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Vermont City Electric

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After receiving her MBA from MIT's Sloan School of Management, Daniela Shazar followed her dual passions for entrepreneurship and alternative energy and moved to Vermont to work at a wind turbine start-up. Complementing her new job, Daniela joined the Citizen's Oversight Board of Vermont City Electric (VCE).[1]

A municipal agency, VCE was formed in 1905 with an explicit mission to lower the cost of providing electric power to Vermont City. In 2008, VCE provided electricity to about 16,000 residential accounts, 2,845 small commercial customers, and 784 large commercial customers in its service area of roughly 16 square miles.

VCE has made a name for itself by focusing on demand side management (DSM) as a way to curtail energy use among the population it serves. But in late 2008, VCE was feeling the effects of the economic downturn and was forced to cut spending on its DSM programs. With help from Daniela and the rest of the Oversight Board, VCE needs to figure out a way to optimize its DSM energy programs.

[1] VCE is a fictious name that has been given to an actual utility.

This case was prepared by Jonathan Potter, MBA 2009, and Professor Robert M. Freund. The purpose of this case is to present a particular quantitative approach to energy conservation issues. Portions of the data contained in this case have been invented for the purpose of the exercise.

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Demand-Side Management

When a municipal agency's goal is to reduce energy costs for residents, one alternative to building new power plants or sourcing new power supplies is to engage in demand-side management (DSM). DSM activities decrease the overall use of energy in the system and/or divert energy use from times of peak demand (and peak cost). With significant investments in DSM starting in 2000, VCE has been one of the pioneering electric utilities in the use of DSM strategies.

Since 2000, the argument for engaging in DSM activities has become even more compelling. The construction of new power plants has become more expensive and is increasingly seen by residents as undesirable. As one VCE document stated, "[Our] customers have been unequivocally clear: the option for future supply that they prefer above all others is the pursuit of additional cost-effective energy efficiency." The underlying cost of energy, in all of its forms, has also increased dramatically. Vermont City, along with many other cities around the world, has made commitments to reduce its carbon outputs as part of the international effort to mitigate climate change.

Demand for Power

Energy vs. Power

Power is the level of electricity used at a given point in time. For example, one 70 watt light bulb requires 70 watts of power at any time, two bulbs require 140 watts, three require 210 watts, etc. Energy is different from power in that it includes a time component as well: if three light bulbs require 210 watts of power, then they would use 210 watt-hours of energy over the course an hour. Typically, the capacity level of an electricity generation unit (such as a coal-fired power-plant) is defined in terms of power, measured in watts, or more typically in megawatts (1MW = 1,000,000 watts). End-users, such as residential customers, purchase energy from the electricity grid in watt-hours, or more typically in kilowatt-hours (1KWh = 1,000 watt-hours) or megawatt-hours (1MWh = 1,000,000 watt-hours).

(The relationship between distance and speed is similar in concept to that of energy and power. The distance an object travels equals speed multiplied by time. Similarly, the amount of energy consumed equals power multiplied by time.)

