ENERGY FUTURES GROUP

Comparative Analysis of Fuel-Switching from Oil or Propane to Gas or Advanced Electric Heat Pumps in Vermont Homes

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May 6, 2015

This report documents the results of a comparative assessment of the impacts of fuel-switching residential oil or propane space heating in Vermont to either gas heating or electric heating using cold climate ductless heat pumps. I have done the analysis from both a customer economics – focusing just on the impacts on just the new customers converting to gas or heat pumps – and a societal economics perspective. In both cases, I have used a 30 year analysis period for a fuel switch taking place in 2017, using a 3% real (i.e. after adjusting for inflation) discount rate (same as VGS in its analyses). I have also looked at the difference in impacts on carbon emissions. Note that my analysis does not address water heating energy use. It is likely that most homes that switch to gas for space heating will do so for water heating as well, and there could be some economic benefits from such a switch. However, there could also be significant benefits from switching to electric heat pump water heaters as well.

What follows is a brief description of the approach and key assumptions I used, as well as the results. This report builds on the report I wrote for VPIRG on June 10, 2014, both by updating some assumptions used in that report and by adding discussion of several related topics.

Customer Economics

The analysis of the customer economics is based heavily on forecasts of future energy prices. I start with an average of the monthly energy prices for the past winter (November 2014 through March 2015) for fuel oil, propane and electricity from the Vermont Public Service Department monthly Vermont Fuel Price Report.[1] For the gas price I use the combination of fixed monthly charges plus variable charges per therm used by Vermont Gas in its analysis of the pipeline project impacts. The resulting total gas cost per therm, for the estimated average baseline heating energy consumption that I assume (90 million BTUs) is very close to the DPS reported average values. These current prices are summarized in Table 1 below.

Table 1: Vermont 2014-2015 Winter Fuel Prices

Fuel	Price
Oil (per gallon)	$3.01
Propane (per gallon)	$2.90
Natural Gas (per therm)	$1.53
Electricity (per kWh)	$0.15

Those starting prices were then adjusted for future years based on the U.S. Energy Information Administration's Annual Energy Outlook (AEO) 2015 price forecast for the New England

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[1] http://publicservice.vermont.gov/publications/fuel_report

residential sector through 2040.[2] Since I wanted to use a 30 year analysis period for installations that take place in 2017, I extended the AEO forecast to 2046, assuming that the average annual increase from 2036 to 2040 would apply in subsequent years as well. Note that VGS used AEO 2014 forecast in the same way in their most recent analysis (which was completed before the AEO 2015 forecast was available). A summary of the average annual rates of increase in forecast prices that I used is shown in Table 2. Note that these are increases in *real* prices – i.e. positive values mean an increase above the average inflation rate for the economy as a whole.

Table 2: Forecast Average Annual Real Fuel Price Changes

	2016 to 2025	2026 to 2035	2036 to 2046
Oil	2.3%	2.2%	2.3%
Propane	1.2%	0.7%	0.8%
Natural Gas	3.2%	0.5%	2.3%
Electricity	1.6%	0.1%	0.8%

As noted above, my analysis assumed that the average Vermont home that would fuel switch currently consumes approximately 90 MMBtu of fuel annually for space heating. That is a little more than VGS's assumed 100 MMBtu for both space heating and water heating (since water heating usage is typically between 15 and 20 MMBtu per year). However, the U.S. Energy Information Administration's Residential Energy Consumption Survey suggests that the average single family oil-heated home in New England consumes a little more than 80 MMBtu for space heating[3] and I would expect consumption in Vermont, where it is colder than much of the rest of New England, to be a little higher.

For homes that fuel-switch to natural gas and install a new natural gas boiler I assume that average annual heating fuel consumption does not change. That is based on the fact that a recent study of the efficiency of existing homes in Vermont found that the average existing oil boiler in the state had an efficiency of 85% and the average propane boiler had an efficiency of nearly 87%[4] - in the range of what I would expect the average new gas boiler to be. For homes that didn't install a new boiler, but instead installed a gas conversion burner on their existing boiler, I also assumed no change in efficiency. For the conversion I assume a new gas boiler cost of $4500 or an average annual conversion burner rental cost of $240. Those assumptions

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[2] See Prices by Sector and Source – with regional breakdown, Table 3.1 (New England) at: http://www.eia.gov/forecasts/aeo/data.cfm

[3] See table CE4.7: http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption#end-use

[4] NMR Group et al., "Vermont Single-Family Existing Homes Overall Report, Final", submitted to the Vermont Public Service Department, 6/13/2013.

