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FINAL REPORT

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Technical Analysis of DOE Supplemental Notice of Proposed Rulemaking on Residential Furnace Minimum Efficiencies

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Executive Summary

On September 23, 2016, The U.S. Department of Energy (DOE) issued a supplemental notice of proposed rulemaking (SNOPR) that proposes a single national standard at a minimum efficiency level of 92% annual fuel utilization efficiency (AFUE) for all mobile home gas furnaces (MHGFs) and for non-weatherized gas furnaces (NWGFs) above 55 thousand Btu/hr (kBtu/h) input capacity. GTI conducted a scenario analysis of the DOE furnace SNOPR to evaluate the impact of the proposed rule requirements and other Trial Standard Levels (TSLs) on consumers. DOE's findings are skewed in favor of the rule based on flawed methodologies and inferior data. GTI SNOPR Integrated Scenarios Int-14.55 and Int-14 combine corrected methodologies and improved data for comparison with the flawed DOE SNOPR proposed rule as follows:

- Replace DOE's technically flawed random Base Case furnace assignment methodology with an improved methodology that uses a Consumer Economic Decision (CED) framework and aligns with AHRI condensing furnace fractions;
- Monetize the impact of imperfect market and non-economic consumer decision making factors within the GTI CED framework with a time-horizon-based distribution function;
- Apply American Home Comfort Study income distributions for fuel switching decisions;
- Replace DOE's engineering estimates and other inferior data with improved data for furnace prices, condensing furnace fractions, and marginal gas prices;
- Incorporate AEO 2016 Clean Power Plan Scenario forecast information; and
- Replace DOE's flawed furnace sizing algorithm based on home size with an improved algorithm based on RECS annual heating consumption.

Table 1 summarizes the difference in consumer impacts when comparing the DOE SNOPR LCC model results with GTI Scenario Int-14.55 for the proposed rule (SNOPR TSL 6) and with GTI Scenario Int-14 for a national 92% AFUE standard (SNOPR TSL 5). DOE and GTI NOPR analysis results (comparable to DOE SNOPR TSL 5) are included for reference. Table 2 and Table 3 provide a more detailed comparison of the DOE SNOPR LCC model results with the comparable GTI Integrated Scenario Int-14.55 and Int-14 results. Key findings include:

- GTI Integrated Scenario Int-14.55, based on CED and non-economic decision criteria coupled with an improved furnace sizing algorithm along with refinements to DOE's input data, shows negative composite average lifecycle cost (LCC) savings for all four NWGF TSLs (90%, 92%, 95%, and 98% AFUE) above 55 kBtu/h input capacity.
- Based on GTI's scenario analyses, there is no economic justification for the proposed rule of a 92% AFUE for NWGFs above 55 kBtu/h input capacity (DOE SNOPR TSL 6), a single product class 92% AFUE national furnace efficiency level (DOE SNOPR TSL 5), or any other condensing furnace efficiency levels with or without the 55 kBtu/h input capacity limit for 80% AFUE furnaces.
- GTI Integrated Scenario Int-14 cases with 80% AFUE furnace input capacity limits ranging from 40 kBtu/h to 160 kBtu/h show negative composite average LCC savings for a separate product class below 90 kBtu/h input capacity when using DOE's furnace downsizing methodology. This finding aligns with the empirical data analysis summarized in GTI Topical Report GTI-16/0003, "Empirical Analysis of Natural Gas Furnace Sizing and Operation."
- No furnace input capacity limit provides a net benefit to the low income market segment.

Table 1: SNOPR and NOPR Lifecycle Cost and Market Impact Comparisons

LCC Model Scenario	Average Furnace Life-Cycle Cost (LCC) Savings per Impacted Case	Fraction of Furnace Population (%)		
		Net Cost	No Impact	Net Benefit
DOE SNOPR TSL 6 (92%/55 kBtu/h)	$692	11%	60%	29%
GTI Integrated Scenario Int-14.55	-$118	15%	73%	12%
DOE SNOPR TSL 5 (92% all capacities)	$617	17%	48%	35%
GTI Integrated Scenario Int-14	-$149	22%	64%	15%
DOE NOPR (92% all capacities)	$520	20%	41%	39%
GTI NOPR Scenario Int-5	-$417	27%	57%	17%

Table 2 LCC Savings – DOE SNOPR TSL 6 vs. GTI Scenario Int-14.55

Scenario	National	North	Rest of Country	Residential Replacement	Residential Replacement - North	Residential Replacement - Rest of Country	Residential New	Residential New - North	Residential New - Rest of Country	Senior Only	Low-Income
LCC Savings Summary - 90% TSL											
DOE SNOPR (Scenario 0.55)	$667	$755	$615	$445	$479	$426	$1,242	$1,369	$1,158	$885	$592
SNOPR Scenario Int-14.55	-$196	-$470	-$23	-$232	-$678	-$47	$309	$203	$494	-$176	-$475
LCC Savings Summary - 92% TSL											
DOE SNOPR (Scenario 0.55)	$692	$749	$654	$502	$532	$483	$1,148	$1,176	$1,125	$890	$611
SNOPR Scenario Int-14.55	-$118	-$286	$17	-$182	-$493	-$23	$239	$153	$404	-$81	-$455
LCC Savings Summary - 95% TSL											
DOE SNOPR (Scenario 0.55)	$609	$617	$601	$499	$511	$489	$840	$783	$900	$770	$592
SNOPR Scenario Int-14.55	-$69	-$206	$53	-$139	-$342	-$18	$171	$13	$466	-$35	-$371
LCC Savings Summary - 98% TSL											
DOE SNOPR (Scenario 0.55)	$543	$502	$600	$447	$419	$488	$777	$677	$913	$724	$674
SNOPR Scenario Int-14.55	-$74	-$123	-$2	-$121	-$149	-$85	$121	-$82	$395	-$10	-$276

Table 3 LCC Savings – DOE SNOPR TSL 5 vs. GTI Scenario Int-14

Scenario	National	North	Rest of Country	Residential Replacement	Residential Replacement - North	Residential Replacement - Rest of Country	Residential New	Residential New - North	Residential New - Rest of Country	Senior Only	Low-Income
LCC Savings Summary - 90% TSL											
DOE SNOPR (GTI Scenario 0)	$582	$701	$530	$361	$430	$334	$1,263	$1,360	$1,210	$755	$440
GTI Scenario Int-14	-$203	-$487	-$88	-$258	-$698	-$113	$294	$166	$489	-$166	-$562
LCC Savings Summary - 92% TSL											
DOE SNOPR (GTI Scenario 0)	$617	$711	$569	$420	$496	$386	$1,177	$1,172	$1,180	$775	$476
GTI Scenario Int-14	-$149	-$309	-$65	-$222	-$519	-$100	$220	$136	$347	-$88	-$506
LCC Savings Summary - 95% TSL											
DOE SNOPR (GTI Scenario 0)	$561	$597	$537	$437	$492	$405	$865	$773	$949	$692	$482
GTI Scenario Int-14	-$104	-$223	-$26	-$185	-$361	-$97	$178	$6	$453	-$57	-$426
LCC Savings Summary - 98% TSL											
DOE SNOPR (GTI Scenario 0)	$506	$487	$528	$399	$405	$394	$801	$668	$956	$662	$554
GTI Scenario Int-14	-$104	-$136	-$69	-$166	-$163	-$169	$139	-$88	$396	-$40	-$344

1 Background

The Energy Policy and Conservation Act of 1975 (EPCA) requires the Department of Energy (DOE) to establish energy conservation standards for select consumer products and equipment and to update these standards when it is determined that in addition to yielding energy savings, the updated standards are technologically feasible and economically justified. Among other provisions, EPCA includes the following seven criteria for DOE to consider in its assessment of economic justification for proposed energy conservation standards:

a. The economic impact of the standard on the manufacturers and consumers of the products subject to the standard;
b. The savings in operating costs throughout the estimated average life of the products in the type (or class) compared to any increases in the price, initial charges, or maintenance expense for the products that are likely to result from the imposition of the standard;
c. The total projected amount of energy savings likely to result directly from the imposition of the standard;
d. Any lessening of the utility or the performance of the products likely to result from the imposition of the standard;
e. The impact of any lessening of competition, as determined in writing by the attorney general, that is likely to result from the imposition of the standard;
f. The need for national energy conservation; and
g. Other factors the Secretary considers relevant.

A DOE Direct Final Rule (DFR), published in the Federal Register on June 27, 2011, proposed to increase the minimum energy efficiency standards for non-weatherized residential gas furnaces to 90% AFUE in 30 states in the North Region of the United States. Under the DFR, these 90% AFUE standards were to take effect in 2013. For the DFR, DOE did not explicitly quantify the impact of fuel switching from gas furnaces to electric heating equipment. Nor did it consider the impact of related fuel switching from gas water heaters to electric water heaters. Based on concerns with the DFR, the American Public Gas Association (APGA) filed a petition challenging the 2011 DFR in court. The APGA petition requested that the court vacate the direct final rule as it applied to residential gas furnaces and remand the matter to DOE for further rulemaking proceedings to establish new efficiency standards. On April 24, 2014, the court ordered that the joint unopposed motion to vacate in part and remand for further rulemaking, filed March 11, 2014, be granted. Following the court approval of the joint motion, DOE committed to using best efforts to issue a notice of proposed rulemaking (NOPR) regarding new efficiency standards for gas furnaces within one year of the issuance of the remand and to issue a final rule within the later of two years of the issuance of the remand or one year of the issuance of the proposed rule.

Because of their concerns about the impact of a new furnace standard on fuel switching and DOE's failure to investigate fuel switching in the DFR, the American Gas Association (AGA) and APGA funded research conducted by GTI to develop and publish information on current and expected fuel switching behavior related to residential heating and water heating systems in new construction and replacement markets at national, regional, and state levels. The survey response data and accompanying spreadsheet and report, published in 2014 (https://www.aga.org/gas-technology-institute-fuel-switching-study), were intended for use in evaluating the impact of fuel switching on the technical feasibility and economic justification for increasing federal minimum efficiency requirements from non-condensing furnace efficiency levels to condensing furnace efficiency levels.

Fuel switching survey responses indicate that incremental fuel switching from gas to electric technology options is expected if the future federal minimum efficiency requirement precludes the availability of non-condensing natural gas furnaces. Fuel switching is expected to occur in both space heating and water heating systems. Differences in behavior are anticipated between builders (new construction) and contractors (new and replacement installations), with differences across regions and states. Compared to builders, contractors expect more fuel switching caused by a DOE condensing furnace rule due to additional cost and system retrofit issues to install a condensing furnace in the replacement market.

During the interim period between the settlement agreement in the DFR appeal and the issuance of a proposed rule by DOE, the gas industry used the published fuel switching survey information and related impact analysis to educate stakeholders on the potential negative societal impacts of fuel switching that would be caused by a condensing furnace minimum efficiency level. At the same time, GTI analysts evaluated the DOE life-cycle cost (LCC) analysis methodology and input parameters in detail to gain a more textured understanding of the DOE LCC model. This included an evaluation of a preliminary LCC analysis spreadsheet provided by DOE in September 2014 as well as participation in a public meeting held by DOE in November 2014 to answer questions about the new LCC spreadsheet application and methodology. With input from GTI and other stakeholders, DOE included fuel switching considerations and marginal gas prices for the first time in the preliminary LCC spreadsheet.

DOE issued a NOPR, published in the Federal Register on March 12, 2015, that proposed a single national standard at a minimum efficiency level of 92% AFUE for non-weatherized gas furnaces and mobile home gas furnaces, as shown in Table 4. Under the DOE NOPR, these 92% AFUE standards would take effect in 2021.

Table 4: DOE NOPR Proposed Standards for Residential Furnaces

Product Class	National Standard
Non-weatherized gas	92% AFUE 8.5 W Standby/Off Mode
Mobile home gas	92% AFUE 8.5 W Standby/Off Mode

In response to major concerns expressed in comments to DOE on the NOPR, DOE issued a notice of data availability (NODA), published in the Federal Register on September 14, 2015, containing a provisional analysis of the potential economic impacts and energy savings that could result from promulgating amended energy conservation standards for residential non-weatherized gas furnaces (NWGFs) that include two product classes defined by input capacity. The NODA did not consider mobile home gas furnaces. In the NODA, DOE outlined a potential alternative furnace efficiency standard that would differentiate between larger furnaces (which would be subject to more stringent minimum efficiency levels) and smaller furnaces (which would be subject to existing minimum efficiency requirements). The NODA analysis estimated impacts for several potential standard level combinations for condensing furnaces and various maximum sizes for non-condensing furnaces.

DOE subsequently issued a supplemental notice of proposed rulemaking (SNOPR) that proposes a single national standard at a minimum efficiency level of 92% AFUE for all mobile home gas furnaces and for NWGFs above 55 kBtu/h input capacity as shown in Table 5. Under the DOE SNOPR, these standards would take effect in 2022.

Table 5: DOE SNOPR Proposed Standards for Residential Furnaces

Product Class	Certified Input Capacity	National Standard
Non-weatherized gas	≤55 kBtu/h >55 kBtu/h	80% AFUE 92% AFUE 8.5 W Standby/Off Mode
Mobile home gas	All	92% AFUE 8.5 W Standby/Off Mode

The SNOPR was published in the Federal Register on September 23, 2016 and open for a 60-day public comment period through November 22, 2016. The SNOPR supersedes the DOE NOPR published March 12, 2015, and updates information provided in the DOE NODA. On September 2, 2016, DOE released a pre-publication SNOPR along with an extensive, 1,198 page, technical support document (TSD) prepared for DOE by staff members of Navigant Consulting, Inc., and Lawrence Berkeley National Laboratory (LBNL). The TSD includes a detailed review of the effects of the SNOPR as well as economic modeling and associated methodologies to assess consumer-level cost impacts, manufacturer impacts, and national impacts.

DOE's LCC analyses summarized in the DFR, NOPR, NODA, and SNOPR all yielded different results for a single product class 92% minimum AFUE national standard. Table 6 and Table 7 compare the LCC savings results adjusted to 2015$ and associated consumer impacts among those versions of the DOE LCC analysis. The LCC savings and fraction of consumers benefiting from a 92% AFUE national minimum efficiency standard increased significantly in southern markets in the SNOPR compared to the DOE DFR LCC analysis. The SNOPR LCC savings increased significantly in all market segments compared to the NODA LCC savings, while the fraction of consumers benefiting from the proposed rule were similar, except for the senior citizen market segment.

Table 6: DOE LCC Savings (2015$) for DFR, NOPR, NODA, & SNOPR (92% AFUE)

National								
	Per Impacted Furnace				Per all 10,000 Trial Case Furnaces			
TSL (% AFUE)	DFR	NOPR	NODA	SNOPR	DFR	NOPR	NODA	SNOPR
90	$202	$449	$348	$582	$96	$240	$164	$271
92	$259	$529	$426	$617	$151	$310	$226	$324
95	$273	$515	$420	$561	$226	$394	$311	$413
98	$51	$451	$344	$506	$51	$449	$342	$501

North								
	Per Impacted Furnace				Per All North Furnaces			
TSL (% AFUE)	DFR	NOPR	NODA	SNOPR	DFR	NOPR	NODA	SNOPR
90	$596	$622	$470	$701	$171	$211	$132	$189
92	$547	$698	$555	$711	$238	$282	$191	$240
95	$463	$624	$513	$597	$357	$380	$290	$335
98	$220	$471	$366	$487	$219	$475	$363	$480

Rest of Country								
	Per Impacted Furnace				Per All Rest of Country Furnaces			
TSL (% AFUE)	DFR	NOPR	NODA	SNOPR	DFR	NOPR	NODA	SNOPR
90	-$20	$359	$292	$530	-$15	$272	$201	$363
92	$26	$428	$357	$569	$21	$341	$246	$419
95	$34	$431	$357	$537	$31	$410	$247	$502
98	-$200	$420	$319	$528	-$200	$419	$220	$526

Low Income								
	Per Impacted Furnace				Per All Low Income Furnaces			
TSL (% AFUE)	DFR	NOPR	NODA	SNOPR	DFR	NOPR	NODA	SNOPR
90	NA	$314	$210	$306	$176	$179	$102	$144
92	NA	$402	$302	$353	$244	$251	$162	$186
95	NA	$442	$364	$403	$371	$336	$267	$288
98	NA	$497	$357	$518	$192	$493	$354	$511

Senior Citizen								
	Per Impacted Furnace				Per All Senior Citizen Furnaces			
TSL (% AFUE)	DFR	NOPR	NODA	SNOPR	DFR	NOPR	NODA	SNOPR
90	NA	$520	$447	$540	$196	$259	$194	$235
92	NA	$608	$522	$582	$266	$332	$256	$283
95	NA	$597	$520	$574	$399	$434	$366	$389
98	NA	$554	$479	$586	$255	$551	$476	$578

Residential - Replacements								
	Per Impacted Furnace				Per All Replacment Furnaces			
TSL (% AFUE)	DFR	NOPR	NODA	SNOPR	DFR	NOPR	NODA	SNOPR
90	-$25	$212	$167	$361	-$12	$115	$79	$169
92	$74	$310	$275	$420	$43	$182	$144	$218
95	$148	$364	$318	$437	$123	$268	$225	$307
98	-$29	$326	$236	$399	-$29	$325	$235	$395

Residential - New								
	Per Impacted Furnace				Per All New Construction Furnaces			
TSL (% AFUE)	DFR	NOPR	NODA	SNOPR	DFR	NOPR	NODA	SNOPR
90	$906	$1,171	$991	$1,263	$423	$598	$463	$580
92	$824	$1,147	$945	$1,177	$474	$670	$517	$639
95	$651	$874	$723	$865	$538	$743	$605	$723
98	$294	$780	$631	$801	$292	$777	$629	$797

Table 7: DOE Consumer Impacts for DFR, NOPR, NODA, & SNOPR (92% AFUE)

TSL (% AFUE)	DFR			NOPR			NODA			SNOPR		
National												
	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit
90	25%	52%	22%	22%	47%	32%	20%	53%	28%	18%	53%	28%
92	26%	42%	32%	20%	41%	39%	18%	47%	35%	17%	48%	35%
95	36%	17%	47%	24%	23%	53%	22%	26%	53%	22%	26%	51%
98	64%	0%	35%	40%	0%	60%	41%	0%	58%	34%	1%	65%
North												
	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit
90	10%	71%	19%	11%	67%	22%	10%	72%	18%	10%	73%	17%
92	11%	56%	33%	10%	60%	30%	9%	66%	26%	9%	66%	25%
95	23%	23%	54%	14%	40%	46%	12%	43%	45%	13%	44%	43%
98	59%	1%	41%	37%	1%	62%	39%	1%	60%	30%	1%	69%
South												
	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit
90	48%	24%	28%	33%	24%	42%	31%	31%	38%	28%	31%	41%
92	48%	20%	32%	31%	20%	49%	28%	26%	46%	26%	26%	47%
95	56%	8%	36%	35%	5%	60%	33%	6%	61%	33%	6%	61%
98	72%	0%	27%	43%	0%	57%	44%	0%	56%	39%	0%	61%
Low-Income												
	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit
90	NA	NA	NA	40%	12%	47%	22%	52%	26%	22%	52%	26%
92	NA	NA	NA	34%	9%	57%	20%	46%	34%	20%	47%	33%
95	NA	NA	NA	33%	3%	64%	24%	27%	50%	28%	27%	45%
98	NA	NA	NA	43%	0%	57%	44%	1%	55%	43%	1%	55%
Senior Citizen												
	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit
90	NA	NA	NA	21%	50%	29%	6%	86%	8%	17%	57%	25%
92	NA	NA	NA	19%	45%	36%	6%	83%	11%	17%	51%	32%
95	NA	NA	NA	23%	27%	50%	9%	69%	22%	22%	30%	48%
98	NA	NA	NA	39%	1%	60%	39%	3%	58%	34%	1%	64%
Residential - Replacements												
	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit
90	31%	52%	17%	28%	46%	26%	25%	52%	22%	24%	53%	23%
92	32%	42%	27%	25%	41%	34%	23%	47%	30%	22%	48%	30%
95	41%	17%	42%	27%	26%	46%	25%	29%	45%	26%	30%	44%
98	67%	0%	32%	44%	0%	56%	46%	0%	54%	39%	1%	59%
Residential - New												
	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit	Net Cost	No Impact	Net Benefit
90	7%	53%	40%	4%	49%	47%	3%	53%	43%	3%	54%	43%
92	9%	42%	49%	4%	42%	55%	3%	45%	51%	3%	46%	51%
95	21%	17%	62%	13%	15%	72%	10%	16%	74%	11%	16%	73%
98	55%	1%	44%	27%	0%	72%	26%	0%	73%	19%	0%	81%

This report is a follow-up to technical reports GTI-15/0002, "Technical Analysis of DOE Notice of Proposed Rulemaking on Residential Furnace Minimum Efficiencies" http://www.gastechnology.org/reports_software/Documents/21693-Furnace-NOPR-Analysis-FinalReport_2015-07-15.pdf, and GTI-15/0003, "Technical Analysis of Furnace Sizing for the DOE Notice of Data Availability on Residential Furnace Minimum Efficiencies" http://www.gastechnology.org/reports_software/Documents/21853-Furnace-NODA-Analysis-Task-Report-10-14-2015.pdf. GTI-15/0002 included a comprehensive technical and economic analysis of the DOE NOPR calling for a minimum national furnace efficiency of 92% AFUE and pointed to significant deficiencies in the DOE NOPR LCC analysis, including:

- A flawed random furnace assignment methodology which deviated from a rational economic decision framework,
- A flawed fuel switching analysis methodology, and
- Use of outdated and inferior input data.

Addressing these deficiencies and shortcomings, GTI's scenario analyses showed the proposed standard in the NOPR, instead of yielding positive national benefits, would instead result in: 1) negative average lifecycle cost savings and 2) increased primary energy consumption and greenhouse gas emissions (from fuel switching from natural gas to electric options that are less efficient on a primary energy basis). GTI's NODA analysis confirmed these findings for a minimum national furnace efficiency of 92% AFUE and highlighted flaws in the DOE furnace sizing methodology for a separate product class based on furnace input capacity.

Table 8 and Table 9 provide a recap of the comparison of the NOPR, NODA, and GTI scenario analysis findings, underscoring the average negative costs, higher proportion of consumers faced with a net cost (27% of the population), and reduced level of consumers who would experience a net benefit (only 17% of the population) in the NOPR. GTI's analysis of the NOPR and NODA shows negative average savings for all single standard TSLs (compared to DOE's findings of positive savings). The single standard results in the NODA did not appreciably alter the overall negative average savings findings in the GTI analysis of the NOPR. For the first time in the NODA, DOE used a new segmentation grouping of "impacted furnaces" in place of "all furnaces" in the LCC savings calculations. The "impacted furnaces" approach to summarizing information was also used in the DOE SNOPR for LCC savings, but not for fuel switching fractions.

A 1,198 page technical support document (TSD) prepared for DOE by staff members of LBNL and Navigant Consulting, Inc. provides the technical rationale for DOE's determination that the proposed standard in the SNOPR is technologically feasible, economically justified, and will save significant amounts of energy. The technical basis of the life cycle cost and payback period analysis described in detail in Chapter 8 of the TSD is a complicated LCC spreadsheet tool developed by LBNL for DOE over a period of several years for use in several rulemakings, including this SNOPR. The DOE LCC model uses an Excel® spreadsheet that invokes the Oracle® Crystal Ball predictive modeling and forecasting software. DOE used this spreadsheet modeling tool to predict the LCC and payback periods (PBP) for the proposed efficiency increases. Figure 1 shows the flow chart for the DOE TSD analysis. Figure 2 and Figure 3 show the summary tables of the results included in the SNOPR for non-weatherized gas furnaces and mobile home gas furnaces.

Table 8: Lifecycle Cost and Rulemaking Market Impact

LCC Model	Average Furnace Life-cycle Cost (LCC) Savings	Fraction of Furnace Population (%)		
		Net Cost	No Impact	Net Benefit
DOE NOPR LCC Model	$305	20%	41%	39%
GTI Integrated Scenario Int-5	-$181	27%	57%	17%

Table 9: National Average LCC Savings for DOE NOPR and NODA LCC Models

TSL (% AFUE)	DOE NOPR Analysis	GTI NOPR Analysis	DOE NODA Analysis	GTI NODA Analysis
	NODA (Impacted Furnaces Only)			
90	$441	-$571	$347	-$592
92	$520	-$417	$425	-$442
95	$507	-$631	$420	-$651
98	$443	-$458	$343	-$475
	NOPR (All Furnaces)			
90	$236	-$215	$163	-$225
92	$305	-$181	$225	-$190
95	$388	-$445	$311	-$462
98	$441	-$447	$341	-$466

It appears that DOE corrected an error in the NOPR in its updated SNOPR LCC model analysis that may have impacted LCC savings calculations in the SNOPR. DOE appears to have changed one of their nested, indexed, if then statements when assigning the AFUE of the existing furnace for each residential trial case. In the SNOPR, DOE revised the "Region ID" for AFUE existing assignment for residential cases as follows:

NOPR: *=IF(INDEX(_Div,D3)<8,INDEX(_Div,D3),IF(INDEX(_Div,D3)=10, 9, 8))*

SNOPR: *=IF(INDEX(_ResCom, D3) = 1, INDEX(BldgRegions, D3), IF(INDEX (BldgRegions,D3) <8,INDEX(BldgRegions,D3),IF(INDEX(BldgRegions,D3)=10, 9, 8)))*

The "Region ID" used to select the "AFUE existing" was always based on the census division in the NOPR for both residential and commercial cases, rather than pulling census division only when commercial, and using RECS regions for residential. The NOPR error biased the selection to cold regions because census divisions 1-9 by chance are cold RECS regions. That would tend to make the NOPR "AFUE existing" relatively higher efficiency on average because cold regions have historically higher adoption rates of higher efficiency furnaces. The DOE NOPR cold climate bias error led to relatively lower building heating loads because DOE estimated building heating load by taking fuel consumption and dividing by the "AFUE existing" efficiency, resulting in erroneously lower potential for gas savings in the NOPR. The SNOPR equation appears to have corrected this error, though no explanation was found in the TSD.

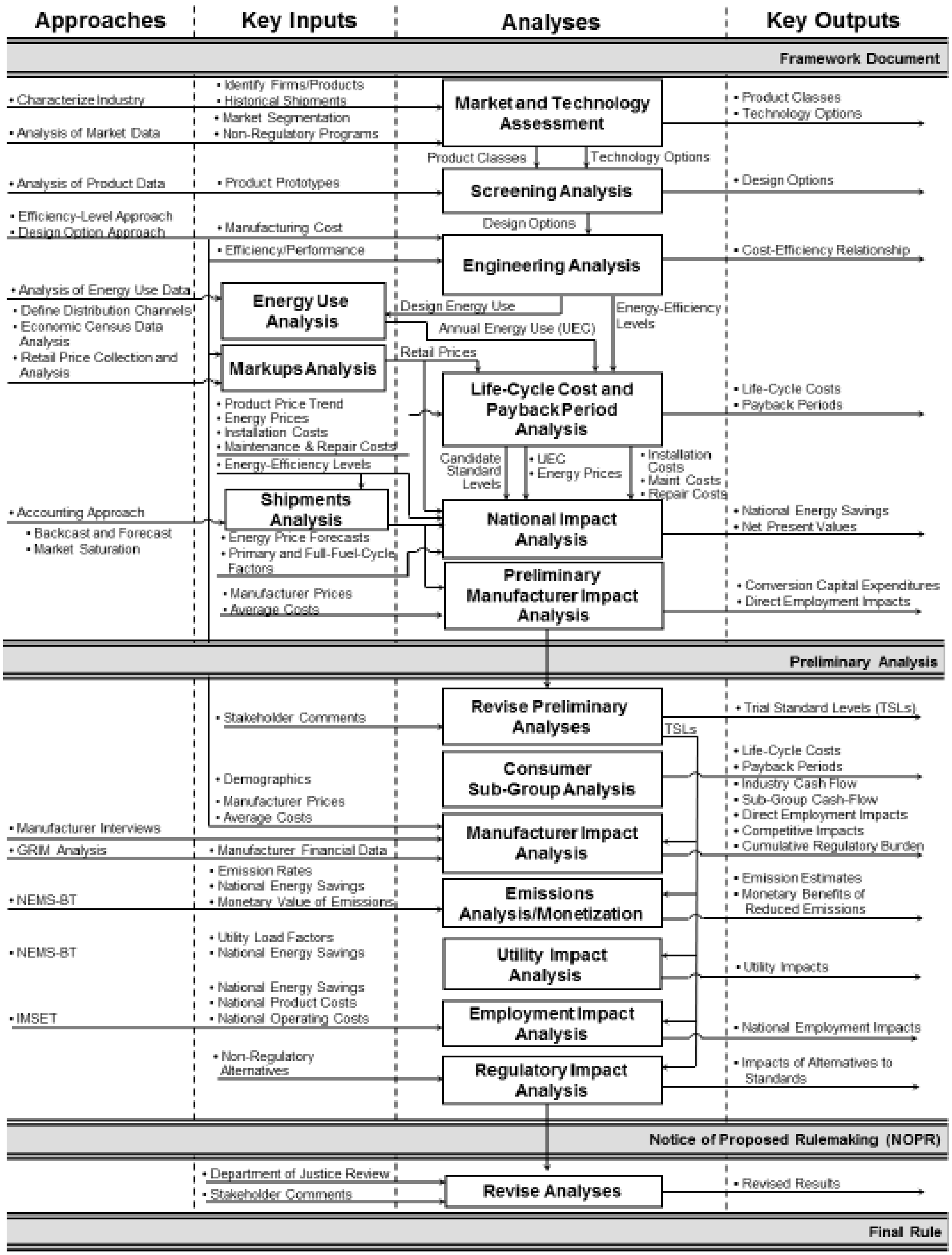

Figure 1: DOE SNOPR Technical Support Document Analysis Methodology

Source: DOE SNOPR TSD Chapter 2[1]

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1 U.S. Department of Energy Docket website. "Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Furnaces." Chapter 2. Analytical Framework. https://www.regulations.gov/document?D=EERE-2014-BT-STD-0031-0217

Table 8.6.1 Average LCC and PBP Results by AFUE Standard Efficiency Level for Non-Weatherized Gas Furnaces

EL	AFUE	Average Costs 2015$				Simple Payback years	Average Lifetime years
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
National							
0	80%	2,175	684	11,020	13,194	N/A	21.5
1	90%	2,597	623	10,026	12,623	6.8	21.5
2	92%	2,635	612	9,859	12,493	6.4	21.5
3	95%	2,742	597	9,608	12,350	6.5	21.5
4	98%	2,858	586	9,403	12,261	6.9	21.5
North							
0	80%	2,370	870	13,868	16,238	N/A	21.5
1	90%	2,919	792	12,675	15,595	7.1	21.5
2	92%	2,962	778	12,460	15,422	6.5	21.5
3	95%	3,083	758	12,149	15,231	6.4	21.5
4	98%	3,217	742	11,867	15,083	6.6	21.5
Rest of Country							
0	80%	1,955	476	7,809	9,763	N/A	21.5
1	90%	2,234	431	7,040	9,274	6.3	21.5
2	92%	2,266	425	6,926	9,192	6.1	21.5
3	95%	2,358	415	6,745	9,103	6.6	21.5
4	98%	2,453	410	6,626	9,079	7.5	21.5

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8.6.9 Average LCC and PBP Results by Efficiency Level for AFUE Standards for Large Non-Weatherized Gas Furnaces with an Input Capacity >55 kBtu/h

EL	AFUE	Average Costs 2015$				Simple Payback years	Average Lifetime years
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
National							
0	80%	2,175	684	11,020	13,194	N/A	21.5
1	90%	2,542	628	10,127	12,668	6.5	21.5
2	92%	2,576	618	9,971	12,547	6.1	21.5
3	95%	2,672	604	9,737	12,410	6.2	21.5
4	98%	2,775	593	9,540	12,315	6.6	21.5
North							
0	80%	2,370	870	13,868	16,238	N/A	21.5
1	90%	2,893	795	12,718	15,610	7.0	21.5
2	92%	2,933	782	12,510	15,444	6.4	21.5
3	95%	3,048	763	12,209	15,257	6.3	21.5
4	98%	3,176	746	11,932	15,108	6.5	21.5
Rest of Country							
0	80%	1,955	476	7,809	9,763	N/A	21.5
1	90%	2,146	440	7,206	9,352	5.3	21.5
2	92%	2,173	434	7,109	9,282	5.2	21.5
3	95%	2,248	425	6,951	9,199	5.8	21.5
4	98%	2,324	420	6,844	9,167	6.6	21.5

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Figure 2 DOE LCC and PBP Results for Non-Weatherized Gas Furnaces

Source: DOE SNOPR TSD Chapter 8[2]

2 U.S. Department of Energy Docket website. "Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Furnaces." Chapter 8. Life-Cycle Cost and Payback Period Analysis. https://www.regulations.gov/document?D=EERE-2014-BT-STD-0031-0217

Table 8.6.29 Average LCC and PBP Results by AFUE Standards Efficiency Level for Mobile Home Gas Furnaces

EL	AFUE	Average Costs 2015				Simple Payback years	Average Lifetime years
		Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
National							
0	80%	1,515	785	12,216	13,731	0.0	21.5
1	92%	1,667	698	10,924	12,591	1.7	21.5
2	95%	1,800	679	10,643	12,443	2.7	21.5
3	96%	1,846	677	10,599	12,445	3.1	21.5
North							
0	80%	1,558	919	14,208	15,766	0.0	21.5
1	92%	1,711	816	12,678	14,389	1.5	21.5
2	95%	1,843	793	12,336	14,179	2.3	21.5
3	96%	1,890	789	12,275	14,165	2.6	21.5
Rest of Country							
0	80%	1,445	569	9,011	10,456	0.0	21.5
1	92%	1,596	508	8,102	9,698	2.5	21.5
2	95%	1,730	496	7,919	9,649	3.9	21.5
3	96%	1,776	495	7,902	9,678	4.5	21.5

Note: The results for each EL are calculated assuming that all consumers use products with that efficiency level. The PBP is measured relative to the baseline product.

Figure 3 DOE Lifecycle Cost and Payback Period Results for Mobile Home Gas Furnaces

Source: DOE SNOPR TSD Chapter 8[3]

The underlying methodology and multiple inter-related variables in the DOE predictive LCC model strongly affect the results of LCC and PBP analyses, which jointly serve as the technical basis for DOE's determination that the proposed rule is economically justified. The methodologies and input data used within the DOE predictive LCC spreadsheet tool used to justify the 92% AFUE furnace standard with or without a separate product class for non-condensing furnaces based on capacity for non-weatherized gas furnaces are the primary focus of this report and accompanying spreadsheets.

3 U.S. Department of Energy Docket website. "Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Furnaces." Chapter 8. Life-Cycle Cost and Payback Period Analysis. https://www.regulations.gov/document?D=EERE-2014-BT-STD-0031-0217

2 LCC Analysis Methodology

2.1 Overview

Energy efficiency regulations for consumer products are legislatively authorized market interventions in response to perceived market failures that may cause consumers not to purchase higher efficiency products even though the consumer would benefit financially. Examples of possible unregulated market or market transformation failures, some of which are highlighted by DOE in the SNOPR, include:

- Split incentives (e.g., home builder vs. homeowner; landlord vs. tenant)
- Ignorance (e.g., consumer is unaware of benefits or costs)
- Limited access to capital (e.g., consumer charges large investments on high interest credit cards)
- Ineffective wealth transfer (e.g., poorly implemented incentives by regulated entities)

Energy efficiency regulations are a powerful tool with no recourse for those impacted, so it is important to ensure that each regulation positively addresses a known market failure not addressed adequately by another means, without the imposition of inordinate costs or unintended consequences. To provide net societal benefits, it is important to ensure that each regulation provides overall financial benefit and minimizes financial loss to consumers negatively impacted by the regulatory intervention.

Under DOE's LCC analysis methodology, financial benefits accrue when the present value of future savings is sufficient to offset the first cost premium of the more efficient product through lower operating costs over the life of the product. Otherwise financial losses accrue. LCC analysis is extremely complex to apply to large populations due to the likelihood of significant differences in LCC benefits across various segments of the impacted population. Variables of interest for the non-weatherized gas furnace LCC analysis include:

- Baseline furnace design
- Higher efficiency furnace designs
- Fuel switching options
- Energy prices
- Furnace capacities
- Furnace prices
- Installation costs
- Furnace life
- Maintenance costs
- Discount rates
- Local and regional factors
- Differences in consumer subcategories

To account for these and other variables, the DOE LCC analysis spreadsheet model methodology uses complex algorithms that include interactive impacts among a large number of input parameters. Some algorithms, such as manufacturer component costs and consumer decision making logic, use proprietary or confidential technical and cost information. DOE's methodology includes a combination of fixed (deterministic) values, partial or full distributions, and random assignments to conduct its forecasting analysis. After incorporating all these various deterministic values, distributions, and random assignments, the DOE LCC analysis model provides a single answer for key parameters rather than a probability distribution of possible results with error bars or other indicator of accuracy, precision, and confidence level.

Building on previous work described in GTI-15/0002 and GTI-15/0003, GTI analysts conducted parametric scenario analyses to evaluate the impact of changes to the DOE SNOPR LCC model in five topical areas:

- Base Case Decision Making Algorithms Incorporating Non-Economic Factors
- Technology and Fuel Switching Decision Making Algorithms
- Furnace Sizing Algorithms
- Input Data Modifications
- Integrated Scenarios

Parametric analyses conducted by GTI analysts in response to the DOE NOPR, NODA, and SNOPR incorporate a higher degree of granularity than was provided in the corresponding DOE LCC spreadsheet model output files and published results. Additional detail was required to conduct the desired analyses on individual trial cases, Base Case assignment decisions, fuel switching decisions, furnace sizing decisions, and subcategory impacts (e.g., state-level, low income, senior citizen, or housing type subcategories).

To explore the impact of various parameters on LCC results, GTI analysts added Excel Visual Basic for Applications (VBA) code to the DOE LCC spreadsheet. The VBA code extracted outputs of interest from each of the 10,000 Crystal Ball trial cases and enabled a detailed analysis of the DOE LCC spreadsheet as well as GTI's parametric scenarios. The code that was used to extract outputs of interest did not affect any calculations in the DOE SNOPR LCC models or any of the GTI parametric runs that examined the Base Case, technology, and fuel switching decision making methodology, furnace sizing algorithms, input data modifications, and integrated scenarios.

Table 10 shows the matrix of parametric scenarios associated with the 2015 DOE NOPR that GTI explored in detail in GTI-15/0002. Appendix A, Sections A.2 through A.10, of GTI-15/0002 provide descriptions of these parametric runs and associated results.

Table 11 shows the matrix of incremental and updated parametric scenarios that GTI explored under the SNOPR for this project. The main body of this report describes and summarizes results of GTI Scenario Int-14 cases and constituent Parametrics. GTI Scenario Int-14, an updated and modified version of GTI NOPR Scenario Int-5, was selected for comparison with the 92% AFUE single product class TSL 5 in the SNOPR (GTI Scenario 0) to address the following issues:

- Base Case furnace assignment that aligns with AHRI condensing furnace fractions and economic decision making criteria,
- Application of American Home Comfort Study information for fuel switching decisions that results in reasonable alignment with DOE fuel switching fractions when using a CED framework for Base Case furnace assignment and fuel switching decisions,
- Improved data for furnace prices, condensing furnace fractions, and marginal gas prices,
- Incorporation of AEO 2016 Clean Power Plan* Scenario forecast information for comparisons with anticipated DOE final rule benefits calculations, and

*Note: The U.S. Supreme Court has temporarily blocked the EPA Clean Power Plan implementation.

- Application of a time-horizon-based distribution function based on the DOE LCC model payback period for each of the 10,000 trial cases for consumer economic decision making that monetizes the impact of imperfect market and non-economic consumer decision making factors into the LCC analysis for comparisons within the GTI CED framework.

GTI Scenario Int-14.55, the SNOPR proposed rule case under GTI Scenario Int-14, was selected to examine the impact of a 55 kBtu/h furnace capacity limit for non-condensing furnaces on rule benefits for direct comparisons with the DOE SNOPR proposed rule TSL 6 (GTI Scenario 0.55). GTI Scenario Int-14.55 includes a furnace capacity algorithm for each trial case based on annual heating consumption rather than home size and uses the DOE furnace "downsizing" methodology.

The following Excel spreadsheets accompanying this report provide tabular results of the GTI parametric analysis of the DOE SNOPR:

- 22063 Short LCC tables - all EL 2016-11-21.xlsx,
- 22063 Short Switching Tables 2016-11-21.xlsx, and
- 22063 Energy Use Tables 2016-11-21.xlsx.

These spreadsheets provide detailed results tables and supporting information for each of the scenarios evaluated in this report, along with the shorter summary tables included in this report. These documents are available to the public at:

http://www.gastechnology.org/reports_software/Documents/Technical-Analysis-of-DOE-Supplemental-Notice-of-Proposed-Rulemaking-on-Residential-Furnace-Minimum-Efficiencies.pdf

http://www.gastechnology.org/reports_software/Documents/22063-Short-LCC-tables-all-EL-2016-11-21.zip

http://www.gastechnology.org/reports_software/Documents/22063-Short-Switching-Tables-2016-11-21.zip

http://www.gastechnology.org/reports_software/Documents/22063-Energy-Use-Tables-2016-11-21.zip

2.2 Consumer Economic Decision Analysis Framework

To demonstrate economic justification for a condensing furnace efficiency rule, the DOE SNOPR LCC analysis methodology needs to show overall financial benefit to those consumers that would otherwise not have selected a condensing furnace without the rule. The use of rational consumer economic decision making and payback principles provides a consistent framework for evaluating the impact of the proposed new rulemaking on consumers. The DOE SNOPR LCC model Base Case furnace assignment methodology fails to use a rational consumer economic decision framework, which results in nonsensical furnace selections and unwarranted claimed rule benefits.

A Consumer Economic Decisions (CED) analysis framework places consumer furnace purchase decisions into four categories based on financial benefit or financial loss:

Category 1: Consumers that choose a condensing furnace and accrue financial benefit
Category 2: Consumers that choose a condensing furnace and suffer financial loss
Category 3: Consumers that do not choose a condensing furnace and do not accrue financial benefit
Category 4: Consumers that do not choose a condensing furnace and do not suffer financial loss

Table 12 characterizes CED categories related to furnace purchasing decisions based on unregulated market factors, market transformations, and regulatory interventions. Based on unregulated market economics, consumers in Categories 1 and 4 are considered market successes, and consumers in Categories 2 and 3 are considered market failures under the CED framework. It is challenging to determine whether a consumer choosing a condensing furnace is in Category 1 or 2, and equally challenging to determine whether an individual consumer not choosing a condensing furnace is in Category 3 or 4.

Market transformation initiatives succeed when they address Category 3 unregulated market failures through incentives coupled with education and outreach, shifting them to Category 1. However, there is also the potential for free riders in Categories 1 and 2 if those consumers would have purchased the condensing furnace without the incentive. Market transformation incentives may also induce consumers in Category 4 based on unregulated market economics to shift to Category 1 or 2, an undesirable outcome for the market transformation initiative. For these reasons, market transformation initiatives such as utility energy efficiency programs receive a great deal of scrutiny and regulatory oversight before such incentive programs are approved.

U.S. natural gas utilities managed energy efficiency and market transformation programs in excess of $1.44 billion in 2014 (according to the Consortium for Energy Efficiency). Of this total, $830 million is aimed at adoption of more energy efficient options for residential ($541 million) and low income consumers ($289 million). A new Federal condensing furnace efficiency standard would curtail the ability of natural gas energy efficiency programs to positively influence consumer selection of high-efficiency furnaces. The loss of consumer incentives could also result in a shift to less source energy efficient electric heating options.

