A Framework for Supporting Organizational Transition Processes Towards Sustainable Energy Systems

by

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ABSTRACT

Economic development over the last century has driven a tripling of the world's population, a twenty-fold increase in fossil fuel consumption, and a tripling of traditional biomass consumption. The associated broad income and wealth inequities are retaining over 2 billion people in poverty. Adding to this, fossil fuel combustion is impacting the environment across spatial and temporal scales and the cost of energy is outpacing all other variable costs for most industries.

With 60% of world energy delivered in 2008 consumed by the commercial and industrial sector, the fragmented and disparate energy-related decision making within organizations are largely responsible for the inefficient and impacting use of energy resources.

The global transition towards sustainable development will require the collective efforts of national, regional, and local governments, institutions, the private sector, and a well-informed public. The leadership role in this transition could be provided by private and public sector organizations, by way of sustainability-oriented organizations, cultures, and infrastructure.

The diversity in literature exemplifies the developing nature of sustainability science, with most sustainability assessment approaches and frameworks lacking transformational characteristics, tending to focus on analytical methods. In general, some shortfalls in sustainability assessment processes include lack of:

- thorough stakeholder participation in systems and stakeholder mapping,
- participatory envisioning of future sustainable states,
- normative aggregation of results to provide an overall measure of sustainability, and
- influence within strategic decision-making processes.

Specific to energy sustainability assessments, while some authors aggregate results to provide overall sustainability scores, assessments have focused solely on energy supply scenarios, while including the deficits discussed above.

This paper presents a framework for supporting organizational transition processes towards sustainable energy systems, using systems and stakeholder mapping, participatory envisioning, and sustainability assessment to prepare the development of transition strategies towards realizing long-term energy sustainability.

The energy system at Arizona State University's Tempe campus (ASU) in 2008 was used as a baseline to evaluate the sustainability of the current system. From interviews and participatory workshops, energy system stakeholders provided information to map the current system and measure its performance. Utilizing operationalized principles of energy sustainability, stakeholders envisioned a future sustainable state of the energy system, and then developed strategies

to begin transition of the current system to its potential future sustainable state.

Key findings include stakeholders recognizing that the current energy system is unsustainable as measured against principles of energy sustainability and an envisioned future sustainable state of the energy system. Also, insufficient governmental stakeholder engagement upstream within the current system could lead to added risk as regulations affect energy supply. Energy demand behavior and consumption patterns are insufficiently understood by current stakeholders, limiting participation and accountability from consumers.

In conclusion, although this research study focused on the Tempe campus, ASU could apply this process to other campuses thereby improving overall ASU energy system sustainability. Expanding stakeholder engagement upstream within the energy system and better understanding energy consumption behavior can also improve long-term energy sustainability. Finally, benchmarking ASU's performance against its peer universities could expand the current climate commitment of participants to broader sustainability goals.

Dedicated to Heena, Kinnari and Saager, for their love and support

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LIST OF ABBREVIATIONS

ABOR	Arizona Board of Regents
ACC	American Campus Communities, Inc.
ACUPCC	American College & University President's Climate Commitment
ADEQ	Arizona Department of Environmental Quality
AP	Acidification Potential
APS	Arizona Public Service
APSES	APS Energy Services Company
ASU	Arizona State University's Tempe campus
BAS	Building Automation System
BDA	BioDesign Building A
BDB	BioDesign Building B
BTU	British Thermal Units
CFC-11	Chloro-Fluoro Methane or Freon
C_2H_4	Ethene
CGT	Combustion Gas Turbine
CHP	Combined Heat & Power
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CP	Central Plant
CPM	Capital Programs Management
CPW	Central Plant West
EH&S	Environmental Health and Safety

EI	Energy Sustainability Principle of Environmental Integrity
EIA	Environmental Impact Analysis
EIS	ASU Energy Information System
EJ	ExaJoules
EO	Energy Sustainability Principle of Economic Opportunity
EP	Eutrophication Potential
FERC	Federal Energy Regulatory Commission
FTE	Full Time Equivalent
GE	Energy Sustainability Principle of Generational Equity
GSF	Gross Square Footage
GW	Gigawatt
HAP	Hazardous Air Pollutants
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
ISTB 1	Interdisciplinary Science and Technology Building 1
kWh	Kilowatt hours
LEED	Leadership in Energy and Environmental Design
MCAQ	Maricopa County Air Quality department
MCDA	Multi-Criteria Decision Analysis
MCF	One Thousand Cubic Feet
MMBTU	Million British Thermal Units
MW	Megawatt
MWh	Megawatt hours

MNRE	Ministry of New and Renewable Energy (Government of India)
Mt	Metric Tons
NETL	National Energy Technology Laboratory
N_2O	Nitrous Oxide
NO_X	Nitrous Oxides
NRC	Nuclear Regulatory Commission
ODP	Ozone-layer Depletion Potential
OECD	Organization for Economic Co-operation and Development
PEFI	Post-secondary Education Facility Inventory and Classification Manual
PG	Energy Sustainability Principle of Participatory Governance
PM_{10}	Particulate Matter particle size 10 micrometers or less
PO_4^{3-}	Phosphate Ions
POCP	Photochemical Ozone Creation Potential
QF	Qualifying Facility
RA	Energy Sustainability Principle of Risk Management and Adaptation
RE	Energy Sustainability Principle of Resource Efficiency and Maintenance
RLFM	Arizona State University Residence Life Facilities Management
RPS	Renewable energy Portfolio Standard
SEA	Strategic Environmental Assessment

SIA	Sustainability Impact Assessment
SO_2^-	Sulfate ions
SO_X	Sulfur Oxides
SP	Space Planning
SWG	Southwest Gas
TBL	Triple Bottom-Line
TCS	Toxic Contamination of Soil
TCW	Toxic Contamination of Water
TES	Thermal Energy Storage
Ton hrs	Chilled Water Ton Hours
UNDP	United Nations Development Programme
U.S. EIA	United States Energy Information Administration
VOC	Volatile Organic Compounds
WCED	World Commission on Environment and Development
WEC	World Energy Council
WUD	Tempe Water Utilities Division

Chapter 1

INTRODUCTION

1.1 General Problem Context – The Unsustainable Use of Energy

In 1683, French scientist Bernard le Bovier de Fontenelle first offered his idea of progress that with "new science and technology, mankind had entered a road of necessary and unlimited progress" (von Wright, 1997). Many philosophers have since evolved the idea that scientific, material, and moral progress of mankind is inevitable and irreversible.

The Industrial Revolution began advancement of science and materialism, leading people to believe it a right to govern nature, and transform it to economically-valued material goods (Worster, 1993). Nature was viewed simply as an inexhaustible resource for human progress. Fossil fuels transformed the economies of Europe and the U.S. from what Sieferle (1982) termed the "agrarian solar energy system" where civilization was primarily dependent on traditional biomass forms of energy. As this transformation spread globally, economic development over the next century was driven by a tripling of the world's population, a twenty-fold increase in fossil fuel consumption and a tripling of traditional biomass fuel consumption (World Bank, 1997). However, the value and efficiency basis of economic development led to broad income and wealth inequities for the labor market, limiting growth in many developing countries (Harkness, 2007).

Today, these development inequities and dependence on traditional energy sources are retaining over 2 billion people in poverty, undernourished and in ill-health, deprived of the access and opportunities realized from modern forms of energy (World Bank, 1996). Emissions from fossil fuel combustion are affecting climatic conditions – mean temperature and frequency and intensity of storms are increasing, sea-level rise is affecting coastal communities and ecosystems, local air quality is harming human health and damaging infrastructure, while fuel production and refining is fragmenting habitats (Intergovernmental Panel on Climate Change, 2008; Chow, 2003). Adding to these inequities and impacts, for most industries, the cost of energy is outpacing all other variable costs (Hanawalt, 2009).

Into the 1970s, it became apparent that the resource-intensive path of western economies could neither be carried into the future at the same rate nor could it be applied globally (United Nations Educational, Scientific and Cultural Organization, 1996). According to Chow et al. (2003), people in developing countries currently use one-sixth of the annual energy consumed by those in developed nations. As countries strive for economic growth, populations are becoming urbanized at unprecedented rates, and the demand for energy will increase accordingly. Clearly, traditional pathways for this growing demand for energy will only exacerbate the already negative impacts on society, environment, and economic growth.

This global growth in energy demand and the associated impacts present a sustainability challenge with "interlinked, temporally and spatially broad-ranging economic, environmental and social issues" (World Commission on Environment and Development (WCED), 1987).

1.2 Specific Problem Context – The Role of Organizations

Approximately 60% of world energy delivery in 2008 was consumed by the commercial and industrial sectors, with approximately 27% consumed by the transportation sector, leaving 13% consumed by the residential sector (U.S. EIA, 2011). According to the Building Energy Data Book (2010), the commercial building and industrial sectors account for 50% of U.S. energy consumption in 2010. Commercial and industrial organizations tend to have fragmented and disparate energy consumption-related decision making due to their diverse demand and operating profiles, compounded by distributed facilities (Brief & Davids, 2011). The combination of these facts points to the importance of organizations in solving the problem of unsustainable energy use and the lack of sustainability-oriented organizational decision making and management.

Institutions consist of many energy consuming entities – consumers, infrastructure, equipment, vehicles, etc. – which impact their economic performance, the environment, and the community within which they serve. These energy systems are not unsustainable, per se, but current management strategies are balanced in terms of sustainability, providing the necessary administrative functions while avoiding adverse effects of energy consumption. A state of balance implies subjective management of necessary functions and adverse effect avoidance, resulting from collective and individual decision processes. This state of balance also implies that the status quo is unsustainable in the long-term.

1.3 Research Gap

The basic definition of assessment is the process by which an evaluation or appraisal is conducted. "Sustainability assessment" has become widely used terminology for the development of tools or processes to assess sustainability. However, the many different approaches and frameworks generally lack several transformational characteristics and tend to focus largely on analytical methods:

- Comprehensive principles of sustainability are not prescribed or operationalized for the application (Janic, 2004),
- Focus is generally limited to future scenarios and not envisioned future states (Afgan et al., 2000, 2002, 2008),
- Widespread stakeholder participation is neglected when defining sustainability indicators (McDowall & Eames, 2007),
- Assessments have been limited to only components of systems, (Zhou et al., 2007), and,

- A final relative measure of sustainability has not been provided (Labuschegne et al, 2005).

Questions that remain unanswered by these studies are how sustainable are the systems that these authors have assessed? What would be the future sustainable state of the subject of these assessments, and how might the assessment change if entire systems were taken into account and stakeholders were involved in the assessment processes? What strategies need to be developed to transition these systems towards future sustainability?

1.4 Research Objectives and Questions

This research project collaboratively designs a decision support system for institutional sustainable energy systems that addresses these deficits and questions.

This research study has several goals. Motivated by the organizational energy issues and sustainability challenges discussed above, the overall goal of this project is to develop a framework to assist the transition of an organization’s energy system towards sustainability. To accomplish this, first a systemic view of an energy system with quantitative and qualitative input from stakeholders is developed. This is followed by a vision of a future sustainable energy system also developed by stakeholders. A comprehensive, integrated sustainability assessment of an energy system is then conducted. Finally, an initial strategic plan is developed to transition an existing energy system towards the future sustainable energy system vision.

The principal methodological questions addressed herein are:

1. How are sustainability assessments conducted today? [Section 2.3.2]
2. What is an energy system? [Section 4.1]
3. What are principles of energy sustainability? [4.2.1 and 4.2.2]
4. How do we craft and assess a vision for a sustainable energy system? [section 4.2.3]
5. How can the sustainability of energy systems be systematically and holistically assessed? [section 4.2.4]
6. How can a transition to sustainability-based decision making be effectively implemented? [section 4.3]

Questions related to the Arizona State University case study include:

7. How can ASU's energy consumption be made more sustainable? [section 4.3]
8. How sustainable is ASU's existing energy system? [section 4.2.4]
9. How can ASU's current and future energy consumption be managed with an integrated, systemic, and adaptive energy sustainability assessment? [section 4.2.4]

1.5 Research Design

This project employs approaches and methods from decision sciences and engineering sciences (interdisciplinarity), and is conducted in collaboration with university administrators and researchers (transdisciplinarity).

Arizona State University's Tempe campus (ASU) was an ideal candidate for this sustainability assessment project, as it is one of the largest energy consumers in the metropolitan Phoenix area, with a large organization consuming energy on a campus with a large number of buildings and equipment for many diverse activities to serve a large population of students, employees and the community. While ASU's energy consuming activities provide economic and social value, there is also environmental and social impact.

Using ASU's energy system in 2008 as a case study, first, the organization's existing energy system was mapped, evaluated, and analyzed. This step provided a baseline of the existing system, stakeholders, operations management. Second, a literature review of sustainability principles was conducted and these principles were adapted for energy sustainability. A comprehensive set of principles was necessary to ensure that the assessment adequately addressed temporal and spatial sustainability issues. A vision for a future sustainable energy state at ASU was developed, based on these operationalized principles of energy sustainability. Third, the sustainability of the mapped energy system was assessed with respect to the envisioned future state. This phase included a review of current sustainability assessment practices to understand advantages and disadvantages, and then, to develop components of a comprehensive, integrated, and holistic approach. Finally, an initial strategic plan was outlined to transition the current energy system towards the future sustainable state.

1.6 Expectations

This research project provides an approach to comprehensively map an energy system with the participation of stakeholders. It also maps stakeholders and their influence across the entire system, identifying gaps in stakeholder management and influence. The project provides energy sustainability principles that are used by stakeholders to envision a future sustainable energy system. This project provides a comprehensive, systemic, integrated, participatory sustainability assessment of ASU's energy system. Finally, the project outlines an initial strategy to transition the energy system towards long-term sustainability.

Chapter 2

RESEARCH DESIGN AND METHODOLOGY

2.1 Overview

This thesis applies a transformational planning and research framework outlined in Wiek and Walter (2009) and Wiek (2010). The major components of the thesis are flowcharted in Figure 1.

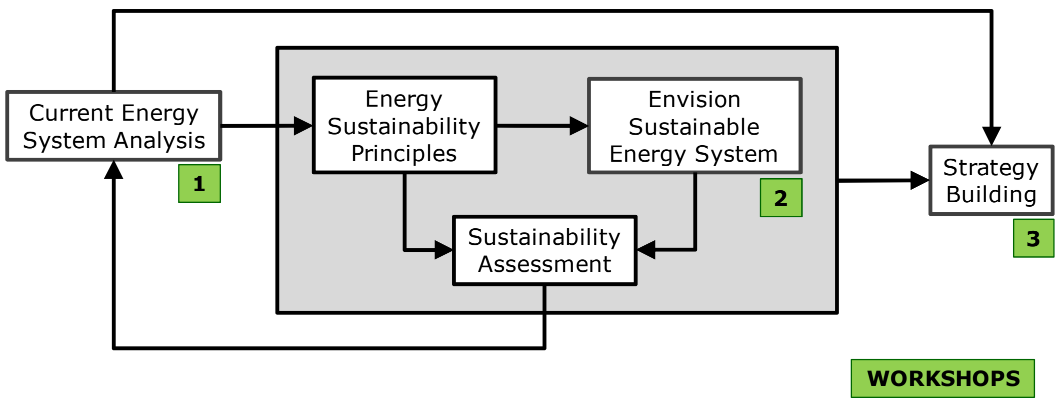

Figure 1. Research Design Flowchart.

Current energy system analysis included a historical inventory, analysis and mapping of the quantitative and qualitative aspects of the entire energy system. This was completed through face-to-face, one-on-one interviews with energy system stakeholders, namely ASU executives, managers and external energy system suppliers. Performance metrics were identified by these same stakeholders during Workshop 1 (identified in Figure 1) in this phase. With principles of sustainability operationalized for energy sustainability, stakeholders participated in Workshop 2 (identified in Figure 1) to develop a vision for a future sustainable energy system. This workshop also provided indicators and targets for system components. Energy sustainability principles and indicators for the envisioned future state were utilized to assess the sustainability of the current energy system. The results of these phases were then utilized in Workshop 3 (identified in Figure 1) where stakeholders outlined an initial strategic plan to transition the current energy system towards the envisioned sustainable state.

Each of the phases of this research project included stakeholder input, from providing the necessary current system information and data, to participating in workshops to provide vision components, indicators, and strategic planning input. Participatory workshop methods included presentations and posters to inform participants followed by focused group activities to engage participants in discussion, encouraging brainstorming and active participation during the various phases of the project.

2.2 Current Energy System Analysis

Energy system analysis and development herein applies the framework proposed by Wiek and Larson (2011) for assessing water governance regimes. Components identified by Wiek and Larson that are critical to resource governance include the need to retain a systems perspective linking the various complex aspects, taking a governance focus on the actors (stakeholders) of the system, and taking a comprehensive approach in terms of sustainability principles.

The primary stakeholder intermediary from ASU's Facilities Development and Management organization was Phil Plentzas, Director of Business Operations. As Director of Business Operations, Mr. Plentzas has overall budgetary responsibility for operation of the energy system functions. As such, he has primary responsibility to manage all energy system suppliers.

With Mr. Plentzas' assistance, internal and external energy system stakeholders were identified and interviewed. Appendix A1 includes ASU's energy system-related organization chart (Figure A1), identifying interviewed stakeholders, the interview questionnaire, the stakeholder list with interview dates, and attendees for each workshop (Table A1). As shown in Appendix A, stakeholders were executives and managers of ASU's energy system, with some external suppliers and consultants also interviewed. These stakeholders varied in responsibility and expertise from supplying energy to ASU's energy system, to managing aspects of the energy demand side, to executive management of the entire system. Twenty two face-to-face interviews were conducted over a period of 16 months with 26 stakeholders, mostly one-on-one, but some with two relevant stakeholders together. The purpose of the interviews was to understand stakeholder roles and responsibilities when operating ASU's energy system, how decisions are made that influence the supply and demand sides of the energy system, energy system impact on decision making, communication methods and tools used to operate and improve the energy system, and operational rules, regulations, and policies that constrain function and operation of the energy system.

Based on information gathered in the interviews, the governance of the energy system was evaluated. This analysis cross-correlated information from different stakeholders as to:

- the operation of the system,
- the goals for system performance and effectiveness,
- the extent of direct or indirect decision making that influences of operation of the system or components of the system, and
- the policies, rules and regulations that constrain system operation.

This governance analysis identified gaps and discrepancies in stakeholder management of the energy system. This analysis also highlighted the varying priority given to different aspects of the energy system.

Historical operating data was also provided by the various stakeholders so that a comparative analysis could be conducted on the energy system.

Workshop 1 was held on January 20, 2011 in the University Services Building, which 20 stakeholders attended (see Appendix A for stakeholder expertise and attendance). The results of the energy system review and analysis were presented to stakeholders, who were asked to brainstorm and submit their metrics for energy system performance measurement.

2.3 Visioning and Sustainability Assessment

2.3.1 Visioning

Standardized visioning exercises have experienced intransparency, insufficient stakeholder involvement, inconsistent vision statements, and incomplete systems mapping resulting in flawed implementation processes (Wiek & Iwaniec, 2011). These results could lead to unproductive or conflicting resource utilization, and in turn, unacceptable outcomes for stakeholders and the energy system. Research in planning and governance has determined that interactive stakeholder participation can build greater capacity for acceptance of outcomes (Wiek, 2010).

Workshop 2, the visioning workshop, was held on March 31, 2011 in the University Services Building, and 15 stakeholders attended (see Appendix A for stakeholder expertise and attendance). The technical and stakeholder mapping of the energy system was presented to the participants, along with principles of energy sustainability. The reasoning behind selecting principles of energy sustainability is detailed in Chapter 4.

The participants were given handouts of the energy sustainability principles for reference during the workshop. The group was divided into two and asked to develop separate visions of ASU's sustainable energy system.

The two separate visions were then collated by the group into an integrated, comprehensive and cohesive vision. Statements were combined where necessary, and participants filtered statements to maintain focus on a future sustainable state (as opposed to focusing on evolved aspects of the current system). Participants were also asked to identify missing system components with respect to the current system and metrics discussed during the first workshop. Inconsistent or conflicting statements were reviewed and amended or eliminated, as appropriate.

The purpose of active filtering was to review vision statements to verify that they were truly focused on the energy system landscape in 25 years. Extrapolating the current state of and the current roles within the energy system may not be envisioning an ideal, sustainable future energy system. Similarly, identifying and evaluating resources, feasibility, or other constraints would begin bounding the vision. When envisioning, thinking about future possibilities in terms of environment, technology, resources, regulations, demographics etc., would be an exercise in scenario development, and again would artificially focus and constrain envisioning. Finally, thinking about how the future sustainable energy system might be achieved would be part of a planning exercise and would divert focus from envisioning. Filtering was actively done during the workshop, and vision statements were modified to correct discrepancies.

Gap and conflict analysis was conducted to compare vision statements with the current system and metrics, to identify areas visioning may have either neglected or conflicted.

Finally, participants were asked to provide metrics to measure performance of this envisioned sustainable energy system, and associated targets for those metrics.

2.3.2 Sustainability Assessment

2.3.2.1 Sustainability Assessment Literature Review

The basic definition of assessment is the process by which an evaluation or appraisal is conducted. The U.S. National Research Council (1999) suggested that to transition towards an overall goal of achieving sustainability based on the Brundtland definition (WCED, 1987), one must ask:

- What has to be sustained?
- What needs to be developed?
- And, what is the intergenerational aspect of achieving this goal?

Sustainability assessment, therefore, implies providing a measure of the sustainability of that being sustained and developed in perpetuity.

In an effort to strive for sustainable practices, 'sustainability assessment' has become widely used terminology for development of measurement tools or processes. The published evolution of the definition of sustainability assessment is discussed below, culminating in a comprehensive definition of sustainability assessment, as applied in this research project.

Devuyst (2001) generally defines sustainability assessment as "… a tool that can help decision makers and policy makers decide which actions they should or should not take in an attempt to make society more sustainable." Ness et al. (2007) further refine this definition by suggesting that sustainability assessment provides decision makers with an "evaluation of global to local integrated nature-society systems in short- and long-term perspectives" to determine which actions improve sustainability.

Many sustainability assessment tools have been published by public and private sector entities, at the national, regional, and local levels. Ness et al. (2007) have broadly reviewed these tools and suggested three categories, in an effort to classify the interpretation and application of sustainability assessment.

First, in Ness et al.'s terminology, indicator and index assessments utilize non-integrated indicators for national or regional comparison and integrated indicators to provide indices for standardized, broader application. According to the authors, indicator- and index-based assessment tends to be temporally retrospective, in that past development (national, regional or product) is evaluated and compared. The authors provide Environmental Pressure Indicators, economic material flow analysis, Ecological Footprint, and Human

Development Index as examples of indicator and index based assessments.

While these indicators or indices (integrated or not) provide comparative measures, they are clearly not assessments. These measures do not assess the long-term sustainability of the subject measurements.

Second, Ness at al. describe product-related assessments that utilize product or service material and energy flow analyses primarily using life cycle methods. Life cycle assessment methods can be temporally prospective, if risks, uncertainties, technologies, policies etc. are considered known and manageable. Product-related assessment tools, specifically life cycle assessment, tend to be limited to global application, without evaluation for regional or local sensitivity of product use and impact. The authors provide Life Cycle Assessment, Life Cycle Costing, product material flow analysis, and product energy flow analysis as examples. By the authors' reasoning, product-related methods are not sustainability assessments.

Finally, Ness et al. suggest that integrated sustainability assessment tools can be temporally prospective focusing on future requirements for systems, with spatially flexible application. Again, however, current tools forecast future requirements based on current constraints and assumptions about the future. The authors provide Multi-Criteria Analysis, Cost-Benefit Analysis, Environmental Impact Analysis (EIA), and Strategic Environmental Assessment (SEA) as examples. These methods come closest to meeting the definition of sustainability assessment.

Several authors have used different terms for EIA- and SEA-based sustainability assessment approaches - Sheate et al. (2001, 2003) use “sustainability appraisal” and “integrated impact assessment”, Eggenberger and Partidário (2000) use “integrated sustainability appraisal”, and Lee (2002) uses “sustainability assessment”. According to Pope et al. (2004), the common theme in these approaches is integration of the traditional triple bottom-line (TBL) implications for assessments, where integration not only means assessing each of the environmental, social, and economic domains, but also the interrelations between the three domains.

Pope et al. identify three types of integrated sustainability assessments.

“EIA-driven integrated assessments” tend to be applied after a project or proposal has been conceptualized, with impact assessment defining whether or not an activity has a sustainability-oriented trajectory. However, the state of sustainability is unknown or undefined. Generally, with EIA-driven assessments, impacts are independently assessed against the TBL domains, with negative impacts minimized as an overall goal, but interrelations between TBL categories being neglected. Finally, the ex-post nature of EIA-driven assessments increases the possibility for biasing projects to favor economic drivers, while neglecting social or environmental impacts, as documented by Weir (2003) and the Australian Environmental Protection Authority (2003). In their review of sustainability assessment practices in policy making, Weaver and Jordan (2008) found that policy assessment practices tend to be hindered by pre-existing policy commitments, organizational boundaries preventing cross-sectoral influence, and typical political priorities such as economic growth and employment. As a result, sustainability criteria are generally applied late (ex-post) in policy analysis.

"Objectives-led integrated assessments" define an overall outcome or vision with integrated environmental, social, and economic objectives at the outset of the assessment, and tend to maximize positive outcomes. Similar to EIA-driven assessments, objectives-led assessments also tend to assess "direction to target", with the target sustainable state unknown (Pope, Annandale, & Morrison-Saunders, 2004).

Based on the work of George, 1999 and 2001, Sadler, 1999 and Gibson, 2001, Pope et al. (2004) propose the "assessment for sustainability" approach to determine "direction to target" and "distance from target". Here, assessment is not only against baseline bottom-up TBL conditions, but also against the top-down state of sustainability as defined from sustainability criteria. The authors suggest that integrated sustainability criteria be based on principles of sustainability to include interrelations between TBL categories, rendering the “whole” state of sustainability as “greater than the sum of its parts”.

Weaver and Jordan (2008) propose an iterative four-stage cycle for Integrated Sustainability Assessment, including problem scoping, which involves systems analysis and problem definition, envisioning, which includes defining common goals and shared understanding, experimenting, which involves comparing outcomes, and evaluation and learning, which develop policy.

The OECD (2008) defines Sustainability Impact Assessment (SIA) as a “systematic and iterative process of ex-ante assessment of the likely economic, social, and environmental impacts of policies, programmes and strategic projects,” with widespread stakeholder participation in an open and transparent process, to enhance positive effects, mitigate negative effects, and avoid transferring negative impacts to future generations.

In addition to the features of integrated sustainability assessment discussed above, Gibson et al. (2005) suggest that integrated sustainability assessment participants must be accountable and share responsibility, identify the most sustainable option with defined trade-off rules, and address direct and immediate as well as indirect and cumulative impacts.

These definitions are compared in Table 1.

Table 1

Comparison of Definitions of Sustainability Assessment

	Ness et al. (2007) Indicators & Indices	Ness et al. (2007) Product-related	Weaver and Jordan (2008)	OECD (2008)	Pope et al. (2004) EIA-driven	Pope et al. (2004) Objectives-led	Pope et al. (2004) - Assessment for Sustainability	Gibson (2005)
Decision-making (ex-ante & planning)	✓	✓	✓	✓	Ex-post	✓	✓	✓
Interlinked Domains of Sustainability	✓	✓	✓	✓	Linkages neglected	✓	✓	✓
Temporally Prospective	Retrospective	Retrospective	✓	✓	✓	✓	✓	✓
Spatially Broad (local to global system perspective)	✓	Global only	✓	✓	✓	✓	✓	✓
Open & Transparent Process	✓	✓	✓	✓	✓	✓	✓	✓
Integrated measure of Sustainability (direction and distance to target)					Direction only	Direction only	✓	✓
Encourage Widespread Participation & Ownership			Participation only	Participation only			Participation only	✓
Vision-based (target state of sustainability)			✓	✓				✓

In summary, common elements in the varying definitions and perspectives of sustainability assessment in literature can be compiled for a comprehensive definition of sustainability assessment.