are the same as assumed by VGS, but considerably lower than the average conversion cost of $12,000 that is estimated by the Vermont Fuel Dealers' Association (VFDA).[5] I am not passing judgment on which of those estimates of conversion costs is more accurate; I simply use the more conservative assumption (i.e. the assumption that gives the most optimistic view of the economics of the gas conversion). However, I also assume that, on average, the home would have had to install a new oil or propane boiler in 10 years (assuming that the average boiler has a life of 20 years and that the average boiler is about half way through its life). Thus, homes that install a new gas boiler as part of the fuel switch receive a credit for pushing out the timeframe for the need for the next new boiler (from year 10 to year 20) and homes that install a conversion burner are only assumed to need it for 10 years.

For the analysis of fuel-switching to a cold climate ductless heat pump, I assumed that the installation would be a multi-head (e.g. 3-head) system. The cold climate versions of those systems are now available in Vermont. A recently completed Northeast Energy Efficiency Partnerships "meta-study" of ductless climate heat pumps – which analyzed and synthesized conclusions from nearly 40 different studies, reports and other documents on the technology – estimated that the average heating season COP is between 2.4 and 3.0.[6] I used the mid-point in that range – COP of 2.7 – in my analysis. Based on both that COP and the results of a recent field test of cold climate ductless heat pumps in central New Hampshire, I estimate that the fuel oil or propane savings from single-head systems would average nearly 40 MMBtu[7] – or nearly 45% of the 90 MMBtu I have assumed for the average home. Based on professional judgment and conversations with Mitsubishi staff, I assume that a 3-head system would meet about 80% of the heating needs of a home; the remainder would still be met with fuel oil or propane. Again based on conversations with Mitsubishi staff, I assume that the cost of a three-head system would be about $7500[8] – or roughly 2½ times the current cost of a single-head system (costs do not increase linearly with number of heads). With a $300 rebate from Efficiency Vermont,[9] the net cost to consumers of a three-head system is currently to be approximately $7200. Alternatively, the same portion of heating load could be met at approximately the same level of efficiency with three single-head units of the type that are on the market today, but at a cost of about $8100 per home (i.e. $3000 per unit, minus the $300 rebate per unit available from Efficiency Vermont). Because a heat pump is assumed to have a life of only 15 years, the analysis includes an additional cost to replace the unit once during the 30 year analysis period.

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[5] Prefiled testimony of Mathew Cota, VFDA, Docket 7970, May 5, 2015.

[6] http://www.neep.org/initiatives/emv-forum/forum-products#Heat Pump Meta Study

[7] The study found that the average metered heat pump consumed 3421 kWh per year on a weather-normalized basis (see: http://www.neep.org/Assets/uploads/files/emv/emv-library/NEEP%20DHP%20Report%20Final%205-28-14%20and%20Appendices.pdf). Using an average seasonal heat pump COP of 2.7 and an average fossil fuel heating system seasonal efficiency of 80% (consistent with an average boiler efficiency rating of 85%, adjusted down five percentage points for distribution system losses), that equates to 39.4 MMBtu/year.

[8] E-mails from Eric Dubin, Mitsubishi's Director of Utility Programs, December 10, 2014 and February 3, 2015.

[9] https://www.efficiencyvermont.com/For-My-Home/ways-to-save-and-rebates/heating-cooling/Cold-Climate-Heat-Pumps/Overview

As shown in Table 3, a partial fuel switch to a cold climate ductless heat pump should be very attractive to consumers, with net present value benefits of roughly $10,000 for homes currently using oil to heat their homes and approaching $20,000 for homes currently using propane to heat their homes. A full fuel switch to gas is even more attractive, with about 30% greater economic benefits. If VFDA's estimates of conversion costs were more accurate, gas fuel-switch would still be cost-effective from the customer's perspective, but likely a little less cost-effective than a heat pump fuel-switch.

Table 3: New Customer Economics of Fuel Switch from Oil/Propane (2015 dollars)

	30 Year NPV		
	To Gas	To Heat Pump	
Starting Fuel		1 Multi-Head	3 Single Heads
Oil	$13,554	$10,032	$8,639
Propane	$23,405	$18,114	$16,721

It is also important to emphasize that the net economic benefits of the gas fuel-switch shown in Table 3 do not account for the costs of either the pipeline extension, the distribution mains or the cost of connecting homes the distribution system. If such costs were to be allocated to new residential customers based on their forecast share of new gas revenues, it would be the equivalent to about $27,000 per home.[10] However, such costs are assumed to be socialized across all gas customers (i.e. not born by just the new gas customers). Put another way, the extent to which existing VGS customers are subsidizing new gas customers does not factor into the economic view of the new gas customers. Though a portion of both the costs of the gas pipeline and the costs of connecting to the pipeline would be borne by the new customers (through system-wide VGS gas rates), I have not attempted to estimate that impact. Thus, my analysis of the economics of the gas conversions for new customers overstates the attractiveness of the gas conversions – even from the narrow perspective of just those customers.

