LEED for New Laboratory Development: Using Green Chemistry to Overcome the Hurdles to Sustainable Laboratory Design

by

Eric D. Fournier

Submitted to the School of Forestry and Environmental Studies

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Abstract

Laboratory facilities are the single building type associated with by far the largest impacts on the natural environment. On a per square footage basis they consume 5-8 times more energy and water than other conventional structures and, in addition to this, they are also responsible for the production of large quantities of hazardous wastes. Despite the criticality of their impacts, laboratories have largely been overlooked by certification programs designed to improve the environmental performance of built structures. This project therefore, is meant to provide a focused contribution to the ongoing discourse surrounding the development of a new dedicated certification system for laboratory facilities within the United States Green Building Council's program for Leadership in Energy and Environmental Design [LEED].

Working with architects and engineers from Perkins + Will, the fifth largest architecture firm in the United States and a specialist in the design and construction of laboratory facilities, we have identified a number of opportunities for the application of Green Chemistry in various laboratory contexts to improve the environmental performance of the building's physical structure. Using case studies from existing laboratory facilities from across the United States we demonstrate that by first reducing or eliminating the need for hazardous chemical materials with a laboratory's processes designers and engineers are then freed to drastically reduce the scale and intensity of the building's electrical and mechanical systems. In conclusion, we advocate that this more integrated approach to the design of wet laboratory facilities should be reflected in the proposed new LEED for laboratories certification program.

Thesis Co-Advisor: Julie Beth Zimmerman
Title: Assistant Professor

Thesis Co-Advisor: Paul T. Anastas, *in absentia*
Title: Teresa and H. John Heinz III Professor in the Practice of Chemistry for the Environment

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I would like to thank my co-advisors, Paul Anastas and Julie Beth Zimmerman. I could not have completed this project without their guidance and insight. Also, I would like to thank Dan Watch, Gary McNay, John Mlade, and Nandita Vyas at the architecture firm Perkins + Will. Their team possesses a wealth of real world experience in applying the LEED certification program to the design and construction of more sustainable laboratory facilities. I am tremendously grateful to them for their willingness to communicate this knowledge to me throughout the evolution of this project. Finally, I would also like to thank my father Paul, my mother Patricia, and my brother Bryan for their continued support of my academic pursuits.

This thesis is dedicated to the memory of my long time friend Julio Arnold Muniz; shall he never be forgotten.

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Chapter 1

Introduction

There is currently a great deal of interest in the development of a new design framework for the construction, operation, and maintenance of more sustainable buildings. This interest reflects society’s growing awareness of and dissatisfaction with an existing building stock that needlessly wastes its water, consumes its energy, pollutes its air, poisons its children, and scars its landscape. The negative attributes of the built environment, of which there are many, reflect a pervasive design failure within the architectural and engineering professions. For too long, issues of public health and environmental impact were either completely ignored or given insufficient weight during the consideration of product and process alternatives for use within buildings.

It is important to realize that there is no physical law, no intrinsic limitation, which prevents our homes, businesses, and places of leisure, from being different, better. Their form reflects a system of values, the expression of which occurs explicitly during the design process. The built environment is extremely fascinating in this regard. It constitutes perhaps the largest and most enduring physical record of our social value system. To survey the landscape and take a reading of this record is to discover that our civilization is in constant flux. The issues and ideas which are important to us change continuously; a fact which is clearly evident in the products which we design and consume.

The value system upon which the performance of buildings was once previously measured has evolved. Now, perhaps for the first time, architects and engineers have begun to seriously consider issues of energy efficiency, waste minimization, indoor environmental quality, and local environmental impacts in a holistic way during the design process. This is evidenced not only by the existence of a new crop of buildings with vastly improved environmental performance but also by the appearance of a number of new certification systems which actively promote “Green Design.” Here in the United States the most prominent of these systems is the U.S. Green Building Council’s (USGBC) program for Leadership in Energy and Environmental Design (LEED). LEED uses a prescriptive checklist to promote and reward the application of various environmental design strategies in new building construction and renovation projects. Perhaps the biggest reason for LEED’s success relative to its competitors has been its capacity to evolve in response to the dynamism of technological growth, shifting social values, and changing environmental priorities. Due to the foresight of its creators, the program has been designed to be amended over time in response to the experiences and critiques of design practitioners, academics, and policy makers.

There are a great many different types of buildings, each of which interacts with the environment in a drastically different way. Thus, in order to address this diversity, the LEED program has developed a set of parallel rating systems for various subcategories of building type. According to its most recent iteration, the list of building subcategories explicitly addressed by LEED include: New Construction and Major Renovations, Core & Shell Development, Schools, Homes, Commercial and Retail Interiors and a planned expansion for Retail New Construction [1]. One of the most serious criticisms of the LEED program however, has been that it has largely failed to influence the design of buildings that are associated with the most acute impacts on the natural environment [2].

On a per square footage basis, chemically intensive laboratory facilities consume approximately 3-8 times more energy and water than a typical office building [3]. Furthermore, they are also responsible for the vast majority of society's toxic and hazardous waste production [3]. In spite of these facts however, laboratories are given no special consideration under the LEED program. Instead, they must conform to the same prescriptive requirements that would be used to guide the design of a library or an auditorium. This is not to say that the need for a new building subcategory within the LEED program dedicated to laboratories has gone unnoticed. In fact, the situation is much to the contrary; there has been a tremendous popular outcry for just such an expansion within the design community [2]. Unfortunately, the founders of the LEED program have neither been able to agree upon what benchmarks should qualify a laboratory facility as being a Leader in Energy and Environmental Design nor how those benchmarks might best be achieved.

In the context of this problem, this paper seeks to make a focused contribution to the discourse currently surrounding efforts to develop a new design paradigm for more sustainable laboratory facilities. The argument which shall be made draws heavily upon the Principles of Green Chemistry in advocating for a more integrated approach to the process of laboratory design. The paper's core thesis is that the aggregate environmental impacts associated with the life cycle of a laboratory facility are strongly dependent upon the scale and intensity of the facility's hazardous materials throughput. Therefore, any serious attempt to improve the environmental performance of a laboratory's physical structure should necessarily be preceded by a critical evaluation of the chemical processes within it so contained, with the express intent of minimizing both the use and production of hazardous chemical substances.

Following this line of reasoning, it will be shown that during the design of a new laboratory facility, by preemptively applying the Principals of Green Chemistry to the scientific processes in the laboratory, one is able to expand the degrees of design freedom available to architects and engineers. A direct result of which is the possibility of being able to either drastically reduce or completely eliminate a number of the facility’s negative environmental impacts in ways that would not have been possible were the building’s physical structure to have been considered in isolation from the processes it was designed to contain.

The principals of Green Chemistry were devised as a unified design framework for the synthesis and engineering of chemical products and processes. This framework fundamentally denies the default assumption of the chemical establishment that there are certain degrees of chemical functionality which can only be achieved through the coproduction of biological toxicity and other adverse environmental consequences. Instead, the disciplines of Green Chemistry postulate that for any hazardous substance or wasteful chemical process a substitute can be imagined which is at once benign to the environment and absent of inherent toxicity while still retaining, at a minimum, all of the desired chemical functionality of the original [4].

The disassociation of function from form is an essential technique employed by Green Chemists. By considering a design problem solely on the basis of desired functionality, and ignoring preexisting forms, designers are liberated from the failures of the past and free to develop new solutions which are often completely oblique to existing ones. It is perhaps in this sense that the discipline of Green Chemistry may have the most to contribute to the discourse surrounding the development of a LEED for laboratories program.

1.1 Risk as a Function of Hazard and Exposure

The essential challenge associated with the design of any laboratory facility can be expressed in terms of a simple equation; the relationship between risk, hazard, and exposure [4].

$$\text{Risk} = f\,(\text{hazard, exposure})$$

The risk associated with a given laboratory design strategy is a function of the hazards contained within the laboratory space and the degree to which the inhabitants of that space are exposed to those hazards. The responsibility of any design professional is to minimize the risk associated with their design product. This means that the designer has two options: either minimize the presence of hazard or minimize the exposure to that hazard. Historically, during the design of laboratory facilities the architect has had little or no power to affect the hazard component of this equation. Thus, in order to fulfill their responsibility to minimize risk, they have been forced to attempt to control exposure.

Controlling the degree of exposure to chemical hazards is a challenging undertaking, one which generally involves the use of complex and inherently unreliable mechanical equipment such as fume hoods, containment cabinets, and active ventilation systems. In addition to the certainty of their eventual failure, the operation of these engineered exposure controls is associated with significant environmental and economic costs. For instance, depending on the specifics of its operational conditions, a single laboratory fume hood can consume 3.5 times as much energy as an average American home [5, 6]. Considering the fact that many large laboratory facilities can contain several hundred such fume hoods, it becomes clear that, in the context of a strategy of exposure control, the responsibility of an architect to ensure the safety of a building's occupants from chemical hazards is in direct conflict with their efforts to minimize energy consumption and reduce environmental impacts.

This contradiction has been the source of disagreement which has thus far been responsible for derailing efforts to develop a LEED for Laboratories program. As part of this paper's analysis, several case studies of existing laboratory facilities will be presented in an attempt to diagram the range of sustainable design strategies which have been implemented thus far. These case studies will be organized on the basis of the "risk as a function of hazard and exposure" equation. In this organizational scheme, exposure controls will be considered as being part of the physical laboratory structure and thus will be attributed to the architects and engineers responsible for the facility's design. Alternatively, hazard reduction programs will be considered as part of the laboratory's experimental and operational protocols and thus will be attributed to the researchers and environmental health & safety staff associated with a facility.

The case study facilities presented in this paper will be considered as being part of one of four possible tiers, each reflecting the various levels of design integration between the physical laboratory structure and its operational protocols. Further consideration will be given to the viability of different strategies in different laboratory contexts. There are a wide range of laboratory types and institutional structures. As a result, it is necessary for the challenges and opportunities associated with different tiers of sustainable design integration be assessed under these different circumstances.

Chapter 2

Buildings and the Environment

The central role which buildings play as both sources and intermediaries of human impacts on the natural environment is an issue which is fairly well established within both academic and professional communities. During the initial development of the USGBC's LEED program and other similar certification systems, a great deal of background research was compiled on this topic order to support their claims that a new design paradigm was indeed necessary [1, 7]. Rather than completely rehash the complete body of work related to the impacts associated with buildings and the environment compiled by the USGBC and others, instead, only a brief overview will be provided here in order to furnish the reader with a necessary context for the primary discussion of this paper: the impact of laboratory facilities on the natural environment.

Buildings impact the environment in a variety of ways, each of which can be understood in the context of the different stages of a building's life cycle. Traditional construction practices in the United States generally conform to the following narrative:

- Prior to construction large areas of land are cleared and graded eliminating habitat for natural organisms and disturbing local bio-physical processes. In addition to these on site preparations, elsewhere, virgin natural resources must be extracted, processed, and transported to the site, usually from great distances. Depending upon the specific materials and processes involved this stage can be responsible for a large proportion of the aggregated environmental impact of a building.

- During the construction process there is a substantial amount of waste associated with inefficient raw material use. This waste is generally not recycled and becomes destined for landfills or incineration.
- During the operation of a building, large mechanical systems are usually needed to maintain a safe and comfortable indoor atmosphere. The operation of these systems generates a continuous demand for energy services which is usually met by the combustion of fossil fuels. This generates carbon emissions and other forms of airborne pollution which contribute to global climate change, contaminate the environment, and jeopardize public health.
- At the end of their useful lives most buildings undergo partial or complete demolition during which a relatively small portion of their materials are separated from the waste stream and sent to be recycled or reused. Here again the remaining waste becomes destined for landfills or incineration.

When these impacts are aggregated across the United States' entire building stock the figures become staggering. In 2006, buildings in the U.S. accounted for 40% of total primary energy consumption, 72% of total electricity consumption, 40% of CO_2 emissions, 13% of total water consumption, and 26% of total non-industrial waste generation [7]. The total amount of urban land area in this country has quadrupled since 1945; a rate of increase which is roughly twice the rate of population growth over the same period [7]. Reflecting this trend towards increasing urbanization, today, the average American spends around 90% of their time indoors[8]. This, while indoor levels of pollutants are generally found to be two to five times higher, and occasionally more than 100 times higher, than outdoor levels [9]. This indoor air pollution, related to the specification of toxic or hazardous materials for use in building interiors has been cited as being a key contributor to the cancer epidemic currently sweeping across the United States.

2.1 Laboratories as a Unique Building Type

Considering the preceding life cycle narrative presented for a typical building in the United States, laboratories represent a rather unique case in terms of the temporal distribution of their aggregate environmental impacts. The aggregate environmental impacts associated with some products are dominated by the processes which occur during a single stage of their life cycle. Take for instance the difference between say a ceramic coffee cup and an electric toaster. The vast majority of the environmental impacts associated with the ceramic cup are related to the raw materials extraction and industrial processes associated with its manufacture. This is because a ceramic cup does not require any energy or resource consumption during the operation phase of its life cycle. Alternatively, consider the example of an electric toaster. With the electric toaster, assuming a standard usage profile, the dominant environmental impact will be associated with the operational phase of its life cycle. This is because the environmental impacts, in terms of pollution and green house gas emissions, which are generated as a consequence of the considerable amount of energy required to operate the toaster over its lifetime end up being more meaningful than the impacts associated with the energy and materials production required to manufacture it.

A building is a product which can be thought of in the exact same terms as that of a ceramic coffee cup or an electric toaster. As alluded to in the introduction, buildings can potentially have very different life cycle environmental impact profiles depending upon the materials and techniques employed in their construction and the nature of the activities engaged within them during their occupational use [10]. A chemically intensive laboratory bears great similarity to the example of the toaster in terms of the distribution of its environmental impacts across the different phases of its lifecycle. Laboratories housing scientific activities which involve the use of hazardous chemicals or biological agents generally require a large number of containment and exhaust devices such as bio-safety cabinets and fume hoods. In addition to these engineered exposure controls, modern scientific research typically also requires the use of large pieces of experimental equipment. These instruments consume a tremendous amount of energy not only in terms of the services which they provide but also by virtue of the cooling loads which they impose upon spaces within laboratories. Dealing with this latent heat discharge is a challenge which is further compounded by the frequent need to condition laboratories' indoor environments to within a narrow range of temperature and humidity levels so as to accommodate atmospherically sensitive experimental protocols. Indeed, the vast number of experimental operations which require the precise engineering of artificial temperature environments has made the issue of maintaining a stable temperature environment within the laboratory one of the most significant challenges associated with modern facility design.

In addition to the process energy requirements and cooling loads associated with the heat which is discharged from active laboratory equipment, there are several other features of chemically intensive laboratories which cause them to have rather distended energy and resource consumption profiles relative to that of more conventional building types. One of these has to do with the frequent need for fail-safe redundant power supplies to support the operation of critical experiments. In many laboratory contexts, researchers engage in delicate experiments involving labor intensive samples, expensive reagents, or extremely long run times. Under these circumstances, they frequently require the installation of fail-safe power supplies which use capacitor banks to provide instant-on supplemental power in the case of a grid outage, facilities maintenances accident, or some other disturbance. These capacitor banks can substantially add to the operational loads associated with the equipment which they are supporting.

2.2 Laboratories on University Campuses

The fundamental difference between laboratory facilities and buildings of virtually every other type in terms of energy and resource consumption can easily be observed in a university campus setting. Large university campuses are completely self contained mini-cities which typically encompass nearly the full range of building types within their bounds [11, 12]. In addition to their diversity of structural forms, university campuses also make good candidates for a comparative study of building performance because of their tendency to have both centralized administrative structures as well as centralized utilities distribution infrastructures. At those institutions where building specific energy monitoring has been installed, there exists a the unique opportunity to assess the composition of energy use of energy consumption in a cross section of facility types for which equipment loads and occupancy patterns are well known.

There are two existing studies that have been conducted on university campuses in which per square footage energy consumption levels were calculated for individual buildings. The first comes from the Massachusetts Institute of Technology and was conducted in 2006 by a student group interested in discovering new opportunities for improving the energy usage efficiency on campus [13, 14]. The product of the MIT study was the production of a color coded campus map which indicated the per square meter electrical and heating energy consumption for all of the campus’ facilities.

