carbon and nuclear and toward renewable sources, leaders of Germany and many other jurisdictions doing likewise (Shahan, 2013) have been mapping an energy path toward sustainability (Heinrich-Böll-Foundation, 2015). Achieving an accurately informed citizenry who have shaped their values to prioritize the future good is our best chance that more leaders will arise to overcome the deadly evasions of sustainability-compelled change. This requires that people everywhere become better educated on the causes and consequences of unsustainability and the strategies and methods for escaping its mortal grip.

Universities train many if not most of the leaders of our civilization. Therefore, the engagement of the universities is key to answering the epic question affirmatively. What problem can be more important to a university than that the civilization in which it resides is not sustainable? Credibly, the prime obligation of the modern university is to become an icon of sustainability allegiance. The changes required in the technological estate are sweeping and call for leaders who are up to the task, in turn missioning universities to educate students to champion transformative change. Thus, dedication to the future good ennobles each university ever more splendidly by the vitality of the sustainability promoting countercurrent it can creatively energize.

1.1.1. Methods

This course-focused review is confined in scope to how *C&S* developed and the advances that have been adopted. Thus, in all sections, the references chosen are those that have been central to the course development or are directly related to the content.

1.2. Strategic thinking: reflections on building sustainability education in chemistry and science

This review describes a first-of-its-kind course (Collins, 1995), now entitled *Chemistry and Sustainability (C&S)*. It follows as a series of author reflections on the 23-year evolution into what has worked in educating students for green science leadership. The target age group is senior level undergraduates and graduates—the split is usually about even. There are no prerequisites and the course is an elective. Younger students sometimes take the course. The class size has been 15–21 in recent years (large for a CMU chemistry elective). The interested reader will not understand *C&S* deeply, especially the reasons for the strong cultural criticisms, without studying and preferably completing the assignments. To summarize the developmental thinking, six questions about constructing academic sustainability follow with the answers that evolved in *C&S*.

1.2.1. How can universities best configure to educate sustainability pathfinders?

Should sustainability education be its own major to provide a pan-disciplinary meeting point (Broman et al., 2002; Missimer and Connell, 2012)? Or should professors in each department tailor distinct sustainability curricula for their disciplines? Or are both approaches important and complementary (Collins, 1995)?

In *C&S*, content has been tested and retained according to its benefits for conveying insight into sustainability leadership. This process has moved the course ever more toward hybridized multidisciplinary material. To gain confidence with the novel material, help was sought globally from scholars in multiple fields. For effective content diversity, the collaborations occurred mostly outside Carnegie Mellon often grounded in technical research (not discussed herein) and nurtured via meetings and electronic communication. Today, academic sustainability may best be advanced in most universities through virtually maintained, multi-institutional "colleges", while each works to acquire critical strength. Sustainability easily unites scholars across disciplines and institutions.

1.2.2. What are the most effective sustainability leadership tools for a course such as C&S?

One example is the *Framework for Strategic Sustainable Development* (FSSD, see Section 2.4 and references in Robèrt et al., 2013) which relies on backcasting, i.e. on imagining a desirable future while informed by basic sustainability principles, on understanding the business case thereof, and then, on mapping a path from the present and defining the tools and assessment protocols required to attain it. The FSSD has been cleverly designed to help people work harmoniously across disciplines, sectors and cultures. It has spread to several institutions as described elsewhere in this Special Issue and I consider it of great significance to the advancement of systematic leadership toward sustainability (Broman and Robèrt, 2015; Broman et al., 2013). Early in *C&S*, the FSSD and its principles are described emphasizing the utility for strategically mapping sustainability solutions.

Another example is the *Tiered Protocol for Endocrine Disruption* (TiPED) (Schug et al., 2013), a joint achievement of environmental health scientists and green chemists (see Section 3.5.5.1). The TiPED is a tool for the design phase of new commercial chemicals to avoid endocrine disruptors (EDs, see Colborn et al., 1996; Vandenberg et al., 2012; TEDX, 2015; Khetan, 2014). EDs are riveting. The mere idea that traces of everyday chemicals, in amounts commonly found in people, could be disrupting cellular development and signaling to impair living things sounds like the plot of a science fiction horror movie. Yet copious evidence from wildlife, lab animals, in vitro studies, biomonitoring, epidemiology including human diseases, purposed human uses (e.g., synthetic estrogen in the reproductive pill), and human accidents indicate that, with EDs, this is precisely what is happening today—see Assignments 3 and 5. Endocrine disruption, and low dose adverse effects in general (Haugen et al., 2015), have changed the meaning of chemicals to human welfare forever. It is an inescapable duty of academia to contribute to understanding, reducing and eliminating developmentally disrupting compounds. By developmentally linking green chemistry and environmental health sciences, the TiPED has increased the ability of each field to contribute to these goals.

1.2.3. How should the content of a transformational curriculum for sustainability be different from contemporary offerings?

Unique content for a chemistry course has been developed in *C&S*, as follows: (i) Sustainability ethics contains the principled ideas that can unite all disciplines to provide leaders with a secure, shared, theoretical foundation for the ordeals of transformative ambitions and action. In *C&S*, students study the ideas of Hans Jonas (Jonas, 1984)—see Assignment 4. Green chemistry is presented as a practical expression of Jonas' call to update our values to deal with the science and technology engendered "whole new dimension of ethical relevance for which there is no precedent in the standards and canons of traditional ethics". The course ends with the Code of Sustainability Ethics for Leaders (COSEL). (ii) Remarkable websites on environmental problems and solutions, including those of Environmental Health News (EHN, 2015), The Collaborative on Health and the Environment (CHE, 2015), PanSwiss (PanSwiss, 2015), The Endocrine Disruption Exchange (TEDX, 2015) and clean energy, Cleantechnica (Cleantechnica, 2015), provide regularly updated content for emphasizing immediacy, relevancy and responsibility. (iii) The surprising revelation from developing *C&S* is that the most stubborn and mordant infarctions clogging the lifeblood of sustainable development in the corpus of the chemical and allied enterprises are not technical, but cultural. Extraordinary feats of scholarship and documentary journalism have made it possible for *C&S* students to dive deeply into the history of unsustainable values, technologies and practices and to fathom why and how these were able to inflict grave injuries on our civilization with impunity—e.g., see Assignment 2. Students who study these histories are better equipped to steer industry away from utterly unsustainable values and evidently unsustainable development.

1.2.4. How should university educators teach dire sustainability facts and challenges?

For *C&S*, this translates into what tone is appropriate and how stark should be the presented facts. It is often said that selling the problems of sustainability doesn't work, but that selling the solutions does. This assertion would hold legitimacy if the entire civilization was driven to solve all the key problems with existing solutions serving as inspiriting motivators.

Unfortunately, only pockets of the civilization function in this way. Too often, the assertion is a cudgel against progress. Those who avow with a smile, "I am an optimist!", especially if they are prone to trample on the messengers of realism as "pessimists", trade in extremely dangerous, self-serving illusion. Their claims are anything but optimistic. In a world where the cradles of oceanic life, the coral beds, are dying off rapidly (Ingleton, 2015), authentic sustainability solutions cannot come packaged in comforting sound bites that anesthetize listeners into believing all is well with the current system. The current system IS the problem. What is called for is neither more optimism nor more pessimism. What leadership at all levels needs more of is realism and competence, understanding the depth of the challenges in combination with a competence to steer away from disaster and head towards attractive solutions.

Too often, the false optimists are richly rewarded for the temporary comfort their assertions provide, all while they enfeeble positive action. As Jonas teaches, we must apply a "heuristic of fear, replacing former predictions of hope" which must "tell us what is possibly at stake and what we must beware of" (Jonas, 1984), an axiomatic harbinger of the Precautionary Principle. In chemistry, authentic sustainability teaching demands a dispassionate analysis of bleak factual content. This serves to alert students into how serious are the challenges their generation must face while it primes future leaders for running the gauntlet of the false optimists. According to the Brundtland Commission, "Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Commission, 1987). In practice, managing this duality in science, where all the toughest challenges reside in the duty to the future, has become a tournament between those who budget on the social power dynamics of the present and those who prioritize the scientific facts of our plight and work for transformative change.

This having been noted, there is reason to celebrate. The world's energy compass is well on the way to being reset toward sustainability with, for example, accelerating growth in photovoltaic energy capture (Shahan, 2014; Wikipedia-1, 2015). As with "carcinogen" in the 20th century, "endocrine disruptor" is becoming a household term in the 21st century (Wikipedia-2, 2015). With such shifts in the global economy and consciousness, the move toward sustainability relevant chemical education should get much easier for universities.

"The chemical enterprise" is a term used herein to capture the chemical-associated collective of, *inter alia*, the universities and

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their scholars and students, all other educational institutions, government, industry, company executives and owners, investors, professional societies, learned academies, trade associations, nonprofit observers and analysts, public commentators, chemical product formulators and users, and retailers. The chemical enterprise is a vital component of the technological estate that is of immense benefit to our present day world and of encompassing importance to its future vitality. In *C&S*, admiration is professed for authentic sustainability-oriented efforts found in each enterprise sector. But the overall tone cannot escape being decidedly critical to shine light on the real challenges while seeking to advance solutions and make the chemical enterprise both profitable and sustainable.

Because sustainability is being severely injured by some everyday–everywhere chemicals, moving away from "No" and toward "Yes" requires the development and teaching of a field that aims at *both* designing sustainable chemicals *and* raising awareness that unsustainable commercial chemicals need to be reduced and eliminated by every means available. Development of just the former leads to an abased field that avoids important challenges when power might be offended to become a distraction from the main mission. Development of just the latter could lead unacceptably to a protest movement. The work in *C&S* to foster an authentic transformation is also grounded in scholarly understanding that the freedom to engage without reserve in controversial subjects that are of great importance to both reason and the public good is the raison d'être of American academic tenure (Collins, 2008). When it comes to duplicitous tactics that protect chemical industry cash flows at the expense of the common and future goods—see Assignment 2—a censorious tone is the only appropriate educational posture.

1.2.5. Will reinventing the curriculum be sufficient to transform universities into safe havens for nurturing sustainability-competent leaders or are other changes necessary as well?

The early thinking of David Orr is excellent for reflection on this question (Orr, 1994). To me, the most important measures of university prowess in sustainability take the form of real accomplishments from research, education, entrepreneurship, and alumni careers in steering the civilization toward scientifically verifiable, future-safe development.