As utilized in this research project, sustainability assessment is an open and transparent decision making tool, applied ex-ante, incorporating interlinked domains of sustainability, to measure the sustainability (distance and direction) of an evolving state of a spatially broad system, with respect to a future, stakeholder-defined sustainable state of the system.

2.3.2.2 Existing Sustainability Assessments

The many different sustainability assessment approaches and frameworks offered in literature exemplify the developing nature of sustainability assessment. Many sustainability assessments have been conducted, and some are discussed below as representative examples of energy and non-energy related assessment methodologies. Some are highly technical and quantitative; others more qualitative in the approaches used.

Janic (2004) conducted a comprehensive sustainability assessment of air transportation. This assessment is technically complete with indicators for technical performance, operational performance, and economic, social, and environmental performance of the air transport system. However, the assessment lacks measurement against comprehensive principles of sustainability operationalized for the air transport system – specifically, consideration should be given to equity, widespread participation, and standard of living issues. Stakeholders are identified as major groups, but the author has not conducted a stakeholder group assessment of sustainability objectives or values. Finally, this assessment neglects to conduct a normative aggregated assessment of sustainability.

Labuschagne et al. (2005) proposed a framework for the sustainability performance of industries by way of a survey on appropriateness of systematic indicators. The authors recognize the importance of the traditional TBL domains and stakeholder participation, but do not propose customizing and operationalizing principles of sustainability to an envisioned state of sustainability. The authors recommend Multi-Criteria Decision Analysis (MCDA) tools to normalize qualitative data.

Lipošcak et al. (2006), Zhou et al. (2007) and Afgan et al., in various articles (2000, 2002, 2008), applied the same methodology in different energy system sustainability analyses that focus primarily on the energy supply side. The authors conduct scenario analyses of generic TBL indicators to develop a "generalized index of sustainability," representing an aggregated measure of sustainability for compared systems. As such, the authors do not involve stakeholders to define a sustainable system vision or operationalize broader principles of energy sustainability

Sheate et al. (2008) included stakeholders and used the European Union's Fifth Framework (BioScene) to baseline principles of sustainability and define objectives and systematic indicators for the assessment of mountain areas of Europe. The authors also developed a combined matrix of indicators with stakeholder involvement, although an aggregated sustainability measure was not developed.

McDowall and Eames (2007) conducted a sustainability appraisal of the hydrogen economy in the United Kingdom. They involved a broad spectrum of expert stakeholders to define various potential visions and provide individual and aggregated appraisals (rankings) based on traditional TBL domains of sustainability.

All of the authors discussed above have conducted spatially broad, open, and transparent sustainability assessments of the status quo and author-defined future scenarios, with well-defined, commonly-accepted, and measurable indicators. As such, these are more academic exercises and not directly intended for integration with decision-making processes. Stakeholder-defined sustainability visions are not provided. The general sustainability principles most commonly utilized are the traditional, commonly accepted, and broad TBL domains, with equal value given by the authors, to each domain. Stakeholders are identified but most often excluded from the assessment process. The MCDA methods used by many authors are a viable option for normalizing and aggregating indicators. These assessments are compared in Table 2.

Table 2

Comparison of Existing Sustainability Assessments

(TBL means Triple Bottom-Line)

	Janic (2004)	Labuschegne et al. (2005)	Lipošcak et al. (2006)	Zhou et al. (2007)	Afgan et al. (2000, 2002, 2008)	Sheate et al. (2008)	McDowall and Eames (2007)
Principles of Sustainability	TBL	TBL	TBL	TBL	TBL	TBL	TBL
Stakeholder-defined Metrics	Author-defined	Author-defined	Author-defined	Author-defined	Author-defined	✓	Expert-defined
Stakeholder-defined Vision	X	X	Author-defined scenarios	Author-defined scenarios	Author-defined scenarios	Stakeholder-defined scenarios	Expert-defined
System-wide, Spatially Broad	✓	✓	Energy supply only	Energy supply only	Energy supply only	✓	✓
Encourage Widespread Participation	X	✓	X	X	X	✓	Experts only
Provide Normative, Aggregated measure of Sustainability	X	X	✓	✓	✓	X	Aggregation of rankings
Open & Transparent Process	✓	✓	✓	✓	✓	✓	✓
Decision-making	No	No	No	No	No	No	No

In summary, Table 2 shows the critical elements of a comprehensive sustainability assessment methodology that is consistent with the definition of sustainability assessment discussed in the previous section.

2.3.2.3 ASU Energy System Sustainability Assessment

Utilizing the principles of energy sustainability, the metrics of the current energy system (Workshop 1), and the metrics of the envisioned energy system (Workshop 2), an Excel-based sustainability assessment was conducted to measure the sustainability of ASU's current energy system as a baseline.

Metrics were evolved into a different number of indices for each energy sustainability principle showing the varying resolution required by the stakeholders to measure each of the principles. This has the potential to bias the impact of certain principles within the overall sustainability score, and is discussed in Chapter 5.

These metrics and indices are detailed in Table 18, with metrics from Workshop 1 and their corresponding indices unshaded, and metrics from Workshop 2 and their corresponding indices shaded green.

The sustainability assessment was conducted with 2008 as the baseline year, so index data for other years was normalized with 2008 indices. After normalizing the data, all indices for each principle were averaged to determine a baseline sustainability score for each principle. The six principles were then averaged to determine an overall sustainability score for the current energy system, as measured against the stakeholder-defined, sustainability principle-based metrics and corresponding indices.

2.4 Strategy Building

Conventional planning methods have relied on short-term objectives, bias from political or organizational objectives, disparate departmental drivers, generally driven by experts and constrained by organizational and political leaders (Wiek, 2010). Conventional forecast planning methods are not readily applicable to the temporal, scale and uncertainty implications of complex sustainability challenges. The inertia of "business-as-usual" practices makes it difficult to address these sustainability issues (Basile, 2010).

To develop and realize long-term solutions to sustainability challenges, planning approaches have to become transformative. Transformative approaches have evolved to include integrated, vision-based and collaborative planning (Wiek, 2010).

Workshop 3, the strategy building workshop, was held on June 7, 2011 in the University Services Building, and 12 stakeholders attended (see Appendix A for stakeholder expertise and attendance). The technical mapping of the envisioned energy system produced from the second workshop was presented to the participants, along with ASU's carbon mitigation plan.

Given this information, the group was divided into three – one group to focus on the energy system supply, another to focus on the energy system demand-side infrastructure, and the third to focus on the energy system consumers. The groups were asked to collaboratively outline plans using backcasting to transition their focus areas of the current energy system towards the envisioned sustainable state, while maintaining consistency and preventing redundancy with the carbon plan. Participants were tasked with identifying activities, infrastructure, policies, training, partnerships, investment, barriers, etc. that might be required for this transition. The participants then reviewed the three plans for consistency, and collated them into a single cohesive exploratory plan.

Chapter 3

CASE STUDY – ARIZONA STATE UNIVERSITY'S ENERGY SYSTEM

There are many large organizations with diverse and distributed energy systems in Arizona. With approximately 10,500 employees, Arizona State University is one of the largest employers in Arizona, with four university campuses serving approximately 68,000 students in 2008. In 2009, ASU had the 7th largest enrollment in the U.S. Arizona State University's Tempe campus was an ideal candidate for this research project due to the compact nature of the campus and associated activities within 225 energy consuming buildings in a small area. Other public and private entities were considered but potential organizational, resource, infrastructure and operational conflicts deemed timely data availability and acquisition to become difficult for this study.

In 1885, when Arizona was still a territory, citizens donated land and resources to build an institution to train teachers, and provide instruction in the areas of agriculture and the mechanical arts. This Teachers College in Tempe was renamed several times through 1945, when after rapid changes in curricula and degree offerings, it became the Arizona State College, and Arizona State University (ASU) in 1958. During the following decades ASU's reputation grew as colleges were added, enrollment increased and the campus was expanded, a lot of it through private donations. In 1994, ASU became one of only 88 universities to be granted Research I (Research Extensive) status by the Carnegie Foundation, as research began to span the full spectrum of disciplines, balanced with broad-ranging professional programs (ASU, 2010).

In July 2002, ASU's president Michael Crow outlined his vision to transform ASU into a new American University. According to Crow, thus far, American universities had measured their academic performance, organizations and student bodies against the "gold standard" of American universities modeled after elite German scientific research institutions. He considered this the "gold standard of the past" (Arizona Board of Regents, 2002).

Dr. Crow envisioned the new American university to be built around a commitment to sustainability– ASU prototyping the new gold standard with the following design imperatives:

1. Embrace its cultural, socio-economic, and physical setting.
2. Become a force, an integral part of the community, not just a place.
3. Become an entrepreneur generating revenues, and not just a State government agency.
4. Conduct use-inspired research, generating knowledge with purpose.
5. Focus on the individual.

6. Encourage intellectual fusion of teaching and research that is interdisciplinarity, multidisciplinarity, and transdisciplinarity.
7. Become socially embedded so that knowledge advancement is integrated with societal transformation.
8. Become globally engaged.

This vision began taking form in 2004, when the Global Institute for Sustainability was established. Built on the cornerstones of education, research, business practices, global partnerships and transformation, the Institute's mission is to identify the grand challenges of sustainability, advance knowledge for applied practical solutions, create new tools for improved decision making, prioritize university-wide efforts toward sustainable practices, and build global research partnerships (Global Institute of Sustainability, 2010).

In 2006, Dr. Crow became a founding member and charter signatory of the American College & University President's Climate Commitment (ACUPCC), which recognizes the need to reverse global warming as a "defining challenge of the 21st century" and commits signatories to achieving climate neutrality. Subsequently, ASU's Climate Neutrality Action Plan was published in September 2009, outlining efforts to achieve ASU's climate neutrality by 2025 (President's Climate Commitment, 2007).

This plan targets five areas for reducing baseline fiscal year 2007 carbon emissions – energy use accounts for 75% of the total carbon emissions of the four ASU campuses, transportation another 20%, 4% are agriculture- and refrigerant-related emissions and, the final 1% of total carbon emissions are from waste-related handling operations (Arizona State University, 2009).

While ASU has actively started to mitigate all carbon emissions on all four campuses, the Tempe campus is responsible for approximately 83% of total emissions. Furthermore, energy use is the single greatest contributor to ASU's Tempe campus carbon footprint contributing approximately 78% (Arizona State University, 2009).

This project was developed based on the stationary energy-consuming activities in 2008 at Arizona State University's Tempe campus (ASU). Stationary energy represents approximately 78% of ASU's energy consumption on the Tempe campus (transportation related energy consumption is approximately 17%).

Chapter 4

RESULTS

4.1 Current State of ASU's Energy System

4.1.1 Overview

ASU's entire energy system for the Tempe campus in 2008 is shown in Figure 2. An energy and stakeholder flow diagram was developed by overlaying primary stakeholders on Figure 2, to show decision-making influence of government agencies, ASU suppliers, ASU employee teams, and consumers of energy at ASU. This energy and stakeholder flow diagram is shown in Figure 3.

ASU's energy system can be divided into four major groupings. Potential system stressors are external system level effects that could impact the entire energy system. Energy sources and regional supply, and energy distribution and local supply represent the supply side of the energy system. Energy consumers represent the human, infrastructure, equipment and other energy consuming activities and entities around and within ASU's Tempe campus. These four groups are discussed section 4.1.2 below. The analysis of the energy system is discussed in section 4.1.3 below.

Stakeholders have different influences on ASU's energy system. External governmental authorities regulate energy suppliers and producers to balance the interests of consumers with market drivers. Energy suppliers and partners work directly with ASU to deliver commodities and services to meet campus requirements.

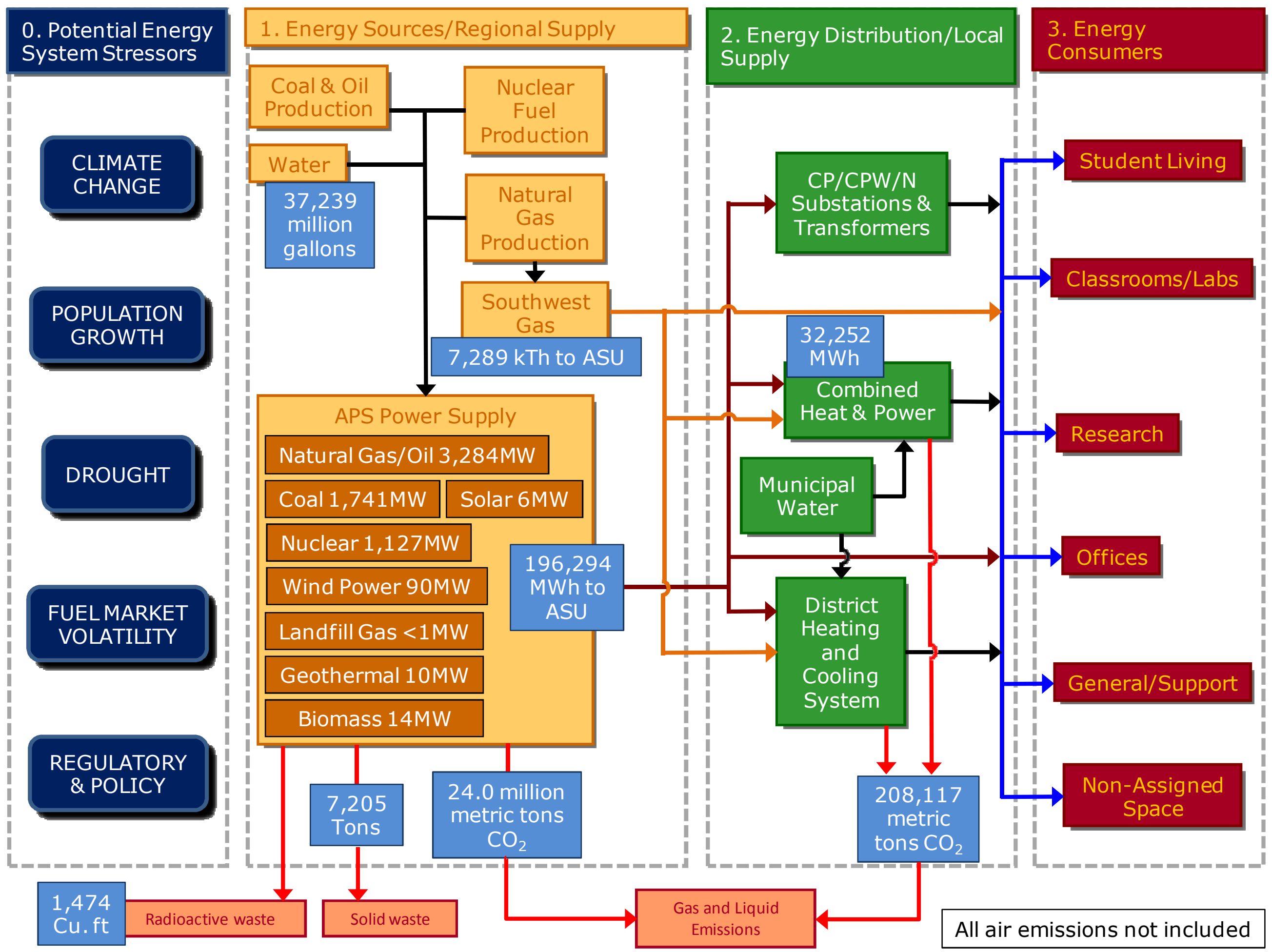

Figure 2. ASU Energy System in 2008.

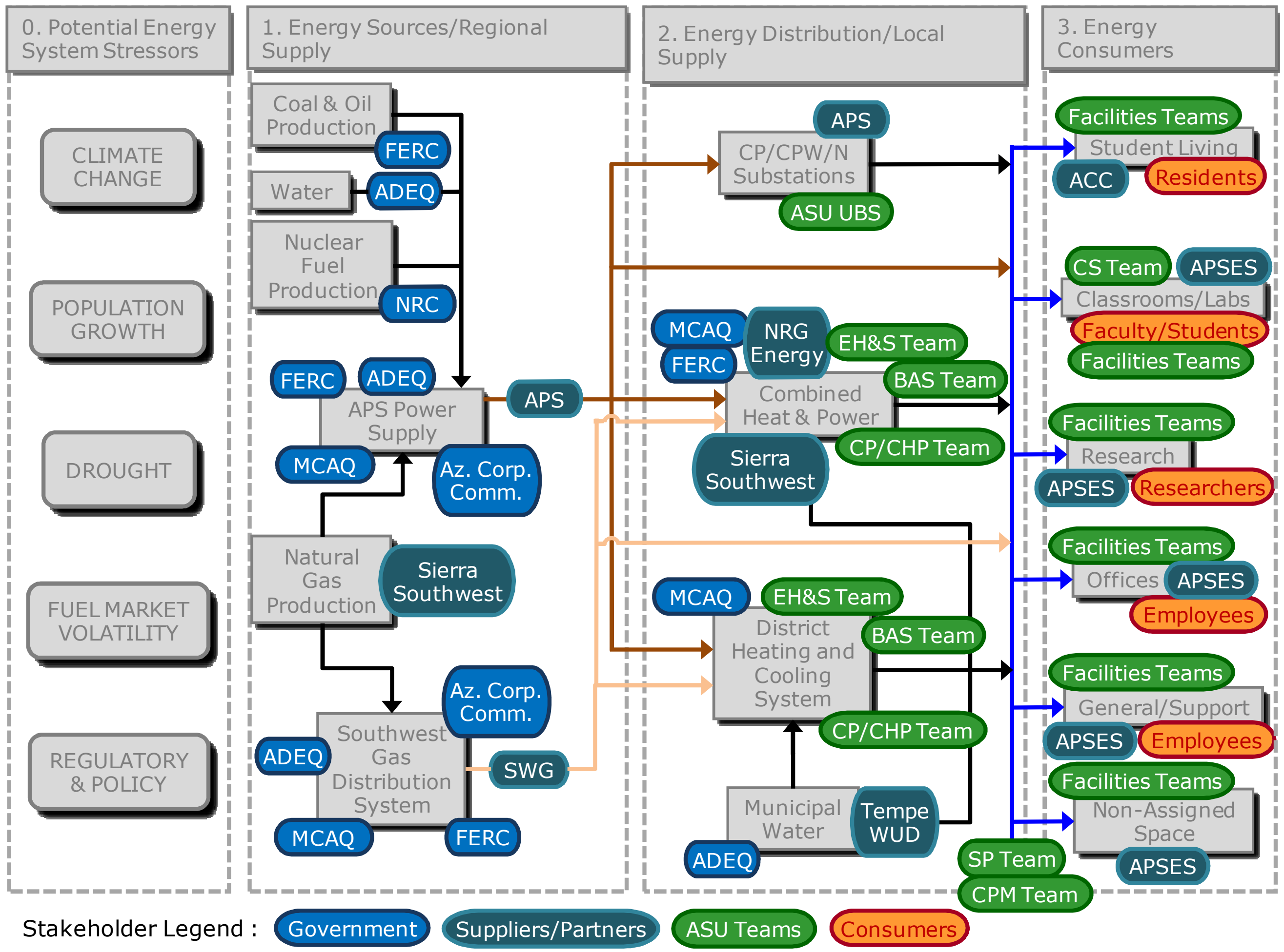

Figure 3. ASU's Energy System Stakeholders in 2008.

ASU's organization is divided into teams that are tasked with ensuring that the university functions effectively while operating within rules, regulations and policies set by external authorities and ASU management to meet the needs of energy consumers around the campus. Energy consumers include residents, students, faculty, researchers, and employees. The direct and/or indirect influences of stakeholder decision-making processes on the energy system are discussed section 4.1.4 below.

Energy system metrics are aligned with each of the four groups of the energy system and summarized in Table 3. Unshaded metrics represent metrics that are currently used; metrics shaded green represent metrics identified by stakeholders to measure performance of the envisioned sustainable energy system.

Fuel market volatility is not currently measured and not envisioned to be a controllable factor for the future envisioned sustainable energy system. This assessment may change in the future for ASU, in which case stakeholders will have to identify an appropriate metric. For energy consumers, space classifications have been specified in column 1 of Table 3, but metrics are specifically identified for each space classification – only student living space has related metrics. These metrics are used to develop indices and conduct a sustainability assessment of ASU's current energy system, which is discussed in section 4.2.4 and Table 18 below.

Table 3

Summary of Metrics for Energy System

	Metrics	Variable	Current State	Units	Sources
0. Potential Energy System Stressors					
Climate Change	Genset Fuel Consumption	Gen MMBTU	3,020	MMBTU	Hunter (2010)
Population Growth	AZ Energy Consumption	AZ MMBTU	1,552,804,727	MMBTU	EIA SEDS (2011)
Drought	AZ State Water Consumption	AZ Gals	7,543,057	Acre-feet	ADWR (2011)
Fuel Market Volatility					
Regulatory and Policy	ASU Total Revenues	Budget $	$ 1,528,690,000	$	ASU UOIA (2011)
	AZ State Funding	State $	$ 482,878,000	$	ASU UOIA (2011)
	NRC National Low-level Radioactive Waste Disposal	US LLRW	2,085,366	Cubic feet	DOE (2011)
1. Energy Sources/Regional Supply					
APS Power Supply	Electricity Cost	$ Elec	$ 17,097,879	$	Plentzas (2010)
	Purchased Electricity	Purchased kWh	210,388,823	kWh	Plentzas (2010)
	ASU Fraction of APS Low Level Radioactive Waste	ASU LLRW	1,474	Cubic feet	APS (2008)
Southwest Gas	Natural Gas Cost	$ NG	$ 9,368,792	$	Plentzas (2010)
	ASU Total Purchased Natural Gas	Therms	7,472,246	Therms	Plentzas (2010)
2. Energy Distribution/Local Supply					
Substations & Transformers	ASU Total Energy Emissions	Tons TE	249,881	Tons	Plentzas (2010)
	ASU Total Waste	Tons TW	76.85	Tons	Plentzas (2010), APS (2008)
	Exported kWh Revenue	Export $	$ -	$	
	Exported kWh	Export kWh	0	kWh	
	ASU Total MMBTUs	Total MMBTU	1,582,564	MMBTU	Plentzas (2010), Gahan (2010)
	ASU Total Renewable Power	ASU Total Renewable Power MMBTU	130,879	kWh	Plentzas (2010)
Municipal Water Supply	Water Cost	$ W	243,515	Tons	Hunter (2010), APS (2008), Lombardo (2011)
	ASU Energy Water Consumption	Gals EW	416,016,247	Gallons	Plentzas (2010), APS (2008)
	RO reject water for cooling towers	Gals RO	0	Gallons	Plentzas (2010)
Combined Heat & Power	Produced kWh (includes recycled energy)	CHP kWh	34,304,277	kWh	Plentzas (2010)
	Steam/Hot Water used	Heat MMBTU	37,095	MMBTU	Gahan (2010)
	Total Chilled Water Tons produced	CW Tons	61,910,316	Tons	Gahan (2010)
District Heating and Cooling System	Chiller Efficiency	%CPE	63%	%	Gahan (2010)
	Boiler Efficiency	%BPE	77%	%	Gahan (2010)
	CHP Efficiency	%CHPE	73%	%	Plentzas (2010)
3. Energy Consumers					
Student/Living	Total Residential Energy	Total Res MMBTU	168,377	MMBTU	ASU EIS (2009)
	# of Residents	# Residents	4,840	#	Smith (2010)
Classrooms/Labs	Total ASU Population	# ASU TP	57,043	#	Stevens (2011)
Research	Percent Buildings Converted/Re-used	BCR	0	%	Plentzas (2010)
Offices	# of Buildings Metered (EIS)	# BM	70	#	Plentzas (2010)
General/Support	# of CO_2 Sensors in Buildings	# CS	16	#	Plentzas (2010)
Non-Assigned Space	# of Buildings Energy Champions	# BC	0	#	Plentzas (2010)
	Total # Buildings	# TB	225	#	Plentzas (2010)
	ASU Tuition Revenue	Tuition $	$ 317,883,434	$	ASU CFO (2011)
	Credit Hours (Tempe, Fall SCH)	# CH	601,336	#	Stevens (2011)
	# of Tempe Graduates	# Grad	10,448	#	Stevens (2011)
	Online Classes	%OC	1.77	%	Plentzas (2010)
	# of ASU Population Informed	# PI	0	#	Plentzas (2010)
	Satisfaction Survey Score	Sat Score	0	#	Plentzas (2010)
	% of Sustainable/Green Suppliers	# SS	0	%	Plentzas (2010)
	Total # of Suppliers	# Suppliers	500	#	Plentzas (2010)
	% Distributed Billing	%DB	0	%	Plentzas (2010)

4.1.2 Sectors of the Energy System

4.1.2.1 Potential Energy System Stressors

Climate change means a warming trend in an already warm local climate, coupled with potentially more extreme weather events.

The result is an increase in demand for electricity and cooling during warmer months, with a higher likelihood for power outages coupled with a higher likelihood for an increase in duration of outages. For steam-driven electric power plants, a warming climate can increase surface water temperatures resulting in reduced water cooling capacity of the water being drawn from rivers, lakes and reservoirs (National Energy Technology Laboratory (NETL), 2009). The response of power plant operators will be to reduce power generation.

The Maricopa Association of Governments (2007) and the Arizona Department of Health Services (2010) have projected that Maricopa County's population will have increased between 45.5% and 67.5% over the 20 year period between 2010 and 2030. Over a 9 year period (2001 to 2009), Arizona Public Service (APS) power generation has grown by a total of approximately 12%. Population growth and the associated growth in demand for electricity will necessarily affect existing and future power suppliers in Arizona and the region.

Water levels in central and southern Arizona aquifers have seen serious declines in the past. Groundwater overdrafting has resulted in the pumping of water becoming uneconomical in some cases, land surface damage (cracking and lowering), aquifer compaction reducing storage space, and water quality deterioration (Arizona Department of Water Resources, 2010). In addition to these ecological impacts, a severe drought would also affect thermal energy and hydroelectric generation sources.

The NETL studied the impacts of drought on electric power generation in two parallel studies in 2009. In the western U.S., more than 94% of power plants that draw fresh surface water for cooling use coal for fuel. Drought conditions that might cause a shutdown of these plants would be replaced by natural gas-fueled power plants. Natural gas plants operate at much lower capacity factors compared to coal plants, and would be the obvious replacement for coal plant shutdowns. Nuclear plants, hydroelectric plants and renewables already operate at high capacity factors and would be unable to replace the power lost from coal plant shutdowns. In areas where excess natural gas capacity is unavailable, an energy shortage could result from drought conditions. Additionally, nuclear power plants that use fresh surface water for cooling will likely face power generation curtailments in response to drought conditions (NETL, 2009). Drought conditions reduce water flow in rivers, and water levels in lakes and reservoirs. In turn, power plants have to curtail production or shut down operations as reduced water intake depth reduces cooling capacity for power production (NETL, 2009).

Fuel price volatility would particularly affect power plant investment decisions. Over the last 30 years, natural gas spot prices have been highly correlated with volatile oil prices. Although international coal markets have exhibited similar volatility, the majority of the U.S. coal market is domestically driven, and therefore, less volatile. This volatility in price would affect private and regulated-utility power generation investment decisions. However, for most electricity consumers within regulated utility markets, regulators allow utilities to incorporate some price volatility risk into tariffs, but buffer the consumer from the extreme volatility of the spot market for fuel (NETL, 2010).

The greatest regulatory risk faced by power plant operators is the passage of CO_2 regulation. While coal plants are the least expensive to build and operate, CO_2 legislation will likely increase variable costs for power plant operators, given that coal plants have the largest carbon emissions factor. The uncertainty of recovering these variable costs from consumers is driving power plant investors to cancel or delay power plant projects (NETL, 2010).