Peak Demand

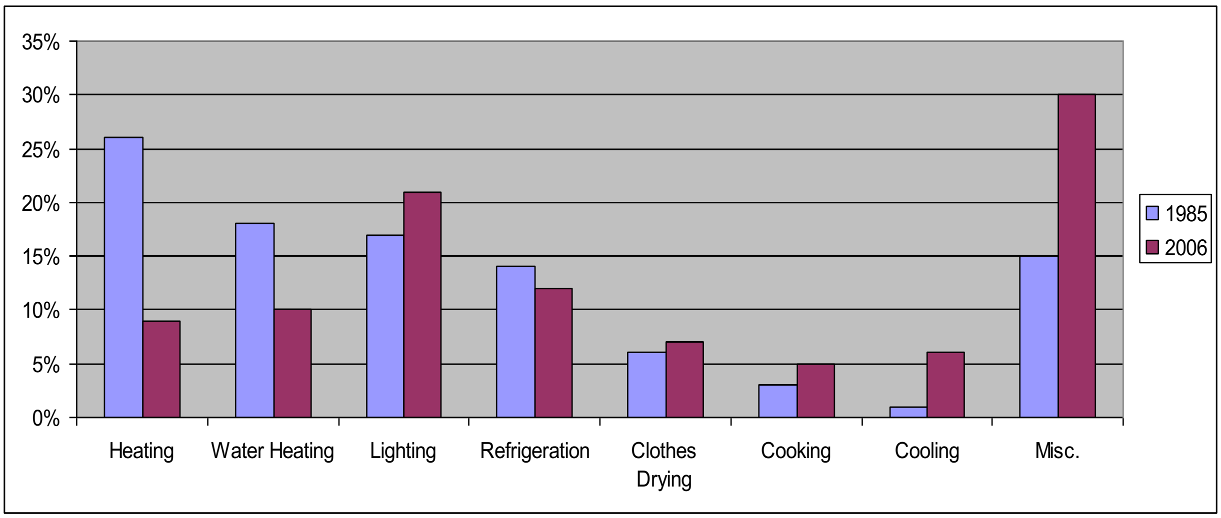
Peak demand, defined as the highest level of power demanded by a system within a given period of time, is measured in units of power. In any given day, peak demand tends to occur in the afternoon; in a given year, peak demand tends to occur on a hot and humid afternoon in the summer.

Growth in Demand for Power

Even with DSM efforts in place, the demand for power within VCE's territory is expected to grow due to increases in population and per capita income. Based on external forecasts, Vermont City's population is anticipated to grow by 0.52% per year, and per capita electricity use growth is anticipated to be 0.22% per year.

The growth in demand for power includes a shifting mix of uses of that power, particularly in residential settings. While in the mid-1980s residential electricity use was devoted largely to water and household heating, by the mid-2000s there was growing demand for electricity devoted to cooling and "miscellaneous" use, which includes appliances such as microwaves, televisions, personal computers, printers, video recorders, and other electronics.[2] (See **Figure 1**.)

Figure 1 Residential Electricity Use, 1985 vs. 2006



Source: Burlington Electric Department Integrated Resource Plan 2008, p. 32.

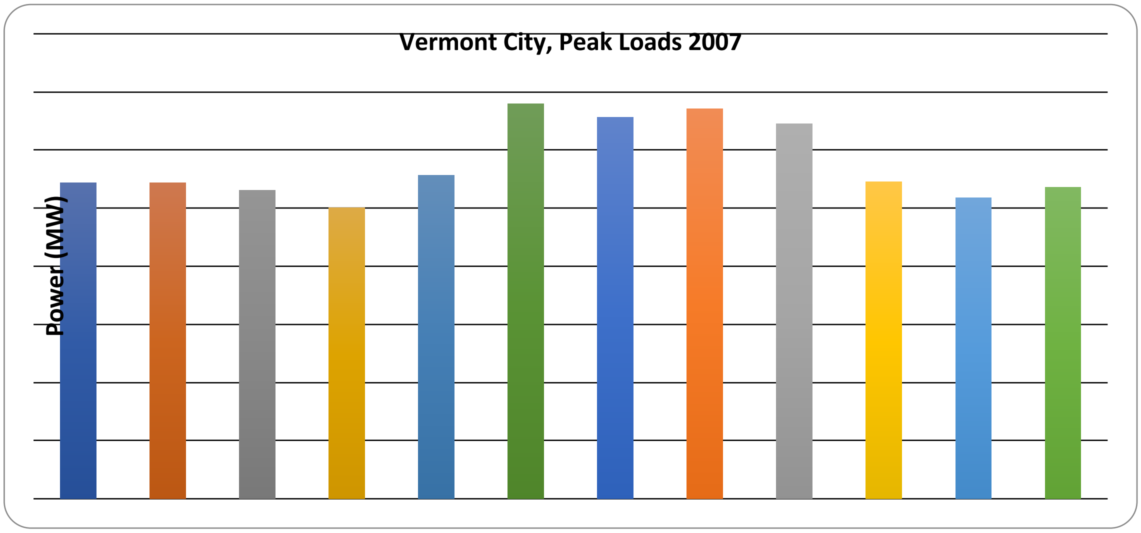
Load Duration Curves

The use of electricity over the course of a year varies considerably. In a typical household, consider the variability in the use of lights, heating and cooling systems, and appliances throughout the course of a day versus an entire year. In commercial and industrial settings, energy use may be even more "lumpy" as entire production systems are powered up and shut down each day.

