Stanford University Energy and Climate Plan

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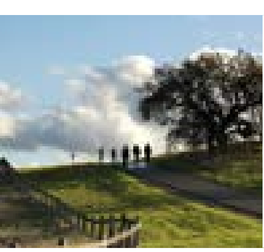
Concept Lead: Department of Sustainability and Energy Management

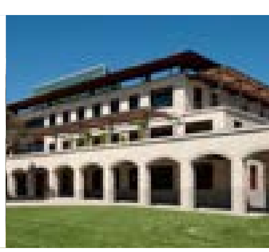
Report Produced by Office of Sustainability, Stanford University

About Us

Formed in 2007, Stanford's Land, Buildings & Real Estate's Department of Sustainability and Energy Management (SEM) brings a unique and particular focus to utilities infrastructure–related sustainability. SEM leads initiatives in campus infrastructure and programs in the areas of energy and climate, water, transportation, green buildings, and sustainable information technology. The Office of Sustainability connects campus organizations and entities and works collaboratively with them to integrate sustainability as a core value. The Office works on long-range sustainability analysis, evaluations and reporting, communications publications, conservation campaigns, and collaborative governance.



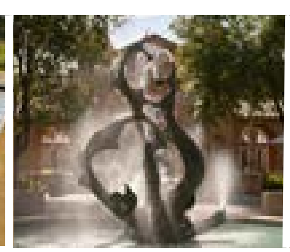
LAND STEWARDSHIP



GREEN BUILDING

TRANSPORTATION

ENERGY



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Clyde "Bob" Tatum, Emeritus Faculty, Civil and Environmental Engineering

SESI program studies also periodically engaged graduate student researchers to supplement industry findings, verify models, and assist with other assessments. Most recently, SEM partnered with the Stanford Solar and Wind Energy Project, a student group, to carry out detailed studies on the campus' solar potential. Solar photovoltaic (PV) integration is one aspect of SESI currently under investigation, and the students provided invaluable data while gaining practical hands-on experience. Stanford staff will continue to partner with students and faculty as additional elements of the Energy and Climate Plan develop.

Stanford recognizes the innovative and dedicated partners who contributed to the project.

Executive Summary

Situated on 8,180 acres, Stanford requires a significant amount of energy to support its academic mission and the research functions housed within more than 1,000 campus buildings. Efficiently managing energy supply and demand, as well as the corresponding greenhouse gas (GHG) emissions, is therefore critical to the university's future. Since the 1980s, Stanford has employed best practices to minimize the cost and environmental impact of its operations. The university has employed energy metering in all its campus facilities, used efficient natural gas-fired cogeneration for its energy supply, retrofitted buildings with efficient systems, implemented stringent building standards, invested in renewable power, conserved water, and reduced automobile commute emissions. However, given that climate change caused by anthropogenic greenhouse gas emissions is the greatest environmental and socioeconomic challenge and opportunity of our time, Stanford accepts the challenge to go beyond these efforts and raise the bar in the use of innovative and renewable energy supplies to further reduce its environmental impact and operational cost. This Executive Summary provides a brief overview of Stanford's Energy and Climate Plan, including:

- Planning Purpose
- Planning Approach
- Benefits to Stanford University and Beyond
- Approval and Implementation

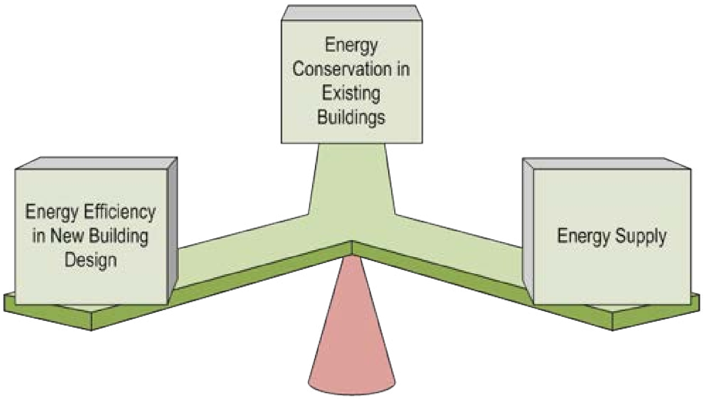
Planning Purpose

Formed in 2007, Land, Buildings & Real Estate (LBRE)'s Department of Sustainability and Energy Management (SEM) brought an integrated and deliberate focus to campus sus-tainability. One of the first major tasks for this newly formed department was to create a long-range energy and climate plan for the campus, with a purpose of striking a balance between the critical needs of climate action and energy production and the requirements inherent in operating a large university.

Stanford's long-range Energy and Climate Plan—developed collaboratively and peer reviewed—incorporates both engineering and financial models and presents a three-pronged, balanced approach to improve infrastructure and dramatically reduce greenhouse gas (GHG) emissions (despite campus growth) without relying on market carbon instruments. Serving as a blueprint for implementation, this plan demonstrates long-term cost effectiveness and sustainable natural resource use; guides development of critical campus infrastructure; and reduces economic and regulatory risks to Stanford's long-term energy supply. It provides a vision for the campus' energy future while maintaining flexibility through a comprehensive, long-term approach to the challenge of reducing campus emissions.

The solutions provided by the Energy and Climate Plan, including the Stanford Energy System Innovations (SESI) program, not only represent the most economical energy op-tion, but also immediately reduce campus GHG emissions by 68 percent and potable water use by 15 percent while opening a path to full energy sustainability over time through greening the campus electricity supply.

FIGURE 0-1 A BALANCED APPROACH TO ENERGY AND CLIMATE SOLUTIONS



PLANNING APPROACH

The plan was designed with the vision of applying Stanford's intellectual resources to provide leadership in climate change solutions through a long-term, holistic, and flexible approach. The first step in its development was a comprehensive analysis of current campus energy use and GHG emissions. Stanford has been accounting for and publically reporting its Scope 1 and Scope 2 carbon emissions since 2006. In 2014, emissions totaled close to 179,000 metric tons CO_2 equivalent. Using this data, campus growth projections were then used to create a GHG emissions forecast that informed the development of the Energy and Climate Plan. Given Stanford's planned growth to support its academic mission, its large and diverse existing campus building inventory, and its historical reliance on natural gas cogeneration for energy (the main source of past GHG emissions), the Energy and Climate Plan provides a balance among investments in new buildings, existing buildings, and energy supply.

HIGH-PERFORMANCE NEW BUILDING DESIGN

Given the university's significant growth plans, constructing high-performance new buildings to minimize the impact of growth on campus energy systems and GHG emissions is a key strategy. The Guidelines for Sustainable Buildings, originally published in 2002 and updated in 2008, in combination with the Guidelines for Life Cycle Cost Analysis and the Project Delivery Process Manual, provide the framework for minimizing energy demand in new construction and major renovation projects on campus. Programs in place to maximize energy efficiency include:

- Optimization of current space through Stanford's Space Planning Guidelines. Before undertaking any building project, Stanford first conducts a rigorous space utilization study to see if renovation of existing buildings can create space for new needs.
- Mandatory efficiency standards for new buildings, which must use less energy than the benchmark energy and water use of peer buildings.
- Guidelines for sustainable buildings that address site design; energy use; water management; materials, resources, and waste; and indoor environmental quality.

All new campus buildings completed in recent years embody these guidelines.

ENERGY CONSERVATION IN EXISTING BUILDINGS

Since the 1980s, Stanford has employed building-level energy metering in all its facilities to understand how and where energy is used in order to facilitate strong energy efficiency programs. Reducing energy use in existing buildings is crucial to creating a sustainable campus, and also a formidable task given the growing energy needs of research universities. However, Stanford has a strong foundation for success, building on a decades-long commitment to energy conservation and efficiency. The university has substantial programs to improve campus energy efficiency, including:

- The Energy Retrofit Program, which improves building energy efficiency and has led to cumulative annual energy savings of 300 billion BTU since 1993.
- The Whole Building Retrofit Program, which targets the campus' most inefficient buildings for retrofits. Fourteen projects have been completed as of spring 2015, and 8 more are under way. The program has already achieved $4 million in annual energy savings.
- The Energy Conservation Incentive Program, which targets reductions in energy use through human behavior, rather than technology.
- The Plug Load Energy Consumption Reduction program, which reduces the energy consumption of the biggest "energy hogs" of equipment identified by Stanford's campus-wide plug load inventory. These include IT equipment, lab equipment, and space heaters.

While the university has pursued aggressive energy conservation for many years, the continuation and expansion of programs like these is another key strategy of the Energy and Climate Plan.

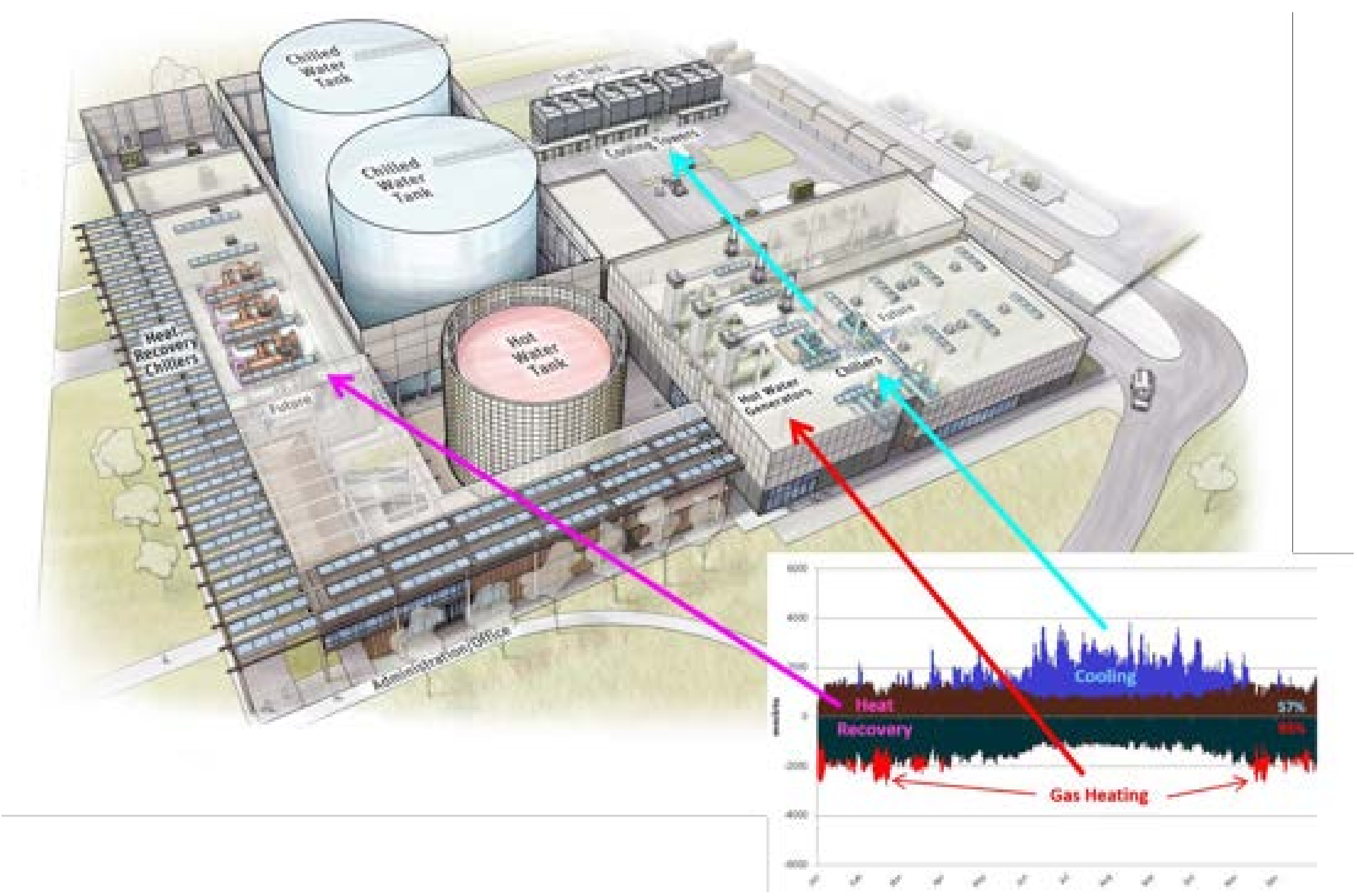
Stanford Energy System Innovations (SESI)

Changes to Stanford's energy supply are the major focus of the Energy and Climate Plan because from 1987 to 2015 Stanford's natural gas-powered cogeneration facility produced 90 percent of Stanford's GHG emissions. As the cogeneration plant approached the end of its useful life, Stanford examined conversion to new options that assured reliability, contained cost, and reduced GHGs. Stanford Energy System Innovations (SESI) is Stanford's new district energy heating, cooling, and electricity system designed to meet the energy needs of Stanford University in a sustainable and economic way.

Prior to the implementation of SESI, Stanford's cogeneration plant produced steam to heat campus buildings and domestic water. Simultaneously, the chilled water system collected unwanted heat from buildings and transported it to the central energy facility, where it was discarded to the atmosphere via evaporative cooling towers.

While much heating is done in winter and much cooling in summer, any overlap of the two provides an opportunity to recover and reuse heat energy that is normally discarded to the atmosphere. The heart of SESI is heat recovery—capturing waste heat from the chilling system to produce hot water for the heating system. In 2009, investigation of sustainable options to succeed the gas-fired cogeneration system uncovered a major real-time overlap of heating and cooling. The study revealed that 70 percent of the waste heat from the chilled wa-ter system could be reused to meet 93 percent of campus heating loads if the heat distribution system were converted from steam to hot water (see "Heat Recovery Potential" graphic below).

Figure 0-2 Heat Recovery Potential at Stanford



To determine the best fit for Stanford's new energy system, nine major options were developed in detail, including:

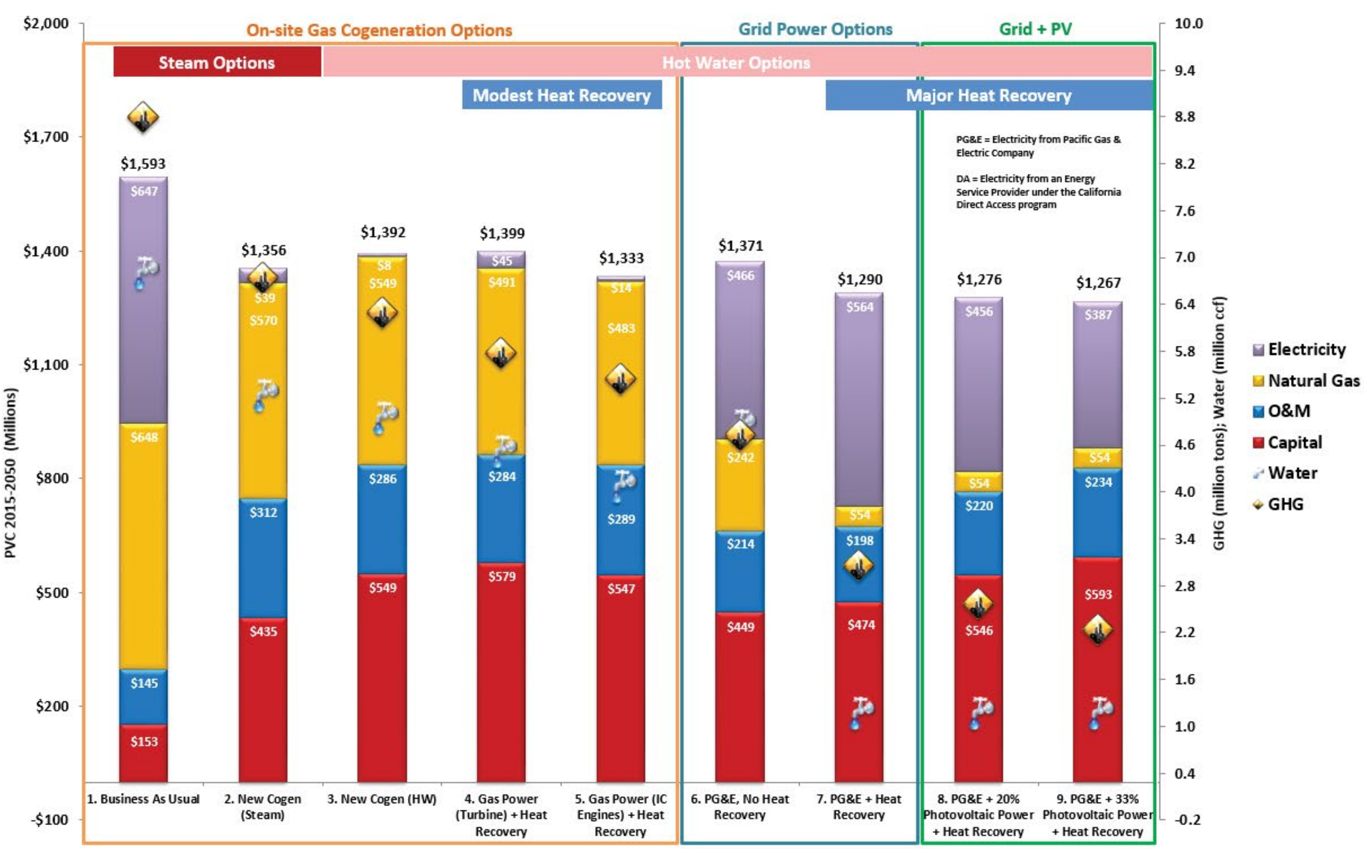
- Gas-fired cogeneration and steam distribution (business as usual Third Party vs. Stanford owned and operated)
- Gas-fired cogeneration with hot water distribution
- Hybrid cogeneration + heat recovery with hot water distribution (Turbine and IC engine options)
- Heat recovery plant with hot water distribution (Grid + Heat Recovery option)
- Conventional boilers and chillers central plant (Grid, No Heat Recovery option)
- Grid + heat recovery plant with 20-33 percent on-site PV power

These options were modeled for energy and exergy efficiency, economics, and environ-mental impact and subjected to substantial peer review. Results are presented in Figure 0-3, which compares the life cycle cost of each option as well as the relative GHG emis-sions and water use. Based on these results, Stanford selected the electrically-powered heating and cooling plant with heat recovery and hot water distribution (Option 7) as its new base energy system. Option 7 represented the lowest life cycle cost and also presented one of the lowest up-front capital cost options since on-site power generation infrastructure was avoided. As this decision was made, Stanford concurrently studied the feasibility of incorporating renewable energy into its power mix.

SESI Approval and Implementation

SESI has set a precedent for campus involvement with major capital improvement projects at Stanford. In setting the vision and principles for this multi-year initiative, the SESI program in-tegrated input and leadership **from all stakeholders on campus** (staff, students, faculty), while maintaining steady communication with Stanford leadership (Executive Cabinet and the Board of Trustees). A GHG reduction options report was prepared in 2008 and presented to the uni-versity administration for initial review. Subsequent reviews with more detailed analysis were held with the Board of Trustees in 2009, 2010 and throughout 2011; two different faculty advisement committees actively participated during this inception phase of the project (President's Blue Ribbon Taskforce in 2008 and 2009 and Board of Trustees Energy Advisory Com-mittee in 2010 and 2011). In total, over the entire course of SESI planning

Figure 0-3 Comparative Cost, GHG, and Water Use of Energy Supply Options



and implementation, more than 25 faculty members and 100 students were involved through student groups and departmental queries. This was truly an all-campus project that solicited, welcomed and bene-fited from faculty and student input throughout the years.

In December 2011, Stanford's Board of Trustees gave concept approval to the $485 million SESI program. In 2012, after a full year of planning, contract negotiation and internal campus coordination, the university broke ground for the conversion of steam to hot water and the construction of the new Central Energy Facility (CEF) on campus. In March 2015, the conversion of steam to hot water was completed, with 22 miles of hot-water piping installed and mechanical rooms in 155 buildings converted to accept hot water (Figure 0-4). In April 2015, the new CEF came online and the university began decommissioning the old cogeneration plant. The CEF includes heat recovery chillers, thermal energy storage tanks, a high-voltage substation, and an advanced controls system. At this time, Stanford also entered into an agreement with SunPower to build 78.5 MW of solar PV, 5.5MW of which will be located on the Stanford campus.