Table 10: GTI Parametric Analysis Scenarios for DOE NOPR

	DOE NOPR	D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14
Scenario 0	X																											
Scenario 1			X																									
Scenario 2				X																								
Scenario 3					X																							
Scenario 4						X	X																					
Scenario 5						X		X																				
Scenario 6						X			X																			
Scenario 7										X																		
Scenario 8			X							X																		
Scenario 9				X		X		X		X																		
Scenario 10						X		X		X																		
Scenario 11						X	X			X																		
Scenario 12						X			X	X																		
Scenario 13			X			X			X																			
Scenario 14			X			X			X	X																		
Scenario 15											X																	
Scenario 16												X																
Scenario 17										X	X																	
Scenario 18										X		X																
Scenario 19	X	X																										
Scenario 20		X				X	X																					
Scenario 21		X				X		X																				
Scenario 22		X				X			X																			
Scenario 23			X			X	X			X																		
Scenario 24				X		X	X			X																		
Scenario 25					X	X	X			X																		
Scenario 26				X						X			X															
Scenario 27				X						X				X														
Scenario I-1															X													
Scenario I-2																X												
~~Scenario I-3~~																												
~~Scenario I-4~~																												
Scenario I-5																			X									
Scenario I-6																				X								
~~Scenario I-7~~																												
Scenario I-8																						X						
~~Scenario I-9~~																												
Scenario I-10																								X				
Scenario I-11																									X			
~~Scenario I-12~~																												
Scenario I-13																											X	
~~Scenario I-14~~																												
Scenario I-15																				X		X					X	
Scenario I-16																X				X		X					X	
Scenario Int 1 (Scenarios 24 & I-15)				X		X	X			X										X		X					X	
Scenario Int 2 (Scenario 23 & I-15)			X			X	X			X										X		X					X	
Scenario Int 3 (Scenarios 18 & I-15)										X		X								X		X					X	
Scenario Int 4 (Scenarios 17 & I-15)										X	X	X								X		X					X	
Scenario Int 5 (Scenarios 24 & I-16)				X		X	X			X						X				X		X					X	
Scenario Int 6 (Scenario 23 & I-16)			X			X	X			X						X				X		X					X	
Scenario Int 7 (Scenarios 18 & I-16)										X		X				X				X		X					X	
Scenario Int 8 (Scenarios 17 & I-16)										X	X	X				X				X		X					X	
Scenario Int 9 (Scenarios 26 & I-16)				X						X			X			X				X		X					X	
Scenario Int 10 (Scenarios 27 & I-16)				X						X				X		X				X		X					X	

Table 11: GTI Parametric Analysis Scenarios for DOE SNOPR

	DOE SNOPR	D2	D4	D5	D8	D11	D12	D13	D14	I2	I6	I13	I17	F1	92% EL only
Scenario 0	X														
Scenario 2		X													X
Scenario 7					X										X
Scenario 24		X	X	X	X									X	X
Scenario 28		X			X	X									X
Scenario 29		X			X		X								X
Scenario 30						X									X
Scenario 31							X								X
Scenario 32								X							X
Scenario 33					X			X							X
Scenario 36		X			X				X					X	X
Scenario 39									X					X	X
Scenario F1														X	X
Scenario I2, I6										X	X				X
Scenario I2,I6, I13										X	X	X			X
Scenario I17													X		X
Scenario Int-11		X	X	X	X					X	X	X		X	
Scenario Int-12		X	X	X	X					X	X	X	X	X	
Scenario Int-13		X			X				X	X	X	X		X	
Scenario Int-14		X			X				X	X	X	X	X	X	

Note: Several Scenarios were run with and without Parametric F1

It is possible that unregulated market factors and market transformation initiatives still do not induce consumers in Category 3 to make energy efficiency decisions that accrue financial benefit. Codes, regulations, and legislation are intended to override those approaches and force Category 3 consumers to shift to Category 1 to accrue the financial benefit. However, these interventions are mandatory, and will force Category 4 consumers to shift to Category 2 and incur financial losses. The interventions may also induce them to switch to electric heating options (that may or may not have financial losses) to mitigate financial losses associated with the higher first cost condensing furnace. They may also induce Category 3 consumers to switch to lower first cost electric heating options (that may or may not have financial losses) to mitigate perceived financial losses associated with the higher first cost condensing furnace.

The implications for the DOE SNOPR are significant. The unregulated market and market transformation shortcomings that the DOE rule addresses are confined to Category 3 consumers, but the DOE rule also impacts consumers in other categories, especially Category 4. However, it is not easy to determine who is actually in Category 3 or Category 4. Numerous financial and operational parameters impact consumers' decisions, and desired analytical information is often scarce or difficult to obtain. Given the myriad options for information, it is also important to prioritize the sources of information for the LCC analysis, and to use the best sources of information that are publicly available whenever possible.

Table 12 Consumer Economic Decision Making Framework

Consumer Economic Decision Making Based on Unregulated Market Factors, Market Transformations, and Regulatory Interventions		
Unregulated Market (Based on Economic Factors)	Financial Benefit (Acceptable Payback)	Financial Loss (Unacceptable Payback)
Select Condensing Furnace (48.5% of purchases in 2014).	**Category 1** Rational decision.	**Category 2** Irrational decision.
Do Not Select Condensing Furnace (51.5% of purchases in 2014).	**Category 3** Irrational decision.	**Category 4** Rational decision.
Market Transformation (Energy Efficiency Incentives)	Financial Benefit (Acceptable Payback or LCC)	Financial Loss (Unacceptable Payback or LCC)
Select Condensing Furnace.	Rational decision. Incentives may induce Category 3 or Category 4 consumers to make rational decision. May also have Category 1 free riders.	Irrational decision. Incentives may induce Category 4 consumers to make irrational decision. May also have Category 2 free riders.
Do Not Select Condensing Furnace.	Irrational decision. Incentives do not induce Category 3 consumers to make rational decision.	Rational decision. Incentives do not induce Category 4 consumers to make irrational decision.
Regulatory Intervention (Codes, DOE Rule, Legislation)	Financial Benefit (Acceptable LCC)	Financial Loss (Unacceptable LCC)
Select Condensing Furnace.	Intervention does not impact Category 1 consumers. May force Category 3 consumers to make rational decision.	Intervention does not impact Category 2 consumers. May force Category 4 consumers to make irrational decision.
Do Not Select Condensing Furnace.	May force Category 3 consumers to fuel switch.	May force Category 4 consumers to fuel switch.

Objective and credible market data, such as AHRI shipment data, furnace prices, furnace sizes, installation costs, marginal natural gas and electricity prices, and heating energy consumption are top priorities to ensure a credible LCC analysis. It is critical for economic parameter calculations such as equipment and installation costs, baseline conditions, required furnace sizing, and energy prices. Where such market data and statistics are not available, topical consumer and industry surveys such as the proprietary American Home Comfort Study and the nationwide fuel-switching survey of builders and installing contractors are valuable in helping understand expected behavior. If these sources of information are not available, construction and engineering principles may be useful, but are prone to systematic and random errors, especially when aggregating component level engineering estimates to system level costs. Finally, if none of the above information is available for a topic, persuasive anecdotal information may also have a role, such as “spot checking” the reasonableness of estimates.

Consumers make purchase decisions based primarily on economics, but consider factors other than economics as well, including product performance or reliability, manufacturer reputation, intangible societal benefits, and perceived risks and rewards associated with the decision. Table 13 characterizes consumer decision making related to condensing furnaces, including economic and non-economic factors, based on unregulated market factors, market transformations, and regulatory interventions. This is a more complete decision making analytical framework because it acknowledges the value consumers attach to differentiating attributes such as delivered air temperature or risk-based decisions due to unique financial circumstances. It is possible to monetize such consumer behavioral decisions, but DOE chose not to address non-economic factors in the DOE SNOPR LCC Base Case furnace assignment methodology. In response to a request for suggested options by DOE in the SNOPR, GTI was able to add a set of parametrics in this report that estimate the relative impact of economic and non-economic factors in consumer purchase decisions within the LCC analysis CED framework.

2.3 Base Case Furnace Assignment Methodology

The DOE SNOPR LCC model includes economic criteria and a distribution of allowable cost recovery times in its trial standard level (TSL) furnace analysis and fuel switching decision algorithm. However, DOE's Base Case furnace assignment algorithm ignores economic decision making parameters for an individual trial case. Instead, the Base Case AFUE, which is the efficiency of the furnace that is chosen by an individual consumer without the influence of DOE's rule, is assigned randomly to each of the 10,000 trial cases in the DOE SNOPR LCC model. The economics of a particular efficiency level selection compared to other levels (e.g., 80% AFUE vs. 92% AFUE) are not considered in DOE's baseline furnace decision for any of the 10,000 Crystal Ball trial cases. Figure 4 illustrates the DOE random Base Case furnace assignment algorithm. Appendix A, Section A.2.1 provides further details on the DOE random Base Case furnace assignment methodology.

DOE's decision to use a random assignment methodology to assign Base Case furnace efficiency to each of the trial cases in the Crystal Ball simulation is a significant technical flaw with meaningful impact on the DOE SNOPR LCC results. A random assignment methodology misallocates a random fraction of consumers that use economic criteria for their decisions and results in higher LCC savings compared to rational economic decision making criteria. DOE's Base Case furnaces in the 10,000 Crystal Ball trial case homes are intended to be representative of the RECS survey furnace distribution across various locations and categories. Random assignment of the Base Case furnace does not achieve this key objective and is not a technically defensible proxy for rational residential decision making processes. Figure 5 shows GTI's Base Case furnace assignment algorithm that incorporates a CED framework into the trial case assignments to provide a reasonable, technically defensible Base Case furnace assignment algorithm for the LCC analysis.

Table 14 and Table 15 provide illustrative examples of Crystal Ball trial case homes that result in overstated savings due to the DOE random Base Case furnace assignment methodology compared to economic decision making criteria. The overstated savings in the DOE SNOPR LCC model occur because DOE's random assignment puts non-condensing furnaces in buildings that would purchase condensing furnaces based on limited economic decisions (Table 14); and puts condensing furnaces in buildings that would not purchase condensing furnaces based on limited economic decisions (Table 15) and categorizes these as no impact. These technical flaws inappropriately skew the DOE SNOPR analysis results significantly in favor of rule benefit.

Table 13 Consumer Economic and Non-Economic Decision Making Framework

Consumer Economic and Non-Economic Decision Making Based on Unregulated Market Factors, Market Transformations, and Regulatory Interventions		
Unregulated Market (Based on Economic and Non-Economic Factors)	Financial Benefit (Acceptable Payback)	Financial Loss (Unacceptable Payback)
Select Condensing Furnace (48.5% of purchases in 2014).	**Category 1** Rational decision based on economic and non-economic factors.	**Category 2** Irrational decision based on economics. Rational decision based on non-economic factors.
Do Not Select Condensing Furnace (51.5% of purchases in 2014).	**Category 3** Irrational decision based on favorable economics. Driven by non-economic factors or market imperfections. Incentives may or may not improve decision.	**Category 4** Rational decision based on unfavorable economics coupled with non-economic factors. Incentives may impact decision.
Market Transformation (Energy Efficiency Incentives)	Financial Benefit (Acceptable Payback or LCC)	Financial Loss (Unacceptable Payback or LCC)
Select Condensing Furnace.	Incentive may have changed rational or irrational Category 3 decision. May also have changed Category 2 or Category 4 economics. May also have Category 1 free riders.	Irrational economic decision. May also have changed Category 4 decision based on non-economic factors. May also be a Category 2 free rider based on non-economic factors.
Do Not Select Condensing Furnace.	Incentives do not induce Category 3 consumers to make a rational economic decision. May also be a rational decision due to non-economic factors.	Rational decision based on unfavorable economics coupled with non-economic factors. Incentives do not induce Category 4 consumers to change their decision.
Regulatory Intervention (Codes, DOE Rule, Legislation)	Financial Benefit (Acceptable LCC)	Financial Loss (Unacceptable LCC)
Select Condensing Furnace.	Intervention does not impact Category 1 consumers. May force Category 3 consumers to make rational economic decision, or may force irrational decision based on rational non-economic factors.	Intervention does not impact Category 2 consumers. May force Category 4 consumers to make irrational decision.
Do Not Select Condensing Furnace.	May force Category 3 consumers to fuel switch.	May force Category 4 consumers to fuel switch.

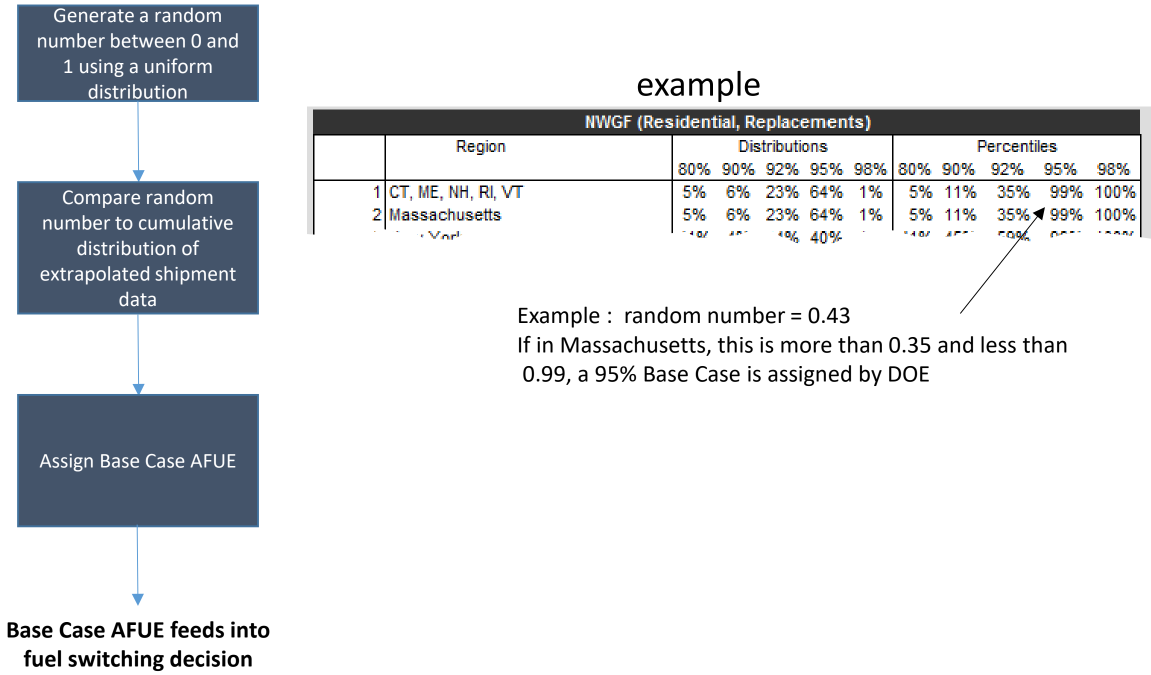

Figure 4 GTI Illustration of DOE Random Base Case Furnace Assignment Algorithm

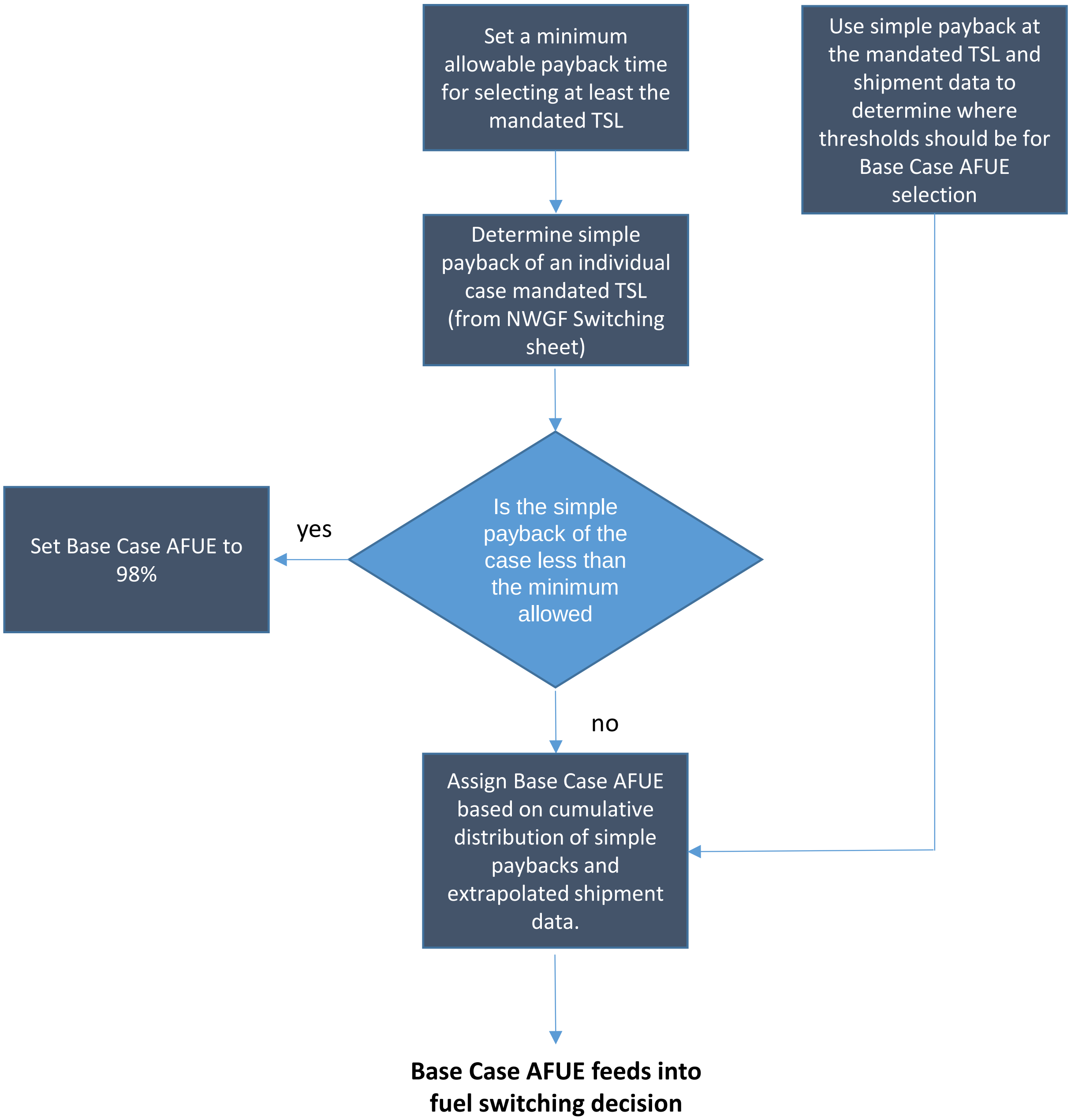

Figure 5 GTI Economic Decision Base Case Furnace Assignment Flow Chart

Table 14 illustrates a subset of TSL 5 trial cases classified by DOE as benefitted by the rule ("Net Benefit") that would almost certainly have condensing furnaces and therefore would not be impacted by the rule. These cases would be excluded from the LCC analysis as "No Impact" under rational economic and non-economic criteria. Table 15 shows a subset of TSL 5 trial cases excluded from DOE's LCC analysis as "No Impact" because they were inappropriately assigned a condensing furnace and excluded from the analysis. These cases would likely be negatively impacted by the rule as "Net Cost" and included in the LCC analysis if decisions were based on economic and non-economic criteria rather than assigned by a random number.

Table 14 Cases Included as "Net Benefit" in the DOE SNOPR TSL 5 LCC Model

Crystal Ball Trial Case	92% vs. 80%		LCC Savings		Region/ Location	Type	Payback (Years)
	Cost Penalty	Annual Savings	DOE	GTI Scenarios			
366	-$1,759	$61	$3,052	No Impact	South / California	Residential Replacement	-29
9122	-$1,620	$151	$4,502	No Impact	North/ New York	Residential New	-11
3682	-$1,592	$43	$2,320	No Impact	South / Carolina	Residential Replacement	-37
2312	-$1,266	$176	$4,120	No Impact	North/ New Jersey	Residential New	-7
6651	-$1,242	$177	$6,371	No Impact	North/ OR, WA	Residential New	-7
8835	-$1,192	$168	$5,621	No Impact	North/ Illinois	Residential New	-7

Table 15 Cases Considered "No Impact" in the DOE SNOPR TSL 5 LCC Model

Crystal Ball Trial Case	92% vs. 80%		LCC Savings		Region/ Location	Type	Payback (Years)
	Cost Penalty	Annual Savings	DOE	GTI Scenarios			
1758	$4,890	$51	No Impact	-$4,183	North/ New York	Residential Replacement	95
7406	$3,937	$113	No Impact	-$3,484	North/ Michigan	Residential Replacement	35
8377	$3,409	$26	No Impact	-$6,299	South/ Carolina	Residential Replacement	132
7010	$1,805	$17	No Impact	-$1,575	South/ California	Residential Replacement	109
9467	$1,548	$1	No Impact	-$1,621	North/ OR, WA	Residential Replacement	1338
5439	$1,192	$17	No Impact	-$1,173	North/ IA, MN, ND, SD	Residential Replacement	71

Table 16 provides comparative results of the Base Case furnace assignments using DOE's random assignment methodology versus a limited rational economic decision framework that accounts for non-economic factors. Of all new installation trial cases in the DOE SNOPR LCC model, 69% (1732/2476) have a negative payback period (i.e., negative first cost premium divided by positive annual energy savings). Of the 1,732 cases with negative payback period, 62% (1000 cases) are assigned an 80% efficient furnace by DOE's random Base Case furnace assignment methodology and therefore are misallocated as "Net Benefit" cases instead of "No Impact" cases. These misallocated cases represent 42% of the total LCC savings projected by DOE under its proposed rule. Under the limited rational economic decision framework used in GTI Scenario Int-14, these cases would be considered "No Impact" because the market would choose a condensing furnace without the DOE rule. The similarly misallocated 284 replacement cases with negative payback account for another 13% of total LCC savings projected by DOE under its proposed rule. A total of 13% (1284/9717) of residential cases and 55% of DOE's claimed rule benefit comes from a combination of builders and consumers that DOE inexplicably claims would otherwise be willing to pay extra for lower efficiency furnaces. This results in excessive claims of benefits and avoided net cost that do not reflect a connection to reasonable and expected consumer behavior and rational decision making by builders or consumers.

Table 16 DOE Random Base Case Assignment Compared to GTI Scenario Int-14

Characteristics of Crystal Ball Trial Cases at 92% TSL	DOE LCC Model		GTI Scenarios	
	Number of Cases	Percent of Total	Number of Cases	Percent of Total
Number of Residential Cases	9717	100%	9717	100%
Replacements	7241	75%	7241	75%
- Payback Period ≤ 0 years	510	5%	412	4%
- Impacted by Rule	284	3%	0	0%
- Payback Period >15 years	3138	32%	3775	39%
- No Impact	1258	13%	1398	14%
New Installations	2476	25%	2476	25%
- Payback Period ≤ 0 years	1732	18%	1472	15%
- Impacted by Rule	1000	10%	0	0%
- Payback Period >15 years	0	0%	0	0%
- No Impact	0	0%	0	0%
Total Residential Trial Cases	9717	100%	9717	100%
- Payback Period ≤ 0 years	2242	23%	1884	19%
- Impacted by Rule	1284	13%	0	0%
- Payback Period >15 years	3138	32%	3775	39%
- No Impact	1258	13%	1398	14%

For long payback period cases, GTI's scenarios have similar numbers of "No Impact" cases as DOE. The difference between the two analyses is that in DOE's random methodology a consumer who has a short payback period is as likely as one who has a long payback period to choose a high efficiency furnace. GTI's scenarios assume that consumers are more likely, but not guaranteed, to choose a high efficiency furnace when the payback period is short. This rational consumer economic decision methodology is supported by DOE's own data that shows the reasonable correlation between payback time and shipment data. Figure 6 shows a clear relationship between condensing furnace market share and payback periods, with high market share being achieved when payback periods reach approximately 10 years.

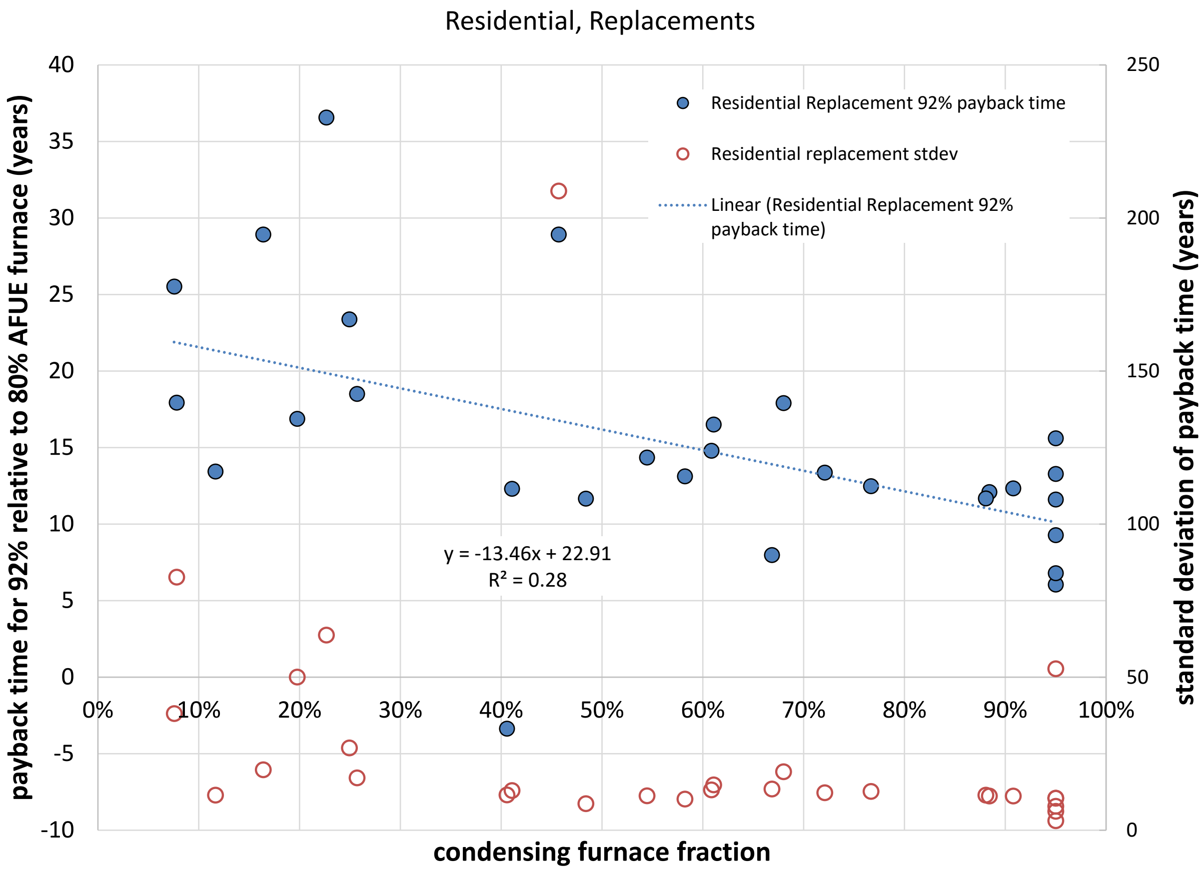

Figure 6: DOE LCC Model Condensing Furnace Market Share vs. Payback Period

2.4 DOE Fuel Switching Decision Making Methodology

Unlike the random allocations in the Base Case AFUE assignment, decisions on whether or not a consumer will choose a fuel switching option are based on consumer economics in the baseline DOE LCC model. Figure 7 illustrates GTI's understanding of the DOE LCC fuel switching decision-making process flow chart.

DOE's random assignment algorithm in the Base Case AFUE assignment also affects its fuel switching analysis, resulting in overstated savings compared to rational economic decision making criteria. There are cases that DOE does not consider in its consumer economics fuel switching algorithm because they are randomly excluded from the LCC analysis before the fuel switching payback calculations are performed. Some of these excluded cases are candidates for fuel switching caused by the rule and would be included in the LCC analysis using CED criteria. There are also cases that DOE has randomly determined will be "Net Benefit" cases due to fuel switching caused by the rule that would likely have fuel switched without the rule based on compelling economic benefits. Such cases would be considered "No Impact" in the LCC analysis using CED criteria.

Also, the LCC spreadsheet algorithm for switching options with higher first cost than the baseline furnace is not explicitly stated in the TSD. Switching options with a negative energy savings payback period relative to the baseline furnace have both a higher first cost and a higher operating cost than the specified NWGF. In the DOE LCC spreadsheet, calculations by the formulas in column AH in the NWGF Switching sheet remove any options where there is no first cost advantage of the switching option compared to the baseline furnace.

The DOE fuel switching model also excludes fuel switching in cases where there is a first cost advantage for the electric technology when comparing to an 80% furnace and an operating cost advantage for the electric technology compared to the TSL furnace. Instead, the DOE LCC analysis chooses the TSL furnace as a "Net Benefit" case, even though fuel switching would accrue incremental benefits to the consumer compared to the TSL furnace. These cases would likely cause fuel switching without the rule in the unregulated market, and would be considered "No Impact" cases when using CED criteria for incremental technology and fuel switching decisions. This results in overstated LCC savings compared to rational fuel switching under a CED framework methodology.

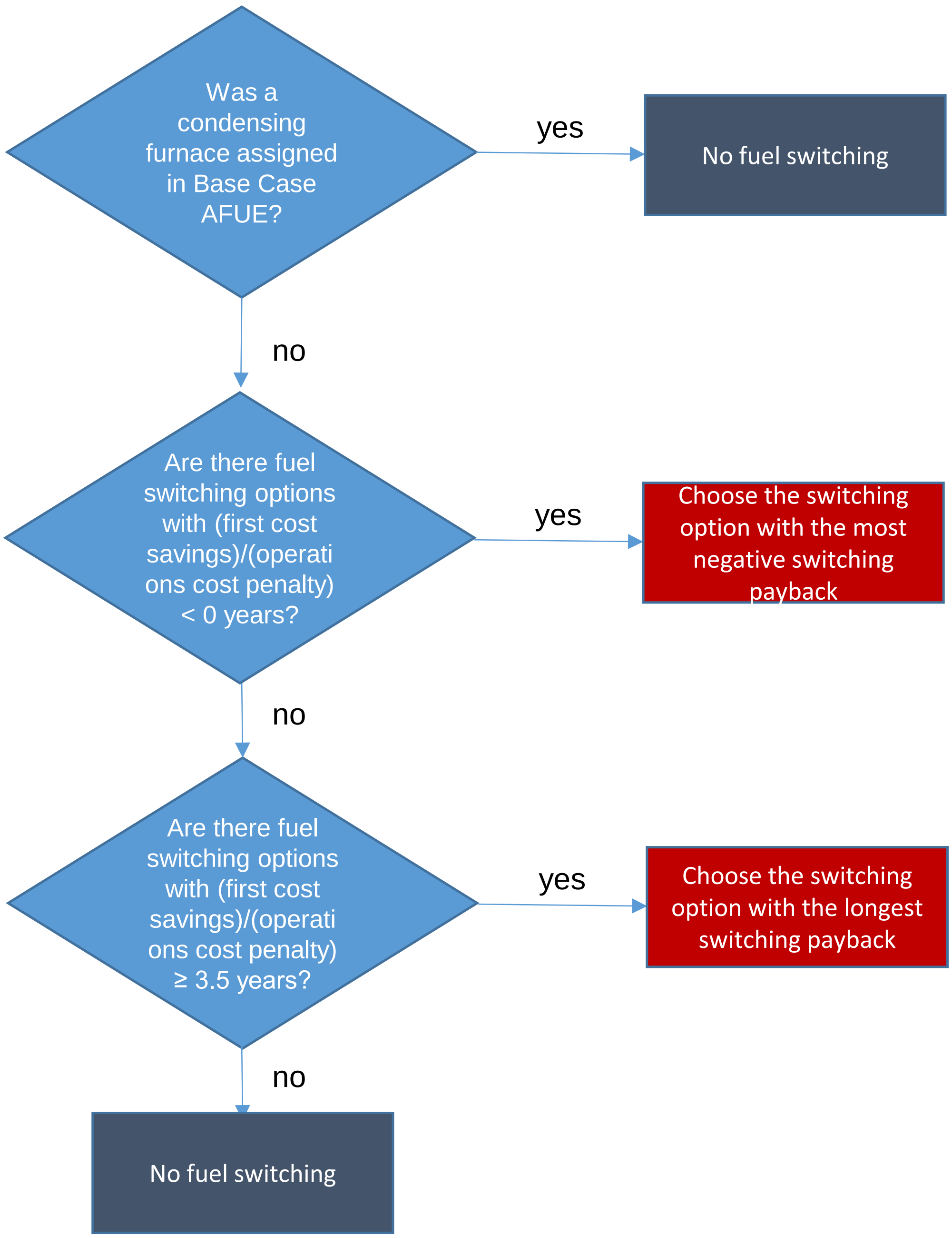

Figure 7 GTI Illustration of DOE Fuel Switching Logic Flow Chart

The distribution of LCC savings for individual trial cases is a non-linear function of switching payback period in the DOE LCC model. LCC savings drop significantly as the switching payback period falls below 4 years, but rise only slightly, with flat LCC savings for longer switching payback periods. Since DOE uses a single 3.5 year switching payback period in its fuel switching decision methodology, savings associated with fuel switching are overstated in the DOE LCC model compared to consideration of the full distribution of fuel switching payback periods. Parametrics D2 and D8 incorporate the distribution of fuel switching payback periods in the fuel switching analysis. Figure 8 shows GTI's fuel switching decision logic algorithm used in Scenarios 24 and 36 that incorporate a CED framework into the LCC analysis. Appendix A, Section A.2.2, provides further details on the DOE fuel switching decision methodology.

2.5 American Home Comfort Study Application

The DOE fuel switching decision algorithm chooses the option with the longest switching payback if more than one option's switching payback period is over 3.5 years. DOE selected the 3.5 year switching payback period as the decision point based on analysis of four versions (2006, 2008, 2010, and 2013) of the American Home Comfort Study (AHCS) published by Decision Analyst.[4] The derivation of the 3.5 year switching payback period criterion used by DOE is described in section 8J.2.2 of the TSD. It comes from the amount consumers responding to the AHCS reported being willing to pay for a 25 percent improvement in the efficiency of their HVAC system and the space conditioning costs determined from the 2001, 2005, and 2009 RECS information. The average amount consumers were willing to pay from the AHCS was divided by 25% of the energy costs for space conditioning derived from the RECS information to arrive at 3.5 years.

The AHCS is a proprietary report available only through private purchase and contains detailed consumer preference information not generally available to the public. According to Decision Analyst, the AHCS is the largest knowledge base of homeowner behavior, perceptions, and attitudes related to energy efficiency, home comfort, and HVAC. Topics include:

- The level of consumers' interest in energy efficiency
- How consumers balance rising energy costs with home comfort
- Consumers' willingness to spend money on options to achieve energy efficiency
- Home comfort differences by region and demographics

Detailed consumer behavior information available in the AHCS allowed GTI to explore fuel switching decision parametric scenarios that were not considered by DOE in its fuel switching decision algorithm. The AHCS contains between 2,849 and 3,803 respondents in each of the years 2006, 2008, 2010, and 2013. It includes enough survey response information to produce distributions of switching payback periods as a function of income groups. Decision Analyst provided this detailed survey response information to GTI, allowing GTI analysts to conduct a more granular evaluation of fuel switching behavior than DOE incorporated into its analysis using the single point average switching payback period algorithm. Appendix A, Section A.3.2, provides additional information on the use of the AHCS information in the GTI scenarios.

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4 Decision Analyst. 2006, 2008, 2010, and 2013. American Home Comfort Study. Arlington, TX. http://www.decisionanalyst.com/Syndicated/HomeComfort.dai

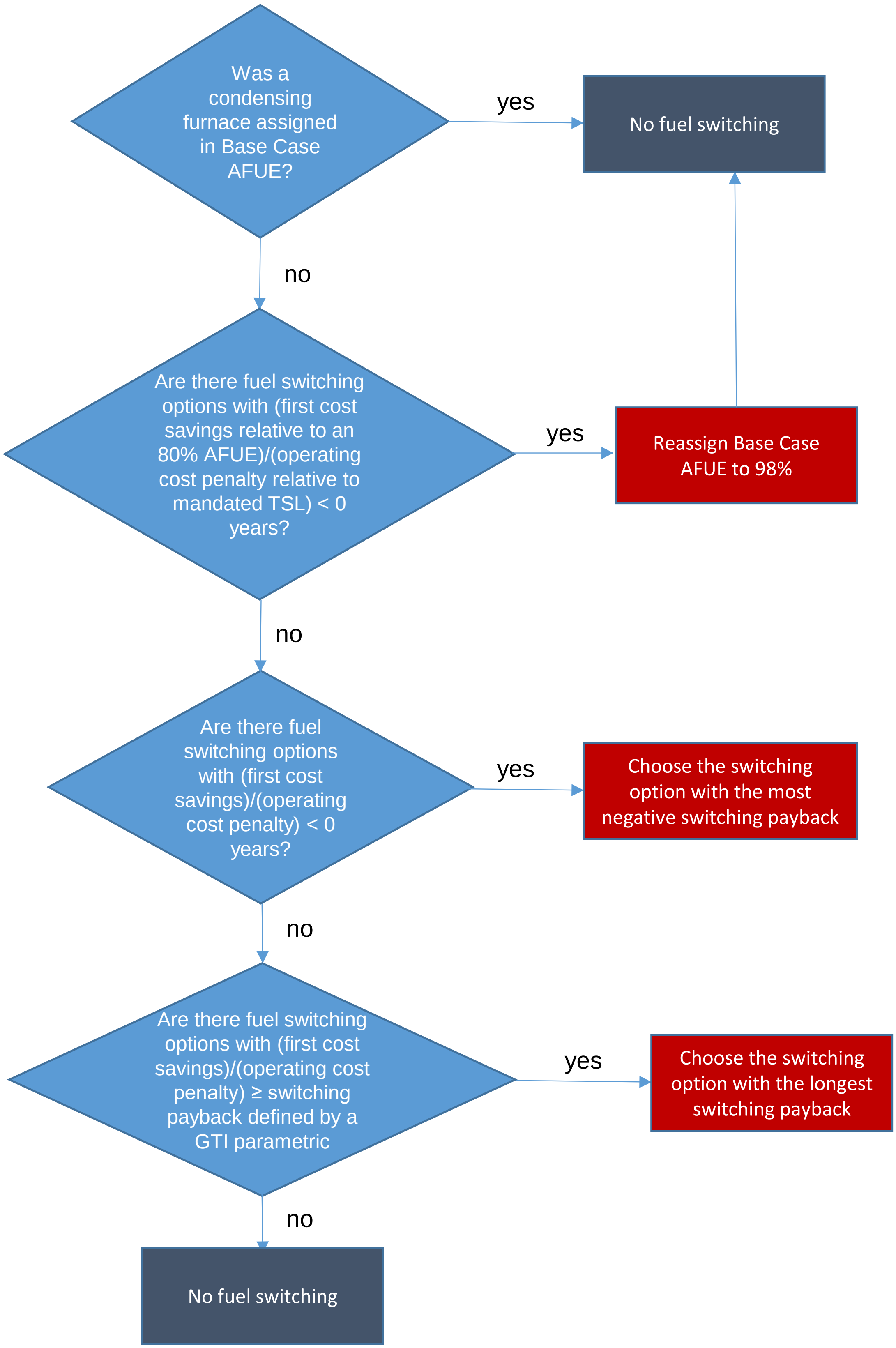


Figure 8 GTI Scenario 24 Fuel Switching Logic Flow Chart

2.6 GTI Decision Making Analysis Methodology

To examine the impact of DOE's random baseline decision making and fuel switching algorithms on modeling results, GTI analysts developed several parametric scenarios for the 2015 DOE NOPR analysis that investigated the impact of economic decision making criteria on LCC model results. The scenarios GTI analysts developed and evaluated include various combinations of data, surveys, studies, and engineering principles to incorporate consumer economic decision making processes into the NOPR LCC analysis. The CED framework, coupled with the availability of detailed information from the AHCS, permitted consideration of a wide range of decision making scenarios under different allowable payback period and "switching payback period" parametrics in the GTI analysis of the 2015 DOE NOPR. GTI-15/0002 includes detailed information on rationale and impacts of the decision making Parametrics and Scenarios considered for the 2015 DOE NOPR analysis as diagrammed in Table 10. These Parametric and Scenario options were also considered as potentially relevant for the current SNOPR analysis, but only Scenario 24, selected as part of GTI Integrated Scenario Int-5 in the NOPR analysis, was selected for continued evaluation in the GTI SNOPR analysis.

It is important to identify and justify the alternative scenario or scenarios that produce credible and technically defensible results for comparisons with DOE LCC model results. For the GTI analysis of the 2015 DOE NOPR diagrammed in Table 10, integrated scenarios included combinations of scenarios that address economic decision making (GTI Decision Making Scenarios 1 through 18 and 23 through 27) and substitution of improved input data for those used by DOE (GTI Input Variable Scenarios I-1 through I-16 were used for that purpose in the GTI NOPR analysis). As noted in Section 2.1, GTI analysts selected Integrated Scenario Int-5, including Scenario 24, as the most credible and technically defensible integrated scenario in the NOPR analysis. Scenario 24 is also included in GTI's Integrated Scenarios for the SNOPR analysis diagrammed in Table 11. The description below focuses on Scenario 24, comprising decision making parametrics D2, D4, D5, and D8, and Scenario 36, that comprises parametrics D2, D8, and D14.

Scenario 24 is a reasonable and technically defensible decision making scenario for use in the CED framework based on overall analytical constraints and assumptions. It corrects the technically flawed DOE SNOPR LCC analysis random Base Case AFUE assignment by substituting rational consumer economic decision making, thereby avoiding extremely unlikely consumer behavior caused by the DOE random assignment. It also incorporates household income into the fuel switching decision based on analysis of data contained in the AHCS. Finally, it generates fuel switching fractions that are reasonably consistent with the DOE baseline fuel switching fractions as well as the 2014 builder and contractor fuel switching survey.

The objective of Scenario 24 was to incorporate the CED framework into the LCC analysis for both baseline furnace assignment decisions and fuel switching decisions. Scenario 24 parametrics included substituting a distribution of switching payback periods for the single average 3.5 year switching payback period used by DOE (Parametric D2); assignment of Base Case furnace using regional shipment data and payback period rather than random assignment (Parametric D4); eliminating negative payback period trial cases from the LCC analysis (Parametric D5); and removing exceptionally rational fuel switching trial cases from the LCC analysis (Parametric D8).

Parametric D2 assigns switching payback periods according to household income rather than the single average value used by DOE. It uses the average payback period for each income group included in detailed survey information collected by Decision Analyst that was summarized in the 2006, 2008, 2010, and 2013 AHCS. Parametric D2 provides a survey-based approach to differentiate the fuel switching decision making across income groups and changes the type and impact of trial cases that are induced to fuel switch by the rule compared to the DOE single point average switching payback methodology that results in overstated LCC savings compared to application of Parametric D2.

Parametric D4 replaces DOE's random Base Case AFUE assignment with rational economic decision making assignments based on simple payback periods. Base Case AFUE assignments in Parametric D4 couple the payback period for the TSL furnace relative to an 80% AFUE furnace with the cumulative distribution of TSL furnace payback periods in the DOE LCC model. GTI analysts used individual trial case information extracted from the DOE LCC model to develop cumulative distributions of TSL furnace payback periods for each region, installation type (new or replacement), and building type (residential or commercial). Parametric D4 combined these cumulative distributions with the extrapolated shipment data provided by DOE to assign payback periods for furnaces at different efficiencies. By matching the condensing furnace fractions with the associated payback period, D4 provided a pathway to incorporating the CED framework into GTI decision making scenarios, and is included in Scenario 24.

Parametric D5 sets the minimum allowed payback to 0 years to avoid negative payback periods from being considered as part of the "Impacted" group. This is done by assigning trial cases with negative payback periods a 98% AFUE furnace, thereby excluding them from further analysis as "No Impact" trial cases. Parametric D5 is combined with Parametric D4 in Scenario 24 to constrain the Parametric D4 CED framework trial cases that are considered for each TSL furnace in the LCC analysis. It is the most conservative of the three similar CED constraint Parametrics (D5, D6, and D7) explored by GTI analysts for the NOPR analysis.

Parametric D8 removes trial cases where a fuel switching option, such as a low-cost electric heat pump, has a lower first cost than an 80% furnace and operating costs savings relative to a TSL furnace that is included as an "Impacted" trial case in the DOE LCC analysis. Such fuel switching occurrences would likely occur in the absence of a rule, thereby excluding them from further analysis as "No Impact" trial cases. Cases are removed from the "Impacted" group by assigning a Base Case AFUE at 98% so they become "No Impact" cases at all TSLs.

In response to DOE assertions about non-economic and imperfect market decision making factors in the SNOPR, GTI analysts developed an LCC model approach to address these factors. The rational economic decision making criteria used in Scenario 24 permitted GTI analysts to monetize the impact of additional non-economic factors within the CED framework. The additional CED methodology developed for the GTI SNOPR analysis incorporates economic and non-economic criteria to characterize the overall consumer decision making process when choosing one furnace option over another. The additional CED methodology uses DOE's LCC model payback period distribution coupled with furnace shipment data to assign Base Case furnaces as well as the manner in which consumers make fuel switching decisions. Parametric D14 replaces the deterministic value for the DOE LCC model payback period in Parametrics D4 and D5 with a distribution function to adjust the payback period for each of the 10,000 trial cases. This approach comports with the "reasonable person" standard of imperfect decision making rather than a random, haphazard approach that yields numerous nonsensical results.