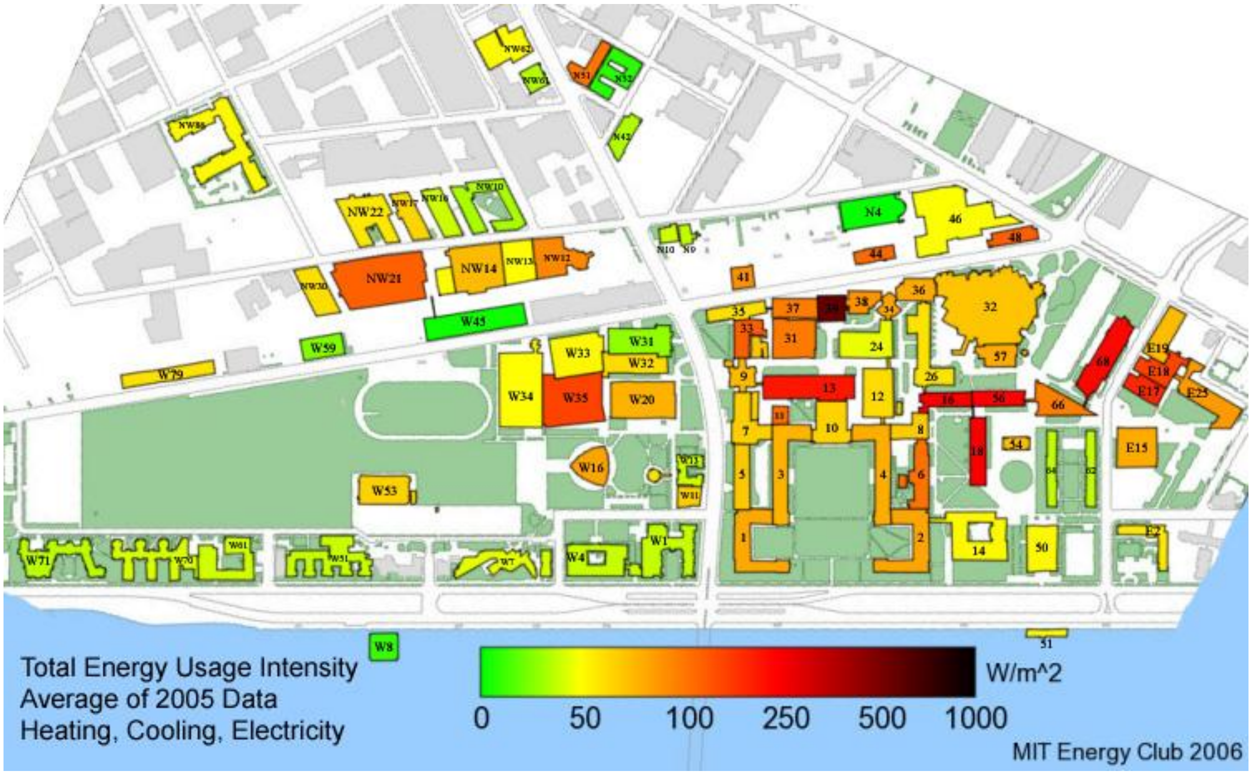


Figure 2-1: Energy Usage Density in Buildings on the MIT Campus

Building	Building Name	Building Type / Occupational Activities	Electricity	
			kWh	kWh/ft^2
39	Building 39 – Computation Center	Computational Center and High Voltage Applications Research Laboratory	8,042,462	106.61
56	Building 56 – Whitaker Life Sciences	Life Science Laboratories and Teaching Spaces	10,817,674	75.43
16	Building 16	Biological Engineering Laboratories and Teaching Spaces	7,674,644	66.05
68	Building 68 – Koch Biology Building	Biological Science Laboratories and Teaching Spaces	13,904133	53.43
18	Building 18 – Dreyfus Chemistry	Chemistry Laboratories and Teaching Spaces	7,208,348	54.09

Figure 2-2: Top Five Energy Consuming Buildings on the MIT Campus

From this map and table we can see that on the MIT campus computing, chemistry, and life science laboratory facilities round out the top five buildings in terms of energy usage intensity per square foot [13]. In fact, the energy consumption associated with these “wet” laboratory facilities (excluding building 39, the advanced computing and high voltage research center) have per square foot energy intensities which are greater than that of even the facility which houses the campus cyclotron and many of the mechanical and electrical engineering buildings. In some cases, the difference is as much as a full order of magnitude.

The second known study of the energy intensities of facilities across a university campus was conducted by the author in 2008 as part of an undergraduate Honors Thesis at Bucknell University, in Lewisburg, PA [15]. In this study, every attempt was made to replicate the methodologies and representational conventions employed by the MIT study so as to maximize comparability between the two. However, it should be mentioned that there are significant data gaps in the Bucknell study due to the relatively limited amount of building specific energy usage monitoring capacity.

There are many reasons why energy would not be monitored on the scale of individual buildings at an institution such as Bucknell; some of which have to do with the age of construction, the cost of metering equipment, and the nature of local energy production and distribution. Bucknell, a small university with a number of old building constructions and limited maintenance funds had only partially completed a campus wide program to retrofit its large facilities with energy metering and data logging equipment at the time that this study was conducted. In addition to this, the University, like many others of comparative size, owned and operated its own central power plant; a co-generation facility which supplied virtually all of the energy and all of the heating and cooling needs for the campus. During the era of low primary energy costs, this centralized production and distribution system provided a strong disincentive to spend money on high resolution energy monitoring equipment.

At Bucknell four of the top five facilities on campus with the highest energy density per square foot are wet laboratory facilities. The largest consumer of energy on campus both on a per square foot basis and in absolute terms is the Rook Chemistry / Olin Science Center; an interconnected science complex housing the chemistry, physics, and mathematics departments [15]. The only non-laboratory facility on the list is Bertrand Library, the university's central library facility. There are two primary reasons for Bertrand's unusually high energy consumption given its building type. The first is that the library plays host the University's information technology infrastructure including the server rooms for network storage and campus email. Secondly, Bertrand is extremely popular as a study area among students and usership is high relative to other buildings on campus. This has forced administrators to make the library one of the only academic buildings which is open 24 hours a day thus effectively doubling its energy profile.

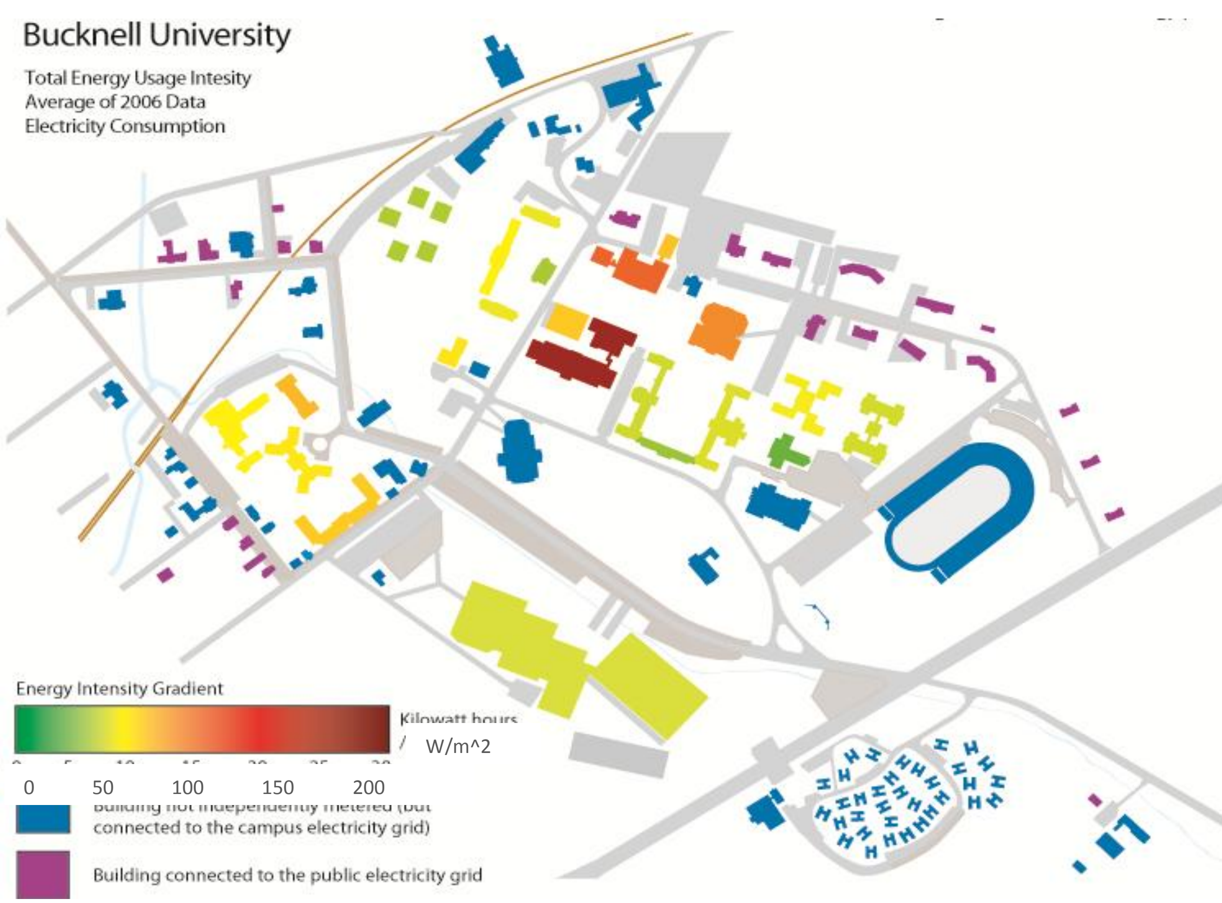


Figure 2-3: Energy Usage Density in Buildings on the Bucknell University Campus

Building Name	Building Type / Occupational Activities	Electricity	
		kWh	kWh/ft^2
Rooke Chemistry Building / Olin Science Center	Chemistry and Physics Laboratories and Teaching Spaces	7,620,345	63.14
Dana Engineering	General Engineering Laboratories and Teaching Spaces	1,229,471	52.86
Breakiron Engineering	Mechanical, Civil, and Environmental Engineering Laboratories and Teaching Spaces	1,722,000	47.22
Biology Building	Biological Science Laboratories and Teaching Spaces	3,584,257	43.05
Bertrand Library	Central Campus Library	2,424,583	37.26

Figure 2-4: Top Five Energy Consuming Buildings on the Bucknell University Campus

While these figures are restricted to the energy consumption of the facilities on these two campuses, similar maps could be constructed on the basis of hazardous material production, water demand or any number of other key environmental impact indicators and they would likely tell the exact same story: laboratory facilities have disproportionate environmental impacts and are among the greatest challenges to improving the sustainability of university, government, and private research campuses.

Some might argue that due to the intrinsic nature of modern scientific research and educational practice laboratory facilities are almost certain to consume more energy, water, and material resources during their operation lifetimes than equally sized buildings of some other type regardless of the efforts invested in improving their environmental performance. And while it may be true that laboratory facilities are likely to always be relatively more impactful that other building types, this is not to say that we should allow ourselves to become complacent about the outrageous current impacts of laboratory facilities in absolute terms.

2.3 Science and Education as Drivers of Economic Growth

The need to address the woeful environmental performance of laboratories has reached a critical stage. This is not only because of the impacts being produced by the existing generation of laboratory facilities but because of the looming disaster that would be if the next generation were to be built using the same design paradigm, making the same mistakes.

The United States is currently in the midst of the most serious economic recession since the Great Depression of the 1930’s [16]. In an effort to stimulate the economy and promote long term growth the federal government has decided to invest heavily in large scale public science and education programs. In a recent whitepaper issued by the Obama Administration’s Office of Science & Technology Policy just prior to the passage of the $787 billion American Recovery and Reinvestment Act of 2009, the need for increased investment in science and technology was defended as being a foundational component of their strategy for generating sustainable economic growth and high quality jobs [17].

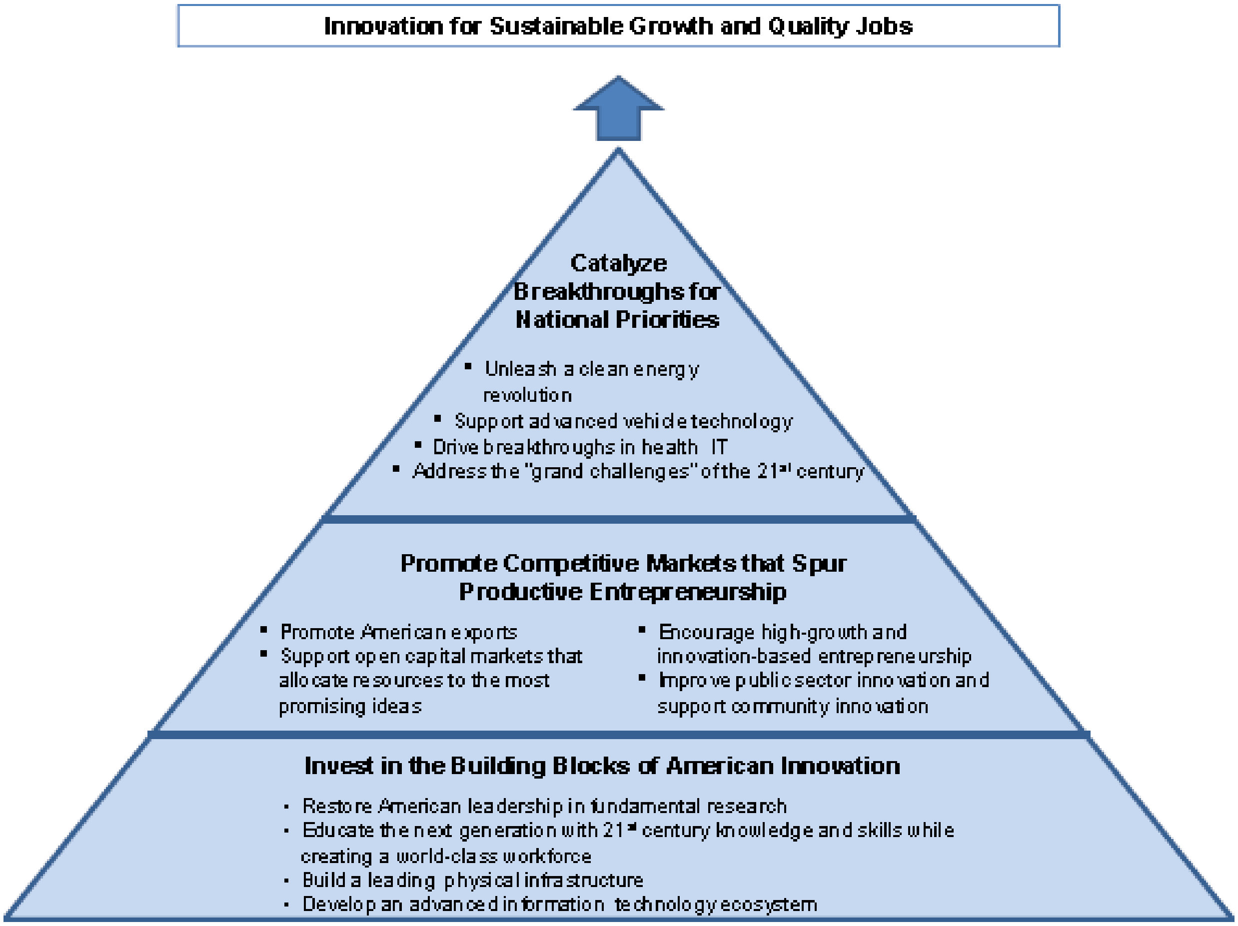


Figure 2-5: Overview Diagram of the White House Strategy for Generating Sustainable Economic Growth and High Quality Jobs

According to this report, “Over the past four decades, Federal funding for the physical, mathematical, and engineering sciences has declined by half as a percent of GDP (from 0.25 percent to 0.13 percent) while other countries have substantially increased their research budgets [17].” In an effort to reverse this trend the Obama administration has devised what it describes as a “national strategy for innovation.” [17] A core component of this strategy has been the largest Research and Development funding increase in our nation’s history, with $18.3 billion being committed to new R & D project and programs. As part of this sweeping funding commitment, the administration has pledged to double the Research and Development budgets of key science agencies including the National Institute of Standards and Technology, the National Science Foundation, and the

National Institutes of Health. Health and Energy related research activities have received special attention due their overlap with the Administrations two other core initiatives: 1) the reform of the United States' health care system to reduce costs and improving patient coverage and 2) the transformation of our national energy economy away from fossil fuels towards more renewable energy sources. Overall, the stated goal of the Obama administration has been to increase national funding for public and private research and development projects to a full 3% of our national GDP [17].

A feature article recently published in the journal *Nature* provided a useful breakdown of the funding distribution from the 2009 Recovery and Reinvestment Act as pertains to various scientific disciplines and institutions [18]. According to their analysis, there is some $12.46 billion which is immediately being made available for the design and construction of various new laboratory facilities; a specific itemization of which is provided in Figure 2-6 [18].

Agency	Allocation Description	Amount (in millions of US dollars)
National Science Foundation (NSF)	Major Research Equipment and Facilities Construction	400
	Academic Research Infrastructure	200
	Ocean Observatories Initiative	106
National Institutes of Health (NIH)	Institutes and Centers, in amounts proportional to regular budgetary action	7,400
	Facilities on Extramural Campuses	1,000
	Facilities on NIH Campus	500
National Oceanic and Atmospheric Administration (NOAA)	Core funding budgetary allocation	830
National Institute of Standards and Technology (NIST)	Core funding budgetary allocation	580
National Air and Space Administration (NASA)	Science – to accelerate Earth-science missions and improve supercomputing capabilities	400
Department of Energy (DOE)	Environmental Molecular Sciences Laboratory at Pacific Northwest National Laboratory in Washington	60
	Atmospheric Radiation and Climate Research Facility	60
	Science Laboratories Infrastructure	108
	Energy Frontiers Research Centers	277
	National Renewable Energy Laboratory Infrastructure	100
	Massachusetts Wind Technology Testing Center	25

Figure 2-6: Overview of Funds Dispersed for New Laboratory Construction as Part of the 2009 Recovery and Reinvestment Act

2.4 Laboratories as a Component of Anticipated New Green Building Development

McGraw Hill Construction is a large U.S. construction firm whose market research division maintains a proprietary database of construction activity in the United States.

Each year, the firm's analysts release a suite of publications intended to provide comprehensive and credible forecasting information about the U.S. building market. In 2005 the firm issued its first "Green Report" which focused exclusively on trends and opportunities across the different green building sectors. In the 2009 edition of this market forecast McGraw Hill analysts projected growth in green construction activities through 2013 for a variety of green building sectors. Some results of their analysis are presented in Figures 2-7 and 2-8 [19].