The Declarative Question for identifying sustainability dutiful academic R&D projects

Is it clear by the best contemporary science that whatever product, process or activity this project is advancing will not injure the future good?

So if this were to become the generally accepted benchmark of excellence, doesn't it follow that universities would perform more excellently by ceasing to promote research programs that greenwash unsustainable technologies? Doing so would undoubtedly reduce the cognitive dissonance that echoes through the halls of academia to confuse students over what sustainable development is or might be, and what it absolutely is not. The key problem, of course, is that mountains of research money are often enough available to study and ally with unsustainable products, technologies and practices. *In sustainability R&D*, it is not the source of the money that counts, it is the sustainability signature of the product, technology or practice that is being advanced. When examining whether an academic project is green science or greenwashing, there is a simple Declarative Question (see Inset). If the answer to this question is negative (I will return to how this can be assessed in Section 3.3), the project is greenwashing. It is not sustainability dutiful and an association with it will damage the sustainability integrity of the university. In *C&S*, students evaluate case histories to develop the skills necessary for articulating verbally and in writing the causes and consequences of environmental degradation. In the process, they sharpen their insight into what is and is not sustainability dutiful. They learn the tactics of unsustainable industries in infiltrating and manipulating academia, the government and the public to block regulatory action and kickback against their existence and expansion—see Assignment 2.

Can a university be authentic in its desire to help build a sustainable future while providing safe harbor for R&D that advances unsustainable technologies and practices? It makes sense that there should always be room for academic engagement with any technology space—academic research is often key to determining the sustainability character of products, processes and activities. And subtleties abound in academic/industry relationships that impact whether or not the common good is advanced. However, whenever an academic researcher partners with industry or engages otherwise in *directly advancing an objectively unsustainable technology that can never be made sustainable*, the future good is injured; in *C&S* such technologies are called "civilization killers." Here, bargains, perhaps unthinking or perhaps Faustian, are struck to trade the intellectual prestige and technical assistance of respected researchers and institutions of higher learning for research and development money—classic examples can be found in the reading material of Assignment 2.

One common academic rationale for struck bargains is that the health and environmental damage of unsustainable technologies will somehow be mitigated by the funded research. However, the principal result is academic participation in "civilicide", a still loosely defined term that can be found on the worldwide web. In *C&S*, civilicide is used to mean "deliberate engagement in advancing civilization killing activities". Another is that the potential benefits of pursuing pure science should outweigh any constraints associated with funding sources. Here it is indeed possible to redirect funding from unsustainable technologies to good purposes. But if the bargain comes at the expense of professors playing along uncritically in misdirected development, cognitive dissonance will invade their institutions. And this can be devastating to the institutional capacity to attain authentic sustainability leadership. Those who knowingly advance unsustainable technologies, and/or who do not take responsibility for their own competence to know the difference, are parties to civilicide. Researchers who claim they might make less odious the oil sands industry of Alberta in the name of green chemistry or who turn blind eyes to the perils of gas fracking in Pennsylvania provide examples in point. If for no other reason than immense CO_2 releases are inescapable, these technologies do not pass the Declarative Question, are abject civilization killers, and should not be being developed—each is associated with many other sustainability negatives (Deyette et al., 2015). While blame for our sustainability plight can be spread widely, it matters not that civilicide in our time amounts to death by a thousand cuts, thus giving knife-wielders cover from ever being identified as having delivered the fatal wound. Every cut not inflicted gives our civilization a better chance of survival. In contrast, some renewable energy technologies pass the Declarative Question.

The above paragraphs are a profession of concern, not an angry accusation, even if bluntly stated. The social dynamics are terribly difficult. How can individual faculty members say no to attainable research funds when research support is so hard to come by and so

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many of the markers of academic achievement and advancement mandate that researchers raise ample funding? How can university administrators say “No!” when the majority voice of local and/or national leaders and donors favors academic engagement to “improve” a technology that can never be made sustainable when universities are so expensive to operate? Even if the professors and university officials comprehend the sustainability perils, the personal and institutional dangers of resisting the political will are considerable. The possibility of a good outcome of such resistance is theoretical in a real-time world and the near-term rewards of going along with the political flow are ever present and often considerable. However, by prioritizing the duty toward sustainability, universities become leaders in reorienting misdirected political power and money streams that follow from such. Taking responsibility for learning the basics of sustainability also provides an opportunity to reorient money streams towards sustainable innovations already in the short term. And vice versa, not having the skills makes it difficult or impossible to “sell” the business case of such ideas to industry. In our unsustainable world, acquiring this competence is an obligatory role.

Academic partnerships with unsustainable industries need not be Faustian at all. An inspiring academic pursuit for advancing sustainability entails helping companies based on unsustainable products, processes or activities to develop sustainable alternatives. This is the presumptive modus operandi of green chemistry. In practice, any such goal needs to pass the Declarative Question and other practical and cultural reality checks. But if realistic strategies for sustainability can be identified, everyone can win in such sustainability dutiful projects.

In summary, a hard question is inescapable for universities wishing to embrace sustainability dutifulness and leadership. Shouldn't the professors and their institutions recognize an ethical mutual exclusivity between the imperative of educating students to build sustainability and accepting research money to promote objectively unsustainable technologies? These questions for universities have likely parallels in all the various institutions of our global civilization, from the governments, to the corporations, to the militaries, to the religions, and so forth.

1.2.6. Are there precepts for forging aspirant leaders, maxims to steel the mind for leading the world toward sustainable technologies and away from obdurate industries that must change direction or be shut down for the future's sake?

In *C&S*, a *Code of Sustainability Ethics for Leaders* (COSEL) has been developed to serve as a set of such precepts as described in Section 4.

2. Principles

Green chemistry has been serving as the first dynamic laboratory for working through the intra- and inter-disciplinary and cross-sector challenges associated with the transformation of a physical science to sustainability-promoting consciousness and action. Therefore, the green chemistry experience could be of value to other fields. Moreover because chemistry is so central to the material domain, the sustainability issues tend to have towering consequences, making of chemistry both a perfect field for transformational construction and perhaps one of the hardest redirections imaginable. Thus, the sharper aspects of this review arise from studying the ancient and forward history of lead and other heavy metals industries and through scrutinizing and sometimes experiencing industry and trade associations maneuvers over the adverse effects of organohalogens, pesticides, micropollutants and especially endocrine disruptors.

2.1. The definition of green chemistry

Green chemistry has aspired to be the field where chemists tackle sustainability problems. The definition encompasses critical goals for social and ecological sustainability on a global scale —“Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances” (USEPA, 2015a).

2.2. Progress in meeting the definition of green chemistry

After almost a quarter century of development, if the field of green chemistry wants to be the champion of chemical sustainability it claims itself to be, then it must more effectively guide the chemical enterprise away from the major chemical assaults on health and the environment and, in conjunction, engage more directly in the huge potential of chemistry to be innovative in the assistance of all societal sectors to solve their chemical problems, and engage in a “market” of immense potential. Again, for companies this is typically more a matter of challenging visions and competence than of public penance.

2.3. The different sets of principles for green chemistry

While one can admire and support the dominant and beautiful work that advances clean reaction processes, green chemistry today is only starting to live up to the promise implicit in its definition. In asking why this is might be so, it is necessary to return first to the incunabula of the field. A 1995 article noted that, “The principles of green chemistry that can energize our classrooms and bring long-term meaning and direction to a component of academic research await clear definition” (Collins, 1995). In 1997, the first suggestions were advanced for what these principles might be. In précis, these are: 1) Green Chemistry aims to protect life, 2) Green Chemistry needs to be interdisciplinary to be successful and, 3) because of the immense complexity, if funders want Green Chemistry to succeed, they will need to back a significant section of the field in the long-term (Collins, 1997). The tentative nature of these earliest suggestions was predicated on the understanding that if inadequate principles became ensconced, the field would be seriously injured.

In 1998, the well-known “Twelve Principles of Green Chemistry” of Paul Anastas and John Warner were published (Anastas and Warner, 1998). At that time, I was not sure what principles would best serve the field. The A&W principles—available also on the internet (Anastas and Warner, 2011)—place minor technical strategies for achieving cleaner syntheses on the same pedestal as expansive tenets for advancing sustainable products and processes. There are clear dangers in this. But all things considered, I chose to ignore my earlier suggestions and promote the A&W principles as the best way to develop the field (Collins, 2002)—today, I regret this.

The A&W principles have become successful rallying ideas for focusing chemists primarily on reducing chemical hazards by changing what goes into, occurs in, and comes out of reaction flasks and reactors. The technical skills and project dynamics are generally familiar to chemists and place a cumulative emphasis on synthetic chemistry. The same goal space is emphasized by the Presidential Green Chemistry Challenge Awards with some non-synthesis flexibility in only two of the five awards (USEPA, 2015b). However, the synthetic problems pale in sustainability significance to the challenges of reducing and eliminating EDs and persistent molecular species, and escaping the releases of toxic elements, methane and CO_2. Updating the categories to better prioritize the chemical challenges of sustainability would make the awards and field more consequential.

2.4. The limitations of a chemistry-focused field of green chemistry

A foreseen danger of the A&W principles has materialized. By highlighting that a particular project conforms to one or more of the A&W synthetic "principles", researchers can argue successfully that it is green chemistry. However, in noteworthy cases, this identification has violated the original and forgotten first principle, "Green chemistry aims to protect life" (Collins, 1997), because the projects in question support the expansion of objectively and irredeemably unsustainable technology domains. Some of the most well supported academic green chemistry programs today are so engaged. The A&W principles as characteristically applied are not able to distinguish greenwashing from green science. The original first principle implicitly asserts, "Don't greenwash!" It must remain indubitable for any field that presupposes that it can design a safe chemical future for a civilization that is bewildered from time to time by scientific revelations of bizarre toxicities and that must negotiate the intemperate product protectionism of unsustainable segments of the chemical and allied enterprises (see Assignments 2, 3, 4 and 5, and Horel, 2014; Markowitz and Rosner, 2002; Moyers, 2001). So whenever anyone examines whether a research project belongs under the umbrella of green science or analyzes an industry/academic relationship for fidelity to sustainability, *The Declarative Question* might well be the best first yardstick.