Parametric D14 accommodates a range of non-economic factors in the LCC analysis by monetizing these factors and incorporating the resultant distribution of paybacks into the GTI CED framework. The distribution function in Parametric D14 acknowledges the increasing uncertainty associated with longer payback periods, as well as the range of consumer knowledge, biases, market imperfections, and behaviors that shift the consumer's effective payback period for the furnace decision away from the DOE LCC model deterministic energy cost payback period under the CED framework in Parametrics D4 and D5. Parametric D14 uses a distribution function whose payback period standard deviation is 50% of the DOE LCC model payback period. Crystal Ball applies that distribution function in place of the deterministic value used in Parametric D4 for Scenario 24 to determine the modeled payback period for each of the 10,000 trial cases in Scenario 36. Parametric D14 is also used in Scenario 39 to isolate the impact of the CED framework coupled with the DOE fuel switching methodology.

Using a distribution function instead of a deterministic value for an individual home's payback period, decisions influenced by non-economic factors such as environmental stewardship, split incentives, imperfect information, and other non-monetary factors can be incorporated into the LCC model and improve its connection to actual market behavior in which the homeowner or their agent (e.g., builder or contractor) makes an imperfect, but not random, economic decision when purchasing a furnace.

2.7 GTI Input Data Analysis Methodology

To examine the impact of DOE's input data assumptions on SNOPR LCC modeling results, GTI analysts developed parametric scenarios using alternative input data with the potential for significant impact on the DOE LCC model results. The GTI SNOPR Input Data scenarios supplemented the parametric scenarios developed for the NOPR analysis as described in GTI-15/0002. In priority order, the GTI Input Data scenarios were based on publicly available market data, targeted surveys, construction and engineering principles, and persuasive anecdotal information. Appendix A, Section A.5, provides additional information on these scenarios.

Similar to the GTI decision making scenarios, the input data scenarios evaluated by GTI analysts incorporate individual and combined parametrics that modify, in the manner specified for each parameter, the DOE LCC model input data parameters. Similar to the approach taken in the GTI decision making scenarios, GTI analysts evaluated alternative input parameters with the potential to produce credible and technically defensible results for comparisons with the DOE LCC model results. GTI SNOPR Scenario I-17, an updated version of GTI NOPR Scenario I-16, replaces Input Data parametric I8 with Input Data parametric I17. The methodology description below focuses on Scenario I-17, comprising Input Data parametrics I2, I6, I13, and I17, which are also summarized. Input Data parametric I8 (AEO 2015 Update) was also included in Scenario I-16, but is no longer relevant since the SNOPR used the AEO 2015 forecasts.

The objective of Scenario I-17 was to incorporate furnace pricing data from the 2013 Furnace Price Guide (Parametric I2); substitute marginal gas prices derived from AGA tariff analysis for the DOE marginal gas prices (Parametric I6); incorporate updated AEO 2016 Clean Power Plan forecasts (Parametric I17), and use a more complete historical trend line of condensing furnace market penetration data from AHRI to revise the DOE forecasted trend line of condensing furnace market share (Parametric I13). These substitutions used superior data and forecasts compared to the information used in the DOE SNOPR LCC model.

Parametric I2 replaced DOE's retail furnace prices that are derived through a tear down analysis of furnaces with a database of actual offered prices of furnaces. GTI tabulated retail prices provided in the 2013 Furnace Price Guide (https://www.furnacecompare.com/furnaces/price-guide.html), segregated models by efficiency level, adjusted the furnace prices for inflation and to account for the use of BPM motors in place of PSC motors, and used the adjusted "delivered to home" furnace prices as inputs to the model.

Parametric I6 replaced the DOE NOPR LCC model marginal gas price factors with the marginal price factors developed by AGA using gas companies' tariff data. Similar to DOE, AGA relied on EIA residential natural gas sales and revenues by state (EIA 2014 NG Navigator). However, in contrast to the DOE methodology described in the SNOPR TSD, AGA developed a fixed cost component of natural gas rates for each state and applied it to the EIA data to develop state level residential marginal price factors. These state level data were then weighted according to furnace shipments using the same approach as DOE to generate marginal rates for each region.

Parametric I13 uses NWGF condensing and non-condensing furnace shipment data trends provided to DOE by AHRI in 2015 to revise the DOE 2022 forecast of Base Case condensing furnace shipment fraction. For the SNOPR analysis, GTI analysts developed a trend line that aligned with AHRI 2014 data and historical shipment data from 1998 through 2005. The GTI trend line did not consider 2006 through 2013 shipment data to avoid concerns with observed perturbations caused by federal energy credits phased out in 2011 that may have influenced shipment numbers between 2006 and 2013. DOE chose to use just 3 years (2012 to 2014) of shipment data in forecasting for years 2015 to 2050 in the SNOPR. To create a 2022 forecast trend line that matched actual 2014 shipment data, GTI used 1998 to 2005 trending years. This combined approach resulted in a 2014 condensing furnace shipment fraction of 48%, which is slightly lower than the actual fraction of 48.5% reported by AHRI. Based on this trend line, Parametric I13 uses condensing furnace shipment fractions of 62.5% (National), 84.1% (North), and 38.6% (Rest of Country) for the 2022 baseline instead of DOE's 2022 furnaces shipment fractions of 53.1% (National), 73.7% (North), and 30.2% (Rest of Country).

Figure 9 compares the DOE SNOPR and GTI Parametric I13 condensing furnace shipment forecast trend line. The GTI trend line shows a much higher market penetration of condensing furnaces without the DOE rule than the DOE LCC model. The GTI forecast trend line indicates a more robust free market for condensing furnaces without the rule in the future than the forecasts in the DOE LCC model.

Parametric I17 replaced the 2015 EIA AEO forecasts and utility prices used in the DOE SNOPR LCC model with the current 2016 EIA AEO forecasts for energy price trends and updated gas and electric utility prices. Since DOE noted that it plans to use the AEO 2016 forecasts for the Clean Power Plan (AEO 2016 CPP) scenario in its final rule, Parametric I17 uses the same AEO 2016 CPP scenario.

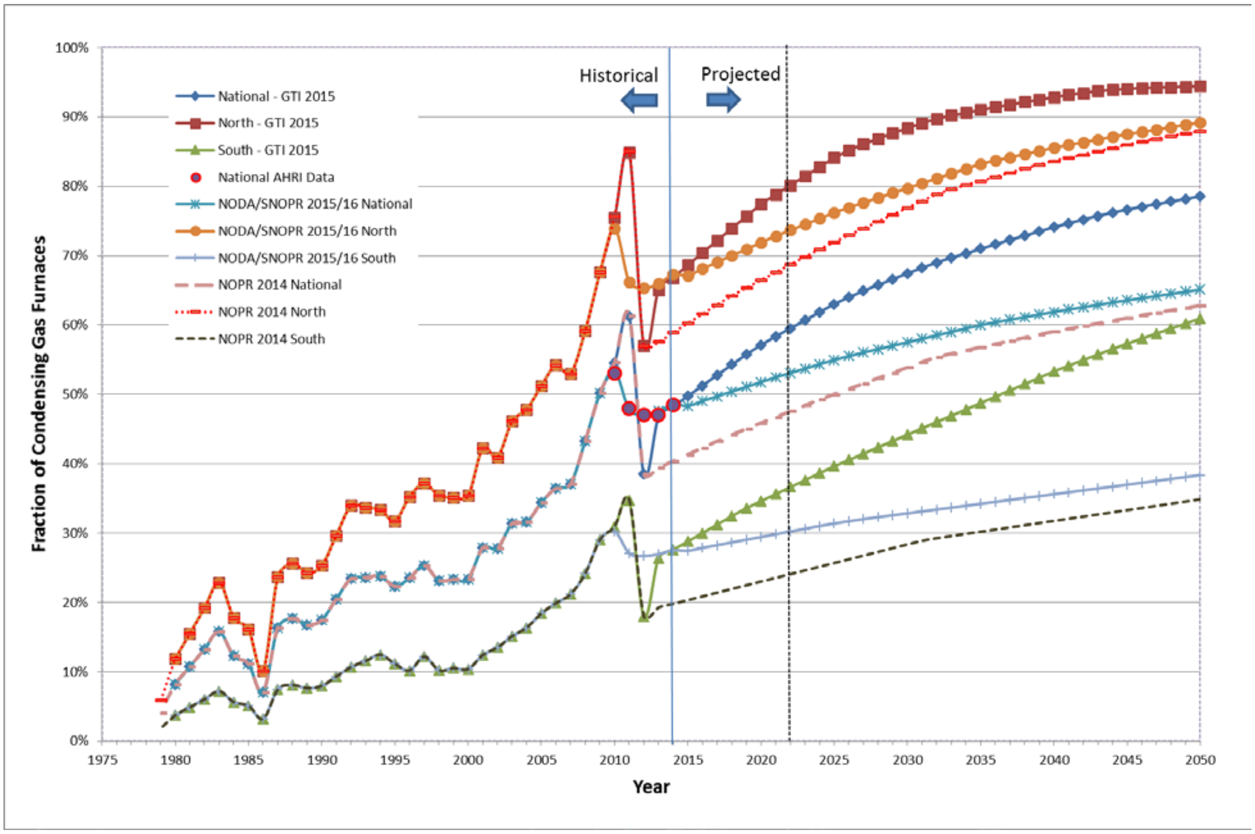


Figure 9 Condensing Furnace Trends – DOE SNOPR Model vs. GTI Parametric I13

2.8 GTI Integrated Scenario Analysis Methodology

GTI analysts developed and evaluated integrated scenarios comprising technically defensible decision making and input parametrics and scenarios to examine the impact of these combinations on LCC results and fuel switching fractions. The integrated scenarios were cross-checked with the 2014 fuel switching survey results and the DOE SNOPR LCC spreadsheet fuel switching fractions to identify scenario combinations that were both technically defensible and consistent with other technical information and data sources. Appendix A, Section A7, provides a detailed description of the integrated scenarios developed for the SNOPR analysis.

As described in GTI-15/0002, GTI developed a set of integrated scenarios for the DOE NOPR LCC model analysis that were also considered for use in the SNOPR analysis. GTI Integrated Scenario Int-5 included several refinements to the DOE NOPR LCC model, including rational consumer economic decision making and improved input data, and formed the primary basis for comparison to DOE's analysis of its proposed furnace efficiency standards in the NOPR. Other technically defensible scenarios based on different assumptions and factors were included in GTI-15/0002 for reference purposes and were not used or updated in the GTI SNOPR analysis.

The GTI SNOPR analysis includes several integrated scenarios that incorporate updated decision making, input data, and furnace sizing parametrics and provide technical information related to issues on which DOE seeks comments in the DOE SNOPR. In response to DOE assertions in the SNOPR about non-economic and imperfect market decision making factors, GTI analysts developed an LCC model approach to address those factors. Based on concerns with the DOE furnace sizing methodology, GTI analysts also developed an alternative furnace sizing methodology for use in the separate product class analysis.

The GTI SNOPR integrated scenarios updated the GTI NOPR CED framework to incorporate non-economic decision making criteria, and substituted a heating consumption furnace sizing methodology for the DOE home size furnace sizing methodology. Building on the GTI NOPR CED framework, GTI SNOPR analysis scenarios include distribution functions that accommodate additional non-economic factors in the CED framework; and furnace sizing algorithms linked to the RECS database that examine the impact of different furnace capacity limits for 80% AFUE furnaces on rule benefits, including national, regional, new construction, replacement, senior, and low income segment impacts. GTI Integrated Scenarios Int-11 through Int-14 and Int-11.55 through Int-14.55 address these two major issues.

GTI SNOPR Scenario Int-14, an updated version of GTI NOPR Scenario Int-5, was selected for comparison with the 92% AFUE single product class TSL 5 in the SNOPR (GTI Scenario 0) to address the following issues:

- Base Case furnace assignment that aligns with AHRI condensing furnace fractions and economic decision making criteria,
- Application of American Home Comfort Study information for fuel switching decisions that results in reasonable alignment with DOE fuel switching fractions when using a CED framework for Base Case furnace assignment and fuel switching decisions,
- Improved data for furnace prices, condensing furnace fractions, and marginal gas prices,
- Incorporation of AEO 2016 Clean Power Plan Scenario forecast information for comparisons with anticipated DOE final rule benefits calculations, and

- Application of a time-horizon-based distribution function based on the DOE LCC model payback period for each of the 10,000 trial cases for consumer economic decision making that monetizes the impact of imperfect market and non-economic consumer decision making factors into the LCC analysis for comparisons within the GTI CED framework, and gives consumers a limited ability to make economic decisions.

GTI Scenario Int-14.55, one of the cases under Scenario Int-14, was selected to examine the impact of a 55 kBtu/h furnace capacity limit for non-condensing furnaces on rule benefits for direct comparisons with the DOE SNOPR proposed rule TSL 6 (GTI Scenario 0.55). GTI Scenario Int-14.55 includes a furnace capacity algorithm for each trial case based on annual heating consumption rather than home size and uses the DOE furnace "downsizing" methodology.

2.9 DOE SNOPR Furnace Sizing Methodology

DOE describes its methodology for furnace sizing beginning on page 7B-17 of the SNOPR TSD. The steps DOE took to assign furnace size in the SNOPR LCC model are the same as in the NOPR LCC model in the NOPR TSD. The DOE SNOPR furnace sizing methodology includes the following steps as noted in the TSD:

1) The Department ranked all the RECS housing units in ascending order by size (heating square foot) multiplied by a scaling factor to account for the outdoor design temperature and calculated the percentile rank of each housing unit using the statistical weight of each of the sample records. The scaling factor is given by: $SF_{design,h} = (65 - T_{design,h}) / (65 - 42)$*, where* $SF_{design,h}$ *= heating design scaling factor, and* $T_{design,h}$ *= average 1 percent ASHRAE design dry bulb temperature (°F) for heating.*

2) The Department constructed percentile tables by input capacity of furnaces based on the historical shipment information and number of models in AHRI Directory (TSD Table 7B.2.13).

3) After selecting a housing unit from the Residential Energy Consumption Survey (RECS) database during each Monte Carlo iteration, DOE noted the size of the selected housing unit and determined the percentile rank from Step 1.

4) To avoid a one-to-one deterministic relation between the housing unit size and input capacity, DOE added a random term to the percentile identified in Step 3 so that the correlation was not perfect. The Department used a normal distribution to characterize the random term. The random term has a mean of zero and a standard deviation of 8 percent.

5) Using the percentile from Step 4, DOE looked up the input capacity from the input capacity percentile table in Step 2.

In the procedure for furnace sizing described in the SNOPR TSD, the distribution of furnace input capacity used in Step 2 was used to split the 10 kBtu/hr size bins based on AHRI shipment numbers for the year 2000 in each size bin. As indicated in the SNOPR (81 Fed. Reg. 65770), furnaces were binned into 5 kBtu/hr size bins using the reduced models dataset from the September 2015 NODA analysis.

Correct furnace fan sizing is important to ensure that the furnace/AC system will provide adequate space conditioning during summer cooling periods in conventional forced air systems with an evaporator coil located adjacent to the furnace. This issue is especially important in warmer climates dominated by cooling demand. Furnace capacity in those cases will not be based solely on the peak heating load, but on the furnace fan capacity linked to the AC system capacity. As a result, the furnace capacity will often be oversized for the heating load to maintain adequate delivered air temperature in heating mode based on the fan output. The amount of oversizing varies, but can limit the minimum furnace capacity in those cases to a higher capacity than calculated based on peak heating load. ACCA Manual S acknowledges this application and permits additional oversizing in those cases. However, DOE chose not to consider the size of an air conditioning (AC) system when determining furnace size. As noted by DOE in the SNOPR, (81 Fed. Reg. 65770):

> *…the furnace fan standards that will take effect in July 2019 require fan motor designs that can modulate the amount of air depending on both heating and cooling requirements. Thus, the size of the furnace fan (and the furnace capacity) will be able to better match the heating requirements of the house.*

As a result, DOE determined the lower limit of furnace input capacity in the DOE LCC model based on the historical shipment information and number of models in AHRI Directory irrespective of the size of the air conditioning system in the 10,000 trial cases.

2.10 DOE Furnace Sizing Model Poor Correlation with Annual Heating Load

Furnace size calculated using the above methodology is located in the Furnace & AC Sizing Sheet in Cell D19 for each Crystal Ball trial case. The annual heating load (i.e., furnace output) for each Crystal Ball trial case is located in the Energy Use Sheet in Cell F78. GTI extracted both furnace size and heating load from each trial case for post-processing and analysis using Visual Basic for Application (VBA) code as described in Section 2.1. This permitted an evaluation of the correlation between furnace size and heating load for the 10,000 trial cases in the DOE SNOPR LCC model.

Figure 10 shows annual heating load vs. furnace size along with a best fit line for all furnaces, whether impacted by the rule or not, using the DOE SNOPR furnace sizing methodology. The correlation between heating load and furnace size using the DOE methodology is extremely weak (R^2=0.11). This is an expected result because the DOE furnace sizing algorithm is based on home size modified by a small random term. Further, as shown by the “continuous operation” curves in Figure 10, the DOE furnace sizing algorithm results in furnace sizes in some instances that cannot meet the average heating load (cases to the right of the “continuous operation” curves). The lack of a strong relationship between heating load and furnace size helps explain the lack of a consistent trend in LCC savings with furnace size in the SNOPR.

As noted above in Section 2.9, the DOE sizing methodology does not consider AC requirements when sizing furnaces. Thus, the lack of correlation between heating load and furnace size is not driven to any meaningful extent by AC size and associated fan requirements. In addition, empirical data gathered by GTI indicates that peak space heating loads in southern climate zones may be relatively higher compared to equivalent size homes in colder northern climate zones due to regional building codes and construction practices that may have lower levels of weatherization. This means that a smaller furnace may not be able to meet the needs of many southern homes as well, especially in the middle of the country with relatively cold design heating temperatures as far south as Texas.

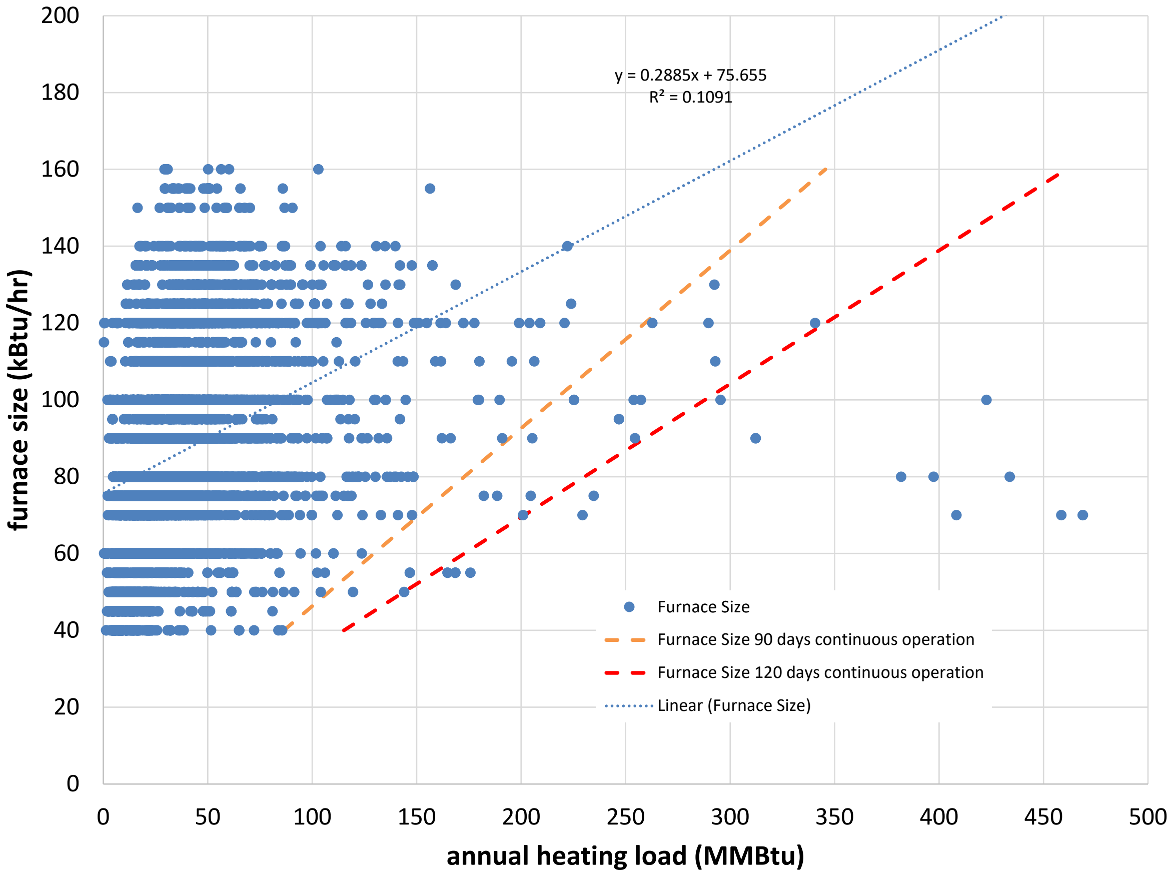


Figure 10: Furnace Size vs. Annual Heating Load Using DOE SNOPR Methodology

2.11 RECS Database Limitations

In both the NOPR and SNOPR, DOE derived annual heating load, existing furnace efficiency level, and existing furnace capacity from limited information in the RECS 2009 database. DOE chose to randomly assign existing furnace AFUE to individual trial cases and derived the annual heating load from the randomly assigned existing AFUE based on annual gas consumption. Available RECS database information includes location, physical size, and annual gas consumption. However, the RECS database does not include critical information on furnace size, monthly heating consumption, or monthly or annual heating load. The lack of this critical information in the RECS database makes it inadequate for use in the furnace capacity and annual heating load assignments used in the SNOPR, both for the single standard level and for separate standard levels for large and small furnaces evaluated in the SNOPR. Additional market information and analytical methodologies are needed for this purpose.

In an effort to address the RECS database shortcomings for use in determining a reasonable furnace size for LCC model calculations, GTI analysts examined detailed empirical data on house characteristics and gas consumption from natural gas company databases and GTI energy efficiency field data acquisition projects. Empirical data included house size, age, monthly heating degree days, outdoor design temperature, and hourly and monthly gas consumption. The empirical data enabled development of a steady-state and setback recovery furnace capacity algorithm based on house characteristics. GTI Topical Report GTI-16/0003, "Empirical Analysis of Natural Gas Furnace Sizing and Operation" (http://www.gastechnology.org/reports_software/Documents/Empirical-Analysis-of-Natural-Gas-Furnace-Sizing-and-Operation.pdf) summarizes the results of this investigation. As shown in Figure 11 through Figure 14, detailed empirical data analysis described in GTI-16/0003 shows the expected strong correlation between annual heating consumption and house "UA" (a combination of thermal efficiency and envelope area), a strong correlation between required furnace capacity and house "UA", but a very weak correlation between annual heating consumption or UA and home size. Unfortunately, the lack of monthly gas consumption data and poor correlation between gas consumption, annual HDD, design outdoor air temperature, and peak heating load in the RECS database used by DOE in the SNOPR LCC spreadsheet model for each of the 10,000 trial cases precluded the use of the GTI empirical model with RECS database information.

2.12 GTI RECS Annual Heating Consumption Furnace Sizing Model

To examine an easily implemented alternative to the DOE furnace sizing methodology, GTI analysts developed a furnace capacity algorithm for each of the 10,000 trial cases based on the RECS database annual heating consumption rather than home size (Scenario F1 in Table 11). Figure 15 shows heating load vs. furnace size along with a best fit line for all furnaces, whether impacted by the rule or not, using the RECS annual heating consumption model furnace sizing methodology. The correlation between annual heating load and furnace size (R^2=0.69) is substantially better with the RECS annual heating consumption model than the correlation using the DOE furnace sizing methodology (R^2=0.11). This is an a priori expectation because annual heating consumption should have a fair to strong correlation with peak heating load, whereas home size has been demonstrated to have poor correlation with peak heating load for a variety of reasons. The RECS annual heating consumption model is also compatible with the furnace "downsizing" methodology used by DOE in the SNOPR proposed rule (TSL 6). It also provided the desired sensitivity to market conditions compared to the DOE methodology. The data in Figure 12 is net delivered energy (before efficiency losses) – not gross furnace input capacity.

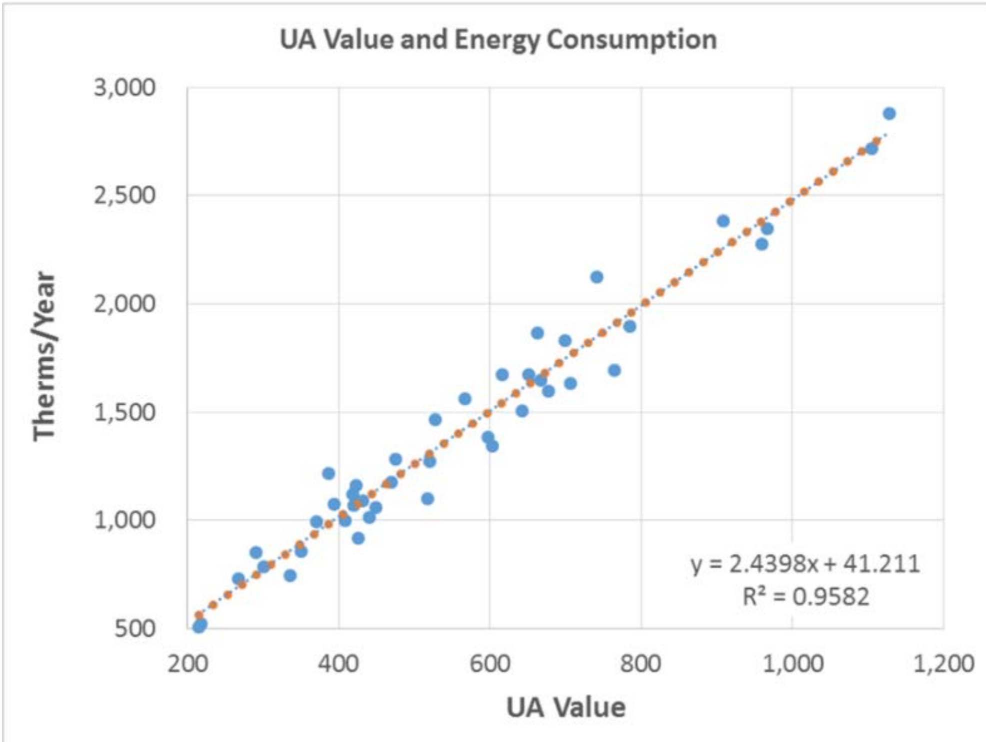


Figure 11: Strong Correlation Between Furnace Natural Gas Use and UA Value

Source: GTI-16/0003, "Empirical Analysis of Natural Gas Furnace Sizing and Operation"

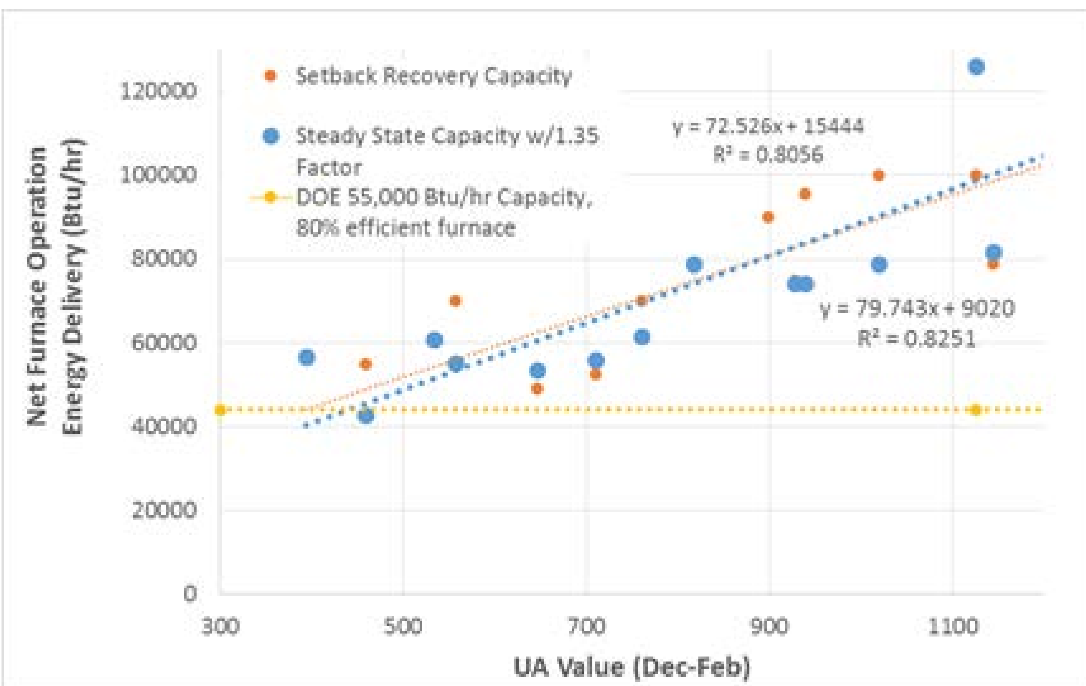


Figure 12: Strong Correlation Between Furnace Energy Delivery and UA Value

Source: GTI-16/0003, "Empirical Analysis of Natural Gas Furnace Sizing and Operation"

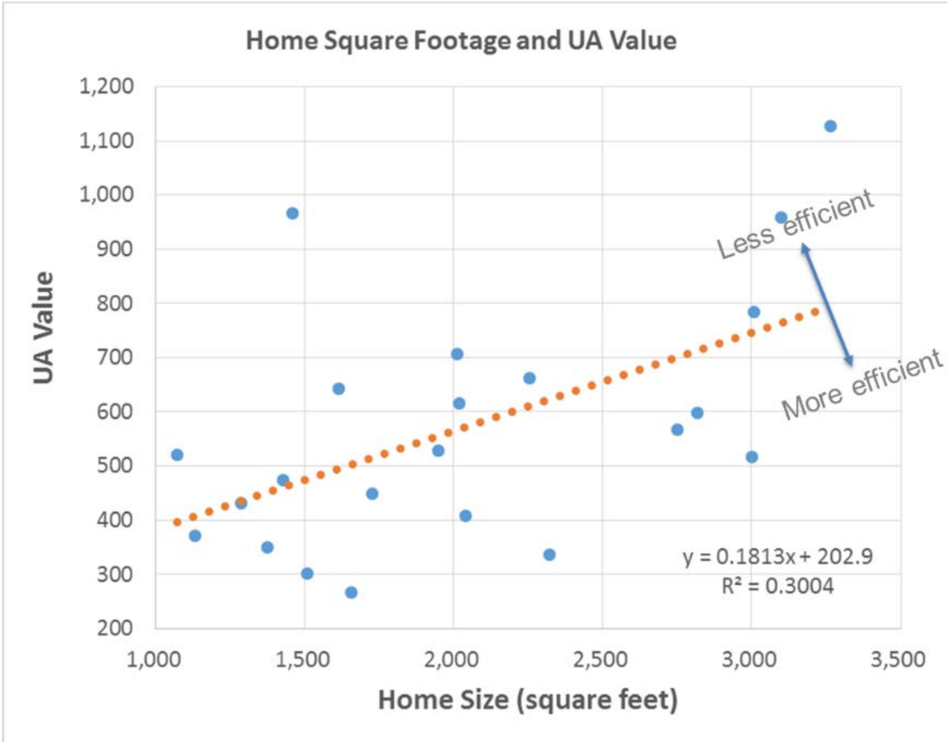


Figure 13: Weak Correlation Between Home Size and UA Value

Source: GTI-16/0003, "Empirical Analysis of Natural Gas Furnace Sizing and Operation"

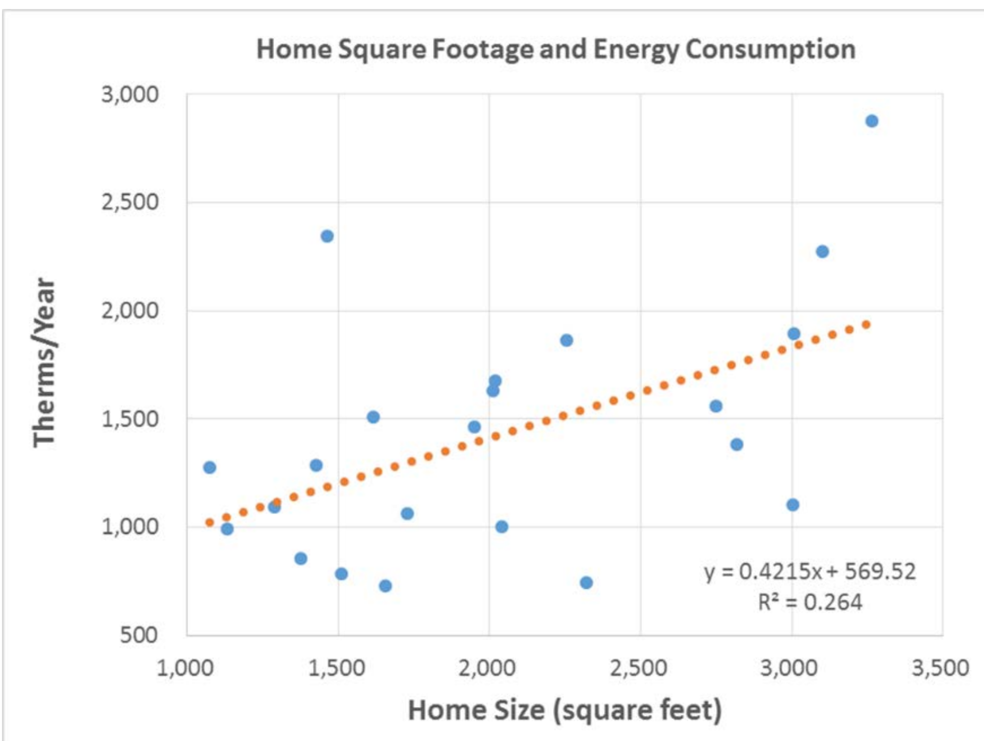


Figure 14: Weak Correlation Between Home Size and Furnace Natural Gas Use

Source: GTI-16/0003, "Empirical Analysis of Natural Gas Furnace Sizing and Operation"

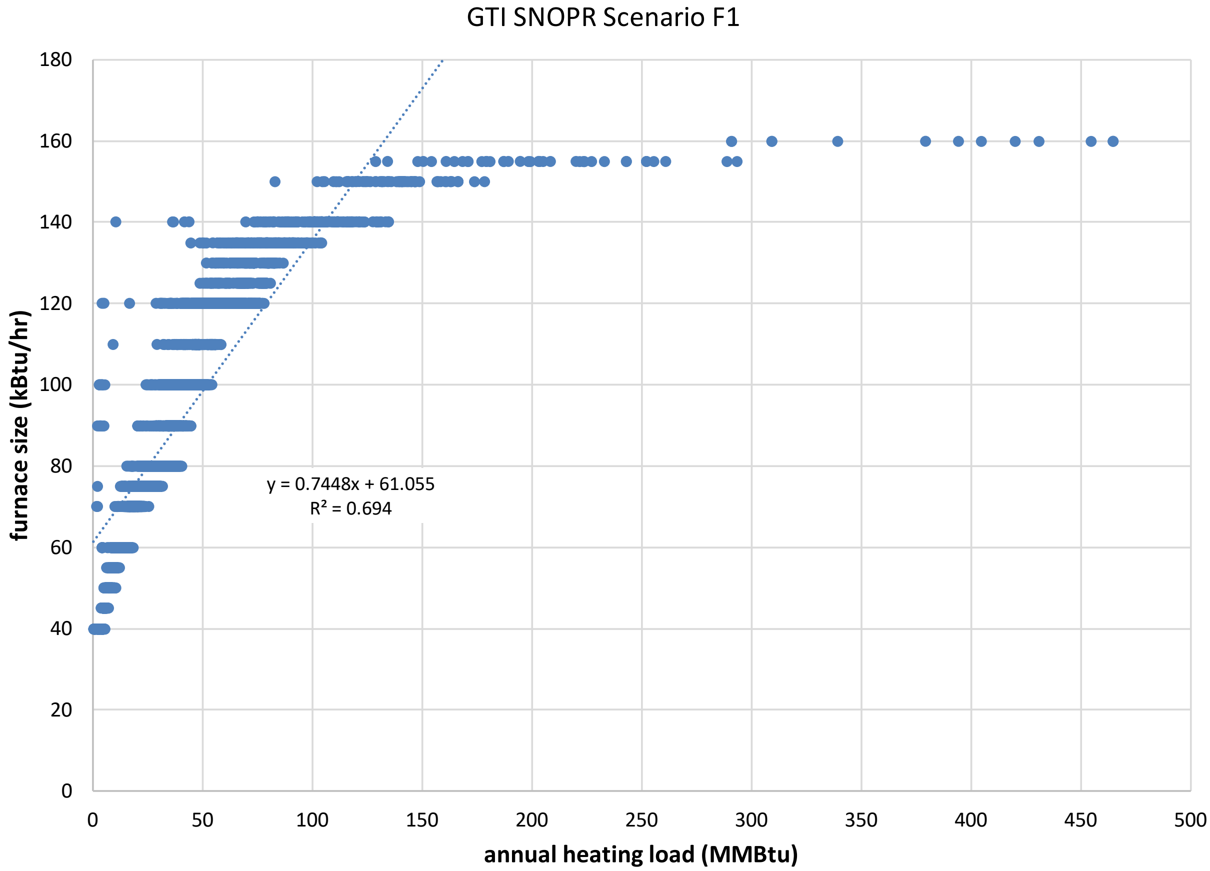


Figure 15: Furnace Size vs. Annual Heating Load with RECS Heating Consumption Model

An examination of DOE's approach to configuring 10,000 trial cases from the buildings in the RECS database further illustrates the impact of DOE's flawed random Base Case assignment methodology, DOE's flawed furnace sizing methodology, and the inherent limitations in the RECS database for LCC analysis purposes. Starting with RECS database Building No. 8113 (RECS Region 27, OR/WA), DOE configured five different residential replacement trial cases (3848, 8785, 8906, 9052, and 9467) by changing selected parameters related to installed costs and other factors. RECS Building 8113 is a 3-story, 3,613 ft^2 home, with a design heating temperature of 9°F and 6,385 HDD_{65}. DOE randomly assigned Base Case efficiencies to each trial case. Using its size-based algorithm, DOE selected a 120 kBtu/h furnace for LCC model analysis. For unknown reasons, the annual furnace gas consumption in the RECS database for that home is 0.97 MMBtu, which indicates virtually no gas consumption for heating compared to the average of 49.6 MMBtu for the buildings used by DOE in RECS Region 27.

Table 17 compares the DOE SNOPR TSL 6 LCC model results (GTI Scenario 0.55) with GTI Scenario Int-14.55 results for the five trial cases that use RECS Building No. 8113. Note that trial case 9467 changes from "Net Cost," as shown previously in Table 15, to "No Impact" using the GTI CED framework coupled with the GTI furnace sizing algorithm based on annual heating consumption. With such a low annual consumption, the GTI methodology assigned the smallest available furnace capacity of 40 kBtu/h to that trial case. DOE's house size methodology assigned a large furnace capacity of 120 kBtu/h to the 3,613 ft^2 home. Both DOE and GTI consider that trial case as No Impact in TSL 6, but for different reasons. DOE randomly assigned a 92% furnace to that trial case, so it considered it never impacted, either in TSL 5 or TSL 6. In Contrast, GTI's 80% AFUE Base Case assignment using the GTI CED framework with non-economic factors considered it impacted in TSL 5 based on the 1,337-year payback of the condensing furnace; but with a 55 kBtu/h limit, the 80% AFUE furnace was not impacted by the rule, which was the understood intent of the capacity limit approach in TSL 6. DOE assigned trial case 9052 a 120 kBtu/h 80% AFUE furnace, so it was impacted under TSL 5, as it was using the GTI methodology, but it remained impacted under TSL 6 because of the flawed DOE furnace sizing methodology, in this case reducing the TSL 6 rule benefit erroneously.

Table 17: DOE and GTI Methodologies Applied to RECS Building No. 8113

RECS Bldg. No. 8113 Crystal Ball Trial Case No.	DOE Base Case AFUE	DOE Furnace Capacity (Kbtu/h)	GTI Base Case AFUE	GTI Furnace Capacity (Kbtu/h)	92% AFUE vs. 80% AFUE		LCC Savings		Region/ Location	Type	Payback (Years)
					Cost Penalty	Annual Savings	DOE	GTI			
3848	80%	120	80%	40	$812	-$1	-$212	No Impact	North/ OR, WA	Residential Replacement	Never
8785	92%	120	92%	40	-$622	-$1	No Impact	No Impact	North/ OR, WA	Residential Replacement	995
8906	95%	120	80%	40	$876	$1	No Impact	No Impact	North/ OR, WA	Residential Replacement	675
9052	80%	120	80%	40	$1,385	$1	-$1,449	No Impact	North/ OR, WA	Residential Replacement	1933
9467	92%	120	80%	40	$1,548	$1	No Impact	No Impact	North/ OR, WA	Residential Replacement	1337

Note: Payback period for Case 8785 is for the higher cost non-condensing furnace.

2.13 DOE SNOPR Furnace Downsizing Methodology

As stated in the SNOPR, if there is a separate product class based on furnace capacity, DOE expects that some consumers who would otherwise install a typically-oversized furnace would choose to down-size in order to be able to purchase a smaller non-condensing furnace. For the SNOPR analysis, DOE identified those sample households that might down-size at the considered small furnace definitions. DOE first determined if a household would install a non-condensing furnace with an input capacity greater than the small furnace size limit without amended standards. In the standards case, DOE assumed that a fraction of such consumers would down-size to the input capacity limit for small furnaces.

The equation for the DOE downsizing algorithm is as follows:

$$Downsizing\ Input\ Size = Original\ Furnace\ Size\left(\frac{Downsizing\ Oversize\ Factor}{Original\ Oversize\ Factor}\right) = Original\ Furnace\ Size\left(\frac{1.35}{1.7}\right)$$

Figure 16 shows the flowchart for the SNOPR furnace downsizing methodology. The SNOPR downsizing methodology assumes a rational consumer response to a market constraint to protect their economic interests. It appropriately employs rational consumer behavior methodology, and it is inconsistent with the random furnace sizing and baseline furnace efficiency assignment methodology used by DOE elsewhere in the SNOPR. The downsizing methodology, however, fails to account for the selection of furnace size based on AC size and associated fan requirements, or differences in regional construction practices that affect furnace sizing requirements in the north and south differently. Nonetheless, as shown in Figure 12, the 1.35 oversizing factor used by DOE in this rational consumer methodology aligns with the empirical dataset in GTI-16/0003 for required furnace output capacity in the Chicago area sample set, and is close to the 1.4 oversizing factor used by ACCA in Manual S calculations for heating-dominated climates.

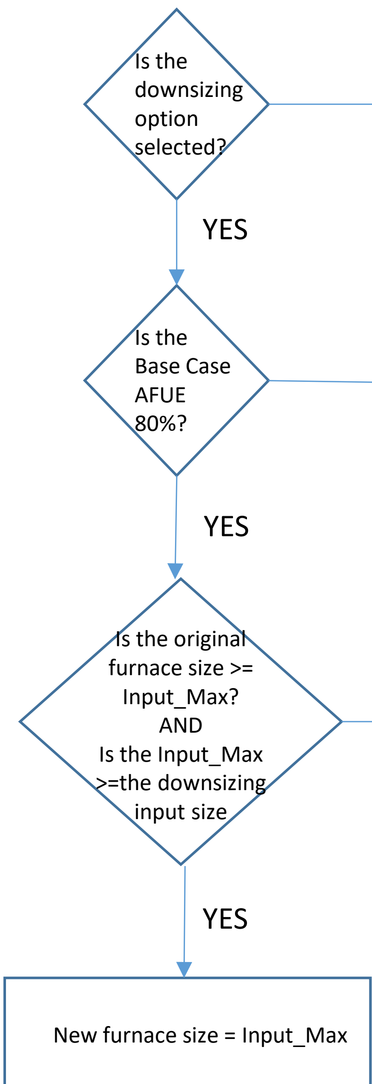


Figure 16 DOE SNOPR Furnace Down-Sizing Methodology

3 LCC Parametric Scenario Analysis Results

3.1 GTI Incremental Scenario Summary Results

Table 19 compares LCC savings for incremental GTI SNOPR analysis Parametrics and Scenarios used to build the GTI integrated scenarios with the DOE SNOPR LCC analysis results for a single national 92% AFUE standard (SNOPR TSL 5, GTI Scenario 0) and the SNOPR proposed rule (SNOPR TSL 6, GTI Scenario 0.55).