A U.S. National renewable energy portfolio standard (RPS) mandating quantities of renewable power generation would also have the potential to stress the energy system. However, a National RPS would have to overcome many technical and logistical hurdles – large scale projects of renewables have yet to be proven for reliability and cost-effectiveness, and wind resources are substantially lacking in certain regions of the U.S. (NETL, 2010). Intermittent renewable resources will have to be supported by additional fossil-fueled peaking capacity to ensure overall grid reliability (NETL, 2010).

As a public institution, ASU's dependence on funds from the State of Arizona presents risk that has already been realized over the last few years of national and regional economic downturn. When State funds to ASU are reduced, ASU must respond with tuition, admissions, employment and other economically impacting social adjustments. This policy risk clearly is actively managed today, but continues to be a substantial risk for ASU's energy system over the long-term.

The result of these potential stressors for ASU would be that external supplies for energy become either short in supply, expensive to purchase, or more impacting on the environment.

4.1.2.2 Energy Sources and Regional Supply

Today's conventional energy systems begin with fuel production, processing or refining, and transportation to energy generation sources. With respect to APS, ASU's electric utility, coal, oil and nuclear fuel are delivered to each of APS's power plants in the Southwest region to produce base load power for APS customers. During peak demand operations, natural gas is also required to operate some APS power plants. For steam turbine and cooling tower operations, these power plants also require water. Southwest Gas Corporation (SWG), ASU's natural gas utility, is a natural gas distribution company and has no production facilities. Both APS and SWG acquire natural gas from third party suppliers on the basis of projected demand.

In 2008 APS was comprised of 56 power generation units at 11 power generation plants (Smith B., 2009). Table 4 below summarizes APS's power generation plant production and environmental impacts in 2008 (Pinnacle West Capital Corporation, 2010; U.S. Energy Information Administration (U.S. EIA), 2009). ASU's Tempe campus is connected to APS's electric utility grid with various accounts and meters. Although Central Plant (CP) and Central Plant West (CPW) are connected through the same meter (account), they have separate substations for distribution. The Time-Of-Use E-35 tariff applies to all customer accounts with monthly maximum demand exceeding 3000kW for three consecutive months in any twelve month period. The E-56 tariff for ASU's Combined Heat and power Facility (CHP), applies to customers who obtain any part of their electric requirements from on-site generation equipment with a continuous nameplate rating of 100 kW or greater for other than emergency purposes requiring supplemental and back-up or maintenance power and energy from APS. The E-32 tariff applies when monthly maximum demand does not exceed 3,000kW for three consecutive months. ASU has 4 accounts on the E-47 tariff, a Dawn to Dusk lighting tariff, activated by an ambient light sensing photocontrol.

Table 4

APS Power Generation and Environmental Impacts in 2008

	MWh (unless stated)	MMBTU
Nuclear power generation	8,511,905	
Coal power generation	13,165,722	
Natural gas generation	6,344,488	
Diesel fuel oil generation	1,583	
Hydroelectric and solar generation	10,404	
Power generated by APS	= 28,034,102	95,655,159
Purchased power	+ 9,587,185	
Total power system energy requirement	37,621,287	
System losses & APS consumption	- 2,236,780	
Power resold to other Utilities	- 6,590,919	
Net power sold to APS customers	28,793,588	
Total coal consumption [a = U.S. EIA, 2009]	8,304,334 Tons	158,186,595
Total natural gas consumption [a]	52,647,762 MCF	54,077,309
Total diesel fuel oil consumption [a]	16,440 Barrels	92,997
Total nuclear and other fuels [a]		89,407,492
Total system efficiency		31.70%
Solid waste to landfills	7,205 tons	
Water consumed at power plants	37,239,000,000 gallons	
Low level radioactive waste	1,474 tons	
Hazardous waste	11 tons	
Carbon monoxide (CO)	3,404 tons	
Lead	0.283 tons	
Mercury	0.48 tons	
Sulfur oxides (SO_x)	26,836 tons	
Nitrous oxides (NO_X)	52,042 tons	
Carbon dioxide (CO_2)	24,200,000 metric tons	
Volatile Organic Compounds (VOC)	183 tons	
Particulate Matter (PM_{10})	2,260 tons	

The Arizona Corporation Commission regulates SWG to acquire, transport and distribute natural gas to its customers and charge customers for the entire service, as well as to allow customers to purchase natural gas from third parties which SWG transports and delivers to the customer with only transportation-related charges being assessed to the customer.

In 2008, ASU had 47 individual accounts with SWG, of which 46 accounts were on the G-25 General Gas Service Tariff. The Tariff, which applies to commercial and industrial customers, is divided into four volume-based sub-tariffs. ASU's remaining account, the CHP facility, is fueled with natural gas from a third-party supplier (Sierra Southwest), and is on SWG's T-1 Tariff for Transportation of Customer-Secured Natural Gas. Under this tariff, SWG charges ASU a basic service charge, plus demand and volume charges, with other adjustments for natural gas balancing and upstream pipeline charges.

The distribution of APS interconnections and SWG accounts is shown in Figure 4 below.

4.1.2.3 Energy Distribution and Local Supply

The next phase of the energy system consists of energy distribution and local supply. Water is delivered from the local municipal water system (Tempe WUD). Electricity and natural gas are delivered to ASU substations, facilities and appliances. The CHP uses natural gas to produce electricity and heat, which is then consumed on

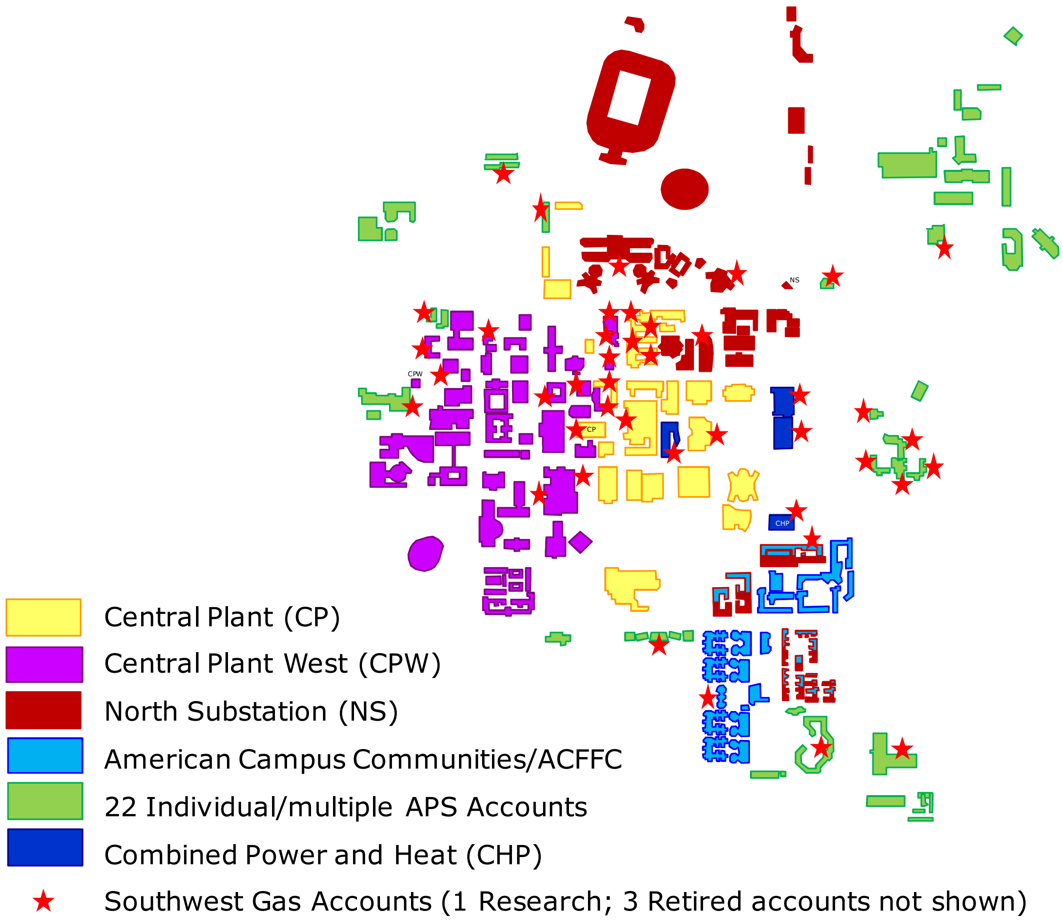

Figure 4. Distribution of APS Interconnections and SWG Accounts.

campus. The CP is the district cooling and heating system for the campus and uses electricity and natural gas to produce chilled water, steam and hot water. The CHP and CP are interconnected to supply campus heating and cooling needs in a cost-effective, reliable manner. Energy is consumed by students, faculty, employees, researchers and residents in the various buildings on campus.

In August 2007, ASU began operation of the CHP facility. This $46 million project provides dedicated power to Biodesign buildings A and B (BDA and BDB) and the Interdisciplinary Science and Technology Building 1 (ISTB1).

In 2007, the upgraded CP and new CHP facilities began operation in tandem to provide heating, cooling and hot water for the entire Tempe campus, with the CHP facility also providing electricity.

The CHP and CP facility system schematic is shown in Figure 5. The minimum electrical load for the CHP is approximately 3MW, consisting of approximately 0.5MW utilized by the CHP facility and approximately 2.5MW of load from BDA, BDB and ISTB1. This minimum load is supplied by the combustion gas turbine (CGT) fueled with natural gas.

The CGT's maximum electricity capacity is 6MW to 7MW (rated at 79.5 million British Thermal Units per hour, or MMBTU/hour). The 1000°F exhaust from the CGT is then used in conjunction with an air-water heat exchanger to recover nominally 25,000 lbs/hr of steam. The CGT exhaust is further utilized to feed a natural gas-fueled duct burner (rated at 53 MMBTU/hour), which then produces additional steam (20,000 lbs/hr nominal). In total, the two steam flows are used to operate a steam turbine which nominally generates an additional 1.5MW to 2MW of electricity. Total electricity produced at the CHP is 7.5MW to 9MW. The final CGT exhaust is vented to atmosphere at 300°F. If the exhaust was cooled any further, the potential for corrosion or emissions issues arise.

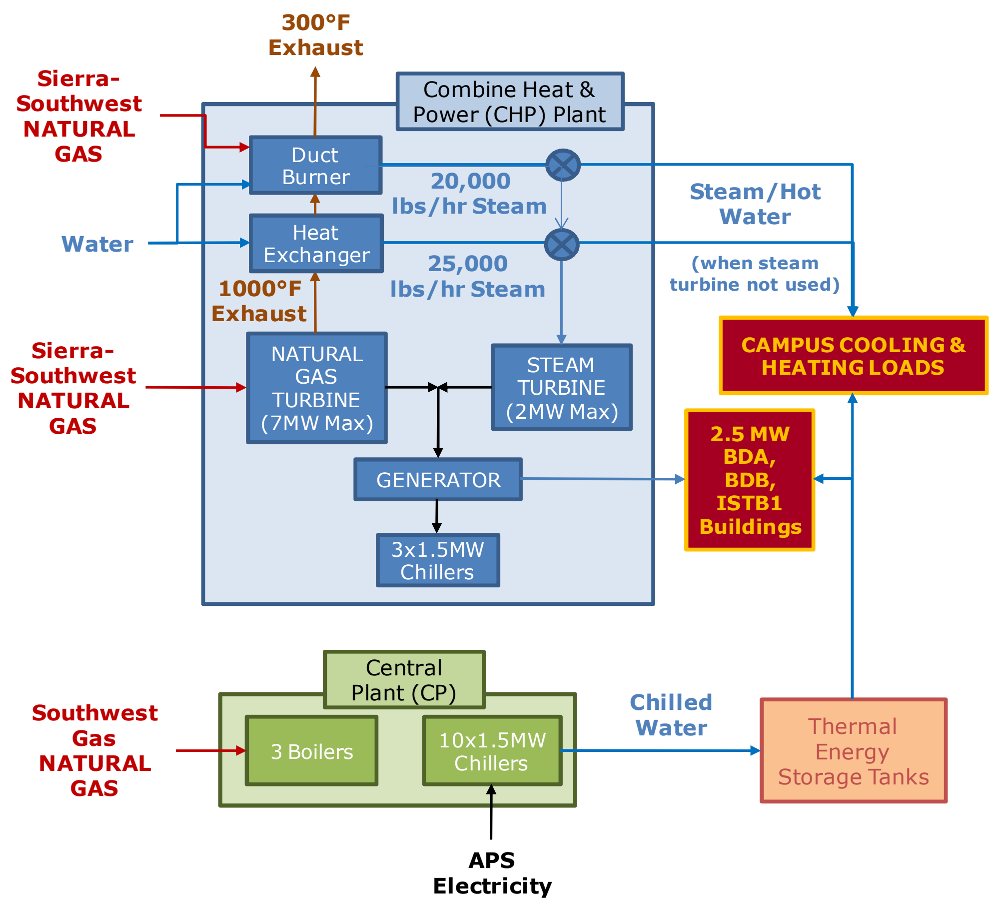

Figure 5. CHP and CP System Diagram.

Hot water and heating for ASU is provided primarily (>80% of the demand) by the CP steam generation system, using two of the three boilers rated at 64 MMBTU/hour, 75 MMBTU/hour and 96.4 MMBTU/hour. The 75 MMBTU/hour boiler was not used in 2008.

ASU cooling needs are supplied by an integrated system consisting of five 2000 ton chillers at the CHP, ten 2000 ton chillers at the CP and a Thermal Energy Storage (TES) system consisting of water tanks installed under the outdoor playing fields at the Student Recreation Complex. To maximize operating efficiency of the CGT and the steam turbine, four of the five chillers at the CHP are always operating, consuming the additional 6MW of electricity from the CHP. Between one and three of the CP chillers are operated to meet cooling demand. The TES system can store 5.5 million gallons of chilled (approximately 40°F) water. The TES is used as a peak-shaver cooling system to supply peak cooling demand that cannot be economically satisfied with the operation of more chillers during peak electrical tariff times.

To satisfy emergency power requirements during electrical outages, in 2008, ASU had two 1,600kW and one 600kW emergency generators at the CP and two 2,000kW emergency generators at the CHP.

ASU's 2008 overall energy consumption and associated environmental footprint is summarized in Table 5.

4.1.2.4 Energy Consumers

Energy demand at ASU is driven by various aspects of the university's operations – the ASU community, facilities, equipment and buildings. From an academic viewpoint, classroom activities of students and faculty drive demand for electricity, cooling and heating during the university's daytime operating hours, while research activities can drive demand year-round. In terms of residential energy demand, ASU had 7,108 student-residents living on the Tempe campus in 2008 (Bentzin, 2010). Again, electricity, cooling and heating is continuously demanded by these residents. On the

Table 5

ASU's Energy Consumption and Environmental Footprint in 2008

ELECTRICITY	**Quantity (kWh)**	**Total Cost**	**$/kWh**
Purchased Electricity (CP)	188,979,000	$ 13,823,103	0.0731
Purchased Electricity (CHP)	7,314,745	$ 989,934	0.1353
CHP Production (Natural Gas cost for CGT)	32,252,487	$ 2,805,622	0.0870
TOTAL	**228,546,232**	**$ 17,618,659**	**0.0771**

FUEL (Therms/Gallons)	**Quantity (Therms)**	**Total Cost**	**$/Therm**
Natural Gas (CP)	709,693	$ 1,253,268	1.77
Natural Gas (CHP STEAM)	4,040,016	$ 4,774,590	1.18
Natural Gas (CHP ELECTRICITY)	2,373,975	$ 2,805,622	1.18
Natural Gas (RESIDENTIAL BOILERS)	165,466	$ 292,201	1.77
TOTAL NATURAL GAS (Therms)	**7,289,150 ****	**$ 9,125,681**	**1.25**
TOTAL DIESEL FUEL (Gallons)	**3,020 ****		

** Fuel consumption for 2 Natural Gas and 18 Diesel generators was unavailable

ASU ENVIRONMENTAL IMPACT	**Units**	**PURCHASES**	**ON-SITE**	**TOTAL**
Solid waste to landfills	tons	50.45		50.45
Water consumed at power plants	gallons	260,746,100		260,746,100
Low level radioactive waste	tons	10.32		10.32
Hazardous waste	lbs	154.04		154.04
Carbon monoxide	tons	23.83	4.62	28.49
Lead	lbs	3.96		3.96
Mercury	lbs	6.72		6.72
Sulfur oxides	tons	200.51	0.27	200.78
Nitrous oxides	tons	364.40	7.06	371.48
Carbon dioxide	metric tons CO_2e	169,448	38,669	208,117
Volatile Organic Compounds (VOC)	tons	1.28	2.00	3.29
Particulate Matter (PM_{10})	tons	15.82	2.72	18.55

administration side, employees and staff use the facilities and equipment to operate the university, again during daytime operating hours of the university.

In 2008, the demand side of ASU's energy system consisted of 285 structures numbered or labeled within the campus building inventory. Of these, 225 were energy consuming buildings, 10 were energy consuming parking structures, and the remaining 50 were various small temporary structures or outdoor areas with minimal or no energy consumption. The Space Planning department at ASU provided the 2008 building space and classification data.

ASU uses the U.S. Department of Education's Post-secondary Education Facility Inventory and Classification Manual (PEFI) for classifying building space. ASU's Tempe campus encompassed 14,855,036 GSF of structured space in its entirety. Of the total, the Net Assignable Area is the space assigned to occupying departments (coded areas 5000-97000) and represents a total of 7,896,263 square feet or 53.16% of the gross square footage area (GSF). The Net Non-Assignable Area is the space that cannot be assigned to occupying departments (coded areas WWW, XXX, and YYY) and represents a total of 2,940,232 square feet or 19.79% of the GSF. The sum of the assignable and non-assignable areas is the Net Usable Area. The area remaining between the GSF and the Net Usable Area is the structural area, 3,117,604 square feet or 20.99%, and cannot be occupied or utilized. ASU's space classifications and area distribution in 2008 are shown in Table 6 and Figure 6.

In 2004, using the services of APS Energy Services Company (APSES), ASU completed the $30 million Phase I of utility infrastructure upgrade projects to reduce electricity, natural gas and water consumption.

Overall, Phase I energy efficiency upgrades installed, implemented and commissioned over two years resulted in annual electricity consumption avoidance of approximately 53 million kWh with a 13MW demand reduction, encompassing eighty buildings and over 6.5 million square feet of campus space, saving ASU approximately $3 million per year over the term of the 15-year performance contract (Arizona State University, 2007). Environmental benefits of Phase I upgrades include annual emissions reductions of approximately 50,317 metric tons of CO_2; 2,014 pounds of VOC; 221,222 pounds of NO_x; 16,748 pounds of CO; 153,700 pounds of SO_2; 12,243 pounds of PM_{10} particulates; and 689,954 milligrams of Mercury (Arizona State University, 2007).

In October 2008, the $40 million Phase II of ASU's energy efficiency upgrade project was initiated by APSES to reduce annual electricity and gas consumption.

Overall, 180 Phase II energy conservation measures will improve 78 buildings and over 5.7 million square feet of campus

Table 6

ASU's PEFI Code Space Classified Areas

PEFI Code	Definition	2008 ASU Square Footage
5000-7000	Unclassified space where areas are unavailable, unusable or unfinished	25,774
11000+	Space classified for classroom instruction	372,188
21000+	Space classified for classroom instruction with laboratory requirements	439,472
25000+	Space classified for research work	702,773
31000-35000	Office and conference room space	1,646,201
40000-46000	Study and library space	314,246
51000-59000	Special use facilities including armory, athletics, clinics associated with athletics, media, animal care and greenhouses	167,575
60000-69000	General use space for auditoriums, assembly halls, exhibitions, museums, galleries, food service, day care, lounges, merchandise service and recreation	641,496
71000-80000	Space used to support central computing, shops, storage, showers, locker rooms, and the police station	1,804,475
83000-89500	Health care facilities	14,403
90000-97000	Residential facilities	1,767,660
5000-97000	**NET ASSIGNABLE AREA**	**7,896,263**
WWW	Circulation area for corridors, elevator lobbies, escalators, bridges, tunnels	2,940,232
XXX	Building service area for custodial services and public restrooms	Included in WWW
YYY	Mechanical area for utility, equipment and communication rooms	Included in WWW
ZZZ	Building structure or construction area that cannot be occupied or utilized	3,117,604
NNN	Non-ASU owned space	798,156
OSC, OSP, OSS	Outside stadium circulation (OSC), outside stadium plaza (OSP), outside stadium seating (OSS)	102,781
TOTAL	GROSS SQUARE FOOTAGE	14,855,036

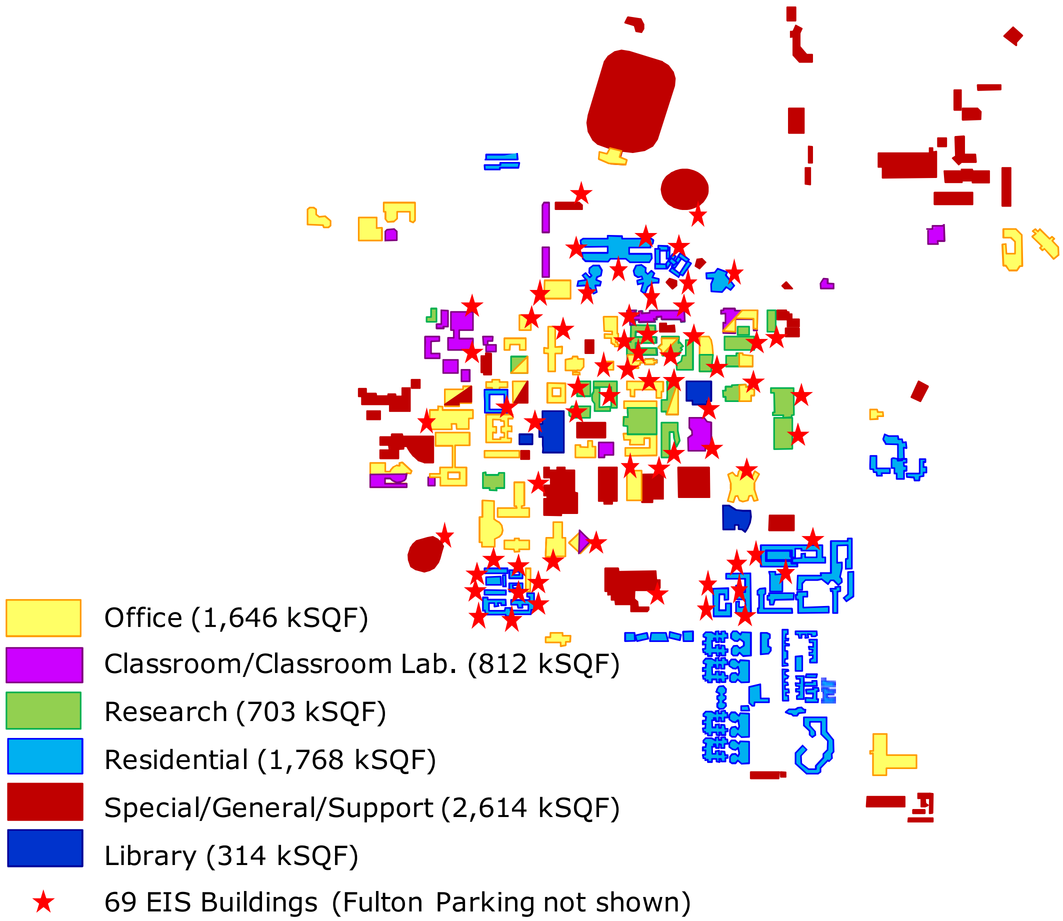

Figure 6. ASU's 2008 Space Distribution.

space. Annual electricity and natural gas consumption is expected to be reduced by 54.5 million kWh and 1.75 million therms, respectively, reducing annual energy costs by over $5.5 million, over the 15-year term of the performance contract. Electricity demand is expected to be reduced by 2,800 kW (Arizona Public Service Energy Services, 2008).

Environmental benefits of Phase II upgrades include annual emissions reductions of approximately 48,838 metric tons of CO_2;

107,622 pounds of NO_x; 25,698 pounds of CO; 52,332 pounds of SO_2 (Arizona Public Service Energy Services, 2008).

4.1.3 Interlinkages and Correlations

Using ACUPCC data, ASU's carbon emissions are compared to those of its peers in Figures 7 and 8.

Of today's 674 signatories to the ACUPCC climate commitment, 24 universities reported carbon emissions in 2008. Figure 7 compares and correlates energy-related carbon emissions for these 24 universities with respect to their GSF. While there are many factors that affect energy consumption and the corresponding carbon emissions, GSF appears to have a fairly strong correlation with energy-related carbon emissions (correlation coefficient = .6848). ASU's energy-related carbon footprint can be

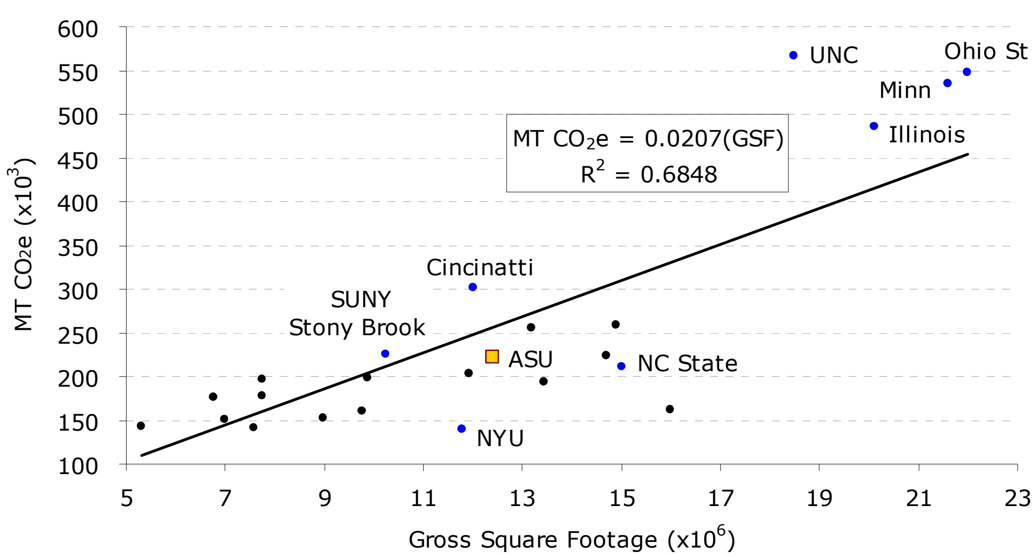

Figure 7. Comparing ASU's Carbon Emissions and Gross Square Footage (President's Climate Commitment, 2007).

considered “average” by this analysis. Its peers on the other hand have widely varying carbon and area footprints. For comparison, both New York University (NYU) and University of Cincinnati have area footprints similar to that of ASU, but their energy-related carbon emissions vary substantially, bracketing those of ASU. Similarly, the State University of New York at Stony Brook (SUNY Stony Brook) and North Carolina State University (NC State) have energy-related carbon footprints similar to that of ASU, but have varying area footprints. The universities with the largest area footprints have correspondingly large energy-related carbon footprints – Ohio State University (OSU), University of Minnesota (Minn), University of Illinois Urbana-Champaign (Illinois) and the University of North Carolina Chapel Hill (UNC).

Figure 8 compares and correlates energy-related carbon emissions for these 24 universities with respect to their Full-Time Equivalent Enrollments (FTE). Here, there is almost no correlation between energy-related carbon emissions and FTE (correlation coefficient = 0.1098). ASU is the most “efficient” university (of the 24 compared) with respect to energy-related carbon footprint and student enrollment.