Plotting electricity use for every hour in a given year shows daily peaks and valleys within larger seasonal waves. **Figure 2** shows a chart of monthly peak electricity use in 2007 with the load peak occurring on June 27 as shown in **Figure 3**.

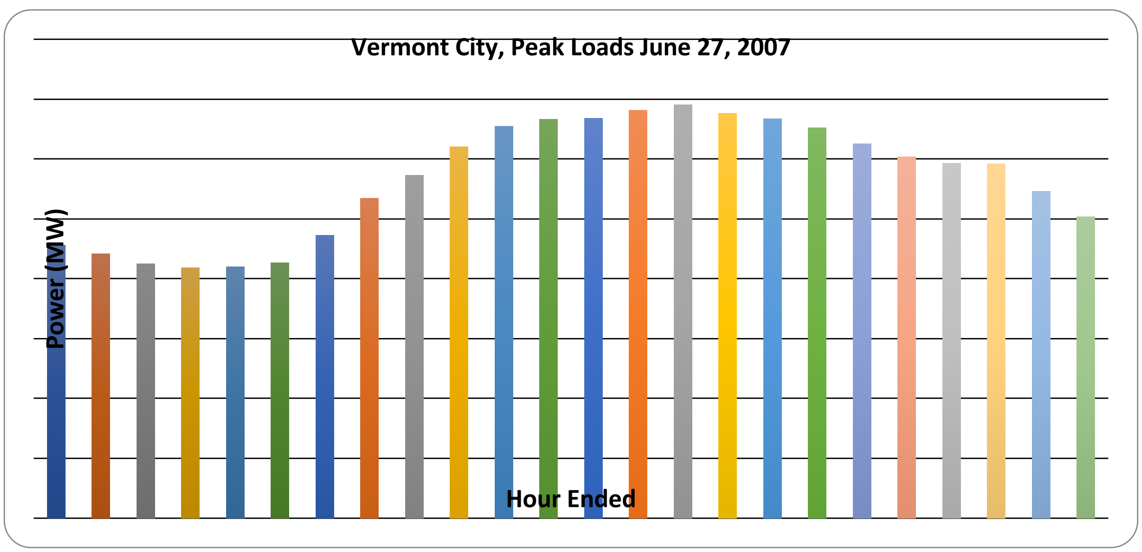
[2] Burlington Electric Department Integrated Resource Plan 2008, p. 32.

Figure 2



Source: Burlington Electric Department Load Research Report 2007, p. 13.

