Energy Trust of Oregon 2018 Windows Market Research Report

Submitted by Apex Analytics, LLC
September 28, 2018

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1. Executive Summary

Energy Trust of Oregon (Energy Trust) has offered incentives to residential homeowners to install higher efficiency windows since 2003. Energy Trust contracted with Apex Analytics (Apex) to conduct market research on the residential windows to obtain more information on the availability and cost/pricing of efficient windows that are currently on the market. This information will help Energy Trust consider changes to program incentive levels, efficiency levels, and program delivery. The overall goals of the research were to:

- Determine the key manufacturers serving the Oregon market.
- Estimate the current and mid-term projections (five-year forecast) for the size and efficiency shares of the windows market in Oregon.
- Assess the incremental cost of energy efficient windows, including the incremental cost at different efficiency levels and what drives these costs.
- Determine how a midstream or upstream program could most effectively increase the adoption of energy efficient windows.

To accomplish the goals for this market research report, Apex conducted three primary tasks:

- Collected secondary research on the windows market and windows energy efficiency programs.
- Designed and ran a hedonic price model, based on almost 2,000 window products harvested from online windows retailers, to determine incremental costs by increased efficiency (U-value) for residential windows.
- Administered a total of eight in-depth interviews with windows manufacturers, glass manufacturers, retailers, and market experts.

Apex grouped key findings and conclusions from the market research into one of six categories: Market Landscape, Supply Chain, Market Share, Incremental Cost, Technology, and Program Design. Apex's conclusions are summarized below.

Market Landscape

Market share by manufacturer is not readily available. None of the window and glass manufacturer interviewees were able to provide estimates for manufacturer

market share and believed the subscription or pay-for reports make speculative approximations of manufacturer shares. In addition, program tracking only included manufacturer for approximately one-third of the rebates. The interviewees, however, were in agreement that the major window manufacturers for Oregon were Anderson, Marvin, Milgard, and Jeld-Wen, followed by secondary manufacturers including Pella, Ply-Gem, and Sierra Pacific.

Approximately 650,000 residential windows are sold in Oregon each year, split approximately evenly between the new construction and replacemment/retrofit market. The estimated range of sales was fairly wide (500,000 to 800,000 windows per year) and was reported to vary based on the economy and new housing starts.

Supply Chain

The residential windows supply chain is undergoing minor changes, but significant transformation is unlikely in the near term. Residential window supply has transitioned to primarily a two-step process (from manufacturer to dealer, from dealer to buyer), though some window suppliers still provide a significant share to production builders and directly to homeowners through single-step channels. Market consolidation has increased through mergers and acquisitions, which some manufacturers believe will help lower pricing due to increased production volumes and economies of scale. Supply disruption via online retailers (e.g., Amazon) was considered unlikely because of the customization and measurement required for residential windows.

Market Share

Efficient windows (below 0.30 U-value) had approximately 66% market share in 2017, forecasted to go up to 72% market share in 2022. Higher-tiered (i.e. more) efficient windows (0.27 U-value and below) had 15% market share in 2017, forecasted to go up to 32% in 2022 (Table 1). The key factors that drive shares of efficient windows are: incentives, local building codes, the ENERGY STAR specification, and new technology.

Table 1. Windows Market Share by U-Value Bins.

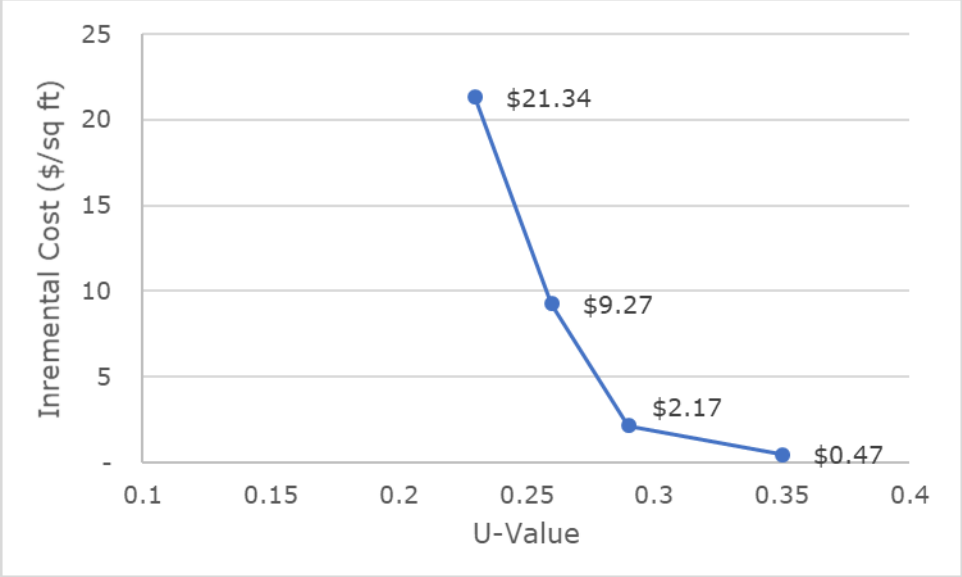
U-Value Tier	2017 Market Share	Estimated 2022 Market Share
> 0.35	4%	4%
0.31 to 0.35	30%	24%
0.28 to 0.30	51%	40%
0.25 to 0.27	11%	24%
0.20 to 0.24	3%	6%
< 0.20	1%	2%
Total	**100%**	**100%**

Source: 2014 Delphi Study and current study interviews

Incremental Cost

The incremental cost of moving from an average inefficient window (0.33 U-value) to a higher-efficiency window (0.28 U-value), purchased from large home improvement retailers, is approximately $1.45 per square foot and increases sharply for windows below 0.27 U-value. The model results showed the non-linear nature of windows pricing, with the price of 0.25 to 0.27 U-value windows approximatley four times the price of 0.28 to 0.30 U-value windows, and tri-pane windows below 0.25 U-value costing approximately ten times more (Figure 1).

Figure 1. Increasing Incremental Cost by U-Value Bins.



The nature of the window production process is the primary driver for increased incremental costs. Window production is very labor intensive, and production of higher-efficiency windows increases the degree of manual input to the process. The fabrication process requires increasing demands from manufacturer staff, coupled with the additional expense of another pane of glass (for tri-pane windows), additional (and more expensive) gas fill, spacers, and materials in general.

Technology

There are several promising on-the-market window technologies and one theoretical product that could offer significant transformation of the windows market. Existing technologies includes dynamic glass (whose savings come primarily from summer cooling) and window automation (automated opening/closing and advanced shading/blinds, again savings primarily from summer cooling). One of the most promising new technologies is called "thin-triple" windows, and involves an ultra-thin glass insert coupled with krypton gas fill that could be integrated within existing windows fabrication processes (obviating the need for frame and sash redesign). Identifying upstream manufacturing partners and downstream utility and government support to develop this technology will be crucial for its success. Other technologies reviewed in our research offer increased efficiency, but they suffer drawbacks or limitations that have prevented significant market penetration and are unlikely to gain traction in the near term.

Program Design

The Energy Trust windows program aligns well with most other Northern ENERGY STAR tier programs. Apex identified 22 other windows programs offering incentives across 32 states—all downstream programs—and Energy Trust incentives were in the mid-range of incentives offered by other program administrators for the 0.28 to 0.30 U-value windows. Energy Trust was one of only several programs that offered tiered incentives, with considerably higher incentive levels for the higher-efficiency windows products.

Downstream incentives were the most preferred program design approach. Every market actor believed that direct-to-consumer rebates are the most effective means of providing support for increasing consumer demand for high-efficiency windows. There was one interviewee who believed that an upstream approach could drive the market for super high-efficiency "thin-triple" glass, particularly since the incremental cost analysis found considerably higher per-square-foot cost of a conventional tri-pane window relative to the assumed cost of providing ultra-thin tri-pane insulated glass units.

Recommendations from the research include:

- *Collect manufacturer name as part of the rebate application.* This would help characterize the market shares—at least through the program—by manufacturer, allowing for more strategic targeting of manufacturers that aren't selling as many rebated products.

- *Adopt the incremental cost findings for planning and other program design assumptions.* Consider the incremental cost if coordinating with window manufacturers to provide upstream incentives.

- *Consider pursuing tri-pane ultra-thin inserts as an upstream program offering with LBNL, willing windows manufacturers, and other partners.* The manufacturers most receptive to this technology included Alpen and Anderson windows. Other interested parties in this effort include the state of California, Canada, and NEEA. Energy Trust should be sure to investigate the concerns related to krypton (losses and pricing) and window frame and sash upgrades, as these were valid concerns.

MEMO

Date: December 31, 2018
To: Board of Directors
From: Mark Wyman, Senior Program Manager
Phil Degens, Evaluation Project Manager
Subject: Staff Response to the 2018 Residential Windows Market Research Report

Energy Trust conducted market research on the availability and cost/pricing of residential efficient windows to help Energy Trust consider changes to program incentive levels, efficiency levels, and program delivery. The research confirmed that few technological advances in residential windows have been made in the last few years or are anticipated in the near future. The research did confirm that Energy Trust's tiered window incentive was appropriate. The research did report higher estimated incremental costs for the more efficient tier of windows. This will lead Energy Trust to do a comprehensive review of incremental costs when the current window measure is renewed.

The discussion of the thin triple pane window technology in the report has already led to a few actions. The Northwest Energy Efficiency Alliance (NEEA) has contracted with Steven Selkowitz to consult on a potential market transformation project involving the thin triple pane window. Energy Trust has also met with Dr. Selkowitz and NEEA to discuss how we might accelerate this technology in the region. There are a few pilots currently underway in California that NEEA and Energy Trust might be able to leverage to start introducing this technology to Oregon in 2019.

2. Introduction and Background

Energy Trust of Oregon (Energy Trust) is an independent nonprofit organization dedicated to helping utility customers benefit from saving energy and generating renewable power. One of Energy Trust's residential offerings provides incentives to single-family residential customers for installing high-efficiency (U-value) windows. Energy Trust has offered incentives for residential windows since 2003. Currently, Energy Trust has two tiers of incentives for residential ENERGY STAR© qualifying windows: windows that only are minimally better than code (0.28 U-value to 0.30 U-value) are offered a $1.75 per-square-foot incentive, while windows that have a U-value of 0.27 or better receive an incentive of $4.00 per square foot. The tiered incentives are designed to push the market to the higher-efficiency windows.

In 2017, Energy Trust contracted with Apex Analytics (Apex) to conduct market research on the residential windows, with the goal of obtaining more information on the availability and pricing of efficient windows that are currently on the market. This information will help Energy Trust gain additional insight into the current windows market. The goal of this research is to help Energy Trust consider changes to program incentive levels, efficiency levels, and program delivery.

In 2014, Apex conducted a study for Energy Trust that assembled a group of windows experts in a Delphi Panel to assess market share of windows by efficiency level, program influence on the market share, incremental cost of windows by efficiency level, and intervention strategies that might spur more widespread adoption of efficient windows. Many of the objectives of the current study overlap with the prior Delphi study, and findings from that study are referenced in this report.

3. Research Objectives

Energy Trust has been interested in establishing a market-transformation model for the residential windows market for several years, with the long-term goal of transforming the windows market by moving consumers toward higher-efficiency windows as the standard. The objective of this study is to characterize the local windows market, gain additional understanding about recent and anticipated changes to the windows market, and determine how Energy Trust can most effectively support the efficient windows market going forward.

Some of the key questions that Energy Trust sought as part of this market research report include the following:

Market Landscape

- Who are the key manufacturers serving the Oregon market?
- What is the Oregon residential windows market share by manufacturer?
- What is the size of the Oregon residential windows market, and how many windows are sold for existing homes (replace and remodel) versus new construction?

