From Carnegie Mellon to Kyoto: How Far Can We Go?

Project Courses at Carnegie Mellon

- Involve real-world, unstructured problems involving technology and public policy.
- Provide students with leadership experience in problem-solving environments.
- Require a multi-disciplinary, team-oriented approach.
  - Department of Engineering & Public Policy
  - Department of Social & Decision Sciences
  - H. John Heinz III School of Management & Public Policy
- Managed by students and monitored by faculty advisors.
- Assisted by a review panel of campus decision makers, specialists, and industry experts.

Introductions: Review Panel

- **In Washington, DC**
  - Alexandra Carr, Department of Engineering & Public Policy, Carnegie Mellon
  - Helen Kerr, BP Amoco
  - Joseph Romm, Global Environment and Technology Foundation
  - Joel D. Scheraga, U.S. Environmental Protection Agency
  - James Zucchetto, National Research Council

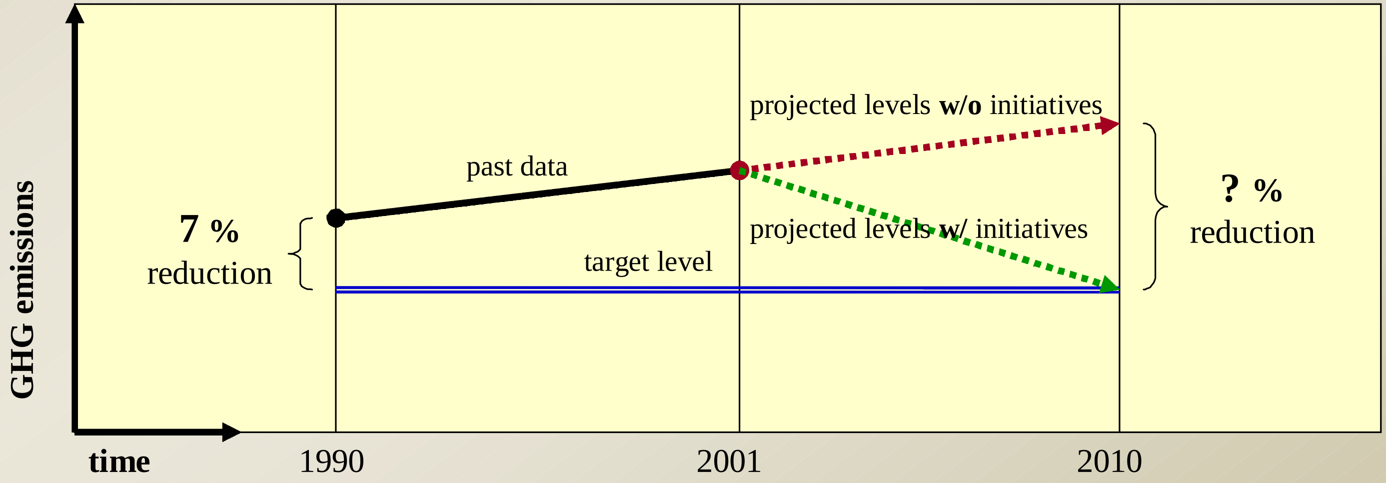
- **In Pittsburgh, PA**
  - Martin Altschul, Facilities Management Services, Carnegie Mellon
  - Jeffrey Bolton, VP for Business and Planning, Carnegie Mellon
  - Jarod Cohon, President, Carnegie Mellon
  - David Dzombak, Professor, Civil & Environmental Engineering, Carnegie Mellon
  - James Ekmann, Assoc. Director, NETL, U.S. Department of Energy
  - Ken Kimbrough, Assistant VP, Facilities Management Services, Carnegie Mellon
  - Barb Kviz, Chairperson, Green Practices Committee, Carnegie Mellon
  - Elizabeth Munsch, Asst. University Energy Manager, University of Pittsburgh
  - John Schenk, University Energy Manager, University of Pittsburgh
  - Thomas Spiegelhalter, Professor of Architecture, Carnegie Mellon

The Environmental Impacts of Greenhouse Gases (GHGs)

- GHG emissions have been cited as a cause of global climate change, causing sea level rises, changes in weather patterns, and health effects.
- GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs), among others.
- CO_2 is by far the dominant GHG.
- Emissions of CO_2 are primarily the result of the burning of fossil fuels, such as coal, natural gas, and transportation fuels.

The Kyoto Protocol

- The Kyoto Protocol is an international treaty aimed at reducing global GHG emissions in industrialized and developing nations under the 1997 U.N. Framework Convention on Climate Change (UNFCCC).
- The Kyoto Protocol would limit U.S emissions of GHGs to 7% below 1990 baseline levels by the period 2008-2012, as shown below:



Project Motivations

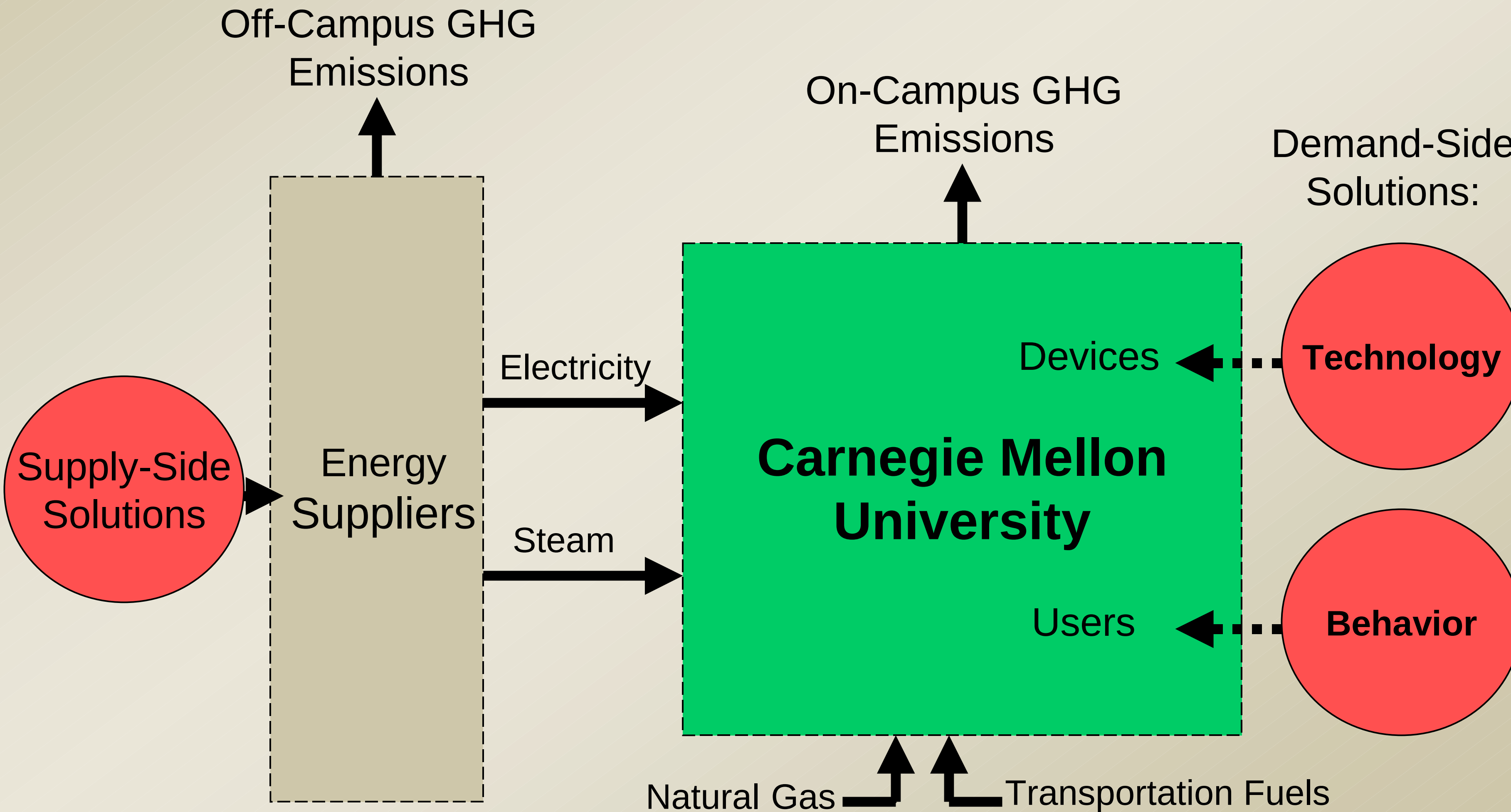
- The United States has chosen **not** to ratify the treaty, arguing that it is not economically feasible, among other things. However, other nations are pursuing ratification.
- A growing number of large corporations (e.g. BP Amoco, AEP) are independently pursuing GHG emissions reductions.
- Can Carnegie Mellon, as part of its environmental initiative, meet the Kyoto Protocol's targets?
  - If so, how? At what cost?
  - If not, why? How far ***can*** we go?

Project Objective

- Determine the feasibility of reducing greenhouse gas (GHG) emissions associated with Carnegie Mellon University in the context of the Kyoto Protocol.

- Process:
  - Analyze Carnegie Mellon's energy consumption and associated GHG emissions.
  - Estimate potential progress toward Kyoto goals.
  - Evaluate possible reduction strategies.
  - Recommend best strategies.
  - Provide other institutions considering voluntary commitment with potentially useful methodologies.

Carnegie Mellon Energy System:



Presentation Outline

- **Carnegie Mellon Energy Consumption and GHG Emissions: A Closer Look**
  - Where is Carnegie Mellon's energy being used?
  - What are our GHG emissions? Kyoto obligations?
- **Behavioral Options to Reduce Energy Demand**
  - What can we do to affect the campus community's behavior in order to decrease energy consumption?
- **Technology Options to Increase Energy Efficiency**
  - What can we do to increase the energy efficiency of campus systems and devices?
- **Supply-Side Options to Reduce GHG Emissions**
  - Can we purchase "cleaner" energy from suppliers?
  - Can we produce our own energy on campus?
- **Policy Evaluations and Recommendations**
  - Who makes the decisions, how are they made, and how can we influence them?
  - What are our final recommendations?
- **Questions & Answers**

Carnegie Mellon Energy Consumption and GHG Emissions

Objectives

- Characterize current Carnegie Mellon energy use.
- Estimate Carnegie Mellon's past (1990) energy consumption.
- Estimate future (2010) energy consumption under 'low' and 'high' scenarios.
- Estimate associated greenhouse gas emissions.

Defining Carnegie Mellon: 2000

Physical Space

- 3.8 million sq ft
- 41 buildings
- Building Functions (% sq ft of total campus):

Academic	38%
Housing Facilities	20%
Research	15%
Common, Admin, etc.	27%

Population

Students	8,500
Faculty/Staff	3,300
Total	11,800

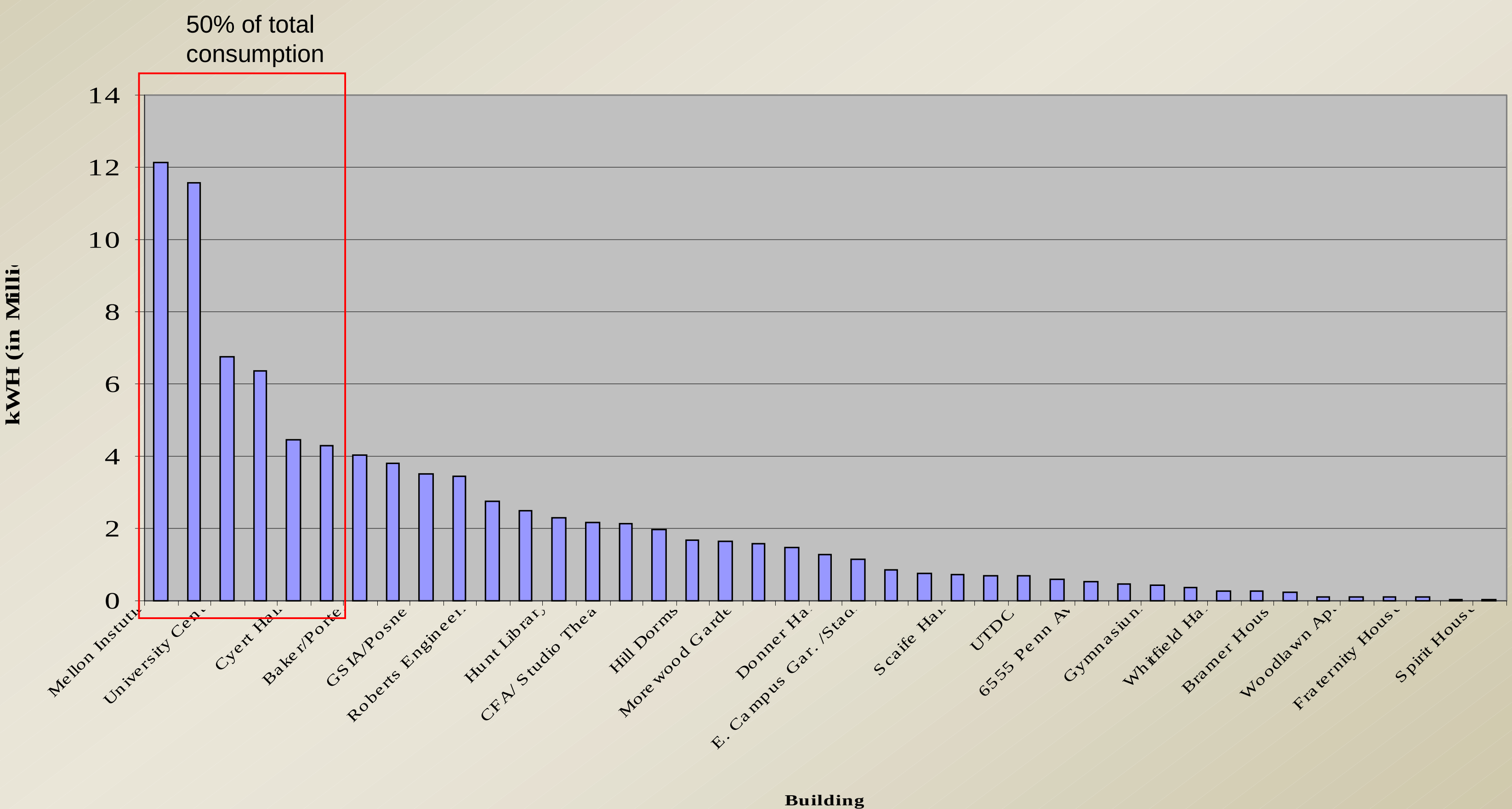
Carnegie Mellon Utilities: 2000

	Total Usage	Total Cost	Price per Unit
Electricity	85,500,000 kWh	$4,890,600	$0.0572 per kWh
Steam	275,560 Mlbs	$2,011,588	$7.30 per Mlb
Natural Gas	38,500 MCF	$201,255	$5.23 per MCF

Total Energy Cost = $7.1 million (~$840 per student)

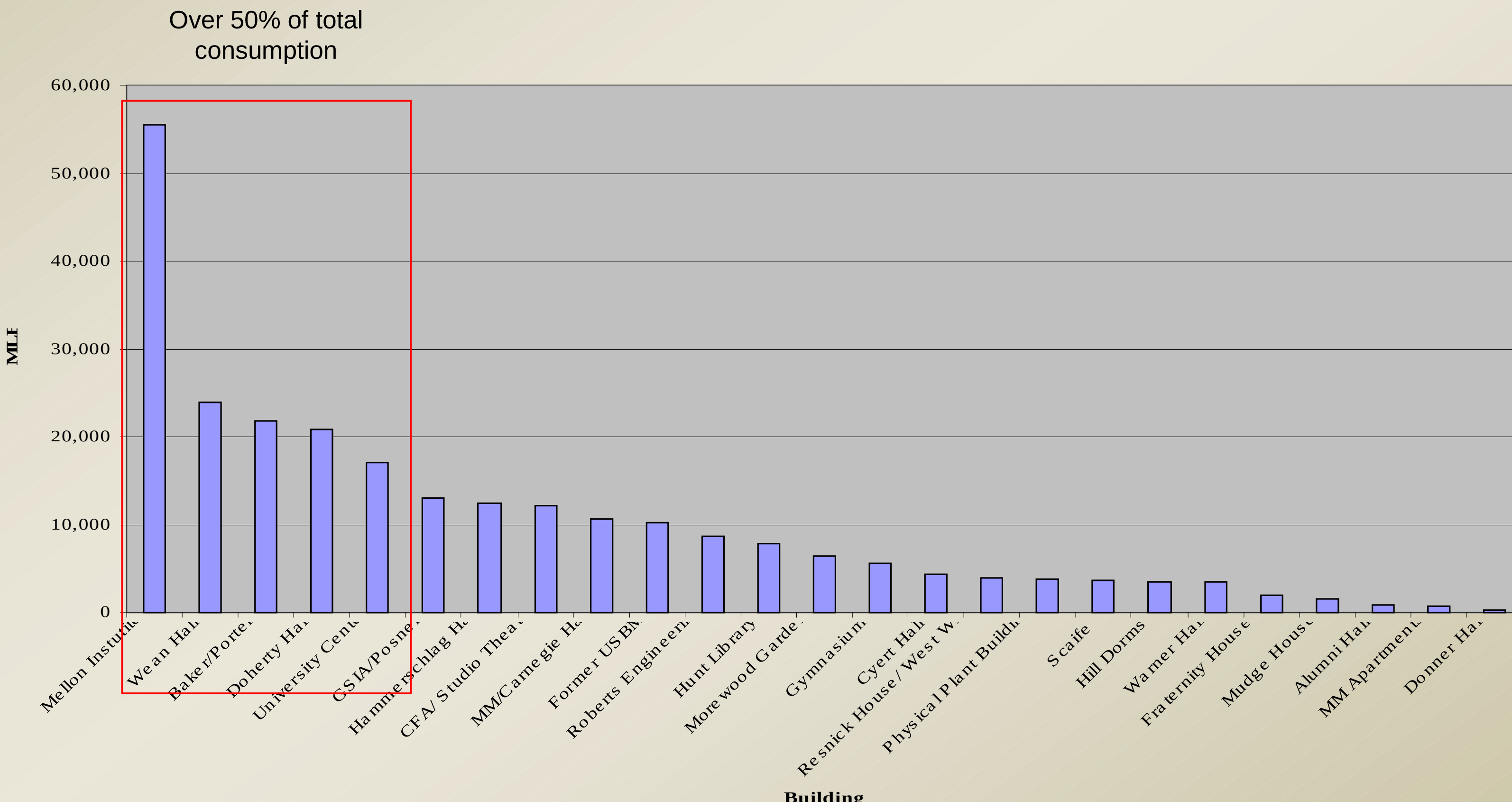
Carnegie Mellon Energy Consumption: 2000

