From:	Pligavko, Andra
To:	Hunt, Marshall; Eilert, Patrick L; Basarkar, Mangesh; Turnbull, Peter
Subject:	FW: Gas furnaces vs heat pumps
Date:	Thursday, February 04, 2016 8:00:00 PM
Attachments:	ACEEE Furnaces and HP paper 1-17-16 mbh9.docx DUNG_finalreport.pdf NWPPC Statement and PG&E calculation.docx PGE Comments - ACEEE HP vs Gas Furnace paper - akp.docx

All –

Combined comments below.

Peter – I added a few of my own thoughts to your paper. The redline is attached here, but I sent Jan a clean version.

The timeline was tight so there wasn't an opportunity to review each others thought before sending.

We'll aim for that next time ☺

I will let you know if Steve has any questions for us.

Andra

Andra Pligavko

Pacific Gas and Electric Company | Energy Efficiency Strategy

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From: Pligavko, Andra
Sent: Thursday, February 04, 2016 7:56 PM
To: Berman, Janice S
Subject: RE: Gas furnaces vs heat pumps

Jan –

Feel free to review and forward on tonight. Please cc me if you do that.

If I don't see something from you by 10pm, I will forward to Steve directly, given the timing.

Sorry for the delay in completing this review.

Steve,

I am sending you these comments directly, given the timing.

Thank you for the opportunity to comment on ACEEE's heat pump vs. gas furnace study.

We are one PG&E, but built up of many individuals. There are three different perspectives reflected in our comments. We offer the following suggestions for your consideration.

From the Policy Strategy & Emerging Technologies teams:

Peter Turnbull (ET) has a keen focus on getting to ZNE in buildings, both for new construction and retrofits.

- New construction: a systems perspective on costs should be reviewed; there is a significant cost benefit to eliminating gas distribution in new construction
- ZNE: a systems perspective should be considered. Reduced need (from deep retrofit) can lead to smaller equipment and a comparative benefit for heat pumps

Peter Turnbull and I are reviewing this from a long term perspective with increasing levels of renewables and a long term de-carbonization goal.

- Long term policy and very high renewables penetration: the paper led with the idea that the driver behind the research was a long term de-carbonization goal; however, the implications of very high renewable penetration are not yet appropriately acknowledged and reflected in the paper. Specifically:
  - Acknowledge that at very high penetrations of renewables overgeneration conditions are likely to exist and marginal carbon cost during these hours may be zero.
  - Should certain efficient heat pump technologies be ability to use low carbon "overgeneration" and store heat energy for later use (e.g. water heat pump), the carbon footprint would decrease even further
- Equipment improvement: paper should reflect that there is more opportunity for efficiency improvements in the electric heat pump technology, whereas the natural gas technology efficiency is already close to the theoretical limit.

The above thoughts are described more thoroughly in the first attachment "PGE - ACEEE HP vs Gas Furnace paper Comments v2016 0204.docx".

From the <u>Codes & Standards team</u>:
Marshall is focused on the information needed to make near term C&S policy decisions.

- Cost to Consumer: There may currently be some modest benefits on the carbon side; however, the customer economics are not favorable. The report should be more explicit about the near term hurdles to adoption.

This and several other specific comments and suggestions directly in the DRAFT ACEEE paper (2nd attached). Marshall also suggests including a reference to the 3rd attachment.

We provide the following suggestions as ways ACEEE could improve the comprehensiveness of the paper. This is an "all of the above list". We would need further internal discussion to prioritize topics if that were requested.

  - A section that does a quantitative economic analysis of the costs & benefits of electric heat pumps for a new construction situation. (and avoiding the construction of a gas distribution system)
  - A section that pairs electric furnaces with a deep retrofit. (or identification of this as an area for further study)
  - Another heat rate scenario that reflects a very high level of renewable penetration (~40% or ~50%) and the zero or low marginal carbon content of energy during overgeneration periods. This might be focused on the regions currently considering that policy direction.
  - A water HP carbon and economic analysis that looks at the possibility of using and storing energy during these overgeneration periods. As this is a future scenario, economic analysis would more appropriately reflect the forecasted wholesale cost of energy during the overgen periods as opposed to a historically based simple or flat

rate structure.

- o Qualitatively discuss the implications of significant technology advances in heat pump technologies on the results, particularly in non-temperate areas.
- o A more robust section on current economic hurdles of adoption through the lens of current rate structures.

Attached is a paper that our ET team developed that goes into more detail on the first two sections. The original ACEEE paper with comments from Marshall Hunt on our C&S team.

Let us know if you have questions as you review our thoughts.

Thanks,
Andra

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From: Berman, Janice S
Sent: Wednesday, February 03, 2016 11:53 AM
To: Steve Nadel; Pligavko, Andra
Subject: RE: Gas furnaces vs heat pumps

Copying Andra who is pulling comments together from a few teams.
--Jan

From: Steve Nadel [mailto:SNadel@aceee.org]
Sent: Wednesday, February 03, 2016 9:21 AM
To: Berman, Janice S
Subject: RE: Gas furnaces vs heat pumps

Jan,

Just a reminder that we're looking for comments by COB tom'w as I'll be revising on a long plane flight on Friday. Tx for your help.

Steve

From: Steve Nadel
Sent: Monday, January 18, 2016 8:07 AM
To: Janice Berman <jsba@pge.com>
Subject: Gas furnaces vs heat pumps

Jan,

As I mentioned to you when I visited your office a few months ago, I've been working on an analysis on gas furnaces vs. heat pumps. Attached find a DRAFT of the analysis and results. You'll see that heat pumps look pretty good for California, but this combines both the north and south – results might be different if the state is divided in two. I'd welcome any comments you have on the draft. I'll also be getting comments from a few others. I've been working on this quietly until after the furnace efficiency standard gets resolved as I suspect the gas industry will not be happy with my preliminary findings. My plan is to get comments in two stages – first from experts who do not have the obvious potential for bias, and then, after I address these initial comments, get comments from folks like AGA, GTI, EEI, EPRI, APPA and NRECA. Given this, please don't share this draft with folks at PG&E who work closely with any of these gas or electric organizations – they'll get their shot a little later after I've had a chance to refine the analysis. I want to be as objective as possible before entering political/philosophical debates. I ook forward to your comments. Would be great to get comments by Thursday Feb. 4th as I have some travels starting Feb. 5th and hope to work on this while traveling. Thanks for your help.

Steve

heating energy, since the majority of residential natural gas goes to space heating. Near the end we briefly look at water heating. Our analysis primarily looks at the relative energy use for different regions and types of heating systems, ~~but~~ we ~~also~~ include a simplified economic analysis, ~~also~~ for different regions and system types. The balance of this paper discusses our methodology and findings. We find that fuel switching may reduce energy use and emissions~~, and~~ save money in some regions and for some system types but not for other regions and system types, with many situations "on the cusp". For example, efficient heat pumps often use less energy in warm states and have moderately positive economics in these states *if* a heat pump can replace both the furnace and a central air conditioner. We end with some recommendations for further research and for initial program efforts.

Comment [mbh2]: Sentence needs a little work

Comment [mbh3]: For the PG&E service territory the cost of a million Btuh delivered to the space using HP is 150% of the cost of the same heat from a natural gas furnace. This argues for discussing the costs of electricity.

Methodology

For this initial analysis, we compared the gas used by gas furnaces to the gas used at a power plant in order to power a heat pump. In the long-term, natural gas is likely to be the marginal generation fuel in many, if not most, regions, so this is a reasonable place to start. And by not getting into inter-fuel comparisons, the analysis can be much simpler.[1]

Comment [mbh4]: A source energy multiplier approach.

At the house level the following systems are analyzed:

1. 80% AFUE furnace (current federal standard)
2. 95% AFUE furnace (most common high efficiency furnace – this is Energy Star for the north)
3. 97% AFUE furnace (Energy Star Most Efficient level)
4. 8.2 HSPF heat pump (current federal standard for split systems)
5. 8.5 HSPF heat pump (Energy Star level)
6. 9.6 HSPF heat pump (Energy Star Most-Efficient)
7. A cold climate electric heat pump (just a very preliminary analysis based on one field test – more products and data needed)
8. A gas-fired heat pump (also just a very preliminary analysis based on projections from one research project – more data, including ultimately field data, will be needed).

Comment [mbh5]: The AC HP working group just approved 8.8 HSPF starting 2023. Can some analysis or comments be made on its impact.

And at the power plant level we looked at four different heat rates:[2]

a. 6161 Btu (HHV)/kWh (the rated efficiency of GE's best turbine; to achieve this level in the field may need some additional improvements)[3]
b. 6503 Btu/kWh (the best actual heat rate in 2014 from EIA's database)[4]

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[1] Of course, other scenarios can also be considered. From a carbon emissions point of view, to the extent sources with lower emissions than natural gas are used on the margin, the comparison will be more favorable to electric heat pumps than shown here. On the other hand, if high emissions sources such as coal-fired power plants are on the margin, the comparison will be more favorable to gas furnaces than shown here.

[2] All are based on higher heating value, meaning that they include the energy recovered by condensing any steam product of combustion.

[3] GE rates their 7H CC at about 5550 Btu/hour based on lower heating value (LHV) -- https://powergen.gepower.com/plan-build/products/gas-turbines/7ha-gas-turbine/product-spec.html?cycletype=Combined_Cycle_1x1 . We increase this by 11% to estimate the higher heating value (HHV) efficiency -- https://en.wikipedia.org/wiki/Combined_cycle .

c. 7667 Btu/kWh (the average combined cycle plant heat rate in 2013 per EIA [2014 data not yet available][5]
d. 10,354 Btu/Kwh (the average steam turbine heat rate in 2013).[6] While gas-fired steam turbines are not common, some coal turbines have been converted to gas, and some additional conversions may happen in the future. Also, this is somewhat of a proxy for the energy use of a typical coal-fired steam turbine.

Comment [mbh6]: CEC finds that NG power plants have a heat rate of 7260.

The analysis is conducted for 16 states plus two 2-state regions. These are the states and two-state regions with data in the 2009 RECS (EIA 2013).[7] The states are Arizona, California, Colorado, Florida, Georgia, Illinois, Massachusetts, Michigan, Missouri, New Jersey, New York, Pennsylvania, Tennessee, Texas, Virginia and Wisconsin. In addition, we examined two 2-state pairs – Oregon/Washington and North/South Carolina. Together these states cover a wide range of regions and climates throughout the US. These analyses are based on average conditions in each state and do not necessarily apply to regions within each state that are significantly warmer or colder than the state average.

The analysis makes use of average space heating consumption data by state for gas-heated homes in the 2009 RECS. We assume that the average furnace captured in RECS has an 80% Annual Fuel Utilization Efficiency (AFUE) and that more efficient furnaces will use proportionately less.[8] We also assume that if they convert to a heat pump, they will need the same number of BTU's output as they get from their current gas system.[9] We estimated the seasonal efficiency for heat pumps at different locations using a methodology developed by the Florida Solar Energy Center (FSEC) that estimates seasonal heat pump efficiency as a function of local winter design temperature (Fairey et al., 2004). Fairey et al. find that depending on winter temperatures, heat pump seasonal efficiency can be as much as 40% below the rated efficiency (e.g., in Minnesota) or as much as 20% above the rated efficiency (e.g., in Florida). Our analysis also includes allowances for electric T&D losses of 5.5%[10] and gas distribution losses of 2%.[11] Additional specifics are provided in the Appendix.

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[4] Most efficient plant in 2014 (preliminary data from EIA). This is TVA's new combined cycle unit at their John Sevier plant and use the first GE 7E turbines.
[5] Source: http://www.eia.gov/electricity/annual/html/epa_08_02.html .
[6] *Ibid*.
[7] For all of the other states, RECS groups three or more states together. These are generally states with lower population than states they examined individually or in pairs.
[8] In 2009, the installed stock of furnaces included a mix of old furnaces with AFUE below 80%, AFUE 80% units, and some condensing furnaces with AFUE of 90% and above. In some colder states the average in 2009 may have been above 80%. To the extent this occurs, our analysis is conservative as we will have underestimated the gas use of AFUE 80% furnaces, and by extension, also underestimated the gas use of condensing furnaces.
[9] Neither our furnace nor our heat pump analysis includes the electricity used to power the blower.
[10] Per EIA data. 5% in 2013, 6% average over previous decade. We use 5.5%. See http://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3 .
[11] 3-4% lost and unaccounted for. We assume 2% are losses and rest are unaccounted for. http://www.scientificamerican.com/article/how-much-natural-gas-leaks/ (mentions 3%); http://www.naruc.org/international/Documents/Technical_losses_in_natural_gas_transportation_distribution_storage_Paul_Metro.pdf (mentions 4%).

Energy Use Comparisons

Detailed tables from our analysis can be found in the Appendix. In particular, in Table A3 we provide the results of five comparisons:

1. Comparing an 80% AFUE furnace with an 8.2 HSPF heat pump (the current federal minimum standards).
2. Comparing a 95% AFUE furnace with a 8.5 HSPF heat pump (the current Energy Star levels)
3. Comparing a 95% and 97% AFUE furnace with a 9.6 HSPF heat pump (comparing current high-efficiency products).
4. Comparing a 95% AFUE furnace with an electric cold climate heat pump.
5. Comparing an electric cold climate heat pump with a gas-fired heat pump.

Below we provide graphical summaries of each of these analyses. Where the electric heat pump uses less energy the bar goes above the zero-line. Where the gas option uses less energy, the bar goes below the zero line. Please note that according to RECS 2009 the average US home uses about 90 million Btu per year for space heating. The differences shown here are generally much smaller and thus while there are energy and carbon savings at stake, at the individual household level, they are not dramatic and hence getting homeowner attention may be difficult.

Comment [mbh7]: This must be the heat to the space to which is then applied the efficiency

Comment [mbh8]: Small enough to be within the uncertainty?

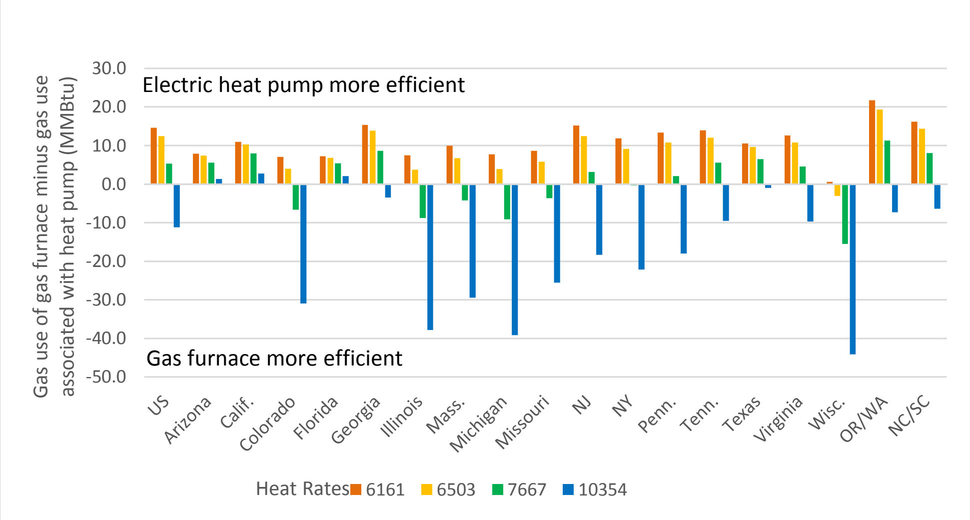

Figure 1. Comparison of an 80% AFUE furnace with an 8.2 HSPF electric heat pump.

Average HR for CA is 7260 for NG fired generation.

In 2023 HSPF at 8.8 and AFUE 80 – a paragraph concerning future efficiency would be good

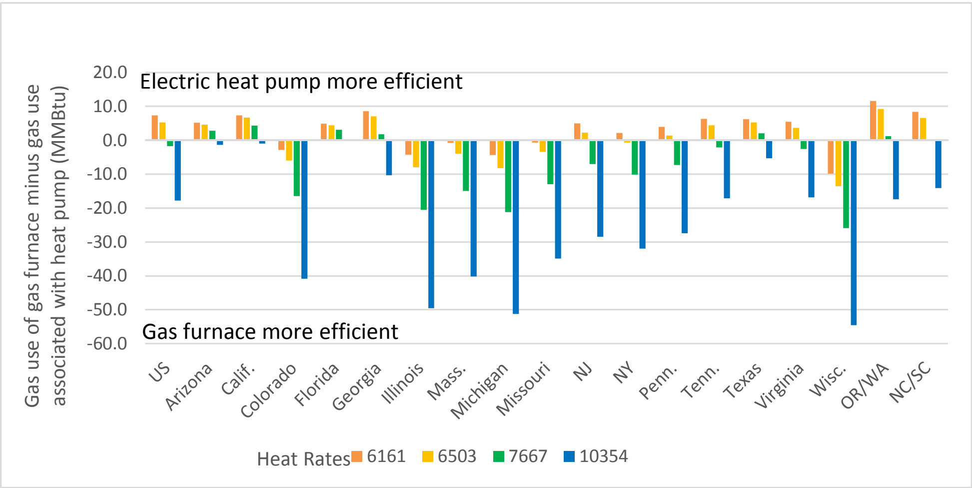

Figure 2. Comparison of a 95% AFUE furnace with a 8.5 HSPF electric heat pump.