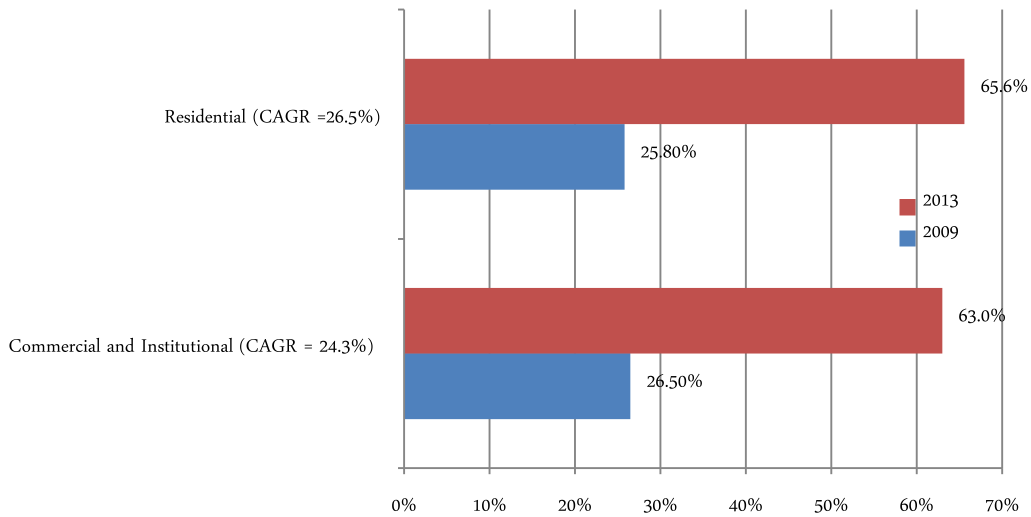


Figure 2-7: U.S. Green Building Market by Segment, 2009 and 2013 Projections in Billions of U.S. Dollars

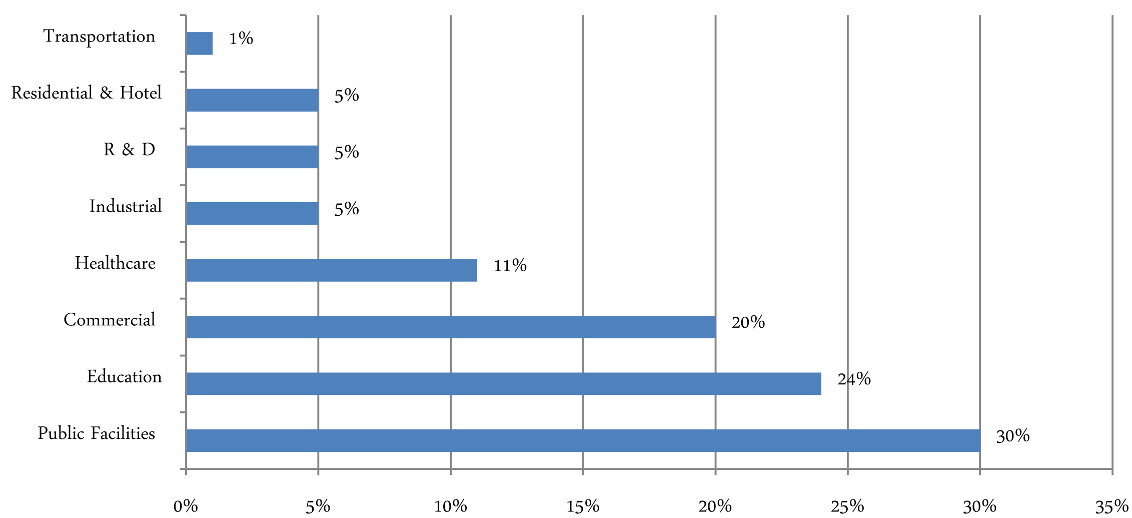


Figure 2-8: Percent of Expected Green Building Activity by Sector in 2009

Figure 2-7 indicates that there is anticipated to be double digit growth in the rates of Green Building development in the Commercial and Institutional sectors through 2009. Figure 2-8 provides a breakdown of the expected Green Building activity by sector in 2009. Here we can see that the dominant growth areas for green construction are predicted to be in the Public Facilities, Educational, and Commercial sectors. Consider this trend however, in the context of the preceding discussion related to the influx of capital which has recently been committed by the federal government and others towards the expansion and renovation of our ageing research and development infrastructure. The green wave which has been sweeping through the construction and architectural design professions has largely ignored the laboratory and R&D sectors. This is in spite of the fact that they are the most egregious consumers of water and energy and are associated with the production of large quantities of hazardous waste. A significant reason for this has to do with the way in which laboratories are considered within the USGBC's LEED program, the dominant green building certification system in the United States.

Chapter 3

Green Building Certification Programs

Perhaps the biggest driver behind the recent expansion of green design principles into the mainstream construction market has been the emergence of a centrally administered certification program capable of standardizing performance metrics and rewarding environmental design innovation. There are many such programs which exist both here in the United States and elsewhere abroad. A brief overview of the national scale programs which currently exist is provided in Figure 3-1. At present, there has not yet emerged a single viable International Green Building certification standard.

Country	Certification Programs
Austrailia	Nabers; Green Star
Brazil	AQUA
Canada	LEED Canada, Green Globes
China	GBAS
Finland	Promise
France	HQE
Germany	DGNB; CEPHEUS
Hong Kong	HKBEAM
India	GRIHA; National Rating System developed by TERI; LEED India
Italy	Protocollo Itaca; Green Building Counsil Italia
Malaysia	GBI Malaysia
Netherlands	BREEAM Netherlands
New Zealand	BERDE; Philippine Green Building Council (PHILGBC)

Portugal	Lider A
Singapore	Green Mark
South Africa	Green Star SA
Spain	VERDE
Switzerland	Minergie
United States	LEED; Living Building Challenge; Green Globes; Build it Green; NAHB NGBS
United Kingdom	BREEAM

Figure 3-1: Green Building Certification Programs by Country of Origin

Here in the United States, there are five national scale Green Building certification programs. They include: the US Green Building Council's LEED program, the Living Building Challenge, Green Globes, Build it Green, and the National Association of Home Builder's (NAHB) National Green Building Program. LEED is not only the oldest of these five programs, having been founded in 1993, but it is also far and away the most popular of the group. Since the year 2000, the USGBC's membership has more than quadrupled comprising, at present, some 19,957 member organizations including corporations and NGO's from across section of the building industry [1, 7]. In September of 2009, the total number of LEED registered projects stood at 25,611 with annual project registrations increasing at double digit rates since the year 2000 [7]. This phenomenal recent success has created a situation where the LEED brand has become almost synonymous with environmental design and construction. In the United States this transformation of LEED into the de facto standard for the evaluation of environmental performance in building design and construction means that in the future it will only come to exercise even greater control over the direction of design innovation.

3.1 The US Green Building Council's LEED Certification Program

LEED is a voluntary certification program that is based up a prescriptive checklist of design elements and performance standards for various different building types. For any building to receive LEED certification it must satisfy a number of basic requirements related to the inclusion of certain design elements or the achievement of minimum performance standards in the following key areas: sustainable sites, water efficiency, energy & atmosphere, materials and resources, indoor environmental quality, locations & linkages, awareness & education, innovation in design, and regional priority [1]. These requirements are specified at critical points in time during the building's life cycle and encompass issues ranging from the recycling of construction waste to the operation of the building's HVAC system. Many of the performance standards involve calculations that must be made during the design phase, prior to construction, and involve the specification of "percentage reductions" of various types of consumptive or productive behaviors [1]. In order to facilitate this process, comparisons are made between the proposed design and a reference design that is based on a hypothetical building of equivalent size and purpose constructed to minimum code standards.

Documented completion of the required elements on the LEED checklist qualifies a building for basic LEED certification. Depending on the extent to which the architects and engineers involved with a project include certain optional environmental design elements or improve the performance of the building's systems beyond recommended levels, a LEED certified building can receive further recognition with an exemplary rating of Silver, Gold, or Platinum[1]. The conferment of these exemplary distinctions is determined by the accumulation of points within a scoring system that is tied to elements of the LEED checklist. In the newest iteration of the LEED program, LEED v3.0, there are 110 possible points. The allocation of these points across the various checklist elements is non-uniform and, prior to the introduction of LEED v.3.0, was made at the discretion of the USGBC council members using an opaque methodological process.

The allocation of points within the system is extremely important and the lack of transparency within the USGBC's previous weighting methodology was a major criticism during the program's early years. This is because the point allocation reflects an implicit prioritization of not only of the different design elements within a building but also of the different environmental problems which they are meant to address.

3.2 Environmental Impact Assessment and Credit Weighting

In order to resolve this problem of methodological transparency, in preparation for the development of LEED v3.0 the USGBC formally adopted the environmental impact category definitions used by the U.S. Environmental Protection Agency's (USEPA) Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) [20]. According to the USGBC's description of the new weighting methodology which they developed for the release of LEED v3.0 [21, 22]:

> *The TRACI categories were selected because they represent a comprehensive, currently available complement to LEED which is appropriate for the North American building market. Layered on top of the TRACI environmental impact categories are weightings devised under the auspices of NIST (National Institute of Standards and Technology) which compare the impact categories to each other and assign a relative importance to each. Together, the TRACI impact categories and the weightings assigned by the NIST process provide a foundation for discussion of the environmental impacts related to the design, construction, operations, and maintenance of the built environment.*
>
> *A matrix is then created which places weighted impact categories on one axis with LEED credits on another axis. This matrix can then be used to evaluate which credits address which impacts, and to what degree. USGBC, working alongside several expert consultants, guided the development of a weightings workbook tool to analyze how each LEED credit interacts with the list of impacts. This tool served as the starting point from which the LEED Steering Committee discussed the reallocation of points in LEED v3.0.*

Included in Figure 3-2 is a breakdown of the relative weights which have been assigned within the LEED v3.0 scoring system on the basis of TRACI's 13 categories of environmental impacts [20]. This list has been sorted in a descending order on the basis of each category's percentage weighting within the scoring system.

TRACI Category	Weights (%)	Description of Category	Informational Source
Greenhouse Gas Emissions	25	Operation greenhouse gas emissions (CO2e/year)	Empirical calculations based on CBECS, the Bureau of Transportation Statistics, and other national data sources
Indoor Environmental Quality	15	Impacts on building occupants and the indoor environment	No model; association based upon credit function
Fossil Fuel Depletion	9	Consumption of non-renewable fossil fuels	SimaPro/USA Input Output 98 library
Particulates	8	Generation of particulate emissions throughout the life-cycle of a building	SimaPro/USA Input Output 98 library/Ecocalculator
Water Use	7	Consumption of water throughout the life cycle of a building	SimaPro/USA Input Output 98 library
Human Health – Cancer	7	Generation of cancer-causing compounds throughout the life-cycle of a building	SimaPro/USA Input Output 98 library
Ecotoxicity	6	Generation of ecotoxic pollutants throughout the life-cycle of a building; Generation of ecotoxic pollutants at the site	SimaPro/USA Input Output 98 library/Ecocalculator
Land Use	5	Consumption of land throughout the life cycle of a building	SimaPro/USA Input Output 98 library
Eutrophication	5	Generation of nutrient pollution throughout the life cycle of a building; Generation of nutrient pollution at the site	SimaPro/USA Input Output 98 library/Ecocalculator
Smog Formation	4	Generation of smog forming emissions throughout the life cycle of a building	SimaPro/USA Input Output 98 library/Ecocalculator
Human Health	4	Generation of non-cancer	SimaPro/USA Input Output

TRACI Category	Weights (%)	Description of Category	Informational Source
– Non Cancer		causing compounds throughout the life-cycle of a building	98 Library
Acidification	3	Generation of “acid rain” emissions associated with acidification throughout the life-cycle of a building	SimaPro/USA Input Output 98 library/Ecocalculator
Ozone Depletion	2	Generation of ozone depleting emissions throughout the life cycle of a building	SimaPro/USA Input Output 98 library/Ecocalculator

Figure 3.2: Overview of TRACI Environmental Impact Categories as Pertains to the LEED Certification Program’s Credit Weight Distributions

As described in the introduction, perhaps the most important component of the LEED program is its capacity to evolve to the ever changing design landscape and the shifting criticality of environmental issues. This evolutionary process occurs largely through the addition or subtraction of design elements from the LEED checklist and the manipulation of the number of points allocated to various checklist items. The process of including a new design element within the checklist or, for that matter, eliminating an existing one begins with the constructive criticism of LEED practitioners, including architects, engineers, product manufacturers, and regulatory agents [7, 23]. Their input regarding the perceived efficacy of the various checklist elements is constantly being collected by the USGBC through regular comment periods and industry colloquiums; the goal being, for this information to be synthesized and beneficially applied to the improvement of the program’s structure and function [7, 23]. While this strategy has been successfully applied to the improvement of many aspects of the LEED program, particularly those relating to the challenges associated with implementing LEED to commercial and existing structures. There is still a great deal of work which needs still to be done.

3.3 LEED Certification for Laboratory Facilities

According to the USGBC LEED was "designed and built using strategies aimed at improving performance across all the metrics that matter most: energy savings, water efficiency, CO_2 emissions reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts." [22] Their claim however, that "LEED is flexible enough to apply to all building types" has been contradicted by the serious difficulties which design practitioners have experienced in their attempts to gain LEED certification for chemically intensive laboratory facilities [2, 3, 22, 24]. Despite the large and growing number of LEED registered projects there are relatively few which have been able to achieve the program's highest ratings. While there are a great number of LEED certified facilities which may claim to be laboratories there are only a handful which actually house operations involving the use of significant quantities of hazardous chemical materials.

The U.S. EPA defines a hazardous waste as any waste that is dangerous or potentially harmful to human health or the environment [25]. Concurrently, a hazardous waste generator is defined any person or site whose processes and actions create hazardous waste [25]. Generators are divided into three categories based upon the quantity of waste they produce [25, 26]:

1. Large Quantity Generators (LQGs) generate 1,000 kilograms per month or more of hazardous waste, more than 1 kilogram per month of acutely hazardous waste, or more than 100 kilograms per month of acute spill residue or soil.
2. Small Quantity Generators (SQGs) generate more than 100 kilograms, but less than 1,000 kilograms, of hazardous waste per month.
3. Conditionally Exempt Small Quantity Generators (CESQGs) generate 100 kilograms or less per month of hazardous waste, or 1 kilogram or less per

month of acutely hazardous waste, or less than 100 kilograms per month of acute spill residue or soil.

As condition of the 1976 Resource Recovery and Conservation Act each class of generator must obtain an individual EPA identification number and is obligated to submit a biennial report of their hazardous waste production and disposal history [26]. By cross referencing this freely available report data with the USGBC's database of LEED registered projects it is possible to determine the number and rating of LEED registered facilities that have been classified as Large Quantity Generators of hazardous wastes.

Excluding the new laboratories being evaluated under the LEED v3.0 standard for which data is not yet available, there are only 9 laboratory facilities in the United States that have earned a rating of LEED Platinum which are now or have at one time been classified as Large Quantity Generators within the RCRA biennial reporting scheme . A list of these facilities is presented in Figure 3-3.

Facility Name	Facility Owner	Location (City, State)
Genzyme Center	BioMed Realty Trust Inc.	Cambridge, MA
NREL Science and Technology Facility	National Renewable Energy Laboratory	Golden, CO
Applied Research & Development Facility	Northern Arizona State University	Flagstaff, AZ
Arizona Biodesign Institute, Phase 2	Arizona State University	Tempe, AZ
Tahoe Center for Environmental Sciences	Sierra Nevada College	Incline Village, NV
Natural Sciences Building	Mills College	Oakland, CA
St. Olaf Science Complex, Reagents Hall	St. Olaf College	Northfield, MN
Donald Bren School of Environmental Studies	University of CA, Santa Barbara	Santa Barbara, CA

Figure 3-3: LEED Certified Wet Laboratories in the United States

The paucity of LEED certified laboratory facilities which house processes that result in the production of large quantities of hazardous waste raises some fundamental questions about the structure of the LEED system, the nature of laboratory processes, and the possible limitations for environmentally benign laboratory design.

One possible interpretation of this finding might be that the current structure of the LEED certification system is fundamentally incompatible with the challenges associated with the design and operation of laboratory facilities. Were this to be the case, modifications to the existing LEED system or the development of a new LEED subcategory which is explicitly dedicated to labs should provide a solution to the problem.

An alternative interpretation however, might also be that it is instead the nature of the scientific processes being housed within laboratory facilities which is fundamentally incompatible with the principles of environmental design. In this case, it would be impossible to design a laboratory facility housing traditional scientific processes which rely heavily on hazardous chemical materials that did not violate the core principles of the LEED certification program. Should this prove to be the correct interpretation, it would seem that in order to successfully design a LEED certified laboratory facility it would first be necessary to reconsider the scientific processes contained within it such that the use of hazardous chemical materials was completely eliminated.

The reality of the situation lies somewhere in between these two extreme interpretations. To be sure, the current practice of evaluating chemically intensive laboratory facilities according to the same general standards which are applied to building’s such as libraries, conference centers, and auditoriums is obviously flawed. However, practitioners who have been involved in previous efforts to devise a new “LEED for Laboratories” program have as yet been unable to come up with a format that is both technically feasible and cost effective while still remaining true to the core principles of environmental stewardship upon which LEED was originally founded. The source of this impasse can be traced back to the inherent difficulties associated with designing a facility that safely allows human occupants to coexist with large quantities of volatile and hazardous chemical materials.

Chapter 4

Labs21: Laboratories for the 21st Century

Much of the impetus for the development of a new LEED for laboratories has come from the members of a voluntary organization known as Laboratories for the 21st century (Labs21) which is jointly sponsored by the U.S. EPA and the U.S. Department of Energy (DOE) [27]. The motivation behind the initial development of the Labs21 program was to provide a venue for the sharing of information between facility designers, engineers, owners, and managers interested in minimizing the environmental impacts associated with the design and operation of their laboratory facilities [27, 28]. Labs21, in contrast to LEED, was never meant to be associated with any sort of third party verification scheme. Instead, the overarching purpose of the program has been to critically evaluate existing best practices in the fields of laboratory design and operation. To this end, the Labs21 program has since developed and continues to update their own Environmental Performance Criteria (EPC), which they consider to be an survey of industry best practices in laboratory design and operation [27].

The format of the Labs21 EPC is of great importance to the goals of this paper because of the prominent role which it has had in shaping draft proposals for a new LEED for laboratories program. In 2003 the USGBC formally sanctioned a committee to begin developing a new dedicated LEED checklist for the certification of laboratory facilities. During this early stage of development the pilot project was known as the LEED-Application Guide for Laboratories (LEED-AGL) [2]. At the core of the LEED-AGL draft committee were several prominent members of the Labs21 program; individuals responsible for the development of the EPC. As a result of this fact, early iterations of the LEED-AGL were merely attempts to codify the recommendations embodied by the Labs21 EPC.

At present, in remains unclear as to whether or not the LEED-AGL pilot program will ever be formally adopted as a part of the LEED certification system. To this end, within the laboratory design community, the efforts of the LEED-AGL development committee are largely considered to have been fruitless. This failure, in conjunction with the knowledge that the early LEED-AGL proposals were based upon recommendations from the Labs21 EPC, indicate that there must be a significant flaw with the Labs21 approach to environmentally benign laboratory design. In order to diagnose the shortcoming of the EPC and, indirectly, the early LEED-AGL proposals it is necessary to provide a brief overview of the underlying philosophy behind the Labs21 program and a discussion of its basic components.