Based on the strength of correlation between energy-related carbon emissions and gross square footage at ACUPCC member institutions, the area distribution at ASU’s Tempe campus was

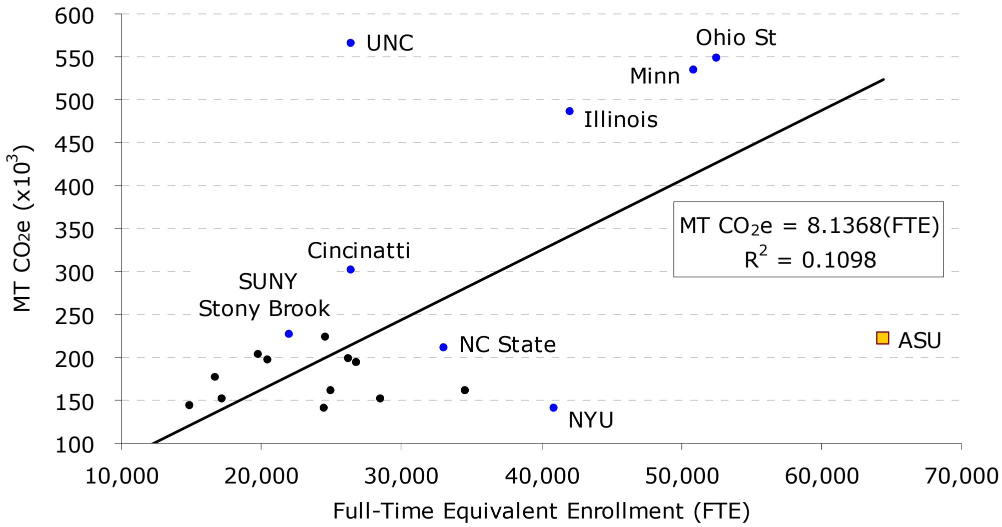

Figure 8. Comparing ASU's Carbon Emissions and Full-time Equivalent Enrollment (President's Climate Commitment, 2007).

evaluated with energy consumption to determine whether a stronger correlation can be identified.

According to the International Energy Agency Energy Conservation in Buildings and Community Systems Group (2008), energy consumption in buildings is driven by (1) climate, (2) building envelope and design, (3) building equipment, (4) building operation and maintenance, (5) indoor environmental conditions, and (6) occupant behavior. The first three factors are non-behavioral while the next three are driven by occupancy and occupant behavior.

Although detailed building energy analysis is beyond the scope of this research project, ASU building performance was compared using the limited non-behavioral data that is readily available to determine if trends or relationships could be identified.

ASU's Energy Information System (EIS) was developed by APSES in 2007 to support the on-going energy efficiency projects. In 2008, 70 buildings were upgraded and wired with monitors and sensors to capture energy consumption data (shown in Figure 6). Stored data included kWh of electricity, BTUs of hot water, BTUs of steam for building heating, and ton hours of chilled water for building cooling. All components were converted to BTUs to determine total BTUs being consumed by each building. For kWh of electricity consumption, data for an additional 15 buildings were available from APS utility bills. Although energy consumed from steam and hot water was measured for several buildings in 2008, the sample size was insufficient ($n<20$) to perform reliable statistical analysis.

The 70 buildings from the EIS database were correlated with area data given the breakdown of each building with respect to assigned areas based on PEFI codes. First, simple regression analyses were performed to evaluate the strength of correlation with respect to each area classification. The analysis was then conducted as a multiple regression with combinations of areas, to determine if the strength of correlation could be increased.

4.1.3.1 Results of Residential Area Regression Analysis

Of the 70 buildings within the EIS database, 26 had residence area within its building space. The results of the simple and multiple regression analyses are summarized in Table 7. The linear correlation of the simple regression analyses are also shown in Figure 9.

Table 7

Residential Area Regression Analysis Results

<table>
<tr><th rowspan="2">Simple/Multiple Regression Variables</th><th rowspan="2">Number of Observations</th><th colspan="3">Correlation Coefficient (%)</th></tr>
<tr><th>Total Energy (BTU)</th><th>Electricity (kWh)</th><th>Chilled Water (ton hrs)</th></tr>
<tr><td>Residential SQF</td><td>26</td><td>94.3</td><td>96.0</td><td>93.4</td></tr>
<tr><td># of Residents</td><td>26</td><td>85.1</td><td>87.2</td><td>86.5</td></tr>
<tr><td>Residential SQF
Net Non-Assignable SQF</td><td>26</td><td>96.5</td><td>96.5</td><td>95.9</td></tr>
<tr><td>Residential SQF
Net Non-Assignable SQF
# of Residents</td><td>26</td><td>96.6</td><td>96.7</td><td>96.3</td></tr>
</table>

The data in Table 7 can be interpreted as follows: for total energy consumption (BTU), 94.3% of the energy consumed can be statistically linked to residential area within campus buildings; suggesting that 5.7% of the total energy consumed is driven by other factors. Also, 85.1% of the total energy consumed can be statistically linked to the number of residents within campus residence halls; suggesting that 14.9% of the total energy consumed is driven by other factors.

As for other factors that may affect energy consumption in residence halls, climate should have a similar effect on all residence halls, whereas inefficient building design could influence the strength of correlation to building envelope (area). In terms of equipment in residence halls, building cooling and heating equipment is similar in

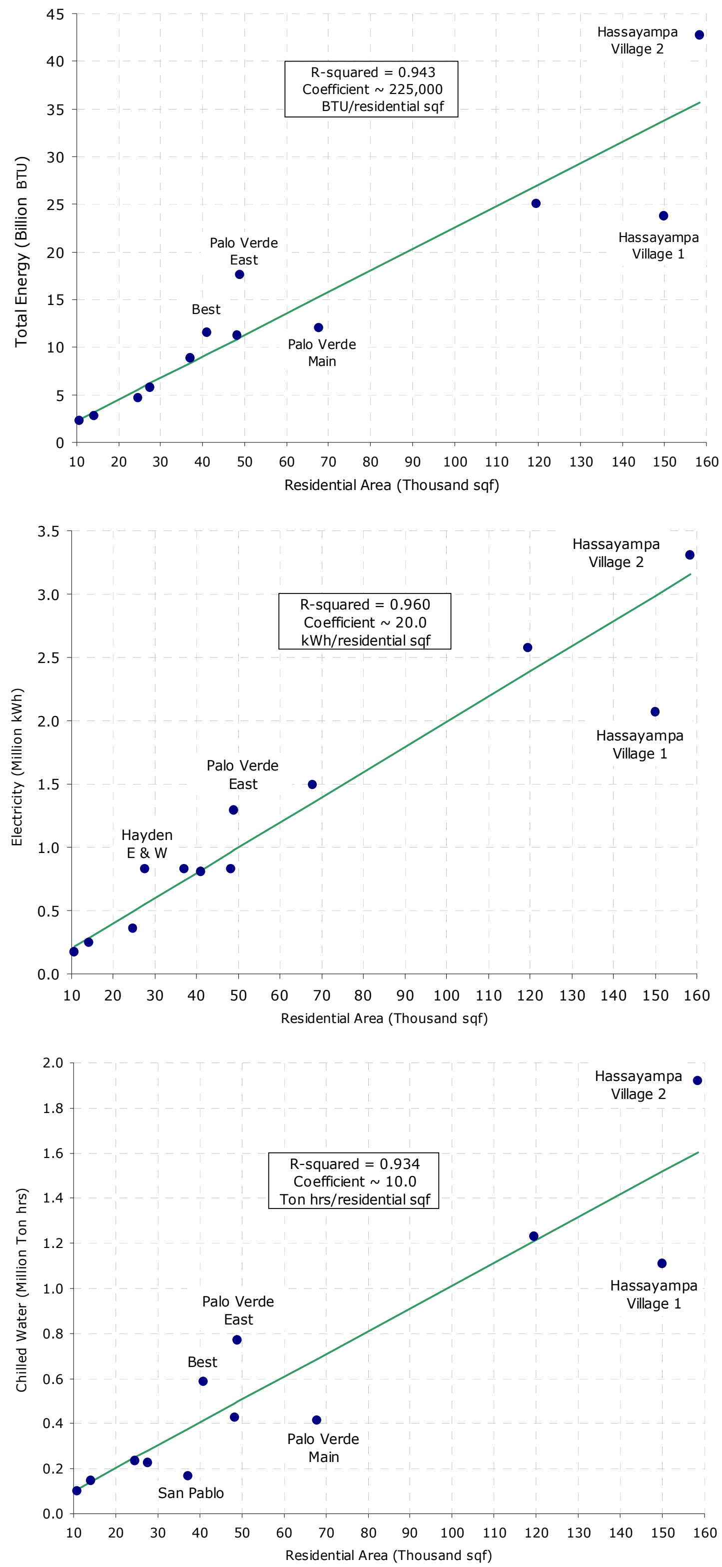

Figure 9. Residential Area Simple Regression Analysis Results.

design, function, and operation, with residents having no influence on governing cooling or heating limits. Resident-owned equipment in residence halls would include lighting, computing, refrigeration and portable cooking. Guidelines limit resident-owned equipment but are not enforced. This can have a varying impact on energy consumption between residence halls, but this equipment is usually only operating when residents are present in the halls, and is primarily driven by resident behavior. Building operation and maintenance schedules are similar for all residence halls, but based on number of residents in buildings, there may be minor variations in operating schedules that affect energy consumption. Indoor environmental conditions are controlled by building operators, with residents having little to no influence on adjusting indoor environmental conditions. These other factors appear to have a limited influence on the strength of correlation between energy consumption and residential area, and only equipment within residence halls having more of an influence on the strength of correlation between energy consumption and number of residents.

Energy consumption has a strong correlation with residential area for all three energy components; simple correlation with the number of residents is marginally weaker. When reanalyzed as multiple regressions, adding net non-assignable area only minimally strengthens the correlations. This analysis indicates that energy consumption in residence halls is strongly correlated with the amount of space classified as residential, with statistically significant, but minimal impact from residence capacity factors or areas considered common (non-assigned).

This can be explained by resident behavior. Students living on campus spend a large portion of time away from residence halls, during which times energy consumption drops. As a result, the correlation between energy consumption and the number of residents is weaker then the correlation with residential area.

Given the strength of correlation with residential area, energy consumption coefficients can be used to nominally predict energy consumption of residence halls. Based on the data available in 2008, for each square foot of residential area, approximately 10 ton hours of chilled water is consumed annually and approximately 20.0 kWh of electricity is consumed annually. Although the analysis suggests that approximately 225,000 BTU of total energy is consumed annually per square foot of residential area, with more complete steam and hot water data for residence halls, this number is likely to increase.

Figure 9 also compares actual energy use for residence halls with predicted energy use, with efficient and inefficient residence halls identified. These residence halls are summarized in Table 8.

The most energy efficient residence halls, based solely on the strength of correlation with residential area, are Hassayampa Village 1 (29.6% less actual total energy consumed compared to predicted total energy use); Palo Verde Main (21.3% under-consumption); and

Table 8

Actual and Predicted Energy Consumption of Residence Halls

Building	Energy Component	Actual Energy Used	Predicted Energy Usage	Excess Actual Energy Used	Excess Actual Energy (% of Predicted)
Hassayampa Village 1	Total Energy (BTU)	23,775,434,350	33,788,308,151	-10,012,873,801	-29.6%
	Electricity (kWh)	2,066,677	2,987,336	-920,659	-30.8%
	Chilled Water (ton hrs)	1,109,948	1,519,254	-409,306	-26.9%
Palo Verde Main	Total Energy (BTU)	12,025,060,790	15,272,408,078	-3,247,347,288	-21.3%
	Electricity (kWh)	1,490,687	1,350,284	140,403	10.4%
	Chilled Water (ton hrs)	415,734	686,707	-270,973	-39.5%
Hayden East & West	Total Energy (BTU)	5,754,678,174	6,209,054,047	-454,375,873	-7.3%
	Electricity (kWh)	829,706	548,963	280,743	51.1%
	Chilled Water (ton hrs)	227,292	279,183	-51,891	-18.6%
San Pablo	Total Energy (BTU)	8,840,514,938	8,364,249,860	476,265,078	5.7%
	Electricity (kWh)	826,563	739,511	87,052	11.8%
	Chilled Water (ton hrs)	169,034	376,089	-207,055	-55.1%
Hassayampa Village 2	Total Energy (BTU)	42,709,936,210	35,673,682,187	7,036,254,023	19.7%
	Electricity (kWh)	3,303,823	3,154,028	149,795	4.7%
	Chilled Water (ton hrs)	1,922,192	1,604,028	318,164	19.8%
Best Hall	Total Energy (BTU)	11,562,907,660	9,235,202,124	2,327,705,536	25.2%
	Electricity (kWh)	807,275	816,515	-9,240	-1.1%
	Chilled Water (ton hrs)	585,996	415,251	170,745	41.1%
Palo Verde East	Total Energy (BTU)	17,602,866,700	11,027,107,014	6,575,759,686	59.6%
	Electricity (kWh)	1,291,970	974,943	317,027	32.5%
	Chilled Water (ton hrs)	769,313	495,822	273,491	55.2%

Hayden East & West (7.3% under-consumption). Hassayampa Village 1 is driven by an under-consumption of both electricity and chilled water. Both Palo Verde Main and Hayden East and West halls' total energy efficiency is driven by under-consumption of chilled water, while both are over-consuming electricity.

The most energy inefficient residence halls, based solely on the strength of correlation with residential area, are Palo Verde East (59.6% over-consumption), Best hall (25.5% over-consumption), Hassayampa Village 2 (19.7% over-consumption), and San Pablo (5.7% over-consumption).

Palo Verde East's inefficiency is driven by an over-consumption of both chilled water and electricity. Over-consumption at Best and Hassayampa Village 2 residence halls is driven primarily by chilled water, although Hassayampa Village 2 is also marginally over-consuming electricity. San Pablo residence hall's inefficiency is driven by an over-consumption of electricity, despite a substantial under-consumption of chilled water.

A review of APSES Phase II energy efficiency upgrades associated with residence halls shows that San Pablo, Best and Palo Verde Main residence halls had a total of 3 upgrades implemented. Based on this analysis, the inefficiencies of Palo Verde East and Hassayampa Village 2 and Best Hall have not been evaluated.

4.1.3.2 Results of Research Area Regression Analysis

Of the 70 buildings within the EIS database, 25 had research area within its building space. The results of the simple and multiple regression analyses are summarized in Table 9. The linear correlation of the simple regression analyses are also shown in Figure 10.

Table 9

Research Area Regression Analysis Results

Simple/Multiple Regression Variables	Number of Observations	Correlation Coefficient (%)		
		Total Energy (BTU)	Electricity (kWh)	Chilled Water (ton hrs)
Research SQF	25	87.7	89.6	89.5
Research SQF / Net Non-Assignable SQF	25	90.9	93.3	93.9

Energy consumption has a strong correlation with research area for all three energy components, with marginal improvement in correlation when net non-assignable area is included.

As for other factors that may affect energy consumption in research buildings, climate should have a similar effect on all research buildings, whereas as inefficient building designs could influence the strength of correlation to building envelope (area). In terms of equipment in research buildings, building cooling and heating equipment is similar in design and function, but researchers have sufficient latitude to modify cooling and heating as required by

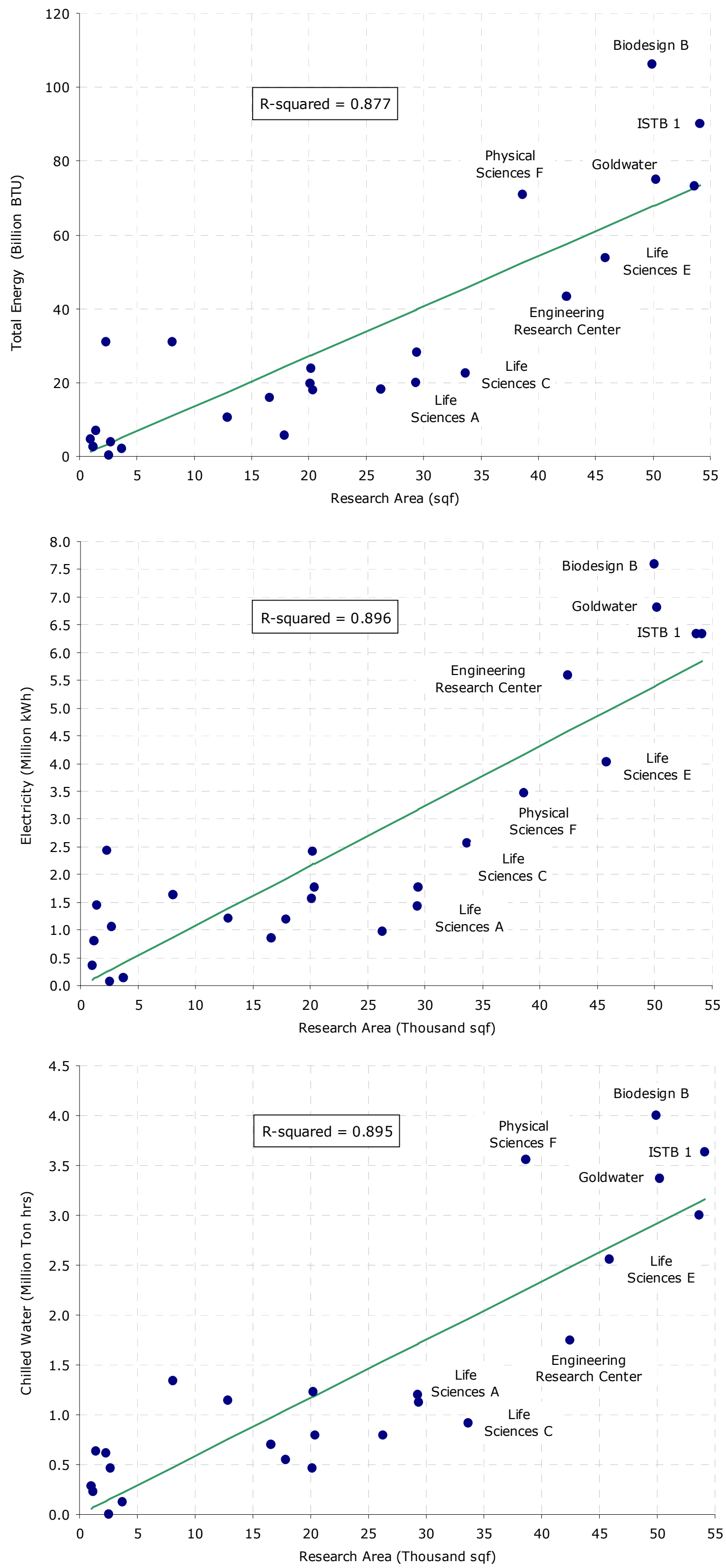

Figure 10. Research Area Simple Regression Analysis Results.

research projects. Furthermore, research buildings require the operation of a wide range of energy-intensive laboratory equipment, which can substantially influence building energy consumption. Unlike residents and residence halls, research buildings can require continuous energy consumption regardless of researcher occupancy or behavior, driven by the requirements of research projects. This can have a varying impact on energy consumption between research buildings. Building operation and maintenance schedules, and indoor environmental conditions for research buildings can vary widely, again, driven by the nature of research projects being conducted. These other factors appear to have greater influence on the strength of correlation between energy consumption and research area.
This suggests that research area within research-classified buildings is the strongest driver of energy consumption, with equipment and research project requirements (indoor settings) likely to be other significant impacts on energy consumption.

Figure 10 also compares actual energy use for research buildings with predicted energy use, with efficient and inefficient buildings identified. These buildings are summarized in Table 10.

The most energy efficient research buildings, based solely on the strength of correlation with research area, are Life Sciences C (50.6% less actual total energy consumed compared to predicted total energy use); Life Sciences A (49.7% under-consumption); Engineering

Table 10

Actual and Predicted Energy Consumption of Research Buildings

Building	Energy Component	Actual Energy Used	Predicted Energy Usage	Excess Actual Energy Used	Excess Actual Energy (% of Predicted)
Life Sciences C	Total Energy (BTU)	22,523,399,630	45,634,531,666	-23,111,132,036	-50.6%
	Electricity (kWh)	2,563,790	3,628,744	-1,064,954	-29.3%
	Chilled Water (ton hrs)	912,305	1,964,899	-1,052,594	-53.6%
Life Sciences A	Total Energy (BTU)	20,004,444,541	39,753,205,744	-19,748,761,203	-49.7%
	Electricity (kWh)	1,429,809	3,161,076	-1,731,267	-54.8%
	Chilled Water (ton hrs)	1,195,496	1,711,665	-516,169	-30.2%
Engineering Research Center	Total Energy (BTU)	43,230,647,450	57,607,424,634	-14,376,777,184	-25.0%
	Electricity (kWh)	5,587,857	4,580,799	1,007,059	22.0%
	Chilled Water (ton hrs)	1,749,571	2,480,419	-730,849	-29.5%
Life Sciences E	Total Energy (BTU)	53,685,592,360	62,177,117,214	-8,491,524,854	-13.7%
	Electricity (kWh)	4,032,506	4,944,169	-911,663	-18.4%
	Chilled Water (ton hrs)	2,557,404	2,677,178	-119,774	-4.5%
Goldwater Center	Total Energy (BTU)	74,976,238,380	68,143,895,980	6,832,342,400	10.0%
	Electricity (kWh)	6,804,176	5,418,632	1,385,544	25.6%
	Chilled Water (ton hrs)	3,366,841	2,934,091	432,749	14.7%
ISTB 1	Total Energy (BTU)	90,011,848,600	73,386,360,161	16,625,488,439	22.7%
	Electricity (kWh)	6,334,873	5,835,500	499,373	8.6%
	Chilled Water (ton hrs)	3,627,732	3,159,818	467,914	14.8%
Physical Sciences F	Total Energy (BTU)	70,934,039,457	52,394,801,129	18,539,238,328	35.4%
	Electricity (kWh)	3,460,227	4,166,304	-706,076	-16.9%
	Chilled Water (ton hrs)	3,557,368	2,255,978	1,301,390	57.7%
Biodesign Institute B	Total Energy (BTU)	106,194,121,000	67,753,254,406	38,440,866,594	56.7%
	Electricity (kWh)	7,600,209	5,387,570	2,212,640	41.1%
	Chilled Water (ton hrs)	4,004,336	2,917,271	1,087,065	37.3%

Research Center (25.0% under-consumption) and Life Sciences E (13.7% under-consumption). The energy efficiency of Life Sciences A, C and E buildings are all driven by under-consumption of both electricity and chilled water. The Engineering Research Center's total energy efficiency is driven by a substantial under-consumption of chilled water, despite over-consumption of electricity.

The most energy inefficient research buildings, based solely on the strength of correlation with research area, are Biodesign Institute B (56.7% over-consumption), Physical Sciences F (35.4% over-consumption), ISTB 1 (22.7% over-consumption), and Goldwater Center (10.0% over-consumption).

Over-consumption of electricity and chilled water drive the energy inefficiency of Goldwater Center, ISTB 1 and Biodesign Institute B. The energy inefficiency of Physical Sciences F is driven by a substantial over-consumption of chilled water, despite under-consumption of electricity.

A review of APSES Phase II energy efficiency upgrades associated with research buildings shows that 16 buildings with research as the majority of classified space had a total of 63 upgrades implemented.

4.1.3.3 Results of Regression Analysis of Other Classified Areas

Simple and multiple regression analyses of energy consumption with respect to areas of other classifications are summarized in Table 11.

Each of the 70 buildings within the EIS database had non-assigned area within its building space. Energy consumption has a moderate to strong correlation with non-assigned area for all three energy components.

As for other factors that may affect energy consumption in buildings with large non-assigned areas, climate should have a similar effect on all buildings, whereas inefficient building designs could influence the strength of correlation to building envelope (area). The moderate strength of correlation can be explained by the fact that non-assigned areas are common, open areas that do not take into account the function, operation or occupancy of the building. As such, building equipment, building operation and maintenance, indoor environmental conditions, and occupant behavior are likely to have a greater influence when correlating energy consumption solely to non-assigned area.

As shown in the previous tables, multiple regression analyses correlating energy consumption with the two variables residential area and non-assigned area (Table 7) and with research area and non-

Table 11

Regression Analysis Results for Other Areas

Simple/Multiple Regression Variables	Number of Observations	Correlation Coefficient (%)		
		Total Energy (BTU)	Electricity (kWh)	Chilled Water (ton hrs)
Non-Assigned SQF	70	69.9	82.9	82.8
Office SQF	55	41.7	57.8	50.6
Office SQF Net Non-Assignable SQF	55	70.0	83.2	82.9
Classroom SQF	27	20.6	30.6	27.3
Classroom SQF Net Non-Assignable SQF	27	76.7	87.0	81.7
Classroom Laboratory SQF	23	27.9	35.2	24.0
Support SQF	48	13.5	25.8	32.4
General SQF	41	0	20.4	11.9

assigned area (Table 9) were also conducted. The correlation coefficients for total energy increased substantially with the two variables compared to the simple linear analysis with non-assigned area, with less of an impact for electricity and chilled water. This suggests that the single largest additional variable to influence energy consumption is building envelope, specifically, area classification.

The correlation between energy consumption and office, classroom laboratory, classroom, support, and general spaces is weak to none. Library, special and health spaces have an insignificant number of observations (less than 20) to show any correlation to energy consumption.

As with residential and research areas, when non-assigned space is included in multiple regression analyses with office and classroom space, the strength of correlation improves, as shown in Table 11.

Since offices are occupied during the day, with heating, cooling and equipment power requirements during those periods, and a substantially reduced energy demand when offices are closed, energy consumption in offices is likely to be driven by occupancy, behavior and office equipment as compared to office area.

Similarly, energy use in classroom areas is also occupant driven, with classroom area less of a driver for energy consumption. This can be explained by reviewing classroom utilization. Classroom usage data for 2008 is presented in Table 12.

The Classroom Scheduling department at ASU provided the 2008 classroom utilization data. Data included building, classroom, meeting time, days of the week, enrollment capacity and total and room capacity. From this information, weekly total time used and enrollment time for each classroom were calculated for 2008 Spring, Summer and Fall semesters. Maximum utilization capacity was also calculated for each classroom, assuming that classrooms are available for 16 hours per day (6AM to 10PM) and for 285 days of the year.

From this information, classroom utilization factors were calculated for each classroom, and for the entire Tempe campus. Of classrooms utilized in 2008, only 0.774% of the maximum utilization

Table 12

ASU Classroom Utilization in 2008

Building	2008 Enrolled Class Hours				# of Classrooms	Maximum Utilization Capacity	Classroom Utilization Factor
	Spring	Summer	Fall	**Total**			
Business Administration	46,011	21,406	42,515	**109,932**	22	4,892,880	2.247%
Business Administration C	33,877	9,881	43,670	**87,428**	15	6,999,600	1.249%
Coor Hall	34,124	9,212	43,349	**86,685**	39	9,192,960	0.943%
Language & Literature	31,325	12,127	37,367	**80,819**	49	7,674,480	1.053%
Physical Sciences H	27,300	13,462	35,418	**76,181**	45	8,157,840	0.934%
Schwada	25,101	2,071	31,823	**58,995**	19	6,224,400	0.948%
69 Others	290,026	81,982	170,092	**542,101**	508	91,578,480	0.592%
Total	487,764	150,141	404,234	**1,042,141**	697	134,720,640	0.774%

capacity of classrooms was actually used. There are likely to be many more classrooms around campus that were not used at all in 2008, so the actual campus-wide utilization may be even lower. Arizona Board of Regents (ABOR) class utilization guidelines recommend a minimum of 15 classes per week, or 45 class hours per week, and 67% seat fill. However, this guideline is for the 50 weekday hours between 7AM and 5PM. Under this guideline, assuming all the enrolled class hours in 2008 occurred during the 50 guideline hours, then the fraction of maximum utilization capacity increases to 1.238%.

This analysis shows that classrooms are significantly under-utilized. Consequently, classroom areas remain idle the vast majority of the time, with low to zero energy demand, explaining the lack of correlation between the two variables. Furthermore, classroom space is primarily equipment-free, with limited demand for heating, cooling or power. Energy consumption in buildings with large classroom spaces must be driven by other areas, and factors, such as other occupants and classified space, occupant behavior, equipment, and building operations.

A review of APSES Phase II energy efficiency upgrades implemented in buildings with majority of space classified as classrooms, classroom laboratories and office space shows that a total of 38 buildings had a total of 88 upgrades implemented.