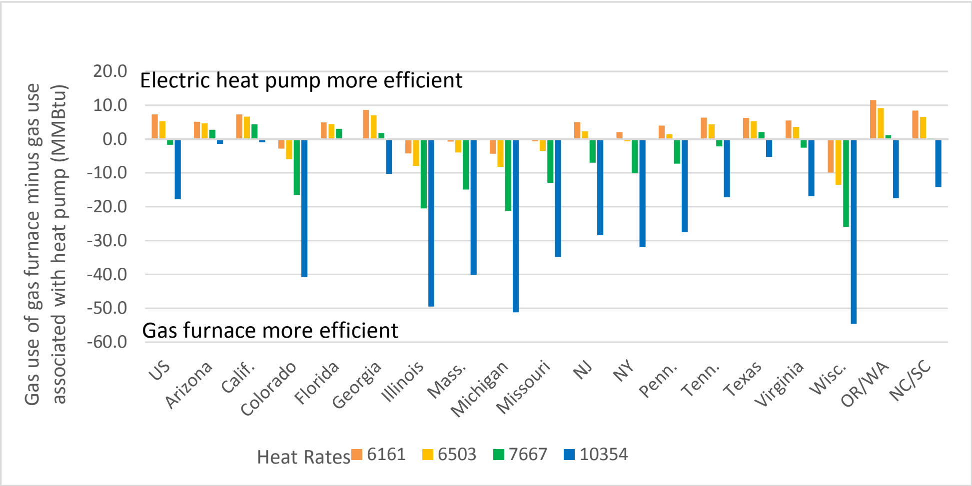

Figure 3. Comparison of a 95% AFUE furnace with a 9.6 HSPF electric heat pump.

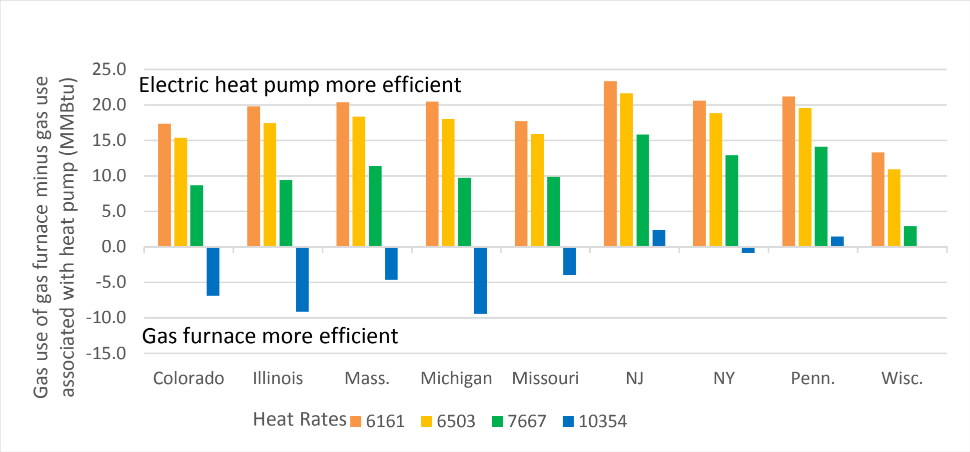

Figure 4. Comparison of a 95% AFUE furnace with a cold climate electric heat pump.[12]

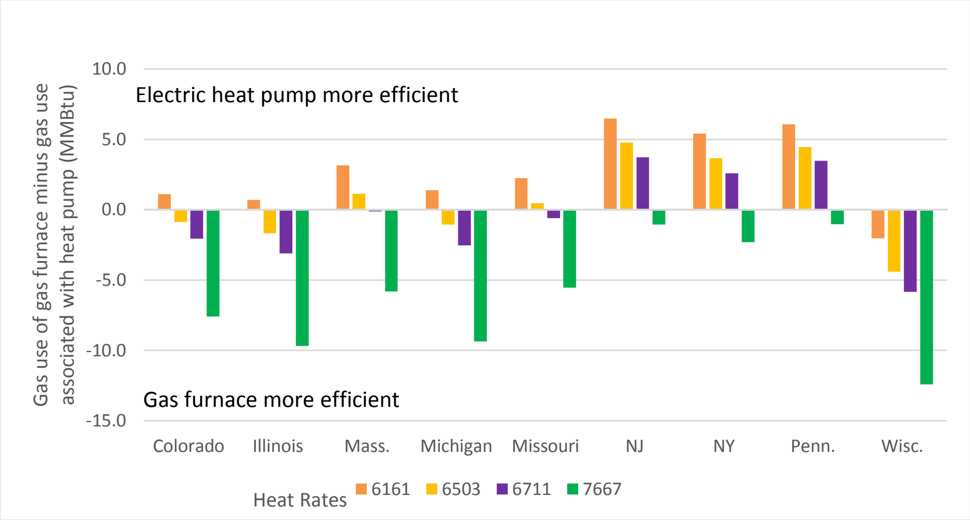

Figure 5. Comparison of gas heat pump with a cold climate electric heat pump.

Comment [mbh9]: Gas heat pump saves gas market share

Note: This analysis is highly approximate as the efficiency of the ~~electric~~gas heat pump data is based on a single field study in one city and extrapolated to other regions and the efficiency of the gas heat pump is based on modeling. Also, the design and average temperatures by state are approximate.

[12] For this comparison we show for 95% AFUE. As shown in Table A3 in the appendix, the results for 97% AFUE are very similar. For this graph and the next one we only looked at colder climates where the conventional heat pump did not do well from an energy-savings point of view.

Based on these comparisons, from an energy point of view:

- In warm states (Arizona, California and Florida) electric heat pumps use less energy on average, regardless of power plant heat rate. Georgia, New Jersey, Pennsylvania, Tennessee, Texas, Virginia, Oregon/Washington and the Carolinas join this list when power comes from a standard combined-cycle plant. And in Colorado, Illinois, Massachusetts, Michigan, Missouri, New York and Wisconsin, heat pumps use less energy than furnaces only when the highest-efficiency power plants (heat rates of ~6500 and lower) are used. These results are ~~pretty much the same~~similar for each of the conventional equipment comparisons, with only minor differences between the three comparisons (e.g. in the coldest states, relative to a 95% AFUE furnace, its takes a 6161 heat rate for an electric heat pump to outperform a gas furnace).

- Relative to a 95% AFUE furnace, the cold climate electric heat pump does well, using less energy at heat rates of 7700 and lower. But for all but the very lowest (best) power plant heat rate, the gas-fired heat pump does better than the cold climate electric heat pump. Data on cold climate electric heat pumps and gas heat pumps are limited, so these findings are subject to large uncertainty – more data are needed.

Economic Analysis

Next, we conducted a preliminary economic analysis from the homeowner point of view comparing the different options. For this analysis we used estimates of installed costs from the most recent US Department of Energy (DOE) Technical Support Documents for furnaces and residential central air conditioners and heat pumps. This analysis only looks at systems that are now widely available – there is presently not enough data to include cold-climate electric heat pumps and gas-fired heat pumps in the economic analysis. We looked at costs assuming that a house did not have central air conditioning but we also did a set of analyses for homes with central air conditioning and assuming a heat pump could be installed instead of a central air conditioner at the time the central air conditioner needs to be replaced. As of 2009, 61% of US homes had central air conditioning, including 35% in the northeast, 66% in the Midwest, 82% in the south and 44% in the west (EIA 2013).

Energy costs were based on average gas and electric costs by state in 2014 from EIA and then adjusted for the expected nationwide increase in energy costs during the operating life of this equipment. Specifically, based on EIA's 2015 Annual Energy Outlook (EIA 2015), we compared estimated residential gas and electric prices in 2025 and 2014 and applied this ratio to the state-specific energy prices from 2014. In some states energy costs vary by season, a factor not addressed in this simple preliminary analysis. We calculated the lifecycle cost for each system type and location assuming an 18-year equipment life and a 5% real discount rate. We then subtracted the lifecycle cost of the gas system from the lifecycle cost of the heat pump system to calculate the net lifecycle cost for each comparison. Further details of the analysis are presented in Table A4 in the appendix.

Based on our analysis, we find that heat pumps are more expensive than furnaces and electricity is generally more expensive per Btu than natural gas, so for all of the comparisons, the furnace has a lower life-cycle cost for homes without central air conditioning. But if a central air conditioner can be replaced with a heat pump, the high-

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Comment [mbh10]: This is the case when TDV metric but Title 24 does not compare HP to Furnace energy use.

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Comment [mbh11]: Supports ET project for NG HP

Comment [mbh12]: The low % of AC in coastal zones moves average down based on population distribution.

Comment [mbh13]: Also PG&E has a tiered rate structure which is masked by averages.

Comment [mbh14]: Break into at least 2 sentences.

efficiency heat pump has lower life-cycle costs in climates from Virginia on south as well as in the northwest. This latter analysis includes cooling energy savings from replacing a central air conditioner meeting federal minimum efficiency standards (SEER 13 in the north, SEER 14 in the south) with a higher efficiency heat pump. This analysis is shown in Figure 6 below.

Comment [mbh15]: This is confusing. In addition, it is often the case that when a furnace is replaced the AC system is also replaced. I do not know of a market study to establish the frequency of full system replacement but it is not "0".
My review of Figure 6 leaves me concerned the inclusion of AC savings for HPs makes mild winter states have lower LCC for HP.
A fair comparison would be to have both the AC and Furnace cases include cooling savings and costs in mild states thereby not making cooling an issue.

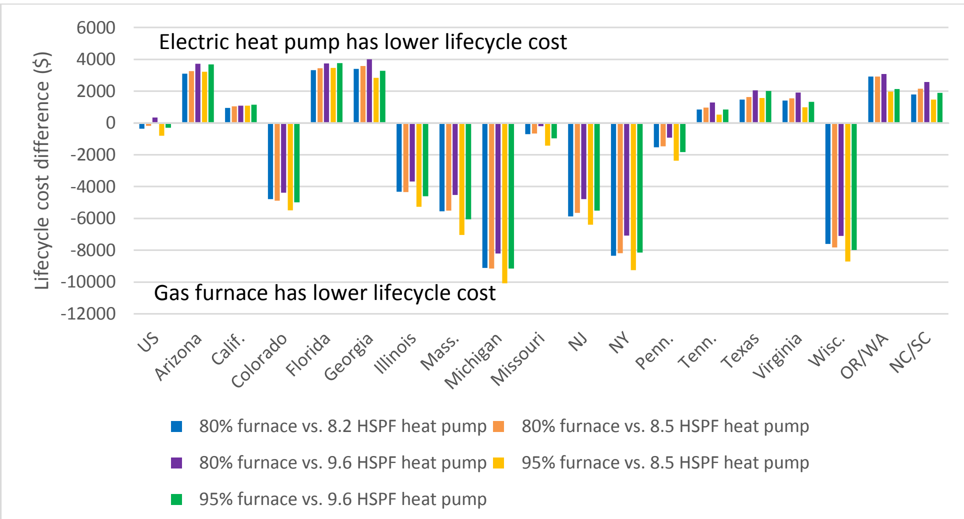

Figure 6. Lifecycle cost comparison of several furnaces and heat pumps in cases where a heat pump can replace a central air conditioner.

Thus, from an economic point of view, gas furnaces have lower life-cycle costs for space heating only. But if a home has central air conditioning, replacing the air conditioner with a heat pump can reduce life-cycle costs from about Virginia on south, and in the northwest. However, where heat pumps are less expensive on a lifecycle cost basis than gas furnaces, the lifecycle-cost savings are typically $1000-3000, which works out to about $55-$165 per year. These savings are modest and may not influence many homeowners unless there is a significant program or policy push.

Comment [mbh16]: Because the low SEER AC is not replaced with the furnace. Not a fair comparison.

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A Briefer Note on Water Heating

Thus far, all of the discussion has been on space heating. But since water heating is also a significant home energy use, we also prepared a single national comparison of gas and electric water heaters from an energy and economic point of view. For this analysis, as with the space heating analysis, we began with average natural gas use for water heating from the 2009 RECS – national average of 21.1 million Btu per year (EIA 2013). We then analyzed an heat pump water heater and a condensing gas water heater that would provide the same amount of hot water as a non-condensing gas water, assuming the average gas water heater in 2009 had an Energy Factor (EF) of 0.54 (the old federal standard), a new non-condensing gas water heater would have an EF of .62 (the new federal standard), a new condensing gas water heater would have an EF of .77 (from Lekov et al. 2011) and the heat pump water

Comment [mbh17]: 211 therms

Comment [mbh18]: A non-condensing tankless water heater would be a better comparison.

heater has an EF of 1.92.[13] The heat pump water heater uses 2712 kWh per year. Adding in the same allowances for gas and electric distribution losses as discussed above for space heating, and assuming the electricity to operate the heat pump comes from a natural gas-fired power plant, the electric heat pump uses less energy than the new non-condensing gas water heater at heat rates of about 6500 and below (i.e., for new high-efficiency combined cycle plants) but the condensing gas water heater uses less gas than the heat pump, even if the electricity comes from the best combined cycle power plant now offered for sale. Details of this analysis can be found in Table A5 in the appendix.

Comment [mbh19]: Supports the push for higher efficiency gas DHW.

We also examined the economics of this conversion, using estimated national average electricity and natural gas prices for 2025 from EIA (2015) and installed costs for gas and electric water heaters from the most recent DOE analysis (Lekov et al. 2011). These costs assume there is already electric and gas service in the home. Under these assumptions, we found that the non-condensing gas water heater is less expensive to install (by about $400) and operate (about $140 less per year). As a result, the non-condensing gas water heater is about $1700 less expensive to purchase and operate over the life of the water heater (net present value, assuming a 5% real discount rate). The condensing gas water heater has the lowest operating costs of all three systems but is the most expensive to install. Overall, the condensing gas water heater has lifecycle costs about $275 more than the non-condensing gas water heater but about $1400 less than the heat pump water heater. Again, details can be found in Table A5 in the appendix.

Comment [mbh20]: Are all of these storage types?

This is a national analysis based on many assumptions -- local and household specifics may be different and all assumptions are subject to substantial uncertainty. For example, not~~n~~ all houses can install heat pump water heaters and the economics of both heat pump water heaters and condensing gas water heaters tends to be better for households with above-average hot water use. Still, this illustrative analysis tends to show that where there is gas service in a home, switching to an electric heat pump water heater is unlikely to make sense given current system costs and projected energy prices.

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Comment [mbh21]: Agrees with the DUNG report by the NWPPC – the Council.

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Conclusions

Which is better from an energy and economic point of view – a natural gas furnace or an electric heat pump? The answer is that "it depends" – varying by state (due to differences in climate, building stock and energy prices), furnace and heat pump efficiency, and power plant heat rate. This analysis tends to show that electric heat pumps use less energy in warm states and have moderately positive economics in these states if a heat pump can replace both the furnace and a central air conditioner. Moderately cold states (as far north as Pennsylvania and Massachusetts) can save energy if electricity comes from the highest efficiency power plants, but from an economic point of view, life-cycle costs for furnaces will be lower than for heat pumps in these moderately-cold states. For cold states, further development of cold-temperature electric heat pumps and gas-fired heat pumps will be useful from an energy point of view. We did not have enough data to analyze the

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[13] Easley and Domitrovic 2015. Results of an EPRI field test in New York State. A 2012 EPRI field study in a variety of climates found lower seasonal EF's (Bush 2012).

economics of these new technologies. Likewise, heat pump water heaters can save energy relative to non-condensing gas water heaters if power comes from efficient natural gas combined cycle power plants, but the economics of conversions are not good.

In terms of next steps, we have three recommendations:

1. Further analysis would be useful, particularly at the state-level using more specific data on different categories of customers. Our analysis is based on state averages and a more nuanced analysis will more clearly identify ~~winners and losers~~cost effectiveness by climate zone.

Comment [mbh22]: This is more neutral. Modify as needed.