Remarkably, for many years the flagship journal, *Green Chemistry*, held the policy that studies containing toxicity experiments should be directed to other journals. This served to further isolate the field from the multidisciplinary skillset that is mandatory for meeting the vision of protecting life, while helping to confine it to a small and inadequate vision for sustainability, that of being a subbranch of synthetic chemistry. Thus, it is fortunate that the TiPED was published in *Green Chemistry* (Schug et al., 2013) to break the restrictive policy and to position the journal for advancing science that can crack the major research and educational problems of chemical sustainability.

Largely because of poor understanding of endocrine disruption and its importance, chemical substitutions to improve safety have backfired badly in recent times. The inadequate chemistry-focus of the A&W principles is reflected in recent claims that green chemical design rules can lead to substitutions with no regrets by looking through the correlated lenses of the physical/chemical properties of molecules and current toxicity knowledge (Zimmerman and Anastas, 2015). This Quantitative Structure Activity Relationship-like (QSAR-like) approach could be helpful. But chemical toxicology today is more complicated than ever before. Effective green chemistry design rules must lead the chemical enterprise away from EDs. It is doubtful that looking forward from chemistry with a property-based predictive approach could ever be powerful enough to penetrate the time-of-exposure dependent, non-monotonic, low dose–response developmental and physiological signaling disruptions by which EDs impair organisms with endocrine systems—just for starters, most available toxicity information is not low dose (TEDX; Vandenberg et al., 2012). A much more powerful approach involves finding the actual ED effects through toxicity studies and then empirically disentangling the mechanisms of action. The living TiPED (Schug et al., 2013) is designed to enable this because it deploys frontier theoretical and experimental assays that can be updated and that are capable of vividly alerting science to the diversity of low dose adverse effects, both known and unknown, both endocrine related or otherwise. And it incorporates numerous assays for working backwards from detected adverse effects in whole organisms to identify mechanisms of action.

In a chemistry-focused field where multidisciplinarity is not embraced, cultural barriers become much more difficult when the scientific information mandating sustainability-required change lies outside chemistry. In green chemistry's growth to date, cultural challenges have been the most divisive, intransigent and confining. Willing green scientists have had to learn how to explain and discuss alarming toxicity facts—see Assignments 2, 3 and 5—and ugly camouflaged behavior (see Assignment 2 and Horel, 2014; Markowitz and Rosner, 2002; Moyers, 2001)—without alienating audiences who know little or nothing about the underlying hazards. It is so much more winsome in real time for knowledgeable chemists to ignore than to address the chemical injuries to humans and the natural world, the malfeasance over toxic chemicals, the misdirected development, the manipulation, buying and cowering of governments, the technologically induced injuries to vulnerable countries that presage future wars, the undermining of civilization, and the tactics that underprice life to maintain steady cash flows based on unsustainable products and processes. The scholarship of these themes has become fundamental to *C&S*. Yet the landscape is so Stygian, for example covering emotionally sensitive topics such as ED damage to the human reproductive tract (Kalfa et al., 2015) and sexuality, and sometimes covering emotionally sensitive topics such as ED damage to the human reproductive tract and sexuality, that the teacher could appear alarmist and antagonistic to lose credibility simply by articulating the facts accurately. However, the student reception of *C&S* is overwhelmingly positive. All optimistic light shines forth from the courage to deal with these very practices and facts. And a willingness to follow this light to steer the world away from the impedimenta of unsustainability defines the backbone of authentic sustainability leadership in chemistry.

2.5. The FSSD sustainability principles (SPs) promise superior principled guidance for green chemistry

As things currently stand, if the object is to teach students a solid grounding in the chemical dimension of sustainability, the green chemistry of today is only a small part of the narrative. Thus, some years ago I began searching for other ideas around which to build *C&S* that weren't my own. While much integrative work remains to be done, the FSSD offers a set of four broader Sustainability Principles (SPs) (Robèrt et al., 2013) that are not as skewed as the A&W Principles toward achieving cleaner processes, but instead floodlight the panorama of technical and cultural sustainability challenges—I will return to this below.

3. Course content

3.1. Course objectives of Chemistry and Sustainability (C&S)

The principal aims of *C&S* are that students should be able to:

- Articulate how sustainability ethics applies to chemistry and know and relate the arguments and logic of Hans Jonas as laid out in *The Imperative of Responsibility* (Jonas, 1984).
- Know how to be guided by the *Framework for Strategic Sustainable Development* (Robèrt et al., 2013) and the *C&S Technology-Sustainability Compass* (TSC; see webinar in Collins, 2013) for evaluating technologies for sustainability.
- Understand how to define *green chemistry* and compare proposed unifying concepts, including (i) the *C&S* Three Principles of Green Chemistry and Bookcase, (ii) the Anastas and Warner Twelve Principles of Green Chemistry, and (iii) the FSSD Four Sustainability Principles (Robèrt et al., 2013), evaluating the strengths and weaknesses of each as foundations for a field of chemistry aimed at securing sustainability by protecting life.
- Identify and explain the major sustainability challenges of chemicals within and beyond green chemistry, know the progress to date in dealing with these and postulate what it will take

to evolve full solutions in both the technical and cultural domains.
- Understand the science of persistent, bioaccumulative and toxic pollutants (PBTs) and think creatively about reducing/eliminating these.
- Give accounts of the long-term histories of pollutants such as lead and dioxin, of the impacts on human health and the environment, of the underlying mechanistic toxicity, and of the cultural barriers that blockaded for decades attempts to deal reasonably with these pernicious assailants of sustainability (Markowitz and Rosner, 2002; Thornton, 2000).
- Discuss scientific understanding of the many other toxic products of the halogen industries and articulate the history of organohalogen pollution (Blum, 2015; Schulz, 2004; Thornton, 2000).
- Hold educated viewpoints concerning how people who control the chemical and allied enterprises sometimes lead our civilization away from sustainability and how people now recognized as sustainability leaders have vanquished the misdirected leadership, these viewpoints being developed by studying histories of sustainability errors, malfeasance and heroism found in such sources as *Deceit and* Denial (Markowitz and Rosner, 2002), *Trade Secrets* (Moyers, 2001) and *Endocrination* (Horel, 2014).
- Identify and describe examples of inspired sustainability leadership in the chemical and allied enterprises from the same material and from the course content on sustainability visionaries.
- Explain especially what endocrine disruptors (EDs) are, why EDs represent major health and environmental hazards, and why the *Tiered Protocol for Endocrine Disruption* (TiPED) (Schug et al., 2013) is the current quintessential example of interdisciplinary research for advancing green science.
- Reflect philosophically on individual and collective motives that lead to the adoption and commitment to technologies that are obviously harmful to health and the environment and think creatively about how to lead individuals and society to think better about advancing sustainability.
- Know the precepts of the *Code of Sustainability Ethics for Leaders* (COSEL) and consider how these can be helpful in building a career in sustainable development (see Section 4).
- Articulate a personal appraisal of what the role of the university should be in advancing sustainability.

The beginnings, developed in 2010, of a *C&S* derivative course in green science for high schools and the public, including 17 short videos, can be found on Carnegie Mellon University's Institute for Green Science (IGS) website (Collins, 2015).

> We stand now where two roads diverge. But unlike the roads in Robert Frost's familiar poem, they are not equally fair. The road we have long been traveling is deceptively easy, a smooth superhighway on which we progress with great speed, but at its end lies disaster. The other fork of the road—the one less traveled by—offers our last, our only chance to reach a destination that assures the preservation of the earth."
> Rachel Carson, *Silent Spring*

3.2. Course structure and course dynamics of C&S

The course opens with a short BBC video (Attenborough, 2011) featuring David Attenborough reciting "What a Wonderful World" (Armstrong, 1970) while some of the wondrous creatures we share planet earth with make cameo appearances—many are endangered, accentuating the need to develop a sustainable human civilization where these also might have a lasting future.

Each class starts with quotes relevant to sustainability (see textbox). The lectures are mostly delivered by commentary on Keynote slides—the students have paper copies on hand. Videos are interjected regularly, e.g., *Trade Secrets* (Moyers, 2001), *Roman Babies* (Warren, 2015). The graded material consists of four (undergraduate level) or five (graduate level) video production and essay assignments—the latest set is featured herein. There are no examinations, but class attendance is compulsory (two absences permitted). The twenty-nine 80-min lectures (Table) cover thematic concepts and the technical and cultural challenges and developing solutions of each *C&S* Bookcase shelf. In-class discussion is encouraged.

3.3. Course content—Technology-Sustainability Compasses (TSCs)

The insight that the technology direction taken should comply with unifying principles suggested the need for a sustainability compass. 'The resulting *C&S* TSC is based on *FSSD* SPs (Robèrt et al., 2013) to serve as a visual aid for comparing the impacts of alternative technologies on sustainability. The current TSC (Fig. 2) combines SP1 and SP2 for "chemically contaminating" and uses SP3 for "physically degrading", but does not include the social principle (SP4) (Missimer et al., 2010). Fig. 2 depicts the author's estimates of the compass settings for the impacts of the fossil carbon industry on sustainability. The intellectual underpinnings of the TSC also derive from the remarkable insight of Covey et al. on the tension between the compass and the clock in American professional life (Covey et al., 1994).

The TSC of Fig. 2 has three needles. Unlike a standard magnetic compass where a single needle points to magnetic north and the direction of motion is determined therefrom (Wikipedia-3, 2015), in the TSC true north is defined as a "fully sustainable technology for which no lasting injury to the natural world can be identified from its operation". From this ideal, less sustainable technologies move the needles away from true north by one of two mechanisms.

First, a technology can be *physically degrading* of the environment, giving rise to the orange needle, a "Determinator (D_{TSC})" that sweeps the right north-south TSC hemisphere. The TSC mechanism makes it clear that sustainable development relies on halting *more and more* encroachment and other physical destruction of fertile land and natural habitats. For example, in West Virginian mountaintop-removal coalmining, an immense physical assault on the environment follows upon the leveling of a mountain to the coal layer with dumping of the tailings in a nearby valley, thus deflecting the orange needle deep into the southern TSC hemisphere. If quantitative analysis of the needle positions eventuates, the impact of any technology under TSC scrutiny should be normalized for comparison purposes. For example, in the energy domain, quantitative D_{TSC} positions would derive from estimating the normalized environmental damage per unit of energy produced for each technology to remove confusion associated with the different scales of compared technologies.