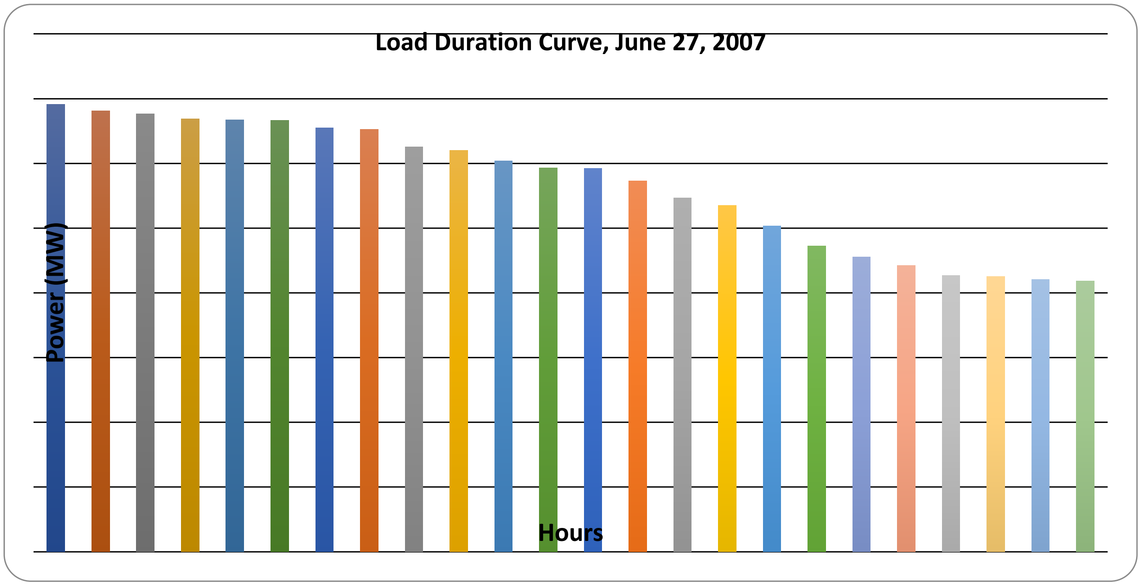
Figure 3



Source: Burlington Electric Department Load Research Report 2007, p. 19.

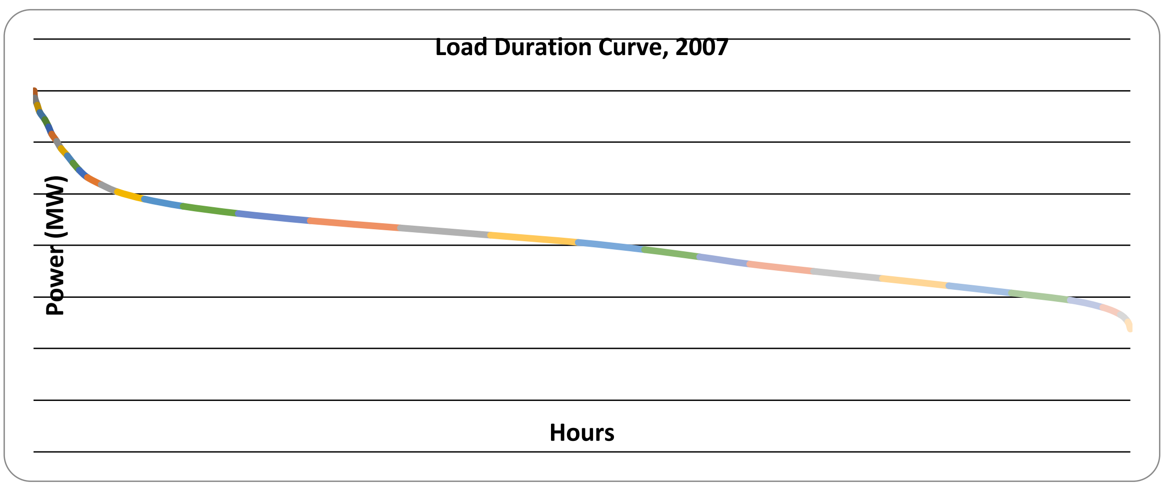
The term *load duration curve* (LDC) captures the number of hours that the system must supply power at a given level. For example, the LDC on June 27, 2007 (**Figure 4)** indicates that there were 11 out of 24 hours in which demand was at least 60 MW. This analysis can be aggregated for all 8,760 hours (365 days * 24 hours per day = 8,760 hours) in an entire year to construct the annual LDC (**Figure 5**).