Supply Chain

- How do windows move through the supply chain from manufacturer to consumer?

Efficient Market Shares

- What are the estimated current and mid-term projections (five-year forecast) for the efficient windows market share in Oregon?
- What is the market share by efficiency level?
- What are the primary drivers behind market share changes (both past and anticipated)?

Incremental Cost

- What is the incremental cost of energy efficient windows?
- How does the incremental cost vary at different efficiency levels (i.e. does the cost increase linearly with the efficiency of the window, or are there break points where the cost increases more steeply due to factors such as manufacturing or production requirements)?
- What are they primary drivers of these costs?

Technology

- What technologies are most likely to gain significant market share over the next five years?

Program Design

- How can a midstream or upstream program most effectively increase the adoption of energy efficient windows?
- Should a midstream/upstream program offer incentives to manufacturers, distributors, contractors/installers, or some combination of market actors?
- What is the optimal incentive level and form? Can incentives be used to drive down manufacturing costs, decrease market barriers, and help production reach economies of scale?

4. Methods

Apex relied on several different sources and methods to address the key research questions, including:

- Compiling secondary research from publicly available sources.
- Designing and running a hedonic price model.
- Identifying, recruiting, and interviewing key windows market actors.

In addition to these data collection efforts, Apex also leveraged the previous 2014 Delphi study that contained a number of similar research questions and objectives as this study. The following table (
Table 2) summarizes the research source used for each of the primary objectives, while the following sections give a more detailed discussion of the methodology used for data collection and analysis of the primary components.

Table 2. Summary of Windows Research.

Source	Secondary Research	Hedonic Price Model	In-depth Interviews
Market Landscape	✓		✓
Supply Chain			✓
Efficiency Market Shares	✓		✓
Incremental Cost	✓	✓	✓
Technology	✓		✓
Program Design	✓		✓

4.1 Secondary Research

Apex gathered and reviewed publicly available existing reports and identified subscription-based resources on the residential windows market structure, trends, sales volumes, and pricing. This secondary research also investigated other program administrators program design, and regional incremental cost assumptions used in other jurisdictions. The secondary research scope was focused predominantly on Northern Tier windows to ensure comparable efficiency

requirements (e.g., U-value and solar heat gain levels) were reviewed. Apex also researched the cost and value of proprietary research reports, including reports published by the American Architectural Manufacturers Association (AAMA) and Freedonia, but ultimately the cost was too high relative to the value of information and therefore outside the budget for this project.[1]

As part of the secondary research, the Apex team identified key pieces of information for this study from the following sources:

Table 3. Summary of Windows Secondary Research.

Source	Market Landscape	Incremental Costs	Other Programs
Efficientwindows.org			✓
Retailer websites		✓	
NAHB.com	✓		
Residential Energy Consumption Study[1]	✓		
Apex Delphi Report[2]	✓	✓	

[1] Energy Information Agency, Department of Energy

[2] Apex Analytics, Energy Trust of Oregon Windows Delphi Study

4.2 Hedonic Price Model

Hedonic price modeling is a statistical technique used to estimate pricing associated with individual product characteristics. By using a sufficiently large product dataset containing a variety of products and their different attributes, a hedonic price regression model can estimate the price associated with different attributes (provided the model can explain changes to pricing with the product attributes in the model and coefficients of the model are statistically significant). Apex collected price and characteristics data on all windows available for sale from online retailer websites. The Apex team identified three large home improvement retailers with presence in Oregon and large enough selection for web harvesting. The scraped data were normalized to dimensions (per square foot), while certain window types

[1] A summary of paid subscription or data service provider secondary publications is included in Appendix E: Listing of Publications and Report Subscription Services. Also, Apex received interview feedback that the data may be speculative and unreliable.

(skylights, storm windows, patio doors) were automatically excluded from the hedonic model but included in the dataset provided to Energy Trust as part of this effort.

Hedonic price modeling results were further corroborated with data from publicly available reports gathered from secondary research and from interviews with windows and glass manufacturers. As can be seen in Table 4 below, two of the retailers' web harvest data had sufficient record count and variability to be included in the price modeling, though the third retailer dataset lacked both and was therefore excluded from the analysis.

Table 4. Summary of Windows Web Harvest Results.

Retailer	Retailer 1	Retailer 2	Retailer 3
Total Raw Records	5,261	7,399	1,232
Included Window Type	5,261	6,098	151
Valid Price Data	5,241	6,955	276
Valid U-Value	4,187	6,894	277
Valid Dimensions	4,635	7,376	107
Limited to Window and Frame Types of Interest (excludes skylights, doors, storm windows, and other window types)	1,421	1,904	107
Limited to Double-Hung, Single-Hung, and Sliding Vinyl and Wood Windows (most common)	1,120	739	22
Outliers Excluded	135	120	0
Sufficient for Inclusion	Yes	Yes	No
Final Analysis Dataset	**985**	**619**	**0**

Source: Web harvest data

The Apex team cleaned, standardized, and transformed the web harvest data. Cleaning and standardizing the data involved creating a consistent naming convention for characteristics and column names. Transforming the data involved assigning binary or dummy variables to the windows attributes selected for the final

model (reviewed in the findings section below). Outlier analysis involved identifying and removing records that showed the top or bottom 1% of price per square foot and U-values that were outside of reasonable ranges.

The Apex team then designed a hedonic pricing econometric model (multivariate regression) to estimate the incremental costs of changes in U-value based on the web harvest data. The equation representing the hedonic pricing model is shown in Equation 1 below.

Equation 1. Hedonic Pricing Model Example.

$$\frac{Price}{Sq\ Ft} = \alpha + \beta_1 X + \beta_2 Y + \ldots + \beta_n Z$$

Where:

- Price/Sq Ft = price of window on a square foot basis
- α = constant, or model intercept
- $\boldsymbol{\beta}_1$-$\boldsymbol{\beta}_n$ = coefficients, representing value for each window feature/attribute
- X, Y, Z = individual window feature/attribute deemed significant for model

The Apex team analyzed the correlation between windows characteristics variables. The goal of the correlation analysis was to identify which variables should be omitted because of collinearity.[2] The Apex team also reviewed several different iterations of the model to understand incremental cost differences based on a universal group of windows relative to a more limited group of most commonly purchased window products. The findings from the various models is presented in the findings section below.

4.3 Market Actor Interviews

Apex conducted eight interviews with key Pacific Northwest windows market actors, including window and glass manufacturers, retailers, and market experts. The interviews utilized the market share and incremental cost estimates from the prior windows Delphi study and the results of the hedonic pricing model from this study as baseline estimates, asking respondents to report changes since 2015 and their expectations for the next five years. The key areas of interest the Apex team explored during the interviews included:

[2] Collinearity in a regression model will result in unbiased estimates but reduced significance of the coefficients.

Market Landscape. Understanding the overall market landscape, serving the pacific northwest market, including:

- major windows manufacturers
- new construction versus replace and remodel sales
- total size of the residential windows market
- how this market has evolved over the past several years

Efficient Market Share. Determining the percentage of windows sales that are represented by efficient windows

Incremental Cost. Determining the incremental retail cost of increasing U-value efficiency in residential windows

Supply Chain and Market Structure. Understanding how windows products flow through the market, from manufacturer to consumer

New Technology. Determining what technologies have potential to transform the windows market

Program Design. Developing an awareness of effective program designs and what tends to work best (e.g., downstream, midstream, or upstream rebates), along with optimal incentive levels

Apex drafted and distributed a recruitment email (see

Appendix A: Recruitment Email) to solicit potential interview participants, including both a mix of previous Delphi study participants, as well as new window and glass manufacturers. Table 5 shows the sample disposition. While the Apex team had an initial goal of at least ten interviews, we were only able to complete eight, despite multiple email and phone outreach attempts. There were two potential interviewees who rejected participation, whereas the remainder did not reply to email nor return phone requests. However, as shown in Table 5, the respondents did include a mix of market actors such as retailers, manufacturers, and industry experts.

Table 5. Windows Actor Interview Disposition.

Market Actor Type	Market Actor Sample Size	Successful Interview
Window Manufacturer	8	5
Glass Manufacturer	3	1
Retailer	3	1
Other/Expert	4	1
Total	**18**	**8**

5. Findings

Findings from the secondary research, hedonic price modeling, and market actor interviews are presented in the following sections. The findings are structured to follow the primary research objectives, which allows the insight from various sources to be compared and synthesized. The key areas reviewed in the Findings section include:

- Market Landscape
- Supply Chain
- Current and Projected Market Share
- Incremental Cost
- New Technology
- Program Design

5.1 Market Landscape

The market landscape review assesses the primary manufacturers serving the Oregon and Pacific Northwest market, as well as the size of the windows market by market event (e.g., existing replacement versus new construction).

5.1.1 Major Manufacturers and Their Market Share

One of the objectives of this research was to identify the primary windows manufacturers that serve the Oregon or Pacific Northwest residential market. This information can help Energy Trust target the market actors that have the most potential to deliver significant savings in the residential windows market. Based on previous discussions with Energy Trust staff and *Windows and Door Magazine* publications,[3] the Apex team identified four major windows manufacturers serving the Pacific Northwest residential market (Figure 2)—Anderson, Marvin, Milgard, and Jeld-Wen—and all the window and glass manufacturer interviewees were in agreement regarding these major manufacturers.

[3] Windows and Door Magazine Top 100 Windows Manufacturers Report, 2018. https://windowanddoor.com/article/may-2018/top-100-manufacturers-2018-report

Figure 2. Major Windows Manufacturers Serving Pacific Northwest Residential Market.

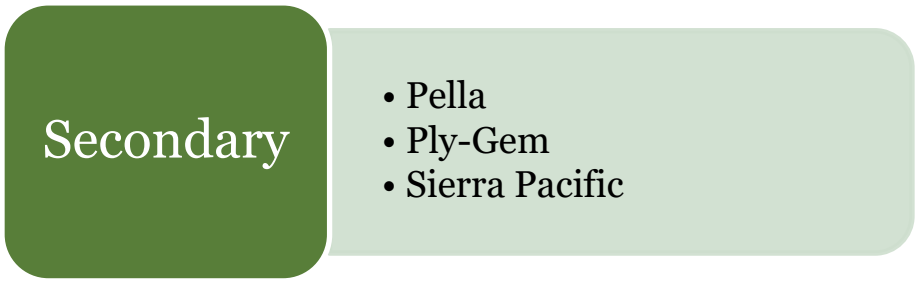
Program participation only partially reflected the importance of these manufacturers. For example, based on 2016–2018 participant tracking data provided by Energy Trust[4], Milgard represented 68% of all incentivized windows in the program where a manufacturer was included. The other manufacturers were either not listed or represented a smaller portion of rebates relative to their stated market size; however, two-thirds of the window rebates in the tracking database lacked manufacturer name.

None of the window and glass manufacturer interviewees, however, were able to provide estimates for manufacturer market share and believed the subscription or pay-for reports tended to make some speculative approximations for the relative market size for the individual manufacturers. One manufacturer even believed the windows companies don't know, stating that most of the large companies sell through distribution or dealer channels and are therefore "blind" with regard to where the windows are eventually installed. Another manufacturer pointed out that market shares depend on the markets served, and market share would be different for multifamily relative to single-family, and between replace and remodel relative to new construction. Another market factor is whether the units are higher or lower end, as Marvin windows are exclusively high end.

The windows market actors also provided feedback regarding second-tier players in the Pacific Northwest, which included Pella, Ply-Gem, and Sierra Pacific. Two manufacturers specifically called out Sierra Pacific being big in the Pacific Northwest region and one of the "fast-growing windows players". One manufacturer believed Ply-Gem has a stronger presence in the replace and remodel market and is especially geared towards the energy efficient replacement windows market in Oregon.