ELECTRICITY in million kWh per building



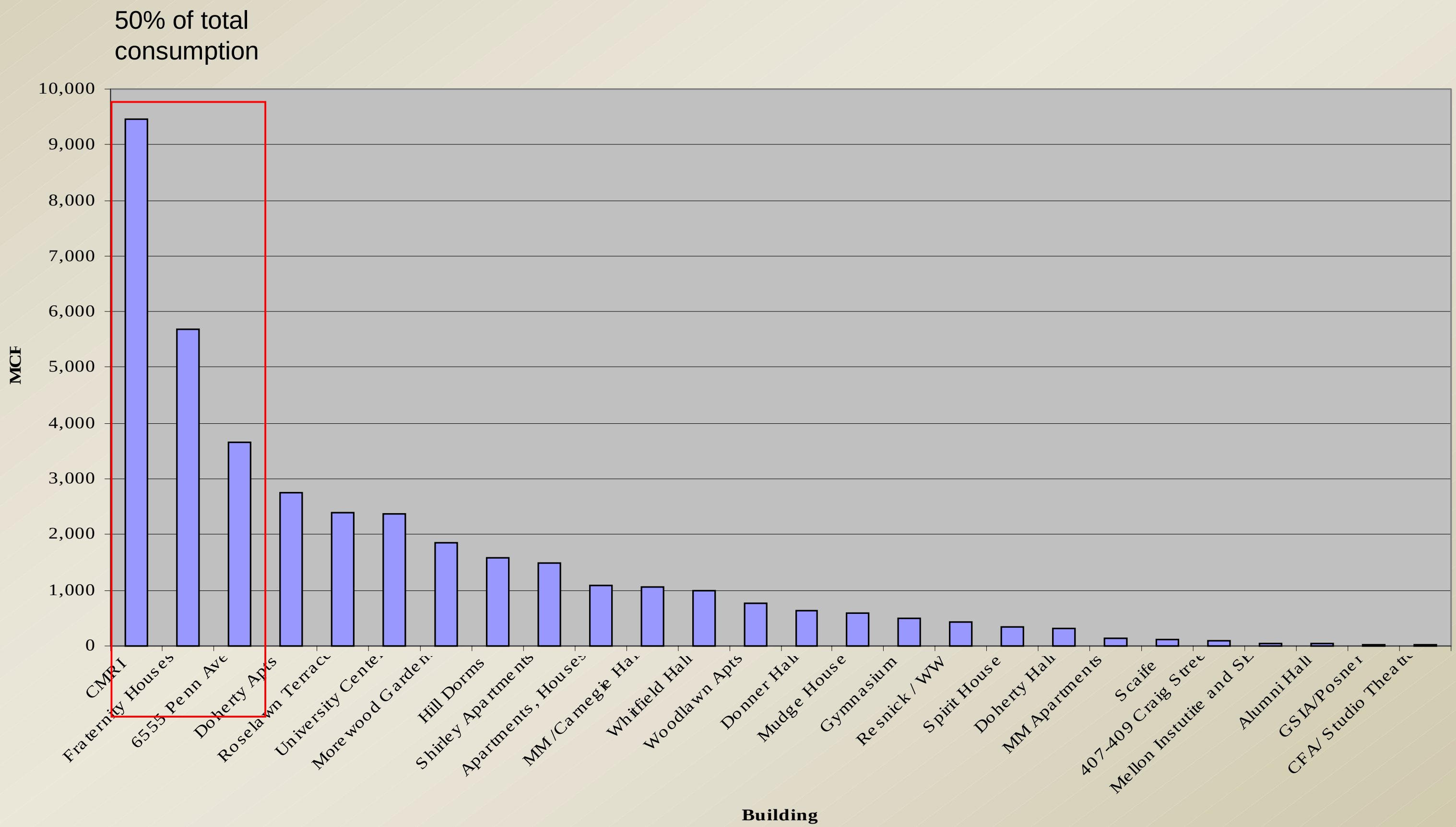
Carnegie Mellon Energy Consumption: 2000

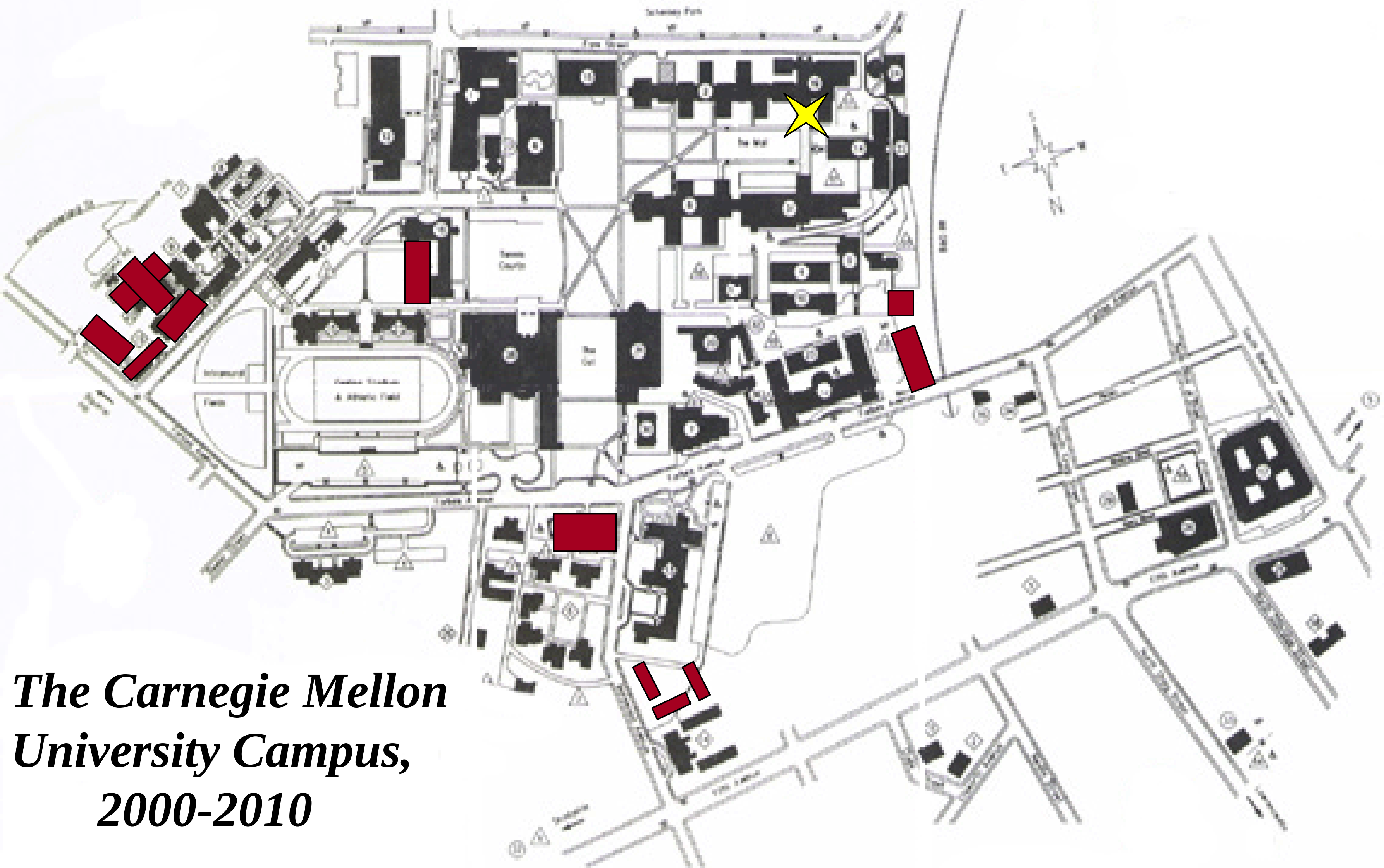
STEAM in million lbs per building



Carnegie Mellon Energy Consumption: 2000

NATURAL GAS in MCF per building





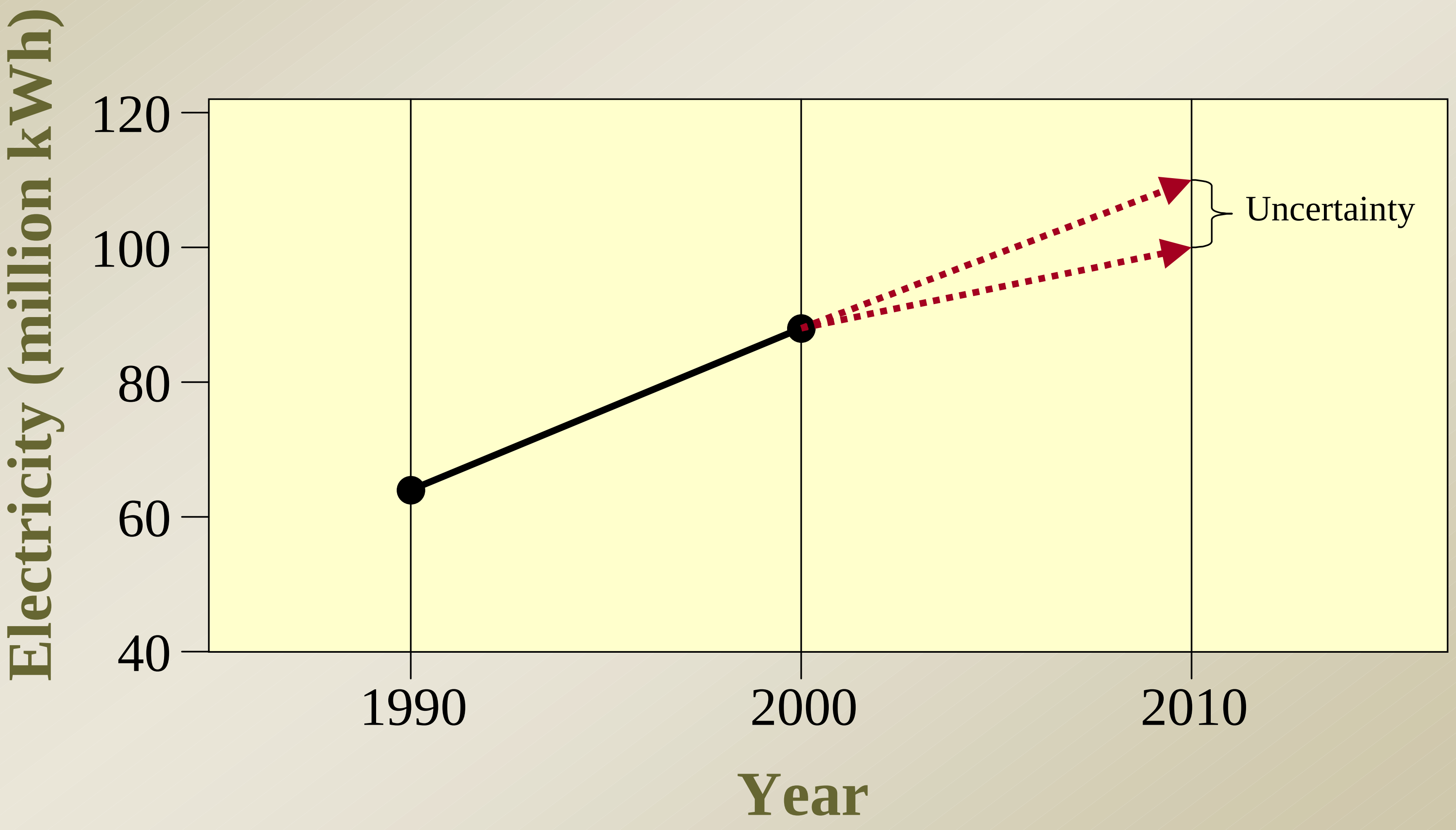
The Carnegie Mellon University Campus, 2000-2010

Projected Campus Growth, 2000-2010

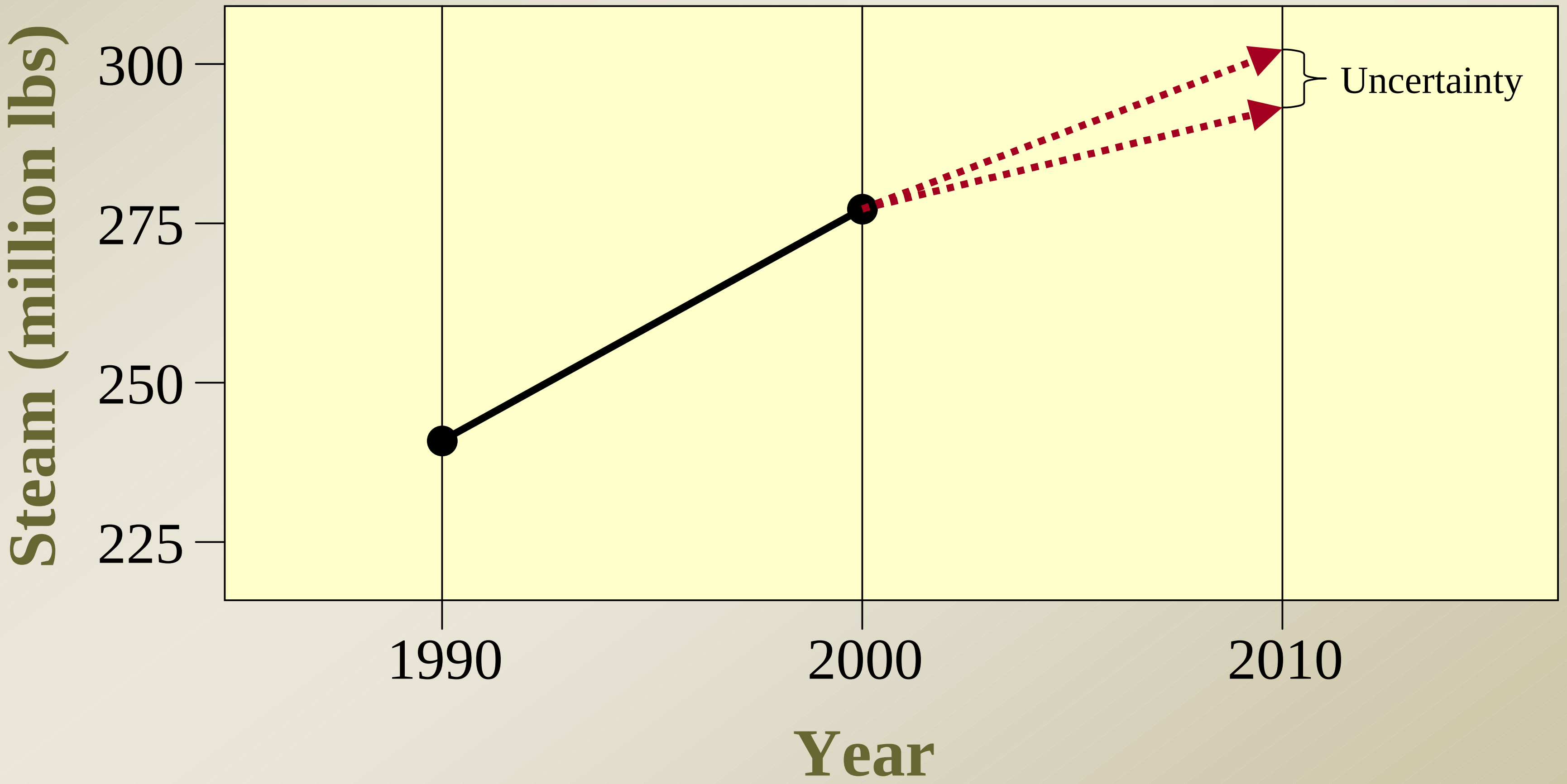
- Campus Area
  - New buildings added = 286,300 ft^2
  - Buildings demolished = <u>81,300 ft^2</u>
  - Net addition = 205,000 ft^2

- Carnegie Mellon Population Growth
  - Estimated 2010 total = ~12,700 students, faculty, and staff.

