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High-Performance Windows Baseline Review

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1. Introduction

The Northwest Energy Efficiency Alliance (NEEA) contracted with Cadmus to review its approach for developing the Naturally Occurring Baseline (NOB) for High-Performance Windows (HPWs) and for establishing a maximum market share when including efforts by NEEA and its partners. NEEA defines HPWs as those with a U-value of 0.22 or less.

Cadmus addressed three primary research questions in this review:

- RQ1: What is the average pre-intervention market U-Value of windows sold in the Northwest (Idaho, Montana, Oregon, and Washington)?
- RQ2: What is the maximum achievable HPW market share with NEEA intervention?
- RQ3: Without NEEA intervention, does the HPW NOB reflect the most likely rate of adoption for HPWs in the Northwest over the next 20 years?

NEEA provided the following evidence for Cadmus to review:

- A memo supporting Cadmus' review of NEEA's HPW assumptions (2023)
- An Excel workbook with data on NEEA's HPW NOB forecast (2023)
- A confidential Word document with insights and lessons learned from engagement and outreach with residential builders installing HPWs (2023)
- *Door and Window Industry Outlook* (2023) – a US residential fenestration industry report prepared by KM&R Key Media and Research group
- [Regional Technical Forum](#)— Single Family Weatherization Unit Energy Savings (2023)
- [Regional Technical Forum](#)— Multi-Family Weatherization Unit Energy Savings (2022)
- [Window & Door Manufacturers Association US Market Industry Research](#) (2022)
- [Industry Pulse Report](#) (2022) — An annual window and door industry survey
- *Ducker Research Company's Study of the U.S. Market for Windows, Doors and Skylights* (2020)
- [Energy Trust of Oregon 2018 Windows Market Research Report](#) (2018)—A report prepared by Apex Analytics for Energy Trust of Oregon

Cadmus included additional sources to inform our review, which include sources cited by NEEA or found by Cadmus during the secondary data review:

- [Study of High-Performance Windows Incremental Manufacturing Cost](#) (2023) —A study of the incremental cost of HPWs commissioned by NEEA
- [High-Performance Windows Market Characterization Study](#) (2022) —A study prepared by Cadeo for NEEA
- [2022 Single Family Residential Compliance Manual](#) (2022) – Created by the California Energy Commission for code compliance in that state
- [Field Validation of High-R Value Windows](#) (2019) – A study prepared by the Pacific Northwest National Laboratory for the US Department of Energy

2. Research Questions & Recommendations

2.1. Research Question 1: Average Pre-Intervention U-Value of Windows

Is NEEA’s approach to estimating the average U-Values of windows sold in the Northwest prior to the program’s intervention reasonable? To investigate this more closely, Cadmus focused on understanding the average U-Value of HPWs (U-Value \leq 0.22) and lower performance windows (U-Value \geq 0.23) being sold for new construction and retrofit applications.

2.1.1. What is the average U-Value of the windows with U-Value 0.23 or more (non-HPW windows) sold in the Northwest in the last two years?

NEEA estimated the average U-Value of the new construction market based on market share estimates from the Energy Trust of Oregon’s (2018) values for Idaho, Montana, and Washington to propose a range of U-Values from 0.28 to 0.29, which is slightly below code requirements at 0.30. For Oregon, NEEA used the new building code requirement of 0.27 as the average U-Value for non-HPW windows.

NEEA received sales data from certain window retailers, which represent a small fraction of the market. Using this dataset, NEEA estimated the market average U-Value for window retrofit applications was between 0.31 and 0.29. NEEA believed that the majority of retailer sales were going to the retrofit market rather than the new construction market (an estimated 60% of Big Box retailer sales focus on remodeling from the DuckerFrontier, 2020 report). This explains the high U-Values seen in this dataset (between 0.31 and 0.29) and a minimum observed U-Value of 0.25.

Cadmus found that NEEA’s U-Value averages for window retrofits were reasonable based on NEEA’s internal data and the Energy Trust of Oregon study. The estimation from Energy Trust of Oregon’s study (2018) was the best estimate of the market share by U-Value (for the combined new construction and retrofit markets), because it was developed with input from multiple industry market actors.

The NEEA calculation using Energy Trust of Oregon (2018) study data provided an overall sales weighted U-Value of approximately 0.29, as shown in Table 1. Note that this data does not specify retrofit or new construction and is for the state of Oregon only.

