SUSTAINABLE ENGINEERING FOR NSLS II

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ABSTRACT

New facilities built in the United States using government funds must comply with sustainable design requirements. Sustainable design principles use a "cradle-to-grave" approach to sum the total economic and environmental impact for new or upgraded facilities. All materials and processes are included in this approach starting with the extraction of raw material and continuing through finished product transportation and installation, and then even beyond to include post-installation operations, maintenance, reuse, and disposal. The United States Department of Energy and Environmental Protection Agency sponsored the development of the Sustainable Building Technical Manual which gives guidelines to apply sustainable principles to the development of a new facility. The National Institute of Standards and Technology sponsored a Building for Environmental and Economic Sustainability (BEES) technical manual and user guide. It is expected that NSLS II will be certified to standards set by the United States Green Building Council's Leadership in Energy and Environment Design (LEED) program using the guidelines within these manuals. These principles must be utilized during the design and construction phases so that a state-of-the-art facility is produced from both the technological as well as the sustainable engineering point of view. This paper focuses on explaining the sustainable engineering concepts applicable to such a facility. From a world-wide perspective, sustainable engineering concepts will help make NSLS II environmentally-friendly in addition to being a world-class research facility.

1. Introduction

The National Synchrotron Light Source (NSLS) was designed in the late 1970s and built in the early 1980s at Brookhaven National Laboratory (BNL). It is the first large-scale user synchrotron light source facility in the United States. Although the NSLS is still a very productive facility in terms of scientific output, it is a second generation light source facility that is gradually becoming technically obsolete. Although several upgraded insertion devices have been added and the performance of the synchrotrons was improved using in-place upgrades, the NSLS building itself constrains the level of upgrade that can be accomplished. When compared to newer facilities, the NSLS facility itself is physically too small to fit a larger number of long straight sections for high-photon flux insertion devices. Additionally, the circumference and design of the rings (i.e. the magnetic lattice) constrain the levels of flux and brightness available from the VUV and X-ray synchrotrons. The present NSLS therefore can not provide sufficient flux and brightness levels to meet state-of-the-art scientific research demands. Preliminary physics calculations have shown that a 3 GeV storage ring using state-of-the-art technology will be able to produce x-rays that are up to 10,000 times brighter than those produced with the NSLS today [1]. In order to provide a light source facility capable of performing state-of-the-art scientific research, the United States Department of Energy (DOE) has granted Critical Decision Zero; the acceptance of critical need. Much effort went into this justification. BNL had initially considered, estimated, and submitted the cost and impact details for an in-place upgrade. An in-place however was neither economically or technically viable. A new facility therefore is necessary.

In building new facilities, the US DOE advocates the use of sustainable engineering principles. Sustainable engineering is an approach to engineering that goes beyond and efficient design-to-cost engineering practices.

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Sustainable engineering is a cradle-to-grave, full life cycle perspective that considers the total economic and environmental impact and performance from material extraction and product manufacture to product transportation, design, construction/fabrication, operations, maintenance, and reuse or disposal. As sustainable engineering principles increasingly become adopted or mandated, a shift in the facility and then product development approaches are anticipated as these principles become imbedded in codes, standards, and regulations. The US DOE and US EPA have been taking a leadership role in the United States in adapting sustainable engineering principles. New facilities funded by the US DOE require LEED certification. The US DOE provides guidelines for sustainable engineering design for new facilities through their Office of Energy Efficiency and Renewable Energy (EETE). This office clearly "supports the development of commercial buildings that are energy efficient, healthy and comfortable places to learn, work, and play" [2]. In December of 2002, Los Alamos National Laboratory (LANL) published a sustainable design guide [3] that "focuses on the issues and design processes for energy-efficient buildings at LANL and provides a powerful overview of important ways that LANL can make a difference in the future sustainability of the laboratory and the nation." This design guide clearly shows LANL's commitment to sustainable design. The commitment level at BNL to sustainable design principles should not be less. For new facilities built with US DOE funds, it is anticipated that the DOE will require that these facilities be built to standards set by the United States Green Building Council's "Leadership in Energy and Environment Design" (LEED) program. The LEED program offers certification to professionals who are knowledgeable in applying sustainable engineering principles to new and renovated facilities. The guidelines for sustainable engineering are available from the "Sustainable Building Technical Manual" which was sponsored by the United States Environmental Protection Agency (EPA) and the DOE. The National Institute of Standards and Technology (NIST) also provides guidelines for applying sustainable engineering principles to the development of new and renovated facilities. NIST sponsored a "Building for Environmental and Economic Sustainability" technical manual and user guide. The information contained in these references (especially from the indicated US DOE sources) and the application of this information to NSLS II is the subject of this paper. As this information is presented, it should be noted clearly that many of the concepts introduced apply to the accelerator components as well as to the facility. Design and project engineers therefore have the ability to build equipment as well as a facility that will have minimal environmental impact upon the world, as well as produce world-class scientific research.