2. Continued work to develop good cold-climate electric air-source heat pumps and gas-fired heat pumps. In locations without natural gas service the preferred option can be heat pumps especially if performance continues to improve. There are good cold climate *ductless* heat pumps available, but currently there are very few systems designed for use with ducts.[14] For both cold-climate and gas-fired heat pumps, work is needed to examine system economics – these systems save energy, but will probably only make economic sense if the cost is not too much higher than current electric heat pumps.

3. The case for converting gas furnaces to electric heat pumps is strongest in warm states, where use of air conditioning is routine, and a heat pump can be purchased for only moderate additional cost relative to a central air conditioner. In these states, it might be useful to consider programs to encourage use of heat pumps, starting with further localized analysis, and perhaps proceeding to pilot programs.

Comment [mbh23]: This paper focuses on existing dwellings. For new construction the economics change. If the cost of bringing gas to the subdivision and the dwelling is included, the LCC will be very different.

References

Comment [mbh24]: Add the DUNG report which Tom Eckman mentioned at the last ASAP steering committee meeting.

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[14] For a list of current systems, see http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump .

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Appendix

Table A1. Analysis of Furnaces and Conventional Heat Pumps

Furnace	US	Arizona	Calif.	Colorado	Florida	Georgia	Illinois	Mass.	Michigan	Missouri	NJ	NY	Penn.	Tenn.	Texas	Virginia	Wisc.	OR/WA	NC/SC
Avg. annual mBtu for a natural gas furnace	51.4	17.1	22.6	61.6	14.4	42.3	72.5	66.5	75.0	57.7	63.0	60.7	58.4	47.5	27.0	44.5	64.9	63.1	48.3
Add gas system distribution losses	52.4	17.4	23.1	62.8	14.7	43.1	74.0	67.8	76.5	58.9	64.3	61.9	59.6	48.5	27.5	45.4	66.2	64.4	49.3
Estimated mBtu for a 95% AFUE furnace	43.3	14.4	19.0	51.9	12.1	35.6	61.1	56.0	63.2	48.6	53.1	51.1	49.2	40.0	22.7	37.5	54.7	53.1	40.7
Add gas system distribution losses	44.1	14.7	19.4	52.9	12.4	36.3	62.3	57.1	64.4	49.6	54.1	52.1	50.2	40.8	23.2	38.2	55.7	54.2	41.5
Estimated mBtu for a 97% AFUE furnace	42.4	14.1	18.6	50.8	11.9	34.9	59.8	54.8	61.9	47.6	52.0	50.1	48.2	39.2	22.3	36.7	53.5	52.0	39.8
Add gas system distribution losses	43.2	14.4	19.0	51.8	12.1	35.6	61.0	55.9	63.1	48.5	53.0	51.1	49.1	40.0	22.7	37.4	54.6	53.1	40.6
Heat pump																			
99% winter design temperature	18	37	40	3	42	26	2	6	2	6	14	10	13	19	29	18	-6	24	23
HSPF adjment factor for a HSPF 8.2 unit	0.1391	-0.1339	-0.1841	0.2998	-0.2186	0.0336	0.3088	0.2715	0.3088	0.2715	0.1867	0.2308	0.1980	0.1266	-0.0095	0.1391	0.3731	0.0613	0.0748
Adjusted HSPF for a nominal 8.2 unit	7.06	9.30	9.71	5.74	9.99	7.92	5.67	5.97	5.67	5.97	6.67	6.31	6.58	7.16	8.28	7.06	5.14	7.70	7.59
kWh per year with an HSPF 8.2 unit	5825	1471	1862	8583	1153	4270	10233	8906	10586	7728	7557	7699	7104	5306	2609	5043	10099	6558	5093
Add electric system distribution losses	6145	1552	1965	9055	1216	4505	10796	9396	11168	8153	7973	8122	7495	5598	2753	5320	10655	6918	5373
mBtu gas consumed as a function of heat rate																			
6161	37.9	9.6	12.1	55.8	7.5	27.8	66.5	57.9	68.8	50.2	49.1	50.0	46.2	34.5	17.0	32.8	65.6	42.6	33.1
6503	40.0	10.1	12.8	58.9	7.9	29.3	70.2	61.1	72.6	53.0	51.8	52.8	48.7	36.4	17.9	34.6	69.3	45.0	34.9
6711	41.2	10.4	13.2	60.8	8.2	30.2	72.5	63.1	75.0	54.7	53.5	54.5	50.3	37.6	18.5	35.7	71.5	46.4	36.1
7667	47.1	11.9	15.1	69.4	9.3	34.5	82.8	72.0	85.6	62.5	61.1	62.3	57.5	42.9	21.1	40.8	81.7	53.0	41.2
10354	63.6	16.1	20.3	93.8	12.6	46.6	111.8	97.3	115.6	84.4	82.5	84.1	77.6	58.0	28.5	55.1	110.3	71.6	55.6
HSPF adjment factor for a HSPF 8.5 unit	0.1467	-0.1422	-0.1954	0.3159	-0.2320	0.0352	0.3254	0.2862	0.3254	0.2862	0.1969	0.2434	0.2089	0.1335	-0.0104	0.1467	0.3926	0.0644	0.0787
Adjusted HSPF for a nominal 8.5 unit	7.25	9.71	10.16	5.81	10.47	8.20	5.73	6.07	5.73	6.07	6.83	6.43	6.72	7.36	8.59	7.25	5.16	7.95	7.83
kWh per year with an HSPF 8.5 unit	5669	1409	1779	8475	1100	4126	10114	8769	10463	7608	7383	7551	6947	5160	2515	4908	10056	6348	4934
Add electric system distribution losses	5981	1487	1877	8941	1161	4353	10671	9251	11039	8027	7789	7966	7330	5443	2653	5178	10609	6697	5206
mBtu gas consumed as a function of heat rate																			
6161	36.8	9.2	11.6	55.1	7.1	26.8	65.7	57.0	68.0	49.4	48.0	49.1	45.2	33.5	16.3	31.9	65.4	41.3	32.1
6503	38.9	9.7	12.2	58.1	7.5	28.3	69.4	60.2	71.8	52.2	50.7	51.8	47.7	35.4	17.3	33.7	69.0	43.6	33.9
6711	40.1	10.0	12.6	60.0	7.8	29.2	71.6	62.1	74.1	53.9	52.3	53.5	49.2	36.5	17.8	34.7	71.2	44.9	34.9
7667	45.9	11.4	14.4	68.6	8.9	33.4	81.8	70.9	84.6	61.5	59.7	61.1	56.2	41.7	20.3	39.7	81.3	51.3	39.9
10354	61.9	15.4	19.4	92.6	12.0	45.1	110.5	95.8	114.3	83.1	80.6	82.5	75.9	56.4	27.5	53.6	109.8	69.3	53.9
HSPF adjment factor for a HSPF 9.6 unit	0.1777	-0.1112	-0.1644	0.3469	-0.2011	0.0662	0.3563	0.3172	0.3563	0.3172	0.2279	0.2744	0.2398	0.1645	0.0206	0.1777	0.4236	0.0954	0.1097
Adjusted HSPF for a nominal 9.6 unit	7.89	10.67	11.18	6.27	11.53	8.96	6.18	6.55	6.18	6.55	7.41	6.97	7.30	8.02	9.40	7.89	5.53	8.68	8.55
kWh per year with an HSPF 9.6 unit	5209	1282	1617	7860	999	3775	9387	8116	9710	7042	6799	6971	6402	4738	2297	4509	9382	5813	4521
Add electric system distribution losses	5495	1353	1706	8292	1054	3982	9903	8563	10244	7429	7173	7354	6754	4998	2424	4758	9898	6133	4770
mBtu gas consumed as a function of heat rate																			
5550	30.5	7.5	9.5	46.0	5.9	22.1	55.0	47.5	56.9	41.2	39.8	40.8	37.5	27.7	13.5	26.4	54.9	34.0	26.5
6503	35.7	8.8	11.1	53.9	6.9	25.9	64.4	55.7	66.6	48.3	46.6	47.8	43.9	32.5	15.8	30.9	64.4	39.9	31.0
6711	36.9	9.1	11.5	55.6	7.1	26.7	66.5	57.5	68.7	49.9	48.1	49.4	45.3	33.5	16.3	31.9	66.4	41.2	32.0
7667	42.1	10.4	13.1	63.6	8.1	30.5	75.9	65.6	78.5	57.0	55.0	56.4	51.8	38.3	18.6	36.5	75.9	47.0	36.6
10354	56.9	14.0	17.7	85.9	10.9	41.2	102.5	88.7	106.1	76.9	74.3	76.1	69.9	51.8	25.1	49.3	102.5	63.5	49.4

Notes for Table A1:

- Gas use by state if for homes with gas space heating, as provided in the 2009 RECS (EIA 2013).
- To estimate total gas use we add 2% distribution losses (discussed in text).
- Gas use for 95% and 97% AFUE furnaces estimated by taking gas use for 80% AFUE and multiplying by 80/95 or 80/97.
- Heat pump seasonal efficiency for 8.2 HSPF units estimated with the following formula from Fairey et al. 2004:
    - Seasonal HSPF = 8.2 * (1 – adjustment factor)
    - Adjustment factor = 0.1392 - 0.00846*Design T - 0.0001074*(Design T)^2+0.0228*8.2
    - Design T is the 99% design temperature and is based on representative values for each state as shown in Table A1.
- Heat pump seasonal efficiency for 8.5 and 9.6 HSPF units are based on a slightly different adjustment factor from Fairey et al. 2004. For 8.5 HSPF:
    - Adjustment factor = 0.1041 - 0.008862*Design T - 0.0001153*(Design T)^2+0.02817*8.5
- To heat pump electricity use we add 5.5% for distribution system losses as explained in the text.
- Natural gas use to supply this electricity is based on a power plant heat rate of 6161, 6503, 6711, 7667 or 10,354 Btu/kWh as explained in the text.

Comment [mbh25]: 40 for CA is high making the kWh low

Table A2. Illustrative Analyses for Cold Climate Air-Source Heat Pumps and Gas-Fired Heat Pumps (only analyzed cold states)

	US	Arizona	Calif.	Colorado	Florida	Georgia	Illinois	Mass.	Michigan	Missouri	NJ	NY	Penn.	Tenn.	Texas	Virginia	Wisc.	OR/WA	NC/SC
Cold climate heat pump																			
Seasonal HSPF				9.00			8.87	9.41	8.87	9.41	10.64	10.00	10.48				7.95		
kWh per year with a cold-climate heat pump				5474			6537	5652	6762	4904	4735	4855	4458				6534		
Add electric system distribution losses				5775			6896	5963	7134	5174	4995	5122	4704				6893		
mBtu gas consumed as a function of heat rate																			
6161				35.6			42.5	36.7	43.9	31.9	30.8	31.6	29.0				42.5		
6503				37.6			44.8	38.8	46.4	33.6	32.5	33.3	30.6				44.8		
6711				38.8			46.3	40.0	47.9	34.7	33.5	34.4	31.6				46.3		
7667				44.3			52.9	45.7	54.7	39.7	38.3	39.3	36.1				52.8		
10354				59.8			71.4	61.7	73.9	53.6	51.7	53.0	48.7				71.4		
Gas-fired heat pump																			
Average winter temperature				34			35	31	30	37	38	26	31				17		
Average COP				1.37			1.37	1.36	1.35	1.38	1.38	1.34	1.36				1.31		
Avg. annual mBtu for a gas-fired heat pump				36.0			42.3	39.1	44.4	33.4	36.5	36.2	34.4				39.6		
Add gas system distribution losses				36.7			43.2	39.9	45.3	34.1	37.3	37.0	35.0				40.4		

Notes:

- We conducted an illustrative analysis for cold-climate air-source heat pumps based on a study for DOE that tested one unit and found a seasonal COP of about 2.8 in New Haven, CT over 2 heating seasons (Johnson 2013). 2.8 COP * 3.412 = 9.55 HSPF. New Haven has a 99% design temp of 7 F, and so a 9.6 HSPF unit there would have a 6.65 adjusted HSPF. Thus the cold T unit is 43.6% higher. We use this factor for each city as an order of magnitude estimate. The DOE field study looked at a Hallowell International Acadia cold climate heat pump, a product no longer available since the manufacturer went out of business. Mitsubishi produces cold climate heat pumps, most of which are ducted but a few can be used in ducted applications -- http://www.mitsubishicomfort.com/sites/default/files/manual/m-series_hyper-heat_brochure.pdf?fid=1010 . Can be linked to an indoor air handler -- http://www.mitsubishicomfort.com/press/press-releases/mvz-multi-position-air-handler-rounds-out-diamond-comfort-systemtm-for-efficient-whole-home-cooling-heating .
- We also conducted an illustrative analysis for gas-fired heat pumps based on Gas Technology Institute (GTI) projections for a research project they have with AO Smith. See Garrabrant (2014). They estimate seasonal COP based on average winter temperature. For each state we used a simple average of monthly temperatures for Nov-March from http://www.weatherbase.com/weather/state.php3?c=US .

Table A3. Furnace and Heat Pump Comparisons by State.

Difference in natural gas use (units are million Btu). In these comparisons, boxes shaded yellow are where gas uses less energy, while unshaded boxes show where electric heat pumps use less energy.

	US	Arizona	Calif.	Colorado	Florida	Georgia	Illinois	Mass.	Michigan	Missouri	NJ	NY	Penn.	Tenn.	Texas	Virginia	Wisc.	OR/WA	NC/SC
80% furnace vs 8.2 HSPF heat pump																			
6161	14.6	7.9	10.9	7.0	7.2	15.4	7.4	9.9	7.7	8.6	15.1	11.9	13.4	14.0	10.6	12.6	0.6	21.7	16.2
6503	12.5	7.3	10.3	3.9	6.8	13.8	3.7	6.7	3.9	5.8	12.4	9.1	10.8	12.0	9.6	10.8	-3.1	19.4	14.3
7667	5.3	5.5	8.0	-6.6	5.4	8.6	-8.8	-4.2	-9.1	-3.7	3.1	-0.4	2.1	5.5	6.4	4.6	-15.5	11.3	8.1
10354	-11.2	1.4	2.7	-30.9	2.1	-3.5	-37.8	-29.5	-39.1	-25.6	-18.3	-22.2	-18.0	-9.5	-1.0	-9.7	-44.1	-7.3	-6.4
	US	Arizona	Calif.	Colorado	Florida	Georgia	Illinois	Mass.	Michigan	Missouri	NJ	NY	Penn.	Tenn.	Texas	Virginia	Wisc.	OR/WA	NC/SC
95% furnace vs 8.5 HSPF heat pump																			
6161	7.3	5.1	7.3	-2.9	4.9	8.6	-4.2	-0.8	-4.4	-0.7	5.0	2.1	4.0	6.3	6.2	5.4	-9.9	11.6	8.4
6503	5.3	4.6	6.6	-6.0	4.5	7.0	-7.9	-4.0	-8.2	-3.5	2.3	-0.7	1.4	4.4	5.3	3.6	-13.5	9.2	6.5
7667	-1.7	2.8	4.4	-16.5	3.0	1.8	-20.5	-14.9	-21.2	-12.9	-7.0	-10.1	-7.3	-2.1	2.1	-2.6	-25.9	1.2	0.3
10354	-17.8	-1.4	-0.9	-40.8	-0.2	-10.3	-49.5	-40.2	-51.2	-34.9	-28.4	-32.0	-27.4	-17.2	-5.3	-16.9	-54.6	-17.4	-14.1
95% furnace vs 9.6 HSPF heat pump																			
6161	13.7	7.2	9.9	6.9	6.5	14.2	7.3	9.6	7.6	8.3	14.3	11.3	12.7	13.1	9.7	11.8	0.8	20.2	15.0
6503	8.4	5.9	8.3	-1.0	5.5	10.4	-2.1	1.4	-2.2	1.2	7.5	4.3	6.2	8.3	7.4	7.3	-8.6	14.3	10.5
7667	2.0	4.3	6.3	-10.7	4.3	5.8	-13.7	-8.5	-14.1	-7.4	-0.9	-4.2	-1.6	2.5	4.6	1.7	-20.1	7.2	4.9
10354	-12.7	0.7	1.7	-32.9	1.5	-4.9	-40.3	-31.5	-41.6	-27.4	-20.2	-24.0	-19.8	-11.0	-1.9	-11.0	-46.7	-9.3	-7.9
97% furnace vs 9.6 HSPF heat pump																			
6161	12.7	6.9	9.5	5.8	6.3	13.5	6.0	8.4	6.2	7.3	13.2	10.2	11.6	12.2	9.3	11.0	-0.3	19.0	14.2
6503	7.5	5.6	7.9	-2.1	5.3	9.7	-3.4	0.3	-3.5	0.2	6.4	3.2	5.2	7.5	7.0	6.5	-9.8	13.2	9.6
7667	1.1	4.0	5.9	-11.8	4.0	5.1	-14.9	-9.7	-15.4	-8.4	-2.0	-5.3	-2.7	1.6	4.1	1.0	-21.3	6.1	4.1
10354	-13.7	0.4	1.3	-34.0	1.2	-5.6	-41.5	-32.7	-43.0	-28.4	-21.3	-25.1	-20.8	-11.8	-2.4	-11.8	-47.9	-10.4	-8.8
	US	Arizona	Calif.	Colorado	Florida	Georgia	Illinois	Mass.	Michigan	Missouri	NJ	NY	Penn.	Tenn.	Texas	Virginia	Wisc.	OR/WA	NC/SC
95% furnace vs cold climate heat pump (tentative and illustrative)																			
6161				17.3			19.8	20.4	20.5	17.7	23.3	20.6	21.2				13.3		
6503				15.4			17.4	18.3	18.0	15.9	21.6	18.8	19.6				10.9		
7667				8.6			9.4	11.4	9.7	9.9	15.8	12.9	14.1				2.9		
10354				-6.9			-9.1	-4.6	-9.4	-4.0	2.4	-0.9	1.5						
	US	Arizona	Calif.	Colorado	Florida	Georgia	Illinois	Mass.	Michigan	Missouri	NJ	NY	Penn.	Tenn.	Texas	Virginia	Wisc.	OR/WA	NC/SC
Gas-fired heat pump vs. cold-climate electric (tentative and illustrative)																			
6161				1.1			0.7	3.2	1.4	2.2	6.5	5.4	6.1				-2.0		
6503				-0.9			-1.7	1.1	-1.1	0.5	4.8	3.7	4.5				-4.4		
6711				-2.1			-3.1	-0.1	-2.5	-0.6	3.7	2.6	3.5				-5.8		
7667				-7.6			-9.7	-5.8	-9.4	-5.5	-1.0	-2.3	-1.0				-12.4		
10354				-23.1			-28.2	-21.8	-28.5	-19.5	-14.5	-16.1	-13.7				-30.9		

Table A4. Economic Analysis for Space Conditioning.