4.1 The Labs21 Environmental Performance Criteria

The Labs21 Environmental Performance Criteria comprises a set of design elements which correspond to the unique challenges associated with laboratory design. The EPC is meant to build upon the prescriptive structure employed by the LEED certification program. It can be thought of as a list of supplementary credits which have been added on to the conventional LEED for new construction checklist to make it more appropriate for the evaluation of laboratory facilities. The most recent version of the EPC, EPC v2.2, has been formatted to coincide with the structure of the LEED v2.2 system. Provided in Figures 4-1 through 4-6 are summary overviews of the existing design elements and performance standards included in the LEED v2.2 checklist for new constructions and major renovations [27]. Shaded in grey are the additional elements associated with the Labs21 EPC. Also, included below the tables for each section are summary descriptions of the requirements associated with each of the proposed new credits/prerequisites as defined by the Labs21 authors.

Credit	Sustainable Sites	16 Points
Prereq 1	Prerequisite: Construction Activity Pollution Prevention	Required
Credit 1	Site Selection	1
Credit 2	Development Density & Community Connectivity	1
Credit 3	Brownfield Redevelopment	1
Credit 4.1	Alternative Transportation, Public Transportation Access	1
Credit 4.2	Alternative Transportation, Bicycle Storage & Changing Access	1
Credit 4.3	Alternative Transportation, Low-Emitting and Fuel Efficient Vehicles	1
Credit 4.4	Alternative Transportation, Parking Capacity	1
Credit 5.1	Site Development, Protection or Restoration of Habitat	1
Credit 5.2	Site Development, Maximize Open Space	1
Credit 6.1	Storm Water Design, Quantity Control	1
Credit 6.2	Storm Water Design, Quality Control	1
Credit 7.1	Heat Island Effect, Non-Roof	1
Credit 7.2	Heat Island Effect, Roof	1
Credit 8	Light Pollution Reduction	1
Credit 9.1	Safety and Risk Management, Air Effluent	1
Credit 9.2	Safety and Risk Management, Water Effluent	1

Figure 4-1: Labs21 EPC Sustainable Sites Credits Checklist Points Breakdown

Credit 9.1 (1 point) Meet all standards and generally accepted guidelines for outdoor protection of workers and general public from airborne chemical, radioactive and biological hazards. Use mathematical modeling, physical modeling and/or post-construction testing and certification to prove compliance. Use effluent controls that minimize generation of waste subject to special regulations.

Credit 9.2 (1 Point) Prevent releases of hazardous chemicals and other pollutants to sanitary sewer, using containment and engineering controls.

Credit	Water Efficiency	7 Points
Prereq	Laboratory Equipment Water Use	Required
Credit 1.1	Water Efficient Landscaping, Reduce by 50%	1
Credit 1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	1
Credit 2	Innovative Wastewater Technologies	1
Credit 3.1	Water Use Reduction, 20% Reduction	1
Credit 3.2	Water Use Reduction, 30% Reduction	1
Credit 4.1	Process Water Efficiency, Document Baseline	1
Credit 4.2	Process Water Efficiency, 20% Reduction	1

Figure 4-2: Labs21 EPC Water Efficiency Credits Checklist Points Breakdown

Prerequisite 1.0: No domestic water at a flow rate greater than 2 gallons per minute shall be used ―once-through‖ for any laboratory equipment, unless it is needed as direct contact process water.

Credit 4.1 (1 point): Calculate and document baseline of annual process water use and process wastewater generation. Install water meters to measure process water use.

Credit 4.2 (1 point): Adopt technologies and strategies to reduce process water use and process wastewater generation by 20%. Document the reductions from baseline.

Credit	Energy & Atmosphere	25 Points
Prereq 1	Fundamental Building Systems Commissioning	Required
Prereq 2	Minimum Energy Performance	Required
Prereq 3	CFC Reduction in HVAC&R Equipment	Required
Prereq 4	Assess Minimum Ventilation Requirments	Required
Credit 1	Optimize Energy Performance	1 to 10
Credit 2	Renewable Energy	1 to 3
Credit 3	Enhanced Commissioning	1
Credit 4	Enhanced Refrigerant Mangagement	1
Credit 5	Measurement & Verification	1
Credit 6	Green Power	1
Credit 7	Energy Supply Efficiency	1 to 5
Credit 8	Improve Laboratory Equipment Efficiency	1
Credit 9.1	Right-Size Laboratory Equipment Load: Measure Comparable Lab	1
Credit 9.2	Right-Size Laboratory Equipment Load: Metering Provision	1

Figure 4-3: Labs21 EPC Energy & Atmosphere Credits Checklist Points Breakdown

Prerequisite 2.0: Establish the minimum level of energy efficiency for the proposed building and systems.

Prerequisite 4.0: To determine minimum ventilation requirements in laboratories based on user needs, health/safety protection and energy consumption.

Credit 1: Achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use.

Credit 2: Encourage and recognize increasing levels of on-site renewable energy self-supply in order to reduce environmental and economic impacts associated with fossil fuel energy use.

Credit 7: Reduce the total non-renewable source energy required for the facility through increased energy supply efficiency.

Credit 8: Use Energy Star® compliant equipment or equipment in the top 25th percentile for at least 75 percent of new Class 1 and Class 2 equipment and at least 30 percent of all Class 1 and Class 2 equipment. Acceptance of equipment in the 25th percentile requires a minimum of 4 different models that meet the functional needs of the research. If only 2 or 3 functionally equivalent models are available, acceptance requires selection of the most energy efficient model.

Credit 9.1 (1 point) Measure base usage of equipment electrical loads in a comparable laboratory space for each functional type of laboratory space and design electrical and cooling systems based on these measurements.

Credit 9.2 (1 point) Design electrical distribution system to provide for portable or permanent check metering of laboratory equipment electric consumption. Design for safe access to electrical feeder enclosures and provide sufficient space to attach clamp-on or split core current transformers

Credit	Materials & Resources	14 Points
Prereq 1	Storage & Collection of Recyclables	Required
Prereq 2	Hazardous Material Handling	Required
Credit 1.1	Building Reuse, Maintain 75% of Existing Walls, Floors & Roof	1
Credit 1.2	Building Reuse, Maintain 100% of Existing Walls, Floors & Roof	1
Credit 1.3	Building Reuse, Maintain 50% of Interior Non-Structural Elements	1
Credit 2.1	Construction Waste Management, Divert 50% from Disposal	1
Credit 2.2	Construction Waste Management, Divert 75% from Disposal	1
Credit 3.1	Materials Reuse, 5%	1
Credit 3.2	Materials Reuse, 10%	1
Credit 4.1	Recycled Content, 10% (post-consumer + 1/2 pre-consumer)	1
Credit 4.2	Recycled Content, 20% (post-consumer + 1/2 pre-consumer)	1
Credit 5.1	Regional Materials, 10% Extracted, Processed & Manufactured Regionally	1
Credit 5.2	Regional Materials, 20% Extracted, Processed & Manufactured Regionally	1
Credit 6	Rapidly Renewable Materials	1
Credit 7	Certified Wood	1
Credit 8	Chemical Resource Management	1

Figure 4-4: Labs21 EPC Materials & Resources Credits Checklist Points Breakdown

Prerequisite 2.0: Develop a system to maintain current information about hazardous material types, quantity, location, and disposal/use histories, and deliver information to a central location.

Credit 8.0: Develop an action plan to eliminate, minimize, substitute, recycle, and dispose of harmful chemicals safely. Plan should improve distribution, and limit quantities, storage and waste.

Credit	Indoor Environmental Quality	18 Points
Prereq 1	Minimum IAQ Performance	Required
Prereq 2	Environmental Tobacco Smoke (ETS) Control	Required
Prereq 3	Laboratory Ventilation	Required
Prereq 4	Exterior Door Notification System	Required
Credit 1	Outdoor Air Delivery Monitoring	1
Credit 2	Increased Ventilation	1
Credit 3.1	Construction IAQ Management Plan, During Construction	1
Credit	Construction IAQ Management Plan, Before Construction	1

3.2		
Credit 4.1	Low-Emitting Materials, Adhesives & Sealants	1
Credit 4.2	Low-Emitting Materials, Paints & Coatings	1
Credit 4.3	Low-Emitting Materials, Carpet Systems	1
Credit 4.4	Low-Emitting Materials, Composite Wood & Agro-fiber Products	1
Credit 5	Indoor Chemical & Pollutants Source Control	1
Credit 6.1	Controllability of Systems, Lighting	1
Credit 6.2	Controllability of Systems, Thermal Comfort	1
Credit 7.1	Thermal Comfort, Design	1
Credit 7.2	Thermal Comfort, Verification	1
Credit 8.1	Daylight & Views, Daylight 75% of Spaces	1
Credit 8.2	Daylight & Views, Daylight 90% of Spaces	1
Credit 9.1	Indoor Environmental Safety, Airflow Modeling	1
Credit 9.2	Indoor Environmental Safety, Fume hood Commissioning	1

Figure 4-5: Labs21 EPC Indoor Environmental Quality Credits Checklist Points Breakdown

Prerequisite 3.0: Meet the minimum requirements of ANSI Z9.5 (latest version).
Prerequisite 4.0: Provide an explicit notification system for all doors leading directly from pressure-controlled laboratory spaces to the outside.
Credit 9.1 (1 point) Optimize indoor airflow based on results of computational fluid dynamics (CFD) or physical modeling.
Credit 9.2 (1 point) Conduct fume hood commissioning that includes ASHRAE-110 Method of Testing Performance of Laboratory Fume Hoods (latest version) As Installed. Scope of testing to include 6.1 Flow

Visualization, 6.2 Face Velocity Measurements and 7.0 Tracer Gas Test Procedures. The hood performance rating for the Tracer Gas Test procedure shall be at least 4.0 AI 0.1 as specified in ASHRAE-110. Credit 9.3 (1 point) Design all alarm systems in the laboratory to be inherently self-identifying and failsafe.

Credit	Innovation & Design Process	5 Points
Credit 1.1	Mini Environments	1
Credit 1.2	Displacement Ventilation	1
Credit 1.3	Optimized Utility Services	1
Credit 1.4	Design for Flexibility and Modularity	1
Credit 2	Design for Catastrophic Events	1

Figure 4-6: Labs21 EPC Innovation & Design Credits Checklist Points Breakdown

Mini Environments: Minimize the space that has rigorous environmental requirements. Use specially enclosed spaces to keep areas requiring tight environmental controls as small as possible. One example is the provision of a clean bench for a process instead of the use of an entire clean room.

Displacement Ventilation: A low-pressure air distribution system in which incoming air originates at floor level and rises to exhaust outlets at the ceiling. Incoming air is delivered to interior rooms by way of floor-level vents. This incoming air displaces upper air, which is exhausted through ceiling-level vents. Air pollutants generated within the building are removed at source and are not recirculated. In addition, heat generated by ceiling level lights is removed, and thus heat is not included when estimating building cooling loads.

Optimized Utility Services: Use equipment without excessive utility service requirements (e.g. high pressure), or provide stand-alone utility services. For example, equipment that requires high-pressure compressed air, water, or steam, or excessively chilled water should be avoided when equipment requiring less intensive service are available to the owner/occupant. Often excessive requirements are driven by low equipment first-cost, but put a significant burden on the laboratory's utility infrastructure. One piece of equipment can dictate the utility service delivery set-point with significant energy impacts. Where lab equipment may dictate utility service set-points, consider stand-a-lone utility systems (e.g. a dedicated chiller).

Design for Flexibility and Modularity: For example, the use of interstitial floors.

Design for Catastrophic Events: Innovative design that minimizes the release of hazardous chemicals into sanitary sewer and storm water during a catastrophic event such as a fire, flood or earthquake.

4.2 Criticisms of the Labs21 Environmental Performance Criteria

The vast majority of the new checklist items proposed in the Labs21 EPC seek to improve the performance of engineered exposure controls within the laboratory. Reflecting upon the discussion of risk as being a function of hazard and exposure first presented in the introduction, this approach can therefore be thought of as merely adhering to the traditional method of risk management through the engineered control of exposure to hazardous materials. Not only is this approach fundamentally at odds with the goals of environmental design, but there is also a practical limit to which the efficiency and effectiveness of engineered exposure controls can ultimately be improved.

With this being said, there is one credit in their proposal which breaks with this traditional paradigm and instead seeks to minimize the presence of hazardous chemicals within the laboratory. This is Credit 8 in the Materials & Resources section, entitled Chemical Resource Management. The fact that only a single credit is devoted to chemical resource management indicates that the authors of the EPC fail to grasp the central role of a laboratory’s hazardous materials throughput in determining the character of the facility’s electrical and mechanical systems. For instance, if a laboratory’s chemical operations were reconceived such that they were able to achieve 20% reduction in the volume of hazardous materials used, that laboratory may no longer need several fume hoods or bio-safety containment cabinets to provide the same degree of functionality/productivity. Furthermore, if that same 20% reduction could have been anticipated during the programming stage of the laboratory’s design, the new greener processes could have been concentrated into a closed spatial area, one which would not require the same number of air changes per hour as a conventional laboratory zone. In this way, a single effort in the category of chemical management could potentially result in beneficial impacts that would have been distributed amongst a number of different credit categories within the LEED program.

Another problematic feature of the Labs21 EPC’s approach to chemical resource management is its failure to provide adequate guidance in terms of exactly how laboratory managers and principal investigators should go about reducing the use of hazardous chemicals in their experimental processes. The following is an excerpt from the list of recommended technologies and strategies associated with the Labs21 EPC Chemical Resource Management credit [27]. Of the nine total recommended technologies and strategies, seven pertain to the development of procedures for the safe handling of hazardous waste within a facility and the optimization of purchasing practices for minimizing the volume of hazardous material on site at any given time.

1. *Develop material handling and processing guidelines as a part of initial building design, and monitor implementation of guidelines as a part of final building commissioning. Guidelines should reduce consumption of hazardous materials, and to prevent potential contamination of the surrounding environment.*
2. *Consider providing dedicated centralized areas for receiving of, return of, or safe disposal of, hazardous materials. Also consider providing dedicated space in each lab for receiving of, return of, or safe disposal of, hazardous materials. Include an area for reporting of all hazardous material transactions to a central inventory system.*

The development and implementation of a materials handling and processing strategy as part of the initial building design is an important environmental health and safety measure; however, it does nothing to reduce or eliminate the volume of hazardous materials being used within a laboratory facility. And, in this way, it fails to positively affect the environmental performance of any of the building's other systems.

3. *Minimize proliferation of hazardous materials in laboratories by developing "just in time" inventory system.*
4. *Provide coordinated materials transport strategy that allows efficient "just in time" delivery of hazardous materials.*
5. *Work with Environmental Health and Safety (EHS) personnel and local code officials in developing action plan.*

The whole concept of "Just in Time" purchasing has only recently been made possible by the advent of advanced computerized systems for the management of chemical inventories in real time. A "Just in Time" purchasing system involves a chemical purchasing strategy in which hazardous materials are only ordered immediately prior to their use in the laboratory and in as small a volume as possible given the requirements of the experimental procedure for which they will be used. There are several advantages to using a "Just in Time" purchasing strategy as compared to traditional stock room practices. First and foremost of which is that “Just in Time” purchasing allows a facility to drastically reduce the floor area that must be designed to accommodate the long term storage of hazardous materials. Code requirements for long term storage areas within a laboratory generally specify the use of chemically resistant finishes, blast and fire resistant constructions, and high hourly air change levels; all of which are amount to significantly increased costs and environmental impacts associated with both the construction and operation of the facility. Another significant benefit has to do with the handling, storage, and disposal of large volume hazardous material vessels. “Just in Time” purchasing ensures that only the minimum volume of a hazardous chemical is delivered at any one time. This reduces the probability of large volume spill events as well as the amount of material in large volume containers that remains following initial use.

The latter benefit has been found to be extremely significant in a number of laboratory cost studies [29]. This is because it is often the case that a material which is not consumed within three years of its initial purchase will likely never be fully consumed throughout the entire life of the laboratory. As a result, the combined cost of the storage of that material as well as its disposal will likely outweigh the cost benefits that were realized through the initial bulk material purchase.

Package Size	1 L	4 L
Purchase price	$42.49	$93.72
Unit purchase price per mL when 200 mL are used	$0.04	$0.02
Unit purchased price per mL used	$0.04	$0.05
Disposal Costs	$0.00	$29.80
Purchase plus disposal costs	$84.89	$123.52
Purchase plus disposal unit cost per mL used	$0.04	$0.06

Figure 4-7: Sample Case Study of the Cost Benefits Associated with Minimizing Container Volumes when Purchasing Xylene

Presented here is a sample cost structure for the purchase of two different quantities of the common laboratory solvent xylene assuming only partial usage of the purchased volume [29]. Despite the fact that the larger volume container has a lower unit purchase price, if the entire volume of the chemical is not consumed, its life cycle cost (taking into account disposal costs) end up being much higher overall. Given this already convincing price structure, it is important to note that it presumes the identity of the chemical material being disposed of is known. In real world laboratory environments however, this is often not the case with material containers frequently being mislabeled or going unlabeled. Keeping this in mind, it should be noted that the storage cost for unknown hazardous chemicals are vastly in excess of that for a known hazardous agents.

While the first four recommended strategies and technologies from the Labs21 EPC Chemical Management credit reflect the traditional paradigm for risk management in chemically intensive laboratory facilities, there are a number of other promising, albeit unfocused recommendations for hazardous materials reduction [27].

6. *Develop decanting procedures that eliminate waste or allow for recycling of waste streams.*
7. *Use automated laboratory equipment that maximizes sample throughput while minimizing sample size, reagent quantity, and waste streams.*
8. *Use alternative equipment or laboratory methods designed to reduce consumption of hazardous materials.*
9. *Minimize use of hazardous materials in relationship to testing/experimental volume.*

These four strategies represent an attempt by the developers of the Labs21 program to articulate an alternative paradigm for risk management in chemically intensive laboratory environments, one that does not work against the efforts to improve the sustainability of the facility’s design. In the context of this new paradigm, it is particularly important to recognize that none of these four strategies makes any reference to specific attributes of the buildings physical structure or operational systems. Instead rather, they are completely focused on the nature of the laboratory's scientific processes.