4.1.4 Stakeholders and Governance Regime

4.1.4.1 Decision Processes for Governmental Stakeholders

Both APS and Southwest Gas are regulated by the Federal Energy Regulatory Commission (FERC) and the Nuclear Regulatory Commission (NRC) at the National level, and the Arizona Corporation Commission at the State level. Additionally, APS and Southwest Gas require environmental operating permits from the Arizona Department of Environmental Quality (ADEQ) and the Maricopa County Air Quality department (MCAQ).

FERC is an independent agency that regulates the interstate transmission and sale of electricity, natural gas, and oil in interstate commerce. FERC also monitors and investigates energy markets but cannot regulate retail sales of electricity, local distribution systems (natural gas or electricity) or approve construction of electric power generation facilities (Federal Energy Regulatory Commission, 2010). FERC also grants “Qualifying Facility” (QF) status to entities permitted to electricity back onto the utility grids. However, exporters are limited to be reimbursed only avoided costs by importing utilities.

NRC regulates commercial nuclear power plants and other uses of nuclear materials, such as in nuclear medicine, through licensing, inspection and enforcement of its requirements (Nuclear Regulatory Commission, 2010).

The Arizona Corporation Commission has authority over the service quality and price charged by public service utilities, trying to balance the consumers' interest in affordable and reliable utility service with the utility's interest in earning a fair profit (Arizona Corporation Commission, 2010).

ADEQ administers programs to improve the health and welfare of Arizona's citizens and ensure that the quality of Arizona's air, land and water resources meets healthful, regulatory standards. However, ADEQ is not responsible for air quality compliance and enforcement in Maricopa County (Arizona Department of Environmental Quality, 2010).

Maricopa County air quality is regulated by the MCAQ, which has compliance and enforcement authority over APS and Southwest Gas facilities in Maricopa County, as well as the power generation, heating and cooling facilities at ASU within Maricopa County. MCAQ follows the air quality standards as set forth in the U.S. Clean Air Act and requires annual monitoring and audit reports from emitters.

FERC, NRC and ADEQ have only an indirect, external influence on energy systems both around the country and within Arizona, resulting from their regulation of local utilities and associated power generation facilities. By authorizing utility tariffs, the Arizona Corporation Commission has an external but direct influence on the energy systems of consumers in Arizona. MCAQ also has an external but direct influence on air polluters in Maricopa County, having the authority to enforce regulations with severe penalties.

4.1.4.2 Decision Processes for ASU Suppliers and Partners

ASU's energy system suppliers include APS supplying electricity through its own generation, transmission and distribution system; SWG providing natural gas from its third party suppliers; natural gas for the CHP purchased from Sierra Southwest and supplied through the natural gas transportation and delivery system of SWG; and the City of Tempe Water Utilities Division (Tempe WUD) supplying water. APSES partners with ASU providing energy efficiency consulting, energy conservation project management, installation and commissioning services for ASU's CP operations, and the Phase II energy efficiency upgrade project. NRG Energy partners with ASU to operate the CHP facility. American Campus Communities, Inc. (ACC) partners with ASU to operate The Barrett Honors College residence halls, housing ASU students.

APS's goal for ASU is to reduce demand at ASU, adjust tariffs as required, minimize cost and demand, while optimizing operations for ASU facilities, and assist ASU in meeting its solar energy goals and with electricity export. APS holds monthly meetings with ASU to make sure issues are being addressed, and twice a year, APS brings key account customers together to provide updates and status of APS operations. ASU is connected directly to APS dispatch, which means there is constant year-round technical support and communication of disturbances. APS is operationally independent from ASU and has little influence on ASU's energy supply or demand; electricity is supplied on a real-time basis as demanded by campus loads (Clawson, 2010).

SWG has no direct impact on energy supply or demand within the ASU energy system, and communication with ASU management is minimal. ASU management is informed of beneficial SWG rebates and incentive programs, such as demand side management, energy efficiency, and combined heat and power programs (Holly, 2010).

For ASU's energy system, the Tempe WUD delivers water to the CP and CHP to be converted to steam and chilled water for ASU's district cooling and heating system. Water supply is real-time and driven by demand. Currently, Tempe WUD has no influence on ASU's energy system supply or demand (City of Tempe, 2010).

APSES provides engineering, project management, and commissioning services to ASU, providing consulting support for operations of the CP and CHP, and working with ASU's facilities teams to install and commission Phase II projects. APSES has a direct impact on ASU energy demand infrastructure, but little influence on the supply side of ASU's energy system. Given the interconnected nature of ASU's relationship with APSES, APSES project and resource allocation actions and recommendations are primarily motivated by ASU budgets, energy economics and university operational priorities (Becker, 2010).

NRG Energy is ASU's partner in operating the CHP facility using natural gas purchased from Sierra Southwest, delivered by SWG through its pipeline system. The CHP facility is an integral part of ASU's on-site power generation system, and is operated in conjunction with the CP. CHP and CP operations are discussed below (Buter, 2010).

ACC own and operates The Barrett Honors College residence halls, and provide facilities management services to the Hassayampa Village (I and II) and Adelphi I and II residence halls. ACC has no impact on energy supply and a direct impact on demand. Other than contract negotiations, ASU and ACC do not meet to discuss energy consumption or costs. Residents' energy demand is only voluntarily reduced with recommendations and suggestions from ACC. There are no mandates, regulations, or policies that affect ACC energy supply or consumption (Cava, 2010).

4.1.4.3 Decision Processes for Energy System Operation

The Office of the Executive Vice President, Treasurer and Chief Financial Officer, headed by Dr. Morgan Olsen, is responsible for leading and managing ASU's financial and business operations and developing ASU's human and capital resources (Arizona State University, 2010).

Within this office is University Services, which is responsible for managing, operating, maintaining, and resourcing ASU's energy system.

This office broadly has a dual responsibility with respect to the energy system. The organization's immediate and short-term priority is to keep the energy system operational, in terms of cost, efficiency, reliability, and resources. Operationally, the organization is prioritized to first meet energy demand, secondly to ensure efficiency and cost are optimized, third, identify opportunities for energy conservation measures in buildings and facilities, and finally, to identify and infuse energy conservation into the organizational culture. In the longer-term, the organization has to transform the energy system to comply with the broader sustainability goals of the university while meeting the growth goals of the university (Brixen, 2010). The University Services department consists of various teams operating and managing the energy system.

The Facilities Management organization's goal is to make sure the energy system is operated to reduce cost, maximize efficiency and reliability, minimize service calls, and look for systemic causes of problems. Energy system management may conflict with maintenance, service and other customer demands for the organization (Pinney, 2010).

Facilities Management is also responsible for optimum operation of the cooling and heating systems of the ASU energy system, which include operation and management of staff and facilities of the CP, CHP and TES to maximize operational efficiency and reliability while minimizing cost; the Building Automation System (BAS), for air scheduling for all campus buildings, with the goal of satisfying customer needs while minimizing energy use; the Electrical, Mechanical and HVAC shops on campus, which support the other departments and work with APSES performing commissioning activities and identify energy system-related issues (Pretzman, 2010). The Facilities Management organization is mostly a proactive decision-making entity, with the minimal reactive decision-making highly politically driven. Customers demand immediate corrective action without regard for the best overall decision for ASU. The overall goal for Facilities Management is to balance total cost of ownership with customer satisfaction (Pinney, 2010).

The CP/CHP team operates the CP, CHP and TES system in a proactive, harmonious manner. Reactive decision making is only necessary in response to short-notice or emergency events. The energy system is operated using the dispatch model, created for ASU by APSES, and environmental (such as weather forecasts) and system drivers (electricity and gas tariffs, and customer demands) to maintain optimal functionality (Gahan, 2010).

According to Buter (2010), the team operates the energy supply system by maximizing reliability and optimizing operation of the CHP, which means maximizing electricity production for continuous economical electricity supply to the Biodesign buildings A and B maximizing chilled water production at the CHP, and then transferring excess cooling load to the CP.

Energy supply decisions are also influenced by the demand side of the energy system, by way of building controls and scheduling of building operations, with the primarily goal to minimize operation and maintenance costs. The team's primary goal is to supply the energy demanded by the operation of the university on a daily basis with little influence on the demand side of the energy system. Complying with individual departmental energy requests, such as weekend or holiday work or research activities tend to add inefficiencies into the system (Gahan, 2010).

The Building Automation Systems team (BAS) is responsible for air handling to most buildings on the Tempe campus, amounting to approximately 150 buildings with four or five air handlers each (on average) and thousands of rooms. With input from the Classroom Scheduling Team, BAS schedules building cooling and heating using programs with set points, and valve controls to regulate hot water, steam, and chilled water flows around campus, in and out of buildings. BAS tries to manage and maintain the system proactively, but customer requests regularly require reactive management. Customer demand is the primary consideration, with energy supply and demand becoming secondary. For example, the summer and winter building temperature setting mandate only applies to classrooms, with exceptions provided for research, art, library and athletics buildings (Cano, 2010). Another example is inefficient energy use resulting from a conflict between current building utility and the original design intent. As such, some buildings are entirely cooled to respond to minimal space cooling requirements (Laroche, 2010).

The Environmental Health and Safety (EH&S) team is responsible for acquiring air permits or modifying existing air permits for ASU for any equipment or appliances that emit exhaust gases to the atmosphere (Hunter, 2010).

EH&S has minimal direct influence on energy supply and demand, but air quality regulations affect operations indirectly as a result of exhaust emissions. EH&S worked with MCAQ to have ASU permitted with a 'synthetic' minor operating permit, with a limit of 49 tons per year or less of total Hazardous Air Pollutants (HAP, includes carbon monoxide, nitrous oxides, sulfur oxides, volatile organic compounds, and particulate matter less than 10 microns in diameter) emissions. This modified permit reduces ASU's monitoring and reporting costs. A new U.S. Environmental Protection Agency rule is anticipated in the near future regarding carbon dioxide emissions reporting for all sources emitting greater than 25,000 metric tons of carbon dioxide (Hunter, 2010).

The Capital Programs Management (CPM) team is responsible for major modifications or renovations of existing buildings and construction of new buildings on campus. New buildings are mandated to be LEED Silver certified as a minimum, and lead to more efficient and energy conserving buildings (Jensen B., 2010).

The goal of the group is to deliver customers' expectations on time and on budget. Projects are prioritized by building users – research facilities are the primary focus, followed by life safety, and building code issues take parallel priority for the remaining buildings around campus. Decisions are driven by design guidelines, building and fire safety codes, the Arizona State Legislature, ABOR and University organization statutes. The statutes and policies may sometimes conflict. An example is that LEED Silver mandates are not necessarily supported by all members of the hierarchy of decision makers (Jensen B., 2010).

The CPM team has no influence on the supply side of the existing energy system. Their work leads to demand reduction and energy efficiency of the energy system, affecting both current and future operation of the system (Jensen B., 2010).

4.1.4.4 Decision Processes for Energy System Consumers

The Space Planning (SP) team is responsible for tracking space utility around the Tempe campus. Building usage is generally defined by number of faculty, students, and employees that may use the building, or intended research within the building, using ABOR guidelines for square footage of space assignable to type of space usage. ABOR uses the nationally-recognized and widely used space planning guides as defined by the Council for Education Facilities Planning International. Energy consumption or energy efficiency is not part of the analysis or design; the only consideration is how the building might be connected to the electrical grid and the campus cooling and heating loops. The SP team currently only influences energy demand indirectly; it is not part of the current role for the team (Laroche, 2010).

The Residence Life Facilities Management (RLFM) team is responsible for facilities management for student housing (Herrara, 2010).

Energy issues within residence halls and related to facilities are not directly discussed in meetings, but indirectly addressed through activities of the team. Energy demand is strictly driven by the residents, and although energy efficiency and conservation behaviors are encouraged, they are difficult to actively implement (Herrara, 2010). Residents freely use as much energy as they need with little regard to efficiency or conservation (Cava, 2010).

Residence housing decisions are driven by colleges, the class of students and the residence life organization. Energy consumption is given little or no priority; however, energy bills, maintenance records, and age of buildings are taken into account when deciding the sequence of occupying residence halls (Herrara, 2010).

There are no specific rules and regulations that regulate residence hall functions – residents must be comfortable, safe, and secure. Residence hall management is primarily driven by safety and security of students and building codes and regulations (Herrara, 2010).

There is nothing formally taught to incoming residents regarding energy use and conservation. Without information on tariffs, energy usage, costs, or any publicized demand reduction goals, it is difficult for this organization to affect demand, and indirectly, affect supply of energy (Smith T., 2010).

From an energy sustainability perspective, Residence Life presents a significant opportunity for ASU to reduce energy consumption. However, enforcement and accountability are critical to reducing consumption.

The Classroom Scheduling Team is responsible for scheduling use of any classroom on the Tempe campus. Most classrooms around campus are oversized and under-utilized, and managed according to the aforementioned ABOR class utilization guidelines. Departments and colleges have strong influence on classroom usage, and energy consumption is not a consideration (Stimson, 2010).

Research areas are scheduled to consume energy on-demand, continuously throughout the year. To successfully support research, energy (and other utilized facility equipment) must be readily available to support the necessary functions of research activities. As such, energy demand reduction is not a primary focus, while research facilities are optimized for energy efficiency as much as possible (McLeod, 2011).

4.1.4.5 Decision Processes for Energy System Evolution

The University Sustainability Office has responsibility to institutionalize sustainability activities. This effort is built around the Sustainability Practices Network, a team of nine working groups and four resource groups charged with creating a plan to develop a more sustainable university. One of the working groups is solely focused on energy use as the largest single contributor to ASU's carbon footprint (Jensen R., 2010).

Communication is critical to changing the culture and behavior, but unlike private entities, where things are mandated and implemented quickly, at a university, funding sources and autonomy of schools and departments make it more difficult (Jensen R., 2010).

This office indirectly influences demand by way of energy conservation programs and activities, but primarily assists with consumption management (Bentzin, 2010).

Key insights of the stakeholder and governance regime are presented in section 4.4.

4.2 Vision and Sustainability Assessment Results

4.2.1 Comparing Principles of Energy Sustainability

The principles of energy sustainability discussed below are derived from generic sustainability principles provided by various authors.

The purpose of this comparison is to validate that Gibson's (2005) sustainability principles are comprehensive and can be operationalized for energy sustainability and used in this study. According to Gibson et al. (2005), a sustainable energy system must be resource efficient, environmentally benign, and economically competitive, encouraging a common equitable standard of living for all generations, with widespread participation from all stakeholders and governed to enhance sustainability, manage risk, and adapt as necessary.

Using the Natural Step's four principles of sustainability (Robèrt, 2002), a sustainable energy system must contribute to people's capacity to equitably and efficiently meet their basic needs, use resources productively and efficiently while preventing the progressive degradation and destruction of the biosphere, and prevent the progressive buildup of substances extracted from the earth or produced by society by replacing limited or harmful resources with abundant or benign options.

Assefa and Frostell (2007) use Sachs' (1999) work on "whole sustainability" to suggest that an energy system is sustainable when it simultaneously satisfies the following criteria:

- Ecological sustainability: maintaining a stable energy resource base without over-exploiting renewable resources or environmental sinks, substituting depleted renewable resources, and maintaining biodiversity.
- Economic sustainability: producing goods and services on a continuing basis, with manageable levels of debt, avoiding sectoral imbalances that damage production.
- Social sustainability: ensuring widespread participation and accountability, with equity in distribution and opportunity.

- Political sustainability: providing an overall framework for national and international governance.

Haas et al. (2008) approach energy system sustainability from the perspective of energy service demand. To transition towards sustainable energy systems, the authors suggest that energy services become environmentally benign and equitably distributed, while improving in energy efficiency. Furthermore, a sustainable energy system should have decreasing energy intensity (energy per unit of economic growth), countering the historical trend of increasing energy service demand with energy service efficiency improvements.

Natural Capitalism (Lovins & Lovins, 2000) suggests that a sustainable energy system is radically resource efficient with respect to supply and demand inherently implying equity and efficiency, eliminating the concept of waste, and shifting to demand for energy services, while actively reversing harmful effects with restoration activities.

In comparing these principles of energy sustainability, environmental impact, economic opportunity, resource efficiency, and equitable distribution of energy are commonly addressed. An aspect that only Gibson et al. (2005) and Assefa and Frostell (2007) suggest is the requirement for widespread participation, with policy and governance that encourage energy sustainability. Although only Gibson and Robèrt address the need to understand and manage risks to the energy system, it can be argued that any forward-looking principles of sustainability would necessarily require addressing assumed future risks. The derived principles of energy sustainability are compared in Table 13.

Table 13

Comparison of Derived Principles of Energy Sustainability

	Gibson (2005)	Robert (2002) The Natural Step's Four System Conditions	Assefa and Frostell (2007)	Haas et al. (2008)	Lovins and Lovins (2000) Natural Capitalism
ENVIRONMENTAL INTEGRITY	The energy system should be operated such that it is environmentally harmless	Prevent the progressive buildup of substances extracted from the earth AND produced by society AND Prevent the progressive degradation and destruction of the biosphere	Ecological sustainability: maintain biodiversity and stable resource base, without over-exploiting resources or sinks	Environmentally benign	Actively reverse harmful effects with restoration activities AND eliminate the concept of waste
ECONOMIC OPPORTUNITY	The energy system should be economically competitive encouraging a common standard of living for all stakeholders	Contribute to people's capacity to equitably meet their basic current and future needs	Economic sustainability: producing sectorally balanced goods and services with manageable debt levels	Decreasing energy intensity (energy service demand)	Shift to demand for energy services
GENERATIONAL EQUITY	The energy system should be generationally equitable over the short- and long-terms	Use all our resources fairly and responsibly to best meet the needs of all generations	Social sustainability: ensure widespread participation and accountability, with equity in distribution and opportunity	Equitably distributed	
RESOURCE EFFICIENCY & MAINTENANCE	The energy system should be resource efficient, in that energy consumption is minimized while maximizing output	Use all mined minerals, natural resources and substances used by society efficiently		Improving in energy efficiency	Radically resource efficient
PARTICIPATORY GOVERNANCE	The energy system should be governed with widespread participation, supportive of supply and demand behavior and policies that promote energy sustainability		Political sustainability: provide an overall framework for national and international governance		
RISK MANAGEMENT & ADAPTATION	The energy system should be operated such that risks are managed, with the system adapted when possible	Exercise caution when modifying nature			

4.2.2 Principles of Energy Sustainability

The sustainability impact of ASU's energy system is assessed herein, operationalizing the basic principles for sustainability assessment proposed by Gibson et al. (2005) as detailed below.

4.2.2.1 Socio-ecological System Integrity

Gibson's first principle for sustainability requires socio-ecological system integrity. Essentially, this principle recognizes the absolute need to protect the life support functions upon which both human and ecological welfare depend. As such, an energy system must be developed that will maintain long-term integrity of the ecosystem from which fuels are harvested, while providing the necessary energy services for the long-term.

From the standpoint of a sustainable energy system, this means utilizing energy sources that do not degrade or harm the integrity and quality of the entire biosphere – the atmosphere, hydrosphere, or lithosphere systems. Specifically, waste emissions from the energy system that are currently deposited back into the biosphere in concentrated amounts with known harmful effects must be reduced and eventually eliminated.

The current global energy system has significant impacts on human and ecosystem welfare, at global, regional, and local scales. The impacts are discussed and compared below for various energy supply technologies.

4.2.2.1.1 Global Environmental Impacts

4.2.2.1.1.1 Climate Change

The primary socio-ecological impact of the energy system at the global scale is disruption of the climate. Fossil fuel combustion produces the most CO_2 of all human activity, changing the composition of the atmosphere, and significantly influencing global climate (UNDP, 2000). The global climate directly affects human and ecosystem welfare, impacting food supply productivity, ecosystem and human health by way of spread of disease, biodiversity abundance and distribution, water availability, and human population liveability due to the changing temperature and humidity, frequency and severity of storms, and impacts of sea-level rising to coastal communities. Additionally, endangered species will be at increased risk since their habitats are already reduced. Biomass energy plantations replacing farmland can actually increase biodiversity - bird species replacing other animals that are negatively affected (IEA, 2002).

Various life cycle assessments have been conducted on environmental impacts of power generation around the world. Using this data, the emissions of various energy sources are compared in Table 14.

As Table 14 shows for CO_2 emissions, coal and refined coal technologies have the greatest potential impact on global climate,

Table 14

Emissions from Power Generation with Potential for Global Environmental Impact

	CO_2 (CO_2-eq. g/kWh)	Methane (CO_2-eq. g/kWh)	N_2O (CO_2-eq. g/kWh)	Total (CO_2-eq. g/kWh)	ODP CFC-11 equiv. (g/kWh)	Sources
Brown Coal (Europe)	1334	2	2	1,338	133×10^{-7}	Gantner 1996
Hard Coal (Europe)	993	76	2	1,071	612×10^{-7}	Gantner 1996
Pulverized, Ultra supercritical, Gasified (Japan)	820-943	40-47	No data	862-992	No data	Uchiyama 1995
Oil	526-882	No data	0.5-2.8	527-885	No data	Dones 2005
Simple Cycle & Combined Cycle Natural Gas (Canada)	747-866, 524-612	59.2 (a)	0.2 (a)	576-925	250×10^{-7} (b)	Beals 1993, (a) Spath 2000, (b) Dones 1994
Liquid Natural Gas (Japan, Sweden)	463-594, 422	45-58, 0.69	No data, 0.12	423-652	No data	Uchiyama 1994, Brännström-Norberg 1996
Nuclear (Japan, Sweden)	7.5-20.0 4-99	0.33-0.88	<0.1 (c)	4-100	32×10^{-7} (d)	Uchiyama 1995, Fthenakis 2007, (d) Dones 1995
Wind (Japan)	33.5	1.35	<0.1 (c)	34.9	5.23×10^{-7} (e)	Uchiyama 1995, (c) Denholm 2005, (e) Martinez, 2009
Biomass (Canada, Sweden)	31, 0 (e)	No data	0 (f)	31	0	Beals 1993, (f) Brännström-Norberg 1998
Hydroelectric (Japan, Sweden)	17.2 .59-.79	0.4 No data	<0.1 (h)	.99-17.6	17.9×10^{-7} (g)	Uchiyama 1995, Brännström-Norberg 1995, (g) Frischnecht 1996
Solar (100kW systems)	9.4-15.6, 16-49	4.5 (g)	4.65-38.75 (j)	14.05-87.75	No data	Sherwani 2010, Fthenakis 2007, (h) Pehnt 2005, (j) Sengül 2011

followed by oil and natural gas technologies and nuclear power. Renewable energy technologies have the least CO_2 emissions over their life cycles.

4.2.2.1.1.2 Ozone layer Depletion Potential (ODP)

The stratospheric ozone layer screens the earth from life-threatening ultraviolet radiation from the sun. Depletion of the ozone layer can contribute to a greater risk of skin cancer and impaired vision in humans, improper development and reproductivity of animals, an increase in plant growth imbalance and risk of disease, a reduction in phytoplankton productivity in the oceans, and a reduction in the outdoor useful life of certain polymer materials used in products (IEA, 2002).

Trace gaseous emissions can substantially accelerate ozone decomposition rates, and ultimately ozone layer depletion. In 1992, the World Meteorological Organization presented Ozone layer Depletion Potentials (ODPs) for various gases, weighted against the baseline, commonly used refrigeration compound CFC-11 (Chloro-Fluoro-Methane or Freon, ODP = 1.0). ODPs are affected by atmospheric lifetimes of the compounds, and some ODPs may take hundreds of years to reach steady-state. The ODPs presented in Table 14 are steady state and represent the combined CFC-11 equivalent ODP for each technology with its various ozone depleting emissions.

Nuclear power and the renewable technologies have the least potential to deplete the ozone layer (IEA, 2002).

4.2.2.1.2 Regional and Local Environmental Impacts

4.2.2.1.2.1 Acidification Potential (AP)

At the regional scale, sulfur oxides, nitrous oxides, and particulates become precursors for acid deposition thousands of miles from the source. Acidification can eliminate low-pH intolerant species and damage ecosystems, crops, and human-built environments, and reduce the productivity of forests, fisheries, and farmlands (International Energy Agency (IEA), 2002). The measure for acidification potential (AP) shown in Table 15 is the amount of hydrogen ions (a measure of acidity of a substance) produced in terms of SO_2^- equivalents.

Coal fuel power generation has, by far, the greatest acidification potential compared to natural gas fueled power plants, nuclear power and renewable fuel technologies. Coal mining produces acidic water as well as refuse piles of rock and dirt that oxidize when exposed to the atmosphere and produce acidic emissions. Furthermore, coal has the highest nitrogen and sulfur content of all the fossil fuels, and combustion releases these as acidic oxide gases (Gantner & Hofstetter, 1996).

Table 15

Emissions from Power Generation with Potential for Regional and Local Environmental Impact

	AP SO_2^- equiv. (g/kWh)	EP PO_4^{3-} equiv. (g/kWh)	POCP C_2H_4 equiv. (g/kWh)	TCW (g/kWh)	TCS (g/kWh)	TOTAL (g/kWh)	Sources
Brown Coal	14.9	12.2	.032	0.00127	0.00313	27.1364	Gantner 1996
Hard Coal	5.15	13.0	.09	0.0853	0.04402	18.3693	Gantner 1996
Oil	1.45-2.98	3.0-8.4	No data	No data	No data	4.45-11.38	Pehnt 2005
Natural Gas	1.533 (a)	1.157 (a)	0.0121 (a)	.0031	0.045	2.7502	(a) Phumpradab 2009, Dones 1994
Nuclear	.0246	0.9856	0 (b)	Radio-active	Radio-active	1.0102	(b) Dones 1995, Tunbrant 1996
Hydroelectric (UCPTE, Sweden, Norway)	0.0186, 0.00528-0.00677 (c), .0039 (d)	0.0756, 0.0305-0.0488 (c)	0.00225, 0.0010-0.0033 (c)	0.00038	0.00038	0.09826	Frischnecht 1996, (c) Brännström-Norberg 1995, (d) Sandgren 1994
Wind	0.00543	0.00057	0.0002-0.0145 (e)	No data	No data	0.0062-0.0205	Martinez 2009, (e) Pehnt 2005
Biomass	0.5222-1.0413	4.421-6.612	0.00735-0.01501	0	0	7.6683	Brännström-Norberg 1998
Solar	0.036-0.283	0.090-0.750	<0.0149 (e)	No data	No data	0.1409-1.048	Sengül 2011

4.2.2.1.2.2 Eutrophication Potential (EP)

Eutrophication is the over-fertilization of terrestrial or aquatic environments with nitrates and phosphates. In terrestrial environments, plant species can become endangered as weaker species overgrow the natural balance. In the aquatic environment, the overproduction and decay of algae and other simple plants causes oxygen levels to decrease. This decline in dissolved oxygen levels reduces fish populations, and impacts fishing, hunting and aesthetic features. Human health can be impacted if drinking water sources are affected by eutrophia (IEA, 2002). Eutrophication potential (EP) is measured as the amount of phosphate ions emitted by power generation, as shown in Table 15.

In coal and natural gas fueled power generation, the EP is primarily driven by NO_x emissions from combustion, while the release of phosphates into surface waters drives the EP for hard coal (IEA, 2002).

Although residues removed for biomass energy take out excess nitrogen through combustion, some of the nitrates and most of the phosphates are returned to, and impact, environments (IEA, 2002).

Nuclear, wind, and hydroelectric power systems have relatively lower eutrophication potentials.

4.2.2.1.2.3 Photochemical Ozone Creation Potential (POCP)

Photochemical ozone is the primary component that drives smog or air pollution. Photochemical ozone, unlike protective stratospheric ozone, is created at ground level from the chemical reaction of unburned hydrocarbons and nitrous oxides. Urban air pollution is primarily driven by an inefficient transportation sector, power generation, and industrial sectors with limited pollution controls, inefficient localized power generation, and refuse burning due to ineffective or non-existent solid waste collection (UNDP, 2000). Photochemical ozone creation potential (POCP) is measured as the amount of ethene emitted by a source, as shown in Table 15. The primary health impact from air pollution is inhalation health of humans and animals, with the young and the elderly being particularly susceptible (IEA, 2002).