Societal Economics

For the assessment of societal economics, I used Efficiency Vermont's cost-effectiveness screening tool, which includes forecast avoided costs (not the same as retail rates/prices used in the customer economics analysis described above) and a carbon dioxide emissions externality cost of $100/ton. The avoided costs are based on the 2013 regional avoided cost

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[10] The pipeline cost is estimated to be $153.6 million, the distribution mains are estimated to cost $5.8 million and the cost of connecting to the distribution system is estimated to be $1600 per customer (VGS Response to DPS Question 6). VGS has forecast that new residential customers will produce nearly 30% of the new gas revenue resulting from the pipeline (Attachment A.DPS.VGS.1-1.1 No IP $153.6 August 2014 2014 EIA to 2049). The average number of new residential customers over VGS' 35 year analysis period is 1800.

study (which includes Vermont-specific values).[11] Note that the screening tool also typically uses a 10% risk discount on costs and a 15% non-energy benefits adder. However, those values are meant to reflect additional benefits of efficiency measures which are arguably not present in the same way or magnitude for pure fuel-switching projects. Thus, I have eliminated those adjustments in our analysis.

Many of the other assumptions in our analysis – including the costs of gas conversion burners or new boilers, the costs of a ductless heat pump (except for the exclusion of the Efficiency Vermont rebate under the societal analysis), the magnitude of the oil/propane savings from both a full gas fuel switch and a partial heat pump fuel switch, etc. – are the same as in the customer economics assessment. However, there are two main differences:

1. The use of societal avoided costs rather than retail energy prices consumers see. This is particularly important for capturing the impacts of electric fuel switching.
2. The inclusion of both an assumed allocation of $27,000 per home to cover a proportional share of the costs of the pipeline and distribution mains and a $1600 cost for connecting the home to the gas distribution system.

As the results presented in Table 4 show, these differences are very important. Under the societal economics view, a fuel switch to gas is at best a break-even proposition and at worst increases costs. In contrast, the partial fuel-switch to efficient heat pumps are very cost-effective from the societal perspective, with net benefits on the order of $20,000 per home.

Table 4: Societal Economics of Fuel Switch from Oil/Propane (2012 dollars)

	30 Year NPV		
	To Gas	To Heat Pump	
Starting Fuel		1 Multi-Head	3 Single Heads
Oil	$819	$22,818	$20,746
Propane	($1,974)	$20,556	$18,484

A couple of aspects of the results of the societal screening, in comparison to the customer economics assessment, merit discussion.

First, it is important to note that the fuel price estimates in the cost-effectiveness screening tool that I used for the societal economics assessment are a little older than the prices and AEO 2015 forecasts changes over time that I used in my assessment of the customer economics. For oil, the prices in the screening tool are similar to the prices that I used for the customer economics. However, the prices in the screening tool is considerably lower for natural gas. As a result, difference in price between oil and gas is considerably higher in the societal economics assessment. Put another way, because the screening tool has somewhat outdated fuel price

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[11] http://publicservice.vermont.gov/sites/psd/files/Topics/Energy_Efficiency/AESC%20Report%20-%20With%20Appendices%20Attached.pdf

assumptions, the societal economics results shown in Table 4 probably significantly overstate the attractiveness – if one can call it that – of the oil to gas fuel switch. On the other hand, the propane prices in the screening tool are lower than the more recent prices and price forecast that I used in the customer economics assessment. Moreover, the degree to which they are lower is roughly the same as the degree to which the gas prices in the tool are lower (on a per Btu basis). Put another way, the differences between propane and gas prices in the screening tool are very similar to the differences between the propane and gas prices I used in the customer economics assessment. In other words, the societal economics results shown in Table 4 appear reasonably accurate for the propane to gas fuel switch.

Second, the heat pump fuel switch looks better under the societal economics assessment. This appears to be largely due to the fact the societal cost of increased electricity consumption for space heating are 40-50% lower than the retail electric rates used for the customer economics assessment.