Strategies 6 and 7 represent a common sense eco-efficiency approach to the greening of laboratory operations. They advocate the augmentation of existing chemical processes to include more intelligent waste recovery systems and decanting methods which are designed to improve efficiency while at the same time reducing the production of hazardous chemicals. While such activities can be extremely useful in the short term, they do not reflect the type of transformative change which has been intimated by the preceding mention of a new paradigm for risk management. The second two strategies on the other hand do point towards such a paradigm.

Take for instance strategy 8 which calls for the use of "alternative equipment or laboratory methods [which are] designed to reduce the consumption of hazardous materials." [27] The proposal of this strategy as a viable option for the greening of laboratory processes makes an important implicit assumption about the fundamental nature of the chemical sciences. In effect, it is making the claim that for any chemical process in which hazardous chemicals are currently used, there exists another alternative process or material capable of providing the same desired level of functionality and performance without the inherent risk. This is a tremendously profound statement which bears great relevance to the issue of how to overcome existing barriers to improving the environmental performance of chemically intensive laboratories. This is because if, as we have proposed, the presence of chemical hazards within wet laboratories is indeed the driving force behind the vast majority of a laboratory's environmental impacts both in terms of the facility's design and operation then minimizing or eliminating the use of hazardous chemicals should be at the heart of any program seeking to improve the environmental performance of that facility.

In terms of the Labs21 EPC and its relationship to a potential new LEED for laboratories program, there is insufficient emphasis placed on the role of chemical management within laboratories. This is evident in the fact that there is only a single performance credit related to this issue and under the proposed weighting scheme it would only be allocated a single point. Another significant issue is that the reference materials associated with the Labs21 chemical management credits do not provide any sort of constructive guidance for how educators, research scientists, and laboratory managers should actually go about reevaluating the chemical processes in their laboratories. If these stakeholders are to be expected to take proactive measures towards reducing the volume of hazardous materials currently being utilized in their laboratories they need to have a systematic methodology for evaluating existing processes as well as access to a community of other, similarly interested parties, who have knowledge and experience working on these same issues.

Chapter 5

Green Chemistry for Laboratory Design

We believe that the discipline of Green Chemistry is capable of addressing the many shortcomings of the existing Labs21 EPC′s approach to the issues of chemical resource management; issues which are of critical importance in determining systemic environmental performance within newly developed laboratory facilities. Furthermore, we also feel that Green Chemistry reflects an alternative philosophical approach to the concept of risk management from that which has been expressed in draft proposals for a new LEED for laboratories program. Specifically, Green Chemistry is based upon the essential idea that risk should be managed in an intrinsic rather than a circumstantial manner. We fear that anticipated new LEED for laboratories program is going to place too strong an emphasis on the development of circumstantial solutions to issues of risk management in the laboratory and that as a result it will prevent laboratory facilities from achieving potential gains in terms of reduced environmental impact.

5.1 The 12 Principles of Green Chemistry

The term Green Chemistry refers to a new approach to the chemical sciences which seeks to address, on a fundamental level, the problems of inherent chemical toxicity, non renewable resource consumption, and environmental degradation that have become the unfortunate legacy of the chemical sciences since the advent of petroleum based synthetic chemistry in the early 1920′s [4]. Not to be confused with environmental chemistry, which deals with the study of chemical process occurring in natural physical and biological systems, Green Chemistry is concerned with the design of products and processes which eliminate the use of hazardous chemicals and minimize the environmental impacts generated across a product's entire life cycle.

As a formal academic discipline, Green Chemistry was first founded in 1998 by chemists Paul T. Anastas and John C. Warner with their publication of the seminal text *Green Chemistry: Theory and Practice* and the inaugural publication of the *Journal of Green Chemistry* by Royal Society of Chemistry (RSC) Publishing Group [4, 30]. In the opening paragraphs of *Green Chemistry: Theory and Practice*, Anastas and Warner discuss the fact that of the ten largest commercial industries in the United States, the Chemical Industry is responsible for the release of more hazardous wastes than the nine others combined [4]. In order to effect change within the both the commercial chemical industry as well as the various fields of academic chemistry research Anastas and Warner sought to develop a set of basic principles which could be applied to the design of any chemical product or process so as to produce a more healthful and sustainable outcome. The product of their efforts was what has now come to be known as the 12 Principles of Green Chemistry [4].

Prevention It is better to prevent waste than to treat or clean up waste after it has been created.
Atom Economy Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
Less Hazardous Chemical Syntheses Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
Designing Safer Chemicals Chemical products should be designed to effect their desired function while minimizing their toxicity.
Safer Solvents and Auxiliaries The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
Design for Energy Efficiency

Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
Use of Renewable Feedstocks A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
Reduce Derivatives Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
Catalysis Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
Design for Degradation Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
Real-time analysis for Pollution Prevention Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
Inherently Safer Chemistry for Accident Prevention Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Figure 5-1: The 12 Principles of Green Chemistry

5.2 Community Development

2008 marked the ten year anniversary of the foundation of the Journal of Green Chemistry [30]. As of that year the journal's impact factor, a measurement of the relative importance of a publication within its field based upon the number times its articles have been cited, was measured to be 4.836, a figure which was up 15% from the previous year and over 100% since the journal's inception [30]. Today, according to this same metric, the Journal of Green Chemistry is the third most important publication currently being produced by the Royal Society of Chemistry publishing group. Furthermore, it ranks strongly within its peer group of chemistry journals put out by other major publishing houses.

The academic community both domestically and abroad have wholehearted adopted the Principles of Green Chemistry into their research and educational agendas. The University of Oregon, an institution at the vanguard of Green Chemistry innovation, maintains a database of researchers, educators, industry professionals, and government agents interested in Green Chemistry and who actively work within the field. The map presented in Figure 5-2 was taken from the website for the University of Oregon's Green Education Materials for Chemists (GEMs) database. It provides a rough impression of the depth and breadth of the global green chemistry community.

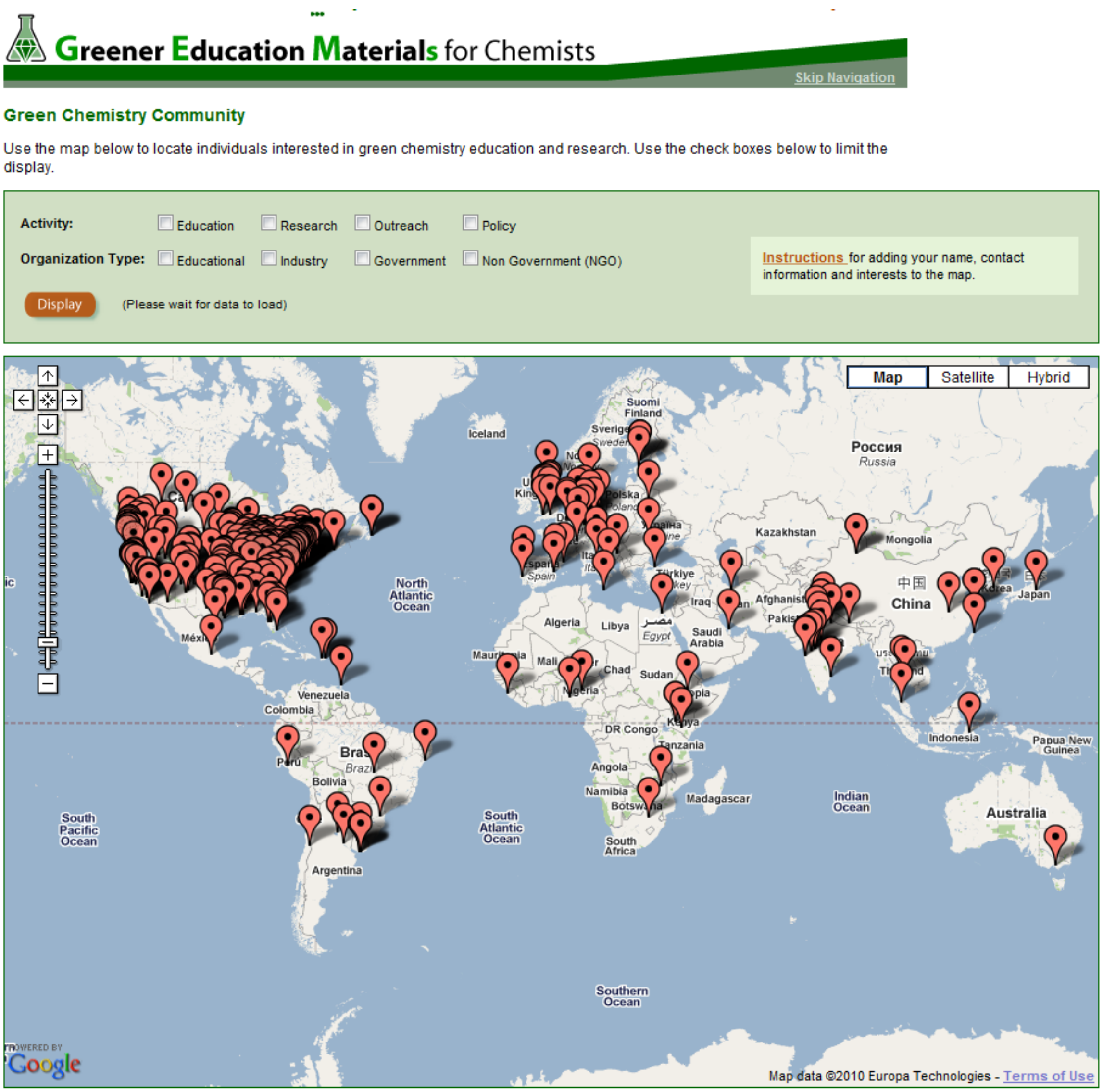


Figure 5-2: Online Map of the University of Oregon GEMS Community Database

Each call out balloon represents an individual researcher or affiliate institution interested in Green Chemistry and available for consultation through the network. In addition to maintaining information about persons and institutions who are interested in Green Chemistry another principle function of the GEMs database is to act as a clearinghouse for research and educational materials related to Green Chemistry. This purpose reflects an unfortunate downside of Green Chemistry's tremendous recent success: the current pace with which new discoveries are being made is vastly in excess of the rate at which they can be cataloged and communicated to the broader academic community.

5.3 Rates of Adoption

While academia has recently been struggling to keep up with the frantic pace of innovation in the field of Green Chemistry, the commercial chemical industry appears to be much more agile in terms of incorporating new innovations into their production processes and product lines. This is because large corporations view Green Chemistry principally as a cost cutting mechanism; one that which allows them to shave expenditures not only on raw materials and process energy but also in terms of environmental regulatory compliance. In 2004, a study was released by a group of policy analysts from the American Chemical Society looking at the rates of adoption of Green Chemistry on the basis of patent awards over a period from 1983 to 2001 [31]. This study found the chemical industry to be responsible for double the number of patent awards as those achieved by universities during the same time period.

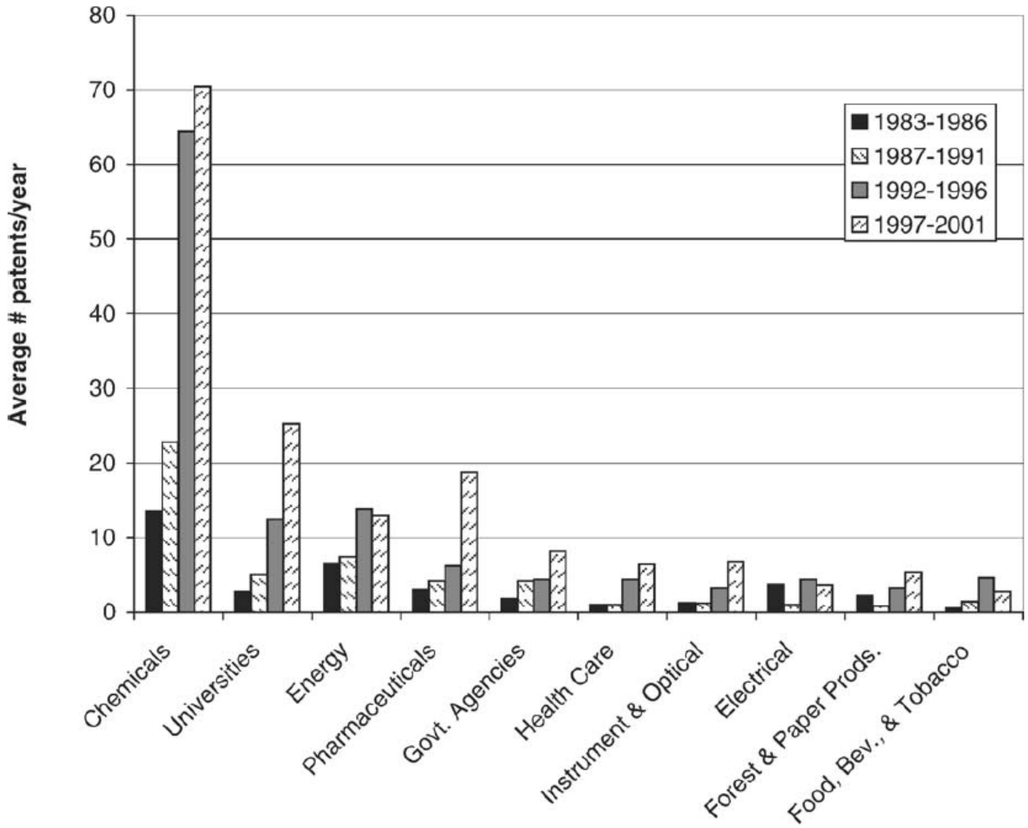


Figure 5-3: Average Number of Green Chemistry Patents per Year in Three Time Periods for Ten Major Economic Sectors

This figure clearly demonstrates that in addition to Universities, a category which in this case can be thought of as being synonymous with the academic community; there are a number of other economic sectors which are actively pursuing new technologies and process innovations through the use of Green Chemistry. In the following table, the authors of this same study attempt to estimate the relative importance of Green Chemistry innovation to each of these ten economic sectors by looking at the ratio of Green Chemistry patents to their total patent activity [31].

Industry group	Green chemistry patents (A)		All chemicals and plastics, polymers and rubber patents (B)		Green chemistry relative activity index (A/B)
	# of patents	Percentage of total patents (%)	# of patents	Percentage of total patents (%)	
Forest and paper products	43	2.6	1,011	0.9	2.95
Universities	188	11.4	5,640	4.9	2.32
Government agencies	63	3.8	3,233	2.8	1.35
Food, beverages and tobacco	37	2.2	2,071	1.8	1.22
Chemicals	674	40.9	43,975	38.3	1.07
Energy	134	8.1	8,891	7.7	1.05
Electrical	40	2.4	2,867	2.5	0.96
Health care	54	3.3	4,837	4.2	0.78
Pharmaceuticals	125	7.6	11,819	10.3	0.74
Instrument and optical	50	3.0	8,959	7.8	0.38
Other	238	14.5	21,537	18.8	0.77

All patent counts are for 1992–2001. All chemicals and all plastics, polymers and rubber patents from Tech-Line® and all US patent data from International Patent Indicators Data. *Note:* Other sectors each comprise less than 2% of green chemistry patents.

Figure 5-4: Green Chemistry Patent Distributions and Activity Indices by Sector

In the context of our proposal for the use of Green Chemistry to improve the environmental performance of laboratory facilities, there are two important lessons which can be derived from this patent study. The first is that Green Chemistry has been adopted, at a substantial benefit, in a wide variety of laboratory contexts across a number of economic sectors. The second is that the rate of adoption has been most significant in those sectors which have received pressure from consumer groups and government regulatory agencies to eliminate the presence of hazardous chemical materials from their products.

As Figure 5-4 illustrates, according to this study's findings the most aggressive adopter of Green Chemistry (in terms of relative patent activity) was actually the forest and paper product sector. At first, this finding may seem somewhat incongruous. However, upon further consideration it actually makes quite a bit of logical sense; particularly in the context of recent changes in both consumer tastes for forest and paper products as well as the environmental regulatory landscape occupied by the industries within this sector. Over the study period, the forest product industry has suffered from tremendous consumer backlash surrounding the revelation that large quantities of hazardous chemicals are used in the treatment and processing of many of their most popular wood products [32-34]. For example, for decades toxic formaldehyde based adhesives have been widely used in the production of composite wood products.

In light of these revelations, in 2006 Professor Kaichang Li of Oregon State University began to collaborate with Partners at Columbia Forest Products on the development of a new adhesive product based upon naturally occurring and non-toxic sour flow [32]. The product which they developed ended up being both stronger and more cost effective than the conventional alternative. One year after their breakthrough, Dr. Kaichang's imaginative use of Green Chemistry to engineer this important product innovation was recognized under the U.S. EPA's Presidential Green Chemistry awards program[35].

5.4 Presidential Green Chemistry Challenge

First established in 1996 within the U.S. EPA's office of Pollution Prevention and Toxics, the Presidential Green Chemistry Challenge Awards recognize approximately five individuals and organizations each year within each of the following categories:

- *A small business for a Green Chemistry technology in any of the three focus area*
- *An academic investigator for a technology in any of the three focus areas*
- *Focus Area 1: An industry sponsor for a technology that uses greener synthetic pathway.*
- *Focus Area 2: An industry sponsor for a technology that uses greener reaction conditions.*
- *Focus Area 3: An industry sponsor for a technology that includes the design of greener chemicals*

A cursory review of the history of previous Green Chemistry Presidential Challenge Award winning projects further supports claims for the universal applicability of Green Chemistry. In a single year, one can find award winning product and processes innovations coming from a major cosmetics manufacturer, a green building materials startup, a clinical assay corporation, and a University research group. Figure 5-5 provides a listing with abbreviated project descriptions of award winning projects from 2007 and 2008 [35]. Links to corporate and research contacts as well as more complete project descriptions are provided.