Second, a technology can be *chemically contaminating* of the environment, giving rise to the purple D_{TSC} sweeping the left TSC hemisphere (Fig. 2). The example of coalmining contributes to *higher and higher* levels of CO_2 into the biosphere leading to lasting ocean acidification, atmospheric warming, ice melting with ocean rise, and ocean heating. Vaporized toxic elements on combustion poison the air, land and the water. The tailings leach toxic elements into surface waters in the long term. A recent newspaper article illuminates the torture imposed on

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Table
2015 *C&S* lecture topics.

L1: The syllabus
L2: The TSC Compass of Sustainability
L3–4: Sustainability Energy
L5: Green Chemistry Defined
L6: Green Chemistry Bookcase
L7: Sustainability and the University
L8–11: Sustainability and Lead
L12: Other Toxic Elements
L13: Mechanistic Lead Toxicity
L14: Greening of Lead Technologies
L15: Trade Secrets
L16: The Corporation
L17: Intro to Persistent, Bioaccumulative Toxic Chemicals (PBTs)–DDT
L18: Intro to PBTs–PCBs
L19–21: PBTs–Dioxins
L22–23: Intro to Endocrine Disruptors
L24:In-class Discussion on Content to Date
L25: Magee Womens Hospital EHS Symposium
L26: Endocrine Disruptors
L27: Sustainability Ethics
L28: Summing Up: COSEL
L29: COSEL and Conclusion

Fig. 1. The bookcase shelves of chemical problem spaces that are most relevant to sustainable development.

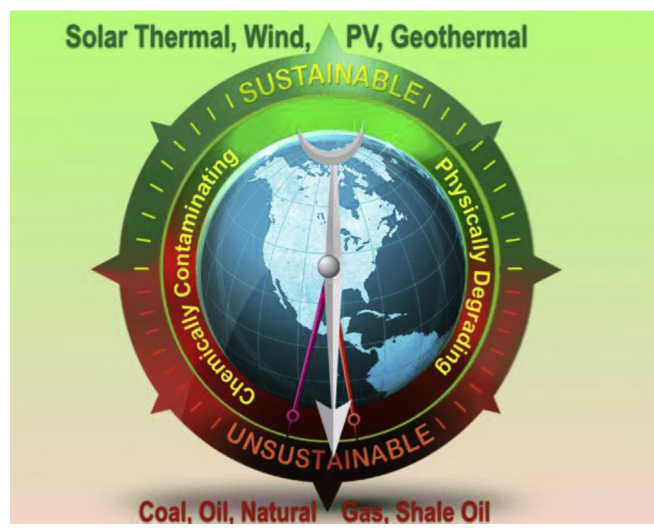

Fig. 2. The *Technology-Sustainability Compass (TSC)* inspired by *FSSD Principles* applied to global carbon energy technologies. The needles are set to show author estimation's of the overall compass settings, which in pointing near due south identify a sector that is a "civilization killer". If current development lines are not rapidly curtailed, these industries will inflict enough environmental damage to produce a "NO" answer to the opening epic question. See this webinar for how the compass operates: https://www.youtube.com/watch?v=1uPA3N1v8Tg.

sustainability by mountaintop removal coalmining and identifies the forces of civilicide in action in West Virginia today (Ward, 2014). The FSSD sustainability principled terminology '*more and more*', and '*higher and higher*' respectively, are essential elements of sustainability understanding.

The sustainability of human civilization cannot equate with no physical or chemical impacts on the ecosphere by man. Otherwise, how would we construct a city, a farm, or a well? Unsustainability does equate with more and more destruction and higher and higher contamination of ecosystems. Technically, this insight enables both the rational assessment of existing impacts and the choice to avoid further negative impacts by asking: "In our enterprise, will we or will we not contribute to 'more and more' and 'higher and higher', respectively?" With persistent synthetic compounds, adverse impacts are likely to occur because of the complexity of the ecosphere (Collins, 2001). To conform with FSSD principles, it is important to either phase out chemicals from consumer goods that are persistent and have not been proven to be safe whether or not the exact impacts are known, or to practice effective stewardship where this is possible. For as long as academic institutions do not foster this understanding, we will continue to run behind reality, fixing the damage of what was erroneously planned in the first place. Once the damage from specific persistent compounds becomes factual, there is usually no easy way out. Ecosystems, including human societies, can remain plagued into the distant future. So have we learned the lessons of the likes of dioxins, PCBs, CFCs, persistent fire retardants, and perfluorinated alkyl compounds well enough to design a better future for the chemical enterprise?

A larger white needle, called the "Integrator (I_{TSC})", combines the two D_{TSC}s to give the integrated sustainability picture for each technology or group. The white needle lies in the same E/W hemisphere as the D_{TSC} that is furthest from true North. An integrated assessment of coal, oil and natural gas with/without fracking, and shale oil technologies, leads to needle settings lying very close to or at true south (Fig. 2). Within their energy domains, most

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countries are heading south quickly through carbon-dominant architectures and are parties to civilicide. Nuclear energy has a different highly unsustainable compass profile.

3.3.1. The TSC as a tool for advancing sustainability in the framing of debates over technology choices

A significant advantage of the TSC is that it can be used simply. It is reasonable to assume that the compass quadrant and even octant for each D_{TSC} can often be readily identified. In *C&S*, students learn to analyze the framing of energy-sustainability arguments around the TSC. Framing is important, because those who get to frame the debate also get to pilot the decision-making. Thus, the pursuit of sustainable energy has often been framed in Pennsylvania as a contest between coal, implicitly acknowledging coal as a civilization killer, and fracking for natural gas, which supporters assert is cleaner. Governments have accepted this framing justifying expansion of gas fracking as a replacement for more ugly coal. Occasionally, the same pursuit is framed as a competition between nuclear and carbon sources, with nuclear supporters hallowing the tiny quantities of fissionable isotopes involved while condemning the vast amounts of matter transformed and released by the carbon industries. Based upon the scientific record, neither framing approach is reasonable or appropriate. There are stark TSC comparisons between those renewable energy technologies that are compatible with a sustainable future (not all are), and the carbon and nuclear incumbents, which are not. For renewables, usually the technology options entail needle settings that are convincingly in the northern TSC hemisphere, almost certainly in the northern most octants. The TSC helps in appreciating that scientifically acceptable framing of the pursuit of sustainable energy leads first to the competition between renewables and everything else and, once this is resolved, to the competition between different renewable options.

3.3.2. The TSC as a tool for monitoring progress in reorienting technology to favor sustainability

The time dimension of sustainable development, symbolized by the TSC needles moving more and more to the north with time, is also crucial. The mindset of doing “less harm”, at the cost of moving strategically and systematically towards sustainability, is deadly to the future good. If we understand true north correctly, we are more likely to pursue realistic paths toward it. Trade-offs in the short to mid-term are still possible, as long as they are seen as strategically competent steppingstones toward true north. The idea that there are two kinds of “sustainability determinants” (Collins, 2008) is also introduced and the dynamic relationship between these and the TSC is explained—a video treatment of sustainability determinants is available (Collins and Walter, 2010). Traffic lights metaphors have been used for some time in combination with the FSSD to mark the sustainability qualities of technologies—(see references in Robèrt et al., 2013).

3.3.3. The TSC as a tool for determining the sustainability duteousness of industry-academic projects

The TSC illuminates that the sustainability duteousness of industry-academic projects is impacted by the life stage of participating industries. First, universities can engage with any industrial domain to build what is clearly by its TSC properties a sustainable product, process or activity. This option is sustainability duteous regardless of the life stage of the industry. Second, universities can help to reduce the environmental footprint of an unsustainable industry. This option is sustainability duteous when working with a mature industry, because regardless of its TSC properties, the industry is a fact of life. However, when an industry with unsustainable TSC properties is in development, such engagement amounts to greenwashing because the development of the industry makes no common sustainability sense and should not be supported. Third, universities can try to help move industrial income bases from unsustainable to sustainable activities, products and processes. In principle, this option is always sustainability duteous.

3.3.4. Future development of the TSC

To date, the TSC has been employed in *C&S* to confer qualitative confidence. To achieve quantitative insight, the meanings of the remaining cardinal directions (W, S, E) and the algorithm relating the I_{TSC} and D_{TSC}s remain to be determined. These would best be achieved by consensus among interested sustainability scholars. Many TSCs can be imagined, including TSCs with more than two D_{TSC}s. The FSSD-based TSC of Fig. 2 will likely be expanded collaboratively to a four D_{TSC} plus I_{TSC} form. Here each D_{TSC} would evaluate one of the four SPs of the FSSD, including the social SP4 (see references in Robèrt et al., 2013), requiring two D_{TSC} argument wheels instead of one, with the relationship between the I_{TSC} and the D_{TSC}s to be determined collaboratively.

3.4. Course content—sustainability ethics

The field of ethics involves systematizing, defending and recommending concepts of right and wrong conduct (Wikipedia-4, 2015). Make no mistake—with the welfare of our descendants in deep peril, *sustainability is about right and wrong behavior with respect to the future good*. Sustainability thirsts for more business leaders, creators, scholars and orators to lead the requisite reorientation of values, technologies and practices and to attract support from every discipline, sector and culture. Sustainability has become so pivotal to the human good, and indeed the good of all life, that arguably the paramount marker of ethical brilliance today is what the leader has done to advance it.

In the technological domain of sustainability ethics, the right and wrong behavior of technology promoters is best determined by ongoing scientific analysis of how the promoted technology advances or diminishes the prospect of a sustainable future. Here, a reflection on the TSC leads to the insight that technology promotions can be more or less right or more or less wrong depending on the D_{TSC} positions. Thus, the TSC tool can be used to add clarity to the ethical content of technological choices that is easy for leaders to articulate and for the public to understand, including dynamic lucidity for promoting steady improvement over time. But even when one technology option is less wrong than another, this does not make it right. For example, the TSC illuminates the flaw in the coal vs. fracking-for-gas framing of sustainable energy. If fracking-for-gas does prove to be less injurious to health and the environment than coal, its needle settings, like those of coal, will still point distinctly into the southern TSC hemisphere because of massive CO_2 and methane releases among numerous other problems (Deyette et al., 2015; Leaton, 2014). Developing fracking-for-gas to replace coal is simply opting for another form of civilicide when, tragically, the gas investments could instead be directed to sustainable renewables.