Key findings of the incremental comparative scenario analysis conducted by GTI analysts using the DOE LCC spreadsheet and Crystal Ball predictive modeling software include:

- Incremental improvements to the flawed methodologies DOE used in its SNOPR highlight the value of an integrated approach to analyzing the SNOPR in totality, as well as prioritizing which improvements have the most impact.
- DOE's technically flawed random baseline furnace assignment methodology has the most significant impact on rule benefits and costs. Replacing DOE's methodology with limited economic decision making criteria that monetizes non-economic factors more closely aligns with real-world consumer choices and significantly reduces the LCC savings of the SNOPR.
- Addition of non-economic factors into the GTI SNOPR analysis (GTI Integrated Scenario Int-14) did not materially change the LCC savings results compared to the rational CED framework used in GTI NOPR Integrated Scenario Int-5 and GTI SNOPR Integrated Scenario Int-12.
- Incorporation of the set of improved Decision Parametrics on their own, without improved input data, result in negative rule LCC savings under a CED framework, and virtually no savings when adding non-economic decision making factors to the CED framework.
- Incorporation of an improved furnace sizing methodology (GTI Parametric F1) provided the desired sensitivity to market conditions compared to the DOE methodology.
- Incorporation of improved input data had a modest, but meaningful negative impact on LCC savings compared to the DOE input information.

Table 18 LCC Savings – DOE SNOPR vs. GTI Decision Scenarios

Increment	GTI Decision Parametrics Compared to DOE SNOPR TSL 5 (92% AFUE Minimum) TSL 6 (80% AFUE ≤55 kBtu/h, 1.35 Oversizing)	LCC Savings (TSL 5)	LCC savings (TSL 6)	LCC Savings (TSL 5 with F1)	LCC savings (TSL 6 with F1)
0	DOE SNOPR	$617	$692	$635	$684
1	Add to Increment 0 income-based fuel switching decision payback period. (D2)	$600	$679	$608	$658
2	Remove from Increment 0 cases where fuel switching was cheaper than an 80% furnace and saved annual cost. (D8)	$504	$599	$495	$580
3	Add to Increment 0 income-based fuel switching decision payback period.; Remove from Increment 0 cases where fuel switching was cheaper than an 80% furnace and saved annual cost. (Combined Parametrics D2, D8)	$486	$585	$467	$553
4	Remove from Increment 0 cases with negative payback period in Base Case AFUE assignment. (D5)	$360	$446	$354	$422
5	Change Increment 0 to give consumers limited ability to make decisions based on economics, aligned with projected shipment fractions; replace payback period for Base Case AFUE assignment with a normal distribution with mean equal to the calculated payback period and standard deviation 50% of calculated payback period. (D14 w/SD 50%)	$99	$155	$102	$125
6	Add to Increment 5 income-based fuel switching decision payback period (Combined Parametrics D2, D14 w/SD 50%)	$41	$103	$43	$65
7	Remove from Increment 5 cases where fuel switching was cheaper than an 80% furnace and saved annual cost. (Combined Parametrics D8, D14 w/SD 50%)	$36	$78	$57	$79
8	Change Increment 0 to give consumers reasonable ability to make decisions based on economics, aligned with projected shipment fractions. (D4, D5)	$32	$57	$45	$61
9	Add to Increment 7 income-based fuel switching decision payback period. (GTI Scenario 36 including D2, D8, D14 w/SD 50%)	-$24	$25	-$2	$19
10	Combine Increments 2 and 8 (GTI Scenario 24 including D2, D4, D5, D8)	-$65	-$37	-$53	-$37

Note: GTI selected Increment 9 for inclusion in GTI Integrated Scenario Int-14.

Table 19 LCC Savings – DOE SNOPR vs. GTI Decision, Input, and Integrated Scenarios

Increment	GTI Decision and Input Parametrics and Scenario Changes Compared to DOE SNOPR TSL 5 (92% AFUE Minimum) and TSL 6 (80% AFUE ≤55 kBtu/h, 1.35 Oversizing)	LCC Savings (TSL 5)	LCC savings (TSL 6)
0	DOE SNOPR	$617	$692
1	Change Increment 0 using annual fuel consumption based furnace sizing. (F1)	$635	$684
2	Change Increment 1 using AEO 2016 with CPP, AHRI shipment data, real world furnace cost, and AGA derived marginal gas prices. (I2, I6, I13, I17, F1)	$456	$517
3	Add to Increment 2 income based fuel switching decision payback period to Increment 2. (D2, I2, I6, I13, I17, F1)	$420	$483
4	Remove cases from Increment 2 where fuel switching was cheaper than an 80% furnace and saved annual cost. (D2, D8, I2, I6, I13, I17, F1)	$297	$386
5	Remove cases from Increment 3 with negative payback period in Base Case AFUE assignment. (D2, D5, D8, I2, I6, I13, I17, F1)	$107	$175
6	Change Increment 0 to give consumers very poor ability to make decisions based on economics, aligned with projected shipment fractions; replace payback period for Base Case AFUE assignment with a normal distribution with mean equal to the calculated payback period and standard deviation 1000% of calculated payback period. (D2, D8, D14 w/SD 1000%, I2, I6, I13, I17, F1)	$81	$136
7	Change Increment 0 to give consumers very limited ability to make decisions based on economics, aligned with projected shipment fractions; replace payback period for Base Case AFUE assignment with a normal distribution with mean equal to the calculated payback period and standard deviation 100% of calculated payback period. (D2, D8, D14 w/SD 100%, I2, I6, I13, I17, F1)	-$114	-$85
8	Change Increment 0 to give Change Increment 0 to give consumers limited ability to make decisions based on economics, aligned with projected shipment fractions; replace payback period for Base Case AFUE assignment with a normal distribution with mean equal to the calculated payback period and standard deviation 50% of calculated payback period. (GTI Scenario Int-14 including D2, D8, D14 w/SD 50%, I2, I6, I13, I17, F1)	-$149	-$118
9	Change Increment 0 to give consumers reasonable ability to make decisions based on economics, aligned with projected shipment fractions. (GTI Scenario Int-12 including D2, D4, D5, D8, I2, I6, I13, I17, F1)	-$179	-$157

Note: GTI selected Increment 8 (Scenarios Int-14 and Int-14.55) for comparison with DOE SNOPR LCC model results.

3.2 GTI Integrated Scenario Int-14.55 and Int-14 Results

Table 20 summarizes the difference in consumer impacts when comparing the DOE SNOPR LCC model results with GTI Scenario Int-14.55 for the proposed rule (SNOPR TSL 6, GTI Scenario 0.55) and with GTI Scenario Int-14 for a single national 92% AFUE standard (SNOPR TSL 5, GTI Scenario 0). Comparable results for the NOPR analysis (updated by DOE as SNOPR TSL 5) are also included for reference. Table 21 through Table 30 provide a more detailed comparison of the DOE SNOPR LCC model results with the comparable GTI Integrated Scenario Int-14.55 and Int-14 results. The main differences, as noted, stem from the removal of the technically flawed DOE random assignment methodology for baseline furnace efficiency that results in (1) overstated Net Benefit cases (29% versus 12%) and (2) understated Net Cost cases (11% versus 15%) for DOE SNOPR TSL 6.

Table 20: SNOPR and NOPR Lifecycle Cost and Market Impact Comparisons

LCC Model Scenario	Average Furnace Life-Cycle Cost (LCC) Savings per Impacted Case	Fraction of Furnace Population (%)		
		Net Cost	No Impact	Net Benefit
DOE SNOPR TSL 6 (92%/55 kBtu/h)	$692	11%	60%	29%
GTI Integrated Scenario Int-14.55	-$118	15%	73%	12%
DOE SNOPR TSL 5 (92% all capacities)	$617	17%	48%	35%
GTI Integrated Scenario Int-14	-$149	22%	64%	15%
DOE NOPR (92% all capacities)	$520	20%	41%	39%
GTI NOPR Scenario Int-5	-$417	27%	57%	17%

Table 21 LCC Savings – DOE SNOPR TSL 6 vs. GTI Scenario Int-14.55

Scenario	National	North	Rest of Country	Residential Replacement	Residential Replacement - North	Residential Replacement - Rest of Country	Residential New	Residential New - North	Residential New - Rest of Country	Senior Only	Low-Income
LCC Savings Summary - 90% TSL											
DOE SNOPR (Scenario 0.55)	$667	$755	$615	$445	$479	$426	$1,242	$1,369	$1,158	$885	$592
SNOPR Scenario Int-14.55	-$196	-$470	-$23	-$232	-$678	-$47	$309	$203	$494	-$176	-$475
LCC Savings Summary - 92% TSL											
DOE SNOPR (Scenario 0.55)	$692	$749	$654	$502	$532	$483	$1,148	$1,176	$1,125	$890	$611
SNOPR Scenario Int-14.55	-$118	-$286	$17	-$182	-$493	-$23	$239	$153	$404	-$81	-$455
LCC Savings Summary - 95% TSL											
DOE SNOPR (Scenario 0.55)	$609	$617	$601	$499	$511	$489	$840	$783	$900	$770	$592
SNOPR Scenario Int-14.55	-$69	-$206	$53	-$139	-$342	-$18	$171	$13	$466	-$35	-$371
LCC Savings Summary - 98% TSL											
DOE SNOPR (Scenario 0.55)	$543	$502	$600	$447	$419	$488	$777	$677	$913	$724	$674
SNOPR Scenario Int-14.55	-$74	-$123	-$2	-$121	-$149	-$85	$121	-$82	$395	-$10	-$276

Table 22 Fuel Switching – DOE SNOPR TSL 6 vs. GTI Scenario Int-14.55

Scenario	National	North	Rest of Country	Residential Replacement	Residential Replacement - North	Residential Replacement - Rest of Country	Residential New	Residential New - North	Residential New - Rest of Country	Senior Only	Low-Income
Percent of Impacted Buildings Switching - 90% TSL											
DOE SNOPR (GTI Scenario 0.55)	18.3%	12.3%	21.9%	20.8%	11.0%	26.2%	14.3%	16.9%	12.6%	19.2%	15.6%
Scenario Int-14.55	10.1%	8.8%	10.8%	10.0%	7.2%	11.2%	13.4%	15.1%	10.3%	11.6%	13.0%
Percent of Impacted Buildings Switching - 92% TSL											
DOE SNOPR (GTI Scenario 0.55)	17.2%	10.1%	22.1%	20.0%	9.1%	26.9%	12.6%	13.4%	12.1%	18.3%	13.9%
Scenario Int-14.55	11.9%	7.7%	14.7%	12.4%	6.9%	15.3%	11.5%	10.2%	13.8%	13.2%	12.5%
Percent of Impacted Buildings Switching - 95% TSL											
DOE SNOPR (GTI Scenario 0.55)	18.3%	6.6%	20.8%	20.8%	6.1%	25.6%	14.3%	8.2%	10.7%	14.5%	12.3%
Scenario Int-14.55	11.8%	5.7%	16.5%	13.2%	6.1%	17.4%	8.6%	5.6%	14.2%	11.9%	13.3%
Percent of Impacted Buildings Switching - 98% TSL											
DOE SNOPR (GTI Scenario 0.55)	12.4%	4.2%	24.2%	13.7%	3.3%	28.8%	10.3%	7.0%	14.9%	11.2%	10.9%
Scenario Int-14.55	10.6%	3.7%	19.6%	10.6%	3.2%	20.2%	12.3%	6.6%	20.0%	9.2%	12.6%

Table 23 Energy and GHG Emissions – DOE SNOPR TSL 6 vs. GTI Scenario Int-14.55

Scenario	Gas Use w/o Rule (MMBtu)	Gas Use w/ Rule (MMBtu)	Electric Use w/o Rule (kWh)	Electric Use w/ Rule (kWh)	change gas use %	change electric use %	change source energy (MMBtu)	change emissions (lbs $CO2_e$)
Impacted Buildings - 90% TSL								
DOE SNOPR (GTI Scenario 0.55)	39.7	30.2	926.1	1,166.1	-24%	26%	-8.0	-1,080.7
Scenario Int-14.55	34.9	28.1	289.7	780.1	-20%	169%	-2.4	-331.4
Impacted Buildings - 92% TSL								
DOE SNOPR (GTI Scenario 0.55)	40.6	31.3	329.5	1,097.8	-23%	233%	-2.2	-313.6
Scenario Int-14.55	35.2	27.9	292.9	847.2	-21%	189%	-2.3	-319.0
Impacted Buildings - 95% TSL								
DOE SNOPR (GTI Scenario 0.55)	40.5	32.7	330.1	915.0	-19%	177%	-2.6	-357.7
Scenario Int-14.55	37.3	30.5	304.7	803.7	-18%	164%	-2.2	-312.0
Impacted Buildings - 98% TSL								
DOE SNOPR (GTI Scenario 0.55)	42.3	34.7	334.4	856.6	-18%	156%	-2.8	-389.9
Scenario Int-14.55	42.5	36.0	319.0	779.6	-15%	144%	-2.3	-315.1

Table 24 LCC Savings – DOE SNOPR TSL 5 vs. GTI Scenario Int-14

Scenario	National	North	Rest of Country	Residential Replacement	Residential Replacement - North	Residential Replacement - Rest of Country	Residential New	Residential New - North	Residential New - Rest of Country	Senior Only	Low-Income
	LCC Savings Summary - 90% TSL										
DOE SNOPR (GTI Scenario 0)	$582	$701	$530	$361	$430	$334	$1,263	$1,360	$1,210	$755	$440
GTI Scenario Int-14	-$203	-$487	-$88	-$258	-$698	-$113	$294	$166	$489	-$166	-$562
	LCC Savings Summary - 92% TSL										
DOE SNOPR (GTI Scenario 0)	$617	$711	$569	$420	$496	$386	$1,177	$1,172	$1,180	$775	$476
GTI Scenario Int-14	-$149	-$309	-$65	-$222	-$519	-$100	$220	$136	$347	-$88	-$506
	LCC Savings Summary - 95% TSL										
DOE SNOPR (GTI Scenario 0)	$561	$597	$537	$437	$492	$405	$865	$773	$949	$692	$482
GTI Scenario Int-14	-$104	-$223	-$26	-$185	-$361	-$97	$178	$6	$453	-$57	-$426
	LCC Savings Summary - 98% TSL										
DOE SNOPR (GTI Scenario 0)	$506	$487	$528	$399	$405	$394	$801	$668	$956	$662	$554
GTI Scenario Int-14	-$104	-$136	-$69	-$166	-$163	-$169	$139	-$88	$396	-$40	-$344

Table 25 Fuel Switching – DOE SNOPR TSL 5 vs. GTI Scenario Int-14

Scenario	National	North	Rest of Country	Residential Replacement	Residential Replacement - North	Residential Replacement - Rest of Country	Residential New	Residential New - North	Residential New - Rest of Country	Senior Only	Low-Income
	Percent of Impacted Buildings Switching - 90% TSL										
DOE NOPR (GTI Scenario 0)	23.2%	12.5%	28.0%	24.0%	11.0%	29.2%	23.5%	18.0%	26.5%	25.3%	20.8%
GTI Scenario Int-14	21.3%	11.2%	25.3%	22.2%	9.7%	26.4%	19.0%	18.1%	20.3%	24.9%	27.5%
	Percent of Impacted Buildings Switching - 92% TSL										
DOE NOPR (GTI Scenario 0)	22.1%	10.4%	28.2%	23.3%	9.2%	29.8%	21.0%	14.3%	25.6%	24.4%	20.0%
GTI Scenario Int-14	22.9%	9.7%	29.9%	24.2%	9.1%	30.4%	20.3%	12.2%	32.4%	25.9%	26.9%
	Percent of Impacted Buildings Switching - 95% TSL										
DOE NOPR (GTI Scenario 0)	18.5%	6.9%	26.3%	20.5%	6.4%	28.7%	15.5%	8.8%	21.6%	19.1%	17.3%
GTI Scenario Int-14	20.7%	7.1%	29.6%	22.7%	7.8%	30.1%	16.2%	6.4%	31.7%	20.8%	23.2%
	Percent of Impacted Buildings Switching - 98% TSL										
DOE NOPR (GTI Scenario 0)	16.2%	4.4%	29.2%	17.1%	3.6%	31.6%	15.3%	7.4%	24.6%	15.2%	15.3%
GTI Scenario Int-14	17.5%	4.5%	31.8%	17.4%	4.0%	32.0%	20.4%	7.3%	35.1%	15.4%	20.1%

Table 26 Energy and GHG Emissions – DOE SNOPR TSL 5 vs. GTI Scenario Int-14

Scenario	Gas Use w/o Rule (MMBtu)	Gas Use w/ Rule (MMBtu)	Electric Use w/o Rule (kWh)	Electric Use w/ Rule (kWh)	change gas use %	change electric use %	change source energy (MMBtu)	change emissions (lbs $CO2_e$)
	Impacted Buildings - 90% TSL							
DOE SNOPR (GTI Scenario 0)	35.3	26.1	300.4	1,118.8	-26%	272%	-1.6	-234.2
GTI Scenario Int-14	30.6	23.1	267.9	865.0	-25%	223%	-2.0	-283.5
	Impacted Buildings - 92% TSL							
DOE NOPR (GTI Scenario 0)	36.3	27.2	305.9	1,071.8	-25%	250%	-2.0	-288.1
GTI Scenario Int-14	31.2	23.1	272.2	933.9	-26%	243%	-1.9	-269.9
	Impacted Buildings - 95% TSL							
DOE NOPR (GTI Scenario 0)	37.1	29.1	311.4	926.2	-22%	197%	-2.4	-334.3
GTI Scenario Int-14	33.8	26.5	287.4	876.7	-22%	205%	-1.9	-273.9
	Impacted Buildings - 98% TSL							
DOE NOPR (GTI Scenario 0)	39.4	31.7	320.0	882.2	-20%	176%	-2.6	-367.1
GTI Scenario Int-14	39.4	32.4	304.7	839.0	-18%	175%	-2.0	-285.3

Table 27 DOE SNOPR TSL 6 (GTI Scenario 0.55) LCC Analysis Summary Results

DOE SNOPR (GTI Scenario 0.55)		National				Replacement				New			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	$667	12%	65%	23%	$313	15%	67%	18%	$1,053	2%	61%	37%
2	NWGF 92%	$692	11%	60%	29%	$364	14%	62%	24%	$993	2%	53%	45%
3	NWGF 95%	$609	15%	40%	44%	$385	17%	46%	37%	$749	9%	25%	65%
4	NWGF 98%	$543	26%	16%	58%	$369	29%	18%	52%	$703	16%	10%	74%

DOE SNOPR (GTI Scenario 0.55)		North - Replacement				Rest of Country- Replacement			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	$418	11%	78%	12%	$271	21%	55%	24%
2	NWGF 92%	$474	10%	72%	18%	$313	19%	52%	30%
3	NWGF 95%	$468	12%	55%	33%	$336	23%	36%	41%
4	NWGF 98%	$394	31%	7%	62%	$342	27%	30%	42%

DOE SNOPR (GTI Scenario 0.55)		North - New				Rest of Country- New			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	$1,301	2%	71%	27%	$916	1%	49%	50%
2	NWGF 92%	$1,126	2%	62%	36%	$903	2%	43%	55%
3	NWGF 95%	$755	8%	29%	63%	$743	11%	21%	68%
4	NWGF 98%	$656	17%	4%	79%	$758	16%	17%	67%

DOE SNOPR (GTI Scenario 0.55)		Senior				Low-Income			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	$610	10%	71%	19%	$360	11%	71%	18%
2	NWGF 92%	$636	9%	65%	25%	$389	11%	66%	23%
3	NWGF 95%	$585	13%	47%	40%	$406	16%	50%	34%
4	NWGF 98%	$585	24%	20%	55%	$509	29%	25%	46%

Table 28 GTI Scenario Int-14.55 LCC Analysis Summary Results

Scenario Int-14.55		National				Replacement				New			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	-$196	13%	79%	8%	-$232	17%	76%	7%	$309	1%	89%	10%
2	NWGF 92%	-$118	15%	73%	12%	-$182	19%	72%	10%	$239	4%	79%	17%
3	NWGF 95%	-$69	28%	53%	19%	-$139	32%	53%	16%	$171	15%	55%	30%
4	NWGF 98%	-$74	46%	24%	30%	-$121	52%	20%	28%	$121	24%	42%	34%

Scenario Int-14.55		North - Replacement				Rest of Country- Replacement			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	-$678	14%	84%	2%	-$47	21%	67%	12%
2	NWGF 92%	-$493	15%	79%	6%	-$23	22%	63%	14%
3	NWGF 95%	-$342	26%	63%	11%	-$18	38%	41%	21%
4	NWGF 98%	-$149	59%	8%	33%	-$85	45%	32%	23%

Scenario Int-14.55		North - New				Rest of Country- New			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	$203	2%	86%	12%	$494	0%	91%	8%
2	NWGF 92%	$153	5%	73%	22%	$404	2%	86%	12%
3	NWGF 95%	$13	22%	44%	34%	$466	7%	68%	25%
4	NWGF 98%	-$82	29%	37%	34%	$395	19%	49%	33%

Scenario Int-14.55		Senior				Low-Income			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	-$176	13%	81%	6%	-$475	15%	78%	7%
2	NWGF 92%	-$81	15%	76%	9%	-$455	18%	73%	9%
3	NWGF 95%	-$35	26%	57%	17%	-$371	31%	54%	15%
4	NWGF 98%	-$10	47%	23%	30%	-$276	53%	23%	24%

Table 29 DOE SNOPR TSL 5 (GTI Scenario 0) LCC Analysis Summary Results

DOE SNOPR (GTI Scenario 0)		National				Replacement				New			
TSL		LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	$582	18%	53%	28%	$361	24%	53%	23%	$1,263	3%	54%	43%
2	NWGF 92%	$617	17%	48%	35%	$620	22%	48%	30%	$620	3%	46%	51%
3	NWGF 95%	$561	22%	26%	51%	$561	26%	30%	44%	$561	11%	16%	73%
4	NWGF 98%	$506	34%	1%	65%	$417	26%	30%	44%	$417	11%	16%	73%

DOE SNOPR (GTI Scenario 0)		North - Replacement				Rest of Country- Replacement			
TSL		LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	$430	12%	74%	13%	$334	36%	30%	34%
2	NWGF 92%	$496	11%	69%	20%	$386	33%	25%	41%
3	NWGF 95%	$492	14%	50%	36%	$405	39%	7%	54%
4	NWGF 98%	$248	14%	50%	36%	$378	39%	7%	54%

DOE SNOPR (GTI Scenario 0)		North - New				Rest of Country- New			
TSL		LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	$1,360	2%	70%	28%	$1,210	3%	36%	62%
2	NWGF 92%	$1,172	3%	60%	38%	$1,180	4%	29%	67%
3	NWGF 95%	$773	9%	26%	65%	$949	14%	5%	82%
4	NWGF 98%	$573	9%	26%	65%	$907	14%	5%	82%

DOE SNOPR (GTI Scenario 0)		Senior				Low-Income			
TSL		LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	$755	17%	57%	25%	$440	22%	52%	26%
2	NWGF 92%	$775	17%	51%	32%	$476	20%	47%	33%
3	NWGF 95%	$692	22%	30%	48%	$482	28%	27%	45%
4	NWGF 98%	$490	22%	30%	48%	$354	28%	27%	45%

Table 30 GTI Scenario Int-14 LCC Analysis Summary Results

Scenario Int-14		National				Replacement				New			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	-$203	20%	70%	10%	-$258	26%	65%	10%	$294	1%	87%	11%
2	NWGF 92%	-$149	22%	64%	15%	-$222	27%	59%	13%	$220	5%	75%	20%
3	NWGF 95%	-$104	35%	42%	23%	-$185	41%	39%	20%	$178	17%	50%	34%
4	NWGF 98%	-$104	54%	12%	34%	-$166	63%	5%	32%	$139	28%	34%	39%

Scenario Int-14		North - Replacement				Rest of Country- Replacement			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	-$698	15%	83%	2%	-$113	38%	44%	18%
2	NWGF 92%	-$519	17%	78%	6%	-$100	39%	40%	21%
3	NWGF 95%	-$361	28%	61%	11%	-$97	56%	15%	29%
4	NWGF 98%	-$163	61%	5%	33%	-$169	64%	5%	31%

Scenario Int-14		North - New				Rest of Country- New			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	$166	2%	86%	12%	$489	1%	89%	10%
2	NWGF 92%	$136	6%	73%	22%	$347	4%	79%	18%
3	NWGF 95%	$6	23%	43%	34%	$453	10%	58%	33%
4	NWGF 98%	-$88	30%	35%	35%	$396	25%	32%	43%

Scenario Int-14		Senior				Low-Income			
	TSL	LCC Savings	Net Cost	No Impact	Net Benefit	LCC Savings	Net Cost	No Impact	Net Benefit
1	NWGF 90%	-$166	19%	72%	8%	-$562	23%	67%	10%
2	NWGF 92%	-$88	21%	67%	12%	-$506	26%	62%	12%
3	NWGF 95%	-$57	33%	46%	20%	-$426	40%	41%	19%
4	NWGF 98%	-$40	55%	11%	34%	-$344	63%	8%	28%

Key findings of the integrated scenario analysis conducted by GTI analysts using the DOE LCC spreadsheet and Crystal Ball predictive modeling software include:

- DOE's random baseline furnace assignment methodology remains technically flawed, with significant impact in terms of overstated rule benefits and understated rule costs. Replacing DOE's methodology with economic decision making criteria that monetizes non-economic factors changes both the characteristics and fractions of "Net Benefit" and "No Impact" consumers and significantly reduces the financial benefit of the rule nationally, regionally, and by subgroup.
- A total of 13% of all residential trial cases and 55% of DOE's claimed rule benefit comes from a combination of builders and consumers that DOE inexplicably claims are willing to pay extra for lower efficiency furnaces – an irrational outcome that stems from DOE's technically flawed baseline furnace efficiency assignment.
- DOE's predictive LCC model results combine random decisions and selective application of economic decisions that overstate LCC savings compared to a CED framework methodology that monetizes non-economic factors.
- Key input data used in the DOE SNOPR LCC model are also inconsistent with market-based information. DOE's predictive LCC model results include engineering estimates of furnace prices that differ from available market data; marginal gas prices derived from the EIA 2014 NG Navigator state level reporting of natural gas sales and revenues that differ from using gas companies' tariff data to supplement EIA data; and condensing furnace shipment forecasts that are lower than the long term historical trend from AHRI shipment data. Taken together, the DOE input information and forecasts associated with using these variables overstate LCC savings compared to credible market data.
- GTI Integrated Scenario Int-14, based on rational consumer economic and non-economic decision criteria and modifications to DOE's input data, shows negative composite average lifecycle cost savings for all four condensing furnace trial standard levels (90%, 92%, 95%, and 98% AFUE) compared to the 80% AFUE baseline furnace, indicating that the 92% furnace proposed in the DOE SNOPR for a single product class as well as any other condensing furnace efficiency levels do not meet the EPCA requirement for economic justification of positive LCC savings and a payback period that is shorter than the equipment expected life.
- The GTI furnace sizing methodology based on annual heating consumption (GTI Sizing Scenario F1) provides the expected trend of increased LCC savings and reduced number of impacted homes as the non-condensing furnace capacity limit increases, whereas the DOE SNOPR methodology, based on building size, is insensitive to incremental changes in capacity limits due to the poor correlation between home size and required furnace capacity to meet the home heating load.
- GTI Integrated Scenario Int-14.55 (Including Scenario F1) combines limited ability to make economic decisions with a more market-sensitive furnace sizing methodology has significant implications for fuel switching compared to the flawed DOE methodologies. As shown by comparing fuel switching results in Table 22 and Table 25, the GTI methodologies predict a much more significant reduction in fuel switching with the second product class than the DOE methodologies. Under the DOE SNOPR, national average fuel switching per impacted building drops from 22.1% to 17.2%, a reduction of 4.9% - roughly a 22% change in fuel switching behavior. Under the GTI Int-14 and Int-

14.55 methodologies, national average fuel switching drops from 22.9% to 11.9%, a reduction of 11% - nearly a 50% change in fuel switching behavior.

- The significant reduction in fuel switching under GTI Scenario Int-14.55 compared to the DOE SNOPR also affects the national impact analysis. While consumer economics are still poor, the mitigation of fuel switching through a separate product class improves the national impact compared to a single product class rule.
- DOE's furnace market penetration methodology is insensitive to distinctions in condensing furnace market adoption in new construction compared to replacements. Since DOE's underlying framework is insensitive to market penetration, the impact of this flaw is not distinguishable in the DOE SNOPR results. Unfortunately, GTI SNOPR analysis scenarios could not address this flaw because no market data was available from AHRI or other sources. However, the impact of this flaw on the GTI market-sensitive methodology is to misallocate market segment benefits between new construction and replacements. Since new construction market share is likely to be higher than replacement market share without the rule, the market segment results in the GTI analysis may be slightly overstating new construction market segment LCC savings and slightly understating replacement market segment LCC savings.

3.3 Separate Product Class Based on Furnace Capacity Results

Table 31 shows LCC savings for the 92% AFUE TSL under GTI Scenario Int-14 compared to the DOE SNOPR LCC analysis results for a separate product class based on furnace input capacity, with and without the DOE downsizing methodology. Figure 17 through Figure 19 compare the incremental and cumulative savings for different furnace capacity limits ranging from 40 kBtu/h through 140 kBtu/h using the DOE SNOPR furnace sizing methodology and the annual heating consumption methodology (GTI Parametric F1). Figure 20 provides results for different market segments.

Key findings of the separate product class analysis conducted by GTI analysts using the DOE LCC spreadsheet and Crystal Ball predictive modeling software include:

- GTI Integrated Scenario Int-14 cases show negative composite average lifecycle cost savings for a separate product class below 115 kBtu/h input capacity, and negative composite average lifecycle cost savings for a separate product class below 90 kBtu/h input capacity when adding DOE's furnace downsizing methodology. These findings align well with the empirical data analysis findings summarized in GTI Topical Report GTI-16/0003.
- LCC savings using the DOE SNOPR furnace sizing methodology show no trend with furnace size. This is consistent with the poor correlation between annual heating load and the DOE SNOPR random Base Case furnace assignment and sizing methodology.
- LCC savings using the GTI Integrated Scenario Int-14 furnace sizing methodology show a flat to negative trend with furnace size up to 110 kBtu/h without downsizing, and a strong upward trend for furnaces above 110 kBtu/h. This is consistent with the CED framework and the strong correlation between annual heating load and the furnace size.
- LCC savings using GTI Integrated Scenario Int-14 show a flat to negative trend with furnace size up to 90 kBtu/h when adding DOE's downsizing methodology, and a strong upward trend for furnaces above 90 kBtu/h. However, results using the DOE downsizing methodology are being confounded by the aggregating approach to cumulative LCC

savings used by DOE. The use of cumulative savings vs. incremental savings at each furnace capacity is misleading due to the significant rule benefits above 120 kBtu/h compared to smaller furnace capacity limit benefits. Incremental savings are masked when using the average savings approach because of the significant contribution to average savings at larger furnace capacity levels.

- There is no capacity limit that provides a net benefit to the low income market segment, under either a current market furnace sizing methodology or when adding the DOE furnace downsizing methodology.

Key findings of the scenario analyses conducted by GTI analysts to examine the impact of different furnace capacity limits for 80% AFUE furnaces on rule benefits using the DOE LCC spreadsheet and Crystal Ball predictive modeling software include:

- The DOE SNOPR furnace size assignment methodology based on home size and design outdoor air temperature derived from the RECS 2009 database is technically flawed and poorly correlated with heating consumption and furnace capacity required to meet peak heating and setback recovery loads.
- The lack of data in the RECS database on the key values of furnace AFUE and capacity makes it an inadequate source of information for use in the furnace capacity and annual heating load assignments used in the SNOPR, both for the single standard level and for separate standard levels based on furnace input capacity evaluated in the SNOPR. Additional market information is needed for this purpose.
- Detailed empirical data analysis described in GTI Topical Report GTI-16/0003 shows the expected high correlation between annual heating consumption and house "UA" (a combination of thermal efficiency and envelope area), a strong correlation between required furnace capacity and home "UA", but a very poor correlation between annual heating consumption and home size (or UA and home size). Unfortunately, the lack of monthly gas consumption data and poor correlation between gas consumption, annual HDD, design outdoor air temperature, and peak heating load in the RECS database used by DOE in the SNOPR LCC spreadsheet model for each of the 10,000 trial cases precluded the use of the GTI empirical model with RECS database information.
- DOE's furnace sizing methodology is not adequate for determining the benefits of different furnace capacity limits on LCC savings, providing inconsistent and misleading results due to the poor correlation between home size and required furnace capacity.
- A furnace capacity algorithm (GTI Parametric F1) developed by GTI analysts based on the RECS database annual heating consumption rather than home size has a relatively strong correlation between annual heating load and associated furnace size (R^2=0.69). The correlation between annual heating load and furnace size (R^2=0.69) is substantially better with the RECS annual heating consumption model than the correlation using the DOE furnace sizing methodology (R^2=0.11). This is an a priori expectation because annual heating consumption should have a fair to strong correlation with peak heating load, whereas home size has been demonstrated to have poor correlation with peak heating load for a variety of reasons. The RECS annual heating consumption model is also compatible with the furnace "downsizing" methodology used by DOE in the SNOPR proposed rule (TSL 6). It also provided the desired sensitivity to market conditions compared to the DOE methodology.

- The incremental cost of going to a higher efficiency furnace does not increase strictly proportionally to furnace size. For example, if an installer needs to put in venting to the outside it is not twice as expensive to vent a 100 kBtu/h furnace compared to a 50 kBtu/h furnace. Similarly, the cost of the furnace is not strictly proportional to size. The cost per Btu/h of a 100 kBtu/h furnace will be lower than the cost per Btu/h of a 50 kBtu/h furnace. However, LCC savings are strictly proportional to the heating load. So, if furnace sizing is responsive to load, a 100 kBtu/h furnace will cost less than twice what a 50 kBtu/h furnace costs, but it will save about twice as much energy. So LCC savings benefits increase as furnace size increases. In DOE's furnace sizing algorithm there is almost no connection between heating load and furnace size, so DOE’s methodology is insensitive to that trend.
- Under an economic decision making framework with a low income distribution for fuel switching decisions, for the fewer and fewer remaining impacted cases, the rule benefits per home go up as a function of load. So at some point, rule benefits are net positive due to less irrational fuel switching at larger furnace sizes caused by the rule, coupled with proportionally higher LCC savings at larger furnace sizes.

Table 31: LCC Savings (92% AFUE TSL) with Furnace Capacity Product Class Options

Furnace Size (kBtu/h)	SNOPR, LCC savings at each size	SNOPR, cumulative average LCC savings	SNOPR, cumulative average LCC savings, with downsizing	Scenario F1, LCC savings at each size	Scenario F1, cumulative average LCC savings	Scenario F1, cumulative average LCC savings, with downsizing	Scenario Int-14, LCC savings at each size	Scenario Int-14, cumulative average LCC savings	Scenario Int-14, cumulative average LCC savings, with downsizing	Scenario Int-14, north, cumulative	Scenario Int-14, south, cumulative	Scenario Int-14, low-income, cumulative
40	$266	$617	$666	$440	$635	$644	-$460	-$149	-$138	-$309	-$65	-$506
45	$166	$624	$671	$547	$638	$643	-$197	-$144	-$138	-$310	-$56	-$502
50	$135	$636	$691	$499	$639	$683	-$224	-$143	-$118	-$307	-$54	-$502
55	$527	$669	$692	$664	$646	$684	-$133	-$138	-$149	-$313	-$37	-$473
60	$500	$674	$741	$413	$646	$748	-$221	-$138	-$83	-$312	-$32	-$469
65	#N/A	$699	$712	#N/A	$689	$765	#N/A	-$120	-$134	-$289	$18	-$537
70	$563	$699	$730	$575	$689	$780	-$155	-$120	-$140	-$289	$18	-$537
75	$559	$727	$727	$486	$713	$846	-$167	-$110	-$155	-$283	$78	-$657
80	$762	$770	$676	$622	$779	$881	$62	-$91	-$35	-$262	$154	-$814
85	#N/A	$773	$676	#N/A	$848	$881	#N/A	-$164	-$35	-$295	$74	-$891
90	$753	$773	$671	$567	$848	$947	-$96	-$164	$52	-$295	$74	-$891
95	$1,286	$780	$695	#N/A	$923	$947	#N/A	-$183	$52	-$307	$91	-$1,046
100	$652	$728	$452	$788	$923	$1,348	-$327	-$183	$224	-$307	$91	-$1,046
105	#N/A	$773		#N/A	$1,003		#N/A	-$61		-$139	$131	-$302
110	$817	$773		$636	$1,003		-$364	-$61		-$139	$131	-$302
115	$443	$763		#N/A	$1,088		#N/A	$48		-$29	$242	-$167
120	$876	$796		$623	$1,088		-$57	$48		-$29	$242	-$167
125	$686	$649		$1,233	$1,836		$78	$357		$323	$478	-$745
130	$561	$635		$1,354	$1,956		$178	$436		$419	$478	-$1,188
135	$202	$685		$1,504	$2,067		$299	$507		$507	$509	-$1,493
140	$522	$1,494		$1,568	$2,623		$457	$912		$1,321	$161	$0
145	#N/A	$6,031		#N/A	$3,723		#N/A	$1,561		$2,528	$271	$0
150	-$18	$6,031		$2,285	$3,723		$864	$1,561		$2,528	$271	$0
155	$12,079	$12,079		$2,635	$4,699		$825	$2,084		$2,625	$460	$0
160	#N/A	#N/A		$12,269	$12,269		$5,860	$5,860		$5,860	$0	$0

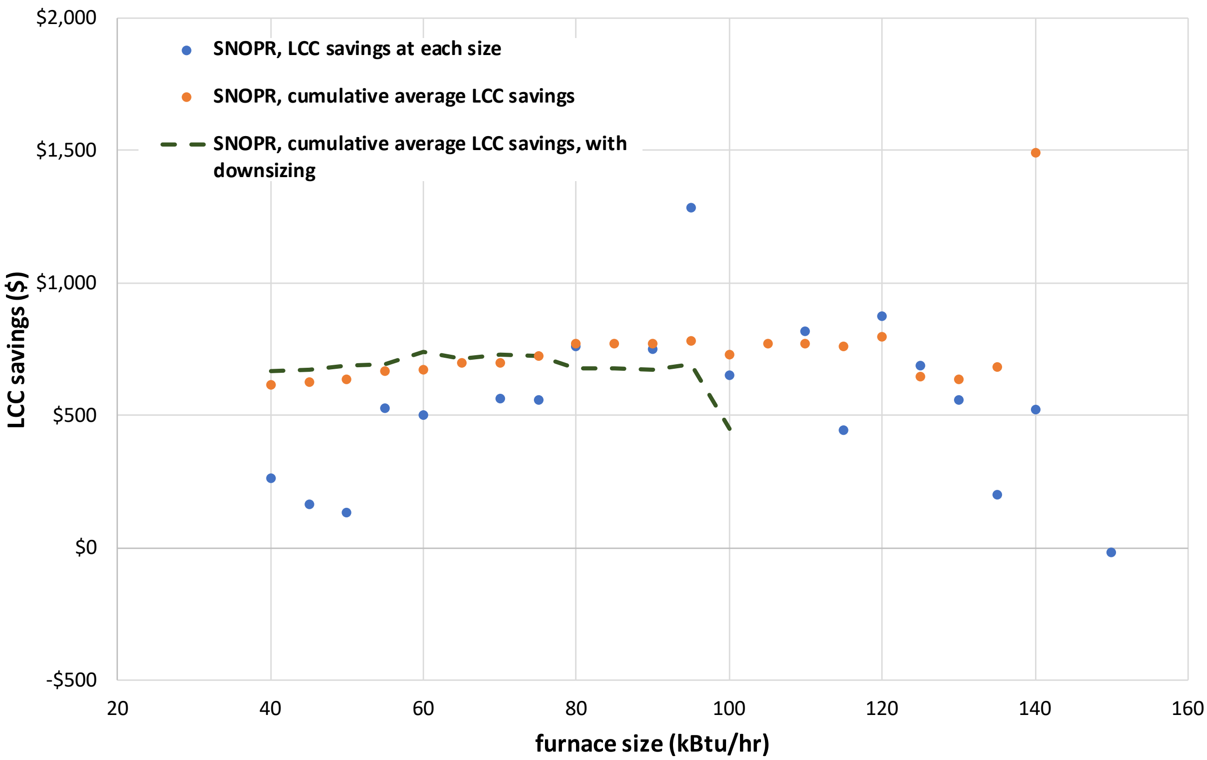


Figure 17: DOE SNOPR LCC Savings with Different Furnace Capacity Limits

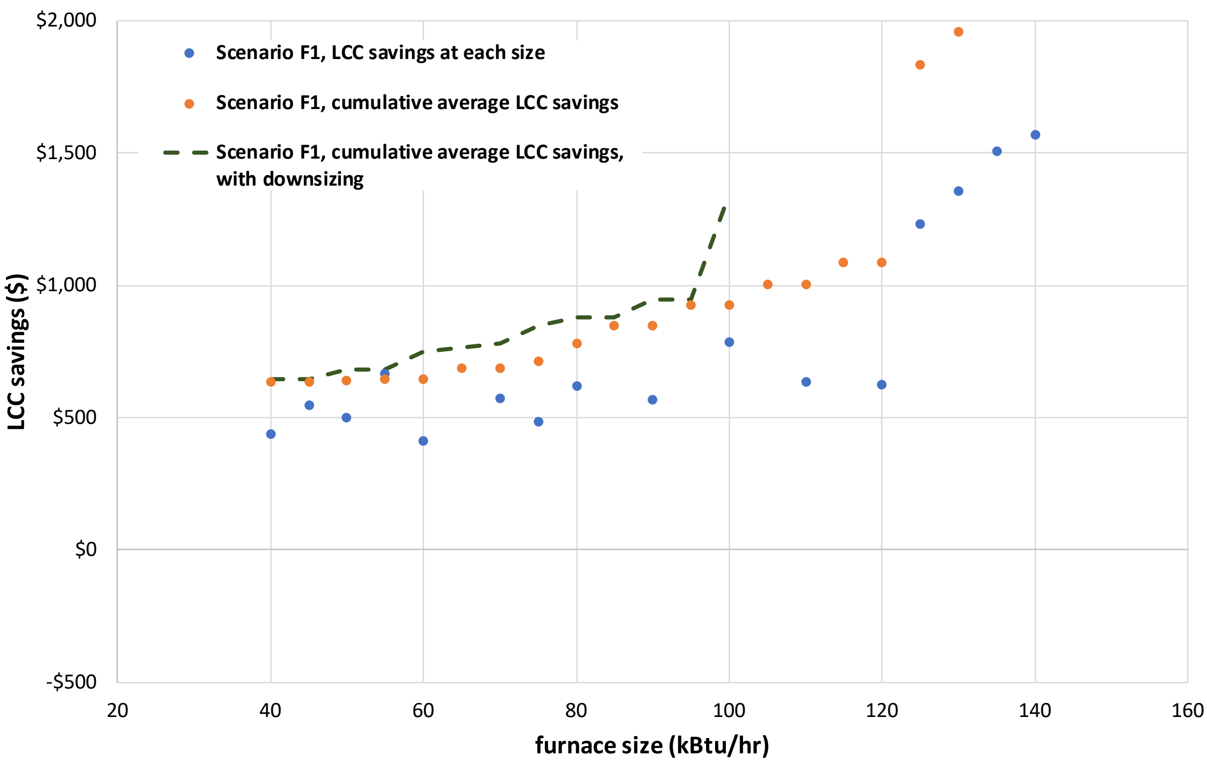


Figure 18: GTI Scenario F1 LCC Savings with Different Furnace Capacity Limits

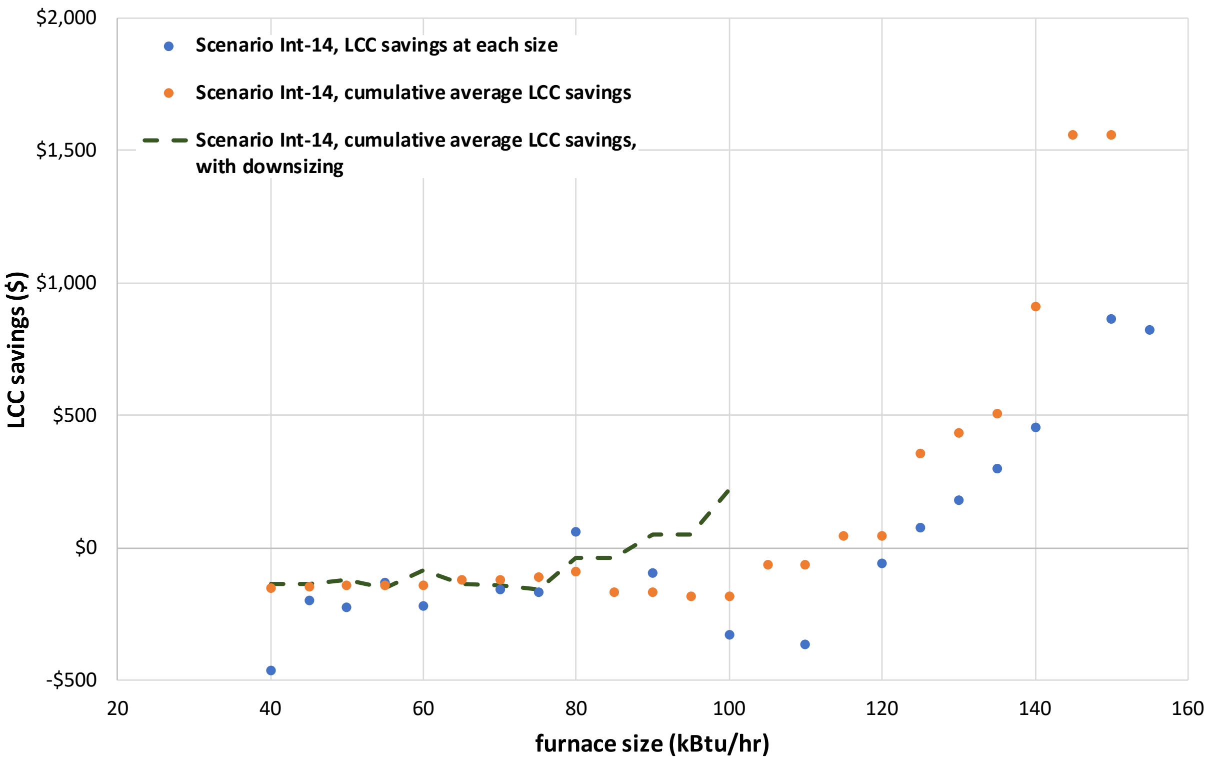


Figure 19: GTI Scenario Int-14 LCC Savings vs. Furnace Capacity Limits

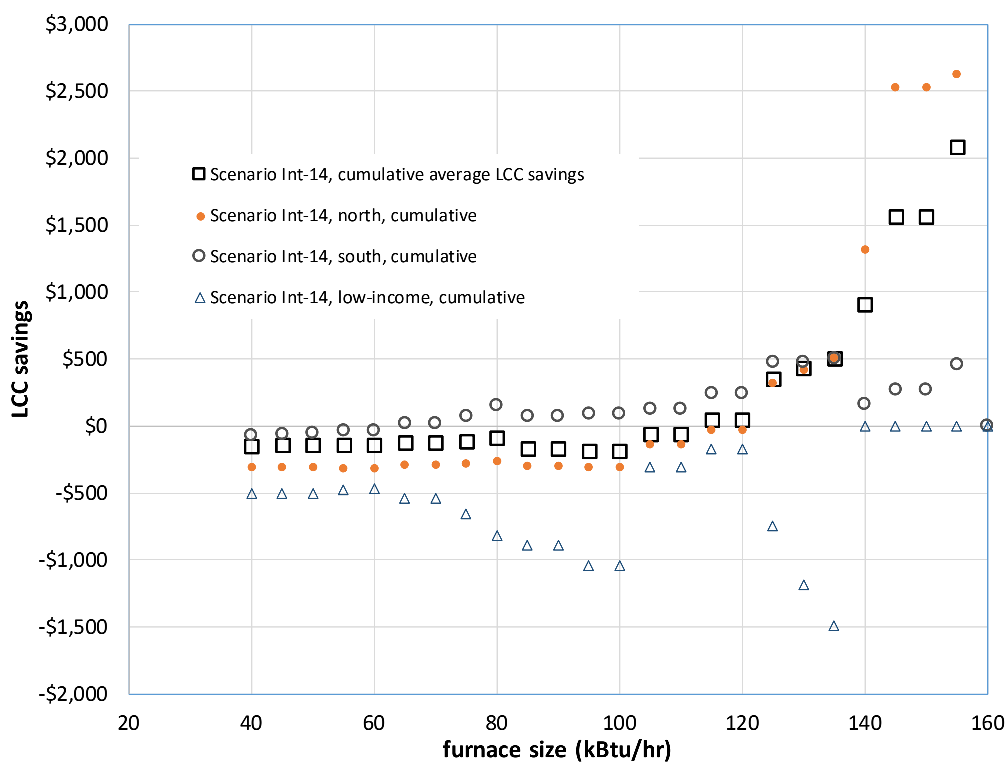


Figure 20: Regional and Low Income LCC Savings vs. Int-14 Furnace Capacity Limits

4 Implications of DOE SNOPR Methodology Technical Flaws

4.1 Random Base Case Furnace Assignment

In the SNOPR (Federal Register Vo. 81 No. 185, p 65789), DOE asserts that "*the assignment of furnace efficiency in the no-new-standards case is not entirely random.*" DOE further asserts that "*the method of assignment, which is in part random, may simulate actual behavior as well as assigning furnace efficiency based solely on imputed cost-effectiveness.*"

DOE's assertion that the Base Case furnace assignment is not entirely random is misleading and does not address the critical technical flaw in the DOE assignment methodology. In addition, the way DOE's LCC model results are calculated and displayed in the SNOPR masks this key technical flaw and meaningful disconnect with current and projected market behavior caused by the DOE random Base Case furnace assignment methodology.