2. Sustainable Design Concepts

The extraction of raw materials and their conversion into finished products all have environmental impacts. Energy, water, air, and various chemicals and gases are used in the extraction and conversion processes which produce waste streams consisting of releases to air, water, and land. Different finished products therefore have different environmental impacts. Various different groups funded by governmental sources such as the US DOE have collected data from fifteen countries and various industry sources quantifying the environmental impacts of more than 6,000 industrial processes. Negative environment results from these industrial processes include global warming, acidification, eutrophication, fossil fuel depletion, habitat alteration, ozone depletion, ecological toxicity, and the resulting non-trivial health effects from air, water, and land pollution. The BEES manual provides an index for each of these factors to quantify their individual and collective impact relatively.

(a) **Global warming** occurs from a greenhouse effect within the earth's atmosphere. A balance occurs between the amount of solar energy absorbed and radiated by the earth. This balance is largely affected by atmospheric and land parameters. De-forestation, smog, and air pollution are large influences. The BEES rates the production of various gases upon global warming and produces a Global Warming Potential for each gram of gas produced.

$$\textbf{Global Warming Index} = \Sigma_i(m_i \times GWP_i)$$

where m_i = mass (in grams) of effluent flow i, and

and GWP_i = CO_2 equivalent (the number of grams of CO_2 with the same heat trapping potential over 100 years as one gram of effluent flow i)

Table 1: Global Warming Potential Characterization Factors (source: BEES manual)

Flow (i)	GWP_i (CO_2 equivalents)
Carbon Dioxide (CO_2 fossil)	1
Carbon Tetrafluiride (CF_4)	57,000
CFC 12 (CCl_2F_2)	10,600
Chloroform ($CHCL_3$, HC-20)	30
Halon 1301 (CF_3Br)	69,000
HCFC 22 (CHF_2Cl)	1,700
Methane (CH_4)	23
Methyl Bromide (CH_3Br)	5
Methyl Chloride (CH_3Cl)	16
Methylene Chloride (CH_2Cl_2, HC-130)	10
Nitrous Oxide (N_2O)	296
Trichloroethane (1,1,1-CH_3CCl_3)	140

(b) **Acidification** occurs when pH-modifying compounds dissolve in water (in any of its' states) or attach to solid particles. These acidifying compounds reach ecosystems through acid rain or wet deposition. Sulfur and nitrogen, mainly from combustion of fossil fuels and other organic material mass are the two principal elements that form the bulk of acidifying compounds Hydrogen chloride and ammonia are two other compounds that contribute to acidification. As with global warming, an index based upon the quantity of hydrogen ion emission with the same acidifying potential has been developed to quantify the effect of various effluents. The BEES rates the production of various gases upon global warming and produces a Global Warming Potential for each gram of gas produced.

Acidification Index = $\Sigma_i(m_i \times AP_i)$

where m_i = mass (in grams) of effluent flow i, and

and AP_i = millimoles of hydrogen ions with the same acidifying effect as one gram of effluent flow i)

Table 2: Acidification Potential Characterization Factors (source: BEES manual)

Flow (i)	AP_i (H-ion equivalents)
Ammonia (NH_3)	95.49
Hydrogen Chloride (HCl)	44.70
Hydrogen Cyanide (HCN)	60.40
Hydrogen Fluoride (HF)	81.26
Hydrogen Sulfide (H_2S)	95.90
Nitrogen Oxides (NO_x as NO_2)	40.04
Sulfur Oxides (SO_x as SO_2)	50.79
Sulfuric Acid (H_2SO_4)	33.30

(c) **Eutrophication** is the addition of mineral nutrients such as nitrogen and phosphorous to soil or water. In water, increases in dissolved minerals tend to increase algae growth. This undesirably decreases the amount of dissolved oxygen in water which kills fish and affects the ecological balance of aquatic life. On land, eutrophication causes reductions in ecological diversity by effecting plant growth. Similar to global warming and acidification, the BEES produces an index for eutrophication produced by various different effluents.

Eutrofication Index = $\Sigma_i(m_i \times EP_i)$

where m_i = mass (in grams) of effluent flow i, and

and EP_i = millimoles of hydrogen ions with the same acidifying effect as one gram of effluent flow i)

Table 3: Eutrification Potential Characterization Factors (source: BEES manual)

Flow (i)	EP_i (N_2 equivalents)
Ammonia (NH_3)	0.12
Nitrogen Oxides (NO_x as NO_2)	0.04
Nitrous Oxide (N_2O)	0.09
Phosphorous to Air (P)	1.12
Ammonia (NH_4^+, NH_3 as N)	0.99
BOD5 (Biochemical Oxygen Demand)	0.05
COD (Chemical Oxygen Demand)	0.05
Nitrate (NO_3)	0.24
Nitrate (NO_3)	0.32
Nitrogenous Matter (unspecified as N)	0.99
Phosphates (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, H H_3PO_4 as P)	7.29