[4] Filename: Res window data 2016-May 2018 5_30_2018.xlsx

Figure 3. Secondary Windows Manufacturers Serving Pacific Northwest Residential Market.



5.1.2 Total Size of Market

Another research goal was to identify the total size of the Oregon residential windows market. For the purposes of this study, the size of the windows market is defined as the total number of windows units sold, where one window unit represents a single household window opening.[5] Only two of the eight interviewees were able to provide total Oregon residential windows sales estimates. The two windows actors provided almost identical estimates, though these estimates were provided as wide ranges (+/- 23%). The total Oregon residential unit sales estimates ranged from 600,000 to 700,000 units from one respondent and 500,000 to 800,000 units from the other respondent.

Using these ranges as a starting point (or top-down estimate), Apex modeled an estimate of total residential window units using secondary data sources (bottom-up approach). This approach is reviewed in the following section below.

5.1.3 New Construction Versus Replace and Remodel (Retrofit)

Understanding the difference between new construction and replace and remodel windows sales is important because the market potential, cost effectiveness, and payback may be dramatically different between the two housing types.[6] As shown in Table 6 below, the respondents were split on the proportion of new construction

[5] Total windows could also be defined by the total square footage of windows sold. For this study, Apex decided to use units as they are more commonly defined and identified in our research.

[6] Selkowitz, S, Hart, R, Curcija, C, "Breaking the 20 Year Logjam to Better Insulating Windows". Proceedings of the 2018 ACEEE Summer Study on Energy Efficiency in Buildings. Differences between housing type payback and cost effectiveness largely depend on input assumptions, including labor costs, equipment costs, and baseline assumptions.

versus replace/remodel, but all felt the range was within 10% of an even 50-50 split (i.e., both the percent of new construction vs. replace/remodel ranged between 40% and 60%). One manufacturer noted that the proportions could vary plus or minus 10% on any given year depending on the economy and new housing starts. Another manufacturer mentioned the old rule of thumb was that approximately 80% of window sales through large home improvement stores were replace and remodel (as opposed to new construction) but was unsure this is still the case. The 2017 and 2018 Windows and Door Manufacturer reports provided additional support for these estimates, reporting that replace and remodel represented approximately 5% higher sales versus new construction.[7]

Table 6. Total Oregon New Construction and Replace & Remodel Residential Windows Sales Estimates.

House Type	Market Actor Response
New Construction Lower (40-45%)	2
Even 50/50 split	3
New Construction Higher (55-60%)	2

Source: Market actor interviews

Apex leveraged the new construction percentage of sales to model a bottom-up total Oregon residential windows sales estimate. Apex used the National Association of Home Builder total 2017 annual housing starts[8] combined with the Department of Energy Residential End Use Consumption Survey average number of windows in a home[9] to determine the total new construction housing demand for window units. The equation used to estimate total window units is shown below.

[7] Window and Door Magazine Top Manufacturer Annual Report: 2017: https://windowanddoor.com/article/marchapril-2017/top-100-manufacturers-2017, 2018: https://windowanddoor.com/article/may-2018/top-100-manufacturers-2018-report

[8] Derived from National Association of Home Builders, available online at https://www.nahb.org/en/research/housing-economics/construction-statistics/national/starts-and-permits.aspx

[9] Derived from Department of Energy Residential End Use Survey (RECS), available online at: https://www.eia.gov/consumption/residential/data/2015/hc/php/hc2.8.php. Apex did sensitivity analysis around the number of windows per home since new homes have gotten larger in more recent years the average number of windows may be greater than the existing building stock. The RECS data showed, on average, slightly over 10 windows per home, but included ranges, so assumed this was on the lower end factoring in new construction.

Equation 2. Total Windows Units.

$$W_T = \frac{(H_{NC} * W_{avg})}{P_{NC}})$$

Where:

- W_T = total window units
- H_{NC} = estimated number of new-construction homes
- W_{avg} = average number of windows per home
- P_{NC} = percent of total sales attributable to new construction

A summary of the total Oregon 2017 residential unit windows sales estimates is shown in Table 7 below. The replace and remodel sales share of 60% of the market would be the closest to the 500,000- to 800,000-unit range provided by the two interviewees. In order for the 40% replace and remodel sales estimates to be close to the interview provided estimates, homes would need to have between 15 and 24 windows, considerably higher than what the Department of Energy Residential End-Use Consumption Survey (RECS) assumes.

Table 7. Total Oregon New Construction and Replace & Remodel (R&R) Residential Windows Sales Estimates.

Sales	Avg No. of Windows Per Home		
	10	12	14
New Construction	200,530	240,636	280,742
Assume 60% R&R, 40% New Construction			
R&R	300,795	360,954	421,113
Total Sales	501,325	601,590	701,855
Assume 50% R&R, 50% New Construction			
R&R	200,530	240,636	280,742
Total Sales	401,060	481,272	561,484
Assume 40% R&R, 60% New Construction			
R&R	133,687	160,424	187,161
Total Sales	334,217	401,060	467,903

Source: Apex estimate from National Association of Home Builders, and 2015 RECS

5.1.4 Recent Changes to Energy Efficient Windows Market

To help understand how the energy efficient windows market has evolved since the previous Delphi study (2014), Apex asked interviewees their opinion on recent changes to the windows market and the primary drivers behind these changes. Interviewee responses varied with respect to the major changes that have impacted the market for efficient windows. Some believed market changes were due to technical innovation, while others believed federal standards and local codes and ENERGY STAR specifications played a larger role.

With respect to the technical innovation, interviewees believed there were various advancements that made headway into the windows market. Windows coatings, in the form of low-e coatings, were noted by all manufacturers has having made some significant strides in the market. Of particular note was the fourth-surface low-e coatings as being the most significant driver of lower U-value windows sales. As one manufacturer noted, "[the windows market] has gotten to the point of almost complete transformation to low-e, with 95% of new construction windows sold as low-e." As another manufacturer noted, "everything is now made with low-e and argon gas fill, and most are at the ENERGY STAR levels." According to recent ENERGY STAR shipments report, almost 85% of windows are ENERGY STAR certified.[10] Yet, another manufacturer had a less rosy outlook for continued technological advancement, stating "there is no technology currently on the market that will significantly impact the manufacturers ability to produce much more energy efficient than what is available today." As another market actor noted, "there just isn't a great degree of innovation in the insulated glass world. After low-e and argon gas, there is now a need to do more to improve the sash, frame, and glass."

Five of the manufacturers noted the significance of ENERGY STAR as being one of the primary drivers for the push to lower U-value windows. One manufacturer mentioned the back and forth between federal code and ENERGY STAR, whereby codes makes the baseline more efficient and ENERGY STAR then has to respond by even higher standards. Another manufacturer mentioned there are municipalities out there that are stretching efficiency goals as well, forcing builders to comply with U 0.27 or less.[11]

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[10] ENERGY STAR® Unit Shipment and Market Penetration Report Calendar Year 2016 Summary, https://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2016_USD_Summary_Report.pdf?7f4f-f90d. Please note the 2017 summary is available but lacked windows market share estimates.

[11] The City of Aspen, although not in the Northwest, was referenced by two separate manufacturers as having some of the most stringent window U-value requirements, at U 0.28. See

Three of the manufacturers also indicated that most consumers are focused on aesthetics, which, according to several interviewees, "is always the most important aspect for windows consumers." As one manufacturer noted, "consumer preference has almost nothing to do with efficiency." Another manufacturer noted an increase in demand for aluminum windows, since they are more aesthetically pleasing, but these windows (aesthetics) takes a back seat to energy efficiency. However, one manufacturer disagreed with this sentiment and believed that consumers are more energy minded now and are looking for socially and economically conscious products, stating that "the general trend over the past few years has been going to higher and higher energy efficient windows".

5.2 Supply Chain

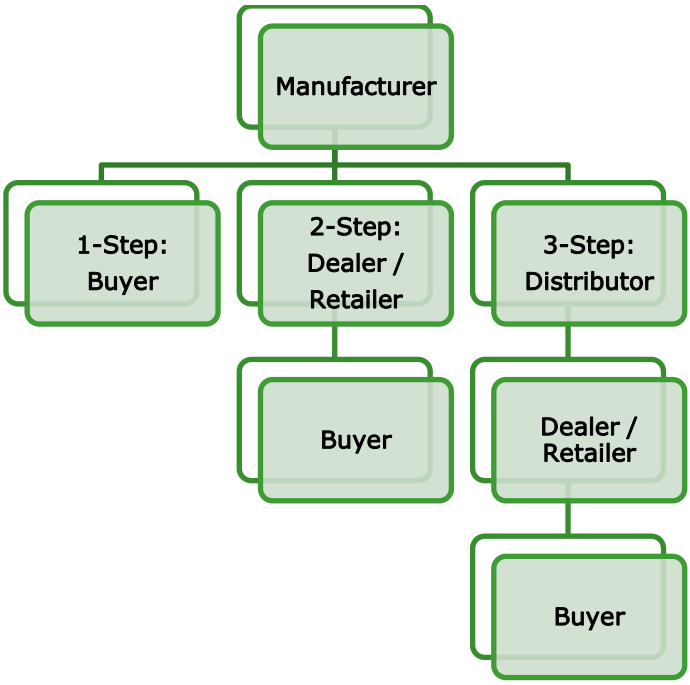
Another aspect of the residential windows market is how windows move through the supply chain from manufacturer to consumer. Starting upstream from the windows manufacturers are the glass manufacturers, and the interviews revealed that most of the major windows manufacturers purchase their insulated glass units (IGUs) from glass manufacturers, rather than manufacturer glass in-house. Milgard was the only major manufacturer that manufactures their own glass units. One glass manufacturer noted that over the last 20 years, glass fabrication has transitioned from a quarterly large "batch" (i.e., bulk manufacturing process) to "one of a kind one of a size, and now make everything to order. We deliver to customers based on tomorrow's production schedule." This glass manufacturer stated this is universal across most glass manufacturers, suggesting that over 90% of the glass is delivered on demand to the window manufacturers.

Moving downstream, the windows manufacturers then deliver their finished products to either homeowners, contractors, or production builders. The windows supply chain is defined as one of three different categories: a one-, two-, or three-step process. One-step processes are direct to builder or homeowner. Two-step would be from manufacturer to dealer/retailer, then to builder or homeowner, while three-step windows move from manufacturer to distributor, to a dealer/retailer,

https://www.cityofaspen.com/DocumentCenter/View/1824/Building-Submittal-Guide---IRC-Single-Family-Duplex-and-Townhome-Projects

then to end user.[12] A summary of the residential windows supply chain processes is demonstrated below in Figure 4.

Figure 4. Windows Supply Channel Process.



According to one manufacturer, historically, the market used to be 50-50 one-step versus two-step, but is now generally two-step (three-step were the least mentioned). Although most manufacturers have moved to a two-step sales approach, one-step sales are still used for large production builders and direct to homeowners through manufacturer outlets. Yet, it is difficult to derive a clear picture of the supply channel process based on conflicting reports from some of the manufacturers–the sales channel process still varies by manufacturer and the buyer channel with which they are working.

[12] Note the 2017 Windows and Door Annual Report showed percentage of companies selling through different channels, but did not include the percentage of actual sales through each of these channels. See https://windowanddoor.com/article/marchapril-2017/top-100-manufacturers-2017 for the report.

5.2.1 Supply Chain Disruptions

Given the disruptions to other retail markets over the past decade, with Amazon online retail displacing a significant market share from other traditional physical stores[13], Energy Trust was interested in understanding whether there may be other similar disruptions possible for the windows market. Most of the interviewees did not believe there were likely to be similar market entrants that could displace significant market share from traditional windows supply chain. As one manufacturer summarized, "[windows] are engineered and precision devices with sophisticated supply chain processes, with each window a unique application, so I don't see that same degree of disruption potential."