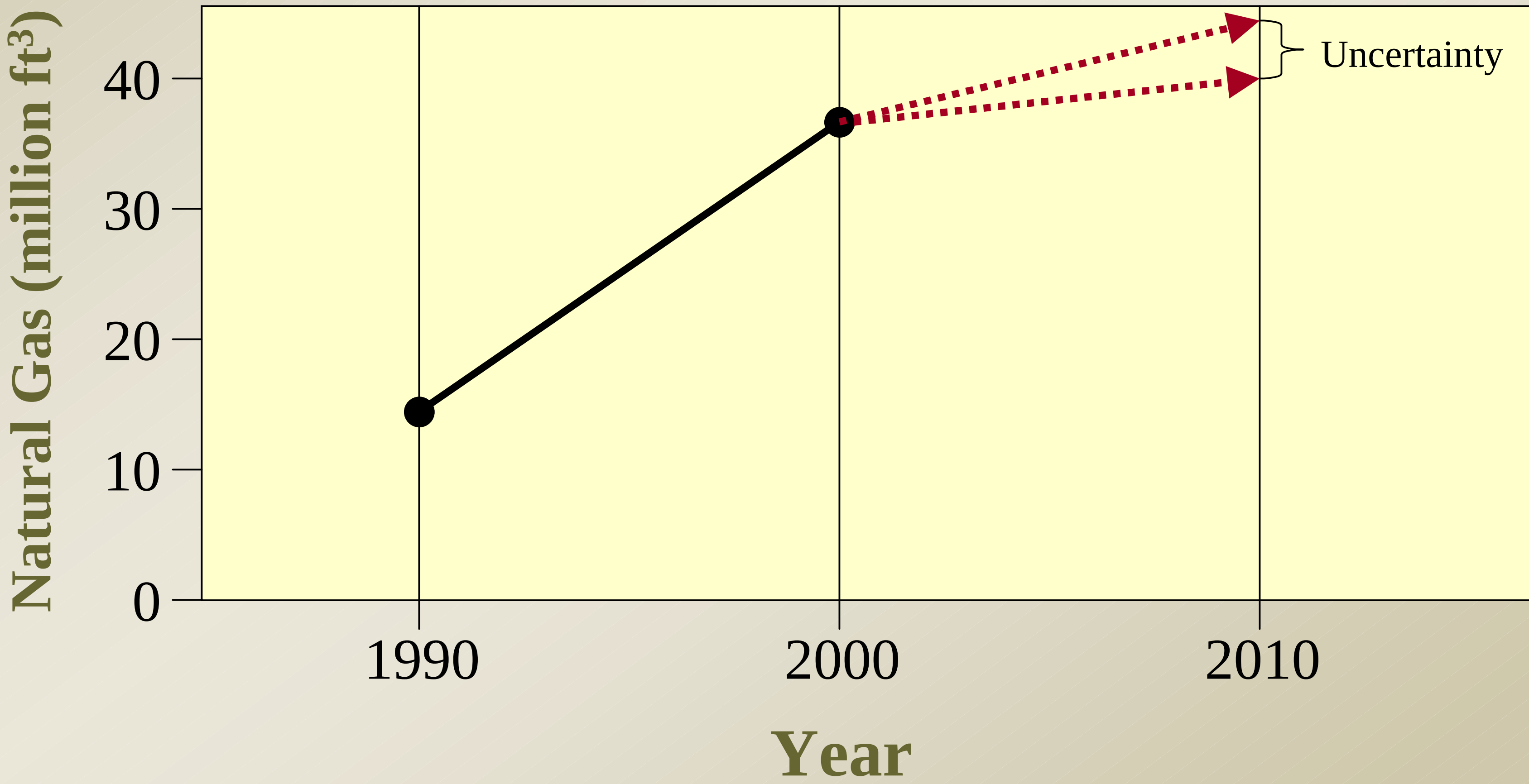
Projected Campus Electricity Use



Projected Campus Steam Use



Projected Campus Natural Gas Use



Sources of Greenhouse Gas Emissions

- Direct University Emissions:
  - Electricity (kWh)
  - Steam (Mlbs)
  - Natural Gas (MCF)
  - Automotive fuels (gal)

- Indirect Emissions:
  - Municipal solid waste
  - Commuter vehicles
  - Airplane travel (students and faculty)

Current GHG Emissions: 2000

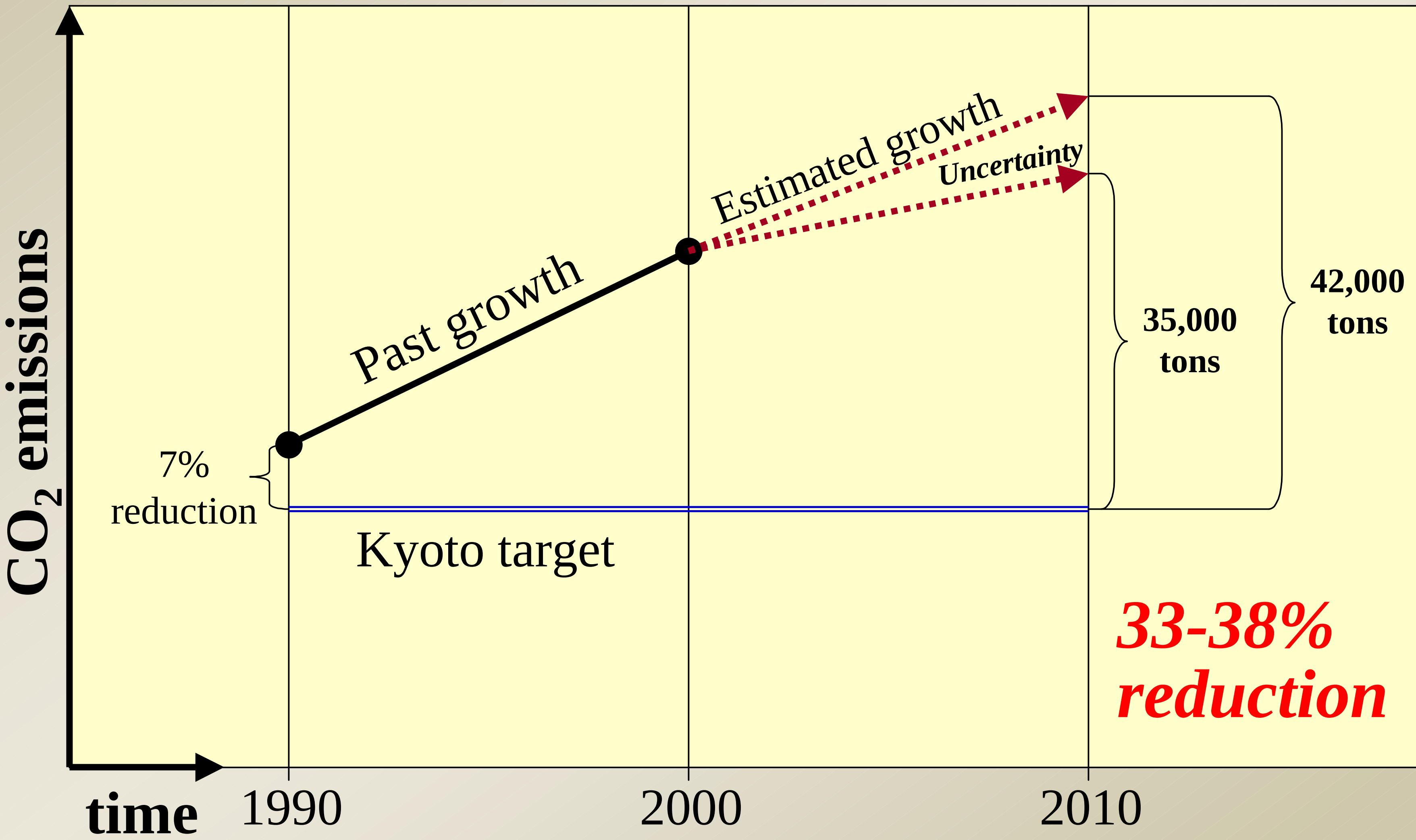
- Electricity Supply:
  - 71% coal, 29% nuclear
  - 0.74 tons CO_2 per MWh
- Steam Supply:
  - 56.5% coal, 43.5% natural gas
  - 0.104 tons CO_2 per Mlbs
- Natural Gas Supply:
  - 0.06 tons CO_2 per MCF
- Carnegie Mellon Vehicles and Other
  - Negligible

Carnegie Mellon CO_2 Emissions

How far do we have to go to reach Kyoto?

	1990	2000	2010 (low)	2010 (high)
CO_2 from electricity (tons)	47,360	63,270	71,970	78,100
CO_2 from steam (tons)	26,700	28,620	30,170	30,980
CO_2 from natural gas (tons)	780	2,310	2,440	2,500
Total tons of CO_2	**74,840**	94,200	**104,580**	**111,580**
Kyoto Target (tons)			69,600	69,600

Total CO_2 reduction (tons)			**34,980**	**41,980**



CO_2 emissions
Past growth
Estimated growth
Uncertainty
42,000 tons
35,000 tons
7% reduction
Kyoto target
33-38% reduction
time
1990
2000
2010

Behavioral Options to Reduce Energy Demand

Objectives

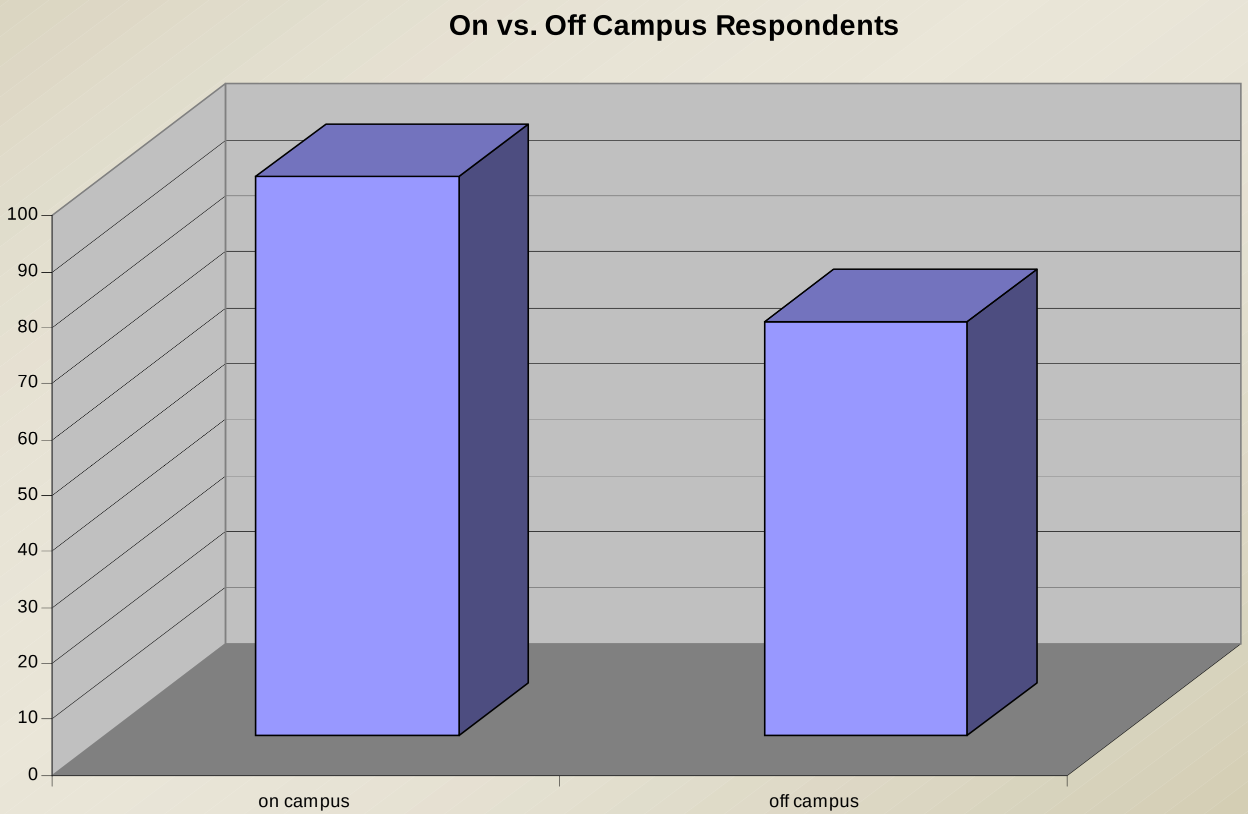
- Identify attitudes and behaviors among the campus community concerning energy use.

- Evaluate possible solutions for energy conservation.

Survey Methodology

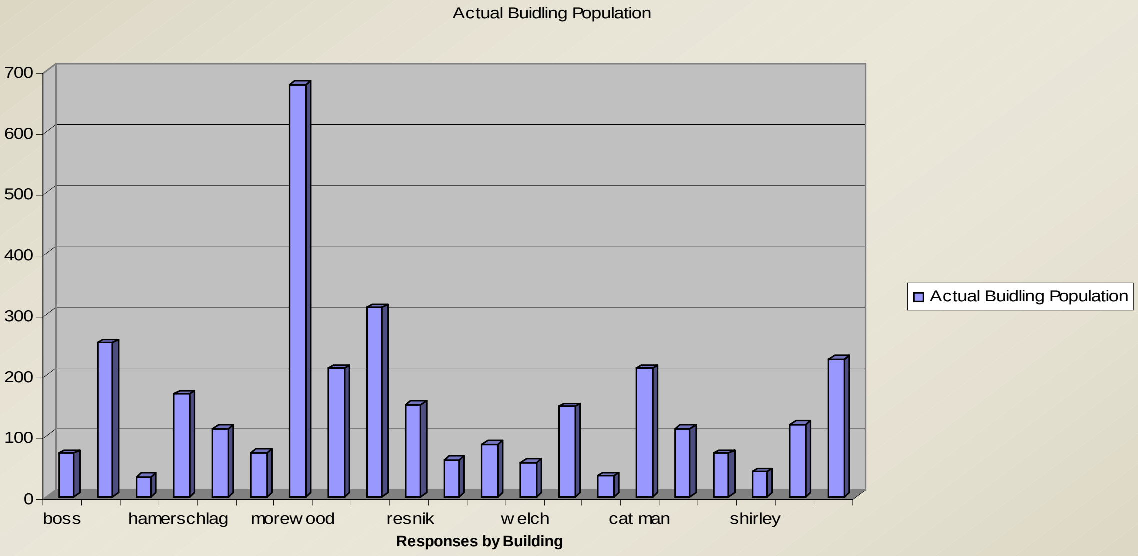
- Surveys showed behavioral patterns and attitudes regarding energy consumption among students at Carnegie Mellon.
- Questions focused on respondents’ support for policies affecting their personal energy consumption.

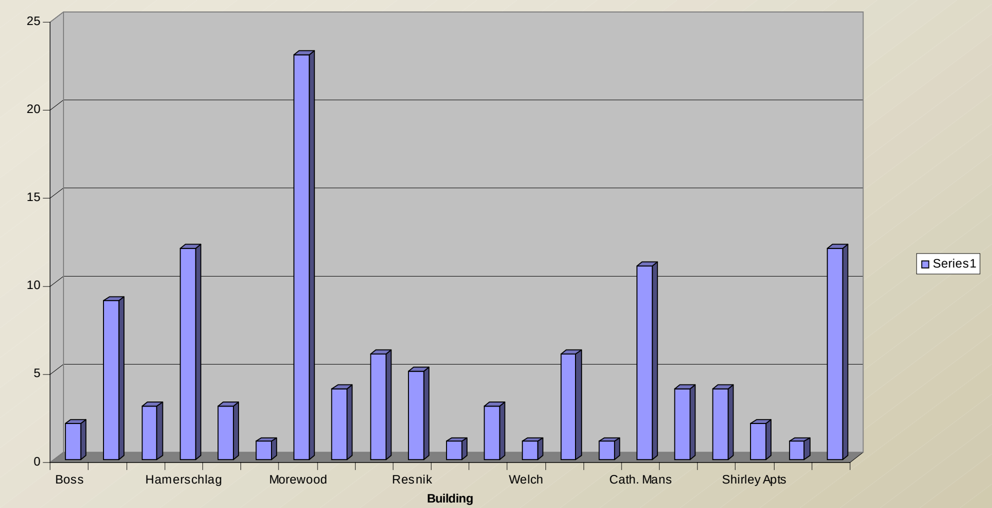
Who took the survey?