Table 1. Sales Weighted U-Value for Non-HPW Windows

Average U-Value	2017 Market Share	2022 Market Share
0.35	4%	4%
0.32	30%	24%
0.28	51%	40%
0.26	11%	24%
0.23	3%	6%
Sales Weighted U-Value	0.291	0.285

Recent findings from Cadeo (2022) for the retrofit market showed continued improvements in average window U-Value compared with Energy Trust of Oregon’s (2018) results, with lower performing windows with a U-Value over 0.30 comprising 18% of the market, compared with 34% in 2017 (Energy Trust of Oregon, 2018).

Given the small range in values, Cadmus recommends using a market average of 0.27 for new construction and 0.31 for retrofit for U-Values instead of a range, as shown in Table 2. Cadmus recommends NEEA revisit this assumption after obtaining more market data.

Table 2. Cadmus Recommended U-Values for New Construction and Retrofit for Non-HPW Windows

New Construction	Retrofit
0.27 (standard practice from Cadeo, 2022)	0.31 (average value from retailer dataset)

2.1.2. What fraction of windows sold recently in the Northwest have a U-Value of 0.22 or less (HPW windows)?

The overall market share of HPW may range from 2% to 10% of total sales for the whole market and encompasses new construction and retrofit. This seems appropriate when looking at the ENERGY STAR most efficient windows list¹, as there are multiple products on the list with U-Factors² 0.20 or lower, indicating commercial availability. Table 3 lists HPW market share of total window sales estimates from various sources.

Table 3. HPW Market Share of Window Sales by Source

Source	Market Share of High-Performance Windows (with U-Values of 0.22 or Less)
NEEA Product Manager	Close to 0%
Cadeo (2022) existing homes	10%
DuckerFrontier (2020)	Triple glazing “Small single digit share”
Energy Trust (2018) forecast for 2022	8%
Energy Trust (2018) estimate for 2017	4% (upper limit)
PNNL (2015 triple pane market share)	2%

NEEA disaggregated this to estimate the HPW market share for new construction and existing homes. Its estimate assumed a 4% overall market share, with 80% of HPW sales to the new construction sector.

2.1.3. Cadmus’ Recommendations on Estimating U-Values for Windows prior to NEEA’s Intervention

Based on results from the literature and input from NEEA’s product manager, Cadmus recommends using the following guidelines in Table 4.

¹ [ENERGY STAR Most Efficient 2023 — Vertical Slider Windows | ENERGY STAR](#)

² ENERGY STAR uses the term “U-Factor”. This term is interchangeable with “U-Value”.

Table 4. Cadmus Recommended HPW Market Share, Average U-Value, and Split between New Construction & Retrofit Installations

Recommendation	Reasoning
4% Pre-Intervention Market Share for HPW in NW	This is conservative, while still being consistent with Ducker Frontier Industry Report (2020) and more closely aligned with NEEA’s product manager’s understanding of current market adoption.
50/50 Split between New Construction and Retrofit Installations³	Since the Energy Trust of Oregon (2018) study found a mix of all products in both new construction and existing homes, with higher end homes being more likely to install HPW in both markets, it is difficult to assess the number of sales going to each. So, instead of estimating that 20% of sales are going to retrofit and 80% to new construction, we believe it may make more sense to follow the NEEA product manager’s understanding of the market and not over-attribute HPW installations in new construction, since he has reflected that builders are rarely using HPW. Therefore, Cadmus recommends adjusting the market share to reflect a 50/50 split, rather than an 80/20, until NEEA is able to learn more about where newly sold products are installed.
0.29 Pre-Intervention Average U-Value for New Construction & Retrofit Markets	With the above 50/50 split in retrofit and new construction applications, this is the average U-Value from the values for the two markets in Table 2.

2.2. Research Question 2: Maximum Achievable Market Share with NEEA intervention

NEEA would like to know whether it is reasonable to estimate that the overall maximum achievable market share of HPWs in the NW would be 80% with influence from NEEA and its partners. This is based on past achievements during its program with ENERGY STAR windows, with version 6.0 achieving 84% of the market with window U-Values ≤ 0.27 .

Cadmus believes that ENERGY STAR 7.0 will push the market to increase adoption of HPW. Given the extra incremental costs and manufacturing challenges to meet ENERGY STAR 7.0, it seems reasonable to assume a smaller maximum market share than ENERGY STAR 6.0 achieved. Furthermore, ENERGY STAR 7.0 allows for products that are not HPW by NEEA’s definition; including some windows with U-Values of 0.23-0.26 in the northern climate zone (which encompasses the entire region of the Alliance) depending on the Solar Heat Gain Coefficient (SHGC)⁴. Originally, NEEA wanted ENERGY STAR 7.0 to require U-Values for northern climates to be 0.20 or better, but received significant industry push back. ENERGY STAR reached an agreement of 0.22 or less as the specification with variable U-Values dependent on SHGC. This suggests a lack of confidence by many window makers to be able to achieve this lower U-Value, focusing instead on manipulating SHGC to maintain an ENERGY STAR rated product. Specifically, we expect that smaller manufacturers not aiming for an ENERGY STAR Most Efficient (ESME) rating will meet the new specification through a coating that improves SHGC, instead of making changes to glazing to attain a U-Value of 0.22 or better. As such, if ENERGY STAR 7.0 achieves 80% market share, it stands to reason that HPW will achieve slightly less market share.