2008 Award Recipients
Greener Synthetic Pathways Award Battelle Development and Commercialization of Biobased Toners (summary)
Greener Reaction Conditions Award Nalco Company 3D TRASAR Technology (summary)
Designing Greener Chemicals Award Dow AgroSciences LLC Spinetoram: Enhancing a Natural Product for Insect Control (summary)
Small Business Award SiGNa Chemistry, Inc. New Stabilized Alkali Metals for Safer, Sustainable Syntheses (summary)
Academic Award Professors Robert E. Maleczka, Jr. and Milton R. Smith, III Michigan State University Green Chemistry for Preparing Boronic Esters (summary)
2007 Award Recipients
Greener Synthetic Pathways Award Professor Kaichang Li, Oregon State University Columbia Forest Products Hercules Incorporated (now Ashland Inc.) Development and Commercial Application of Environmentally Friendly Adhesives for Wood Composites (summary)
Greener Reaction Conditions Award Headwaters Technology Innovation Direct Synthesis of Hydrogen Peroxide by Selective Nanocatalyst Technology (summary)
Designing Greener Chemicals Award Cargill, Incorporated BiOH™ Polyols (summary)
Small Business Award NovaSterilis Inc. Environmentally Benign Medical Sterilization Using Supercritical Carbon Dioxide (summary)
Academic Award Professor Michael J. Krische University of Texas at Austin Hydrogen-Mediated Carbon–Carbon Bond Formation (summary)

Figure 5-5: Presidential Green Chemistry Challenge Award Recipients for 2007 & 2008

Chapter 6

The Asymptotic Approach to Design Innovation

Having demonstrated the suitability of Green Chemistry as a platform for chemical resource management in any laboratory context, it then becomes important to reconcile the underlying philosophy of the discipline with that of the LEED certification program. This is because any attempt to integrate two competing design frameworks which are philosophically incompatible will ultimately be doomed to failure.

In mathematics, the asymptote of a curve is a line such that the distance between the curve and the line approaches zero as they tend to infinity. Many have used this concept to draw an analogy to Green Chemistry's approach to the achievement of its environmental performance goals. For any neophyte to Green Chemistry, a first reading of its 12 Principles may perhaps raise more questions than answers. For instance, what does inherently benign mean? Does this restriction apply only to humans or to all species? Etc. According to the asymptotic design principle advocated by Green Chemistry, the answers to all of these types of questions must necessarily be addressed using the most expansive possible interpretation. For example, in the context of the aforementioned questions related to chemical toxicity, Green Chemists define inherently benign as meaning that the chemical should not result in any adverse consequences for the health safety of a human being or any other biological organism.

The asymptotic performance standard can perhaps best be understood through the following visualization. Green Chemistry, as a discipline, intentionally pursues a set of performance goals that, in concert, may in fact be impossible to fully achieve. This pursuit, over time, is plotted as the solid line in the figure. This line can also be referred to as the performance curve. This curve begins at the origin when the 12 principles of Green Chemistry are first applied to a design challenge. Over time and with progressive iterations the performance curve begins to approach the horizontal broken line. This line is the asymptote to the performance curve; it reflects absolute perfection in the context of a given definition of performance. Importantly, while it is possible to approach this performance limit through the use of Green Chemistry, it can never actually be achieved.

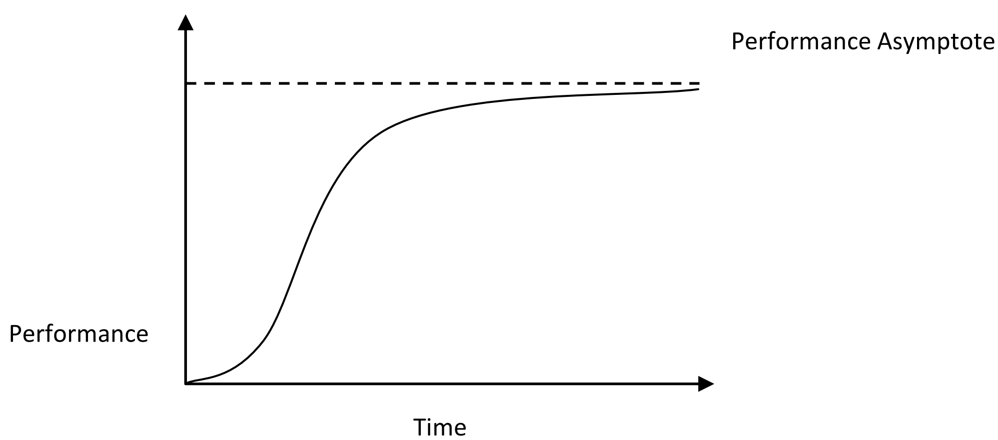


Figure 6-1: Schematic Diagram of the Asymptotic Design Principle

Green Chemists believe that this approach to the challenges of molecular design is likely to yield substantially more progress than other alternatives which instead focus on the pursuit of more short term achievable goals. This is because if one approaches a design challenge with a nearsighted perspective they are very likely to attempt to simply refine an existing solution. Such practices give rise to a path dependency in design which can inhibit the development of truly innovative ideas. The design strategy which is advocated by Green Chemists constantly questions the validity of existing solutions and provides a framework for the development of new ideas which may be completely oblique to the traditional narrative of thought. For instance, when faced with an existing process which may involve the use of toxic chemicals or the consumption of large amounts of energy and resources a Green Chemist will first inquire as to what is the essential function or service of the process in question. In the Green Chemist′s mind, this function exists independently of the process which is currently in use. Moreover, the existing process represents just one of a nearly infinite number processes which could potentially be used to provide the exact same functionality. The entire discipline of Green Chemistry therefore can be thought of as a structured way of identifying those individual product or process solutions which optimize for the conditions of minimized environmental impact and chemical toxicity.

6.1 A Green Chemical Purchasing Tool

An interesting example of this functional based approach to the chemical sciences being put into practice in a real world laboratory setting has been the development of a Green Chemical Purchasing tool by researchers at the Massachusetts Institute of Technology (MIT) [36]. During a 1998 inspection by regulatory compliance officers from the US EPA the university was cited for 18 violations of the federal hazardous waste laws, the Clean Air Act, and the Clean Water Act. In 2001, MIT reached a settlement with the federal government in which they agreed to a structured compensation program. According to a US EPA press release, under the terms of the settlement MIT agreed to develop a computer-based ‘virtual campus' compliance assistance tool which would be designed to help universities and colleges all over the country comply with environmental laws [37]. One component of this tool was an online portal designed to help assist researchers in selecting greener alternative products and processes during the chemical procurement process.

When a user logs into the Greener Alternative Purchasing Wizard they are greeted by a set of dialogue screens which attempt to automate the process of critical performance analysis embodied within the 12 Principles of Green Chemistry [36]. The first step is to identify whether or not the user wants to search for alternatives for a specific chemical product or an entire chemical process. Then, depending upon their selection, they are directed to a drop down menu of input products or processes for which greener alternatives have been identified and compiled into the tool's database. Once a selection is made, a list of greener alternative options is populated. For each new suggested replacement material or process a detailed explanation is presented describing its pros and cons as a substitute for the material or process in question. Additionally, links are provided which can take the user directly to materials safety data sheets for the product, an online product vendor, and peer reviewed scholarly references for the claims made in the summary description. A visual illustration of this process workflow is provided in Figures 6-2 through 6-4.

1. Specify whether it is a product or process for which a greener alternative is desired.

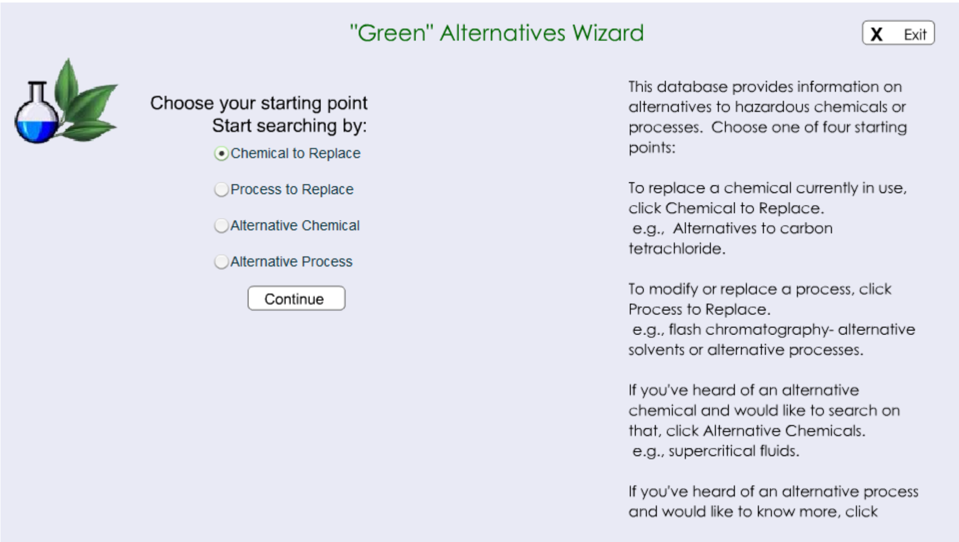


Figure 6-2: Green Alternatives Wizard Introductory Menu

2. Select the specific chemical product or process for which a greener alternative is desired.

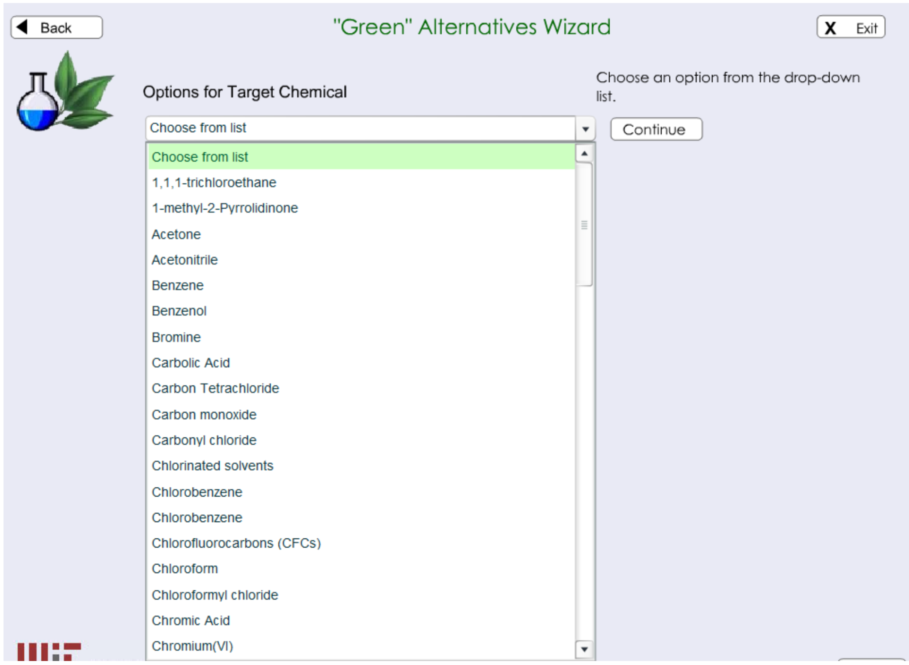


Figure 6-3: Green Alternatives Wizard Target Chemical Submenu

3. Evaluate the product or process alternatives on the basis of your required performance specifications.

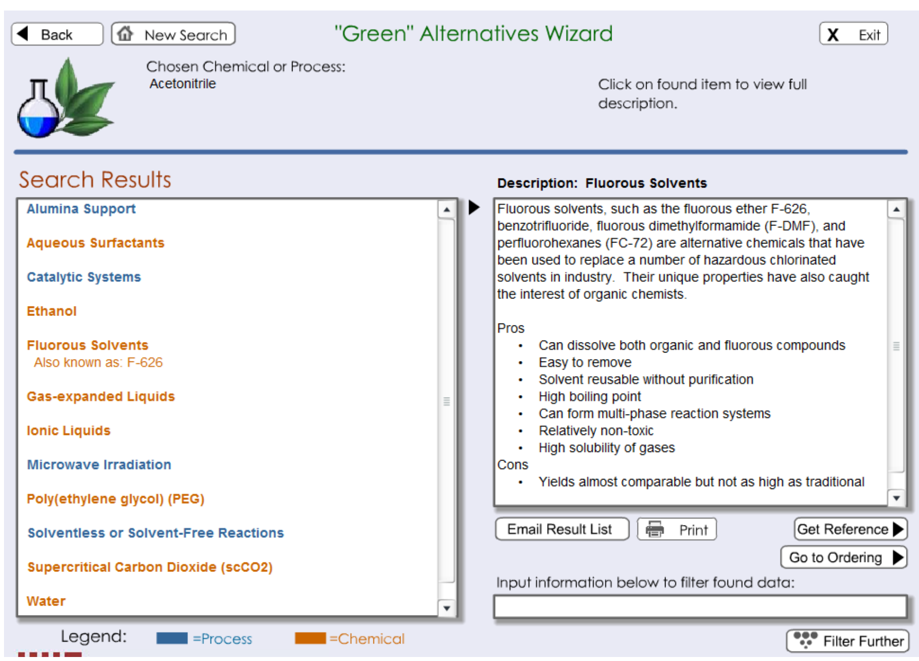


Figure 6-4: Green Alternatives Wizard Search Results and Product Descriptions

While the circumstances which lead to its initial development were perhaps less than ideal, the MIT Green Chemical Purchasing Wizard has become tremendously valuable not only as a resource for researchers but also as an example for how the 12 Principles of Green Chemistry can guide the process of hazardous waste source reduction in laboratory facilities. This tool demonstrates a proactive approach to chemical resource management which is distinctly separate from retroactive processes such as hazardous material recycling, remediation, and reuse.

In an interview with Dr. Jeffery I. Steinfeld, the MIT chemistry faculty liaison who consulted on the project's development, a question was posed regarding whether or not the development and implementation of the tool on MIT's campus had indeed made a measurable impact on the hazardous materials throughput in their laboratories. He replied that the impact of the tool, while decidedly positive, has been difficult to gauge precisely. This, he said, is largely due to the rapid expansion in the number and scale of MIT's chemically intensive laboratory facilities since the date of the tool's introduction. Susan Leite, the Environmental Health Safety officer responsible for maintaining the tool's website and database of references said that information regarding the size and location of the tool's usership both within MIT's campus and elsewhere abroad have been maintained since the project's inception. While this data could not be made available for this paper, Ms. Leite was able to reveal that the rate of usership has grown steadily since the tools introduction with individuals logging in to use the tool from over 100 different countries. According to Ms. Leite the true effectiveness of this program cannot and should not be gauged in terms of the exact volume of hazardous materials eliminated from year to year, but rather by the extent to which it has transformed the attitudes and awareness of students and researchers about the health safety and environmental implications of the products and processes with which they are commonly engaged.

Chapter 7

Green Chemistry for Different Laboratory Contexts

The term laboratory facility encompasses a wide variety of building types designed to house an equally wide variety of scientific processes. Modern laboratory facilities can be classified on the basis the nature and the purpose of the scientific activities which are contained within them. In previous sections, it was proposed that Green Chemistry was capable of reducing the environmental impact of the design and operation of all laboratory types. The extent to which improvements can be made however and the precise ways in which Green Chemistry can be applied vary considerably in different laboratory contexts. Thus it is important to now consider in greater detail the specific opportunities and limitations associated with the use of Green Chemistry in different laboratory contexts.

To begin with, Green Chemistry is most well suited to make a positive contribution to the design and operation of those laboratories in which large quantities of hazardous chemical materials will be used to conduct regular experimental operations. And, it is for this reason, that this broad category of laboratories has been the focus our discussion thus far. With this being said however, chemically intensive laboratories can be built to serve a variety of purposes. For instance, on a single university campus it would not be uncommon to find different laboratory facilities being used for the education of students, the housing of graduate research activities, and, in some cases, even the production of commercial products. The opportunities available for the use of Green Chemistry in each of these different laboratory contexts may vary enormously.

7.1 Research Laboratories

Laboratories which have been purpose built to house pure research activities represent perhaps the most challenging context for the integration of Green Chemistry both in the design of a facility's physical structure and in the development of its chemical resource management protocols. Typically, researchers who are investigating a novel chemical product or process do not want to be constrained in any way. Their pursuit is a single minded one, with success generally being defined by the development of some novel functionality or mechanistic process. In the context of this very focused goal set, research scientists typically only care about the design of the facility in which they are working to the extent to which it allows them to efficiently and effectively achieve their research goals, with the amount of energy or material resources being consumed in the process being of little or no concern.

Given this prevailing attitude, the argument for the use of Green Chemistry in a research laboratory context is forced to take on a more philosophical bent. For instance, while it is indeed true that application of the 12 Principles of Green Chemistry will constrain the activities of research scientists and the character of their experimental programs, the imposition of these constraints is by no means arbitrary. Rather, the 12 Principles of Green Chemistry embody an implicit ethical decision that the health and safety of human beings and other biological organisms should not be placed at risk merely to achieve some novel chemical functionality. Furthermore, the 12 Principles also reflect the idea that the measure of a product or process' technological performance should be considered on equal terms with measures of its ecological or environmental performance. To this end, over the years researchers in the field of

Green Chemistry have introduced a number of important environmental performance metrics which can be used in research laboratories to ensure that the quest for novel chemical products and processes does not proceed at the expense of human health or the stability of our natural environment [4].

Presented in Figure 7-1 is a table describing five of the most influential Green Chemistry performance metrics which have been invented to date. These metrics can and should be used in a research laboratory context to evaluate the environmental performance of novel products and processes generated during the research process.