Analysis of Hans Jonas' chapter, “The Altered Nature of Human Action” (Jonas, 1984), presents students with an opportunity to comprehend the deeper meaning of the course content—Assignment 4. Students generally struggle with Jonas' complex language. The class will be culled if Jonas is taught very early on, ahead of the factual content that establishes the need for his prescriptions. Essays and course evaluations show that almost invariably, students identify with the powers Jonas confers to look fearlessly out over the world of sustainability maladies. Mankind today is in great need of a sharp sustainability conscience. As Jonas eloquently explains, prior to the technological age, “The short arm of human power did not call for a

C&S Assignment 4: On Hans Jonas' The Imperative of responsibility: In Search of an Ethics for the Technological Age

With humanity embarked on a new millennium, a novel uncertainty stands before us: "*Is a large technologically powerful human population sustainable on the earth?*" Many associated challenges are chemical in nature. The human economy is inextricably linked with flows of matter to and from the ecosphere, e.g., oil, coal and gas extraction and carbon dioxide release. Inside these flows, their magnitudes and their impacts on health and environmental welfare, lies the vital substance of technological sustainability. Green scientists work to develop sustainable energy, renewable feedstocks and technology that does not pollute. While more knowledge is needed, we have considerable scientific understanding of the problems. Sustainability beckons us to advance existing solutions and to increase research and development to find others. As we examine the challenges, I hope students will learn to be articulate across disciplines, sectors and cultures and this begs the bigger question of whether any set of ideas can unite the human race to think well together about sustainability.

But there are other important challenges than the scientific ones. And at the center lies a struggle with our own nature where unifying ideas can help the most. Our species-wide focus on making as much money as quickly as possible has prevented us from developing workable sustainability strategies and is leading us ever more hopelessly down unsustainable pathways. America, in particular, is captive to these dynamics. China and India and many others countries have followed suit. The question is one of how we should reorient the human sustainability determinants you have heard about in class to more positively impact the natural ones. If you wish to become a leader in this effort in your time, you can be assisted by powerful unifying insight that comes from the field of ***sustainability ethics***.

The thinking of Hans Jonas (1903–93) is foundational to sustainability ethics (although Jonas did not use this name for his remarkable contributions to philosophy), http://en.wikipedia.org/wiki/Hans_Jonas). Jonas began lecturing in the area in 1959, decades ahead of his time. His book, *The Imperative of Responsibility*: *In Search of an Ethics for the Technological* Age is a masterpiece. You will focus on the first chapter, *The Altered Nature of Human Action*. While we will study Jonas in class, I consider it important that you also explore independently how to extract meaning and direction from him.

Assignment: Read the chapter "The Altered Nature of Human Action" and, *by strong reference to the substantive points made in the text*, write a two-page essay (single-spaced, 12 point type—Calabri or equivalent) analyzing Jonas' major points. In doing so, explain how you think Jonas' new ethics can guide you as a sustainability leader. What should we do to advance Jonas' new ethics? What do you think we should do about the hegemony of money? If you disagree with Jonas, or believe that money's seduction and power is not the main problem, explain carefully why and back up your points with cogent arguments.

long arm of predictive power". All prior ethics had no need to be concerned for the distant future—"Precisely because the human good, known in its generality, was considered to be the same for all time, its realization or violations at each time and its complex locus is always the present."

This captures the core ethical programing in nearly all of us. Most of humanity has not been taught to look beyond the near horizons in both time and space circumscribed by prior ethics. But technological power has made these boundaries meaningless and ushered transgenerational justice to the center of our civilization's ethical stage. Jonas alerts us that because of the powers we have acquired through science and technology, we now, as never before, control from the present the human good out into the distant future. In fact, we will control the good of all life for as long as we are technologically powerful. In *C&S*, students are taught the history of the major steps in our acquisition of these powers. Since "responsibility is a correlate of power", they are asked to think through an updating of the global sense of right and wrong conduct to contain our new powers and their expanded reach in time and space. To highlight this, Jonas recommended that the supreme principle of morality should become: "Act so that the effects of your action are compatible with the permanence of genuine human life".

A universally accepted sustainability ethics would arm the world with compelling insight into what is right and wrong conduct for achieving "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Commission, 1987). Jonas inspires in this way.

It could appear that sustainability will have long since become unattainable by the time such an ethics might permeate the global civilization. But if every university taught this ethics as a keystone of sustainability leadership, it would transform core thinking among leaders across humanity, while blessing our species with values that can help unite us all in defense of the future. It would not be hard at all to do. By engaging in the assignments of this course, academics from any field can quickly get the picture and start teaching Jonas- and Brundtland Commission-style ethics. Moreover, the democratization of the responsibility to build economies that can work both for today and forever (as determined by science) is categorically within the reach of modern man. To herald once again a remarkable advance of the common good in our time, communal ownership of the responsibility to pursue sustainability is not only feasible, it is flourishing in the energy sector of Germany—examples of which can be seen here (Jansa, 2012, 2015)—and similarly special jurisdictions.

3.5. Course content—the C&S bookcase of chemical sustainability challenges

The above-noted weaknesses led to an early search for a codifying system (Collins, 2001) to help orient the field toward the more important chemical sustainability problems. The *C&S* Bookcase is the resulting conceptual tool (Fig. 1), which is used to focus students on the critical problem spaces for sustainability and to highlight where collaborations are needed with other fields. The bookcase currently has six shelves, each representing a major area for sustainability scholarship and research. Every shelf is important, but integrating the importance to sustainability, the technical and cultural difficulties for chemists, the challenges for building requisite collaborative programs, and the dangers looming from the pushback of power and inertia leads to placing the least challenging set of problems on the bottom shelf progressing to the most challenging on the top shelf.

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3.5.1. Constructing chemistry/sustainability books

In *C&S*, each book is constructed in a way that highlights the chemistry-sustainability interface of a product or process where the chapters are ordered approximately as follows:

- The importance of the product or process, including the underlying chemistry and commercial uses.
- The history and scholarship of the evolving understanding of toxicity and ecotoxicity to include:
  - the early (sometimes including ancient) toxicity evidence and the integrated history of public health impacts,
  - the clinical evidence of toxicity and determined endpoints,
  - the importance of toxicity assays and their interpretations including the assays of green science used for preemptive design,
  - the pharmacokinetics and mechanisms of toxic action,
  - the persistence and bioaccumulation properties of the full life cycle of degradation products,
  - the presence of endocrine disruption or any other toxicity requiring special consideration of low dose adverse effects,
  - an analysis of conflicting studies including the history of industry/scientific relationships, partnerships and disputes,
  - the importance of experimental controls in toxicity studies,
  - an analysis of the confidence levels inherent in the experimental statistics which, by necessity, can differ widely between fields and provides essential understanding for respectful cross-disciplinary communication (Bergen, 2015).
- The history of the handling of the sustainability threat by different governments including:
  - the history of mendacity concerning the toxicity where this is well documented,
  - the obstacles to public and environmental protection of proprietary information and trade secrets on compositions and of grandfathered protections,
  - an analysis of government/industry relationships on the progress toward sustainable solutions,
  - the critical role of toxicity assays in creating the scientific case for protecting the future,
  - an analysis of sustainability leadership pertinent to each product or process.
- An analysis of whether the product or process is vital, or, when sustainability challenges are serious, can be done without, and on whether replacement or winding down is appropriate.
- The roles and contributions of activists, the media, those deploying advanced communications technology effectively and non-profit engagement in highlighting the sustainability issues.
- The progress in greening unsustainable technologies including alternatives assessments and stewardship.
- Future challenges: This is an area of great potential. The challenges are primarily about envisioning a future sustainable world, where all basic the Sustainability Principles of the FSSD are met and asking how all the sectors of society could comply with the SPs *together*, and how green chemistry might assist all sectors to make this happen? Changing, for example, products and processes, energy systems, traffic-systems, agriculture practices, forestry, societal infrastructures, water use and treatment, all to become sustainable entails a massive undertaking with potential for the design or discovery of myriad future-safe chemical products and processes on which to build a vibrant economy.

In this way of thinking, a key measure of success in building the chemical dimension of sustainability is the growth of the book collection as chemists and collaborators expand the literature of problems defined and solutions achieved. Many years ago, my hope in designing the *C&S* Bookcase had been that it would focus interpretation of the A&W Principles on the higher and more challenging shelves—today, this is happening. Obviously, neither the bookcase nor the books are static. Extra shelves can be added and books can be updated as new understanding is developed.

3.5.2. Shelves 1 and 2: green synthesis and renewable feedstocks

These shelves are straightforward for any chemist to study. Content is updated by summarizing achievements from the USEPA's Green Chemistry Challenge Awards.

C&S Assignment 1: Getting to Know You

A basic premise of the energy section of this course is that redirecting this sector of our civilization toward sustainability and expanding nuclear or fossil carbon consumption are mutually exclusive. You have been presented with a brief synopsis of global environmental breakdown associated with fossil carbon and nuclear. So what alternatives do we have?

Your generation is critical for providing the leadership the world needs to accomplish an appropriate global redirection of the energy sector. Such leadership is hard to acquire as an individual because it involves understanding and action across multiple disciplines, sectors and cultures. Accordingly, as a modest start, we ask you to form teams of three members to work in cooperation on this assignment—please sort out the team compositions among yourselves by … and deliver these to me by email.

This is how the homework will work. Each team has just been granted a 30-second advertising slot on national television to be played at halftime in the Super Bowl 2014. The goal of the assignment is to give you an opportunity to show your creativity in sustainability leadership. Ideally, you will work to persuade the audience to want to have the United States move away from burning fossil fuels in favor of using renewable energy. You may instead pursue another theme of your choice aimed at providing systematic leadership toward sustainability in the energy sector.

Assignment: Working in teams of three, produce a 30-second Quicktime or comparable video to be shown at halftime on Super Bowl Sunday (aka, *C&S* class on …) that shows off your team's prowess for leading the United States to advance renewable energy as quickly and as expertly as possible.