Another manufacturer believed the business-to-business market will continue to expand, with larger big home improvement retailers likely to realize the majority of the increased market share. As an example, this manufacturer stated that one of the large home improvement retailers has seen increasing share of sales, especially for the retrofit market, with a comparable decline of "mom and pop" lumberyards, and this movement will be accelerated into the near term. There will also be more consolidation, with the larger home improvement chains acquiring the smaller ones.

One manufacturer indicated that they believed Retailer 2 (see Table 4) has been thinking about online window sales, though they acknowledged selling online is extremely complicated. Another manufacturer gave some credence to the potential for an Amazon supply disruption. This manufacturer believed if anyone could do it, it would be Amazon. They noted Amazon does have a "home services" section, which provides certified installation contractors for other products.[14] Apex investigated this section and could not identify any current windows and door contractor database on Amazons website. It should be noted that Amazon does currently offer windows products and is actively selling (as of September 2018) "Park Ridge" and "American Craftsman" windows products. As one manufacturer indicated, the "sold-installed" model could be one area that has the most potential for disruption. Yet, there are still many factors that need to be assessed, and every market actor interviewed doubted a significant number of homeowners will be likely to order windows online.

Complications to online ordering include ensuring homeowners measure correctly and know exactly the correct window type. Returning a sneaker because it doesn't

[13] https://finance.yahoo.com/news/chart-shows-quickly-amazon-apos-183713948.html

[14] https://www.amazon.com/b?ie=UTF8&node=8098158011

fit is a small price online retailers can absorb, but windows manufacturers are not able to absorb the cost if a homeowner orders a wrong product; this is a significant obstacle. As one manufacturer claimed, "windows customers ultimately want to buy from the entity measuring and installing it."

To address some of these concerns, some companies have expanded their consumer features. As one example, several manufacturers and retailers now have visualizer tools, which allows consumers to get an advanced mock-up of what their home will look like with new windows, an important aspect given the important of aesthetics.[15] Even more critically, one manufacturer believes there are companies working on developing smartphone applications that will allow perfect rough openings measurement for exact sizing when ordering online. Still, according to one interview, "the majority of products are still going through builders, and they are not the ones going online to shop for product."

5.3 Current and Projected Market Share

The market share looks at how the sales of windows varies across various efficiency bins (for Northern tier windows, this analysis is mostly focused on U-value).[16] As noted above, Apex relied on the market actor interviews to develop estimates of market share by efficiency level.

5.3.1 U-Value Bins

Market actors were asked their opinion of recent (2017) and forecasted (2022) windows market shares based on the U-value efficiency of the windows. The same question was asked during the 2014 Delphi panel. Apex summarized the Delphi panel average market share by U-value bin and presented these values to interviewees, allowing respondents to revise the estimates based on their understanding of the market.

Table 8 below shows the estimated 2017 market share, which was derived from the Delphi panel and provided as the basis for interviewees to either confirm or provide adjusted current market share values. The second column, "Estimated 2022 Market Share", represents the interviewees expectations for market shares over the mid-

[15] https://www.plygem.com/wps/portal/home/ideas-and-learning/inspiration/visualizer; https://www.renewalbyandersen.com/get-inspired/visualizer; https://www.windowworld.com/visualizer/; https://www.Retailer 3.com/main/services/Retailer 3-app/augmented-reality/c-19473.htm;

[16] Solar heat gain is also considered but U-value is more important for the Northern ENERGY STAR zones.

term. Again, the original Delphi panel estimates, which were based on participants expectations for future market shares, were provided to interviewees for their feedback. To calculate the estimated 2022 market shares, Apex used a weighted average of those that believed the Delphi-provided shares were most accurate (n=4) relative to two other interviewees who provided adjusted market share estimates.

Table 8. Windows Market Share by U-Value Bins.

U-Value Tier	2017 Market Share	Estimated 2022 Market Share
> 0.35	4%	4%
0.31 to 0.35	30%	24%
0.28 to 0.30	51%	40%
0.25 to 0.27	11%	24%
0.20 to 0.24	3%	6%
< 0.20	1%	2%
Total	**100%**	**100%**

Source: 2014 Delphi Study and current study interviews

All manufacturers that were able to provide feedback on U-value-based market shares agreed with the current estimates (using 2017 as the basis year) as presented in the table above. As one manufacturer stated, "I think it is a great summation—more generic low-e coatings, with argon filled, are 0.28 to 0.3, fourth-surface low-e would be 0.25 to 0.27 products, while the 0.2 to 0.24 are tri-pane. Lines up exactly with my understanding of the market." It should be noted that two of the interviewees were unable to provide insight into the efficiency shares of the market, citing too much uncertainty and a lack of tracking sales according to efficiency levels.

5.3.2 Primary Drivers for Current Market Shares

The primary drivers for shifts to higher efficiency windows were touched on above in Section 5.1.4. The key drivers were building codes coupled with ENERGY STAR specifications,[17] while technology changes also helped drive the market towards U-values down to 0.3 or lower.

[17] ENERGY STAR specification ca be found online at https://www.energystar.gov/products/building_products/residential_windows_doors_and_skylights/key_product_criteria

There were other factors that market actors believed had a role in influencing the market for efficient windows. Some of these factors included the following:

Marketing and education. Marketing the role efficient windows plays is important, especially directed at homeowners. As noted by one manufacturer, "some manufacturers are skipping builders, marketing directly to homeowners, and this requires education, building awareness with homeowners. Few homeowners know what U-values are." They went on to mention the importance of ENERGY STAR in education, that the ENERGY STAR designation offers some value to buyers, and ENERGY STAR markets the windows products as adding comfort to homes.

Slowing of replace and remodel, rebound in new construction. According to two interviewees, there has been a steady decrease in replace and remodel growth, with research showing consumers spending on non-window remodeling.

Reduction in federal tax credit. The federal tax credit was credited by three manufacturers as supporting efficient windows growth, but the reduction in the tax credit (was $1,500 during ARRA funding, but has been reduced to $200)[18] has resulted in a slowing of the efficiency market, which, according to one manufacturer, "moves opposite of the economy."

Impact of energy costs. Low energy costs are also a factor. One manufacturer believed that higher energy prices will help bring efficient windows back into the conscious of consumers. With low gas-heating costs, homeowners do not have efficiency in the forefront.

Impact of brand recognition. Brands can also play a role. Two manufacturers mentioned brand recognition and "halo" effects, and how Marvin, Anderson, and Pella tend to be more expensive, while Milgard and Jeld-Wen offer lower price points with the same efficiency ratings. One of these manufacturers mentioned brand recognition within the region and, as a result, their market presence is huge for consumers.

Role of niche markets. Niche markets have played a minor, but supporting, role in driving efficient market shares. Niche markets include passive house design and net-zero house design. As one manufacturer claimed, "these two applications will be market leaders and early adopters for this technology, unfortunately, the numbers are so small."

[18] ARRA tax credits found here: http://www.lancerwindows.com/products/logo_venders/taxcredit.pdf Current tax credits found here: https://www.energystar.gov/products/building_products/residential_windows_doors_and_skylights/tax_credit

5.3.3 Primary Drivers for Future Market Share Changes

Market actor interviewees were asked what primary drivers will help continue pushing the market to higher efficiency windows. Many of the drivers were the same as indicated for the current market shares—building codes, ENERGY STAR, and technology—though cost was also frequently cited. In fact, one manufacturer stated, "Cost and code are the two main drivers, unless something drastically changes on the buyers or technology side of the equation." For those interviewees that provided either confirmation of the Apex-provided future market share or for those that provided adjusted shares, every single interviewee mentioned the importance that codes will play in driving the market. As one interviewee noted, "the U 0.20 to 0.24 share doubling to 7% is too aggressive, there are no current or anticipated code changes driving that." As another manufacturer stated, "there needs to be an incentive to do better than U 0.28, for builders, a fourth-surface low-e window may help but ultimately code changes will be necessary." One manufacturer believed the higher-efficiency units need to become the de-facto "standard offering, so the choice is not a conscious decision by consumers, [with code] it just becomes standard."

As one example of the importance of code, a manufacturer cited the California state building code is still at U 0.32[19], and changes planned for 2019 maybe shift that to 0.28 to 0.3 windows, at most.[20] A different manufacturer disagreed with the anticipated 2019 Title 24 California code changes, and they believed the code would only marginally impact windows. They believed Title 24 changes would still allow 0.32 windows and there would be no real change. This interviewee believed builders could just increase their insulation package, which would provide alternatives to higher efficiency windows. To this manufacturer, it all came down to cost; if windows suppliers could reduce tri-pane costs to be comparable with the incremental cost of insulation, then builders would consider this in their equation. According to this manufacturer, "it is all about volume and cost—California is critical to this since they have the volume."

Three of the manufacturers mentioned the important role that ENERGY STAR will continue to play. One manufacturer noted that ENERGY STAR has been on a holding pattern for revisions and is one and a half years behind schedule for V7 updates. Apex confirmed this delay in the lack of any documentation related to V7 for

[19] http://www.energy.ca.gov/2015publications/CEC-400-2015-032/chapters/chapter_3-Building_Envelope_Requirements.pdf

[20] Based on manufacturer interview. Apex could not identify specific 2020 U-values planned for Title 24 changes.

windows on the ENERGY STAR website. Given the uncertainty around ENERGY STAR revisions, this manufacturer believed the earliest any change would go into effect would be 2020/21 and would likely result in a negligible impact on the efficiency specification. Another manufacturer believed that the original V6 ENERGY STAR Northern zone change would have pushed windows down to U 0.26 to 0.27, but the recession hit and they eased up on the specification. This manufacturer noted if windows actors can make it cheap to comply, then it becomes easier for ENERGY STAR to lower the requirement. ENERGY STAR- and National Fenestration Rating Council (NFRC)-testing procedures, as well as energy modeling, were mentioned by one interviewee as being "outdated" and overlooking several critical attributes (including air conditioning saturations, winter fan savings, proper fan sizing, and home orientation).

Window costs were another driver that will impact future shift to higher-efficiency windows. Several manufacturers mentioned the continued importance of rebates, especially considering the reduced federal tax incentives, to drive behavior. One manufacturer mentioned the cheap price of energy, and how difficult cheap energy makes the decision to switch to more expensive higher-efficiency windows for budget-minded consumers. This manufacturer went on to say he believed it would require "natural gas prices need to be $2 per therm for consumers to pay attention. With some window costs—example being tri-panes with 40- to 50-year payback periods—and cheap heating prices, it is hard to get demand for the more expensive products."

Some manufacturers believed bigger shifts in energy-efficient windows will have to come from cheaper but better products. This opinion implied that cost-driven approaches need to be taken, including making efficiency more mainstream, and to factor in the influence of production builders. Production builders, in the single-family new construction realm, are building large numbers of homes, and some builders do exceed basic energy efficiency standards. As one manufacturer noted, "a turning point will be if those big players start to recognize the importance of quality and higher-efficiency products versus the cheapest vinyl they can find." As another manufacturer claimed, "a difference of $1 between windows, builders will go for cheaper windows every time." Therefore, costs need to be reduced on the supply side as well.

Additionally, there is a high degree of business risk trying to transform a market without sufficient support from consumers, and one manufacturer noted "most of the current low U-values sold are based on PUD incentives". From a manufacturer's

perspective, "it is extremely costly and risky to design and retrofit our production to accommodate a triple-pane window, so if there was a way to make this transition trivial for them, including a drop-in triple-pane replacement, there will still be increased incremental cost, but if cost is low enough, this will open door for people to adopt." They went on to note that incentives could help the market in this direction and that technology that is cost effective enough to not end up increasing customer costs is critical. The most common higher-efficiency windows are currently capped at 0.24 (according to one manufacturer), and any window below this would require complete redesign of the window fabrication. According to one manufacturer, this redesign would involve "millions in upfront costs to produce this."