	US	Arizona	Calif.	Colorado	Florida	Georgia	Illinois	Mass.	Michigan	Missouri	NJ	NY	Penn.	Tenn.	Texas	Virginia	Wisc.	OR/WA	NC/SC
2014 gas rate	10.97	17.20	11.51	8.89	19.02	14.45	9.59	14.50	9.33	10.83	9.69	12.54	11.77	10.13	11.16	12.07	10.52	11.16	12.27
2014 electric rate	0.125	0.120	0.163	0.122	0.120	0.116	0.114	0.174	0.145	0.106	0.158	0.201	0.133	0.103	0.118	0.112	0.139	0.096	0.117
2025 gas rate	13.28	20.82	13.93	10.76	23.03	17.49	11.61	17.55	11.30	13.11	11.73	15.18	14.25	12.26	13.51	14.61	12.74	13.50	14.85
2025 electric rate	0.141	0.135	0.184	0.138	0.135	0.131	0.129	0.197	0.164	0.120	0.179	0.227	0.151	0.117	0.134	0.127	0.157	0.108	0.132
Annual heating cost (2025 energy prices, 2013$)																			
80% furnace	683	356	315	663	332	740	842	1167	847	757	739	922	832	583	365	650	827	852	717
95% furnace	575	300	265	558	279	623	709	983	713	637	622	776	701	491	307	548	696	718	604
97% furnace	563	294	260	547	273	610	694	963	699	624	610	760	686	480	301	536	682	703	591
8.2 HP	823	199	343	1182	156	559	1320	1752	1736	925	1350	1745	1072	620	349	638	1586	711	673
8.5 HP	801	191	328	1167	149	540	1305	1725	1715	911	1319	1712	1048	603	336	621	1579	688	653
9.6 HP	736	174	298	1082	135	494	1211	1597	1592	843	1215	1580	966	553	307	571	1474	630	598
Purchase cost including installation (2013 $)																			
80% furnace	2218	2218	2218	2218	2218	2218	2218	2218	2218	2218	2218	2218	2218	2218	2218	2218	2218	2218	2218
95% furnace	2847	2847	2847	2847	2847	2847	2847	2847	2847	2847	2847	2847	2847	2847	2847	2847	2847	2847	2847
97% furnace	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975
8.2 HP	5242	5242	5242	5242	5242	5242	5242	5242	5242	5242	5242	5242	5242	5242	5242	5242	5242	5242	5242
8.5 HP	5393	5393	5393	5393	5393	5393	5393	5393	5393	5393	5393	5393	5393	5393	5393	5393	5393	5393	5393
9.6 HP	5969	5969	5969	5969	5969	5969	5969	5969	5969	5969	5969	5969	5969	5969	5969	5969	5969	5969	5969
SEER 14 central AC	4299	4299	4299	4299	4299	4299	4299	4299	4299	4299	4299	4299	4299	4299	4299	4299	4299	4299	4299
SEER 13 central AC	4115	4115	4115	4115	4115	4115	4115	4115	4115	4115	4115	4115	4115	4115	4115	4115	4115	4115	4115
Life-cycle cost (18 year life, 5% real discount rate)																			
80% furnace	10198	6380	5899	9968	6094	10868	12057	15864	12121	11061	10857	12990	11945	9027	6482	9819	11880	12179	10602
95% furnace	9567	6352	5947	9373	6111	10131	11133	14338	11186	10294	10122	11918	11039	8581	6438	9248	10984	11235	9907
97% furnace	9556	6408	6011	9367	6172	10109	11090	14230	11142	10269	10100	11859	10998	8591	6492	9244	10944	11191	9889
8.2 HP	14866	7572	9251	19060	7068	11772	20675	25725	25531	16059	21024	25646	17769	12487	9319	12701	23784	13554	13115
8.5 HP	14760	7624	9224	19037	7135	11703	20647	25560	25446	16043	20811	25404	17643	12438	9322	12652	23855	13439	13021
9.6 HP	14575	8000	9451	18623	7551	11742	20125	24635	24579	15826	20169	24443	17257	12438	9558	12639	23194	13337	12958
Life-cycle cost if heat pump replaces a central AC unit																			
8.2 HP	10567	3273	4952	14761	2769	7473	16376	21426	21232	11760	16725	21347	13470	8188	5020	8402	19485	9255	8816
8.5 HP	10461	3325	4925	14922	2836	7404	16532	21445	21331	11928	16696	21289	13528	8139	5023	8353	19740	9324	8722
9.6 HP	10276	3701	5152	14508	3252	7443	16010	20520	20464	11711	16054	20328	13142	8139	5259	8340	19079	9222	8659
Air conditioning																			
Avg kWh/year for central AC 2009	1980	5205	1288	503	4557	3056	1022	319	371	1797	1094	548	875	2295	4256	2290	296	557	2293
Avg kWh/year for central AC SEER 13	1523	4004	991	387	3505	2351	786	245	285	1382	842	422	673	1765	3274	1762	228	428	1764
Avg kWh/year for central AC SEER 14	1414	3718	920	359	3255	2183	730	228	265	1284	781	391	625	1639	3040	1636	211	398	1638
Avg kWh/year for central AC SEER 14.5	1366	3590	888	347	3143	2108	705	220	256	1239	754	378	603	1583	2935	1579	204	384	1581
Avg kWh/year for central AC SEER 17	1165	3062	758	296	2681	1798	601	188	218	1057	644	322	515	1350	2504	1347	174	328	1349
Additional LCC savings for cooling																			
HSPF 8.5/SEER 14.5	81	203	68	64	178	115	123	58	57	200	182	116	123	77	164	83	43	56	282
HSPF 9.6/SEER 17	412	1039	350	147	910	589	279	133	129	455	414	263	279	395	838	427	98	128	642
	US	Arizona	Calif.	Colorado	Florida	Georgia	Illinois	Mass.	Michigan	Missouri	NJ	NY	Penn.	Tenn.	Texas	Virginia	Wisc.	OR/WA	NC/SC
Comparisons with replacing central AC	(negative numbers mean gas has lower LCC; these cells are shaded in yellow)																		
80% furnace vs. 8.2 HSPF heat pump	-369	3108	947	-4793	3325	3395	-4319	-5562	-9111	-698	-5868	-8356	-1524	840	1463	1418	-7604	2924	1786
80% furnace vs. 8.5 HSPF heat pump	-182	3258	1042	-4890	3436	3579	-4352	-5522	-9154	-666	-5657	-8183	-1460	966	1623	1549	-7816	2911	2162
80% furnace vs. 9.6 HSPF heat pump	334	3719	1096	-4394	3751	4014	-3674	-4524	-8215	-195	-4783	-7075	-918	1283	2061	1906	-7101	3084	2584
95% furnace vs. 8.5 HSPF heat pump	-813	3230	1090	-5485	3453	2842	-5276	-7048	-10088	-1433	-6393	-9255	-2367	520	1578	978	-8713	1967	1467
95% furnace vs. 9.6 HSPF heat pump	-297	3690	1144	-4988	3768	3278	-4598	-6049	-9149	-962	-5518	-8147	-1825	837	2017	1335	-7997	2141	1890

Notes for Table A4:

- Electricity costs are from the Feb. 2015 EIA Electricity Monthly -- http://www.eia.gov/electricity/monthly/current_year/february2015.pdf . Natural gas costs from http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm .
- 2025 costs estimated from 2014 costs by state and projected national costs for 2025 and 2014 as explained in the text.
- The installed cost of different systems comes from DOE Technical Support Documents as follows:
  - For furnaces, costs from DOE Feb. 2015 TSD (http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0031-0027), p. 8-16. For 97% AFUE we interpolated the cost of a 97% AFUE unit from the 95% and 98% costs in the DOE TSD.
  - For heat pumps, costs from DOE August, 2015 TSD (http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0029), p. 8-33. We used the baseline for 8.2 HSPF, TSL 2 for 8.5 HSPF, and TSL 7 for 9.6 HSPF. For central air conditioners, we used the current minimum standard – SEER 13 in the north and SEER 14 in the south. For the US we use SEER 14 as this applies to majority of AC sales. Costs come from p. 8-32 in the DOE August, 2015 TSD (baseline for SEER 13, TSL 3 for SEER 14).
- Average kWh per year for air conditioning comes from the 2009 RECS (EIA 2013). We assume these data are for SEER 10 units and adjusted consumption downward based on the SEER of the new unit (SEER 13 for a basic new unit in the north, SEER 14 for a basic new unit in the south, SEER 14.5 for the HSPF 8.5 heat pump [both are Energy Star levels] and 17 for the HSPF 9.6 unit [based on slide 29 in DOE Oct. 26/27, 2015 presentation to CAC and HP ASRAC Working Group[15]]).

Comment [mbh26]: The $0.12 kwh is too low. We need to get the file and run some analysis.

[15] This can be found at: http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0052 .

Table A5. National-Level Comparison of Gas and Electric Heat Pump Water Heaters.

Average gas water heater	21.1	mmBtu; from 2009 RECS (EIA 2013)
For unit with EF .62	18.3	mmBtu
With 2% distribution losses	18.7	mmBtu
For unit with EF .77	14.8	
	15.1	
Electric HPWH equivalent	2712	kWh
With 5.5% distribution losses	2861	
HPWH gas use by heat rate:		
6161	17.6	
6503	18.6	
7667	21.9	
10354	29.6	
Breakeven heat rate	6540	(same energy used as for EF .62 + losses)
	5266	(same energy used as for EF .77 + losses)
2025 prices, US		From EIA 2015
Gas	13.28	per mmBtu
Electric	0.141	per kWh
Average annual operating costs		
Gas (.62 EF)	244	
Gas (.77 EF)	196	
Electric (2.0 EF)	382	
Difference	139	For EF .62
	186	For EF .77
Installed cost		From Lekov et al. 2011
Gas (.62 EF)	1171	
Gas (.77 EF)	1893	
Electric (2.0 EF)	1574	
Difference	403	For EF .62
	-319	For EF .77
Life-cycle cost		
Gas (.62 EF)	$3,460	
Gas (.77 EF)	$3,736	
Electric (2.0 EF)	$5,166	
Difference	$1,706	For EF .62
	$1,430	For EF .77

Council Policy Statement

The Council recognizes that there are applications in which it is more energy efficient to use natural gas directly than to generate electricity from natural gas and then use the electricity in the end-use application. The Council also recognizes that in many cases the direct use of natural gas can be more economically efficient. These potentially cost-effective reductions in electricity use, while not defined as conservation in the sense the Council uses the term, are nevertheless alternatives to be considered in planning for future electricity requirements.

The changing nature of energy markets, the substantial benefits that can accrue from healthy competition among natural gas, electricity and other fuels, and the desire to preserve individual energy source choices all support the Council taking a market-oriented approach to encouraging efficient fuel decisions in the region.

PG&E Assessment using Current Residential Rates

Efficiency		$/MMBtu to the space
AFUE	80	$ 32.69
AFUE	92	$ 28.43
AFUE	95	$ 27.53
HSPF	8.2	$ 47.72
HSPF	8.5	$ 46.03
HSPF	8.6	$ 45.50
HSPF	9.6	$ 40.76
$/Therm Tier 2		1.83057
$/kWh Tier 2		0.27389

Direct Use of Natural Gas:
Economic Fuel Choices from the Regional Power System and Consumer's Perspective

Council document 2012-01

Background

Is it better to use natural gas directly in water heaters and furnaces or to generate electricity for electrical space and water heating systems that provide these services? The Council has deliberated on this question since its inception. Over the years, the Council has performed several studies and issued papers addressing the issue. The topic has gone under different names; total-energy efficiency, fuel switching, direct use of gas, and others.

The natural gas companies brought suit against the Council after the First Power Plan, one among the few law suits the Council has faced. The concern was that by providing incentives for improved electricity efficiency the Council would disadvantage natural gas companies and encourage more use of electricity. Over time the concerns have morphed into arguments that direct use of natural gas is more efficient and more benign for the environment.

In 1994, the Council analyzed the economic efficiency of converting existing residential electric space and water heating systems to gas systems.[1] That study showed there were many cost-effective fuel-switching opportunities within the Region, representing a potential savings of over 730 average megawatts. However, the Council has not included programs in its power plans to encourage the direct use of natural gas. The Council has not promoted conversion of electric space and water heat equipment to natural gas equipment.

The Council's prior analysis indicated that intervention was not necessary because fuel choice markets were working well. That is, regional customers appeared to be making appropriate choices and conversions without intervention. We do not have more recent data on fuel conversion activity, but data on overall fuel shares gives some indication of consumers' choices over longer periods of time for both new construction and conversions. Consider, for example, the substantial electricity price increases in the early 1980s. The electric space heating share stopped growing in the region while the natural gas space heat share in existing homes increased from 26 to 37 percent. Although data is limited, fuel conversion of existing houses to natural gas has been an active market as well, often promoted by dual fuel utilities.

The Council's findings and policy on this issue have been very consistent. Analysis has found that direct use of natural gas is often more thermodynamically efficient than using electricity generated from natural gas. However, economic efficiency is the Council's primary measure of merit.

[1] Northwest Power Planning Council. "Direct Use of Natural Gas: Analysis and Policy Options". Issue Paper 94-41. Portland, OR. August 11, 1994.

Economic efficiency depends on the specific situation regarding natural gas and electricity prices, home size and energy use, cost of heating equipment and ductwork, and other factors. The Council has found that fuel switching is not conservation under the Northwest Power Act, which defines conservation as the "more efficient use of electricity". Further, the Council also has determined that fuel choice markets are reasonably competitive and that those markets should be allowed to work without interference.

Thus, the current Council policy, which has been reaffirmed several times, is:

Council Policy Statement

The Council recognizes that there are applications in which it is more energy efficient to use natural gas directly than to generate electricity from natural gas and then use the electricity in the end-use application. The Council also recognizes that in many cases the direct use of natural gas can be more economically efficient. These potentially cost-effective reductions in electricity use, while not defined as conservation in the sense the Council uses the term, are nevertheless alternatives to be considered in planning for future electricity requirements.

The changing nature of energy markets, the substantial benefits that can accrue from healthy competition among natural gas, electricity and other fuels, and the desire to preserve individual energy source choices all support the Council taking a market-oriented approach to encouraging efficient fuel decisions in the region.

In light of changing technologies and energy prices and of growing climate concerns, in 2008 the Council was again asked to look at the direct use of natural gas issue. The analysis is called for in the Action Plan (ANLYS-16) of the Sixth Power Plan. This paper describes the analysis and findings and provides recommendations regarding the Council's existing policies.