N = 174

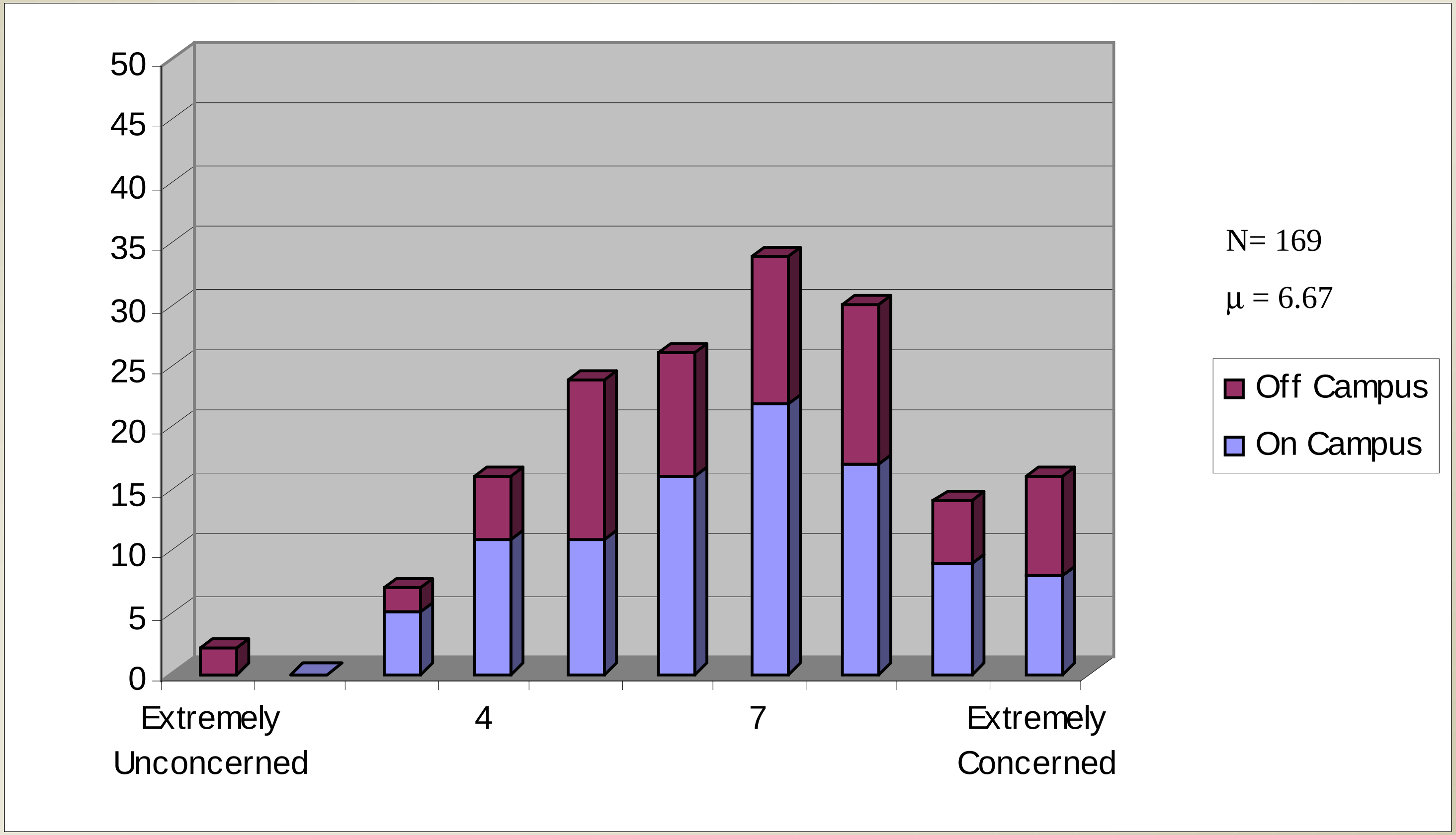
On-Campus Distribution



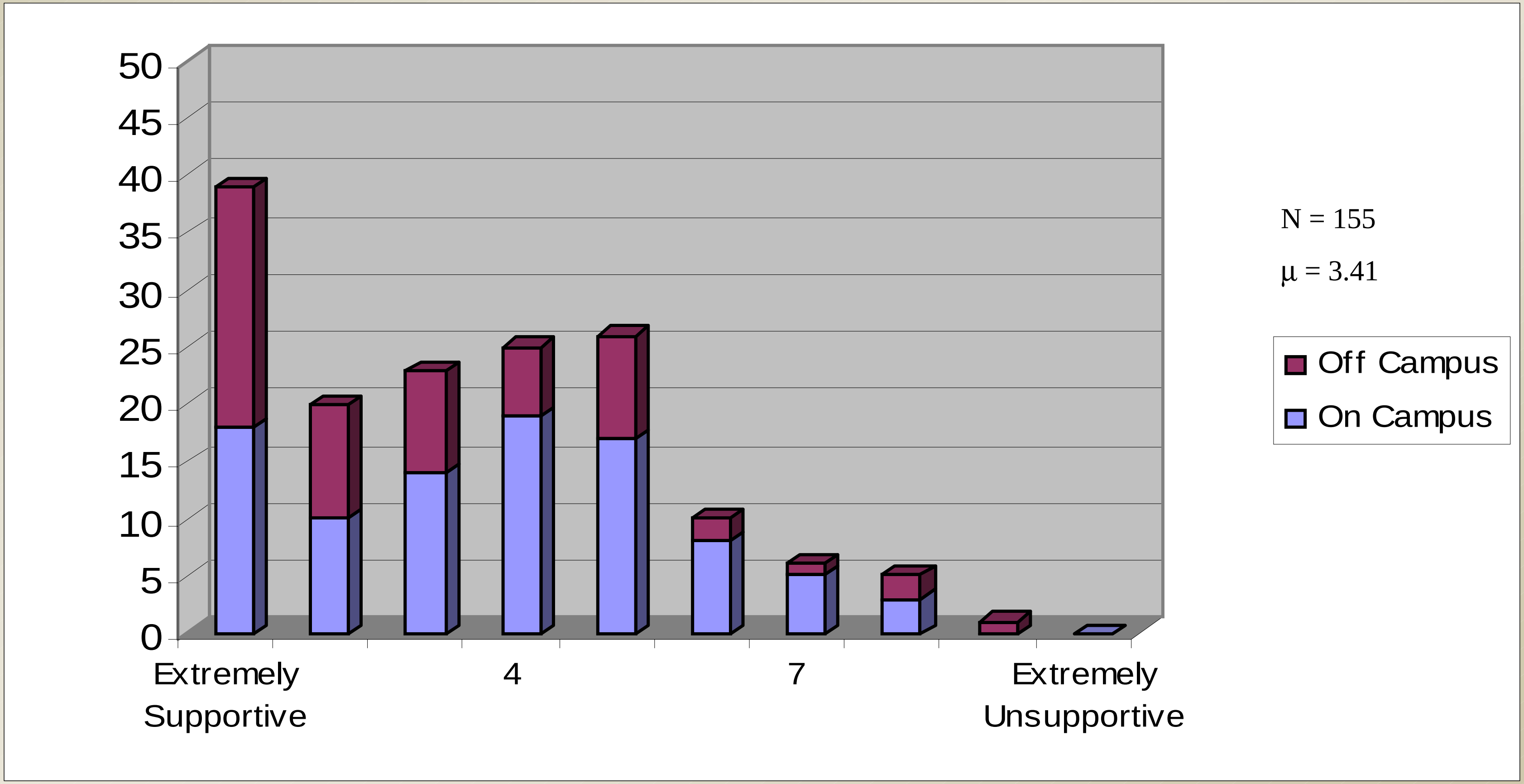


Overall Attitudes Concerning Environmental Policies

Environmental Concern



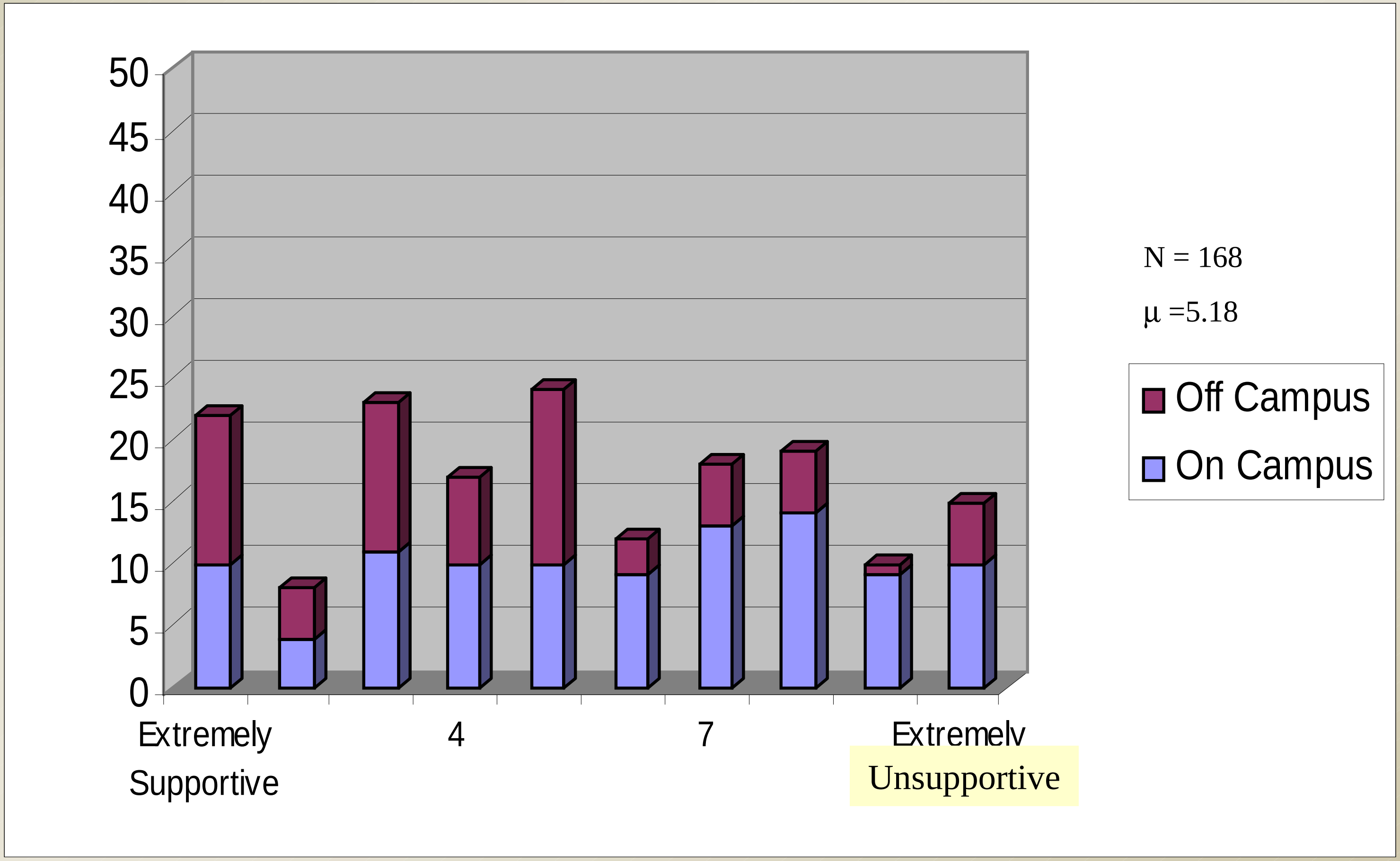
Green Campus Initiative



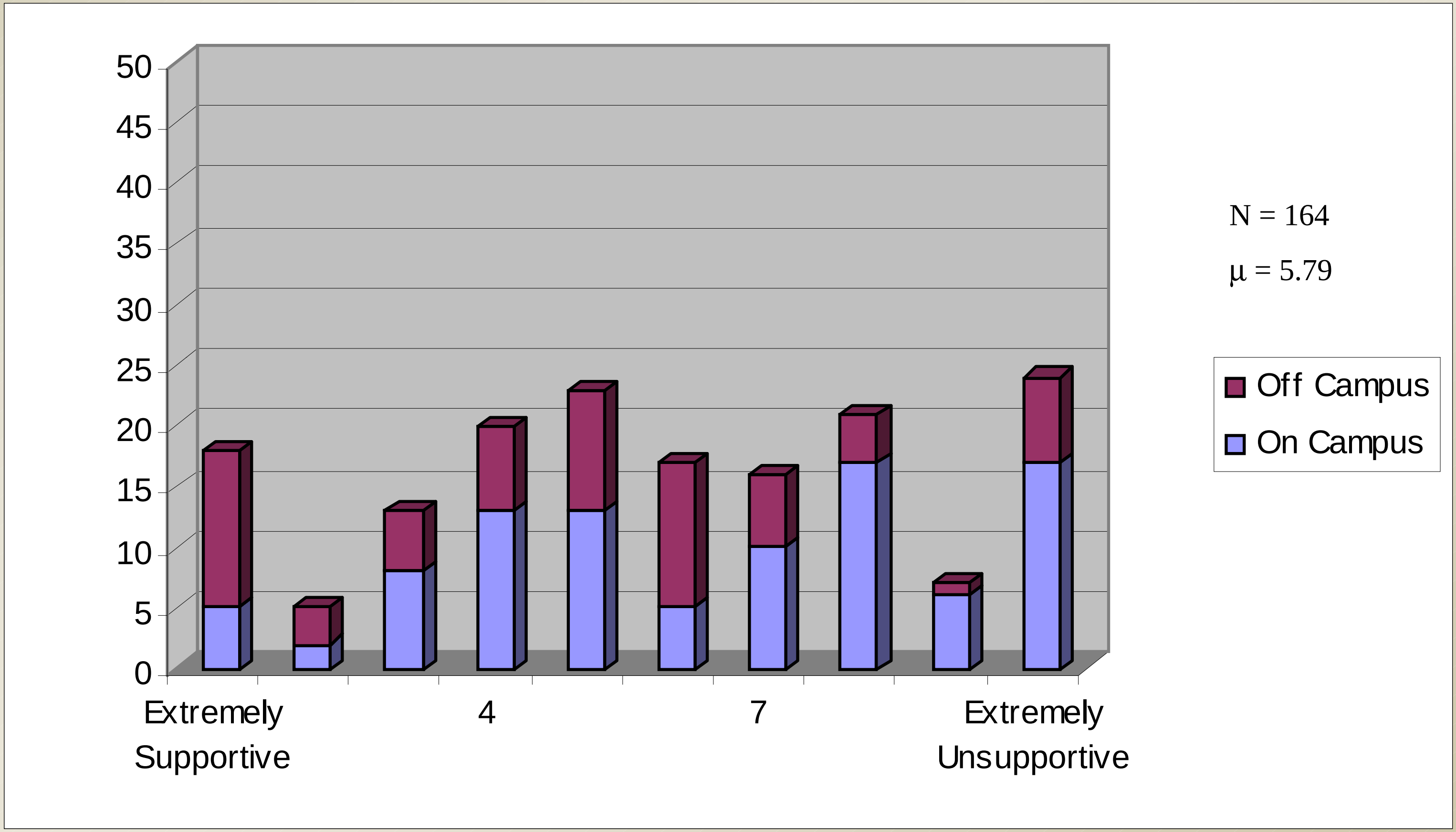
Dormitory Options:

Can students be more efficient and save money at the same time?