Figure 4



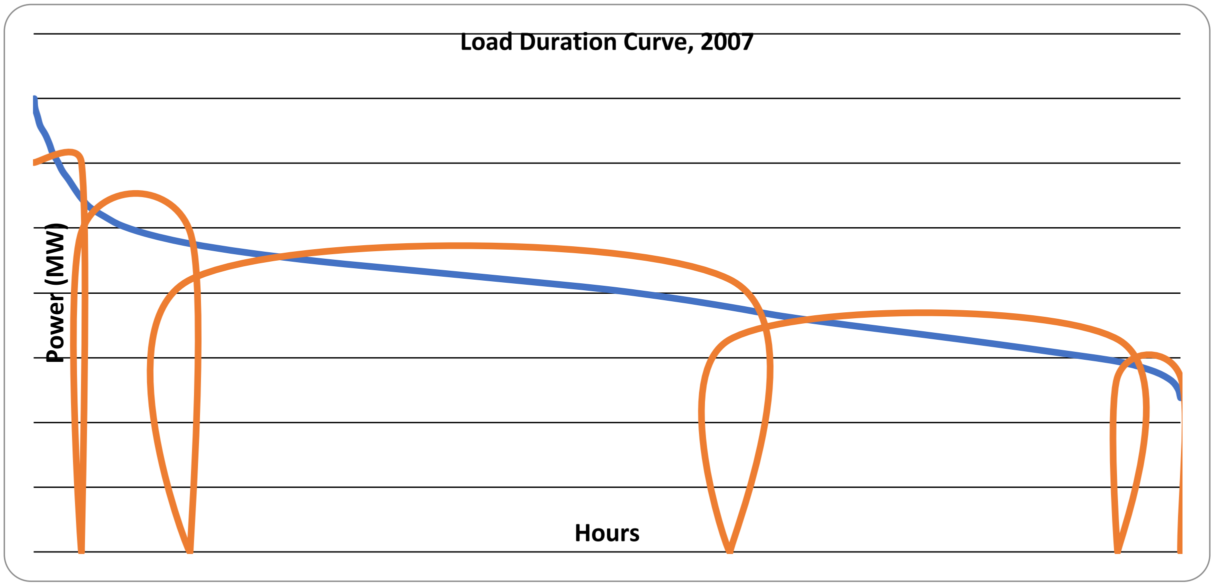
Source: Burlington Electric Department Integrated Resource Plan 2008, p.32.

Figure 5



Source: Casewriter data based on the peak load estimate of 70.3 MW as referenced in Burlington Electric Department Integrated Resource Plan 2008, p. 2 and the ISO-NE curves in Paul Peterson, et al., "The New England Experiment: An Evaluation of the Wholesale Electricity Markets," Synapse Energy Economics, Inc., June 2003, p. 10 and 11.

To simplify the analysis, **Figure 6** breaks the annual load duration curve into five approximated blocks. Blocks 1 and 2 represent the 14% of hours in the year with the highest loads, typically summer daytime hours; Blocks 3 and 4 represent the vast majority (81%) of all hours in the year; Block 5 represents low energy use, occurring during the night in months with moderate temperatures.



Block	Number of Hours	Average Load (MW)
1	365	60.1
2	830	49.4
3	4125	42.0
4	2960	32.8
5	480	27.1

Figure 6

Source: Casewriter data extrapolated from Paul Peterson, et al., "The New England Experiment: An Evaluation of the Wholesale Electricity Markets," Synapse Energy Economics, Inc., June 2003.

Supply of Power

There are many ways electric utilities supply power to their customers. VCE's power sources fall into three primary categories:

1. *Power generation* – VCE owns and operates two power generation facilities: the McNeil Generating Station (McNeil) and the Vermont City Electric Gas Turbine (VCE GT). McNeil is a relatively low-cost option that is wood-powered. The wood for McNeil is sustainably harvested, making it a non-carbon intensive, renewable energy source. VCE GT is a relatively high-cost option that is only used to mitigate peak loads. It runs on fuel oil, and therefore is carbon-intensive.

2. *Medium-term contracts from specific providers* – Current providers included the New York Power Authority (NYPA), New York State Electric and Gas (NYSEG), and Vermont Electric Power Producers Inc. (VEPPI). These contracts vary in length and are typically renewable at competitive rates. All three existing contracts are from hydroelectric sources (VEPPI also includes wood) and are not carbon-intensive.