When determining rule benefit per impacted building compared to the "no-new-standards" case, the DOE Base Case furnace assignment methodology is entirely random. The DOE SNOPR LCC model uses a random distribution function to assign the "Base Case AFUE" to each of the 10,000 trial cases, with the probability based on a specific region and building category, as illustrated in Figure 21.

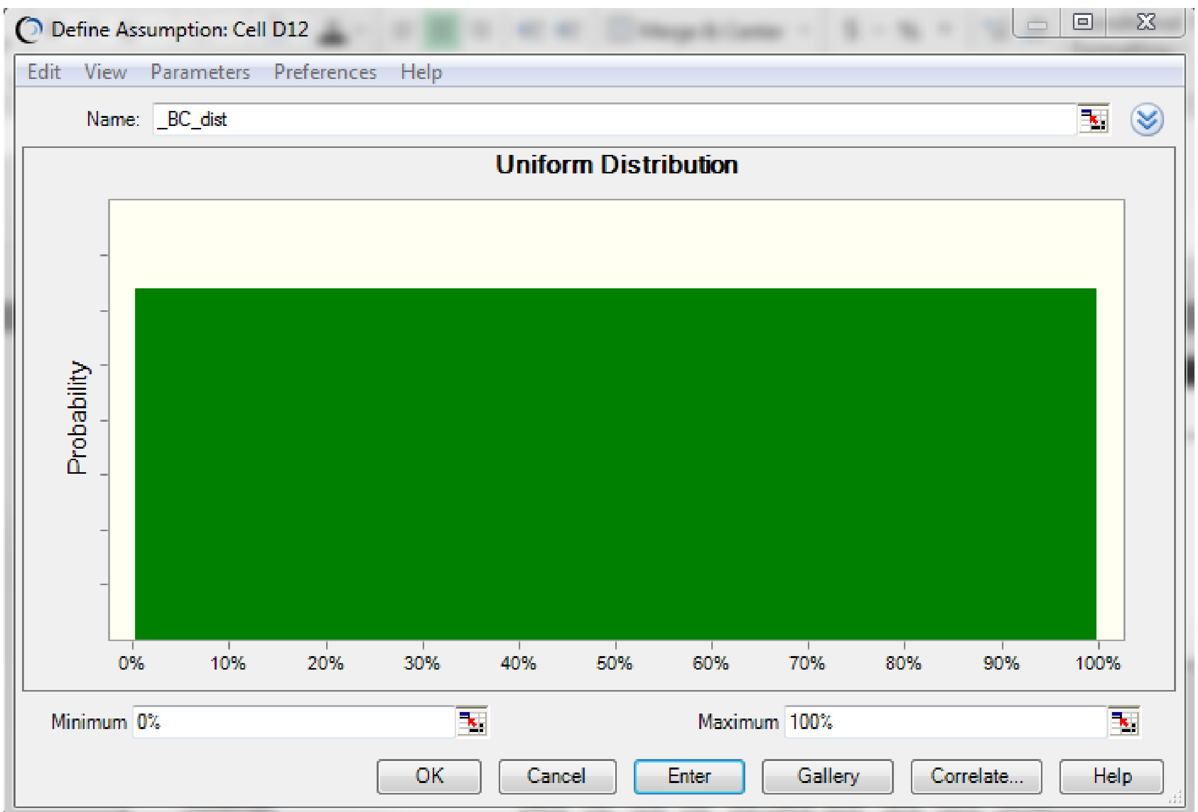


Figure 21: Random Assignment of Each Trial Case Base Case Furnace

In sheet "Base Case AFUE" cell D12, a uniform random number is generated by Crystal Ball. This random number is then used to determine the base case furnace efficiency using a lookup table based on DOE's regional estimates of condensing furnace shipment fractions applied to homes of a given major category in that region. This quasi-deterministic "not entirely random" approach changes the number of homes of a given type and region that are impacted by the rule, but it does not affect the projected savings or costs caused by the rule for an individual trial case building within that region.

The entirely random DOE Base Case furnace selection for an individual building does not consider any individual building's characteristics that significantly influence rule benefit and cost for that building, including size, age, annual heating load, heating energy consumption, rational economic decisions by builders for new construction, cost to replace existing furnaces, or other potentially important parameters when using this random number assignment approach. Any building of a given type in a given region has the same probability of being assigned a non-condensing furnace as any other building of that type in that region. As a result, any individual building is as likely as any other to be considered impacted by the rule in any given region and major building type.

The DOE random assignment approach results in a quasi-deterministic number of buildings of a given type within each of the 30 RECS or 9 CBECS regions that are considered not impacted by the rule because of the furnace shipment fractions in that region. But whether a specific trial case building will be one of those not impacted cases is strictly and totally random, dramatically biasing the model results "per impacted building" toward rule benefit.

DOE does not consider economics for decision making associated with Base Case AFUE assignment. The shipment data projections affect the number of impacted buildings only on a per region and type basis, not the LCC savings per impacted home, within a certain region and type, caused by a rule. For a given region and type the LCC savings per impacted building will be the same regardless of the condensing furnace shipment numbers. (new/replacement, residential/commercial).

DOE's assertion that *"the method of assignment, which is in part random, may simulate actual behavior as well as assigning furnace efficiency based solely on imputed cost-effectiveness"* is demonstrably false and disconnected from market behavior. The inherent result of the DOE SNOPR LCC model random assignment methodology is a finding of LCC savings in any region where LCC savings are present on average whether or not the shipment data projects a very high or very low rate of condensing furnace market share in the "no-new-standards" Base Case. For example, if market penetration of condensing furnaces is projected at 90% for a given region and type of home, and LCC savings associated with condensing furnaces is <u>on average</u> positive for the region, a net LCC savings due to rule would be determined by the model without consideration of the economics associated with the 10% of consumers impacted by the rule separate from the non-impacted group. This is a critical technical flaw in the model, as shown in Figure 22. The only way LCC savings on a national basis are affected by DOE's approach is by changing the number of impacted buildings based on region and type.

This has the effect of causing the DOE model to "find" LCC savings nationally as long as consumers on average benefit from condensing furnaces nationally. The model is a priori precluded from finding that, on average, the consumers that tend to benefit are the consumers that tend to purchase condensing furnaces.

To illustrate this effect and its significant impact on results, GTI analysts developed a simplified market penetration sensitivity scenario for different assumed initial condensing furnace market penetrations within the overall DOE analytical framework. For this analysis, it was necessary to remove the numerous confounding factors that mask the total market disconnect in DOE's results summaries that were caused by deterministic regional differences in market penetration of condensing furnaces. To isolate the known lack of market sensitivity of the DOE random methodology and compare it with the market-sensitive approach used in GTI Scenarios, only 80% and 92+% AFUE furnaces were considered in this analysis, and all regions were assigned the same market penetration.

Figure 22 highlights this key technical flaw when using the DOE random methodology. The graph compares results using the DOE methodology with results using the market-sensitive methodology in GTI Scenario Int-14 that incorporates a combination of rational economic and non-economic decisions in the Base Case furnace assignment methodology. This example illustrates the total disconnect from market conditions, with high bias toward rule benefit, when using the DOE random assignment methodology. This market disconnect and bias are necessarily the case when using the DOE random assignment methodology for this purpose. <u>The DOE model is guaranteed to show LCC savings regardless of the modeled market's functional behavior.</u> This critical flaw fundamentally undermines the DOE LCC model results.

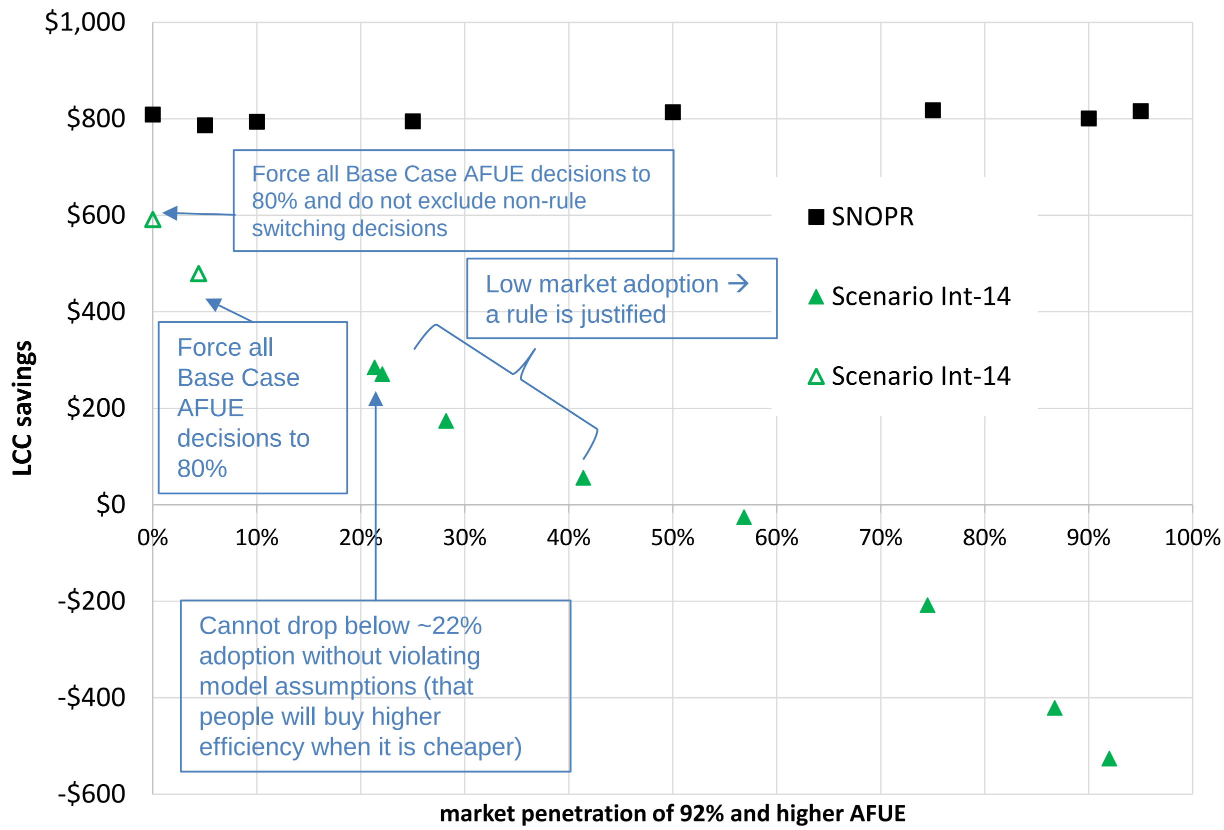


Figure 22: DOE LCC Model Market Disconnect Addressed by GTI Scenario Int-14

Figure 23 further illustrates the irrational disconnect from the marketplace when using the DOE random assignment methodology. As shown by the cumulative distribution function (CDF), with DOE's random Base Case furnace assignment of 80% AFUE furnaces in the new construction market in its LCC model, builders would willingly pay higher first cost for lower efficiency 75% of the time without the rule. Builders clearly do not have a split incentive, but – according to DOE – make obviously bad decisions for themselves most of the time according to the DOE methodology. This is a nonsensical, irrational result caused by the DOE random assignment methodology. Builders will not, in any significant number, hurt themselves directly by paying extra for a lower efficiency furnace that does not help them sell homes.

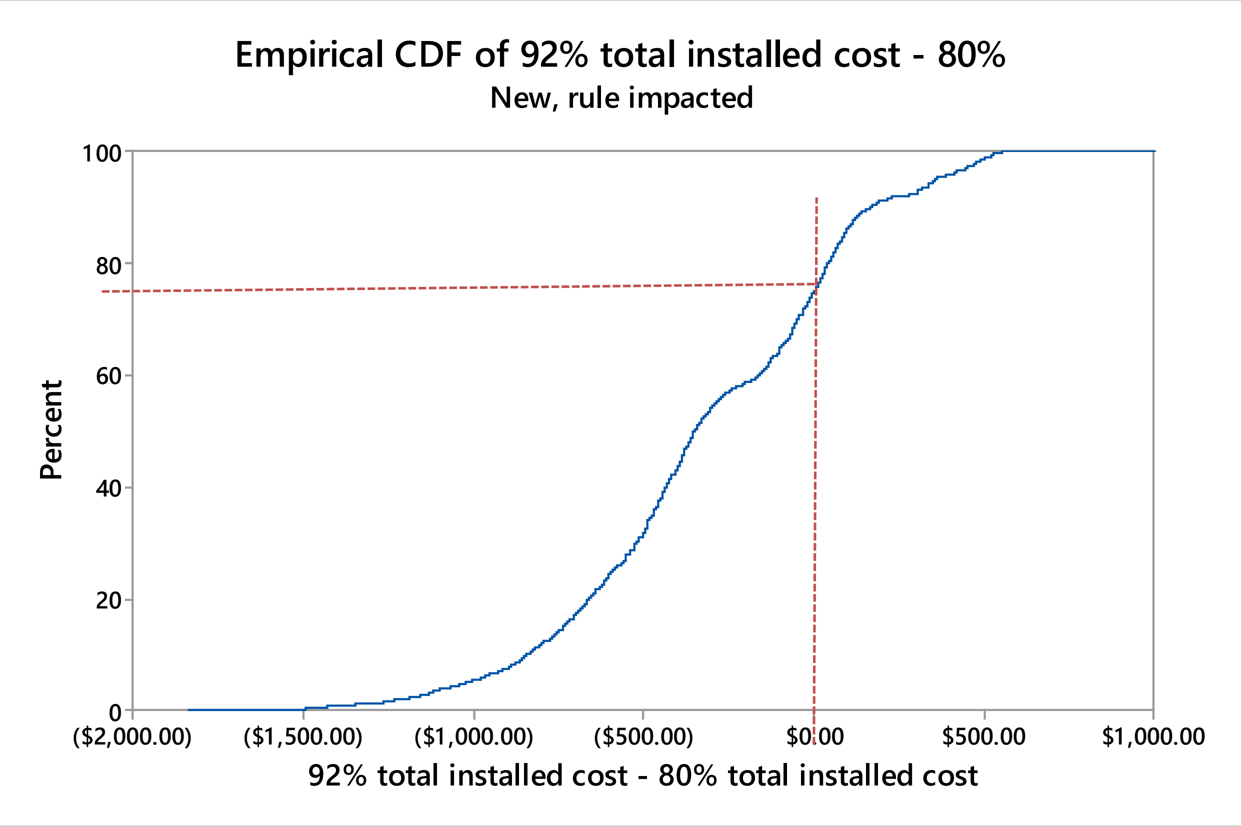


Figure 23: DOE Random Assignment Irrational Impact on New Construction

In contrast, GTI Scenario Int-14, including rational economic and non-economic factors in its decision algorithm, is sensitive to initial market conditions. This was also an a priori expectation using economic rather than random Base Case furnace assignment. The higher the initial condensing furnace market penetration for the LCC analysis, the less likely the rule will have remaining benefits for those consumers with more challenging economics such as difficult installation requirements (northern installations), long payback periods (southern installations), or residual new construction challenges (a very small fraction of new construction). DOE's assertion that these two fundamentally incompatible Base Case furnace assignment methodologies are equivalent from a market behavior perspective is demonstrably false.

4.2 AHCS Allowable Payback Period Distribution Based on Income

In the SNOPR, DOE asserts that the proprietary AHCS survey it used to develop a deterministic 3.5 year switching payback period did not provide sufficient information to develop a distribution function of fuel switching payback periods based on income or other factors that was transferable to its analytical framework. It further asserted that commenters did not provide such information or data. From Federal Register Vo. 81 No. 185, p 65792,

> *"DOE acknowledges that different consumers are likely to use different criteria when considering fuel switching, but the survey used by DOE does not provide sufficient information to derive a distribution of required payback periods that is transferable to DOE's methodology. Commenters did not provide any additional data on this point, nor did they suggest a more suitable source. As DOE is not aware of any better data source, it maintained its existing approach for this SNOPR."*

The necessary information was constructively available to DOE during its NOPR, NODA, and SNOPR development period, requiring only a brief supplemental interaction between LBNL and the study's author, Decision Analysts, after LBNL purchased the proprietary AHCS. As noted on Page 21 of GTI-15/0002:

> "*Detailed consumer behavior information available in the AHCS allowed GTI to explore fuel switching decision parametric scenarios that were not considered by DOE in its fuel switching decision algorithm. The AHCS contains between 2,849 and 3,803 respondents in each of the years 2006, 2008, 2010, and 2013. It includes enough survey response information to produce distributions of switching payback periods as a function of income groups. Decision Analyst provided this detailed survey response information to GTI, allowing GTI analysts to conduct a more granular evaluation of fuel switching behavior than DOE incorporated into its analysis using the single point average switching payback period algorithm.*"

Further evidence of the constructive availability of this information to DOE during the NOPR is from Page A-9 of GTI-15/0002:

> *"DOE used the AHCS to determine its switching payback period by converting the average amount consumers were willing to pay for an efficiency improvement combined with the average HVAC energy costs to arrive at a single switching payback period. However, the AHCS contains significantly more detailed information than simple averages. According to Decision Analyst, the AHCS is the largest knowledge base of homeowner behavior, perceptions, and attitudes related to energy efficiency, home comfort, and HVAC. Topics covered in the AHCS include:*
>
> - *The level of consumers' interest in energy efficiency*
> - *How consumers balance rising energy costs with home comfort*
> - *Consumers' willingness to spend money on home improvements to achieve energy efficiency*
> - *Home comfort differences by region and demographics*
>
> *It contains between 2,849 and 3,803 respondents in each of the years 2006, 2008, 2010, and 2013. It includes enough data to produce distributions of switching payback periods as a function of income groups to produce a more granular evaluation of fuel switching behavior than DOE incorporated into their analysis using the single point average switching payback period."*

Regarding the assertion that DOE was not able to transfer this information to DOE's analytical framework, GTI-15/0002 for the NOPR, specifically Section A.3.2 - Parametrics D1, D2, and D3, includes sufficient explanatory text to easily enable a shift from a deterministic value for switching payback period to a distribution function based on income group if DOE wanted to develop such a distribution.

As noted in that description, the distribution function based on income is important because the distribution is highly skewed, with long switching payback periods for higher income consumers skewing the average result. This makes the single 3.5 year average switching payback period used by DOE insensitive to market conditions and biased toward rule benefit. GTI SNOPR Scenario 36, including Parametric D2, addresses this skewed distribution in a conservative manner by averaging the allowable switching payback period distribution available from the four AHCS surveys in 2006, 2008, 2010, and 2013.

In the NOPR analysis described in GTI-15/0002, the minimum payback period that was allowed (smallest bin of payback periods) was 0.5 years. The analysis has been expanded in this report to use the amount consumers were willing to pay for efficiency improvements from the AHCS as well as how much consumers spent on space conditioning from the RECS database, both as a function of income. This controls both switching and Base Case AFUE decisions. Parametric D13 also included payback times down to 0 years which came from AHCS respondents that indicated they were willing to pay nothing for improved efficiency.

Table 32 shows the dramatic impact of using the full distribution of AHCS allowable payback periods on LCC analysis results. Incorporation of the full distribution of payback periods available within the AHCS data set drives poor economic decision making with respect to fuel switching which makes LCC savings negative across all groups. The data needed to incorporate the full distribution is included in data sets DOE already used for this analysis (AHCS and RECS).

Because the full AHCS distribution function did not align well with projected fuel-switching fractions associated with the DOE rule shown in the SNOPR, these scenarios were not selected for comparison with the DOE SNOPR overall results, but are shown here to illustrate the significant effect of including a distribution function rather than a single value for payback periods as a function of income.

Table 32: LCC Analysis Results Using Full AHCS Payback Period Distribution

Scenario		National	North	Rest of Country	Residential Replacement	Residential Replacement - North	Residential Replacement - Rest of Country	Residential New	Residential New - North	Residential New - Rest of Country	Senior Only	Low-Income
		LCC Savings Summary - 92% TSL										
DOE SNOPR	LCC	$617.38	$711.32	$568.83	$420.49	$495.74	$386.11	$1,176.53	$1,171.96	$1,179.59	$775.23	$476.48
	Number Affected	5247	1788	3459	3760	1179	2581	1345	539	806	706	431
GTI Scenario 2 (D2)	LCC	$599.87	$690.32	$553.12	$408.57	$492.05	$370.43	$1,141.56	$1,110.40	$1,162.40	$745.51	$346.12
	Number Affected	5247	1788	3459	3760	1179	2581	1345	539	806	706	431
GTI Scenario 32 (D13)	LCC	-$1,928.77	-$3,282.13	-$1,035.96	-$1,592.35	-$2,597.29	-$1,066.43	-$4,751.53	-$6,011.94	-$907.29	-$1,506.69	-$2,353.64
	Number Affected	4687	1863	2824	4014	1379	2635	567	427	140	640	407
GTI Scenario 33 (D8,D13)	LCC	-$2,022.88	-$3,473.42	-$1,080.96	-$1,617.65	-$2,640.53	-$1,084.20	-$5,742.84	-$7,019.60	-$1,555.46	-$1,569.48	-$2,370.33
	Number Affected	4605	1813	2792	3994	1369	2625	505	387	118	631	405
GTI Scenario 33&I16	LCC	-$2,458.68	-$4,140.12	-$1,358.57	-$2,029.31	-$3,315.97	-$1,346.69	-$6,881.97	-$8,074.78	-$2,475.86	-$2,228.43	-$3,225.02
	Number Affected	4579	1811	2768	4010	1390	2620	460	362	98	639	404

4.3 Uncertainty and Confidence Limits Applied to LCC Savings Results

DOE intends to make a rule based on LCC savings that are ~0.5% of life cycle costs using technically flawed methodologies and selective application of uncertainty principles. Because DOE will be interfering with the free market and regulated incentive programs that may already be working adequately without further intervention, it is critical for DOE to clearly demonstrate analytically that its rule is statistically distinguishable from the null hypothesis that the rule has no benefits. DOE has chosen to selectively use random or market-sensitive methodologies; deterministic, distribution, or random methodologies; and market data or engineering estimates coupled with highly uncertain future forecasts as the basis of its assertion that the DOE SNOPR LCC model savings are positive and meaningful. With the extensive number of variables and associated uncertainties, the DOE results may be statistically indistinguishable from the null hypothesis of no rule benefit.

In such cases, uncertainty in LCC savings requires methodologies that are sensitive to distributions of effects wherever known market behaviors include such distributions. This sets a high bar for what must be taken into account to make a positive finding of rule benefits when analytical benefits are so close to zero. DOE selectively uses a Monte Carlo analysis to acknowledge the complexity of the problem and uncertainty compared to a much simpler payback period analysis approach. But the DOE LCC model chooses to ignore known market uncertainties associated with several key parameters, including:

- Energy prices
- Furnace manufacturing costs
- Condensing furnace market penetration
- Consumer discount rates
- Labor costs

The AEO retrospective acknowledges the limited precision and accuracy of its own predictions of energy prices over time. But, DOE assumes these values are fixed and does not incorporate uncertainty into the Monte Carlo analysis. Similarly, DOE assumes that their estimates of manufacturing costs, condensing furnace market penetration forecasts, consumer discount rates, and labor costs contain no uncertainty. These factors are major drivers of the LCC savings. By selectively ignoring these sources of uncertainty, the DOE LCC model fails to arrive at a best estimate of overall uncertainty in LCC savings, further diminishing confidence in the DOE LCC model results.

4.4 Application of Non-Economic Factors in the CED Framework

In the SNOPR (Federal Register Vo. 81 No. 185, p 65790), "*DOE recognizes that its approach to allocating the efficiency level of a new gas furnace across RECS households within States may not fully reflect actual consumer behavior. However, it is far from clear that allocating the efficiency of furnaces based solely on estimated cost-effectiveness is likely to be any more accurate than the method currently used by DOE. An attempt to more explicitly model consumer choices across furnace efficiency would have to take into account the non-monetary preferences and market failures outlined above, in addition to the economic tradeoffs. At the present time, DOE does not have a method to include site specific economics as well as noneconomic decision making criteria in the Monte Carlo simulation, as suggested by ACEEE. However, this is an issue that DOE intends to investigate, and it welcomes suggestions as to how it might incorporate economic and other relevant factors in its assignment of furnace efficiency in its analyses.*"

DOE's assertion that a random approach to Base Case assignment is as accurate as a methodology based solely on estimated cost-effectiveness is inconsistent with DOE's findings elsewhere in the DOE SNOPR LCC model that incorporate rational economic decisions by various stakeholders, including consumers. For example, DOE chose to monetize the non-economic "comfort" value of the rebound effect when switching to a lower operating cost option such as a condensing furnace. To avoid use of a distribution function or other means of incorporating this effect, DOE simply assumed its monetary value to the consumer was exactly the same amount as the annual savings without consideration of the rebound effect. This selective use of monetizing consumer behavior increased rule benefits compared to the known reduction in energy savings due to the rebound effect in consideration of improved comfort.

DOE's approach to determining fuel switching decisions also used an economics-derived point at which consumers will make decisions about fuel switching. Under DOE's fuel switching decision methodology, consumers can and do think about economics when switching from gas to electric options. In contrast, the DOE random Base Case furnace assignment methodology asserts that these same consumers are somehow unable to consider economics when decided between two gas appliances.

DOE's citations used to support the contention that ignoring consumer decision making is as accurate as considering economic decision making do not support DOE's claims. Arguments in those citations align much more closely with the GTI CED framework, and make the point that many consumers aren't good at making decisions based on economics, especially long range economics or large purchases. Those citations refute rather than support DOE's contention that consumers do not think about economics at all when making decisions on large appliances, and therefore random assignment should be used instead of a CED framework.

In its furnace downsizing methodology, DOE assumes furnaces are improperly oversized in today's marketplace. Because of this perceived market failure, DOE concludes that a downsized furnace is still likely to meet consumer comfort needs and other utility functions provided by the furnace, such as offsetting incremental ventilation loads, reasonable setback recovery period, and accommodation of variations in building construction characteristics. DOE applies the analytical equivalent of consumer economic decision making by assuming a consumer runs a steady state peak load calculation and picks the furnace only on that criterion. DOE's "rational" downsizing decision approach ignores other utility functions of a furnace and the range of consumer risk tolerances regarding known variability in design calculations and accommodation of their own behavior (e.g., opening a window when it is -10°F outside for desired ventilation). It then connects this methodology to current furnace sizing practices that may already be accounting for such "oversizing" factors by using a simple adjustment factor. Regulation of installation practices such as furnace sizing in this rulemaking is being done using an analytical framework and underlying RECS database that were not intended for that purpose, and are demonstrably inadequate for use in regulations based on furnace size.

4.5 DOE SNOPR LCC Modeling Results Reporting Issues

Except for LCC Savings and Average and Median Simple-First Year Payback, other DOE SNOPR LCC reported results are based on the average of 10,000 trial cases, including the significant fraction of homes not impacted by the rule (e.g., 48% of trial cases are not impacted under TSL 5), rather than average of impacted trial cases only (e.g., 52% of trial cases under TSL 5). DOE's reporting choice is potentially important in operating cost, life cycle cost, and fuel switching fractions reporting, but it is highly misleading in favor of rule benefits when reporting payback period.

As shown in Table 33 and Table 34, the simple payback period for NWGFs is reported in SNOPR Table V.5 as 6.4 years for TSL 5, and 6.1 years for TSL 6 (the proposed rule). In contrast, the first year average payback period in the LCC spreadsheet analysis summary sheet, based only on impacted trial cases, shows a payback period of 13.9 years for TSL 5, a much longer, less misleading statistic.

Table 33: DOE SNOPR Table V.5 Results Based on Average of 10,000 Trial Cases

TABLE V.5—AVERAGE LCC AND PBP RESULTS FOR NON-WEATHERIZED GAS FURNACE AFUE STANDARDS

TSL	AFUE (%)	Average costs (2015$)				Simple payback (years)	Average lifetime (years)
		Installed cost	First year's operating cost	Lifetime operating cost	LCC		
1	92/80*	2,375	652	10,512	12,887	6.1	21.5
2	92/80*	2,469	635	10,244	12,714	6.0	21.5
3	95/80**	2,552	625	10,108	12,661	6.4	21.5
4	92/80*	2,512	628	10,126	12,638	5.9	21.5
5	92†	2,635	612	9,859	12,493	6.4	21.5
6	92/80*	2,576	618	9,971	12,547	6.1	21.5
7	95†	2,742	597	9,608	12,350	6.5	21.5
8	95/80*	2,672	604	9,737	12,410	6.2	21.5
9	98 (Max-Tech)†	2,858	586	9,403	12,261	6.9	21.5

* The first number refers to the standard for large NWGFs; the second refers to the standard for small NWGFs. The input capacity threshold definitions for small NWGFs are as follows: TSL 1: 80 kBtu/h; TSL 2: 70 kBtu/h; TSL 4: 60 kBtu/h; TSL 6: 55 kBtu/h; TSL 8: 55 kBtu/h.
** The first number refers to the efficiency level for the North; the second number refers to the efficiency level for the Rest of Country.
† Refers to national standards.
Note: The results for each TSL are calculated assuming that all consumers use products at that efficiency level. The PBP is measured relative to the baseline product.

Table 34: DOE SNOPR LCC Analysis Summary Results for TSL 5

Level	Description	Installed Price	First Year Oper. Cost	Lifetime Oper. Cost*	LCC	LCC Savings	Simple LCC Savings	Net Cost	No Impact	Net Benefit	Simple PBP	First Year Average	First Year Median
		Average LCC Results									Payback Results		
0	NWGF 80%	$2,175	$684	$11,020	$13,194	NA	NA	NA	100%	NA			
1	NWGF 90%	$2,597	$623	$10,026	$12,623	$582	$571	18.3%	53.5%	28.2%	6.8	17.7	8.9
2	NWGF 92%	$2,635	$612	$9,859	$12,493	$617	$701	17%	48%	35%	6.4	13.9	6.8
3	NWGF 95%	$2,742	$597	$9,608	$12,350	$561	$844	22%	26%	51%	6.5	12.2	7.8
4	NWGF 98%	$2,858	$586	$9,403	$12,261	$506	$934	34%	1%	65%	6.9	14.3	10.0

The DOE misleading payback period reported in the SNOPR is of concern for the NWGF analysis, but it may be even more significant for the MHGF analysis. DOE reports in its MHGF LCC analysis results (SNOPR Table V.7) that the simple payback period is 1.7 years, which would appear to satisfy the EPCA rebuttable presumption that the standard is economically justified if the additional cost to the consumer is less than three times the value of the energy savings during the first year. However, if the first year average payback considering only impacted cases is more than three years, the rebuttable presumption would no longer hold for the MHGFs.

The DOE SNOPR also contains a reporting error in cases in which it evaluated a separate product class based on furnace input capacity (SNOPR TSLs1, 2, 4, 6, and 8). When a trial case qualifies for NWGF downsizing, the equipment and installation costs calculated for the downsized 80% AFUE furnace are also being assigned to condensing furnace alternatives and consequently included in their average Installed Price, First Year Operating Cost, Life Time Operating Cost, LCC, and Simple PB reported in LCC spreadsheet Summary and Federal Register. This error does not impact LCC savings or first year average payback results because homes that qualify for 80% AFUE furnace downsizing exemption are excluded from the impacted population and therefore not included in calculation of averages for these two parameters.

In addition, downsized non-condensing furnace cases excluded from the analysis based on input capacity have their furnace price and installation cost calculated before downsizing. So a 60 kBtu/h furnace downsized to 55 kBtu/h is still priced as a 60 kBtu/h furnace. That inconsistency impacts average results for those parameters (e.g., Installed Price) reported by DOE as averages for all 10,000 trial cases.

DOE’s fuels switching reporting choice is also misleading. Fuel switching fractions reported in DOE SNOPR Table V.3 are 11.5% of all consumers under TSL5, and drop to 6.9% of all consumers under TSL 6 (the proposed rule). These reported fractions mask the true impact of the rule because they include all consumers rather than just impacted consumers, thereby reducing the apparent fuel switching fractions. In contrast, as shown in Table 22 of this report, the fuel switching fraction is 17.2% of remaining impacted consumers. While both statistics are valid, the DOE choice is insensitive to different scenarios and remaining relevant fuel switching caused by the rule.

5 National Primary Energy and Emissions Impact Assessment

The DOE SNOPR LCC model results provide input information to the DOE SNOPR National Impact Analysis (NIA) that is summarized in the DOE NIA spreadsheet. The underlying model used to estimate national impacts of the proposed rule is the National Energy Modeling System (NEMS) model, an economic and energy model of U.S. energy markets created and maintained by EIA (https://www.eia.gov/forecasts/aeo/nems/overview/pdf/0581(2009).pdf). NEMS projects the production, consumption, conversion, import, and pricing of energy. The model relies on assumptions for economic variables, including world energy market interactions, resource availability (which influences costs), technological choice and characteristics, and demographics. DOE's NIA spreadsheet summarizes the results of the NEMS model, but provides no opportunity to adjust impacts based on different LCC model results.

Few private sector organizations outside of EIA are staffed and equipped to run parametric analyses by modifying the NEMS model. GTI analysts do not have the resources necessary to manipulate and modify the NEMS model for a parametric analysis of national impacts in the DOE NIA model. Although GTI was not able to adjust the DOE NIA model inputs to determine the national impact of the DOE SNOPR LCC model technical flaws, the LCC analysis provided enough annual energy consumption information to estimate the national impact of the proposed rule, similar to the analysis that was conducted by GTI in response to the NOPR in 2015. GTI analysts had planned on conducting a 30 year analysis of the projected national impact of the proposed furnace rulemaking based on the DOE SNOPR LCC model results and the GTI Integrated Scenario Int-14.55 analysis results. However, due to the limited comment period and extensive effort to address LCC savings scenarios and issues, this analysis was not conducted.

Based on the annual energy and GHG emissions savings results, the a priori expectation is that the national impacts of the proposed rule would have been similar under GTI Integrated Scenario Int-14.55 compared to the DOE SNOPR NIA results.

6 Summary and Conclusions

DOE issued a SNOPR that proposes a single national standard at a minimum efficiency level of 92% AFUE for all MHGFs and for NWGFs above 55 kBtu/h input capacity. The SNOPR was published in the Federal Register on September 23, 2016 and open for a 60-day public comment period through November 22, 2016. The SNOPR supersedes the DOE NOPR published March 12, 2015, and updates information provided by DOE in a NODA published on September 14, 2015, containing a provisional analysis of the potential economic impacts and energy savings that could result from promulgating amended energy conservation standards for residential NWGFs that include two product classes defined by input capacity. Accompanying DOE's 134-page SNOPR was a 1,198 page technical support document (TSD) prepared for DOE by staff members of Navigant Consulting, Inc. and Lawrence Berkeley National Laboratory (LBNL). The TSD includes a detailed review of the effects of the SNOPR as well as economic modeling and associated methodologies to assess consumer-level cost impacts, manufacturer impacts, and national impacts.

GTI conducted a technical and economic analysis of the DOE furnace SNOPR to evaluate the impact of the 92% AFUE minimum furnace efficiency requirements along with other TSLs on consumers, as well as the impact of a potential product class for small NWGFs. The GTI SNOPR analysis updates previous analyses conducted in response to the DOE NOPR and NODA. The GTI SNOPR analysis included:

- Comparison of DOE NOPR, NODA, and SNOPR results, along with updated versions of selected GTI analyses conducted in response to the NOPR and NODA;
- DOE SNOPR TSD modeling approach, assumptions, and results;
- DOE SNOPR LCC analysis spreadsheet and Crystal Ball model;
- An updated CED framework and related methodologies developed by GTI analysts to incorporate non-economic factors;
- Surveys (e.g., American Home Comfort Study) and data on input variables judged to have potential impact on LCC analysis results;
- Estimates of consumer benefits and costs associated with a national 92% furnace standard as well as other trial standard levels of furnace efficiency;
- Estimates of consumer benefits and costs associated with a national 92% furnace standard as well as other trial standard levels of furnace efficiency coupled with a national 80% furnace standard for a separate product class for non-weatherized gas furnaces based on input capacity; and
- Impact of AEO 2016 Clean Power Plan Scenario parameters on results.

Table 35 summarizes the difference in consumer impacts when comparing the DOE SNOPR LCC model results with GTI Scenario Int-14.55 for the proposed rule (SNOPR TSL 6, GTI Scenario 0.55) and with GTI Scenario Int-14 for a single national 92% AFUE standard (SNOPR TSL 5, GTI Scenario 0). Comparable results for the NOPR analysis (updated by DOE as SNOPR TSL 5) are also included for reference.

Table 35: SNOPR and NOPR Lifecycle Cost and Market Impact Comparisons

LCC Model Scenario	Average Furnace Life-Cycle Cost (LCC) Savings per Impacted Case	Fraction of Furnace Population (%)		
		Net Cost	No Impact	Net Benefit
DOE SNOPR TSL 6 (92%/55 kBtu/h)	$692	11%	60%	29%
GTI Integrated Scenario Int-14.55	-$118	15%	73%	12%
DOE SNOPR TSL 5 (92% all capacities)	$617	17%	48%	35%
GTI Integrated Scenario Int-14	-$149	22%	64%	15%
DOE NOPR (92% all capacities)	$520	20%	41%	39%
GTI NOPR Scenario Int-5	-$417	27%	57%	17%

The following Excel spreadsheets accompanying this report provide tabular results of the GTI parametric analysis of the DOE SNOPR:

- 22063 Short LCC tables - all EL 2016-11-21.xlsx,
- 22063 Short Switching Tables 2016-11-21.xlsx, and
- 22063 Energy Use Tables 2016-11-21.xlsx.

These spreadsheets provide detailed results tables and supporting information for each of the scenarios evaluated in this report, along with the shorter summary tables included in this report.

The GTI NOPR analysis, conducted in 2015 and described in detail in GTI-15/0002, "Technical Analysis of DOE Notice of Proposed Rulemaking on Residential Furnace Minimum Efficiencies" http://www.gastechnology.org/reports_software/Documents/21693-Furnace-NOPR-Analysis-FinalReport_2015-07-15.pdf, uncovered a serious technical flaw in the methodology DOE used to establish the homes that would be impacted by the proposed rule. Specifically, the Base Case furnace assignment algorithm used by DOE ignores any form of economic decision making by individual consumers or their representatives (e.g., builders or installing contractors). Instead, the Base Case AFUE, which is the efficiency of the furnace that is chosen by an individual consumer without the influence of DOE's rule, is assigned randomly in the DOE SNOPR LCC model. DOE's baseline furnaces in the 10,000 Crystal Ball trial case homes are intended to be representative of the 2009 Residential Energy Consumption Survey (RECS) furnace distribution across various locations and categories throughout the country projected out to 2022 (the first year the rule would be enforced). Random assignment of the baseline furnace does not achieve this objective. The economics of a particular efficiency level selection compared to other levels (e.g., 80% AFUE vs. 92% AFUE) are not considered in DOE's baseline furnace decision making methodology. DOE's methodology assumes that individual consumers or their representatives do not consider economics when choosing a furnace. This serious technical flaw resulted in significantly overstated LCC savings in the NOPR. Despite this finding, DOE chose to continue to use this technically flawed random methodology in the SNOPR, with similarly overstated LCC savings for each of the TSLs included in the SNOPR.