³ This is discussed later in the report on page 7. See also, Table 8.

⁴ The Solar Heat Gain Coefficient is a measure of how well the windows block sunlight. It ranges from 0 to 1, with lower values blocking more incidental solar heat.

According to a recent industry survey with manufacturers, dealers/distributors, and suppliers (Industry Pulse Report, 2022), 27% of respondents will focus product development dollars on energy efficiency, which Cadmus assumes will primarily be the larger manufacturers in our calculation below (see Table 4). Figure 1 shows about 20-40% of respondents were considering triple pane or thin triple pane (referred to as “skinny triples” below). If this happens, some manufacturers will not be able to adopt the technology needed to meet the new specifications; they “may [stratify] their product offering and accept that some percentage of their products will no longer qualify for the ENERGY STAR rating”. Respondents to the survey went on to share, “Moving to triples in a significant way in the U.S. will certainly require a pretty significant investment from an equipment standpoint”, and “If you look at the costs of what it might take to achieve an ENERGY STAR window, I think that’ll be another hurdle window companies will have. Some of these smaller players just won’t have the technology or internal engineering force to get the numbers they’re talking about.”

Figure 1. Industry Pulse Report Efficiency Technology Survey Question

WHAT TECHNOLOGIES ARE YOU CONSIDERING TO FURTHER ENHANCE EFFICIENCY?

- Triple pane: 40%
- Gas fill: 32%
- None: 23%
- Dynamic glass: 22%
- Other: 21%
- Skinny triples: 19%
- Aerogel: 3%

*Respondents could select more than one option.

Other responses include new technology in metal forms, fourth-surface low-E, concealed hardware, thermal steel and thermally broken aluminum.

Cadmus estimated the revenue of the 16 largest window manufacturers using resources from NEEA as well as research performed by Cadmus and grouped them by revenue (over \$2 billion or under \$2 billion). Assuming no manufacturer would produce only HPW, we assumed the largest companies by revenue could achieve an 80% maximum market share, and smaller companies could achieve 50% HPW market share (assuming the smaller companies adopted later and used higher efficiency components offered off the shelf by suppliers). **This translated into an overall maximum achievable market share of 70%, as shown in Table 4.** This maximum market share percentage was calculated from a weighted average from window makers’ share of revenue multiplied by the maximum HPW share for each manufacturer group (over \$2 billion or under \$2 billion revenue per year).

Table 4. Estimation of Maximum Achievable HPW Market Share

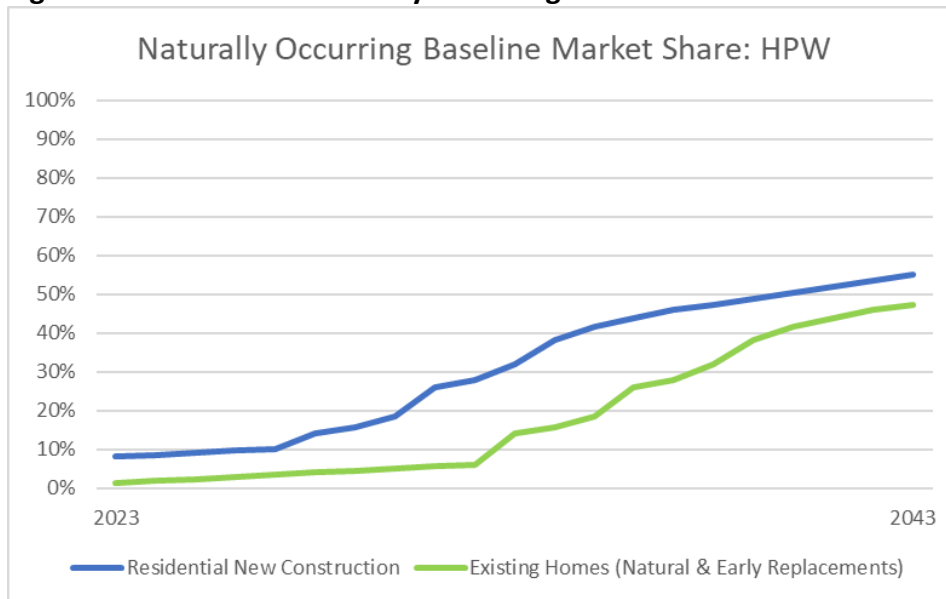
Manufacturer Group	Share of Manufacturers (n=16)	Share of Revenue	Maximum HPW Share (Cadmus assumption)
Revenue over \$2B	44%	68%	80% (some manufacturers will likely accept some of their products will no longer meet ENERGY STAR)
Revenue under \$2B	56%	32%	50%
		Market Average	70%