Scope and Structure of Analysis

With the financial support and cooperation of the Northwest Gas Association and Puget Sound Energy, the Council has updated its economic analyses. The Council's Regional Technical Forum oversaw the study and its scope. The study examines fuel conversion for residential space and water heating equipment in existing homes where conversion is feasible. The Council's goal for this analysis was to recreate its 1994 study with up-to-date information. The scope of the analysis was expanded to test the cost, risk, and carbon-emission impact of conversions. Unlike the 1994 study, the study considers conversions of electric space and water heating systems both to and from natural gas. Another major difference from the previous analysis is that all direct use of natural gas alternatives are modeled as "resources" directly in the Council's Regional Portfolio Model (RPM). This allows the Council to directly compare the cost and risks of any conversion.

Study Objectives

This study had two specific objectives. The first was to determine which residential space and water heating systems have the lowest total resource cost (TRC) while presenting an acceptable level of risk to the region. The second objective was to determine whether the ***retail market*** will lead consumers to choose those same space-conditioning and water-heating systems. If the systems selected based on the regional cost and risk perspective are similar to those selected based on consumer economics, and they are generally being chosen by consumers then it would appear that no policy intervention is needed.

This analysis therefore examines the economics of direct use of natural gas from two perspectives -- the "regional" perspective and the "consumer" perspective. The regional perspective adopts total resource cost (TRC) economics. Selections are determined using the cost of future power supply options and wholesale prices for electricity and natural gas. Selections are made from forecasts of the market prices four times each year over the twenty-year planning horizon.[2] The effect of all the "fuel choice" decisions appears in the magnitude and timing of new generating resource additions as well as the cost associated with those additions. These costs also include possible carbon mitigation cost and the cost of incremental natural gas and electricity use. In contrast, from the consumers perspective, selection of space and water heating systems are based strictly on the retail prices for electricity and natural gas. In particular, it does not account for system level impacts such as the need to build new generation or expand gas distribution networks.

Analytical Approach

Of the 3.6 million existing households in the Pacific Northwest, about 2.6 million are eligible for converting to the alternative fuel source over the next 20 years.[3] This implies that on average about 130,000 "fuel choice" decisions will be made annually.

The first step in this analysis was to estimate the existing mix of space and water heating systems used in region by these 2.6 million households. Data from a regional customer characteristics survey[4] were used to assign existing residential dwellings to "segments groups" [5] according to characteristics associated with their energy use. These characteristics were housing type (e.g., single family vs. multifamily), size (e.g., 1050 sq. ft. vs. 2250 sq. ft.), and equipment fuel and type (e.g., gas forced-air furnace vs. electric heat pump). A total of 95 unique segment groups were identified. A complete list of these segment groups appears in Appendix A.

The next step was to estimate the energy use and the cost of replacement. The study developed estimates of the annual energy use for space heating, cooling and water heating for the five representative climates used by the Council and RTF for each space conditioning and water heating system and fuel type.[6] Appendix B provides a list of all of the space and water heating system replacement options considered for each of the 95 segment groups. Appendix C contains a summary of the energy use, and equipment, operation, and maintenance costs used in this analysis.

[2] The frequency is determined by the architecture of the RPM.
[3] "Eligibility" was determined based on whether gas service could be provided through the extension of an existing gas main or both main and service line to the home.
[4] The 2008 American Community Survey (ACS) and the Pacific Northwest Regional Energy Survey published in 1992 (PNRES92)
[5] We use the term ***segment groups*** for consistency with the earlier Global Energy Partners (GEP) work on this study. A segment group refers to a group of households with identical attributes and circumstances relevant to the selection of replacements. We concede that the term ***segment*** would be more standard. GEP reserved the term segment, however, for a particular segment group ***and*** a particular selection of replacement appliances. Therefore, for each segment group there may be dozens of segments, each one a candidate replacement pair of space and water heating appliances. Only one pair would be chosen at a particular point in time as the least-cost replacement solution for a given segment group.
[6] The Council/RTF uses Portland, Seattle, Boise, Spokane and Kalispell as representative of the major climate types found across the region.

Appendix H lists reasons why particular space and water heating system combinations were, or were not, explicitly evaluated.

The study assumes replacements would, at a minimum, satisfy the new federal efficiency requirements. Recently adopted federal standards will require efficiency upgrades when consumers replace certain space and water heating systems. Among these space and water heating systems are natural gas furnaces, central air conditioners, heat pumps, and both gas and electric water heaters. For example, for gas water heaters with capacities above 55 gallons, the new federal standard requires a minimum Energy Factor (EF) of 0.75. For electric water heaters with capacities above 55 gallons, the new federal standard requires a minimum EF of 2.0.

The resulting conversion cost and energy use estimates for 1,470 space and water heating systenm type pairs served as input to the RPM. The consumer life cycle cost (LCC) analysis used the same data. In both modeling processes, each of the 95 different segments is provided with between eight and 24 replacement options from which to choose. In both the RPM and the LCC simulation models, consumers can install the same type of equipment they already have or install a different technology. For example, in one identified market segment, the home has electric forced air furnace (FAF) for space heating and an electric resistance water heater. Both the RPM and LCC analyses assume that when the electric FAF fails, it could be replaced “in kind” with another electric FAF. It could also be replaced by a gas FAF or a gas/heat pump hybrid system. Likewise, when the electric resistance water heater fails it could be replaced with a new model of the same type of water heater. It could also be replaced by a gas tank water heater, a tankless gas water heater, or a heat pump water heater.

Use of the RPM provided the study with a fresh look at how the issue of risk might impact the Council's conclusions and recommendations. To understand the results of the RPM and this study, it is useful to understand a few principles of the model. In particular, the RPM evaluates resource strategies under 750 different futures. These futures differ significantly, one from the other. The scale of variation corresponds to that of "scenario" analyses that utilities perform for their integrated resource plans (IRPs). Risk is measured by the average net present value cost in the 10% (75) highest-cost futures. If decision makers select least-risk strategies, therefore, they are lending particular weight to the performance of those strategies under these high-risk futures.

The least risk strategies that emerge from Council's risk model protect ratepayers from the high cost-futures. Often, the high costs result from high wholesale prices for natural gas and electricity. Over the course of the study, it became evident that evaluating appliance life-cycle cost directly resulted in appliance choices as good as those the risk model could obtain. However, in order to mimic the results of the RPM, the simplified Fuel Choice Model needed to assume gas prices over $9.50/MMBTU and the use of the fully allocated electricity cost of a CCCT instead of the short run wholesale market price for electricity. While such natural gas prices sound high from today’s perspective, they predominate in “risky” futures. Such futures have a high carbon mitigation penalty, unfavorable regulatory treatment for environmental mitigation, or other features disadvantageous to natural gas.

As mentioned in the Objectives, the RPM captures the region’s total resource cost. Specifically, the cost of natural gas provided for direct use in space and water heating systems is added to the cost for fuel to natural-gas fired combustion turbines. Both uses of natural gas reflect the carbon penalties that arise in a future. Electricity loads met by generation reflect conversion, as does the amount of electricity energy efficiency available for economic or risk mitigation acquisition.[7] Credit for transmission and distribution equipment costs is reflected in the RPM's accounting for electricity costs. On the natural gas side of the ledger, the RTF concluded that long-term transmission cost impacts are fairly reflected in commodity cost. A characterization of the incremental distribution cost impacts was not available. It was generally held, however, that the study's explicit treatment of service extension cost captured most of the distribution system cost effects. The study did not attempt to capture gas energy efficiency programs, so no assessment is made of any conservation effect on gas use. In contrast, the study did include the option for improvements in the efficiency of electric space and water heating through the selection of higher efficiency systems, so the conservation effect of such efficiency upgrades is reflected in the results.

The Council developed a Fuel Choice Model (FCM) to prepare data for the RPM analysis. The model has various tools for exploring both input and output data. It also contains the logic to select space and water heating systems for each segment based on the direct cost estimate, as described in the previous paragraph. A version of the model is available on the Council's website at the following link. (http://www.nwcouncil.org/dropbox/DUG/FCM10.xlsm) The model contains a link to detailed documentation of the model.

Findings from the Regional Economic Perspective

Table 1 provides key information about the 95 segment groups described above. A review of this table shows that for nearly three quarters (73%) of the households it would not be economically advantageous from a regional perspective to switch space conditioning or water heating fuel source. It shows that for approximately 22 percent of the households it would be economical to convert from electric space heating or water heating to gas space or water heating. These conversions over 20 years reduce annual regional electrical loads by roughly 360 average megawatts and increase annual natural gas consumer use by about 15 trillion BTU.

Just under five percent of the region's households converted to heat pump water heaters from gas storage tank water heaters. All of the households in these market segments, however, use water heaters with capacities above 55 gallons. Table 1 shows the effect of these conversions over 20 years. Conversion to heat pump water heaters would increase regional electric loads by 24 average megawatts and decrease natural gas use by just under 2 trillion BTU annually.

A very small fraction of the region's households (less than one percent) converted from electric to gas space heating and from gas to electric water heating. These households converted from electric forced-air furnaces to gas force-air furnaces and gas tank water heaters to heat pump water heaters. The net impact over 20 years of these conversions was a three megawatt decrease in loads and about a 70 billion BTU increase in natural gas use.

Across all households, regional electric loads decrease around 340 average megawatts and natural gas use by customers increases 13 trillion BTU. However, less natural gas is used by the power generation turbines that would otherwise have served those electric space and water heating systems. After netting out the 21 trillion BTU decrease of gas use by these turbines, total regional natural gas consumption falls 8 trillion BTU per year by the end of the 20–year study.

[7] Due to the complex feedback effects inherent in conversion and EE potential, this is reflected in sensitive studies that capture the effect at either extreme of conversion.

Appendix A shows the replacement space conditioning and water heating systems selected based on both the regional and consumer economic perspective for each of the 95 market segments considered in this study.

Many policymakers are concerned about the implications of carbon dioxide emissions policies. Carbon dioxide emissions are monetized in the Council's risk model and are a significant source of cost risk. If the least-risk choices from the Council's model prevail, however, the impact on carbon dioxide emissions is negligible.

Electric space and water heating systems, of course, produce carbon dioxide through the combustion of fossil fuels required to produce the electricity that they use. The study shows that direct use of natural gas produces less carbon dioxide than do the least efficient electric space and water heating systems. This is due to the fact that the thermodynamic efficiency of even the most efficient gas-fired generation, plus losses in the transmission and distribution of electricity is below that of today's gas furnaces and water heaters.

Little CO_2 emission change can be ascribed to converting, however. The number of conversions is small. Even for a larger number of conversions, however, the result would not be dramatic. Efficient gas and electric space and water heating systems are becoming more cost-effective, reducing the gap in relative CO_2 production. For example, hot water heat pumps transport heat rather than extract heat from chemical bonds. This requires much less energy consumption. Consequently, the overall efficiency of heat pumps, including the generation of the electricity they require, is comparable to direct use of gas. The production of carbon dioxide is thus also comparable. [8]

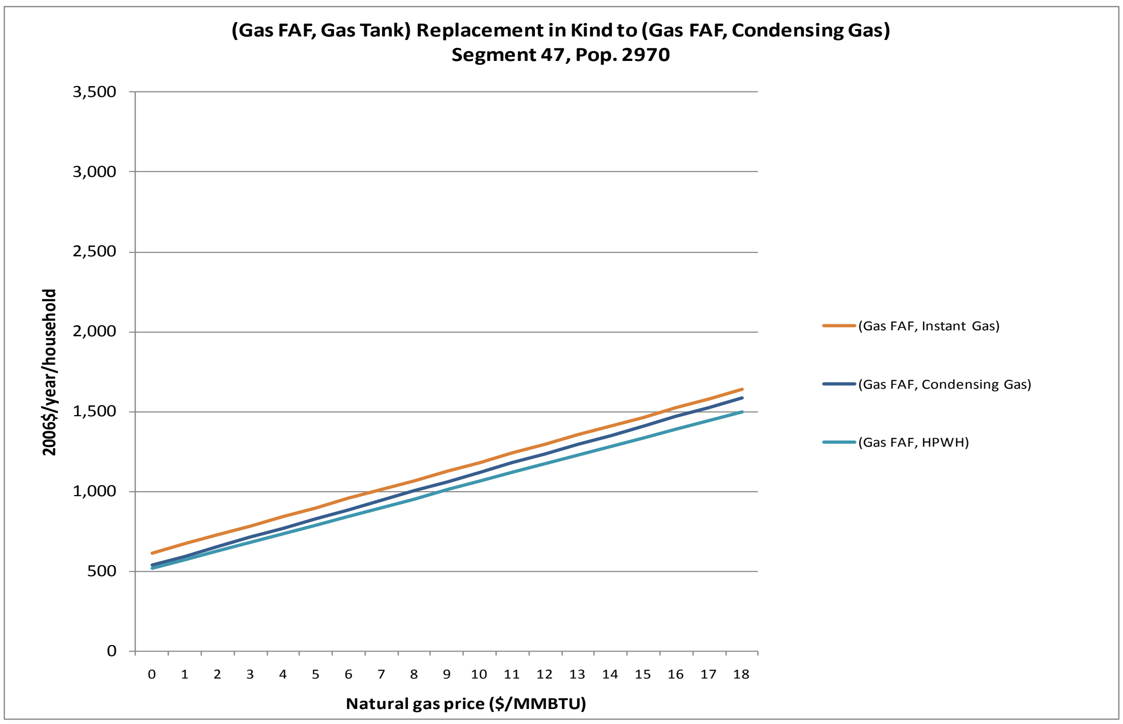
[8] Measuring efficiency at the point of use does not convey a complete picture. An electric resistance water heater converts virtually 100 percent of the electricity it consumes into heated water while typical new gas tankless water heater coverts just over 80 percent of the gas used to hot water. The current generation combined cycle combustion turbines convert just under 50 percent of the energy they consume into electricity. Roughly 10 percent of this electricity is lost as it is transferred from the point of generation to end users. Therefore, from a total system perspective the electric water heater's efficiency is only 45 percent (50% combustion efficiency x 90% transmission & distribution efficiency x 100% water heater efficiency) which is significantly below that of the gas water heater. Alternatively, heat pump water heaters have efficiency ratings that are twice those of a standard electric resistance water heater producing a total system efficiency of 90% (50% combustion efficiency x 90% transmission & distribution efficiency x 200% water heater efficiency) above that of most gas tankless water heaters.

Table 1 - Disposition of Market Segments Based on Resource Portfolio Model's Selection of Least Risk Plan										
	No. Segments Represented	No. Households /yr	20-year Total Households	Share of Total	Existing Use (MWa/yr)	Existing Use (MMBTU/yr)	Annual Change in Use (MWa/yr)	Annual Change in Use (MMBTU/yr)	Change in Use (MWa by 20th yr)	Change in Use (MMBTU by 20th yr)
Replace w/Same Fuel & Same Equipment	20	48,412	968,235	37.3%	4.92	2,500,094	-	-	-	-
w/Higher Efficiency Space Heating Equipment Only	14	1,807	36,145	1.4%	1.96	-	(1)	-	(10)	-
w/Higher Efficiency Water Heating Equipment Only	10	33,439	668,785	25.8%	21.51	-	(6)	-	(118)	-
w/Higher Efficiency Space & Water Heating Equipment	14	11,142	222,835	8.6%	15.26	-	(5)	-	(95)	-
Sub-Total	*58*	*94,800*	*1,895,999*	*73.1%*	*43.65*	*2,500,094*	*(11)*	-	*(223)*	-
Conversions from Electricity to Gas										
Space Heating only	11	1,520	30,400	1.2%	1.57	-	(1.55)	56,890	(31)	1,137,793
Water Heating only	6	21,197	423,940	16.3%	8.05	-	(8.05)	364,532	(161)	7,290,630
Space & Water Heating	6	5,745	114,900	4.4%	8.49	-	(8.29)	331,070	(166)	6,621,393
Sub-Total	*23*	*28,462*	*569,240*	*21.9%*	*18.11*	-	*(18)*	*752,491*	*(358)*	*15,049,817*
Conversions from Gas to Electricity										
Space Heating only	0	-	-	0.0%	-	-	-	-	-	-
Water Heating only	6	6,262	125,240	4.8%	0.10	98,713	1.21	(98,713)	24	(1,974,263)
Space & Water Heating	0	-	-	0.0%	-	-	-	-	-	-
Sub-Total	*6*	*6,262*	*125,240*	*4.8%*	*0.10*	*98,713*	*1*	*(98,713)*	*24*	*(1,974,263)*
Conversions from Electric Space Heating and Gas Water Heating to Gas Space Heating and Electric Water Heating	8	168	3,360	0.1%	0.16	2,648	(0.13)	3,536	(3)	70,723
Totals	*95*	*129,692*	*2,593,839*	*100%*	*58*	*2,601,455*	*(27.97)*	*657,314*	*(559)*	*13,146,277*
Changes Net of Efficiency	37	34,892	697,840	27%	18	101,361	(16.81)	657,314	(336)	13,146,277

Reduction in cost and improvements in the efficiency of heat pumps, condensing gas, and conventional space and water heaters have narrowed the economic and emission performance of these technologies. On inspection of the TRC analysis, an electric appliance may have only a small advantage over a gas appliance, or vice versa.