Table 15 again shows the greater relative impact of fossil fuels compared to nuclear and renewable energy technologies.

4.2.2.1.2.4 Contamination of Water and Soil

Toxic contamination of water (TCW) and soil (TCS) comprises the metallic ions, such as those of cadmium, copper, mercury, zinc, lead, and chromium that are deposited into water and their respective metallic salts into soil. Toxicity has the potential to harm plant and human life (IEA, 2002). As shown in Table 15, hard coal and natural gas have the highest emissions of toxic chemicals to water and soil.

4.2.2.1.2.5 Radioactive Contamination of Air, Water and Soil

Environmental impact unique to nuclear power is radioactivity. Radioactive emissions are hard to quantify and can occur during mining and milling. Radioactive radon gas is released during mining activities. Mill residue is returned to the mine and buried, but residual radioactivity can still leak into groundwater.

The largest radioactive emissions occur during electricity production. Emissions to water are more critical then to air because the heavier compounds emitted to water have longer lifetimes.

The most controversial environmental impact arises from high-level spent nuclear fuel. Spent fuel is radioactive for a very long time, and must be properly contained to prevent harm to humans, animals, and the environment (IEA, 2002).

4.2.2.1.2.6 Habitat Alteration

Habitats in all three subsystems of the biosphere can be altered by power generation emissions. Particulate matter emissions from fuel mining and power generation can contribute to haze and increase the potential for imbalancing atmospheric condensation. Mining can impact soil acidity, erosion, and the potential for seismic activity. Mining affects aquatic habitats and soil hydraulics if removed groundwater is not restored. Heat deposited into the soil through water waste can create thermal pollution (IEA, 2002).

Biomass energy crops can both help habitats by resisting erosion and harm habitats by damaging sensitive ecosystems, while forest residue can create surface runoff problems (Kort, 1998). At the local scale, household use of biomass fuels has various environmental impacts: local forest depletion, localized desertification, soil nutrient depletion, and air pollution, both outdoor and indoor (UNDP, 2000).

Lakes formed by hydroelectric power plants can increase local humidity with an increase in evaporation, affecting local cloud cover or creating fog (Moreira, 1993). Dams can increase seismic activity and affect geologic stability, and change the chemical and thermal properties of released water, deteriorating downstream ecosystems, reducing species diversity and productivity, and affecting erosion patterns. Stagnant conditions in the bottom layers of reservoirs can create anoxic conditions, concentrating toxic substances in the reservoir, harming the aquatic habitat, and possibly increasing eutrophic effects within the reservoir (IEA, 2002).

The natural gas fuel cycle has been shown to fragment wildlife habitats caused by above-ground pipelines (IEA, 2002).

4.2.2.1.2.7 Impacts on Human Health

On a broader, economic development scale, although no causal relation has been shown between per-capita energy use and human health, the evidence clearly shows an increase in infant mortality, illiteracy, and fertility, and the decrease in life expectancy for people with reducing access to commercial energy (World Bank, 1997).

Acute occupational risk is the risk associated with immediate harm due to particular activities and is highest in the mining and plant construction phases of the life cycle. Occupational disease and carcinogenic risk is risk associated with the potential for cancer or other diseases caused by long-term exposure to particular activities; such risk is also highest in the mining phase of the life cycle. Public fatality risk is risk to the general public associated with particular activities and is highest in the plant operation and waste disposal phases of the life cycle. Of all power generation technologies, the coal energy life cyle presents the greatest health risks.

In the biomass energy life cycle, micro-organisms grow within the stored biomass, including dangerous mold spores. Occupational risk is primarily associated with allergic reactions to these micro-organisms and lung diseases from the dust generated by these micro-organisms. Power plant ash also produces dust that can have long-term impact on workers (Rosen-Lidholm, Sundell, Dahlberg, & Welander, 1992). The indoor use of biomass fuels has health implications disproportionately targeting women and children (Leach, 1992; Dasgupta, 1993).

For hydroelectric power, indirect health impacts that have been observed, but for which data is not available, include malaria-spreading mosquitos in stagnant reservoirs in warm countries, reduced water quality of groundwater near reservoirs, and reduced water flows reducing dilution and concentrating pollutants. It is estimated that during the 20th century, 30–60 million people were flooded off their lands by dams (Dunn, 1998).

4.2.2.2 Livelihood Sufficiency and Opportunity for Current and Future Generations

Combining Gibson’s next three principles for sustainability, livelihood sufficiency and opportunity are required for current generations and future generations. As such, the basic needs for everyone and every community are ensured, and opportunities for improvement are provided, ensuring that gaps in sufficiency and opportunity of the diverse segments of current society are addressed, while preserving or enhancing opportunities and capabilities of future generations.

From the standpoint of a sustainable energy system, this means utilizing energy sources that allow people from all segments of the community the opportunity to achieve and maintain a common standard of living, while providing future generations sufficient access to the same energy resources and the same standard of living.

Today, 1.7 billion people do not have access to electricity, while approximately 2 billion people primarily depend on unsafe, traditional biomass energy (UNDP, 2000).

In terms of choice, fuel usage for activities appears to be driven primarily by income. The poor default to fuels that are inexpensive, inefficient, and unhealthy (Leach, 1992; Reddy & Reddy, 1994). The poor's hardship is understated when put in merely economic terms, because they spend more money, time, and effort on acquiring energy services. For the poor in developing countries, lack of access to commercial energy services prevents their movement up the "energy ladder" towards cheaper, more efficient, and healthier fuels (Hosier & Dowd, 1987; Reddy & Reddy, 1994). In industrialized countries, the poor tend to spend a larger portion of income on energy services.

Choice and access to commercial energy services will begin improving standards of living and providing opportunity for growth.

4.2.2.3 Resource Maintenance and Efficiency

Gibson's fifth principle for sustainability requires resource maintenance and efficiency. From the standpoint of a sustainable energy system, this principle suggests maximizing the energy resource base for enhancing sustainability, while reducing extractive damage and waste, and increasing the efficiency of material and energy consumption.

Today, approximately 80% of world energy consumption is generated from fossil fuels (oil, natural gas and coal), approximately 14% is fueled by renewable fuels (biomass, large hydroelectric, solar, wind, geothermal, small hydroelectric, and marine sources), and approximately 6% is fueled by nuclear power. At current energy consumption rates, energy consumption is forecasted to triple in the next fifty years (UNDP, 2000). Table 16 shows the world energy consumption and projected reserves for various sources (UNDP, 2000). Hydroelectric power is renewable, with current global runoff rates suggesting that there is an economic capacity of 925,000 GW (technical and theoretical capacities are higher), with 660 GW currently installed, and 126 GW under construction (UNDP, 2000). These figures imply that there is potentially over one thousand years of hydroelectric power construction capacity.

Table 16

World Energy Consumption and Resources in 1998

			Resource Base-Production Ratios (Years)		
Source	Primary Energy (Exajoules)	Percentage of Total	Constant Production (Conventional Resources)	Include Non-Conventional Resources	Dynamic Production
Fossil Fuels	**320**	**79.6**			
Oil	142	35.3	45	~200	95
Natural Gas	85	21.1	69	~400	230
Coal	93	23.1	452	~1,500	~1,000
Renewables	**56**	**13.9**			
Large Hydroelectric	9	2.2	<------- Renewable ------->		
Traditional Biomass	38	9.5	<------- Renewable ------->		
New Renewables	9	2.2	<------- Renewable ------->		
Nuclear	**26**	**6.5**	**50**	**>>300**	
Total	**402**	**100.0**			

In 1996, estimates of biomass consumption ranged from 33–55 exajoules (EJ) (WEC, 1998; Hall, 1997). The theoretically harvestable bioenergy potential is estimated to be 2,900EJ, of which 270EJ could be considered technically available on a sustainable basis (Hall & Rosillo-Calle, 1998). Hall and Rao (1994) conclude that the biomass challenge is not availability but sustainable management, conversion, and delivery to the market in the form of modern and affordable energy services.

Solar energy has the potential to supply between 4 and 124 times the 1998 primary energy consumption of the world (402 EJ), with the largest potential in the Middle East, Africa, the former Soviet Union and North America (IEA, 1998; Nakicenovic, Grübler, & McDonald, 1998).

The greatest potentially harvestable wind energy is in Africa, North America, Eastern Europe, and the former Soviet Union, with an estimated world total in the range from 230EJ to 640EJ (Grubb & Meyer, 1993; WEC 1994).

Competitive energy prices support economic development while increasing environmental and social impacts, and dependence on conventional sources. Energy efficiency is important for a sustainable energy future because it can reduce the amount of energy needed for the same energy service to help mitigate the conflicting characteristics of energy policy. The overall global energy efficiency is approximately 37% of the 402EJ of primary energy, almost 300EJ are delivered as final energy, and an estimated 150EJ are converted to useful energy with end-use devices (UNDP, 2000).

The energy density is the amount of fuel used to produce a given amount of energy; energy footprint is the area required to produce a given amount of energy. Energy densities and energy footprints of various energy resources are summarized in Table 17. Clearly, the challenge for renewable technologies is in improving energy footprint.

Table 17

*Energy Densities and Footprints (IAEA, 1997; **Goodland, 1995)*

1000 MW Plant	Annual Fuel requirement (metric tons [mt])	Area required (km^2)	Energy Density per km^2 (MWh/mt)	Energy Footprint (MWh/km^2)
Coal fueled	2.6 million	1-4	0.84-3.37	2.19-8.76 million
Oil fueled	2.0 million	1-4	1.1-4.38	2.19-8.76 million
Nuclear	30	1-4	73,000-292,000	2.19-8.76 million
Biomass	8.76 million	4,000-6,000 (province)	0.00017-0.00025	1,460-2,190
Solar	Renewable	20-50 (small city)		175,200-438,000
Wind	Renewable	50-150 (city)		58,400-175,200
Hydroelectric**	Renewable	4.98-5,824		3,518-27,375

4.2.2.4 Transparent, Informed and Participatory Decision Making

Gibson's sixth principle for sustainability requires transparent and informed decision making by all stakeholders (individuals, communities and collective authorities) through the building of capacity, incentive, and habit to foster collective responsibility and integrated decision-making practices.

From the standpoint of a sustainable energy system, this principle encourages the involvement of all energy system stakeholders to make collective, integrated decisions that contribute to the long-term sustainability of the energy system.

In terms of practical application, this principle suggests that local, regional, and national governments put policies in place that encourage energy supply and consumption efficiency and energy demand reduction behavior, while mitigating and eventually eliminating socially and environmentally harmful energy-related activities. Furthermore, this principle suggests that energy consumers not only participate in decision making, but also contribute to successful implementation of policies.

The slow adoption and commissioning of renewable energy projects around the world is a good example of ineffective policy implementation.

Despite renewable energy technologies presenting viable opportunities to provide energy and combat the impacts associated with conventional fossil fuel technologies, widespread implementation is slow due to existing cost structures.

Natural demand for renewable technologies will slowly increase as market-driven fossil fuel prices increase. For renewable technologies to gain widespread use, governments will have to correct the cost structure of fossil fuel energy sources by internalizing environmental impacts, and encouraging adoption of renewable technologies to achieve the economies of scale necessary for widespread market-driven implementation. For developing countries, renewable technology adoption is vital at these early stages of development to prevent fossil fuel technologies from gaining sufficient economic and social inertia and directing these countries towards an unsustainable, fossil fuel driven economy. The U.S., Europe, and India are prime examples of renewable energy policy development.

European and U.S. renewable policy frameworks are similar, and a variety of incentive instruments are used to support renewable energy projects. Incentives include fiscal incentives, such as tax exemptions, tax credits, and accelerated depreciation schedules, special tariffs for feed-in laws with mandated purchase of renewable electricity fed into the utility grid, quotas based on RPS, and capital subsidies for projects (Stenzel, 2003).

European nations have introduced substantial renewable energy policies and incentive programs at the national-level that have been successful primarily with feed-in tariffs. In the U.S., other than a 1.5

cents/kWh federal production incentive and various fiscal policies, a national renewable energy incentive policy is yet to be defined, but individual states have achieved success to a smaller degree, compared to the Europeans (Stenzel, 2003).

The government of India formed what became the Ministry of New and Renewable Energy (MNRE) in 1992; it is the first and only country today with a ministry exclusively focused on renewable energy development (MNRE, 2006). In 2004, the Indian government mandated that every household would receive a minimum of 1kWh per day (MNRE, 2006). However, institutional (Riedy, 2008) and operational (Martinot, 2001) barriers are preventing widespread development of renewable energy projects in developing countries.

4.2.2.5 Managing Risk, Uncertainty and Adaptation

Gibson’s seventh principle for sustainability requires understanding risk and uncertainty, and managing for adaptation.

From the standpoint of a sustainable energy system, this principle suggests that a sustainable energy system would be operated such that risks are known and managed to minimize impact on the system, and the system can adapt to changing conditions as necessary.

Factors external to the energy system include climate change, population growth, drought conditions, fuel price volatility, and the regulatory environment. The impacts of these potential external system stressors were discussed in Chapter 3.

4.2.2.6 Holistic, Mutually-supportive Application

Gibson's eighth principle for sustainability requires applying all principles of sustainability together, seeking mutually supportive benefits and multiple gains, for immediate as well as long-term benefit.

From the standpoint of a sustainable energy system, this principle suggests that concurrent positive gains should be achieved in all areas of the energy system with respect to the principles of energy sustainability:

1. The energy system should be operated such that it is environmentally harmless,
2. The energy system should be economically competitive encouraging a common standard of living for all stakeholders,
3. The energy system should be generationally equitable over the short- and long-terms,
4. The energy system should be resource efficient, in that energy consumption is minimized while maximizing output,
5. The energy system should be governed with widespread participation, supportive of supply and demand behavior and policies that promote energy sustainability, and
6. The energy system should be operated such that risks are managed, with the system adapted when possible to promote energy system sustainability.

4.2.3 Vision of ASU's Energy System

4.2.3.1 Envisioned Sustainable Energy System at ASU

The envisioned energy system will evolve such that, in 25 years, next to quality education and research, sustainability will be the most important principle at ASU, with energy sustainability utilized as a fundamental design principle for infrastructure and resource evolution. ASU will be the leader in energy efficiency and innovation by building a strong, cohesive university network, partnering in energy efficiency and innovation technology teaching, research, development, and transfer. Widespread stakeholder participation in the shared ownership of the vision and responsibility for the energy system will lead to continuous institutional innovation and cultural change. The entire energy system will be operating economically with benign impact to the environment, and positive influence and impact on the local and regional community. Energy supply will be balanced, transparent, and efficient, while demand will be equitable within and between campus communities.

The supply side of ASU's envisioned energy system will be self-sufficient such that ASU will minimize power import from the local utility, and also produce and export as much power into the local community to generate revenue, resulting in a net-zero power import-export condition. To support this net-zero operation of ASU's community microgrid, new storage technologies will have been developed to allow energy buffering to balance import and export.

ASU will also have a substantial portion of its energy demand supplied from renewable sources, on-site as well as through regional partnerships. A highly efficient utility grid will support electricity import and export, and where practical, the utility grid will utilize DC mode for electricity transmission.

Compared to the current energy system, energy and resource flow from supply through to the consumers in the envisioned system will be less unidirectional. The envisioned system will have closed-loop feedback of the various campus and community microgrids with the regional utility grid to optimize supply and demand such that the entire system operates sustainably. Unlike the current system, the envisioned system will have more involvement from energy consumers – infrastructure and occupants.

With respect to the environment, the entire energy system will have zero net impact, with only benign emissions into the biosphere. All wastewater streams will be actively reclaimed and reused in the energy system, and buildings will also have zero impact by continual re-use or conversion. The heating and cooling system will capitalize on geothermal properties (geothermal heat pump) to minimize energy consumption, replacing water with an environmentally benign heat transfer fluid.

From the demand side's consumer perspective, ASU's population of students, faculty, and employees will share ownership of the vision for ASU's energy system, and will also share responsibility for making it sustainable over the long-term, which requires involvement of all consumers contributing to efficient energy demand. Shared responsibility will also mean equitable use of energy across campus communities to balance energy efficiencies, costs, and impacts, which will also contribute to a common “standard” of living across campus communities. To encourage total participation, responsible actions, and contribution to the vision, the energy system operation will be transparent to all consumers. This will promote behavior modification and adaptation to environmental and other campus constraints, such that energy demand is efficient with only the necessary energy being consumed.

From the demand side’s infrastructure perspective, all buildings will incorporate intelligent design, controls and automated operation to contribute to energy demand efficiency. This means that while occupants will have optimized their energy consuming behavior, equipment operation within buildings and environmental conditioning of buildings will be automatically adjusted to optimize energy consumption. As such, building equipment and occupants will have become adapted to environmental constraints, such that all energy-consuming needs within buildings will work harmoniously with building operations to minimize energy demand. Use of some buildings may be dedicated by functionality to make efficient use of space, with dedicated-use building clusters around campus to minimize energy waste and encourage energy recycling.

From a campus-wide perspective, virtual classrooms and telecommuting will be maximized to optimize energy consuming facilities. A strong cohesive university system will allow ASU to lead in innovation and efficiency, by building key partnerships to initially demonstrate proof-of-concept projects and then transferring the technology to contribute to continuous innovation and efficiency gains, and promote energy sustainability in the local community. The efficient operation of the entire energy system will be managed in a real-time manner leveraging state-of-the-art information systems. All buildings and campuses will allow all campus communities to consume energy in a balanced, equitable manner, with continuous reinvestment of savings back into ASU's communities to compound efficiencies and savings. This broad vision statement for ASU's sustainable energy system in 25 years is shown as a hierarchy schematic in Figure 11 and a system diagram in Figure 12.

4.2.3.2 Vision Statement Deficits and Conflicts

First, visioning addressed energy demand efficiency, but did not specifically address balance and equity in energy consumption within and between campus communities. A truly sustainable energy system would actively attempt to maintain equity and balance in energy demand.

For an energy system to be sustainable, energy savings must also be reinvested back into the broader ASU community to continuously assist in further savings. This component of the vision

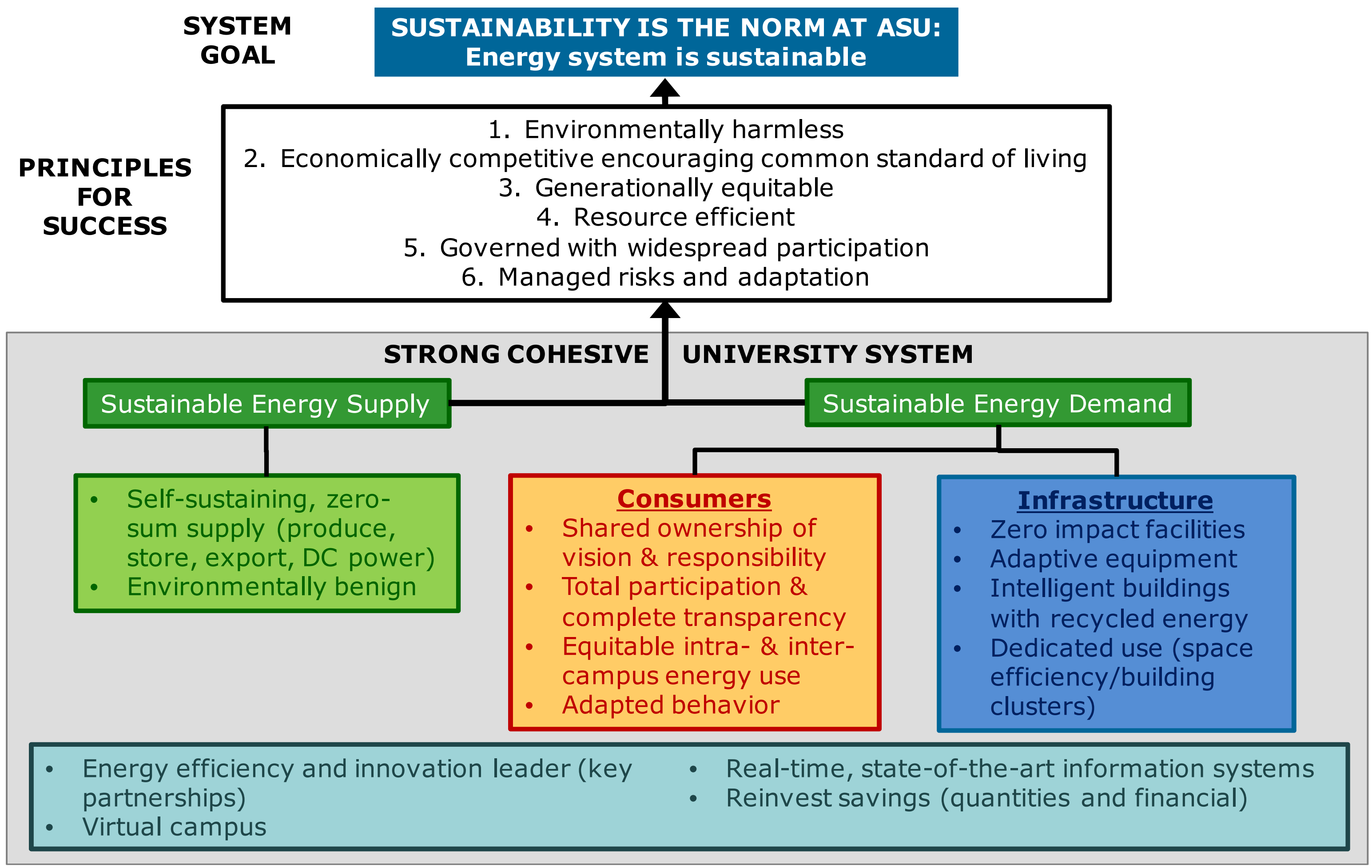

Figure 11. Hierarchy Schematic for ASU's Envisioned Sustainable Energy System.

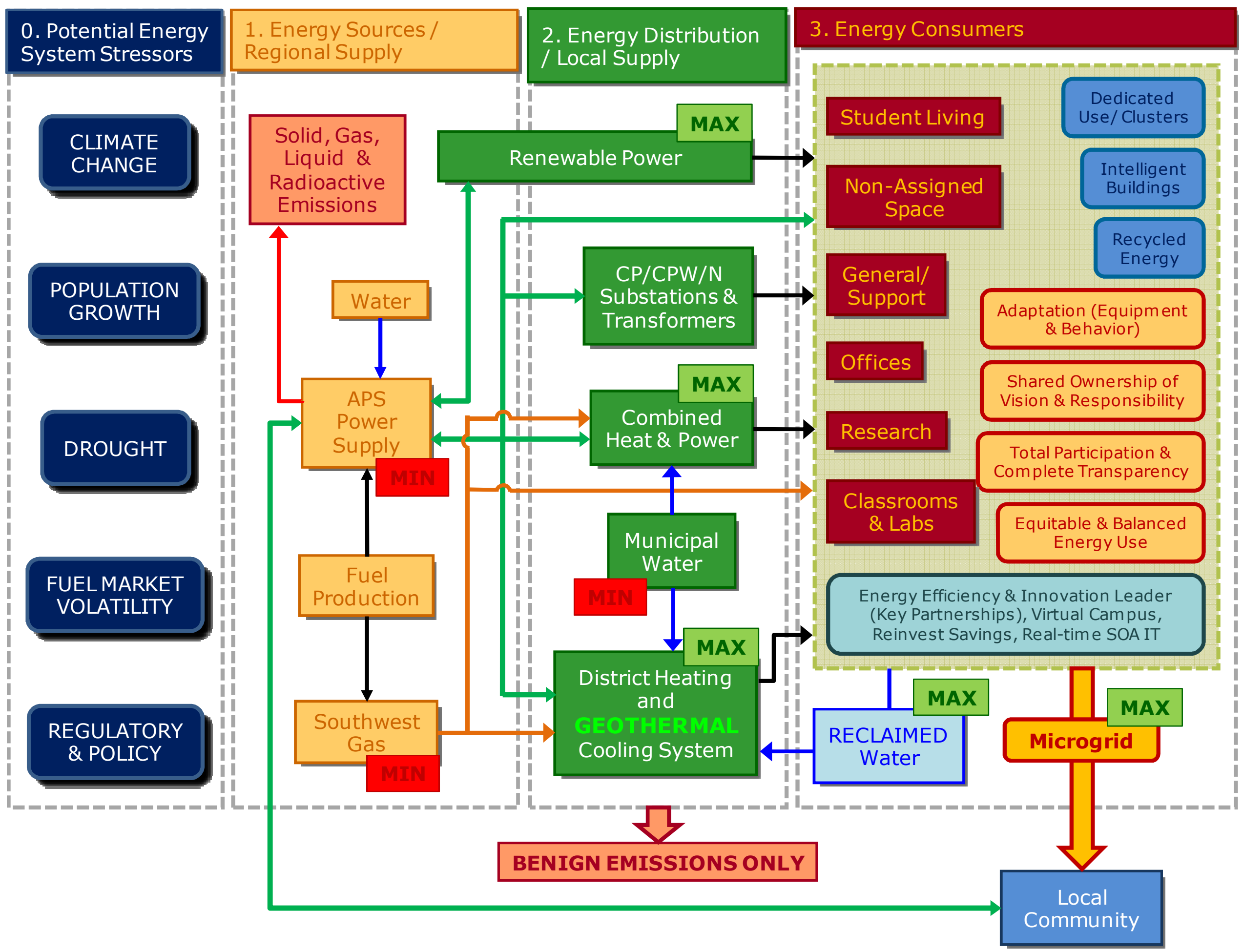

Figure 12. ASU's Envisioned Sustainable Energy System.

was neglected during the visioning exercise, and added later by stakeholders.

The conflict matrix is shown in Figure 13 with numbered vision statements. Conflicting vision statements are italicized here with their statement numbers in parenthesis.

The vision statement that *a utility grid would not exist* (15) in the future created conflict with several other vision statements. The absence of a utility grid would make a *zero-sum energy system* (10) difficult to operate, because electricity export [*produce/store/distribute to the local community* (12)] would not be possible, and all produced electricity would have to be continuously utilized on campus. The absence of a utility grid would mean that *loss-reducing DC electricity transmission* (11) could be unnecessary, and an *efficient utility grid* (14) would be irrelevant. Similarly, the absence of a grid would make *partnering with local populations for energy projects (18)*, such as using trust land for wind and solar power projects, unviable.

All other vision statements were complementary, consistent, and mutually supportive.

In summary, the conflicting vision statement that a utility grid would not be necessary in the future was removed from the overall, comprehensive vision for ASU’s energy system.

#	Vision Statements	#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	**Sustainability is the norm includes:**	1																										
2	Modified occupant behavior	2																										
3	Only use what we need	3																										
4	Shared ownership of responsibility/vision	4																										
5	100% ASU population involvement	5																										
6	**Zero net environmental impact includes:**	6																										
7	Water reclamation/no water for cooling (geothermal)	7																										
8	Zero impact facilities (building re-use/conversion)	8																										
9	**Self-Sustain (all resources) includes:**	9																										
10	Zero sum energy system	10															**X**											
11	DC Power	11															**X**											
12	**Produce/Store/Distribute to community (energy -> income) includes:**	12															**X**											
13	New storage technologies developed	13																										
14	Efficient global utility grid	14															**X**											
15	No utility grid (no imports/exports)	15																	**X**									
16	Strong cohesive university system	16																										
17	**Partner for energy exchange (all resources – academic, research …) includes:**	17																										
18	Trust land for energy (partner with local population)	18																										
19	**ASU Leads energy innovation, efficiency includes:**	19																										
20	Build partnerships for proof-of-concept demonstration and technology transfer	20																										
21	**Energy systems are transparent to ASU population (Sustainable Sun Devil) includes:**	21																										
22	100% ASU population involvement	22																										
23	**Intelligent buildings includes:**	23																										
24	Adaptive occupants and equipment	24																										
25	**Dedicated use buildings (space efficiency)**	25																										
26	**Leveraged the cloud**	26																										

Figure 13. Vision Statement Conflict Matrix ('**X**' indicates vision conflict).