5.4 Incremental Cost

Incremental cost was estimated through the hedonic pricing model and then compared with benchmarked values from other jurisdictions, plus reviewed during the market actor interviews. The findings from each of these tasks is discussed below.

5.4.1 Hedonic Price Model Results

Apex used a hedonic price model to determine the incremental cost of increasing U-value efficiency for an "average" window. As noted above, the model relied on an established set of window attributes to explain the price (on a per-square-foot basis). For modeling purposes, an average window was defined as a wood or vinyl window, purchased through a major home improvement retailer, that is a slider, single- or double-hung type, and is double- or triple-paned glass. As part of the modeling process, Apex tested correlations across the attributes to avoid collinearity issues (see Figure 5 below). The following attributes were removed from the Hedonic regression equation due to high correlation:

ENERGY STAR Northern designation: removed due to high correlation with U-value

Aluminum windows: removed due to high correlation with U-value

Casement, awning, and accent/picture windows: removed due to Energy Trusts-preferred focus on standard double- and single-hung and slider windows (the most commonly sold windows)

Figure 5. Hedonic Pricing Model Correlation Coefficients.

	Price_Sq_Ft	*SHGC*	*U_VALUE*	*ES_Northern*	*Panes*	*Aluminum*	*Wood*	*Vinyl*	*ACCENT_PICTURE*	*AWNING*	*CASEMENT*	*DOUBLE*	*SLIDING*	*SINGLE*	*HomeDepot*
Price_Sq_Ft	100%														
SHGC	50%	100%													
U_VALUE	24%	67%	100%												
ES_Northern	-9%	-32%	-36%	100%											
Panes	8%	-8%	-47%	7%	100%										
Aluminum	60%	62%	55%	-27%	-22%	100%									
Wood	-2%	-10%	-12%	24%	-2%	-14%	100%								
Vinyl	-48%	-44%	-37%	6%	20%	-74%	-57%	100%							
ACCENT_PICTURE	53%	63%	30%	-1%	14%	48%	-14%	-30%	100%						
AWNING	0%	-3%	20%	23%	-20%	3%	9%	-9%	-14%	100%					
CASEMENT	3%	-14%	-13%	42%	0%	-15%	35%	-12%	-20%	-10%	100%				
DOUBLE	-21%	-23%	-19%	-22%	7%	-16%	9%	7%	-30%	-15%	-20%	100%			
SLIDING	-15%	-17%	-13%	-12%	-3%	-18%	-16%	26%	-26%	-13%	-18%	-28%	100%		
SINGLE	-22%	-12%	0%	-13%	-8%	-6%	-14%	15%	-23%	-11%	-16%	-24%	-21%	100%	
HomeDepot	28%	4%	6%	13%	-10%	11%	14%	-19%	23%	21%	24%	-29%	0%	-28%	100%

Source: Web harvest data.

The model returned statistically significant results at the 90 percent confidence level, though it should be noted that the model only moderately explained the window price variation (an R-squared of 0.31). The final equation used for the model is shown below in Equation 3, while the results of the final model are shown in Table 9.

Equation 3. Final Hedonic Pricing Model.

$$\frac{Price}{Sq\ Ft} = \alpha + B_1 Frame + B_2 Type + B_3 Retailer$$

Where:

- Price/Sq Ft = price of window on a square foot basis
- α = constant, or model intercept
- B_1, B_2, B_3 = Parameters that account for the relationship between individual windows characteristics variables (listed below) and price per square foot
- Frame = Frame type, dummy variable represented by binary value for each type included. Final model included wood and vinyl (aluminum excluded due to collinearity).
- Type = Window type, dummy variable represented by binary value for each window type. Final model included double-hung, single-hung, and sliders (accent, picture, awning, and casement excluded).
- Retailer = Retailer, dummy variable represented by binary value for each window retailer. Final model included two of the three retailers.

Table 9. Final Overall Model Results.

Price/Sq. Ft.	Coefficient	Standard Error	t-statistic	P>t	90% Lower Confidence Interval	90% Upper Confidence Interval
U-Value	$(29.07)	3.95	(7.37)	0.00	$(35.56)	$(22.58)
Wood	$6.44	1.01	6.41	0.00	$4.79	$8.10
Double	$4.46	0.59	7.52	0.00	$3.49	$5.44
Sliding	$7.58	0.62	12.32	0.00	$6.57	$8.59
Retailer	$9.10	0.49	18.75	0.00	$8.30	$9.90
Constant	$23.43	1.33	17.57	0.00	$21.23	$25.62
$R^2 = 0.31$						

Source: Web harvest data and Apex Analytics analysis.

Using the U-value coefficient from the final overall model, we are able to determine the incremental cost of moving from an average inefficient window (at U-value 0.33) to a higher-efficiency window (U-value 0.28). The per-square-foot cost is based on a 0.05 reduction in U-value, so the incremental cost is the product of lowering the U-value by five (-0.05) and the U-value coefficient -$29.07, which translates to $1.45 per square foot (i.e., -0.05*-$29.07).

Apex also tested a model with five U-value bins (defined in the model as dummy variables) to understand the non-linear relationship of price and U-value. This non-linear relationship was used to account for costs such as third- or fourth-surface low-e coatings, differentiated spacers, and triple-pane glass for anything at or below U 0.25. The results of this model are shown in Table 10 below. The interpretation of these results is that there is a minimal premium for increases in U-value above 0.3 ($0.47 to reduce U from above 0.35 to 0.35 to 0.31, and is not statistically significant), while there is a $11.64 premium (the difference between $21.34 and $9.75) to attain 0.25 or lower U-value. This $11.64 premium effectively represents the cost of adding a third pane of glass.[21] It should also be noted that the results of the two models show consistency, as the two show similar estimates for incremental costs to move from U 0.33 to U 0.28 (well within the confidence interval across the two models).

[21] This would include the cost of the glass, spacers, gas, essentially everything that is necessary to accommodate a tri-pane frame.

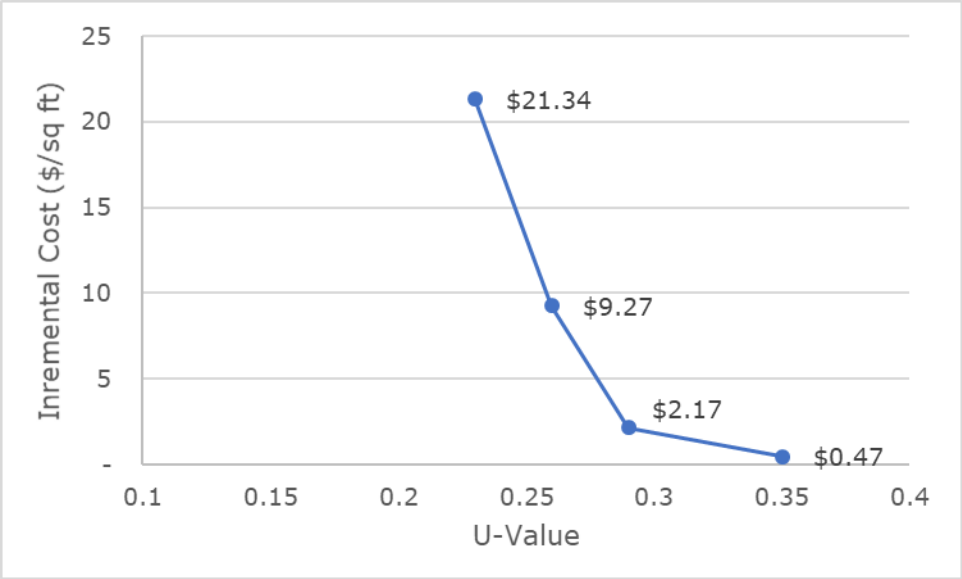
Table 10. U-Value Bins Model Results

Price/Sq. Ft.	Coefficient	Standard Error	t-statistic	P>t	90% Lower Confidence Interval	90% Upper Confidence Interval
U 35-31	$0.47	1.33	0.35	0.73	($1.73)	$2.67
U 28-30	$2.27	0.62	3.64	0.00	$1.24	$3.29
U 25-27	$9.75	1.04	9.41	0.00	$8.05	$11.46
U < 25	$21.34	2.19	9.74	0.00	$17.74	$24.95
Wood	$6.00	0.98	6.14	0.00	$4.39	$7.61
Double	$3.76	0.60	6.27	0.00	$2.77	$4.75
Sliding	$6.57	0.61	10.85	0.00	$5.57	$7.57
Retailer 2	$9.86	0.53	18.72	0.00	$8.99	$10.72
Constant	$12.46	0.54	23.08	0.00	$11.58	$13.35
$R^2 = 0.34$						

Source: Web harvest data and Apex Analytics analysis.

The results of the U-value bins model are also demonstrated below in Figure 6. As can be seen in this figure, the incremental costs are non-linear and follow a steep upward sloping curve as U-value declines (and efficiency increases).

Figure 6. Increasing Incremental Cost by U-Value Bins.



Source: Web harvest data.

5.4.2 Benchmark Incremental Cost Values

Apex compiled a series of secondary, source-based incremental costs from web-based research to benchmark the hedonic price model estimates. A summary of the incremental cost benchmarking is shown in Appendix C: Benchmarked Incremental Costs. The incremental cost assumptions showed a high degree of variability. Some estimates were based on new construction, and some on a per-unit basis with no dimensions provided to normalize the values. Further, the timeline on some of the studies are almost ten years old and are outdated. Incremental cost estimates varied from a low of $0.04 to a high of $1.13 per-square-foot U-value. Apex normalized all reported incremental cost values so that they could be compared. Of particular note, we added "lower efficiency levels" in the notes to indicate that the incremental costs were for considerably lower-efficiency windows. The results of the secondary-research benchmark values help to support the notion that incremental costs have high uncertainty and a high range of likely values. This conclusion is further supported with the market actor interviews, reviewed below.

5.4.3 Market Actor Incremental Cost Estimates

Apex asked market actor interviewees about their impressions of the incremental cost estimates. Interviews revealed some mixed responses from market actors, though the majority of interviewees agreed with the general range of the $1.45 per-square-foot cost estimate for a more generic, commonly sold window. As one manufacturer noted, "if your data came from big box [home improvement], then on the shelf cost, yes, your estimate looks good, since double-hung are competitively priced. Yet there are so many nuances, including manufacturer, frame type, etc., it is really difficult to isolate." One manufacturer believed the estimates seemed low. This manufacturer believed that the higher-end products, of which theirs is one, are probably twice the $1.45 per-square-foot cost estimate, and Apex's estimate is more in line with upstream manufacturer costs, not retail costs. Still, this manufacturer noted that, for the average window, the $1.45 per-square-foot cost estimate is probably close for the mid-and lower-range manufacturers (i.e., those windows sold through large home improvement stores).

5.4.4 Primary Drivers for Incremental Cost

In general, there are basic inputs required to fabricate windows: materials, including glass, spacers, frame, sash, and gas fill; and labor. Based on the interviews, the incremental cost of increasing efficiency can be attributable to increased materials cost (e.g., better insulating and sealing spacers, better glass,

more expensive gas such as krypton, and additional panes of glass) and increased labor, which is required to fabricate more advanced windows. The increased labor was highlighted as an additional cost by one manufacturer, who reported that the process of building low U-value windows roughly halves productivity due to the addition of different foam spacers, more materials, and a more manual fabrication process (by nature, the window manufacturing process is not highly automated; windows are mostly manually fabricated). One manufacturer reported that, when factoring in tri-pane glass, it is more than double the cost of a double-pane low-e window, due to a third pane of glass, a second air piece, a second, third, or fourth low-e coating, and edge fabrication costs. When factoring in the different frame or sash design to accommodate the tri-pane glass, "well that sends your costs through the roof" as one manufacturer stated.