3. *Wholesale market* – VCE purchases electricity on the wholesale market from Independent System Operators of New England (ISO-NE or "Market"). The price of this electricity depends on the level of Market demand in a given hour. During periods of low Market demand, the Market can be the least expensive source of power, whereas during periods of high demand, it can be the most expensive. The level of Market demand is itself highly correlated with the level of demand within Vermont City. ISO-NE's power sources include natural gas (38.1% of total), fuel oil (24.4%), nuclear (14.4%), coal (9.2%), hydro-electric (5.5%), pumped storage (which is a version of hydro-electric) (5.4%), and other renewable (3%).

Figure 7 shows the anticipated profiles for VCE's power sources in 2009.

Figure 7

	Available Power (MW)	2009 Cost ($ per MWh)					Carbon Emissions (tons CO2/ MWh)	Fuel Type
		Block 1	Block 2	Block 3	Block 4	Block 5		
McNeil	26.5	$50.90	$50.90	$50.90	$50.90	$50.90	0.028	Wood
Contracts	14.9	$60.00	$60.00	$60.00	$60.00	$60.00	0.022	Hydro
VCE GT	18.0	$150.00	$150.00	$150.00	$150.00	$150.00	0.717	Oil
Market	50.0	$300.00	$170.00	$65.00	$43.00	$15.00	0.491	Mix

Source: Casewriter.

VCE also expects to develop its own wind power generation capacity that will be ready in 2012 (**Figure 8**).

Figure 8

	Available Power (MW)	2012 Cost ($ per MWh)					Carbon Emissions (tons CO2/ MWh)	Fuel Type
		Block 1	Block 2	Block 3	Block 4	Block 5		
VCE Wind	5.2	$76.80	$76.80	$76.80	$76.80	$76.80	0.018	Wind

Source: Casewriter.

The cost of running the McNeil plant is expected to increase 3% per year through 2014, and the cost of wind generation is expected to remain flat through at least 2014. The price of all other sources of energy is expected to grow 4% per year until 2014. Since money received or spent in the future is not as valuable as money received or spent today, a fractional multiplier called the *discount factor* (based on an annual "discount rate," in the language of finance) is associated with each future year, to reflect the decreased value of the money received or spent in that year. The discount factors for 2009 through 2014 are summarized in the following chart:

Year	Discount Factor
2009	1.00
2010	0.93
2011	0.87
2012	0.82
2013	0.76
2014	0.71

For example, $1.00 received in 2014 is valued the same as $0.71 received in 2009.

DSM Programs

VCE is implementing nine DSM programs, described as follows:

- *Business: New Construction* – This service helps commercial and industrial builders and developers incorporate energy efficient products and systems into new buildings and renovations.

Working early in the process with designers and owners, VCE assists in the choice of energy efficient systems, products, materials, and construction techniques.

- *Business: Existing Facilities* – This service works with companies when they replace equipment—heating, ventilation, cooling, water heating, refrigeration, motors and drives, and industrial process applications—as part of the normal course of business. This program offers a free energy audit, low-interest loans for capital expenses, and referrals to consultants and contractors.

- *Residential: New Construction* – This service aims to improve the efficiency of all new homes and substantial renovations. It addresses all major end uses: space heating, water heating, central cooling, ventilation, major appliances, and lighting for high-use areas.

- *Residential: Existing Homes* – This service aims to improve the efficiency of all existing residential buildings. VCE offers financing options to customers with electric heat who convert to a less-expensive source, such as natural gas or oil.

- *Retail Products* – By offering on-site consumer rebates at retail stores, this service aims to increase sales of energy efficient home products such as lights, washing machines, refrigerators, freezers, ceiling fans, and room air conditioners.

- *Commercial Smartlight* – This service provides an innovative financing option for commercial customers to pay for energy efficient lighting. With no up-front cost, these lights are paid for directly through VCE's billing system over a period of 36 months. The efficiency-related cost savings more than cover the monthly fee.

- *Commercial Heating and Air Conditioning* – This service provides support for businesses that are upgrading or installing new heating or cooling systems. These systems are typically the largest source of energy use for commercial customers. VCE provides technical assistance for these products in a specialized program that goes above and beyond the services provided for other existing facilities. Additional services include operating cost projections and feasibility studies.