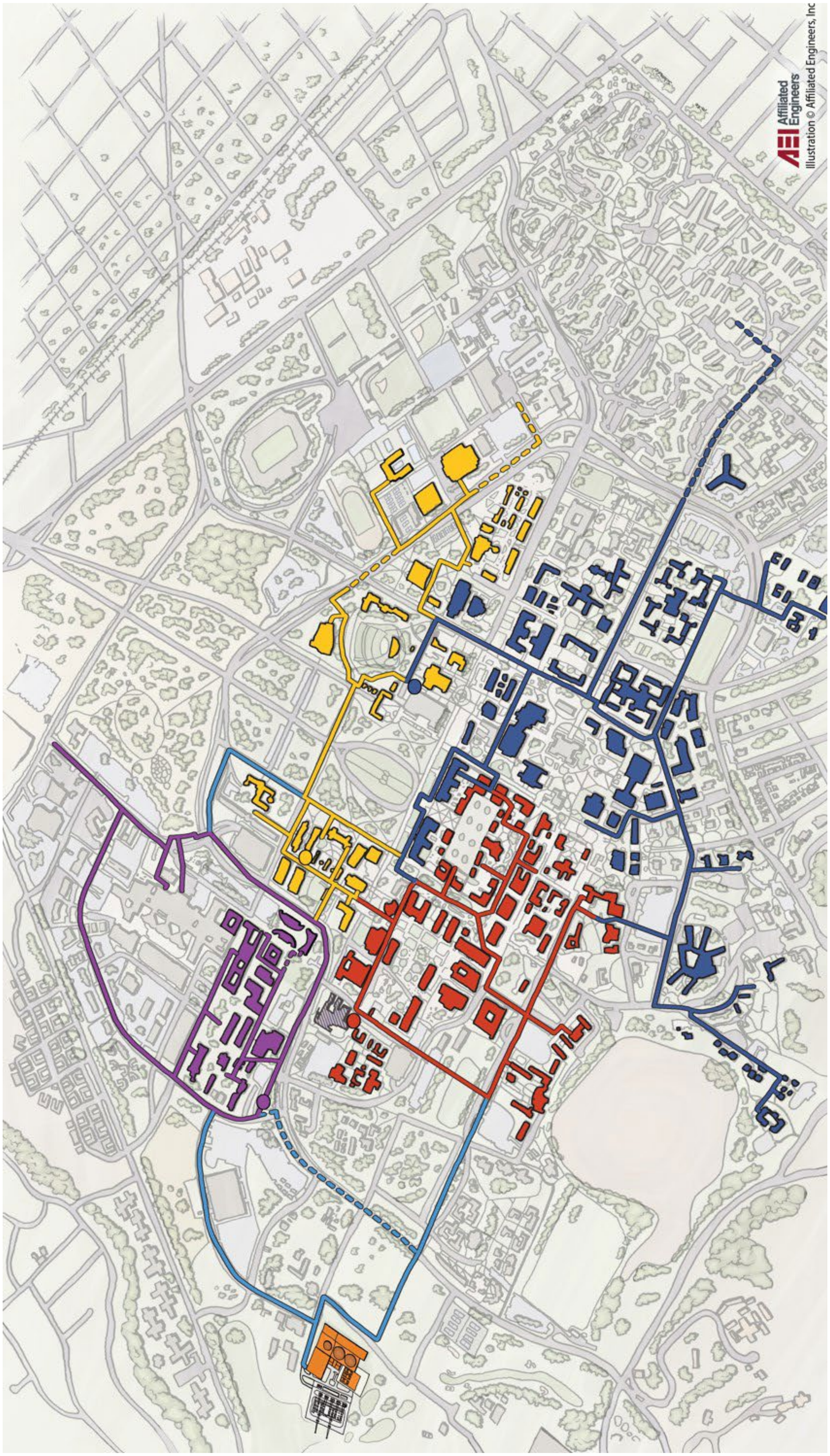
SESI has been a steady source of education for Stanford students and community members. Not only were students involved during the planning of SESI, but student and campus community outreach was pervasive during the implementation stages. The Department of Project Management and Office of Sustainability launched a comprehensive outreach effort and met with over 30 campus departments and entities to explain the importance of energy action and Stanford's leadership role with SESI, as well as to coordinate the schedule of widespread construction. The campus community was very supportive, despite the short-term inconvenience. The SESI website (sustainable.stanford.edu/sesi) provides a wealth of information on the project including fact sheets, videos, technical documentation, news coverage, and more.

Benefits to Stanford University and Beyond

The Energy and Climate Plan signifies a new chapter for Stanford as the campus moves to lead sustainability by example through a balanced approach to emissions reduction. SESI, the most significant component of the plan, represents a major transformation of the university's en-ergy supply from 100 percent fossil fuel–based cogeneration to a more efficient electric heat recovery system, powered by a diverse mix of conventional and renewable energy sources.

Photos: The Central Energy Facility

Figure 0-4 Hot Water Piping Conversion Map

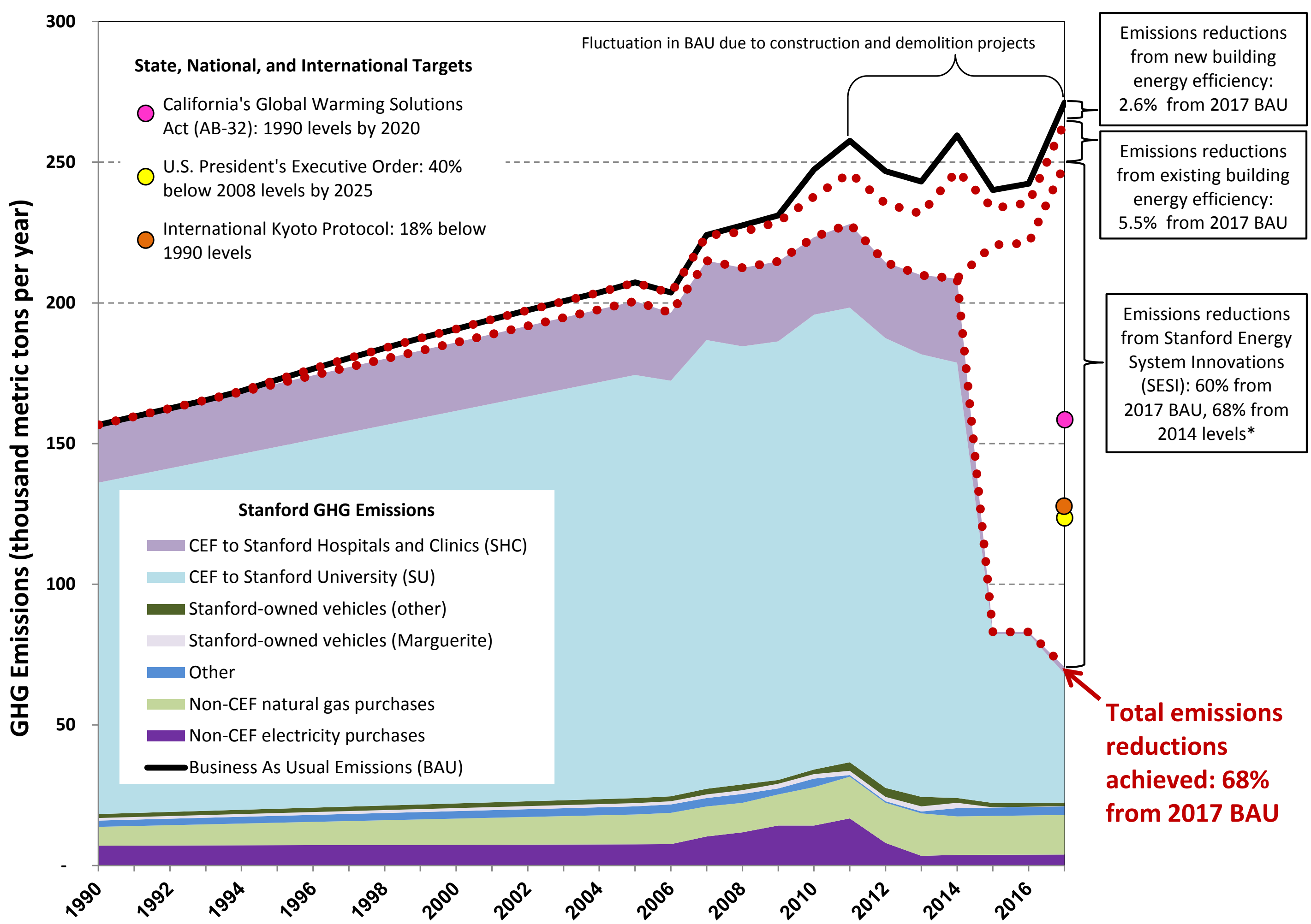


Although developed independently by Stanford from 2009 to 2011, SESI may be the first large-scale example in the world of employing the technology roadmap for building heating and cooling recommended by the International Energy Agency, which the United Nations Environment Program also recently discussed in a comprehensive report for district-level implementation.

The new CEF has reduced campus emissions by 50 percent from current levels, and renewable power procurement will reduce emissions by another 18 percent, leading to a total of 68 percent emissions reduc-tions from the SESI project. (see Figure 0-5 Emissions Reduction Wedges & Targets). The SESI project also reduced campus potable water consumption by 15 percent from the elimination of cool-ing towers to evaporate waste heat. The energy and cost efficiencies gained from the SESI project will save the university $420 million over the next 35 years.

SESI's impact reaches beyond the Stanford campus. Combined with demand-side manage-ment programs that target energy efficiency in both existing and new buildings, SESI has made Stanford a pioneer in the low-carbon energy future. Although developed independently by Stanford, SESI may be the first large-scale example in the world of employing the technology roadmap for building heating and cooling recommended by the International Energy Agency. It encompasses the best of both North American and European district heating and cooling system advances, with engineers, manufacturers, and constructors from both continents col-laborating to develop SESI's state-of-the-art infrastructure. SESI demonstrates that heat re-covery at a district level is possible for others across North America. The technology used is highly transferrable, and thermal storage enables application in almost all climate zones. Stan-ford will share its patented energy modeling system with any entity interested in determining the overlap in heating and cooling and the subsequent potential for heat recovery.

FIGURE 0-5 EMISSIONS REDUCTIONS WEDGE AND TARGETS



The CEF is a learning center for students and public alike, with classroom and meeting spaces built in and much of the plant's equipment visible through viewing windows. In-depth tours take interested groups through the CEF to experience sustainability solutions first-hand. Because the CEF was designed and built for future growth and expansion, it also provides an unparalleled platform for real-time experimentation of innovative research and development. By demonstrating that even an energy-intensive research institution can reduce its greenhouse gas emissions to climate-stabilizing levels without compromising its core mission, Stanford hopes to provide inspiration, confidence, and a blueprint for other entities to follow suit.

Next Steps for Caretakers of a Legacy

Stanford's Energy and Climate Plan is built on the principle of innovation and flexibility to adapt to new technologies; the university aims to meet the needs of the future without compro-mising the needs of the present. By design, SESI is a balance of pragmatism and vision, meet-ing short- and long-term needs of an institution of higher learning that leads sustainability by example.

While the core elements of the SESI program are complete, feasibility studies of additional enhancements to the campus energy system progress, including development of a ground source heat exchange (GSHE) system to complement the core heat recovery process. Also, in recognition that a path to full energy sustainability has been opened up through conversion of the campus from gas to electricity, the university will continue to build out the renewable sources of its electricity portfolio. Stanford will evaluate opportunities for geothermal and wind energy to complement the 78.5 MW of solar PV to which the University has already committed.

Chapter 1: The Need for Climate Action

Stabilization and reversal of greenhouse gas (GHG) emissions into the atmosphere from human activity is a challenge that requires s solutions in the areas of both research and implementation. Climate science has instilled a sense of urgency upon climate action. The UN Intergovernmental Panel on Climate Change (IPCC) has found that developed countries, as a group, need to reduce emissions by 25–40 percent by 2020 and 80–95 percent by 2050 from a 1990 baseline in order to contain warming to a 2.0–2.4 degree temperature increase believed to be manageable.[1] Most widely recognized GHG reduction goals specify both interim (2010 to 2020) and long-term (2050) reductions.

Such significant reductions worldwide will require strong carbon regulations and effective technology implementation both globally and locally. This provides an opportunity for any entity to take local action within a global regulatory and economic framework. This chapter outlines the key events in climate action in both arenas to contextualize Stanford University's approach toward its long-range Energy and Climate Plan, initiated in 2008.

Major Events in Global Climate Action

International recognition of climate change as a serious global issue began in 1988 with the establishment of the IPCC. This group consists of the world's leading climate scientists. Its first report on climate change science was published in 1990.The fifth and most recent assessment, published in 2014, warned that recent climate fluctuations have already had widespread impacts on humans and natural systems.[2] The following key steps have shaped climate action globally and locally and have informed Stanford's decisions and analytical framework for climate action planning.

UNFCCC: International efforts to address climate change began in 1992 with the passage of the United Nations Framework Convention on Climate Change. The UNFCCC established the aim of stabilizing atmospheric GHG concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system."[3]

Kyoto Protocol: In 1997, the Kyoto Protocol quantified UNFCCC's objective by establishing specific targets and timetables for GHG reduction. The Kyoto Protocol set binding targets for developed countries to reduce GHG emissions (7 percent below 1990 levels for the U.S., 8 percent for Europe) by the 2008-12 commitment period, but did not mandate reduction commitments for developing countries.[4] In 2012 the Kyoto Protocol was amended to include a second commitment period from 2015 to 2020, which sets a target of reducing GHG emissions 18 percent below 1990 levels by 2020 for developed countries.[5]

In response to the international recognition of climate change, the United Nations and individual countries and regions have developed a variety of mechanisms to reduce global GHG emissions and meet reduction targets. The European Union led the way in 2005 with its Greenhouse Gas Emission Trading Scheme (EU ETS). Since then, approximately 30 national and over 20 sub-national jurisdictions have put a price on carbon, either through

1 Ref: IPCC http://www.ipcc.ch/ (Box 13.7 in the IPCC Fourth Assessment Report)

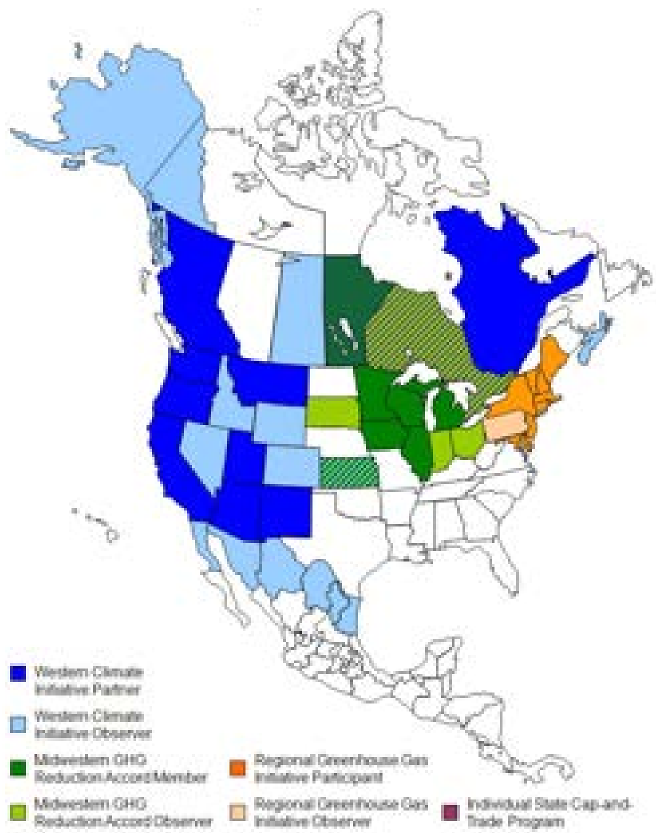
2 IPCC Fifth Assessment Report (https://www.ipcc.ch/report/ar5/)

3 UNFCC, 1992

4 UNFCC, 1997

5 http://unfccc.int/kyoto_protocol/items/2830.php

Figure 1-1 North American Cap and Trade Initiatives



Source: Center for Climate and Energy Solutions

a cap-and-trade program or a carbon tax. Other GHG reduction mechanisms include the United Nations' Clean Development Mechanism (CDM) and the Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN REDD). In the last few years, private-sector initiatives, such as results-based financing and voluntary carbon offsets, have also started to contribute to international GHG reduction efforts.

Major Events in Regional and National Climate Action

The United States is party to the UNFCCC but not to its implementing treaty, the Kyoto Protocol. Following the issuance of the 1997 Byrd-Hagel Resolution,[6] which expressed the U.S. Senate's concern over the potential negative economic impacts of emissions restrictions and its objection to participation in a treaty that did not also cover developing countries, the administration did not send the Kyoto Protocol to the Senate for ratification. Despite lack of international commitment, the United States has made progress toward regulating its GHG emissions.

6 https://www.nationalcenter.org/KyotoSenate.html

Supreme Court Ruling that CO_2 is a pollutant: On April 2, 2007, the Supreme Court handed down Massachusetts v. EPA, its first pronouncement on climate change. The Court ruled that carbon dioxide is a pollutant under the Federal Clean Air Act and said the EPA "abdicated its responsibility" under that act in deciding not to regulate carbon dioxide.[7] In 2009, the EPA officially added to the Clean Air Act that six key well-mixed greenhouse gases constitute a threat to public health and welfare, and that the combined emissions from motor vehicles cause and contribute to climate change.

Corporate Average Fuel Economy (cafe): First enacted by Congress in 1975, the purpose of CAFE is to reduce energy consumption and GHG emissions by increasing the fuel economy of cars and light trucks.[8] In 2010, the National Highway Traffic Safety Administration set standards to increase CAFE levels rapidly until 2016. In 2016, the average standard will be 37.8 miles per gallon for passenger cars and 28.8 miles per gallon for light trucks.

Clean Power Plan: On June 2, 2014, the U.S. Environmental Protection Agency (EPA), under President Obama's Climate Action Plan, proposed a plan to cut carbon pollution from power plants.[9] Nationwide, the Clean Power Plan aims to reduce emissions from the power sector by 30 percent from 2005 levels. The plan sets a unique carbon intensity goal for each state's power sector. Each state is expected to meet the goal by 2030 and develop a plan on how to do so by 2016. California's goal is one of the lowest in the country at 537 lbs. CO_2e/MWh (0.000244 metric tons CO_2e/kWh).

U.S. Joint Announcement with China on Climate Action: On November 11, 2014, President Obama announced a 2025 target to cut U.S. GHG emissions 26-28 percent below 2005 levels. At the same time, President Xi Jinping of China announced targets to peak emissions around 2030 (with the intention to try to peak early) and to increase the non-fossil fuel share of all energy to approximately 20 percent by 2030.[10] Significant for global climate action, this is the first time both the U.S. and China made international commitments to reduce emissions, and together the two countries account for over one third of global GHG emissions.

7 http://www.justice.gov/enrd/3589.htm
8 http://www.nhtsa.gov/fuel-economy
9 http://www2.epa.gov/carbon-pollution-standards/clean-power-plan-proposed-rule
10 https://www.whitehouse.gov/the-press-office/2014/11/11/fact-sheet-us-china-joint-announcement-climate-change-and-clean-energy-c

President's Executive Order: On March 19, 2014, President Obama issued an Executive Order (EO) committing government agencies to reduce their GHG emissions by 40 percent from 2008 levels by 2025.[11] This EO builds on President Obama's original EO addressing climate change, issued in 2009, and is one of the federal government's first steps in implementing measures to meet the U.S. emissions reduction target announced in November 2014. The EO has led to several major federal suppliers, such as IBM and General Electric, to set emissions reduction targets of their own.

The following regional and sector-based commitments have also provided context for Stanford's climate action.

Western Climate Initiative (WCI): Launched in 2007, the WCI is a collaboration of jurisdictions working together to identify, evaluate, and implement emission-trading programs to mitigate the impacts of climate change at a sub-national level. Current WCI members are British Columbia, California, and Quebec. In November 2011, WCI transitioned into WCI, Inc., a nonprofit corporation that provides administrative and technical assistance to support the implementation of state and provincial greenhouse gas emission trading programs. Under the auspices of WCI, Inc., California and Quebec linked their cap-and-trade programs on Jan. 1, 2014.

American College and University Presidents' Climate Commitment (ACUPCC): Launched in 2007, the American College & University Presidents' Climate Commitment (ACUPCC) is a high-visibility effort undertaken by a network of colleges and universities that have made institutional commitments to eliminate net greenhouse gas emissions from specified campus operations and to educate all students on climate change and sustainability. Twelve presidents agreed to become founding members of the Leadership Circle and launched the ACUPCC; membership now comes close to 700 universities. Stanford University is not a signatory to the ACUPCC, but the university has chosen and implemented a bold program to reduce its GHG emissions, guided by its Energy and Climate Plan.

Major Events in State Climate Action

California is pioneering GHG regulation in the United States. The sixth largest economy and 12th largest GHG emitter in the world, California has the leadership and legislative potency to define an emissions management standard for the entire nation. Below is a list of California's most impactful actions in response to climate change. A full list of California's Climate Legislation can be found at http://www.climatechange.ca.gov/state/legislation.html.

Executive Order S-3-05: In 2005, California Governor Arnold Schwarzenegger signed Executive Order S-3-05, committing California to specific emissions reduction targets and creating a climate action team to help implement them. Three specific emissions targets have been established: 2000 levels by 2010, 1990 levels by 2020, and 80 percent below 1990 levels by 2050.

Assembly Bill 32: California next demonstrated national and international leadership in climate action by passing Assembly Bill (AB) 32 in 2006, the Global Warming Solutions Act. AB 32 codified the middle target of Executive Order S-3-05, requiring the state to reduce its emissions to 1990 levels by 2020. In early December 2008, the California Air Resources Board finalized a scoping plan to fulfill the key provisions of AB 32. The plan suggested that California implement a cap-and-trade program that links with other WCI partner programs to create a regional market system.

California Cap-and-Trade Program: Cap-and-trade sets a firm limit (or cap) on total GHG emissions. Capped sectors can trade emissions permits (allowances) to ensure that the most cost-effective reduction measures are implemented. The California Air Resources Board launched California's initial cap-and-trade program in 2013 for electricity generators and large industrial facilities emitting 25,000 $MTCO_2e$ or more annually. In 2015, the program's scope will extend to distributors of transportation, natural gas, and other fuels. The cap was set in 2013 at approximately two percent below the emissions level forecast for 2012. It declined two percent in 2014 and will decline three percent annually between 2015 and 2020.

11 https://www.whitehouse.gov/the-press-office/2015/03/19/fact-sheet-reducing-greenhouse-gas-emissions-federal-government-and-acro

California Renewable Portfolio Standard: Under a number of senate bills from 2002 to 2011, California has established one of the most ambitious renewable portfolio standards (RPS) in the country. The RPS program created a “loading order” that requires electric service providers to meet new energy demand with energy efficiency and renewable energy before building conventional fossil fuel power plants and requires them to increase procurement from eligible renewable energy resources to 33 percent of total procurement by 2020.[12] It also limits utilities to investing in power plants that meet a set emissions performance level, effectively banning new coal-powered generation for the state.

The growing awareness of climate change and the need for timely action is converging with the national scope of regulatory and business action; there are regulatory GHG reduction targets in place, local governments and businesses are realizing economic gain from tighter resource management, and the dependence on fossil fuel is now politically unpopular. However, it remains uncertain whether timely action will be taken that will cumulatively bring the CO_2 concentration down to a steady state.

Many institutions, including Stanford University, are compelled to act to meet the timetable determined by the earth’s atmospheric balance. Often referred to as a long-term problem that now requires a short-term solution, climate change poses the difficult task of innovating and implementing new solutions in parallel.

Climate Action at Stanford University

Since the late 1980s, Stanford has been participating in the IPCC and spearheading numerous initiatives on climate change solutions, such as the Global Climate and Energy Project, the Precourt Institute for Energy, and the Program on Energy and Sustainable Development.