(d) **Fossil Fuel Depletion** occurs from the consumption of coal, oil, and natural gas, all of which are limited resources that were formed thousands of years ago. To a large extent, it is expected that market forces will continue to increase the unit price of fossil fuels as scarcity increases. These market forces should cause gradual shifts in consumption as economics make alternative energy sources more viable. Presently, as fossil fuel reserves are depleted, the amount of extraction effort per unit of extracted fuel increases and higher extraction cost sources (such as offshore deposits) replace lowest-cost sources. For fossil fuel depletion, the BEES considers only the impact of the resource depletion itself in this category. Other impacts from effluents such as methane gas from coal mining are accounted for in other indices. The BEES index for fossil fuel depletion is:

Fossil Fuel Depletion Index $= \Sigma_i(c_i \times FP_i)$

where c_i = consumption (in kilograms) of fossil fuel i, and

and EP_i = megajoule input requirement per kilogram of fossil fuel i.

Note: Uranium has not yet been included in this index, but will be when sufficient data is available.

Table 4: Fossil Fuel Depletion Potential Characterization Factors (source: BEES manual)

Flow (i)	FP_i (surplus MJ/kg)
Coal (in ground)	0.25
Natural Gas (in ground)	7.80
Oil (in ground)	6.12

(e) **Indoor Air Quality** is often affected by release of volatile organic compounds (VOCs), aerosols, and particulates. Of particular concern to indoor air quality is the performance of building products such as floor coverings, building materials (such as sheathing, insulation, etc), interior wall finishes, and furniture. Of special concern are products that emit carcinogenic fibers, chemicals, or particles, and chemically impregnated materials such as cellulose products that use adhesives and/or other chemicals to retard fire. Total emissions for the anticipated product life are considered. In this category, indoor air performance in based upon heuristics.

(f) **Habitat Alteration** is the human use of land that diminishes the natural habitat for threatened and endangered species. The density of threatened and endangered species used to help quantify the potential undesirable impact of habitat change. This index is often used during the site selection and planning stage for a new or refurbished facility. The Habitat Alteration Index is based upon an estimated count in the reduction of threatened and endangered species:

Habitat Alteration Index $= \Sigma_i(a_i \times TED_i)$

where a_i = surface area (in m^2) of disrupted land for each land parcel i, and

and TED_i = US threatened and endangered species density (count per m^2) for each listed land impact category i.

Table 5: Habitat Alteration Potential Characterization Factors (source: BEES manual)

Flow (i)	TED_i (T&E count/m^2)
Land Use (installation waste)	6.06E-10
Land Use (replacement waste)	6.06E-10
Land Use (end-or-period waste)	6.06E-10

(g) Water Intake is particularly important in areas where water is scarce, such as in the western United States. This category addresses water intake only and not water pollution. Water pollution is addressed in other categories such as eutrophication. Water intake for each product from cradle to grave in liters per functional unit is used directly and recorded in the BEES life cycle inventory.

(h) **Criteria Air Pollutants** are solid and liquid particles from activities such as combustion, vehicle operation, power generation, materials handling, crushing, grinding, etc. which are found in the air. These particles contribute directly to respiratory ailments and diseases and aggravate existing respiratory conditions such as asthma. An index for this category has been developed that uses Disability-Adjusted Life Years per gram of air pollutant.

Criteria Air Pollutant Index = $\Sigma_i(m_i \times CP_i)$

where m_i = mass (in grams) for each effluent i, and

and CP_i = US threatened and endangered species density (count per m^2) for each listed land impact category i.

Table 6: Critical Air Pollutant Characterization Factors (source: BEES manual)

Flow (i)	CP_i (microDALYs/g)
Nitrogen Oxides (NO_x as NO_2)	0.002
Particulates (>PM10)	0.046
Particulates (≤PM10)	0.083
Particulates (unspecified)	0.046
Sulfur Oxides (SO_x as SO_2)	0.014

(i) **Human Health Index** measures the direct human health impact from exposure to industrial and natural substances. The effects may range from mild irritation to permanent disability or death. The human health index uses Toxicity Equivalency Potentials using factors that relate the various health effects of exposure. Carcinogenic effects are expressed in terms of benzene equivalents and non-cancerous effects are expressed in toluene equivalents, and a ratio (21,000kg/kg) was developed to convert benzene to toluene equivalents.

Human Health Index = $\Sigma_i(m_i \times HP_i)$

where m_i = mass (in grams) for each effluent i having a potential human health effect, and

and HP_i = grams of toluene with the same potential harmful human health effect as flow i (from table in Appendix).

(j) **Smog formation potential** - in the atmosphere, smog is generated when ozone reacts with oxides of nitrogen and volatile organic components. A smog index has been developed that uses nitrogen oxides for reference to compares various different smog-forming compounds.