- *Commercial Outdoor Lighting* – VCE also provides consultative services from initial design to installation and wiring of the poles to support energy efficient outdoor lighting for businesses. Services include comprehensive lighting analysis, property inspection, needs evaluation, lighting solution recommendations, site planning, and assistance in meeting Illuminating Engineering Society (IES) standards.

- *LED Streetlight Program* – VCE is contractually obligated to provide street lighting for all Vermont City streets. In this role, VCE is responsible for all installation, maintenance, and response to citizen complaints as it maintains specified service levels. Through its LED Streetlight Program, VCE is systematically replacing all of Vermont City's conventional streetlights with high-lumen LED lighting.

Figure 9 presents the anticipated costs and savings for VCE's DSM programs in 2009.

Figure 9

Program	Direct Cost	MW Saved per Block				
		1	2	3	4	5
Business: New Construction	$240,480	0.246	0.228	0.201	0.184	0.164
Business: Existing Facilities	$353,622	0.313	0.259	0.213	0.176	0.143
Residential: New Construction	$103,852	0.026	0.018	0.013	0.010	0.100
Residential: Existing Homes	$127,170	0.085	0.153	0.147	0.138	0.132
Retail Products	$88,861	0.128	0.142	0.139	0.136	0.137
Commercial Smartlight	$26,205	0.024	0.016	0.014	0.012	0.012
Commercial Heating and A/C	$30,165	0.016	0.018	0.020	0.022	0.024
Commercial Outdoor Lighting	$18,432	0.008	0.010	0.009	0.010	0.011
LED Streetlight Program	$46,240	0.032	0.028	0.024	0.026	0.032
Total	$1,035,027	0.878	0.873	0.780	0.715	0.755

Source: Burlington Electric Department 2006 Annual Energy Efficiency Report and casewriter.

While the costs associated with these programs are one-time costs, it is anticipated that the energy reductions will last for six years. For example, the LED Streetlight Program has a capital cost of $46,240 in 2009, but will save 0.032 MW in Block 1 for each of the six years starting in 2009 and ending in 2014, and similarly for Blocks 2, 3, 4, and 5.

In past years, VCE has been able support the capital costs of all nine DSM programs. However, due to budgetary policies stemming from the aftershocks of the 2008 economic downturn, VCE's internal

Finance Committee decided in October 2008 to limit total direct spending on DSM activities in 2009 to at most $800,000.

Daniela's Project

Given the new budget restrictions, it is no longer sufficient to conduct an analysis of each DSM program separately, as VCE had done in prior years. Instead, VCE needs to optimize its DSM programs in concert, maximizing total benefit while eliminating certain programs in order to stay within the DSM total direct spending limit. In addition to VCE's internal analysis of the DSM programs, the Citizen's Oversight Board wants to conduct its own independent assessment. In Daniela, they see the opportunity to have fresh eyes re-examine a set of programs that most board members have been looking at for almost a decade.

Daniela has some ideas on how to perform an independent and up-to-date evaluation of the nine DSM programs that would help determine which programs should be retained and which should be postponed and/or eliminated.

Armed with her knowledge of optimization modeling, Daniela set out to resolve the DSM dilemma by tackling two key questions:

1. Given the current budgetary environment, which of the nine DSM programs should VCE retain and which should it eliminate?
2. What is the total carbon impact of the DSM strategy?

Modeling Assignment

In order to answer Daniela's questions, you should construct and solve a mixed-integer optimization model that will compute VCE's least-cost electricity supply plan for the years 2009 through 2014, both without and with DSM impacts. All of the data in the case is contained in the spreadsheet VermontCityElectric.xls, which you should use as the basis for constructing your model. Here is a suggested plan to use as you build your model:

I. Start by building a linear optimization model for least-cost electricity supply for the year 2009 under the presumption of no DSM activities. Given current capacities of various power sources, the model should determine which power sources should be used at which levels in each load block in 2009, in order to minimize the cost of supplying electricity. Be sure to model demand in each load block separately. Please be careful to keep your units consistent, and note that power is in MW, energy is in MWh, demand data in each block is in MW, energy costs are stated in $/MWh, etc. You may find it more convenient to formulate the key decision variables in MW. You should assume that "today" is December 2008. We recommend that your objective function be stated in net present value with 2009 being the base year. Also, keep in mind that the different demand blocks are really re-arrangements of the hours in the year, and there is no structural relationship between different blocks, so that operating or not operating a powerplant in one block has no structural effect on operating that powerplant in any other block.