4.2.3.3 Compliance with Sustainability Principles

The vision of a self-sustaining (zero-sum), environmentally benign energy system relating solely to the supply side can be incompatible with some energy sustainability principles.

The supply infrastructure's current incompatibility with environmental integrity is balanced by the requirement that it be environmentally harmless. Conversely, the expense and inefficiencies associated with the requirement for renewable or other clean technologies will be balanced with future (assumed) economic competitiveness and technical efficiencies. Generational equity is also balanced by eliminating environmentally impacting technologies to benefit future generations, while risk and uncertainty can be readily mitigated by a self-sustaining, environmentally benign energy system. A vision focused solely on the supply side of the energy system can neglect widespread participation, which would be addressed by assessing and actively managing the demand side of the energy system.

By sharing both the ownership of the vision for the energy system and responsibility to realize this vision, ASU's entire population can satisfy all the principles of energy sustainability. This requires total participation and transparency between the supply and demand sides, which would encourage adapting behavior to evolving energy system constraints. A critical component for consumers is to ensure equitable energy consumption between campus communities and within campus communities, an obvious example being active management of per capita energy consumption within residence halls.

Proof-of-concept projects would necessarily comply with all principles of energy sustainability, with gaps continuously targeted for research and development. With a virtual campus environment, facility requirements will be reduced, contributing to all the principles of energy sustainability.

Intelligent buildings operating with energy recycling and adaptive equipment will contribute to environmental, economic, generational, and resource principles of sustainability and mitigate risk. Building configurations and operations will not directly encourage widespread participation.

Each vision statement individually has varying degrees of compliance with energy sustainability principles. However, when the vision statements are combined and the vision reviewed in its entirety, principles of sustainability are comprehensively satisfied. The compliance matrix of vision statements with principles of energy sustainability is shown in Figure 14.

4.2.4 Sustainability of Current State of ASU's Energy System

The visioning workshop identified qualitative and quantitative measures with corresponding metrics, as summarized in Table 18. Note that most metrics are already utilized today (unshaded), while metrics added for the envisioned energy system are shaded green in Table 18. These metrics are again arranged by their compatibility with

VISION COMPONENT	EI	EO	GE	RE	PG	RA
Self-sustaining, zero-sum supply (produce, store, export)	Red	Green	Orange	Green	Orange	Green
Environmentally benign	Green	Orange	Green	Orange	Orange	Green
Shared ownership of vision & responsibility	Green	Green	Green	Green	Green	Green
Total participation & complete transparency	Green	Green	Green	Green	Green	Green
Equitable intra- and inter-campus energy use	Green	Green	Green	Green	Green	Green
Adapted behavior	Green	Green	Green	Green	Green	Green
Intelligent buildings/Recycled energy/Adaptive equipment	Green	Green	Green	Green	Orange	Green
Dedicated use (space efficiency/clusters)/Zero Impact	Green	Green	Green	Green	Orange	Green
Energy efficiency and innovation leader (key partnerships)	Green	Green	Green	Green	Green	Green
Virtual campus	Green	Green	Green	Green	Green	Green
Real-time, state-of-the-art Information systems	Green	Green	Green	Green	Green	Green
Reinvest savings	Green	Green	Green	Green	Green	Green

Figure 14. Vision Statement Compliance Matrix.
Vision Statements Color Code (See Figure 11): Green – supply; Orange– Consumers; Blue – infrastructure; Light Blue – all components of energy system
Sustainability Principles Color Code – Green = compliance; Orange = partial compliance; Red = non-compliance)
EI=Environmental Integrity; EO=Economic Opportunity; GE=Generational Equity; REM=Resource Efficiency and Maintenance; OG=O=Participatory Governance; RMA= Risk Management and Adaptation

Table 18

Metrics for Envisioned Energy System Measurement

(Statements and metrics from the first workshop are unshaded; statements and metrics added during second workshop are shaded green)

ENERGY SUSTAINABILITY PRINCIPLE	WORKSHOP STATEMENTS	METRICS		NORMALIZED INDICES		UNITS
Environmental Integrity (EI)	Delta Emissions Carbon Uses Fuel Usage (Natural Gas) for SOx, NOx, Monthly	ASU Total Energy Emissions	Tons TE	Emissions Index	Tons TE / Total MMBTU	Tons/MMBTU
	Delta Water Consumption	ASU Energy Water Consumption	Gals EW	Water Consumption Index	(Gals EW + Gals RO) / Total MMBTU	Gals/MMBTU
	Water Usage Gallons/Day, Yearly	RO Reject Water for Cooling	Gals RO			
	Waste Production	ASU Total Waste from APS	Tons TW	Waste Index (including Freon Leaks)	Tons TW / Total MMBTU	Tons/MMBTU
	ASU Fraction of APS Low Level Radioactive Waste	ASU Fraction of APS Low Level Radioactive Waste	ASU LLRW	ASU Low Level Radioactive Waste Index	ASU LLRW / Total MMBTU	Cu. Ft/MMBTU
	Percent Buildings Converted/Re-used	Percent Buildings Converted/Re-used	BCR	Building Re-use Index	1- BCR	%
Economic Opportunity (EO)	Dollars	Electricity Cost	$ Elec	Electricity Price Index	($ Elec - Export $) / (Purchased kWh - Export kWh)	$/MMBTU
	Consumer Cost	Natural Gas Cost	$ NG	Natural Gas Price Index	$ NG / Therms	$/Therm
	Use/Cost per Day	Water Cost	$ W	Water Cost Index	$ W / (Heat MMBTU + CW Tons MMBTU)	$/MMBTU
	Delta Cost Over Time	Exported kWh Revenue	Export $			
	ASU Tuition Revenue	ASU Tuition Revenue	Tuition $	Tuition Cost Index	Tuition $ / Total MMBTU	$/MMBTU
Generational Equity (GE)	Improved Metrics for People per Unit of Energy	Total ASU Population	# ASU TP	Per Capita Energy Index	Total MMBTU / # ASU TP	MMBTU/Person
	Occupancy (Deltas, Seasons) by Residence Hall	# of Residents	# Residents	Resident Energy Index	Total Res MMBTU / # Residents	MMBTU/Resident
	Mixed Use Space in Residence Halls - Difference Between Uses	Total Residential Energy	Total Res MMBTU			
	Credit Hours (Tempe, Fall SCH)	Credit Hours (Tempe, Fall SCH)	# CH	Education Index	Total MMBTU / # CH	MMBTU/Credit Hour
	# of Tempe Graduates	# of Tempe Graduates	# Grad	Graduation Index	Total MMBTU / # Grad	MMBTU/Graduate
	Internal Environment Settings	# of CO_2 Sensors in Buildings	# CS	Sensor Index	1 - (# CS / # TB)	%
	Stakeholder Satisfaction	Satisfaction Survey Score	Sat Score	Satisfaction Index	1- (Sat Score)	%

Table 18

Metrics for Envisioned Energy System Measurement (continued)

(Statements and metrics from the first workshop are unshaded; statements and metrics added during second workshop are shaded green)

ENERGY SUSTAINABILITY PRINCIPLE	WORKSHOP STATEMENTS	METRICS		NORMALIZED INDICES		
Resource Efficiency and Maintenance (RE)	Natural Gas/kW/kWh Purchased	Purchased Electricity	Purchased kWh	Purchased Electricity Index	(Purchased kWh MMBTU - Export kWh MMBTU) / Total MMBTU	%
	Exported kWh Revenue	Exported kWh	Export kWh			
	BTUs (Total Energy)	Produced kWh (includes recycled energy)	CHP kWh	Produced kWh Index (incl. recycled energy)	1 - ((Recyc MMBTU +CHP kWh MMBTU) / Total MMBTU))	%
		MMBTU Recycled/Recovered	Recyc MMBTU			
	Monthly kWh/kWh/Therms Overall Supply Campus Totals % MMBTU Reduction MMBTU/sqf Classifications Building Level kW/sqf, kW/ton, Water Gallons/Ton Energy Savings Consumption/sqf (kWh/sqf, MMBTU/sqf, Tonhrs/sqf)	ASU Total Purchased Natural Steam/Hot Water Used Total Chilled Water Tons ASU Total MMBTUs	Therms Heat MMBTU CW Tons MMBTU Total MMBTU	Natural Gas Index	Therms MMBTU / Total MMBTU	%
	Total Percentage Photovoltaic APS Renewable Progress % of Renewable Energy Total Generation by Renewables	ASU Total Renewable Power	ASU Total Renewable Power MMBTU	ASU Renewables Index	1 - (ASU Total Renewable Power MMBTU / Total MMBTU)	%
	Reliability/Availability Delta Efficiency System Reliability Maintenance of Boilers and Turbines Occupancy/Weather --> Adjusting Equipment for Efficiency	Chiller Efficiency Boiler Efficiency CHP Efficiency	%CPE %BPE %CHPE	Chiller Efficiency Index Boiler Efficiency Index CHP Efficiency Index	1 - (%CPE) 1 - (%BPE) 1 - (%CHPE)	% % %
Participatory Governance (PG)	Partnering with Sustainability Oriented Suppliers	# of Sustainable/Green Total # of Suppliers	# SS # Suppliers	Sustainability Supplier Index	1 - (# SS / # Suppliers)	%
	Distributed Billing	% Distributed Billing	%DB	Distributed Billing Index	1 - (%DB)	%
	# of ASU Population Informed	# of ASU Population Informed	# PI	Participation Index	1 - (# PI / # ASU TP)	%
	Accurate Metering	# of Buildings Metered (EIS) Total # Buildings	# BM # TB	Metering Index	1 - (# BM / # TB)	%
	Buildings Energy Champions	# of Buildings Energy	# BC	Champion Index	1 - (# BC / # TB)	%
	Online Classes	Online Classes	%OC	Online Class Index	1 - (%OC)	%
Risk Management & Adaptation (RA)	SAIFI/SAIDI Ratings Power Consumption of Gensets	Genset Fuel Consumption	Gen MMBTU	Genset Fuel Index	Gen MMBTU / Total MMBTU	%
		AZ Energy Consumption	AZ MMBTU	ASU Energy Index	Total MMBTU / AZ MMBTU	%
		AZ State Water Consumption	AZ Gals	ASU Water Index	Gals EW / AZ Gals	%
		ASU Total Revenues AZ State Funding	Budget $ State $	Funding Risk Index	State $ / Budget $	%
		NRC National Low-level Radioactive Waste Disposal	US LLRW	LLRW Risk Index	ASU LLRW / US LLRW	%

each principle of energy sustainability, with similar workshop statements clustered as appropriate and assigned representative metrics, with guidance from participants. Using annual metrics data acquired from relevant stakeholders, indices were created to link individual metrics to energy supply or consumption metrics as appropriate. These indices are included in Table 18.

Under the principle of environmental integrity, stakeholders added ASU's proportion of low-level radioactive waste associated with APS's nuclear power generation. Also, the proportion of buildings that were either converted or re-used was selected as a metric to monitor and maintain zero-impact from ASU's facilities over time. For economic opportunity, the impact of the energy system on tuition revenue was added as an index measure of economic impact to students as energy consumption changed. Generational equity metrics added in this visioning workshop included ASU's annual graduates and annual credit hours of instruction provided with the intent to link ASU's fundamental academic productivity with energy consumption.
Also added were metrics to assess the proportion of campus buildings that have CO_2 sensors, and a stakeholder satisfaction score, acquired by way of a campus-wide survey, to assess stakeholder satisfaction with respect to energy system performance. For resource efficiency and maintenance, the only metric added was a measure of energy recycled or recovered.

In a future, sustainable energy system at ASU, participatory governance would be measured,

- assuring that all ASU energy system suppliers were considered sustainable or "green";
- departments and colleges would be individually billed for energy use;
- the entire stakeholder population would be informed regarding the energy consumption and influence on the energy system;
- buildings would be accurately metered to assure efficient facility operation;
- all buildings would have energy champions to assure energy consumption practices were effective; and
- More online classes would be offered to optimize facility, equipment, and energy resources.

Under the principle of risk management and adaptation, ASU's energy and water consumption, with respect to Arizona's consumption, would be monitored, as well as ASU's dependence on State funds, and ASU's impact on the nation's generation of low-level-radioactive waste. Many of these risks are interlinked with other metrics. For example, once ASU's energy system minimizes electricity import from APS, ultimately reaching zero import, and becomes an electricity exporter, then risk associated with low-level radioactive waste is mitigated, and the potential for Arizona population growth related risk is also mitigated.

To develop overall sustainability scores, the indices in Table 18 associated with these metrics were then normalized with the year 2008 as the baseline year for this case study.

Each index in Table 18 was developed such that as the index approaches zero, a more sustainable path is realized for the energy system. For example, as waste, water consumption, and emissions per MMBTU are reduced, ASU's energy system is progressing towards a more sustainable future, with the ultimate goal of achieving zero emissions.

While achieving zero for indices is an ultimate goal, many ASU performance metrics can be linked to the performance of ASU's peer universities to define a threshold level of acceptable performance, ultimately leading towards a sustainable level. Examples are the amount of energy system-related water consumed, waste produced, energy quantities purchased, and academic performance with respect to energy consumed (tuition, graduates, credit hours etc.). These threshold comparisons do not exist today, and can be developed as part of the ACUPCC commitment.

Other metrics achieve "sustainable performance" once they are maximized. For example, when all buildings are converted or re-used, have energy champions, are metered, and have CO_2 sensors installed, then ASU is actively managing the energy system's infrastructure to be more sustainable.

It must also be noted that some metrics and associated indices may not achieve the final desired zero condition, such as emissions, purchased electricity and natural gas, electricity import and stakeholder participation. The purpose of this assessment is to drive each of these indices to as low a score as possible (best sustainability score) to maximize positive sustainability gains for the energy system. As this assessment is evolved, indices that have achieved this best sustainable score may be replaced with more appropriate measures.

By averaging all indices for each principle, a normalized average overall sustainability score for each principle was determined. Similarly, by averaging all principles, a normalized average overall sustainability score for the energy system was developed. These sustainability scores are measures of the current energy system measured against the metrics and indices for the envisioned sustainable energy system. The results are shown in Table 19 for five years of ASU's energy system performance.

The quantities in Table 19 can be directly compared and represent "distance-to-target vision". Noting that the overall goal of each index, each principle, and the overall sustainability score is zero, in 2005 and 2006, the overall sustainability score for the current energy system is 1% and 4% more sustainable than in 2008, respectively. This is primarily driven by unsustainable activity in the

Table 19

Current Energy System Sustainability Assessment Scores based on Envisioned Energy System Indices

ENVISIONED ENERGY SYSTEM	2005	2006	2007	2008	2009	GOAL
Environmental Integrity (EI)	118%	102%	93%	100%	152%	0%
Economic Opportunity (EO)	86%	91%	89%	100%	107%	0%
Generational Equity (GE)	88%	92%	103%	100%	100%	0%
Resource Efficiency & Maintenance (RE)	134%	129%	94%	100%	104%	0%
Participatory Governance (PG)	104%	102%	100%	100%	97%	0%
Risk Management & Adaptation (RA)	64%	62%	124%	100%	90%	0%
OVERALL SUSTAINABILITY SCORE	99%	96%	101%	100%	108%	0%

areas of environmental integrity and resource efficiency and maintenance. With respect to environmental integrity, water consumption, emissions and waste production all resulted in 2005 and 2006 being environmentally more impacting than 2008. With respect to resource efficiency and maintenance, without the CHP facility in operation, more electricity was purchased from APS in 2005 and 2006.

In contrast, in 2007, the overall sustainability score of 101% is essentially the same as in 2008, when improvements in environmental, economic opportunity and resource efficiency and maintenance measures were offset by a substantial increase in risk associated with electricity outages of the APS utility grid.

In 2009, the indices resulted in an 8% less sustainable energy system compared to 2008. This was driven by a substantial increase in waste produced by APS, significantly impacting environmental integrity, and increases in ASU's energy and water consumption relative to Arizona's energy and water consumption, substantially increasing risk management and adaptation.

To compare annual performance of each energy sustainability principle for the envisioned energy system, Figure 15 graphically compares several years of performance in a radar plot.

Environmental integrity (EI), economic opportunity (EO), and risk management and adaptation (RA) all show less sustainable "direction-to-target vision," while the other three principles indicate little change from 2008.

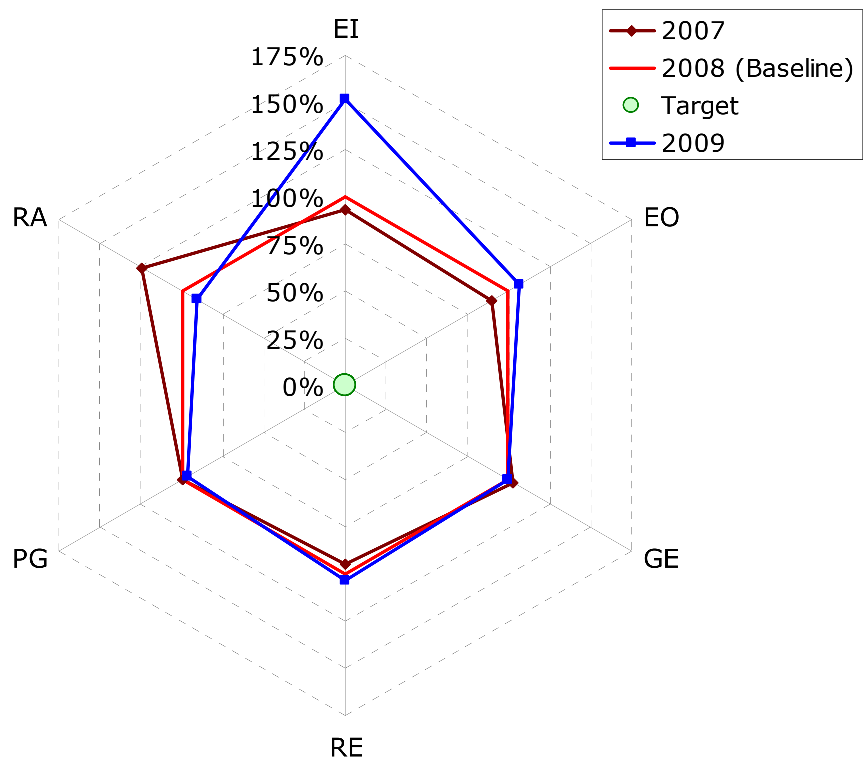

Figure 15. Sustainability Performance Comparison of Sustainability Principles relative to Envisioned Indices.

Finally, Figure 16 compares the overall sustainability score for the current energy system with respect to envisioned metrics and indices over five years. The general trend ("direction-to-target vision") is in an upward, unsustainable direction.

Since the target for each principle and the overall sustainability score is zero, both Figures 15 and 16 also indicate "distance-from-target". From Figure 15 it can be seen that all principles of sustainability need to be driven towards zero. Figure 16 shows that on an overall basis, the ASU energy system was 8% less sustainable in 2009 (compared to 2008) and is 108% from the stakeholder-defined sustainable state of zero.

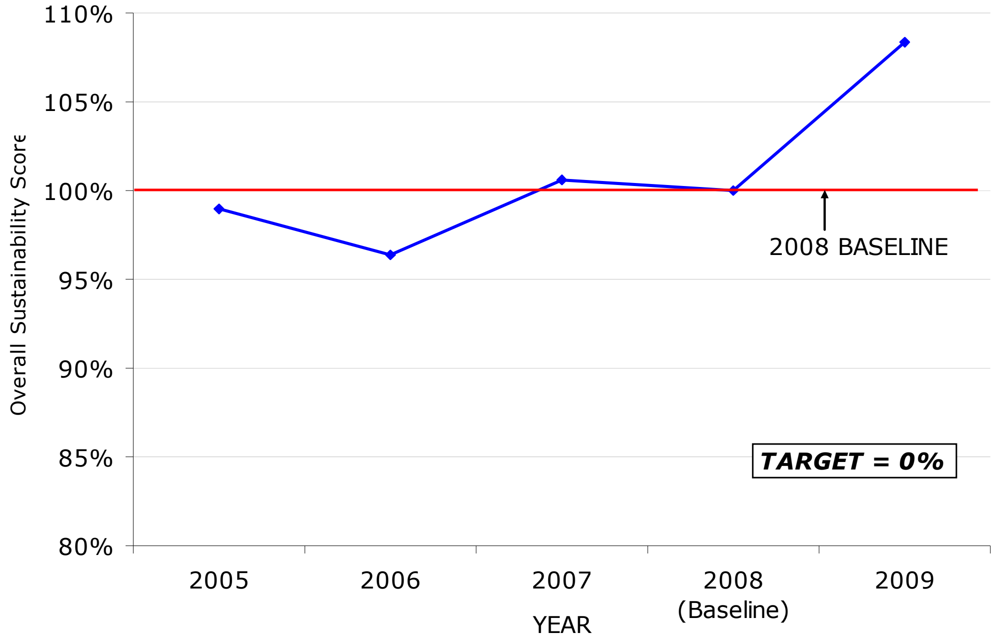

Figure 16. Energy Sustainability Trend.

4.3 Outline of a Transition Strategy for ASU's Energy System

The transition strategy for the various components of the envisioned sustainable energy system (Figure 11 and 12) is summarized below.

4.3.1 Sustainable Energy Supply

In order to develop a self-sustaining, environmentally benign, zero-sum energy supply, ASU energy system management will have to work with APS, SWG, and other potential energy suppliers to understand and evaluate energy supply options (such as solar hot water, and the geothermal heat pump discussed in Chapter 6) and the technical, economic, and regulatory viability and constraints of net-metering and support policies that incentivize power exports.

That being said, ASU will have to develop a working formula for energy sustainability to ensure that energy supplies not only meet economic and technical requirements, but also satisfy energy sustainability metrics, such as an emissions map, and plan for eliminating all harmful emissions. ASU's existing carbon neutralization plan can readily be integrated into this overall sustainable energy supply plan.

4.3.2 Sustainable Energy Demand from Consumers

ASU energy system managers will have to understand energy consumption behavior across campus communities. Energy use patterns will emerge from this knowledge and identify opportunities for behavior adaptation and efficiency gains. Also, consumers' participation will be measured and will present opportunities to increase participation. By educating consumers of energy consumption patterns, consumption impacts, and opportunities to improve energy sustainability, ASU's energy system consumers will be gradually transitioned towards a sustainable energy system.

When utilized as an active, on-going process, energy consumers will begin to participate in the ownership of the energy system vision, and take responsibility for its sustainable operation. By encouraging total participation, ASU energy system managers can direct the system towards equitable energy use within campus communities and between campuses.

4.3.3 Sustainable Energy Demanding Infrastructure

In the near term, ASU energy system managers will have to understand energy consumption behavior across campus infrastructure and develop a plan to transition buildings into intelligent systems. To develop this knowledge, all buildings will be added to the EIS system, all buildings will have CO_2 sensors installed, and all buildings will have energy champions assigned. A distributed billing program will be implemented, along with intelligent space planning to optimize space needs. Vendor spaces will be sub-metered to properly allocate energy usage and costs. Buildings will be evaluated for dedicated use; creating building clusters for office, research, etc. to minimize energy use, encourage energy recycling, and optimize swing space requirements.

In the mid-term, a zero-impact plan will be created for building conversion or re-use to minimize waste and energy consumption, and maximize cost-effectiveness.

For the longer term, a plan to evaluate and integrate state of the art adaptive equipment and technology will be developed. This adaptive equipment and technology will inform ASU energy system managers about consumer energy consuming habits. Pilot projects will be implemented to evaluate localized as well as distributed building control systems, before broad system-wide integration.

4.3.4 Organizational and Campus-wide Energy Sustainability

For ASU to become the leader in energy efficiency and innovation, a map of key technologies and partnerships must be developed, along with criteria and metrics to assess energy leadership in academics, research, infrastructure, and resources. ASU must be promoted as a demonstration portal for energy technologies, academics, and research. To encourage energy efficiency and innovation across campus communities, a development plan must be created to reinvest energy related savings back into the organization. The building planning and funding processes need to be streamlined between the university and the State legislature.

To develop an effective virtual campus, the benefits and impacts of telecommuting and online classes must be assessed. The campus information systems must evolve to state of the art technology, with storage centralization, creating effective communication pathways and optimizing wireless utilities.

Regular communication and support from ASU's leadership team for the comprehensive adoption and implementation of these activities and policies would ensure the transition towards a sustainable energy system.

Key insights of the visioning and sustainability assessment are presented in section 4.4.

4.4 Summary of Findings

4.4.1 Current Energy System

The current energy system is heavily dependent on external energy sources, which encumbers ASU with economic, environmental and social impacts. This system is unidirectional, in that energy flows through the system to produce output from ASU, but consumers have limited knowledge and accountability for the system's performance or impact.

FERC, MCAQ and the Arizona Corporation Commission have the greatest external potential to directly impact ASU's energy system sustainability, with electricity import/export regulation, environmental impact control, and on-site power generation constraints.

Of ASU suppliers and partners, APS provides the majority of externally-produced electricity, and has the greatest impact on ASU's energy system sustainability, by way of economic, environmental and social impacts. APSES assists ASU energy system management in reducing demand with efficiency improvements, but has little influence on the energy system supply side. ACC has a direct impact on ASU's energy system sustainability through the operation and maintenance of residence halls. However, currently ASU and ACC are not actively making efforts to manage and optimize energy demand.

Although annual energy system environmental compliance is a necessary part of the operating energy system, ASU's carbon neutrality and campus sustainability goals are expanding environmental impact management beyond mere compliance.

Energy system analysis shows that energy consumption in buildings can be correlated to building space distribution. Energy consumption in buildings appears to have a strong correlation with area in buildings with substantial residential and research space. Offices and classrooms have a much weaker correlation between energy consumption and space classification. This is because classrooms and offices have substantial traffic flow and equipment operation when occupied. When unoccupied, these areas have little energy consumption. Infrastructure efficiencies are integrated as much as possible, but energy consumption behavior of stakeholders remains to be addressed. Infrastructure energy consumption patterns need to also be better understood.

Today, energy system management balances energy cost-effectiveness, energy efficiency and overall system reliability with customer demand and customer satisfaction. The longer term goal is to infuse energy conservation and integrate university sustainability goals into the organizational culture. However, energy system management operates on the fundamental premise that the customers' demand for energy must be continuously met, with limited consideration given to energy demand efficiency.

As such, there is a misalignment of goals within energy system sectors – energy demanding consumers are disconnected from the operational goals of the energy supply, and the overall sustainability goals of the University. APS is an independent, profit-making external entity with business priorities and goals that do not necessarily align with ASU's sustainability mission.

4.4.2 Visioning and Sustainability Assessment

Sustainability assessment in literature demonstrates the evolving nature of the science with shortfalls in terms of thorough stakeholder participation in systems and stakeholder mapping, participatory visioning, aggregation of results to provide a measure of sustainability, and influence within decision-making processes. Even principles of sustainability are not comprehensively addressed by researchers. Consequently, the development of sustainability assessment presented above reveals key common elements needed to make up a comprehensive, integrated sustainability assessment that can dynamically inform and influence decision making.

Current energy system management is focused on traditional technical and economic performance metrics. In other words, the energy system is managed by an organization that traditionally relies on bottom-line economic performance, which is underpinned by technical performance of the supply-side of the energy system. After introduction of operationalized energy sustainability principles, the stakeholders expanded metrics to include economic opportunity for consumers, generational equity, participatory governance, and risk management.

Metrics were evolved into different numbers of indices for each energy sustainability principle with:

- five indicators were developed for the principle of environmental integrity,
- four indicators were developed for the principle of economic opportunity,
- six indicators were developed for the principle of generational equity,
- seven indicators were developed for the principle of resource efficiency and maintenance,
- six indicators were developed for the principle of participatory governance, and
- five indicators were developed for the principle of risk management and adaptation.

These differing numbers of indices artificially created weightings for all principles, in turn biasing the impact of some principles compared to others.

The most critical finding in this study is the current unsustainability of ASU's energy system. Compared to 2008, ASU's energy system is less sustainable in 2009 with respect to environmental integrity, economic opportunity, and risk management and adaptation, while the other three principles indicate little change from 2008.