Smog Index = $\Sigma_i(m_i \times SP_i)$

where m_i = mass (in grams) for each smog-forming effluent i, and

and SP_i = grams of nitrogen oxides with the same potential for smog formation as one gram of flow i (from table in Appendix).

(j) **Ozone Depletion Potential** – the ozone layer protects the earth against harmful effects of ultraviolet light by acting as a filter. Ozone gas in the stratosphere acts as a filter, absorbing short wavelength ultraviolet electromagnetic waves while allowing longer wavelength light to pass through to the earth. Depletion of the ozone layer allows more of the harmful shorter wavelength light to pass through, with resulting damage to flora and fauna. An increase in the rate of cataracts and melanoma (skin cancer) as well as suppression of the immune system are attributed to the depletion of the ozone layer. The BEES method uses CFC-11 as the reference substance to compare the effects of various effluents.

Ozone Depletion Index = $\Sigma_i(m_i \times OP_i)$

where $\mathbf{m_i}$ = mass (in grams) for each ozone depleting effluent i, and

and $\mathbf{OP_i}$ = grams of CFC-11 with the same ozone-depleting potential as flow i (from table in Appendix).

(k) **Ecological Toxicity** measures the impact of a chemical released into the environment to directly harm terrestrial and aquatic ecosystems. The BEES method uses 2,4-dichorophenoxy-acetic acid as the reference substance to compare the effects of various effluents.

Ecological Toxicity Index = $\Sigma_i(m_i \times EP_i)$

where $\mathbf{m_i}$ = mass (in grams) for each effluent i, and

and $\mathbf{EP_i}$ = grams of 2,4-dichorophenoxy-acetic acid with the same ecological toxicity potential as flow i (from table in Appendix).

Summation: The US EPA Office of Research and Development developed normalization data for each of the impacts so that summations and comparisons can be made. This allows sustainable engineering trade-offs to be made that consider global health and environment implications for future generations to come.

Overall performance (combine environmental & economic scores):

$$Score_i = \left(\left(EnvWt \times \frac{EnvScore_j}{\sum_{j=1}^{n} EnvScore_j}\right) + \left(EconWt \times \frac{LCC_j}{\sum_{j=1}^{n} LCC_j}\right) \right) \times 100$$

where LCC_j = total economic life cycle cost in present cost units (e.g. $) and EnvWt + EconWt = 1 and

$EnvScore_j = \Sigma IAScore_{jk}$, where p = # of environmental impacts

$IAScore_{jk}$ = characterized, normalized score for product alternative j from environmental impact k

Note: weighting & normalization factors apply to each environmental impact k:

$$IAScore_{jk} = \frac{IA_{jk} \times IVwt_k}{Norm_k} \times 100,$$

where $IAwt_k$ = impact category weight for impact k

$Norm_k$ = normalization value

$IA_{jk} = \Sigma\, I_y \times IAfactor_i$ where i = inventory flow i, n = # of total flows

I_y = inventory flow for alt j from flow i

$IAfactor_i$ = impact factor for flow i

(reference: Appendix A, BEES Technical Manual and User Guide)

3. Facility Building and Site Selection Considerations

Buildings account for 25% of the world's wood harvest, 40% of the world's material and energy flows and 17% of the world's fresh water withdrawals[4]. Within the United States, US building emissions include 35% of carbon dioxide emissions, 49% of sulfur dioxide emissions, 25% of nitrous oxide emissions, and 10% of particulate emissions. In terms of environmental impact, one wood-framed home consumes over one acre of forest and generates three to seven tons of waste. A sustainable engineering approach considers both economic and environmental impacts to energy, water, materials, air quality, waste and indoor environment over the entire life cycle. As mentioned in the previous section, the cost of most facilities is relatively small compared to the operational costs (e.g. salaries) over a thirty year life span. Improvements within the facility to improve worker efficiency and reduce maintenance and operational costs therefore should pay for themselves many times over the life of the facility.

In the United States, LEED certification is presently encouraged for all new facilities built using government funds. It is anticipated however that LEED certification will become a requirement however for all new DOE facilities. In order to obtain LEED certification, several aspects of a new facility are considered. The initial cost of a new facility over a thirty year period, although substantial, is considered to be approximately two percent of the total costs; operations and maintenance accounting for six percent and personnel costs comprising ninety-two percent of total costs. [5] Some of the factors involve may be intuitively obvious, while other are not.