Examples of irrational results when using the DOE random Base Case furnace assignment include:

- Homes that would have selected a condensing furnace without the rule were randomly assigned 80% AFUE furnaces. This irrational assignment primarily affected new construction cases where the condensing furnace installed cost was less than the installed cost of an 80% AFUE furnace, and should therefore have been eliminated as "No Impact" cases. This has the effect of inflating the benefits of the proposed rule by taking credit for unwarranted LCC savings.
- Homes that would have selected an 80% AFUE non-condensing furnace without the rule were randomly assigned condensing furnaces. This irrational assignment primarily affected replacements having extremely long payback periods for condensing furnaces, and should therefore have been "Net Cost" cases. This inflates the benefits of the proposed rule by not including appropriate LCC costs.

The GTI NOPR analysis conducted in 2015 also uncovered a serious technical flaw in the methodology DOE used in its fuel switching analysis in the NOPR. DOE used a single switching payback value of 3.5 years for fuel switching decisions in its algorithm based on an average tolerable payback period for more efficient appliance purchases derived from proprietary American Home Comfort Study (AHCS) survey information. However, more detailed inspection of the available granular AHCS information showed that tolerable switching payback periods are a strong function of income and are dominated by large numbers of very low payback periods, with small numbers of much larger payback periods. This skewed distribution by income level reduces the benefit of the proposed rule compared to DOE's single average switching payback period approach whenever the rule induces low income consumers with low tolerable payback periods to fuel switch to low first cost options despite negative LCC impacts. In addition, the DOE fuel switching analysis includes as a rule benefit cases in which rational fuel switching would accrue significant incremental benefits to the consumer compared to the TSL furnace. These cases would likely cause fuel switching without the rule in an unregulated market, and would be considered "No Impact" cases when using economic criteria for incremental technology and fuel switching decisions. Despite this finding, DOE chose to continue to use this technically flawed single switching payback period methodology in the SNOPR, with similarly overstated LCC savings for each of the TSLs included in the SNOPR.

Key input data used in the DOE SNOPR LCC model are also inconsistent with market-based information. DOE used engineering estimates of furnace prices that differ from available market data. DOE's marginal gas prices derived from the EIA 2014 NG Navigator state level reporting of natural gas sales and revenues differ from gas companies' tariff data to supplement EIA data; and condensing furnace shipment forecasts that are lower than the long term historical trend from AHRI shipment data. Taken together, the DOE input information and forecasts associated with using these variables overstate LCC savings compared to credible market data.

As described in GTI-15/0002, GTI developed a set of integrated scenarios for the DOE NOPR LCC model analysis that remain relevant for the SNOPR analysis. GTI Integrated Scenario Int-5 included several refinements to the DOE NOPR LCC model, including rational consumer economic decision making and improved input data, and formed the primary basis for comparison to DOE's analysis of its proposed furnace efficiency standards in the NOPR. Other technically defensible scenarios based on different assumptions and factors were included in GTI-15/0002 for reference purposes and were not updated in the GTI SNOPR analysis.

The GTI SNOPR analysis incorporated several integrated scenarios that incorporate updated decision making, input data, and furnace sizing parametrics and provide technical information related to issues on which DOE seeks comments in the DOE SNOPR. In response to DOE assertions in the SNOPR about non-economic and imperfect market decision making factors, GTI analysts developed an LCC model approach to address these factors. Scenarios of interest addressed in the GTI SNOPR analysis focused on updating the GTI NOPR CED framework to incorporate non-economic decision making criteria, and development and application of alternative furnace sizing methodologies. Building on the GTI NOPR analysis, GTI SNOPR analysis scenarios include distribution functions that accommodate additional non-economic factors in the CED framework; and a furnace sizing algorithm linked to the RECS database annual heating consumption that examines the impact of different furnace capacity limits for 80% AFUE furnaces on rule benefits, including national, regional, new construction, replacement, senior, and low income segment impacts. GTI Integrated Scenarios Int-11 through Int-14 and Int-11.55 through Int-14.55 address these issues.

GTI SNOPR Scenario Int-14, an updated version of GTI NOPR Scenario Int-5, was selected for comparison with the 92% AFUE single product class TSL 5 in the SNOPR (GTI Scenario 0) to address the following issues:

- Base Case furnace assignment that aligns with AHRI condensing furnace fractions and economic decision making criteria,
- Application of American Home Comfort Study information for fuel switching decisions that results in reasonable alignment with DOE fuel switching fractions when using a CED framework for Base Case furnace assignment and fuel switching decisions,
- Improved data for furnace prices, condensing furnace fractions, and marginal gas prices,
- Incorporation of AEO 2016 Clean Power Plan Scenario forecast information for comparisons with anticipated DOE final rule benefits calculations, and
- Application of a time-horizon-based distribution function based on the DOE LCC model payback period for each of the 10,000 trial cases for consumer economic decision making that monetizes the impact of imperfect market and non-economic consumer decision making factors into the LCC analysis for comparisons within the GTI CED framework.

GTI Scenario Int-14.55, one of the cases under Scenario Int-14, was selected to examine the impact of a 55 kBtu/h furnace capacity limit for 80% AFUE furnaces on rule benefits for direct comparisons with the DOE SNOPR proposed rule TSL 6 (GTI Scenario 0.55). GTI Scenario Int-14.55 includes a furnace capacity algorithm based on RECS annual heating consumption rather than home size and uses the DOE furnace "downsizing" methodology.

Key findings of the GTI SNOPR scenario analyses include:

- GTI Integrated Scenarios Int-14.55 and Int-14, based on consumer economic and non-economic decision criteria coupled with refinements to DOE's inferior input data and an improved furnace sizing algorithm, each show negative composite average lifecycle cost savings for all four condensing furnace trial standard levels (90%, 92%, 95%, and 98% AFUE). Based on these findings, there is no economic justification for the proposed rule of a 92% AFUE for NWGFs above 55 kBtu/h input capacity (DOE SNOPR TSL 6), a single product class 92% AFUE national furnace efficiency level (DOE SNOPR TSL 5), or any other condensing furnace efficiency levels with or without the 55 kBtu/h input capacity limit.
- GTI Integrated Scenario Int-14 cases run with different 80% AFUE furnace input capacity limits ranging from 40 kBtu/h to 160 kBtu/h show negative composite average lifecycle cost savings for a separate product class below 115 kBtu/h input capacity, and negative composite average lifecycle cost savings for a separate product class below 90 kBtu/h input capacity when adding DOE's furnace downsizing methodology. These findings align with the empirical data analysis summarized in Topical Report GTI-16/0003, "Empirical Analysis of Natural Gas Furnace Sizing and Operation."
- There is no capacity limit that provides a net benefit to the low income market segment, under either a current market furnace sizing methodology or when adding the DOE furnace downsizing methodology.
- The overall market relevance of the proposed rule is reduced in Scenario Int-14.55 and Int-14, with more furnaces in the "No Impact" category than the comparable DOE scenarios. Through application of rational economic decision making criteria that also incorporates non-economic factors, coupled with other analytical refinements incorporated into GTI Integrated Scenario Int-14.55 and Int-14, the number of consumers with a "Net Benefit" is reduced and the portion of consumers who experience an increase in "Net Cost" rises. Together, these impacts result in negative Life-cycle Cost Savings under Scenarios Int-14.55 and Int-14.
- DOE's random Base Case furnace AFUE assignment methodology remains technically flawed and is meaningfully disconnected from market factors, resulting in overstated LCC savings in the SNOPR compared to market-sensitive consumer economics methodologies. A total of 13% of all residential trial cases and 55% of DOE's claimed rule benefit comes from a combination of builders and consumers that DOE inexplicably claims are willing to pay extra for lower efficiency furnaces.
- Replacing DOE's technically flawed methodology with rational economic decision making criteria that incorporates non-economic factors in the GTI CED framework as applied in GTI Integrated Scenario Int-14 cases substantially shifts both the characteristics and fractions of "Net Benefit" and "No Impact" consumers and appreciably lowers the LCC savings of the proposed rule.
- DOE's random Base Case furnace AFUE assignment methodology is insensitive to assumed initial year market penetration of condensing gas furnaces, providing the same level of benefit irrespective of variations in assumed market penetration of condensing furnaces in the initial year of the analysis. The GTI methodology is demonstrably sensitive to market penetration of condensing furnaces in the initial year of the analysis, indicating a close connection to market factors compared to the DOE random assignment approach that is insensitive to the key market factor of interest for this rulemaking.

- The DOE SNOPR LCC model results overstate LCC savings compared to the updated CED framework included in the GTI LCC analysis. This occurred because DOE used a combination of random decisions and limited application of economic decisions in the fuel switching algorithm. The DOE fuel switching decision algorithms do not consider low income economics, while the GTI CED framework methodology using a full distribution of economics across incomes provides a reasonable and conservative fuel switching decision making algorithm for low income consumers.
- The DOE SNOPR LCC model results include inferior input data than the input data selected for inclusion in GTI Integrated Scenario Int-14 cases. The DOE SNOPR LCC model includes engineering estimates of furnace prices that differ from available furnace price market data. Marginal gas prices derived from the EIA 2014 NG Navigator state level reporting of natural gas sales and revenues that differ from using gas companies' tariff data to supplement EIA data. DOE's condensing furnace shipment forecasts are based on three years of statistics (2012-2014) from the AHRI shipment data that were impacted by residual effects of the removal of incentives in 2011, and are substantially lower than the long term historical trend from AHRI shipment data. Based on this trend line, GTI Scenario Int-14 uses condensing furnace shipment fractions of 62.5% (National), 84.1% (North), and 38.6% (Rest of Country) for the 2022 baseline instead of DOE's 2022 furnaces shipment fractions of 53.1% (National), 73.7% (North), and 30.2% (Rest of Country). Taken together, the DOE input information associated with these parameters overstates DOE SNOPR LCC savings compared to credible market data.
- The lack of data in the RECS database on the key values of furnace AFUE and capacity makes it an inadequate source of information for use in the furnace capacity and annual heating load assignments used in the SNOPR, both for the single national standard level and for separate standard levels based on furnace input capacity evaluated in the SNOPR. Additional market information is needed for this purpose.
- The DOE SNOPR furnace size assignment methodology based on home size and design outdoor air temperature derived from the RECS database is technically flawed and poorly correlated with home heating consumption and furnace capacity required to meet peak heating and thermostat setback recovery loads.
- DOE's furnace sizing methodology is not adequate for determining the benefits of different furnace capacity limits on LCC savings, providing inconsistent and misleading results due to the poor correlation between home size and required furnace capacity.
- LCC savings using the DOE SNOPR furnace sizing methodology show no trend with furnace size. This is consistent with the poor correlation between annual heating load and the DOE SNOPR random Base Case furnace assignment and sizing methodology.
- A furnace capacity algorithm (GTI Parametric F1) developed by GTI analysts based on the RECS database annual heating consumption rather than home size has a relatively strong correlation between annual heating load and associated furnace size (R^2=0.69). The correlation between annual heating load and furnace size (R^2=0.69) is substantially better with the RECS annual heating consumption model than the correlation using the DOE furnace sizing methodology (R^2=0.11). This is an a priori expectation because annual heating consumption should have a fair to strong correlation with peak heating load, whereas home size has been demonstrated to have poor correlation with peak heating load for a variety of reasons. The RECS annual heating consumption model is also compatible with the furnace "downsizing" methodology used by DOE in the SNOPR

proposed rule (TSL 6). It also provided the desired sensitivity to market conditions compared to the DOE methodology.

- Detailed empirical data analysis described in Topical Report GTI-16/0003 shows the expected high correlation between annual heating consumption and house “UA” (a combination of thermal efficiency and envelope area), a strong correlation between required furnace capacity and house “UA”, but a very poor correlation between annual heating consumption and home size (or UA and home size). Unfortunately, the lack of monthly gas consumption data and poor correlation between gas consumption, annual HDD, design outdoor air temperature, and peak heating load in the RECS database used by DOE in the SNOPR LCC spreadsheet model for each of the 10,000 trial cases precluded the use of the house UA empirical data with RECS database information.
- GTI SNOPR Integrated Scenario Int-14.55 and Int-14 results differ from the GTI NOPR Scenario Int-5 results that showed increased annual primary energy consumption and greenhouse gas emissions for SNOPR TSL 5 compared to the “no rule” baseline. In the SNOPR analysis, both GTI Integrated Scenario Int-14.55 and Int-14 results and the DOE SNOPR LCC model results show decreased annual source energy consumption and greenhouse gas (GHG) emissions, though the GTI scenarios show smaller reductions than the DOE scenarios. Due to time constraints, the reason for the different result between the NOPR and SNOPR was not investigated in detail, but may be related to the DOE heating load calculation error in the NOPR that reduced the rule benefits compared to the SNOPR.
- GTI analysts had planned on conducting a 30 year analysis of the projected national impact of the proposed furnace rulemaking based on the DOE SNOPR LCC model results and the GTI Integrated Scenario Int-14.55 analysis results. However, due to the limited comment period and extensive effort to address LCC savings scenarios and issues, this analysis was not conducted.Based on the annual energy and GHG emissions savings results, the a priori expectation is that the national impacts of the proposed rule would have been similar under GTI Integrated Scenario Int-14.55 compared to the DOE SNOPR NIA results.

Appendix A Supplemental Information

A.1 VBA Code for Detailed Parametric and Scenario Analysis

This report contains a higher degree of granularity than exists in the DOE LCC spreadsheet model and published results. Many of the desired outputs of DOE's model were not provided in sufficient detail to conduct analysis on individual case and subcategory results. The addition of Visual Basic for Application (VBA) code that exported outputs of interest to a new spreadsheet enabled this level of detailed analysis. The VBA code used for this purpose stepped the baseline model through each of the 10,000 individual trials while the Crystal Ball simulation was running and enabled capture of key information related to individual trial cases. The VBA code to capture data output did not affect the calculation of any parameters for the DOE SNOPR LCC Model (referred to as Scenario 0 and Scenario 0.55 in this report and accompanying spreadsheets). Nor did it affect the calculations in any of the GTI parametric runs that examined the decision making methodology, input data assumptions, and integrated scenarios. However, additional VBA code was added as necessary to apply GTI parametric decision making methodology algorithms described in this Appendix.

A.2 DOE LCC/Crystal Ball Spreadsheet Model Decision Making Analysis

A.2.1 DOE Base Case Furnace Efficiency Levels

The DOE LCC Model includes economic criteria and a distribution of allowable cost recovery times in its trial standard level (TSL) furnace analysis and fuel switching decision algorithm. However, DOE's baseline furnace decision algorithm ignores economic decision making by the consumer and is in conflict with its other analysis and decision making algorithms. Instead, the Base Case AFUE, which is the efficiency of the furnace that is chosen by an individual consumer without the influence of DOE's rule, is assigned randomly in the baseline model. This random assignment occurs in the "Base Case AFUE" sheet in cell D12. A random number between 0 and 1 with a uniform distribution is generated by Crystal Ball for each of the 10,000 trials, representing an individual consumer choice. The random number is compared to the cumulative distribution of extrapolated shipment data for geographic regions, residential vs. commercial, and new vs. replacement. If the random number is smaller than the percentage of furnaces that are expected to be 80% AFUE furnaces, an 80% AFUE furnace is assigned as the Base Case AFUE. If the random number generated is above the expected fraction of 80% AFUE furnaces but below the expected cumulative 80% plus 90% AFUE fraction, then a 90% furnace is assigned as the Base Case AFUE. If the random number exceeds this level, a 92% AFUE furnace is selected in the 92% AFUE TSL case. This process continues through the 98% AFUE TSL. The favorable economics of a particular TSL compared to other levels (e.g., 80% vs. 92% AFUE) are not considered in the decision making.

DOE includes two conflicting assumptions in its SNOPR LCC model that combine to overstate the number and type of impacted trial cases. DOE assumes that it is reasonable to linearly extrapolate condensing furnace shipments into the future, while simultaneously assuming that condensing furnace installed costs will drop relative to 80% AFUE furnaces. The combination of these two assumptions causes more cases to be considered "Net Benefit" than would experience first cost increases when selecting a condensing furnace. Using DOE's combined assumptions, some Base Cases choose lower efficiency furnaces even when higher efficiency ones are less expensive. This is especially true in new construction.

Similarly, cases where the payback for the 92% AFUE furnace was very poor, DOE's random assignment algorithm selected these cases as "No Impact," i.e., not affected by the DOE rule. According to DOE's random assignment methodology, the consumer would have freely chosen a 92% or higher efficiency furnace even though the simple payback period exceeds 100 years, causing that consumer to incur a financial loss. Under an economic decision making algorithm, such as Scenario 24, most consumers with long payback periods would have been considered "Net Cost," i.e., negatively affected by the DOE rule, and would have been included in the LCC calculations, reducing the overall benefit of the rule. Another flaw in the random assignment methodology is the rational fuel switching that would be expected to occur if the fuel switch to a low cost (compared to an 80% AFUE furnace), efficient electric technology is a superior choice to the 92% furnace, as is the case in Crystal Ball trial case 8785. In that case, rational fuel switching is considered unregulated market behavior and is excluded from the economic decision making scenarios as "No Impact" as well, but for economic reasons, not by random assignment.

A.2.2 DOE Fuel Switching Decision Making Methodology

Unlike the random decisions in the Base Case AFUE assignment, decisions on whether or not a consumer will choose a fuel switching option are based on consumer economics in the baseline DOE LCC model. Figure 7 in the main report describes GTI's understanding of the DOE LCC fuel switching decision-making process flow chart. The flow chart aligns with the process that is coded into the LCC spreadsheet rather than the limited description in the TSD. Cases that have selected a furnace with efficiency higher than 80% in the Base Case AFUE sheet are excluded from fuel switching in the LCC&PB Calcs sheet in a large range of cells in columns P through DG using statements like "=IF(AND(optSwitch=1, Index(iBase,1=0),…" which has the effect of verifying that fuel switching in the DOE model is turned on and that the selected furnace is an 80% AFUE furnace. Cells D63 through D66 in the DOE NWGF switching sheet look for cases that have negative payback and cases that have payback periods above the 3.5 year "switching payback period" (a term explained below) set in cells D48 and D49 in the same sheet. They are coded by DOE such that negative payback options will be selected first, followed by those with the largest switching payback period over the 3.5 year payback period threshold.

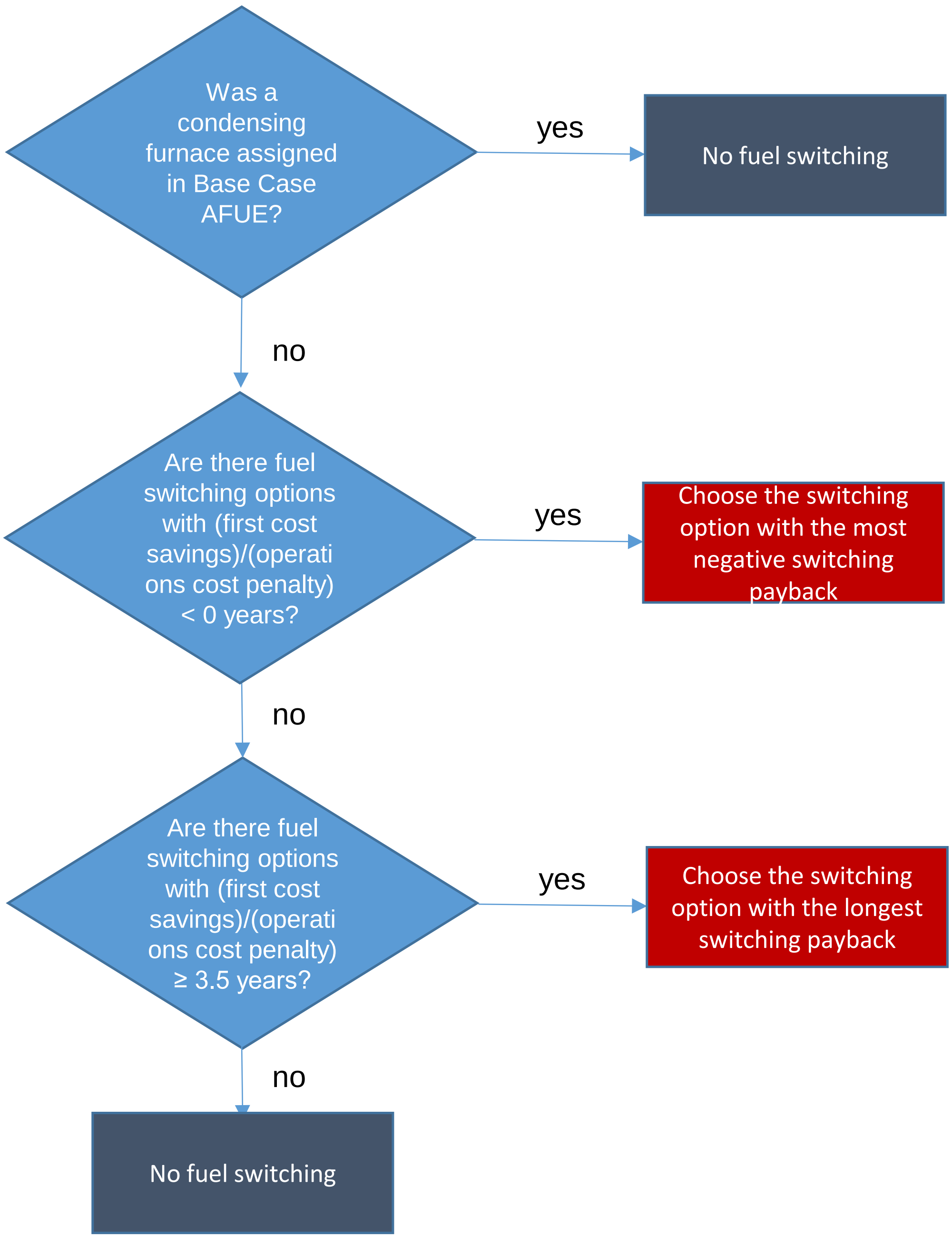


Figure 24 GTI Illustration of DOE Fuel Switching Logic Flow Chart

The TSD includes a confusing definition of payback period as applied to the LCC spreadsheet fuel switching algorithms. The TSD states (at pages 8J-5 and 8J-6): "DOE calculated a PBP [payback period] of the potential switching options relative to the NWGF at the specified EL." However, the fuel switching PBP definition actually used by DOE in the LCC spreadsheet differs from traditional PBP applied elsewhere in the DOE LCC analysis. The spreadsheet "payback" calculation in column AH of the NWGF Switching sheet calculates the time after which the first cost advantage of a switching option relative to a NWGF is offset by the higher operating cost of the switching option. Thus, the "payback period" used in the DOE fuel switching analysis calculations (versus the PBP described in the TSD) is actually the period after which a consumer begins losing money due to higher operating costs of the lower first cost option. This report refers to the DOE fuel switching version of "payback" as the "switching payback." This term is needed to distinguish the "switching payback period" from the usual definition of "payback period," which is the period after which a consumer begins saving money due to the lower operating costs of the higher first cost option.

If DOE's Base Case AFUE assignment were based in economics, the first decision point in the flow chart would be reasonable. A consumer that freely chooses a condensing furnace based on its economic benefits, even if below the TSL (e.g., chooses a 90% furnace instead of either the 80% furnace or a 92% furnace), is unlikely to instead switch to an electric option. Because DOE has chosen to use a random assignment algorithm in the Base Case AFUE assignment, there are likely to be cases that DOE does not consider in its fuel switching algorithm that may actually be candidates for fuel switching, and other cases that DOE has determined will benefit from fuel switching that would have fuel switched without the rule and should not be included in the analysis.

The second decision evaluates whether or not there are electric options that have both lower first cost and lower operating cost (options that do not have lower first cost are not allowed) relative to a non-weatherized gas furnace (NWGF) at the TSL. If there is such a case, its switching payback will be negative (i.e., "negative" first cost penalty divided by positive energy savings), and the model will select it. The DOE model does not look for cases where there is a first cost advantage when comparing to an 80% furnace and an operating cost advantage compared to the TSL. These cases should cause fuel switching that would happen in the unregulated market, and should be removed from the Base Case and not be considered fuel switching due to the rule. This flaw motivated a GTI decision making parametric that removes these cases from the subset that are affected by the rule in the model.

The final decision looks for cases where the switching payback period is at least 3.5 years. The DOE algorithm chooses the option with the longest switching payback if more than one option's switching payback period is over 3.5 years. DOE selected the 3.5 year switching payback period as the decision point based on analysis of four versions (2006, 2008, 2010, and 2013) of the American Home Comfort Study (AHCS) published by Decision Analyst. The AHCS is a proprietary report available only through private purchase and contains detailed consumer preference information not generally available to the public. Some of the more granular information available in the AHCS used in GTI's fuel switching and decision methodology analyses was not used by DOE in its algorithm. The derivation of the 3.5 year payback period criterion is described in section 8J.2.2 of the TSD. It comes from the amount consumers responding to the AHCS reported being willing to pay for a 25 percent improvement in the efficiency of their HVAC system and the space conditioning costs determined from the

RECS 2001, 2005, and 2009. The average amount consumers were willing to pay from the AHCS was divided by 25% of the energy costs for space conditioning derived from the RECS to arrive at 3.5 years. The 3.5 year average value used by DOE can be found in the DOE SNOPR LCC model spreadsheet in the Labels sheet at cell G38. It is also referenced by cells D48 and D49 in the NWGF Switching sheet, where it is used in fuel switching decision making.

Interpreting condensing to non-condensing furnace cost differentials from DOE's top level LCC spreadsheet can be misleading as well. A more textured understanding of the modeled consumer choice requires extracting and analyzing data from all 10,000 cases. For instance, LCC spreadsheet Summary, Statistic and Forecast Cells sheets labeled NWGF 90 to 98% report composite numbers for NWGF and fuel switching equipment impacts. Based on individual cases, DOE considers fuel switching to heat pumps to be quite inexpensive because DOE discounts the delivered price and installation cost of the heat pump by assuming replacement of an equivalent air conditioner irrespective of the age of the air conditioner. This overstates the benefit of fuel switching considerably for homes with newer air conditioners that otherwise would not have been replaced when the furnace was replaced.

A.3 GTI Decision Making Parametrics

To examine the impact of DOE's random baseline decision making algorithms on modeling results, GTI analysts developed several parametrics that improve the logical processes in the LCC model. There is a distinction made here between a parametric and a scenario. Parametrics alter aspects of the model as described below. Scenarios are the output of the model run with the alterations described by the parametrics. In some cases, parametrics are run by themselves as a scenario and in some cases they are combined with other parametrics in a scenario to see the combined impact. Also, in some cases a parametric cannot be run by itself because its logic cannot stand on its own (such as parametric D4) or because it conflicts with other parametrics (such as D0 with D1, D2, D3, D8, D9, or, D10).

A.3.1 Parametrics D1, D2, and D3

Figure 25 shows the effect of the switching payback period on LCC savings in the DOE model. This was generated simply by changing the values of cells D48 and D49 in the NWGF Switching sheet. The distribution of LCC savings is non-linear. Because of the shape of the response, any distribution of switching payback periods with an average of 3.5 years will have lower LCC savings than the use of a single 3.5 year switching payback period. The data available in the AHCS contains a wide distribution of payback periods that are a function of household income. These factors motivated the development of parametric modifications to the baseline model which represent more thoroughly the detailed distribution of consumer preferences in the AHCS.

DOE used the AHCS to determine its switching payback period by converting the average amount consumers were willing to pay for an efficiency improvement combined with the average HVAC energy costs to arrive at a single switching payback period. However, the AHCS contains significantly more detailed information than simple averages. According to Decision Analyst, the AHCS is the largest knowledge base of homeowner behavior, perceptions, and attitudes related to energy efficiency, home comfort, and HVAC. Topics covered in the AHCS include:

- The level of consumers' interest in energy efficiency

- How consumers balance rising energy costs with home comfort
- Consumers' willingness to spend money on home improvements to achieve energy efficiency
- Home comfort differences by region and demographics

It contains between 2,849 and 3,803 respondents in each of the years 2006, 2008, 2010, and 2013. It includes enough data to produce distributions of switching payback periods as a function of income groups to produce a more granular evaluation of fuel switching behavior than DOE incorporated into their analysis using the single point average switching payback period.

Figure 26 shows the full distribution of switching payback periods from the AHCS for each income group, calculated following the DOE methodology described in the TSD but for the whole distribution of data from the AHCS instead of an average. The distribution of responses reported by Decision Analyst was used to simulate 5,000 data points for each income group in each of the four years (2006, 2008, 2010, and 2013) of the AHCS. Data from all four years were combined to yield the distributions shown.

Several features stand out in the AHCS distribution. First there is a clear trend with income; lower income households are more tolerant of short switching payback periods than higher income groups. The AHCS distribution information shows that low income households are more first cost sensitive on average than higher income households. Also the distributions are not normal distributions that would align reasonably well with an average value. The distributions are instead skewed, with a large number of consumers having very short switching payback periods, and a small number of consumers having very long switching payback periods. Averaging these disparate distributions into a single value results in an average switching payback period of 3.5 years.

Histograms shown in Figure 27 for the highest and lowest income groups from the 2010 AHCS data further illustrate the skewed allowable switching payback distribution. As shown in Figure 25, switching payback periods much shorter than 3.5 years have a significant negative effect on LCC savings while switching payback periods much greater than 3.5 years have little positive incremental effect on LCC savings. Application of a single average value to this skewed distribution as DOE continued to do in its SNOPR LCC model overstates LCC savings compared to using the full distribution of switching payback periods as was done in the GTI scenarios.

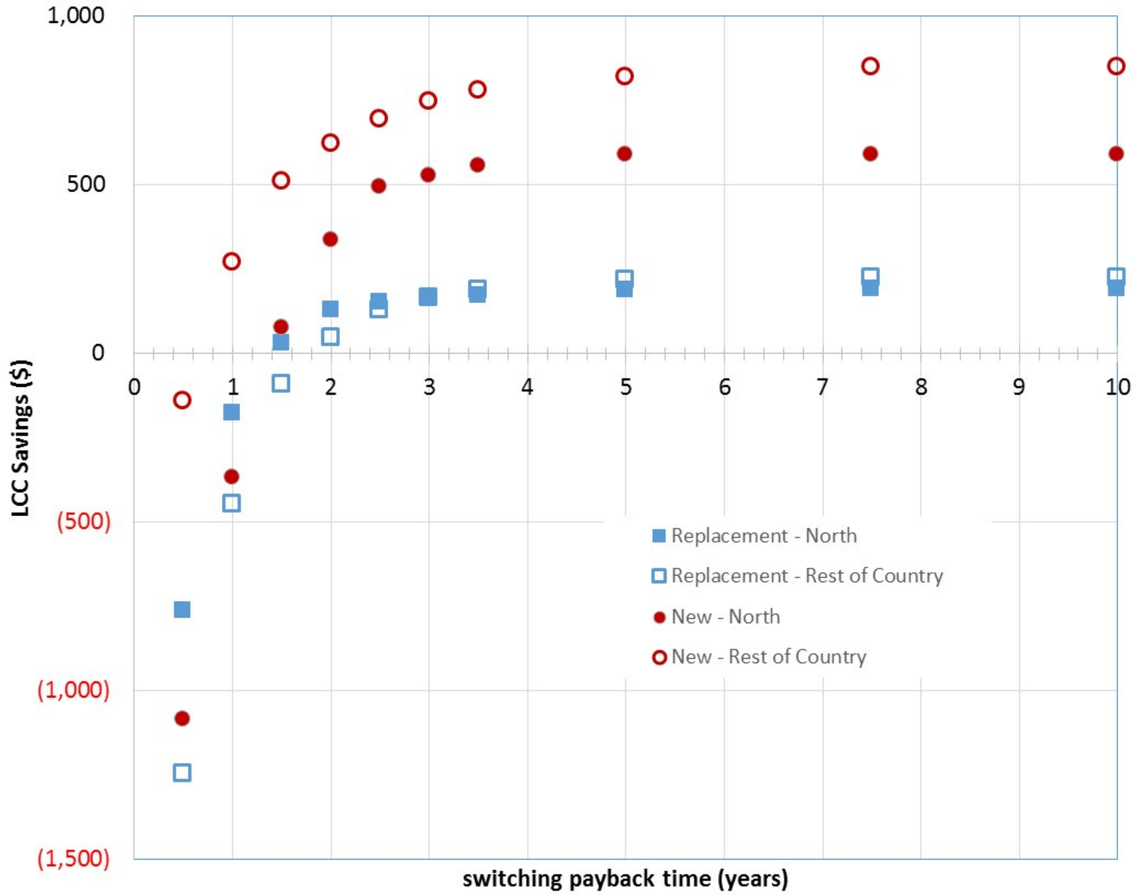


Figure 25 Non-linear LCC Savings Distribution vs. Switching Payback Period

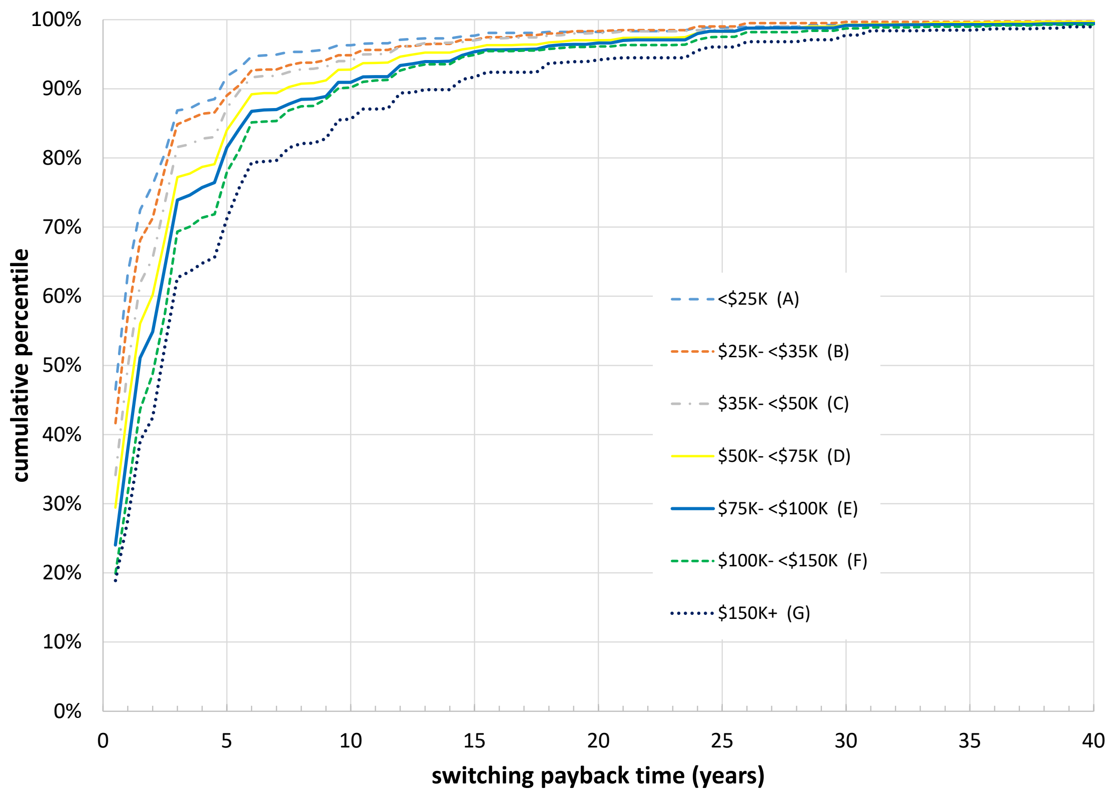
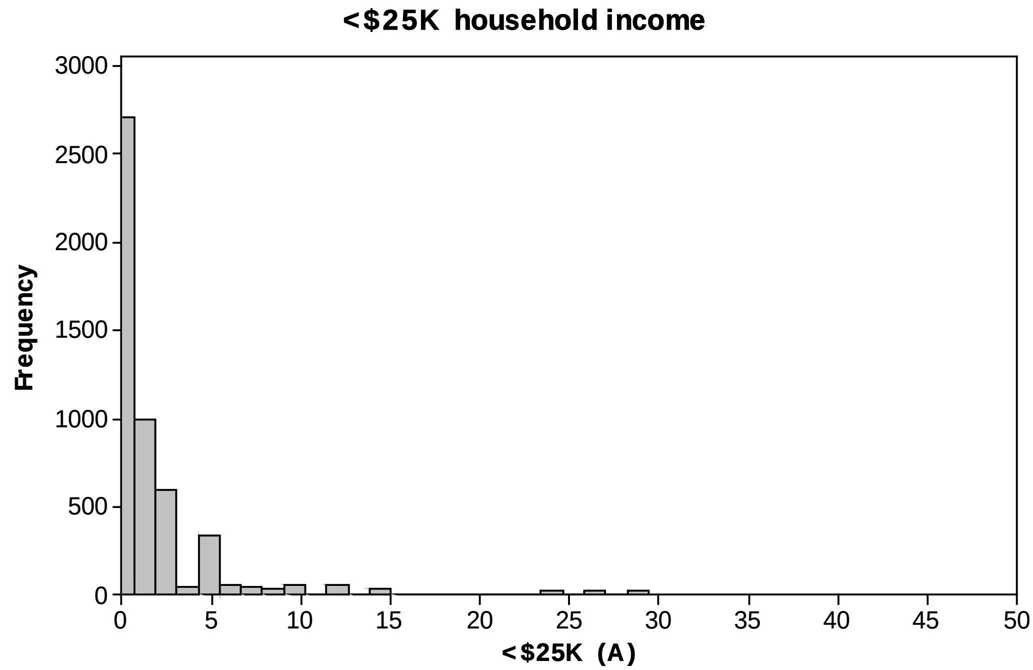


Figure 26 Switching Payback Distribution for Different Income Levels

Source: American Home Comfort Study[5]

5 Decision Analyst. 2006, 2008, 2010, and 2013. American Home Comfort Study. Arlington, TX. http://www.decisionanalyst.com/Syndicated/HomeComfort.dai



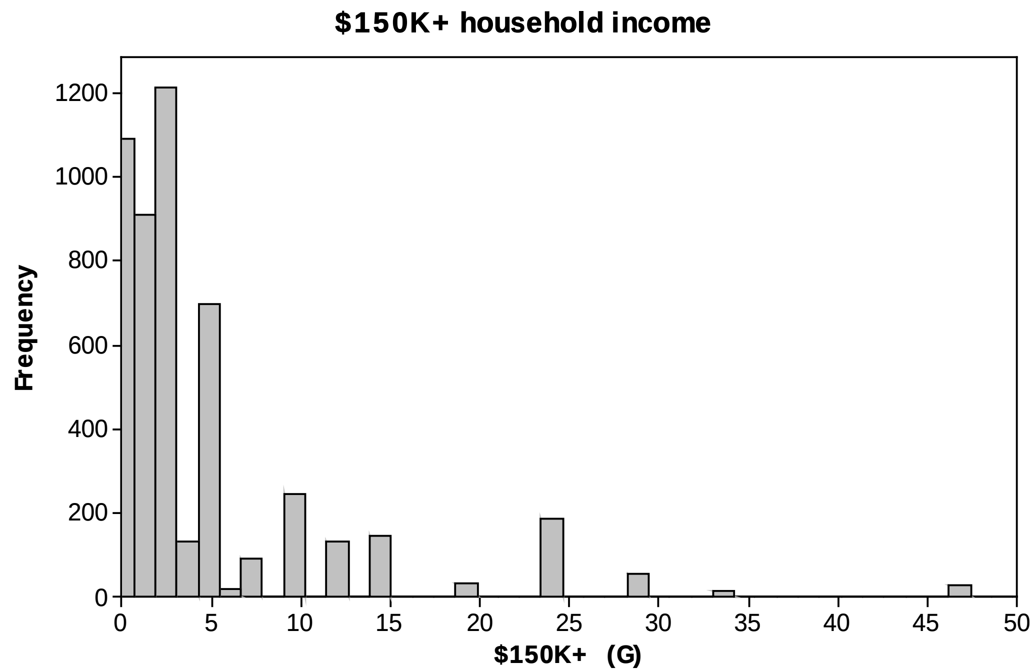


Figure 27 Allowable Switching Payback Distribution by Income Group

Source: American Home Comfort Study[6]

6 Decision Analyst. 2010. American Home Comfort Study. Arlington, TX. http://www.decisionanalyst.com/Syndicated/HomeComfort.dai

Decision making parametric D1 uses the cumulative distributions shown in Figure 27 combined with income data from the RECS 2009 data available in the DOE LCC model and a random number generator to replace the 3.5 year single switching payback period given in the baseline LCC model.

Two other parametrics were based on a less complete use of the AHCS data than parametric D1, but still more complete than the DOE analysis. As shown in Figure 28, there is a consistent trend in all years of the AHCS between tolerable payback periods for consumers and household income. Decision making scenario D2 assigns payback periods according to household income using the average payback period calculated for all 4 years of the AHCS data (2006, 2008, 2010, and 2013). Tolerable payback periods in the 2013 AHCS were somewhat lower than in previous years. Decision making scenario D3 uses a linear fit to the 2013 AHCS data only.

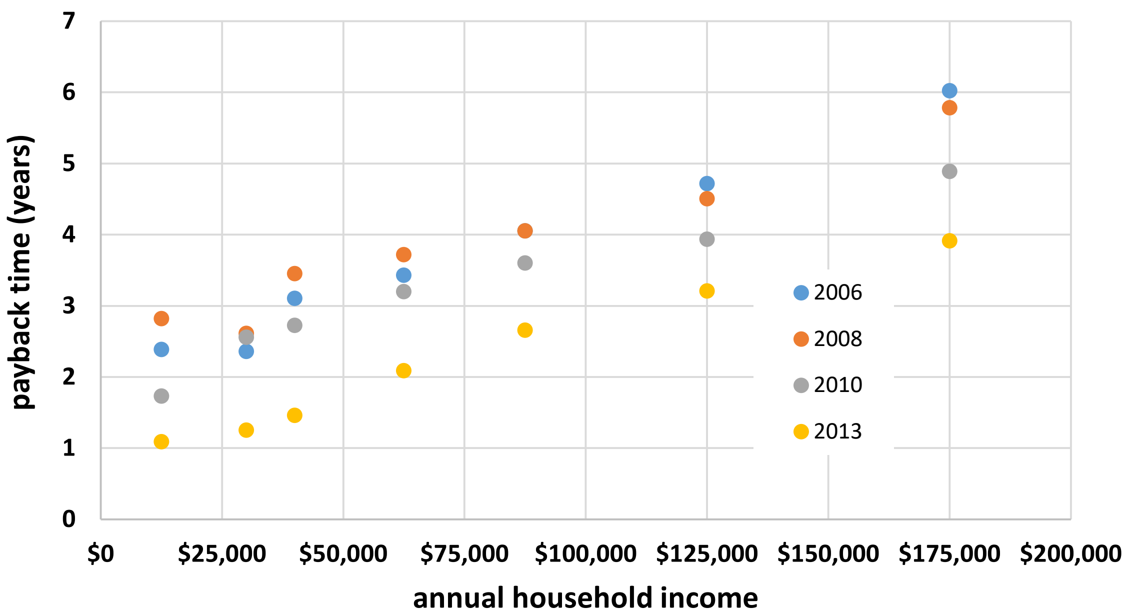
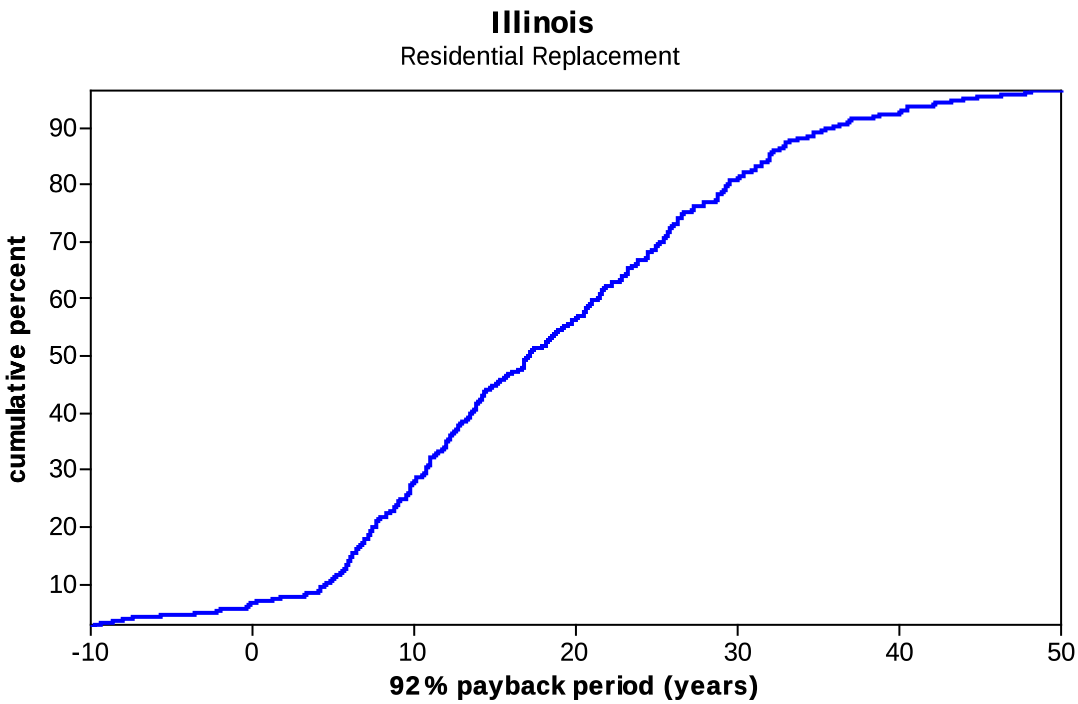


Figure 28 Tolerable Switching Payback Periods for Lower and Higher Income Households

A.3.2 Parametric D4

This parametric replaces DOE's random Base Case AFUE assignment with economic decision making, giving consumers a reasonable ability to make economic decisions. Base Case AFUE assignment by this parametric is based on the payback period for the TSL furnace relative to an 80% AFUE furnace. This payback period is already calculated and available in the LCC model in the NWGF Switching sheet in column AI (specifically in cell AI13 in the case of a 92% AFUE TSL). The DOE LCC model calculates in for every case whether the case is affected by the rule or not. GTI analysts ran the baseline model and collected data on all payback periods so that cumulative distributions could be produced for each region, installation type (new or replacement), and building type (residential or commercial). Figure 29 shows two example cumulative distributions of payback periods for Illinois and Georgia. Parametric D4 combines these cumulative distributions with the extrapolated shipment data provided by DOE to assign payback periods for furnaces at different efficiencies. The method of assigning payback periods is illustrated for Illinois residential replacements and Georgia residential new construction in GTI-15/0002, along with implications for the rulemaking that apply to the SNOPR as well.