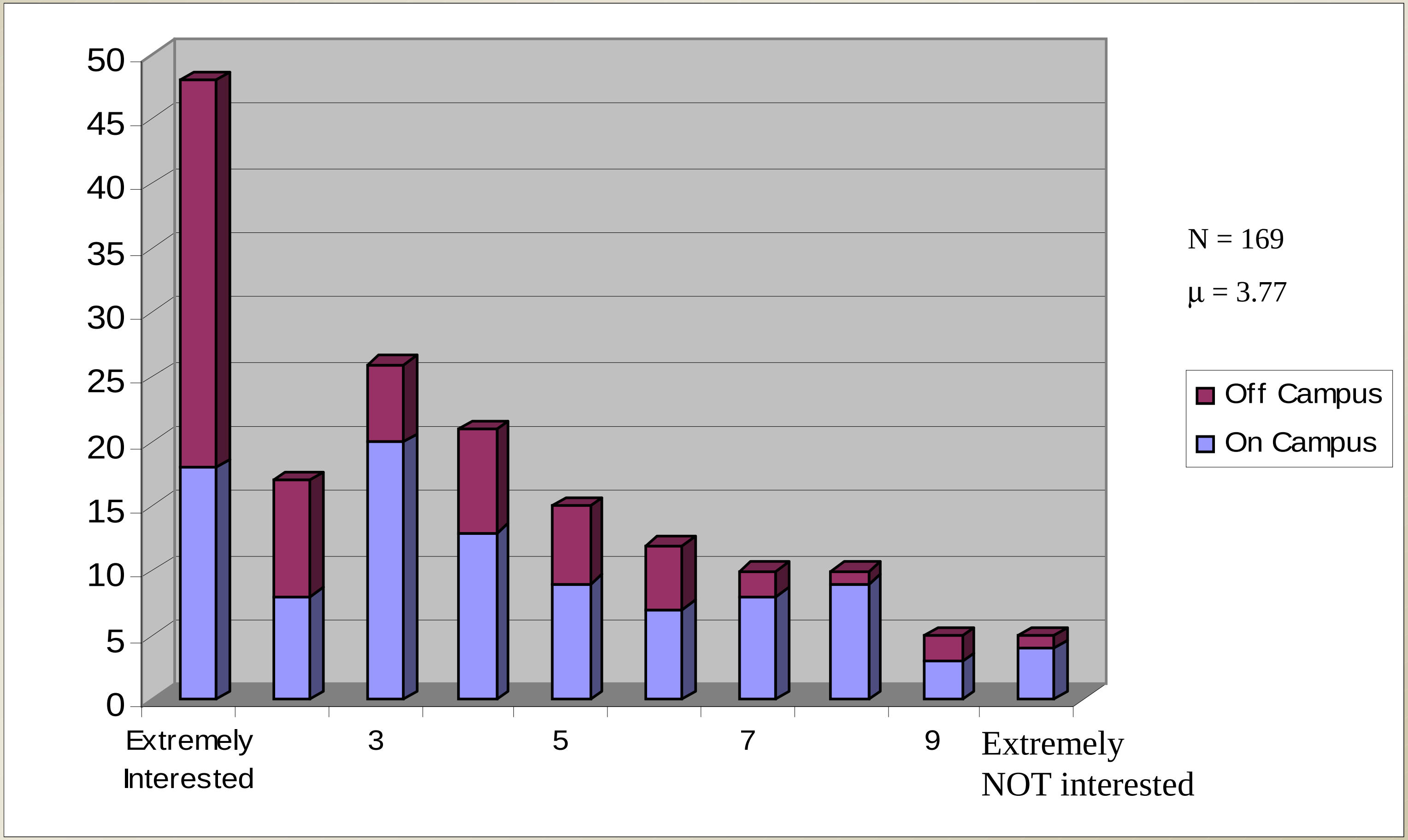
Lower Housing Fee/Pay Utilities



Energy Quota



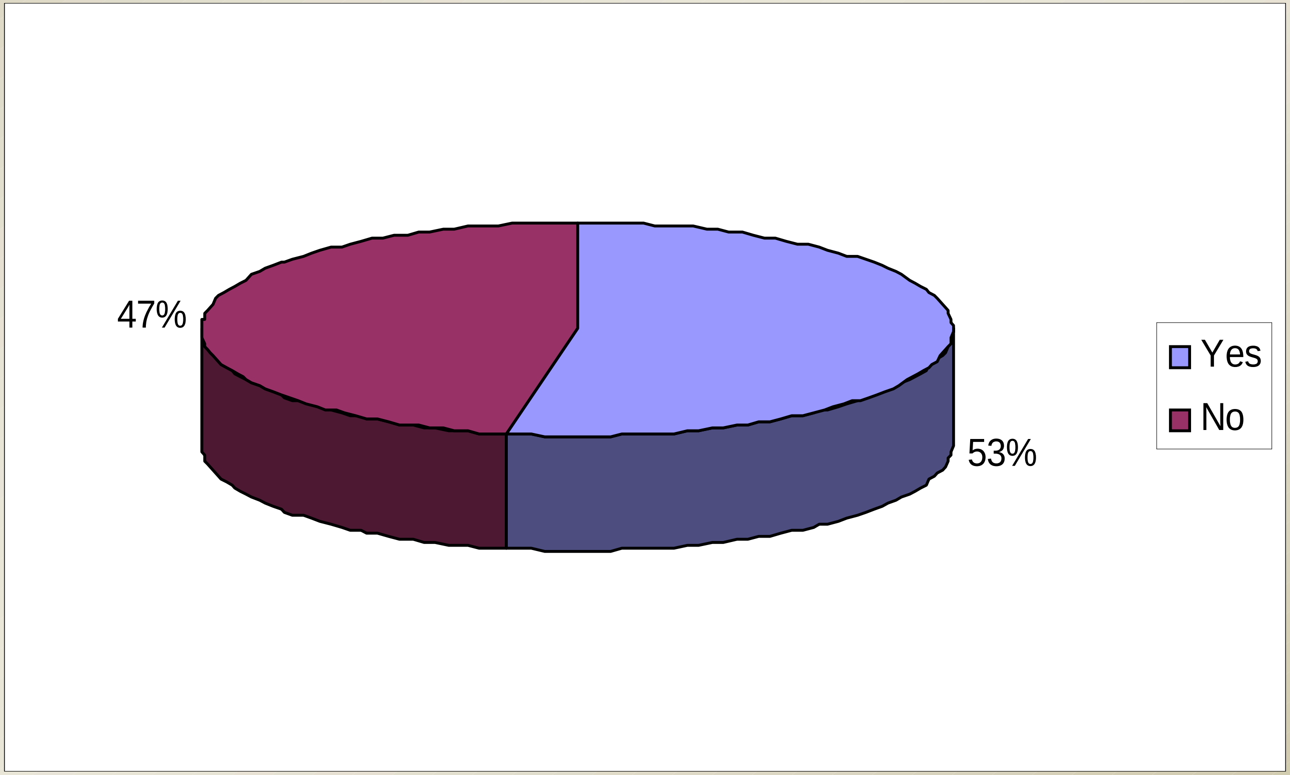
Environmentally Conscious Dorm



Energy Devices

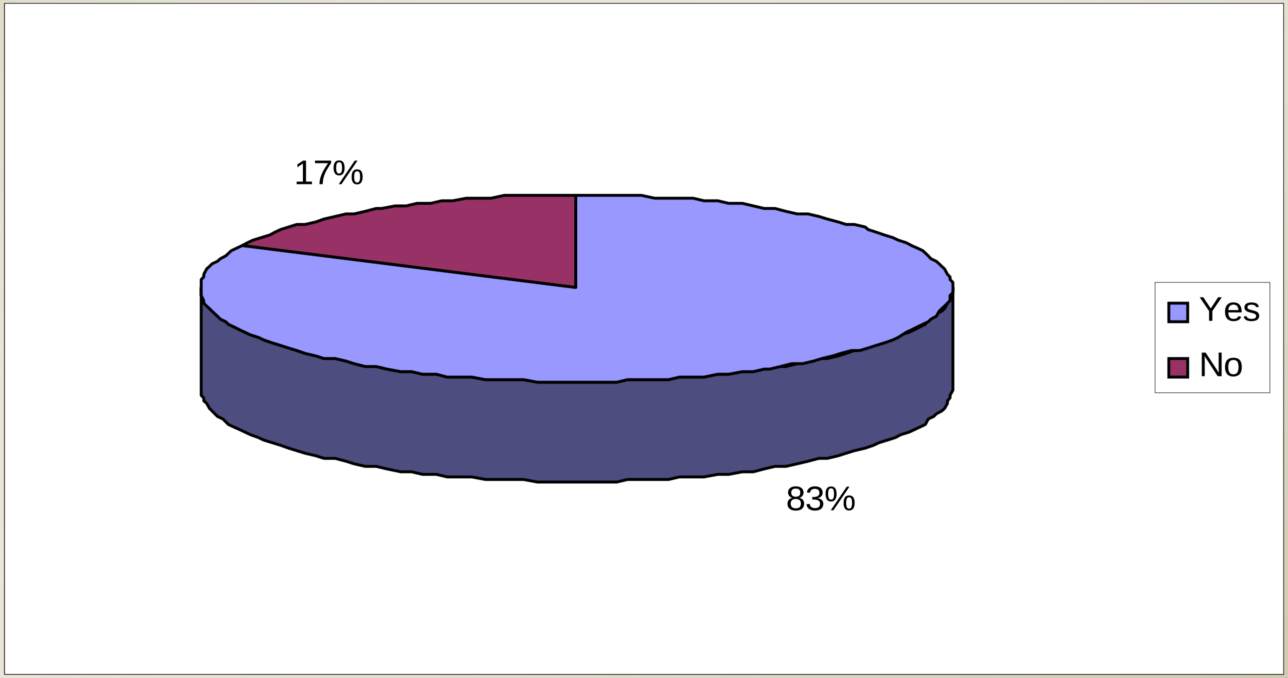
Heating Control

Do you control the heating in your room?



Heating Control

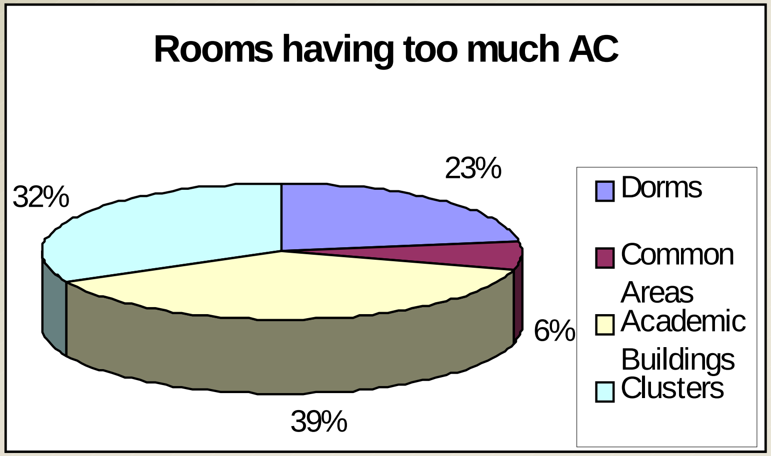
Would you be happier if you had an individual thermostat in your room?

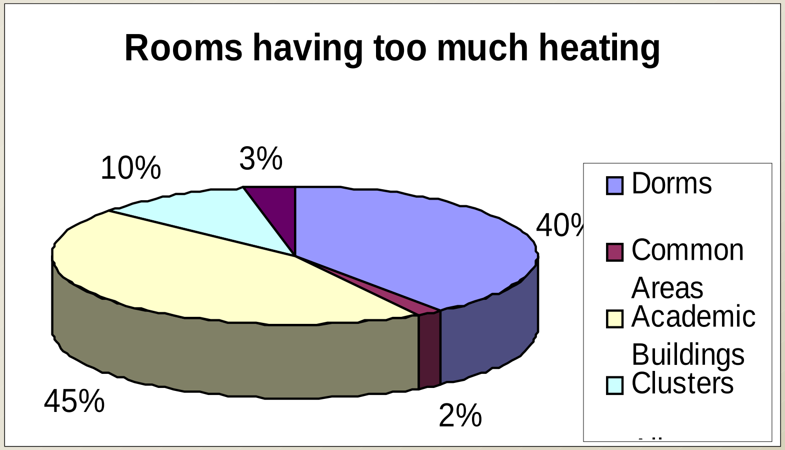


How Students Deal with Uncomfortable Room Temperatures

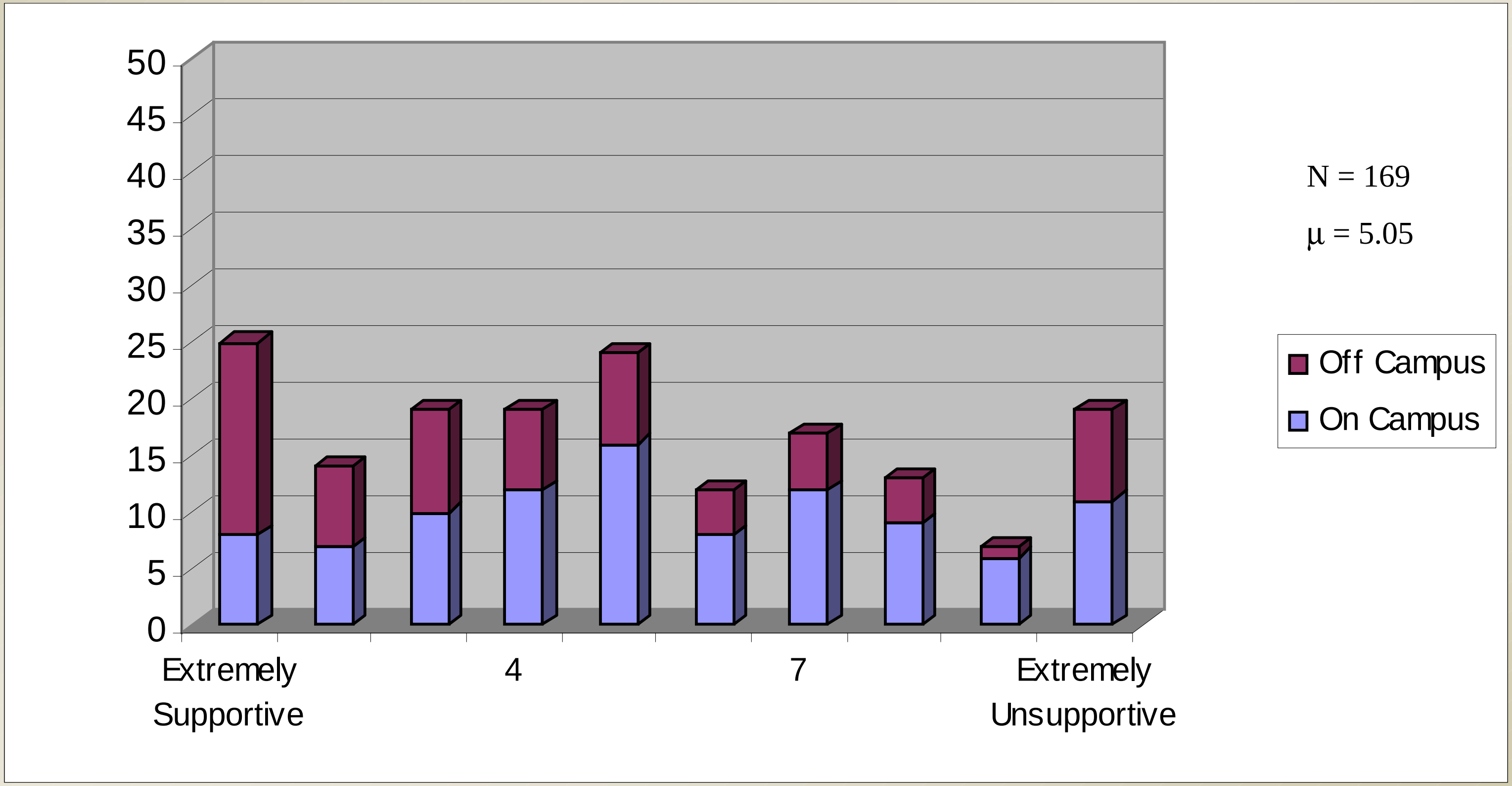
- 62.8% open windows
- 19.8% use fans
- 6.6% wear more clothing
- 3.6% use space heaters
- 2.4% complain