Figure 1 illustrates the point. The graph shows the relative economics of the three most competitive choices for a segment group that currently uses natural gas for space and water heating. The economics are expressed in real levelized annual cost per household. This particular segment group is replacing a gas forced-air furnace and gas storage tank water heater. Because the size of the tank exceeds 55 gallons, the options available for replacement are limited by federal standards to condensing gas or tankless gas water heaters and electric heat pump water heaters. Figure 1 shows only the three most competitive options out of a dozen available to this segment group. Each line corresponds to a particular pair of replacement space and water heating systems. These all retain gas forced-air furnaces for space heating. It is evident that while heat pump water heaters are the simple winner, condensing gas and instantaneous tankless gas water heaters are very close in cost. A small change in the relative purchase costs among these three could produce an different winner.

Figure 1: Gas Tank Water Heating Conversion to HPWH (Simplified)



Graphic displays of the results of the regional analysis are shown in Figures 2 and 3. Figure 2 shows space heating replacement choices. The central pie diagram shows the current mix of heating equipment and fuel. The satellite pies show how each type of heating equipment would be replaced. In general, it is most cost-effective to replace space heating equipment with the same fuel type. In only 5 percent of households is there a change in fuel source. Those changes were all from electricity to natural gas in homes without air conditioning, water heaters less than 55 gallons, and with access to natural gas already in the home or neighborhood. One clear result is that electric forced air furnaces should be replaced with different equipment, the specific replacement depending on many factors such as gas availability, relative prices, house size, and presence of air conditioning.

Figure 3 shows the results for water heating equipment choices. Here it is clear that electric resistance water heating is no longer cost-effective. The analysis shows it being replaced by either natural gas tank water heaters, if natural gas is available, or heat-pump water heaters where natural gas is not available or the water heater is greater than 55 gallons. Gas tank water heaters are replaced with the same equipment. The two small segments that will be required by federal standards to use either a condensing natural gas or heat pump water heaters because they are greater than 55 gallons are converted to heat pump water heaters.

Figure 2: Space Heating Equipment Replacement Choices - Regional Perspective

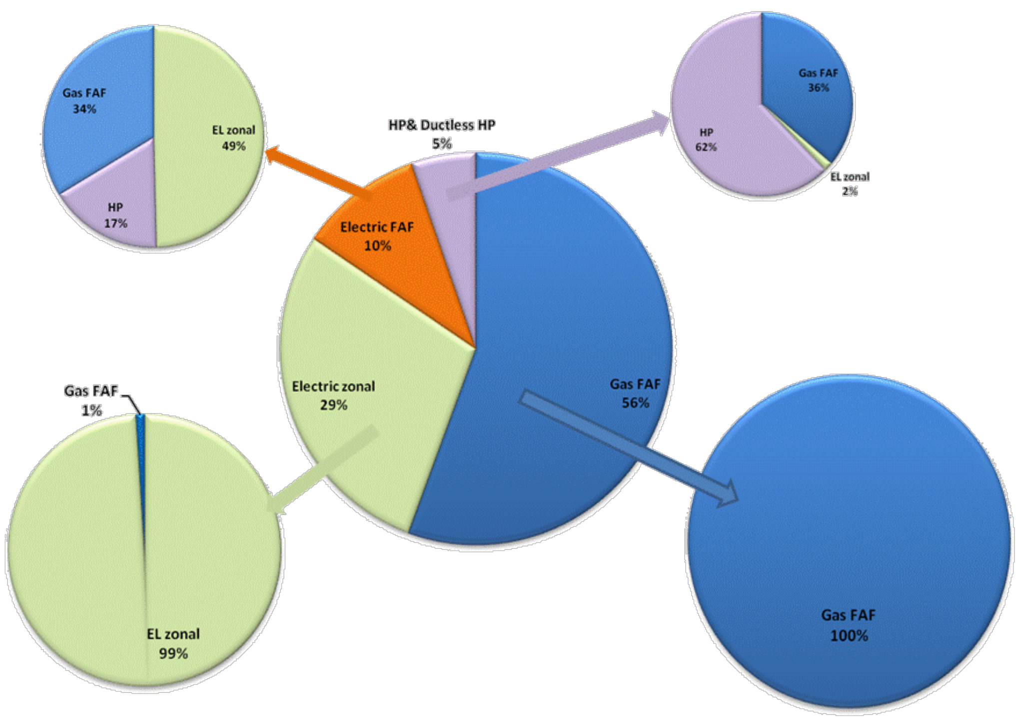
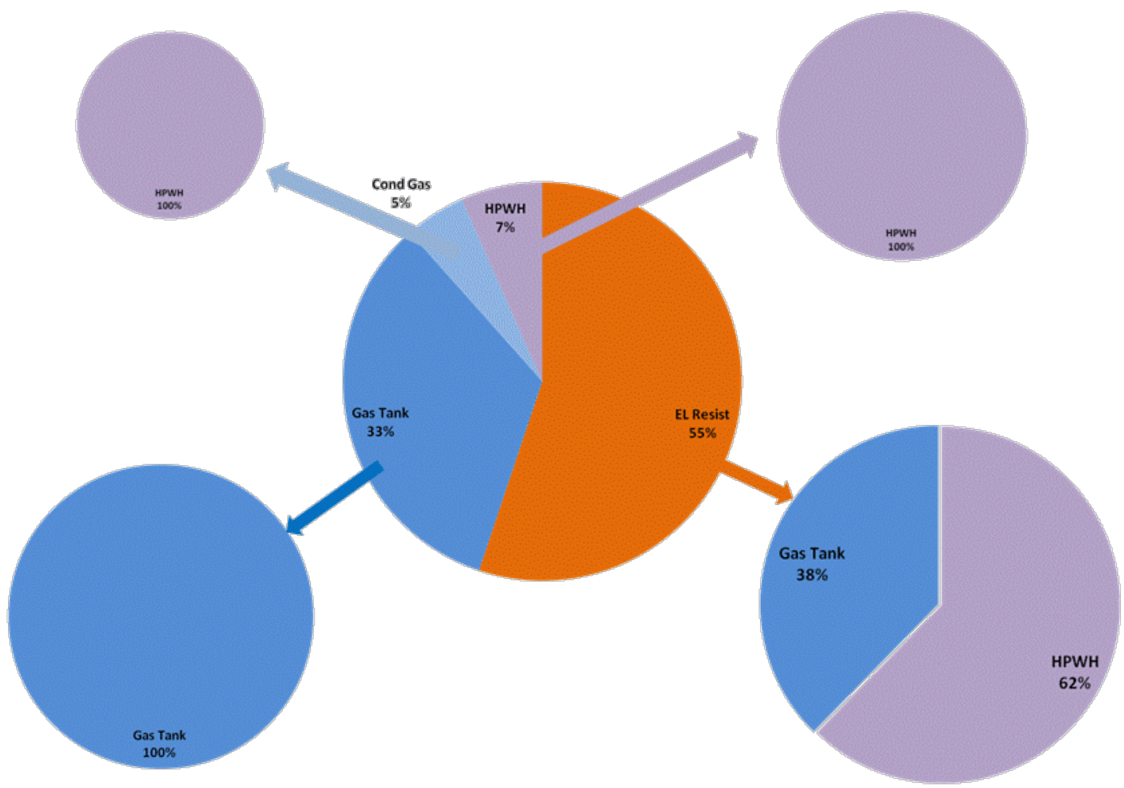


Figure 3: Water Heating Equipment Replacement Choices - Regional Perspective



Findings from the Consumer Economic Perspective

As summarized above, analysis using the Resource Portfolio Model (RPM) revealed that conversion of approximately 22 percent of existing households currently employing electricity for space and/or water heating to systems using natural gas prices could reduce total regional cost and risk. This analysis also found that conversion of a very small number (less than 1 percent) of households now using natural gas for water heating to electric water heaters would result in lower total regional cost. The objective of this phase of the Council's analysis was to assess whether consumers would generally select the space and water heating systems found to be the economic choice from the regional perspective. If this is the case and consumers appear to be selecting those systems, then there is little justification for the Council to modify its current policy on fuel choice/switching. On the other hand, if the most economic system selections from a consumer perspective do not generally mirror those found to be economically desirable from a total regional cost perspective and/or consumers do not appear to be selecting those systems, then policy intervention may be necessary.

The stakeholders agreed that two metrics should be used to represent the economic decision making criteria used by consumers when selecting a space and/or water heating system. These metrics are the "first cost" (FC) and "life cycle cost" (LCC) of the space and water heating systems. First cost (FC), as its name implies, is the initial purchase cost of space and water heating systems and the labor cost of installing them. The second metric, life cycle cost (LCC), is the discounted present value of all costs. These costs include those for purchase, installation, financing, maintenance, and operation, over the expected lives of the space and water heating systems.[9] The FC is independent of retail electricity and natural gas rates; LCC is not. Retail electric rates vary across the region by a factor of five while retail natural gas rates vary by less than two-to-one. Heating and cooling energy use are a function of the severity of the climate, which also varies significantly across the region.

In order to capture this diversity in rates and climates, the Council developed a Monte Carlo LCC model which uses a distribution of retail rates for natural gas and electricity that includes all electric and gas utilities in the region and estimates of energy use for space conditioning across five representative climate locations across the region.[10]

The LCC model was also designed capture any underlying correlation between retail gas and electric rates associated with regional geography.[11] The LCC model divides the region into five “service territories” that match climate with utilities.[12] For example, Western Oregon is represented by the Portland climate. The LCC calculation for the “Portland service territory” uses gas rates from two natural gas utilities and electric rates from twenty electric utilities that serve this general geographic area.

The LCC model performs 20,000 games, calculating a distribution of LCC for each of the 1,470 space conditioning and water heating system combinations using this distribution of natural gas and electric rates and energy use to reflect the proportion of customers facing each pair of rates within each of the five “service territories” found across the region. That is, the LCC results for each segment group from the “Portland service territory” are combined with the results from the other four “service territories” to determine the “regional average LCC” for that segment. This results in a more representative picture of diversity of net present value and costs for each space conditioning and water heating system. Figure 4 illustrates the results of the LCC model for a market segment representing just over 387,000 existing single family homes which average 1900 square feet in size, and heat with a gas furnace and have gas storage tank water heater.

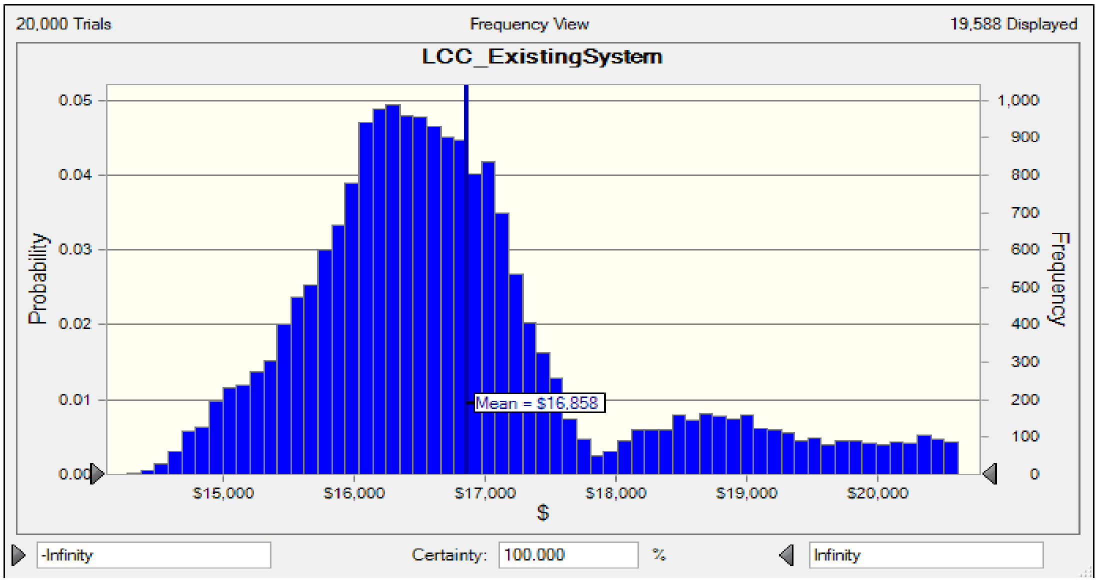
[9] In this analysis it was assumed that consumers would finance the purchase of their space conditioning and water heating system replacement at a six percent nominal interest rate for 20 years. This is simplifying assumption, since most water heater replacements are likely either paid for in cash or financed short term on credit cards. However, the discount rate in this analysis was set equal to the interest rate. As a result, the discounted present value cost of all systems is equivalent to their first cost. If a discount rate higher than the finance rate had been assumed the present value of all systems would have been below their first cost. Therefore, while the financing/discount rate assumption tends to slightly favor lower first cost systems, economic theory generally does not support the use of a discount rate below the cost of financing. The operating and maintenance and annual energy cost of all systems were treated (i.e. discounted) equivalently.

[10] The LCC model, including all of its input assumptions, can be downloaded from the Council website dropbox at: http://www.nwcouncil.org/dropbox/DUG/DUGRetailFuelChoiceModel_PNW_v2.1.xlsm

[11] To reduce computational complexity, the Regional Economic analysis assumes energy use is fixed for each segment. That is, each combination of segment group and appliance choice has fixed gas and electricity use representing the estimated regionally weighted average use for that system. Since the regional economic analysis is based on wholesale gas and electricity prices and new generating facility cost it does not require “localized” energy cost.

[12] The five territories are represented by Portland, Seattle, Boise, Spokane and Kalispell.

Figure 4: Life Cycle Cost Results for Market Segment 45(Single Family, 1900 sq.ft., Gas FAF and Gas Tank DHW, Existing Gas Access)

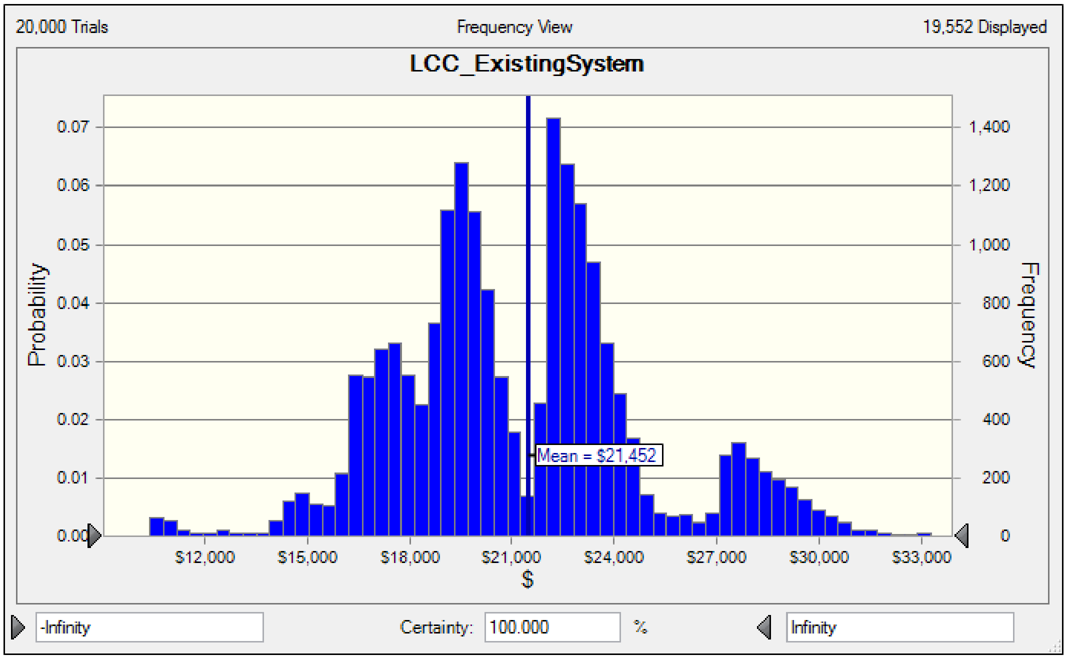


As can be seen from a review of Figure 4, the mean LCC for this space and water heating system is $16,858. However, the LCC for this space and water heating system combination could be as low as $14,000 or above $20,000 due to variations in retail gas retail rates, gas price escalation rates and climate. Despite this range, most of LCC results for this segment cluster between $15,000 and $17,500.