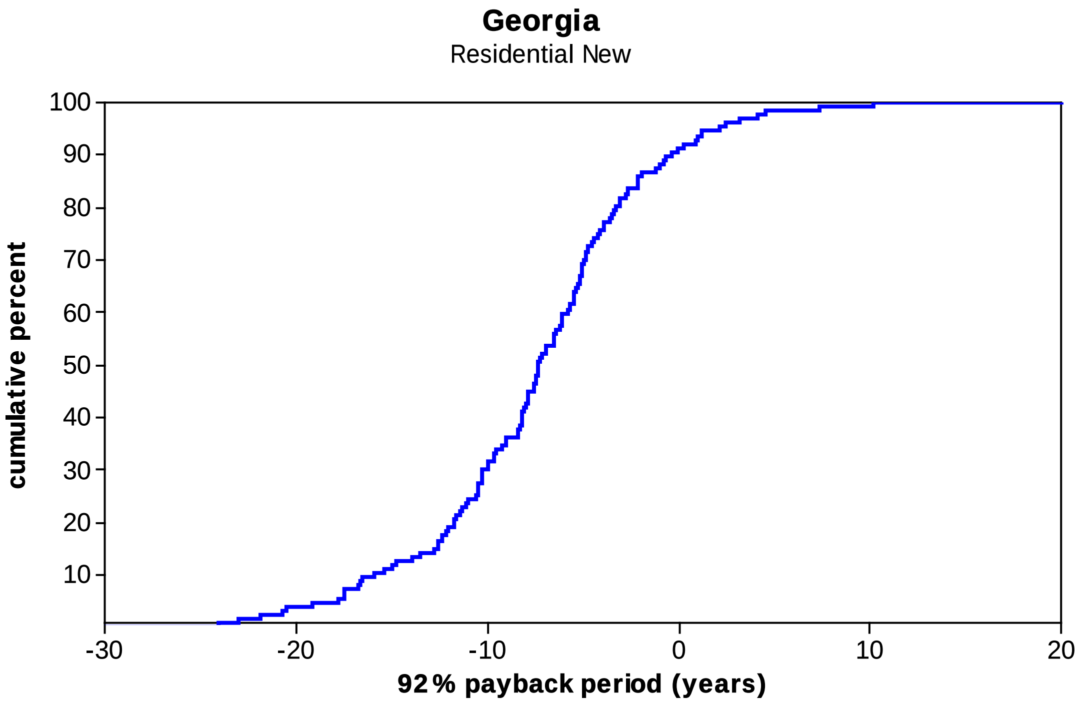


Figure 29 Cumulative Distribution of Payback Periods in DOE Model

Because of the prevalence of negative payback periods within the DOE model caused by DOE's projections that condensing furnace total installed costs will drop relative to 80% AFUE furnaces, even applying CED will result in substantial numbers of consumers being considered Impacted when they would experience first cost savings by choosing a furnace at the mandated TSL. Therefore, Parametric D4 was never run alone. It was always combined with another scenario such as D5 to remove these highly improbable negative and extremely low payback period cases from the "Net Benefit" category.

A.3.3 Parametric D5

Parametric D5 sets the minimum allowed payback period for Base Case furnace assignment to 0 years from the AHCS. The 0 year minimum payback period in D5 results in more consumers being considered impacted by the rule than a 3.5 year allowable payback period for decisions or a full distribution function aligned with the full AHCS survey information. To avoid negative and very short payback periods from being incorrectly assigned to the "Net Benefit" group, parametric D5 is combined with parametric D4. The full flow chart for Base Case AFUE assignment, including parametrics D4 and D5 is shown in Figure 5.

A.3.4 Parametric D8

This parametric removes cases where a fuel switching option has a lower first cost than an 80% furnace and operating costs savings relative to a TSL furnace. Those switching occurrences should occur in the absence of a rule. Cases are removed from the affected group by assigning a Base Case AFUE high enough that the case becomes considered not affected by the rule. The addition of parametric D8 to the fuel switching decision making is illustrated in Figure 8.

A.3.5 Parametric D11 and D12

While parametric D4 does not preclude economically poor decisions, it does make decisions based on economic criteria according to the simple payback period of a NWGF at the mandated TSL relative to an 80% NWGF. A household with a shorter payback period will always be more likely to choose a condensing furnace of a particular TSL compared to a household with a longer payback period under Parametric D4. This brings up the possibility that even though one household has better economics than another for a particular decision, it may not act accordingly.

Parametrics D11 and D12 use the same simple payback periods used in D4, but only remove trial cases as "No Impact" from the LCC analysis if their payback periods are below 0 and 3.5 years, respectively. Both parametrics also force trial cases to choose an 80% AFUE furnace if the TSL furnace has a payback period over 15 years. If the payback periods fall between these extremes, Base Case AFUE is assigned randomly, the same way as in the DOE algorithm. These parametrics provide an upper limit on LCC savings compared to the Base Case furnace. In these two parametrics, trial cases that have extremely good economics will definitely choose a furnace at the mandated TSL, while trial cases with extremely poor economics for a condensing furnace will definitely choose an 80% AFUE furnace. All other trial cases will be assigned a baseline furnace efficiency randomly without considering economics.

A.3.6 Parametric D13 and D14

Parametric D13 uses a more complete implementation of the AHCS, sets payback periods for furnace selection and for fuel switching, and adjusts percentages to align with AHRI shipment percentages. This parametric uses the full distribution of amounts consumers would pay in each income range to determine a payback time using a random number generator and a lookup table for each income range. This is used for both switching and furnace AFUE selection, AFUE selections are adjusted to match the AHRI shipment numbers as closely as possible.

Parametric D14 acknowledges that consumers are better at making decisions for items with short payback periods than they are for items with longer payback periods. It provides a reasonable way to monetize a variety of non-economic factors within the CED framework. D14 modifies the combined parametrics D4 and D5 that use deterministic DOE LCC model payback periods for each trial case by adding a normal distribution function whose payback period standard deviation is 50% of the DOE LCC model calculated payback period. This gives consumers a more limited ability to consider economics in decision making than combined parametrics D4 and D5. The thresholds for decision making are still based on projected shipment fractions, so regions with higher market penetration generally will tolerate longer payback periods than those with lower market penetrations. D14 also prevents trial cases with negative payback periods from being impacted by the proposed rule using the same logic as D5.

A.4 GTI Decision Making Scenarios

As described in the preceding section, scenarios represent the outputs of the LCC model when one or more parametric modifications are included in the LCC model. For the GTI SNOPR analysis, decision making parametrics were incorporated into scenarios according to the matrix in Table 11. Some of these scenarios were run only to illustrate the impact of the selected parametrics, whether or not they are technically defensible on their own. This section describes the rationale for inclusion of each scenario in the GTI SNOPR analysis. Summaries of LCC savings, fuel switching for impacted buildings, and energy use for impacted buildings can be found in the spreadsheets accompanying this report.

The DOE and GTI LCC analysis results include information on energy consumption by fuel type. GTI analysts used this information to evaluate the impact of the rule on site energy consumption, primary energy consumption, and greenhouse gas emissions (CO_2e emissions). Energy use and emissions results tables in the spreadsheets accompanying this report, for the decision making, input, and integrated scenarios, summarize national level average results using national values for primary energy conversion factors and CO_2e emissions for natural gas and electricity. GTI's Source Energy and Emissions Analysis Tool (available at: www.cmictools.com) was used for this analysis. These results are helpful to gain an understanding of the environmental impacts of the proposed rule, including the impact of fuel switching.

A.4.1 Scenario 2

Scenario 2 illustrates the impact of changing the fuel switching payback periods using a more comprehensive analysis of the AHCS than DOE chose to use in the SNOPR. Scenario 2 does not address any other decision making in the LCC model. Scenario 2 fuel switching percentages are similar to the DOE SNOPR LCC model and the GTI fuel switching survey results. While future market behavior in response to the DOE SNOPR cannot be known in advance, the GTI fuel switching survey that informed the DOE SNOPR LCC model is the most recent market information available, and may be useful as a metric for comparing the scenario results.

Scenario 2 shows reduced LCC savings relative to the DOE NOPR LCC Model. Low income households show a particularly large reduction in LCC savings compared to other categories. This result is expected because parametrics D1, D2, and D3 all produce shorter switching payback periods, especially for low income trial cases, compared to the DOE NOPR LCC Model.

A.4.2 Scenario 7

Scenario 7 incorporates only parametric D8 that eliminates as "No Impact" any cases where fuel switching would have been economically driven without the proposed rule. It serves to illustrate the impact of that single adjustment. Also, it significantly reduces fuel switching at all TSLs because it is removing fuel switching that would have occurred in the absence of a rule from being considered in the model.

A.4.3 Scenario 24

Scenario 24 combines CED in the Base Case AFUE assignment with a minimum threshold of zero years, removal of fuel switching cases that are unrelated to the rule, and modification to the fuel switching payback periods. Scenario 24, including parametrics D2, D4, D5, and D8, and shows very significant decreases in LCC savings relative to the DOE SNOPR LCC Model. Scenario 24 yields fuel switching levels that are similar to the DOE SNOPR LCC Model and the 2014 GTI fuel switching survey.

A.4.4 Scenario 36

Scenario 36 combines CED with monetized non-economic factors in the Base Case AFUE assignment with a minimum threshold of zero years, removal of fuel switching cases that are unrelated to the rule, and modification to the fuel switching payback periods. Scenario 36, including parametrics D2, D8, and D14, and shows very significant decreases in LCC savings relative to the DOE SNOPR LCC Model. Scenario 36 yields fuel switching levels that are reasonably close to the DOE SNOPR LCC Model and the 2014 GTI fuel switching survey.

A.5 GTI Input Data Parametrics

In addition to improving decision making over the Baseline AFUE assignment in DOE LCC Model, input parameters were also changed to more technically defensible ones when such information was available.

A.5.1 Parametric I2

This parametric replaces DOE's retail prices that were derived through a tear down analysis of furnaces with a database of actual offered prices of furnaces. GTI tabulated retail prices provided in the 2013 Furnace Price Guide (https://www.furnacecompare.com/furnaces/price-guide.html), segregated models by efficiency level, adjusted the furnace prices to account for the use of BPM motors in place of PSC motors, and used the adjusted "delivered to home" furnace prices as inputs to the model. The list of actual direct-to-consumer prices offered over the Internet listed in the 2013 Furnace Price Guide covers 25 brands and a wide range of efficiencies and capacities. A total of 1,222 records were extracted from 2013 Price Guide (569 for 80% AFUE NWGF, 29 for 90%, 215 for 92%, 409 for 95%, and none for 98%). A linear curve fit was derived only for the 80%, 92% and 95% AFUE NWGFs.

There was not sufficient data for 90% AFUE furnaces in the 2013 Furnace Price Guide for a reasonable curve fit, and there were no 98% AFUE furnaces in the 2013 Furnace Price Guide.

To estimate prices for 90% and 98% AFUE furnaces, differential prices between 92% and 90% as well as 95% and 98% from the DOE 2014 LCC spreadsheet were applied to 92% and 95% AFUE groups from 2013 Furnace Price Guide as inputs to the model.

Price decreases over time followed the DOE learning curve baseline assumptions. This parametric represents real offered prices rather than a large number of manufacturing cost estimates for every component and assembly where each aggregation is subject to error.

Figure 30, Figure 31, and Figure 32 illustrate the 2013 Furnace Price Guide curve fitted data for 80%, 92% and 95% AFUE NWGF.

As illustrated in Figure 33, the curve fitted 2013 Price Guide price trends show a $326 differential between the 92% and 80% AFUE 80,000 Btu/h furnace, and a $452 differential for 120,000 Btu/h furnace. The DOE SNOPR 92% AFUE retail prices were similar, but DOE's 80% AFUE furnace price is higher than the 2013 Price Guide furnace price. Also, the 2013 Price Guide 95% AFUE furnace retail price is much higher than DOE's price.

To make the 2013 Price Guide compatible with 2022 fan motor assumptions, the 2013 Price Guide numbers were adjusted by adding the upgrade cost from a PSC motor to a BPM motor based on percentages of PSC motors being installed in each AFUE efficiency group in equipment currently available per the X16_RF_SNOPR_AnalysisInputs_2016-08-30.xlsm sheet "Furnace Fan Motor Types."

Current Fractions of PSC and BPM Motors are shown in Table 36 and 2022 motor type fractions used in the DOE SNOPR LCC model are shown in Table 37. The cost of the motor upgrade is based on DOE numbers listed on page 5-23 of the TSD, shown in Table 38.

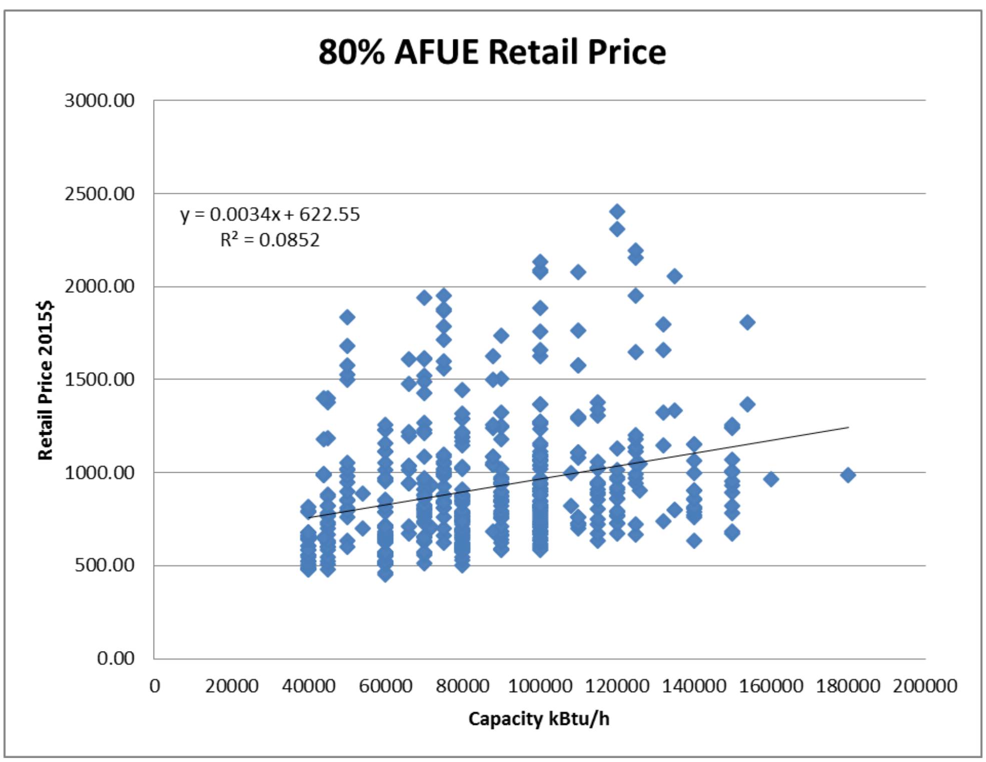


Figure 30 Retail Price vs. Capacity at 80% AFUE

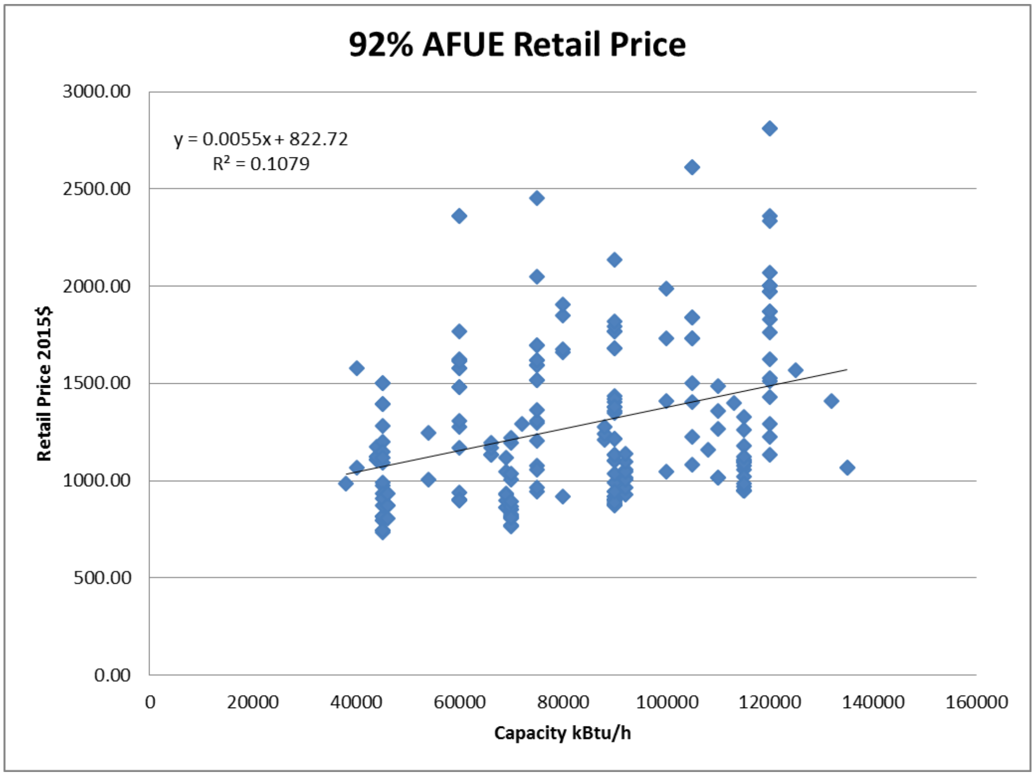


Figure 31 Retail Price vs. Capacity at 92% AFUE

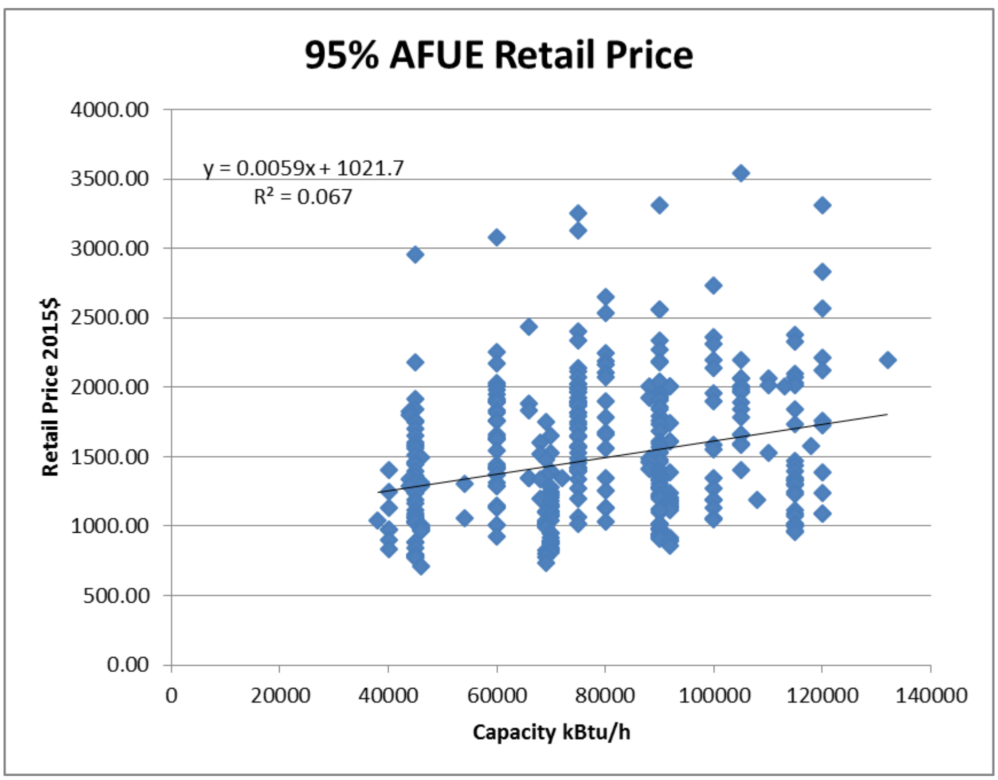


Figure 32 Retail Price vs. Capacity at 95% AFUE

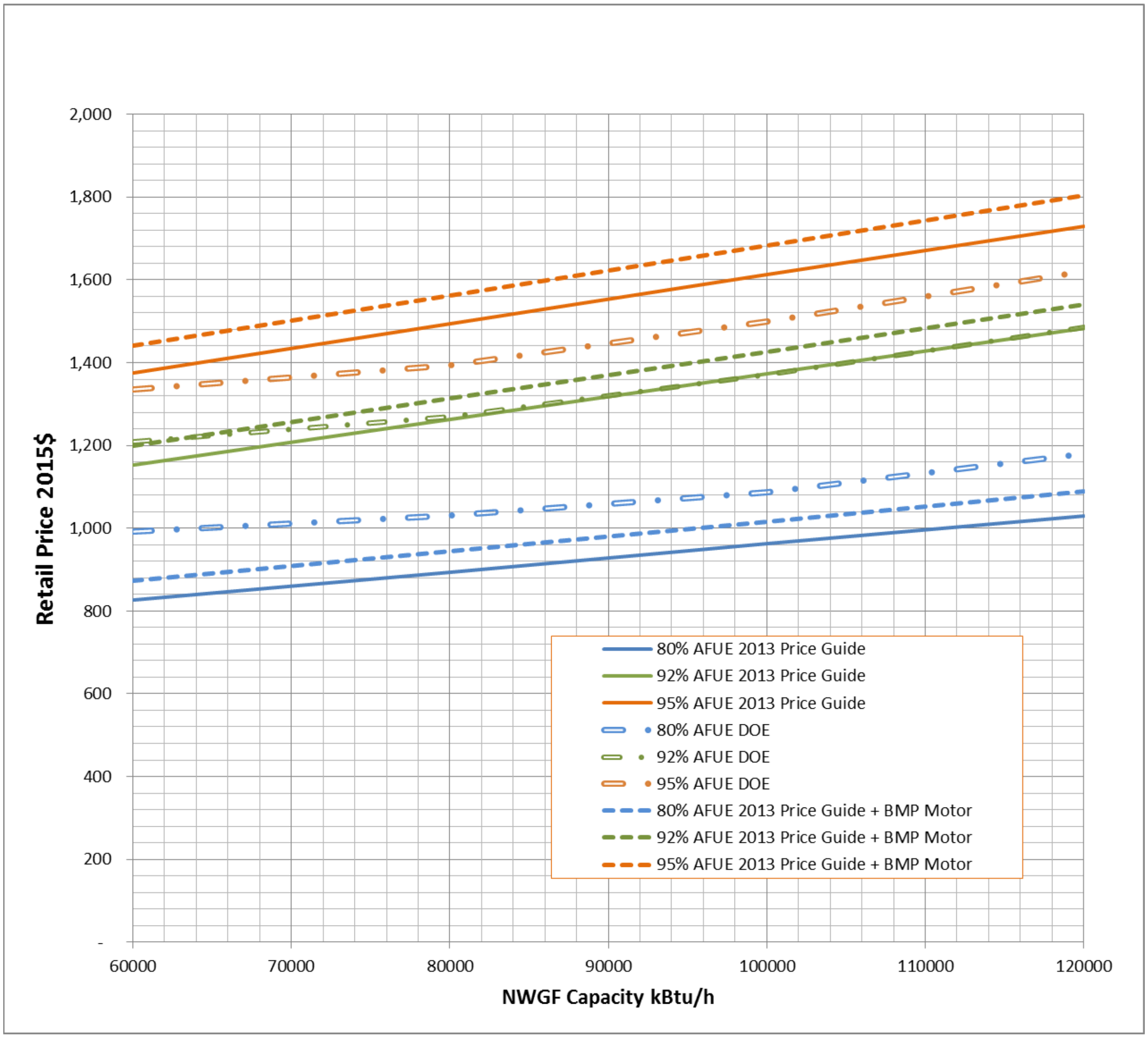


Figure 33 Retail Price Comparison –DOE LCC Model vs. 2013 Price Guide

Table 36 Current Fractions of PSC and BPM Motors

Fraction of Furnaces by Motor Type (Based on Model Data)						
	PrdClass	AFUE	PSC	BPM Constant Torque (Single Stage)	BPM Constant Torque (Two-Stage)	BPM Constant Airflow
0	NWGF	80	67%	14%	4%	15%
1	NWGF	90	78%	5%	0%	16%
2	NWGF	92	86%	1%	0%	13%
3	NWGF	95	29%	12%	11%	47%
4	NWGF	98	0%	0%	0%	100%
0	MHGF	80	100%	0%	0%	0%
1	MHGF	92	100%	0%	0%	0%
2	MHGF	95	53%	40%	0%	7%
3	MHGF	97	0%	0%	0%	100%

Table 37 2022 Motor Type Fractions

Crystal Ball Assumptions																		
Description		NWGF 80%		NWGF 90%		NWGF 92%		NWGF 95%		NWGF 98%		MHGF 80%		MHGF 92%		MHGF 95%		MHGF 97
Improved PSC	1		1		1		1		1		1	100%	1	100%	1	50%	1	50%
X13, Single Stage	2		2		2		2		2		2	0%	2	0%	2	40%	2	40%
X13, Multi-Stage	3	85%	3	85%	3	85%	3	50%	3	0%	3	0%	3	0%	3	0%	3	0%
ECM, Multi-Stage	4	15%	4	15%	4	15%	4	50%	4	100%	4	0%	4	0%	4	10%	4	10%

Table 38 Additional Cost for Motor Upgrades

Table 5.8.1 Additional Cost (Including Motor, Controls, and Wiring) to Switch from PSC to Improved PSC or BPM Blower Motor

Product Class	Input Capacity (kBtu/h)	Incremental Cost Increase for Improved PSC ($)	Incremental Cost Increase for Constant-torque BPM ($)	Incremental Cost Increase for Constant-airflow BPM ($)
Non-weatherized Gas	60	-	38.43	92.35
	80	-	42.56	94.41
	100	-	46.68	96.47
	120	-	50.80	98.53
Mobile Home Gas	80*	6.30	42.56	94.41

A.5.2 Parametric I6

Parametric I6 replaces the DOE SNOPR LCC model marginal gas price factors with the marginal price factors developed by AGA. The DOE methodology used EIA residential natural gas sales and revenues by state (EIA 2014 NG Navigator) to estimate the marginal price factors within each RECS geographical area as described below:

> *"EIA provides historical monthly electricity and natural gas consumption and expenditures by state. This data was used to determine 10-year average marginal prices for the RECS 2009 geographical areas, which are then used to convert average monthly energy prices into marginal monthly energy prices. Because a furnace operates during both the heating and cooling seasons, DOE determined summer and winter marginal price factors."* (SNOPR TSD Section 8E.3.3)

AGA also used EIA 2014 NG Navigator data. However, in contrast to the DOE methodology that used average RECS database prices, AGA developed a fixed cost component of natural gas rates for each state based on tariffs and monthly consumption and applied it to the EIA data to develop state level residential marginal price factors. These state level data were then weighted according to furnace shipments in the same manner that DOE used to generate marginal rates on a regional basis.

AGA calculated natural gas utility marginal cost by deducting the fixed charge portion from the total bill. The full 12 month residential gas bill was calculated from the reported total monthly residential sales data collected by EIA. AGA conducted an Internet search of utility tariffs to obtain the customer charges for about 200 of the largest utilities (representing roughly 90 percent of the total market). A month's worth of customer charges for all 200 companies was deducted from each total monthly bill or total residential sales. The resulting net monthly bill was divided by the monthly usage to get the marginal cost per Mcf or therm. Dividing the net bill by the total bill yielded the marginal cost factor. The remainder of the calculations followed DOE methodology – seasonal rates, use of shipment data to develop weighting of the state rates.

This approach is conservative in estimating the marginal cost. Use of the customer charge by itself ignores other changes in gas rates as the volume changes. For example, at least 20 large utilities use declining block rates, which, if incorporated into the analysis, could reduce the marginal cost factor even more. Table 39 shows residential natural gas marginal price factors developed by AGA and percentage change from factors used by DOE.

The marginal rates section in TSD Appendix 8E does not describe how DOE actually calculated marginal rate factors for use in the DOE SNOPR LCC model. DOE is using EIA state level monthly NG consumption and corresponding revenue. The year is divided into two seasons with summer months (April to October) and winter months (Jan to March and Nov. to Dec.) For each season, DOE calculates the average slope of change in NG revenue as a function of consumption. It also calculates average revenue per 1000 cf sold. The ratio of these two calculated values is assumed to be the marginal rate factor for the season considered. Marginal rate factor calculations are averaged for years 2005 to 2014 for each state. Next the state numbers are converted to RECS regional numbers where multiple states are aggregated using a weighting factor related to furnace shipments to each state. DOE assumes that shipments are good approximation of NG gas use by furnace in each state.

Table 39 AGA Marginal Gas Price Factors

Region	AGA NG Residential			DOE SNOPR			AGA Factors vs. DOE	
	Div. & Lrg. State	Non-Winter	Winter	Div. & Lrg. State	Non-Winter	Winter	Non-Winter	Winter
CT, ME, NH, RI, VT	1	0.58	0.87	1	0.82	0.91	71.1%	95.1%
Massachusetts	2	0.88	0.97	2	0.90	1.03	97.8%	93.4%
New York	3	0.51	0.82	3	0.73	0.92	69.9%	90.1%
New Jersey	4	0.80	0.94	4	0.81	1.01	98.9%	93.2%
Pennsylvania	5	0.68	0.91	5	0.70	0.94	97.8%	96.5%
Illinois	6	0.66	0.88	6	0.68	0.98	97.4%	89.1%
Indiana, Ohio	7	0.47	0.82	7	0.64	0.92	72.7%	89.4%
Michigan	8	0.70	0.91	8	0.78	0.94	90.1%	96.6%
Wisconsin	9	0.59	0.88	9	0.80	0.99	74.1%	89.0%
IA, MN, ND, SD	10	0.66	0.90	10	0.72	1.00	92.8%	89.4%
Kansas, Nebraska	11	0.59	0.86	11	0.66	0.91	89.7%	94.8%
Missouri	12	0.42	0.80	12	0.55	0.77	76.0%	104.6%
Virginia	13	0.64	0.89	13	0.65	0.92	98.4%	96.9%
DE, DC, MD	14	0.66	0.90	14	0.68	0.93	97.4%	97.0%
Georgia	15	0.98	0.99	15	0.56	0.86	176.3%	115.6%
NC, SC	16	0.59	0.90	16	0.62	0.93	95.8%	96.8%
Florida	17	0.72	0.82	17	0.64	0.84	112.8%	98.2%
AL, KY, MS	18	0.73	0.92	18	0.70	0.87	104.0%	104.7%
Tennessee	19	0.62	0.90	19	0.71	0.93	86.8%	96.8%
AR, LA, OK	20	0.60	0.85	20	0.63	0.85	95.6%	99.7%
Texas	21	0.49	0.78	21	0.56	0.83	87.8%	93.5%
Colorado	22	0.62	0.85	22	0.66	0.90	93.6%	94.7%
ID, MT, UT, WY	23	0.72	0.93	23	0.85	0.93	85.1%	99.2%
Arizona	24	0.55	0.83	24	0.63	0.82	87.7%	101.3%
NV, NM	25	0.54	0.83	25	0.69	0.86	77.4%	95.6%
California	26	0.89	0.95	26	0.86	1.05	103.1%	90.3%
OR, WA	27	0.76	0.92	27	0.84	0.96	90.3%	95.7%
Alaska	28	0.79	0.91	28	0.85	0.97	92.8%	94.4%
Haw aii	29	0.89	0.90	29	0.94	1.02	95.1%	88.6%
West Virginia	30	0.68	0.91	30	0.77	0.95	88.1%	96.1%
U.S. Avg	US	0.67	0.89	US	0.72	0.94	92.7%	94.6%

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A.5.3 Parametric I13

Parametric I13 uses NWGF condensing and non-condensing furnace shipment data provided to DOE by AHRI to revise the DOE 2022 forecast of Base Case condensing furnace shipment fraction. AHRI provided updated information in May 2015 regarding NWGF shipment data for the years 2010 through 2014. However, GTI analysts used only AHRI 2014 data to avoid concerns with possible perturbations caused by federal energy credits phased out in 2013 that may have influenced shipment numbers between 2010 and 2013. To create a 2022 forecast trend line that matched actual 2014 shipment data, GTI used 1998 to 2005 trending years. This combined approach resulted in a 2014 condensing furnace shipment fraction of 48%, which is slightly lower than the actual fraction of 48.5% reported by AHRI. Based on this trend line, Parametric I13 uses condensing furnace shipment fractions of 62.5% (National), 84.1% (North), and 38.6% (Rest of Country) for the 2022 baseline instead of DOE's 2022 furnaces shipment fractions of 53.1% (National), 73.7% (North), and 30.2% (Rest of Country).

DOE chose to use just 3 years (2012 to 2014) of shipment data in forecasting for years 2015 to 2050 in the SNOPR to avoid the market distortion associated with the 2005 tax credit, implemented in 2006 (http://energy.gov/savings/residential-energy-efficiency-tax-credit), that expired in 2011. This approach resulted in a flatter slope of annual change in forecasted condensing market share without the rule in DOE's LCC model compared to taking advantage of the entire available AHRI historical shipment data. GTI started the data trending using 1998 data to exclude the earlier time period when condensing furnace technology was less mature. Extrapolating the 1998 through 2005 trend line matches the 2014 AHRI data quite well. Each of these choices helped align the GTI 2022 forecasting trend line closely with the actual 2014 AHRI condensing furnace fractions and long term observed market dynamics. Figure 36 and Figure 37 compare the DOE SNOPR and GTI condensing furnace shipment forecast trend line. The GTI trend line shows a much higher market penetration of condensing furnaces without the DOE rule than the DOE LCC model. The GTI forecast trend line indicates a more robust free market for condensing furnaces without the rule in the future than the forecasts in the DOE LCC model.

A.5.4 Parametric I17

Parametric I17 replaced the 2015 EIA AEO forecasts and utility prices used in the DOE SNOPR LCC model with the current 2016 EIA AEO forecasts for energy price trends and updated gas and electric utility prices. Since DOE noted that it plans to use the AEO 2016 forecasts for the Clean Power Plan (AEO 2016 CPP) scenario in its final rule, Parametric I17 uses the same AEO 2016 CPP scenario.

A.5.5 Discount Rate Parametric Analysis (GTI NOPR Parametric I5)

This parametric updates the GTI NOPR Parametric I5 analysis to examine the effects of consumer discount rate on LCC savings. Discount rate is expected to have a significant effect on the LCC calculation of long lifetime equipment such as residential furnaces. In its analysis, DOE used the Federal Reserve Board's Survey of Consumer Finances (SCF) to estimate consumer opportunity cost of funds (TSD pg. 8-26). DOE used information in the SCF to determine equity and debt percentages of income groups which were then used to determine distributions of discount rates for each income group. (for a full description, see TSD pg. 8-30). DOE used distributions of discount rates based on income group. The weighted average of discount rates used in the DOE SNOPR LCC model is 4.3%.

DOE used all asset and debt classes to determine discount rates. In the NOPR, AHRI commented that debt was the only available instrument for the majority of consumers when purchasing a new furnace with a cost of $3,000 - $4,000, and DOE should be using a marginal rate rather than an average rate. In the SNOPR, DOE refuted the AHRI argument, saying that consumers have an ability to "re-balance their debt and asset holdings over the entire time period modeled in the LCC analysis." In this assertion, DOE selectively assigns consumers a sophisticated ability to manage their finances. This methodology is in contrast with their random Base Case AFUE assignment which implies that consumers have no ability to make any decision related to economics. DOE's methodology to assign discount rates based on long term rational portfolio re-balancing is an example of DOE's selective use of consumer economic decision making, and overstates the resulting LCC savings in the DOE SNOPR LCC model compared to higher discount rates without re-balancing.

DOE's assertion that consumers can re-balance debt and equity over long periods of time ignores critical short term consumer decisions. HVAC contractors expect to be paid at the time of installation. In cases with high debt load, especially for low income consumers but also higher income consumers with high debt, the furnace purchase will incur additional debt at a much higher interest rate than the DOE SNOPR LCC model discount rate. In addition, the inclusion of the mortgage interest debt type may not be reasonable in all cases. Mortgages may be a reasonable debt type to consider when a furnace is included in the price of a new home, but it may not be reasonable to include it when considering replacements. Credit card debt, especially for emergency replacements, is likely to be a more reasonable debt type for consumers already experiencing significant personal debt that cannot be easily re-balanced.

Table 40 shows the types of debt or equity by percentage for each income group. Mortgages represent a very significant portion of consumer debt – more than 24% for the top five income groups defined in Table 41. Mortgage debt is also a very low interest debt type. It becomes especially low interest when DOE considers the tax deductibility of mortage and home equity loan interest and inflation (TSD pg 8-28). DOE does not appear to account for the observation that the mortgage interest tax deduction is only available to taxpayers with more than the standard deduction for tax payers that itemize deductions. Many taxpayers in the lower income groups may not qualify for the itemized mortgage interest deduction if they have no other significant itemized deductions. In that regard, in testimony before the Committee on Ways and Means, Eric J. Toder submitted that 24% of tax units (married couples or singles) will benefit from the deduction, while 47% of those tax units pay home secured debt interest. (Eric J. Toder, Testimony before the Committee on Ways and Means April 25, 2013 http://www.taxpolicycenter.org/UploadedPDF/1001677-Toder-Ways-and-Means-MID.pdf). Toder's testimony indicates that 49% of mortgage holders do not qualify for the tax deduction. DOE's tax deductibility assumption reduces the effective discount rate, particularly for lower income households, and overstates the resulting LCC savings in the DOE SNOPR LCC model.

Table 40 DOE SNOPR Types of Household Debt and Equity

Table 8.2.26 Types of Household Debt and Equity by Percentage Shares (%)

Type of Debt or Equity	Income Group					
	1	2	3	4	5	6
Debt:						
Mortgage	18.9%	24.1%	33.1%	38.1%	39.3%	25.0%
Home equity loan	3.1%	3.3%	2.6%	3.6%	4.5%	7.2%
Credit card	15.3%	13.0%	11.8%	8.7%	6.0%	2.7%
Other installment loan	25.1%	20.6%	17.3%	13.2%	9.6%	4.7%
Other residential loan	0.7%	0.6%	0.6%	0.7%	1.0%	1.2%
Other line of credit	1.6%	1.5%	1.3%	1.5%	2.1%	1.8%
Equity:						
Savings account	18.5%	16.0%	12.7%	10.6%	10.4%	7.9%
Money market account	3.6%	4.5%	4.0%	4.5%	5.0%	8.6%
Certificate of deposit	7.0%	7.8%	5.5%	5.0%	4.4%	4.2%
Savings bond	1.8%	1.7%	1.9%	2.2%	1.7%	1.1%
Bonds	0.2%	0.4%	0.5%	0.7%	0.8%	3.8%
Stocks	2.3%	3.1%	4.4%	5.7%	7.6%	15.8%
Mutual funds	2.1%	3.5%	4.3%	5.7%	7.6%	15.9%
Total	100.0	100.0	100.0	100.0	100.0	100.0

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, 2010, 2013.

Table 41 DOE SNOPR Definition of Income Groups

Table 8.2.25 Definitions of Income Groups

Income Group	Percentile of Income
1	1st to 20th
2	21st to 40th
3	41st to 60th
4	61st to 80th
5	81st to 90th
6	91th to 99th

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, 2010, 2013.

Table 42 DOE SNOPR Effective Interest Rates by Income Group

Table 8.2.28 Average Real Effective Interest Rates for Household Debt

Type of Debt	Income Group					
	1	2	3	4	5	6
Mortgage	6.6%	6.2%	6.1%	5.2%	5.0%	4.0%
Home equity loan	7.0%	6.9%	6.7%	5.9%	5.7%	4.3%
Credit card	15.2%	15.0%	14.5%	14.2%	14.0%	14.5%
Other installment loan	10.8%	10.3%	9.9%	9.4%	8.7%	8.6%
Other residential loan	9.8%	10.2%	8.9%	8.2%	7.7%	7.4%
Other line of credit	9.1%	10.9%	9.6%	8.8%	7.4%	6.1%

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, 2010, and 2013.

As shown in Figure 34, the DOE SNOPR LCC model analysis used exceptionally low rates, currently at 50 year lows. Historically, rates have been much higher than the DOE SNOPR LCC model. Rates have been historically low due to recent Federal Reserve choices for quantitative easing policy coupled with very low inflation levels. There is very little expectation that rates will remain at 50 year lows for next several decades. The DOE SNOPR LCC model overstates resulting LCC savings compared to higher discount rates likely to prevail in the future.

DOE has not provided tabular data or spreadsheets containing each of their full distributions of consumer discount rates for each debt and asset class and for each income group. Without this information, discount rate parametric analysis such as removal of mortgages from consideration on replacement furnaces would require repeating the entire DOE discount rate analysis. Even if repeating the DOE discount rate analysis were feasible, the fundamental rationale for the DOE methodology is arguably flawed. Aggregating debt and equity together to determine a discount rate based on opportunity cost appears to ignore that the purchase of a furnace, particularly in the replacement market, is not likely well represented by an aggregate of all debt and equity for a particular consumer. A marginal rate that is specific to the financial instrument used to purchase the furnace would be a more defensible value. For example, a homeowner with a mortgage of $100,000 and savings of $1,000 that needs to purchase a new furnace which costs $3,000 will not experience the weighted average rate of 99% mortgage interest rate and 1% savings interest rate. They will more likely experience a rate represented by 1/3 savings and 2/3 credit card, yielding a rate closer to 12% than to 3%.