3.5.3. Shelf 3: safe or sustainable energy

Two lectures on sustainable energy are presented early to highlight the potency of the technology–sustainability relationship. Students focus first on the actual and advancing environmental degradation by fossil carbon and nuclear approaches. The German and other jurisdictional successes in leaving these technologies behind for renewables are then highlighted. In Germany's ever more remarkable Energiewende, or energy transformation, which aims to power the country almost entirely on renewable sources by 2050, on May 11, 2014 the German national grid reached >74% renewable sources for a period (Kroh, 2014)—undoubtedly this record will be broken time and again. The scientific underpinnings of solar thermal,

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PV, biogas, wind, geothermal and other alternatives are briefly described.

In the energy classes, students learn of estimates that stress the existence of a supreme strategic leadership opportunity. The rapidly accelerating rebirth of the energy domain as renewables could be coupled to achievable ecosystems restoration; "The little appreciated fact is that a significant amount of excess atmospheric CO_2 comes from centuries of ecosystem destruction and degradation. As a consequence ecosystem restoration at scale could pull half a degree worth of potential CO_2 generated global warming out of the atmosphere. That would be reforestation, restoration of degraded grasslands, agricultural land and coastal wetlands." (Lovejoy, 2014). Such a coupling enacted cooperatively by nations could unite humanity and promote peace around the lodestone of transgenerational justice as perhaps no other leadership channel. By comparison, for those who propose to advance sustainability by incorporating CO_2 into anthropogenic products, a scale question is worth considering; "Carbon dioxide (CO_2) emissions from fossil fuel burning and cement production increased by 2.3% in 2013 with a total of 9.9 ± 0.5 GtC (36 $GtCO_2$) emitted to the atmosphere. These emissions were the highest in human history and 61% higher than in 1990, the Kyoto Protocol reference year" (Friedlingstein et al., 2014; Global Carbon Project, 2014). This begs the question of whether or not mankind has product spaces big enough to absorb multiple gigatonnes of CO_2 assuming energy efficient conversion processes could be developed and Carbon Capture and Storage is not a viable option (Williams et al., 2014). Polymers are conceivably the greatest potential sink; "Worldwide polymer production was estimated to be 260 million tonnes per annum in the year 2007 for all polymers including thermoplastics, thermoset plastics, adhesives and coatings, but not synthetic fibers." (Hopewell et al., 2009). Don't these God's-eye view facts provide convincing evidence that this trajectory can only lead to sterile ground for sustainability?

The rapidly changing energy-sustainability fulcrum requires the content to be updated each year. Renewables costs are declining precipitously (Shahan, 2014). Innovations are improving the technical, health and environmental performances. Renewable energy is a greater source of jobs than nonrenewable (Marcacci, 2014). In contrast with fracking, renewables jobs are mostly not itinerant. The entailed wisdom is not technical. Rather it is the validation of the inspirational insight that our civilization has proven capabilities to power itself sustainably and reverse the forces of civilicide (Jacobson, 2015). By luxuriating regularly in Cleantechnica news on renewable advances, one can comprehend the tragedy of the unnecessary carbon-dominant TSC settings, weakening long-term economic competiveness while rotting for the US the democratic vision of the Founding Fathers and fostering "intimiopathy", which I define here to mean "the disorder of destroying all intimate forces that bind human beings to value the common and future good." This section also provides an opportunity for students to get to know each other—see Assignment 1.

Assignment 2: Cultural Barriers to Sustainability

A book concerning the ethics and behavior of the lead and chlorine industries in dealing with the toxicity of their products was published in 2002. *Deceit and Denial*: *The Deadly Politics of Industrial Pollution* is an exposé of the deliberate efforts of both industrial sectors to prevent the public from understanding the hazards of the substances associated with their products. You will deal with the lead part of the book in the introduction and first four chapters to page 138. Read these chapters carefully.

Assignment: In a three-page essay (Calibri 11 point, 1.5 line spacing) referring to the substantive evidence in the book, explain what the material means to you. In doing so:

- Imagine that you are trying to persuade some group close to you, such as your family members or your friends, of the importance of understanding and extracting strategic sustainability insight from the historical evidence presented.
- Pick a person in the book whose actions you least admire and a person whose actions you most admire and explain your choices.
- Explain what you believe the different types of behavior have meant to the American people and people elsewhere.
- Articulate the importance of reacting to the evidence in some correctional sort of way—What would you recommend doing so that the types of negative acts the book describes never happen again with respect to chemical products and processes?

3.5.4. Shelves 4 and 5: toxic elements and persistent molecular pollutants

When *C&S* started in 1992/93, it appeared to me that green chemistry would be a technical subject. While science underpins the content today, study in these two areas has caused a shift to emphasis to the cultural barriers impeding sustainability in the chemical and allied enterprises. Time and again, existing technically and economically effective sustainable solutions have simply been ignored while unsustainable incumbents have been expanded, often deliberately regardless of health and the environment. Macabre cover-ups of toxicity with ferocious treatment of pioneering sustainability scientists and leaders crater these technology landscapes with some of the most deplorable and destructive history of the chemical and allied enterprises (Assignment 2). Without doubt, low dose effects of the products and processes represented on these shelves matter to humans and especially to children (Lanphear, 2014).

For example, *C&S* lead lectures emphasize the remarkably well-documented history of lead poisoning throughout human history, the extraordinary American experience with corporate, academic and government corruption that kept lead in household paint for many decades after the first European bans and restrictions and made a major product of leaded gasoline to hideously injure the American people—Assignment 2 (Markowitz and Rosner, 2002), the biochemistry of lead toxicity (Klassen, 2001), and the modern progress with replacing lead and improving stewardship. The halogen industry histories have often been similarly disfigured (Markowitz and Rosner, 2002; Moyers, 2001; Thornton, 2000).

Carbon-based energy is also associated with these shelves in liberating toxic elements, CO_2 and toxic combustion byproducts. In Pittsburgh, the discourse on the imagined economic impossibility of going to renewables has drummed along for years, in blissful or studied ignorance of the international proofs and burgeoning national evidence of viability. Meanwhile, the fracking industry has captured much of Pennsylvania to steer the State away from sustainable renewable options.

Assignment 3: A Public Face for Endocrine Disruption

Our Stolen Future: *are we threatening our fertility, intelligence, and survival?* describes an example of how personal greatness, fate, timing, and circumstances can lead to the discovery of insight that has the power to change the future of civilization forever.

In this case, it is the person of Theo Colborn, who in struggling to deal authentically and uncompromisingly with scientific data on the health of Great Lakes wildlife and with related information, formulated ideas that led to the endocrine disruption hypothesis for chemicals. The hypothesis that certain synthetic (and natural) chemicals can disrupt the endocrine system leading to impairments has now been validated repeatedly. The knowledge forever changes the meaning of synthetic chemicals and the chemical enterprise to the future of our civilization and to the welfare of all living things. The 2nd author, J. Peterson (Pete) Myers (who is an Adjunct Professor of Chemistry in at CMU), coined the name “endocrine disrupting chemical”. In the 17 years since OSF was first published, Dr. Myers has become one of the world's greatest leaders of the health and environmental intelligentsia and one of the most effective at bringing about change for the better over the dramatic toxicity problems the book begins to describe. Diane Dumanoski has gone on to author another important book: The End of the Long Summer: Why We Must Remake Our Civilization to Survive on a Volatile Earth.

Assignment: Read *OSF* to the end of Ch. 5 and write a 2-page essay (single-spaced, 11 point—Calibri) describing what the material means to you with reference to the substantive scientific information in the book. In doing so, imagine that you are trying to persuade some group close to you (your family or friends) of the importance of understanding the scientific information in the book and of reacting to it in some sort of correctional way.

Assignment 5: The Literature of Endocrine Disruption (Graduate Students only)

The public face of endocrine disruption science was launched with the 1996 publication “Our Stolen Future” which you now know well. In 2012, a key review in Endocrine Reviews with the following title was published: *Hormones and Endocrine-Disrupting Chemicals*: *Low-Dose Effects and Nonmonotonic Dose Responses*, Laura N. Vandenberg et al. This review has come to represent the second most significant step after OSF in educating the scientific intelligentsia of the world on the importance of the field of endocrine disruption science.

Assignment: Read the attached review in its entirety and produce a two-page essay (single-spaced 11 point Calibri) analyzing 20 points about EDs that you consider to be especially significant from the review.

3.5.5. Shelf 6: endocrine disruptors (EDs)

For extensive easy-to-follow treatments, students are referred to The Endocrine Disruption Exchange website which features the *Critical Windows of Development* tool (TEDX, 2015). The green design capabilities of chemists are significantly constrained by educational limitations in toxicity and ecotoxicity (Collins, 2003). Students of science typically focus their studies in one or other of the branches of science that evolved historically into the contemporary departments. On the one hand, disciplinary specialization is invaluable for educating highly skilled scientists and technocrats. But on the other, specialization in what are mostly fields that federated in the 20th century is now impeding other educational goals that are at least as important for sustainable development. The obvious solution is for the classical disciplines to embrace the 21st century challenges of sustainability and *C&S* is an attempt at such integration. In the healthiest kind of evolution, the extant professoriate would encourage and participate in the process. Endocrine disruption is so chemical, so biological, so amazingly complex and so sustainability critical that it serves as one perfect intersection for developing an exemplary cross-disciplinary education for 21st century chemists. As it becomes clearer that engagement with health and environmental performances will actually improve the economic and technical performances of new chemicals, enthusiasm will grow and this is where the TiPED comes in.

3.5.5.1. The TiPED. The *Tiered Protocol for Endocrine Disruption* or TiPED arose in part from green chemists asking of the discoverers of endocrine disruption, “What information would we need to convince you environmental health scientists that candidate green chemicals are not EDs by the endpoints you study?” For several years the nonprofit *Advancing Green Chemistry* led a large team in regular telephone analyses, several retreats and communal writing to produce the TiPED; the archetypical paper was published in *Green Chemistry* (Schug et al., 2013). The TiPED has five tiers of assays: 1 Computer Based, 2 Targeted Cell, 3 Cell Processes, 4 Fish and Amphibians, 5. Mammals. Illustrative research of how the TiPED protocol can focus green chemists on the important assays of environmental health science was launched while it was under design. TAML activators (Collins, 1994, 2002, 2011; Collins et al., 2009; Ryabov and Collins, 2009), full functional mimics of oxidizing enzymes which promise new water treatment approaches among many other things, were scrutinized for endocrine activity during this period (Ellis et al., 2010; Mills et al., 2015; Truong et al., 2013). I regard this as an immense privilege and great benefit to my technical research program and the enlightening collaborations are continuing. In its highest tiers (4 and 5), the TiPED is capable of collectively elucidating low dose adverse effects, whether of endocrine disruption origin or otherwise. Thus, it can bring the most powerful assurance currently available to the design of safe chemical products and processes.