In contrast, Figure 5 shows four distinct "clusters" of the LCC results. Figure 5 depicts the LCC results for the 88,000 existing homes in the region that have an average size of 1900 square feet, heat with an electric forced air furnace and use an electric resistance water heater. A review of this figure shows that the LCC results for this market segment vary over a much larger range, from below $12,000 to over $33,000. Moreover, although this segment's regional mean LCC is $21,452 very few consumers are actually represented by this value. Rather, this "mean LCC" more accurately represents the average four large subgroups with LCC's centered around $17,000, $19,000, $23,000 and $28,000.

The LCC results for gas space and water heating systems and electric space and water heating systems consistently demonstrated these two distinct types of distributions. Gas system LCC results displayed a strong "central tendency" while electric systems were "multi-modal." These observations lead to the conclusion that simple averages do not capture important features of the LCC distributions. The initial LCC analysis selected space- and water-heating systems for each segment group based on the lowest regional average LCC. In order to reflect the differences in range of LCCs for gas and electric systems a second set of LCC analysis was conducted. This analysis selected the systems with lowest regional average LCC cost from among those within a single standard deviation from the mean for each segment group. This second set of results identified the space and water heating systems with lower "risk." That is, these systems exhibit less variance in LCC across the region.

Figure 5 - Life Cycle Cost Results for Market Segments 5 and 7 (Single Family, 1900 sq. ft., Electric FAF and Electric Resistance Tank DHW, No Existing Gas Access)



The consideration of risk makes the economically preferred space and water heating system selection more complex. The "unconstrained" LCC analysis favored electric space and water heating systems more frequently than the LCC analysis which was constrained by limiting the standard deviation of economically preferred systems. While the "average" LCC for these electric systems may be lower than gas systems, the variance of such systems across the region is much larger. This is consistent with the earlier observation that there is greater diversity among regional electricity rates than for retail gas prices found across the region. Moreover, it illustrates that the system with the lowest regional average LCC is not a reliable predictor of which system will be most economical for an individual consumer served by specific gas and electric utilities.

Independent of the consideration of risk is the possibility that consumers select their space and water heating systems on the basis of "first cost" or perhaps, consider both the initial cost and life cycle cost when making their decision. Figures 6 plots the first cost of six alternative space and water heating system combinations against their regional average LCC for a 1900 square foot single family home with a forced air furnace with central air conditioning and with existing gas service access.

A review of this graph reveals that gas forced air furnaces with central air conditioning and either a heat pump water heater or condensing gas water heater have very similar LCC and first costs. Figure 7 plots the first cost of six alternative space and water heating system combinations against their regional average LCC for a 1050 square foot multifamily dwelling with zonal electric space heating. For this segment group, retention of a zonal electric heating system in combination with either a heat pump water heater or gas storage tank water heater have similar LCC and first cost. Given this information one might reasonably expect consumers in these two segment groups to select one of these two system combinations based on the fact that they have both the lowest first cost and the lowest life cycle cost.

Figure 6 - Life Cycle Cost vs. First Cost of Alternative Space and Water Heating Systems for a 1900 sq. ft. Single Family Home with Forced Air Furnace and Central Air Conditioning and Existing Gas Service Access

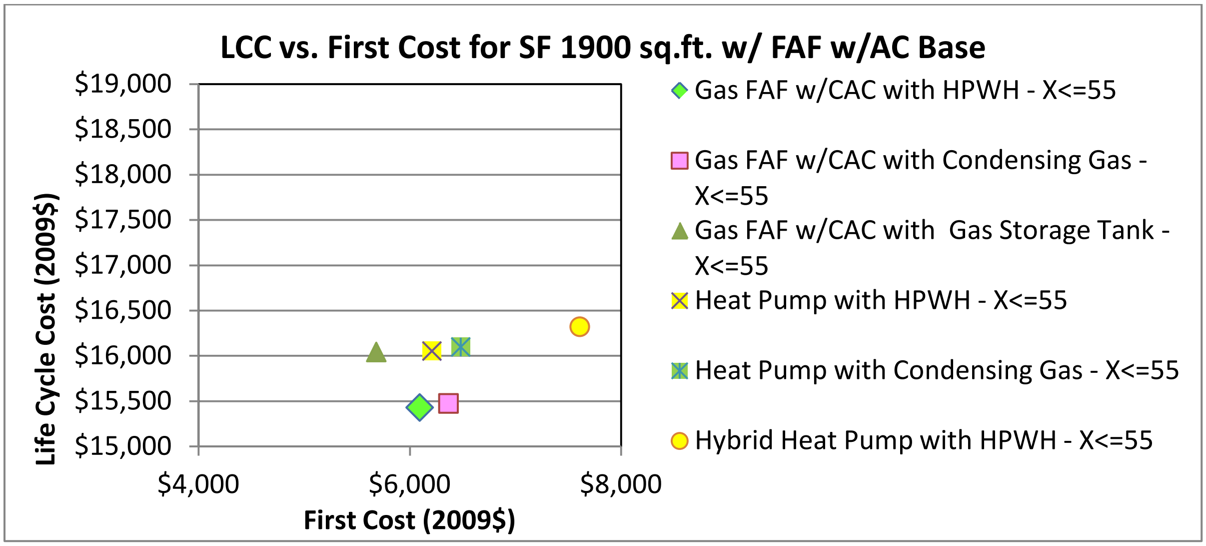
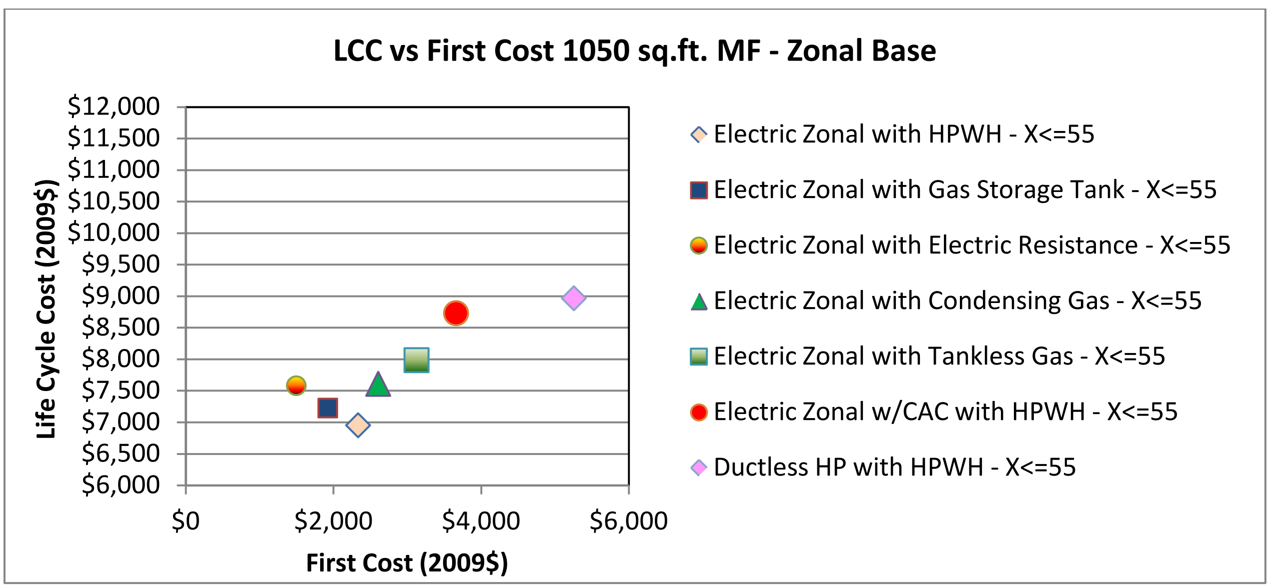


Figure 7 - Life Cycle Cost vs. First Cost of Alternative Space and Water Heating Systems for a 1050 sq. ft. Multifamily Dwelling with Zonal Electric Heating Regardless of Gas Access



Appendix D contains a detailed summary of the first cost and average regional LCC results for all space and water heating system combinations considered in this analysis under both the unconstrained and constrained conditions for each of the six housing types (i.e., two multifamily and four single family homes) used in this analysis.

Impact of Gas Service Extension Cost

The Regional Economic analysis model and the LCC models use identical input assumptions for the first cost and annual operation and maintenance cost of all space and water heating systems. However, the Regional Economic analysis model incorporates estimates of the cost of extending gas service (lines and mains) to homes for those market segments that do not have existing gas service. From a regional perspective, these costs are incurred when a gas line or main is installed to service a home. However, the allocation of gas extension cost to individual consumers who are adding gas service is less clear. The share of gas line extension costs paid by individual consumers varies considerably due to differences distance from a gas main, local soil conditions, access, anticipated gas consumption of the home and other conditions. It also varies across the region due to differences in regulatory policy regarding how such cost allocated across existing and new gas customers.

In order to test the sensitivity of the LCC results to assumption regarding how the cost of new gas service is recovered, two scenarios were analyzed. In Scenario A, the cost of gas service extension to a home without existing gas service was assumed to be recovered entirely from the consumer in that home. In Scenario B, the cost of gas service extension to a home without existing gas service was assumed to be recovered across all gas customers through gas retail rates. These two scenarios bracket the range of cost that might be incurred by an individual consumer adding gas service.

As might be expected, the addition of gas service extension cost to the cost of installing a gas space and/or water heating system significantly alters its LCC. Figure 8 shows the existing market share of gas and electric space heating systems and the market share of these systems in the year 2030 assuming that all consumers select those systems with the lowest regional average LCC under both scenarios. This figure also shows the market share of gas and electric space heating systems by year 2030 assuming consumers selected their space heating systems based on a regional economic perspective (labeled RPM). A review of Figure 8 reveals that under Scenario A the market share of gas forced air furnaces in 2030 remains basically unchanged from existing conditions. In contrast, under Scenario B the market share of gas forced air furnaces increases from around 55 percent today to just over 70 percent by 2030. These two results bracket the 60 percent market share for gas forced air furnaces in 2030 that was produced using the regional economic perspective (RPM).

It is also notable that both the Regional Economic analysis and the consumer LCC analysis indicate that conversion of existing electric forced air furnaces to either natural gas or higher efficiency electric systems reduces both regional and consumer costs. The Regional Economic analysis found that conversion to electric zonal systems was the economically preferred option while the LCC perspective selected heat pumps or ductless heat pumps under Scenario A and gas furnaces and heat pumps/ductless heat pumps under Scenario B. The difference between the Regional Economic analysis and the consumer LCC is a result of restricting the conversion of homes with central forced air systems to systems which also have central forced air (i.e., not zonal or ductless heat pumps) in the LCC analysis. Had this constraint not been in place the LCC results would be similar to the RPM results.

Figure 8 - Comparison of Existing Space Conditioning System Market Share with Market Shares in 2030 for System Selected based on Regional Economic and Consumer Economic Perspective

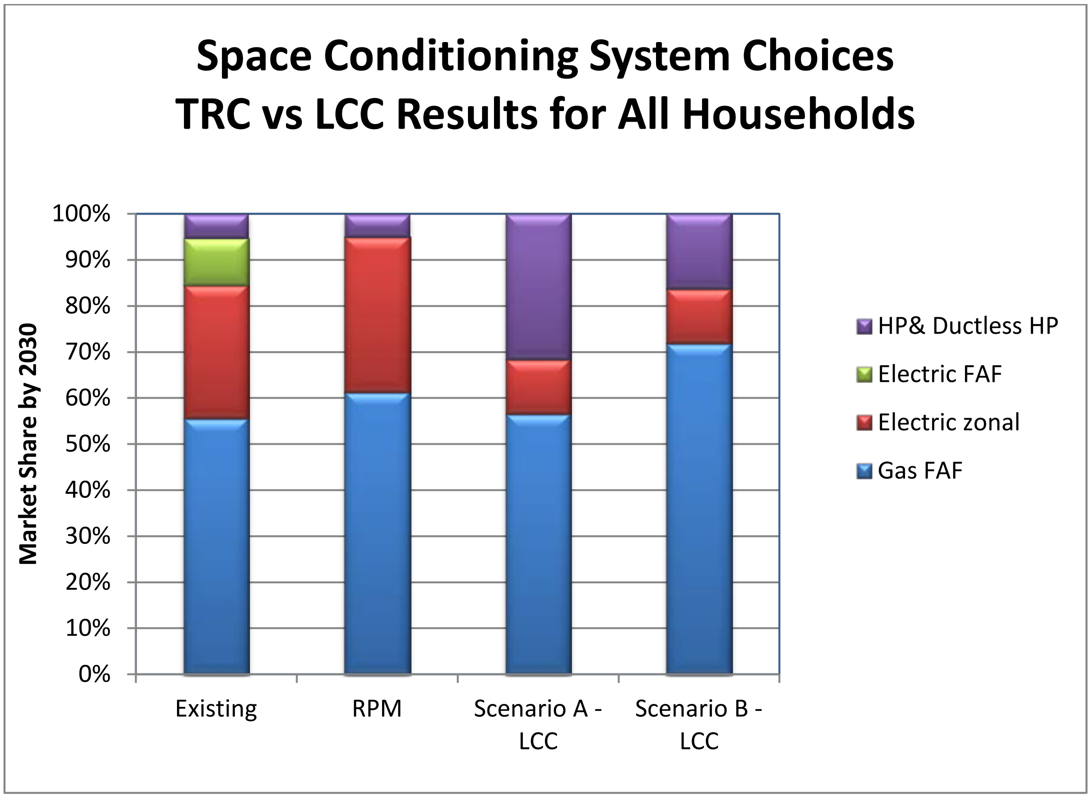
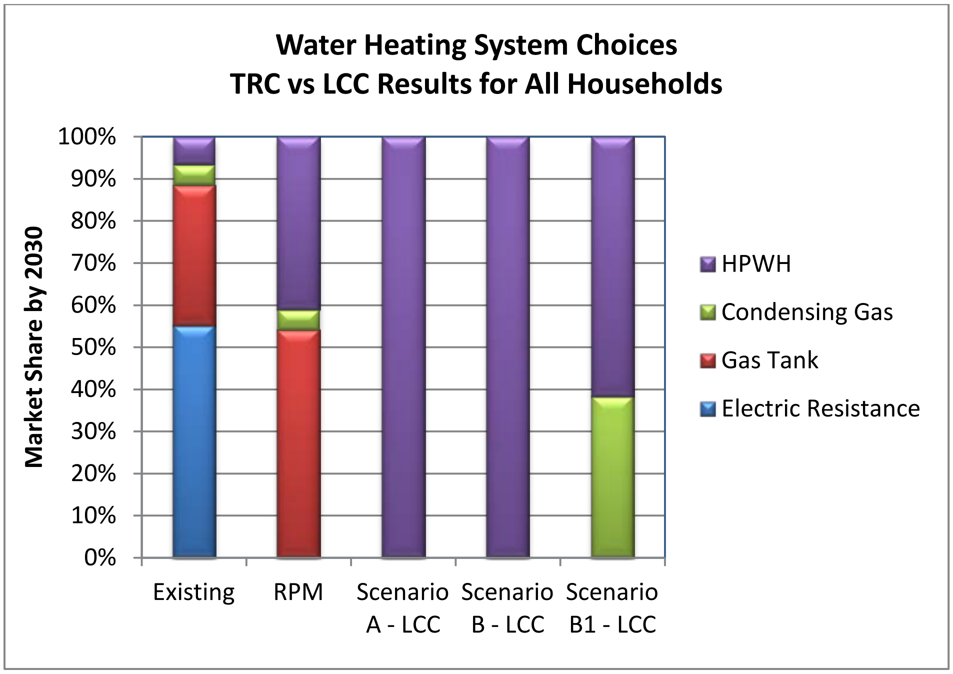


Figure 9 compares the Regional Economic and consumer LCC choices for water heating systems. The water heating equipment choices differ considerably between the two perspectives. The Regional Economic study selected gas tanks; the LCC model chooses a heat pump water heater (HPWH), even under Scenario B, which assumes that the cost of gas access is recovered in retail rates and not wholly from the individual customer. The conversion of all of the region's water heaters to heat pump water heaters over the next two decades is clearly unrealistic. As was shown in Figure 6, inspection of the LCC results revealed that condensing gas water heaters and heat pump water heaters are economically indistinguishable by this model. Given the uncertainties in all of the inputs to the LCC model, small differences in LCC between these two systems should not be viewed as significant. A modification of Scenario B (B1) was made to determine the share of market segments that would adopt a condensing gas water heater if it had a LCC within one percent of the LCC of heat pump water heaters. Under this scenario, nearly 40 percent of water heater replacements would install condensing gas water heaters rather than a heat pump waters.