2.3. Research Question 3: HPW Naturally Occurring Baseline Forecast

2.3.1. Question 3A: What is the residential window market share by new construction and replacement?⁵

NEEA created market share estimates of HPW (U-Value ≤ 0.22) and non-HPW windows (U-Values > 0.22) recently sold in the Northwest to establish the NOB, shown in Figure 2. These are based on limited sales data and information available about the market (Energy Trust of Oregon, 2018; Cadeo, 2022), which constrained our ability to effectively estimate the market condition prior to NEEA’s market intervention. NEEA will update these estimates if it acquires a more complete dataset.

Figure 2. NEEA’s HPW Naturally Occurring Baseline Market Share



To assess NEEA’s approach to constructing this baseline, Cadmus investigated the residential windows replacement and new construction market shares.

Replacement Market—According to 2022 estimates by US GOV drawn from 2020 Census data on owner-occupied and total housing units in the NW, there are over 6 million living places currently available and about 65% of them are owner-occupied (see Table 5).

Table 5. Owner-Occupied Housing Units in Northwest States

State	Owner Occupied units	Total Housing Units	Percentage of Owner Occupied units
ID	571,419	796,958	72%
MT	365,644	529,152	69%
OR	1,175,133	1,859,387	63%
WA	2,107,952	3,314,390	64%
Total	4,220,148	6,499,887	65%

⁵ Note: Cadmus added this question, as it is needed to inform later research questions.

We then used the Regional Technical Forum’s (RTF) rates for window replacement and assumed that renter or vacant units (or second homes) would have a longer replacement rate (one window every 60 years⁶), while owner occupied units would be replaced at a shorter rate (one window every 45 years⁷). By taking the inverse of the window lifetime (1/window lifetime) we were able to get window replacement rates. We multiplied the total housing units by this replacement rate for both the owner occupied and renter/vacant categories to get the number of units which would replace windows in the Northwest. Finally, we multiplied this number by the average number of windows per housing unit from the Cadeo (2020) report. This resulted in a total of about 809,000 windows replaced annually throughout the region served by NEEA (see Table 6). Cadmus rounded this number to the nearest thousand to reflect that this number is not exact.

Table 6. Replacement Window Installation Rate

Housing Unit	Window “life”	Replacement Rate	# Units with New Windows	Windows/Unit	Total windows
Owner Occupied ⁶	45 years	2.22%	93,687	7	655,809
Renter or Vacant ⁵	60 years	1.67%	38,072	4	152,288
Total windows replaced each year across the four states					~809,000

New Construction—For new construction we used the historical number of annual new construction buildings from NEEA’s calculation (65,000 units) and multiplied by 64.9% (owner occupied units divided by total units from Table 5) to estimate the portion of new single family homes and new construction multifamily buildings. Cadmus estimates nearly 718,000 windows are used in the new construction market annually (see Table 7), rounded to the nearest thousand to reflect that this number is not exact.

Table 7. New Construction Window Installation Rate

New Construction Type	# of Units	Windows/Unit	Total Windows
Single family unit	39,632	13	515,216
Multifamily unit	25,368	8	202,944
Total windows installed each year			~718,000

Finally, we compared our results with those in the literature, as shown in Table 8.

Table 8. New Construction/Replacement Window Mark Share Comparison

Source	New Construction	Replacement
Cadmus Calculation	47%	53%
Cadeo (2022)	45%	55%
Energy Trust (2017)	50%	50%
Industry Pulse Report (2022)	49%	51%

Conclusion— The bottom-up calculation conducted by Cadmus was within the range of those found in the literature and most closely aligned with the value reported by Energy Trust of Oregon (2017). For

⁶ Cadmus’ estimate for the life of a residential window in single family and multifamily applications in non-owner-occupied housing.

⁷ RTF assumption for the life of a residential window is 45 years in single family and multifamily applications (RTF, 2023).

this reason, we recommend using a 50/50 split for new construction/replacement window market shares.