5.4.5 Primary Drivers for Changes to Incremental Cost

Market consolidation, volume, demand, and technology were the factors most commonly cited by market actors as the drivers of future incremental cost changes. One manufacturer believed market pricing will be largely driven by the continued consolidation of manufacturers, which will help drive prices down.[22] Consolidation would drive prices down because manufacturing costs are highly dependent on volumes, which provide greater economies of scale for the manufacturers (as noted by one interviewee). From the production side, there has to be significant volume, especially for the higher efficiency windows. As noted previously, triple-pane production is not as efficient, and according to one manufacturer "we need big advancements in production; if markets went whole hog into triple-pane, we have enough raw materials to make the units, but the North American market is still constrained on glass capacity."

Volume impacts not only window manufacturing but is a critical piece of the upstream manufacturing of glass. Based on feedback from one manufacturer, the "price of raw glass has been too low, in order to get investment payback on float plants[23], 25% of the capacity was mothballed due to the recession, and still hasn't come back online." Transitioning window manufacturing to incorporate more automation would help alleviate some of the issues. Yet there must be demand to

[22] Windows and Door Magazine 2018 Top 100 Manufacturers Report, https://windowanddoor.com/article/may-2018/top-100-manufacturers-2018-report, "*2018 has already seen some notable acquisitions involving Masonite, Andersen, Ply Gem and Jeld-Wen, to be noted in next year's Top 100 List.*"

[23] Float plants are the standard window glass manufacturing process, whereby sheets of glass are created by "floating" molten glass on a bed of molten metal.

invest the capital to retrofit production facilities. One example of lower incremental cost improvements was the availability of "low touch points" technology in fourth-surface low-e glass. Fabrication productivity is not impacted by the incorporation of fourth-surface low-e glass, and manufacturers were able to incorporate the new glass in existing processes with minimal disruption to fabrication. As one manufacturer claimed, "any significant technological improvement with lower costs has to come from glass, and glass is automated, so glass doesn't disrupt the fabrication process."

5.5 New Technology

Windows market actor interviewees were asked what technologies have the potential to play a significant role in transforming the efficiency of windows within the next five years. One of the most commonly cited areas for windows advancements were centered around home automation technology. Smart homes, and window automation in particular, have taken a more prominent role, and this technology could play into energy efficiency as well. As one interviewee noted, "automation is likely the biggest movement." One of the manufacturers provided three most likely home automation developments that could drive windows efficiency (either directly or indirectly):

Faux Windows: Faux windows are based on OLED screen with daylight LED technology displaying live feed from hi-res video. One manufacturer noted energy costs are lower than having a hole in the wall with windows in it, and costs continue to decline. One interviewee even had a prototype in his office, using daylight LED to simulate real day light. Since most homes are air conditioned, the internal environment is completely conditioned and fresh air through windows is not an issue.

Smart Windows: Smart windows sense the inside and outside temperature and weather conditions, allowing automated venting to cool/heat. The technology is readily available but has not been marketed. This technology is also easily adaptable and, for new construction, would be low cost.

Smart/Automated Aerogel Screen/Shutter: To reduce cooling costs, automated screens open/close for heating/cooling. Application works best in high-cooling-load environments.

Another manufacturer believed the more direct windows technology would contribute to higher efficiency over the next five years. This interviewee expected

fourth-surface low-e to become ubiquitous, and greater demand will help drive cheaper development of these windows. While they acknowledged the perception of condensation issues, they believed fourth-surface low-e windows will help raise the bar and open the window for the next innovative technology.[24] This interviewee did not anticipate any "game changing technology" but believed that triple-pane windows will have the most likely significant impact. The issues with triple-pane windows remain: the need for a thicker sash, increased weight, and additional spacers and gas, which (as noted above) depend on labor-intensive manufacturing processes and are therefore very expensive.

Another interviewee also mentioned glass technology, but changes are likely to occur with smaller incremental steps. A major leap, like triple-pane, would have to be based on revolutionary glass technology. This is because the window units would still need to fit into existing sashes and frames. This interviewee noted that historically, glass technology has been the key driver for leaps in efficiency, including spacers and low-e, all built around the glass. They also provided details on four potential technologies, but noted that there are still significant drawbacks or issues with each of them:

Nano Tech Coatings: This coating is a paint-on application with claimed thermal resistance and UV filtration. The technology is obtainable, but, according to one manufacturer, is not scaled. Apex was unable to identify primary data-validated studies on the energy impacts.[25]

New Glass Technology: This technology represents a broad category of dynamic glass that changes transparency based on either environmental conditions or user inputs. These changes include photochromic (due to light), thermochromic (due to heat), and electrochromic (due to electric current).

Aerogel: This technology is a silica-based, non-gas fill with low convection properties. There are several known issues: not 100% clear glass[26], insufficient

[24] Condensation issues have been noted in various publications. https://www.dwmmag.com/fourth-surface-low-e-coatings-a-prescription-for-pane-but-not-without-side-effects/. https://www.brikbase.org/sites/default/files/BEST4_6.2%20Rogers_0.pdf. https://arpa-e.energy.gov/sites/default/files/04%20-%20Wright%20ARPA-E-2014_r2%20-%20FINAL.pdf.

[25] See https://drywired.com/liquid-nanotint-insulation-for-glass/ for an example product.

[26] One manufacturer stressed the fallacy of crystal-clear glass as promoted by the industry. This interviewee indicated that up to 70% of windows are not even looked through (Apex could not verify this number). This manufacturer believed the industry should consider differentiating "view" versus "light" windows.

production capacity, previous production plants have apparently exploded[27], and, according to one windows expert, after "30 years of R&D is not yet a commercially viable window option".

Vacuum Glass: This technology is a fabrication process that removes all gas between window panes, thereby limiting heat transfer. Current limitations include extremely limited sizing availability, durability issues, high production cost, and lack of U.S. production facilities.

One of the most promising new efficient windows technologies is ultra-thin drop-in replacement insulated glass to create tri-pane windows without the need to retrofit current windows sash and frame elements.[28] This technology, dubbed "thin-triple," has been chiefly promoted by Stephen Selkowitz with the Lawrence Berkeley National Laboratory. This technology promises to drop current double-pane windows to U-values between 0.15 to 0.2, at an incremental manufacturing cost of $2.30 per square foot (based on double-pane low-e windows). According to interviews with and papers submitted by Mr. Selkowitz, the incremental cost to produce these windows is low because they do not require the retrofitting of existing production facilities to accommodate the thin glass inserts; existing frames and sashes can accommodate the 1 mm or thinner glass insert. Furthermore, existing spacers can also accommodate the new insert without additional fabrication techniques.

In discussing the thin-triple idea with manufacturers, several had heard about it, while one manufacturer was very familiar with the concept and had some concerns regarding the "real-world" application of the manufacturing process and stated costs. The biggest issue noted by this manufacturer is the effectiveness of the krypton fill. According to this manufacturer, it will take three volumetric exchanges to get a fill level of better than 90%,[29] which is required for the stated performance of the windows. This manufacturer believed the analysis had not properly accounted for the volumetric gas loss and that krypton prices are not anywhere near what was being reported. Mr. Selkowitz acknowledged this concern but indicated he had been working with the primary supplier of krypton gas in the U.S. and had established

[27] Plant explosion cited during interview and documented here: http://www.aerogel.org/?p=824

[28] Selkowitz, et all, 2018 ACEEE.

[29] According the this manufacturer, each individual gas volumetric exchange will show incremental saturation of krypton, the first exchange will push saturation to 60%, second to 80%, and the third to 90% saturation. This process produces high-gas losses.

the costs based on discussions with each of the suppliers of the critical components to these windows.[30]

Another concern that this manufacturer pointed out was that if a manufacturer can manage to get an R-7 piece of glass into an existing window, it will still be inside the "same old sash." This does not account for any frame redesign work or upgrades. As this interviewee stated, it is "like putting radial tires on a model-T." He wanted to stress that there needs to be a coincident push to bring the sash up to date as well. Mr. Selkowitz did address the need to upgrade the frame/sash coincident with the high-R glass, but the current paper did not fully address the cost or implications of a full window frame/sash upgrade.[31]

There are other outstanding uncertainties to be address, as producing a test case model of this technology is one thing but scaling it up to get it to retail is another. As Mr. Selkowitz indicated, "We need one or more leaders to move into the market, stand apart from other [manufacturers], then it has a chance in succeeding." He then pointed out other entities that are interested in this model, referencing Canada, which has a very aggressive push to require efficient windows,[32] California,[33] and NEEA.[34] He noted that achieving a critical mass of support (a sufficiently large enough market demand for this product) will be an absolute requirement for success.

The conversation regarding the thin-triple technology also acknowledged the barriers. As Mr. Selkowitz noted, "the bottom line is that no one [i.e. manufacturers] wants to change and go to triple." He did indicate that two companies, one large (Anderson) and one small (Alpen) showed interest in pursuing the development of these windows. There is also potential for smaller- or middle-tier companies, like Sierra Pacific or Ply-Gem to enter into this market, since smaller companies may have more willingness to research and develop new market potential.

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[30] Due to sensitive company disclosure policies, we were not able to review any of the basis cost data used to develop the estimates in the thin-triple paper.

[31] Selkowitz, 2018. As noted in the paper, "*The figure shows that a COG performance much better than that obtained by our thin-triple IGU designs will not result in much whole window performance improvement without further enhancements to the frame*"

[32] See https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/emmc/pdf/2018/en/18-00072-nrcan-road-map-eng.pdf for more details. Table 3-2 shows the short, mid, and long-term planned national window requirements.

[33] http://www.energy.ca.gov/title24/2019standards/documents/2018_Title_24_2019_Building_Standards_FAQ.pdf

[34] https://neea.org/success-stories/high-efficiency-windows

5.6 Program Design

Apex summarized other residential windows rebate programs throughout the Northern ENERGY STAR windows zone. This report section provides Energy Trust with comparative programs currently (2018) offered through the Northern U.S.

5.6.1 Other Utility Window Programs

The Apex team identified a comprehensive windows program summary online which provided the bulk of the benchmark program summaries.[35] We focused our research on either larger public utilities or regional collaborative efforts and did not investigate smaller individual municipal windows offerings. A listing of the states and utilities that were reviewed are included in Appendix D: Northern Tier Windows Programs. Apex identified 8 out of 32 ENERGY STAR Northern tier states and 22 out of 65 utilities that offered some form of windows specific programs during 2018. The Apex team was able to identify only downstream incentive programs; as of 2018, there were no Northern Tier windows program that offered upstream incentives. Most of the programs relied on an efficiency level that matched ENERGY STAR, with most programs requiring a U 0.3 or less window to qualify. Incentives were offered either on a per-unit basis (per frame unit) or on a per-square-foot-of-window basis. Incentives ranged from a low of $1/square foot for U value 0.30 or less windows (Wyoming, Oregon, Idaho, Arizona) to $4/square foot for U value 0.27 or less (Oregon). Michigan windows programs showed the most extreme differences, with one program offering per unit incentives as low as $15 per window (DTE and Consumers Energy) to $70 per window unit (Xcel).