3.5.5.2. How endocrine disruption course content was developed in a chemistry course. Endocrine disruption has been taught in *C&S* since 2002. Beyond extensive reading on the topic, since 2003, endocrine disruption scientific leaders have visited and delivered seminars at Carnegie Mellon or lectured at the Environmental Health Symposia of Magee Womens Hospital (a famous Pittsburgh birthing hospital), which *C&S* students attend. For many years, students have analyzed *Our Stolen Future* (Assignment 3) and, more recently, the review of Vandenberg et al. (Assignment 5) and the TiPED design tool; grading the essays helps to firm up my insight as the teacher. The film, *Endocrination* (Horel, 2014), highlights the tensions that EDs are engendering between the four critical performances (technical, economic, health and environment) in present day European political and regulatory dynamics.

4. Course content—Code of Sustainability Ethics for Leaders (COSEL)

A healthy civilization is like a healthy body wherein all the compartments, structures, organs, and connections are disease free and in good and cooperative working order. Sustainable development can be crippled by dysfunction in any vital component, especially in the head, the universities that are too often absent without leave from the sustainability frontline. The prognosis calls for academia to deploy the tonic of speaking truth to power and to diagnose and treat sustainability maladies with tools such as the FSSD, the TSC, the TiPED and the expanding green activities. The civilizational heart is mostly infirmed by the absence of values to guide and sustain sustainability pathfinders. In trying to fill this void, I have developed over a number of years the following 10-precept code and I use it as the focus of the final section of the *C&S* course. Authentic sustainability leadership is as much a calling as a career and aspirants should prepare for the equivalent rigor of attaining the highest levels of mastery in a difficult martial art.

4.1. COSEL precept 1: dedicate your life to learning and pursuing what sustainability requires

Careful scholarship on the health and environmental performances of chemicals is a sine qua non for a chemist to achieve authentic leadership in sustainability—each discipline will have its own essential sustainability knowledge base. Students learn explicitly in *C&S* that they can only guide the world toward sustainability if they know the vital facts of the challenges and are thinking creatively and courageously about developing solutions. Some solutions may be created within chemistry, e.g. the Shelf 1 problems of green chemistry. But in general, sustainability leadership requires excellent scholarship, communication and collaboration across disciplines, sectors and cultures. Armed with an open and scholarly mind, transformative leaders will bring to the table the knowledge base and technical virtuosity of chemistry, tap into and enrich the corresponding assets of other disciplines, integrate the near and long term goals effectively, and teach others to do likewise.

4.2. COSEL precept 2: shape your life's work by imagining how you can best serve future generations

It is commonly understood that technologically induced maladies are ominous of an apocalyptic future. But still, how does one teach and build sustainability leadership under the purview and power of weak or failed leadership? Human beings are herd animals. When too many power figures are stampeding the species into the morass of unsustainability, what can sustainability dutiful leaders do but dig in their toes, turn to face the charge and bellow, "'Stop!—and here is why you must, and here is how you can"? As Jonas points out, "The nonexistent has no lobby, and the unborn are powerless" (Jonas, 1984). Thus, authentic sustainability leaders favor the future over the present and work for solutions they imagine to be worthy of the gratitude of future generations. By this stratagem, sustainability leaders gain psychological armor against the inevitable attacks of change-averse incumbents and the frailties of those potential allies who will surrender to the power and money of the present. And they arm sustainability fields in development with a special integrity that both safeguards leadership building from internal and external corruption while promoting *the ability of future generations to meet their own needs*. Learn to cope with this being lonely work if you find it so. Seek like-minded leaders and you will find them—then support each other.

4.3. COSEL precept 3: teach that sustainability is not a pictured endpoint, but a direction that can be logically identified and realistically followed by everyone

The TSC provides compelling representations of the comparative sustainability character of different technologies. Sustainability leaders might use it, or any preferred approach, to show that the real time pursuit is all about choosing the direction of development. If human societies head toward the TSC true north, they have a chance of getting there—if they head away from it, they do not.

When one lives in a country where collective leadership is misdirecting economic development, the sustainability leader must do everything in his or her power to change course, even if this is only to teach well.

If and when the course has been optimized in any technology domain, the principal leadership task is accomplished. Naturally, incremental course corrections will be likely with the advent of new discoveries and inventions, but these seem sure to be welcomed once a scientifically credible path toward sustainability has been agreed upon. The secondary leadership task then becomes one of encouraging everyone to accelerate along the new path.

Unquestionably, there is a strong element of heroism involved in wrestling for the helm to change the direction of something as massive as the developmental trajectories of our global civilization. The harder are the essential course corrections, the greater is the heroism. And in the chemical domain there are many heroes. For example, the nonprofit health and environmental spaces overall represent a glistening heroic dimension and there are valiant pockets of government, business, religion and academia as well.

4.4. COSEL precept 4: champion biodiversity and everything needed to sustain it

Respect for life is the most crucial foundation of sustainability leadership. Foresight for the future good that authentic leaders embody opens myriad paths for acting in homage to life, limited only by the bounds of the leader's imagination and courage. As one of the many pressures on biodiversity invoking new leaders to rally and reset the course, up to one-sixth of all species may go extinct from business as usual in the energy domain with its associated climate change (Urban, 2015). As another, chemists today can champion biodiversity by learning why certain everyday-everywhere chemicals are EDs (Colborn et al., 1996; Khetan, 2014; TEDX; Vandenberg et al., 2012) and acting to ensure new commercial chemicals are not EDs (Schug et al., 2013).

4.5. COSEL precept 5: teach that a money-first-in-all-things civilization will perish from the earth

Two performances have defined the technological landscape of our civilization—the technical performance and the economic performance. Reflecting this, chemical products and processes are emphasized in chemistry courses that work well at whatever task these were discovered or designed to perform when the economic performance is also high. Sustainability requires that two additional performances should become equally important in a new value proposition that controls which potential products and processes are commercially developed or avoided and which existing ones are expanded or wound down. These are the health and environmental performances. The fact that these have not been sufficiently included across the entire material domain of technology, with the exception of medicine for health (but not for environment), weakens for sustainability literally every functional aspect of the civilizational corpus. It makes the conception of the money of today of dubious value for tomorrow.

For example, *C&S* students learn about a barbaric case of ignoring the health and environmental performances in the use of dioxin-tainted Agent Orange and related Agents in the Vietnam War (Northrup, 2014). Both the Vietnamese people and American and allied military personnel and their progeny have been massively injured and the problems persist in Vietnam to this day. Agent spraying started in 1961 and ended in 1970. Yet at least one manufacturer knew for sure by 1965 about the severe low dose systemic toxicity of dioxin and chose to keep this secret. The decades that followed became a horror story of corporate mendacity (Thornton, 2000). The money once earned by the chlorine companies in selling Agents must be dwarfed by many orders of magnitude by the still inadequately acknowledged costs of the collateral dioxin damage—and as it has been aptly noted, “Not everything that counts can be counted, and not everything that can be counted counts” (Cameron, 1963).

The dioxin tragedy is anything but a singularity: money too often is made in the present where the scientific case is indisputable that the cost to the future overwhelms its near-term value. With the current carbon energy expansion, one has to ask: “What is it worth not to submerge the atoll nations?”; “What it is worth not to drown substantial parts of Bangladesh and other vulnerable countries, including large parts of the USA?”; “What are the coral beds of the oceans that we are killing worth?”; “What is it worth to avoid disrupting development in living things with EDs and carcinogens that accompany carbon energy?”; and so forth. And “worth” in this context engages multiple currencies, including and most significantly the merit in our individual and collective spirits that are the most important operational foundations of our large civilization. Students can learn powerful directing lessons on how to build a better world by studying dioxin history and like material. The wartime use of dioxin-contaminated Agents unmasks a reigning values system and incompetence within the responsible companies and the governments of the day and decades-long aftermath that is antithetical to a sustainable future.

There is today much reason for optimism! Many of the large chemical corporations are attempting to reorient toward sustainability. Each time a chemical company advances a verifiably sustainable technology or winds down an unsustainable one, the civilization becomes a more just and noble place—transgenerational justice is honored.

However, some companies are advancing both sustainable and unsustainable technologies simultaneously, even if a growing willingness to jettison unsustainable technologies can be detected. How companies wind down unsustainable products and processes is crucial to their sustainability integrity. Does a company sell its unsustainable technologies, or does it scuttle these? To my thinking, selling is a sustainable option, if and only if the purchasing party is configured to fix the sustainability flaw. This can happen, as with the sale of Saran Wrap by Dow to S. C. Johnson and Son in 2002 (Schulz, 2004; Wikipedia-5, 2015)—the latter company designed chlorine out of Saran after taking ownership of the brand, eliminating the danger of dioxin contamination of food upon the adventitious burning of the food wrap, for example, on barbeques. But sustainability is usually not advanced by sales of unsustainable technologies from one company to another. When companies resist regulations, it makes it all the more difficult to contemplate scuttling unsustainable products and processes, or to envision how society can help make this economically palatable, because winding down in weakly regulated markets strengthens competitors (see in this Special Issue “The prisoner's dilemma”, Robèrt, 2015). On this theme, endocrine disruption presents an extraordinary and disorienting challenge for some chemical companies. And the demands ED adverse effects make for the reduction and elimination of many products are turbocharging unsustainable reflexes and strategies within the chemical enterprise (Horel, 2014).

A new generation of leaders must develop an all-inclusive balance of the four critical performances to redefine the real and lasting value of chemicals in a sustainable world. This is not beyond our reach. For example, a TiPED-passed new product goes out the door with much of the environmental and health performances built in. Thus, *C&S* has evolved to assist students to understand the health and environmental performances of commercial chemicals, to evaluate the scientific and cultural ingredients therein, and to think strategically about solutions.