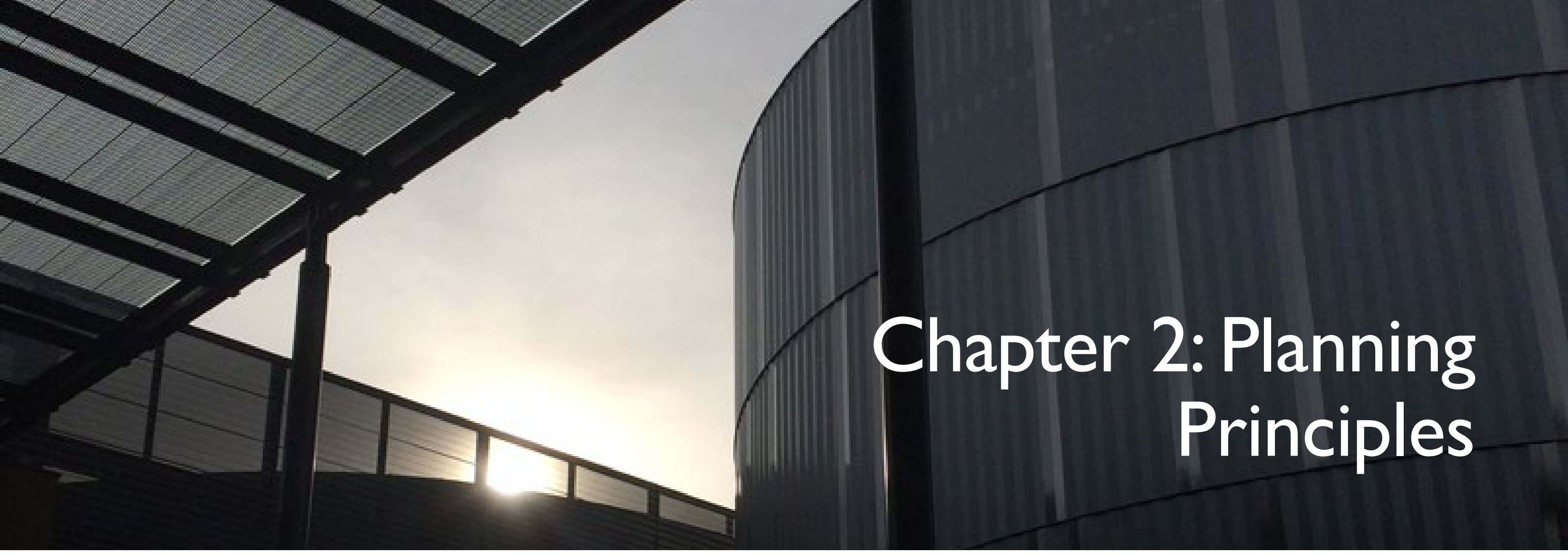
Photo: Student members of the Stanford Solar Car Project stand behind their car Luminos, which can reach speeds up to 70mph.

In 2006, President Hennessy announced the Stanford Challenge, a university-wide academic program seeking solutions to the century’s most pressing global challenges. One of the key aspects of the Challenge is the *Initiative on the Environment and Sustainability*, which promotes interdisciplinary research and teaching across Stanford’s schools, centers, and institutes in recognition of the fact that solutions to complex challenges demand collaboration across multiple fields. The Initiative is coordinated by the Stanford Woods Institute for the Environment, an interdisciplinary institute that harnesses the expertise and imagination of university scholars to develop practical solutions to the environmental challenges facing the planet. The institute brings together prominent scholars and leaders from business, government, and the nonprofit sector through a series of dialogues and strategic collaborations designed to produce pragmatic results that inform decision-makers.[13]

The action taken in response to climate change on the international, national, and state levels, and Stanford’s academic leadership in contributing to climate solutions set the stage for the university to address its own greenhouse gas emissions. Stanford wanted its leadership in academics to be reflected by its leadership in operations and commissioned new approaches to energy generation and use on campus. Ultimately, Stanford’s Energy and Climate Plan combines ambition, practicality, and flexibility into a portfolio of solutions that will enable the university to meet or exceed state, national, and international GHG reduction targets, and lead campus sustainability by example.

12 http://www.cpuc.ca.gov/PUC/energy/Renewables/

13 Final Report on the Initiative: http://thestanfordchallenge.stanford.edu/highlights-by-initiative/environment-sustainability/



Chapter 2: Planning Principles

The previous chapter discussed Stanford's commitment to climate action in the context of state, national, and international developments. This chapter outlines the key principles, planning, and analysis approach used to develop Stanford's Energy and Climate Plan.

Guiding Principles

Three principles underlie Stanford's Energy and Climate Plan: holistic and long-term approach, vision, and flexibility. Stanford adhered to these principles by following the guidelines listed below.

1. **Holistic and Long-Term Approach:**
    - Recognize that emissions reduction may come from a number of areas in campus facilities design, construction, operations, and maintenance, affecting a diverse group of students, staff, and faculty across all academic and administrative departments as well as the surrounding community.
    - Recognize that Stanford has to operate within the broader context of energy infrastructure, emissions reduction, and regulation.
    - Recognize that both short- and long-term improvements are needed, and that the long-range impacts of many upcoming decisions on long-lived buildings and infrastructure must be considered before those decisions are made.
2. **Vision:** Apply Stanford's intellectual and financial resources to provide leadership in climate change solutions, even if these efforts may differ from popular perceptions of how to pursue GHG reduction or are greater than governmental regulations may require.
3. **Flexibility:** Recognize that achieving the ultimate vision of climate stability could take decades and require technologies that may not yet exist. Stanford chose to address both short- and long-term actions to achieve GHG goals with flexibility to accommodate new technologies and changes in climate science as they develop.

Energy and Climate Plan Process

Stanford took the following key steps to develop this Energy and Climate Plan.

High-Level Summary of Steps

(Note: Though these steps are shown chronologically, several steps happened in parallel, and iteration was required as new information became available.)

1. Formation of an analysis team under the **leadership** of the executive director of the Department of Sustainability and Energy Management (SEM).
2. Preparation of an **inventory** of current campus energy uses and GHG emissions; development of campus growth projections and subsequent base-case energy demand and GHG emissions forecasts (Chapter 3); development of **options** and costs for:

- Levels of energy efficiency in new building standards (Chapter 4),
- Energy conservation in existing facilities (Chapter 5), and
- Energy supply sources (Chapter 6).

3. Creation of a composite **energy model**—including all viable supply-side GHG reduction options—to allow detailed comparison and prioritization of options for minimizing, and then meeting, campus energy demands, while reducing GHG emissions (Chapter 6).
4. Creation of financial models and budget schemes to support the most efficient choice and preparation of final recommendations for campus and Board of Trustees approval (Chapter 6).

Leadership

The Stanford University administration felt strongly that the plan be developed in the departments directly responsible for implementing it. The planning exercise began in the department of Sustainability and Energy Management (SEM), under the leadership of its executive director. In addition, staff and faculty members of the Sustainability Working Group (SWG) and Utilities staff came together for the initial, intermediate, and final evaluations of emissions reduction options.

Inventory, Base Case and Initial Options

As a member of the California Climate Action Registry (CCAR) and then the Climate Registry (TCR), Stanford has been accounting for its Scope 1 and Scope 2 emissions since 2006 (Chapter 3).[14] The energy and climate planning exercise benefited from existing accounting processes but also considered Scope 3 emissions. In 2007, the campus prepared an expanded inventory that included emissions from commuter traffic, business travel, and provision of steam and chilled water to the Stanford Hospital and Clinics from the Stanford central energy facility (CEF), the Cardinal Cogeneration plant, which cogenerated electricity and steam from natural gas. This inventory was the base case for energy demand and GHG emissions.

A team of staff and faculty then proposed various options for energy conservation and alternative forms of energy supply to reduce operating cost and the campus emissions footprint. This effort yielded close to 40 options, including ideas for reducing energy use in existing buildings, designing new buildings to require less energy, promoting travel alternatives, and switching to more efficient, less carbon-intensive energy sources. Initiatives in many of these areas were already in progress as a pilot or at greater magnitude.

The options were then organized and screened for practical application at Stanford to create a toolbox of possible options for constructing a long-term GHG reduction plan. The use of carbon instruments such as renewable energy credits and carbon offsets was evaluated but not relied on for any significant role in planning due to scientific, regulatory, and financial uncertainty (Appendix B).

To test the effectiveness and prioritize the many options identified for GHG reduction, a long-term campus energy model was constructed, with continuance of a third-party, on-site cogeneration plant as the business-as-usual (BAU) scenario. Two other major long-term options for campus energy supply were then developed and compared to the BAU scenario for potential cost and GHG reduction:

1. A new high-efficiency combined heat and power (CHP) cogeneration plant, sized appropriately for university needs only and owned and operated by the university.
2. A new high-efficiency separate heat and power (SHP) plant using gas-fired boilers and electric chillers, owned and operated by the university and importing electricity from the off-site grid.

Next, the team identified the projects from the toolbox with the highest potential to increase cost efficiency and reduce emissions in the long run. These energy conservation and alternative energy supply projects were then evaluated under the three options in the long-term energy model and ranked within each scenario based on their emissions reduction potential and average cost per metric ton of CO_2 reduced.

14 Scope 1 encompasses direct GHG emissions from on-site energy production or other industrial activities. Scope 2 accounts for energy purchased off-site (this is primarily electricity, but can also include, for example, steam). Scope 3 is much broader and can include anything from employee travel to “upstream” emissions embedded in purchased or processed products to “downstream” emissions associated with transporting and disposing of products. (World Resources Institute and the World Business Council on Sustainable Development Protocol)

Based on these findings, an initial GHG Reduction Options Report was prepared in 2008 that recommended the campus move to the use of high-efficiency gas-fired boilers and electric chillers at the CEF upon retirement of the cogeneration plant in 2015. After assessing the findings, and with agreement on the analysis approach and findings thus far, work began on a far more in-depth analysis of long-term energy and climate management with extensive optionality for the energy supply side of the Energy and Climate Plan.

Composite Energy Model with Options – Energy supply

The analysis team took some in-depth approaches toward modeling the energy flow (input and output) in the overall campus energy system (applying concepts of thermodynamics and numerous cost variables) to compare and prioritize options for minimizing and meeting campus energy demand and reducing GHG emissions (see Chapter 6). The modelling process included the steps described below.

- The team calculated future energy and GHG emissions projections, based on projected growth in building space and energy use intensity of the space (Chapter 3).
- Two parallel and complementary energy models (one for CHP and one for SHP) were developed to compare options for meeting campus energy load. The models were periodically calibrated and reconciled to assure reliable results for decision-making (Chapter 6).
- To facilitate advanced modeling, Utilities assembled even more detailed information on campus energy flows, including hourly energy flows into and out of the CEF for a full year. Along the way, the team discovered the potential for recovering heat from existing buildings and reducing heat distribution line losses by switching from steam to hot water—both offering significant increases in efficiency. Calculations showed that a heat recovery system could reclaim about 70 percent of the heat from the chilled water system and satisfy 93 percent of Stanford's heating load, substantially reducing the necessity for heat generation at the cogeneration plant. Though extra electricity would be required to reclaim this available heat, the net energy gain was still attractive, and switching from CHP to SHP would allow the power component of Stanford's energy portfolio to be supplied with renewable energy if desired. This appeared to be a better proposition for emissions reduction and the utilities budget in the long run. Given the high emissions reduction potential of a heat recovery system, the team focused on analyzing its long-term viability at Stanford (Chapter 6).
- Originally, the Energy and Atmosphere Sustainability Working Team of SWG created a subcommittee to investigate the role of carbon instruments in Stanford's Energy and Climate Plan. The team advised that carbon instruments should not play a critical role in the planning process, given the rapidly evolving and uncertain market and mechanism for these instruments in California and nationwide. In 2015, as Stanford was deciding on its initial electricity portfolio to serve the new Central Energy Facility, it re-evaluated whether to include carbon instruments and once again decided not to pursue them for the time being (Appendix A).

Peer Review, Board Approval, and Implementation

In 2009 and 2010, after completion and internal peer review of this Energy and Climate Plan, SEM commissioned an external peer review of its analyses and conclusions. Two independent consulting firms reviewed the models and assumptions used and examined whether any other major options for long-term energy supply should have been considered. They also provided advice on the cost, methods, timeframes, and other considerations involved in converting the campus steam distribution system to a hot water system. The detailed peer review reports are available upon request, and the summary findings are presented in the Energy and Climate Plan (Chapter 6).

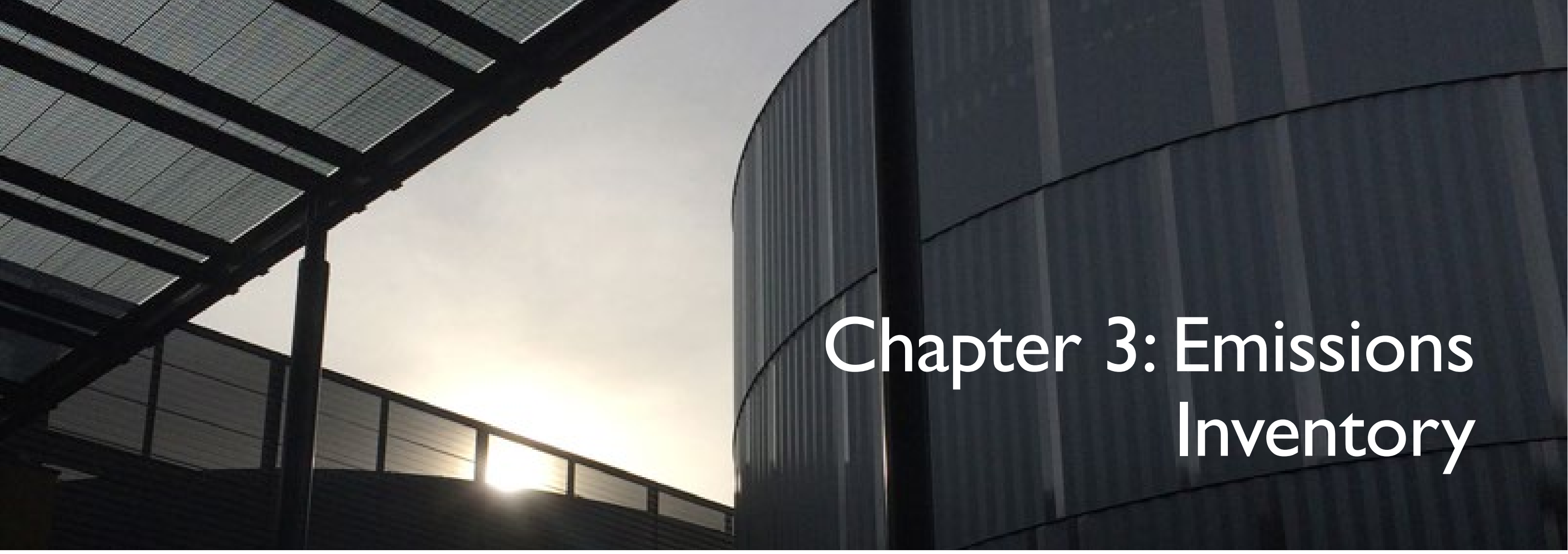
After a series of Board of Trustees subcommittee level review, in December 2011, the Board of Trustees gave concept approval to the recommendations that came out of the Energy and Climate Plan's energy supply options

–Stanford Energy System Innovations (SESI), specifically a grid-based energy supply system with heat recovery. Following SESI approval, Stanford began implementing the plan, including the design and building of a new central energy facility (CEF) and the conversion of the steam distribution system to hot water.

In April 2015 the conversion of steam to hot water was completed and the new CEF came online. At this time Stanford also entered into an agreement with SunPower to build 78.5 MW of solar PV, 5.5 MW of which will be on the Stanford campus. Stanford's implementation of SESI will reduce greenhouse gas emissions by 68 percent and potable water consumption by 15 percent from 2013 levels.

The full implementation of the Energy and Climate Plan reduces campus GHG emissions by 68 percent compared to 2017 business as usual. This version (August 2015) of the Energy and Climate Plan captures the progress to date.

The following chapters provide details on the emissions inventory and various energy and climate solution options.



Chapter 3: Emissions Inventory

Making an inventory of the sources and magnitude of emissions is the first step in preparing an energy and climate plan. Stanford has been accounting for its Scope 1 and Scope 2 emissions as a member of the California Climate Action Registry (CCAR) and The Climate Registry (TCR) since 2006. This accounting process expedited the development of opportunities for emissions reduction in the Energy and Climate Plan. This chapter describes the protocols the Stanford emissions inventory follows, quantifies the campus emissions, and outlines the campus emissions growth trends underlying short- and long-term energy and climate planning.

Protocols for the Emissions Inventory

In 2001, the State of California created the nonprofit CCAR to facilitate the voluntary accounting and reporting of greenhouse gas (GHG) emissions within the state. CCAR established a General Reporting Protocol based on the World Business Council for Sustainable Development (WBCSD) Greenhouse Gas Protocol. In 2010, CCAR transitioned its membership to TCR, a nonprofit emissions registry for North America.

The WBCSD has defined three scopes of GHG emissions to avoid overlap in accounting by different organizations. The WBCSD Greenhouse Gas Protocol requires organizations to separately account for and report on Scope 1 and 2 emissions, with optional Scope 3 accounting and reporting. Likewise, the CCAR General Reporting Protocol required participants to file inventories of Scope 1 and 2 emissions with independent third-party verification, and encouraged them to file inventories of Scope 3 emissions. Stanford used this protocol to prepare and file its GHG emissions inventories through 2009. In 2010, Stanford transitioned to the TCR protocol. All of Stanford's emissions inventories are third-party verified.

Organizational Boundary

The organizational boundary of Stanford's emissions inventory encompasses all the facilities and operations that Stanford owns or controls within the geographic boundary (the state of California). Stanford reports all of the associated GHG emissions for those operations and facilities that it wholly owns or over which it has operational control.

Scope Descriptions

Scope 1: Direct GHG Emissions

Scope 1 GHG emissions are directly emitted from sources owned or controlled by the organization. Examples are emissions from combustion in owned or controlled boilers, furnaces, or vehicles.

Scope 2: Electricity Indirect GHG emissions

Scope 2 GHG emissions result from the generation of electricity purchased by the organization. Scope 2 emissions occur at the facility where electricity is generated, not at the end user site.

Climate Registered™

Scope 3: Other Indirect GHG emissions

Scope 3 emissions include all other indirect emissions; they are a consequence of the activities of the organization but come from sources it does not own or control. Examples include extraction and production of purchased materials and use of sold products and services. Stanford's Scope 3 emissions include commuting emissions from students, faculty, and staff that drive to campus and emissions associated with business air travel.

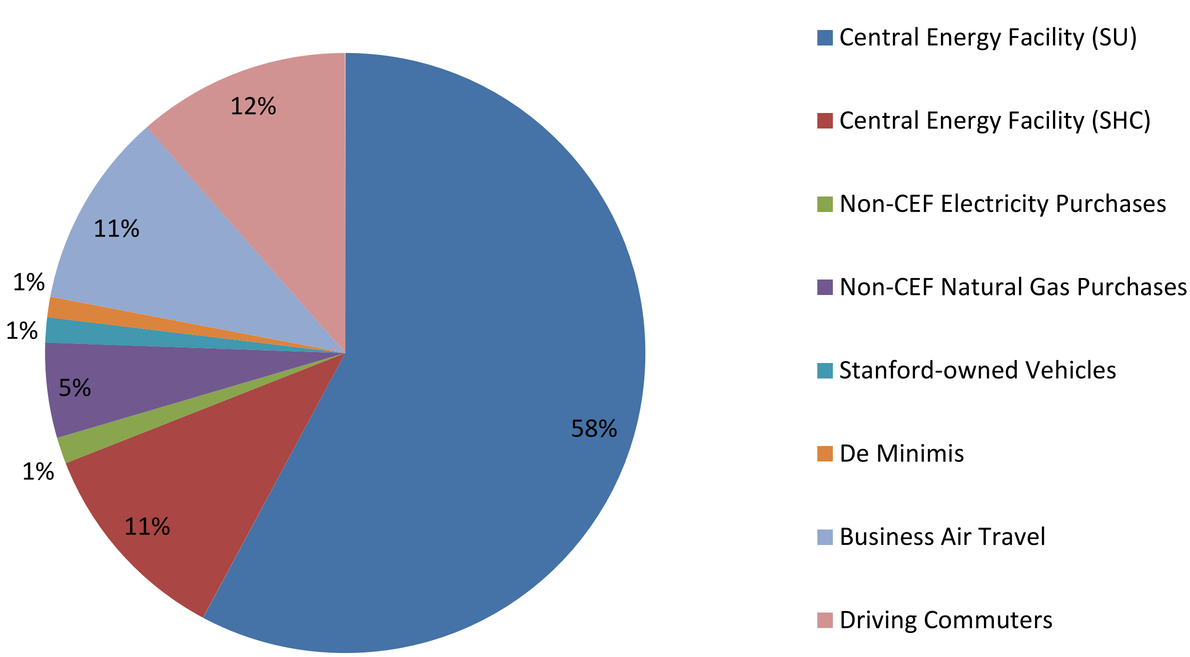
Stanford University Emissions Inventory

Figure 3-1 shows the official Scope 1 and 2 emissions inventory and the unofficial Scope 3 emissions for the university (SU), plus Central Energy Facility (CEF) emissions attributable to steam and chilled water deliveries to Stanford Hospital and Clinics (SHC). GHG emissions from Scope 1, 2, and 3 emissions totaled 267,467 metric tons of CO2 equivalent in 2014.

Stanford reports its official Scope I and II emissions publicly on TCR's website.[15] The inventory's geographic boundary includes the Stanford main campus and leased spaces but not emissions from Stanford Hospital and Clinics (SHC) or SLAC National Accelerator Laboratory. In 2014, Stanford's publically reported emissions totaled 178,753 metric tons of CO2 equivalent.