Temperature Problems with Campus Rooms

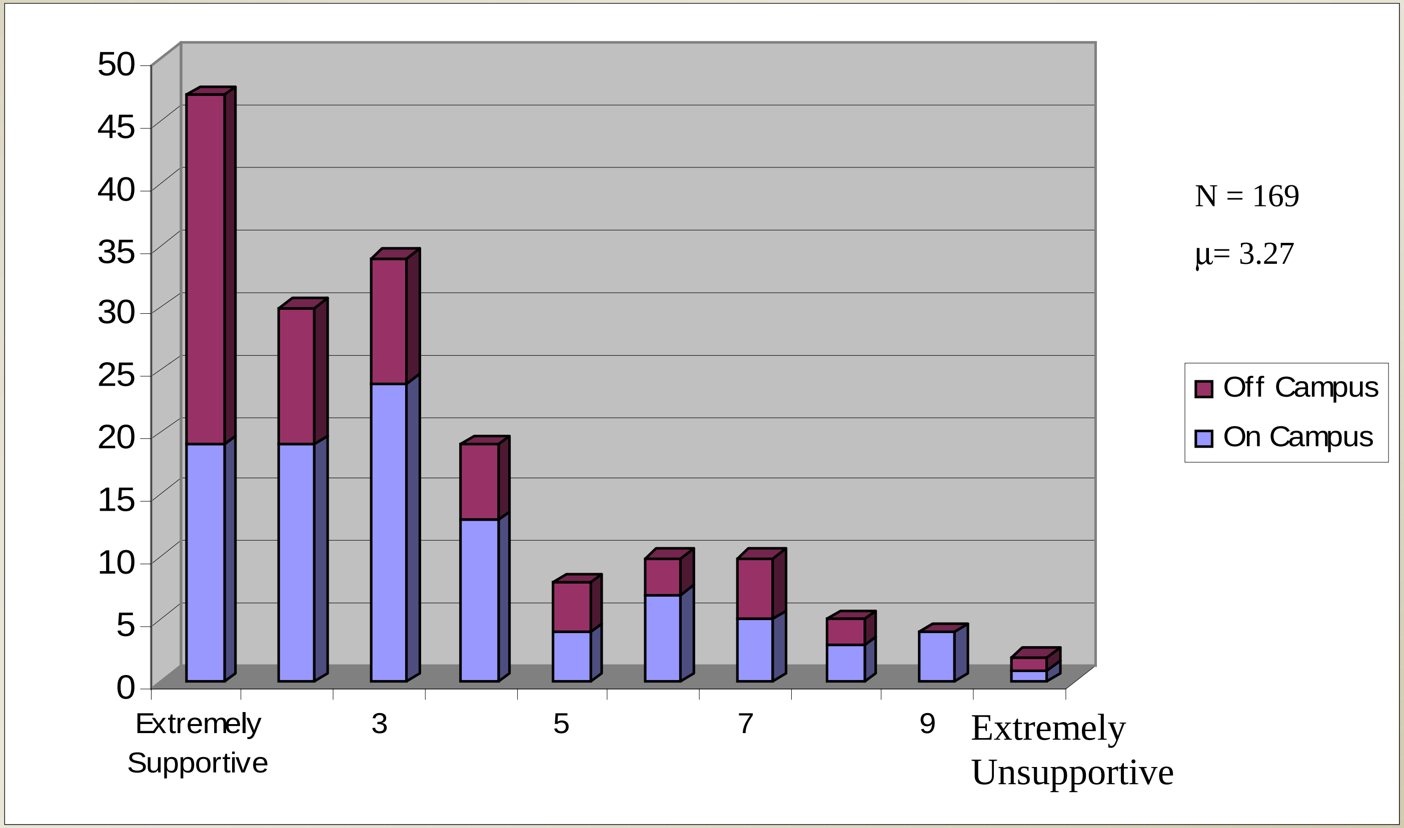




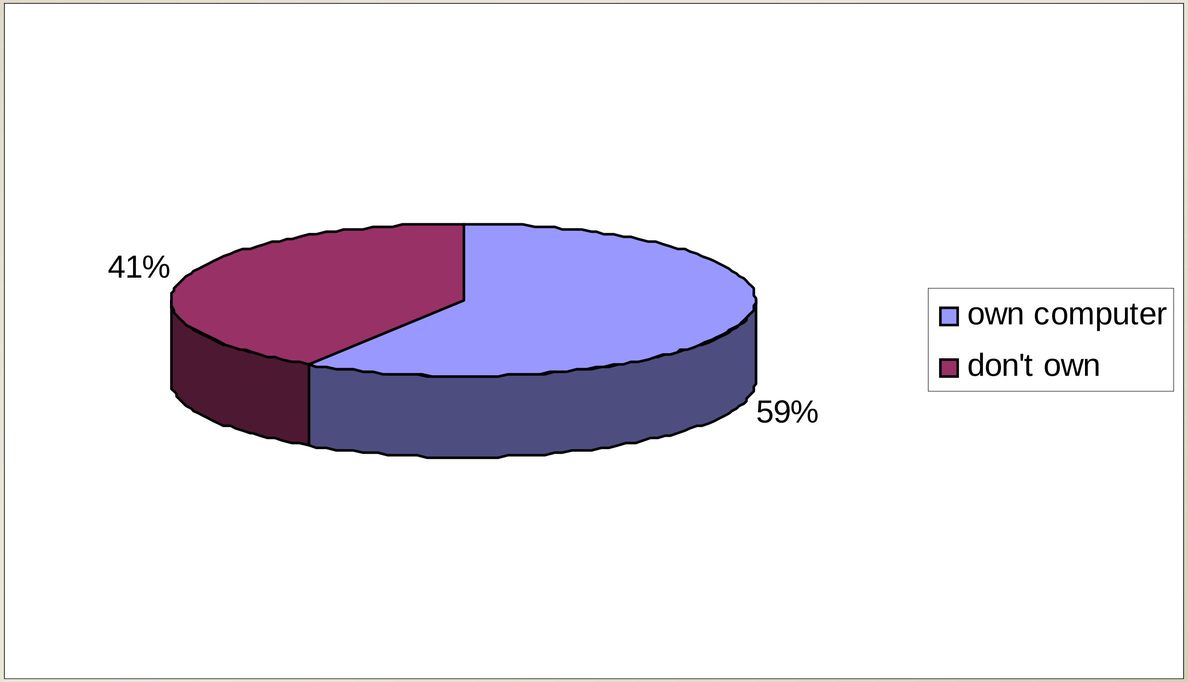
Reduced Heating/Air Conditioning



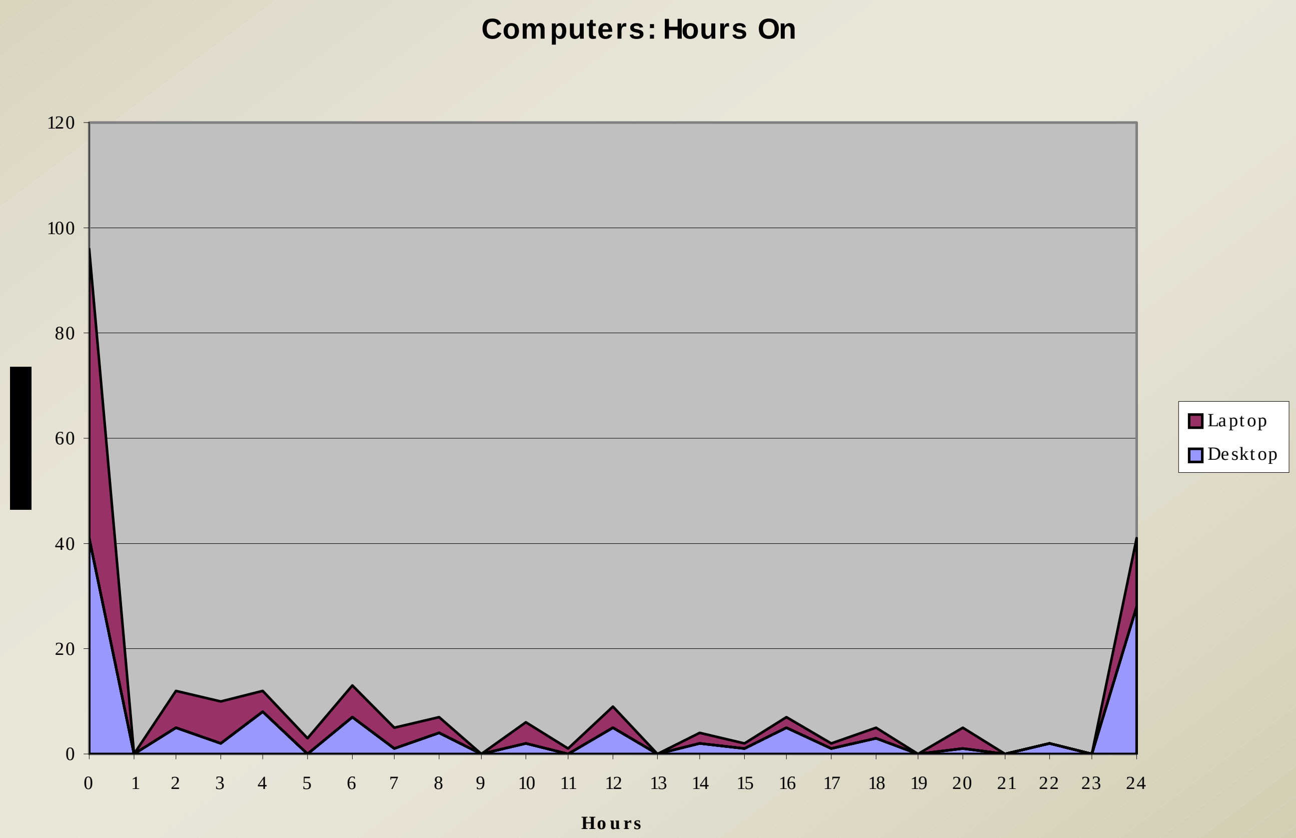
Occupancy Sensors



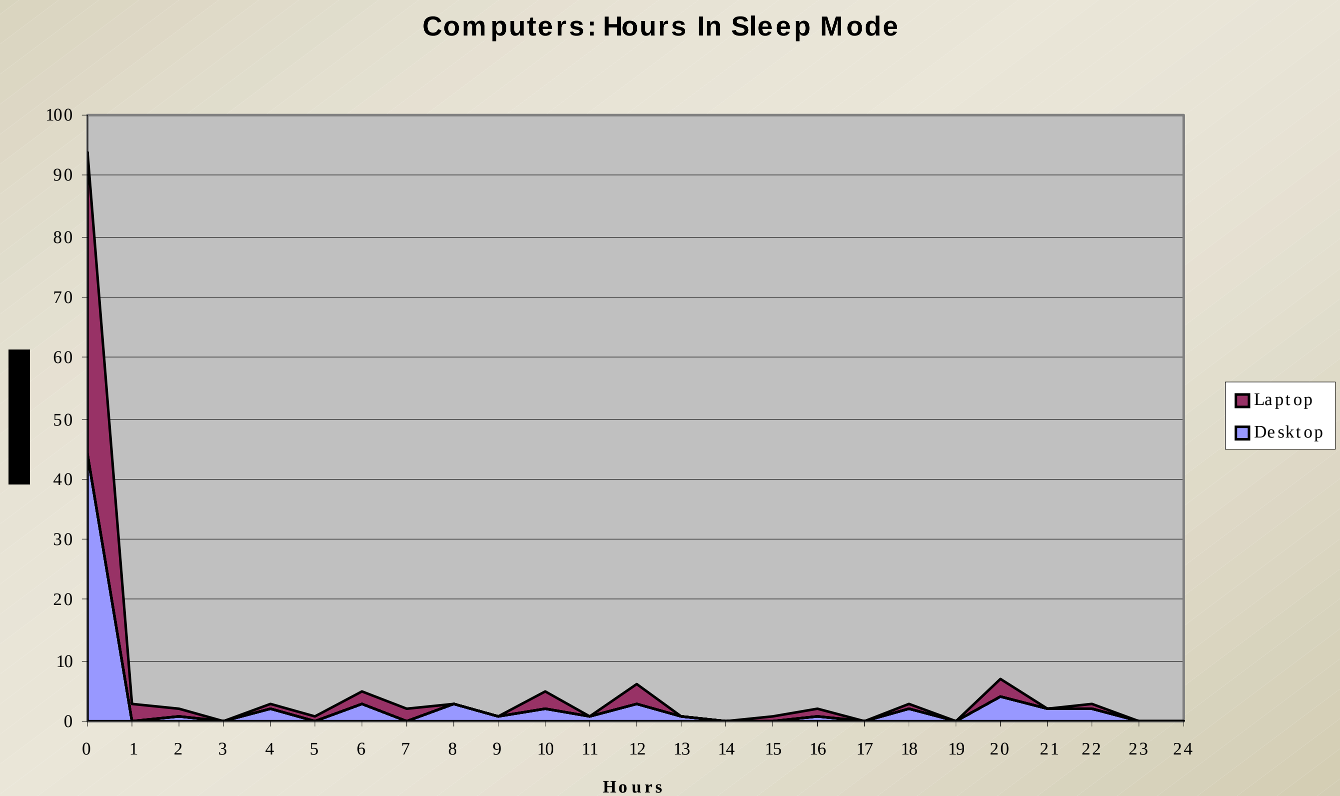
How many students own personal computers?



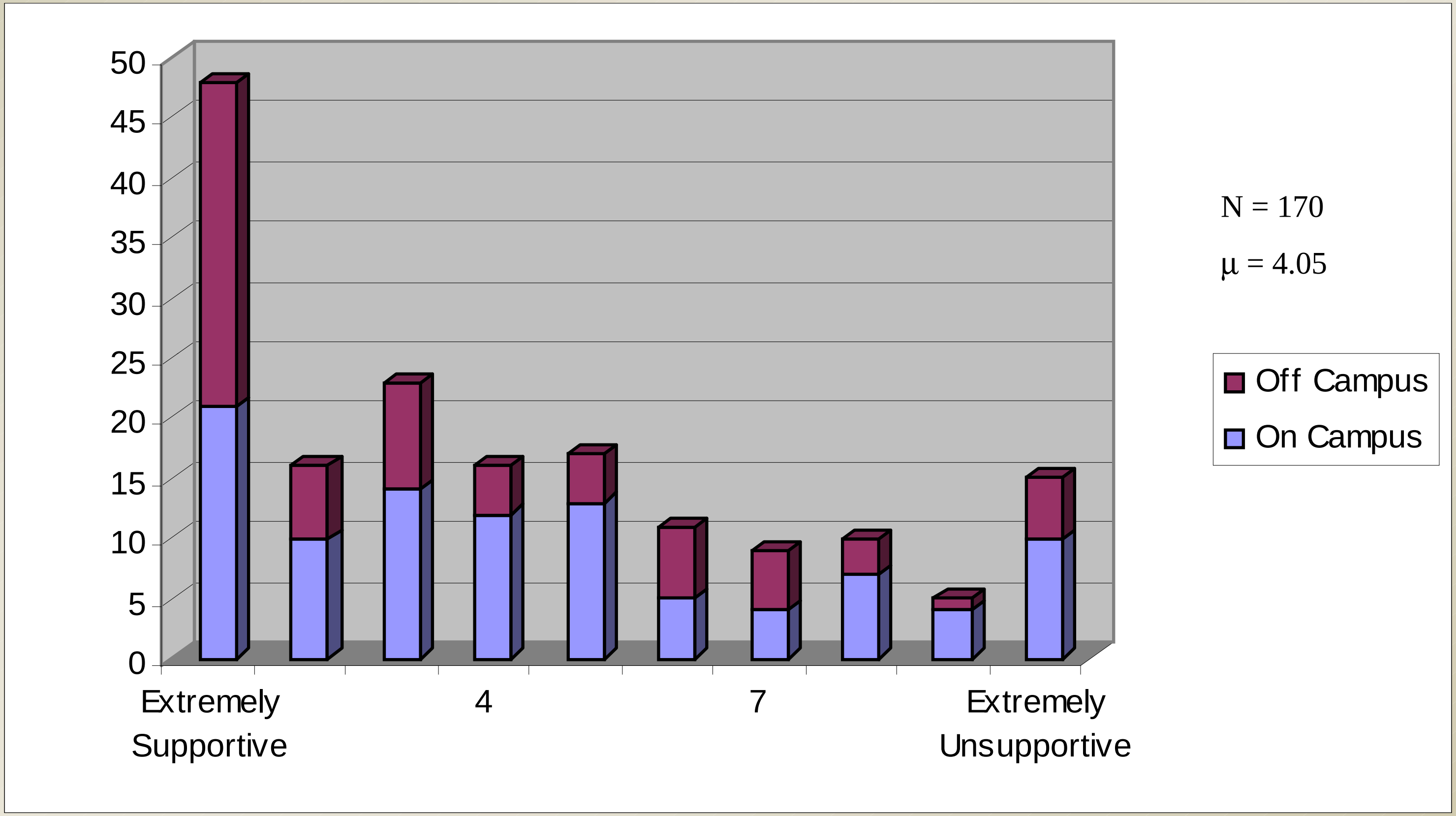
Computers: Hours ON



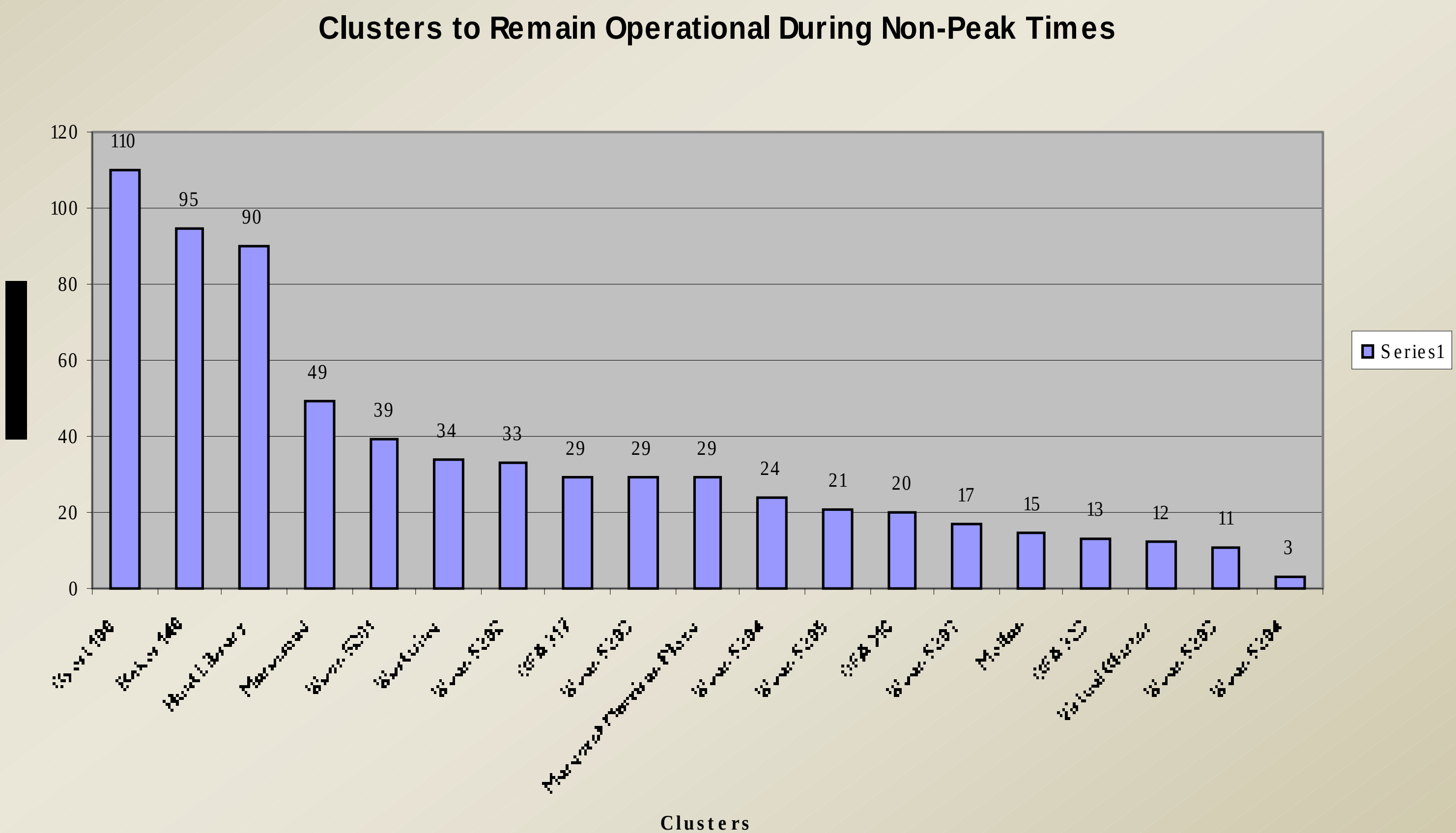
Computers: Hours in “Sleep Mode”