Metric	General Description	Empirical Formulation
Effective Mass Yield	Effective mass yield is defined as the percentage of the mass of the desired product relative to the mass of all non-benign materials used in its synthesis.	Effective Mass Yield (%) = Mass of Products x 100 / Mass of Non-Benign Reagents
Carbon Efficiency	Carbon efficiency is a simplified formula developed by scientists at the major pharmaceutical corporation GlaxoSmithKline. It is used to measure the efficiency with which carbon is utilized in a chemical process.	Carbon Efficiency (%) = Amount of Carbon in Product x 100 / Total Carbon Present in Reactants
Atom Economy	Researcher Barry Trost invented atom economy as a method by which organic chemists would pursue “greener” chemistry. The simple definition of atom economy is a calculation of how much of the reactants remain in the final product.	For a generic multi-stage reaction: A + B → C C + D → E E + F → G Atom Economy = M.W of G x 100 Σ (Molecular Weights of A,B,D,F)
Reaction Mass Efficiency	Reaction Mass Efficiency was also developed by researchers at the pharmaceutical corporation GlaxoSmithKline, the reaction mass efficiency takes into account atom economy, chemical yield and stoichiometry.	Reaction Mass Efficiency = Mass of product C x 100 / Mass of A + mass of B
Environmental (E) Factor	This is one of the earliest general green chemistry metrics and was first conceived by Dr. Roger Sheldon. The E-factor can be made as complex and thorough or as simple as required. Assumptions on solvent and other factors can be made or a total analysis can be performed.	The E-factor calculation is defined by the ratio of the mass of waste per unit of product: E-Factor = Total Waste (kg) / Product (kg)

Figure 7-1: Popular Green Chemistry Performance Metrics

7.2 Commercial Laboratories

The rate of the adoption of Green Chemistry metrics and methods within the commercial sector has been so rapid that it is almost unnecessary to comment on the ways in which such laboratories might benefit from the implementation of Green Chemistry. For decades now, the 12 Principles of Green Chemistry have been utilized by commercial laboratory managers to eliminate hazardous materials at the source of production therefore improving both the health safety and environmental performance of their products and manufacturing processes.

The financial burden associated with violating environmental legislation or dealing with litigation from worker health and building occupant safety claims can be enormous. Therefore, as a business manager, allowing any material or process which possesses an inherent risk to remain within your facility is tantamount to inviting future losses. This is especially true in the context of ever more stringent air, soil, and water emissions regulations at both the state and federal levels. There have only been a handful of studies which have attempted to track the rate of growth in environmental legislation since the first federal environmental statutes were passed in the late 1800's. Perhaps the most comprehensive of these studies was published by J.A. Cusumano in a 1992 issue of the journal *Chemtech* [38]. Cusumano's original dataset included information on federal environmental laws spanning from 1870 to 1992. Due to the fact that this data is now almost 20 years old however, there have been substantial changes in our country's environmental statues during the intervening period. As a result, in an effort to update the figure, Cusumano's original dataset was updated with the new information being superimposed on the original figure (Figure 7-2).

In Figure 7-2 time is represented on the horizontal axis with the and the vertical axis showing the cumulative number of laws which have been passed constraining the activities of individuals for the purpose of preserving some desirable characteristic or condition of the environment. The information from Cusumano's original figure shows that the rate of passage of environmental legislation increases markedly beginning in the early 1970's. This rapid rate of increase is then sustained through the turn of the millennium and, as the updated information indicates, well on into the present period [38].

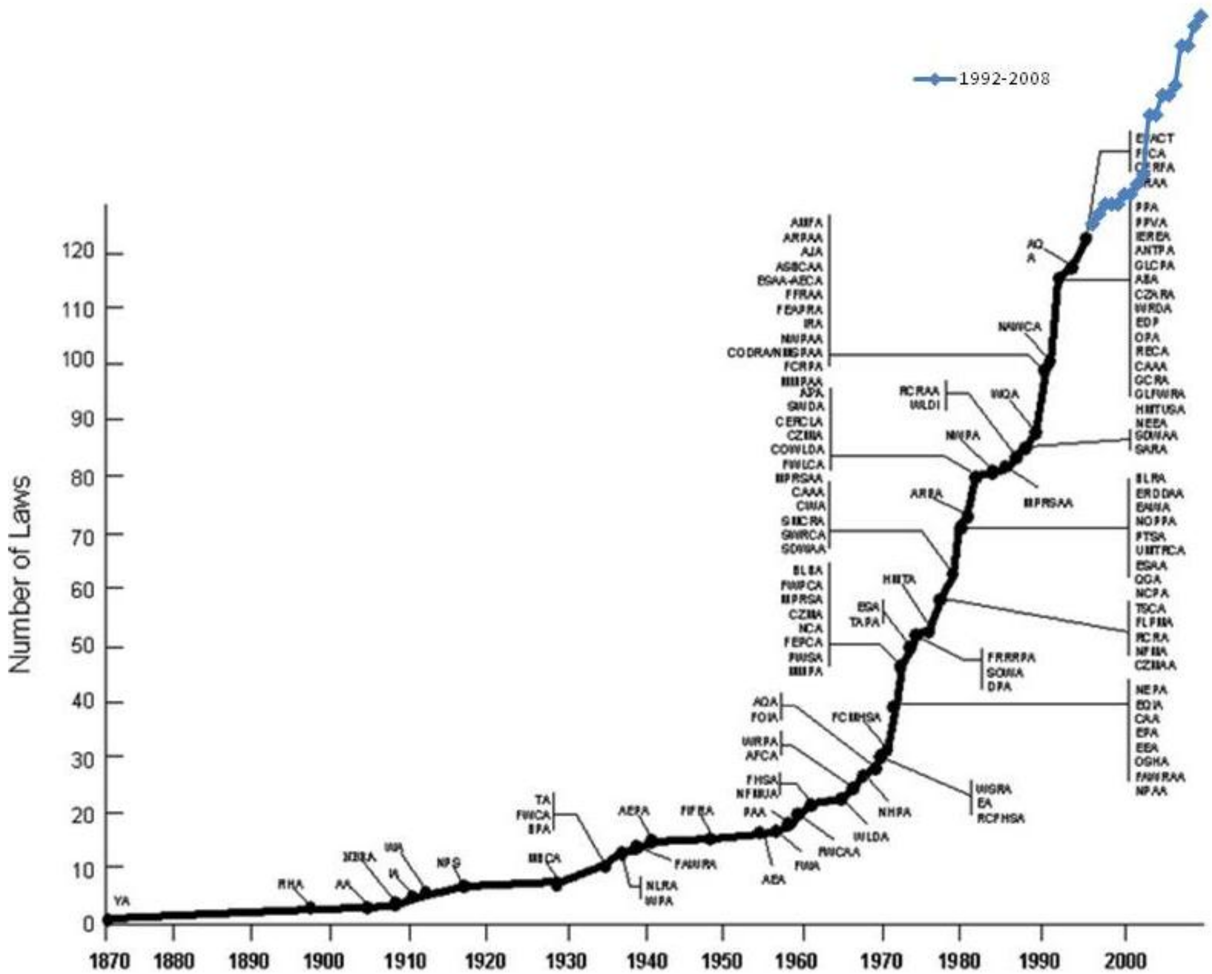


Figure 7-2: Growth in Environmental Legislation over Time

Businesses which utilize products or processes that rely upon hazardous chemical materials have become well aware of this trend towards an ever tightening environmental regulatory landscape. As a result, many of the more forward looking firms were among the first to adopt Green Chemistry as a means of eliminating inherent chemical risk from the products and operational processes.

The opportunities for the use of Green Chemistry in commercial laboratory context are numerous and varied. As the previous review of Green Chemistry innovations from the Presidential Green Chemistry Challenge Awards illustrated, commercial enterprises have pioneered the use of new micro-reactors, the development of advanced high efficiency catalysts, the implementation of low energy reaction conditions, and the use of renewable bio-based feedstock materials.

In most commercial laboratories workers employ a fixed standard operating procedure to produce a known product with known physical properties. This is a very different situation from say a research laboratory, where researchers are continuously modifying their experimental procedures based on the production of unpredictable products with sometimes unknown physical properties. In the context of their ability to leverage the 12 Principles of Green Chemistry towards improved environmental performance, commercial laboratories benefit tremendously from the stability of their laboratory operations. They have time to investigate and evaluate the relative performance of different green alternative materials which might act as substitutes in an existing production line. Similarly, because they have a known endpoint, their product, the can experiment with radically new processes which might be capable of providing either the exact same existing product or some new and expanded one with improved functionality and better environmental credentials.

7.3 Educational Laboratories

Most educational laboratories share the same characteristic of operational stability that can be found in commercial laboratory contexts. As a result, it is reasonable to expect that Green Chemistry should have at least the same potential for improving the environmental performance of educational laboratories as it has thus far had in improving commercial laboratory operations. In reality, educational laboratories exhibit a number of other unique traits which make them perhaps even better suited to the implementation of Green Chemistry.

In an educational laboratory, students are provided with a set laboratory procedure that guides them through the process of the production of a chemical compound, indentifying an unknown material, or answering some other question related to the theoretical concepts being introduced in their lectures. There are three main purposes for conducting educational laboratory experiments: (1) to familiarize students with the use of certain laboratory equipment (2) to give them an understanding of certain experimental techniques, and (3) to give a tangible demonstration of certain theoretical concepts in practice. When one considers these three basic functions it becomes clear than that educational laboratories are by no means obligated to use traditional chemical experiments which require the use of hazardous materials and the consumption of large quantities of energy and resources. Instead, Green Chemistry can be used to teach students about the exact same theoretical concepts, how to use the exact same laboratory equipment and experimental techniques, only without the safety risk of having them handle hazardous materials or the economic and environmental costs of having to manage and dispose of them.

Many high school and university chemistry departments have begun to incorporate Green Chemistry experiments into their laboratory curriculums as a means of cutting laboratory operations costs, minimizing the opportunity for student injury from the improper handling of hazardous materials, and reducing the net environmental impact of the educational process. In order to facilitate this process of curricular adaptation a number of print and electronic resources have been developed which guide educators through the transition towards greener curriculums. The University of Oregon maintains an open access Green Education Materials (GEM's) database which indexes high school and college level green chemistry laboratory experiments that have been published in peer reviewed journals such as the *Journal of Green Chemistry* and the *Journal of Chemical Education*. In addition to this resource, several colleges and universities which have been proactive about developing their own dedicated Green Chemistry laboratory course curriculums have published both their laboratory workbooks and instructional guides for how to integrate green chemistry modules into their lesson plans. A sampling of these published texts is listed in Figure 7-3.

Title	Author	Publisher	Description
Going Green: Integrating Green Chemistry into the Curriculum	Parent, Kathryn & Kirchhoff, Mary	American Chemical Society Washington, DC, 2004	A how-to resource for faculty, this booklet provides an introduction to green chemistry in education and offers insights and tools for integrating 21st century chemistry into the traditional chemistry curriculum. Contributed essays from green chemistry educators around the world serve as useful models of diverse approaches to integration.
Green Organic Chemistry: Strategies, Tools, and Laboratory Experiments	Doxsee, Kenneth & Hutchison, James	Brooks Cole 2003	This text was developed and successfully tested as a direct replacement of the traditional organic chemistry laboratory curriculum. It demonstrates how conceptual themes and experimental techniques important to the modern practice of organic chemistry can be taught in the context of more environmentally-benign laboratory experiments. Students acquire the tools to assess the health and environmental impacts of chemical processes and the strategies to improve develop new processes that are less harmful to human health and the environment.
Experiments in Green and Sustainable Chemistry	Roesky, Herbert; Kennepohl, Dietmar; & Lehn, Jean-Marie	Wiley-VCH, First Edition 2009	This text brings together a set of 46 simple experiments, each of which has been developed by recognized experts in the field of Green Chemistry, which are intended to be incorporated into an undergraduate level university chemistry course. Experiments are divided into five main areas: catalysis, solvents, high yield and one-pot synthesis, limiting waste and exposure, as well as special topics
Chemistry for Changing Times (11th Edition)	Hill, John W. and Kolb, Doris W.	Prentice Hall 2006	A chemistry textbook for non-chemistry majors. This 11th edition incorporates the concepts of green chemistry throughout. Extensively revises key subject areas such as

Title	Author	Publisher	Description
			Energy, Fitness and Health, and Drugs. Features new color photographs and diagrams throughout to help readers visualize chemical phenomena. Personalizes chemistry for today's reader, encouraging a focus on evaluating information about real-life issues rather than memorizing rigorous theory and mathematics. For anyone interested in learning about chemistry and its effect upon our everyday lives.
Real World Cases in Green Chemistry	Cann, Michael C. & Connelly, Marc E.	American Chemical Society Washington, DC 20036 2000	The 72-page book, designed to be used in a variety of ways in undergraduate courses, contains descriptions of ten projects that have won or been nominated for the Presidential Green Chemistry Challenge awards. The book can also serve as a resource for anyone wishing to be better informed about specific ways in which the redesign of chemical products and processes is preventing pollution and solving environmental problems.

Figure 7-3: Published Reference Materials for Green Chemistry Education

In most cases, the experiments published in these works are organized according to theoretical concepts taught, instrumentation used, and bench techniques employed; the three core purposes of educational laboratory exercises. Frequently, the authors of these publications go to great lengths to articulate the fact that the quality of the educational experience is no way diminished by the substitution of tradition chemistry reactions or experiments with greener alternatives. However, as the use of Green Chemistry has spread to educational laboratories around the world there has become less and less of a need for this sort of apologetic justification. At universities such as St. Olaf College, Oregon University, and the University of Massachusetts Lowell, where entire laboratory courses are taught focusing exclusively on Green Chemistry techniques, students have remarked that the new laboratories have provided them with a much richer educational experience [39]. Specifically, they seem to value the fact that their laboratory exercises are now incorporating lessons about how the work that they are doing is relevant to issues of environmental health in the world outside the laboratory.

Chapter 8

Case Studies of Green Chemistry Implementation

The German-Austrian Politician Klemens Wenzel once said “Any plan conceived in moderation must fail when the circumstances are set in extremes.” [40] This statement is exemplified by recent failures to utilize the LEED certification system to guide the development of more sustainable laboratory facilities. This is because laboratories constitute an extreme building type; one in which the linkage between the design of the building’s structural form and the activities housed within it is of critical importance. Keeping this linkage in mind, there are four basic ways in which the principles of Green Chemistry can be incorporated into the design of a laboratory facility. These four tiers of implementation can be represented diagrammatically on the basis of the degree to which Green Chemistry is incorporated in the laboratory’s experimental processes and then, in turn, the degree to which this application of Green Chemistry is reflected in the design of the building’s physical structure.

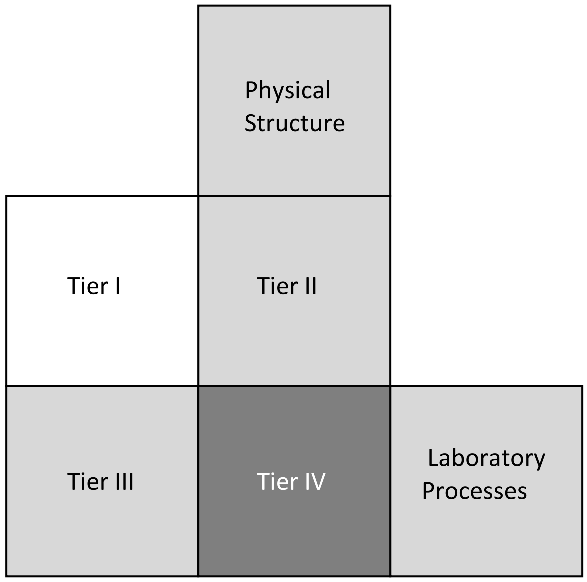


Figure 8-1: The Four Tiers of Green Chemistry Implementation in Laboratory Design

8.1 The Four Tiers of Green Chemistry Implementation in Laboratory Design

Tier I:

In this diagram, tier one reflects a situation in which no reference to the principles of Green Chemistry has been made in the design and construction of the facility as well as the design of the experimental processes housed within it. Inside these types of traditional laboratories:

- Engineered control mechanisms are utilized to limit exposure to toxic chemical agents.
- Materials flow through the facility in a linear manner entering as useful products and leaving as hazardous and nonhazardous wastes.
- Building users are disconnected from the functioning of the building's systems, uneducated and unaware about how their behaviors interact with the building to affect its environmental performance.

- The chemical and biological processes operating within the building pay no mind to the principles of Green Chemistry. They have not been optimized for increased atom economy or reduced energy consumption. They utilize a number of intrinsically hazardous chemical materials.
- The laboratory personnel are generally unaware of the interaction between their experimental or procedural activities, the functional performance of the building, and the aggregate impact of the facility on the environment.

Tier II:

In tier two facilities the building's physical structure has been optimized to reduce the energy and material resource consumption associated with engineered systems designed to limit human exposure to hazardous materials. Laboratory processes contained within the facility continue to utilize large quantities of intrinsically hazardous substances and laboratory personnel remain relatively ignorant as to how their experimental actions fit into the context of the building's overall environmental performance. In this type of facility:

- Substantial investment has been undertaken in ensuring that the facility is designed and constructed in such a way as to minimize aggregate environmental impact. Increasingly, this effort is recognized by application for certification within one of a number of existing Green Building certification programs such as the USGBC's LEED program or BREEN initiative in Great Britain.
- Materials are sourced within short to moderate distances from the building site. Energy requirements and other similar environmental impacts are considered during material selection and emphasis to recycled or reused materials is given.
- Engineered exposure control systems such as fume hoods and HVAC networks have been optimized for minimum energy consumption as a result of their operation.

- Building occupants remain uneducated and unaware about the nature and functioning of the building's various maintenance systems. They do not appreciated how their actions impact system performance and the overall environmental impact of the facility.

Tier III:

With tier three, the principles of Green Chemistry weigh prominently in the design of processes housed within the facility and the operational and management protocols. However, the reduction in hazardous materials throughput has not been incorporated into the design the facility's physical structure. This scenario generally occurs in situations where green chemistry has been incorporated into the experimental protocols of a laboratory following its initial design and construction. In tier 3 facilities:

- A conscious effort has been made by the facility's staff to transform the chemical processes with which they are engaged using the 12 principles of Green Chemistry.
- Process materials move along cyclical paths within the facility being recycled and reused wherever possible.
- Hazardous materials use is consciously minimized.
- The physical structure of the building retains many of the same characteristics as a Tier 1 facility. However, the associated environmental impact, particularly as pertains to the operation of the facility, is greatly reduced by the minimized need to exercise engineering control mechanism. Set points for HVAC systems can be dialed back, air exchange requirements minimized, and the volume of hazardous materials requiring disposal greatly reduces.