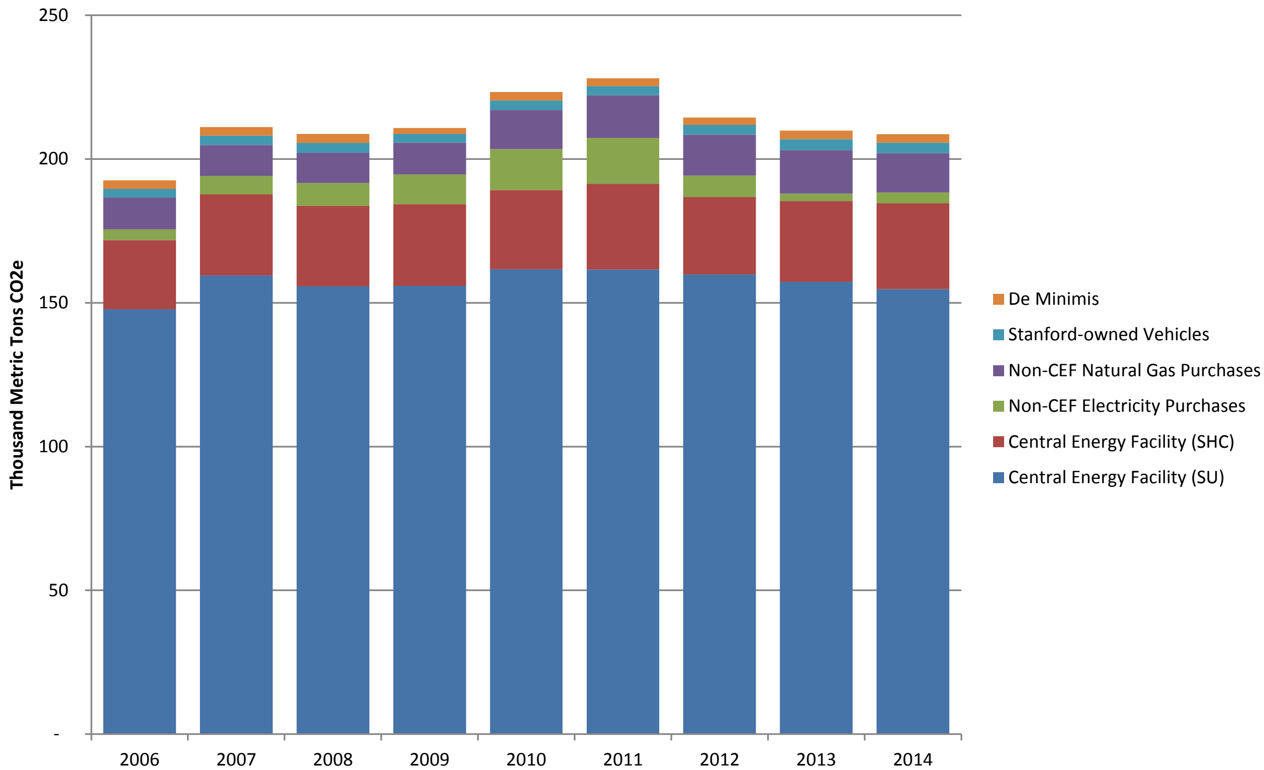
Figure 3-2 shows Stanford's annual emissions over time. It includes Stanford University's official scope 1 and 2 emissions reported to TCR. It also includes emissions from the CEF to Stanford Hospital and Clinics. The mitigation measures outlined in the energy and climate plan focus on this subset of emissions.

Figure 3-1 CY 2014 Emissions Inventory: All Scopes



15 http://tcrreports.org/reportingpage/

Figure 3-2 Publically Reported Emissions: CY 2006-2014



Campus Emissions Trends

SEM calculated Stanford's future energy consumption and GHG emissions based on projections of growth in gross square feet (GSF) of building space and expected average energy intensity per square foot (BTU/GSF).

Growth in campus building space was based on planned growth outlined in the campus capital plan, which covers the period through approximately 2020. For the period of 2020 to 2050, the following three growth scenarios were developed consistent with the campus Sustainable Development Study, developed by the Planning Office in 2009:[16]

- **Aggressive Growth:** 300,000 GSF/year
- **Moderate Growth:** 200,000 GSF/year
- **Minimal Growth:** 115,000 GSF/year

Projections of average energy intensity per square foot were calculated by first determining the overall net growth rates in energy demand over the past 20 years. These rates—4 percent for electricity, 6 percent for chilled water, and 2 percent for steam—were then divided by actual growth in GSF over the same period to derive an average change in energy intensity per GSF. The resulting percentages were applied to the GSF projections above to develop growth projections for each of the three energy services.

16 The Sustainable Development Study is available at http://sds.stanford.edu/.

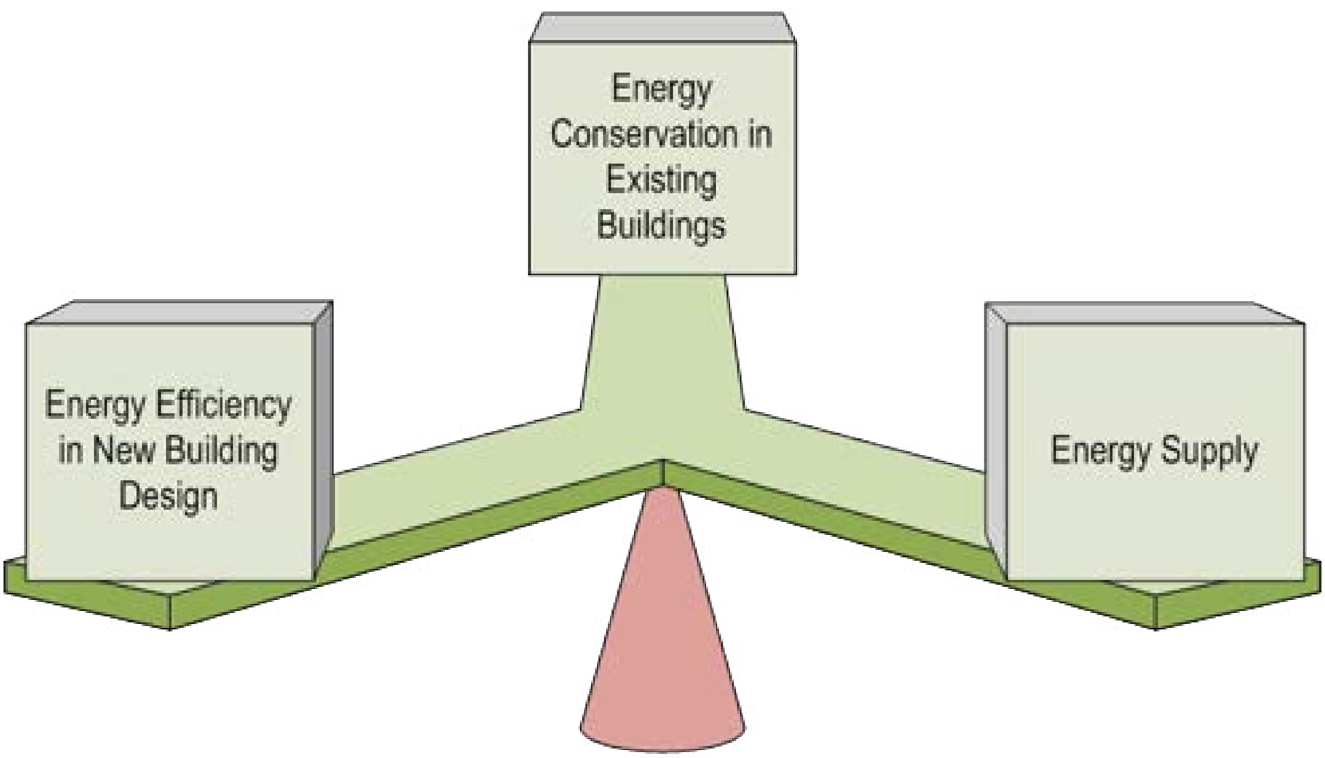
The moderate growth projection was chosen for calculating Stanford's business-as-usual GHG emissions. The emissions projection is included in Figure 7-1 of Chapter 7, along with mitigation wedges that show how emissions will be reduced below business-as-usual.

Three Critical Paths: A Balanced Approach to Finding Solutions

Given Stanford's plans for significant growth to support its academic mission, its large and diverse existing campus building inventory, and its transition from a campus reliant on natural gas cogeneration for energy to one almost completely reliant on grid-sourced electricity, a successful long-range Energy and Climate Plan requires a balance among investments in new buildings, existing buildings, and energy supply.

- **High-Performance New Building Design:** Given the university's significant growth plans, constructing high-performance new buildings to minimize the impacts of growth on campus energy systems and GHG emissions is a key strategy. The Guidelines for Sustainable Buildings, originally published in 2002 and updated in 2008, in combination with the Guidelines for Life Cycle Cost Analysis and the Project Delivery Process Manual, provide the framework for minimizing energy demand in new construction and major renovation projects on campus (Chapter 4).
- **Energy Conservation in Existing Buildings:** Since the 1980s, Stanford has employed building-level energy metering of all its facilities to understand how and where energy is used in order to facilitate strong energy efficiency programs. While the university has pursued aggressive energy conservation for many years, the continuation and expansion of programs like the Whole Building Energy Retrofit Program is another key strategy of the Energy and Climate Plan (Chapter 5).
- **Greener Energy Supply:** From 1987 through 2014, Stanford relied on a natural gas-fired combined heat and power plant for virtually all its energy demand. Although efficient, its fossil-fuel-based source caused the plant to produce 90 percent of Stanford's GHG emissions. Stanford Energy Systems Innovation (SESI) is the university's energy supply program that meets the campus' energy needs through 2050 while allowing for flexibility in energy procurement and significantly reducing GHG emissions. SESI is the transformation of the university from fossil-fuel-based combined heat and power to a more efficient electric heat recovery system powered by renewable energy (Chapter 6).

Figure 3-3 A Balanced Approach to Energy and Climate Solutions



Chapter 4: Minimizing Energy Demand in New Consruction

Stanford's original master plan designer, Fredrick Law Olmstead, envisioned a resource-conserving campus that would respond to its climate and context to achieve beauty and functionality. Stanford's historic buildings were built to reflect California's culture and climate, with the Main Quad's mission-style architecture featuring timeless energy efficiency characteristics such as high thermal mass, shaded outdoor walkways, and natural ventilation.

While the university has pursued aggressive demand-side energy management for many years, continued campus expansion calls for even greater attention to initial demand reduction and energy efficiency in new building design. In addition, the energy efficiency and water conservation standards for new buildings, existing buildings, and major renovations are no longer reviewed in isolation, but in the context of the whole campus, as each project ties into the electricity, heat, chilled water, and domestic water loops. This chapter outlines the key standards for Stanford's high-performance, sustainable built environment.

Optimized Space Utilization

Before any building project, Stanford conducts a rigorous space utilization study to see if renovation of existing buildings can create space for new needs. The Department of Capital Planning has updated the university's Space Planning Guidelines and conducted numerous studies to ensure that Stanford adds new space only when truly necessary. Studies confirmed that offices applying the guidelines could recover up to 10 percent of their existing space.

To further encourage more efficient use of office space, Stanford requires selected schools to pay a charge for underutilized space. Several schools are working to reduce this charge through efforts such as conducting master space plan studies and renovating spaces in conformance with the revised Space Planning Guidelines.

New Building Standards

As described in Stanford's Project Delivery Process (PDP) manual, the university is committed to providing a sustainable and inspiring built environment for its students, faculty, staff, and visitors. At Stanford, sustainability refers to ensuring that buildings not only use energy, water, and other natural resources efficiently, but also provide a safe, productive, and educational environment and meet the teaching and research needs of faculty, staff, and students. Stanford recognizes that the building industry has a tremendous impact on the natural environment, both regionally and globally, and the university has the opportunity to take a leadership role in creating buildings that conserve resources and inspire users. This requires an integrated process with sustainability as a base criterion in all development stages.

Stanford's PDP manual therefore incorporates sustainability through the Guidelines for Life Cycle Cost Analysis, the Guidelines for Sustainable Buildings, salvage and recycling programs, and strict commissioning processes. In 2008, Stanford updated the Guidelines for Sustainable Buildings to include aggressive energy and water goals: new buildings should be designed to use 30 percent less energy than code (ASHRAE 90.1-2004 / CA Title 24) and consume 25 percent less potable water than comparable buildings. Setting energy and water goals instead of designing prescriptive measures allows the project teams flexibility to choose the best technologies and practices that meet the needs of the occupants and fit within the project budgets. These standards have reduced energy use by 156,000 million BTU and carbon emissions by approximately 13,000 metric tons for buildings built between 2008 and 2015.

With the consistent goal of maintaining its leadership in sustainable buildings, in 2015 Stanford replaced the 30 percent-beyond-code energy efficiency goal with a new method for designing energy efficient buildings: whole-building energy performance targets derived specifically for each new building. The target will be more stringent than the energy consumption of the newest Stanford buildings of a similar type because the target is set by considering the energy consumption of peer Stanford buildings and peer regional and national buildings, as well as the building's own best possible energy performance.

This new method allows Stanford to continuously improve the energy performance of its buildings by incorporating lessons learned into each new project. Moreover, because the whole building energy targets capture all energy loads of a building, not just those regulated by code, the design team has more flexibility in meeting the target. This way, the operations team has a much better understanding of how much energy the building should be consuming than with the original design goal of 30 percent beyond code. The newest lab building, which will house the Institute for Chemical Biology and the Institute for Neuroscience and is scheduled to come online in 2017, is the first building that will utilize the whole-building energy performance target. The building is being designed to consume 148,000 BTU per square foot annually, 15 percent less than Lokey Stem Cell building, a laboratory building of similar research intensity. National leaders in energy research, such as the National Renewable Energy Laboratory (NREL), are embracing this new method of target setting as the most holistic method for designing high-performance buildings.

Core Sustainability Features

In the new high-performance buildings on campus, natural ventilation, sophisticated control systems, and daylight-focused design leverage Stanford's climate and maximize energy-saving opportunities. See Appendix B for a description of each of Stanford's high performing buildings.

Continual Innovation and Learning Through Building Design

Stanford's internal guidelines also encourage experimentation with new technologies. The university recognizes that not all new building projects will individually achieve established efficiency targets, but Stanford engineers and architects transfer information learned through design, construction, and operation of new buildings to subsequent buildings with the goal of achieving these targets in the overall building portfolio.

For example, the anchor building of the second Science and Engineering Quad (SEQ2), the Yang and Yamazaki Environment and Energy Building (Y2E2), exceeded Stanford's Guidelines for Sustainable Buildings and solidified the case for high-performance buildings. The success of Y2E2 spurred the university to commit to constructing the subsequent three buildings in the 500,000-square-foot complex "to the same level of environmental standards [as Y2E2], so that we can become a leader not only in research, but in the practice of building new facilities" (as Stanford President John Hennessy told the Faculty Senate in 2009). Similarly, former Stanford Board of Trustees Chair Burt McMurtry lauded Y2E2 as a "model for what we should be thinking about for practically all of our construction" in terms of environmentally sustainable buildings.

It is no coincidence that the university's new high-performance buildings house many of its most cutting-edge, interdisciplinary, and recognized academic programs. In many ways the sustainable design features directly support the mission of these programs. Whether by passive facilitation of collaboration through its circulation patterns and inclusion of open space or by active engagement through its use as a research subject, each new building serves as a teaching tool for the university. A detailed review of high-performance buildings on campus is included in this Energy and Climate Plan (Appendix B).

Chapter 5: Reducing Energy Use in Existing Buildings

Reducing energy use in existing buildings is central to creating a sustainable campus, and also a formidable task given the growing energy needs of research universities. However, Stanford has a strong foundation for success, building on a decades-long commitment to energy conservation and efficiency, as well as the advantages of a temperate climate and aggressive state building energy codes.

Current energy-saving strategies continue to decrease consumption in existing buildings, but campus growth is likely to outpace those savings, requiring new efforts. Total energy use increased 12 percent from 2000 to 2013, due to new construction, more energy-intensive research, and more people and electricity-using equipment in existing buildings. However, energy intensity (energy use per square foot) has decreased about 6 percent since 2000. Building on Stanford's substantial successes and drawing on its culture of innovation and leadership, demand-side energy management will continue to be critical to reducing campus GHG emissions. This chapter outlines the key initiatives and strategies for this management.

Energy-Saving Programs

Stanford has several substantial programs to promote energy efficiency and conservation on campus. Each program is designed to serve a unique market sector and provide enabling incentives to associated decision makers.

Energy Retrofit Program (ERP)

The purpose of the ERP is to reduce overall energy costs on campus by improving the energy efficiency of building components. Since 1993, over 500 ERP projects have been completed for cumulative annual energy savings of over 37 million kWh, or about 17 percent of the current electricity consumption baseline. ERP projects typically fall into one of three main categories—lighting, HVAC, or plug load. Because they are low risk, use technologies that are well understood, and have a positive return on investment, they are an important part of Stanford's GHG emissions reduction strategy.

Whole Building Retrofit Program

The university has allocated $30 million for major capital improvements to the most energy-intensive buildings on campus: the Whole Building Retrofit Program. Fourteen projects have been completed, saving 9.5 million kWh, 5 million ton-hrs of chilled water, and 71 million pounds of steam annually—totaling $4 million in avoided energy costs and over 14,000 metric tons of avoided GHG emissions. Common energy efficiency measures of the program include:

- HVAC controls upgrades—these allow advanced monitoring and enable energy-saving techniques such as scheduled setbacks, temperature setpoint deadbands, and demand-based air supply temperatures and pressures
- Conversion of constant-volume ventilation systems to variable air volume systems
- Reduction in building exhaust air flow quantity and exhaust stack velocities
- Replacement of steam-based humidification systems with ultrasonic systems

Energy Conservation Incentive Program (ECIP)

Introduced in spring 2004, this program aims to give schools and administrative units a financial incentive to use less electricity. The program sets a budget based on past consumption and lets participants "cash in" unused kilowatt-hours; those that exceed their electricity budgets pay the difference out of their own funds.

Participants collectively use an average of four percent less electricity than budgeted for a given year– netting an average annual rebate of $320,000. The program aims to reduce electricity use by 5 percent from a 2003 baseline. A number of schools and administrative units have achieved this goal, but others have had their baselines adjusted upward to accommodate additional electricity use from new buildings and expansions of research-driven activity.

Plug Load Energy Consumption

Stanford University completed a comprehensive 220 building equipment inventory in 2014 to quantify plug load-related electricity consumption on campus. The goal of the project was to collect high resolution plug load data to inform systemic and targeted plug load reduction strategies. Twelve student interns inventoried nearly nine million square feet of building space, comprising 86percent of the main campus (Student Housing was not included in the study for privacy reasons). A smart phone/tablet application was developed to facilitate the data collection effort. The application combined electronic floor plans of campus buildings and a secure web application for data entry to track equipment room by room. In addition to inventorying 55 types of electronic equipment, student interns also collected data on water fixtures, occupancy, environmental safety measures, and motion sensors. The inventory revealed that plug loads comprise approximately 22percent of total campus electricity consumption and cost $6.8 million per year. Some of the largest "energy hogs" include servers, laboratory freezers, and space heaters.

In the next few years, Stanford will reduce plug load-related energy consumption via the following existing and new program pathways, which could save from $260,000 to $2.3 million annually.

Direct Timer Install: Funded by ERP, Stanford will install timers on equipment for which the energy savings will have less than a one-year payback, such as coffee makers and cable boxes. This program has the potential to save over 230,000 kWh or $13,500 annually.

Space Heating: Stanford conducted a follow-up study on electric space heaters to identify systems-level heating and cooling issues in the 17 buildings with the highest numbers of space heaters. Adjustments made to heating and cooling systems as a result of this study allowed for the removal of 5 percent of space heaters on campus. The study also captured valuable feedback on space heater use and occupant preferences that will inform future space

Photo: New high-efficiency ultrasonic humidifer in operation

Photo: Department of Biology greenhouses were outfitted with efficient LED lighting under the ERP program, saving 248,000 kWh/year heater minimization efforts. One important takeaway was that the significant majority of building occupants report using space heaters sparingly.

Sustainable IT: Since 2008, Stanford has offered a comprehensive program aimed at increasing the energy efficiency of equipment associated with information technology. Initiatives include centrally-controlled desktop power management, deployment of smart power strips, procurement of Energy Star and EPEAT certified equipment, and increased data center energy efficiency, including server consolidation and virtualization and HVAC system improvements. The program has already saved $2.5 million in electricity costs and $760,000 in avoided cooling costs. The plug load inventory has identified further opportunities for improvement in this area.

Green Labs: Lab equipment comprises 49 percent of the plug load energy use on campus. Energy reduction for lab equipment is part of a comprehensive Green Labs program that also addresses water, waste, and green chemistry. The Green Lab program offers rebates for energy efficient lab equipment.

Building Operations

Stanford deployed its first centralized energy management and control system in the 1980s to monitor building-level utility interfaces, control major building systems, and perform system scheduling. This system, which controls over 150 buildings across campus, is used alone or in combination with 69 local Direct Digital Control (DDC) systems to optimize control of heating and air conditioning systems. Coupled with an experienced operations and maintenance (O&M) staff, adept building operating strategies have been able to achieve significant energy savings.

Photo: Data center end-aisle isolation

- **Scheduling:** Turning off building HVAC systems when they are not needed saves energy and reduces GHG emissions at minimal cost. Established campus-wide indoor temperature guidelines also achieve savings. Both can be implemented with relatively simple software solutions and increased communication between organizations and control systems.
- **Advanced Control Sequences:** DDC systems enable deployment of sophisticated control strategies to improve system energy efficiency. These include supply air temperature and pressure resets, zone-level temperature setbacks during unoccupied periods, and use of CO_2 sensors to adjust air flow.
- **Excessive Use Monitoring:** Stanford has employed an automated excessive use monitoring software tool since 2004. This speeds up the identification and correction of significant problems with building operation. A number of options for enhancing this system are currently being evaluated. These include new monitoring-based commissioning and fault detection and diagnostic tools that can build upon the growing number of metering and control system points available in campus buildings.
- **HVAC Recommissioning:** Building HVAC recommissioning is a process for periodically reviewing operations of building heating, ventilation, and air conditioning systems to ensure they perform at optimum design efficiency. Energy savings of 1-10 percent, particularly in steam and chilled water, are achievable by "tuning up" existing systems without making any physical improvements to buildings or systems. In addition, the process helps identify opportunities for physical upgrades to buildings and systems that may be funded through the ERP or other programs.