Carbon Emissions Impacts

In addition to the economic analysis, I also did a quick comparative assessment of the impact of fuel switching to gas or heat pump heating on carbon emissions. For that assessment I used the same carbon dioxide emission rates for oil, propane and natural gas that are used in the Efficiency Vermont screening tool. Note that those rates only account for emissions associated with the actual burning of the fuel. For electricity, I used the Vermont-specific marginal emission rates at the generator that were estimated in the regional 2013 avoided costs study and increased them by marginal winter line loss rates. Table 5 provides a summary of the resulting emission rate assumptions.

Table 5: Carbon Dioxide Emission Rate Assumptions for Different Fuels

Fuel	Starting Assumption	Tons per MMBtu Input	Average Heating System Efficiency	Tons per MMBtu Output
Oil	73.15 kg/MMBtu	0.080	80%	0.101
Propane	63.07 kg/MMBtu	0.069	80%	0.087
Natural Gas	53.06 kg/MMBtu	0.058	80%	0.073
Electricity	1117 lb/MWh	0.164	270%	0.061

As Table 5 shows, the emissions rate per MMBtu of fuel consumed is highest for electricity. However, one must also adjust these rates to reflect the average seasonal efficiency of the heating systems that would be installed with each fuel to obtain rates per unit of heat produced. The most efficient heating system for oil, propane and natural gas are all less than 100%. In contrast, the average COP for the heat pumps analyzed in this assessment is 2.7, or essentially 270% efficient. As a result, the carbon dioxide emissions per unit of heat produced is actually lowest for heat pumps (17% lower than for natural gas). Thus, as shown in Table 6, I estimate the reduction in carbon emissions from the partial fuel-switch to electricity to be greater than the carbon emission reductions from a full fuel switch to natural gas.

Table 6: Carbon Emission Reductions from Fuel Switching to Gas or Heat Pump

Baseline Fuel	New Heating Fuel	
	Natural Gas	Electric Heat Pump
Oil	27%	32%
Propane	16%	24%

Cooling Impacts of Heat Pump Fuel Switching

I am aware of two studies that have examined cooling impacts of ductless heat pumps, one in New Hampshire[12] and another in Maine[13]. The New Hampshire evaluation estimated that cooling energy use would have declined (relative to the base case) for those customers who either already had or were planning to add cooling. It further found that most of the customers who installed the ductless heat pumps either already had or were planning to add cooling. Thus, it estimated a net reduction in cooling energy consumption for the population it studied. The results from the Maine study were a little different. It found that cooling energy use in homes that already had cooling was relatively unchanged. On the other hand, cooling energy use in homes that didn't previously have cooling increased by about 3.3 kWh per day, or about 300 kWh over the entire summer. It also found that roughly half of the customers were in each of those groups, so it concluded that the average cooling energy use increased by about 1.6 kWh per summer day, or about 150 kWh over the entire summer. However, that estimate was based entirely on whether each customer had or did not have cooling before they installed the heat pump. The evaluation did not address whether the customers were planning on adding cooling. To the extent that some of the participants who didn't previously have air conditioning but were planning on installing it or could be expected to install it in the future, any increase in cooling energy use would be smaller than estimated in the Maine study.

I have also attempted to analyze likely cooling impacts for Vermont given typical system cooling efficiencies, Efficiency Vermont's estimates of average run-times for residential cooling and estimates of air conditioning saturations in the state. That is a challenging task because of uncertainty about saturations of residential air conditioning. One 2009 study suggested that

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[12] Northeast Energy Efficiency Partnerships, "EM&V Forum: Primary Research – Ductless Heat Pumps", April 2014 (http://www.neep.org/initiatives/emv-forum/forum-products#Emerging Technologies Research)

[13] Energy Market Innovations, Inc., "Bangor Hydro Electric and Maine Public Service Heat Pump Pilot Program: Interim Report on Summer Impacts", October 30, 2013.

only 40% of Vermont homes have some form of air conditioning (mostly window units).[14] On the other hand, a recent high level analysis of Vermont electric bills conducted by Efficiency Vermont suggested that on the order of 80% of residential customers have some form of electric cooling.[15] If air conditioning saturations are on the low end of that range (i.e. 40%), I estimate that the average home adding a heat pump would see increased cooling kWh of about 260 kWh per year. That would represent only about 4% of the total electricity consumption of a Vermont heat pump. If air conditioning saturations are on the higher end of that range (i.e. 80%), or even likely to grow to the higher end of that range over the next decade or two, then the average home adding a heat pump would not see any increase in electricity use for cooling and could even see a small decline.