2.3.2. *Without NEEA interventions, does the HPW NOB reflect the most likely rate of adoption for HPWs in the NW over next 20 years?*

Cadmus recommends a few modifications to the HPW NOB. This section presents how we developed a slightly different NOB using evidence from NEEA staff and other sources.

- We did not see evidence that market share of HPWs differs in new construction and replacement applications. The revised NOB starts at 4% in 2022/2023 as mentioned in RQ1 and uses a single curve that tracks the overall market share.
 - If NEEA has to track HPW market shares of new construction and replacement separately, Cadmus recommends using the same curve but lagging the replacement market behind the new construction market by five years.
- The Apex report (2018) cites the following market drivers for residential window purchases:
 - ENERGY STAR specifications play an important role in influencing manufacturers.
 - Cost: Builders and remodelers generally try to find the lowest cost window that meet code or ENERGY STAR specifications. Manufacturers will need to spend millions of dollars in upfront costs to produce windows with U-Values under 0.24 (the focus of the Apex report) and presumably more to reach 0.20.
 - Energy Code –California Title 24 will influence what products are available as that market is large. 2022 Title 24 requires a maximum U-Value of 0.30 (California Energy Commission, 2022). As a result of California’s market being large and influential, there will be stock of windows sold above the 0.22 value for HPW windows across other markets outside of California, including the Northwest market.
- There are additional impediments to naturally occurring adoption.
 - Low energy costs (like in the Northwest) impede adoption.
 - The incremental cost between double-and triple-pane windows has not declined in the past decade (Apex, 2018).
 - In the short term, supply costs are increasing.

To develop an alternative NOB, Cadmus modeled the likely maximum U-Value for ENERGY STAR and WA code adoption without NEEA influence.

Table shows the historical and forecasted (below green row) adoption of ENERGY STAR specifications.

Based on the NEEA product manager’s input and interviews from the HPW market characterization report (Cadeo, 2022), Cadmus assumes naturally occurring code improvement of 0.03 U-Value every 20 years and that ENERGY STAR specifications would be slightly less stringent. Supporting evidence found in the Cadeo study (2022) shows that 23 respondents who offered an opinion on whether windows are likely to get more efficient believe that windows are likely to become more efficient over time (n=27). ENERGY STAR updates to window specifications might occur every 6-7 years. We assume 8 years between the next few updates as efficiency gains slow down.

Table 9. Forecast of ES Specifications and Code U-Values without NEEA interventions

Version	Years between Spec Dates	Spec Effective Date	Max U-value	ES Max U-Value W/o NEEA (assume slightly higher U-value)	Code Max U-Value (WA) w/o NEEA
ES v4	n/a	~2003	U<=0.35		
ES v5	6	2009	U<=0.30		
ES v6	7	Jan 2016	U<=0.27		
ES v7	7	Oct 2023	U<=0.22	0.24	0.3
ES v8 (forecasted)	8	2032		0.22	0.28
ES v9 (forecasted)	8	2040		0.20	0.27

Cadmus then developed the following NOB. We note that ENERGY STAR guiding principles state: “Specifications for more slowly advancing products are reviewed every three years or when market share reaches 35%.⁸” The NOB modified by Cadmus shows a steady increase in market adoption following expected ENERGY STAR specification updates. When compared with the original NOB (Figure 1), the revised NOB shows a sharper increase by 2032 due to other efficiency advocates pushing ENERGY STAR v8 specifications in NEEA’s absence, but similar market share in 2040 as a result of ENERGY STAR v9. Since U-Values required by code do not drop significantly, we do not believe they will play a role in pushing those who have not adopted HPWs and, as such, about half of the market will not meet HPW requirements at the end of the forecast period. Table 10 shows the revised and original NOB for select years.

Table 10. Revised and Original NOB for Select Years

Year	Revised HPW NOB	Source	Original NOB – New Construction	Original NOB – Replacements
2017	4%	From RQ1	-	-
2022	4%	From RQ1	-	-
2032	35%	Baseline ENERGY STAR specs reach U=0.22 effective in 2032. ENERGY STAR develops specifications when market share reaches 35%.	27.7%	6.1%
2040	50%	ENERGY STAR v9 adopted this year, WA code drops to max U-Value of 0.273. Assume at least 35% of market share is better than U=0.20, with 50% 0.22. Since code allows 0.273 windows, half will be higher than 0.22.	50.3%	47.2%

⁸https://www.energystar.gov/sites/default/files/asset/document/ENERGY_STAR_Strategic_Vision_and_Guiding_Principles.pdf