Review and Adoption of Emerging Technologies

While continually deploying energy efficiency best practices within existing buildings, Stanford also looks to the future for new technologies that will further reduce energy needs. The university has a formal process for identifying, screening, evaluating, and demonstrating emerging energy-efficient technologies. By participating in user groups, producing technical studies, and deploying on-campus projects, Stanford promotes the development and adoption of new solutions. Examples of these technologies include the following products.

High Efficiency Transformers

Low-voltage transformers convert the 480-volt power delivered at a building's entrance to the 120-volt power supplied at its electrical outlets. A typical building may have as many as half a dozen distribution transformers in various electrical rooms. The amount of power a transformer loses in the conversion process is a measure of its efficiency. Efficiency increases can substantially affect total building electrical consumption because transformers operate continuously, whether outlets are in use or not. Furthermore, because transformers emit wasted electricity as heat, inefficient transformers place a higher burden on a building's cooling system.

Stanford entered a partnership with Powersmiths® that will lead to extensive use of high-efficiency transformers for new construction and building renovations. The E-Saver-3 transformers meet the Department of Energy's CSL-3 standard, which offers the optimal life cycle balance between improved efficiency and additional cost. Upgrading only 75 standard low-voltage transformers to the CSL-3 standard would save approximately 450,000 kWh each year.

Room-Temperature Biological Sample Storage

Stanford University piloted a project to evaluate an innovative technology that promises to achieve sustainability goals by reducing laboratory energy consumption, optimize use of valuable lab space, and better protect priceless biological samples in the event of an earthquake or other disaster. Using a stabilization technology developed by Biomatrica®, biological samples such as DNA and RNA can be safely protected and stored at ambient (room) temperature as opposed to traditional storage in ultra-cold freezers.

The four-month project engaged 12 research laboratories to assess the number of samples that could be moved from freezers to room-temperature storage, validate the storage technology, actually transfer 70,000 samples from freezer storage to room-temperature storage, and extrapolate the potential benefits to the entire campus over 10 years. Adoption of this technology for the existing sample collection alone could reduce annual electricity use by nearly 2 million kWh and chilled water consumption by

Photo: Room Temperature Biological Sample Storage program. Left: Samples are stored in energy-intense freezers. Right: samples are kept at a constant humidity in a dry storage cabinet. The new technology is in the wells of the plates and tubes, offering the advantage of a dense storage footprint.



Photo: Lighting projects across campus work to improve energy efficiency. Left: Typical outdoor lighting fixture. Center: PIlot LED outdoor streetlamp. Right: High-efficiency LED stage lighting.

over 300,000 ton-hours (about 2 percent and 0.5 percent of the campus totals, respectively), thereby avoiding more than 800 metric tons of carbon dioxide emissions. Such an investment could pay for itself within two years.

Phase Change Materials

Heat can be absorbed and released using bio-based phase change materials that melt and solidify at room temperature. This material is being used in the ceiling and wall panels of several buildings, including Stanford's Central Energy Facility administration offices, stabilizing indoor temperatures both day and night. This simple, passive approach to saving energy provides greater comfort for building occupants and a more efficient HVAC system.

Outdoor LED Lighting

Lighting of outdoor spaces such as paths, streets, parking lots, and congregating areas serves multiple purposes. In addition to providing general illumination, the lighting must satisfy aesthetic and security requirements. Stanford's outdoor lighting study quantified the baseline inventory of outdoor lighting fixtures and the potential energy savings of various emerging technologies, including LED and induction lighting. Such technologies have since been deployed on a limited basis to assess their impact on perceived color and the comfort of passersby. Future full deployment of high-efficiency outdoor lighting will reduce total campus electricity consumption about 1 percent.

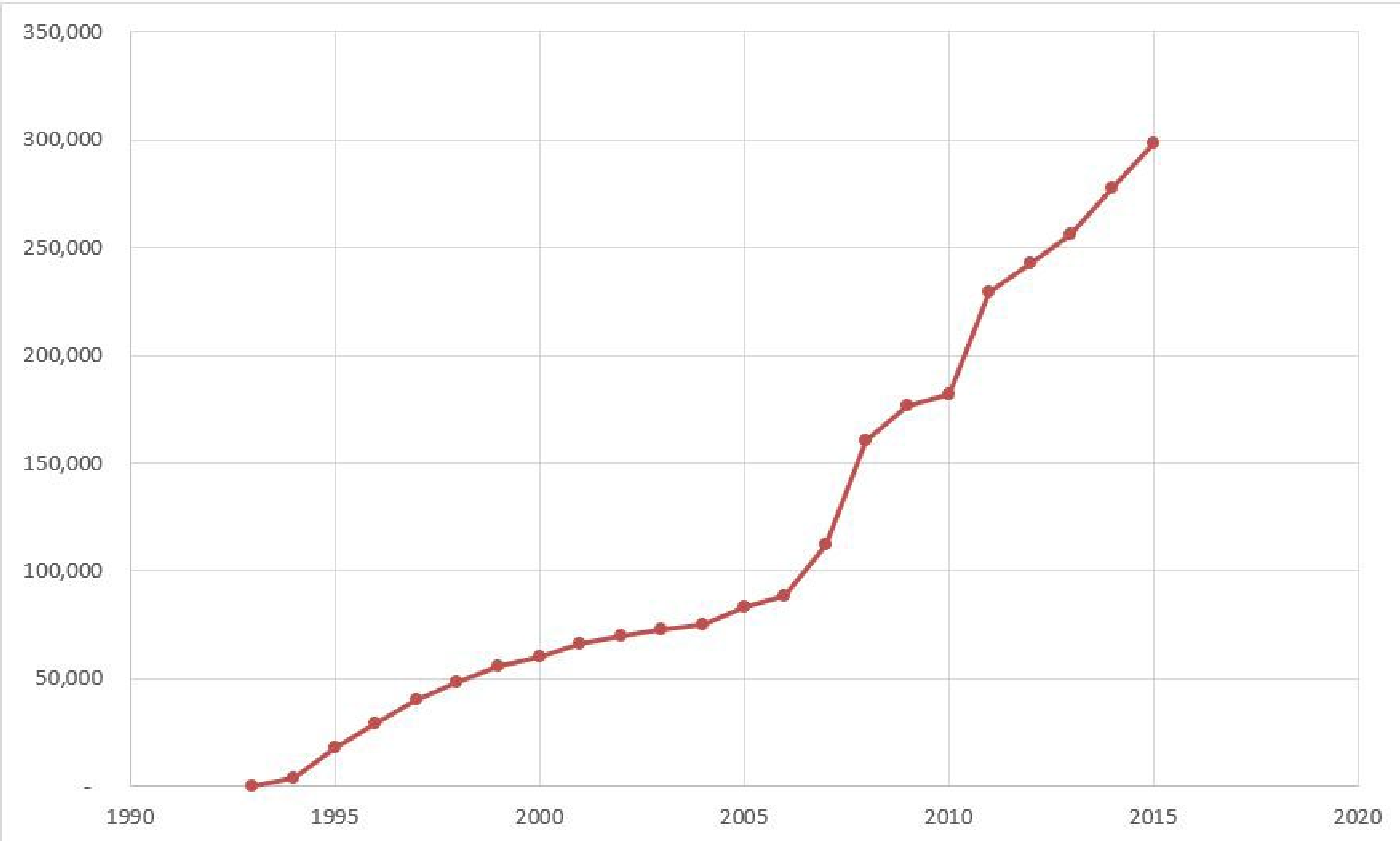
Automated Fault Detection and Diagnostics Software

On the operations side, Stanford launched a pilot project in 2012 to evaluate the efficacy of new third-party automated fault detection and diagnostics software. This tool imports high volumes of HVAC control system operating data, analyzes trend data over a time period specified by the user, and identifies anomalies. The output is a list of faults, their likely causes, and their quantified energy costs. This enables an HVAC technician to quickly identify the most important maintenance opportunities. It also enables maintenance to be planned prior to a complete failure of associated equipment.

Program Impacts

The various energy-saving programs for existing buildings have produced impressive results since the first ERP project in 1993. The cumulative, recurring annual savings in electricity, steam, and chilled water are approximately 300 billion Btu per year. This is about 11 percent of the 2014 annual energy consumption baseline for Stanford Utilities. This translates to 5.5 percent of total emissions reduction compared to 2017 business as usual levels.

FIGURE 5-1 CUMULATIVE ANNUAL ENERGY SAVINGS FOR EXISTING BUILDING PROGRAMS



Chapter 6: Stanford Energy System Innovations (SESI)

An innovative energy supply is the third key strategy of Stanford's Energy and Climate Plan, complementing strong energy efficiency standards in new buildings to reduce the impacts of growth (Chapter 4) and adept conservation measures to reduce energy use in existing facilities (Chapter 5). This chapter describes the long-term energy supply options considered by Stanford, provides an analysis of the costs and GHG emissions of meeting campus energy needs under each option, and presents key findings regarding energy supply.

Energy Supply Options

From 1987 to 2015, Stanford University employed a **district energy system** comprised of a gas-fired combined heat and power (CHP) central energy facility (CEF) and power, steam, and chilled water distribution systems to provide electricity, heating, and cooling to its buildings. Although efficient, its fossil-fuel based source caused the CHP to produce 90 percent of Stanford's GHG emissions and consume 25 percent of the campus' potable water supply. Stanford's contract to purchase energy from this plant ended in 2015, when the plant turned 28 years old and neared the end of its useful life. This gave Stanford the opportunity to reevaluate its energy supply, optimizing for both cost and GHG emissions reductions. Stanford considered the following options in its evaluation:

1. **On-site gas cogeneration (aka combined heat and power, CHP) options:** systems that primarily use **natural gas** to meet campus energy needs, including the following:
    - **New Cogen (Steam):** a new on-site combined cycle gas turbine (CCGT) cogeneration plant
    - **New Cogen (hot water):** a new on-site CCGT cogeneration plant, coupled with conversion of the campus steam distribution system to hot water
    - **Gas Power (Turbine) + Heat Recovery:** option one(b), plus ~20 percent heat recovery from the chilled water system to augment heat provided by the cogeneration unit
    - **Gas Power (Internal Combustion (IC) Engines) + Heat Recovery:** a new on-site gas fired IC engine cogeneration plant, including some heat recovery (~20 percent) from the chilled water system to augment heat provided by the cogeneration unit, coupled with conversion of the campus steam distribution system to hot water
2. **Grid Options:** systems that primarily use **electricity** to meet campus energy needs, including the following:
    - **Heat Recovery:** a plant that maximizes heat recovery (~70 percent) from the chilled water system to meet the majority (~93 percent) of campus heating needs, coupled with conversion of the campus steam distribution system to hot water
    - **Separate Heat and Power (SHP):** a gas-fired hot water production and electricity-powered chilled water production plant, without any heat recovery, but coupled with conversion of the campus steam distribution system to hot water
    - **On-site PV Power:** a significant amount of on-site PV electricity generation to supplant a portion of grid electricity imports

Heat Recovery: A True Potential at Stanford

Heat recovery, as shown in Figure 6-2, captures and reuses most of the waste heat collected by the chilled water system that is normally discarded into the atmosphere via cooling towers. It differs from cogeneration in that it productively uses heat naturally supplied by the environment (mostly from solar heating of buildings) rather than heat supplied by the combustion of fossil fuel.

Heat recovery for domestic heating and hot water service has potential application anywhere that cooling systems collect and discard heat from buildings or processes at the same time that low-grade heat (<175°F) is produced for heating, hot water, or other applications. Whenever there is a real-time overlap in the two processes or ability to use hot and cold thermal storage, there is an opportunity to use the heat collected by the cooling process (which can be thought of as a waste heat collection process) to meet low-grade heating needs instead of burning fossil fuel. This overlap will vary with the nature of facilities and their climate; however, productive use of any overlap may be a major tool in energy conservation and GHG reduction.

At Stanford, analysis of a full year of hourly heat and chilled water production data at the CEF revealed a real-time 70 percent overlap between (a) the collection of heat by the chilled water system (normally discarded via cooling towers) and (b) the generation of heat by fossil fuel and its delivery to buildings via the steam distribution system. This overlap can be seen as the green-shaded areas on the typical daily heating and cooling load charts of Figure 6-3, as well as the overall annual heating and cooling load chart of Figure 6-4. Adding in chiller machine heat energy (also normally discarded via the cooling towers) the university determined that recovered heat could meet about 93 percent of the total campus heating load, supplanting a significant amount of fossil fuel use and its associated energy cost and GHG emissions.

If other productive uses of this recovered heat can be found, in addition to building heating and hot water, heat recovery can reduce cost and GHG emissions even further. For example, if ground-source heat pumping or other means to collect heat occurring freely in the environment in winter can be devised using the heat recovery system, substantial additional reductions in fossil fuel and associated cost and GHG reduction may be possible.

Because evaporative cooling towers are used for discharging waste heat, heat recovery also saves a significant amount of water. The CHP plant cooling towers consumed about 25 percent of the total campus domestic fresh water supply. Using heat recovery as described above reduces CEF potable water use by 70 percent and overall campus potable water use by about 15 percent.

Although a heat recovery system requires more electricity to operate than a standard chilled water system, use of recovered heat means that it requires far less natural gas or other fossil fuel equivalent. Furthermore, the potential for meeting this and other electricity loads with renewable energy provides desirable flexibility that could allow further energy, water, and cost efficiencies, along with GHG reductions as grid electricity production technologies advance.

Figure 6-1 Cogeneration, Also Known as Combined Heat and Power

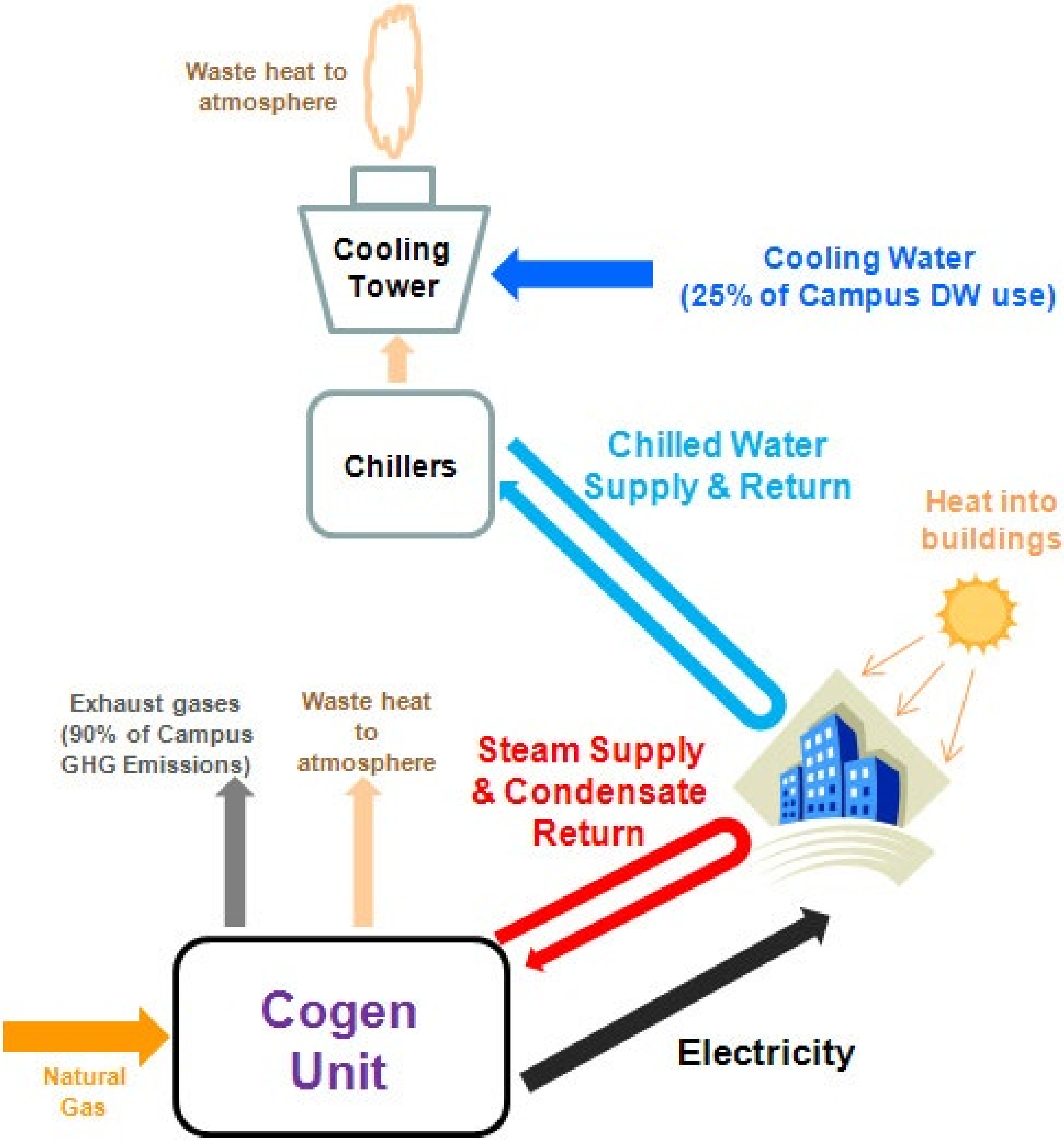
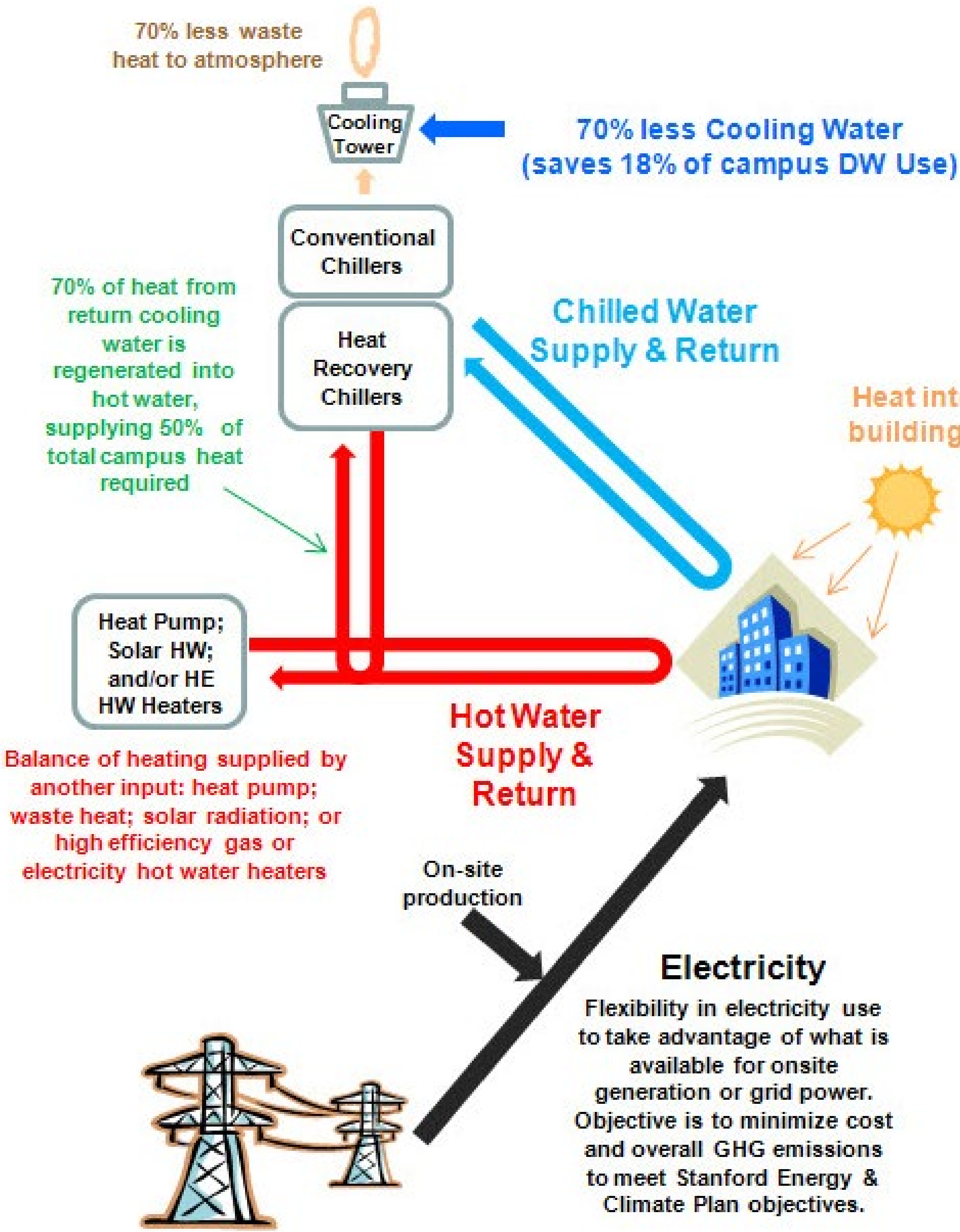


FIGURE 6-2 HEAT RECOVERY SYSTEM



Figures 6-1 and 6-2 depict the general arrangements of the gas-fired cogeneration and electrically powered heat recovery systems considered by Stanford for its long-term energy supply with the decommissioning of the existing gas-fired cogeneration plant. Detailed variations not shown include a modest amount of heat recovery in the cogeneration scheme and addition of on-site PV power generation in the grid options.

Formulating Options for Campus Decisions

As the district-level application for heat recovery unfolded, the campus moved toward aggregating all the considerations and decision criteria for redesigning its future energy supply. Major decision criteria are discussed below.

GHG Reductions Considerations

One key decision in selecting a long-term campus energy system was whether it supports society's need to reduce its collective GHG emissions. Some national and state-level strategies have encouraged distributed natural-gas-based power generation (such as fuel cells) and cogeneration technologies on the assumption that these would displace less efficient or more GHG-intensive energy systems, such as coal power or older low-efficiency gas-grid power plants. However, when considering new capital investment in energy production, one should compare different new power plant options, not one new power plant option to the existing power plant fleet. When society is collectively investing capital in new energy supply systems (thermal or electric), it is prudent to select the best new energy system option, rather than selecting the most convenient one because it offers some marginal improvement. This is especially true in the absence of a long-term plan that provides a bona fide strategy to achieve the GHG reductions required for our planet. Promoting the installation of many small, new distributed gas-based generation technologies may actually undermine other strategies in the power sector, such as implementation of a renewable portfolio standard for electricity production, and/or foreclose other GHG reduction strategies, such as large central station carbon capture and sequestration.