Energy Efficiency within a new facility is important from both an economic and environmental perspective. An average twenty-five percent of operating expenses are spent on energy, half of which is spent on creating an artificial indoor climate via heating, cooling, ventilation, and lighting. Simple design changes that use natural day lighting and natural heating and cooling may be both economically and environmentally beneficial over the life of the facility. Minimizing the amount and hours of usage for outdoor and indoor lighting and maximizing use of photovoltaics, light sensors, and cut-off devices to sense occupancy help reduce electric needs. Systems and sensors are available that maximize energy savings by dimming or turning off lights when sufficient natural light is available. Maximum gain however is realized when the facility is designed and situated to take maximum advantage of solar heating and lighting. To do this, solar path analyses are used to design and place building apertures and use light shelves maximally (see figure 1). Window glazings are available that transmit visible light effectively, while blocking infrared rays. Windows using electrochromic glass are being engineered which darken with the application of electric current. The use of passive and active solar heating and cooling with thermal storage systems more than pay for themselves. (see figure 2). Increased ventilation rates using outside air economizers and heat recovery systems improve indoor air quality, reduce respiratory illness rates, and economically improve occupant satisfaction.

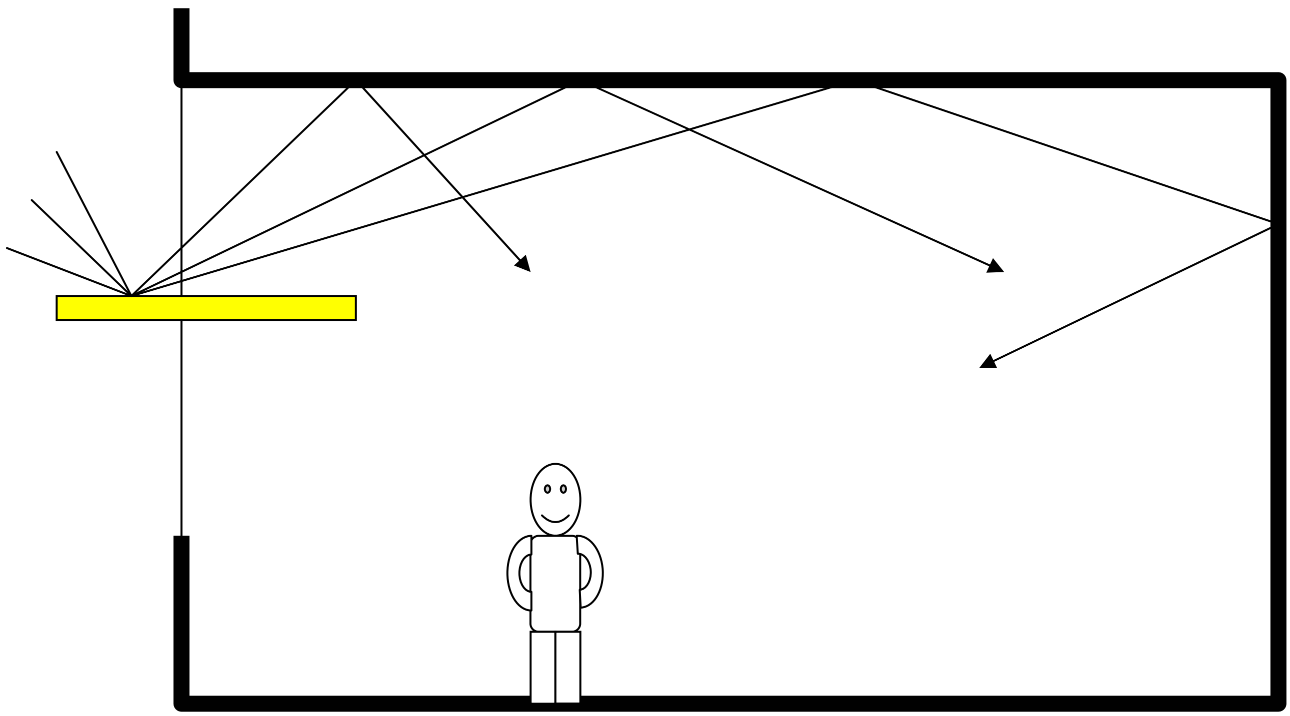


Figure 1: Light Shelf (source – Sustainable Building Technical Manual)