Computer Clusters: Light Shutdown



Computer Clusters to Keep Open



Behavioral Options: Conclusions

Overall Attitudes

- Carnegie Mellon students are concerned about the environment, and overwhelmingly support ideas such as the Green Campus Initiative.

- If a push toward energy conservation is made, students will follow.

Accepted Measures

- Reducing the heating and air conditioning in public buildings.
- Leaving only certain clusters on during off-peak hours.
- Establishing an Environmentally Conscious Dormitory.
- Installing thermostats in dormitory rooms.

Energy Savings

- Morewood Gardens as an Environmentally Conscious Dorm:
  - 10% reduction in energy would save 700 tons of CO_2 per year (~950,000 kWh).
- Shutting down all but three clusters:
  - Reduction would save 565 tons of CO_2 per year (~506,000 kWh).
- Adjusting temperatures in academic buildings and common areas by three degrees would save significant energy and money.
  - Energy savings of 3-6%, ~1000-2000 tons of CO_2 per year.
- Installation of occupancy sensors:
  - Analyzed in the Technology Options presentation.

Technology Options to Reduce Energy Demand

Objectives

- Identify campus areas where energy efficiency improvements can reduce Carnegie Mellon's energy consumption and associated CO_2 emissions.
- Analyze the cost and effectiveness of alternative technology options.

Two General Approaches:

- Incorporate “green design” into future campus construction/expansion.

- Retrofit/replace existing systems with more energy-efficient technologies.

What Can Be Accomplished?

- Energy conservation projects elsewhere have achieved substantial energy savings:
  - International Netherlands Group Bank uses 92% less energy than an average building of the same size.
  - Savings depend on depth of "green design" integration into facilities. The most successful retrofitting projects have saved 50 – 60% in overall energy use.

Available Energy-Efficient Technologies

- Lighting:
  - Compact Fluorescent Bulbs
  - Fluorescent tubes
  - Occupancy sensors
  - Photo sensors
  - LED exit signs
- Heating & Cooling:
  - Insulation
  - Windows
  - Steam traps
  - Programmable thermostats
  - Efficient chillers
  - Window A/C

Available Technologies (cont'd)

- Information Technology:
  - Energy Star computers
  - Energy Star monitors
  - Printers, copiers, fax machines
  - Network infrastructure
- Appliances:
  - Refrigerators
  - Freezers
  - Fans
  - Ovens
  - Microwaves

Questions:

- How much energy can efficient technologies save at Carnegie Mellon?
- How much CO_2 can we reduce?
- At what cost?

Difficulties Faced

- Carnegie Mellon does not currently have a detailed energy audit.
  - Electricity and steam use are generally available only at the building level.
  - No inventory of major energy-using devices.
  - Little or no data on actual end-use consumption.
- Limited information on energy savings of alternative technologies.

Carnegie Mellon Case Studies

- Lighting Options:
  - Efficient fixtures
  - Occupancy sensors
  - Photoelectric control
- Heating & Cooling:
  - Air conditioning
  - Radiators, thermostats, insulation
  - Windows

Basic Methodology

- Compare the cost-effectiveness of each technology option based on:
  - Capital cost
  - Annual energy savings
  - Net annualized cost (6% interest rate)
  - Annual CO_2 reduction

- Cost-Effectiveness = Net cost per ton CO_2 reduced

Lighting Case Study

- Three switch-technology options considered for installation in six space categories.
  - Photoelectric switches, photoelectric dimmers, and occupancy sensors
- Three fixture upgrades considered for campus-wide implementation.
  - Tube lamps, CFLs, LED Exit signs
- Sample audits conducted of technologies currently in place to determine effectiveness.

Lighting: Improved Fixtures

Device	Device Count	Improvement	Energy Savings	$ / Device
Tube Lamp	1000	T-8 retrofit	20%	8
Light Bulb	500	25 W CFL	67%	20
Exit Sign	100	LED Exit	98%	60

- Opportunities limited because there has already been widespread implementation of these devices on campus.

Lighting: Automatic Switch-off Options

Technology	Space	Room Count	Energy Savings	$ / Space
Photo Switch	Office	1500	33%	100
	Dorm Room	1500	33%	100
	Classroom	300	25%	100
	Open Area	50	8%	200
Photo Dimmer	Office	1500	53%	500
	Classroom	300	53%	1,200
	Open Area	50	53%	1,500
Occupancy Sensor	Office	1500	32%	100
	Dorm Room	1500	32%	100
	Classroom	300	43%	150
	Restroom	300	30%	100
	Open Area	50	55%	200
	Corridor	500	55%	200

Lighting Example: Occupancy Sensors

Technology	Space	Room Count	Energy Savings	$ / Space
Occupancy Sensor	Office	1500	32%	100
	Dorm Room	1500	32%	100
	Classroom	300	43%	150
	Restroom	300	30%	100
	Open Area	50	55%	200
	Corridor	500	55%	200

- Average net annualized cost: -$95 per year.
- On average, -$154 per ton CO_2 reduced.
- Average payback period: 1.8 yrs for 4 of 6 implementations.

Air Conditioning Case Study

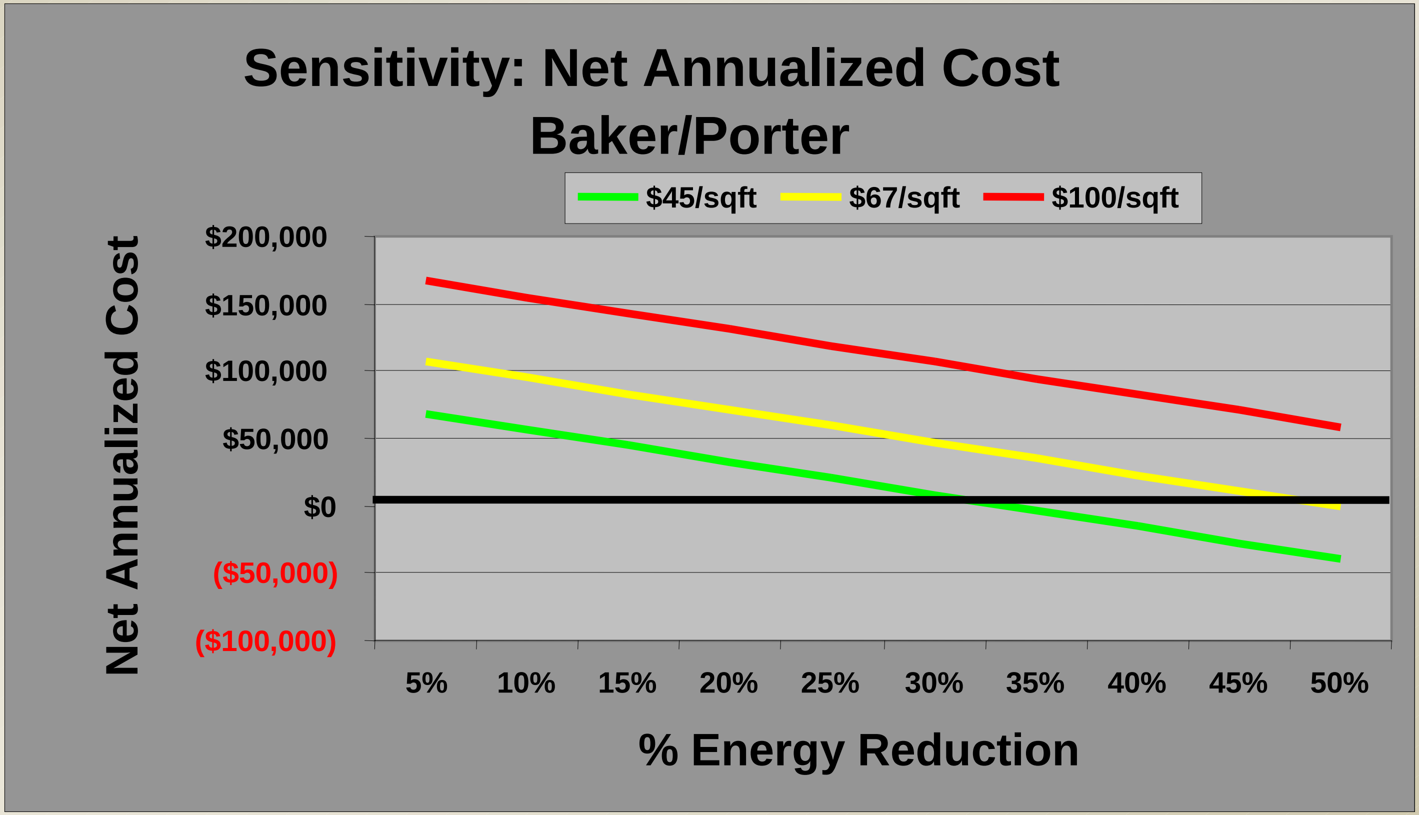
- Case study compared three different options:
  - High Efficiency Retrofit
  - Standard Efficiency Retrofit
  - Remodel with Central A/C
- Standard Efficiency Retrofit Cost
  - $60/ton of CO_2 reduced, based on immediate replacement of existing window units.
  - -$80/ton of CO_2 reduced, based on replacement of retired units.
- Campus-wide savings of 79 tons CO_2 per year (based on 367 window units).

Doherty Hall: A Case Study in Energy Waste

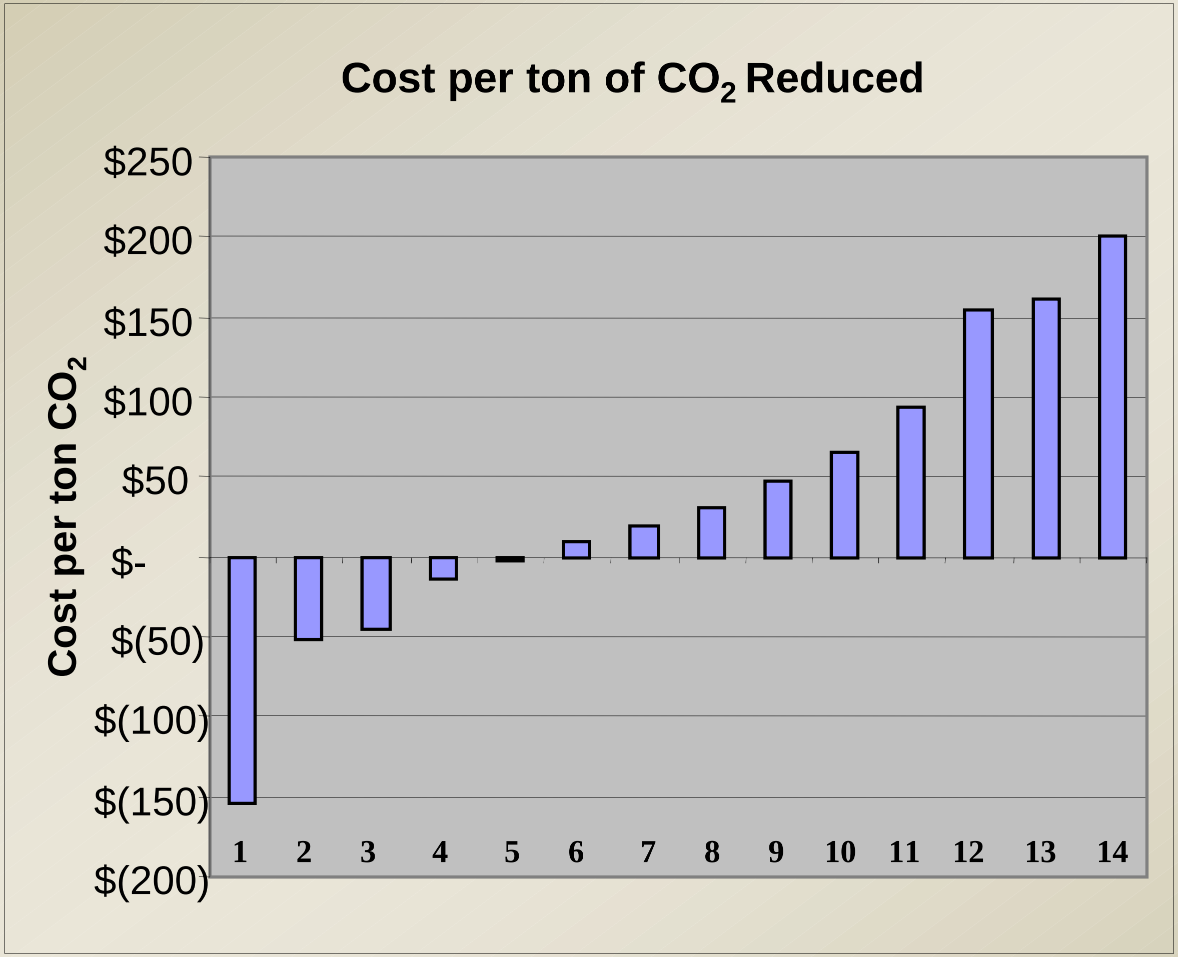
- Many offices and labs overheated (85^{o}F) with no ability to control temperature, except by:
  - Opening windows (where possible).
  - Running air conditioners all winter!

- Improved controls yield annual savings of ~1000 tons of CO_2.