Energy Price Risk and Budget Stability

Market energy price was another important factor considered when examining the different options. CHP relies completely on natural gas to meet all campus energy needs. This lack of diversity exposes the university to greater energy price risk because natural gas is traded in a deregulated market known for extreme volatility. Energy modeling showed that the SHP and heat recovery options would reduce direct reliance on natural gas by 60 percent and 80percent, respectively. Natural gas use would be limited to heat production in hot water generators only for 10 percent of the coldest days of the year, when heat recovery would not be enough. While these options would require importing a significant amount of electricity, there would be a number of ways to at least partially decouple that supply from the price volatilities of natural gas, something not possible with CHP. As a customer with Direct Access, the university could choose to procure power off the California market, which currently comprises about 40 percent natural gas generation and has shown good price stability over the past six years, even as gas and oil prices have shown extreme volatility. Under this or other potential energy supply strategies, the university could also control the carbon content of its electricity portfolio and meet its power needs by incorporating renewable power purchases.

Flexibility to Adopt New Technologies

Investment in a cogeneration plant would greatly reduce flexibility to adopt potential new technologies that could further reduce cost and GHG emissions. For example, heat recovery, for which great potential at Sanford was only recently uncovered, could not be rapidly adopted without decommissioning the cogeneration plant. Conversely, the modular nature of a heat recovery-based SHP plant provides greater opportunity to move to advanced technologies as they become available, because individual pieces of plant equipment are typically acquired and retired in staggered succession over time. In essence, one could "rotate the stock" in a modular SHP plant but not in a large, single-component cogeneration plant.

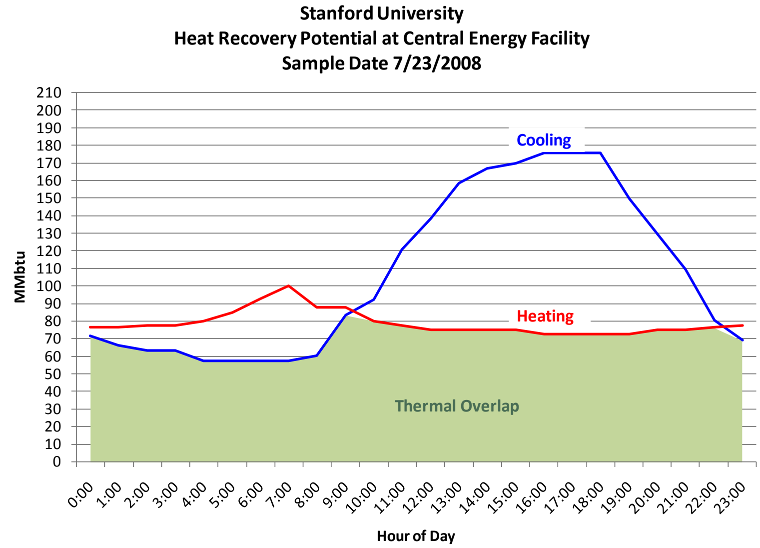
Compatibility with CHP and SHP

Because CHP burns fossil fuel to make electricity and uses the waste heat to meet heating demands year-round, it would allow little room for processes that supply heat by other means, particularly in the warmer months when there is typically already a surplus of heat in the environment. More sustainable forms of low-grade heat production, such as heat recovery from cooling processes, or direct production of heat via renewable sources, such as solar hot water generators and ground-source heat pumps, would be limited.

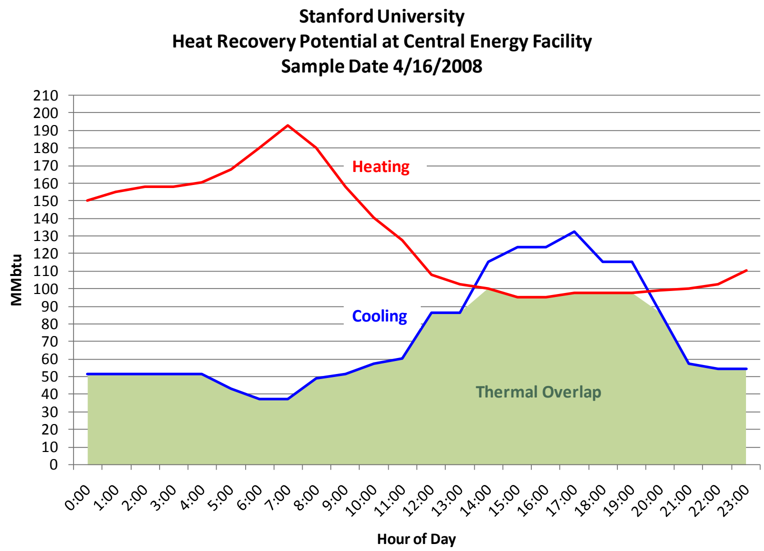
SHP, on the other hand, is fully compatible with heat recovery and alternative forms of heat production. SHP heat production processes would not be dependent upon or tied

Figure 6-3 Daily Heat Recovery Potential

Summer



Spring/Fall



Winter

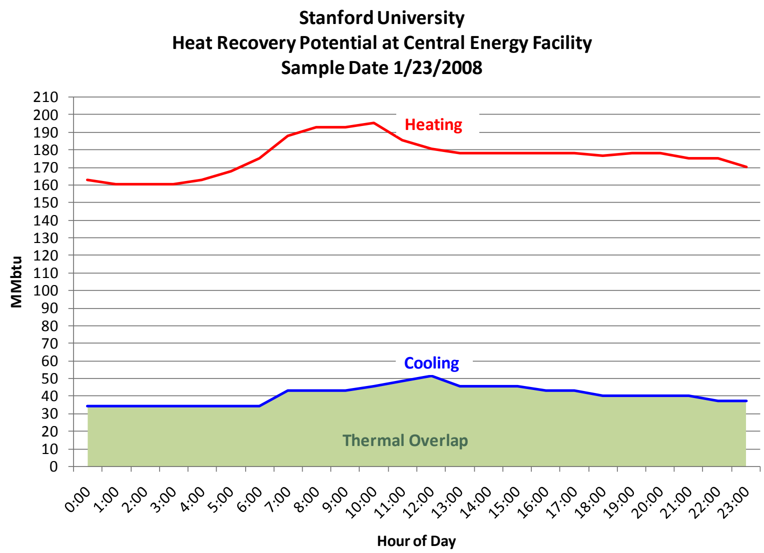
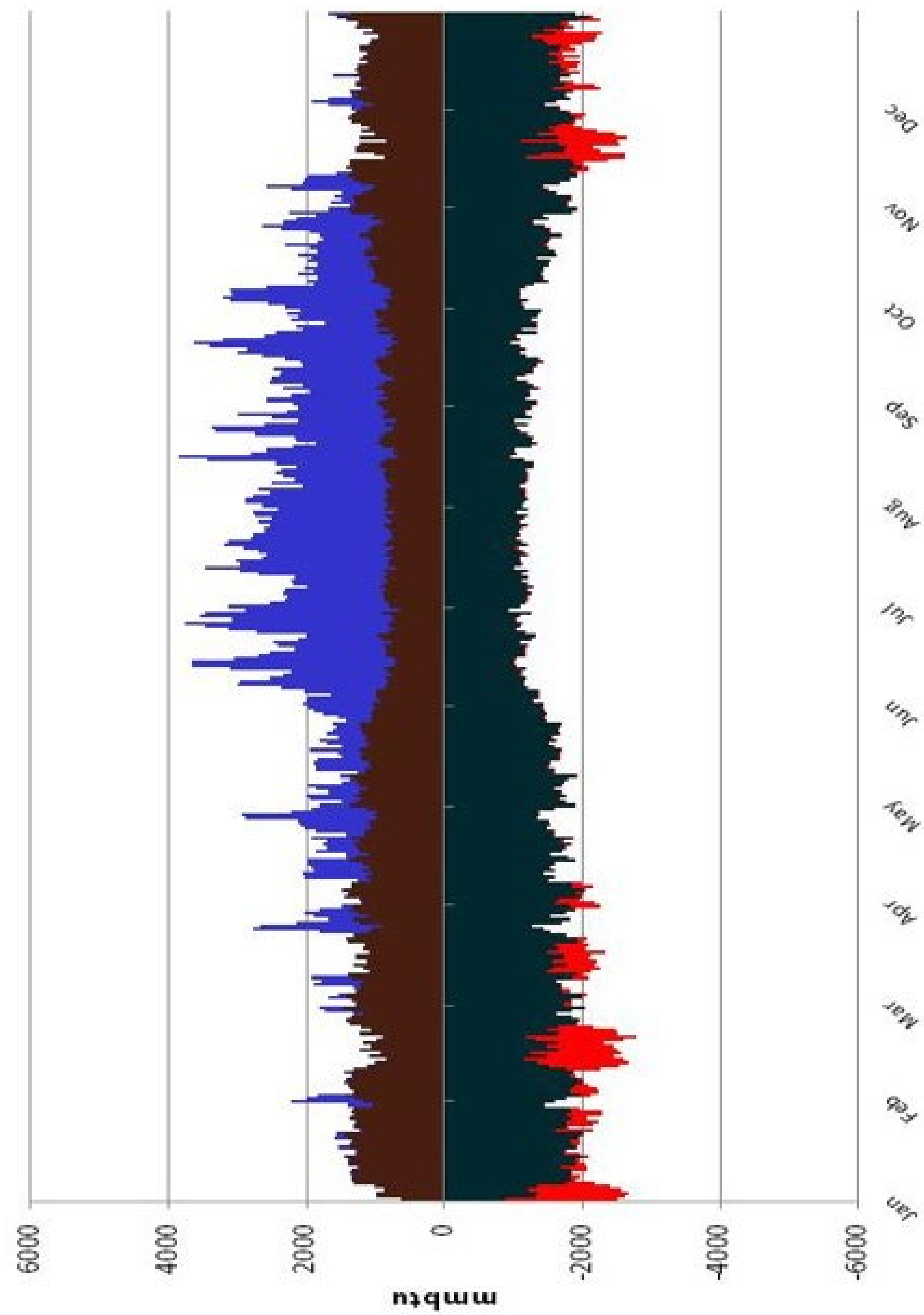


FIGURE 6-4 ANNUAL HEAT RECOVER POTENTIAL



to electricity generation. This separation allows maximum use of sustainable, low-grade heat generation, which would also often result in lower cost than heat generation by fossil fuel via CHP.

Converting to a Hot Water Distribution System

Implementing heat recovery at this scale would require a complete conversion of the campus heat distribution system from steam to hot water because low-grade heat recovery does not reach temperatures suitable for steam production. Though this conversion would represent a significant cost and operational challenge, lower system heat loss, O&M costs, and future capital costs justify it even apart from heat recovery.

- The conversion could reduce heating system line losses from about 14 to four percent.
- A hot water system would reduce O&M costs by 75 percent.
- The conversion could avoid substantial capital costs for replacement of aging portions of the steam system.
- Capital costs for future system expansion and interconnection to new buildings would be much lower with hot water.

More information on the benefits of converting the steam distribution system to hot water, along with case histories of similar applications and a conceptual phasing plan, is available on the SESI website.

Considerations for Equipment Redundancy, Plant Space Use, and Capital Cost

A CHP cogeneration plant requires redundant boilers of equal capacity to provide backup service during scheduled or unscheduled outages. In contrast, an internal-combustion(IC)-based cogeneration or SHP boilers-and-chiller plant is modular in nature, with multiple pieces of smaller equipment rather than one large cogeneration unit. Therefore, instead of backing up the entire heating plant, redundancy requires only extra equipment equal to the largest individual IC engine, chiller, or boiler. This difference considerably reduces capital investment and further separates these options from a conventional CHP cogeneration plant.

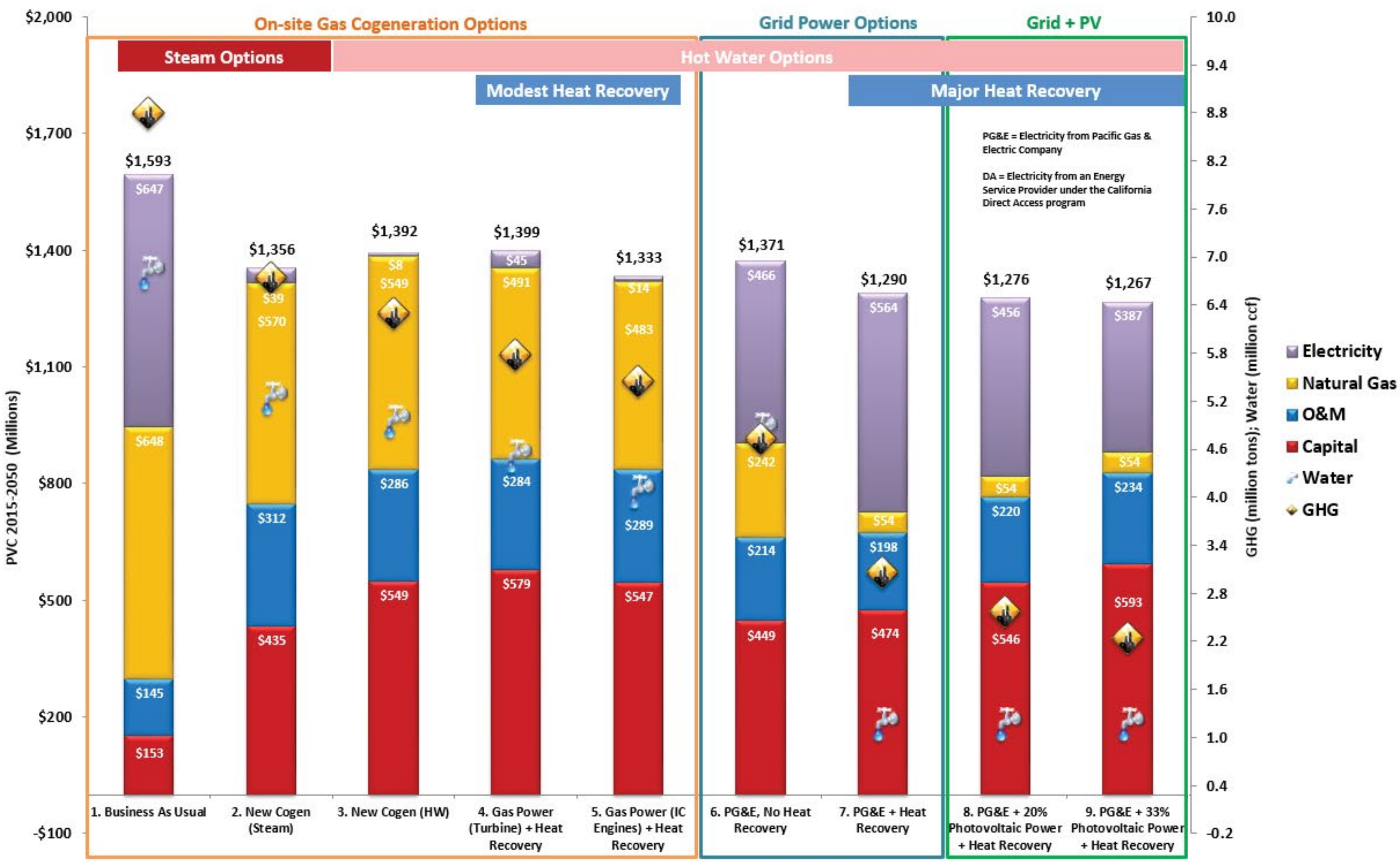
After considering all these factors, the university concluded, in keeping with the planning principles, that diversifying campus energy sources, perfecting direct access to open energy markets, and decoupling its energy supply from the volatilities and environmental impacts of fossil fuel to the greatest extent possible offered a better long-term strategy for supporting its mission. It determined that continued reliance on natural gas as its primary energy source would greatly limit the potential for direct reduction in GHG emissions, whereas moving to an electrically-powered energy facility of similar or greater efficiency would pave the way to full sustainability through the development of sustainable electricity generation technologies.

Economics and Selected System

Economic models of the different energy supply options described above were developed, and side-by-side comparisons were made of the net present value (NPV) life cycle costs. Figure 6-5 shows the comparative costs, GHG emissions, and water use of the options considered. These options were presented to the Board of Trustees throughout 2011 and a decision was made in December of that year.

Throughout the implementation of SESI, various factors contributed to cost reductions that further maximized the cost savings potential of the project. Figure 6-7 shows the progression of the net present value of the project as it evolved. Key factors include Stanford achieving Direct Access to the California grid, and inclusion of renewable power in its energy portfolio, discussed later in this chapter.

Figure 6-5 Comparative Cost, GHG, and Water Use of Energy Supply Options



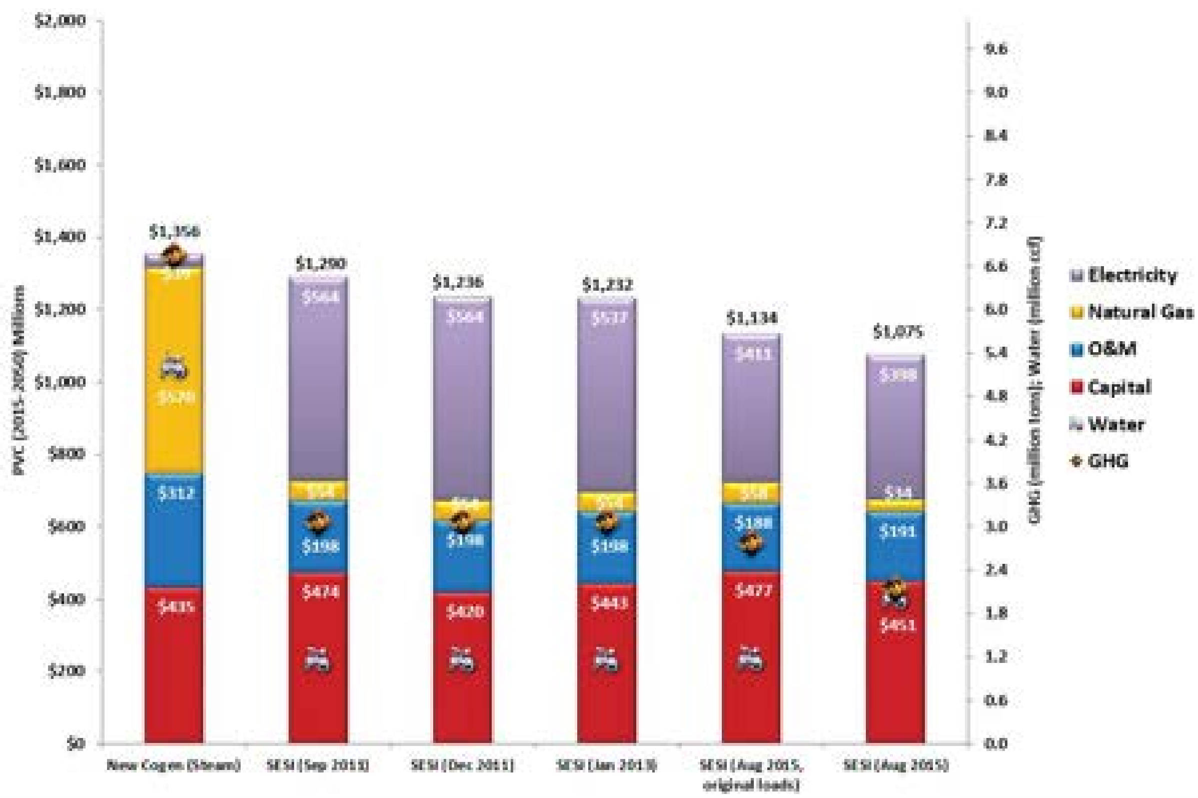
Summary of comparative costs, carbon emissions, and water use across various energy generation options. Life-cycle cost decision criteria are shown in bars. The segments include: initial capital investment in red, operations and maintenance cost in blue, cost of purchasing electricity in purple, and cost of purchasing natural gas in yellow. Net present value (NPV) of each energy generation option is shown in the $ figure above the composite bars. Environmental attributes are shown in bubbles via total GHG and water use icons.