II. In order to keep account of the carbon impact of the solution, create an equation that will compute the total carbon impact in 2009. Even though carbon emissions are not necessarily optimized in the model, total carbon emissions need to be computed in order to understand the carbon impact of meeting electricity demand.

III. Run your 2009 model. Does the solution make good intuitive sense? Why or why not? If not, re-check your formulation and data to ensure that your solution is intuitively sensible.

IV. Once you are satisfied that your model produces an intuitively justifiable solution for 2009, expand the model to include the years 2010, 2011, 2012, 2013, and 2014, still under the presumption of no DSM activities. Remember to add the VCE Wind Power capacity starting in 2012. The new model should have six times the number of decision variables as in the original model, and six times as many constraints as in the original model. Similar to the 2009-only model, be sure to create an equation to keep track of carbon emissions for each year of the 6-year model. You should also use the discount factors in your objective function equation in the 6-year model so that your model will minimize the net present value of costs over the 6-year time horizon. Your 6-year model will have many decision variables and constraints. In order for Solver to run this large model, you will need to click on **Options** in the **Solver Parameters** window, and change the **Iterations** from 100 to 9999 and **Max Time** from 100 to 1000 seconds. And of course, you should also remember to check "**Assume Linear Model**" as well as "**Assume Non-Negative**."

V. Run your 6-year model (under the presumption of no DSM activities) and try to validate that the solution makes good intuitive sense.

VI. You are now ready to add the DSM activities to your model. To assess the impact of DSM activities, assume that DSM activities can be implemented in 2009 and only in 2009, but that the impact of DSM activities on demand will occur in years 2009 through 2014. Further assume for each DSM program that its impacts on demand are the same in each of the six years. Create a binary decision variable for each of the nine DSM activities. Also, be sure to create a budget constraint that limits DSM capital expenditures in 2009 to at most $800,000. Be careful to account for the way each DSM decision variable impacts the demand for electricity in each load block in each year and for the capital cost of each of the nine DSM activities in the objective function.

VII. Before running your model, you will need to click on **Options** in the **Solver Parameters** window, and change the **Tolerance** from **5%** to **0%**. (This will guarantee that the Solver will compute an optimal solution as opposed to just a nearly-optimal solution.) You are now ready to run your 6-period mixed-integer optimization model with binary decision variables for the DSM activities.

VIII. Solve your model. Which of the nine DSM programs does the model recommend be implemented? Does this solution make sense to you? Why or why not? Try to figure out why the model's recommendation is indeed the best solution.

Analysis Assignment

1. Once you are convinced that your model is doing what it is supposed to, use the model (in conjunction with your good judgment) to analyze the DSM program choices. Be sure to examine the carbon impact as well. Prepare a quantitative rationale for/against implementing a DSM strategy for VCE for 2009. You should write this up as an efficiently-worded memo to the Citizen's Oversight Board with appropriate (but not excessive) back-up of tables and other analysis as needed.

2. According to your analysis, does the $800,000 budget restriction have an impact on VCE's optimal choice of DSM programs? If no, why does the budget restriction not matter? If yes, can you make a sound case why the budget restriction should be increased by the Finance Committee?

Optional Thought Question

What would be the implications if the federal government were to enact a simple carbon tax, effective January 1, 2014, in which VCE would pay a fixed tax for each ton of CO_2 emitted in meeting the demand for electricity? How might such a tax make a difference in how VCE optimally meets demand in 2014, and in carbon emissions from meeting VCE's electricity demand, or do you think it might not make any difference? Consider only the year 2014 when evaluating this possibility.