Figure 9 Comparison of Existing Water Heating System Market Share with Market Shares in 2030 for System Selected based on Regional Economic and Consumer Economic Perspective



What this additional sensitivity analysis reveals is that the economics of these choices are close, similar to the case for the Regional Economic study. In nearly all of these market segments, the "next lowest" LCC cost option for water heating is generally a condensing gas water heater. Typically, only a few hundred dollars out of a total LCC of $6,000 - $15,000 separates these two options. Either heat pump water heaters or condensing gas water heaters will be required to be installed for all tanks above 55 gallons in capacity beginning in 2015. Both of these technologies currently have very small market shares in the region. Therefore, it is too soon to predict which technology will be preferred by the marketplace, especially given their roughly equivalent LCC.

Overall Findings and Recommendations

This review finds that from a regional perspective the vast majority (73%) of households should not convert existing space conditioning or water heating systems. This is particularly true for space heating where 95 percent of households should remain with their current heating fuel. From the Regional Economic perspective, the cost of extending natural gas service to households without service is an economic impediment for electricity customers to change fuels. Similarly, the cost to produce the electricity required to meet the additional demand of the electrical appliance renders conversion from a gas appliance uneconomic for many households. These consumers will nevertheless find significant opportunities for energy efficiency improvements irrespective of their fuel use.

This study finds that about 23% of households would reduce total regional cost by converting either a space heating appliance or a water heating appliance. Most of these opportunities occur for water heating, which accounts for 80 percent of the conversions. These households would see water-heating conversion as attractive from the consumer perspective, at least “on average” across the region. The economic advantages of converting from electric to natural gas water heating, while clear for these households from the regional perspective where gas is available, is more ambiguous from the perspective of individual consumers. Gas (condensing gas water heaters) and electric (heat pump water heaters) technologies are roughly equivalent economically. Therefore, it appears premature to “pick a winner” in the water heating technology race.

Gas forced air furnaces with central air conditioning appear more attractive from both a regional and consumer perspective where gas service is already available. However, from a regional perspective the additional cost of extending gas service results in heat pumps being the economically preferred space conditioning system, while consumers might select the gas forced air furnace with air conditioning when the cost of extending gas service is recovered across all gas sales. Moreover, as in prior Council analysis, this study again found that from a consumer perspective the economic selection of residential space conditioning and water heating systems is highly dependent upon the gas and electric rates of individual consumers. Electric rates, and to some extent gas rates, vary widely across the region. The optimal choice therefore depends on the utility and the climate.

Although this analysis has identified situations where it would be regionally cost-effective to convert fuels, the overall effects on electricity use, natural gas use, and carbon emissions would be negligible. Across all households, regional electric loads decrease around 340 average megawatts or about 1.5 percent of forecast 2030 loads. While natural gas use by customers increases 13 trillion BTU, less natural gas would be used by the power generation turbines that would otherwise have served those electric space and water heating systems. After netting out the 21 trillion BTU decrease of gas use by these turbines, total regional natural gas consumption would be 8 trillion BTU per year, or about 1 percent, less by the end of the 20–year study.

The study does not directly address the issue of whether incentives for improved efficiency of electricity use are affecting consumers’ equipment replacement choices, because there is little reliable data on replacement choices at the regional level. Existing fuel shares align well with the results of this analysis indicating that markets have not been seriously distorted by efficiency incentives to date. However, changing market dynamics and asymmetric equipment incentives offered across fuels may impact the conversion market. These potential impacts warrant continued monitoring by the Council and other stakeholders.

With the exception of work underway to evaluate the impact of equipment incentives on the marketplace, the foregoing analysis suggests that policy intervention is not currently necessary to ensure that selection of space and water heating systems found to be least cost/risk from the regional perspective are chosen by consumers. There is general alignment between the systems that are economically preferred from a regional perspective and those that are most economical from the “average” regional consumer’s perspective. Further, the fuel conversions that are found to be cost-effective in the analysis would have only very small effects on energy use and carbon emissions. Therefore, the staff recommends that the Council retain its existing policy regarding the direct use of natural gas, including continued monitoring of equipment replacement decisions to ensure that electricity efficiency incentives are not contributing to less efficient fuel choices.

APPENDICES

Appendices A, B, C, E, F, and G are all contained in one Excel workbook. The workbook is available on the Council's website dropbox at the following link:
http://www.nwcouncil.org/dropbox/DUG/DUGAppendicesA_G,%20exceptD_110411.xlsx
The appendices are separate tabs in the workbook with the appropriate labels. Their contents are described below:

Appendix A - Existing Residential Segment Groups and Economically Preferred Replacement Segments from the Regional and Consumer Perspectives

Appendix B - Conversion Options Considered for Each Residential Segment Group

Appendix C - Space Conditioning and Water Heating Energy Use and System Cost Assumptions

Appendix E - Summary of Distributions for Retail Electricity and Natural Gas Rate and Escalation Rates Used in LCC Analysis

Appendix F - Disposition of Existing Residential Segment Groups Based on Regional Economic Perspective

Appendix G - Projected 2030 Market Share for Space and Water Heating Systems Based on Regional and Consumer Perspective

Appendix D - Life Cycle Cost Results by Dwelling Type for Constrained and Unconstrained Cases. The appendix is available on the Council's website dropbox at the following link:
http://www.nwcouncil.org/dropbox/DUG/DUGAppendixD_LCCSystemSummaries_110411.xlsx

Appendix H - Study Constraints on Replacement of Space and Water Heating Systems. Appendix H is included in this document.

Appendix H – Study Constraints on Replacement Space and Water Heating Systems

This analysis did not explore all possible technological options for space and water heating system replacement. It placed constraints on the selection of replacement space and water heating systems. These constraints and the reasoning behind them are detailed below.

1. Exclude from consideration all **gas hydronic space heating**, both as existing and as a retrofit technology. Reason: This segment is very small and the economic hurdle for adopting a different heating appliance is too high.
2. Limit zonal electric system replacement options to **ductless heat pumps** instead of conventional a heat pump as a retrofit space heater. Other central forced air heating systems are available as replacement options for zonal electric. Reason: Ductless heat pumps do not require the expense of installing ductwork, but it was not viewed as providing equivalent consumer utility in situations where a heat pump or furnace with central air conditioning system are already present.
3. Limit selection of water heaters to **high-efficiency condensing gas, tankless gas,** and **heat pump water heaters** (**HWPH)** equipment options as replacement for water heaters with capacity over 55 gallons. Reason: The efficiency levels required by the 2015 federal standards preclude the use of lower efficiency electric resistance and non-condensing gas storage tank water heaters.
4. Assume **high-efficiency condensing gas, tankless gas and heat pump water heaters** are available for selection irrespective of tank size. Reason: While federal standards will limit the selection of replacement water heaters to **high-efficiency condensing gas, tankless gas,** and **heat pump water heaters** (**HWPH)** for tank capacities over 55 gallons, these technologies are available for use by consumers with smaller tank sizes.
5. Exclude hot water heaters over 55 gallons from multi-family households. Reason: Multi-family housing is smaller and has occupants than single-family homes.
6. Only households with existing gas service or the potential for economic gas service as the potential population for consideration in this study. Reason: Households without potential for economic gas service (i.e., no natural gas service available via a main extension) only have the option of upgrading the efficiency of the electric space and water heating systems.
7. Exclude existing **zonal space heating** conversions to **electric FAF**. Reason: Replacement of an electric FAF with a zonal electric space heating increases cost and annual energy use, hence it would never be selected as a more economic option.
8. Assume segment groups without air conditioning and without a heat pump for space conditioning will not add air conditioning in conversion. Segment groups with air conditioning or heat pumps will always replace the air conditioners in kind or choose heat pumps for space conditioning. Consequently, segment groups without existing heat pumps can ignore cost, efficiency, and power usage assumptions for air conditioning. Reason: The cost and energy consumption of the AC will be a wash. We assume only one kind of AC appliance. Existing heat pumps, on the other hand, introduce a connection between heating and cooling cost and service.

9. Assign no credit for or value to the cooling service of heat pumps, if they are chosen for a segment that does not have an existing heat pump.[13] Include, however, the energy requirements associated with the cooling load in the economic assessment. Reason: While we recognize the inconsistency and bias against conversion to heat pumps, we believe the information necessary to properly discount the heat pump cost and energy does not exist. The RTF, moreover, has indicated they would prefer not to assign a value to the cooling service.
10. Exclude **gas/HP hybrid** as an explicit retrofit appliance. Reason: Initially, we excluded this option because we did not have adequate cost or performance data. For the final analysis, this system was included in the consumer LCC analysis. Based on the economic and efficiency data provided by stakeholders this system was not found to be economically competitive with alternative systems. Given the general alignment between the LCC and RPM findings it is highly unlikely that these systems would be selected as an economically preferred option by the RPM.

The possible value for each field that describes a segment appears below.

	Existing SH	Existing WH	Retro SH	Retro WH	Water heater size	Household	Basement	Gas Availability	Air conditioning
number	**4**	**2**	**5**	**5**	**2**	**2**	**2**	**3**	**2**
	FAF Electric	Electric Resistance	FAF Electric	Electric Resistance	X<=55	SF	Yes	M	Yes
	Heat Pump	Gas Tank	Heat Pump	HPWH	X>55	MF	No	E	No
	Zonal Electric		Ductless HP	Gas Tank				Existing	
	Gas FAF		Zonal Electric	Instant Gas					
			Gas FAF	Condensing Gas					

Figure 4: Possible Values for Each Field Describing a Segment

With the constraints enumerated above, the number of segments is reduced to 1,470 from 9,600.

Source: q:\MS\Plan 6\Studies\Model Development\Direct Use of Gas\101004 Study\Developing new segment groups\Development of segments 110112.docx)

[13] After the study, it was observed that if we wished to know how heat pump replacement faired if the cooling service were considered, we can look at those segments ***with*** existing AC. For all segments without existing heat pump, there are two segment segments that are identical except for existing AC. Of course, if a segment has an existing heat pump space heater, the issue is moot. The replacement must have AC.

Comments on the ACEEE Comparison Paper on Heat Pumps and Gas Furnaces

1. Look at new construction and existing construction separately. The comparison should analyze the gas furnace vs. electric heat pump issue separately for newly constructed residential buildings existing construction: the nature of the choices and the drivers behind them are different qualitatively and quantitatively. In sum, a whole building approach is most appropriate for new construction; appliance by appliance analysis is appropriate only for equipment replacement choices in existing construction. There is a significant issue to be tackled around housing stock "deep retrofit" and replacement. All cases can be considered "additively" in a summary section.

2. Take the long view focused on regional carbon emissions: given that 2050 is often used as a benchmark year for carbon emissions targets, we should frame the "choice" question around where we ~~wish to be in~~ are developing strategies to get to by 2050, not "today." Although regional differences in climate conditions and the power grid mix are substantial and must be considered, both and grid technologies (generation mix, storage, grid control) and end-use technologies are changing rapidly and will look very different in 35 years. Very high penetration of renewables is expected to lead to hours of overgeneration in which the marginal carbon cost of the energy is effectively zero. Also, ~~W~~we should not rely strictly on today's equipment performance data, both "average" and "best available," as if it is static over time; performance values are changing rapidly and prospects for gas technology improvement do not necessarily mirror those for electro-technologies. Making the best choice based strictly on today's performance without a close look at clearly emerging trends means will be living with choices made under a 30+ year old decision framework once we reach 2050.

More detail . . .

1. The new construction vs. existing construction issue: a whole building analysis, not a heating only analysis, is the correct approach. There are a number of reasons to analyze new construction decisions vis a vis gas and electricity differently than those for existing construction; several decision vectors are in play for new construction which are generally moot for existing construction. Roughly, we add about 1% per year of new residential housing units (with similar increases in commercial square footage). By 2050, about a third of the housing stock will have been built from "today" (2020) on. Therefore, separate consideration of the new construction scenario is very important.

- For new construction, supplying the building with electricity only is less costly than providing both gas and electricity; the ACEEE analysis does not consider this savings. Although the specifics vary locally, there is significant savings to the builder/developer (and ultimately to the consumer) if a newly constructed building is served with electricity only vs. both gas and electricity: *this is a key choice facing the builder*. At the subdivision (or large multi-unit) complex, this includes savings from not needing expanding/uprade the existing gas grid "in the street." At the building level, there is savings from not connecting at the property line and not running piping, metering and safety infrastructure from the street to the building and then throughout the building. This savings is not considered in the existing analysis; it is substantial.

- Therefore, in new construction, the cost of an entire all-electric package (space-, water-heating, cooking and clothes drying) should be compared to a full dual service package. At a practical level, this is the key choice facing the builder. For new construction, the all-electric choice should be considered, but considered with whole building analysis, not space heating (only) analysis.
- Capital cost savings from equipment downsizing should not be ignored. Based on better envelope construction and other improvements (required in code today with further improvement coming by 2020), space conditioning equipment is significantly smaller per square foot of dwelling than in even the recent past: for example, a ZNE home in California has about ½ the heating load of a code minimum home from as recent as 2005. For new construction, equipment sizing cost analysis should be based on much smaller heating units (and correspondingly smaller AC units). This phenomenon will favor electric-only space heating / cooling options from an economic perspective; it is unclear if electric options for high efficiency water heating and clothes drying will be less costly than high efficiency gas options.
- Lower loads mean lower energy costs: Energy cost savings to the consumer for new construction should be modeled based upon the significantly reduced loads we will see based on new construction improvements as well as the reduced usage from highly efficient end use equipment (whether gas or electric): the absolute magnitude of energy consumption will be significantly lower and not based on existing construction models.

2. Take the long (2050) view. Issues around carbon emissions, the larger issue, should be clearly separated from issues around energy savings per se, a smaller issue. The key question: are regional carbon emissions under a scenario where *combustion is allowed in buildings* lower compared to a scenario where *combustion is not allowed*? There could be differences in the answer regionally, but the emissions question is the key question. End use efficiency and performance of the equipment itself contributes to the answer but is not the only factor.

- As we know, as grid decarbonization increases, grid-related emissions associated with electro-technologies decrease: the trend is increased grid decarbonization, although there are stark regional differences
- The paper should acknowledge that as the penetration of renewables increase, there may be hours of overgeneration when the marginal carbon cost of electricity is zero.
- Some California models have shown ~10% of hours of the year with over-generation (dump energy) at 40% renewables. The number of hours of over-generation was preliminarily modeled increase disproportionately as the renewable penetration level goes beyond that level. The state goal is currently 50% renewables.
- To the extent an efficiency technology like HP water heaters can also be controlled to preferably use and store heat energy during these over-generation periods, carbon reduction is much greater than the # of overgeneration hours of the year. Hot water storage has been claimed to be more cost effective than battery storage for a comparable amount of energy.

- Higher penetration of increasingly efficient residential electro-technologies coupled with grid decarbonization strategies is emerging at the preferred method for carbon reduction
- Customer site emissions from gas combustion equipment are largely unaffected by grid decarbonization, although efficiency improvements with combustion equipment can of course reduce emissions.
- Gas technologies installed today, no matter how efficient, lock in a future carbon emissions stream for decades going forward. The important policy issue to address is around not installing gas technologies for space (and water) heating which foreclose today on significant de-carbonization opportunities in the coming 10, 20 and 30 years
- We should avoid over-reliance on analyses which rely mainly on today's equipment performance values. Absent some difficult-to-imagine breakthrough with combustion technologies, there is very little potential for advanced furnaces and gas water heaters to capture any meaningful efficiency gains beyond where they are today: the best ones today have efficiencies above 95% (as high as 97%)— they are, essentially, at their theoretical limits already. Electric heat pumps, on the other hand, are not bound by the same upper limit: they have far more potential for continued improvement for both water and space heating.
- Therefore, long-term policy should encourage replacement of gas with electric technologies, especially for new construction (as detailed above), and also for "deep retrofits" go beyond one-for-one equipment change out.
- Short-term, policy should provide opportunities to capture substantial improvements in efficiency by way of one-to-one equipment replacement; one-to-one replacement programs should be designed to capture high levels of savings where these exist and deeper savings potential does not—to the extent possible, such efforts should "future proof" the building by designing programs and incentives to permit combustion replacement at a future date.
- Policy and programs encouraging "deep retrofits" and replacement of existing housing stock should be developed in an effort to eliminate and replace lower performing buildings and capturing the emissions savings available from conversion from combustion to non-combustion equipment by way of new construction and "deep retrofits."

So, while it is reasonable for ACEEE to conclude that "the answer" is "it depends," that answer should be understood in full context with emerging trends both on the grid and with end-use technologies, and should focus on "the long view."