Tier IV:

The principles of Green Chemistry and Green Engineering are heavily referenced both in the design and construction of the building's physical structure, the development of the laboratory's operation and maintenance protocols, and the planning of chemically intensive experimental processes houses on the premises. With tier 4 facilities:

- During the design phase, information about the nature of the chemical and biological processes that will be utilized within the facility is communicated from potential users to the facility design team. In this way, efforts are made to reinforce the implementation of Green Chemistry within the facility through sympathetic design elements.
- Engineered systems which control the exposure of users to toxic or hazardous materials are scaled down or eliminated from the facility's design, obviated by the use of the Principles of Green Chemistry to minimize or eliminate the use of those types of materials in experimental or educational processes.
- Building occupants are rigorously informed about the nature of the building's control systems and how their behaviors interact with them to positively or negatively influence the building's aggregate environmental performance.
- Materials flow through the facility in an increasingly cyclical manner as physical design features facilitate process material recycling and reuse.

8.2 Tier II Case Study: The National Renewable Energy Laboratory Science and Technology Facility

Figure 8-2: Science & Technology Facility, National Renewable Energy Laboratory, United States Department of Energy

Location: Golden, Colorado

Facility Overview: Research facility combining a one story office wing with a two story laboratory wing (plus mechanical penthouse)

Size: 71,347 gross ft^2

Cost: $21.2 million

$297/$ft^2$ excluding design costs of ~$1.5 million

Design & Construction Team: SmithGroup, Phoenix AZ (architect, MEP engineer); Paul Koehler Leffler Consulting Structural Engineers LLC, Broomfield CO (structural engineer); Martin & Martin, Las Vegas NV (civil engineer); MA Mortenson, Denver CO (contractor)

Timeline: Conceptual design completed in 1999; final design completed 2003; construction commenced in 2004 and was completed in 2006

LEED Platinum certification

Scientific Activities and Processes: A laboratory facility designed to house processes related to the characterization of photovoltaic materials and devices as well as process development for the commercialization of advanced photovoltaic energy technologies. It has a high-hazard occupancy classification (H5) with research focuses including thin-film photovoltaics and nanostructures, requiring advanced vacuum metallization and vapor deposition equipment [41].

Discussion of Design Solutions: The National Renewable Energy Laboratory Science and Technology facility was designed to house advanced chemical and physical research processes associated with the development of novel energy technologies. The facility has a high throughput of hazardous chemical materials. In order to manage the risk experienced by humans who are interacting with these intrinsically hazardous materials the facility incorporates several layers of intelligent mechanical systems designed to limit exposure during the research process. The most basic design element for the reduction of human exposure is the inclusion of a service corridor which runs the length of the facility that is dedicated to the handling of hazardous materials [41]. As a further means of physical separation, toxic and flammable substances are remotely housed in fortified and secure areas and then are piped into the laboratory spaces through stainless steel tubing in a ventilated raceway [41].

The facility also incorporates advanced systems for the monitoring of accidental exposure events. For instance, each laboratory boasts an ultra-sensitive gas leakage detection system which monitors in the indoor air quality. These systems include a set of dedicated LCD monitors which are installed at various locations in each laboratory such that the indoor air quality can be readily monitored by research staff [41].

According to the MEP engineers, the building uses 41% less energy than a comparable facility designed under the ASHRAE 90.1 Standard [41]. This reduction in energy consumption over the reference baseline was achieved through the extensive use of passive day lighting within the facility and an optimized Variable Air Volume (VAV) Heating Ventilation and Air Conditioning (HVAC) system [41]. The HVAC design provides supply and exhaust air to all of the laboratory facilities. For H5 category facilities such as this, the International Building Code specifies the minimum occupied supply airflow to be 1 ft^3 air/min/ft^2 [41]. In order to generate this flow, there are six dedicated, direct drive 20,000 ft^3/min exhaust fans. These fans are designed such that they can be turned on and off progressively, in stages [41]. This allows the laboratory to maintain the required negative air pressure in the laboratories with minimum energy consumption under both full and partial occupancy conditions.

The HVAC system also incorporates fan coil heating and cooling units which directly service the laboratory spaces. According to the project engineers "This strategy allows the HVAC system to supply only the tempered air required for minimum ventilation and makeup air for exhaust devices." [41] Having the ability to spatially tune the performance of the HVAC system is essential to minimizing energy consumption in laboratories. This is because certain pieces of research equipment can generate large quantities of latent heat in a localized area. In addition to this flexible HVAC setup, all of the laboratory spaces are outfitted with high performance and laminar flow fume hoods [41]. Additional HVAC efficiency strategies employed include the use of: "a high efficiency condensing boiler, a variable speed chiller, indirect evaporative cooling, and a heat exchanger that allows cooling water to bypass chillers and be cooled directly by the cooling tower." [41]

These extensive mechanical systems are prone to malfunction however, and it has been the experience of laboratory research staff that the downtime required for system maintenance and repair can be extensive. That downtime translates into reduced research productivity and increased operational and maintenance costs associated with the repairs and replacement parts. Although one of the primary objectives for the design of this facility was to provide a safe working environment for researchers, there was no concerted effort on the part of the architects or the research team to systematically reduce the volume of hazardous materials used in the facility's research operations. The thin film photovoltaic technologies which are the laboratory's primary research focus rely on the use of exotic metals such as indium, gallium, selenium, and arsenic which have unfavorable toxicological profiles [42]. The continued use of these materials necessitates constant vigilance both in terms of occupant behavior and in terms of the performance of mechanical exposure control systems. Even momentary lapses in either of these two system types can result in serious accidental exposures to chemical hazards.

While this facility is one of the few chemically intensive research laboratories in the country to have achieved a rating of LEED platinum, the failure of its designers to incorporate the principles of Green Chemistry into their research program means that the building’s overall performance is not as stellar as what it might otherwise have been. In order to provide a safe working environment for the facility’s research staff, the architects and engineers were forced to develop a complex system of mechanical exposure controls. And while this system may be a technological marvel, boasting best in class efficiencies and performance characteristics, the financial and environmental burden associated with constructing and maintaining it could have been largely avoided through a commitment to green the research agenda of the institution using aforementioned techniques.

8.3 Tier III Case Study: Yale University, Sterling Chemistry Laboratory

Figure 8-3: Yale University Sterling Chemistry Laboratory

Location: New Haven, Connecticut

Facility Overview: Combined research and educational teaching facility housing research laboratories, classrooms, lecture halls, and offices.

Size: 184,256 gross ft^2

Cost: $1.85 million ($23 million, adjusted for inflation)

10$/$ft^2$ ($124/$ft^2$, adjusted for inflation)

Design & Construction Team: Delano & Aldrich (architect)

Timeline: construction completed in 1923

Scientific Activities and Processes: Sterling Chemistry Laboratory was designed some 90 years ago to house laboratory operations for research and education in the chemical sciences as well as offices for chemistry department staff.

No LEED Certification

Discussion of Design Solutions: As the practical nature of the chemical sciences have evolved and intensified over time so too have the size and sophistication of the mechanical systems in chemistry buildings been forced to change. Three times since its initial construction, the Sterling Chemistry laboratory has been forced to undergo extensive renovations to its HVAC system. These measures were taken out of the necessity to keep up with evolving code standards for the required number of air changes per hour in chemically intensive laboratory spaces.

From a sustainable design perspective, the physical structure of Sterling Hall leaves much to be desired. In fact, the building predates the concept of sustainability entirely. Its development occurred during a time period not only when the chemical sciences posed less of an intrinsic risk to humans but also when energy was cheap and the management of chemical risk using engineered controls was the least cost proposition. Its interior design largely mirrors its foreboding castle like exterior façade. The walls and floors are made from solid stone, the only material available in 1923 capable of resisting the effects of corrosive chemical agents.

This antiquated architectural design provides the perfect foil from which to observe the evolution of modern chemical sciences since the early 1920's; an era which witnessed the birth of modern synthetic chemistry. The stark contrast between the modernity of the building's equipment and mechanical systems and its physical structure makes it quite easy to observe the numerous instances where stop gap solutions have been engineered to prolong its useful life. Some, like the gleaming metal stacks from the fume hood exhaust fans, are even visible from the building's exterior.

Inside the building's ageing laboratories, pieces of research and educational equipment which look at home in other more modern facilities appear cramped an uncomfortable. For instance, the exhaust ducts leading away from the laboratory's fume hoods have been fastened to the ceiling rather than hidden away in an interstitial space. This has been done out of shear necessity due to the small size of the above head plenum. In the building's laboratories possessing high hazardous materials throughputs the original stone tile floors have been overlain with a poured in place epoxy resin that provides an unbroken chemically impervious surface. These floors have an engineered height gradient which causes them to drain into a centralized catchment basin. This measure, again a recently updated code requirement, had to be taken because over time, with wear, small micro-fractures begin to form in the surface of the tiles creating a porosity that tends to absorb hazardous chemicals like a sponge. Evidence of this phenomenon can be seen on some of the laboratories old Transite work bench counter tops which bear permanent residues from accidental chemical spills over the decades.

Due largely to the ex post facto construction of its HVAC system, Sterling Chemistry Hall is notorious for its energy consumption, even among the campus' other laboratory facilities. The facility is also responsible for a substantial portion of the university's overall hazardous waste disposal burden. In order to compensate for these facts, university staff both in the Chemistry Department and the office of Environmental Health and Safety have begun the process of implementing an aggressive new Green Laboratories program which seeks to leverage the institution's considerable academic resources in the field of Green Chemistry to eliminate hazardous materials from laboratory operations and reduce both the cost and environmental impact of operating laboratory facilities. Part of this effort has been the development of a Yale specific voluntary "Green Laboratory Certification Program" which is meant to provide "a self assessment of what current green practices their labs are conducting or could easily implement and then see what other longer term changes they could put in place to create a more sustainable laboratory working environment."

While such efforts to Green the laboratories operations through the installation of solvent recycling equipment and a redesign of educational laboratory curriculums will go a long way towards improving the environmental performance of facilities such as the Sterling Chemistry Laboratory, the substantial transformative gains which are necessary can only be achieved through integrated design. Now, it is clear that integrating the design of a laboratory's physical structure with its operational processes is at best impractical and at worst impossible in the context of an existing facility. However, this is why it is so important that this concept be formalized into the LEED building certification program; a system which, by virtue of its tremendous forward momentum, is likely to direct the future path of innovation for years to come.

8.4 Tier IV Case Study: St. Olaf College, Regents Hall

Figure 8-4: St. Olaf College, Regents Hall

Location: Northfield, Minnesota

Facility Overview: Combined research and education teaching facility housing 28 teaching laboratories, 7 tiered classrooms, 8 flat-floored classrooms, 9 seminar/conference rooms, 7 dedicated computational labs, 8,000 ft^2 science library, and informal gathering spaces.

Size: 200.000 gross ft^2

Cost: $63 million

Design & Construction Team: Holabird & Root (architect); The Weidt Group (sustainable design consulting services); Oscar J. Boldt Construction Company (general contractor); ML Baird & Co. (landscape architect)

Timeline: initial conceptual development (2001) construction commenced (2006) construction completed (2008) dedication (2009)

Scientific Activities & Processes: St. Olaf's Regents Hall is one of the first major science facilities in the United States designed with an emphasis on green chemistry. It houses a mixture research and educational laboratories for both graduate level and undergraduate students.

LEED Platinum Certification

Discussion of Design Solutions: Regents Hall is the product of a long term collaborative planning effort between design architects, MEP engineers, and, critically, the research and educational staff who were to become the building's occupants. The project began with an ambitious vision statement that has come to be referred to as the "Seven I's" which painted a very clear picture of the desired endpoint of the design process [43].

Interdisciplinary A building which provides a rigorous teaching of the standard disciplines represented by current mathematics and natural science departments while also enhancing the interdisciplinary teaching and research that is at the cutting edge of modern science.
Investigative A building which provides teaching and research spaces that promote investigative work and student exploration.
Interactive A building which is designed for student-student, student-faculty and faculty-faculty interactions.
Innovative A Building whose design incorporates the technology-driven pedagogical innovations present in St. Olaf College's current academic and research programs, and is flexible enough to adapt to emerging technologies.
Inviting A building whose landscapes has been designed to be inviting, with many interesting features that draw people in and encourage them to linger.
Integrity A building which honors the environment in a variety of ways. From the use of wood gathered from the trees that made way for the building's construction to the reforesting of the surrounding environs with new plantings of native species. The building should evince the college's commitment to environmental stewardship.
Interconnected A building which not only fosters connections between disciplines and academic programs across campus but also employs building design elements that reinforce awareness of the interconnectivity of physical space.

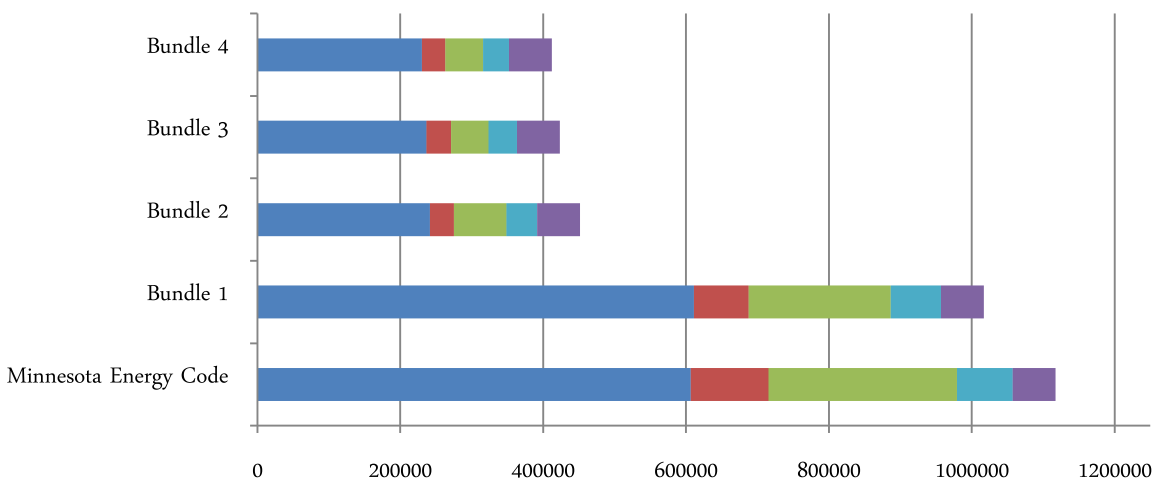
Figure 8-5: The "Seven I's" of St. Olaf College's Design Vision for Regents Hall

From the outset of this project the College's Chemistry department made it clear that they wanted the building to embody a new direction in chemistry education, one which was founded upon the 12 Principles of Green Education. In order to achieve this goal researchers and educators made pre-emptive calculations about the volume of hazardous materials which could likely be eliminated through the selection of more benign solvent systems in research laboratories, a more aggressive chemical recycling program, and the restructuring of the College's chemistry laboratory course curriculums to incorporate Greener substitute reactions. As a result of this planning process they were able to deliver a revised program to the building's design team which exhibited significant reductions in the anticipated hazardous chemical load anticipated to be experienced in specific portions of the laboratory.

Figure 8-6 illustrates the results of series cost calculations performed by the project's sustainable design consultants from the Weidt Group. The data in the figure was generated from a comparative analysis of different design scenarios for Regents Hall using a DOE-2 based energy simulation model [43]. The bar at the base of the figure corresponds to a reference scenario in which anticipated building operating costs were calculated for a hypothetical structure designed to minimally satisfy Minnesota's building code requirements. The next design scenario, bundle 1, demonstrates the cost benefit (from reduced energy consumption) associated with an optimization of the fume hood system in the laboratories, using an advanced Variable Air Volume design with active occupancy control sensors. Bundle 2 illustrates the benefits that can be achieved by applying the programmatic reductions estimated through the incorporation of Green Chemistry into the laboratories processes. This corresponds to the elimination of several fume hoods and the reductions in the required rate of air changes per hour for significant portions of the building's interior volume. Bundles 3 and 4 reflect the application of advanced interior day lighting strategies and an HVAC exhaust air heat recovery system (respectively).

It should be noted that none of these calculations were performed using life cycle costs. As such they reflect only the operational cost reductions associated with the implementation of the various design strategies and not necessarily the cost of that implementation. In light of this fact, the already dramatic cost reductions associated with the implementation of Green Chemistry in the laboratory processes become even more astounding. This is because as an exercise in planned source reduction, it is associated with virtually no cost increases.

While the data which was made available by the Weidt Group for the development of this figure was in terms of dollar cost, these units could easily be converted to reflect the energy consumption and thus a portion of the building's aggregate environmental impact. The take home message from this illustration is that the potential for environmental performance gains from improvements in the engineered exposure controls present within laboratory are dwarfed by the possibility for transformative improvements associated with the use of Green Chemistry for targeted hazardous material source reduction.



	Minnesota Energy Code	Bundle 1	Bundle 2	Bundle 3	Bundle 4
Heating	606618	611186	241278	236735	230278
Cooling	108825	76433	33651	34407	32738
Fans/Pumps	263731	199128	73644	52391	53000
Lights	78135	69929	43016	39708	36041
Equipment	60053	60053	60053	60053	60053

Figure 8-6: St. Olaf College, Regents Hall, Design Scenario Data (Annual Operating Costs in Dollars)

Chapter 9

Conclusions: LEED, Green Chemistry, and a Vision for the Future of Laboratory Design

Hazardous material throughput is the critical design parameter responsible for determining the overall environmental impact of chemically intensive laboratories. In light of this fact, the current framework for sustainable laboratory design embodied by the Labs21 program, a precursor to the anticipated new LEED for laboratories certification program, does not (1) place nearly enough emphasis on the systemic benefits which can be achieved through hazardous materials source reduction nor does it (2) provide any sort of meaningful advice for how such source reduction might be practically achieved.

This paper demonstrates the feasibility of Green Chemistry as a central component of a new more integrated design framework meant specifically for chemically intensive laboratory facilities. Green Chemistry possesses not only the appropriate theoretical foundation for this purpose but also boasts a track record of successful implementation in a wide variety of laboratory contexts as well as an active community of practitioners capable of supporting interested designers, researchers, and educators. The example of Regents Hall at St. Olaf College illustrates the transformative advances that are possible through the proactive use of Green Chemistry in the planning and design of laboratory facilities. We believe however, that in order to successfully reproduce these advances it necessary to take the additional step of formally incorporating Green Chemistry into a new LEED for laboratories program. In this way we can finally begin to reduce the enormous quantities of energy consumed and hazardous wastes produced by the commercial, research, and educational facilities which are the source of technological innovation and long term economic growth.

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