Figure 6-6 Comparative Cost, GHG, and Water Use of Energy Supply Options

Option Category	Name	Description	Advantages	Disadvantages
Gas	On-site gas cogeneration options	These options explore burning fossil fuel on site to meet campus power and thermal needs.	Potential for low-cost long- term natural gas supply; 100% on-site power generation	Dependence of all campus energy on single fossil fuel source; lack of environmental sustainability
#1, with NPV $1.593 billion	Steam option—business as usual (BAU)	Extend current cogen operation to 2050 under existing third-party agreement	Lowest direct capital and O&M costs because third party owns and operates plant	Highest overall cost, GHG emissions, and water use due to third-party overhead and profit and lowest plant efficiency
#2, with NPV $1.356 billion	Steam option— new cogen plant	Install new Stanford–owned and operated combined cycle gas turbine (CCGT) cogen plant	Lower capital cost than other new Stanford-owned cogen options because includes no new hot water system; lower GHG emissions and water use than BAU	Higher overall cost than high-efficiency hot water–based IC cogen systems; only modest overall emissions and water use reductions
#3, with NPV $1.392 billion	Hot water option—new gas turbine (GT) cogen	Install new Stanford–owned and operated CCGT cogen plant with hot water–based heat distribution system	Modest reductions in GHG emissions and water use over new steam- based cogen plant	No economic advantage over new steam-based cogen plant
#4, with NPV $1.399 billion	Hot water option—new GT cogen with heat recovery	Install new Stanford–owned and operated CCGT cogen plant with hot water–based heat distribution system and some heat recovery	Slight emissions reduction, slight water use reduction over standard GT cogen with hot water, due to modest amount of heat recovery possible	Higher capital cost ($579 million), higher overall cost than hot water– based GT cogen without heat recovery
#5, with NPV $1.333 billion	Hot water option—GT cogen using internal combustion (IC) engines with heat recovery	Install new Stanford–owned gas-fired IC engine cogen plant with hot water–based heat distribution system and some heat recovery	Best overall gas-fired cogen option with additional modest GHG, water use, and cost reductions over GT-based cogen without heat recovery	High capital cost ($546 million); higher GHG emissions, water use, and overall cost than grid + heat recovery (option #6)

Option Category	Name	Description	Advantages	Disadvantages
Grid	Options using grid power for electricity instead of on-site cogen	These options explore combinations of grid power for electricity, an on-site thermal energy plant with optional heat recovery, and hot water–based heat distribution.	Optimality from overall economic, risk, flexibility, and environmental sustainability standpoints	Modestly higher up-front capital costs than retaining cogen with steam- based distribution
#6, with NPV $1.371 billion	Grid, no heat recovery	Get electricity from grid; install new gas boilers, electric chillers thermal plant; install hot water–based distribution system	Better option than BAU; simpler ownership and operation than cogen plants; more long-term flexibility	No real improvement over gas-based IC cogen plant, more expensive investment and less water savings.
#7, with NPV $1.290 billion	Grid + heat recovery	Get electricity from grid; install new electricity-based heat recovery plant and hot water– based distribution system	Best overall option, with relatively low cost, GHG emissions, and water use	Higher up-front capital cost ($485 million) than retaining existing cogen with steam- based distribution, which is financed, owned, and operated by a third party
Grid + On-site PV	Grid power options with on-site photovoltaic (PV) power generation	These options explore combinations of grid and on-site PV power for electricity, an on-site thermal energy plant with heat recovery, and hot water–based heat distribution.	Optimal environmental sustainability; lower capital costs	No economic advantage over new steam-based cogen plant
#8, with NPV $1.276 billion	Grid + 20% PV + heat recovery	Same as grid + heat recovery option but using same total capital that would be required by best cogen option to buy some on-site PV plant	Further improvement upon best overall option (grid + heat recovery) if total up-front capital equivalent to that required for best cogen option is allocated; ability to absorb PV power behind the meter	Higher up-front capital cost than base grid + heat recovery option; land use requirement
#9, with NPV $1.267 billion	Grid + 33% PV + heat recovery	Same as grid + heat recovery option but allocating enough land and capital to meet full 33% California Renewable Portfolio Standard for electricity use via on-site PV	Further improvement upon best overall option (grid + heat recovery) if additional up-front capital and land are allocated; partial long-term power cost stability	Very significant land use requirement; possibility that exports of PV power to grid would be required in some hours

Figure 6-7 Stanford Energy System Innovations Life Cycle Cost Estimates



Board of Trustees Approval

In December 2011, after approval by the trustee advisory board, Stanford's Board of Trustees gave concept approval to **Option #6 Grid + Heat Recovery** as the new base energy system for the university from 2015 to 2050. This option of an electrically-based heat recovery plant with grid power offers superior economic and environmental performance via lower energy price risk and greater flexibility to adapt to changing energy technologies over time, which results in a clearer path to sustainability.

Options #8 and #9, which add some amount of on-site PV power generation to the base energy supply system selected, were determined as destination choices with superior environmental and economic benefits as long as the conceptual economics could be verified and land use challenges for them could be resolved. In energy system planning it was also determined that some amount of on-site ground source heat exchange (GSHE) might be possible to augment the base heat recovery scheme. Based on the two positive preliminary PV and GSHE feasibility studies, the Board also directed that additional studies of these options be conducted in parallel to implementation of the chosen new base heat recovery system. During this approval state, the official name to the program became Stanford Energy System Innovations (SESI).

Benefits for Stanford

Financial Benefit and Payback

There was no 'do nothing' option for Stanford's energy infrastructure because the CHP facility had approached the end of its useful life and a replacement was required. The business-as-usual (BAU) option had the lowest capital investment ($153 million), but it also had the highest overall long-term cost, much greater emissions and water use, and inflexibility to change with future technologies. With a net present value of $1.17 billion, a grid-powered central energy facility with heat recovery was the option with one of the lowest life-cycle costs. Although the capital investment was $485 million, which was among the lowest considered, this option will provide significant life cycle cost savings ranging from $43 million to $109 million over all the other base energy system options. It will save Stanford $420 million over the next 35 years compared to the BAU scenario.[17]

17 Option #1 BAU NPV $1,593 million – Option #6 "Grid + Heat Recovery" NPV $1,170 million = $423 million relative gain

Environmental Benefits

Key environmental benefits of the SESI program include:

- **Higher System Efficiency:** The new energy system is 70 percent more efficient than the previous combined heat and power plant, due to significant heat recovery and lower line losses from hot water distribution compared to steam.
- **Greater Reliability and Flexibility in Energy Procurement:** Powering the CEF with grid-based electricity provides higher reliability, lower costs, and greater flexibility for greener power procurement than the previous natural-gas-fired power plant. Stanford procures its electricity through Direct Access (wholesale purchases as opposed to purchasing from a retail utility), which enables the university to decide how much of its electricity will come from renewable sources. Stanford has committed to procure much of its electricity from solar power plants by the end of 2016.
- **Reduction in Greenhouse Gas Emissions:** The energy efficiency gains of the CEF and hot water distribution, along with the ability to power the plant with renewable electricity, will reduce Stanford's Scope 1 and 2 greenhouse gas emissions by 68 percent compared to current levels.
- **Reduction in Potable Water Consumption:** The CEF's heat recovery system will reduce Stanford's potable water consumption by 15 percent, as the majority of the waste heat from the chilled water loop is reused instead of discharged through evaporative cooling towers.
- **Improvements to Built Environments:** As the 22 miles of new hot water piping was laid, 155 buildings had their mechanical rooms upgraded to connect to the new hot water distribution system. In the process, those buildings received efficiency improvements. The carbon and water reductions mentioned above include these energy efficiency improvements.

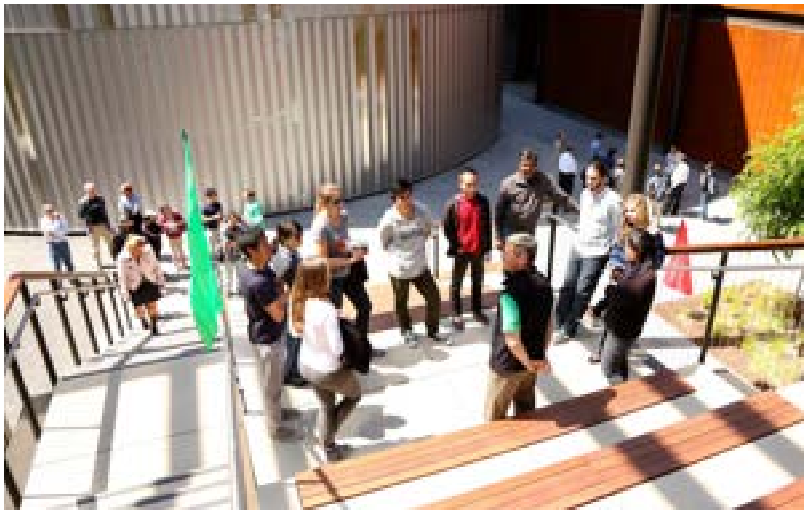


Photo: Tours of the Central Energy Facility are offered to campus and community members throughout the year.

Social Benefits

Key social benefits of the SESI program include:

- **Improved Safety:** Keeping the campus community safe and informed is of the utmost importance at all times. Steam systems pose more injury and safety concerns than hot water systems. Replacement of the legacy steam system reduced the risk of facility damage and public and staff injury from system leaks or failures. The Department of Land, Buildings & Real Estate made it a priority to inform campus community members about the ongoing progress of the pipe replacement project, as well as its benefits to the university and the environment.
- **Campus Engagement:** SESI set a precedent for campus involvement with major capital improvement projects. Determination of the vision and principles for this multi-year initiative integrated input and leadership from all stakeholders on campus (staff, students, and faculty), while maintaining steady communication with Stanford leadership (the executive cabinet and the Board of Trustees) from 2009 to 2012. Faculty and leadership played an active role in making major social and environmental impact decisions throughout planning. For example, to test and prioritize the many GHG reduction options available, a long-term campus energy model was constructed and various scenarios were developed to determine which solutions

satisfied the long-term need for campus energy supply and demand. The results from each scenario were compared to the current energy model for potential cost and GHG reduction. Based on these findings, an initial GHG Reduction Options Report was prepared in 2008 for review by the university administration. Subsequent reviews with more detailed analysis were held with the Board of Trustees in 2009, 2010, and 2011, and two faculty advisement committees (President's Blue Ribbon Taskforce in 2008 and 2009 and Board of Trustees Energy Advisory Committee in 2010 and 2011). Over the entire course of SESI planning and implementation, more than 25 faculty members and 100 students were involved through student groups and departmental queries. This is truly an all-campus project that has solicited, welcomed and benefited from faculty and student input throughout the years.

- **Campus-Wide Education:** SESI has been a steady source of education for Stanford students and community members. Not only were students involved during planning, student and campus community outreach was extensive during implementation. Initially, the Department of Project Management and Office of Sustainability launched a comprehensive outreach effort and met with over 30 campus departments and entities to explain the importance of energy action and why the campus took a leadership role with SESI, as well as to coordinate the scheduling of the pervasive construction.
- During construction, the campus community was extremely supportive, despite the short-term inconvenience of the construction. The SESI website launched in the summer of 2012 to provide an avenue for interested community members to learn about the program and follow associated construction on a real-time interactive campus map that showed the current and future construction zones and project progress.
- Now that the Central Energy Facility has been completed, it serves as a living laboratory for exploring sustainable energy solutions. The CEF has classroom and meeting spaces built in,

Photo: SESI represents a transformation of university energy supply from 100 percent fossil-fuel-based combined heat and power plant to grid-sourced electricity and a more efficient electric heat recovery system much of the plant's equipment is visible through large viewing windows, and in-depth tours are offered, making the facility a learning center for students and the public alike. Because the CEF was designed and built for future growth and expansion, it will also provide an unparalleled platform for realtime experimentation of innovative research and development.

Implementation of SESI

Implementation of the SESI program involved significant work throughout the campus between 2012 and 2015. The Department of Project Management managed design and construction of 22 miles of hot water pipe, conversion of 155 buildings to receive hot water instead of steam, and installation of the Central Energy Facility (CEF). This work was carefully sequenced in multiple phases to minimize disruption to campus life. As each phase of piping and building conversion was completed, that section of campus moved off steam and transitioned to hot water via a regional heat exchanger that converted steam from the cogeneration plant to hot water at a district level. A full transition to the new CEF took place in April 2015, whence the regional heat exchange stations were removed, and decommissioning began on the CHP plant to make way for new academic buildings within the campus core.

The New Central Energy Facility

The new CEF includes heat-recovery chillers, three large water tanks for thermal energy storage, a high-voltage substation that receives electricity from the grid, a control room, and administrative and classroom space.

- **Heat-Recovery Chillers (HRCs):** Each HRC has a 2,500-ton cooling capacity for chilled water and can simultaneously produce 40 million BTUs of heat per hour, enough to cool and heat approximately 500 houses simultaneously. The HRCs send out chilled water to campus at 42°F, which returns at 56-60°F. The heat removed from the chilled water to cool it back down to 42°F is used by the HRC to reheat spent hot water from 130°F back up to 170°F to supply for buildings that need heat. The CEF actively operates three HRCs, and has the space to install another for future needs.
- **Thermal Energy Storage:** While the recovery of heat and new efficient equipment is the key to the system's energy efficiency, thermal storage is the key to its economic efficiency. Thermal storage tanks allow flexibility to operate the HRCs and other equipment at times with the lowest energy pricing and then store the hot and cold water for later use when the buildings need it. Moreover, thermal tanks cost much less than an equivalent capacity of additional heat pumps, chillers, and hot water generators. They also contribute to the system's energy efficiency by allowing the equipment to run at optimal load settings, and, in the case of regular chillers (incorporated into the facility as backup for peak-load days), when outside air temperatures and humidity favor evaporative cooling. The capacity of each chilled water tank is 5 million gallons, and the hot water tank holds 2.3 million gallons.
- **High-Voltage Substation:** The substation runs on two different transmission feeds from both the north and south to power the entire core Stanford campus, not including faculty housing (which is on an external utility system). About 1/3 of the electricity consumed at Stanford will be used to operate the new thermal energy plant, while the rest will supply power to buildings for lighting, machinery, and plug loads. The substation is designed to handle about twice Stanford's current load or about 100 MW, which is enough to power about 100,000 homes. This is both for redundancy and to allow room for growth in the future. The facility also has an emergency generator for powering emergency lighting, elevators, and safety systems, and provides enough power to operate the thermal energy storage tank pumps to provide hot and cold water for the hospital during emergencies.
- **Advanced Control System:** To assure optimal operation of the CEF for both service reliability and economic performance, Stanford invented and patented a new Central Energy Plant Optimization Program (CEPOM). Stanford then collaborated with the company already hired to design and develop the CEF base control system, Johnson Controls, to transform CEPOM into an industrial-grade software system suitable for

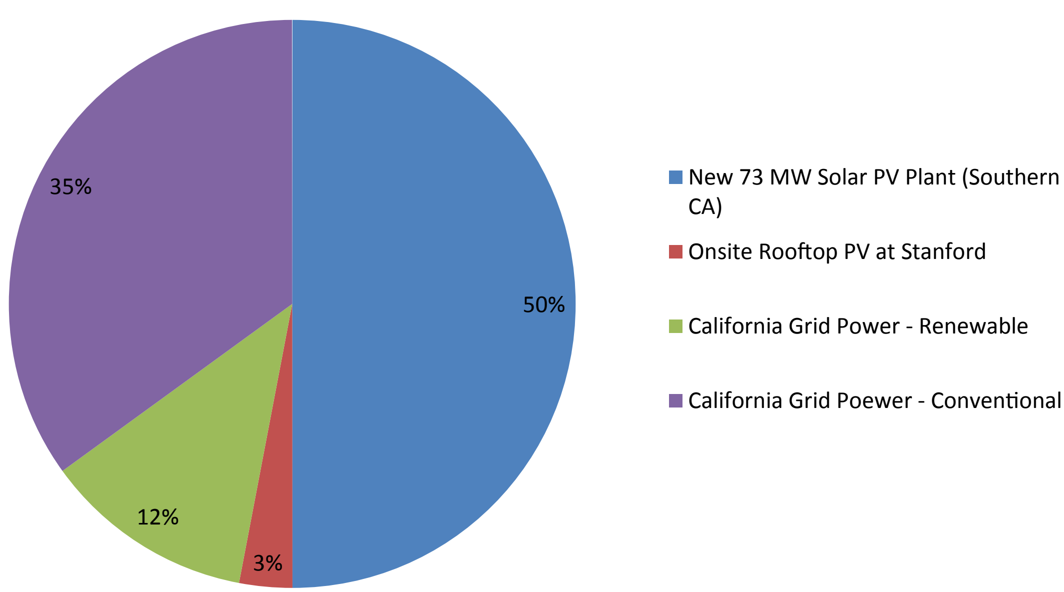
actual plant operation and hardwire it into the new campus energy system. Johnson Controls has named the industrial grade version of CEPOM the Enterprise Optimization Solution (EOS).

- EOS is an energy modeling and dispatch system that uses over 1220 variables (including building occupancy, ambient conditions, time of year, projected energy prices, weather forecast, current system conditions, etc.) to develop plant dispatch plans that show the optimal way to run the plant every hour for the next seven days—essentially an "autopilot" for the plant.
- Each HRC uses about 10 percent of the campus' total electricity, so the university must be adept at how and when they are used to minimize electrical impact on the grid and the corresponding 'demand' charges paid for use of the grid. Therefore, EOS also predicts the university's background electrical profile (electricity used by the buildings) for the next seven days and schedules HRC operation in hours each day so as to minimize the overall electrical footprint of the university on the grid. EOS performs this forward-looking analysis and recalibrates the HRC operating schedule as needed every 15 minutes on a continuous basis. It can either be used be used in advisory or fully automated modes, and the control room is staffed 24/7 to monitor operations.
- **Administrative and Meeting Spaces:** In addition to the mechanical operations, the facility also includes administrative, classroom, and meeting space that contribute to the educational component of the plant. As is true throughout the facility, these spaces feature the latest in efficient design. Sustainable highlights include:
  - LED lighting An open-air floor plan, with high ceilings, fans, and windows on each side of the building to facilitate cross breezes
  - Flooring that utilizes radiant heat and chilled beam systems for heating and cooling
  - Ceiling panels with energy absorbing filler that absorbs heat, and as the room cools off it releases it for heating purposes

Renewable Energy Procurement

Now that the new CEF and conversion from steam to hot water are complete, Stanford has started procuring electricity from renewable resources. Development of onsite renewable energy supplies will provide lower long-term costs, stabilize operating budgets, and allow Stanford to achieve top-tier emissions reductions. By the end of 2016, 65 percent of Stanford's electricity will be generated from renewable sources—approximately 200 million

Figure 6-8 Stanford's Renewable Energy Procurement



kilowatt hours (kwh) per year. The sources of renewable energy include the following:

Off-site Solar PV: In April 2015, Stanford entered into an agreement with SunPower to build an off-site 73 MW solar photovoltaic (PV) plant that will supply 50 percent of Stanford's electricity for at least the next 25 years. The PV plant will be built in southern California and is anticipated to start generating electricity in late 2016. The new plant will use SunPower's state-of-the-art PV technology with single axis tracking. It will easily meet the university's peak electricity demands of 42 MW and generate enough electricity to power approximately 20,000 homes.

On-site Solar PV: Also in 2015, Stanford finalized a contract with SunPower for an additional 5.5 MW of solar PV to be installed at 15 sites on campus. Initially, over 60 campus sites were audited and analyzed for their suitability for photovoltaic systems. Sites were selected based on aesthetic and historical impact to campus along with orientation, roof size and slope, and construction. Stanford plans to have the panels fully installed and generating power in late 2016.

Renewables in California's Grid: Stanford's combined on- and off-site solar electricity generation will comprise 53 percent of Stanford's electricity consumption. This will result in 65 percent of Stanford's total electricity supply coming from renewable sources due to the fact that one-fourth of the remaining electricity that comes from California's electricity grid is also renewable. This percentage will only increase over time as California's grid meets its 33 percent renewable portfolio standard by 2020, and Stanford continues to explore renewable energy options.

In 2013, Stanford's greenhouse gas (GHG) emissions totaled 209,834 metric tons. The new Central Energy Facility has reduced campus emissions by 50 percent from current levels, and renewable power procurement will reduce emissions by another 18 percent, leading to a total of 68 percent emissions reductions from the SESI project.

Chapter 7: Conclusion: A Comprehensive and Integrated Plan

As earlier chapters have demonstrated, a comprehensive energy and climate plan at a growing research institution must consider three key energy components:

1. demand-side management for new construction,
2. demand-side management and efficiency programs for existing buildings, and
3. supply-side solutions that offer a clear path to sustainability.

The plan must also take a holistic, long-term approach rather than considering only short- or intermediate-term strategies and goals. Building design, energy infrastructure, and energy supply decisions that must be made over the coming decade will be long lived, and thus the planning horizon must be at least as long as the life cycle of the investments to be made.

Moreover, even adept infrastructure planning is incomplete if it yields only incremental improvements, however significant. Until systems and human behavior transform enough to achieve the necessary sustainability solutions to mitigate the effects of climate change, challenges will remain, and incremental improvements can only buy time.

The Stanford Energy and Climate Plan takes this into account, and not only provides very significant improvements but also enables a future of true energy sustainability. Converting campus energy systems from a fossil fuel base to an electricity base opens a clear pathway toward sustainability through renewable electricity generation. Implementation of this plan will not stop with the projects and programs outlined herein, but will continue through ongoing pursuit of economical and sustainable technologies. As Stanford uncovers and develops sustainable electricity supplies or makes significant further advancements in demand-side management, this Energy and Climate Plan will be updated.

Summary View: Emissions Reduction at Stanford

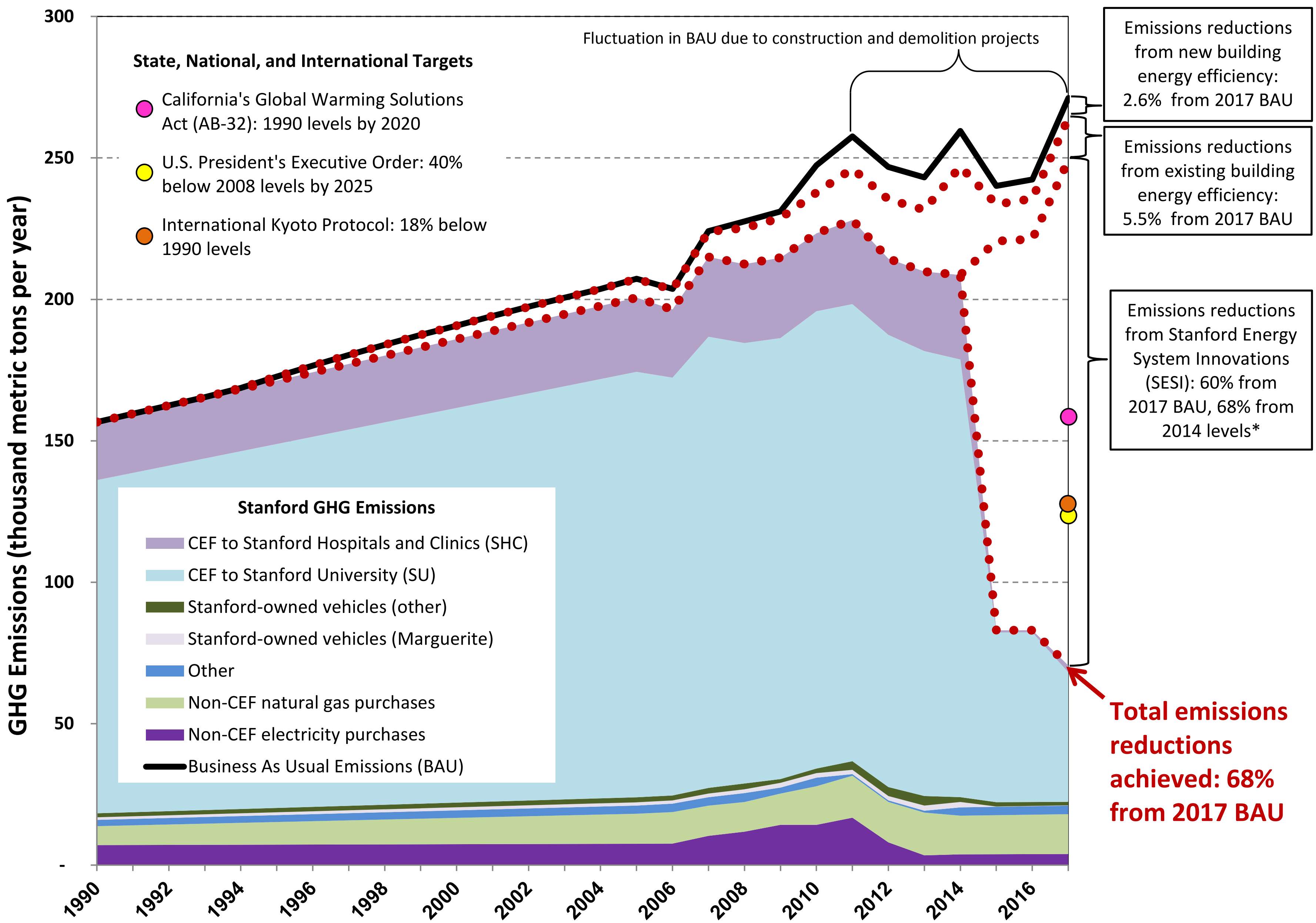
Chapters 4, 5, and 6 discuss how Stanford is addressing energy and GHG emissions from three perspectives: energy efficiency in new construction, energy efficiency in existing buildings, and greener energy supply through Stanford Energy System Innovations (SESI). These three strategies are consolidated into an overall plan that balances investment among them to optimize overall results in managing capital and operating costs, as well as GHG emissions.