The unsustainability of the current energy system is largely due to ASU's dependence on external energy supplies, which has primarily economic and environmental impact. Specifically, ASU's 2009 sustainability score was greatly impacted by a substantial increase in waste produced by APS, significantly impacting environmental integrity. This particular issue clearly exemplifies the interlinked, cross-sectoral nature of sustainability challenges. ASU's substantial dependence on an external unsustainable energy supply has a significant impact on ASU sustainability score.

Internally, the energy system realized increases in ASU's energy and water consumption relative to Arizona's energy and water consumption, substantially increasing risk management and adaptation. Furthermore, the lack of participation of consumers and lack of knowledge of energy use equity impact the principle of generational equity.

4.4.3 Strategy Building

A reduced number of ASU energy system stakeholders outlined an initial plan to transition the energy system towards sustainability. ASU energy system stakeholders identified critical energy supply, energy-consuming infrastructure, and energy consumer evolution steps to transition the system. However, details need to be developed for this high-level outline to evolve into an implementation strategy. The plan created herein was consistent with and complementary to current ASU carbon neutrality and campus sustainability goals.

With focused and championed effort, and continued application of this assessment, ASU energy system managers can begin to transition ASU's energy system towards long-term sustainability.

Chapter 5

DISCUSSION

5.1 Critical Reflection of Methodology

During the period of this study, energy system analysis was conducted with energy consumption data on only one-third of the infrastructure. This introduces a level of uncertainty for the analysis results. As more data becomes available, the energy system correlation with building area classifications can become more accurate.

It was hypothesized that the correlation of university carbon footprint with gross campus area would mean that energy consumption would be correlated with refined campus area classifications. This hypothesis was partially proven for campus residential and research areas. However, the connection between carbon footprint and energy consumption assumes that campus energy systems are primarily fossil-fueled. With 2008 data from ACUPCC this happened to be true; however, as ASU and many campuses around the U.S. transition their energy systems to include a larger portion of renewable power supplies, the ACUPCC may have to transition to collecting energy consumption data and not solely carbon emissions.

The list of stakeholders was developed, and stakeholders were identified and interviewed as recommended by current energy system management. The sufficiency and appropriateness of stakeholders was assumed to be complete. Other stakeholders could be identified and have influence on the energy system sustainability assessment. External energy system experts and governmental stakeholders were not interviewed for this study. Their input may have affected how the energy system was mapped and analyzed.

Energy consumers are large in number and representatives were not identified and interviewed for this study. Specifically, resident students, students from various departments with varying degrees of energy-consuming behavior, employees and faculty representatives could have added value to this study.

Stakeholder bias was identified during interviews and likely introduced in workshops. During interviews, stakeholders identified critical issues that affect the performance of their area of responsibility.

There is inherent bias in the management of a stakeholder's area of responsibility that may negatively affect overall performance of the energy system. Energy consumers were specifically identified as have little regard for energy consumption inefficiencies and impacts. Stakeholders may make "local" corrections for consumer bias, but the outcomes may not be ideal for the energy system as a whole.

During workshops, statements, metrics and plan components were offered by stakeholders; however, as attendance decreased from the first workshop through to the third workshop, attending stakeholders inherently biased activities.

The sustainability assessment conducted herein averaged the indicators developed for each principle and, in turn, averaged all principle scores to derive an overall sustainability score. Although directed by stakeholders to equate all principles in this study, sustainability assessment sensitivity and bias can be tested by weighting indicators and principles.

The selection and number of metrics and corresponding indices was defined by stakeholders. Since all principles of sustainability did not have an equal number of indices (see Table 18), overall principle sustainability scores could have differing resolution or sensitivity. This "dilution" effect can be overcome in future iterations of the sustainability assessment by equating the number of indices for each principle. This "artificial" equal weighting of all principles can provide a good baseline sustainability assessment but it can cause plans to be focused on the incorrect areas of the energy system and resources to be incorrectly allocated.

On the other hand, stakeholders could intentionally utilize more or less metrics for different principles (as was the case in this assessment), if a particular set of metrics and indices is deemed critical and necessary for correct performance measurement. This approach is likely to result in accurate planning and resource allocation, as long as stakeholders diligently decide how to bias principles, metrics and corresponding indices.

The quality of metrics and corresponding indices could also be debated. Some metrics may not have technical or quantitative merit, such as "percent buildings converted/re-used" or "stakeholder satisfaction" (see Table 18), but provide qualitative value to stakeholders. As such, these qualitative metrics may have bias built-in, but this will be averaged out to provide a representative measure. Retaining qualitative metrics may also motivate stakeholder participation, as their input will be deemed valuable.

Finally, for this sustainability assessment process to have timely value, data must be made readily available to provide current sustainability scores. As an example, the sustainability assessment discussed herein is baselined with respect to 2008 and compared to 2009 data. A complete data set for 2010 was unavailable for this analysis. Appropriate planning activities, resource allocation and project implementation can be proactively managed with timely data availability.

5.2 Critical Reflection of Findings

5.2.1 Current Energy System

5.2.1.1 Sectors of the Energy System

Potential external stressors that could impact the long-term sustainability of ASU's energy system relate to climate change, population growth and regulatory and policy issues. ASU energy system managers should become aware of the potential impacts of climate and population related increases in energy demand, the associated costs, and the potential impacts to ASU's community of stakeholders. Near term policy and regulatory issues for ASU's energy system relate to potential future carbon regulation, a potential National renewable portfolio standard and the university's dependence on State funds. ASU is responding to both the carbon regulation and the renewable portfolio standard, with the university's carbon neutrality commitment. ASU's recent tuition- and employment-related responses to State funding issues would be unsustainable for the long-term, and ASU administration is actively working to address this for the long-term.

The potential energy system stress from drought or fuel supply volatility is insignificant in the near term. For the longer term, replacing water in the cooling system with an effective and benign substitute will mitigate the effects of droughts.

ASU's energy supply is substantially provided by APS. For ASU, this lack of control over its energy supply results in substantial environmental impact and potential economic and social impact into the future. ASU administration and energy system managers have recognized this and effectively manage the entire supply side, including on-site power generation to maximize cost-effectiveness and reliability.

With respect to environmental impacts, fossil fueled technologies clearly have a substantially greater impact to the environment when compared with renewable energy technologies, but have a substantially smaller energy footprint. On the other hand, renewable energy technologies have logistical and technical problems – large-scale production, cost-effectiveness, and reliability are unproven and the intermittence of some technologies is hindering widespread adoption.

5.2.1.2 Interlinkages and Correlations

This study shows that energy consumption in buildings is strongly correlated for residential and research areas. Energy consumption in other classified areas is likely to be driven more by occupants, occupant behavior, and equipment operation requirements. Infrastructure energy consumption may be better understood with the assistance of APSES, but cross-comparisons should be conducted within and between campuses to understand inefficient energy consumption of infrastructure.

APSES has targeted the buildings with highest potential for energy efficiency gain from the perspective of appliances, lighting, equipment etc. With the focus on research, classroom, and office buildings, the substantial potential for residence hall energy efficiency has yet to be tapped.

5.2.1.3 Stakeholders and Governance Regime

A possible shortcoming of this study is that potential external stressor stakeholders or experts were neglected. The assumption made here was that ASU system managers can adequately foresee downstream and future system risks resulting from these external stressors. This assumption may be invalid and improper assessment of risks to the entire system could impose economic, productivity or resource issues for future system planning and implementation. This could be rectified by including these experts in future sustainability assessments to assist in guiding ASU's energy system to minimize the impact of these risks.

ASU energy system managers currently focus heavily on downstream (internal) impacts of system operation. The limited engagement with upstream stakeholders, such as government regulators, can present unexpected challenges for the energy system. Regularly engaging these stakeholders and potential external stressor experts can help mitigate these challenges.

For example, ASU has previously reviewed the potential for energy exporting by way of QF status through FERC. However, current regulations make it uneconomical to do so. ASU should be actively involved in evolving QF rules, net-metering and general power exporting policy discussions at the State and National levels. Power export will be a key requirement to realizing sustainability of ASU's energy system.

ASU energy system managers should actively work with energy system suppliers that can help improve energy system sustainability and identify more "green" suppliers. This would require assessing the trade-offs between cost-effectiveness, environmental impact, and social balance in terms of participation and equity. Examples include working with ACC to better understand equipment or behavior-related demand drivers in residence halls, and working with APSES to identify infrastructure demand drivers. Fuel and energy supply diversity is also an area where energy supply sustainability may be improved by mitigating risk. ASU is installing substantial amounts of renewable energy equipment and also evaluating biofuel generation potential.

ASU's energy system demand side presents the greatest opportunity for sustainability impact.

ASU's current energy system is unidirectional, in that energy flows from supply through to demand, where the supply side is well managed in terms of technical, economic, and environmental measures. In other words, ASU's current energy system efficiently allocates resources to continuously satisfy inefficient demand.

However, with respect to long-term sustainability, ASU energy consumers currently lack the knowledge of energy consumption patterns and impacts, which translates into lack of participation from consumers. This is changing with the work of the University Sustainability organization. Participation from consumers can be encouraged and improved by first understanding the energy demanding behavior of consumers and energy demanding patterns of infrastructure, then effectively transfusing that knowledge to consumers. This will ultimately begin the transition towards long-term sustainability in the social domain. Given their lack of knowledge of the energy system, and the lack of organizational influence, ASU student, residential and employee stakeholder groups were not directly interviewed in this study. This should be rectified in further iterations of this sustainability assessment.

Finally, the effectiveness of a workshop for measurement of the current energy system is debatable. Since the current energy system is already measured by each individual stakeholder, the workshop did not necessarily add value in terms of system measurement. These metrics could just as easily have been acquired during the interview phase of the research.

5.2.2 Visioning and Sustainability Assessment

5.2.2.1 Visioning

Clearly, there are many different principles of sustainability offered in literature that could be operationalized for energy sustainability. Gibson's (2005) principles of sustainability not only satisfy the economic, environmental and societal domains, in general, but also reflect the interlinking of these domains.

In contrast to the current energy system, ASU's envisioned sustainable energy system will have a closed-loop feedback-oriented configuration.

In other words, <u>ASU's sustainable energy system will comprise sustainable demand based on widespread, equitable energy consumption knowledge and participation from consumers driving a sustainable energy supply system</u>.

5.2.2.2 Sustainability Assessment

Based on the literature review conducted for this study, a comprehensive, integrated sustainability assessment of any system should follow the guidelines detailed below:

1. It is performed ex-ante, to prevent bias or hindrance from pre-existing policies, constraints, or criteria (OECD, 2008 and Gibson (2005).
2. It is based on widely accepted principles of sustainability that are applied equally and with interconnections accounted (Gibson, 2005). Conventional planning methods prioritize economic growth. Sustainability challenges are temporally and spatially broad, requiring an approach balancing the interlinked domains of economy, environment, and society.
3. It targets a stakeholder-defined vision of a desired future sustainable state (Weaver & Jordan, 2008; OECD, 2008; Gibson, 2005). Without future sustainable states being collaboratively developed, sustainability transitions can result in flawed implementation with unacceptable or ineffective outcomes (Wiek & Iwaniec, 2011 and Wiek, 2010).
4. It is an open, transparent process (Ness et al., 2007; Weaver & Jordan, 2008; OECD, 2008; Pope et al., 2004; Gibson, 2005). Transparency and openness is critical to encourage participation and ownership from stakeholders.

5. It encourages widespread participation from accountable and responsible stakeholders to define metrics, indicators, visions, plans, and scenarios (Weaver & Jordan, 2008; OECD, 2008; Gibson, 2005). Successfully transitioning systems towards sustainable states will require effort and contribution from all stakeholders.
6. It is spatially broad including direct and indirect local, regional, and global impacts of the quantitative, qualitative, and governance aspects of the entire energy system (Weaver & Jordan, 2008; OECD, 2008; Pope et al., 2004; Gibson, 2005). Incomplete system mapping will also provide ineffective outcomes.
7. It balances trade-offs to maximize net, cumulative gains and minimize negative impacts (Gibson, 2005).
8. It provides a normative, aggregated measure of sustainability of the energy system measured using stakeholder-defined metrics and indicators (Pope et al., 2004; Gibson, 2005). Without an aggregated single measure, system sustainability performance will be difficult to gauge.
9. It is continually evolved, improved, and reapplied at strategic and tactical levels of decision making (Weaver & Jordan, 2008; OECD, 2008; Gibson, 2005). Sustainability transitions are long-term and will require diligence from all stakeholders to effectively realize the transition.

There may be some trade-offs at both the strategic and tactical levels of an overall sustainability assessment. Sustainability assessment demands site- or case-specific evaluation in a private sector context, as well as the broader, more accessible measurement in a public sector application. Strategically, the trade-off is between standardized, transparent assessment for broader public use and customized, undisclosed assessment for internal, organizational purposes. Internal to the assessment process there could be trade-offs within and between sustainability priorities.

The fact that in 2009 the energy system became less sustainable compared to 2008 would then identify the areas where ASU can focus to begin making gains on the sustainability score.

ASU's energy system will transition towards the sustainable energy system vision as unsustainable energy supplies are reduced or eliminated, and infrastructure and energy consumers are actively involved in the operation of the energy system.

5.2.3 Strategy Building

The strategy building step in this study only provided an initial exploratory strategic plan for transitioning the energy system towards long-term sustainability. Without regular reapplication of this process, reassessment, and associated active decision making, sustainability transitions will be difficult.

Chapter 6

CONCLUSIONS

6.1 Current Energy System

This research study was limited in its scope to ASU's energy system at the Tempe campus. Furthermore, the energy system was viewed by stakeholders and analyzed by the author as a whole, single entity.

To improve the sensitivity and precision of the assessment, it could be expanded to include all campuses, as a macro-assessment. This would allow for cross-campus comparisons as well as provide an overall assessment for ASU, the entire university. Within each campus, sensitivity and precision can be improved by conducted micro-assessments by colleges, departments, or infrastructure units. These macro- and micro-assessments would then also diversify the pool of stakeholders.

Energy auditing, energy demand reduction, energy efficiency improvement, and energy supply optimization are widely available, mature services and industries. APSES is providing these services for ASU today. However, in the energy system section of this research project, ASU could investigate the relationship and energy consumption patterns within its infrastructure. By understanding how buildings differ in their energy consumption, ASU could become better able to understand infrastructure, equipment, and resource inefficiencies and, in turn, better allocate its resources within each campus.

Understanding energy consumption behavior within ASU's population presents the greatest opportunity to improve overall sustainability. Further research could be done to understand how different segments within ASU's population consume energy, and how attitudes and behaviors might be changed to contribute to energy system sustainability.

6.2 Visioning and Sustainability Assessment

As shown and discussed earlier, ASU's current energy system is unsustainable in the long-term as assessed using stakeholder-defined metrics and indicators, against a principled approach to energy sustainability.

Moving forward, the energy system must be evolved to reduce reliance on unsustainable external energy sources. Internally, stakeholders must become involved in the sustainable operation of the system, while contributing to equitable energy consumption. Infrastructure must be improved to actively contribute to sustainable energy consumption.

The ACUPCC has brought together American universities and colleges to commit to climate change. Research could be conducted to assess and compare the energy-related technical, economic, environmental, and social performance of ACUPCC member colleges and universities, thereby expanding the existing commitment to more sustainability principles.

For ASU energy system managers, continued application and improvement of the sustainability assessment decision support framework presented herein should help transition the energy system towards long-term sustainability.

6.3 Strategy Building

This project only had an exploratory strategy building step, where stakeholders outlined an initial strategy to transition the current unsustainable energy system towards the sustainable vision for the energy system.

Strategic planning for a sustainable energy system could be accomplished by adapting the Transformative Planning Framework (Wiek, 2010), broadly depicted in Figure 17.

Figure 17 shows how the major components of this research study can be merged with this decision support framework. Boxes 1 and 2 (Figure 17) represent the current state of the energy system. Box 3 reflects the visioning stage of this research study. The principled, participatory, and normative sustainability assessment is inherent to Box 3. Box 4 includes the initial strategy building step of this research study.

As the energy system transition is initiated, the strategy building step is repeated as necessary utilizing techniques such as backcasting (Robèrt et al., 2002) or scenario construction and analysis to build a roadmap towards the comprehensive sustainable energy system vision. Timely sustainability assessment of scenarios will provide direction- and distance-to-target vision trajectories and measures, respectively. Based on the results, strategic plan and the operating system deviation and intervention points will be identified. Incremental strategy testing can also be conducted with pilot projects around campus to test the impact (positive or negative) on the sustainability assessment scores. This becomes a cyclical, routine process by which the energy system can be incrementally transformed towards the envisioned future sustainable state.

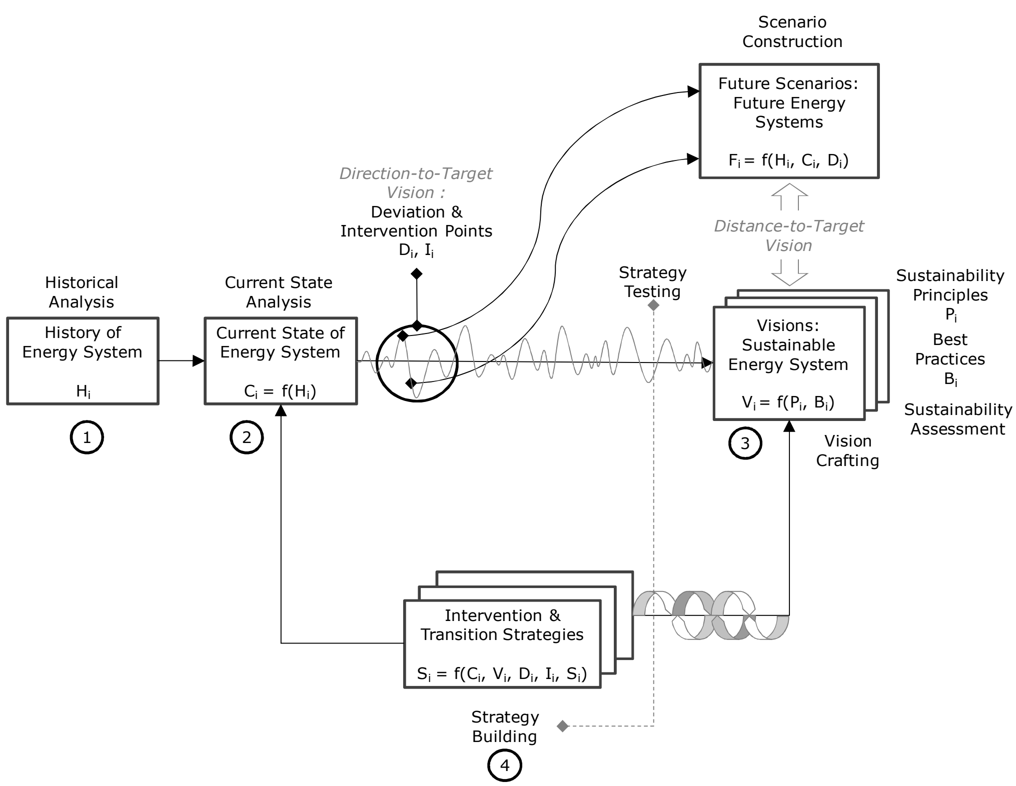

Figure 17. Decision Support Framework for a Sustainable Energy System (adapted from Wiek, 2010).

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APPENDIX A

ASU ENERGY SYSTEM STAKEHOLDER INTERVIEWS

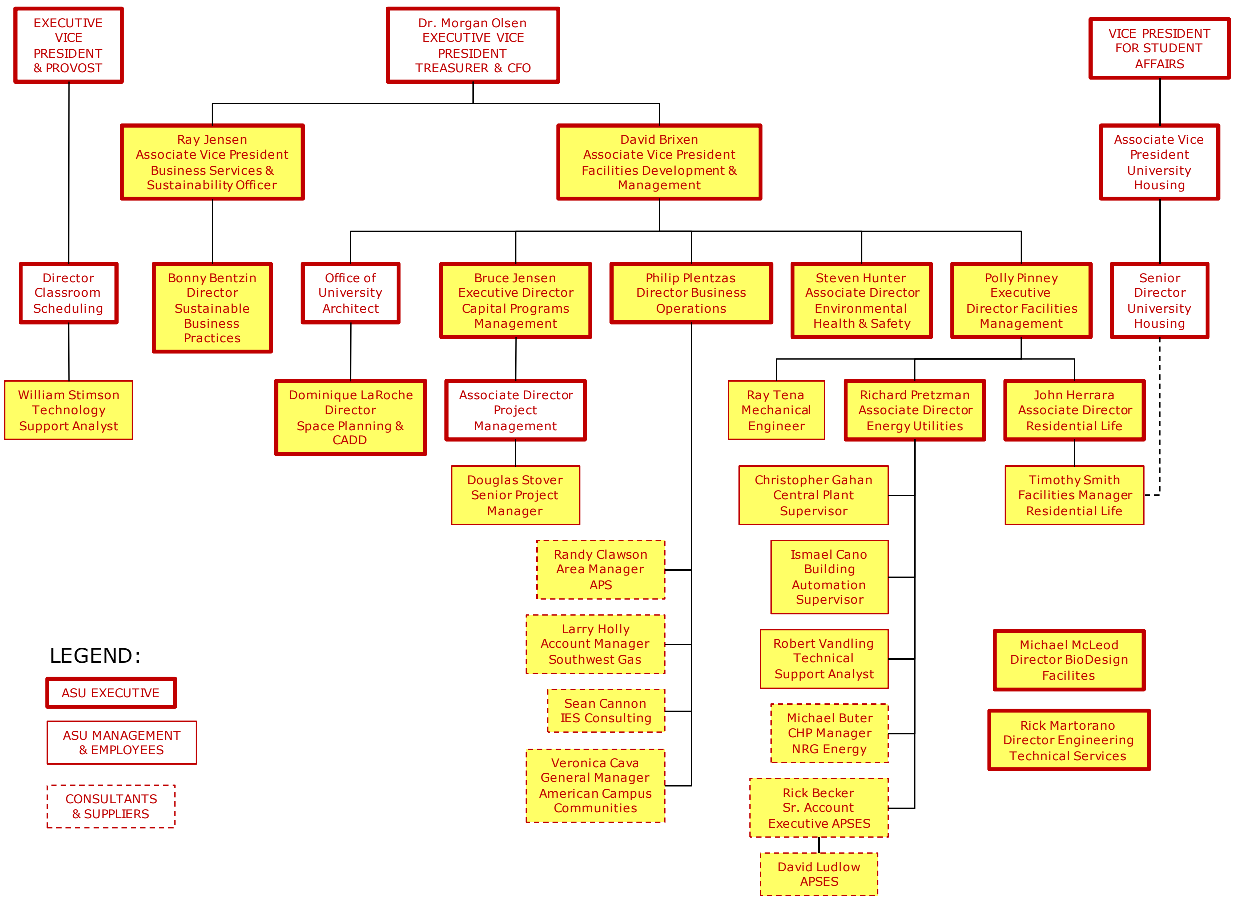

Figure A1. ASU University Services Organization in 2008.
(Interviewed stakeholders identified by yellow shaded boxes)

Interview Questionnaire

Attendees: Meeting Date:

1. How does the energy system function annually with respect to on site generation and imported generation?
2. What is your role in the ASU Energy System and what are its major tasks?
3. What percentage of time is spent on major tasks, and who are the people you interact with to do these tasks?
4. How do you measure success in your job?
5. What kind of are decisions made? (Proactive vs. reactive, real-time, etc.)
6. How do you influence energy supply decisions? (Timing of operations, tariff effects, operating vs. capital budgeting, resources, etc.)
7. How do your decisions influence energy demand?
8. How does supply and demand affect your decision making?
9. What rules/regulations/policies/codes do you follow or guide you in your decision making?
10. How are decisions communicated? (meetings, memos, etc.)
11. Are there any tools, processes or methods used to enable decisions?
12. Identify other internal and external stakeholders influencing the energy system?
    a. Direct influencers and indirect influencers
    b. Types of influence: regulatory, policy/organizational, operational/functional, cultural, etc.
13. What is your perspective of energy sustainability at ASU? (Environmental issues, social issues etc.)

Stakeholder Interview List (interview dates in parentheses)

1. Dave Brixen, VP USB (10/23/2009 and 12/09/2010)
2. Phil Plentzas, Business Services Director, (multiple interviews, 2010-2011)
3. Chris Gahan, Central Plant Manager, (5/21/2010)
4. Dave Ludlow, APSES Consultant, (5/21/2010)
5. Randy Clawson, APS Account Manager (5/27/2010)
6. Bonny Bentzin, Director, Sustainable Business Practices (5/28/2010)
7. Tim Smith, Residence Life, reports to Melissa Krewson (7/12/2010)
8. Mike Buter, CHP Manager, reports to Rick Pretzman (7/13/2010)
9. Sean Cannon, IES Consultant, behavioral assessment (7/29/2010)
10. Ray Tena, Facilities Manager (9/23/2010)
11. Rob Vandling, Controls (met with Ray Tena) (9/23/2010)
12. Dominique Claude-Laroche, Director, Space Planning (10/1/2010)
13. Rick Becker, APSES Phase 2 Performance Contract Manager (10/5/2010)
14. Steve Hunter, Associate Director, EH&S (10/08/2010)
15. Ishmail Cano, Building Automation Supervisor (10/08/2010)
16. Bill Stimson, Technology Support Analyst, classroom scheduling (10/08/2010)
17. Larry Holly, Southwest Gas Account Manager (11/2/2010)
18. Bruce Jensen, Executive Director, Capital Programs (11/4/2010)
19. Doug Stover, Sr. Project Manager (works for Bruce) (11/4/2010)
20. Polly Pinney, Executive Director (11/5/2010)
21. Rick Pretzman, Assoc. Director, Energy/Utilities, (11/5/2010)
22. John Herrara, Director, Residential Life (11/16/2010)
23. Veronica Cava, Facility Manager, (11/16/2010)
24. Ray Jensen, University Sustainability Officer (11/29/2010)
25. Rick Martorano, Director, Engineering Tech Services, School of Engineering (12/20/2010)
26. Mike McCleod, Biodesign Facilities (1/11/2011)

Table A1

Workshop Attendees and Expertise

STAKEHOLDER	EXPERTISE	ATTENDANCE		
		Workshop 1	Workshop 2	Workshop 3
David Brixen	Energy system executive management	Yes	Yes	No
Phil Plentzas	Budget and supplier management	Yes	Yes	Yes
Chris Gahan	Central plant operations	Yes	Yes	No
Dave Ludlow	Central plant operations	Yes	No	No
Randy Clawson	APS account manager	Yes	No	No
Bonny Bentzin	University sustainability practices	Yes	Yes	Yes
Tim Smith	Residential life facilities management	Yes	Yes	No
Mike Buter	CHP plant operations	No	No	No
Sean Cannon	Energy demand behavior consultant	No	No	No
Ray Tena	Special projects engineer	Yes	No	Yes
Rob Vandling	Building system controls	Yes	Yes	Yes
Dominique Laroche	Space planning	Yes	Yes	Yes
Rick Becker	APSES manager	Yes	No	No
Steve Hunter	Environmental management	Yes	Yes	Yes
Ishmail Cano	Building automation management	Yes	Yes	Yes
Bill Stimson	Space scheduling	No	No	No
Bruce Jensen	Capital programs management	Yes	Yes	Yes
Doug Stover	Capital programs management	No	No	No
Polly Pinney	Facilities management	Yes	Yes	No
Rick Pretzman	Energy utilities management	Yes	Yes	Yes
John Herrara	Residential life facilities management	Yes	Yes	Yes
Veronica Cava	Residential life facilities management	Yes	No	No
Ray Jensen	Sustainability executive management	Yes	No	No
Rick Martorano	Engineering energy demand management	No	Yes	Yes
Mike McCleod	Biodesign energy demand management	Yes	Yes	Yes
	TOTAL ATTENDEES	**20**	**15**	**12**