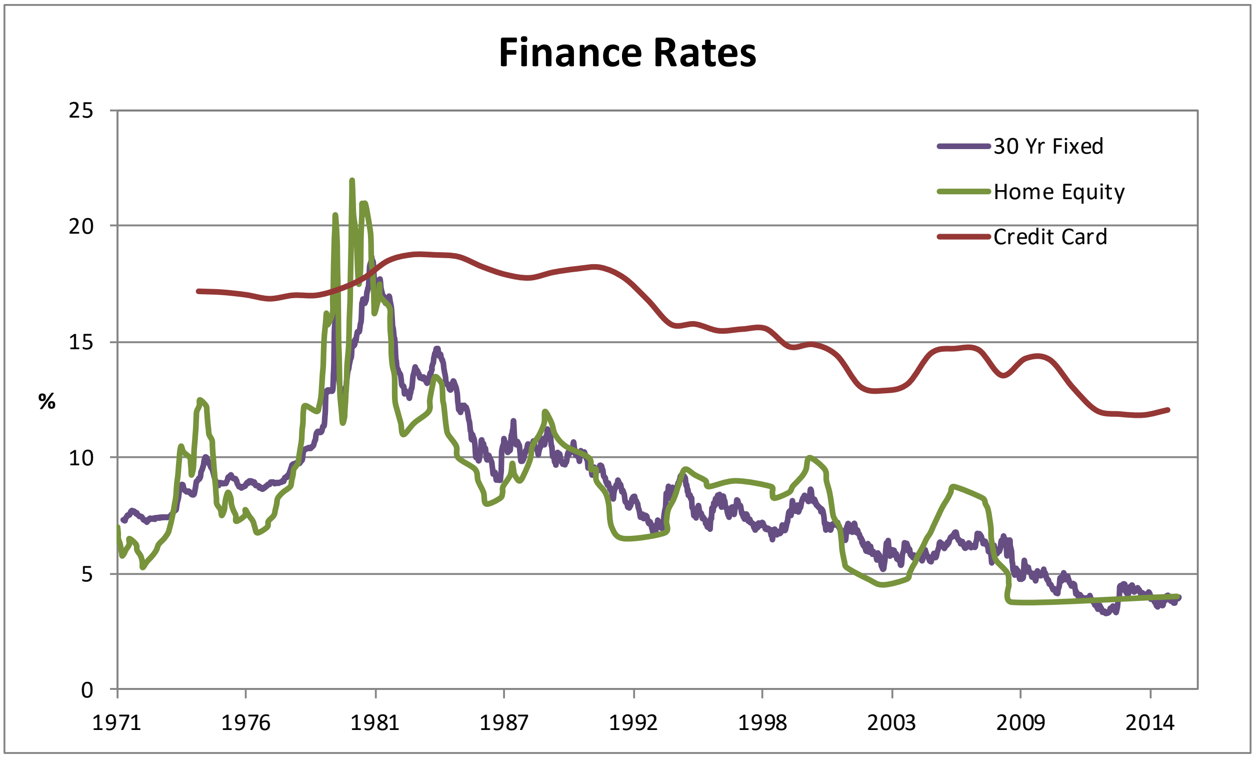

Figure 34: Finance Rate Trends – 1971 through 2015

Source: Freddie Mac, Federal Reserve

Sufficient time was not available within the 60-day comment period to modify the DOE model to account for much higher rates for each future replacement furnace. Instead, GTI analysts ran parametric analyses with varying discount rates using the same distributions as DOE but increased discount rates by 0.5% and 1% (i.e., a 5% rate is increased to 5.5% and 6%). A truncated normal distribution was also included with varying mean and a standard deviation of 5%. The normal distribution was truncated such that all of the distribution above 23% or below 0.5% were assigned a discount rate of 23% or 0.5% respectively. As shown in Figure 35, a truncated full normal distribution impacted the LCC savings significantly more than the DOE SNOPR LCC model limited distribution of discount rates. LCC savings decrease roughly linearly with increasing discount rate and drive LCC savings to zero at a discount rate below 18%, less than the rate charged by many credit cards.

Modified discount rates were also incorporated in GTI Scenarios Int-14 and Int-14.55 using a truncated normal distribution with means of 5 and 10% and a standard deviation of 5%. As shown in Table 43, either parametric substantially reduces the LCC savings under each scenario. When combined with other reasonable assumptions, the GTI parametric analysis of discount rates shows that the proposed rule will result in negative LCC savings.

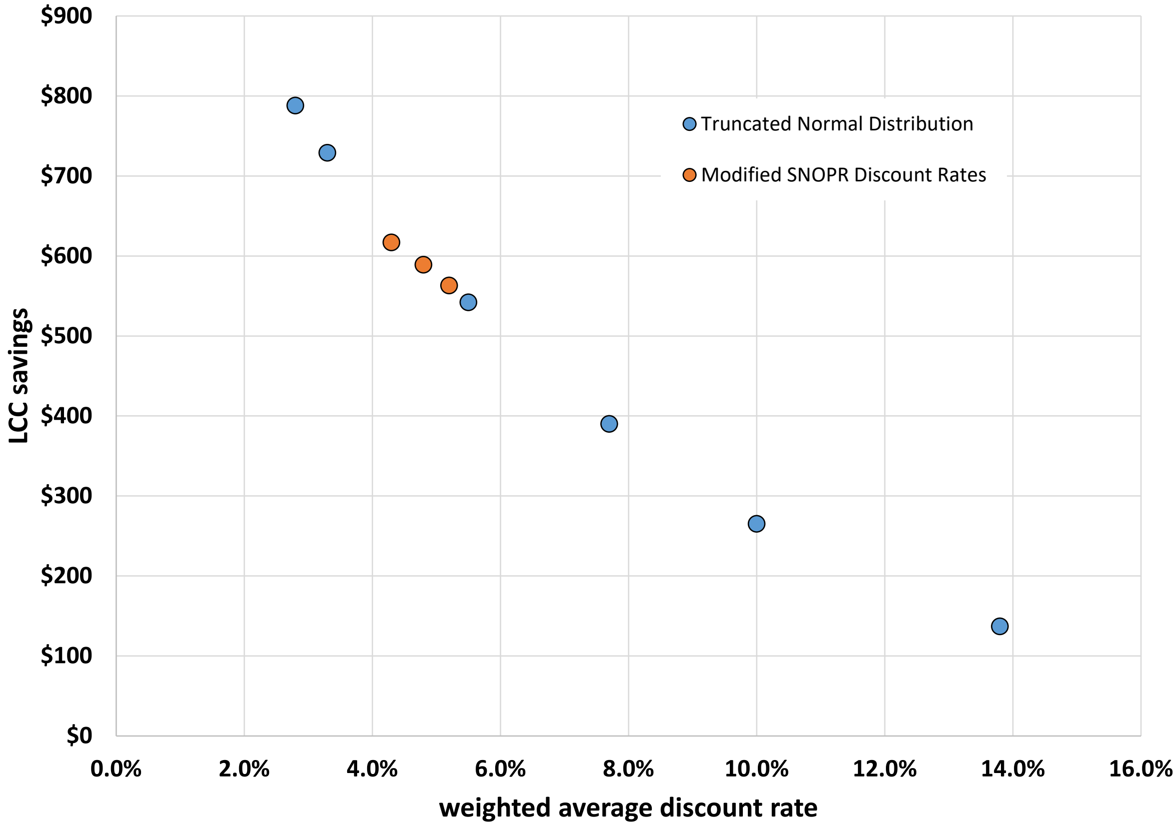

Figure 35: LCC Savings vs. Discount Rate with Truncated Full Normal Distribution

Table 43: LCC Savings – DOE SNOPR vs. GTI Incremental Discount Rate Scenarios

Scenario	weighted average discount rate	LCC savings, single standard	LCC savings, ≤55 kbtu/hr exempt
SNOPR Scenario 0	4.3%	$617	$692
SNOPR Scenario 0 with 0.5% increase in discount rate	4.8%	$589	$661
SNOPR Scenario 0 with 1.0% increase in discount rate	5.2%	$563	$633
SNOPR Scenario 0 with truncated normal distribution with mean 1% and stdev 5%	2.8%	$788	$858
SNOPR Scenario 0 with truncated normal distribution with mean 2% and stdev 5%	3.3%	$729	$799
SNOPR Scenario 0 with truncated normal distribution with mean 5% and stdev 5%	5.5%	$542	$609
SNOPR Scenario 0 with truncated normal distribution with mean 7.5% and stdev 5%	7.7%	$390	$452
SNOPR Scenario 0 with truncated normal distribution with mean 10% and stdev 5%	10.0%	$265	$319
SNOPR Scenario 0 with truncated normal distribution with mean 15% and stdev 5%	13.8%	$137	$187
GTI Scenario Int-14	4.3%	-$149	-$118
GTI Scenario Int-19 (Int-14 with I5 with discount rate mean 5% stdev 5%)	5.5%	-$194	-$176
GTI Scenario Int-19 (Int-14 with I5 with discount rate mean 10% stdev 5%)	10.0%	-$378	-$364
GTI Scenario Int-12	4.3%	-$179	-$157
GTI Scenario Int-20 (Int-12 with I5 with discount rate mean 5% stdev 5%)	5.5%	-$221	-$211
GTI Scenario Int-20 (Int-12 with I5 with discount rate mean 10% stdev 5%)	10.0%	-$391	-$381

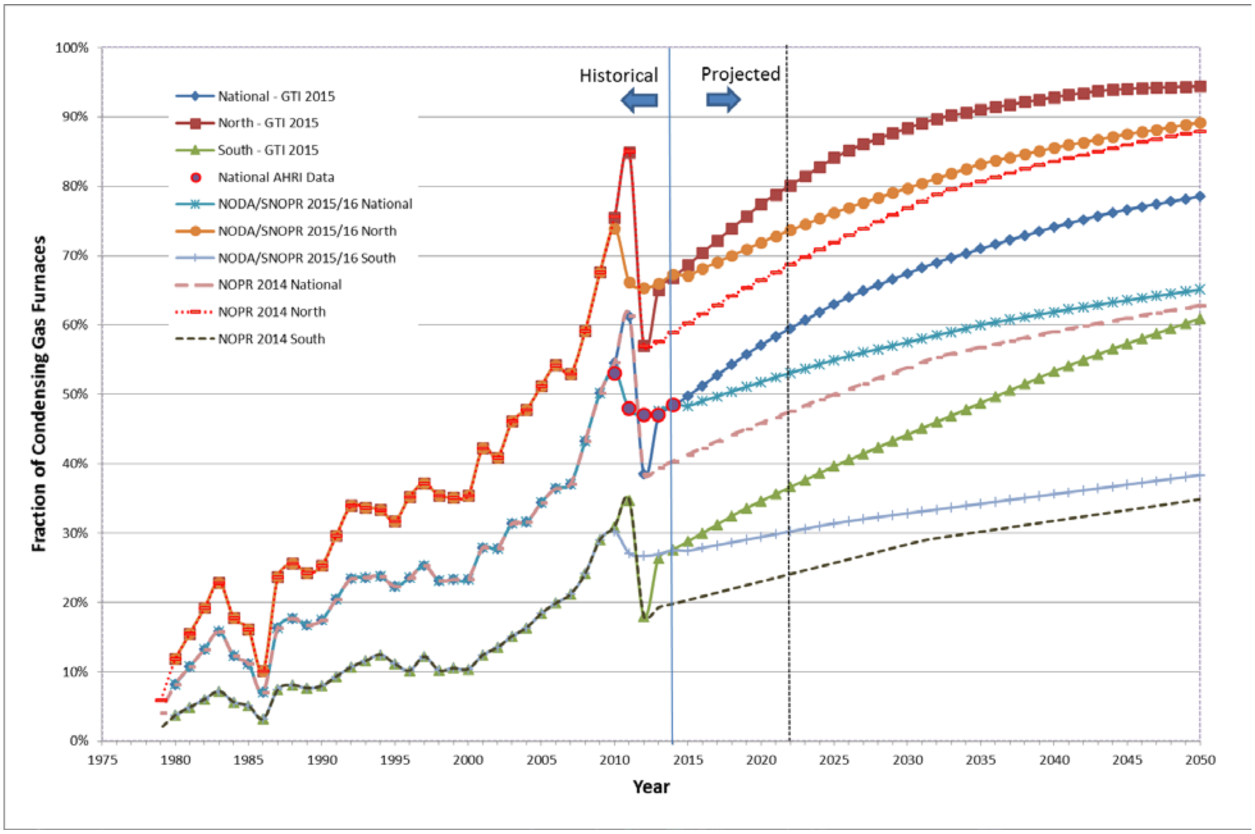

Figure 36 Condensing Furnace Trends – DOE SNOPR Model vs. GTI Parametric I13

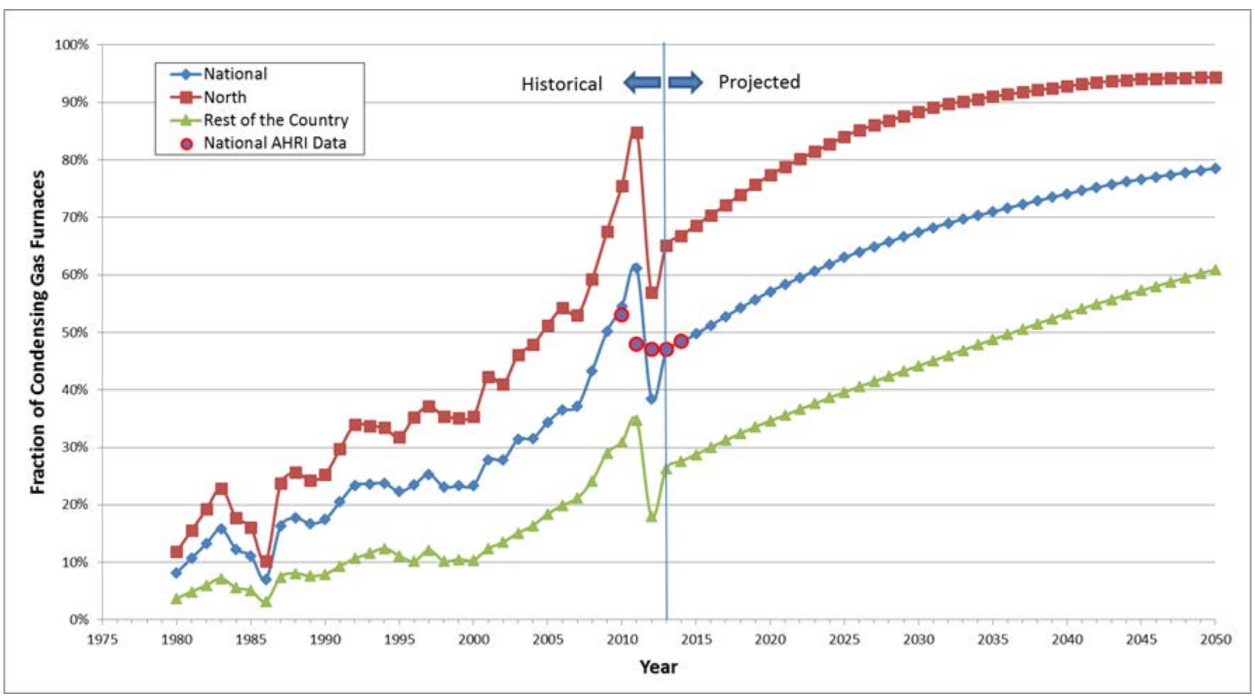

Figure 37 Historical and Projected Condensing Furnace Fractions – GTI Parametric I13

A.6 GTI Input Data and Furnace Sizing Scenarios

The parametrics in the preceding section were incorporated into scenario combinations according to the matrix shown in Table 11.

A.6.1 Scenario Combinations I-2, I-6, I-13, and I-17

Each of these scenario combinations contains the listed input parametrics as described in the previous section. All show reductions in LCC savings compared to the DOE SNOPR LCC Model. Compared to the decision making scenarios, impact on fuel switching is relatively small with the exception of GTI Scenario I-2 that examines retail furnace pricing.

A.6.2 Scenario F-1

GTI Sizing Scenario F-1 uses a furnace capacity algorithm for each of the 10,000 trial cases based on the RECS database annual heating consumption rather than home size. The GTI furnace sizing methodology provides the expected trend of increased LCC savings and reduced number of impacted homes as the 80% AFUE furnace capacity limit increases, whereas the DOE SNOPR methodology, based on building size, is insensitive to incremental changes in capacity limits due to the poor correlation between home size and required furnace capacity to meet the home heating load.

To better show the distribution of heating loads within the furnace size bins, Figure 38 and Figure 39 show the distribution of heating loads for a range of kBtu/h furnace size bins. The distributions overlap substantially, and all of the distributions contain a significant fraction of buildings with very low heating loads. These distributions clearly illustrate the disconnect between the DOE furnace sizing methodology and annual heating load.

A.6.3 Results Summaries for Input Data and Furnace Sizing Scenarios

Summary results for LCC savings, fuel switching, and energy use for the input variable scenarios are given in the spreadsheets accompanying this report.

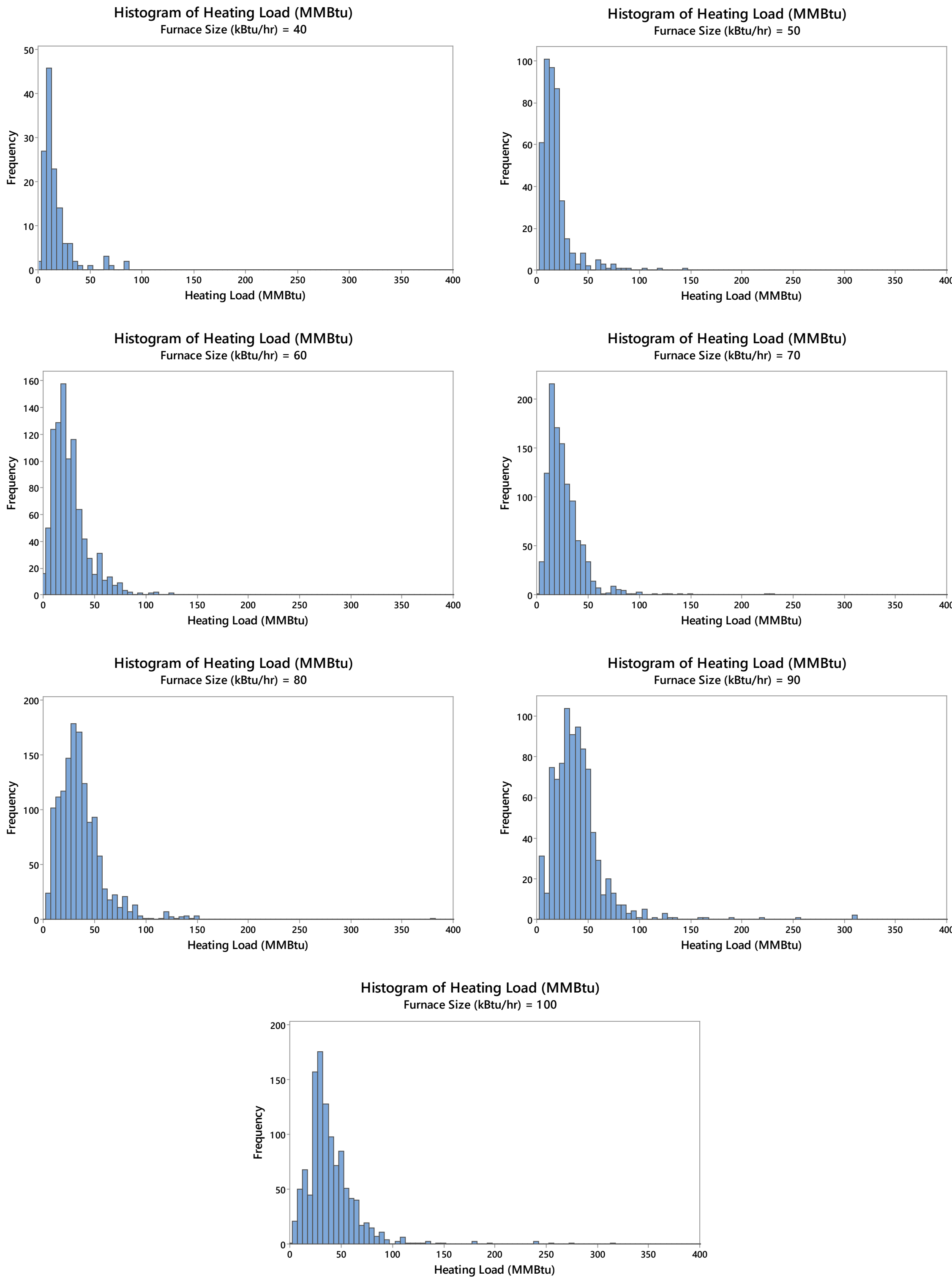

Figure 38: Heating Load Distribution for Selected Furnace Size Bins (40 to 100 kBtu/hr)

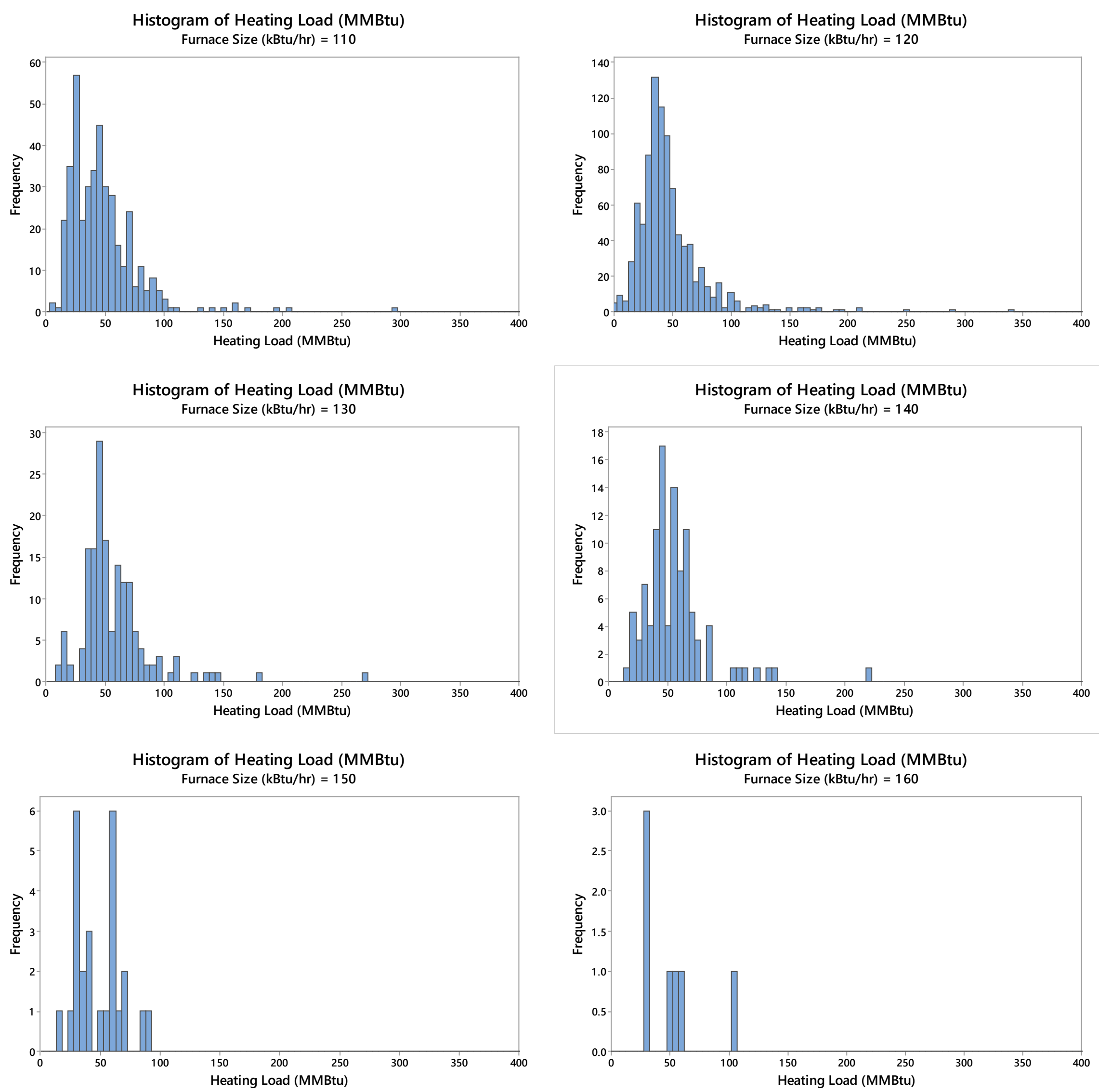

Figure 39: Heating Load Distribution for Selected Furnace Size Bins (110 to 160 kBtu/hr)

A.7 Integrated Scenarios

GTI analysts combined selected parametrics that comprise technically defensible decision making and input scenarios into integrated scenarios to examine the impact of these combinations. Table 11 shows the parametric matrix that defines these scenarios. All of the chosen integrated scenarios include parametrics that address Base Case AFUE selection (D4 with D5, or D14), remove fuel switching that would occur in the absence of a rule (D8), and modify switching paybacks (D2). In addition, all of the integrated scenarios include the modified condensing furnace shipment data in alignment with the AHRI data trend line (I13), AGA marginal rates (I6), and the updated AEO forecast (I17) inputs. Integrated scenarios also include modified retail prices found in the 2013 Furnace Price Guide (I2).

A.7.1 Scenarios Int-11 and Int-12

Scenarios Int-11 and Int-12 are updated versions of GTI NOPR Integrated Scenario Int-5, and use the GTI CED framework (Scenario 24) as the basis of the economic decisions. Int-11 uses AEO 2015 forecasts, while Int-12 uses AEO 2016 forecasts. Scenarios Int-11.55 and Int-12.55 include a second product class for 80% AFUE furnaces at or below 55 kBtu/h.

A.7.2 Scenarios Int-13 and Int-14

Scenarios Int-13 and Int-14 are also updated versions of GTI NOPR Integrated Scenario Int-5. However, these scenarios and use the GTI CED framework updated to incorporate non-economic decision factors (Parametric D14 instead of D4 and D5) as the basis of the economic decisions. Int-13 uses AEO 2015 forecasts, while Int-14 uses AEO 2016 forecasts. Scenarios Int-13.55 and Int-14.55 include a second product class for 80% AFUE furnaces at or below 55 kBtu/h.

A.7.3 Integrated Scenario Results

The summarized results for LCC savings, fuel switching, and energy use and greenhouse gases can be found in the spreadsheets accompanying this report.

A.8 Mobile Home Gas Furnaces

In the SNOPR (pg 65817) DOE asserts that, "*The payback periods for all MHGF AFUE TSLs meet the rebuttable-presumption criterion*." As noted in Section 4.5 of this report, that assertion is highly suspect since the DOE rebuttable presumption payback period was calculated incorrectly for this purpose.

As noted in TSD page 8J-1 footnote a, "*DOE did not analyze switching for mobile home gas furnaces (MHGFs) because the installation cost differential is small between condensing and non-condensing products, so the incentive for switching is insignificant.*" This assertion is misleading and incomplete. Installation cost differential is only one element of the consumer fuel switching decision criterion. The correct criterion is total installed cost differential, including both furnace price and installation cost. By failing to include this important fuel switching decision, the DOE SNOPR LCC model overstates LCC savings compared to a fuel switching impact analysis.

When possible, GTI made parametric modifications to mobile home gas furnaces. Unfortunately, there is no way to include a fuel switching option in the MHGF analysis without fully re-writing the DOE LCC model. The following discussion therefore focuses only on the changes in methodology and input data that show a significant reduction in LCC savings compared to the DOE SNOPR LCC analysis.

As shown in Table 44, LCC savings never goes negative in the case of MHGFs, but are reduced by nearly $600 when incorporating improved decision making and input data. DOE has decided that MHGFs are less likely than NWGFs to switch to electric options. This decision is disconnected from the marketplace in which owners of mobile homes tend to be on the lowest end of the income distribution and are even more motivated to save first cost expense than owners of NWGFs. The difficulty in changing from gas to electric options in mobile homes that DOE cites certainly does not apply to electric resistance heaters, including low-cost space heaters, that many of these consumers would switch to if they were unable to finance a replacement furnace, reducing rule benefits significantly.

Table 44: LCC Savings – DOE SNOPR vs. GTI Scenarios for MHGFs

Increment	GTI Decision and Input Parametrics and Scenario Changes Compared to DOE SNOPR TSL 5 (92% AFUE Minimum)	LCC Savings (TSL 5)
0	DOE SNOPR	$1,049
1	Change Increment 0 using annual fuel consumption based furnace sizing. (F1)	$1,043
2	Add to Increment 1 AHRI shipment data, AGA marginal natural gas prices. (I6, I13, F1)	$1,037
3	Change Increment 2 using AEO 2016 with CPP. (I6, I13, I17, F1)	$1,042
4	Remove from Increment 0 cases with negative payback period in Base Case AFUE assignment; use annual fuel consumption based furnace sizing. (F1, D5)	$794
5	Change Increment 3 to give consumers limited ability to make decisions based on economics, aligned with projected shipment fractions; replace payback period for Base Case AFUE assignment with a normal distribution with mean equal to the calculated payback period and standard deviation 50% of calculated payback period. (D14 w/SD 50%, I6, I13, I17, F1)	$465
6	Change Increment 3 to give consumers reasonable ability to make decisions based on economics, aligned with projected shipment fractions. (D4, D5, I6, I13, I17, F1)	$433

The DOE SNOPR LCC model analysis for MHGFs shows a 10%, 19%, and 22% average installed price increase for 92%, 95%, and 96% AFUE MHGFs respectively, as shown in Table 45. This installed cost difference is high enough that simple payback periods for 92% AFUE MHGFs are less than 3.5 years less than 20% of the time, as shown in Figure 40. This is the same “payback period” DOE defined for fuel switching decisions, which clearly indicates a high probability of rule-driven fuel switching in the mobile home market. Furthermore, mobile home owners typically have lower incomes than other single family home owners and are more likely to have lower payback period tolerance (i.e., <3.5 years), and are therefore at least as likely as the NWGF group to fuel switch, if not more so. Out of the 10,000 trials there are 432 low-income households in the NWGF sample and 1,410 low-income households in the MHGF sample for TSL 5. This finding strongly suggests that the DOE assertion that fuel switching for mobile homes can be safely ignored is wrong. However, because the DOE LCC Model was not constructed to allow mobile home fuel switching and would have required a substantial re-coding of the model to include, the analysis presented here is incomplete as it also does not consider fuel switching for mobile homes.

Table 45: MHGF LCC Analysis Summary Results – DOE SNOPR TSL 5

		Average LCC Results									Payback Results		
Level	Description	Installed Price	First Year Oper. Cost	Lifetime Oper. Cost*	LCC	LCC Savings	Simple LCC Savings	Net Cost	No Impact	Net Benefit	Simple PBP	Average	Median
0	MHGF 80%	$1,515	$785	$12,216	$13,731	NA	NA	NA	100%	NA			
1	MHGF 92%	$1,667	$698	$10,924	$12,591	$1,049	$1,140	8%	29%	63%	1.7	5.6	1.2
2	MHGF 95%	$1,800	$680	$10,643	$12,443	$1,020	$1,288	14%	15%	71%	2.7	8.5	3.5
3	MHGF 96%	$1,846	$677	$10,599	$12,445	$864	$1,286	25%	0.20%	75%	3.1	10.1	4.6

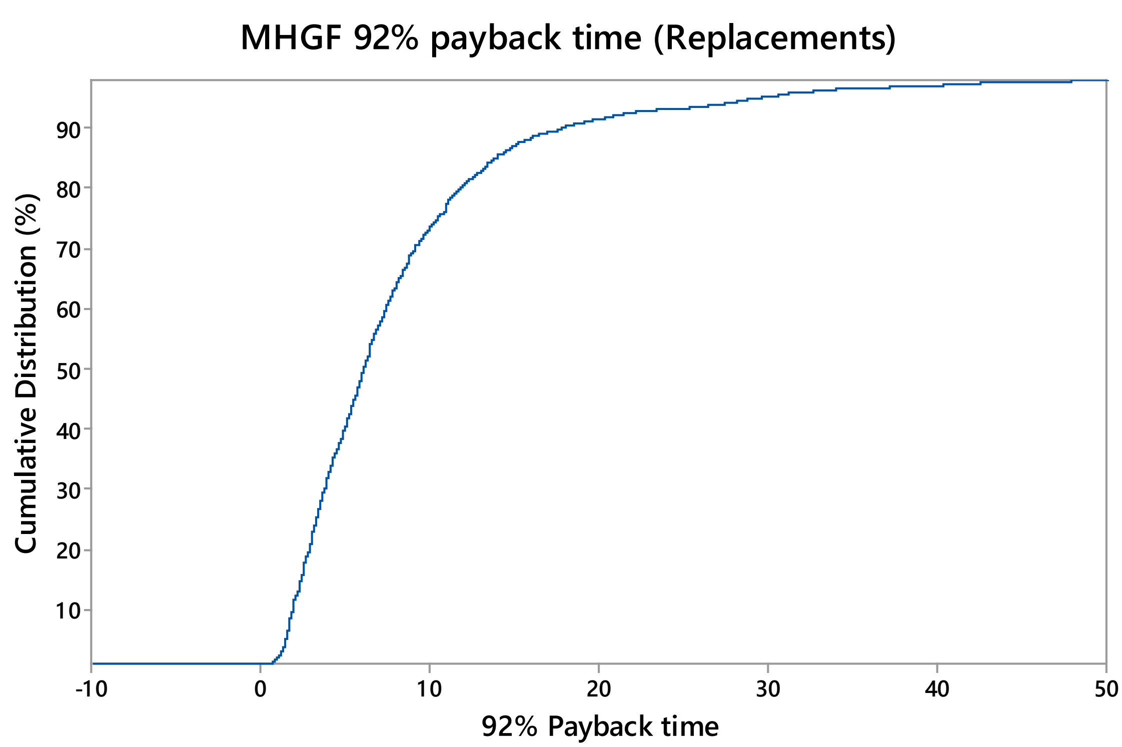

Figure 40 MHGF Payback Distribution – 92% AFUE

Several incremental scenarios for decision making that do not involve fuel switching were run for mobile homes, with results shown in Table 44 above. The scenario most closely aligned with GTI Integrated Scenario Int-14 is Increment 5, including Parametrics D14, I6, I13, I17, and F1. The scenario most closely aligned with GTI Integrated Scenario Int-12 is Increment 6, including Parametrics D4, D5, I6, I13, I17, and F1. However, since the DOE LCC model does not include an ability to examine the impact of fuel switching, Parametrics D2 and D8 could not be included in the GTI MHGF analysis. Table 46 compares the DOE SNOPR LCC model results with Increments 5 and 6. When CED is used for Base Case AFUE assignment, LCC Savings are substantially reduced at all TSLs. The percentage of "No Impact" cases also increases significantly, particularly at low TSLs. It is very likely that the addition of fuel switching Parametrics D2 and D8 to Increment 5 would show negative LCC savings as occurred in the NWGF case. As a minimum, DOE should have permitted this scenario to be examined.

Table 46 MHGF LCC Analysis Summary Results – DOE SNOPR vs. CED Framework

Simulation Results NATIONAL - 10000 samples		SNOPR MHGF Scenario 0			
Level	Description	LCC Savings	Net Cost	No Impact	Net Benefit
MHGF					
0	MHGF 80%			100%	
1	MHGF 92%	$1,049	8%	29%	63%
2	MHGF 95%	$1,020	14%	15%	71%
3	MHGF 96%	$864	25%	0%	75%

Simulation Results NATIONAL - 10000 samples		MHGF Increment 5			
Level	Description	LCC Savings	Net Cost	No Impact	Net Benefit
MHGF					
0	MHGF 80%			100%	
1	MHGF 92%	$465	10%	65%	25%
2	MHGF 95%	$989	13%	20%	67%
3	MHGF 96%	$1,061	18%	6%	76%

Simulation Results NATIONAL - 10000 samples		MHGF Increment 6			
Level	Description	LCC Savings	Net Cost	No Impact	Net Benefit
MHGF					
0	MHGF 80%			100%	
1	MHGF 92%	$433	11%	62%	28%
2	MHGF 95%	$954	14%	14%	72%
3	MHGF 96%	$1,050	18%	1%	81%

Similar to NWGFs, DOE's random assignment methodology caused 3236 trials to be considered impacted by the rule when the payback period was negative. This accounts for 32% of total trials and 58% of the total LCC savings attributed to mobile homes. The bulk of these, 3200 trials, come from new installations. Again, as in the NWGF case, builders of mobile homes will not, in any meaningful numbers, spend more money to buy a lower efficiency product that does not help them sell homes.

As shown in Figure 41, DOE reports market penetration for replacement furnaces that is correlated with DOE's expected market share. However, in the case of mobile homes DOE does not project high rates of market adoption in either the replacement market or new construction. DOE does not project condensing furnace market share above 48% for either new or replacement MHGFs even though their own results show that 63% of the new MHGF have negative payback periods. Either DOE has miscalculated costs or expected market share, or both.

As shown in Figure 42, the DOE SNOPR MHGF furnace sizing uses the same home size-based methodology as in the NWGF analysis, and produces a similar lack of correlation to heating load. Using the same methodology as in the NWGF, GTI replaced this methodology with parametric F1, with similar resulting improved correlation with heating load as shown in Figure 43.

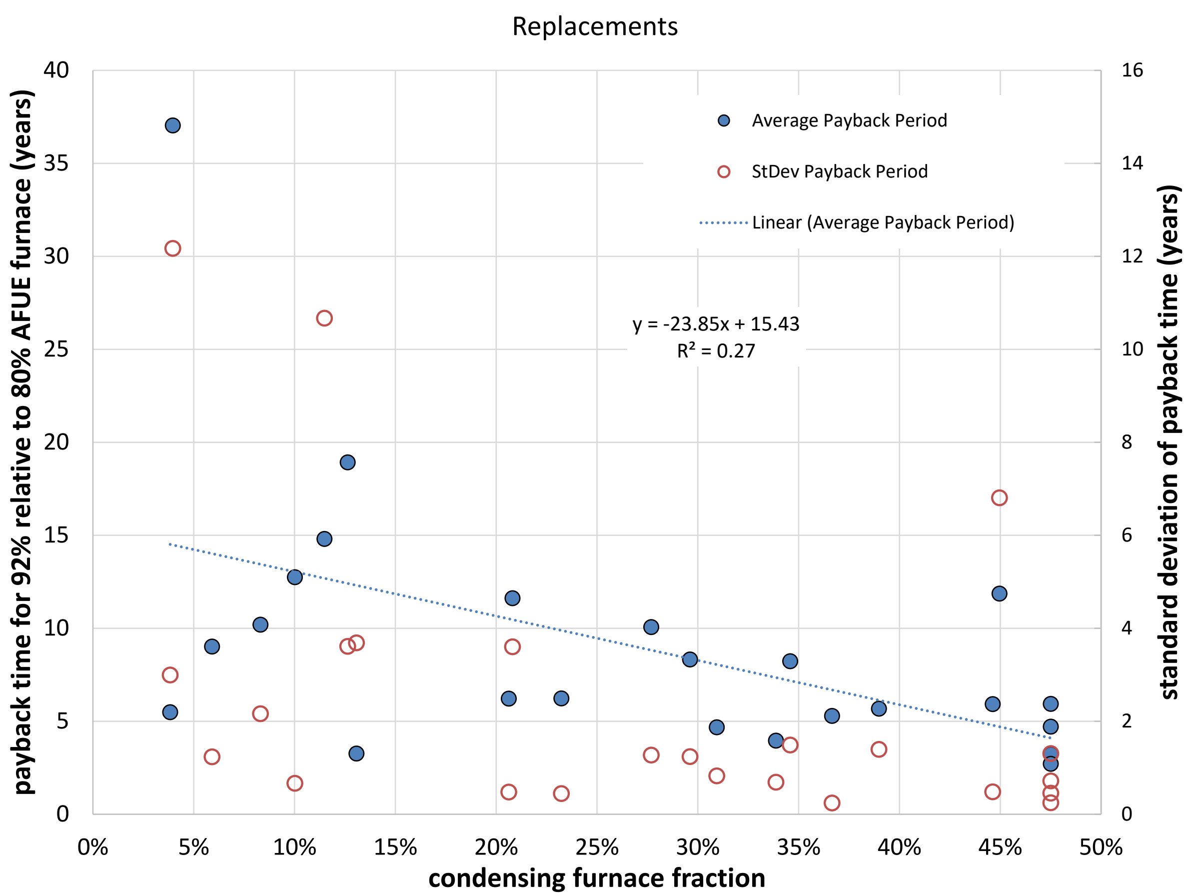

Figure 41: DOE SNOPR LCC Market Penetration for Replacement MHGFs

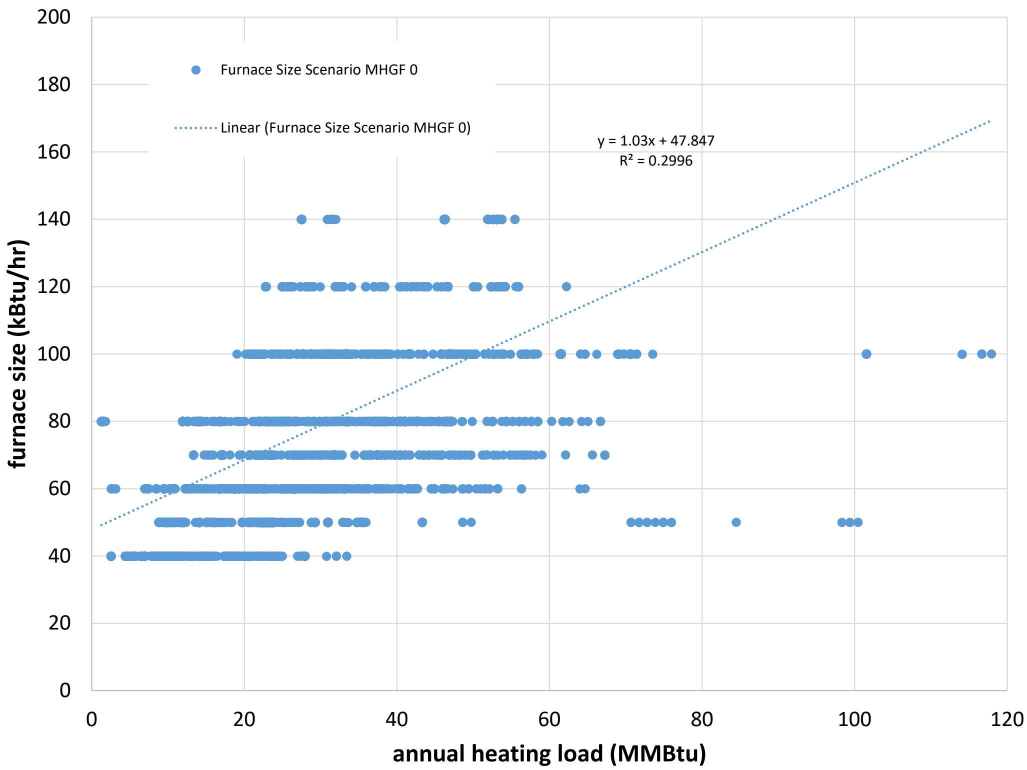

Figure 42: Furnace Size vs. MHGF Annual Heating Load – DOE SNOPR Methodology

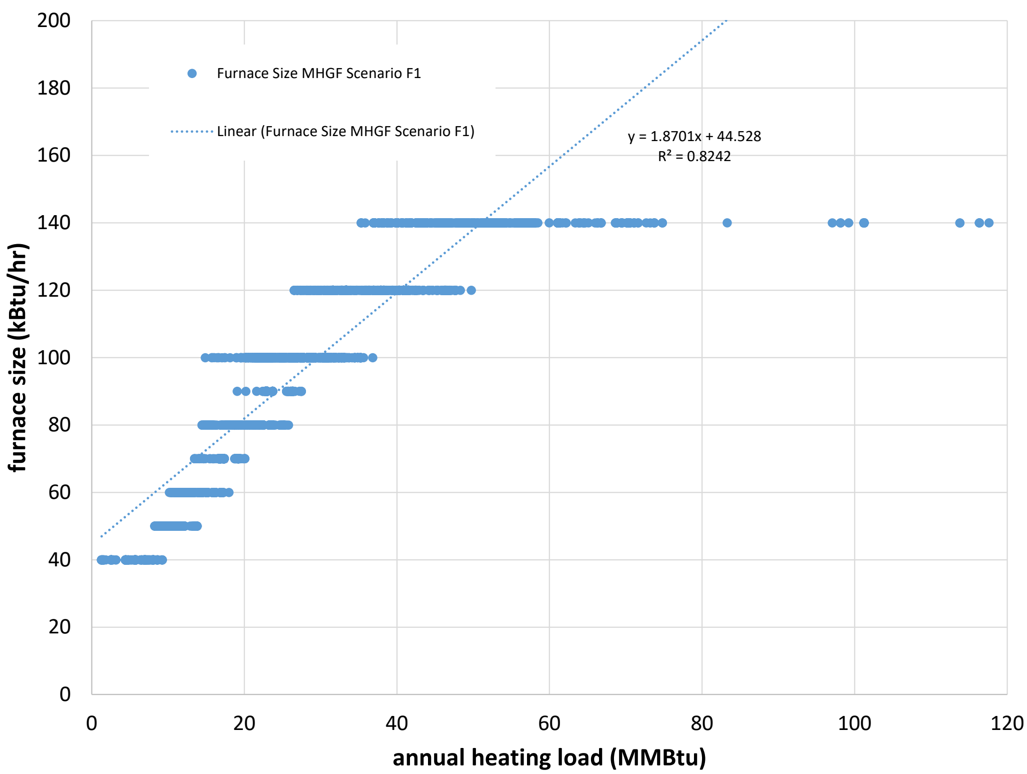

Figure 43: Furnace Size vs. MHGF Annual Heating Load – Consumption Methodology