To the extent that there are any increases in cooling energy use, I have not factored them into my economic analysis because the costs of the added cooling electricity use is at least counter-balanced by the increased "amenity" the customers receive (otherwise they would not use the air conditioning). However, it would be appropriate to account for the impacts of any increased cooling use on carbon emissions. As Table 7 shows, under the low estimate of existing air conditioning saturations the average carbon emission reduction per home from a heat pump installation would be about two percentage points lower than the change one would see from looking at just heating impacts. However, the heat pump fuel switch would still reduce carbon emissions by more than the gas fuel switch. Under the higher estimate of residential air conditioning saturations heat pump cooling would not have any material impact on carbon emissions. It should be emphasized that these estimates are based solely on emissions at the point of combustion; they do not account for any greenhouse gas emissions associated with either the production or transportation to Vermont of gas or other fuels.

Table 7: Carbon Emission Reductions from Gas Fuel Switch or Heat Pump (including cooling)

Baseline Heat Fuel	Switch to Natural Gas	Switch to Heat Pump		
		Heating Impacts Only	Heating & Cooling Impacts – low existing A/C saturation assumption	Heating & Cooling Impacts – high existing A/C saturation assumption
Oil	27%	32%	30%	32%
Propane	16%	24%	22%	24%

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[14] Nexus Market Research et al., "Analysis of Onsite Audits in Existing Homes in Vermont – Final", submitted to the Vermont Department of Public Service, June 24, 2009 (http://publicservice.vermont.gov/sites/psd/files/Topics/Energy_Efficiency/EVT_Performance_Eval/VT%20Existing%20Home%20Onsite%20final%20report%20062409.pdf)

[15] Personal communication with Jake Marin, Vermont Energy Investment Corporation, December 15, 2014.

Impacts of Heat Pump Fuel Switching on the Electric Grid

A presentation by VELCO on its forecast of the impacts of increasing heat pump saturations on peak demands in the state concluded that summer peak demands will actually decline in the next several years and that it would take 13 years of growth in heat pump saturations to get us back to current peak demands.[16] Even as far out as 2034, with more than 25% of homes using heat pumps, VELCO estimates that the state's peak demand would only be about 6% or 7% higher than today. VELCO also concluded that the state would remain summer peaking, with the difference between summer and winter peaks not being appreciably different than today. Indeed, even with more than 25% saturation of heat pumps, the winter peak 20 years from now would be lower than the current summer peak.

It is important to note that this all presumes that the baseline against which we should be comparing ourselves is one of no new policies to promote electrification. Since electrification of building space heating (and transportation) is one of the likely pathways to achieving the state's 2050 energy policy objective of meeting 90% of its energy needs with renewables,[17] one could question whether a policy status quo is an appropriate baseline. Put another way, it may be necessary to incur the modest grid impacts described above (and more) regardless of the relative economics today of fuel switching to gas versus fuel-switching to heat pumps.

Conclusions

The results presented above lead to some interesting high level conclusions:

- There is a significant difference between customer economics and societal economics when analyzing the relative cost-effectiveness of residential fuel switching to gas vs. fuel switching to ductless heat pumps. In general, public policy decisions should be made on societal economics.
- Under societal economics, the cost-effectiveness of residential fuel-switching to natural gas is questionable once one includes the cost of the infrastructure investment necessary to get the gas to the new residential customers.
- Under societal economics, the ductless heat pump appears to be very cost-effective.

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[16] VELCO and Itron, "Heat Pump Impact on Load Forecast", Power Point presentation in Docket 8311 Workshop, September 30, 2014.

[17] Vermont Department of Public Service, "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals", December 8, 2014 (http://publicservice.vermont.gov/sites/psd/files/Pubs_Plans_Reports/TES/TES%20FINAL%20Report%2020141208.pdf)

- It is unclear whether promotion of fuel-switching to heat pumps for space heating will increase cooling energy use. The answer depends on what one assumes about both current and future changes in baseline cooling saturations. However, even if cooling consumption does increase, its impact appears relatively small.
- Significant increases in heat pump saturations do not appear to have dramatic impacts on the electric grid, at least not up to saturations of 25%.
- Fuel-switching to cold climate ductless heat pumps appears to lead to fewer greenhouse gas emissions under current marginal emission rates for electricity than fuel switching to gas heat. It is difficult to forecast how marginal electric emission rates will change in the future. However, if there is eventually serious effort to address climate change, they could conceivably improve. My analysis assumes no such improvement.
- The analysis of the relative benefits of gas and heat pump fuel switches are sensitive to a variety of assumptions, particularly future fuel prices, the portion of the home that can be heated by a three-head ductless heat pump and the portion of the pipeline and related infrastructure costs that are allocated to new residential gas customers in a societal analysis.