As shown in Figure 7-1, Stanford's GHG reduction strategies will enable the university to outperform the international, national, and state reduction targets early. By the end of 2016, Stanford will have reduced its emissions by 68 percent below business-as-usual (BAU) levels or 55 percent below 1990 levels. Figure 7-1 shows the emissions-saving wedge of each strategy.

Demand-Side Management via New Construction Standards

In 2007, Stanford adopted energy efficiency standards for new buildings, originally as 30 percent-better-than-code requirement and now as benchmark-based energy targets (see Chapter 4). This wedge represents savings from constructing new facilities to these standards, which reduces emissions to 2.6 percent below 2017 BAU levels.

Figure 7-1 Emission Reduction Wedges and Targets



*17,000 metric tons transfered to separate SHC inventory, due to SU no longer supplying that heating load with its CEF. This transfer is not included in percent emission reduction calculations.

Demand-Side Management via Existing Building Efficiency

This wedge represents the GHG emissions reductions from continuance of the energy efficiency and conservation programs for existing campus buildings (see Chapter 5). These include minor non-capital improvements to buildings and equipment, improvements in how buildings operate, and impacts of occupant behavior. This wedge also reflects emissions reductions that can be "mined" from Stanford's existing stock of large buildings through comprehensive study and major capital retrofits with state-of-the-art HVAC systems and other energy-efficient technologies. Tackling each building as a whole (rather than piecemeal) will maximize energy use reductions, which can be on the order of 30–50 percent. These efforts reduce emissions to 5.5 percent below 2017 BAU levels.

SESI

This wedge represents the reduction in GHG emissions from Stanford's new energy supply system, including a grid-based central energy facility with heat recovery, conversion from steam to hot water, and 78.5 MW of solar PV (see Chapter 6). It reduces emissions to 60 percent below 2017 BAU levels, or 68 percent below 2013 levels.

Final Thoughts

Stanford's Energy and Climate Plan is built on the principle of innovation and flexibility to adapt to new technologies; Stanford aims to meet the needs of the future without compromising the needs of the present. Although the core elements of the SESI program have been implemented, feasibility studies of additional enhancements to the campus energy system are underway, including development of a ground source heat exchange (GSHE) system to complement the core heat recovery process. Also, in recognition that a path to full energy sustainability has been opened up through conversion of the campus from gas to electricity the university will continue to build out the renewable sources of its electricity portfolio. Stanford will evaluate opportunities for geothermal and wind energy to compliment the 78.5 MW of solar PV to which the university has already committed. By design, SESI is a balance of pragmatism and vision, meeting short- and long-term needs of an institution of higher learning that leads sustainability by example.

Although developed independently by Stanford, SESI may be the first large-scale example in the world of employing the technology roadmap for building heating and cooling recommended by the International Energy Agency.[18] It encompasses the best of both North American and European district heating and cooling system advances, with engineers, manufacturers, and constructors from both continents collaborating to develop SESI's state-of-the-art infrastructure. SESI demonstrates that heat recovery at a district level is possible for others across North America. The technology used is highly transferrable, and thermal storage enables application in almost all climate zones. Stanford will share its patented energy modeling system with any entity that is interested in determining the overlap in heating and cooling and the subsequent potential for heat recovery.

Stanford's leadership in all three approaches to energy management and climate mitigation has put the university on a path to achieving carbon neutrality and provided a blueprint for others to follow.

18 https://www.iea.org/publications/freepublications/publication/technology-roadmap-energy-efficient-buildings-heating-and-cooling-equipment.html

Appendices

Appendix A: The Role of Carbon Instruments

Appendix B: High-Performance Buildings

Appendix A: The Role of Carbon Instruments

Carbon pricing instruments reduce global greenhouse gas emissions by putting a price on carbon and allowing market mechanisms to dictate the most economic carbon mitigation measures. There are a number of different carbon instruments, some voluntary and some that are driven by policy. This chapter provides background information on carbon instruments relevant to Stanford, including renewable energy credits (RECs), carbon offsets, and California's Cap-and-Trade program, as well as Stanford's current perspective on these instruments.

Renewable Energy Credits (RECs)

RECs are purchasable and verifiable credits from a power provider who produces or procures power solely from renewable energy sources (solar, wind, biomass, and geothermal). RECs represent the environmental attributes associated with renewable energy, such as the reduction of air pollution from not burning fossil fuels.

One REC represents one megawatt hour (MWh) of renewable electricity generated and delivered somewhere on the power grid. Theoretically, each MWh of clean renewable electricity results in one less MWh of dirty power. In the renewable energy market, the RECs can either be bundled with electricity or sold separately (unbundled). In other words, consumers can continue to purchase electricity from their existing supplier and "green" it by purchasing RECs from a renewable energy source of their choosing.[19]

Stanford's on and offsite solar projects can be categorized as bundled RECs because the university procures electricity and the RECs from these renewable energy sources together. By the end of 2016, 53 percent of Stanford's electricity will be sourced from bundled renewable energy; all RECs will be retired.

Unbundled RECs are less valuable than bundled RECs because they are not guaranteed to be additional. California's Renewable Portfolio Standard (RPS) requires 33 percent renewable content by 2020 and limits the amount of unbundled RECs that can be used to meet this goal to less than ten percent[20]. Although Stanford is not an energy service provider and therefore not subject to California's RPS, the university continues renewable energy procurement on bundled sources, as mentioned above.

Carbon Offsets

Carbon offsets represent the reduction of one ton of greenhouse gas carbon equivalent (CO_2e) resulting from project activities that retire or capture carbon from the atmosphere. Offsets can include emissions reduction resulting from a variety of approaches, including methane capture, sustainable forestry, fuel switching, etc. Companies use carbon offsets to "balance" emissions of GHGs produced in one place by procuring GHG reductions from somewhere else.[21]

Since originally conceptualized, carbon offsets have come a long way in terms of validity. Strong protocols now exist to ensure that offsets are both legitimate and additional (see requirements below). The California Air Resources Board (CARB) has acknowledged certain offset programs as a legitimate reduction strategy in California's Cap-and-Trade program for 8 percent of an entity's emissions.[22] Because offsets can be purchased from a number of organizations and can vary substantially in quality, to ensure legitimacy offsets should be purchased through a registry that follows the protocols required by CARB, The Climate Registry, or an organization of similar expertise and mission.

Although Stanford prioritizes emissions reductions through direct reduction measures, it recognizes that some emission sources can currently only be mitigated with offsets, such as fugitive emissions from research gases. Stanford is not pursuing offsets at this time because the direct emission-reduction measures outlined in this Energy and Climate plan will already reduce Stanford's emissions by 68 percent, enabling the university to far

19 http://www.epa.gov/greenpower/gpmarket/rec.htm

20 http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/33RPSProcurementRules.htm

21 http://www.worldbank.org/en/programs/pricing-carbon

22 http://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm

outperform state, national, and global GHG emissions reduction targets. Stanford may reevaluate this decision as it continues to reduce its emissions in the future.

Legitimacy Requirements for Offsets

Carbon offsets are market products that reduce emissions on a global basis, only if they meet the criteria outlined below. Much of the controversy associated with offsets originates from the failure to justify one or more of the following criteria:

- **Real:** The quantified greenhouse gas (GHG) reductions must represent actual emissions reductions that have already occurred.
- **Additional:** The project-based GHG reductions must go beyond what would have happened anyway or in a business-as-usual scenario.
- **Permanent:** The GHG reductions must be permanent and backed by guarantees if they are reversed (for example, re-emitted into the atmosphere).
- **Verifiable:** The GHG reductions must result from projects whose performance can be readily and accurately quantified, monitored, and verified.

CARB acknowledges the following three offset programs as legitimate: American Carbon Registry, Verified Carbon Standard, and Climate Action Reserve.4 The Climate Registry also acknowledges these three providers as legitimate, along with Climate Leaders, Gold Standard, Joint Implementation, Pacific Carbon Standard, and Clean Development Mechanism.[23]

California's Cap-and-Trade Program

California demonstrated national and international leadership in climate action by passing Assembly Bill 32 (AB-32) in 2006, authored by Fran Paley and Fabian Nunez. AB-32—*Global Warming Solutions Act*—requires that the state's global warming emissions be reduced to 1990 levels by 2020. To meet AB-32's emissions reduction goal, CARB has instituted the Cap-and-Trade Program, which will run from 2013 through 2020.

The cap represents the total GHG emissions permitted from all sources in the system during a given compliance period. The scope of the cap in AB-32 covers about 85 percent of California's emissions, which includes direct emissions from all entities that emit 25,000 metric tons of CO_2e or more annually. The cap was about two percent below the 2012 emissions levels forecast for 2013, declined two percent in 2014, and declines three percent annually from 2015 to 2020[24].

CARB tracks compliance of the emissions cap through allowances. Each allowance represents one metric ton of CO_2e. The number of allowances that an entity holds must be equivalent to the amount of greenhouse gases emitted by that entity annually. Allowances are fundamentally different from RECs and offsets in the sense that they represent the 'right to pollute' as opposed to an entity acting as a direct agent of emissions reduction. As a mechanism, allowances work in reducing overall emissions as the total number of allowances decrease (in relation to the cap) over time. CARB auctions off allowances on a quarterly basis and, once in the market, allowances can be traded between entities. Trading allows entities the flexibility to seek out and implement the lowest cost options to reduce emissions.

Stanford is not subject to California's Cap-and-Trade program because its direct (scope I) emissions fall below the threshold of 25,000 metric tons CO_2e per year.

23 http://www.theclimateregistry.org/wp-content/uploads/2014/11/TCR_GRP_Version_2.0-1.pdf

24 http://www.arb.ca.gov/cc/capandtrade/guidance/cap_trade_overview.pdf

Appendix B: High-Performance Buildings

Many recently completed high-performance building projects meet or far exceed energy and water efficiency recommendations outlined in Stanford's guidelines. Across the board, each subsequent high-performance building emphasizes the success of its predecessors and capitalizes on important lessons learned to achieve greater sustainability within the built environment.

Leslie Shao-Ming Sun Field Station at the Jasper Ridge Biological Preserve (2002)

The 10,000-GSF Leslie Shao-Ming Sun Field Station is located on the 1,200-acre Jasper Ridge Biological Preserve southwest of the main campus. From the beginning, the Sun Field Station was designed to demonstrate principles of sustainability and energy efficiency with a goal of net zero annual carbon emissions. Another key design principle was the extensive use of recycled or reclaimed building materials to reduce consumption of virgin materials. The Sun Field Station provides an award-winning natural laboratory for researchers and rich educational experiences for students.

Key sustainability features include:

- A 22kW grid-connected photovoltaic (PV) system
- Daylight harvesting
- A solar thermal system for space heating and domestic water heating
- A sophisticated energy monitoring system used for educational purposes and performance measurement
- Waterless urinals, dual-flush toilets, and tankless water heaters
- Use of salvaged materials for siding, brick paving, casework, furniture, and bathroom partitions
- High-volume fly ash concrete

Photo: Leslie Shao-Ming Sun Field Station

Carnegie Institution Global Ecology Center (2004)

The 11,000-GSF GEC is a two-story laboratory and office building with a research focus on sustainability and minimizing climate change. It is an extremely low-energy building that emits 72 percent less carbon and uses 33 percent less water than a comparable building constructed with conventional practices. According to a report prepared by the Rocky Mountain Institute in 2011, the GEC is one of the most energy-efficient labs in the United States.

Key sustainability features include:

- A night-sky radiant cooling system
- Daylight harvesting
- Natural ventilation
- High-volume fly ash concrete
- Exterior made from salvaged wine-cask redwood

Photos: Yang &Yamazaki Environment & Energy Building (Y2E2)

Yang & Yamazaki Environment & Energy Building (2008)

Y2E2 showcases high-performance design and construction well beyond Stanford's guidelines. It provides a home for multidisciplinary research and teaching focused on sustainability, and the building itself serves as a learning tool and living laboratory.

The 166,500-GSF building uses 42 percent less energy than a traditional building of comparable size and 90 percent less potable water than one with traditional fixtures and systems. Significant portions of the building require no air conditioning, and much of it relies on natural light during the day. Y2E2 is currently undergoing certification by the LEED for Existing Buildings program.

Key sustainability features include:

- A high-performance envelope (roof, walls, windows, sunshades, and light shelves) that reduces heating and cooling loads
- Active chilled beams to supply heating and cooling more efficiently
- Natural ventilation via four internal atria, windows, and vents
- A 14kWdc grid-tied solar PV installation using three different types of modules to both offset electrical use and provide a learning opportunity for students
- Water conservation systems including waterless urinals, dual-flush toilets, and dual plumbing throughout the building for the use of recycled water Extensive use of recycled materials and sustainable products, such as bamboo and drywall
- Exposed concrete floors, which significantly reduce carpet use and mitigate the use of tons of raw materials
- Extensive electrical and HVAC monitoring to improve building performance and provide a learning opportunity for students

Photo: Jen-Hsun Huang Engineering Center

Jen-Hsun Huang Engineering Center (2010)

The Huang Engineering Center (HEC) is the second completed building of the four that make up the award-winning SEQ2. HEC is mostly offices and conference rooms but also houses a large auditorium, a popular café, and a large separately metered server room. Like Y2E2, HEC epitomizes high-performance design and construction. The 130,000-GSF building uses 46 percent less energy than a traditional building of comparable size.

Key sustainability features include:

- A high-performance envelope (roof, walls, windows, sunshades, and light shelves) that reduces heating and cooling loads
- Daylight and photocell technology to reduce electrical lighting loads
- A combination of natural ventilation and active and passive chilled beams
- Rapidly renewable materials in architectural woodwork and furniture
- Use of the university's recycled water system to flush toilets and urinals
- A 30kWdc solar PV installation to reduce electricity demand
- Salvaged seats from the demolition of Kresge Auditorium; the seats were refurbished and redeployed to complete the NVIDIA auditorium

Photo: Spilker Engineering and Applied Science

Spilker Engineering and Applied Science (2010)

The 104,000-GSF Spilker Engineering and Applied Science building is the third building in SEQ2 and supports interdisciplinary programs, including research at the atomic scale with a range of applications—new drugs, innovative designs for new semiconductors, improved communications networks, and improved water purification methods. Spilker Engineering was designed with many of the same features as Y2E2 and HEC and shares their ambitious energy and water goals.

Key sustainability features include:

- A high-performance envelope (roof, walls, windows, sunshades, and light shelves) that reduces heating and cooling loads
- Extensive use of daylight and photocell technology
- Rapidly renewable materials in architectural woodwork and furniture
- Use of the university's recycled water system to flush toilets and urinals
- A 30kWdc solar PV installation to reduce electricity demand

Photo: Lorry I. Lokey Stem Cell Research Building

Photo: Li Ka Shing Center for Learning and Knowledge

Lorry I. Lokey Stem Cell Research Building (2010)

The Lorry I. Lokey Stem Cell Research Building (SIM1), a 200,000-GSF School of Medicine building, has a basement vivarium and three above-grade floors with research labs and support facilities. Stanford established targets comparable to a LEED-Silver rating for the project. An example of high-performance building in the face of highly technical programmatic requirements, SIM1 serves as a national model for laboratory design and construction. It was built with a goal of 32 percent below similar laboratory buildings of its type but has far exceeded expectations during its first year of operation.

Key sustainability features include:

- Segregated laboratory and other occupancy types to increase HVAC operating efficiency
- Sloped ceilings in labs for increased daylighting and solar photo cells for lighting control
- Reusable animal cages throughout the vivarium, eliminating cage wash equipment and avoiding the use of approximately nine million gallons of water annually
- Elimination of relative humidity controls from air-handling equipment and the vivarium rooms due to the local climate
- Innovative room-level heating and cooling approach that reduces energy use significantly

Li Ka Shing Center for Learning and Knowledge (2010)

The Li Ka Shing Center for Learning and Knowledge, a 118,000-GSF School of Medicine building, includes medical simulation and virtual reality environments to advance teaching, learning, and knowledge management. The Li Ka Shing Center was designed to use 25 percent less energy and 40 percent less water than buildings of similar function. Four above-grade floors house a conference center, classrooms, and study areas. The basement features the Center for Immersive and Simulation-based Learning.

Key sustainability features include:

- Dual plumbing in toilets and urinals for the use of recycled water High-performance glazing, sun shades, and a reflective roofing surface
- An HVAC system with chilled beams and displacement ventilation
- Diversion of 95 percent of construction and demolition debris from landfill

Photos: Knight Management Center

Knight Management Center (2011)

The Knight Management, a facility of eight buildings, houses the Stanford Graduate School of Business (GSB). The center received a LEED-NC Platinum certification, the USGBC's highest rating for sustainability in the built environment. The 360,000-GSF facility underscores what is taught in many GSB electives, such as Environmental Entrepreneurship and Environmental Science for Managers and Policy Makers, as well as in core classes covering sustainability across business functions and the MBA/MS Environment and Resources joint degree program.

Among many significant sustainability features, the GSB solar PV system stands out. The system generates over 500,000 kWh per year, enough electricity to meet 12.5 percent of the center's demand. Rated for a peak output of 355 kW, the PV installation was the largest on campus at the time it was built. As with other features of the new facility, the university's careful monitoring and commissioning programs will ensure performance meets design expectations.

Key sustainability features include:

- A high-performance envelope (roof, walls, windows, sunshades, and light shelves) that reduces heating and cooling loads
- Natural ventilation and night flush, including operable windows and ceiling fans
- Active chilled beams to supply heating and cooling more efficiently
- An extensive building monitoring system to continually evaluate building performance
- Water conservation systems, including dual-flush toilets and dual plumbing throughout the building for the use of recycled water Extensive use of recycled materials and sustainable products, including Forest Stewardship Council–certified wood
- A 355 kWdc PV system

Photo: William H. Neukom Building

Photo: Shriram Center for Bioengineering and Chemical Engineering

William H. Neukom Building (2011)

The William H. Neukom Building, a LEED-Gold equivalent project set to use 30 percent less energy and water than required by code, strengthens the law school community and overall campus integration by fostering the interdisciplinary collaboration essential to a rich educational experience. Prominently situated south of the existing law school complex, this 65,000-GSF building creates a new focal point along the route that connects the campus's residential and academic precincts and provides much-needed clinic, seminar, meeting, and office space.

Key sustainability features include:

- A high-performance envelope (roof, walls, windows, sunshades, and light shelves) that reduces heating and cooling loads
- Daylight and photocell technology to reduce electrical lighting loads
- Maximized use of natural light
- Automated lighting and HVAC control systems
- Operable windows and ceiling fans to allow natural ventilation

Shriram Center for Bioengineering and Chemical Engineering (2014)

The new Shriram Center for Bioengineering and Chemical Engineering is the last of the four buildings in SEQ2. The 227,000-GSF building matches the architectural character of the neighboring Y2E2, HEC, and Spilker Engineering and Applied Science buildings. Shriram comprises both wet and dry laboratory spaces designed for intensive research, as well as shared specialty labs available to faculty based in other campus facilities. The building's energy and water goals match those of the other buildings in SEQ2.

Key sustainability features include:

- A high-performance envelope (roof, walls, windows, sunshades, and light shelves) that reduces heating and cooling loads
- A 125 kWdc grid-tied solar PV system to reduce electric demand
- Water conservation systems, including dual-flush toilets, and dual plumbing throughout the building for the use of recycled water Extensive use of recycled materials and sustainable products, such as bamboo and drywall
- Exposed concrete floors, which significantly reduced carpet use and avoided use of tons of raw materials
- A variable air volume fume hood system
- An innovative room-level heating and cooling approach that reduces energy use significantly

Photo Credits: L.A. Cicero/Stanford News Service; Chester Manuel; Whiting Turner; ZGF Architects; Office of Sustainability; HVAC Shop; Green Living Council; Campus Planning & Design, Parking and Transportation Services; Peninsula Sanitary Service, Inc; Stanford Residential & Dining Enterprises; Stanford Farm Project; Steve Gladfelter; Stanford Solar Decathlon; Garrett Gunther; Stanford Solar and Wind Energy Project; Camille Kirk; Mike Abbott; Precourt Institute for Energy; Facilities Energy Management; Michael Chen; Chris Gardener; Ashley Dean; Engineers for a Sustainable World; Kat Wade; Amy Pickering; Stanford Energy Club; Stanford Solar Car; Buildings and Grounds Maintenance; Stanford University Medical Center; Stanford Woods Institute for the Environment; and SLAC National Accelerator Laboratory.

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