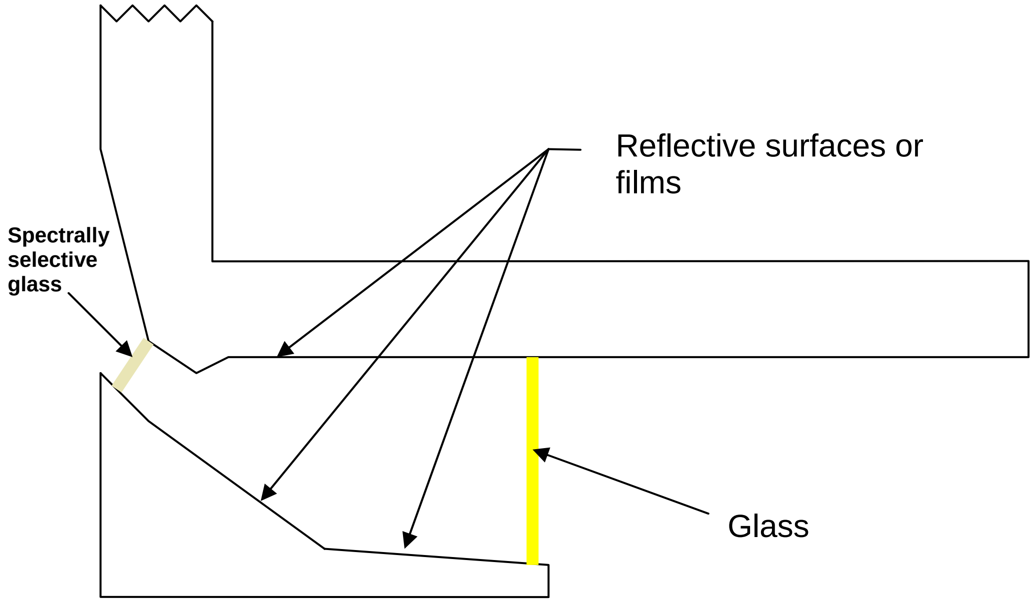


Figure 2: Advanced Light Shelf (source – Lawrence Berkeley National Laboratory)

Site selection is an important consideration that goes well beyond minimizing disruption to the natural environment; the impact to the natural environment needs to be considered as well as other factors such as the location of the facility relative to the people who will occupy it. The location of mass transit connections, vehicular infrastructure, and utility and telecommunication networks have environmental impacts that should be considered over the life of the building. Does the site support efficient waste removal? Will it impact groundwater and surface runoff? Does the position of the building allow use of solar heating and lighting? Is the building situated to take advantage of natural air movement patterns? Is the soil acceptable, or have any past commercial or agricultural activities left pesticides, carcinogenic compounds or other contamination? Can problems be anticipated from radon, ground water movement, unstable soil, or erosion? How will the new facility disrupt the local ecosystem? Are any endangered species effected? What is potential for natural hazards (flood, mudslides, wind or storm damage, earthquake potential, volcanic activity, etc)? How will local traffic patterns be affected?

All of these factors influence economic and environmental costs. A site located to minimize utility and transportation costs, utilize gravity (versus pumped) sewer systems, redevelop previously developed land, and selecting an environmentally stable site location causes minimum disruption to the environment and makes economic sense. Similarly, situating and orienting the facility on the site so as to take maximum advantage of natural land, water, air and solar effects helps minimize HVAC and other costs.

Materials selection also has large economic and environmental impacts and wise choices during the design process can easily have large environmental effects. The extraction process, manufacturing process, packaging and transportation processes for particular materials differ and each has differing direct environmental and energy impacts. Life cycle analyses are used to quantify and compare the entire costs of materials from extraction to disposal or recycling. This information is available from the BEES manual. It groups building materials into usage categories. To expedite analysis however, a computer software tool, "Tool for the Reduction and Assessment of Chemical and other environmental Impacts" (aka TRACI) is available from the US EPA (reference http://www.epa.gov/nrmrl/std/sab/traci/) at no cost. This tool includes the many tables referenced within the LEED categories above and performs automated assessments so the engineers and designers can compare various approaches and materials relatively quickly. The tool may be downloaded from the US EPA website listed. The tables are too extensive to include within this paper.

When selecting materials, several goals should kept in mind. First is to minimize material use and scrap. Then, during selection, the use of reused and salvaged materials should be considered next, followed by the use of recycled materials, that is, those materials with the largest recycled content. The next consideration should be minimum transportation costs. Local material sources and regionally-appropriate materials are preferred. Life-cycle costs and maintenance requirements should also be considered, followed by resource recovery considerations which occur at the end of the material's life cycle. Typical engineering decisions sometimes include material property and economic considerations only, but wise engineers often include maintenance requirements and lifetime cost factors as well. A sustainable engineering approach however considers the overall impact to the environment over the material's full life cycle. This added information gives engineers the ability to take part in improving the environment on a day-by-day basis.

Water efficiency through conservation and the use of improved design can decrease water consumption by thirty percent or more. This reduces the need for water treatment facilities. Water efficiency can be achieved through use of fixtures designed for lower water consumption and through recycling, collection, and roofing and irrigation systems that collect rainwater and utilize it for effectively. This is discussed in the LEED Certification section.

Waste reduction includes construction-related materials, which comprise approximately twenty-five percent of landfill content. Recycling and reuse of construction materials in many places has been the result of refusal or increased fees for construction material waste.

4. LEED Certification

LEED certification refers to a trademarked rating system of the US Green Building Council (USGBC). It offers a menu of factors to consider when designing and constructing a building that reflect sustainable practices. Point values are assigned within each LEED category or "program" according to pre-set criteria. Some of the LEED categories relate closely to the concepts that were previously defined such as indoor air quality, but LEED does not address other topics discussed above directly like acidification, for example. LEED addresses these topics indirectly by guiding engineers to make wise environmental choices, for example, improved energy efficiency may indirectly reduce coal use and thus acidification.