5.6.2 Best Energy Efficiency Program Approach

As part of the market research effort, Apex sought to identify alternative program design approaches that could lead to increased consumer adoption of efficient windows. To compile information, Apex reviewed the program information detailed above and asked market actor interviewees their impressions of the most effective delivery approach. As noted above, all current program offerings throughout the Norther tier ENERGY STAR region are downstream consumer rebate programs, and all but one respondent believed that a direct to consumer or downstream rebate is

[35] Incentives and Rebate for Energy-Efficient Windows Offered through Utility and State Programs. Available online at https://www.efficientwindows.org/downloads/UtilityIncentivesWindows.pdf. Updated January 2018. Efficient Windows Collaborative.

the most effective way to drive consumer demand for efficient windows. As noted by several of the interviewees:

- "[Direct] to the consumer is more effective, not upstream."
- "Rebates. Rebates. Rebates. On a per window basis."
- "Consumer driven rebates are the number one driver."
- "Yes, consumer downstream is best bet, market will dictate what manufacturers do."
- "From personal experience–having cash back, rebate system, is great."
- "Supply side is wrong place to look, it really is demand, so need to push demand, offering incremental reductions in U-value."

One manufacturer, however, believed there was still opportunity for an upstream or market transformation potential. This respondent believed that partnering with a small manufacturer in a niche market (e.g. Nano-film technology or vacuum glass) could provide more traction in that niche market. This manufacturer stressed that it costs manufacturers hundreds of thousands, if not millions, of dollars to get new product line into market. Therefore, there needs to be a concerted effort both on the supply AND demand side in order for successful market transformation, and utility programs are one of the key elements of this dynamic.

Another respondent believed that the current higher-efficiency tier incentive of $4/square foot could go most if not all of the way to buy down the incremental cost of the thin-triple pane. A review of the cost estimates did support that this program support could offset the cost of this technology, assuming that the cost modeling done in this paper is substantiated in the real-world manufacturing realm. Additional follow up emails indicated that the respondent is in conversations with two manufacturers and has their backing to work on the development of this technology.

Another potential area of focus for programs is to try and monetize the non-energy benefits or, as one manufacturer said, "the cost of discomfort. If someone needs to set heating to 74 to be comfortable but could set to 68 with higher performance windows and be more comfortable. We know standard double pane are not going to

deliver sufficient comfort during heating season, especially picture (larger) windows."

5.6.3 How Can Energy Trust Support Efficiency Windows?

The upstream approach for efficient window technology comes back to the chicken versus the egg argument: consumers are not coming to manufacturers asking for triple-pane or super-high efficiency windows, and manufacturers are unwilling to risk the exposure to unmet supply. Several of the interviewed manufacturers noted the importance of consumer education, regardless of any eventual program design changes. As one manufacturer noted, "change has to come from demand, 99% of homeowners have no clue that advanced glass is available, and no idea about the opportunity to upgrade." Multiple manufacturers also stressed that a minimum level of energy code is required to move the market.

Several manufacturers agreed that collaboration is required if a significant transformation is to be undertaken. In fact, one manufacturer even noted the significance of the interview (that is, showed Energy Trust's level of involvement) and were very grateful for the opportunity to contribute their feedback. As this manufacturer stated, "This [interview] is a big step towards your goal, shows support and interest in trying to move the market." They went on to recommend having a council of manufacturers and partners working together, to demonstrate the potential of a well-coordinated effort to push the market. This idea was also corroborated by Mr. Selkowitz, who argues that a concerted effort is required from both sides: market push (developing the technology on the supply side with reduced production costs) with a coincident pull from codes, ENERGY STAR, early adopters, and utility programs.[36]

[36] Similar to the idea of a council, Mr. Selkowitz has started the California High Efficiency Windows Collaborative, and is interested in including additional market actors that are interested in driving these higher performance windows. He also recommended a series of demonstration or pilot programs, which can demonstrate the savings and the value proposition (increased home comfort, reduced HVAC system requirements) for thin-triple glazing window products.

6. Appendix A: Recruitment Email

July XX, 2018

[Market Actor Name]:

As you may already know, Energy Trust of Oregon offers incentives for the installation of high-efficiency windows in Oregon homes. As an [MFG or Retailer: key player in the PNW windows market; Expert: expert in energy efficiency], we would like to get your impressions of the current market for residential windows and your thoughts on the availability and cost/pricing of efficient windows that are currently on the market. [For those that had participated in the previous Delphi panel: You may recall participating in a survey and Delphi panel several years ago, and this effort is an update to that study]. This information will help Energy Trust consider changes to program incentive levels, efficiency levels, and program delivery. We are requesting your participation in a brief interview sometime in late July.

Energy Trust has contracted with Apex Analytics to conduct this research. As a thank you for your time and effort, we are going to share the results of our research with you and provide the full report XX. If you choose to participate in this effort, your responses will not be associated to your organization, and all results will be presented in aggregate. This effort is purely for Energy Trust program planning purposes.

As background, we have included a document with a brief description of the goals of the study and the type of information we are looking for to help you prepare for the interview. In this document you will find the current estimates for several key characteristics of windows pricing and market shares – these elements will be discussed during our interview and will help provide you with our current understanding of the windows market.

If you would like to participate in the study, please call or email Noah Lieb of Apex Analytics at 303-590-9888 ext.103 or noahl@apexanalyticsllc.com. If you have any questions about this study, please contact me at the number below.

We thank you in advance for your insights into the evolving high-efficiency windows market.

Sincerely,

Phil Degens
Evaluation Sr. Project Manager
Energy Trust of Oregon
503-445-XXXX

7. Appendix B: Interview Guide

Click or tap here to enter text.

Research Objectives

1. Determine the key manufacturers serving the Oregon market
2. Estimate the size of the windows market in Oregon (retrofit vs new construction, by efficiency level, by manufacturer)
3. Assess the incremental cost of energy efficient windows, including the incremental cost at different efficiency levels and what drives these costs
4. Determine how a midstream or upstream program could most effectively increase the adoption of energy efficient windows

Interviewee Name: _____
Interviewee Company: _____
Manufacturer/Retailer/Market Actor: _____

7.1 Introduction

Thank you for taking the time to participate in this Northwest residential windows study. Your insights and feedback will help Energy Trust of Oregon refine its programs to support high-efficiency windows in the Northwest windows market. The information you provide will be kept confidential to the extent permitted by law. All responses will be reported in aggregate and individual comments will not attributed to any respondent.

7.2 Market Landscape

[Note: Windows experts can skip this section]

A1. One of our goals is to understand the window manufacturers who serve the Oregon residential market. Our past research has shown that the major windows manufacturers serving the Pacific Northwest residential market include Anderson, Marvin, Milgard, and Jeld-Wen. Is this consistent with your understanding, or are there other manufacturers not mentioned that have a significant market share?

a. _____ [RECORD RESPONSE]

A2. Our current research shows approximately XXX residential windows units sold and the following residential windows market share by manufacturer. Is your understanding of the current windows market consistent with this, or do

you believe the market shares should be shifted? What percentage of the energy efficient windows market specifically do you believe each manufacturer held in 2017?

Manufacturer/Distributor/ Market Actor	2017 Market Share, Overall	2017 Market Share, EE Windows
Anderson		
Marvin		
Milgard		
Jeld-Wen		
Other 1		
Other 2		

A3. Our research shows that there is a fairly even split between new construction versus retrofit existing windows sales, is this consistent with your understanding of the residential windows market? If not, what do you believe the new construction versus retrofit split is, and why do you believe it is different?

1. New Construction: [Enter percentage]
2. Existing Homes: [Enter percentage]

A4. What changes have you seen in the market for efficient windows since 2015? What do you believe were the driving forces behind these changes?

a. _____ [RECORD RESPONSE]

7.3 Market Share Size (Including Five-Year Forecast)

B1. For the purposes of this study, we have established five efficiency tiers for windows solely based on the U-value. These tiers go from inefficient windows, at greater than 0.35, all the way to windows at or less than 0.20. I am going to introduce each of these windows efficiency tiers and would like to understand whether you believe the current and projected 2022 **Oregon** market share **for your own company** to be different from the assumptions below [NOTE: IF

UNABLE TO ESTIMATE OR, THEN ASK ABOUT PACIFIC NORTHWEST OR NATIONAL OVERALL]. We have provided estimates from our previous study, which you should have received with the initial invitation to participate. [Sum up the percentages and make sure they add to 100%] [IF THEY CANNOT PROVIDE THIS DETAIL, THEN ASK: IS THERE A CLEAR TIPPING POINT FOR U-VALUE AND SALES ON WINDOWS? DO WINDOWS DECREASE SALES AT A NON-LINEAR RATE AFTER A CERTAIN U-VALUE?]

U-Value Tier	Market Share (2017)	Estimated 2022 Market Share
> 0.35	4%	4%
.31 to .35	30%	22%
.28 to .30	51%	37%
.25 to .27	11%	27%
.20 to 0.24	3%	7%
< .20	1%	3%
Total	100%	100%

B2. What do you believe are the primary drivers behind the market shares? (DO NOT READ i.e. customer preference, customization, marketing)

a. [RECORD RESPONSE]

B3. [VERIFY 2022 SHOWS INCREASE IN .27 OR LOWER SHARES, IF NOT, THEN ASK: WHY DON'T YOU BELIEVE THERE WILL BE AN INCREASE IN EFFICIENT MARKET SHARES, OTHERWISE ASK:] What will be the strongest drivers of an increase in 0.27 or lower U-value market share over the next 5 years?

a. [RECORD RESPONSE]

7.4 Incremental Cost

C1. Incremental cost is the difference in the cost of an average non-ENERGY STAR inefficient window compared to the cost of an ENERGY STAR or higher efficiency window. All else equal, knowing that there are other factors that drive the retail cost of windows, our previous research showed that windows market actors believed the additional cost of going from a U-value of 0.33 to 0.28 was

$1.43 per square foot, or just over $14 for the average 10 square foot window. Our current research, using market data and statistical models, shows these costs may vary, based on retailer, window type, frame type, among other factors, but on average, are still approximately $1.43/sq ft for double/single-hung or slider windows. Do you feel this estimate is correct, or is it too high or too low? Why? What do you believe is the current incremental cost of moving up from one level of efficiency to the next? And what direction do you believe these costs are headed in the next five years? [IF THEY CANNOT PROVIDE THIS DETAIL, THEN ASK: IS THERE A CLEAR TIPPING POINT FOR U-VALUE AND INCREMENTAL COST ON WINDOWS? DO WINDOWS INCREASE COST AT A NON-LINEAR RATE AFTER A CERTAIN U-VALUE?]

U-Value Tier	Incremental Cost	Estimated 2022 Cost
.28 to .30		
.25 to .27		
.20-.24		
< .20		

C2. What do you believe are the primary drivers behind such incremental costs? (DO NOT READ i.e. the number of panes, gas fill, manufacturing costs, production requirements)

a. [RECORD RESPONSE]

C3. What will be the strongest drivers of a decrease in the cost of 0.27 or lower U-value windows?

a. [RECORD RESPONSE]

7.5 Incentive Structures

D1. I would now like to discuss the windows supply chain and market structure, namely, how windows products move through the market, from manufacturer to consumer. Can you help shed some light on the supply chain? [Frame this based on whether you are speaking to MANUFACTURER vs Distributor or Retailer/contractor: What percentage of the residential windows you sell are through retail stores relative to big box, direct to contractor, distributors, production builders, or customers etc?]

a. [RECORD RESPONSE]

D2. Do you foresee any major changes to the supply chain over the coming several years? [PROBE: DISRUPTIONS, ONLINE RETAIL (AMAZON), ETC]

D3. Is this structure specific to your company, or do you believe most companies follow the same supply chain?

a. [RECORD RESPONSE]

D4. Are you familiar with the Energy Trust windows program, and other utility sponsored residential windows programs across the country?

a. [RECORD RESPONSE]

D5. [IF YES, then ask:] In your experience, what residential windows program features tend to be most effective in driving BOTH increased consumer demand AND increased manufacturer/distributor/retailer supply for higher efficiency windows? [PROBE: how do incentives, marketing, and other program factors play a role]

a. [RECORD RESPONSE]

7.6 Technology

E1. What efficient windows technologies have the most potential to COME TO the windows market [SOON, AS IN NOW, BUILDING PLANT NOW, VS NEXT 5 YEARS, WAY OUT IN FUTURE]?

a. [RECORD RESPONSE]

E2. In what ways can Energy Trust help support the development and market roll-out of these products?

a. [RECORD RESPONSE]

7.7 Closing

F1. Are there any other comments or relevant market details that you would like to share with us? [Enter open ended response here].

b. [RECORD RESPONSE]

F2. Finally – is there a windows market research report that your company relies upon that you would recommend that we purchase?

c. [RECORD RESPONSE]

Those are all the questions that we have for you today. Energy Trust thanks you again for taking the time out of your busy schedule to help us with this effort.