Baker/Porter Window Replacement Case Study



Comparison of Cost Effectiveness



1. Occupancy Sensors
2. CFL
3. LED Exit Signs
4. T-8 Retrofit
5. Photoelectric Switch
6. Window Replacement
7. Radiator Valves
8. Valve and Insulation
9. Pipe Insulation
10. Standard Window AC
11. Photoelectric Dimmer
12. Valve, Insulation, Thermostat
13. Efficient Window AC
14. LCD Computer Monitors

Conclusions

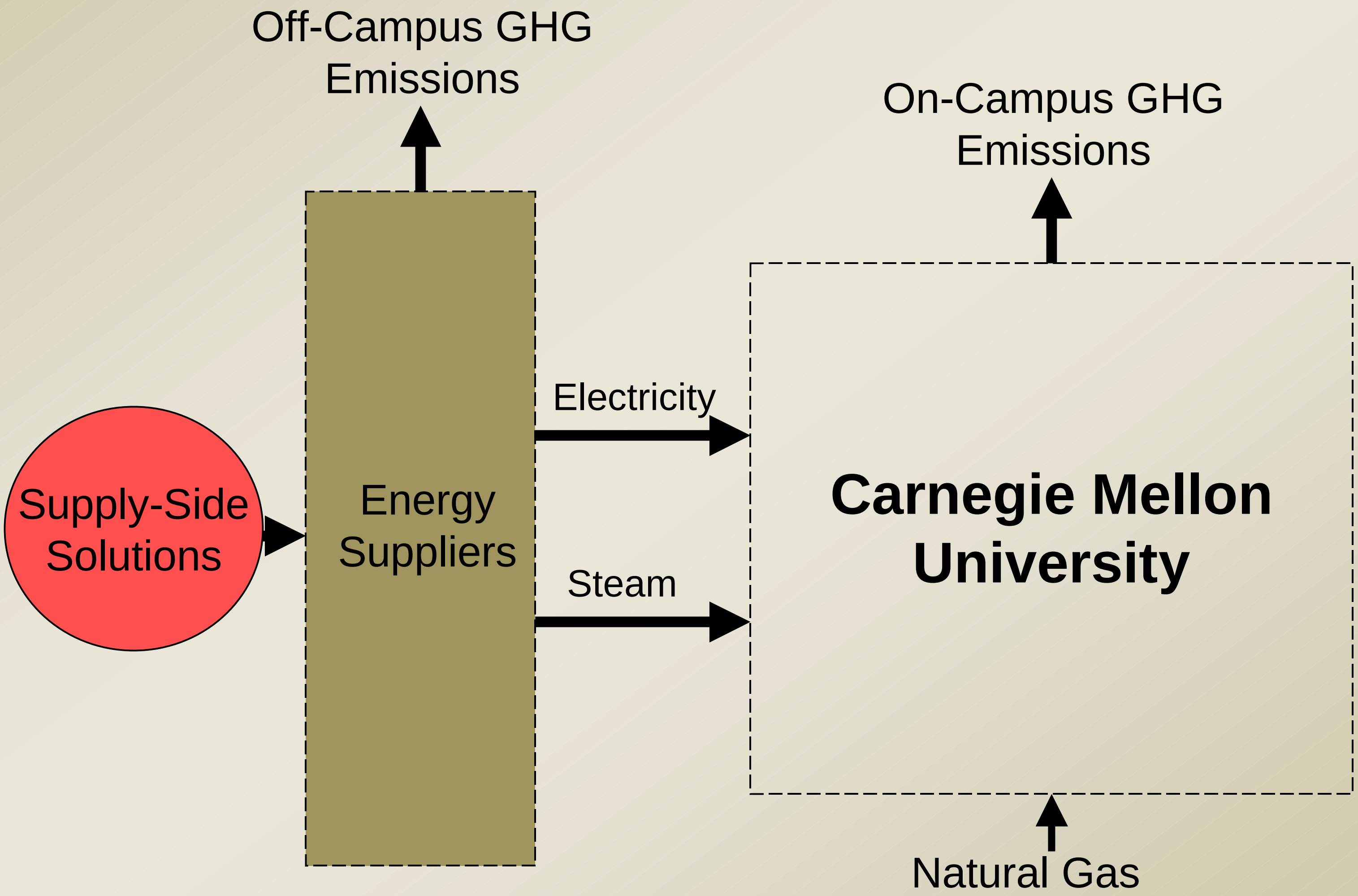
- There are significant opportunities to reduce campus energy use at little or no net cost, or at a net savings.
- Cost-effective solutions can likely reduce CO_2 emissions by roughly 10-15% or more.
- More detailed consumption and inventory data and improved savings estimates are needed to refine and extend the current case studies.

Energy Supply Options to Reduce GHG Emissions

Objectives

- Identify options for supplying campus energy from low or zero-carbon sources.
  - Off-campus supplies
  - On-campus generation
- Evaluate options with respect to:
  - Emission reduction potential
  - Cost
  - Availability

Carnegie Mellon Energy System



Current Energy Suppliers

- Steam:
  - Bellefield Boiler Plant
- Electricity:
  - Duquesne Light/Orion Power
  - Wind (Community Energy/Exeleon Power)
- Natural Gas:
  - Dominion Peoples

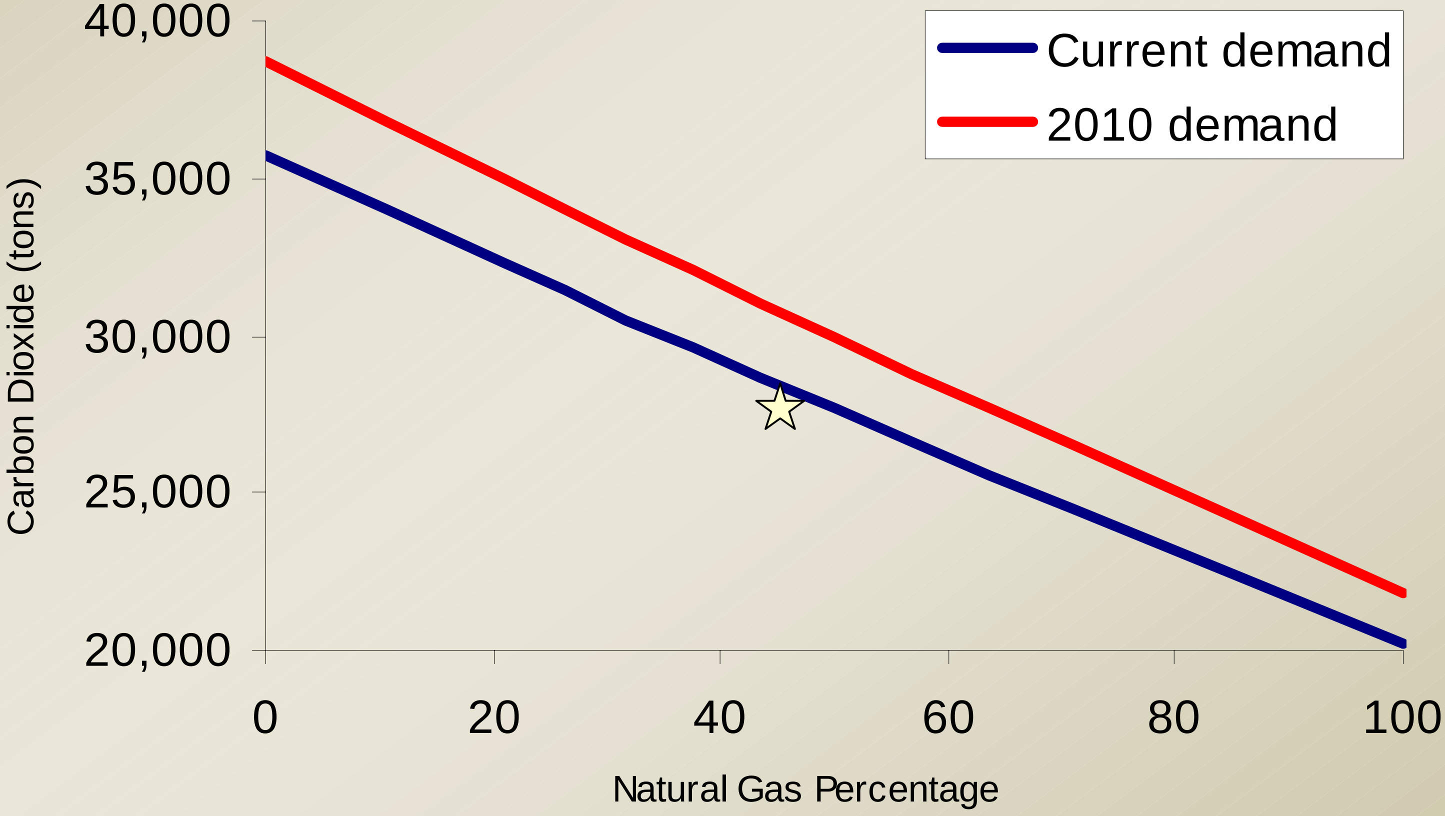
Options for Future Steam Use

- Current fuel mix:
  - 56.5% coal, 43.5% natural gas

- Small natural gas boilers are to be added to the Bellefield Boiler Plant to meet growing demand.

- Future plans are being evaluated by an engineering contractor.

CO_2 Emissions from Bellefield as a Function of Fuel Mix



Cost Effectiveness of Natural Gas for Steam Production

- 100% Natural Gas used for steam production:
  - New steam cost: $8.55 per Mlb
  - Total additional cost: $350,000 per year (based on current demand)
  - CO_2 reductions: 8,500 tons/yr
  - Cost per ton CO_2: $41

Alternative Electricity Suppliers

- Carnegie Mellon now purchases 5% of its electricity from a wind farm in Somerset, PA (as of October 24th, 2001).

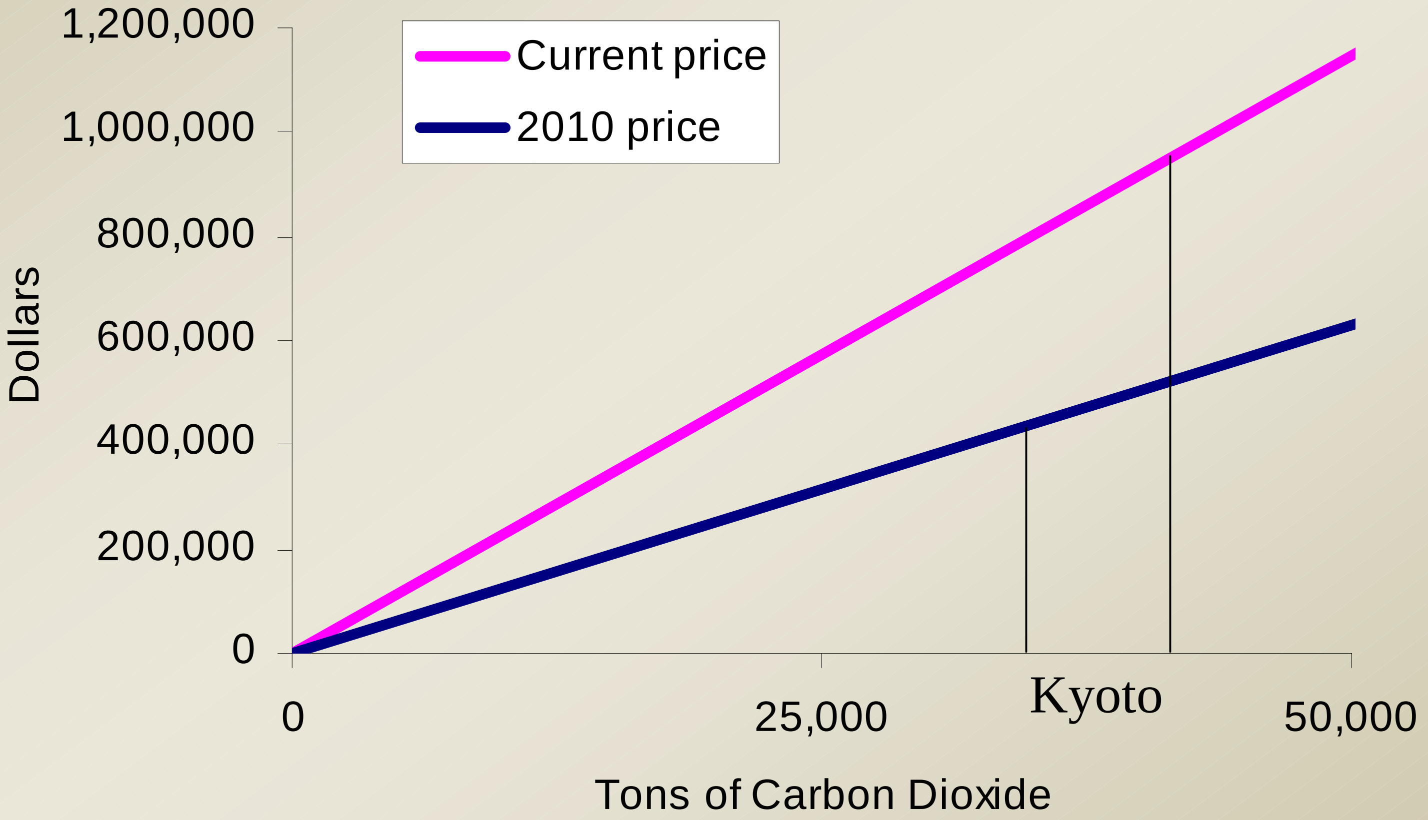
- Emissions reductions:
  - 3,500 tons per year of carbon dioxide.
  - Additional reductions of nitrogen oxides, sulfur dioxide, particulates, and mercury from coal-fired plants.

Cost Effectiveness of Wind Power

- Total added cost is $81,000 per year.
- Current cost per ton CO_2 reduced = $23
- Future cost of wind power expected to decline by about 20%.
  - 2010 cost per ton CO_2 reduced = $13

Using Wind to get to Kyoto Protocol

Cost to meet the Kyoto Protocol: $440,000 - $960,000



Alternative Power Suppliers

- We contacted over 15 energy suppliers and consultants to ask about current availability of “green” power for Carnegie Mellon.

- No suppliers were able to provide 100% green power to Carnegie Mellon today.
  - Green Mountain Energy (supplies residential customers only)

- Additional efforts needed to find alternative sources and suppliers.

On-Campus Supply Options

- Co-generation systems can provide both electricity and heat more efficiently than current energy sources.

- Greenhouse gas emissions per unit of energy are reduced significantly.

- Solid oxide fuel cells (SOFC) were studied as a potential future option for Carnegie Mellon.

Siemens-Westinghouse Fuel Cells

- SOFC (solid-oxide fuel cell)
- Input: Natural Gas
- Output: 250 kWh electricity, 120 kWh heat
- Operating availability: >98%
- Overall dimensions: 9.8’ H x 8.5’ W x 35.3’ L
- Operation: Unattended, remote, or local dispatch
- Estimated lifetime = 8-10 years
- Estimated cost:
  - 2004: $4000/kW
  - 2008: $1000-1500/kW

Fuel Cell Capital Cost

- Annualized cost of fuel cell:
  - Assume lifetime = 8 yrs, discount rate = 6%, $1500/kW in 2008
  - Buy in 2004: $160,000 per year
  - Buy in 2008: $60,000 per year

- Total annualized capital cost (including infrastructure costs):
  - Buy in 2004: $185,000 per year
  - Buy in 2008: $84,500 per year

Cost Effectiveness of SOFC Fuel Cell

- Cost per ton of CO_2 reduced:
  - Buy in 2004: $84
  - Buy in 2008: $13

- Sensitivity Analysis for 2008:
  - 10 year lifetime, $1000/kW, 70% efficiency
  - Cost per ton CO_2 reduced = -$12

Carbon Sequestration

- Natural sequestration can offset some or all of Carnegie Mellon’s emissions.
- 19,000 acres of sinks will cover all of our emissions under the Kyoto Protocol.
- Markets exist today at relatively low cost.
  - $1-2 per ton CO_2 sequestered
- Viability and terms of sinks under the Kyoto Protocol is still not developed.

Conclusions

- Several alternative supply options can get us to the Kyoto Protocol's targets.
- Costs are expected to decrease significantly in upcoming years.
- Fuel cells might be able to supply some portion of Carnegie Mellon's energy yielding a net cost savings.
- More work is needed to identify suppliers of low carbon power for short-term emissions reductions.

Policy Recommendations and Conclusions

Objectives

- Identify key criteria for policy options to aid decision-makers in evaluating options.
- Review what we have learned about supply, behavioral, and technology options.
- Identify a plan and the institutions best suited for implementing it.

The Kyoto Challenge

- 2000 energy emissions are 95,000 tons CO_2 per year.
- The Kyoto Protocol goal is 70,000 tons CO_2 by 2010.
- Projected 2010 levels range from 105,000 to 112,000 tons CO_2.
- Reduction needed:
  - Between 35,000 - 42,000 tons CO_2 by 2010.

Evaluation Criteria

- Magnitude of GHG reduction
- Affordability
- Uncertainty
- Ease of implementation
- Invisibility
- Campus image

Behavioral Options

- Students are prepared to accept campus energy and environmental programs.
  - Green Campus Initiative
  - Environmental dorms
  - Occupancy sensors
  - Only selected clusters at non-peak hours
  - Reduced heating, A/C in public areas

Technology Options

- Occupancy and photoelectric sensors.
- Address inefficiencies in valves, thermostats, and windows; comprehensive audit needed.
- Track technology improvements.
- Conform to government-recommended standards in new construction.
- Improve metering of University facilities.

Supply Options

- Bellefield Boiler Plant – encourage energy-efficient technologies for our steam production.
- Wind energy & fuel cells – adopt these as they mature into economically viable alternatives.
- Examine secure alternative energy suppliers.
- Examine $C0_2$ sequestration.

What Needs to Happen?

- Energy Initiative
- More comprehensive metering
- Commitment to meeting Government standards in construction of new campus buildings.
- Close tracking of technologies and costs.
- Bench-marking to other institutions.

Policy Implementation

- President’s Council:
  - Articulate spirit of University guidelines.
- Commit resources to GHG reductions.
- Environmental Practices Committee:
  - Implement specific practices and programs to reach university’s goals.
  - Closely monitor progress and opportunities.

Questions & Answers

- Carnegie Mellon Energy Consumption
- Demand-Side Energy Solutions
  - Behavioral
  - Technology
- Supply-Side Energy Solutions
- Policy & Implementation