The six major LEED categories for new construction include Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, and Indoor Environmental Quality. It is also possible to achieve points for Innovation. The USGBC is continually revising its rating systems and developing new systems for other types of construction, such as existing buildings or residential construction. It is important to start LEED planning in the earliest stages of building design, so that opportunities can be captured cost-effectively. Since achieving LEED certification requires submittals of required documentation to the USGBC, good organization is essential. The LEED program not only offers environmental benefits through conservation of natural resources, reduction of solid wastes, and improved air and water quality; but it also provides economic benefits by improving employee health, productivity, and satisfaction, reducing overall operating costs, and optimizing life-cycle costs.

Sustainable Sites was already discussed in part under site selection. Fourteen points are available in this category. The re-development of an existing (Brownfield) site yields more points than selection of a Greenfield site. Erosion and sedimention control are required for all sites however with storm water rate, quantity, and treatment criteria also considered. Site-specific sedimentation and erosion-control plans must meet the requirements of EPA 832/R-92-005 Storm Water Management for Construction Activities (Chapter 3) or local erosion and sedimentation control standards and codes, whichever is more stringent. The plan must prevent the loss of soil during construction via water run-off and erosion and must protect topsoil by stockpiling for reuse. It must also prevent sedimentation in storm sewers and receiving systems, and prevent polluting the air with particulate matter. Other considerations are the development density (preference should be given to locating facilities in already densely-developed areas), alternative transportation (public transportation access, bicycle storage and changing rooms, alternative fuel vehicles), parking capacity (e.g. tuck-under and shared parking is preferred to the use of additional site space for parking), and carpooling. The encouragement of alternate fuel vehicles and carpooling for example can be accomplished through the use preferred parking and refueling stations. The location of a facility within one half mile from railway or subway station or within one quarter mile from public bus lines is preferred. Site disturbance is also a consideration with the site footprint and amount and type of open space used as criteria. Lastly, landscape and exterior design of the site (and roof) must reduce heat islands (thermal gradient differences between developed and undeveloped areas) and light pollution must be reduced.

Water efficiency includes water-efficient landscaping, water use reduction, and innovative water use reduction. A maximum of five points are available in this category. As an example, a twenty percent reduction in water use may achieve an award of one point and a thirty percent reduction would receive two points (e.g. compared to the baseline fixture performance of the Energy Policy Act of 1992). If for example, no potable water is utilized for landscaping or no irrigation is employed, another point would be received. In this category, the use of impervious materials is discouraged for site storm water runoff and roofing systems that capture and re-use rain water are encouraged. Water management systems should be implemented for sites where water imperviousness is reduced by fifty percent. Points are awarded for reuse of storm water (i.e. through irrigation, custodial use, toilet and urinal flushing, etc) and reduction in potable water use.

Energy and Atmosphere includes fundamental building systems commissioning, minimum energy performance criteria, and CFC reduction in HVAC&R equipment. A total of seventeen points in this category can be attained for reductions in renewable energy, additional commissioning, ozone depletion, measurement and verification, and green power. Points in this category can be attained by minimizing energy use through solar and stored-energy technologies, minimum use of unnecessary or excessive unnatural lighting, etc. For new buildings, a fifteen percent reduction in energy use (relative to design per ASHRAE/IESNA Standard 90.1-1999) would earn one point and up to nine more points may be awarded for each five percent reduction up to sixty percent. Points are also available for using "green" power from solar, wind, geothermal, biomass, or low-impact hydroelectric sources.

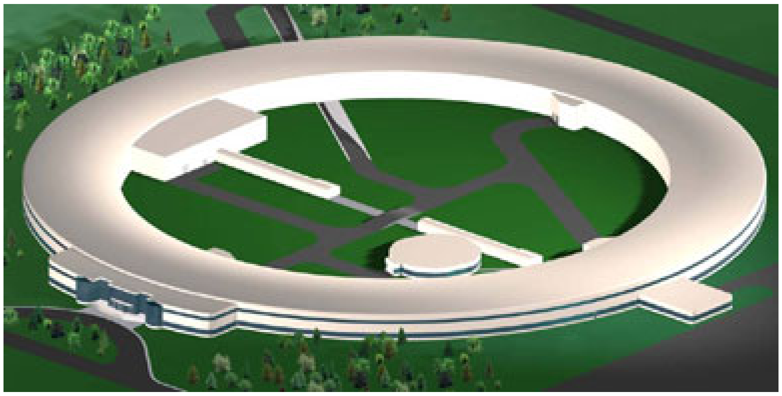
Material and resources includes storage and collection of recyclables, reuse of existing building shell, construction waste management, resource reuse, recycled content, use of local or regional materials, and the use of certified wood and rapidly-renewable materials. Thirteen points are available in this category. Points are awarded for dedicated areas and programs to efficiently collect and recycle materials, the reuse of construction materials from previous facilities (as a percentage of materials used for shell and non-shell structure) and the use of materials from construction, demolition, and site clearing waste. The number of points awarded is dependent upon the percentage of materials reused. During the construction process, the use of a high percentage of post-consumer and post-industrial recycled content materials is encouraged. As previously mentioned, the use of materials manufactured regionally, and extracted-and-manufactured regionally is preferred. The use of rapidly-renewable materials such as bamboo, pine, mahogany, oak, cotton-batt insulation, wool carpets, etc should be considered first.