4.6. COSEL precept 6: work to make jobs, wealth and sustainability mutually reinforcing

While protest against the reigning money-first-in-all-things paradigm is an important strategy for ensuring that the world will have sustainability competent leaders, sustainability leadership is not a protest movement. The clustering of humanity in densely populated cities simply cannot exist without multifaceted technological reinforcement, especially from chemistry. The sustainability leadership training that *C&S* seeks to perfect is about building a sustainable economy and society. This having been noted, future human beings seem certain to hold many who protest against the current abrogation of their interests as among the great human spirits of our time.

4.7. COSEL precept 7: oppose the denial of sustainability problems

Political power in our time is being reduced more and more to a commodity for sale to the highest bidder. This pattern is especially evident in the political life of the United States where the government has increasingly been subject to the will of imperious oligarchs whose fortunes are based on unsustainable technologies and practices. How can sustainability leaders even begin to engage meaningfully over something as sacrosanct as the future good with politicians whose judgment and energies have been purchased? Such engagement can only amount, at best, to a fascinating play in the theater of the absurd—a play that is predetermined to end in tragedy for sustainability. The future good encompasses everything that is precious, beautiful and worth keeping. Yet it cannot be turned into easy cash to buy political protection. Compromised political leadership is the instigator of all the deadliest cuts to our civilization in our time. It has given rise to rampant denial of the unimpeachable scientific case that we have been committing civilicide in the energy domain (Stewart, 2014). Sustainability leaders must keep their crosshairs on the contrivance by which denial and civilicide are being forced upon the world and work to free the political will from the electrified cage that is powered by money from unsustainable technologies and practices.

4.8. COSEL precept 8: always resist distortion of science that compromises the common good

The raising of personal or tribal wealth and power above all else by those who derive it from unsustainable technologies and practices herds the young into unsustainable career paths and dependent fealty while it plunders their future. And to do this more effectively, the business category of scientific influence mongering has emerged, so unmistakably evident in the chemical domain in *Deceit and Denial* (Markowitz and Rosner, 2002), *Trade Secrets* (Moyers, 2001), Pandora's Poison (Thornton, 2000) and *Endocrination* (Horel, 2014). One of the best ways for academic sustainability leaders to combat this malevolent force is to learn and teach its many well-documented histories.

4.9. COSEL precept 9: never devalue sustainability for money, tribute or political support

A sustainability leader should always resist the temptation to be party to anything that undermines sustainability. The "Declarative Question" is a powerful guiding tool. But in seeking strides for sustainability, a degree of risk-taking is unavoidable—acknowledging this is not the equivalent of moral relativism. The need to search experimentally for positive directions can perhaps best be explained by mapping the devotional dimension of sustainability leadership and offering allegorical guidance.

In times of great peril throughout human history, orders of knights have formed to bring focus to protecting the common good. The forces of civilicide today are the greatest menace to ever confront humanity. The language of chivalry is thus appropriate for inspiring a transformational crusade. To a considerable extent, the good future of life and especially our species lies in the hands of knights who are committed to the quest for sustainability. I will name them the "Knight Champions of Sustainability". These knights exist today. Even if not formally constituted as an order of chivalry, they function loosely as such.

Princes of unsustainability commonly attempt to vanquish knight champions of sustainability using three tactics. In the first, the prince will attempt to buy the knight's service, or bribe him to abandon his endurance with the lure of money, olive garlands and fame, or entice him into a treaty that focuses all chivalric force outside the principality. In the second, the prince will use his powers to confer titles on the weak and trumpet them as the true sustainability knights to demean and disorient the quest. And in the third, the prince will attempt to weaken the knight's political and material support. Both princes of unsustainability and knight champions of sustainability are clearly evident in the chemical and allied enterprises today. By articulating widely the combat taking place over the life or death of our civilization, knight champions can herald opportunities for good kings and queens to protect the future, literally as close as the children and grandchildren, by supporting heroism when and where they perceive it. Such good kings and queens also exist today, including some who are enthroned at the apexes of political or corporate power.

However, it is important to remember that unsustainability, and not always its aristocracy, is the real affliction. Princes of unsustainability are often such because of their station in life, perhaps achieved without appreciating the novel threats to the future of technological might. While knowledge is essential and caution prudent, knight champions should consider allying themselves with princes who they believe, for whatever reasons, want to redirect their principalities toward sustainability. Much money today is generated by commerce in unsustainable products and processes. It is important to aid willing princes in moving their capital to sustainable alternatives.

The desire for money, tribute and political support and the will to be a knight champion of sustainability are not mutually exclusive—simply stated, the latter drive reigns over authentic knights. The needs of the knight to protect and nourish his or her own personal and professional estates, to understand and be understood, to be free to create and recreate, to enjoy the respect and affection of fellow knights and the wider world, and to have the wherewithal to leave a distinctive legacy are appropriately innate to the human nature of knight champions of sustainability. It cannot be allowed that the only route to becoming a knight champion is that of the martyr. The more this territory is openly taught and debated, the safer the true knights and the more achievable their quest will become.

Furthermore, it is inappropriate and unrealistic to expect true knights to be perfect human beings. The beautiful paradox of sustainability leadership is that the future good must be prioritized by ordinary mortals, each facing this noble calling with the unique set of strengths and weaknesses that is the personal makeup of each human being. Because the future of humanity and so much of life itself is on the line, through sincerity and energy brought to the quest for sustainability, mere mortals can rise to become great human spirits in our day. And therefore, the capacity to earnestly forgive the errors of sincere comrades-in-arms and the courage to discuss these openly to optimize paths toward sustainability is an essential knightly virtue.

Chivalry as it applies to sustainability is dynamic. Princes of unsustainability and knight champions of sustainability sometimes change roles depending it seems on how they weight at any given time the needs of the common good against their own needs. Insecurity in knights can be deadly for sustainability, which is a tough reality because insecurity is pandemic across our species. In the chemical domain, when any knight loses track of the quest, which is to help save sublime life in distress from the ravishing and pillaging of unsustainable technologies and practices, and makes the mission about him- or her-self, all glowing armor falls off and the promise of great virtue is lost to the certainty of withering self-indulgence, insecurity and irrelevance.

4.10. COSEL precept 10: Ally yourself with people you can trust to keep faith with sustainability

Sustainability leadership is a steel reinforced test of insight and character. Having reached this point, the reader will have realized that standing up for the future means standing up to the present. Aspirant sustainability leaders can rest assured that real people are doing precisely this today. Real people, whose work and leadership is featured in *C&S*, even if not always by name herein, have resisted bribes. They do speak truth to power. They do struggle excessively for funding and risk weaker incomes and even penury for the sake of the future good. They do brave attacks on their professional and personal integrity. They do make carefully considered and often heroic decisions concerning the alliances they engage in. While they may make mistakes from time to time, they are always driven to advance the common good. They do pour themselves mind, body and spirit into the most important and inspirational professional work that our civilization has to offer. They are often victorious. Sometimes their heroism is recognized and rewarded in their lifetimes. They are all heartwarming and fascinating human beings. Find them in your time—there is no more rewarding professional company on this earth.

Selected Course Comments from 2014 to 2015*

- By far, this is the best course I have ever taken. The content is extremely important and relevant for understanding environmental sustainability. Every engineer and scientist should take this course either in the undergraduate or graduate level. It is an honor to attend lectures of a very well known professor as Pr. Collins who has influence worldwide in environmental sustainability.
- This was a really great class. The material covered in class is really interesting and important! I hope in the future this course becomes a part of general requirements because it is a science that will be important for years to come. It is something that would benefit people in every major, as every aspect of a product goes through many areas, even if they are not directly chemically related. I hope to see the whole campus take on more green initiatives as well! Wonderful class!

- I really enjoyed this course. Professor Collins challenged me to think about aspects of the environment that I had never really thought about before and made me understand the impact that certain synthetic chemicals can have on both the environment and the public health. I think this should be a required course for all chemistry students, but that it should be offered to students of other disciplines as well.
- A version of this course should be required for every student at this university.
- This is one of those rare types of courses where the material learned is not easily forgotten, and will stay in mind years down the road since it has such real meaning to everyday life and choices. The material should be taught to a much broader audience, especially since sustainability is a very real issue that no one is immune-to the effects if we as a society do not collaborate to change course. It was especially impactful because the class was firmly grounded in facts and solid scientific evidence, explaining plausible chemical mechanisms for phenomena such as endocrine disruption when possible. In fact, the only way the class could be improved is if it was taught university-wide; the scientific background, though certainly helpful, was not necessarily prerequisite to understanding the overall concepts and their importance, and there are definitely interdisciplinary opportunities for the course.
- We need MORE COURSES like this one taught at Carnegie Mellon. Sustainability (ethics, etc.) on some level should be a REQUIREMENT for graduating students. We need to train leaders to understand the concepts and language of sustainability. CMU has the opportunity to be at the forefront of sustainability, and courses like this are very important for our future.
- I strongly recommend that this course be expanded to a wider audience because it is very important even for non-chemistry majors to learn the effects of the chemicals around us.
- This is a class that really needs to be given to ALL students at the university level—especially to students at such a prestigious university like CMU. All majors need to have a sustainability type class because it is such a persistent and immensely important concern in this time. Terry, specifically, is highly passionate and is a great catalyst for that kind of passion. I, and I'm sure other students, have come to realize the importance of the challenges our community and our world face in the coming decades and this knowledge of what is coming should not be avoided in a setting such as the university. I think this class and others like it should be taught to everyone and all majors (grad and undergrad) should be required to have at least one course in sustainability within their field.

*All comments provided positive endorsements.

5. Professorial assessment of students and student assessment of *C&S*

Grading *C&S* assignments is a sublime privilege that typically delivers deep-seated admiration for the intelligence and idealism of CMU students on the doorsteps of their independent careers. The resulting insight into unspoiled virtue, combined with the sustainability integrity in the energy domain of Germany and other similarly special jurisdictions, the power of people to create their own energiewende (Shahan, 2014), the progress in dealing with EDs, and the inspiring company of knight champions of sustainability brings me hope that an affirmative answer to the Epic Question is not beyond humanity's reach.

Overall, the students have keenly received *C&S* and have expressed enthusiasm for expanding the content and making versions of the course more widely available (see Inset). Because of time constraints, *C&S* is handled each year by cherry-picking material for one semester. Sufficient material has been developed that would allow for an expansion to two or more semesters. The course could also be retooled for larger and cross-disciplinary courses offered earlier in the bachelor's degree—such expansions would be resource intensive.

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