8. Appendix C: Benchmarked Incremental Costs

Table 11. Comparison of Other Windows Incremental Cost Estimates.

Source	Units	U-Value Base Case	U-Value Efficient Case	Reported Incremental Cost	Standardized Per Sq Ft and Per-U-Value Incremental Cost	Notes
Hedonic Pricing Model	**Per Sq Ft**	**0.33**	**0.28**	**$1.45**	**$0.29**	
ENERGY STAR (2011)	Per Window	0.30	0.27	$34	$1.13	No size assumption, so assumed 10 sq ft for standardized estimate
ACEEE Paper (2008)	Per Sq Ft	0.37	0.35	$0.13	$0.07	Considerably lower efficiency levels
ACEEE Paper (2008)	Per Sq Ft	0.37	0.25	$0.50	$0.04	Considerably lower efficiency levels
PNNL (2012)	Per Sq Ft	0.35	0.32	$0.18	$0.06	Considerably lower efficiency levels
MA RNC Study (2013)	Per Sq Ft	0.31	0.29	$1.12	$0.56	
MA RNC Study (2013)	Per Sq Ft	0.31	0.25	$2.38	$0.40	
CPUC (2013)	Per Sq Ft	0.40	0.32	$0.71	$0.09	Considerably lower efficiency levels
EWC (2010)	Per Sq Ft	0.34	0.27	$6.25	$0.89	
WDMA (2017)*	Per Sq Ft	0.30	0.20	$10	$1.00	Based on interview

*Note this estimate was provided from an interview based on prior knowledge of a WDMA study. Apex does not have access to this study and therefore is unable to confirm this estimate.

9. Appendix D: Northern Tier Windows Programs

State	Program Provider	Program Title	Qualifying Attributes	Incentives	Disqualifying Attributes	Cap?	Link
OR	Energy Trust of Oregon	Home Upgrades and Cash Incentives	U-value of 0.28 to 0.30 and U-value of 0.27 or less	**$1.75/sf and $4.00/sf**			https://www.energytrust.org/incentives/windows/#tab-two
AZ	Southwest Gas	Residential Rebate Program	ENERGY STAR® qualified for appropriate climate zone	$1.00/sf		up to 75% of equipment cost	https://www.swgas.com/en/rebate/arizona-windows-homeowner/renter
CO	Efficiency Works	Residential Rebate Program	Replacement ENERGY STAR windows in gas-heated homes and electric-heated homes	Up to $750 for gas-heated homes and up to $1000 for electric-heated homes	New construction not qualified	$750 and $1000	https://efficiencyworks.co/for-home/home-efficiency-audits/
CO	Energy Smart Colorado	Rebate Program	Windows with a U-value of 0.28 or less	Rebate of up to $500		$500	http://www.energysmartcolorado.com/rebates/
ID	Avista Utilities	Residential Rebates	Single pane or metal frame double pane with windows with a U-value of 0.30 or less. Windows must be contractor installed. Rebates require a minimum of 8,000 kilowatt-hours or 340 therms annual usage.	$1.50/sf and a $1.00/sf rebate for storm windows.		None mentioned	https://www.avistautilities.com/savings/rebates/Pages/idahorebates.aspx

State	Program Provider	Program Title	Qualifying Attributes	Incentives	Disqualifying Attributes	Cap?	Link
ID	Rocky Mountain Power	Residential Energy Efficiency Rebate Program	U-value of 0.23 to 0.30 and U-value of 0.22 or lower.	$1.00/sf and $3.00/sf		None mentioned	http://www.homeenergysavings.net/homeowner/category/weatherization/in/idaho/windows?region=idaho
MI	Efficiency United	Window Replacement	Must have a 0.3 or less U-value or SHGC rating. May be self-installed. Limit six. Must be a residential account holder of a participating utility at the time of equipment installation. The application must be received within 60 days of equipment installation. The equipment must be purchased and installed between January 1, 2018 and December 31, 2018.	$35/window		Says "no limit" and "limit of six"	https://efficiencyunited.com/residential/windows/window-replacement

State	Program Provider	Program Title	Qualifying Attributes	Incentives	Disqualifying Attributes	Cap?	Link
MI	SEMCO Energy Michigan Gas Utilities	Window Replacement	"Must have a 0.3 or less U-factor or SHGC rating. May be self-installed. Limit six. Must be a residential account holder of a participating utility at the time of equipment installation. The application must be received within 60 days of equipment installation. The equipment must be purchased and installed between January 1, 2018 and December 31, 2018."	$20/Window		Says "no limit" and "limit of six"	http://efficiencyunited.com/residential/windows/window-replacement
MI	DTE Energy	Window Replacement	ENERGY STAR® for Northern Climate Zone (U-value < .30) Single-family homes and homes with less than five connected housing units are eligible.	$15/window (per unit)	New construction not qualified		https://www.newlook.dteenergy.com/wps/wcm/connect/dte-web/home/save-energy/residential/rebates/insulation+and+windows

State	Program Provider	Program Title	Qualifying Attributes	Incentives	Disqualifying Attributes	Cap?	Link
MI	Consumers Energy	Residential Rebate Program	Replacement ENERGY STAR window or ENERGY STAR glass door	$15 or $40		$400	https://new.consumersenergy.com/residential/save-money-andenergy/rebates/windows-and-insulation
WA	ETO	Residential Incentive Program	ENERGY STAR windows with a U-value of 0.28 to 0.30 or ENERGY STAR windows with a U-value of 0.27 or less. Windows must be NFRC certified.	$1.75/sf or $4.00/sf		None mentioned	http://www.energytrust.org/incentives/windows/
MI	Xcel Energy	Residential Incentive Program	ENERGY STAR windows. Must have certified values.	$70/window		No max	https://efficiencyunited.com/residential/windows
MT	Mission Valley Power	Windows	U-value less than 0.3 or lower, electric heat	$3.00/sq ft	New construction not qualified		http://missionvalleypower.org/conservation-programs-2016/
MT	Flathead Electric Cooperative	Window Replacement	U-value less than 0.30. Single pane with or without a storm window (any frame material). Double pane with an aluminum frame	$3.00/sq ft			https://www.flatheadelectric.com/save-money-save-energy/rebates/window-replacements/

State	Program Provider	Program Title	Qualifying Attributes	Incentives	Disqualifying Attributes	Cap?	Link
OR	Consumers Power Inc.	Residential Rebate Program	U-value of 0.30 or less, on electrically heated homes or U-value of 0.22 or less. Storm windows: • Emissivity < 0.22 • Solar Transmittance > 0.55 • Glass thickness > 3 mm • Minimum 10-year warranty • If the Low-E storm window is an exterior storm window, weep holes or other means to dissipate water	$3.00/sf or $4.00/sf or $2.00/sq ft		None mentioned	http://www.cpi.coop/rebate/window-replacement/
RI	Pascoag Utility District	Windows/ Skylights and Doors Incentives	U-value of .30 or lower	$15/window		10 windows	http://www.pud-ri.org/wp-content9999/uploads/2013/05/Windows-and-Doors-Rebate.pdf
WA	Avista Utilities	Residential Rebate Program	Replacement, single pane or metal frame double pane, U-value of 0.30 or less or qualifying storm windows. Must be contractor installed.	$1.50/sf or $1.00/sf		None mentioned	https://www.avistautilities.com/savings/rebates/Pages/WashingtonCustomerRebates.aspx

State	Program Provider	Program Title	Qualifying Attributes	Incentives	Disqualifying Attributes	Cap?	Link
WA	Pacific Power	Residential Rebate Program	U-value of 0.25 or lower	$0.65/sf	New construction not qualified	None mentioned	https://www.homeenergysavings.net/homeowner/category/weatherization/in/washington/windows?region=washington
WA	Puget Sound Energy	Residential Rebate Program	For electrically heated homes. Existing windows must be single pane, single pane with storm window, or metal frame double pane windows. Upgrading to ENERGY STAR.	$50/window		$750	http://www.pse.com/savingsandenergycenter/Rebates/Pages/Windows-rebate.aspx
WY	Rocky Mountain Power	Residential Energy Efficiency Rebate Program	U-value of 0.30 or less	$1.00/sf	New construction not qualified	None mentioned	https://www.homeenergysavings.net/homeowner/category/weatherization/in/wyoming/windows?region=wyoming
WY	Black Hills Energy	Heating, Cooling and Appliance Replacement, Insulation and Windows 2018 Residential Rebate Application	U-value of 0.32 or lower	$50/window assembly			https://www.blackhillsenergy.com/sites/blackhillsenergy.com/files/residential_rebate.pdf

10. Appendix E: Listing of Publications and Report Subscription Services

Source	Description	Link	Publication Date	Cost	NCvsRET	MarketShare: Efficiency Level	MarketShare: Windowtype	MarketShare: Manufacturer	Geography

AAMA	AAMA 2017/2018 Study of the U.S. Market for Windows, Doors and Skylights	https://pubstore.aamanet.org/pubstore/ProductResults.asp?cat=1	May 2018	$3,300 ($675 for membership + report)	x	x	x		
IBIS World	Window Installation - US Market Research Report (2013-2018)	https://www.ibisworld.com/industry-trends/specialized-market-research-reports/specialist-engineering-infrastructure-contractors/general/window-installation.html	March 2018	$990			x		

Azoth Analytics	Global Low-E Glass Market (Value, Volume) – Analysis By Type (Single, Double, Triple), By End-Use (Residential, Commercial), By Region, By Country (2018 Edition): Forecast to 2023 –– By Region (North America, Europe, APAC, ROW), By Country (US, Canada, UK	https://www.marketresearch.com/Azoth-Analytics-v4068/Global-Low-Glass-Value-Volume-11550045/	March 2018	$2,000	Covers each of these, but for Low-E Windows, specifically

Freedonia	Reports & Studies Custom Research Subscriptions Press Releases About Us Global Windows & Doors by Product, Material, Market and Region, 8th Edition	https://www.freedoniagroup.com/industry-study/global-windows-doors-by-product-material-market-and-region-8th-edition-3588.htm	December 2017	$6,700	x	x			x
HNY Research	2018–2023 Global and Regional Energy-Efficient Window Glass Industry Production, Sales and Consumption Status and	http://www.marketresearchstore.com/report/2018-2023-global-and-regional-energy-efficient-window-209544	November 2017	$3,500			x	x	Only down to US, unclear if more specific

	Prospects Professional Market Research Report								
Technavio	Global Energy Efficient Windows Market 2017–2021	https://www.technavio.com/report/global-energy-efficient-windows-market	July 2017	$2,500	x	x		x	Only down to US, unclear if more specific
ReportLinker	Growth Opportunities in the Global Door and Window Market	https://www.reportlinker.com/p04837539/Growth-Opportunities-in-the-Global-Door-and-Window-Market.html	March 2017	$5,000					