Indoor Environmental Quality considers the performance of systems to improve indoor air quality. New facilities require an indoor environment that is free from tobacco smoke and mandated minimum air quality system performance. A total of fifteen points are available in this category. Points within this category are awarded for carbon dioxide monitoring systems and verification effectiveness and several other parameters which include indoor air quality during construction and before occupancy. The use of low-emitting adhesives and sealants, carpet, paint, composite wood and agrifiber materials, and indoor chemical and pollutant source control systems are included as well. The specification of low-Volatile Organic Compound (VOC)-emitting construction materials, flooring materials, paints, and coatings will help to improve indoor air quality during initial occupancy. Efficient HVAC systems that provide fresh air with minimal energy will provide a productive, comfortable environment for occupants. This category also includes the controllability of perimeter and non-perimeter, thermal comfort and monitoring systems, and the use of daylight and views for interior spaces. Such goals may be met through the use of operable external windows (one per 200 square feet of regularly-occupied space is suggested).

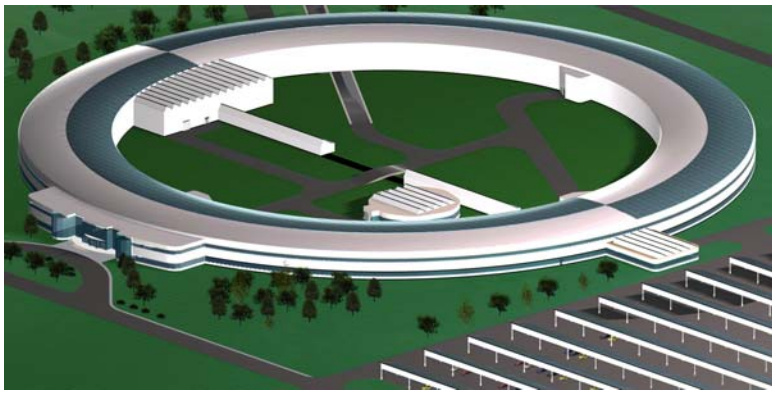
Innovation and Design Process allows for up to five points for improving parameters beyond the specific requirements given. For example, the use of a LEED-accredited professional to evaluate that requirements have been met is encouraged within this category. Points within this category are available for other strategies that substantially exceed performance in any other LEED category and for improvements in areas such as acoustic performance, education of occupants, community development, or life cycle analysis of material selections.

From a total of 69 possible points, certifications are classified as follows:

LEED certified:	26-32 points
Silver:	33-38 points
Gold:	39-51 points
Platinum:	52-69 points



(a) NSLS II, full-energy linac version without solar photovoltaic panels.



(b) NSLS II, full-energy linac version with 2.6MW solar photovoltaic capacity.
Figure 3: NSLS II, 630 m storage ring version

5. Conclusions and Recommended Actions

Sustainable engineering principles add an additional dimension to guide the design of new facilities. This added dimension extends the decision criteria for site selection, materials selection and design beyond optimized performance and economic criteria. Sustainable engineering adds environmental criteria to assure that our descendants enjoy a healthy, natural, clean living environment relatively free from air, water, and land pollution. Only by taking the necessary steps now to practice environmentally-conscious engineering from a world-wide perspective can we be assured of passing on a healthy, natural environment to our future generations. The sustainable engineering principles, references, and the software program listed herein provide adequate framework to make wise engineering decisions that are economically and environmentally conscious. When considering new designs, such questions as "How can this component be designed so it can be easily and quickly refurbished with minimal material replacement?", "What materials can I use that meet performance and economic objectives that are also environmentally friendly?", "How can I minimize transportation and energy costs when purchasing materials or components?", "Can I use local sources of raw and finished materials, and are any of these materials rapidly-renewable?", and "Can I use previously-used materials in my new design?" If these questions remain in your memory after reading this paper, then you will be on the path to improving our world for future generations. It is suggested that each reader stay on this path and seek additional information as it becomes available.

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[1] reference http://www.nsls2.bnl.gov/
[2] reference http://www.eere.energy.gov/buildings/highperformance/
[3] reference http://www.eere.energy.gov/buildings/highperformance/lanl_sustainable_guide.html
[4] Source: Sustainable Building Technical Manual, produced by Public Technology Inc./US Green Building Council, sponsored by the US Department of Energy and the US Environmental Agency
[5] Source: "Leonard Dean Management" by Joseph J. Roman